The State of Coral Reef Ecosystems of the U.S. Pacific Remote Island Areas

Rusty Brainard[1], Jim Maragos[2], Robert Schroeder[1,3], Jean Kenyon[1,3], Peter Vroom[1,3], Scott Godwin[4], Ronald Hoeke[1,3], Greta Aeby[5], Russell Moffitt[1,3], Marc Lammers[1,6], Jamison Gove[1,3], Molly Timmers[1,3], Stephani Holzwarth[1,3], Steve Kolinski[7]

INTRODUCTION AND SETTING

The U.S. Pacific Remote Island Areas (PRIAs) are nine sovereign Federal territories that straddle the equator in the central Pacific. All are single reef ecosystems that are a part of a large central Pacific biogeographic and geological province consisting mostly of ancient low reef islands and atolls (Figure 12.1; Stoddart, 1992). Six of the PRIAs are atolls or atoll reefs: Johnston Atoll (16˚N, 169˚W), Palmyra Atoll (5˚53´N, 162˚05´W), Kingman Reef (6˚25´N, 162˚23´W), which constitute the three northernmost of the U.S. Line Islands; Rose Atoll (14˚S, 168˚W), the easternmost of the Samoan Islands; Wake Atoll (20˚N, 155˚W), the northernmost of the Marshall Islands; and Midway Atoll (28˚N, 177˚W), near the northwestern end of the Hawaiian Archipelago. The remaining three PRIAs are low reef islands within one degree latitude of the equator: Jarvis Island (00˚S, 160˚W), in the central U.S. Line Islands, Howland Island (00˚18´S, 160˚01'W); and Baker Island (00˚13´N, 176˚38´W), the two northernmost of the U.S. Phoenix Islands. All except Wake and Johnston are National Wildlife Refuges (NWRs) administered by the U.S. Fish and Wildlife Service (USFWS) and all fall under co-jurisdiction of the U.S. Department of Interior (DOI) and the U.S. Department of Commerce (DOC), except Johnston, which is managed by the U.S. Department of Defense, and Palmyra, which is under the joint jurisdiction of DOI, DOC, and The Nature Conservancy.

Although all nine are outside the political jurisdiction of other U.S. Pacific States and Territories (Hawaii, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands [CNMI]), Rose and Midway Atolls are geographically a part of American Samoa and Hawaii, respectively. For organizational purposes, Midway Atoll is mostly treated in the chapter on the Northwestern Hawaiian Islands (NWHI), and Rose Atoll is partially covered in the chapter on American Samoa. Swains Island (14˚S, 168˚W), the northernmost island in American Samoa, is also a remote reef island but it is not technically a PRIA because it falls under the jurisdiction of the Territory of American Samoa.

All of the PRIAs were uninhabited at the time of their discovery by Americans and Europeans over the past two centuries, although Polynesians (and Micronesians, in the case of Wake) probably visited all of the islands periodically over many centuries to harvest fish and wildlife. The U.S. claimed most of the islands via the Guano Act of 1856. Except for Palmyra, Kingman and Rose, the PRIAs lie within arid zones of the tropical Pacific, with insufficient groundwater and rainfall to support continuous human habitation. Moreover, Kingman, lacks vegetated islets, and the land area at Rose is too small and vulnerable to storms to allow habitation. Although Palmyra is certainly capable of supporting human settlements, it is unclear as to why it remained uninhabited during recent centuries. The lack of human habitation allowed the coral reef ecosystems of the PRIAs to remain completely pristine until the early 20th century. Even today all lie beyond the influence of urban centers, associated pollutants, and major shipping lanes.

Most of the PRIAs were materially modified during the World War II (WWII) era: the U.S. constructed and occupied military bases at Johnston, Palmyra, Wake, Midway, and Baker, while Kingman, Jarvis, and Howland were also briefly occupied or utilized during the war era. With the closure of the military base at Johnston in early 2004, only Wake Atoll remains an active U.S. military base. The seven NWRs in the PRIAs were established between 1924-2001, and all are presently no-take island and marine protected areas (MPAs) except Palmyra, on which limited catch and release sport fishing for bonefish and offshore pelagic catch for local consumption are allowed.

1 NOAA Fisheries, Pacific Islands Fisheries Science Center
2 U.S. Fish and Wildlife Service
3 University of Hawaii, Joint Institute for Marine and Atmospheric Research
4 Bishop Museum
5 Department of Land and Natural Resources, Division of Aquatic Resources
6 University of Hawaii, Hawaii Institute of Marine Biology
7 NOAA Fisheries, Pacific Islands Regional Office

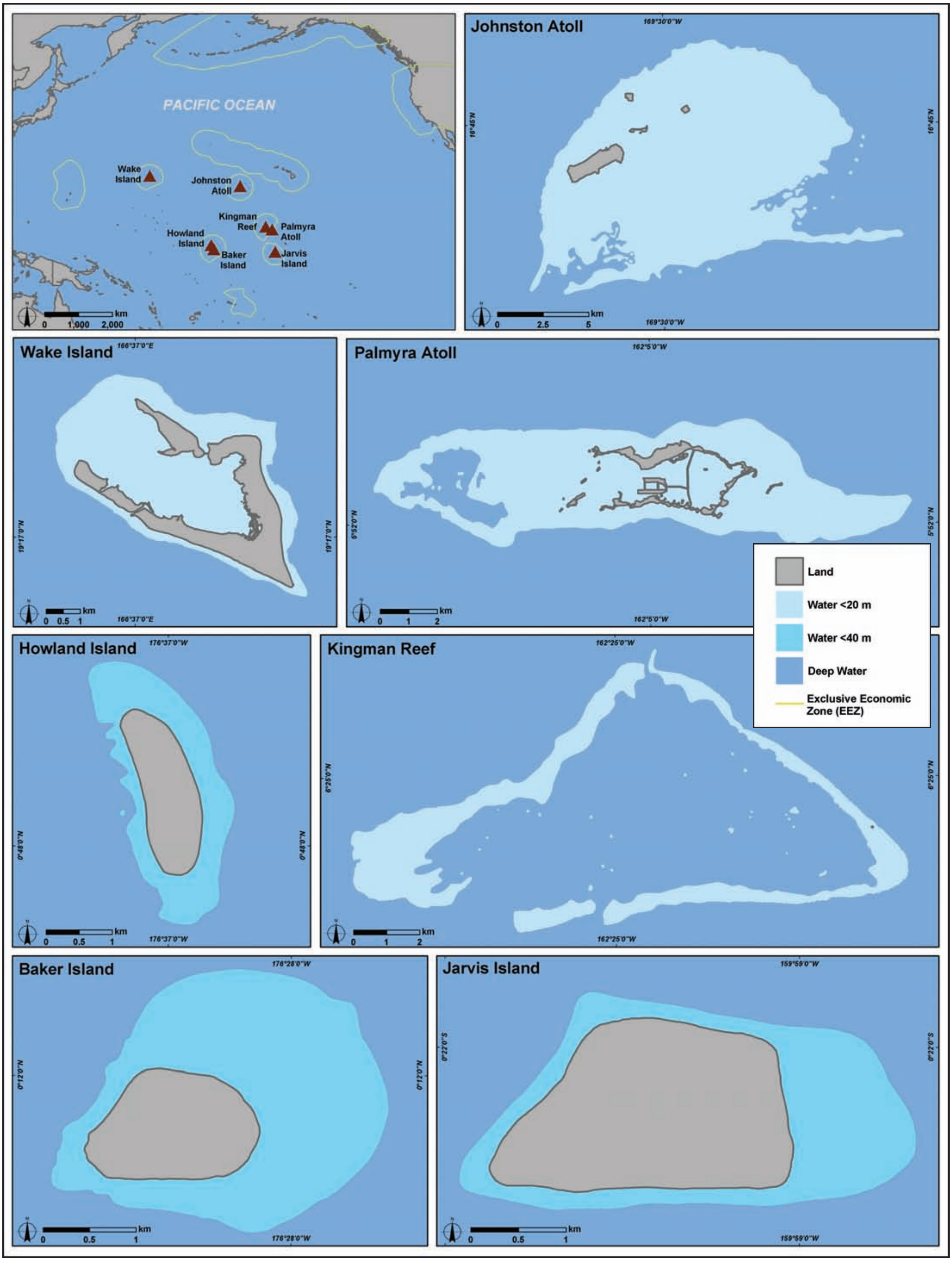


Figure 12.1. Locator map for the Pacific Remote Insular Areas (PRIAs). Map: A. Shapiro.

Ocean currents transport and distribute larvae among and between different atolls and islands, and particularly in the Pacific equatorial region, define sea surface temperatures (SSTs) and available nutrient regimes. The North Equatorial Current (NEC), Equatorial Counter Current (ECC), Equatorial Undercurrent or Cromwell Current (EUC), and South Equatorial Current (SEC) provide the mechanism by which many species are distributed among the PRIAs, nearby central Pacific islands, the main Hawaiian Islands (MHI), as well as other distant regions.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Federally sponsored coral reef surveys conducted between 1979-2004 reveal that all PRIAs have experienced coral bleaching during the past 25 years. Pre-2000 observations by Maragos (1979, 1994) include reports and photographs of localized coral bleaching of the ocean reefs at Wake in mid-1979 and mass coral bleaching in progress at Rose off all reefs to depths of 25 m in April 1994. NOAA and USFWS scientists who visited Wake in 1998 did not report any bleaching. Several USFWS visits and surveys of Rose between 1995-1999 and recent surveys of Rose in 2002 and 2004 sponsored by the National Oceanic and Atmospheric Administration (NOAA) reveal that corals are still recovering from a mass bleaching event of 1994. Coral bleaching was also reported at Johnston and Kingman in the 1990s (P. Jokiel, pers. comm.). The four NOAA and USFWS-sponsored expeditions to Baker, Howland, Jarvis, Kingman, and Palmyra between 2000-2004 strongly suggest that mass bleaching occurred within the few years before 2000, and that corals have remained in recovery phase since then. Additional evidence on recent bleaching at Palmyra reveal that the reefs off the broad western reef terrace at Palmyra supported thriving *Acropora* staghorn coral thickets in 1987 (Maragos, 1988) that died and degenerated to rubble deposits by November 1998 (Molina and Maragos, 1998). The distribution of large *Porites* heads and numerous small *Pocillopora* coral heads present on the terrace in late 1998 suggest mass coral bleaching in the mid-1990s rather than coral mortality caused by storm waves at Palmyra.

During 12 benthic surveys at Johnston Atoll in January 2004, mild bleaching of relatively few coral colonies were found at eight of the 12 sites. Mild bleaching was observed on *Montipora patula, M. capitata,* and *Acropora cytherea*.

During much of June through December 2002, both remotely sensed and *in situ* measurements of SST around Jarvis Island, Baker Island, and Howland Island were extremely high, at times 2˚C or more above maximum mean conditions, for prolonged periods (Figure 12.2). Prolonged temperature anomalies such as these have been implicated in most widespread coral bleaching events. Due to their remote nature, these reefs were not surveyed during or immediately after this period of SST increase. Biological monitoring by experienced scientists in early 2004 did not yield visual evidence that widespread coral mortality had occurred in the wake of a possible bleaching event in 2002.

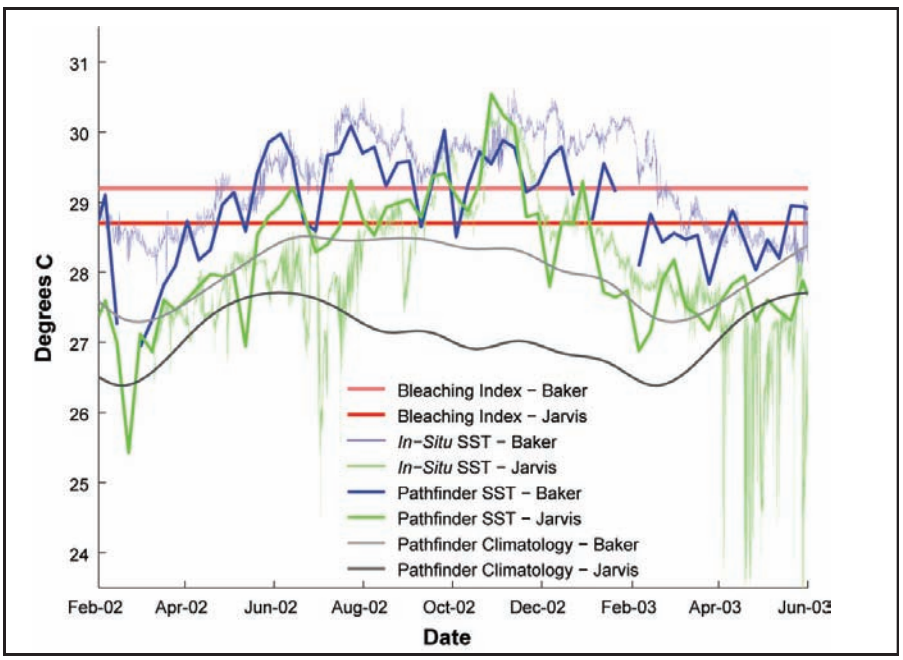


Figure 12.2. Satellite and *in situ* temperatures at Baker and Jarvis Islands during 2002 and 2003 showing anomalously high SST. Both satellite Pathfinder SST (Baker – thick blue line, Jarvis – thick green line) and *in situ* temperatures (z~=-15 m) at Baker (thin blue line) and Jarvis (thin green line) show values significantly 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 are included for reference. Source: Brainard et al., 2004.

Diseases

Johnston Atoll

In January 2004, surveys were conducted at 12 sites at Johnston Atoll to quantify and characterize coral disease. Surveys were limited to sites within the lagoon due to harsh weather conditions. Signs of coral disease were evident at 92% of the sites surveyed. The average prevalence of disease (no. of diseased colonies/total no. of colonies) was estimated at 3.1%, which is higher than what has been reported for the NWHI (average estimated prevalence=0.5%; Aeby, NWHI chapter). Types of diseases included growth anomalies on *Acropora* and *Montipora*, white syndrome on the table coral, *Acropora cytherea*, *Montipora* tissue loss syndrome, and *Montipora* patchy tissue loss. These diseases have also been observed in the NWHI. One disease that has not yet been found in the NWHI was *Montipora* ring syndrome, where affected corals have abnormal growths with tissue death in the center producing a ring-like lesion (Figure 12.3). Work et al. (2001) found similar disease signs at Johnston Atoll during a qualitative assessment of coral disease.

Howland and Baker Islands

A qualitative assessment of coral disease was conducted at six sites around Howland Island and six sites around Baker Island during January 2004. The corals were found to be in good condition with few colonies having any signs of disease. Small patches of denuded skeleton were frequently observed on acroporids and seemed to be associated with damselfish (*Plectroglyphididon* sp.) activities.

Figure 12.3. *Montipora patula* from Johnston Atoll with abnormal growths, January 2004. Photo: G. Aeby.

Tropical Storms

In general, the PRIAs of Johnston, Kingman, Palmyra, Jarvis, Howland, and Baker experience low frequencies of tropical storm events, although occurrences at Johnston are much more common than the other areas. 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 (Figure 12.4). 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 PRIAs. Cyclogenesis (storm formation) to the west/northwest of the PRIAs produces tropical depressions and storms that head away from the PRIAs toward the western Pacific. Additionally, due to their proximity to the equator, the U.S. Line and Phoenix Islands are located out of the path of almost all tropical cyclones of any intensity. No tropical cyclones of any magnitude have been observed within the Exclusive Economic Zones (EEZs) of Howland, Baker, or Jarvis Island in the past 60 years. Three cyclones have been observed in the Kingman/Palmyra EEZ. However, only one of these three, Ekeka in 1992, reached wind speeds in excess of 60 knots (Figure 12.4).

Because Johnston is located at a higher latitude than the other areas, it is subjected to a greater degree of tropical storm activity, catching storm systems out of the eastern Pacific center that travel between 10 and 20 degrees latitude. As a result, Johnston experiences a higher frequency of tropical storm events than both the U.S. Line and Phoenix Islands to the south and the NWHI to the north. Significant hurricanes that have passed near Johnston since 1979 include Hurricane John in 1994, Hurricane Keoni in 1993, and Hurricane Keli in 1984 (Figure 12.4).

While the impacts of these tropical storm events on coral reef ecosystems in the PRIAs are not documented, any damage to reef habitats associated with these storms would have been caused primarily by extreme wave energy events. In summary, tropical storms represent a moderately frequent disturbance event experienced by coral reefs at Johnston Island, potentially influencing physical and biological reef structure, although certainly not to the degree experienced by reefs and terrestrial environments in the western Pacific. Kingman, Palmyra, Jarvis, Howland, and Baker, on the other hand, are rarely, if ever, directly subjected to significant tropical storms and hurricanes.

Significant Wave Events

While the direct impacts of tropical storms on the coral reef ecosystems of most of the PRIAs islands and atolls are relatively rare, the impacts of large wave events resulting from distant tropical and extratropical storms may be significant. Episodic events with wave heights around 2-3 m and periods of 15-20 seconds occur at frequent intervals throughout the year in the equatorial PRIAs (Baker, Howland, Jarvis, Palmyra, and Kingman). Although this is an order of magnitude less than NWHI wintertime wave events, the equatorial PRIAs are much less seasonal in terms of wave energy and these relatively more moderate events occur throughout the year (Figure 12.5). These events generally approach this area from the northeast through the northwest during the boreal winter, from the southwest in the boreal summer, and to a smaller extent, from the west during the northern hemisphere's typhoon season. The wave climate of Johnston Atoll is likely very similar to that of the NWHI and MHI, with a large number of extremely energetic events in the wintertime and very consistent, moderate waves in the summer.

