The State of Coral Reef Ecosystems of the Pacific Remote Island Areas

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INTRODUCTION AND SETTING

This report is the third in a series of assessments of the current status of coral reef ecosystems in the Pacific Remote Island Areas (PRIA). PRIA are defined as isolated U.S. sovereign islands and atolls not within the jurisdiction of any U.S. state or territory. Seven of the eight PRIA (except Midway) are discussed in this chapter including: Howland, Baker and Jarvis Islands; Johnston, Palmyra, Kingman and Wake Atolls. Midway is included in the chapter on the Northwestern Hawaiian Islands (NWHI). Rose Atoll and Swains Island are a part of the Territory of American Samoa and are covered in the chapter on American Samoa.

The first State of the Reefs Report (Turgeon et al., 2002) provided a broad overview of the status of the seven islands, atolls and reefs covered in this chapter and concluded that “all the [PRIA] coral reefs are generally in excellent-to-good condition.” In the second PRIA State of the Reefs Report, Brainard et al. (2005) identified specific threats to the coral ecosystems observed before 2005 and described the oceanographic and biological monitoring methods being applied across the PRIA. In addition, the 2005 report concluded that the coral reef ecosystems of the PRIA remained quite healthy and productive, with limited impacts noted from unauthorized fishing, abandoned WWII material and ship groundings. The report also recommended that Pacific Reef Assessment and Monitoring Program (RAMP) surveys of all PRIA continue on a biennial basis.

Six of the seven PRIA are National Wildlife Refuges (NWR) under the jurisdiction of the U.S. Fish and Wildlife Service (USFWS), Department of the Interior (DOI). Palmyra Atoll is unique in that part of it (Cooper Island) is privately owned by The Nature Conservancy (TNC), with the remainder of the atoll being managed and operated by the USFWS. Wake Atoll, the only PRIA that is not a NWR, is under the control of the DOI and operated by the U.S. Air Force, with a population of 150-250 Air Force personnel and contractors, who primarily provide infrastructure support. Wake has an active airstrip that is used mostly by the U.S. military as a refueling stop. Johnston, Kingman, Palmyra, Baker, Howland, Jarvis, and Rose (American Samoa) were proposed to be added to the U.S. Tentative List for World Heritage Sites and are now being evaluated as “Ramsar” (1971 Convention on Wetlands of International Importance at Ramsar, Iran) sites.

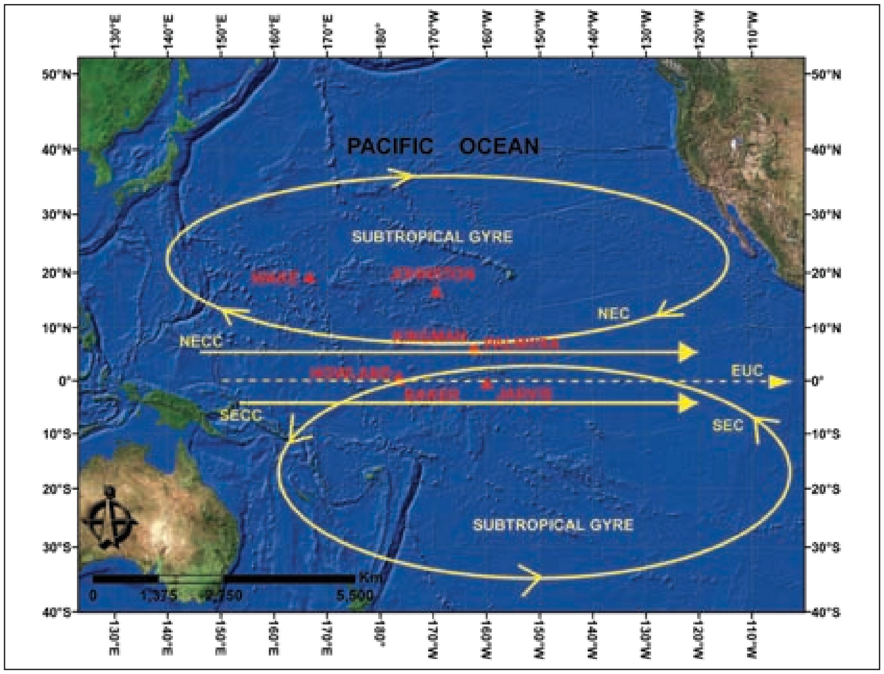

Figure 11.1. Topographic map showing location in Pacific Ocean of the PRIA and major ocean currents in the region: North Equatorial Current (NEC), South Equatorial Current (SEC), North Equatorial Counter Current (NECC), South Equatorial Counter Current (SECC), Equatorial Undercurrent (EUC). Source: PIFSC-CRED.

The seven islands and atolls of the PRIA discussed in this report are dispersed over a vast and remote area in the central Pacific Ocean and influenced by varying oceanographic and climatic conditions and processes (Figure 11.1).

From north to south (Figures 11.1 and 11.2):

Wake Atoll (19° 17’N, 166° 36’E) and **Johnston Atoll** (16° 45’N, 169° 31’W) are influenced primarily by easterly trade winds, the westward-flowing North Equatorial Current (NEC), and significant winter swell from the North Pacific. The climate is tropical and relatively dry with rainfall of generally less than 300 mm/year. Wake Atoll is the northernmost atoll of the Marshall Island seamount chain, while Johnston Atoll is considered by some to be the northernmost atoll of the Line Island Chain (although it is geographically closer and biologically more similar to the Hawaiian Archipelago).

1. NOAA National Marine Fisheries Service, Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division
2. Joint Institute for Marine and Atmospheric Research
3. U.S. Fish and Wildlife Service
4. NOAA Papahanaumokuakea Marine National Monument

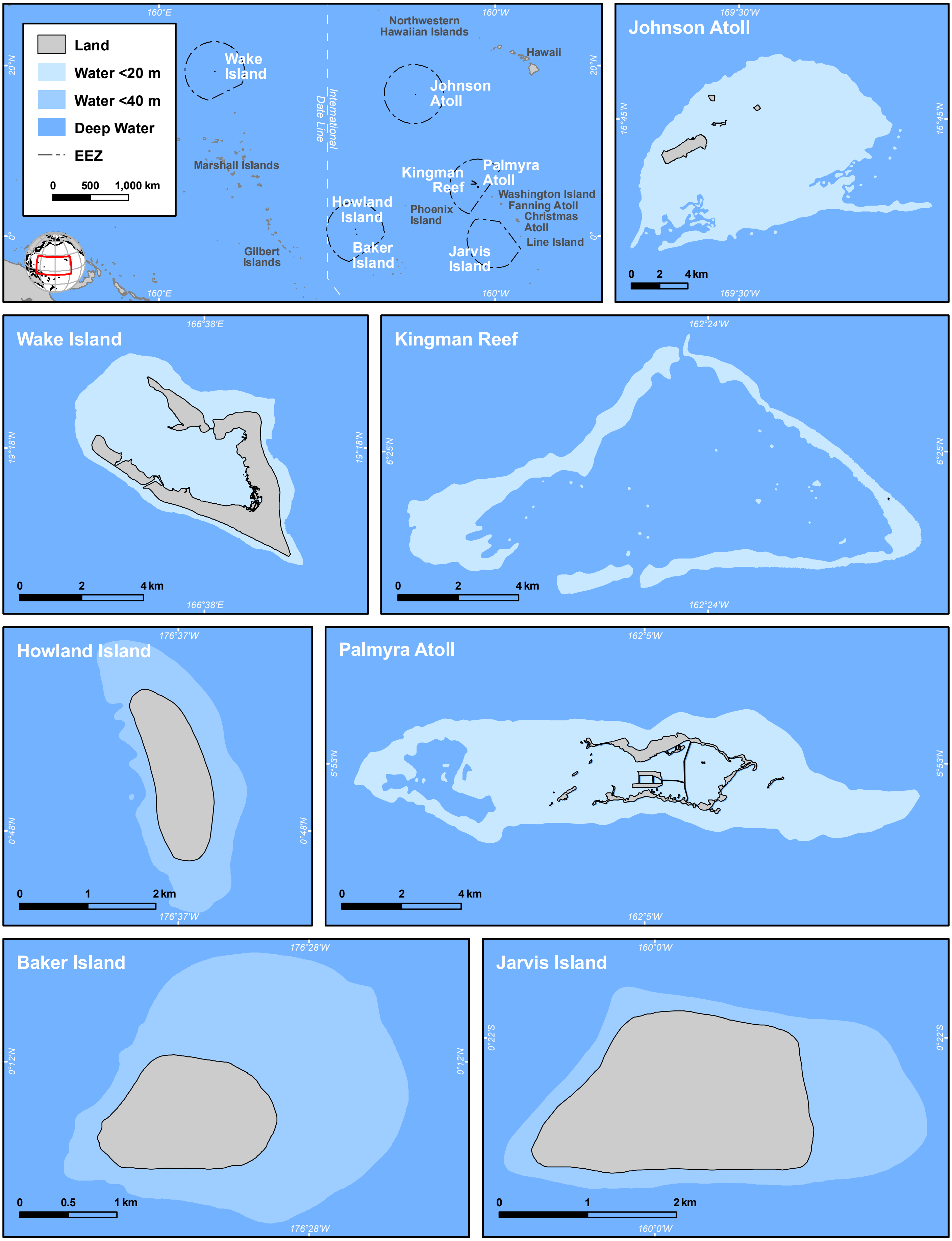

Figure 11.2. Locator map for the PRIA. Map: K. Buja. **NOTE:** *Island/atoll/reef abbreviations in figures and tables are as follows: JOH=Johnson Atoll; WAK=Wake Island; BAK=Baker Island; HOW=Howland Island; JAR=Jarvis Island; PAL=Palmyra Atoll; ROS=Rose; and KIN=Kingman Reef.*

Kingman Reef (6°24′N 162°24′W) and **Palmyra Atoll** (5°52′N 162°6′W) are both influenced seasonally by the eastward-flowing NECC and the westward-flowing NEC. Weather and sea conditions at both atolls are strongly influenced by their location within the Intertropical Convergence Zone (ITCZ) during the summer months. When within the ITCZ, both atolls experience mostly light, variable winds, extremely high precipitation (4.5 m of rain per year at Palmyra) and a humid tropical climate. During the winter months, both atolls experience moderately strong easterly trade winds and seas. Both are part of the Line Islands seamount chain.

Baker Island (0°12′N 176°29′W), **Howland Island** (0°48′N 176°37′W) and **Jarvis Island** (0°22′S 160°03′W) all lie near the equator under the influence of both the westward-flowing SEC at the surface and the strong (1-1.5 ms^{-1}) eastward-flowing EUC with a core depth of approximately 50-200 m. The EUC causes localized topographic upwelling on the western side of all three islands that varies with time (e.g., El Niño/La Niña conditions). All lie within the arid zone of the equatorial Pacific with insufficient groundwater and rainfall to support continuous human habitation. Jarvis Island is a southern member of the Line Islands group and Howland and Baker Islands are northernmost members of the Phoenix Islands group and Tokelau Ridge.

The history of the PRIA are covered in a companion report (Maragos et al., 2008) and the 2005 edition of this report. Between October 2005 and April 2007, NOAA conducted biennial Pacific RAMP cruises at all seven locations, staffed by scientists from the Pacific Islands Fisheries Science Center's Coral Reef Ecosystem Division (PIFSC-CRED), the USFWS and collaborating institutions. In addition, the Scripps Institution of Oceanography (SIO) sponsored surveys at Palmyra and Kingman in August 2005, Palmyra in August 2006 and Kingman in August 2007. Since 2005, military use and occupation at Johnston Atoll has ceased, and all permanent residents were removed in 2005. TNC constructed a research station at Palmyra Atoll in 2006 that now accommodates up to 20 researchers for parts of the year. Numerous new research projects at Palmyra were proposed and initiated in 2005. In August 2006, Typhoon Ioke, the strongest storm ever reported in the Central Pacific, struck Johnston as a Category 2 hurricane and Wake as a Category 4 typhoon.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

The threats and anthropogenic stressors of the PRIA prior to 2005 were discussed by Turgeon et al. (2002) and Brainard et al. (2005) in previous reports. This section updates the changes in the stressors that have been detected in the PRIA since previous surveys in 2004 and 2002.

Significant observations of environmental and anthropogenic stressors in the PRIA between 2005 and 2007 include:

- Surveys of coral disease showed a relatively low mean overall prevalence of coral disease across the region.
- Surprisingly few coral reef ecosystem impacts were apparent at Wake after Super Typhoon Ioke hit in August 2006.
- A shipwreck of a 26-m fishing vessel of unknown origin was discovered at Kingman.
- Residual metal from WWII military debris at Baker contributed to the spread of invasive cyanobacteria to adjacent reef habitats.
- Unauthorized fishing within NWR boundaries was suspected at several of the PRIA where surveillance and monitoring efforts are presently inadequate to discourage these activities.
- Alien insects were decimating the *Pisonia* beach forest at Palmyra and with non-native black rats (*Rattus rattus*) and coconut trees (*Cocos nucifera*) were thought to be limiting seabird nesting and recovery of *Pisonia* forests.
- Significant spreading of the corallimorph *Rhodactis howesii* was observed on reefs at Palmyra in 2007.

Climate Change and Coral Bleaching

Global warming is a climate change term used to describe the overall increase in the Earth's atmospheric and oceanic temperatures over the course of the last century from increased anthropogenic greenhouse gas emissions (primarily carbon dioxide, CO_2) from the combustion of fossil fuels (IPCC, 2007). The rapid rate of increase in atmospheric and oceanic temperatures suggests a difference from natural climate variability. Increasing temperatures can lead to changes in sea level, weather patterns, precipitation, storm frequency and magnitude, ocean currents and local biota (IPCC, 2007). The interconnectivity of the Earth's systems suggests that changes associated with global warming will have many known and unknown cascading effects on ecosystems around the globe (IPCC, 2007).

The future effects of increasing temperatures are difficult to quantify due to the unknown and complicated nature of climatic sensitivity, environmental feedback mechanisms and greenhouse gas emissions. Anthropogenic global warming and associated sea level increases may continue for centuries due to the time scales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized (IPCC, 2007). It is predicted that coral reef ecosystems will be under great strain as a result of global warming and climate change (Hoegh-Guldberg, 1999). In addition, projections predict temperature increases and that CO_2 will increase beyond levels that reefs have experienced over the past half-million years (Hughes et al., 2003). Two of the major impacts from global warming on coral reef ecosystems are coral reef bleaching and ocean acidification (Kleypas, 2006).

The increase in water temperatures associated with global warming (1-2°C per century), coupled with regionally specific El Niño-Southern Oscillation (ENSO) events, appears to be the main driver of the breakdown between coral-algal symbiotic relationships (coral bleaching) in the Pacific. Reef-building corals are thought to live near their thermal maxima, making them good indicators for changing conditions, and the thermal tolerances of reef-building corals are forecast to be exceeded within the next few decades (Hoegh-Guldberg, 1999). Small increases in water temperature of 1-2°C can stress corals, causing them to expel their symbiotic algae. When these algae, which contain the photosynthetic pigments that give corals their distinct colors, are expelled from coral tissue, the coral looks white or bleached. If the corals are not able to recruit new symbiotic algae in time to fulfill their nutritional needs (which can sometimes take weeks to months), the bleaching can result in mortality of the affected coral.

A major concern is that the accelerating rate of environmental change, including increasing temperatures, could exceed the evolutionary capacity of coral and algal species to acclimate and/or adapt to these changes (Hughes et al., 1993). Bleaching events can stretch across thousands of square kilometers of ocean and immediately cause high levels of coral mortality. In addition, coral bleaching can lead to habitat phase shifts where corals are replaced by other benthic groups, along with changes to the nutrient cycling processes that are thought to be major drivers of high coral reef productivity. Recent research shows that algal-dominated areas occur naturally on many healthy Pacific reef systems (Vroom et al., 2006a). However, algal overgrowth of areas where corals have been reduced by bleaching or other factors can lead to decreased ecosystem health, decreased accumulation of calcium carbonate, and negative impacts to the reef fauna that depend on the structural complexity and food sources provided by corals.

Six major coral bleaching events have occurred since 1979, with massive coral mortality affecting reefs around the globe (Hoegh-Guldberg, 1999). The effect of bleaching events in the PRIA before surveys began in 2000 cannot be determined, and the effects of these events on the PRIA after 2000 are inconclusive. Increasing temperatures associated with global warming are likely to increase the frequency and magnitude of coral bleaching events. The proximity of some of the PRIA to the equator (Howland, Baker and Jarvis Islands) exposes them to some of the greatest changes in temperature during ENSO warming events in the Pacific, and in some cases the islands have experienced conditions that exceed predicted bleaching thresholds (Figure 11.3).

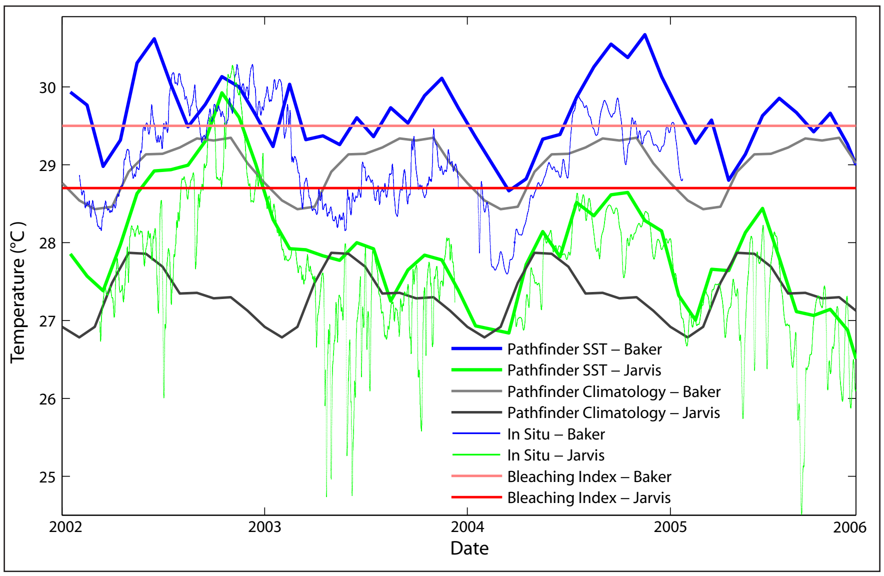

Figure 11.3. Satellite and in situ *temperatures at Baker and Jarvis Islands from 2002 to 2006 showing anomalously high sea surface temperatures. Both satellite Pathfinder SST (Baker – thick blue line, Jarvis – thick green line) and* in situ *temperatures at about 15 m depth at Baker (thin blue line) and Jarvis (thin green line) show temperature values exceeding long-term mean climatological values (Baker–light gray line, Jarvis–dark gray line). Coral Reef Watch bleaching threshold of maximum monthly mean SST plus 1°C is shown for reference. Source: Brainard et al., 2005; NODC/SOG, 2006.*

Calcification/Ocean Acidification

The current and projected rates of atmospheric CO_2 increase, primarily from the burning of fossil fuels, are estimated at 100 times the rate that has occurred over the past 650,000 years. By the mid-21st century, it is predicted that the increased concentration of atmospheric CO_2 will decrease the saturation state of carbonate minerals in tropical ocean waters by 30% and biogenic-carbonate precipitation by 14 to 30% (Kleypas et al., 1999). Coral reef calcification is dependent on the saturation state of carbonate minerals in ocean waters. Reduced carbonate-saturation state promotes dissolution in reef-building corals, and decreased carbonate production makes it more difficult for marine calcifying organisms to form biogenic-carbonate minerals (Orr et al., 2005). Coral reefs are particularly threatened because reef-building organisms secrete metastable forms of carbonate minerals; however, the biogeochemical consequences for calcifying organisms in other marine ecosystems may be equally severe (Kleypas et al., 1999). In addition, the rising atmospheric CO_2 levels are irreversible on human timescales (Kleypas et al., 2006). Uptake of CO_2 by the ocean helps moderate the rising atmospheric concentrations; however, the associated and linked changes previously described in the oceanic-carbonate-chemistry system increase the concentration of hydrogen ions [H^+] in solution, resulting in lowered sea-surface pH and "ocean acidification".

El Niño-Southern Oscillation

ENSO, resulting from the large-scale global coupling of atmospheric and oceanic circulation, is an interannual climatic phenomenon (occurring approximately every two to eight years) that creates significant temperature fluctuations in tropical Pacific Ocean surface waters. ENSO has two distinct signatures in the Pacific Ocean: El Niño and La Niña. These signatures are defined as sustained sea surface temperature (SST) anomalies of magnitude greater than 0.5°C across the central tropical Pacific Ocean (Trenberth, 1997). El Niño is associated with positive anomalies (warmer temperatures) and

La Niña with negative anomalies (colder temperatures). El Niño conditions have been linked to large-scale mortality of reef-building coral probably due to the increased temperatures and UV exposure, as well as decreased nutrients (Hoegh-Guldberg, 1999). La Niña conditions, which usually follow El Niño events, are associated with colder temperatures and increased storm activity. ENSO events can have a significant impact on coral reef ecosystems due to changing surface winds, ocean currents, water temperatures, nutrient availability, storm frequency and magnitude, etc. ENSO is a naturally occurring phenomenon; however, there is uncertainty regarding how global warming and the associated climate changes have affected the frequency and/or magnitude of this cycle and, in turn, how that will affect coral reef ecosystems.