These episodic wave events subject the shallow-water coral reef communities to a great deal more energy than the average energy level. As such, wave climate likely plays a

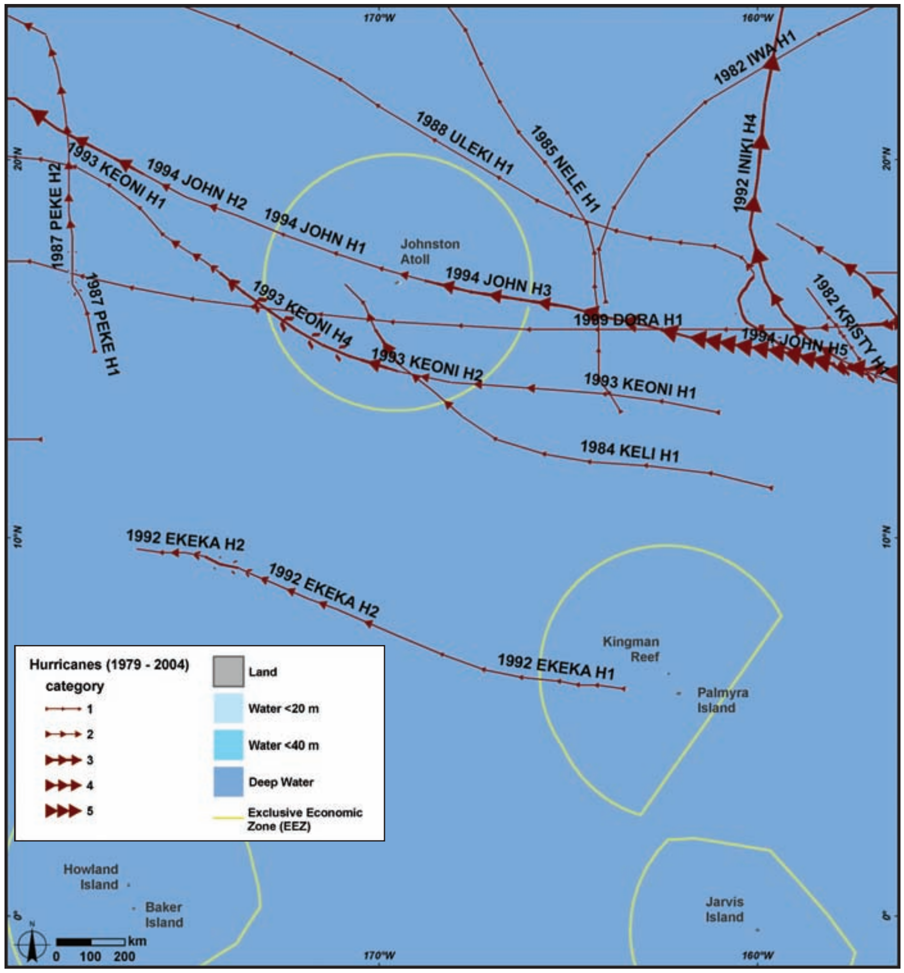


Figure 12.4. A map showing the paths and intensities of tropical storms passing near the PRIAs, 1979-2004. Year of storm, storm name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

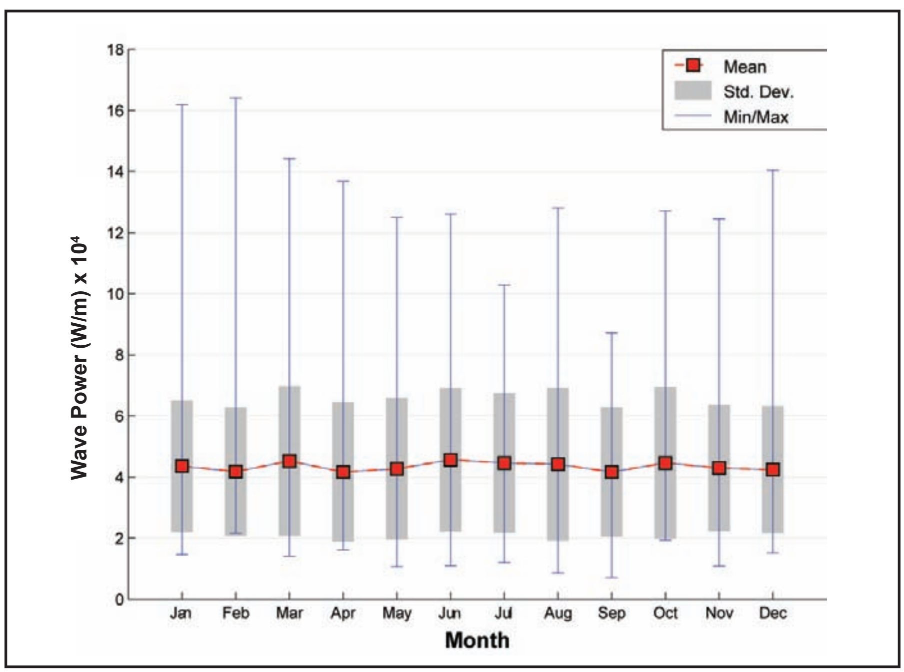


Figure 12.5. Climatological values of wave power (W/m) derived from NOAA Buoy #51028 located along the equator at 154°W near Christmas Island from 1997-2004. Source: NOAA National Data Buoy Center.

fundamental role in forming and maintaining biogeographic (spatial and vertical) distributions of corals, algae, fishes, and invertebrates of the coral reef ecosystems of the PRIAs.

Coastal Development and Runoff

There has not been any coastal development in the PRIAs since the W.W.II era. An atoll research station at Palmyra is being proposed and coordinated by The Nature Conservancy and the USFWS that will be funded by foundations and several participating research institutions and universities. During the past year, all but a few of the Johnston Atoll buildings and facilities were demolished by the U.S. Department of Defense (DoD) prior to the closure of the military base there in early 2004.

Surface runoff is nearly non-existent in the PRIAs. Most of the PRIAs lie within the arid zone of the tropical central Pacific, one (Kingman Reef) lacks permanent land, and all have porous carbonate soils characteristic of atolls and low reef islands. The paved runways at Wake, Midway, and Johnston are designed as catchments for collecting rainfall as a source of freshwater. The PRIA runways at Palmyra, Jarvis, Howland, and Baker have deteriorated or lie within an arid zone, and all are incapable of collecting rainfall and generating surface runoff.

Coastal Pollution

The military bases at Palmyra, Midway, and Johnston Atolls housed up to several thousand military personnel for periods exceeding a decade or more, thus generating sewage pollution and various toxic and hazardous chemicals, and leaving behind abandoned fuels, solvents, and numerous contaminants. The DoD's Defense Environmental Restoration Program funded the draining and demolition of underground fuel storage tanks at Palmyra and some burning of fuel in drums at Howland and Baker in the late 1980s, but many contaminants remain, especially at Johnston and Palmyra. Johnston was also the site of post-war high atmospheric nuclear testing, storage of chemical munitions, and stockpiling of Agent Orange defoliants, all of which released contaminants to the atoll environment. Although the Johnston Atoll Chemical Agent Disposal System completed the task of destroying all chemical agents and associated fuels and explosives in 2003, nuclear waste, dioxins, and other chemical contaminants have not been removed. The USFWS is presently urging the DoD to conduct additional cleanup of military contaminants and toxics at Johnston as part of an acceptable transfer of the atoll to USFWS management.

Coral monitoring data collected off the northwest coast of Baker in 2000-2004 showed evidence of impacts from a nearby W.W.II military debris dump, including periodic dieback of *Acropora* corals (Figure 12.6) and proliferation of cyanobacteria characteristic of sites generating dissolved iron from corroding metallic debris. Additional eco-toxicological studies at the sites are now being proposed.

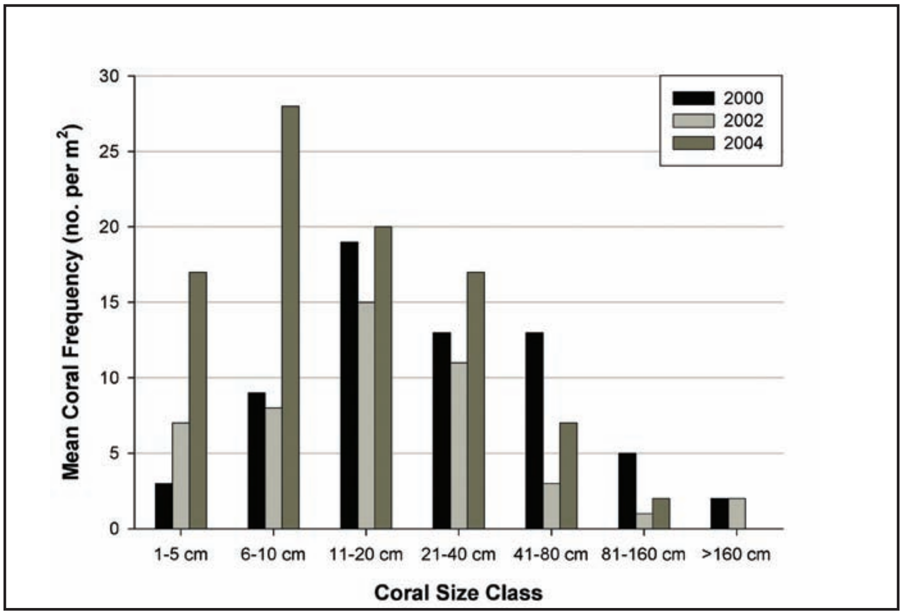


Figure 12.6. Evidence of periodic *Acropora* dieback at USFWS permanent monitoring site BAK-5P near the abandoned WWII military ocean dump site off the northwestern coast of Baker Island. Source: Maragos and Veit, 2004.

The status of military contamination and pollution at Wake Atoll could not be assessed at this time.

Tourism and Recreation

The 2004 termination of military activities at Johnston Atoll permanently closed all sport-fishing activity at the atoll. Presently, The Nature Conservancy sponsors and promotes compatible ecotourism activities at Palmyra Atoll, including

a) catch-and-release sport-fishing for lagoon bonefish, b) blue water sport-fishing of offshore pelagic species, with catch limited to what can be consumed on the island, c) sport diving, d) snorkeling, e) hiking, f) beach-going, g) touring historic sites, and h) birding. Aside from Palmyra, all other central Pacific NWRs are closed to commercial fishing. Access to any NWR requires a Special Use Permit issued by the NWR manager. Permits are granted only for actions compatible with the conservation and protection of fish, wildlife, and vegetation inhabiting the refuges. The military facility at Wake Atoll allows sport diving, beach-going, touring historical sites, and other recreational activities for resident DoD workers and some visitors, although Wake is not a tourism destination.

Fishing

The islands and surrounding waters of Howland, Baker, and Jarvis; Kingman Reef; and most of Palmyra Atoll are currently NWRs under the management of the USFWS. Fishing and unauthorized entry in these waters are prohibited; however, current levels of poaching are largely unknown. Anecdotal evidence of possible fishing activity includes the presence of fishing lines entangled on the reef >50 m deep, as seen on NOAA's Pacific Island Fisheries Science Center-Coral Reef Ecosystem Division's (PIFSC-CRED) towed-optical assessment device video surveys in 2004. The Nature Conservancy owns one-third of Palmyra, primarily for ecotourism (e.g., catch-and-release fishing for bonefish [*Albula* spp.] in the lagoon). In recent years, occasional trips have been made by Hawaii-based fishing vessels to Kingman and Palmyra for coastal sharks (fining) and bottomfish. There is also recent anecdotal evidence of occasional fishing at Kingman and Palmyra (e.g., Fijian fishers on tuna boats based out of San Francisco). However, it is presently not possible to quantify such effort or catch, nor whether by foreign vessels or passing yachts. Johnston Atoll is under the control of the U.S. military with overlay status as a NWR. Recreational and subsistence fishing is regularly practiced by the temporary workers on the island. Based on a survey during the late 1980s, catch was dominated by soldierfish (Holocentridae). Other fish taken included bigeyes (Priacanthidae), flagtails (Kuliidae), mullet (Mugilidae), goatfish (Mullidae), jacks (Carangidae), parrotfish (Scaridae), and surgeonfish (Acanthuridae). It was also common for island residents to regularly ship coolers of fish and corals to Hawaii; however, this practice has recently been prohibited.

Trade in Coral and Live Reef Species

Trade in live reef organisms in the Pacific is primarily for live food fish and ornamental aquarium species, including colorful fish, corals, other invertebrates, and "live rock." Total value of the trade exceeds $1 billion (USD) per year (Barber and Pratt, 1997; Sadovy and Vincent, 2002). Large species of fish, such as humphead wrasse (*Cheilinus undulatus*), large groupers (Serranidae) and emperors (Lethrinidae) are captured and ordered live in upscale restaurants, primarily in Southeast Asia (e.g., Hong Kong), where prices can exceed $100 (USD) per kg. The practice can be harmful as sodium cyanide is often used to facilitate capture, resulting in mass mortality of coral reef communities. Targeted large fish are characteristically long-lived and can be rapidly depleted locally. This results in collection operations moving eastward from Southeast Asia in search of more productive reefs (e.g., Micronesia and the Marshall Islands). There is no evidence to date that live reef fish harvesters have reached the PRIAs. Any such take would be illegal as these areas are no-take NWRs, with one (Wake) under control of the U.S. military. However, the targeted species/sizes do occur at these islands, which are remote and largely unprotected due to the lack of enforcement. The long transport distance of live product to Asian markets may render these U.S. islands economically unfeasible for operations, with the possible exception of Wake Atoll, an active, occupied military base.

There is currently no known live reef ornamental fishing operating in the PRIAs. However, some export of live corals was documented in the 1980s from Johnston Atoll to Hawaii, though DoD and USFWS cooperatively eliminated this activity thereafter. The DoD closed its operations at Johnston in 2004, and the atoll is again an uninhabited NWR. As such it is now vulnerable to unauthorized collection by fishers from nearby Hawaii (1,500 km to the northwest) because of the present lack of on-site enforcement and surveillance.

Ships, Boats, and Groundings

All the PRIAs are uninhabited except for several caretakers and students at Palmyra and DoD workers at Wake. Periodic transports call at Wake to offload supplies, food, and fuel. Otherwise, ship traffic is limited to: a) NOAA oceanographic research vessels every one to two years to all PRIAs except Wake; b) irregularly scheduled supply vessels to Palmyra; and c) unauthorized fishing vessels near the uninhabited NWRs. Tour ships do not call at any of the PRIAs except periodically at Palmyra Atoll.

All PRIAs are vulnerable to ship groundings since most are low lying, poorly chartered, and lack beacons and aids to navigation. Wake suffered a major tanker grounding and fuel spill in the mid-1970s. All of the PRIAs except Wake, Johnston, and Palmyra are rodent-free, due to the concerted rodent eradication efforts of the USFWS and specialists over the past three decades. However, ship groundings always run the risk of re-introducing rodents and other alien species that can decimate native wildlife and vegetation. Fuel spills from ruptured vessels run the risk of mass kills of nearshore marine life, migratory shore birds, sea turtles, and resident seabirds. Dissolved iron from corroding wreckage can also fuel localized outbreaks of invasive cyanobacteria that can displace native species and smother reef building organisms.

Marine Debris

Fishing nets and anthropogenic objects were recorded during towed-diver surveys by the PIFSC-CRED in 2001, 2002, and 2004 in the U.S. Line and Phoenix Islands. During the 2004 season, there was no notable debris accumulation at Howland, Baker, Jarvis, Palmyra, and Kingman. Several anchors and chains are present off the northwestern anchorage of Baker, which served as a temporary forward Allied Forces air base during the W.W.II assault on Tarawa Atoll. After the battle, Baker was abandoned and military debris and material was dumped off the northwestern anchorage.

Long-line gear was encountered at all sites. The majority of the noted debris from Howland, Baker, and Jarvis during all three survey years consisted of encrusted anchors and chains, probable remnants from their guano mining past. In 2004, one large fishing net was found along a previously surveyed 2002 track on the southern forereef zone of Kingman Reef. This net, with an estimated size of 6 m by 12 m, was not noted during the 2002 season. Although the density of nets encountered during towed-diver surveys is low, nets have been seen during each survey year.

Having served as a Pacific military base for refueling during WWII, nuclear testing in the 1960s, and chemical storage and disposal in the 1970s and 1980s, Johnston Atoll contained the majority of marine debris noted during towed-diver surveys in the U.S. Line and Phoenix Islands. Over 200 anthropogenic objects were seen and recorded. Documented items include tires, bottles, metal racks, barrels, steel pipes, frames, and cables.

Aquatic Invasive Species

The efforts by the PIFSC-CRED and the USFWS sponsored Pacific Biological Survey performed by the Bishop Museum, both based in Hawaii, have provided information concerning marine alien species in the PRIAs. Documentation of marine alien species occurred through regular survey and monitoring activities by the PIFSC-CRED in 2002 and 2004. These surveys involved 27 sites at the U.S. Phoenix Islands, 33 sites at the U.S. Line Islands, and 12 at Johnston Atoll. An intensive inventory focusing on marine alien species was conducted at 11 sites at Johnston Atoll by the Bishop Museum.

Compiled data from these efforts reveal that marine alien species exist in these remote islands and that 85% are at either Johnston or Palmyra Atoll. Both of these sites were active military installations with many of the alien species reaching the atolls via the hulls and ballast waters of arriving vessels. These two remote atolls have experienced the greatest physical alteration historically and the majority of alien species documented are associated with these altered habitats. A compiled list from the combined efforts is provided in Table 12.1, including species name, native range (if determined) and a status of either alien or cryptogenic. The cryptogenic term refers to species of unknown status that are most likely introduced. Comparable data for Wake Island, an active military base, are not available.

Table 12.1. List of marine alien species reported from the PRIAs since 2000. Source: Godwin and Vroom, unpublished data.

SPECIES	NATIVE RANGE	STATUS IN PRIAs
Sponge species 1 (Unidentified)	Undetermined	Cryptogenic, Palmyra Atoll only
Sponge species 2 (Unidentified)	Undetermined	Cryptogenic, Palmyra Atoll only
Pennaria disticha (hydroid)	W. Atlantic	Alien
Branchiomma nigromaculata (polychaete)	Undetermined	Cryptogenic, Johnston Atoll only
Armandia intermedia (polychaete)	Indo-west Pacific, Atlantic	Cryptogenic, Johnston Atoll only
Balanus amphitrite amphitrite (barnacle)	SW Pacific, Indian Ocean	Alien
Bugula vectifera (bryozoan)	Undetermined	Cryptogenic, Johnston Atoll only
Caulibugula dendrograpta (bryozoan)	Undetermined	Alien, Johnston Atoll only
Didymozoum triseriale (bryozoan)	Indo-Pacific	Cryptogenic, Johnston Atoll only
Halysis diaphana (bryozoan)	Undetermined	Cryptogenic, Johnston Atoll only
Ascidia sydneiensis (tunicate)	Undetermined	Alien, Johnston Atoll only
Diplosoma listerianum (tunicate)	Undetermined	Alien, Palmyra and Johnston Atolls
Microcosmus exasperatus (tunicate)	Undetermined	Alien, Johnston Atoll only

Marine alien species in these remote areas have just recently become an issue of interest, due to survey efforts in other parts of the tropical Pacific. Efforts should be focused on minimizing the likelihood of coral reef habitats being exposed to marine alien species through the spread of organisms already established in altered habitats and transport of new species from outside of the PRIAs. This can be achieved by management efforts directed towards all activities that have the potential for acting as mechanisms of transport, especially visiting ships and airplanes as well as the shoes and clothing of visitors.

Security Training Activities

Security training activities are not practiced at any of the NWRs in the PRIAs. Data are not available for Wake Atoll, which is currently an active military installation.

Offshore Oil and Gas Exploration

Offshore oil and gas exploration has never occurred, is not being contemplated, nor would it currently be feasible in the PRIAs. All are small low-lying atolls and reef islands surrounded by deep oceanic waters. The possibility of any commercial oil and natural gas formations is highly unlikely.

Other

Crown-of Thorns Starfish

Counts of the crown-of-thorns starfish (COTS), *Acanthaster planci*, were conducted around the U.S. Line and Phoenix Islands in 2001, 2002, and 2004 in conjunction with 50-minute towed-diver habitat surveys (see towed-diver method in the 'Benthic Habitat' section).

All 2001 and 2002 tows at Palmyra were resurveyed in 2004, and four new tows were added. Surprisingly, COTS were not observed at Palmyra in 2004, even though the survey efforts increased and they were recorded in 2001 and 2002 (Table 12.2). Aggregations of COTS were recorded by the USFWS and The Nature Conservancy divers in mid-2001 and 2002 off the southwestern terrace, but these apparently disappeared by 2004. COTS have yet to be observed by towed-divers at Baker, Jarvis, and Howland Islands.

Table 12.2. Total number of COTS recorded during towed-diver surveys and the total distance (km) surveyed in 2001, 2002, and 2004. Source: PIFSC-CRED, unpublished data.

LOCATION	2001 TOWED KM	2001 COTS	2002 TOWED KM	2002 COTS	2004 TOWED KM	2004 COTS
Johnston Atoll	N/A	N/A	N/A	N/A	63.2	182
Howland Island	10.1	0	10.8	0	20.8	0
Baker Island	9.9	0	5.4	0	17	0
Jarvis Island	11.3	0	11.1	0	19.9	0
Palmyra Atoll	17.8	4	31	28	41.7	0
Kingman Atoll	26.6	140	27.4	378	37.8	752

In the 2004 survey year, COTS were recorded at Johnston Atoll and Kingman Reef (Table 12.2). For the 63.2 km of surveyed habitat at Johnston, divers recorded 2.9 COTS/km. The COTS were most noticeable at Kingman Reef where recorded sightings in 2004 increased 44% from 2002 and 160% from 2001. Towed-divers surveyed 26.6 km of habitat in 2001 and recorded 5.3 COTS/km. In 2002, 27.4 km of habitat was surveyed with 13.8 COTS/km and in 2004, 37.8 km of habitat was surveyed with 19.9 COTS/km (Figure 12.7). In addition to resurveying all 2001 and 2002 tows, two additional towed-diver surveys recorded 162 COTS, 21.5% of all recorded COTS at Kingman in 2004. The towed-diver estimating habitat reported that 13% of the coral habitat along those two tows appeared white due to COTS predation. Counts of COTS from towed-diver surveys typically underestimate abundance since juvenile and adult COTS may hide underneath plate corals and other structures.

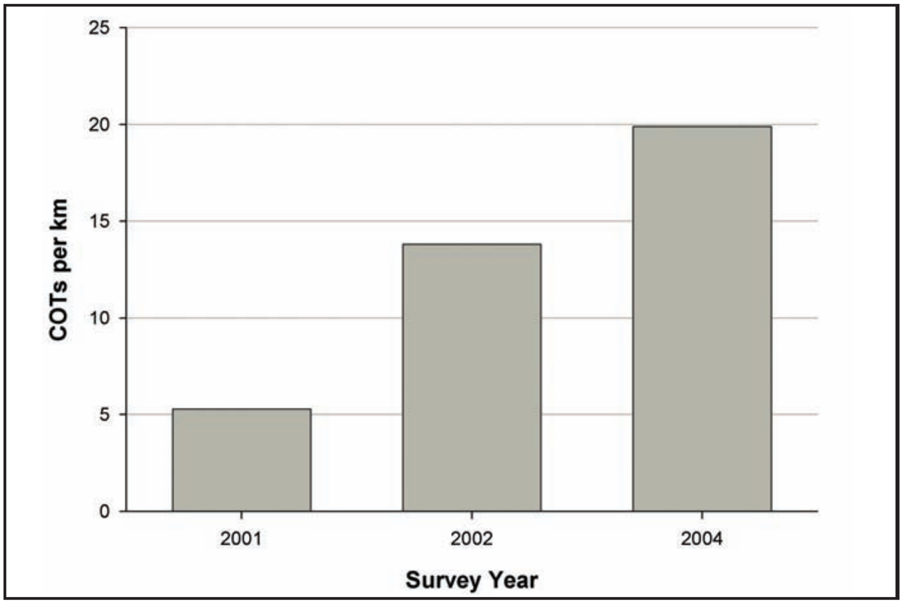


Figure 12.7. Recorded COTS per towed kilometer (km) at Kingman Reef in 2001, 2002, and 2004. Source: PIFSC-CRED, unpublished data.

CORAL REEF ECOSYSTEMS—DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

The health, functioning, and biogeography of the coral reef ecosystems of the PRIAs are primarily controlled by the oceanographic conditions to which fish, algae, corals, and other invertebrates of the ecosystem are exposed. This broad and diverse biological community is heavily influenced by time-varying ocean currents, waves, temperature, salinity, turbidity, nutrients, and other measures of water quality and oceanographic conditions. As these conditions change, so do the health, distribution, and species diversity of each reef community. Table 12.3 provides a list of long-term oceanographic and water quality monitoring programs in place in the central equatorial Pacific. Figure 12.8 shows the locations of many of these monitoring sites.

Table 12.3. Oceanographic monitoring systems in the PRIAs.

SYSTEM	VARIABLES MONITORED	DATES	AGENCY
Deepwater CTDs* at select locations near the islands	temperature, salinity, dissolved oxygen, and chlorophyll versus depth to a depth of 500 m	Feb. 1999 - present	PIFSC-CRED
Shallow-water CTD* - multiple sites each island/atoll	temperature, salinity, turbidity	Feb. 2001 - present	PIFSC-CRED
Coral Reef Early Warning System (CREWS) Buoys - 1 Enhanced – (Palmyra)	Enhanced: temperature (1 m), salinity, wind, atmospheric pressure, ultraviolet radiation, photosynthetic active radiation	Feb. 2002 - present	PIFSC-CRED
Sea Surface Temperature (SST) Buoys – 4 (Johnston, Howland, Jarvis, Kingman)	Temperature at 0.5 m	Feb. 2002 - present	PIFSC-CRED
Subsurface Temperature Recorders (STR) – 24	Temperature at depths between 0.5 m and 5 m	Feb. 2002 - present	PIFSC-CRED
Ocean Data Platforms (ODP) – 2 (Baker, Jarvis)	temperature, salinity, spectral directional wave motion, current profiles	Oct. 2002 - present	PIFSC-CRED
Wave and Tide Recorders (WTR) – 1 (Johnston)	spectral wave motion, tides, temperature	July 2003 - present	PIFSC-CRED
Tide Gauges	tidal fluctuations, sea level	?	NOAA Ocean Service, Pacific Tides Branch
Wave Monitoring Buoys – SE of Kiritami (Christmas) Island	wave height & period, wind speed & direction, atmospheric pressure, temperature	1997 - present	NOAA National Weather Service, National Data Buoy Center
Satellite Remote Sensing	sea surface temperature, winds, sea surface height, ocean color	SST -1981 SSH – 1992 Wind – 1995 Ocean Color - 1994	NOAA Satellites and Information, Hawaii Coastwatch
Model Fields	waves / surface circulation		NOAA National Weather Service, Wave Watch 3 Naval Research Laboratory, Navy Coastal Ocean Model

* CTD: Conductivity, Temperature, and Depth

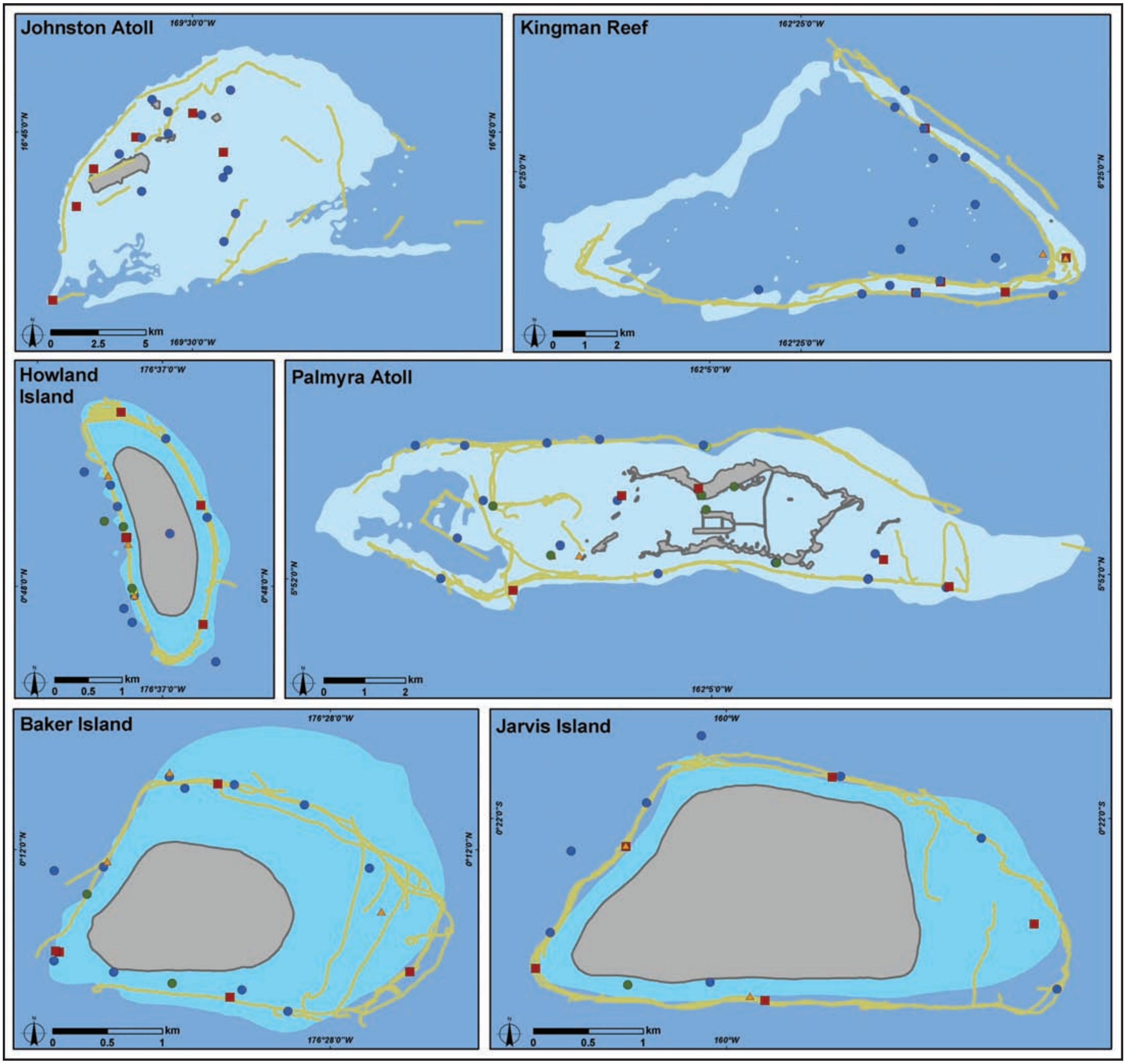
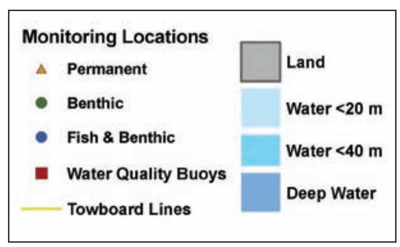


Figure 12.8. Monitoring locations in the PRIAs. Map: A. Shapiro. Source: PIFSC-CRED.



Ocean currents transport and distribute larvae among and between different atolls and islands, as well as define SSTs and available nutrient regimes. The equatorial region is home to several well-defined, though variable, currents: the NEC, ECC, EUC, and SEC. These currents are highly influential to the ecosystems of these islands and atolls: the ECC is the major pathway of larval transport and connectivity to regions of high biodiversity to the west; the deeper flowing EUC brings colder water and nutrient enrichment to islands nearest the equator (Figure 12.9); and the NEC and SEC are generally well mixed and nutrient poor. The magnitude and mean position of these current systems are highly dependent on El Niño/Southern Oscillation (ENSO), and ENSO-related changes to oceanographic conditions in this region are generally much greater than annual changes. Figure 12.10 shows this dependence; SST at all central Pacific PRIAs exhibit greater interannual variability and dependence on ENSO than seasonal changes, with the exception of Johnston Atoll which exhibits a more annual cycle similar to that experienced by the Hawaiian Archipelago.

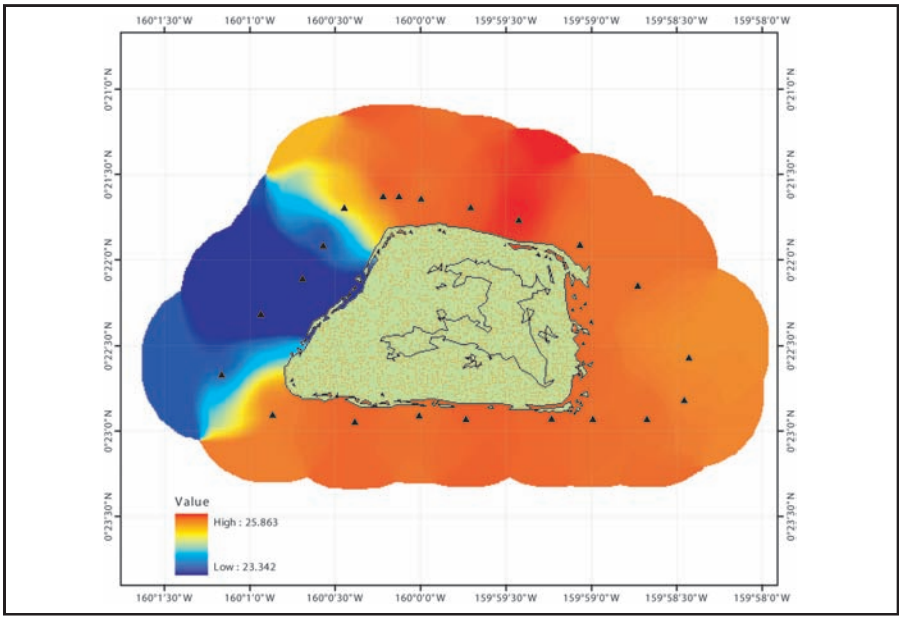


Figure 12.9. Upwelling of cooler, nutrient rich waters originating from the Equatorial Undercurrent near Jarvis Island. Upwelled waters influence fish assemblages and distributions, coral growth rates, and a number of other components of the local

Starting in 1999, hydrographic measurements and oceanographic parameters near these island and atoll environments have been measured using shipboard acoustic Doppler current profilers (ADCP), deep and shallow water conductivity, temperature, and depth device (CTDs), and an array of instrument moorings aboard the NOAA ships *Townsend Cromwell* (1999, 2000, and 2001) and *Oscar Elton Sette* (2002 and 2004) during regular scientific cruises for the PIFSC-CRED. Based on data from these cruises, as well as other satellite derived and *in situ* data sources listed in Table 12.4, a number of physical/biological linkages have been observed:

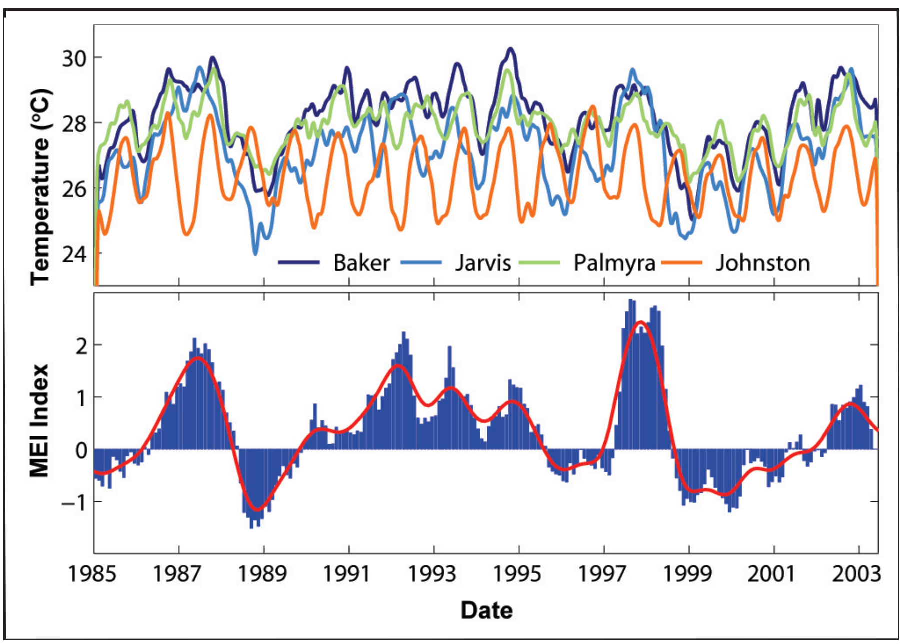


Figure 12.10. Relationship of NOAA Pathfinder derived SST with ENSO Multivariate Index (MEI) at the PRIAs of the central Pacific. Note Jarvis extreme dependence on ENSO contrasting with Johnston's annual cycle. Source: PIFSC-CRED, unpublished data.

- A link between areas of upwelling EUC water with benthic habitat composition and distribution of reef fishes, especially planktivores, at Jarvis and Baker islands;
- Extreme interannual variability of water temperatures, upwelling, and other mixing phenomena (connected with nutrient supply and primary productivity) at Jarvis and Baker and the dependence of this variability on the ENSO cycle;
- Evidence of weak but consistent upwelling along Palmyra Atoll's southern side and its connection to high biomass measured with bioacoustics; and

- Poor water circulation within Palmyra Lagoon and backreef areas and associated large diel variations in water temperature (Figure 12.11).

Continued monitoring and analysis of oceanographic conditions and ecological assessments are required to establish quantitative linkages between ecosystem health and the ever-changing physical environment.