With regard to the equatorial areas near the PRIA, ENSO has a profound impact on SST, ocean currents, winds and biological production (Philander, 1990; McPhaden et al., 1998; Figure 11.4). During an El Niño period, trade winds weaken and occasionally reverse in the equatorial Pacific, resulting in anomalously warm SST and eastward surface transport (Yu and McPhaden, 1999). These wind anomalies are typically westerly wind bursts in the Western Pacific that generate equatorial-trapped Kelvin waves propagating eastward, altering the sea surface slope and depressing the thermocline. The EUC, previously documented as the source for upwelling at Jarvis Island (Hendry and Wunsch, 1973; Roemmich, 1984; Gove et al., 2006), has been observed to weaken and, on rare occasions, reverse direction during an El Niño (Firing et al., 1983; Roemmich, 1984).

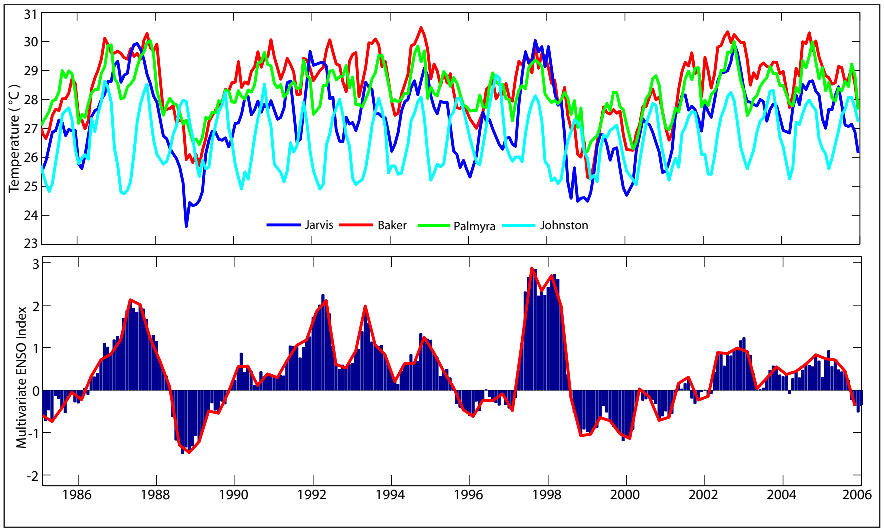

Figure 11.4. Relationship of NOAA Pathfinder-derived SST (top) and ENSO Multivariate Index (bottom) at the PRIA. Note Jarvis' extreme dependence on ENSO contrasting with Johnston's annual cycle. Source: PIFSC-CRED, unpub. data.

Diseases

Because the PRIA lie beyond the influence of most human disturbance, disease surveys and monitoring in this region provide a basis against which to compare levels of disease prevalence in human impacted coral reef environments. As part of Pacific RAMP, coral disease surveys were conducted at Johnston Atoll (n=18), Howland (n=8), Baker (n=6) in 2004 and 2006; Jarvis Islands (n=9), Palmyra Atoll (n=13) and Kingman Reef (n=14) in January–March 2006; and at Wake Atoll (n=12) in April–May 2007. Rapid Ecological Assessment (REA) surveys, each covering from 200-500 m^2, were completed at a total of 68 discrete sites in 2006, following the methodology developed, tested and implemented in the NWHI by Greta Aeby (see Friedlander et al., 2005). Prevalence of disease at each site was computed as the percent of diseased colonies (counts) relative to the estimated total number of colonies within each survey area, as follows: P=[(total no. disease cases per site × 100) ÷ (colony density per site × total area surveyed for presence of disease per site)].

The 2006 quantitative assessments indicate that the mean overall prevalence of coral disease across the region is relatively low, affecting between 0.01 and 2.8% of colonies at each of 80 survey sites (Figure 11.5). These values are comparable to the levels reported for the NWHI. Prevalence and distribution of coral disease varied greatly both within and among coral reef locations. Of the 80 sites visited, 39 (48.8%) revealed disease, and Johnston Atoll exhibited the greatest occurrence of coral disease (78% sites) and the highest mean overall prevalence values (0.7 ± 0.2%; mean ± SE). Two shallow, western lagoon sites near Johnston Atoll exhibited overall prevalence of 2.5 and 2.8%. In contrast, low prevalence (0.1%) was detected at northern and central lagoon sites, far away from any land mass. Lesion types and prevalence values documented in 2006 are commensurate with prior quantitative coral health assessments conducted in 2004 by Aeby (Brainard et al., 2005); ob-

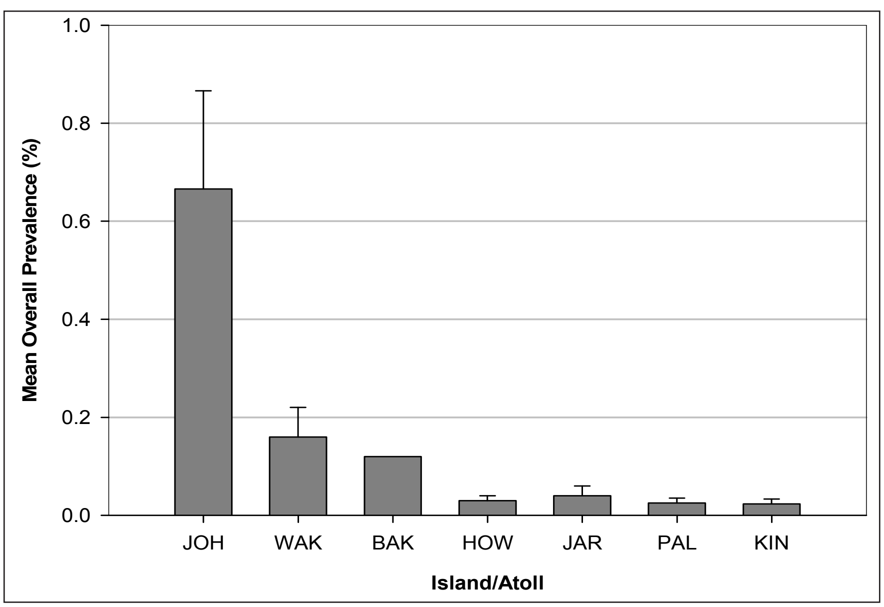

Figure 11.5. Mean overall prevalence (%) of coral disease in the PRIA. Prevalence for each disease state was calculated relative to the total coral density (number of colonies/m^2) at each site surveyed. Source: PIFSC-CRED, unpub. data.

served disease states were primarily composed of skeletal growth anomalies including "ring syndrome" (Brainard et al., 2005) and tissue loss lesions (including *Acropora* white syndrome; Figure 11.6). Skeletal growth anomalies represented 75% of the cases recorded and white syndrome/tissue loss 25%, respectively. Disease conditions were noted on three coral genera: *Montipora* (75%), *Acropora* (23%) and *Pocillopora* (2%). Of potential concern is the *Acroporid* white syndrome, which results in severe and rapid tissue loss on the tabular *Acropora cytherea* (Willis et al., 2004; Bythell et al., 2004). Based on ecological monitoring at 12 permanent stations, stands of *A. cytherea* at Johnston Atoll have suffered approximately 50% population reduction between 2004 and 2006. Thus, continued monitoring of this disease and its host species are needed. More detailed information on coral disease appears in the Benthic Habitats section of this chapter.

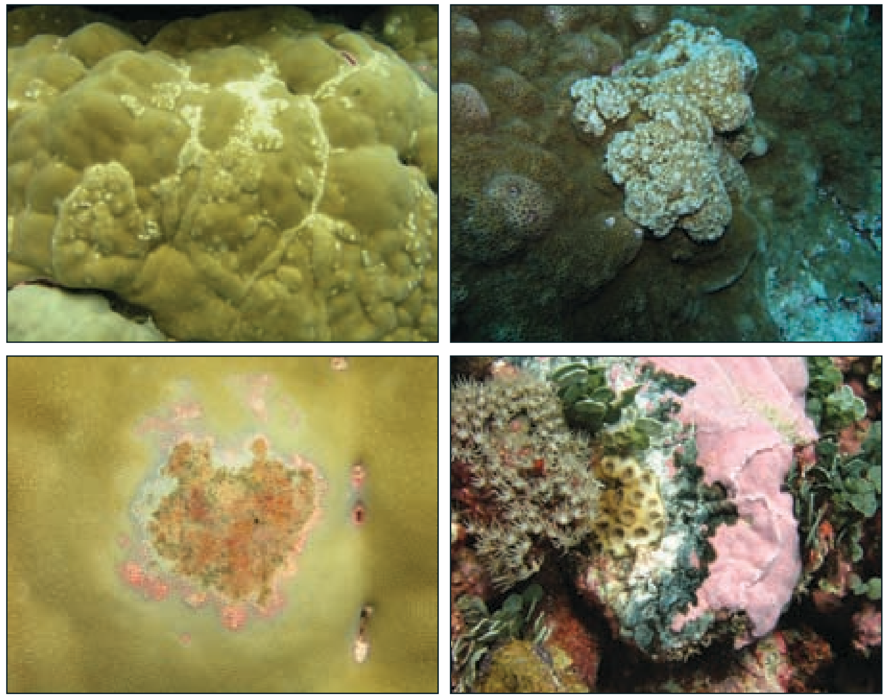

Figure 11.6. Underwater photographs illustrating the field appearance of lesions affecting scleractinian corals and coralline algae in the U.S. PRIA 2006; from top left, clock-wise: Porites *growth anomaly;* Montipora *growth anomaly;* Porites *tissue loss and pigmentation response; and black fungal disease of crustose coralline algae. Photos: Bernardo Vargas-Ángel, PIFSC-CRED.*

No prior records of coral disease occurrence are available for Wake Atoll because no disease surveys were conducted prior to PIFSC-CRED's Wake-Marianas Pacific RAMP cruise in April-May of 2007. During the surveys, mean overall disease prevalence at Wake Atoll was found to be low (0.16 ± 0.06; Figure 11.7) with skeletal growth anomalies being the most abundant disease state (73% of cases), followed by other lesions and white syndrome/tissue loss (16 and 11%, respectively). Disease conditions affected six different coral genera, with *Porites* exhibiting 50% of cases, followed by *Goniastrea* (21%), *Montipora* (8%), *Acropora* (8%) and *Astreopora* (8%).

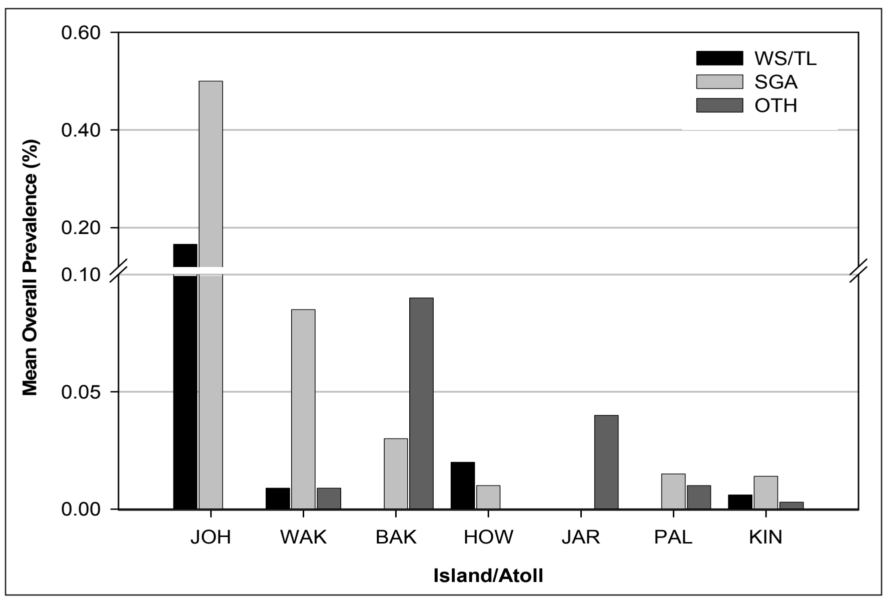

Figure 11.7. Mean overall prevalence of white syndrome (WS/TL), skeletal growth anomalies (SGA), and "other lesions" (OTH) including unusual discolorations, irritations and pigmentation responses, tube-worm infestations and unidentified lesions causing deterioration of coral condition in the U.S. PRIA. Prevalence for each disease state was calculated relative to the total coral density (no. colonies/m^2) at each site surveyed. Source: PIFSC-CRED, unpub. data.

Disease prevalence was notably low at Howland and Baker (0.01%, 0.03 ± 0.02%, respectively), with skeletal growth anomalies on staghorn *Acropora nobilis* being the only type of lesion observed. Additionally, a few colonies were affected by tube-worm infestations. For Palmyra Atoll and Kingman Reef, occurrence of disease was low, comparable to Howland and Baker Islands. Disease states enumerated at Palmyra Atoll included skeletal growth anomalies (32%), other lesions (68%) such as pigmentation responses and discoloration, and tube-worm infestations. Disease was documented at 54% of survey sites visited, and mean prevalence amounted to 0.05 ± 0.01% (range 0.02–0.1%). The coral genera affected included, in descending order: *Porites* (68%), *Acropora*, *Pocillopora* (10.5% each), and *Favites* and *Hydnophora* (5.5% each). Three main disease states, skeletal growth anomalies (60%), tissue loss (5%), and other lesions (35%), were visible at 6 of the 14 sites visited (43%) at Kingman Reef. In descending order of importance, diseases affected corals in the following genera: *Porites* (75%), *Acropora* and *Pocillopora* (10% each), and *Herpolitha* (5%). Mean disease prevalence for Kingman was lower than for Palmyra (0.02 ± 0.01%; range 0.01–0.04%).

The 2006 surveys revealed diseases for algae as well. Cases of a black fungal disease affecting crustose coralline algae (Littler and Littler, 1998) were encountered at Palmyra and Kingman. Although present in relatively low abundances (1.0 ± 0.38 case/100 m^2; range 0.5–7.5 cases/100 m^2), these observations expand the geographical range of the black fungal coralline algal disease, which until now was only known from American Samoa (Littler and Littler, 2003).

Tropical Storms/Wave Action

In general, the PRIA of Johnston, Kingman, Palmyra, Jarvis, Howland and Baker experience low frequencies of tropical storm events. These islands and atolls are located in between the major eastern and western Pacific tropical storm centers, which are most active in late summer and early fall. Most storms that develop off the coast of Mexico and head west undergo cyclolysis (storm death) or spin off northwards before reaching the longitude of the PRIA.

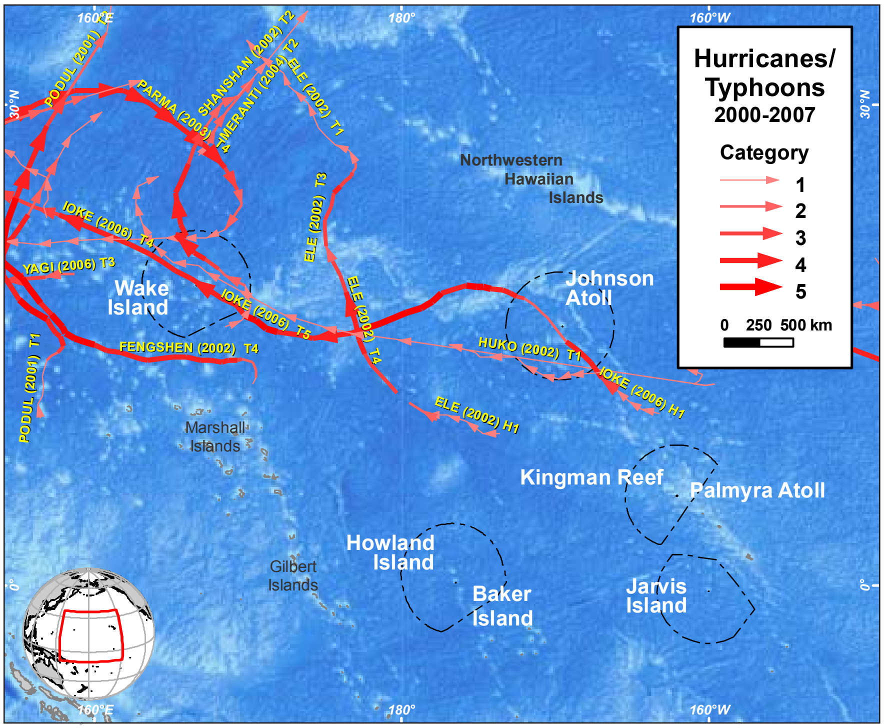

Figure 11.8. A map showing the path, name, year and intensity of tropical storms passing near the PRIA from 2000-2007. Map: K. Buja. Source: http://weather.unisys.com/hurricane/.

In late August and early September 2006, Hurricane/Typhoon Ioke (Figure 11.8 and 11.9), one of the strongest storms ever recorded in the Central Pacific, struck the two northernmost islands of the PRIA. Ioke passed over Johnston Atoll as a Category 2 hurricane and over Wake Atoll as a Category 4 typhoon. Wake Island, completely evacuated of all 188 residents due to Ioke's projected path, sustained winds of over 320 km per hour, driving a storm surge over the island and forcing powerful waves into the lagoon (Figure 11.10). Large concrete cubes filled with coral rubble and sand used to build a seawall on the eastern side of the island were dislodged and thrown tens of meters up the beach (Figure 11.11). In addition, some of the WWII-era concrete bunkers on the beach were overturned.

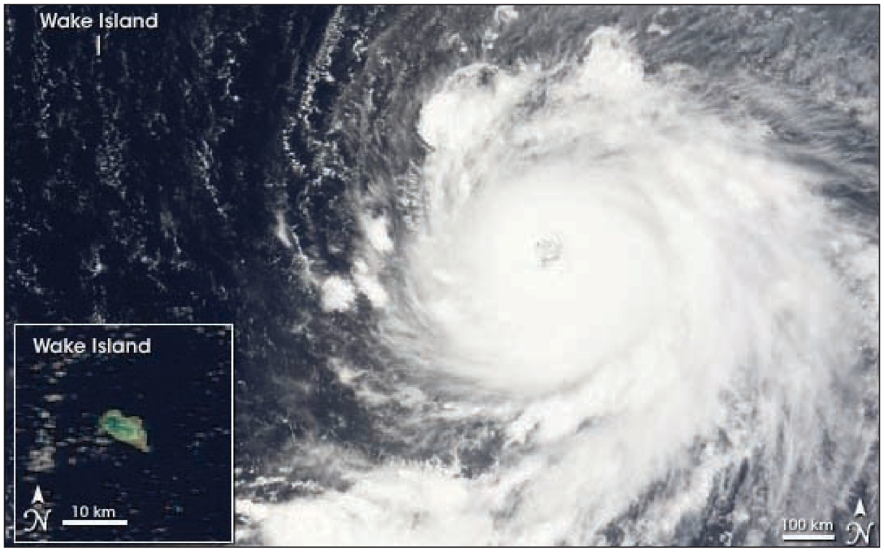

Figure 11.9. Super Typhoon Ioke, August 31, 2006. Source: NASA Earth Observatory.

According to PIFSC-CRED interviews of a Wake resident in 2007 (S. Sweistac, pers. comm.) the concrete, coral/concrete and cinder block structures, mostly built during WWII, fared much better than more recent buildings that were constructed of weaker materials. Numerous buildings were entirely destroyed and roof damage was extensive; recovery operations were still underway eight months after the storm. Fortunately, two large tanks containing aviation fuel survived the storm intact, but a third empty tank sustained considerable damage. Australian ironwood (*Casuarina)* trees on the island were denuded by the storm, but had made a significant come-back over the following eight months.

Coastal Development and Runoff

Most of the PRIA are uninhabited and have experienced few contemporary impacts from coastal development and runoff. However, there are residual impacts from military occupation and use of Johnston, Palmyra and Wake Atolls. Ship channels were dredged into the lagoons of all three, and defensive perimeter land areas were constructed around Palmyra and Wake. During WWII, Palmyra was attacked by Japanese aircraft, and Wake was taken and occupied by Japanese forces for the duration of the war. The military dredging and filling operations drastically changed water circulation patterns that still affect marine life at all three atolls.

After WWII, military use of Johnston Atoll included high-atmospheric nuclear weapons testing, chemical munitions storage and their destruction via incineration and radioactive waste cleanup after two failed Thor launches. A 25-acre landfill

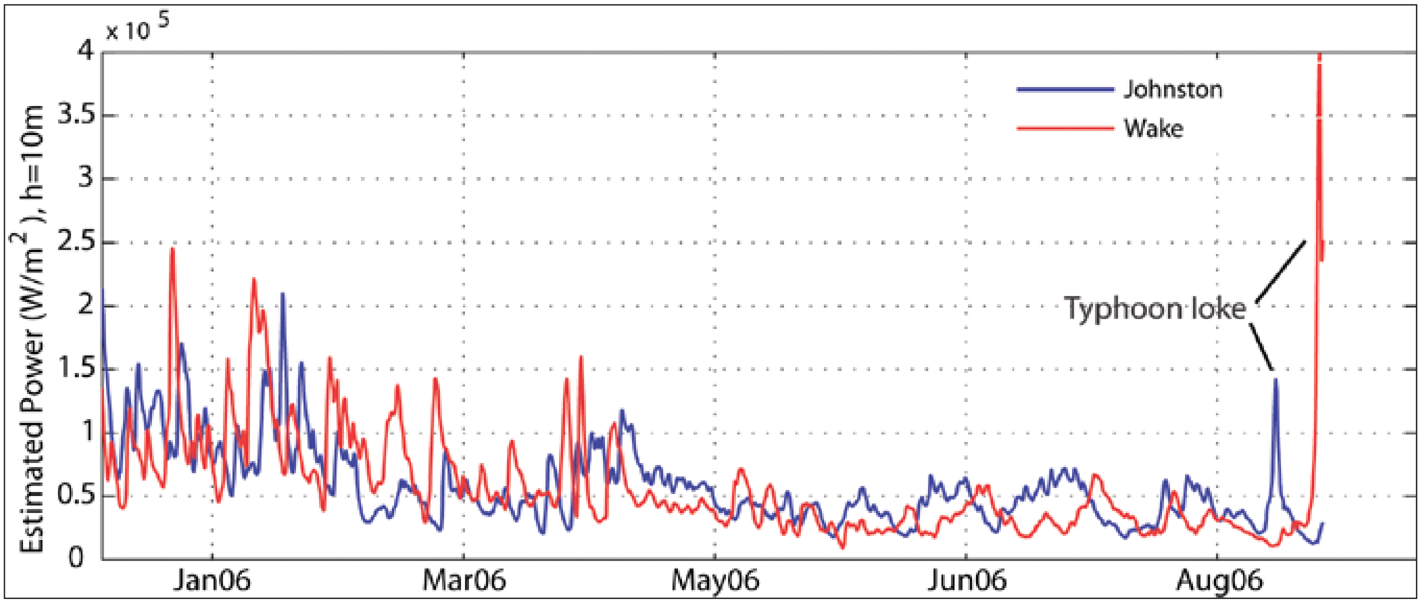

Figure 11.10. Modeled wave heights for January to mid-August 2006 from Johnson Atoll and Wake Atoll showing the anomalously large wave power associated with Hurricane/Super Typhoon Ioke. Source: PIFSC-CRED, unpub. data.

on Johnston Island still contains radioactive plutonium debris and soils. Johnston Atoll was deactivated by the military in 2005, and all personnel and structures, except one building, were removed from the island. At present, the U.S. Air Force is planning to relinquish the atoll, and the USFWS is likely to acquire the entire atoll and expand the NWR boundaries beyond those that were established by Presidential Executive Order in 1926.

Figure 11.11 Concrete blocks filled with sand and coral rubble to form a seawall were carried tens of meters up the beach on Wake Island. Photo: J. Miller.

In 2000, Palmyra was purchased by TNC, and in 2001 the USFWS purchased all of Palmyra from TNC except for the main island (Cooper) and established the Palmyra Atoll NWR. In 2006, TNC completed construction of a research station at Cooper Island. The station's research agenda includes lagoon restoration, climate change, shifting baselines for healthy coral reefs, invasive species and other global environmental threats with the goal of discovering and developing new conservation strategies for island habitats throughout the Pacific and the world. The USFWS oversees conservation management and research at the atoll in cooperation with TNC, which manages the research station and related activities on Cooper Island. Members of the research consortium include Stanford University, SIO, American Museum of Natural History, California Academy of Sciences, University of California at Santa Barbara and at Irvine, University of Hawaii, U.S. Geological Survey, TNC and Victoria University of Wellington, New Zealand. Funded by the Gordon and Betty Moore Foundation and built at a cost of $1.5 million, the station offers accommodations for up to 20 researchers, including a new galley, guest cabins, flush toilets, shower house, boat shed, a water catchment and treatment system to generate 100,000 gallons of potable water, environmentally-friendly sewage treatment, electrical generators, a maintenance shop, research laboratory, and TNC and USFWS offices. A satellite-based Internet and communications system was also installed.

Wake Atoll continues to be inhabited by military and contracting personnel. Operations buildings and residences have been largely repaired and the runway is in excellent condition. No other construction is currently planned.

Coastal Pollution

No coastal pollution was reported in the PRIA during this time period. However, researchers noted sedimentation and resultant stress on the corals located on a reef south of Johnston Island in 2006. The source and cause of the sedimentation was not determined.

Tourism and Recreation

TNC and USFWS employees deployed to Palmyra NWR to manage the research station and refuge participate in recreational activities for an average of 0.5-0.75 days per person per week. Detailed logs of recreational activities in the refuge (snorkeling, diving, swimming, boating, sport fishing, kayaking, wildlife observation and photography) are maintained by USFWS. Palmyra has historically been a popular stopover for yachts sailing in the central Pacific because of safe anchorage and plentiful freshwater. Yachts are still permitted by the NWR to visit Palmyra, but are limited to seven-day stays. In 2006, nine recreational yachts visited the Palmyra Atoll NWR in five months. Six of these vessels pre-arranged their visits, and three were unannounced. The average number of passengers and crew aboard was three per vessel and the average stay was five days per vessel. During this five-month period, a total of 165 visitor-use days were recorded on the refuge from visiting yachts. Visiting yachters also participated in recreational activities

Wake Atoll is a closed facility and not subject to visits from recreational yachts or tourists. There is a 14-hole (un-watered) golf course on the island for use by the resident population, which also has access to two small sport fishing vessels and a number of kayaks at the facility's recreational beach. There is also a small recreational diving club on the island.

Fishing

Commercial fishing is prohibited by law within the boundaries of NWRs. Baker, Howland and Jarvis have 3-nm boundaries that extend seaward from the territorial baselines (island shorelines). Twelve nm boundaries were established for Kingman, Palmyra and Midway after President Reagan extended U.S. territorial seas from 3 to 12 nm via Presidential Executive Order in 1986. However, as reported in the 2005 PRIA chapter, it is suspected that occasional incursions by commercial fishing vessels occur; little monitoring activity is possible in these remote areas, but evidence of commercial fishing incursions, such as the grounding of fishing vessels at Palmyra (1991), Rose (1993) and Kingman (2007) is apparent.

The USFWS monitors inshore vessel activity within the Palmyra Atoll Refuge, but limited access to offshore vessels prevents monitoring offshore. When visiting the atoll, yachts sometimes report the presence of commercial fishing vessels. Using radios, it is sometimes possible to determine whether a vessel is fishing within the 12-nm NWR limit or simply transiting the waters. In some cases, lights from fishing vessels can be seen at night from Palmyra, but contact via radio may or may not be possible.

At Palmyra Atoll, limited offshore blue-water fishing is allowed for subsistence purposes. No fish or coolers of fish are allowed to be taken off island by plane or ship. The fishing occurs primarily on the southern and western sides of the atoll, and yellowfin tuna (*Thunnus albacares*) and wahoo (*Acanthocybium solandri*) are the most commonly caught species. As an example of typical fishing activity, between May and September 2006, 28 tuna (weighing between 4.5 and 28 kg) and eight wahoo (weighing between 8.6 and 15 kg) were caught during 17 fishing trips. Non-target species, primarily grey reef sharks, are caught as bycatch, but are dehooked and released whenever possible. In the same period, 13 grey reef sharks were landed, 10 of which were released. Bonefish (*Albula vulpes*) fishing and catch-and-release fishing are also allowed at Palmyra for recreational purposes, but no such activities were recorded between May and September 2006. At Wake Atoll, the residents currently use two small fishing boats for subsistence and recreational fishing. Wahoo is the most commonly caught pelagic fish. Stuffed trophies of large tuna and marlin that have been caught around the island are displayed in the operations office.

Trade in Live Coral and Live Reef Species

There is no documented trade in live coral or reef species in the PRIA.

Ships, Boats and Groundings

Baker Island

The anchorage off the western leeward side of the island was used by guano miners during the late 19th century and by U.S. forces during the WWII era. Coral surveys during 2000-2006 near the site reveal increased levels of cyanobacteria and corallimorphs that appear to be stimulated by dissolved iron from discarded metallic debris. A dive survey to a depth of 35 m off the anchorage in 2006 revealed numerous corroding anchors and chains, but no vessels or other bulky military material. Upwelling waters may be transporting dissolved iron and other chemicals up the western slope from greater depths. In addition, large sections of anchor chain and ground tackle were noted during towed-diver surveys along the western reef slope. Coral populations monitored at the permanent REA monitoring site off the island landing appear to be gradually declining and the corallimorph *Rhodactis howesii* increasing. More detail on coral populations appears in the Benthic Habitats section of this chapter.

Johnston Atoll

A barge wreck site was identified at Johnston Atoll using multibeam sonar in 2006; divers also examined the wreck. In the area of the wreck, significant changes in the coral assemblage were determined based on a high abundance of the corallimorph *Rhodactis howesii*.

Palmyra Atoll
A Japanese longline fishing vessel that wrecked at Palmyra in 1991 was corroding badly in 2006, resulting in the rapid spread of *Rhodactis howesii*. The corallimorph was smothering corals and algae up to 100 m downcurrent of the wreck in 2006 and has now spread to areas over 2 km away from the wreck site.

Kingman Reef
The grounding of a wooden 26-m fishing boat at Kingman was investigated during the USFWS and SIO expedition in August-September 2007. The hull was still intact, and the impacts are presently limited to cyanobacteria outbreaks within 20 m of the wreck. It is not yet known whether the ship still contains fuel. The cumulative impacts to the reef would be much greater if the ship breaks up before being removed from the reef. At present, the U.S. Coast Guard is taking the lead in further action regarding the wreck.

Wake Atoll
Wake was the site of a furious WWII battle in 1941, and there are numerous wrecks around the atoll, on beaches, in shallow waters and in deeper waters. NOAA towed-diver surveys noted the presence of eight large anchors and associated ground tackle west of the harbor entrance in waters between 15-20 m deep. In addition, towed-diver surveys noted a large cyanobacteria bloom near a shallow wreck (R/C *Stoner*) on the eastern side of the harbor entrance in 2007, which was not readily apparent during surveys completed in the same area in 2005. The locations of deeper wrecks are not well documented, but one possible wreck approximately 200 m in length was identified from the 2007 multibeam surveys on the eastern side of the island in water depths between 430 and 460 m.

Marine Debris
Marine debris in the PRIA occurs primarily in the form of WWII-era debris and is discussed above. No attempts to characterize other sources of marine debris in the islands have been undertaken.

Security Training Activities
Naval Defensive Sea boundaries established by Presidential Executive Order prior to WWII remain in effect out to 3 nm for all of the PRIA covered in this chapter. Military vessels or military-contract vessels are occasionally seen near Palmyra Atoll. When possible, contact is made with the vessels to determine the nature of the activities. For example, on June 11, 2006, an unknown vessel was sighted and contacted by the TNC and USFWS managers. It was determined to be the Sumner, a U.S. Navy contract vessel performing bathymetric surveys. TNC and USFWS managers informed the vessel that the protected boundaries of the NWRs extend 12 nm around Palmyra and Kingman Reef. At Wake Atoll, security training activities are conducted regularly.

Offshore Oil and Gas Exploration
No offshore oil and gas exploration currently occurs in the PRIA.

Other
Crown-of-thorns Sea Star (Acanthaster planci)
In 2006, monitoring for evidence and impacts of crown-of-thorns sea star (COTS) predation indicated the presence of scars and active feeding, particularly at Johnston Atoll and Kingman Reef (Figure 11.12). COTS predation was verified at 30% of REA sites surveyed at Johnston, particularly at exposed fore reef habitats. At Kingman, feeding was documented to be most prevalent in back reef and patch reefs locales. Sites KIN-8 and KIN-3 in the north and southeast lagoon revealed as many as 44 and 29 feeding scars, respectively, in an area of approximately 500 m^2 each. Feeding scars and active feeding at Kingman Reef most commonly occurred on colonies of *Porites*, but also on *Astreopora*, *Acropora*, *Montipora*, *Pocillopora*, and occasionally on *Favia* and *Fungia*.

The presence of snail (*Drupella*) predation on corals was also noted at Baker Island, Palmyra Atoll, and Kingman Reef (Figure 11.12). At Baker, *Drupella* feeding activity was concentrated on the staghorn *Acropora nobilis*, with all eight sites visited exhibiting snail infestation and predation scars. At Palmyra and Kingman, snail corallivory occurred mainly on *Pocillopora*, but also on massive *Porties* and laminar *Montipora* (PIFSC-CRED, unpub. data).

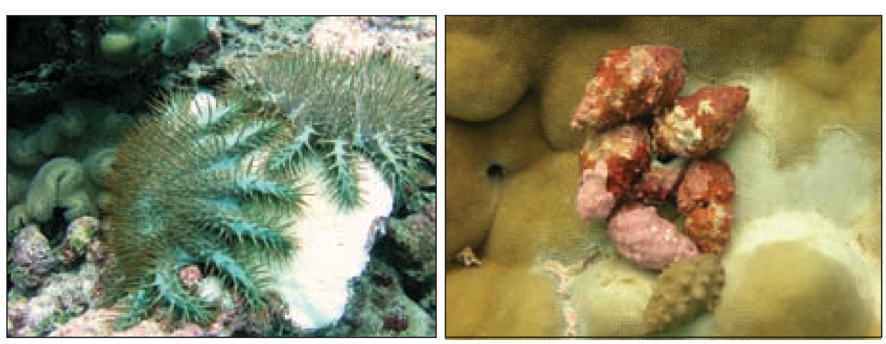

Figure 11.12. COTS on colonies of Porites *sp at Kingman reef (left) and active feeding and feeding scars of corallivorous* Drupella *(right). Photos: B. Vargas-Ángel.*

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Biota and habitat monitoring, data collection and analyses, and summaries of published studies concentrate on three functional and structural components of coral reef ecosystems: marine water quality and oceanographic conditions, benthic habitats and coral reef-associated fauna (Table 11.1). Methods described in the 2005 report are listed, with a brief discussion of changes or new protocols added since 2005. An assessment of the overall condition of each ecosystem component is also presented. Monitoring sites are depicted in Figure 11.13.

Table 11.1. Research Programs in the Pacific Remote Island Areas. Source: J. Miller and J. Maragos.

PROGRAM	OBJECTIVES	FIRST YEAR	FUNDING	AGENCIES
Bird Monitoring	Nesting seabirds and migratory shorebirds	1985	DOI	USFWS
Oceanographic Monitoring	Water chemistry and carbonate production	2000	NOAA	PIFSC-CRED
	Circulation patterns and water movement	2006	NOAA	PIFSC-CRED
	Tide and temperature monitoring	2006	SEA	SEA
	Educational oceanography	2006	TNC/FWS	PARC
Coral Monitoring	Permanent coral/clam monitoring sites	2000	DOI	FWS
	Microbial and coral diversity	2006	NOAA	PIFSC-CRED
	Benthic dynamics and coral recovery	2006	TNC/FWS	PARC
Habitat Mapping	Produce moderate-depth habitat map	2001	NOAA	PIFSC-CRED
	Algae monitoring	2003	NOAA	PIFSC-CRED
Marine Mammal and Reptile Monitoring	Monitor and assess populations	2006	NOAA	PIFSC
	Sea turtle assessments	2006	TNC/FWS	FWS/PARC
Fisheries Monitoring	Fisheries stock assessment and monitoring	1950	NOAA	PIFSC
	Reef fish monitoring	2000	NOAA	PIFSC-CRED
	Blacktip shark monitoring	2006	TNC/FWS	PARC
	Dynamics of larval fish	2006	TNC/FWS	PARC
	Compare fish populations	2006	TNC/FWS	PARC
	Apex predators and reef ecosystem effects	2006	TNC/FWS	PARC
	Production and energy flow of fishes	2007	TNC/FWS	PARC
	Mullet and gobi diversity	2006	TNC/FWS	PARC
	Bonefish diversity and post-release stress	2006	TNC/FWS	PARC
Other Biological Studies	Opisthobranch mollusk recovery	2006	TNC/FWS	PARC
	Octopus and stomatopod diversity	2006	TNC/FWS	PARC
	Bottom dwelling diversity	2006	TNC/FWS	PARC
	Barnacle diversity	2006	TNC/FWS	PARC
	Polychaete diversity	2006	TNC/FWS	PARC
	Echinoderm diversity	2006	TNC/FWS	PARC
Geological Studies	Palmyra lagoon changes due to WWII	2006	TNC/FWS	PARC

PARC = The Palmyra Atoll Research Consortium
SEA = Sea Education Association

Since 2000, NOAA PIFSC-CRED and the USFWS have sponsored biennial cruises to monitor the ecosystems of the PRIA. Except at Palmyra and Wake, virtually all monitoring and assessment activities conducted in the PRIA have been done by scientists from the USFWS and PIFSC-CRED, working in collaboration with the University of Hawaii's Joint Institute for Marine and Atmospheric Research. Cruise reports for 2005-2007 with appendices that include preliminary data analyses can be accessed at http://www.pifsc.noaa.gov/library/cruise.php (Timmers et al., 2006; Vroom et al., 2006b; Schroeder et al., 2006; Ferguson et al., 2006; Ferguson et al., 2007). Protocols used in the PRIA are similar or identical to those used during Pacific RAMP surveys of U.S. jurisdictions throughout the Pacific, allowing direct comparison of results that have been obtained using the same methods and, in many cases, by the same scientists.

The Palmyra Atoll Research Consortium has initiated a variety of ecosystem research projects at the recently established Palmyra research facility. In particular, SIO conducted detailed ecological surveys at the five northern Line Islands in August-September 2005, including Palmyra and Kingman, and followed up with additional surveys at Palmyra in 2006. In August and September 2007, SIO sponsored another expedition to Kingman involving microbe, coral, fish and algal surveys at multiple depths (5 m, 10 m, 20 m) at 15 fore reef sites and at more than 50 sites in other major habitats (back reef, pinnacle, reef pool).

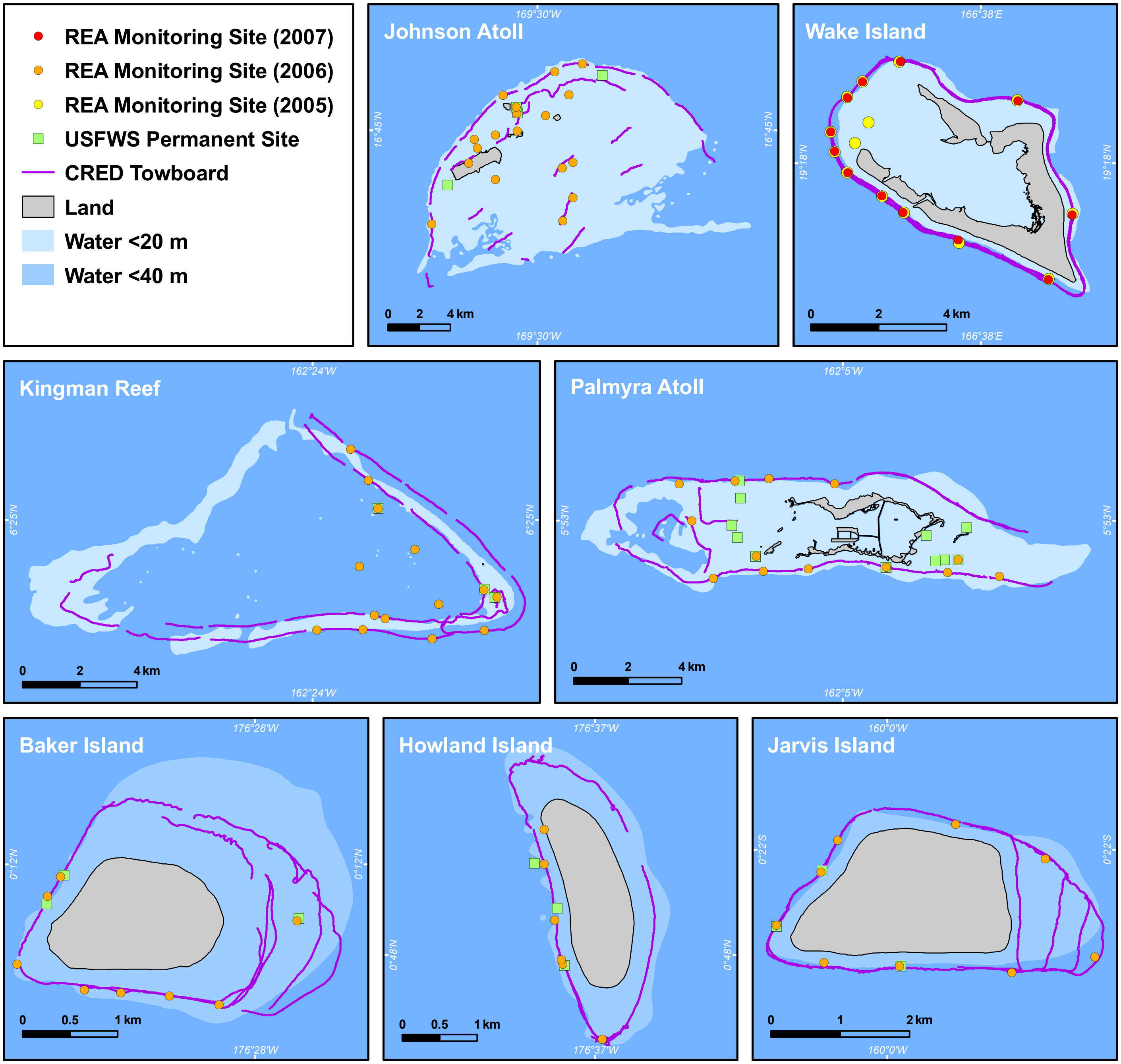

Figure 11.13. Map of monitoring locations discussed in this chapter. Map: K. Buja.

WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

The health, functioning and biogeography of the PRIA coral reef ecosystems are influenced by the regional oceanographic conditions. The broad and diverse biological communities that make up these ecosystems (fish, corals and other invertebrates, algae, turtles and marine mammals) are subject to fluctuations of time-varying ocean currents, waves, temperature, salinity, turbidity, nutrients and other measures of water quality and oceanographic conditions. As these conditions change over time, so do the physical condition, distribution, abundance and species diversity of coral reef communities. Table 11.2 presents long-term oceanographic monitoring methods and equipment used in the PRIA since 1999.

Palmyra Atoll lies approximately 5.5° north of the equator in the ITCZ where the northeast and southeast trade winds meet. The prevailing wind climate is light and variable, and is punctuated by periods of northeasterly winds (Figure 11.14). Palmyra Atoll experiences periodic fast-moving squalls, which generally proceed from east to west and are associated with heavy rainfall.

Table 11.2. Oceanographic monitoring systems in the PRIA. Source: PIFSC-CRED.

SYSTEM	VARIABLES MONITORED	DATES	AGENCY
Deep-water CTDs* at select locations near the islands	Conductivity (salinity), temperature, depth, dissolved oxygen, chlorophyll to a depth of 500 m	February 1999-Present	PIFSC-CRED
Shallow-water CTDs - multiple sites each island/atoll	Temperature, salinity, turbidity	February 2001-Present	PIFSC-CRED
Water Samples	Chlorophyll and nutrients (nitrate, nitrite, silicate, phosphate) concurrent with deep and shallow-water CTDs at select depths	July 2003-Present	PIFSC-CRED
Coral Reef Early Warning Buoys - 1 enhanced (Palmyra)	Enhanced: Temperature (1 m), conductivity (salinity), wind, atmospheric pressure, ultraviolet radiation, photosynthetically available radiation	February 2002-Present	PIFSC-CRED
Sea Surface Temperature (SST) Buoys - 6 (Johnston, Kingman, Wake, Jarvis, Baker, Palmyra)	Temperature at 0.5 m	February 2002-Present	PIFSC-CRED
Subsurface Temperature Recorders - 44 (all islands)	Temperature at depths between 0.5 and 30 m	February 2002-Present	PIFSC-CRED
Ocean Data Platforms (ODP) - 2 (Baker, Jarvis)	Temperature, conductivity (salinity), spectral waves, current profiles	October 2002-Present	PIFSC-CRED
Wave and Tide Recorders (WTR) - 1 (Johnston)	Wave and tidal heights	July 2003-Present	PIFSC-CRED
CTD*= Conductivity, temperature and depth.			

The physical interaction of ocean currents around Jarvis Island has been the focus of two historical oceanographic surveys, which showed that the blocking of the EUC by Jarvis results in current-flow stagnation and shallowing of isotherms on the upstream or western side of the island (Hendry and Wunsch, 1973; Roemmich, 1984). More recently, a study by Gove et al. (2006) focused on the time dependency of nearshore temperature fluctuations, and showed that upwelling at Jarvis can be highly variable on seasonal-to-interannual time scales. The superposition of internal tides on EUC-driven upwelling can produce rather remarkable temperature changes, some as great as 4°C and occurring multiple times a day (Figure 11.15).

Variable upwelling can provide a significant source of nutrients to the surrounding ecosystem, helping to fuel productivity to an otherwise oligotrophic environment. Water quality samples recently collected from Jarvis showed a marked increase in nutrient and chlorophyll concentrations in upwelled waters, and in some cases, showed three to four times greater concentrations compared to samples collected at other locations around the island (Figure 11.16).

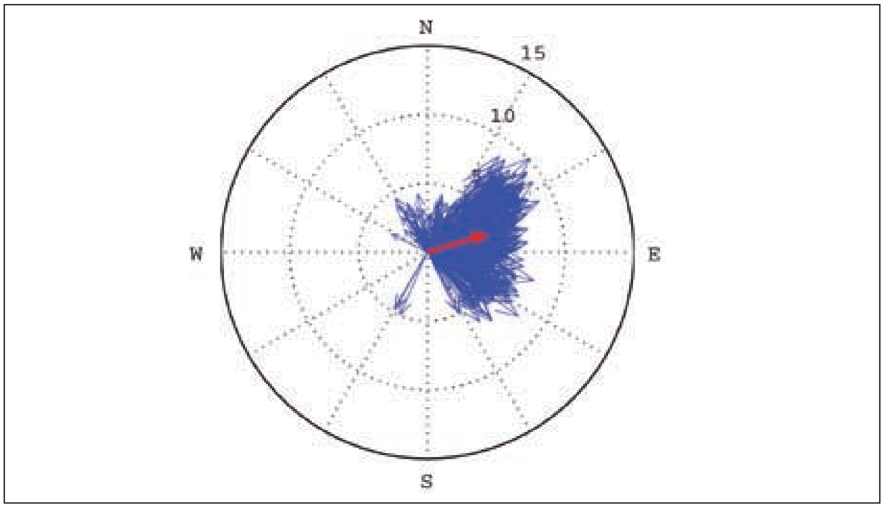

Figure 11.14. Wind plot for Coral Reef Early Warning System buoy data 2 m above the sea surface at Palmyra Atoll. Blue arrows depict the daily averaged wind direction and magnitude (from 0–15 m/s) for the time period from March 30, 2004–April 12, 2006 and the red arrow is the average wind direction and magnitude for that entire time period. Data points outside of three standard deviations from the mean were removed prior to plotting. Source: PIFSC-CRED, unpub. data.

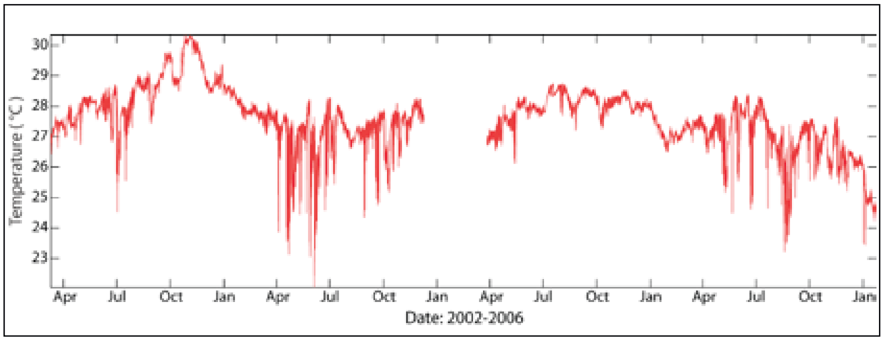

Figure 11.15. In situ *temperature at approximately 15 m depth from the west side of Jarvis Island shows variable upwelling superposed with periods of high frequency temperature fluctuations of 1–4 °C occurring one/two times daily. Source: Gove et al., 2006.*

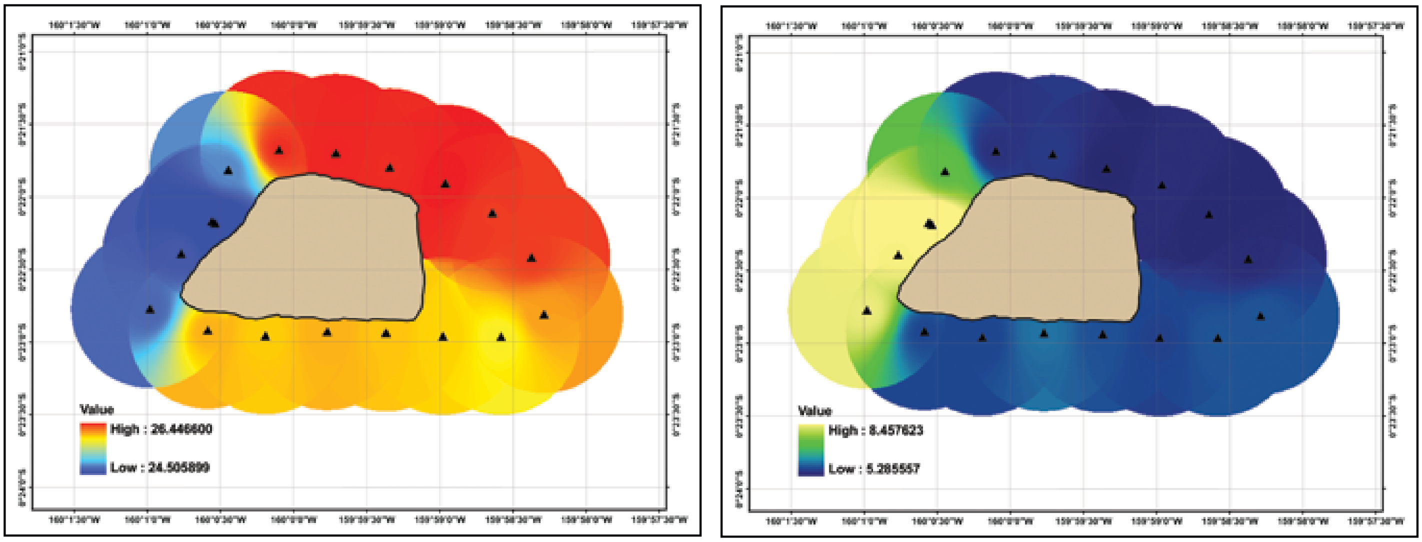

Figure 11.16. The left panel depicts Jarvis Island water temperature at 30-m depth showing the upwelling of cooler, nutrient-rich waters originating from the EUC near Jarvis Island. Upwelled waters influence fish assemblages and distributions and other components of the local coral reef ecosystem. The right panel depicts Jarvis Island total nitrogen concentration at 30-m depth illustrating nutrient enrichment following upwelling patterns. The black triangles in both plots indicate in situ *sampling sites for temperature and nutrients. Source: Gove et al., 2006.*

BENTHIC HABITATS

The PIFSC-CRED Pacific RAMP conducts biennial cruises to understand benthic community structure at all PRIA and to monitor the health of the coral and algae habitats over time. The Pacific-wide scope of this monitoring program, using similar protocols in the Hawaiian Archipelago, the Mariana Archipelago, American Samoa and the PRIA provides scientists with a wealth of integrated ecosystem observations that can be compared and contrasted with information across the Pacific region. During 2006 and 2007, multibeam surveys were conducted to provide baseline maps for a better understanding of the underlying structures and environments that support coral and algal habitats. New benthic habitat research at Palmyra Atoll provides more focused research on Palmyra-specific benthic habitats.

Habitat Mapping

In support of the U.S. Coral Reef Task Force's mission to "produce comprehensive digital maps of all shallow (<30 m) coral reef ecosystems in the United States and characterize priority moderate-depth reef systems," NOAA has initiated comprehensive mapping of the Pacific Islands region. For the PRIA, the USFWS and NOAA purchased and have made available IKONOS imagery that is used as base layers for habitat analyses.

The NOAA Coral Reef Conservation Program supported moderate-depth multibeam mapping surveys in the PRIA during Pacific RAMP cruises in 2006 and 2007. Submersible dives and multibeam surveys in deeper waters were also conducted around Jarvis Island, Kingman Reef and Palmyra Atoll by the Hawaii Undersea Research Laboratory of the University of Hawaii with support from NOAA as documented at http://www.noaanews.noaa.gov/stories2005/s2487.htm.

Methods

NOAA multibeam bathymetric surveys were conducted in 2006 and 2007 by personnel from PIFSC-CRED using mapping systems aboard the NOAA Ship *Hi'ialakai* and the survey launch R/V *Acoustic Habitat Investigator* (*AHI*). Bathymetric data were processed aboard ship and grids of the 2006 bathymetric data were published on the Internet in October 2006 at http://www.soest.hawaii.edu/pibhmc. Multibeam backscatter grids, which provide additional information about the roughness and hardness of the seafloor; derivative data products, such as slope, rugosity, and bathymetric position index; and limited optical validation data collected in 2001 are also available at this Web site. These products provide information about benthic habitats in water depths ranging from 3 to 3000+ m with complete bathymetric coverage at all sites except for Johnston, Palmyra and Kingman Atolls (Table 11.3). The total area surveyed in the PRIA is 4461 km^2. Multibeam bathymetric surfaces reveal interesting similarities and differences among the seven PRIA discussed here: Baker, Howland and Jarvis are isolated islands that rise from abyssal seafloor (4,000+ m) whereas Kingman, Palmyra, Johnston and Wake have been built on top

Table 11.3. PRIA Multibeam Coverage. Source: PIFSC-CRED, unpub. data.

SITE	WAKE	JOHNSTON	PALMYRA	KINGMAN	BAKER	HOWLAND	JARVIS
Survey Date	April 26-30 2007	Jan. 18-23 2006	March 24-28 2006	March 29-April 3 2006	Jan. 27-29 2006	Jan. 30-Feb. 1 2006	March 20-22 2006
Coverage (km^2)	668	992	1082	926	221	256	316
% Completion (10-3,000 m)	99	~85	~90	~75	100	100	100

of larger underlying ridges that are shallower than 4,000 m. These seven PRIA are located in the Central Pacific Basin on seafloor that ranges in age from 83-160 million years ago (Ma). After seafloor formation, extensive Cretaceous (70-100 Ma) volcanism took place throughout the central Pacific.

Geological ages (Clouard and Bonneville, 2005) for the individual islands are only well defined for Johnston Atoll (71.3 Ma), Kingman Reef (69.8 Ma; Davis et al., 2002) and Baker Islands (70.1 Ma; Koppers and Staudigel, 2007). The geologic history of the PRIA is discussed in more detail in the concurrent National Coral Reef Institute 2008 volume on Coral Reefs of the USA (Maragos et al., In press). Baker, Howland and Jarvis are all within one degree of latitude of the Equator and are all steep-sided, very small islands with little evidence of mass wasting on the flanks (Figure 11.17). Baker and Howland Islands are located in the Phoenix Island group on the Tokelau Ridge, while Jarvis Island is one of the four PRIA of the Line Islands group (the others are Johnston, Kingman and Palmyra). The three equatorial PRIA are also located near the Clipperton Fracture Zone. All three are tiny islands with previous sea level stands that can be inferred from small shelf areas that have been detected at up to 500-m depths on the radiating rift zones. The bank areas in shallow water are very limited in size, and there is little potential for coral growth on the steep, deeper flanks of Baker, Howland or Jarvis.

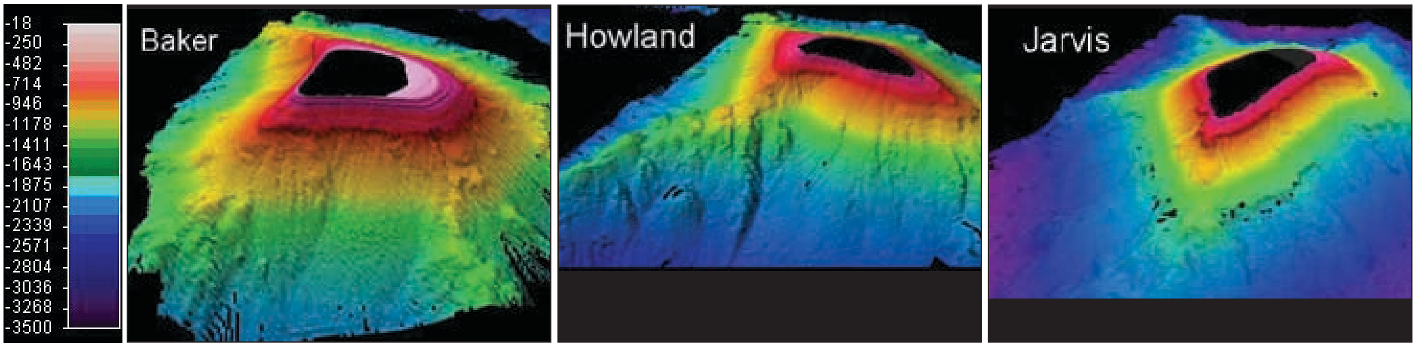

Figure 11.17. 3-D images of Baker, Howland and Jarvis Island bathymetry. Source: PIFSC-CRED.

In contrast, Palmyra and Wake Atolls, Johnston Atoll and Kingman Reef are morphologically much more complex and highly variable in structure. Johnston is the farthest north of the Line Islands. Although its name implies an atoll, the emergent perimeter reef extends only along the northwest side of Johnston. (Figure 11.18).

Keating's (1987) and Emery's (1956) research strongly suggest that geological forces have caused the bank around Johnston Island to tilt to the southeast. The multibeam bathymetry shows limited areas of shallow (<20 m) offshore bank on the southeast and southwest corners. Moderate-depth multibeam maps show steep slopes on the south and east sides of the banks with extensive evidence of mass wasting on these slopes. Several very narrow shelves occur around the island in depths less than 130 m; such shelves are indicators of previous sea level stands. On the northwest side, there is a 6-8 km wide area of low slope in depths ranging from 500-1,800 m.

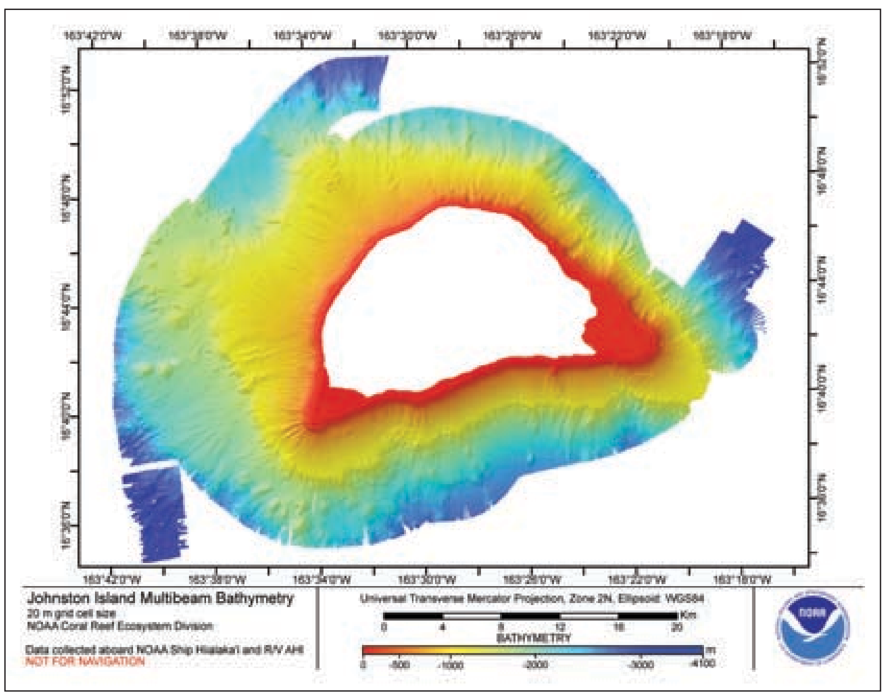

Figure 11.18. Johnston Atoll multibeam bathymetric map. Source: PIFSC-CRED.

Palmyra Atoll, Kingman Reef, Christmas Atoll, Fanning Atoll and Washington Island are all located on a broad ridge-like area that is over 1,100 km long and up to 280 km wide. Palmyra has a secondary peak about 3 nm to the west of the atoll that rises to less than 1,000 m (Figure 11.19). The northern flank of the atoll is extremely steep with canyons cutting into the sides to very shallow depths, but the southern flank slopes more gradually. Extensive evidence of mass wasting is seen everywhere except on this steep northern flank. Except for areas with depths less than 20 m, there is no evidence of shelves that would indicate previous sea level stands on the flanks of either Palmyra Atoll or Kingman Reef.

Kingman Reef, located about 50 km north of Palmyra, also lies on a broad ridge-like structure with a secondary peak about 5 km to the west (Figure 11.20). Steep, incised slopes are seen on the northeast, northwest and south sides of the structure. However, anomalous conical structures are seen on the southeast and southwest sides of Kingman and continue to the adjacent bank, following what are likely rift zones. While these might be evidence of mass wasting, they do not occur on the flanks as is expected with erosional features, and the conical shape is more typical of volcanic features.

Wake Atoll (Enen Kio) lies 2,800 km west of Johnston Island in the Marshall Island chain on seafloor that was formed over 160 Ma. No age is available for Wake Atoll, but its neighbor in the Marshall Islands, Enewetak Atoll, was dated at 75.84-76.26 Ma (Clouard and Bonneville, 2005). Beyond the shallow water (<25 m), habitats surrounding the island, Wake Atoll drops off steeply on all sides from 20 to 500 m and almost vertically at the northwest corner (Figure 11.21). No shelf structures occur between 25 and 300 m that would indicate previous sea level stands. However, the ridge that extends out from the southeastern corner of the island has a relatively low slope in depths greater than 500 m and, from nautical charts, appears to extend over 22 km to the east. Evidence of mass wasting is seen on the south and east sides of the island at 2000-3500 m depths.