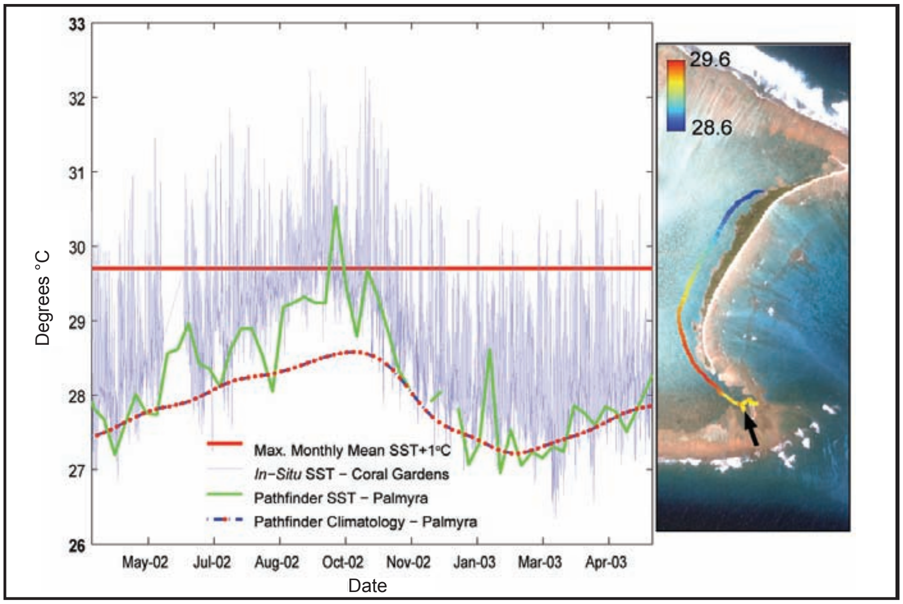


Figure 12.11. Water temperatures recorded by *in situ* STR and shallow water CTDs in a Palmyra backreef (commonly know as the Coral Gardens) as compared to pelagic, NOAA pathfinder SST. Black arrow on overview of CTD temperature track at right indicates position of the STR. Highly elevated daytime temperatures and spatial variation in water temperatures indicate poor circulation and a potentially greater risk of coral bleaching. Source: PIFSC-CRED, unpublished data.

BENTHIC HABITATS

CORALS

Several techniques have been used since 2000 by PIFSC-CRED and USFWS to assess and monitor coral biodiversity, distribution, abundance, population structure, and condition in the PRIAs including the U.S. Phoenix Islands (Howland and Baker); U.S. Line Islands (Jarvis Island, Johnston Atoll, Palmyra Atoll, and Kingman Reef); and American Samoa (Rose Atoll). These techniques include towed-diver surveys each averaging about 2 km in length, rapid ecological assessments (REA) each covering between 1,000-5,000 m^2 per site, photo-quadrat/video surveys at permanently marked 50-100 m transects, and recruitment studies at three of the islands/atolls.

Methods

Rapid Ecological Assessments

REAs are concurrently conducted by algal, coral, other invertebrate, and fish specialists along three 25 m transects (Figure 12.12). Between 2000 and 2002, 98 REA surveys at 78 sites were conducted to assess coral populations in the U.S. Phoenix and Line Islands. During these years, REA protocols focused on visually inventorying species and estimating their relative abundance in broader areas surrounding the transect lines using the DACOR (Dominant, Abundant, Common, Occasional, Rare) system. Assessment activities were initiated at Johnston Atoll in 2004, and 29 sites were resurveyed in the U.S. Phoenix and Line Islands (Table 12.4). Sites were selected so

Figure 12.12. A USFWS coral biologist and two NOAA fish biologists survey along the same transect lines at Kingman Reef. Photo: J. Kenyon.

as to initiate monitoring in locations for which previous qualitative and/or quantitative data were available. In 2004, protocols were revised to shift towards *in situ* quantitative coral population data collection. At each site, two of the three 25 m transect lines were videotaped for use in analyzing percent cover of primary benthic components and as a record of condition of the benthos. Each coral whose center fell within 1 m of the first two transect lines was identified to genus and assigned to one of seven size classes based on the estimated length (cm) of its longest diameter: <5, 6-10, 11-20, 21-40, 41-80, 81-160, and >160 cm. In addition, digital photographs were taken of coral species, including those within a broader area beyond the transect lines, to provide a more complete inventory of coral biodiversity at each site. The revised REA protocols are described in Maragos et al. (2004).

Table 12.4. Summary of coral assessment and monitoring activities conducted by PIFSC-CRED and USFWS in the PRIAs from 2000-2004. REA = rapid ecological assessment, TDS = towed-diver survey. Source: PIFSC-CRED, unpublished data.

	2000		2001		2002		2004	
LOCATION	REA	TDS	REA	TDS	REA	TDS	REA	TDS
Johnston Atoll	NA	NA	NA	NA	NA	NA	12	27
Howland Island	5	8	7	6	6	4	3	9
Baker Island	6	6	6	6	6	2	3	8
Jarvis Island	6	9	4	4	5	4	5	11
Palmyra Atoll	8	12	5	8	11	13	9	21
Kingman Reef	5	10	9	11	9	11	9	18

Towed-diver Surveys

Broad-scale assessment of the shallow-water (<30 m) benthic habitats around the U.S. Phoenix and Line Islands were conducted during 2000-2002 (110 surveys) and 2004 (67 surveys) (Table 12.4) by the PIFSC-CRED. Survey paths in 2004 attempted to replicate selected paths covered in other years to monitor for change, or to fill in gaps in areas not previously surveyed. Benthic towed-diver surveys were initiated at Johnston Atoll in 2004 (Table 12.4). During each survey, two divers maneuver separate boards equipped with a digital video or still camera and temperature and depth recorders, while being towed behind a small boat. The tow path is recorded by a global positioning system (GPS) receiver onboard the boat, and a layback model is applied to the data to more accurately map the position of the imagery. Percent cover of salient benthic categories is quantified by whole-image analysis of still frames sampled at 30-second intervals. Towed-diver surveys bridge a gap between large-scale mapping efforts using satellite data and small-scale traditional belt-transects or roving diver assessments, thereby providing a mesoscale spatial assessment of reef habitats.

Permanent Transects

At each permanent site, a 50 m surveyor's tape was laid along each transect alignment marked with stainless steel stakes installed at 5 m intervals. A 1 m^2 quadrat was laid sequentially and photographed along the entire transect at 1 m intervals for a total coverage of 50 m^2 per transect. These data will be later analyzed for the same parameters as the REA coral census data including percent coral cover, size class distribution, frequency, mean diameter, and generic diversity. More detailed information on the choice and installation of permanent transects is reported in the NWHI chapter of this report.

Recruitment Plates

In 2002, recruitment plates were attached to the base of Coral Reef Early Warning System moorings in the Palmyra Atoll and Kingman Reef (Figure 12.13) lagoons and to

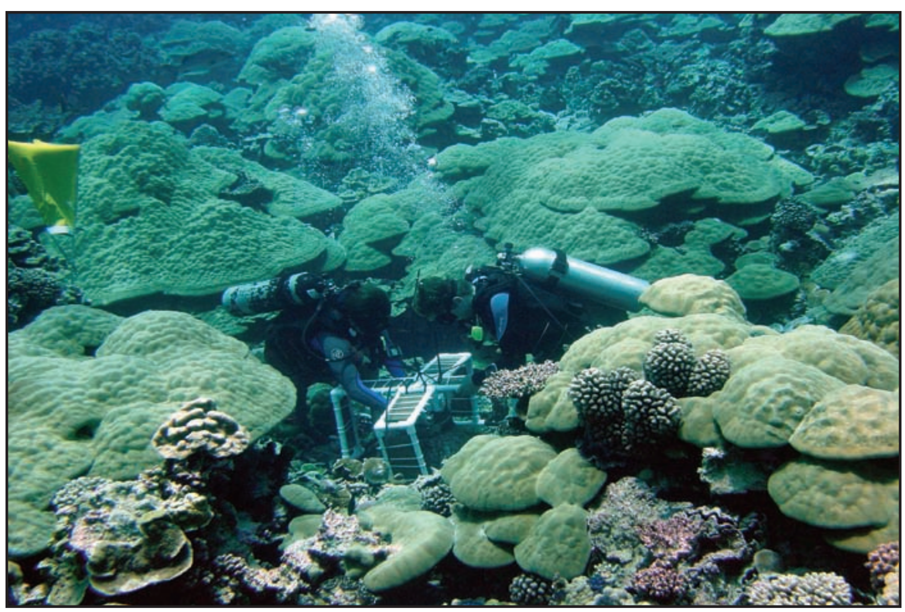


Figure 12.13. Divers install recruitment plates in the lagoon at Kingman Reef. Photo: K. Wong.

a subsurface ocean data platform at Baker Island to assess larval recruitment by calcareous organisms. Their deployment in physical association with the instrumented moorings will enable coupling of biological data with physical data collected by the instruments. Biennial collections and deployments of these plates will address levels of larval recruitment as well as spatial and temporal differences among the sampled areas.

Results and Discussion

Coral community structure from REA surveys

Following surveys conducted in 2000–2002, the coral fauna tallied for the U.S. Phoenix and Line Islands included: Baker (80 species), Howland (91 species), Jarvis Island (49 species), Palmyra Atoll (170 species), and Kingman Reef (155 species). Relative abundances of cnidarians occurring within belt-transects at sites surveyed in the U.S. Line Islands in 2004 is reflected in Table 12.5. Genera comprising more than 10% of colony abundance in each location are highlighted in bold type.

Table 12.5. Relative abundance of cnidarian colonies in the U.S. Line Islands, based on REA surveys at 23 sites conducted by PIFSC-CRED and USFWS in 2004. All cnidarian genera for which at least one colony was tallied in at least one location are listed.

	PERCENT OF CNIDARIAN FAUNA		
GENERA	JARVIS ISLAND	PALMYRA ATOLL	KINGMAN ATOLL
Acropora	0.10%	3.60%	1.10%
Alveopora	0.00%	0.00%	0.00%
Astreopora	0.00%	0.40%	0.80%
Cladiella	0.00%	0.00%	1.30%
Chryptodendrum	0.00%	0.10%	0.00%
Coscinaraea	0.10%	0.00%	0.00%
Dendronephthya	0.00%	0.40%	0.00%
Echinophyllia	0.00%	0.10%	0.40%
Favia	0.30%	5.60%	6.70%
Favites	0.90%	1.90%	1.60%
Fungia	2.70%	5.10%	**41.9%**
Gardineroseris	0.00%	0.00%	0.20%
Goniastrea	0.00%	0.20%	0.10%
Halomitra	0.00%	0.10%	0.00%
Herpolitha	0.00%	0.20%	0.40%
Heteractis/Stichodactyla	0.00%	0.10%	0.20%
Hydnophora	0.00%	2.00%	0.40%
Leptastrea	0.00%	0.20%	0.40%
Leptoseris/Pachyseris	0.80%	0.60%	0.10%
Lobophyllia/Symphyllia	0.00%	1.20%	0.10%
Merulina	0.00%	0.00%	0.10%
Millepora	1.50%	0.10%	0.00%
Montastraea	0.00%	1.00%	0.80%
Montipora	**20.0%**	4.70%	3.70%
Palythoa	0.00%	1.80%	0.10%
Pavona	9.90%	**11.0%**	1.10%
Platygyra	0.00%	1.40%	0.40%
Pocillopora	**50.4%**	**24.4%**	4.40%
Porites	1.00%	**16.9%**	**22.7%**
Psammocora	0.80%	0.40%	0.50%
Rhodactis	0.00%	0.00%	0.10%
Sandalolitha	0.00%	0.10%	0.00%
Sarcophyton	0.00%	5.90%	3.20%
Scapophyllia	0.00%	0.00%	0.10%
Sinularia/Lobophytum	9.90%	6.10%	5.80%
Stylaster/Distichopora	0.70%	0.80%	0.00%
Stylocoeniella	0.00%	0.00%	0.00%
Stylophora	0.00%	0.40%	0.10%
Tubastraea	0.80%	0.00%	0.00%
Turbinaria	0.00%	3.30%	1.40%
Total cnidarians counted	**1061**	**3684**	**5896**
Area surveyed (m^2)	**600**	**750**	**725**

Size class distributions of cnidarians for three of these locations in American Samoa are shown in Figure 12.14. Analyses of coral colony size-frequency distributions can reveal important characteristics of reef populations, and can be used as a tool to estimate the response of coral populations to the reef environment. These data will serve as a baseline to which future size class determinations at the same sites can be compared.

The total number of cnidarian corals and anemone species reported historically at the PRIAs and adjacent atolls are shown in Figure 12.15. The pattern clearly shows that coral and anemone species diversity is higher at Palmyra and Kingman, both in the path of the ECC. The ECC travels through much of the higher marine biodiversity region of the western Pacific and may be transporting larvae of additional species to the two reefs. The ECC and the two reefs may serve as important pathways and stepping stones for species dispersal to the atolls and reef islands of the central Pacific. The total number of cnidarian corals and anemone species reported at the PRIAs and adjacent atolls are shown in Figure 12.15.

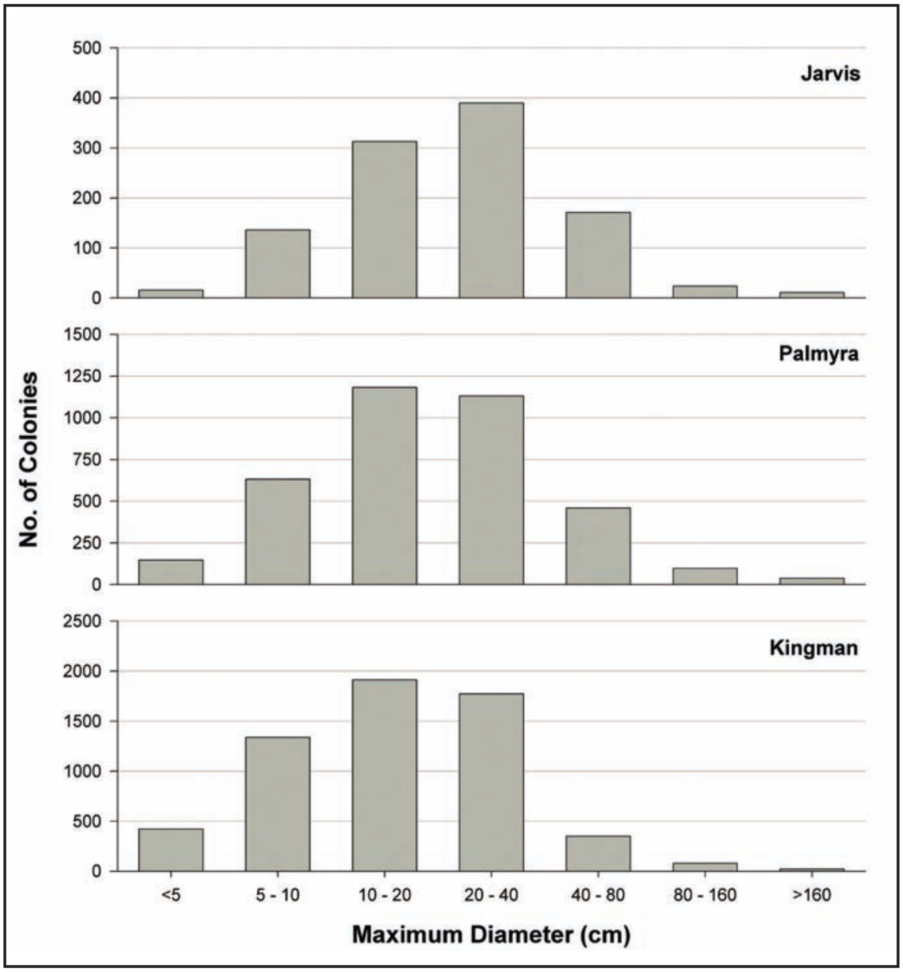


Figure 12.14. Size class distributions of cnidarians surveyed in REA belt-transects in the U.S. Line Islands during 2004. Source: PIFSC-CRED, unpublished data.

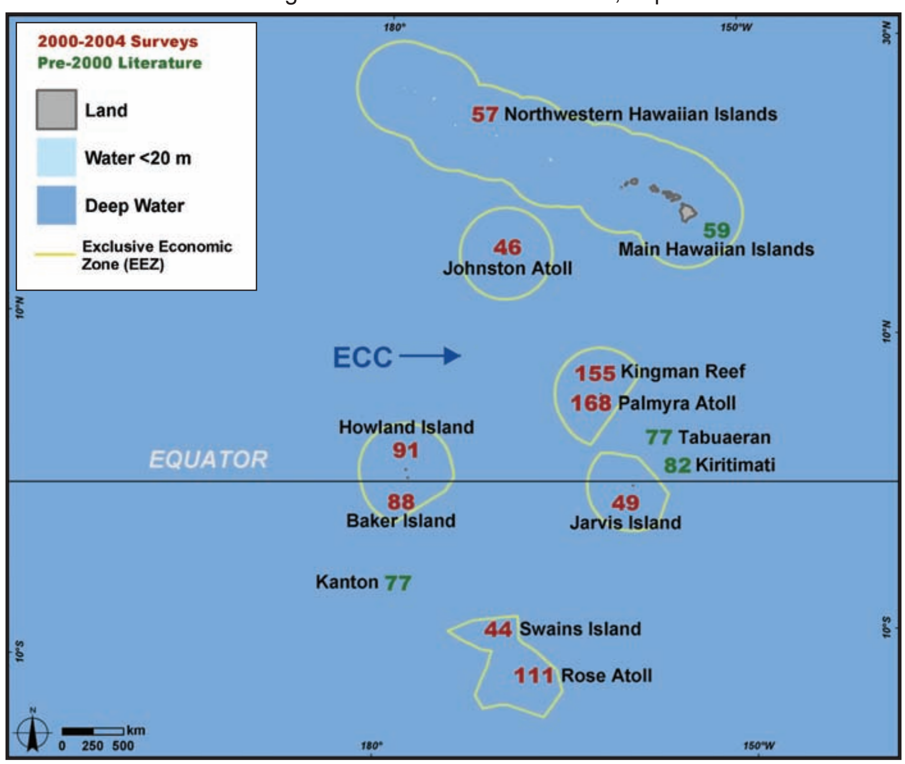


Figure 12.15. Coral and anemone species totals reported at all surveyed central Pacific reefs. Blue arrow shows the direction of the equatorial countercurrent (ECC). Sources: Maragos, 1974, 1995, 1997, 2004; Maragos and Jokiel, 1978, 1986; Maragos et al., 2003; Coles et al., 2000; J. Kenyon and S. Godwin, pers. comm.

Shift in coral community structure from 1999 to 2004

Forty permanent 50 m or 100 m transects were gradually established in the PRIAs, American Samoa, and the Marshall Islands between 1999 and 2004. These transects include nine sites each at Johnston and Rose; five sites at Palmyra; three sites each at Baker, Howland, Jarvis, Kingman, and Swains; and two sites at Ailinginae Atoll in the Republic of the Marshall Islands. Many of the older PRIA sites at Baker, Howland, Jarvis, Kingman, Johnston, Rose, and Palmyra have now been resurveyed up to three times through early 2004, providing an opportunity to track changes in coral community structure over a two to five year period at specific sites. Figure 12.16 documents the decline of *Acropora*, *Montipora,* and *Pocillopora* and the concomitant increase of *Porites* between 2000-2004.