Coral Communities in the PRIA

Coral assessment and monitoring activities in the PRIA have continued through the cooperative research efforts of PIFSC-CRED, USFWS and partner institutions noted above, including scientists from SIO, Bishop Museum, University of Hawaii (UH) and Oceanic Institute. Survey techniques are described in detail in the 2005 edition of this report (Brainard et al., 2005) and include REAs and towed-diver surveys that average about 2 km in length. These techniques have focused on collecting data to compute metrics of coral biodiversity, frequency, mean diameter, distribution, abundance, percent cover and size structure.

Since 2005, REA activities have followed the revised protocol established in 2004 (Brainard et al., 2005; Maragos et al. 2004) with several modifications. The line-intercept method was added in 2005 with data collected at 50-cm intervals along the first two 25-m transects to estimate percent cover of live coral and other benthic categories. In 2006 this method was further modified to include all corals whose colony center fell within 0.5 m on each side of the transect line. Quantitative disease assessments, initiated in 2004 at Johnston, Baker and Howland have now been expanded to all REA sites in the PRIA. Extended deployments allowed the establishment of three new REA sites at Johnston and two at Kingman. Figure 11.13 shows the locations of REA sites

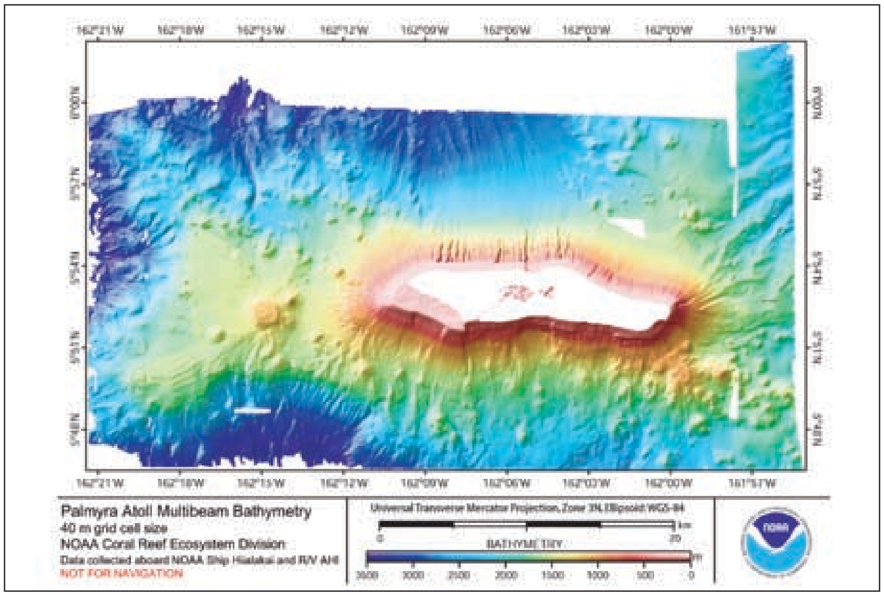

Figure 11.19. Palmyra Island multibeam Bathymetry. Source: PIFSC-CRED.

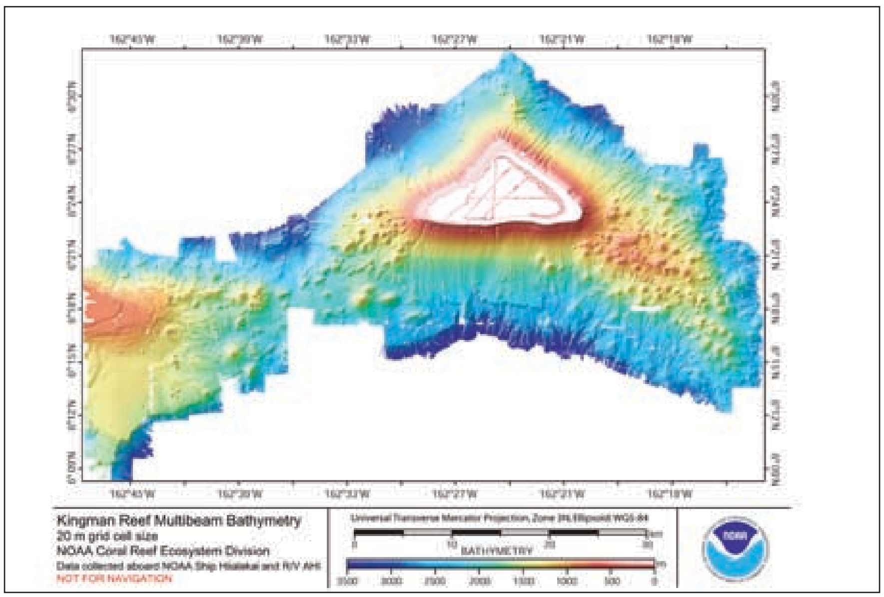

Figure 11.20. Kingman Reef multibeam bathymetry. Source: PIFSC-CRED.

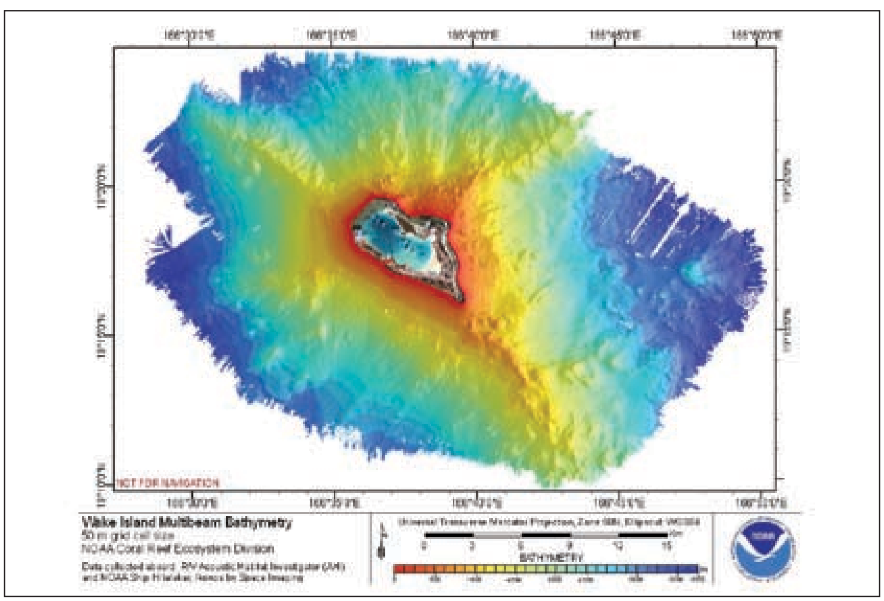

Figure 11.21. Multibeam bathymetric map of Wake Island. Source: PIFSC-CRED.

visited between 2005 and 2007. Table 11.4 summarizes the number of study sites at each location.

Table 11.4. Summary of coral rapid ecological assessment (REA), permanent transect (PT), and towed-diver (TD) surveys in the PRIA in 2005-2007. Source: PIFSC-CRED.

	2005		2006			2007	
Location	**REA**	**TD**	**REA**	**PT**	**TD**	**REA**	**TD**
Wake	14	19	-	-	-	12	19
Johnston	-	-	18	4	27	-	-
Kingman	-	-	16	2	22	-	-
Howland	-	-	6	3	6	-	-
Baker	-	-	8	4	10	-	-
Palmyra	-	-	13	2	22	-	-
Jarvis	-	-	9	2	12	-	-

Coral Communities at NWR in the Line and Phoenix Islands in 2006

Howland Island Coral Communities

Corals were most recently surveyed at Baker Island NWR and Howland Island NWR between January 28-February 1, 2006, including five REA sites at Howland. As has been the case during prior visits, onshore winds and swells prevented surveys off the eastern half of Howland, except for one site near the south end (HOW 9). Strong currents off the southern and northern reef terraces of the island prevented stationary dives, although towed-diver surveys were successfully completed there. Hence, REA surveys at Howland are still limited in coverage. A total of 98 species and 30 genera of corals and anemones have now been reported from Howland. The species total for cnidarians (stony corals, anemones and corallimorphs) is slightly higher at Howland vis-à-vis Baker, but the generic total at Howland is much lower than at Baker Island (92 species, 38 genera) where all sides of the island and habitats have been surveyed. The mushroom coral (*Podabacia crustacea)* was reported for the first time at Howland in 2006. Table 11.5 summarizes 2006 population data collected at five sites at Howland. Unfortunately, only one REA site (HOW 16, off the NW coast) was surveyed during both 2004 and 2006. At this site, coral cover declined from 60 to 26%, coral densities increased from 2.9-11.4 colonies/m^2, and mean coral diameters declined from 50-21 cm. Nevertheless, the surveys elsewhere reveal an increase in coral densities, a shift from larger to smaller corals, and an increase in overall abundance by 2006. The values range from 23-38% live coral cover at three sites in 2004 and 26-65% at five sites in 2006. Density values rose from a range of 2.9-3.9 colonies/m^2 in 2004 to a range of 8.1-15.2 colonies/m^2 in 2006. In addition, *Psammocora* was abundant in several size classes in 2006 but absent altogether in 2004. Moreover, several genera (*Fungia*, *Hydnophora*, *Leptastrea*, *Pocillopora*) were substantially more common in most size classes in 2006.

Table 11.5. Numbers of corals per genus, frequency, mean diameter and cover by site reported at Howland in January 2006. Bold=increases and italics=decreases since 2004 at sites 5P and 16. Source: J. Maragos, unpub. data.

HOWLAND ISLAND NWR 2006 CORAL SITES							
Genus	**Site Number Number of Corals/Genus**					**Total / Genus**	**% of Total**
	14P	**11P**	**5P**	**16**	**10**		
Acropora	60	41	*6*	**30**	15	152	5.3
Cycloseris	1		**2**			3	0.11
Cyphastrea	1			**1**		2	0.07
Echinopora			**1**			1	0.04
Favia	11	5	**10**	*4*	15	45	1.58
Favites	9	1		**6**	2	18	0.63
Fungia	15	93	**74**	**37**	1	220	7.74
Gardineroseris	19	9	**3**	**4**	1	36	1.27
Herpolitha		1				1	0.04
Hydnophora	7	7	1	**8**	56	79	2.78
Leptastrea	14		**20**	*2*		36	1.3
Lobophytum		19				19	0.67
Montipora	59	223	*10*	**51**	21	364	12.8
Palythoa				**1**		1	0.04
Pavona	97	62	**52**	**113**	77	401	14.1
Pocillopora	115	241	**123**	**259**	176	914	32.2
Podabacia				**1**		1	0.04
Porites	79	56	**23**	*46*	161	365	12.8
Psammocora	4	1	**1**	**6**	20	32	1.13
Rhodactis			**78**			78	2.74
Tubastraea					74	74	2.6
Total No. /Site	491	759	**404**	**569**	619	2,842	99.98
Mean Diameter (cm)	30	22.1	*25.5*	*20.7*	23.2		
Density (colonies/m^2)	9.8	15.2	**8.1**	**11.4**	12.4		
No. of Genera	14	13	**14**	**15**	12		
% Coral Cover	53.8	65.3	**43.5**	*26.1*	45.5		

Baker Island Coral Communities

A total of eight REA sites were surveyed at Baker. One dive at site BAK 5 was made to a depth of 30 m to collect photos and sediment samples for toxicity analyses. Collectively, 42 cnidarian and 36 stony coral genera have now been found at Howland and Baker although 15 of these genera are found only at one island or the other. New records for corals at Baker were *Rhizopsammia verrilli* and *Cladopsammia eguchii*. Table 11.6 summarizes all coral population data collected in 2006. Coral species richness was high at all but one site and ranged from 8-11 genera in 2004 compared to a range of 5-13 genera in 2006. Density values ranged from 2-4 colonies/m^2 in 2004 to 2-9 colonies/m^2 in 2006. Baker site 16p had a lower number of coral genera (five) on the transect compared to other sites, due to the dominant staghorn *Acropora* that monopolized substrates. Abundance of *Acropora* staghorn corals appears to have increased at most stations and survey counts of this genus are collectively among the most abundant corals in the PRIA.

Coral population data were collected at the same three Baker REA sites in 2004 and 2006 (BAK 2, 7 and 9). Coral densities in 2006 at the three sites were substantially higher (8.9, 3.2, 6.5 colonies/m^2, respectively) than in 2004. In 2006, the largest corals densities at the three sites were comparable to those observed in 2004, but there was a major increase in the numbers of corals in the 4 smallest size classes. The 2004 percent coral cover estimates for the three sites were 16, 49 and 27%, respectively, compared to 16, 27 and 68%, respectively, in 2006. The red invasive corallimorph, *Rhodactis howesii,* showed a dramatic increase at site BAK 5P in 2006 and is now present at site BAK 11P. Both of these sites served as boat landings, and corroding iron from long-abandoned anchors and chains may be stimulating the growth of this species.

Table 11.6. Numbers of corals per genus, frequency, mean diameter and cover. Bold=increases and italics=decreases since 2004 at sites 9, 2, 7 and 5P. Asterisk (*)=anemone and two asterisks (**)=corallimorph. Source: Maragos, unpub. data.

2006 BAKER ISLAND NWR CORAL SITES										
Genus	Site Number Number of Corals/Genus								Total/ Genus	% of Total
	16P	9	2	7	5P	11P	3	6		
Acropora	112	**166**	**163**	**279**	**254**	151	157	190	1,472	60.7
*Aptasia			*0*		*0*				0	0
Cyphastrea		**2**	**2**		**3**	1			8	0.33
*Entacmaea							1		1	0.04
Favia		**22**	**6**	*2*	**1**	9	8	3	51	2.1
Favites		**2**		2			1	1	6	0.25
Fungia		**62**	**107**	**5**		11	102	16	303	12.5
Halomitra			*0*	**1**					1	0.04
Herpolitha				**1**	**1**		2		4	0.17
*Heteractis							2		2	0.08
Hydnophora		*0*					1		1	0.04
Leptastrea		*0*	**2**	**1**	**1**	1		1	6	0.25
Leptoseris		**3**	**8**	*0*		2			13	0.54
Montipora		**9**	*4*	*0*	**22**	2	1		38	1.57
Palythoa		*0*	**1**						1	0.04
Pavona	1	*4*	**18**	**5**	*1*	21	14	1	65	2.68
Pocillopora	1	*50*	**118**	*13*	**24**	31	76	32	345	14.23
Porites	1	*1*	**16**		**3**		5	1	27	1.11
Psam-mocora	1	*3*	*0*	**1**			2		7	0.29
**Rhodactis				*0*	**70**	2			72	2.97
Tubastraea			**1**						1	0.04
Total No. /Site	116	**324**	**446**	**310**	**380**	231	372	245	2,424	99.97
Mean Diameter (cm)	128	*37.3*	*16.8*	*26.1*	*16.6*	22.4	24.1	28.5		
Density (colonies/m^2)	2.3	**6.5**	**8.9**	**6.2**	**7.6**	4.6	7.4	4.9		
No. of Genera	5	11	**12**	**10**	**10**	10	13	8		
% Coral Cover	87.2	**68.3**	15.9	*27*	*15.6*	17.7	32.1	33.7		

Jarvis Island Coral Communities

Coral communities were censused at nine Jarvis REA sites between March 21-22, 2006. Calm sea conditions allowed the REA team to survey three sites off the north side of the island and two off the east side, providing more complete coverage than previous surveys at Jarvis. Table 11.7 summarizes the results of coral population censuses at all nine sites. No new genera or species of corals were added in 2006 to the total of 50 species previously reported at the island. The coral fauna at Jarvis is unusual in that it is low in diversity compared to other Line Islands (except Johnston) that have been surveyed for corals during the past several decades. Its geographic isolation and small size may account for this anomaly. Jarvis lies west of the main northwest-southeast axis of the Line Islands, with its nearest neighbors being Kiritimati Atoll (200 nm to the northeast) and Malden Island (350 nm to the southeast). The northern and western sides of Jarvis are exposed to large swells from the northwestern Pacific. Some REA sites that are protected from swells support larger and more numerous corals and high coral cover (JAR 2, 4Pa).

Three REA sites at Jarvis (JAR 1, 8, 10) were surveyed during 2004 and 2006. In all cases coral populations were more abundant and diverse in 2006. Many more corals and higher densities were also reported at all three sites in 2006; density values ranged from 1-2.5 colonies/m^2 in 2004 compared to 2-7 colonies/m^2 in 2006. Corals in smaller size classes were more numerous in 2006, except one larger size class (41-80 cm in diameter) that was more abundant in 2004. Diversity increased from 3-4 genera/transect in 2004 to 5-8 genera/transect in 2006.

Johnston Atoll Coral Communities

The first surveys by PIFSC-CRED and USFWS at Johnston were completed in January 2004; the second set of surveys were completed in January 2006. Corals were censused at 17 sites between January 18-23, 2006, including 11 REA sites previously surveyed in 2004. Johnston supports three hydrozoan stony corals (*Millepora*, *Distichopora*, *Stylaster*) not found farther north in Hawaii. Johnston has also historically supported prolific growths of at least 10 species of table corals in the genus *Acropora,* especially within the semi-protected lagoon. Most of these species are believed to have colonized Hawaii (450-800 nm north) via Johnston Atoll (Maragos and Jokiel, 1986). Unexpectedly, the otherwise protean Pacific coral genera of *Porites* and *Pocillopora* contribute only minor fractions of the coral fauna at Johnston compared to *Montipora*, *Acropora* and *Pavona*. Coral REA surveys were accomplished in 2006 at windward ocean-facing fore reef

Table 11.7. Numbers of corals per genus, frequency, mean diameter and cover by site reported at Jarvis Island NWR in January 2006. Bold=increases and italics=decreases since 2004 at sites 8, 1 and 10. Source: J. Maragos, unpub. data.

2006 JARVIS ISLAND NWR CORAL SITES											
Genus	**Site Number Number of Corals/Genus**									**Total/ Genus**	**% of Total**
	9	**8**	**1**	**10**	**4P**	**2**	**12**	**7P**	**11P**		
Acropora				*0*	1	3				4	0.22
Distichopora				**87**						87	2.69
Favia	2			**1**		1		2		6	0.22
Fungia	27	**1**			7	1	24			60	1.88
Hydnophora							1			1	0.03
Leptoseris	1	**2**	**1**	**1**						5	0.15
Millepora	1			**12**	6		22	3	18	62	1.92
Montipora	182	**53**	**57**	**8**	240	404	71	322	285	1,622	50.1
Pavona	23	**20**	**28**	**34**		2	13	6	9	135	4.17
Pocillopora	123	**22**	**36**	**243**	390	76	71	131	86	1,178	36.4
Porites	2	**1**	**2**	*0*				16	25	46	1.42
Psam-mocora	2	**1**								3	0.1
Sinularia	1	**2**	**1**	**1**				17		22	0.68
Tubastraea							1			1	0.03
Total No. /Site	364	102	125	387	644	487	203	497	423	3,232	100.01
Mean Diameter (cm)	29.3	*11.3*	*11.5*	*19.4*	27.4	29.9	16.1	27.2	22.9		
Density (colonies/m²)	7.3	**2**	**2.5**	**7.7**	12.9	9.8	4.1	9.9	8.3		
No. of Genera	10	**8**	**6**	**8**	5	6	7	7	5		
% Coral Cover	37.7	*1.8*	**2.4**	*13.4*	70.8	60.4	14.1	45.2	25.7		

sites (JOH 14, 15, 16, 17) for the first time. Coral densities, percent cover and mean diameters were lowest and generic diversity highest at ocean sites. Evidence of persistent wave action and active predation by COTS were observed on the fore reef and are likely the cause of reduced coral abundance. COTS counts yielded 4-5 per 100 m^2 at three of the sites. Table 11.8 summarizes results for the 11 sites surveyed in 2004-2006.

Comparisons of coral population size structure at 2004 and 2006 REA sites revealed substantial changes during the two-year interval. All 11 sites showed declines in mean coral diameter, most showed reductions in larger corals and increases in density of smaller coral colonies, and all but one site showed declines in coral cover in 2006. (Table 11.8). Overall, average coral cover declined from nearly 30% in 2004 to 25% in 2006. The number of colonies in the largest size class of table corals (*Acropora cytherea*) declined from 25 in 2004 to 12 in 2006, and all but one of the 41 largest *Montipora* colonies and the four *Pavona* disappeared or fragmented into smaller colonies. The large increase in small *Montipora* colonies in the northern lagoon (JOH 4, 5P, 8, 9, 11,12) was insufficient to offset the loss of larger colonies at the surveyed sites; thus, overall coral cover declined. All but two species (*Fungia* and *Pocillopora*) declined in abundance during the two-year period.

Palmyra Atoll Coral Communities in 2006

Palmyra has been surveyed for corals on nine occasions since 1987, and more than 190 species and 50 genera of corals and other cnidarians have been reported. Corals were censused at 13 REA sites in March 2006. Calm sea conditions allowed the REA team to expand coverage of REA sites further to the northeast and southeast. Coral surveys in 2006 were more extensive than during any previous surveys. Despite a number of previous efforts, new records continue to be reported, including two during the 2006 visit: the octocoral *Pachyclavularia violacea* and an unidentified scleractinian, *Echinophyllia* sp. The coral faunas at Palmyra and nearby Kingman are much more diverse than at the other surveyed Line Islands. Possible reasons are that Palmyra has been much better sampled, is larger, and has a more varied habitat than neighboring reef islands (Jarvis, Teraina, McKean, Howland, Baker). Both Palmyra and Kingman are often in the path of the eastward-flowing NECC, which may transport larvae of additional coral species from the more diverse western Pacific. Table 11.9 summarizes the characteristics of coral populations at all Palmyra 2006 REA sites.

Six of the REA sites at Palmyra (PAL 1, 10, 16P, 19, 25, 26) were surveyed both in 2004 and 2006; all of them are located on the south side of the atoll. At all sites coral populations showed larger mean colony diameters and lower density values, except for a slightly higher density value at site PAL 1 in 2004. Much of the shift to a smaller mean size is attributed to more numerous small coral recruits in 2006. The soft coral *Lobophytum* showed phenomenal increases in 2006, and another octocoral, *Stereonephthya* also increased in abundance. The stony lobe coral *Porites*, and disc coral *Pavona*

Table 11.8. Coral population characters, numbers of corals per genus and coral size frequency distributions in 2006 at the same 11 sites surveyed in 2004. Bold=increase and italics=decrease in values since 2004. *Source: J. Maragos, unpub. data.*

CORAL POPULATION CHARACTERS AT JOHNSTON SITES RESURVEYED IN 2006													
	Site Number Number of Corals/Genus											2004	2006
	1	*2*	*3*	*4*	*6*	*7*	*8*	*9*	*10P*	*11*	*12*	MEANS	
Mean Diameter (cm)	22.1	18.6	16.7	8.8	36.9	16.1	7.9	10.2	18.3	23.5	21.5	**28.9**	*18.24*
Density (colonies/m²)	**9.3**	**11.7**	**7.5**	**42.6**	1.4	**9.5**	**13.6**	**15.2**	**7.1**	**10.8**	**12.5**	*5.49*	**12.84**
No. of Genera	4	4	**5**	3	6	**6**	**7**	**6**	4	4	**5**	*4.45*	**4.9**
% Coral Cover	**52.6**	**53.9**	7.06	**20.7**	14.2	8.57	5.53	7.92	20.4	45.9	38.6	**29.66**	*25.03*
NUMBER OF CORALS/GENUS AT 11 JOHNSTON SITES RESURVEYED IN 2006												**TOTALS**	
Acropora	*14*	*6*	*36*	**18**	*34*	**61**	*20*	*3*	*10*	**13**	*7*	**302**	*222*
Fungia		*0*			*0*		**15**				**1**	*11*	**16**
**Heteractis*			**1**									*0*	**1**
Leptastrea						**2**		**1**				*0*	**3**
Millepora					2		**25**	*2*		*0*		*12*	**29**
Montipora	**419**	**564**	*260*	**2112**	**30**	**257**	**600**	**733**	**382**	**441**	**615**	*3,128*	**6,413**
Pavona	*2*	*1*	*61*		1	**101**	**18**	**16**	*1*	**50**	*1*	**331**	*252*
Pocillopora	**31**	**16**	**19**	*0*	*2*	**48**	*4*	*4*	*0*	**36**	**2**	*84*	**162**
Porites					**2**	**4**						*0*	**6**
Sinularia						*0*						**1**	*0*
CORAL SIZE FREQUENCY DISTRIBUTIONS AT 11 RESURVEYED 2006 SITES												**TOTALS**	
1-5 cm	**33**	**133**	*59*	**776**	**17**	**60**	**503**	**392**	**36**	**153**	**73**	*731*	**2235**
6-10 cm	**96**	**125**	*127*	**829**	*19*	**181**	*66*	196	**162**	**119**	**181**	*999*	**2,101**
11-20 cm	**182**	**149**	*93*	**434**	*6*	**144**	*59*	81	**96**	**90**	**146**	*880*	**1,480**
21-40 cm	**109**	**137**	*79*	*81*	*11*	**61**	*34*	**60**	**80**	**90**	**154**	*753*	**896**
41-80 cm	**40**	*38*	*17*	*10*	*11*	**23**	*17*	*29*	*15*	**71**	**66**	**412**	*337*
81-160 cm	*1*	*4*	*2*	*0*	*3*	*4*	*3*	*1*	*0*	*13*	*5*	**135**	*36*
>160 cm	*3*	*1*	*0*		*4*	*0*	*0*	*0*	**4**	*4*	*1*	**50**	*17*
TOTALS	**466**	**587**	*377*	**2130**	*71*	**473**	**682**	**759**	**393**	**540**	**626**	3,869	**7,104**

showed increases in small and medium size classes at most sites. The brain corals and relatives (*Montastrea*, *Leptastrea*, *Lobophyllia*, *Hydnophora and Favites*) and the agaricid corals (*Gardineroseris* and *Leptoseris)* all showed increases at one or more sites in 2006, with no coral genera showing declines over the same period. At PAL 6 a corallimorph, *Rhodactis howesii,* is undergoing a population explosion likely stimulated by dissolved iron from the 1991 long-liner wreck site just north of the dredged channel. This site should be added for future intensive monitoring since the corallimorph appears to be reaching nuisance/invasive levels quickly. Additional observations in September 2007 (Work and Aeby, 2007) reveal that the corallimorph has now spread to areas more than 2 km from the wreck and has colonized other reef sites where iron chains, buoys and moorings have been established.

Kingman Reef Coral Populations 2006

Kingman has been surveyed for corals on seven occasions since 2000. Table 11.10 summarizes the results of the 2006 coral censuses at the 13 REA sites. Until 2005-2007, very little survey effort had been focused on the western half of the atoll reef, ocean reefs off the east tip and the northeast fore reef. Nevertheless, more than 180 species and 53 genera of corals and other cnidarians have already been reported at Kingman, including a new record of the genus *Pachyseris* at the far western end (site KIN 22) in depths of 30-35 m. Several species of corals belonging to the genera *Porites* and *Acropora* have yet to be described.

Six 2004 REA sites, including four in the lagoon (KIN 3, 7, 8, 12) and two off the south ocean reef (KIN 11, 13), were resurveyed in 2006. The range in mean diameters were higher for all six sites in 2004 were substantially larger in 2006 (ranging from 17 to 47 cm) than at the same sites in 2006 (ranging from 11 to 22 cm). However, the colony frequency levels at all six 2006 sites ranged from 9.4 to 32.2 colonies/m^2, two or three times higher than the counterpart 2004 frequencies (4.4 to 6.8 colonies/m^2). Large numbers of smaller corals recruited to all six sites during the two-year period, helping to explain these trends. Corals in the smallest size class were substantially more abundant in 2006. Only the two oceanic sites (KIN 11, 13) surveyed in 2004 showed a greater abundance of corals in the two largest size classes in 2006. None of the 38 coral genera posted decreases in abundance and most posted increases in 2006. The large influx of corals of many types and size classes during the two-year period serve as positive indicators of the healthy status of coral populations at Kingman Reef.

Table 11.9. 2006 data on coral generic diversity, density, percent cover and mean diameter at the same seven REA sites surveyed in 2004 at Palmyra Atoll NWR. Bold=increase and italics=decrease in values since 2004. Source: J. Maragos, unpub. data.

PALMYRA ATOLL NWR CORAL SITES RESURVEYED IN 2006									
Genus	**Site Number Number of Corals/Genus**							**TOTALS AT ALL 13 SITES**	**% OF TOTAL**
	25	**10**	**19**	**26**	**1**	**16P**	**15P**		
Acropora	**3**	*2*	**1**	**1**	*0*	**14**	208	252	3.1
Astreopora	*0*			**4**			**33**	38	0.47
Cladiella		**3**						27	0.33
Cycloseris			**3**	**2**				5	0.061
*Cryptodendrum**					*0*			0	0
Distichopora		**1**						1	0.01
Echinophyllia		*1*						3	0.036
Favia	**26**	**57**	**38**	**22**	*8*	**4**	**6**	331	4.1
Favites	*1*	*11*	**25**	**14**		*0*		159	1.96
Fungia	**29**	**56**	**30**	**2**	**37**	*20*	*6*	506	6.2
Gardineroseris		**8**	1					10	0.12
Halomitra	**3**	*0*						3	0.036
Herpolitha		*1*	1	**1**				16	0.2
*Heteractis**	**1**							1	0.012
Hydnophora	**8**	*8*	**21**	**18**	*0*			116	1.43
Leptastrea	**4**	**7**	**8**	**2**			**21**	86	1.06
Leptoseris	**13**	**16**	**9**	*1*	*1*			85	1.05
Lobophyllia	**8**	**42**	*5*		*15*			111	1.37
Lobophytum	**97**	**85**	**171**	**13**	**4**			1,080	13.3
Millepora				*0*				1	0.012
Montastrea	**2**	**4**	**12**	**22**	**1**		**3**	122	1.5
Montipora	**9**	**13**	**15**	**24**	*1*	**41**	*275*	476	5.9
Palythoa	**9**	12	**8**	**9**	*0*			92	1.13
Pavona	**43**	**81**	**71**	**69**	*20*	7	**8**	819	10.1
Platygyra	**4**	*1*	**15**	**5**				65	0.8
Pocillopora	**28**	**92**	**126**	**96**	*58*	**140**	*53*	1,219	15
Porites	**194**	**131**	**228**	**189**	**58**	*0*	**2**	1,462	18
Psammocora	*1*	**7**	**9**	*0*	**3**	**1**		62	0.76
Sandalolitha	*0*		**1**	*0*				1	0.012
Sarcophyton	*34*	*22*	*11*	*15*	*0*			466	5.7
Sinularia			*0*					0	0
*Stichodactyla**	*0*							0	0
Sterionephthya	**5**	**1**		**23**				44	0.54
Stylaster	**24**	4		6				55	0.68
Stylocoeniella			*0*					0	0
Stylophora	**13**	**2**						84	1.03
Turbinaria	**35**	**10**	**151**	**53**				354	4.36
Total No. /Site	**594**	**677**	**960**	**589**	*206*	**227**	**615**	8,257	101
Mean Diameter (cm)	**22.7**	*18.2*	*19.9*	*24.4*	*12.5*	*13.7*	*24.3*		
Frequency	**12.6**	**13.5**	**19.2**	**11.8**	*4.1*	**4.5**	**11.6**		
No. of Genera	**24**	**26**	23	**21**	*11*	7	*10*		
% Coral Cover	*49.4*	**31.4**	**66.7**	**65.5**	*6.3*	*5.81*	*54.4*	**Mean: 36.8%**	

Table 11.10. Coral generic diversity, density, percent cover and mean diameter at the seven REA sites surveyed in 2004 and 2006 at Kingman Reef NWR. Bold=increase and italics=decrease in values since 2004. Regular text indicates no change/no comparisons possible. Asterisk (*)=anemone and two asterisks (**)=corallimorph. Source: J. Maragos, unpub. data.

Genus	Site Number Number of Corals/Genus							TOTALS AT ALL 13 SITES	% OF TOTAL
	11	13	8	7	12	3	5P		
Acropora	**16**	**34**		*3*	*0*	**1**	*0*	163	1.7
Alveopora					*0*	**4**		7	0.07
Astreopora			*2*	**3**	*2*	**18**		25	0.26
Cladiella	**66**	*1*		*0*				77	0.79
Cryptodendrum*	**1**							2	0.02
Cycloseris					**1**			8	0.08
Distichopora	**2**							2	0.02
Echinophyllia	**8**		*8*	*0*			**2**	17	0.18
Favia	**58**	**87**	18	*28*	**9**	**20**	**42**	804	8.3
Favites	**24**	**15**	*0*	*13*	**5**	**3**	1	287	2.96
Fungia	**79**	**220**	**11**	*6*	*4*	*20*	*636*	1,687	17.4
Gardineroseris	1	*0*						11	0.11
Goniastrea				*0*	**2**	**3**		7	0.07
Halomitra	**4**							5	0.05
Herpolitha	**4**		1		6	**5**	**2**	21	0.22
Heteractis*		**1**				**2**		8	0.08
Hydnophora	**11**	**14**	*0*	**4**	*1*	**2**		50	0.52
Leptastrea	**18**	**3**	**4**	**5**	**10**	**4**	**3**	62	0.64
Leptoseris	**3**	**4**				*0*		10	0.1
Lobophyllia	**20**	**23**						43	0.44
Lobophytum	*0*	**72**	**87**	**71**	**107**	**55**	**6**	631	6.51
Millepora		**1**		*0*				2	0.02
Montastrea	1	**1**		**26**	**3**	1		55	0.57
Lobophyllia	**20**	**23**						43	0.44
Lobophytum	*0*	**72**	**87**	**71**	**107**	**55**	**6**	631	6.51
Millepora		**1**		*0*				2	0.02
Montastrea	1	**1**		**26**	**3**	1		55	0.57
Montipora	**15**	**35**	*0*	*25*	41	**18**	*20*	360	3.72
Pachyclavularia	**30**	**33**	**1**	**12**		**8**		89	0.92
Palythoa	**8**			**1**				36	0.37
Pavona	**31**	**60**	2	**5**	*1*	**9**	**2**	666	6.88
Platygyra	**12**		**3**	*2*		**2**		31	0.32
Pocillopora	**47**	**124**	*d*	**13**	**1**	*4*	*0*	578	5.97
Porites	**228**	**174**	**238**	**240**	**296**	**244**	**176**	3,277	33.8
Psammocora	**2**		*2*	**9**	*1*	**25**		59	0.61
Rhodactis**					2			12	0.12
Sandalolitha		**2**						3	0.03
Stylaster	2							4	0.04
Stylophora	**2**	**24**						27	0.28
Turbinaria	**28**	**7**	**61**	**18**	**110**	**15**	**6**	462	4.77
Sarcophyton	*1*	*0*	**33**	*8*	*2*	**6**		82	0.84
Sinularia	*0*		**3**	*0*	**6**	**4**	**1**	16	0.16
Total No. /Site	**594**	**935**	**466**	**492**	**610**	**473**	*897*	9,686	99.94
Mean Diameter (cm)	*22.8*	*14*	*16.9*	*13.6*	*12.2*	*16.9*	**18.5**		
Density (colonies/m^2)	**14.4**	**18.7**	**9.3**	**9.8**	**12.2**	**9.5**	*17.9*		
No. of Genera	*28*	**21**	*14*	19	**20**	**23**	**12**		
% Coral Cover	*52.9*	42.1	**21.5**	**20.7**	**17.1**	*25.7*	*49.6*	**Mean: 29.51 %**	

Wake Atoll Coral Communities

REA surveys were conducted at Wake Atoll in October 2005 and April and May 2007 by PIFSC-CRED using methods that have been applied at other Pacific reef locations since 2002. In 2005, REA surveys were conducted at 13 sites and a qualitative snorkel survey assessing occurrence of coral taxa was conducted at one back reef site. In 2007, only the 12 fore reef sites were resurveyed. Only two coral surveys at Wake were accomplished before the 2005 Pacific RAMP surveys. Together these studies included 50 scleractinian species representing 23 genera, two *Millepora* (Class Hydrozoa) species and an unspecified suite of octocorals.

During 2005 surveys at Wake, at least 92 cnidarian taxa were recognized, photographed and/or collected including 81 putative scleractinian species: an additional four or five *Montipora* sp. that appeared to be distinct but whose identification is still under investigation, a hydrozoan, a zoanthid and five octocoral genera. This makes a total of 102 scleractinian taxa currently reported from Wake Atoll. Of the 81 putative scleractinian species, at least 46 were new records, as were the zoanthid and all five octocoral genera. There were no new cnidarian records resulting from 2007 Pacific RAMP surveys.

Pocillopora, *Montipora*, *Goniastrea* and *Favia* dominated the coral fauna at fore reef sites. Octocorals accounted for 10.2% of colonies enumerated in 2005 and 8.3% in 2007. The relative contribution of taxa to the coral fauna was highly similar in 2005 and 2007, indicating that August 2006 Typhoon Ioke did not have a selective pruning effect on fore reef coral composition at 10-17 m depths.

In 2005 coral cover at fore reef sites ranged from 22.5–81.4% (Figure 11.22) which seemed to correlate with degree of exposure to oceanographic wave and swell conditions. Low coral cover values were consistently found along south and southwestern exposures, while high coral cover values were found along west and east exposures. The highest coral cover was found along northwest and north exposures. Coral cover at the single site assessed in the lagoon was 14.7%.

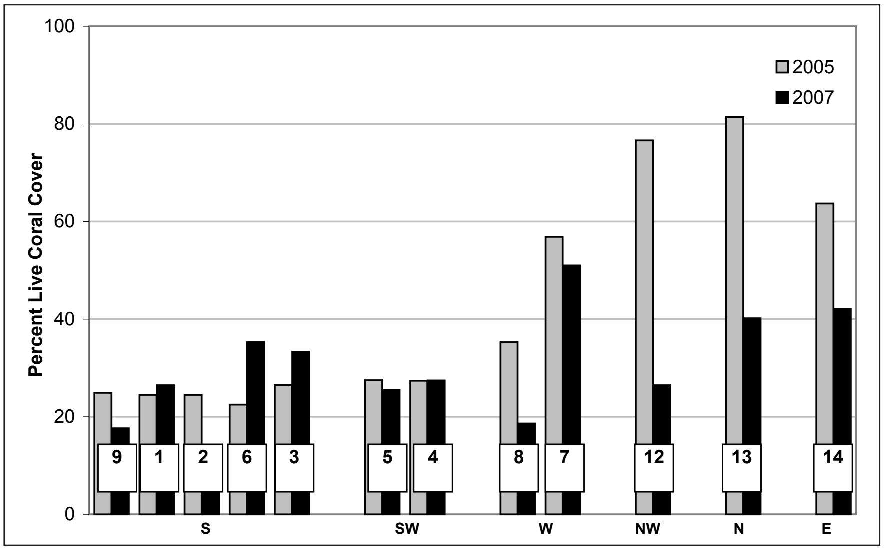

Figure 11.22. Percent live coral cover at 12 fore reef sites at Wake Atoll surveyed in 2005 and 2007. Site numbers are shown at the base of each column. Sites are arranged by geographic sector. S=south, SW=southwest; W=west; NW=northwest; N=north; and E=east. Source: PIFSC-CRED, unpub. data.

In 2007, coral cover at fore reef sites ranged from 10.8%– 51.0%. Sites (12, 13 and 14) that were in the path of Super Typhoon Ioke exhibited the greatest changes in percent live coral cover. These three sites experienced, on average, a decrease in percent live coral cover of more than 37%, compared to average changes of 2.7% for all the other sites combined. Despite the strength of Typhoon Ioke, site-specific surveys did not reveal evidence of storm damage such as dislodged or toppled colonies or bottom scouring. There was no statistically significant difference in overall coral cover ($p > 0.05$) at fore reef sites based on the 2005 and 2007 data.

The size class distribution of anthozoan colonies occurring within fore reef belt transects indicates these communities are characterized by an abundance of large (>20 cm maximum diameter) colonies, particularly when compared to Guam, the closest geographic region surveyed by PIFSC-CRED using similar methods. The close similarity of the 2005 and 2007 distribution of anthozoans is another line of evidence suggesting Typhoon Ioke did not have a substantial effect on the fore reef communities at Wake Atoll at in depths of 10-17 m.

Towed-diver surveys

In 2005, estimates of hard coral cover derived from towed-diver surveys at Wake averaged 32% (range 1–75%). The highest coral cover was noted during two surveys in the southwest corner (average 42% and 37%), and the lowest coral cover (1–5%) was found near the channel to the small boat harbor.

In 2007, estimates of hard coral cover averaged 19% (range 1– 50%). The highest cover (mean 29%) was recorded during a survey near the southwest corner of the atoll (Figure 11.23).

As noted from REA surveys, storm damage from Typhoon Ioke was much less than expected. Several large *Porites* colonies (>1 m diameter) along the eastern shore appeared to have been severed from their bases (Figure 11.24), but the vast majority of colonies was intact and appeared healthy. Small clumps of branches from terrestrial shrubs or trees were packed into small crevices at depths of 13–30 m along the southeast fore reef. No other storm damage was noted. The 2007 towed-diver surveys outside the harbor entrance near the shipwreck of the R/C *Stoner* noted a marked increase in cyanobacteria that was not observed in 2005.

Summary Findings For Coral Reef Communities in the Seven PRIA

The quantitative REA data document important characteristics of the benthic assemblages in the PRIA and provide an opportunity to monitor for change in response to alterations in the reef environment at a larger scale. An abridged analysis of these data indicates that live coral cover in excess of 40% commonly occurred in protected, leeward, and lagoon habitats (Figure 11.25). Conversely, coral cover in wave- and swell-exposed habitats generally did not exceed 20%. Howland and Jarvis reported the highest mean percent live coral cover, and both exhibited prolific coral reef development along west-facing shores. Differences among the oceanic atolls (Johnston, Wake, Palmyra and Kingman) in mean percent live coral cover were not statistically significant ($p=0.76$; one-way ANOVA).