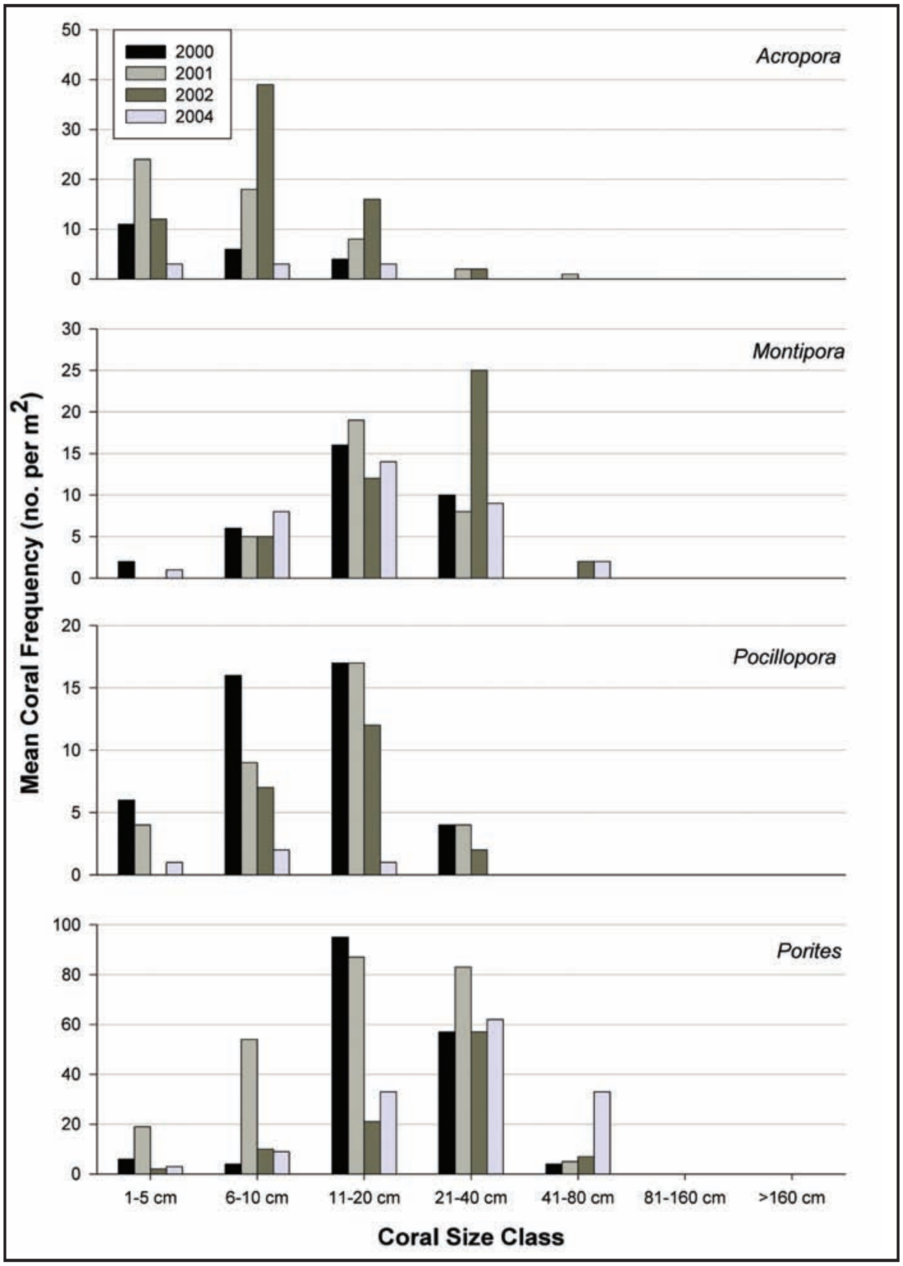


Figure 12.16. Coral size and abundance at Kingman Reef site 5P from 2000-2004. *Acropora*, *Montipora* and *Pocillopora* corals have declined, while *Porites* coral has shifted from small and numerous to large colonies. Source: Maragos and Veit, 2004.

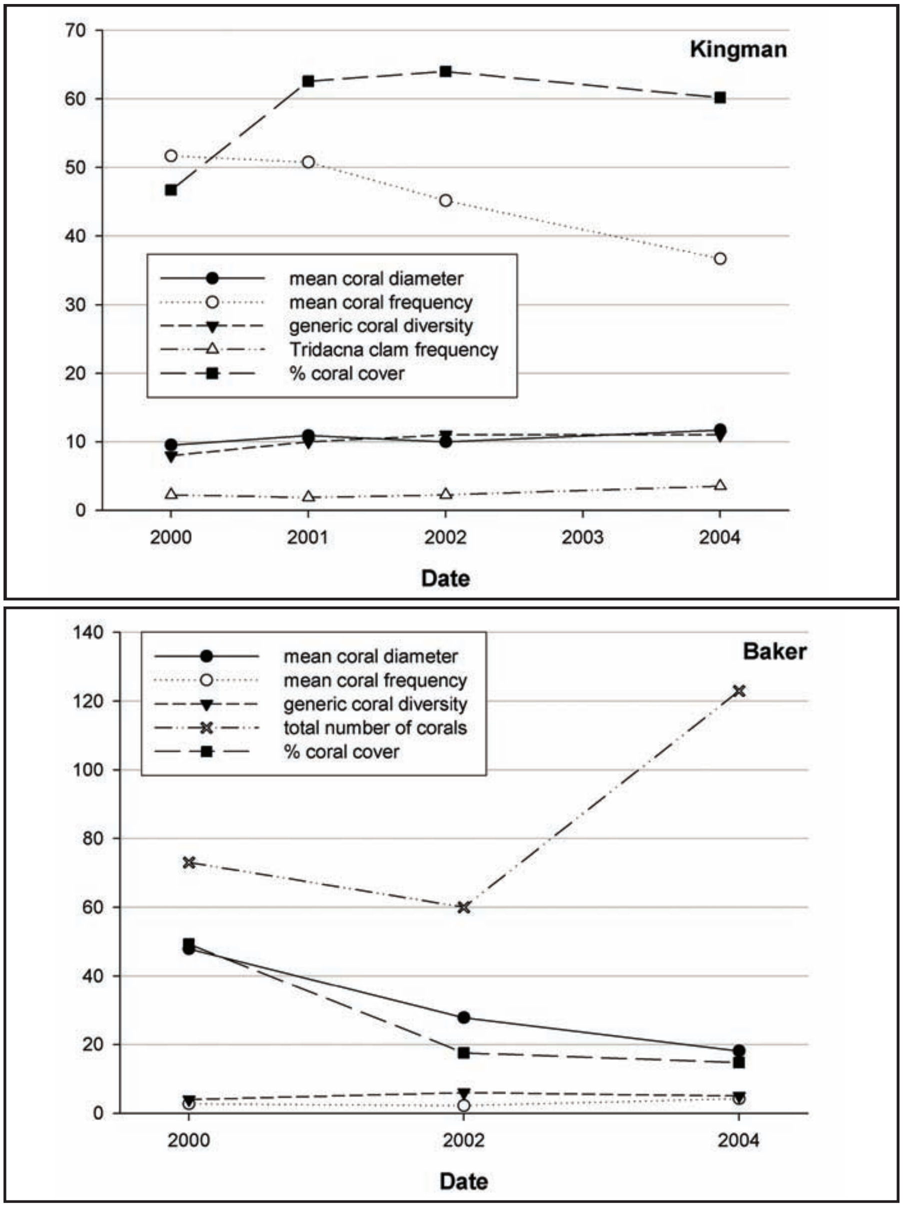


Figure 12.17. Summary of trends in mean coral diameter, mean coral frequency, generic diversity, coral percent cover, and *Tridacna* clam frequency at Kingman Reef site 5P (upper panel) and at Baker site 5P (lower panel) between 2000-2004. Source: Maragos and Veit, 2004.

Figure 12.17 provides representative examples of changes at two of the older monitoring sites, KIN-5P in the east shallow lagoon of Kingman Reef and BAK-5P at Baker Island, over the same time period. At the Kingman Reef site, the 2002 photoquadrats along the permanent transect showed numerous COTS (*Acanthaster*) feeding scars and two of the starfish actively feeding on corals. The photos and other observations show that many types of corals are potential prey for the starfish at Kingman but that incidence of predation was higher on *Pocillopora*, *Montipora* and *Acropora* than on *Porites* when all four groups are present (as was the case at site KIN-5P). The data show a gradual shift to larger more abundant *Porites* over the four years of monitoring, with COTS predation on the other coral groups likely contributing to this trend.

These examples represent the preliminary findings at just two of 40 permanent monitoring sites in the PRIAs and neighboring reefs. The findings are also consistent with those of Timmers (this report) that document the movement of COTS towards the eastern lagoon of Kingman Reef in 2002, based on towed-diver surveys at Kingman Reef, and illustrate the value of multiple strategies in assessing and monitoring coral reef life at remote sites where dive time and dive days per locale are extremely limited. Monitoring corals and conspicuous macroinvertebrates at permanently marked sites has the advantage of isolating temporal trends in a set area. Analyses of all permanent monitoring data will allow comparison to coral data collected at adjacent REA sites at each of the PRIAs and help elucidate larger-scale geographic and temporal trends for coral population dynamics in the PRIAs. The findings should help NWR managers focus on assessing and eliminating anthropogenic stressors at these vulnerable reefs.

ALGAE

Methods

Quantitative algal sampling performed by the PIFSC-CRED in the Pacific has been limited by four factors: short visits to each site (40-50 minutes/year), the inability of phycologists to work away from the “fish transects,” only having one phycologist per benthic team, and the lack of expertise in the field. The techniques presented here were written by phycologists with first-hand experience from previous research missions, and give divers the ability to sample on and slightly away from the fish transect line, quickly record percent cover using photoquadrats, and sample species without the aid of trained phycologists. Advantages to these techniques include:

• One person analyzes all images for analytical consistency, which minimizes error associated with having multiple divers with varying levels of expertise subjectively determining percent cover in the field;

• Fish transects are usually laid at a constant depth. Previous phycologists have been frustrated by seeing large amounts of algae growing in shallower water a short distance away from the fish transect, and being unable to sample those areas because of sampling constraints placed on the benthic team. This method allows phycologists to move off the main transect into shallower water; and

• Specimens collected from each photoquadrat will allow for easier species determination, including analysis of epiphytes.

Because no quantitative algal sampling has ever occurred on the PRIAs before the PIFSC-CRED research expeditions, it is impossible to tell how the present state of the reefs compares to past conditions. However, the lack of obvious algal blooms or alien species on the reefs combined with high percent covers of crustose coralline algae and moderate abundance of macroalgae suggests that these reef systems are very healthy.

Results and Discussion

Historically, algal collections from the U.S. Line and Phoenix Islands were solely qualitative, intermittent, and often biased towards large, macroscopic species (Dawson et al., 1955; Dawson, 1959; Tsuda and Trono, 1968). South et al. (2001) added considerable detail to our knowledge of microscopic turf and epiphyte species of islands relatively close to the U.S. Phoenix Islands; however, the paucity of algal collections from U.S. equatorial islands undoubtedly underrepresents the true algal diversity present in these ecosystems. To ameliorate this problem, PIFSC-CRED expeditions to American Samoa over the past four years have focused on *in situ* sampling of algal diversity. Most data have not been thoroughly analyzed and are stored at the PIFSC-CRED office in Honolulu.

From an algal perspective, the US equatorial islands contain many unique habitats and are likely to contain endemic species new to science. Expeditions during 2001-2004 addressed ecologically-based algal questions for common species in the PRIAs for the first time. Additionally, quantitative baseline assessments of algal cover using a protocol devised specifically for remote tropical reef ecosystems (Preskitt et al., 2004) were conducted. Detailed photoquadrat analysis combined with voucher specimens and field notes will allow for percent cover determination of algae and invertebrates at the species level. Oceanographic monitoring studies conducted concurrently with algal sampling will aid in defining algal distributional patterns throughout the US equatorial islands. Baseline assessment data for all of the U.S. Line and Phoenix Islands are in-hand and available for future analyses.

Algal monitoring in the U.S. equatorial islands is still in its infancy. Biannual visits to established sites throughout the U.S. Line and Phoenix Islands will enable long-term data sets to be established that may reveal change over years or decades if environmental or anthropogenic changes occur. Preliminary monitoring results have helped determine the relative abundance of algal genera (Table 12.6).

Table 12.6. Algae of Johnston Atoll, Howland Island, Baker Island, Jarvis Island, Palmyra Atoll, and Kingman Atoll. Bold numbers indicate the number of photo-quadrats in which an alga occurred; italicized numbers indicate the alga's relative abundance (rank) in relation to other algae occurring in the same photo-quadrat. Standard deviation of island averages are given in parentheses. Asterisks indicate algae found during the random swim that did not occur in photo-quadrats sampled. Source: Page and Preskitt, 2004.

	JOHNSTON ATOLL AVERAGE	HOWLAND ISLAND AVERAGE	BAKER ISLAND AVERAGE	JARVIS ISLAND AVERAGE	PALMYRA ATOLL AVERAGE	KINGMAN REEF AVERAGE
GREEN ALGAE						
Avrainvillea		**8.33 (11.79)** *4.17 (0.24)*			**11.46 (14.04)** *4.68 (0.8)*	**9.26 (19.30)** *4.88 (0.99)*
Bryopsis	*		**11.11 (16.39)** *3.9 (0.36)*			*
Caulerpa	**12.50 (19.62)** *3.15 (1.30)*	**6.25 (7.98)** *5 (0)*			**3.13 (6.20)** *5 (1.41)*	**3.70 (4.39)** *4.25 (0.96)*
Codium				**1.39 (3.4)** *5*		
Dictyosphaeria	**2.77 (4.10)** *4.75 (1.26)*	**2.08 (4.17)** *5*	**5.56 (6.8)** *4 (1)*	**5.56 (8.61)** *4.75 (0.35)*	**26.04 (23.75)** *4.05 (1.03)*	**9.26 (12.11)** *5 (0.41)*
Halimeda	**10.42 (17.81)** *3.08 (0.44)*	**33.33 (19.25)** *3.21 (0.57)*	**26.39 (38.16)** *3.17 (0.58)*	**27.78 (12.55)** *3.65 (0.38)*	**70.83 (26.35)** *2.82 (0.61)*	**71.3 (28.29)** *2.72 (0.47)*
Microdictyon						**34.26 (28.7)** *4.01 (0.68)*
Neomeris					**1.04 (2.95)** *4*	**29.63 (22.86)** *4.38 (0.59)*
Valonia				**5.56 (13.61)** *3.5*	**3.13 (4.31)** *4.67 (0.58)*	**5.56 (8.33)** *4.33 (0.58)*
Ventricaria	**4.17 (9.73)** *2.67 (1.15)*					**0.93 (2.78)** *7*
RED ALGAE						
Amphiroa						
Chrysymenia	**0.69 (2.41)** *5*					
Dasya	*					
Galaxaura			**4.17 (10.21)** *4.67*		**12.5 (35.36)** *3.58*	
Haloplegma	*					
Halymenia						
Hypnea						
Jania			**1.39 (3.4)** *3*			**3.7 (8.45)** *5.83 (0.24)*
Laurencia			**16. 67 (16.67)** *3.63 (1.03)*			
Peyssonnelia			**4.17 (6.97)** *3.75 (1.77)*	**2.78 (4.3)** *3 (1.41)*	**5.21 (6.2)** *3.75 (0.96)*	**11.11 (16.67)** *3.83 (0.82)*
Wrangelia		**37.5 (19.84)** *3.73 (0.36)*				
branched coralline	**11.81 (23.42)** *2.17 (0.58)*		**5.56 (10.09)** *2.67 (0.94)*	**12.5 (23.42)** *3.32 (0.25)*	**1.04 (2.95)** *3*	**16.67 (23.94)** *3.33 (0.84)*
crustose coralline	**48.61 (29.69)** *2.25 (0.50)*	**97.92 (4.17)** *1.54 (0.32)*	**81.94 (20.01)** *1.97 (0.79)*	**91.67 (7.45)** *1.87 (0.47)*	**93.75 (9.71)** *1.7 (0.24)*	**83.33 (20.83)** *2.15 (0.35)*
BROWN ALGAE						
Dictyota	**2.27 (7.54)** 2.67 (1.89)	*	**36.11 (33.61)** *3.15 (0.6)*	**5.56 (13.61)** *4.25*	*	
Lobophora	**11.81 (20.56)** 3.08 (0.67)	**64.58 (28.36)** *2.62 (0.54)*	**66.67 (39.09)** *2.24 (0.99)*	**69.44 (25.09)** *2.86 (0.89)*		
orange crust					**65.63 (34.05)** *2.99 (0.63)*	**13.89 (18.63)** *4.02 (0.99)*
Turbinaria					*	
CYANOPHYTES	**13.19 (18.96)** *2.53 (0.98)*	**6.25 (7.98)** *3.25 (0.35)*	**23.61 (26.57)** *2.6 (0.25)*		**5.21 (8.84)** *4.33 (0.58)*	**10.19 (10.02)** *3.94 (0.14)*
TURF	**92.36 (6.61)** *1.21 (0.46)*	**93.75 (4.17)** *1.87 (0.21)*	**79.17 (15.59)** *2.18 (0.45)*	**94.44 (13.61)** *1.51 (0.34)*	**94.79 (4.31)** *2.31 (0.57)*	**97.22 (8.33)** *1.32 (0.43)*

ASSOCIATED BIOLOGICAL COMMUNITIES

Virtually all monitoring and assesement activities conducted in the PRIAs are accomplished by scientists from the USFWS and PIFSC-CRED, working in collaboration with the University of Hawaii's Joint Institute for Marine and Atmospheric Research (JIMAR). Their protocols involve various methods and are similar to methods used in many other jurisdictions across the Pacific.

FISH

Quantitative assessment and monitoring of shallow reef fish assemblages were conducted around the U.S. Pacific Islands as an integral part of PIFSC-CRED's mission to improve the scientific understanding of these fish resources. Fish are the primary sustainable living resource on Pacific coral reefs, and survey results contribute to the scientific basis essential for sound management. Related objectives include: creating a baseline to measure MPA effectiveness; monitoring size-frequency assemblages; assessing the status of target, indicator or keystone species; assessing fish community response to possible ecosystem impacts (e.g., overfishing, habitat damage, sedimentation, prey size changes); assessing species composition and diversity by area; and assessing effectiveness of temporal monitoring of managed areas.

Field surveys were conducted in 2000, 2001, 2002, and 2004 in the U.S. Line (Jarvis, Palmyra Atoll, Kingman Reef) and Phoenix (Baker, Howland) Islands, and in 2004 at Johnston Atoll (Figure 12.8). Fish data from 2000 were largely qualitative with the primary focus on site selection. An initial species inventory was a prerequisite for comprehensive assessment of reef fish assemblages in each area. Subsequent biennial monitoring surveys are planned for each geographic sub-region to document temporal variability in reef fish assemblages. Habitat types surveyed included mainly outer reef slopes around most islands, but also included lagoon patch reefs, bays, backreefs, and shallow oceanic banks where present.