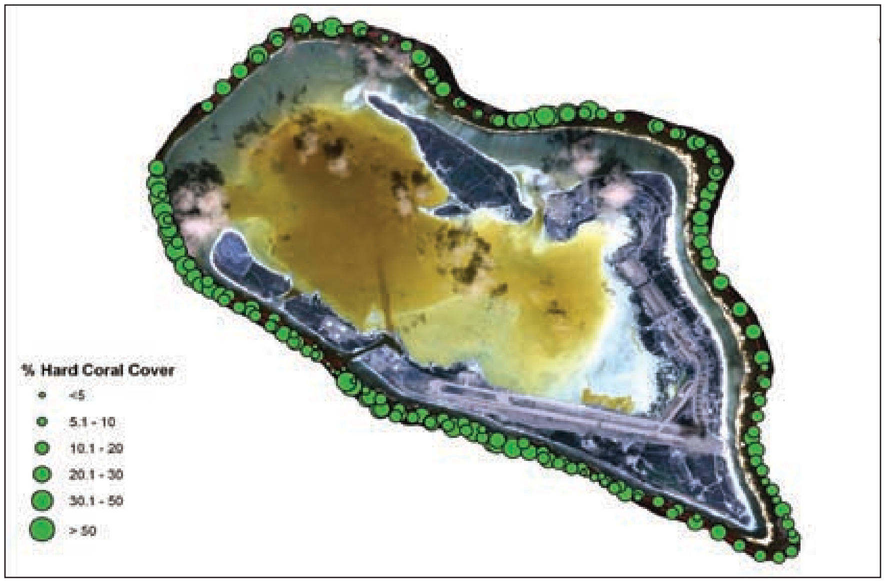

Figure 11.23. Percentage of (live) hard coral cover around Wake Atoll from towed-diver benthic surveys in 2007. Each colored point represents an integrated estimate over a five-minute observation segment covering a survey swath of approximately 150–250 x 10 m (about 1,500–2,500 m^2). Source: PIFSC-CRED, unpub. data.

Towed divers recorded three different estimates pertaining to coral cover (hard coral, stressed coral as a subset of hard corals, and soft corals) at all seven PRIA during the period 2005-2007 (Figure 11.26). The data reveal that Howland (35%), Baker (33%) and Wake (2005: 32%) had the highest cover of hard corals followed by Kingman (25%). However, when both hard and soft corals are combined, Palmyra (44%), Kingman (41%), Baker (38%), Wake (2005: 38%) and Howland (36%) reported the highest combined coral cover. Conversely, the lowest combined coral cover was observed at Jarvis (24%), Johnston (25%), and Wake (2007: 28%).

Figure 11.24. Porites *colonies that appeared to have been recently detached and subjected to high levels of wave and/or current energy along the eastern fore reef of Wake Atoll. Photos: PIFSC-CRED.*

Algae

During the 2006 Pacific RAMP surveys, quantitative algal monitoring continued with 15 sites surveyed in the Phoenix Islands (six at Howland, nine at Baker), 35 sites surveyed in the U.S. Line Islands (nine at Jarvis, 12 at Palmyra, 14 at Kingman) and 18 sites surveyed at Johnston Atoll. Quantitative algal sampling began for the first time at Wake Island with 14 sites surveyed in 2005, of which 12 sites were resurveyed in 2007. Previously, only two reports on the flora of Wake Island had been published (Tsuda et al., 2006; USFWS, 1999). Continued use of the algal monitoring protocol established in 2003 (Preskitt et al., 2004) assured uniformity of data sets for statistical temporal analyses. However, at poorly sampled sites such as Wake Atoll, many new records of range extensions are still being found. As a result, results of temporal analyses should be viewed cautiously until a uniform baseline is established.

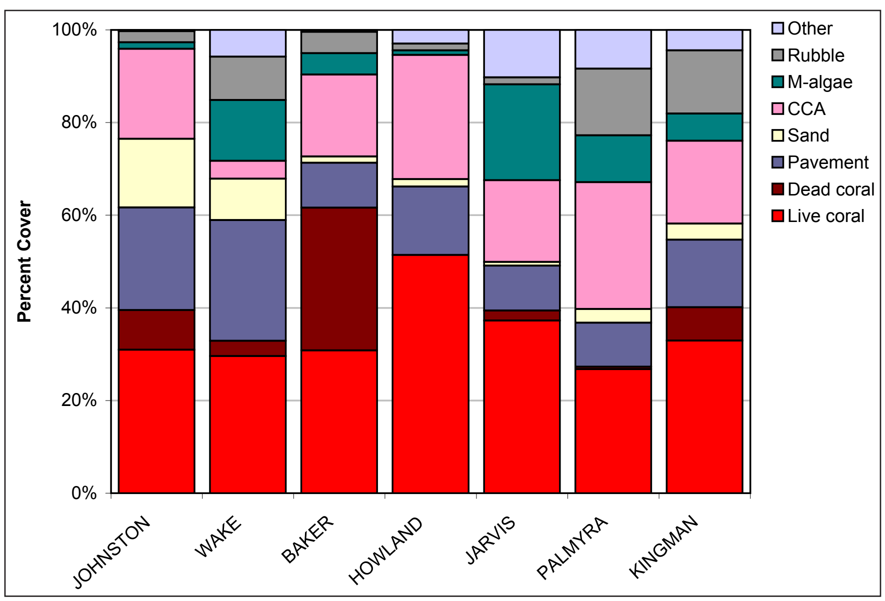

Figure 11.25. Patterns of variability in percent benthic cover, derived from 80 independent REA surveys in 2006-2007. Source: PIFSC-CRED, unpub. data.

A joint effort between PIFSC-CRED and the Bishop Museum is addressing algal biodiversity at many of the PRIA, based on PIFSC-CRED collections and other surveys (Tsuda et al. in review; Table 11.11). For Howland and Baker Islands, 85%

of species reported are new records for these locations. For Jarvis Island and Kingman Reef (analyses underway) 100% of the species are new, since no algal collections from these geographic locations have been described in past literature. Algal collections from Palmyra, Johnston, and Wake remain frozen at PIFSC-CRED and are awaiting critical taxonomic analyses.

Preliminary analyses of the Wake Atoll flora suggest many new records. Despite the passage of Typhoon Ioke in August 2006, the only obviously disturbed site (from an algal community viewpoint) was near a dredged channel on the south side that separates Wilkes and Wake Islands. Cyanobacteria there were overgrowing all substrates and on algae that is typically epiphyte-free (e.g., *Liagora* spp.). This site also had large amounts of metallic debris from a nearby shipwreck. The disturbed nature of the site was not considered a result of Super Typhoon Ioke.

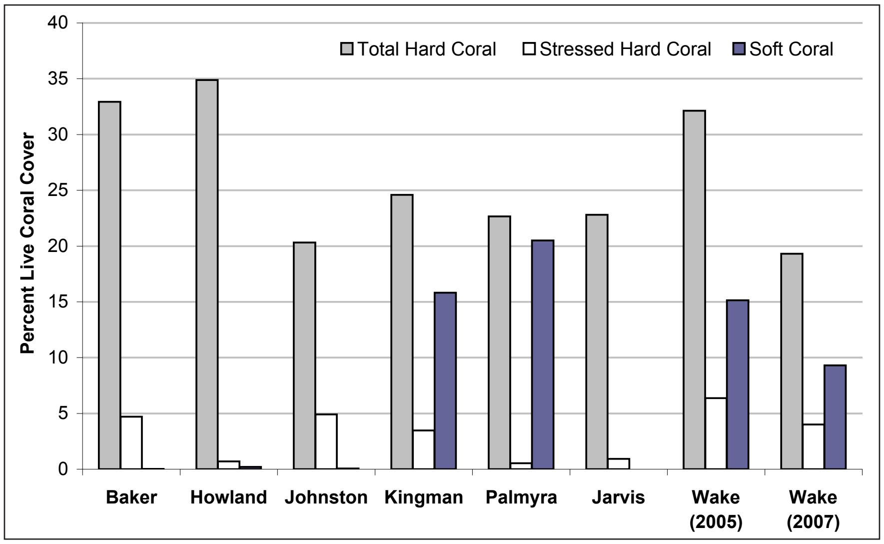

Figure 11.26. Coral cover from 2005–2007 towed-diver surveys in the PRIA. Source: PIFSC-CRED, unpub. data.

Table 11.11. Tentative number of marine benthic algal species identified from Howland, Baker, and Jarvis Islands and Wake Atoll. Wake Atoll numbers include past findings, plus 14 tentative new records for 2007. Laboratory examination of turf algal communities will likely raise the numbers. Source: Tsuda et al., 2006.

Island	Cyanophyta	Rhodophyta	Chrlorophytal	Phaeophyta	Totals
Howland	3	25	15	4	**47**
Baker	6	48	22	7	**83**
Jarvis	5	84	21	5	**115**

Multivariate statistical analyses of species-level benthic cover and fish abundance at Howland and Baker Islands find the two islands to be biologically distinct from each other despite the fact that they lie only 60 km apart (Vroom et al., in preparation). Using data collected in 2004, combined algal functional groups (not including cyanophytes) occupied 55-84% of the substratum at these islands, while corals occupied only 15-45% of the substratum. Macroalgal cover was greater than or equal to coral cover at 50% of the Howland and Baker sites, while crustose coralline red algal cover was greater than coral cover at 80% of the sites. Similar studies on the remaining PRIA are pending.

Vroom et al. (2006a) compared percent cover of macroalgal, turf algal crustose-coralline algal and coral populations at eight islands across the Pacific Ocean basin, including Howland, Baker and Jarvis Islands. Relying on 2004 data, Howland and Baker Islands exhibited among the highest percent cover of living coral (about 30%) of all islands compared, the lowest turf algal cover and the highest crustose-coralline red-algal cover. Heterogeneity of benthic substrate cover around the islands revealed that dense coral communities are limited to certain oceanographic and environmental regimes, underscoring the necessity to protect relatively small coral-dominated areas.

ASSOCIATED BIOLOGICAL COMMUNITIES

Results from quantitative assessment and monitoring of shallow reef fish assemblages at the PRIA by PIFSC-CRED from 2000 to 2004 are summarized in previous State of the Reef Reports (Turgeon et al., 2002, Brainard et al., 2005). Results from the 2005 and 2007 surveys are summarized here. Quantitative belt transects, stationary point counts (SPC), random swims (for species presence) and towed-diver fish surveys (for large fishes) were conducted at previously visited sites and some new sites, using the same PIFSC-CRED methodology as in previous years. See the PRIA chapter in the 2005 edition of this report for additional details.

PRIA Regional Summary for Fish

Reef fish populations in the PRIA continued to exhibit some of the highest densities and biomasses surveyed by PIFSC-CRED in the Pacific. Jarvis Island was the most notable with the highest target species densities (snappers, groupers, jacks and sharks; Figure 11.27) and the highest large fish biomass (>50 cm total length or TL; 1.5 ton ha^{-1}; Figure 11.28) of all PIFSC-CRED-surveyed islands. Wake Island was a distant second for large fish biomass at 0.5 ton ha^{-1}, although this is still exceptionally high compared to most reefs around the Pacific. The U.S. Line and Phoenix Islands had similarly high large fish biomasses at around 0.3 ton ha^{-1}, although medium-sized target species densities were much higher around the Phoenix Islands. Johnston Atoll had the lowest target species densities and large fish biomass (0.05 ton ha^{-1}) of the PRIA. The values from Johnston are more similar to those found at populated islands such as Tutuila in the Territory of American Samoa.

Howland and Baker Islands (2006)
Fish were resurveyed around Howland and Baker Islands from January 28 to February 1, 2006. The towed-diver fish survey team conducted seven surveys around Howland (12 ha) and 10 surveys around Baker (19 ha).

Medium-large reef fish biomass at Howland (1.6 ton ha^{-1}) was slightly higher than at Baker (1.5 ton ha^{-1}). A total of 210 species of coral reef fishes were documented at Howland and Baker Islands by the fish REA team. Damselfishes were represented by 16 species; the fusilier damsel (*Lepidozygous tapeinosoma*) was most abundant and commonly found in large schools. This species, along with two anthiine serranid species, Bartlett's anthias (*Pseudanthias bartlettorum*) and Whitley's splitfin (*Luzonichthys whitleyi*), were observed at all sites. These three species were numerically dominant at both islands. Surgeonfish were common and abundant at all sites at Howland and Baker Islands. Dominant species included the bluespotted bristletooth (*Ctenochaetus marginatus*) the bluelip bristletooth (*C. cyanocheilus*) and the goldrim surgeonfish (*Acanthurus nigricans*). Convict tang (*A. triostegus*) were often observed in large schools, typically at shallower depths above the transects. The most abundant unicornfish was the orange-spine unicornfish (*Naso lituratus*). Wrasses were the most speciose family, with 32 species observed. Numerically, the most abundant wrasse was the bluntheaded wrasse (*Thalassoma amblycephalum*), due to large numbers of new recruits. The humphead wrasse (*Cheilinus undulatus*) was rare. The grey-reef shark (*Carcharhinus amblyrhynchos*) and the whitetip reef shark (*Triaenodon obesus*) were the most abundant sharks recorded. Groupers included large peacock hind (*Cephalopholis argus*), the coral hind (*C. miniata*) and the darkfin hind (*C. urodeta*). The slenderspine grouper (*Gracila albomarginata*) was also common along drop-offs. Snappers were a prominent component of the fish communities at both Howland and Baker Islands. The species most frequently encountered were smalltooth jobfish (*Aphareus furca*), twinspot snapper (*Lutjanus bohar*) and onespot snapper (*L. monostigma*). The most commonly observed angelfishes at both Howland and Baker Islands were the flame angel (*Centropyge loricula*) and the lemonpeel angel (*C. flavissima*). The most prevalent species of triggerfish was the orange-striped triggerfish (*Balistapus undulats*). Parrotfish included six species, of which the most common was the large redlip parrotfish (*Scarus rubroviolaceus*) and the bridled parrotfish (*S. frenatus*). The bigscale soldierfish (*Myripristis berndti*) was the dominant soldierfish. Hawkfishes were common, represented mostlty by the arc-eye hawkfish (*Paracirrhites arcatus*).

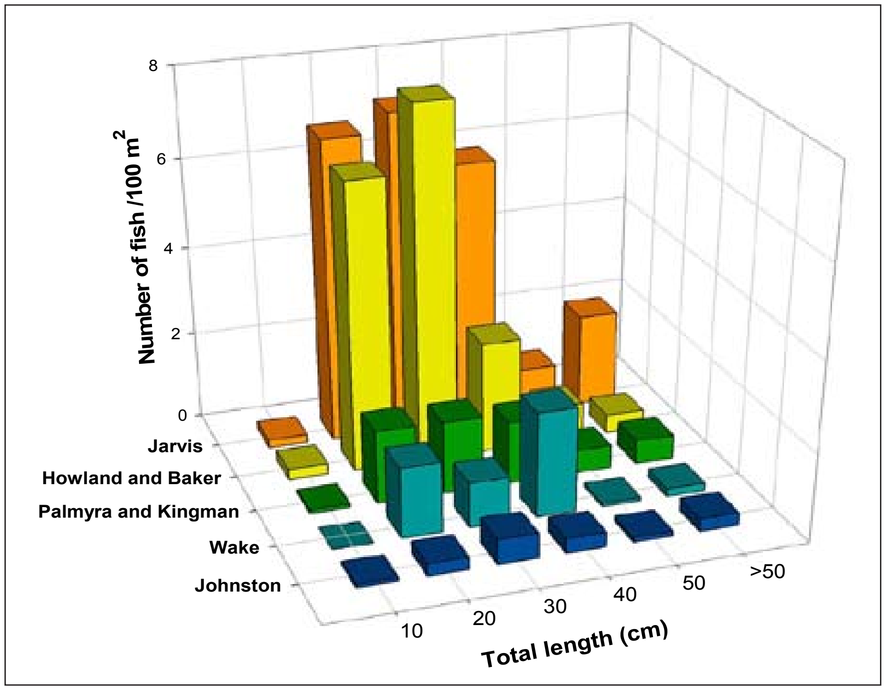

Figure 11.27. Fish density by size of target families (groupers, snappers, jacks and sharks) as measured on belt transects. Source: PIFSC-CRED, unpub. data.

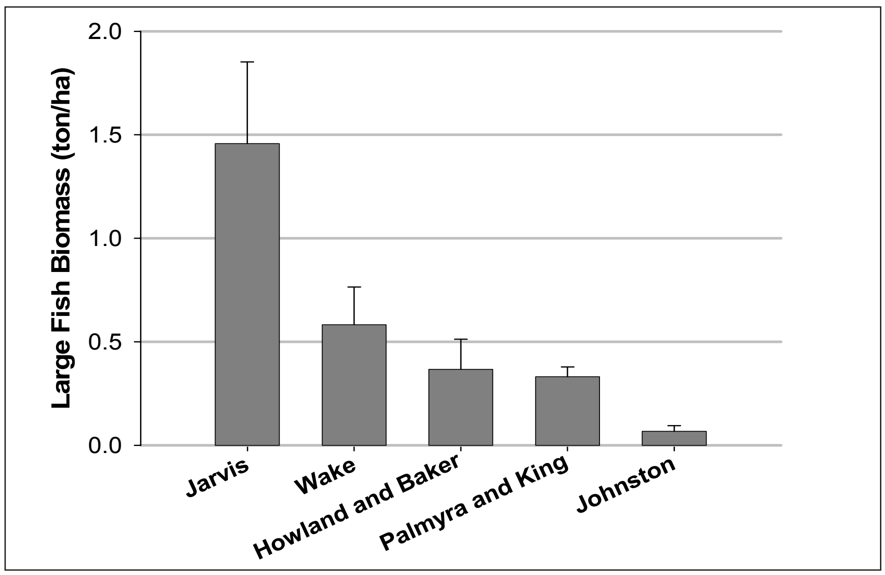

Figure 11.28. Large fish biomass (>50 cm TL) measured by towed-diver surveys (mean and standard error). Source: PIFSC-CRED, unpub. data.

Towed-diver surveys of large fish recorded a total of 602 individual fishes at Howland and 269 at Baker. Snappers dominated, the majority of which were the twin-spot snapper (*L. bohar*, n=217). Sharks (Carcharhinids) were the next most numerous family with 166 observations primarily of the grey reef shark (*C. amblyrhynchos*, n=158), 147 of which were observed at Howland; 138 barracuda (*Sphyraena* spp.) were observed at Howland as well. Jacks accounted for 116 observations, 55 of which were black trevally (*Caranx lugubris*), 24 were giant trevally (*C. ignobilis*) and 21 were bluefin trevally (*C. melampygus*). Other notable sightings included schools of scalloped hammerhead shark (*Sphyrna lewini*) and several large humphead wrasse (*C. undulatus*).

Jarvis Island (2006)

Fish were resurveyed at Jarvis Island from March 20-22, 2006. Belt transects, SPCs and REA surveys were conducted at nine sites, generally at 13-15 m depth, using the same methodology and sites as in previous years, with one additional site. The towed-diver fish survey team conducted 12 surveys totaling 26 ha around the entire island.

The reefs around Jarvis Island support exceptionally high medium-large fish biomass of reef fishes (9.4 ton ha^{-1}), by far the highest of any reefs surveyed by PIFSC-CRED across the Pacific (Figure 11.29). Sharks, groupers, jacks and snappers were common at every REA site surveyed. A total of 165 fish species were recorded by the fish REA divers at Jarvis. Numerically, three fish species dominated the fish fauna at Jarvis; collectively, Bartlett's anthias (*P. bartlettorum*), Whitley's splitfin (*L. whitleyi*) and the fusilier damselfish (*L. tapeinosoma*) made up 60% of all the fish observed. Schools of these three species of small-bodied planktivores were observed at nearly every site with groups sometimes including thousands of individuals. Among larger-bodied fishes, black jacks (*C. lugubris*), spotted hind (*Cephalopholis miniata*), doublebar goatfish (*Parupeneus insularis*) along with several species of surgeonfish including the bluespotted bristletooth (*C. marginatus*), the bluelip bristletooth (*C. cyanocheilus*) and the goldrim surgeonfish (*A. nigricans*) were most abundant. Grey reef sharks (*C. amblyrhynchos*), whitetip reef sharks (*T. obesus*) and manta rays (*Manta birostris*) were also abundant.

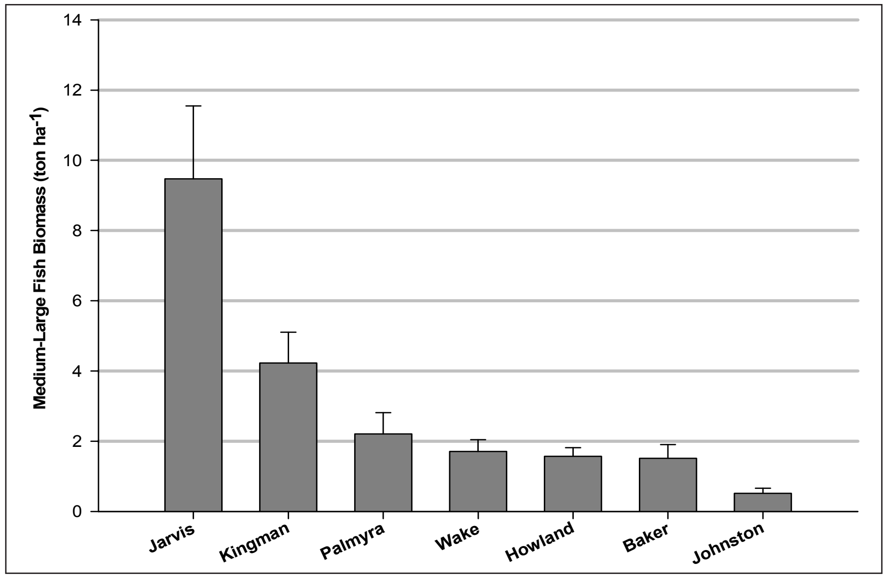

Figure 11.29. Medium-large fish (TL >25 cm) biomass measured on SPCs. Source: PIFSC-CRED, unpub. data.

The towed-diver surveys recorded a total of 2,551 fishes at Jarvis. Jacks were the most abundant family with 1,278 sightings, including a large school of 1,000 bigeye trevally (*Caranx sexfasciatus*). Sharks sightings (n=369) were dominated by the grey reef shark (*C. amblyrhynchos*, n=309) with fewer sightings of white tip (*T. obesus*) and black tip reef sharks (*C. melanopterus*). Six scalloped hammerhead (*Sphyrna lewini*) and two great hammerhead sharks (*S. mokarran*) were also seen at Jarvis. Black-margin barracuda (*S. qenie*) were common, with 333 individuals seen primarily in two large assemblages. Other notable observations were nine manta rays (*M. birostris*), two humphead wrasses (*C. undulatus*) and one bumphead parrotfish (*B. muricatum*).

Johnston Atoll (2006)

Fish were resurveyed at Johnston Atoll from January 18-23, 2006. Belt transects, SPCs and REA surveys were conducted at 12 previously visited monitoring sites and six newly established sites, using the same methodology as during the previous visit. Most REA sites were inside the lagoon due to challenging sea conditions outside. The towed-diver fish survey team conducted 11 surveys covering 52 ha around the atoll.

Medium-large fish biomass at Johnston Atoll was the lowest of the PRIA, at only 0.5 ton ha^{-1} (Figure 11.29). A total of 120 species of coral reef fishes was documented at Johnston. The bullethead parrotfish (*Chlorurus sordidus*) was seen at every site and was numerically the most abundant parrotfish observed. The palenose parrotfish (*Scarus psitticus*) was also abundant. In sheltered areas the most common species of damselfish were the Hawaiian dascyllus (*Dascyllus albisella*) and the blue-eye damsel (*Plectroglyphidodon johnstonianus*), while at more exposed sites, the dwarf chromis (*Chromis acares*) and agile chromis (*C. agilis*) were common. The diversity and abundance of damselfishes were remarkably low compared to other U.S. Pacific Island surveys. Also lacking were new damselfish recruits. Surgeonfish were common and relatively abundant at Johnston and constituted a major proportion of the fish observed at all sites; the greatest concentrations were found on the outer reef slope. The blue-lined surgeonfish (*Acanthurus nigroris*) was the most common species, followed by goldring surgeonfish (*Ctenochaetus strigosus*) and orange-spine unicornfish (*Naso lituratus*). Wrasses appeared to constitute the most specious family with 17 species. The saddle wrasse (*Thalassoma duperrey*) was recorded at every site and had the highest abundance of the labrids. Hybrids of the saddle wrasse that crossed with the sunset wrasse (*T. lutescens*) and the fivestripe wrasse (*T. quinquevittatum*) were also observed in relatively high numbers. Other species of note included the ringtail wrasse (*Oxycheilinus unifasciatus*) and the sling-jaw wrasse (*Epibulus insidiator*), both of which were present at every site. The belted wrasse (*Stethojulis balteata*) was fairly common and was made up of mostly juveniles. Of the 12 species of butterflyfish, the chevron butterflyfish (*Chaetodon trifascialis*) was the most common and abundant. Other moderately common species included the threadfin butterflyfish (*C. auriga*), the saddleback butterflyfish (*C. epihippium*), and the oval butterflyfish (*C. lunulatus*). Of goatfish, the yellowstripe goatfish (*Mulloidichthys flavolineatus*) was most abundant and was often seen in schools of more than 10. The multibar goatfish (*Parupeneus multifaciatus*) and the doublebar goatfish (*P. insularis*) were also seen frequently. Jacks were common but not abundant at

Johnston Atoll, and the bluefin trevally (*C. melampygus*) was the most numerous species. For snapper, the smalltooth jobfish (*A. furca*) was moderately common. The grey reef shark (*C. amblyrhynchos*) was the only shark observed by the REA fish team at Johnston Atoll, with occasional solitary individuals. Spotted eagle rays (*Aetobatis narinari*) were observed on several occasions, and a single manta ray (*M. birostris*) was observed along the current-swept outside reef.

Towed-diver fish surveys reported the highest large fish density in fore reef habitats. Most common was the bluefin trevally (*C. melampygus*), of which approximately 214 were seen in a large school during a single tow; this group may have constituted a spawning aggregation. The second most common large fish species was the grey reef shark (*C. amblyrhynchos*; 67 individuals). Other notable fish included 22 cornetfish (*Fistularia commersonii*), 12 redlipped parrotfish (*Scarus rubroviolaceus*), 12 green jobfish (*Aprion virescens*) and schools of black trevally (*C. lugubris*).

Palmyra Atoll and Kingman Reef 2006
Fish were resurveyed at Palmyra and Kingman reefs from March 23 to April, 3 2006. Belt transects, SPCs and REA surveys were conducted at 13 (Palmyra) and 16 (Kingman) previously visited monitoring sites. Towed-diver fish surveys included 18 surveys totaling 42 ha around Palmyra Atoll and 22 surveys totaling 50 ha around Kingman Reef.

Medium-large fish biomass around Palmyra (2.2 ton ha^{-1}) made up only half of the biomass found at Kingman but was still very high compared to other regions of the U.S. Pacific (Figure 11.29). Collectively 176 species of reef fishes were recorded at Palmyra. The three schooling planktivores that dominated the numbers of fish at Jarvis Island were not nearly as abundant at Palmyra. The most abundant species on belt transects were dwarf chromis (*Chromis acares*), Vanderbilt's chromis (*C. vanderbilti*) and bicolor chromis (*C. margaritifer*). Diversity was highest among wrasses (35 species recorded) and surgeonfish/unicornfish (25 species). Large fish, including sharks, were generally less abundant at Palmyra than at Jarvis with the exception of the twinspot snapper (*L. bohar*). Humphead wrasses (*C. undulatus*) and manta rays (*M. birostris*) were encountered commonly, but rarely passed within the quantitative boundaries of the surveys.

The most abundant large (TL >50cm) fish sighted on towed-diver surveys around Palmyra was the twinspot snapper (*L. bohar*, 444 individuals). The second most abundant species was the Pacific steephead parrotfish (*Chlorurus microrhinos*, 61 individuals), followed by grey reef shark (*C. amblyrhynchos*; 58 individuals). The giant trevally (*C. ignobilis*) was also common at Palmyra (29 sightings). Other notable observations included two bumphead parrotfish (*B. muricatum*) and 18 humphead wrasse (*C. undulatus*).

Kingman Reef includes several habitat types not found at Jarvis and Palmyra. Kingman is a submerged atoll that consists of exposed outer reef, extensive back reef, a series of small, scattered pinnacles and a submerged western atoll rim. Fish surveys were conducted at one or more sites within each of these habitat types. Medium-large fish biomass was particularly high at Kingman Reef (4.2 ton ha^{-1}; Figure 11.29), which represents the second highest value in the PRIA. Numerically, damselfish (family Pomacentridae) dominated, although species composition varied greatly around the atoll. Surgeonfish (family Acanthuridae) were also very abundant at most sites. Among larger-bodied fishes surveyed, twinspot snapper (*L. bohar*) were abundant at all sites. Large aggregations of yellowback fusiliers (*Caesio teres*), blackfin barracuda (*Sphyraena qenie*) and rainbow runner (*Elagatis bipinnulata*) were observed at scattered sites. Sharks appeared to be more abundant at Kingman than at Palmyra, but less abundant than at Jarvis. No humphead wrasse or bumphead parrotfish were observed by the fish REA team at Kingman.

The most abundant species observed on towed-diver surveys at Kingman was the twinspot snapper (*L. bohar*) with 477 individuals. The Pacific steephead parrotfish (*C. microrhinos*; 260 individuals) was the second most frequently observed large fish. These were followed by the grey reef shark (*C. amblyrhyncos*; 93 individuals), and the whitetip reef shark (*T. obesus*; 47 individuals). Another notable fish sighting at Kingman was the giant grouper (*Epinephelus lanceolatus*).

Wake Atoll (2005, 2007)
Fish were surveyed for the first time by PIFSC-CRED at Wake Atoll from October 18 to 22, 2005, and again from April 30 to May 3, 2007. Belt transects, SPCs and REA surveys were conducted at 13 newly established sites with the same methodology used elsewhere in the U.S. Pacific Islands. The towed-diver fish survey team conducted 19 surveys, around the atoll totaling 40 and 44 ha, respectively, during the two visits to the atoll.

In general, Wake appeared to support healthy populations of fish that are typically more depleted in other areas that are exposed to fishing and other human activities. Observations in both survey years were generally consistent. Medium-large fish biomass was around 1.7 ton ha^{-1}, which is slightly below the average for the PRIA (Figure 11.29). Further, large, potentially wary species were easily approached by divers. A total of 190 species of coral reef fishes were documented at Wake. Parrotfish were the most common medium-large fish, and were commonly found in schools of up to 100 that included many very large individuals. The tan-faced parrotfish (*Chlorurus frontalis*) and rainbow parrotfish (*Scarus forsteni*) dominated. The large bumphead parrotfish (*B. muricatum*), very rare in most other areas of the U.S. Pacific, was encountered on nearly every dive, occasionally in schools of up to 30 individuals. Also common in both years were humphead wrasse (*C. undulatus*) and several species of commercially exploited grouper. Other common medium-large fish included jacks (primarily two large schools of *C. sexfasciatus*) and a consistent presence of bluefin trevally (*C. melampygus)*. Gray reef sharks (*C. amblyrhynchos*) were occasionally seen, as was one tiger shark (*Galeocerdo cuvier*).

Most sites exhibited a high degree of similarity in terms of fish species composition. There also seemed to be little change with depth to about 20 m, the depth limit of the REA surveys. Few deep water species were observed along the steep outer reef drop-offs. Circulation in the lagoon at Wake was significantly altered by the construction of a causeway. Only one survey dive was conducted in the near-zero visibility lagoon; fish fauna was patchily distributed on patch reefs smaller than the length of the transect lines. Based on previous checklists by Lobel and Lobel (2004) and the USFWS and NMFS (1999), new records were likely found at Wake for the following 10 species: black-spotted puffer (*Arothron nigropunctatus*), stareye parrotfish (*Calotomus carolinus*), multi-barred angelfish (*Centropyge multifasciata*), tiger shark (*G. cuvier*), blackear wrasse (*Halichoeres melasmopomus*), wedge-tailed wrasse (*Labropsis xanthonota*), whitemargin unicornfish (*Naso annulatus*), redtooth triggerfish (*Odonus niger*), bridled parrotfish (*Scarus frenatus*) and bigeye scad (*Selar crumenophthalmus*). A possible new species of wrasse (*Pseudojuloides* sp. B) was also observed and collected.

The most notable observation of the towed-diver large fish surveys at Wake was the abundance of bumphead parrotfish (*B. muricatum*; 68 sightings). The humphead wrasse (*C. undulatus*; 90 sightings) was also common in both years. Another notable observation was the high abundance of spotted eagle rays (*A. narinari*; 27 sightings). The most numerically abundant fish, however, was bigeye jacks (*C. sexfasciatus*), which were observed in schools of up to 1,200 individuals with approximately 70% over 50 cm TL. A large school of milkfish (*Chanos chanos*, about 200-250 fish) was also seen. Grey reef sharks (*C. amblyrhynchos*) were among the top three most abundant species on towed-diver surveys. Parrotfish of several species, as well as planktivorous unicornfish were abundant (particularly *Naso brevirostris*), though only a few were of sufficient size (>50 cm TL) to be recorded during towed-diver surveys.

Marine Mammals

Marine mammals are regularly monitored by the USFWS at Palmyra Atoll. In summer 2006, a mesoplodon whale carcass washed ashore in the east lagoon, which was the third dead beaked whale stranding on Palmyra Atoll NWR in one year. Preliminary results indicate that these whales are potentially a new and undescribed species of beaked whales. Two sightings of a large (7-10 m) brown or tan beaked whale were reported at Kingman Reef in August and September 2007. Further observations or photos of the whale were not possible (J. Maragos, pers. obs.).

Marine Macroinvertebrates

Towed-diver benthic surveys were conducted in shallow water habitats around all of the PRIA, and divers recorded habitat composition and character and enumerated conspicuous macroinvertebrates. Molluscs, echinoderms, and holothuroids were tallied, specifically the giant clam, *Tridacna* spp., COTS, and all urchins and sea cucumbers. (Figure 11.30). The Line and Phoenix Islands were surveyed in 2006 aboard the NOAA ship *Hi'ialakai*. The overall lack of macroinvertebrate fauna throughout the fore reef habitats at Palmyra Atoll is of specific interest, as is the high concentration, but patchy distribution of COTS at Kingman Reef. In addition, Kingman Reef exhibited an overall high abundance and diversity of macroinvertebrates and the highest concentration of giant clams in the PRIA. Jarvis Island had an overall low concentration of macroinvertebrates, with the most abundant and diverse values recorded at sites on the western side of the island. Johnston Atoll has the second highest concentration of COTS in the PRIA; over 60% of observed COTS were found on the fore reef. No COTS were observed at either Howland or Baker. Low densities of both urchins and giant clams were observed at both islands as well.

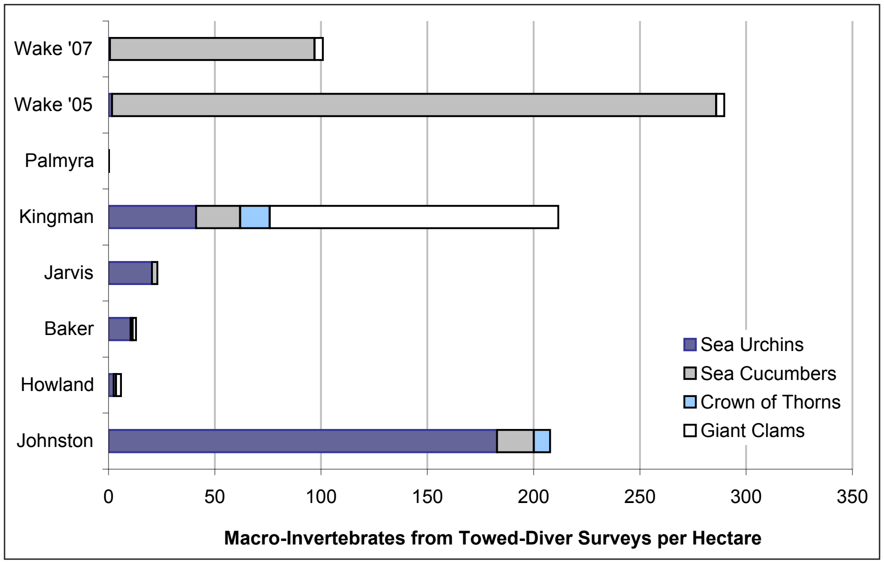

Figure 11.30. Macroinvertebrates from towed-diver surveys per hectare. Source: PIFSC-CRED, unpub. data.

Wake Atoll was surveyed by towed divers in 2005 and 2007. Surprisingly, only a single COTS was recorded during all surveys for both years around Wake Atoll. The most abundant macroinvertebrates observed around Wake were sea cucumbers; an average of approximately 7,000 was recorded along the southern coastline during the two survey periods (Figure11.31).

Figure 11.31. Distribution of estimated population densities of COTS, giant clams, sea cucumbers and sea urchins around Wake Atoll from towed-diver benthic surveys completed in 2005 and 2007. Source: PIFSC-CRED, unpub. data.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The USFWS and NOAA will continue to collaborate on biennial research expeditions to Johnston, Kingman, Palmyra, Baker, Howland and Jarvis Islands. Research expeditions to Wake Island are conducted under NOAA sponsorship with permission and assistance from the DOI and the U.S. Air Force.

World Heritage and Ramsar Conventions

In 2002, the United Nations Education, Scientific, and Cultural Organization (UNESCO) held an international marine World Heritage workshop in Hanoi, Vietnam. The workshop was attended by nearly 100 marine experts who were charged with developing a list of priority areas for World Heritage (WH) status. The paucity of WH sites in the Pacific Ocean was particularly highlighted and the Line and Phoenix Islands were two of 16 Pacific areas proposed for WH evaluation. Subsequently, additional workshops were held in Kiritimati (Christmas Island, Republic of Kiribati); Durban, South Africa; and Honolulu, Hawaii, in 2003, 2005 and 2007, respectively, to enlist the support and participation of the U.S., Republic of Kiribati, the Cook Islands and French Polynesia as part of a broader “Central Pacific WH Project” focusing on the low reef islands and atolls in the region. Five of the PRIA (Baker, Howland, Jarvis, Kingman and Palmyra NWR) and Rose Atoll NWR were proposed for tentative listing and nomination as a serial site for World Heritage by the U.S. Assistant Secretary of Interior for Fish and Wildlife and Parks on March 4, 2005. Johnston Atoll NWR was not added to this list because of ongoing negotiations between the Departments of Interior and Defense on the future status of the atoll. Unfortunately, the U.S. Tentative List was closed for additions at that time and further action was suspended. Although the Tentative List was eventually reopened in early 2007 for three months, and despite the support of TNC and the Governor of American Samoa, the application for the five PRIA and Rose Atoll could not be processed and reviewed in time to meet the deadline for submissions. All six areas are now being evaluated as Ramsar (1971 Convention on Wetlands of International Importance at Ramsar, Iran) sites by DOI and UNESCO. Meanwhile the Republic of Kiribati created the Phoenix Island Protected Area that covers over 400,000 km^2 in February 2008 and is nominating all eight of its Phoenix Islands for World Heritage status. If this latter initiative succeeds, it may be possible to add the U.S. PRIA via more streamlined procedures as part of a trans-boundary nomination.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

Cooperative biennial Pacific RAMP surveys should continue at these remote islands in order to: 1) improve the scientific understanding of these ecosystems as a basis for sound management; 2) improve and extend monitoring of spatial and temporal changes at multiple depths at the same sites and within additional habitats in these ecosystems in response to natural and anthropogenic forces; 3) collaborate more closely with other research institutions in the region; 4) help elucidate associations between fish (a primary resource) and other components of the coral reef ecosystem; and 5) assist the USFWS, TNC, NMFS and other resource managers in efforts to improve the scientific basis for protecting the coral reef ecosystems and the associated fish and wildlife resources in the PRIA.

Although the PRIA are in excellent condition as a whole (Figure 11.32), stressed areas need further examination to determine whether additional remediation or restoration is warranted. The following is a list of the priority areas for future monitoring:

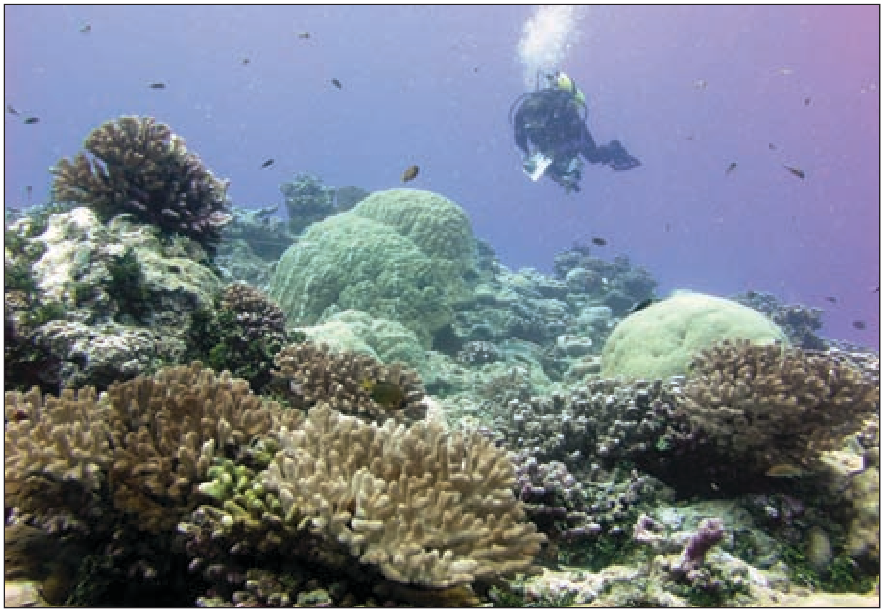

Figure 11.32. The coral reef ecosystem resources in the PRIA are generally in excellent condition. Photo: PIFSC-CRED.

- Northwest boat landing area at Baker Island that is likely stressed from dissolved iron
- Other historic boat landings at Howland and Jarvis
- Ship grounding sites including the two at Kingman and Palmyra to assist future efforts to remove the debris
- Sites where the invasive corallimorph *Rhodactis howesii* is established
- Evaluate and possibly deploy remotely placed sensors and other remote satellite surveillance technology to discourage unauthorized visitors and fishers
- Expand the REA and permanent transect monitoring to multiple depths and habitats
- Assist or collaborate in special studies to assess and evaluate possible restoration options for Palmyra's lagoon
- Continue evaluating the decline of coral communities in Johnston and Wake lagoons

It is recommended that all six PRIA covered in this chapter (along with Rose Atoll NWR) should eventually be added to the U.S. Tentative List and nominated as a single serial candidate for World Heritage status or added as part of an inscribed World Heritage property.

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