Inventories and assessments of shallow reef fishes have now been completed by the PIFSC-CRED at all U.S. Pacific Islands (except Wake Island and Farallon de Mendinilla [CNMI] which are restricted areas), and monitoring has begun. Ongoing analysis of this growing database will enable species-specific numerical and biomass densities to be calculated, fish assemblage structure to be described at various spatial and temporal scales, and statistical correlations to be determined. Further analysis of PIFSC-CRED's oceanographic and biological data will aid in understanding patterns of fish distribution and abundance as well as ecosystem associations.

Methods

Several complementary, non-invasive underwater surveys were used to enumerate the diverse components of diurnally active shallow-water reef fish assemblages. Survey types included: 1) REA to document simple species presence at a station or reef/bank; 2) Belt transects to quantify relatively small-bodied and abundant fishes; 3) Stationary point counts (SPC) to quantify relatively larger (>25 cm total length [TL]) and more mobile fish species; 4) Towed-diver/video surveys (TDVS) to quantify relatively large-bodied (>50 cm TL), wide-ranging fishes over a broad-spatial scale, in conjunction with towed-diver/habitat video; and 5) Sound scattering layer echo-sounds (SSL) to identify patterns of migration in pelagic communities using sonar. Each method was replicated at sites within and/or among the various habitat types present around each island, atoll, or reef. Fish length-class was estimated for all quantified fish to provide an estimate of numerical size structure and biomass densities by taxa.

REA Protocol

A pair of diver-observers conducted an arbitrary swim at each site, recording fish presence and identifying them to the lowest recognizable taxon. This method was typically used at deeper, time-limited sites or where the current was too strong to conduct transects. The REA protocol was also used following completion of a belt-transect or SPC, dive time permitting. The REA data complement the other visual protocols to assemble more complete reef-and archipelago-specific fish species inventories at each island, atoll, or reef.

Belt Transect Protocol

A pair of scuba diver-observers conducted parallel swims along three 25 m long transect lines, recording size-class specific counts of all fishes encountered (using TL) and identifying them to the lowest possible taxon, within visually estimated belt-transects: 4 m wide for fishes ≥20 cm TL (100 m^2 area) on the initial swim-out, and 2 m wide for fishes <20 cm TL (50 m^2 area) on the subsequent swim back. Transects lines were typically set at depths of 10-15 m. Reef ledges and holes were visually searched. Stations were completed on all sides of the island/atoll/reef, weather and sea conditions permitting.

SPC Protocol

One SPC diver-observer conducted surveys in conjunction with, but at least 10 m away from, the two belt-transect divers. All fishes ≥25 cm TL that entered a 20 m diameter cylinder (area about 314 m^2) during a 5-minute period were counted and identified to the lowest possible taxon. Individuals or groups were estimated to the nearest 5 cm TL size-class bin. Four replicate, 5-minute surveys were conducted at each station. Care was taken to avoid overcounting large transient or schooling species.

TDVS Protocol

A pair of divers were towed about 60 m behind a small boat about 1 m above the bottom, at a speed of about 1.5 knots across about 2 km of coral reef habitat (during a 50-minute survey), generally at a constant isobath around the island. One diver recorded all fish ≥50 cm TL within a 10 m wide swath. The other diver quantified benthic habitat composition by type and macroinvertebrate densities. Fish were identified to lowest possible taxon and recorded in 25-50 cm TL size-class bins. Both towboards were equipped with digital cameras (video for fish and still for habitat) and temperature/depth/time recorders for more detailed future analysis. The towboat concurrently logged a GPS track position every 5 seconds. The fish diver performed a 360° scan during the first minute (plus another scan at the end of the tow), recording all large fish within visible range, and then completed 10 5-minute survey segments. Laboratory analyses of the digital videos recorded during towed-diver fish surveys are ongoing.

Results and Discussion

Preliminary results from the US Line and Phoenix Islands are presented here as full analysis of the data from these assessments is ongoing. The major effort by the PIFSC-CRED during its first few years focused primarily on field assessments.

U.S. Line and Phoenix Islands

Results of the PIFSC-CRED assessments found that numerical densities of reef fishes were high at these islands. Small fish (particularly planktivores such as *Pseudanthias*, *Lepidozygus* and *Luzonichthys*) were quite abundant at Howland, Baker, and Jarvis Islands, particularly along the west side where upwellings occurred; fewer reef fishes occurred at Palmyra were also discovered for these species (e.g., basslets). Densities of large fish (e.g., sharks, jacks, grouper, snapper, parrotfish) were higher in the U.S. Line Islands than in the U.S. Phoenix Islands or NWHI (Figure 12.18). Certain species of groupers, snappers and emperors occurred only at the southern or northern islands of the U.S. Line Islands.

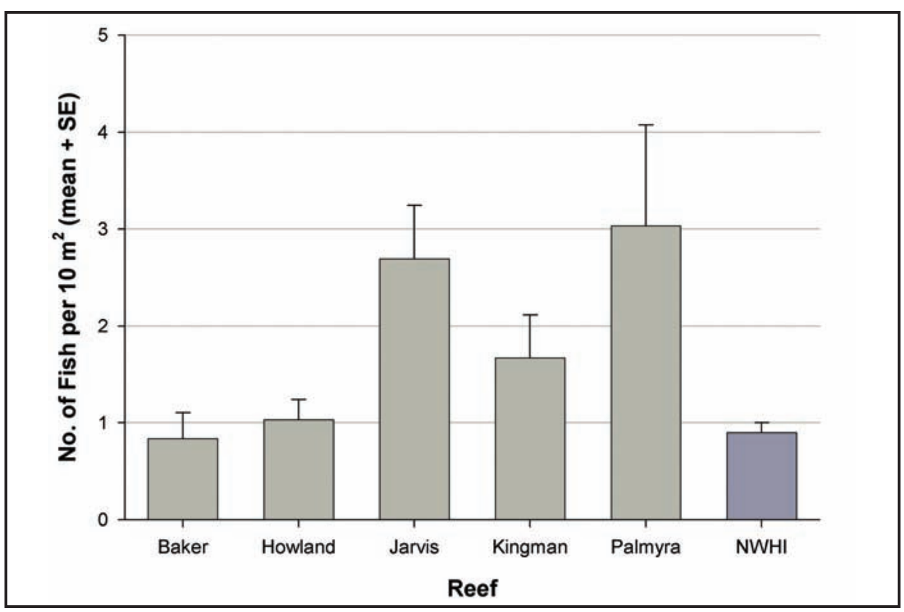


Figure 12.18. Density of large fish (>20 cm TL, all species pooled) in the U.S. Line and Phoenix Islands from belt-transects, compared to the NWHI in 2002. Source: PIFSC-CRED (R. Schroeder), unpublished data.

Biogeographic patterns indicate that the majority of these reef fishes are widespread Indo-Pacific species that occurred at all five islands. A total of 480 fish species was recorded in the U.S. Line and Phoenix Islands in 2002. Total number of species was highest at Palmyra (343), followed by Howland (302), Jarvis (252), Baker

(241), and Kingman (225). Many new records for species presence at these islands were found: over 96% at Kingman (where very few previous surveys were conducted), 78% at Baker, 72% at Jarvis, 60% at Howland, and 35% at Palmyra (where most earlier sampling focused). Inter-island differences in species patterns were also found. These islands include a significant component of south-central Pacific endemic species not found at other U.S. reefs. The U.S. Line and Phoenix Islands appear to be at the junction of two biogeographic areas, one centered in French Polynesia and a larger one centered in Micronesia. This is exemplified by the contribution of the PIFSC-CRED data to a recent revision of the surgeonfish genus *Ctenochaetus*, which demonstrated that the U.S. Phoenix Islands are the only area of co-occurrence for a western-central Pacific species and an otherwise French Polynesian species. A few fish specimens were collected (by permit) in 2002 and 2004 from each of these islands for genetic study to further clarify taxonomic relationships and to help understand dispersal patterns. A collaborative study California-Santa Cruz evaluated species differentiation in one group of Indo-Pacific fishes (the three-spot damselfish, *Dascyllus trimaculatus,* species complex) that includes the recently described gold-finned domino, *Dascyllus auripinnis,* found in the U.S. Line and Phoenix Islands. The distribution of mtDNA genotypes within the group was consistent with geographic separation but incongruent with external characteristics that define some of the nominal species, indicating that more work on the systematics of this group and likely many other central Pacific fishes is needed. The occurrence of south-central Pacific Ocean species in the U.S. Line and Phoenix Islands is unique among U.S. coral reef ecosystems and adds to the exceptional conservation value of these five islands.

Preliminary analysis of the towed-diver fish data for the U.S. Line and Phoenix Islands focused on trends within four families of carnivorous fish. Jacks (Carangidae), snappers (Lutjanidae), sharks (Carcharhinidae, Sphyrnidae), and grouper (Serranidae) were recorded in substantially higher numerical densities in the U.S. Line and Phoenix Islands than in American Samoa or in most other U.S. Pacific Islands surveyed by the PIFSC-CRED. This phenomenon of consistently high densities of top carnivores may be a result of the remoteness of the islands and oceanic conditions conducive to enhanced productivity. Within the U.S. Line and Phoenix Islands, jacks and snappers were recorded in the

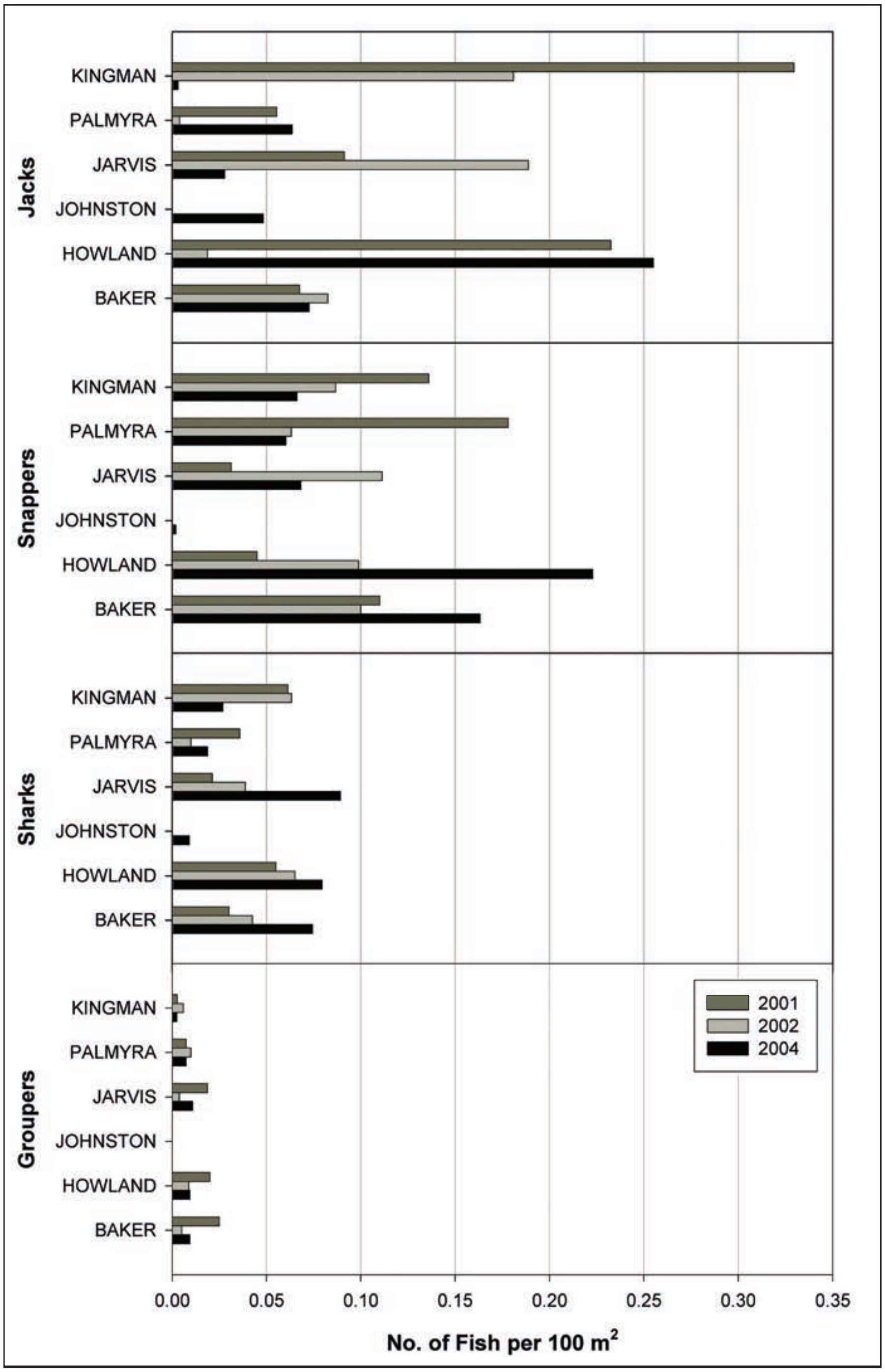


Figure 12.19. Density of common large fish (>50 cm TL, all species pooled) by family from towed-diver surveys conducted in the U.S. Line and Phoenix Islands (2001, 2002, 2004) and Johnston Atoll (2004 only). Source: PIFSC-CRED (S. Holzwarth), unpublished data.

greatest densities, followed by sharks and then groupers (Figure 12.19). When the data were grouped by island, it was evident that the abundance of large predators fluctuated considerably between years and sites (Figure 12.20). In general, large fish densities appeared to increase at Howland and Baker from 2002 to 2004, while decreasing at Kingman and, to a lesser degree, Palmyra (for three of the four families).

Howland and Baker Islands (U.S. Phoenix Islands)

Baker Island is characterized by a subsurface eastward flowing EUC that lies beneath the westward surface flowing SEC. This causes an upwelling of cooler, nutrient- and plankton-rich waters along the west side of the island, which contributes to enhanced ecosystem productivity. In 2002, the density of planktivorous fishes was higher along the west side (Figure 12.21).

Fish were resurveyed at Howland and Baker Islands from January 21-24, 2004. Observations from 11 belt-transects and SPCs (five at Howland and six at Baker) yielded the following preliminary results: 164 and 166 fish species were documented at Howland and Baker, respectively, compared to 126 and 127 species seen in 2002. Species richness averaged 118 and 117 species (median among stations) at the respective islands.

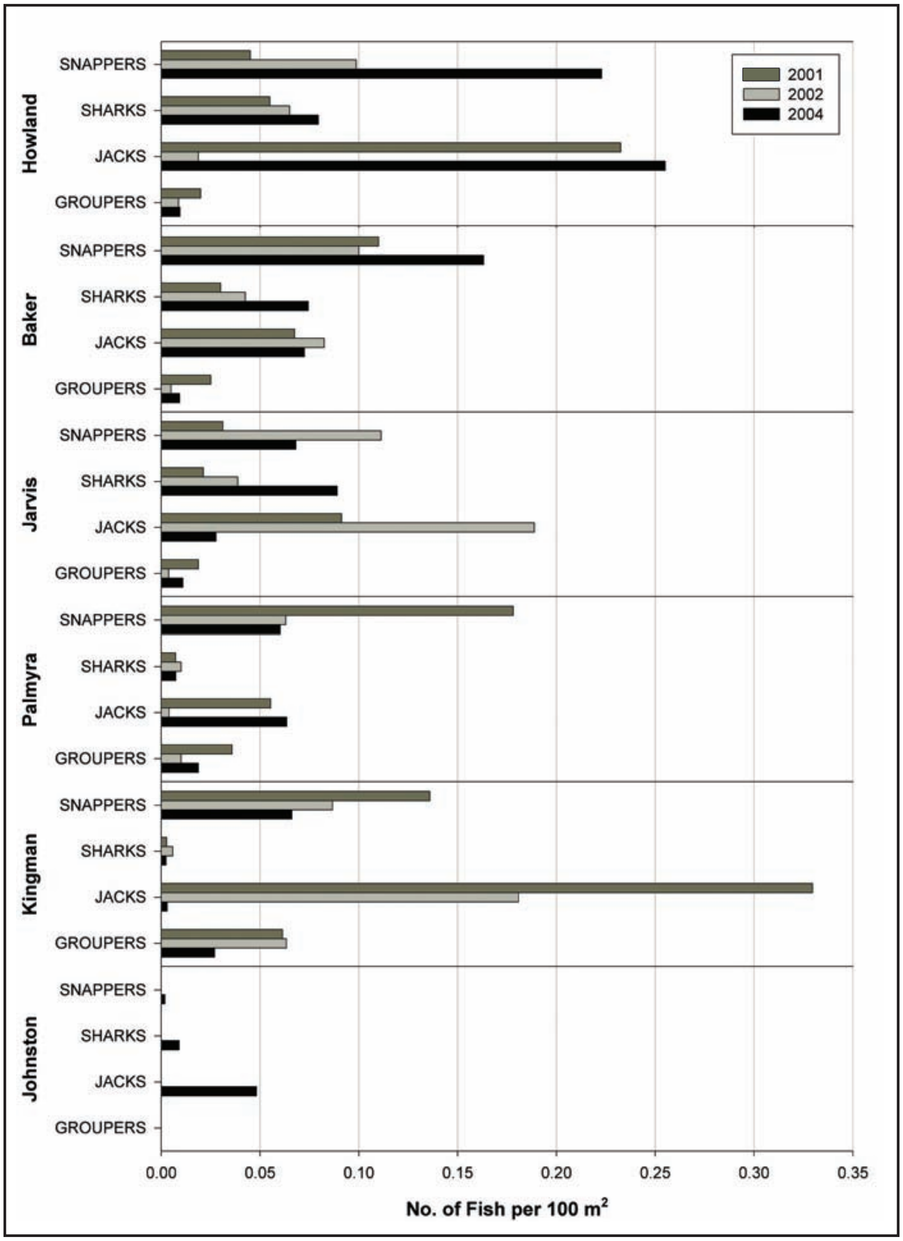


Figure 12.20. Density of common large fish (>50 cm TL, all species pooled) by family from towed-diver surveys conducted in the U.S. Line and Phoenix Islands (2001, 2002, 2004) and Johnston Atoll (2004 only). Source: PIFSC-CRED (S. Holzwarth), unpublished data.

Together with observations from other dive teams (e.g., towboard fish team), a grand total of about 210 fish species were recorded at Howland and Baker. Both numerical and biomass densities of resident reef fish species remained high (as observed on the 2001 and 2002 surveys). A trophically diverse fish fauna, representative of healthy coral reef ecosystems, contributed to the high biomass. The body size distributions of fishes spanned a broad range of sizes, further indicative of a healthy fish assemblage. Three species of small-bodied (<10 cm TL) zooplanktivores were numerically dominant, including two species of anthiine basslets (*Pseudanthias bartlettorum* and *Luzonichthys whitleyi)*, and the basslet-like damselfish, *Lepidozygus tapeinosoma*. Major contributors to biomass included numerous medium-sized (10-20 cm TL) benthic fishes (both herbivorous surgeonfishes and parrotfishes as well as benthivorous carnivores) and diverse, large-bodied (generally 25-60 cm TL) piscivores. In terms of biomass, the mid-water piscivore community near the reef was dominated by twinspot snapper (*Lutjanus bohar*), grey reef sharks (*Carcharhinus amblyrhynchos*), reef whitetip sharks (*Triaenodon obesus*), and several carangids (primarily the black jack [*Caranx lugubris*], rainbow runner [*Elegatis bipinnulatus*], and bluefin trevally [*C. melampygus*]). A half dozen species of grouper (primarily the peacock grouper [*Cephalopholis argus*], blacktip grouper [*Epinephelus fasciatus*], coral hind [*C. miniata*], flagtail grouper [*C. urodeta*], and slenderspine grouper [*Gracilla albomarginata]*), also contributed to fish biomass near reefs.

The density of groupers at both Howland and Baker Islands appeared substantially higher than at sites in American Samoa and CNMI, particularly where substantial fishing occurs (e.g., Tutuila, Guam, Saipan). In 2002, two- to four-fold differences were found between Howland and Baker Islands in terms of mean densities of epinepheline groupers and pygmy angelfishes.

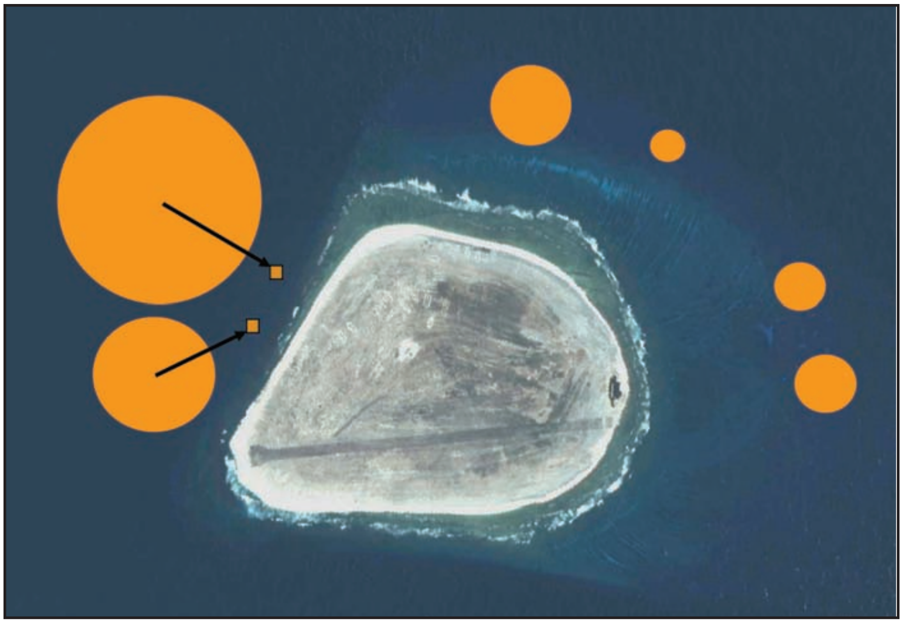


Figure 12.21. Relative distribution of planktivorous fishes from belt-transect surveys around Baker Island (2002), indicating higher densities along the western upwelling side (size of circle proportional to density of planktivores at that station; mean 8-161 fish/100 m^2). Source: PIFSC-CRED (R. Schroeder), unpublished data.

Quantitative surveys of large fish were completed by towed-divers in 2001, 2002, and 2004 at the U.S. Phoenix Islands. Snapper and shark numerical densities appeared to increase in 2004 at Howland and Baker Islands, while decreasing at most of the U.S. Line Islands. This could reflect differences in illegal fishing pressure (e.g., undocumented shark fining), or simply natural population fluctuations. The majority of sharks observed were gray reef sharks (*Carcharhinus amblyrhynchos*), but there were also galapagos sharks (*C. galapagensis*), blacktip and whitetip reef sharks (*C. melanopterus* and *Triaenodon obesus*), and hammerhead sharks (Family *Sphyrnidae*). Twinspot snapper (*Lutjanus bohar*) were very abundant at both islands. Bigeye jacks (*Caranx sexfasciatus*) were found in large schools at Howland, and black jacks (*C. lugubris*) were very common at both islands. In 2004, the towed-diver fish team saw one large humphead wrasse (*Chelinus undulatus*) at Howland and three in deep water at Baker, while none were encountered by the fish REA team. Overall, large fish remained abundant at the U.S. Phoenix Islands (Figures 12.19 and 12.20).

Jarvis Island (U.S. Line Islands)

Fish were surveyed at Jarvis Island from March 26-27, 2004. Preliminary observations from six belt-transects and six SPCs, all re-surveys of sites established by the PIFSC-CRED in February of 2001 or 2002, indicated that stock abundances appeared relatively unchanged from the high levels recorded in previous years, including a significant apex predator presence. The total number of coral reef fish species documented at Jarvis by PIFSC-RED was 148 in 2002 and 171 (from 34 families) in 2004. Planktivores remained abundant, especially along the west side; in 2004 they were also found to be abundant on the southeast reef terrace in 2004. Jarvis, like Howland and Baker, is in line with the EUC, resulting in enhanced upwelling and productivity on the west side of the island. The density of large fish remained high at all sites. Sharks, mostly gray reef (*Carcharinus amblyrhynchos*) and white tips (*Triaenodon obesus*), were common (typically >10 individuals from 130-180 cm TL per site), but seemed to be slightly less common along the west side than in earlier years. Groupers were very abundant at all sites surveyed in 2004. The most common species were flagtail grouper (*Cephalopholis urodeta*), coral hind (*C. miniata*), and peacock grouper (*C. argus*). Lyretail grouper (*Variola louti*) were also somewhat common and quite large (>50 cm TL). Jacks were common at all sites, including the black jack (*Caranx lugubris*) and the bluefin trevally (*C. melampygus*). Snappers were rare at Jarvis, except for the twinspot snapper (*Lutjanus bohar*); some individuals were >70 cm TL. Only six species of parrotfish were observed; most common were the bridled parrotfish (*Scarus frenatus*), redlip parrot (*S. rubroviolaceus*), and Pacific steephead parrot (*Chlororus microrhinos*), some of which exceeded 60 cm TL. Density of surgeonfishes was relatively low and primarily represented by whitecheek surgeonfish (*Acanthurus nigricans*) and spotted bristletooth (*Ctenochaetus marginatus*).

Towed-diver fish data from Jarvis Island suggest that densities of jacks were lower in 2004 compared to previous years, groupers and snappers were of similar range, and sharks were higher (Figure 12.19). Sharks were represented by gray reefs (*Carcharhinus amblyrhnchos*), blacktips (*C. melanopterus*), and whitetips (*Triaenodon obesus*). In addition, a school of 15 large (400-500 cm TL) great hammerhead sharks (*Sphyrna mokarran*) were encountered in deep water on the edge of the southeast terrace. A relatively high number of manta rays and a single whale shark (*Rhincodon typus*) were also seen in this area of the reef. Turtles were also abundant, with over 60 recorded during tow surveys in 2004. With the exception of jacks, large fish remained abundant at Jarvis in 2004.

Palmyra Atoll (U.S. Line Islands)

Fish were surveyed around Palmyra Atoll from March 29 to April 1, 2004. No surveys were conducted in the heavily dredged, sediment-laden lagoon. Preliminary observations from 10 belt-transects and 10 SPCs, all re-surveys of sites established by PIFSC-CRED in February of 2001 or 2002, indicate that stock abundances appeared relatively unchanged from the high levels recorded in previous years. The total number of coral reef fish species documented at Palmyra by PIFSC-CRED was 193 in 2002 and 209 (from 34 families) in 2004. Large fish were common but not as abundant as at Jarvis. Sharks (mostly blacktip, followed by gray reef and white tip) were small (130-160 cm TL), and occasionally seen, but seemed to be slightly less common than two years earlier. About 16 species of grouper were seen at Palmyra, with most common being the peacock grouper (*Cephalopholis argus*; 15-35 cm TL) which were present at every site. The flagtail grouper (*C. urodeta*) and the camouflage grouper (*Epinephelus polyphekadion*) were somewhat less common. Jacks were common at all sites, including large giant trevally (*Caranx ignobilis*; about 100 cm TL), bluefin trevally (*C. melampygus*), and black jacks (*C. lugubris*). Snappers were very common at Palmyra, with the twinspot snapper (*Lutjanus bohar*), humpback snapper (*L. gibbus*), smalltooth jobfish (*Aphareus furca*), and onespot snapper (*L. monostigma*) observed at every survey site. Most twinspot snapper ranged from 30-40 cm TL, smaller than those seen at Jarvis Island. Humpback snappers were observed in loose aggregations of up to 50 individuals.

Preliminary results from towed-diver fish surveys indicated differences in mean counts (numerical density) between fish families and years (Figure 12.20). Snappers were most abundant in 2001. Densities of jacks were least abundant in 2002. Shark abundance was fairly consistent between years, although a predominance of juvenile gray reef sharks (85% were less than 150 cm TL) may be indicative of fishing pressure. Most reef whitetip and blacktip sharks appeared to be mature size. Pooled grouper species at Palmyra varied in number among the three surveyed years. Most of the grouper >50 cm TL recorded were lyretail grouper (*Variola louti*), but relatively large individuals of the genera *Epinephalus* and *Cephalopholis* were also counted.

Kingman Reef (U.S. Line Islands)

Fish were surveyed at Kingman Reef from April 2-4, 2004. Preliminary observations from nine belt-transects and nine SPCs, all re-surveys of sites established by PIFSC-CRED in February of 2001 or 2002, indicate that stock abundances appeared relatively unchanged from the high levels recorded in previous years. However, overall fish density for both small and large fish appeared to be lower than in previous years, with the possible exception of fish assemblages along the outer reef slopes. The total number of coral reef fish species documented at Kingman was 165 in 2002 and 187 (from 35 families) in 2004. Sharks were less abundant and smaller at Kingman than at either Jarvis or Palmyra. An average of only one or two sharks was seen at most sites (none at some sites), compared to approximately 12 sharks observed on a typical dive in 2002. The same three shark species–reef whitetip (most common), blacktip, and grey reef–were most abundant. Groupers were not as abundant at Kingman compared to Palmyra or Jarvis. The peacock grouper (*C. argus*) was most common, observed at every survey site. Also relatively common were the flagtail grouper (*Cephalopholis urodeta*) and the camouflage grouper (*Epinephelus polyphekadion*). Six species of jacks were observed at Kingman but were generally less abundant than at Palmyra or Jarvis. Most common were bluefin trevally (*Caranx melampygus*) and black jacks (*C. lugubris*). The twinspot snapper (*Lutjanus bohar*), observed at every survey site, was the only common large snapper at Kingman, although most were smaller than those observed at Palmyra or Jarvis. Humpback snapper (*L. gibbus*) and smalltooth jobfish (*Aphareus furca*) were present in lesser numbers. No maori wrasse (*Cheilinus undulatus*) or bumphead parrotfish (*Bolbometopon muricatum*) were observed by any dive team, consistent with previous years. Like Palmyra and Jarvis, Kingman is a NWR and levels of historical or recent fishing are unknown. There are, however, occasional unconfirmed reports of fishing, especially at Kingman and Palmyra. The lower densities of sharks and large fish found in 2004, compared to earlier survey years, may suggest possible recent poaching activity. The USFWS may need to increase its enforcement presence at Kingman.

Preliminary results of the 2004 towed-diver fish surveys suggest that snapper, shark, jack and grouper densities all declined at Kingman, compared to previous years (Figure 12.20). No large schools of bigeye jacks (*Caranx sexfasciatus*) were seen, as in previous years, and black jacks (*Caranx lugubris*) were mostly smaller than 50 cm TL. Gray reef sharks were rare in 2004, however reef whitetip density increased. Parrotfish, especially steephead parrots (*Chlorurus microrhinos*), were more abundant in 2004 than in past years. Milkfish (*Chanos chanos*) were also more common in 2004. The large fish data from towed-diver surveys suggest a shift or disturbance may have taken place at Kingman Reef between 2002 and 2004. The PIFSC-CRED biennial monitoring surveys planned for the U.S. Line Islands will document long-term (e.g., annual to decadal) trends in large fish densities and, together with comprehensive PIFSC-CRED data on the coral reef ecosystem, should help reveal causative factors.

Johnston Atoll (U.S. Line Islands)

Fish were surveyed at Johnston Atoll for the first time by the PIFSC-CRED from January 12-16, 2004. Preliminary observations from belt-transects and SPCs at each of 12 stations indicate that reef fish diversity was low; many abundant Hawaiian species, including endemics, were either absent or rare, and several widely distributed Indo-Pacific species (abundant in Hawaii, the closest neighbor islands) were conspicuously absent (e.g., bigeye emperor, *Monotaxis grandoculis*; bluespine unicornfish, *Naso unicornis*). Overall, numerical densities of reef resident species appeared low, possibly due to the general scarcity of juvenile fishes. Standing biomass also appeared relatively low, mostly due to few large-bodied species. Carangids like the bluefin trevally (*Caranx melampygus*) were infrequently observed and often small in size; no giant trevally (*C. ignobilis*) were encountered. Grey reef sharks (*Carcharhinus amblyrhynchos*) appeared to be in robust body condition but uncommonly observed. The observed scarcity of both jacks and reef sharks likely reflects the location of survey sites within lagoons. Due to a large northwest storm swell, surveys were restricted to within the atoll (11 were conducted in the lagoon and one on the backreef). Conclusions are therefore limited because of the near or total lack of data for backreef and forereef habitats, respectively. It is very possible that the dearth of juvenile life-stages, including older young-of-year-sized fish, is a reflection of the infrequent, low-intensity recruitments that occur at a very isolated atoll inhabited by substantively self-seeding reef fish populations.

At Johnston Atoll, towed-divers completed 26 surveys during the initial baseline assessment in 2004. During the survey period there was a large northwest swell that complicated the surveying the exposed fore-reef and generated sub-optimal survey conditions with decreased visibility. Although the large swell hampered diving operations in general, the tow team was able to tow over a variety of habitats throughout the atoll, covering areas that were inaccessible to the other dive teams. Fish assemblages at Johnston are more similar to Hawaii than to the U.S. Line and Phoenix Islands. Johnston had almost no shallow-water large groupers or large snappers (Figure 12.20). Jack and shark densities appeared low at Johnston compared to other islands, due in part to the difficult survey conditions encountered there in 2004. The shallow backreef and submerged terrace, areas with fewer large fish, received comparatively more of the survey time than the forereef, because of safety considerations. The tow team was able to dive on the forereef, but not extensively, and this is where most jacks and sharks were seen. Solitary large jacks were mostly bluefin trevally (*Caranx melampygus*) and a school of about 200 bigeye jacks (*C. sexfasciatus*) were recorded. In addition to a number of small to medium-sized sharks, several very large Galapagos sharks (*Carcharhinus galapagensis*) and gray reefs (*C. amblyrhychos*) were seen, as well as a 2.5 m tiger shark (*Galeocerdo cuvier*).

SSL Protocol

Methods

SSLs are comprised of pelagic communities of small fish, shrimp, and squid that occur in waters deeper than 300 m during the day and rise into the photic zone at night. SSLs are common in pelagic waters and along coastlines, where they form the mesopelagic boundary community. In Hawaii, boundary community SSLs are thought to play an important role in the coastal ecosystem as a major link between zooplankton and higher trophic levels. The observed horizontal migration towards shore at night of the Hawaiian community also suggests SSLs may play a significant role in the coral reef ecosystem through input of biomass and nutrient cycling. Little is known about the character of boundary community SSLs associated with islands outside of the main Hawaiian Archipelago. To improve our understanding of these communities, island-associated SSLs were investigated using ship-based echo-sounders during a PIFSC-CRED cruise to Jarvis Island, Palmyra Atoll, and Kingman Reef in 2004.

Results and Discussion

Jarvis Island

Echo-sounder surveys were conducted along the southern and western shores of Jarvis Island during afternoon and night/morning hours on March 26 and 27, 2004. Survey lines were run approximately 400-600 m from shore in waters 300-600 m deep. Each line was conducted at approximately 00:00, 02:30, 05:00, and 14:00 hours.

The surveys revealed a clear diurnal trend in the occurrence of a layer of surface-associated biomass. At night, the layer is generally concentrated in the top 130 m, just above the thermocline and centered on the chlorophyll maximum observed during CTD casts (Figure 12.22). The layer's nighttime density was more or less constant along both transect lines. During the day, the layer was absent from the southern transect, but was very dense towards the northern end of the western transect. Because trawling for samples was not feasible during this cruise, the biological composition of the layer is presently unknown.

Palmyra Atoll

Echo-sounder surveys were conducted along six transect lines around Palmyra Atoll between March 30 and April 1, 2004. Transect line lengths ranged from 4 to 9 km. Two lines were run along the edge and on the southwestern bank of the atoll, one along the southern shore, one along the edge of the southeastern bank, one along the northeastern edge of the bank, and one along the northern shore. All but the northern and northeastern transects were run multiple times during the same and/or successive nights, as well as during the day.

The data revealed that a dense SSL exists around the entire perimeter of the atoll at night. This community resides primarily along the atoll's steep slopes at a depth 120-180 m and is centered on the thermocline (Figure 12.23). A secondary, less dense layer of organisms occurs above the thermocline in patches. Opportunistic observations made during transits perpendicular to the atoll's edges indicate that both layers extend well offshore (4-6 km) along the southwestern side of the atoll, but that they are restricted to less than 2

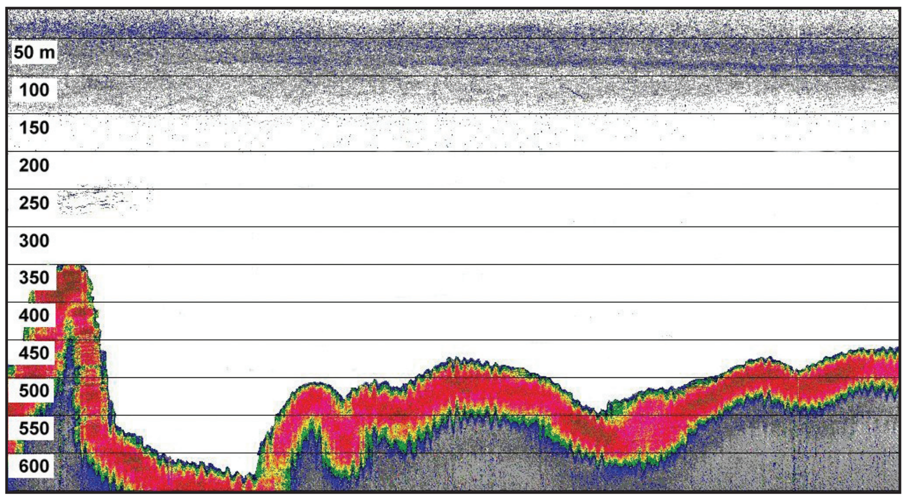


Figure 12.22. Echogram of the SSL at Jarvis Island. Depth is plotted on the y-axis, horizontal distance on the x-axis (2.6 km). Red regions represent the bottom. Source: M. Lammers, unpublished data.

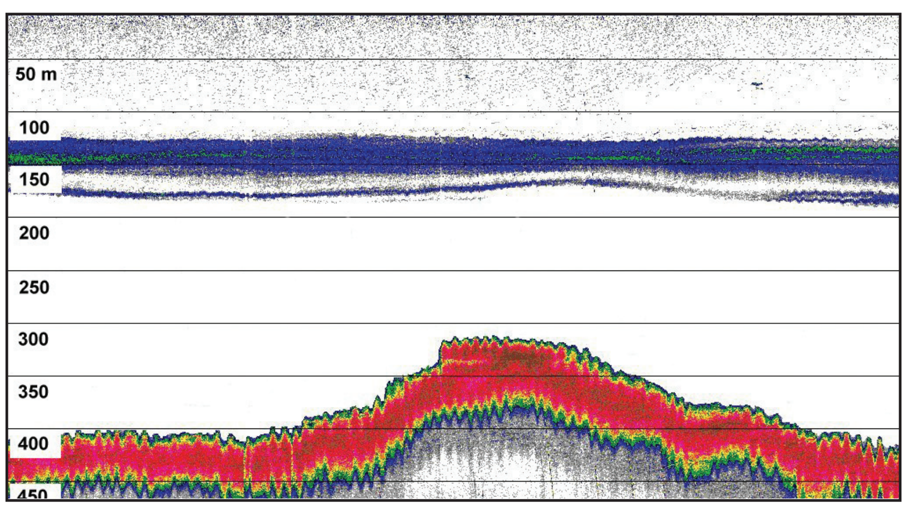


Figure 12.23. Echogram of the SSL at Palmyra Atoll. Depth is plotted on the y-axis, horizontal distance on the x-axis (2.6 km). Red regions represent the bottom. Source: M. Lammers, unpublished data.

km offshore along the other sides. A tentative explanation for this observation is that the southwestern side is enriched by nutrients flowing out of the lagoon. The main channel into the lagoon lies on the southwest corner and the prevailing tradewinds blow from the northeast, probably creating a net movement of water towards the southwest. Coincidentally, several observations of melon headed whales (*Peponocephala electra*) were made along this side of the atoll. This species is known to feed primarily on squid.

Kingman Reef
Echo-sounder surveys were conducted along four transect lines along the southern and eastern sides of the atoll between April 2-4, 2004. Two transect lines were run parallel to the atoll's slopes and two were perpendicular. The two parallel transects were conducted at 18:00, 21:00, 0:00, and once towards the middle of the day. The perpendicular transects were run at 19:00 and at 01:00. Echo-sounder data were also collected opportunistically on one occasion while transiting along the southwestern corner of the atoll.

An assessment of the data collected indicates that a SSL is conspicuously missing along most parts of the eastern and southern sides of the atoll. Both night and daytime transects revealed only dispersed patches of mid-water organisms. These patches were very localized and ranged in depth between 80 m and 130 m. The most prominent patch was observed along the southwestern corner of the atoll. This again coincided with the primary channel into and out of the atoll, similiar to that seen at Palmyra.

The echo-sounder data collected at the three sites reveal that each location is quite distinct in the density and distribution of the mid-water biomass occurring there. Jarvis and Palmyra appear to be much more productive than Kingman. Furthermore, Palmyra supports a dense, thermocline-associated community that was not observed at either Jarvis or Kingman.

It is interesting to note that three locations are quite distinct oceanographically and ecologically. Jarvis Island is the top of a steep pinnacle rising from the ocean floor. It is located almost at the equator and is fed by upwelling from the EUC and is also a major seabird colony. Nutrient inputs from these two sources probably contribute to the mid-water productivity observed there. Palmyra, on the other hand, is a forested network of islets that also supports a significant seabird population. Nitrogenous and organic outflows from the terrestrial ecosystem are likely a contributing factor behind the productivity observed there, particularly along the southwestern side where the lagoon's waters flow out. Finally, Kingman Reef is influenced by neither the EUC nor any terrestrial-based ecosystem. A minimal or reduced influx of nutrients at Kingman may explain the lack of a well-defined SSL there.

MARINE MAMMALS

Very little is presently known about the marine mammal populations in the U.S. PRIAs. Although no systematic marine mammal surveys have ever been conducted in these areas, recent visits during the PIFSC-CRED operations revealed that all sites visited do have cetacean populations associated with local island or atoll ecosystems. Of the odontocetes encountered, bottlenose dolphins (*Tursiops truncatus*) were by far the most common species sighted. Populations of 50 to 100 or more animals occur at Johnston, Howland, Baker, Jarvis, Palmyra and Kingman. Repeated sightings made during consecutive days suggest that these populations are resident. Palmyra also supports a population of melon-headed whales (*Peponocephala electra*). These were seen on successive days over a three-day period and were consistently located near the southwest side of the atoll. Anecdotal accounts from USFWS staff familiar with Palmyra (J. Maragos, pers. obs.) report having seen both *T. truncatus* and *P. electra* on past visits. Similarly, USFWS staff familiar with Jarvis Island (M. Rauzon, pers. comm.) report having seen *T. truncatus* and sperm whales (*Physeter macrocephalus*) there previously.

Although not directly observed, beaked whales may also be present at some PRIA sites. A skeleton tentatively identified as Cuvier's beaked whale (*Ziphius cavirostris*) was found at Kingman Reef. In addition, the oceanographic and bathymetric conditions (upwelling, deep waters) found at Jarvis are characteristic of habitat known to be exploited by beaked whales.

Mysticetes were reported only for one location visited by the PIFSC-CRED cruises. Humpback whales (*Megaptera novaeagliae*) were observed at Johnston Atoll. This finding is rather significant as there are no modern records of this endangered species there. According to observer accounts, all social roles typically found on winter mating grounds are present at Johnston, including mothers and calves with male escorts, competitive groups, and singers. It is speculative, but Johnston Atoll may represent a relatively newly established or re-established mating ground of the north Pacific humpback whale population.

The role that marine mammals play in the ecosystems of PRIA sites is presently not well understood. The high metabolic needs characteristic of mammals suggest that their role is probably not trivial. Recent modeling work on the impacts of great whales (including sperm whales) on global primary productivity has revealed that up to 62% of the ocean's primary production may have gone to sustaining whales during pre-whaling times (D. Croll, unpublished data). Although similar estimates are not presently available for smaller cetaceans, this does suggest that a more detailed assessment of the composition and abundance of marine mammals in the PRIAs is warranted.

MARINE INVERTEBRATES OTHER THAN CORALS

Historically, biodiversity assessments and monitoring programs for coral reefs have focused on cnidarians and fish, so less information is available for other invertebrates. However, the sponge, mollusk, echinoderm, crustacean, annelid, bryozoan, and tunicate fauna associated with coral reefs are also integral components to the overall biodiversity.

Most data collection efforts in the PRIAs have focused on fish, ciguatera, algae, and corals, but some information on non-coral invertebrates is available from baseline faunal surveys conducted in the mid-1960s (Brock et al., 1966; Amerson and Shelton, 1976). A presentation of the species richness of non-coral invertebrates for the PRIAs will be a compilation of studies conducted since the early 1900s and collections held at the Bishop Museum. The information reported here will only provide data for porifera, hydroids (Cnidaria; Order Hydroida), anemones (Cnidaria; Order Actiniaria), selected mollusks, and echinoderms. To date, the data for all invertebrate groups are preliminary but these particular species have the most complete species richness data. Only species recorded from coral reef and associated shoreline areas will be included in the species richness data provided in this section in Table 12.7.

Table 12.7. Species richness data for selected non-coral invertebrates. Sources: Godwin, 2004, 2002; Coles et al., 2000; Brock, 1979; Amerson and Shelton, 1976; Brock et al., 1966; Kay, unpublished data.

PHYLUM PORIFERA	20
PHYLUM CNIDARIA	
Order Hydroida	5
Order Actiniaria	9
PHYLUM MOLLUSCA	
Class Gastropoda	247
Class Bivalvia	47
PHYLUM ECHINODERMATA	67

The PRIAs possess marine invertebrate diversity and richness contained in habitats with a broad spectrum of anthropogenic influence. Locations such as Kingman Reef in the northern U.S. Line Islands represent locations with very little anthropogenic influence, while the coral reef habitats at Johnston Atoll are heavily impacted by alterations. Despite this vast difference, each of the PRIAs provides a refuge for marine invertebrate communities that recruit from a variety of source locations. For example, the giant clams *Tridacna maxima* and *Tridacna squamosa* can be found commonly in most of the PRIAs, with Kingman Reef possessing the most abundant communities. These clams have been heavily depleted in other parts of their range and the PRIAs represent a refuge for these species, if existing management and protection remains in place there.

Overall Conditions and Summary of Analytical Results

NOAA, USFWS, Bishop Museum, and other scientists and volunteers have now completed species inventories (including many new records) and assessments and initiated monitoring of reef fishes and corals using several complementary underwater survey techniques at most of the PRIAs: the U.S. Line and Phoenix Islands, Johnston Atoll, and Rose Atoll. Based on the inventories, assessments, and monitoring thus far, several summary statements can be made:

- Based on the fish assemblage composition surveyed from 2000-2004, coral reef ecosystems of the PRIAs appear to remain quite healthy and productive.
- Levels of unauthorized fishing around the U.S. Line and Phoenix Islands are unknown, but believed to be negligible to light. Overall, reef fish assemblages at these islands appear to be basically healthy, with large apex predators common.
- There is presently no known harvesting for the coral and live reef fish/species trades in these islands.
- Substantial COTS predation on corals has been observed at Kingman and Palmyra but appears low elsewhere in the PRIAs.
- High densities of small planktivorous fishes found along the west side of the equatorial islands (Jarvis, Baker, Howland) were associated with upwellings caused by impingement of the EUC.
- Coral larvae transported in ECC from the western Pacific may be responsible for the substantially higher levels of coral species diversity at Palmyra and Kingman.
- Surveys conducted at Kingman in 2004 suggest an apparent decline in large fish densities (e.g., gray reef sharks, jacks, groupers) from earlier years.
- Abandoned WWII material, military construction, occupation, and ship groundings continue to be sources of stress, alien species, and perhaps coral disease to resident reef ecosystems.
- Although uninhabited atolls and islands serve as important minimally-disturbed refuges, they are also vulnerable to unauthorized fishing and collecting due to the lack of on-site surveillance and enforcement.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The USFWS and NOAA will continue to collaborate on research expeditions to the 10 NWRs with coral reefs that are co-managed in the U.S. Line Islands, U.S. Phoenix Islands, Guam, American Samoa, and Hawaii. The USFWS and NOAA will continue to monitor fish and wildlife resources, assess impacts of residual anthropogenic stress to these ecosystems, and work with partners to restore ecosystems. As part of a new initiative, the USFWS will prepare and coordinate the development of comprehensive conservation plans for all of its NWRs beginning in 2004. The USFWS will work with partners to improve surveillance and enforcement and discourage unauthorized access and poaching of fish and wildlife. All but two of the NWRs in the PRIAs will continue to be managed as no-take MPAs, and catch-and-release fishing at the remaining two NWRs will be adjusted accordingly to protect resident fish and seabird stocks. The USFWS will vigorously defend all of its refuges against commercial fishing, destructive fishing, and unauthorized fishing.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

Cooperative biennial surveys should continue at these remote islands to: 1) improve the scientific understanding of these fish and wildlife resources as a basis for sound management; 2) monitor spatial and temporal changes in fish and wildlife assemblages in response to natural and anthropogenic forces; 3) help elucidate associations between fish (the primary resource of interest) and other components of the coral reef ecosystem; and 4) assist the USFWS and other resource managers to improve the scientific basis for protecting fish and wildlife within NWRs and other MPAs.

REFERENCES

Amerson, A.B. and P.C. Shelton. 1976. The natural history of Johnston Atoll, Central Pacific Ocean. Atoll Research Bulletin 192: 1-477.

Barber, C.V. and V.R. Pratt. 1997. Sullied Seas: strategies for combating cyanide fishing in Southeast Asia and beyond. World Resources Institute and International Marinelife Alliance, Washington, D.C. 215 pp.

Brainard, R.E., E. DeMartini, J. Kenyon, P. Vroom, J. Miller, R. Hoeke, J. Rooney, R. Schroeder, and M. Lammers. 2004. Multi-disciplinary spatial and temporal monitoring of reef ecosystems of the US-affiliated Pacific Islands. In: Proceedings, International Coral Reef Symposium, Okinawa.

Brock, R.E. 1979. A statistical study of *Cypraea tigris* in the Central Pacific. Veliger 22: 166-170.

Brock, R.E., W. Van Heukelem and P. Helfrich. 1966. On ecological reconnaissance of Johnston Island and the effects of dredging. University of Hawaii, Hawaii Marine Laboratory technical report 11.

Coles, S.L., R.C. DeFelice and D. Minton. 2000. Marine species survey of Johnston Atoll, Central Pacific Ocean, June 2000. Bishop Museum Technical Report 19, Honolulu.

Dawson, E.Y. 1959. Changes in Palmyra Atoll and its vegetation through activities of man, 1913-1958. Pacific Naturalist 2: 1-51.

Dawson, E.Y., A.A. Aleem and B.W. Halstead. 1955. Marine algae from Palmyra Island with special reference to the feeding habits and toxicology of reef fishes. Allan Hancock Foundation Publications 17: 1-39.

Godwin, L.S. 2002. Rapid ecological assessment of the marine invertebrate fauna of American Samoa and the U.S. Equatorial and Line Islands. National Oceanic and Atmospheric Administration, Pacific Islands Fisheries Center, Coral Reef Ecosystem Division, Honolulu.

Godwin, L.S. 2004. Bishop Museum, Honolulu. Personal communication.

Godwin, L.S. 2004. Cruise Report OES-04-01,02,04. Rapid ecological assessment of the marine invertebrate fauna of American Samoa and the U.S. Equatorial Islands, U.S. Line Islands and Johnston Atoll. National Oceanic and Atmospheric Administration, Pacific Islands Fisheries Center, Honolulu.

Gove, J.M., 2005. Upwelling variability at Jarvis Island. MS thesis, University of Hawaii.

Jokiel, P.L. University of Hawaii at Manoa. Honolulu, HI. Personal communication.

Kay, E.A. Unpublished. List of marine mollusks reported from Johnston Atoll. University of Hawaii at Manoa.

Kenyon, J. 2004. NOAA Fisheries, Honolulu, HI. Personal communication.

Maragos J.E. 1974. Reef Corals of Fanning Atoll. Pacific Science 28 (3): 247-255.

Maragos, J.E. 1979. Environmental assessment and field survey, Wake Atoll. Unpublished manuscript. U.S. Army Engineer Division, Pacific Ocean.

Maragos, J.E. 1988. Notes on the abundance and distribution of reef corals and reef features at Palmyra Atoll, Line Islands. Unpublished manuscript. U.S. Army Corps of Engineers, Pacific Ocean Division, Defense Environmental Restoration Program, Fort Shafter, HI. 16 pp plus 11 plates and map.

Maragos, J.E. 1994. Reef and coral observations on the impact of the grounding of the longliner *Jin Shiang Fa* at Rose Atoll, American Samoa. Review draft. Program on Environment, East-West Center, Honolulu. 21 pp. plus tables.

Maragos, J.E. 1995. Revised checklist of extant shallow-water stony coral species from Hawaii (Cnidaria: Anthozoa: Scleractinia). Bishop Museum Occasional Papers 42: 54 - 55.

Maragos, J.E. 1997. Ecological surveys of corals and reef environments at Kiritimati Atoll for the proposed HOPE-X Landing Site Project. Dames and Moore, Honolulu. 21 pp.

Maragos, J.E. 2004. Diversity of corals and anemones at eleven remote atolls and reef islands in the central Pacific. In: Proceedings, 10th International Coral Reef Symposium.

Maragos, J.E. and P.L. Jokiel. 1978. Reef Corals of Canton Atoll: I. Zoogeography. Atoll Research Bulletin 221: 57-70.

Maragos J.E. and P.L. Jokiel. 1986. Reef corals of Johnston Atoll: One of the world's most isolated reefs. Coral Reefs 4: 141-150.

Maragos, J., D. Potts, G. Aeby, D. Gulko, J. Kenyon, D. Siciliano and D. VanRavenswaay. 2003. 2000-2002 rapid ecological assessment of corals on the shallow reefs of the Northwestern Hawaiian Islands. Part 1: Species and distribution. Pacific Science 58(2): 211-230.

Maragos J. and A. Veit. 2004. Monitoring corals and other macro-invertebrates at fixed sites at U.S. Pacific remote islands and atolls. Poster presentation. In: Proceedings of the10th International Coral Reef Symposium Okinawa.

Molina, M. and J. Maragos. 1998. List of coral species at Palmyra Atoll, November 1998. Unpublished manuscript. U.S. Fish and Wildlife Service Pacific Islands Ecoregion, Honolulu.

Page, K.N. and L.B. Preskitt. 2004. Appendix C: Benthic-Algae REA Team Activity Summary. National Marine Fisheries Service. Cruise Report No. OES-04-04. 21 March - 9 April, 2004. NOAA ship Oscar Elton Sette. Pacific Islands Fisheries Science Center, Honolulu, HI. 70 pp.

Preskitt, L.B., P.S. Vroom and C.M. Smith. 2004. A Rapid Ecological Assessment (REA) Quantitative Survey Method for Benthic Algae using Photo Quadrats with SCUBA. Pacific Science 58: 201-209.

Rauzon, M.J. Volunteer, U.S. Fish and Wildlife Service, Honolulu, HI. Personal communication.

Sadovy, Y.J. and A.C.M. Vincent. 2002. Ecological issues and the trades in live reef fishes. pp. 391-420. In: P.F. Sale (ed.) Coral reef fishes: dynamics and diversity in a complex ecosystem. Academic Press, San Diego.

South, G.R., P.A. Skelton and A. Yoshinaga. 2001. Subtidal benthic marine algae of the Phoenix Islands, Republic of Kiribati, Central Pacific. Botanica Marina 44: 559 - 570.

Stoddart, D.R. 1992. Biogeography of the tropical Pacific. Pacific Science 46 (2): 276-293.

Tsuda, R.T. and G. Trono. 1968. Marine benthic algae from Howland Island and Baker Island, Central Pacific. Pacific Science 12: 194-197.

Work, T., S. Coles and R. Rameyer. 2001. Johnston Atoll reef health survey. US Geological Survey, National Wildlife Health Center, Hawaii Field Station. 28 pp.