The State of Coral Reef Ecosystems of Palau

Yimnang Golbuu[1], Andrew Bauman[2], Jason Kuartei[1], Steven Victor[1]

INTRODUCTION AND SETTING

The Republic of Palau, part of the Caroline Islands group, is the westernmost archipelago in Oceania located 741 km east of Mindanao in the southern Philippines and about 1,300 km southwest of Guam. Palau is composed of 12 inhabited islands and 700+ islets, stretching 700 km from Ngeruangel Atoll in the Kayangel Islands in the north to Helen Reef in the south (Figure 17.1). The archipelago consists of a clustered island group (including Babeldaob, Koror, Peleiu, Angaur, Kayangel, Ngeruangel, and the Rock Islands; Figure 17.2) and six isolated islands (Helen Reef, Tobi, Merir, Pulo Anna, Sonsorol, and Fana) that lie approximately 339 to 599 km to the southwest. Babeldaob, the second largest island in Micronesia after Guam, is the biggest island in the Palauan chain; however, the country's capital and greatest population is located on Koror. The volcanic island of Babeldaob and its reefs are separated from Koror and the southern islands of the group by a deep (30-40 m), east-west pass called Toachel El Mid.

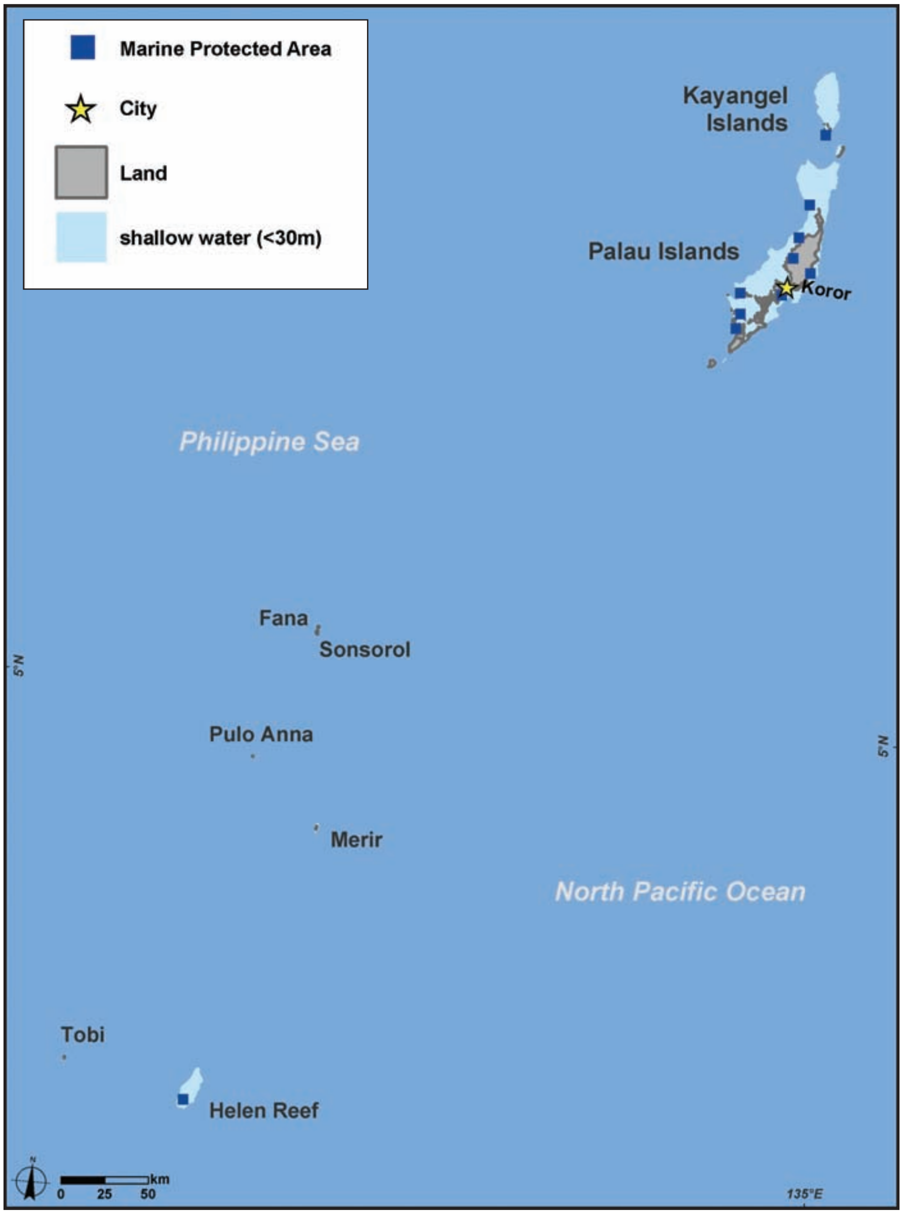

Figure 17.1. The nation of Palau is an archipelago in the Caroline Islands. Most Palauans reside in the cluster of northern islands (see Figure 17.2 for detail of main island group). Map: A. Shapiro.

Palau has numerous island and reef types, including volcanic islands, atolls, raised limestone islands, and low coral islands. A barrier reef surrounds much of the main island cluster, from the northern tip of Babeldaob down to the southern lagoon, merging into the fringing reef with Peleliu in the south. The barrier reef is well-developed on the west and less developed and discontinuous on the east. For example, Babeldaob has a barrier reef in the southeast, a submerged barrier reef (5-10 m below sea level) on the central east coast and no barrier reef in the northeast. The southern lagoon has a much more extensive barrier reef, lacking passages on the west side, while the southeast side has numerous gaps and passes that extend into the lagoon.

Palau has the most diverse coral fauna of Micronesia and the highest density of tropical marine habitats of comparable geographic areas around the world. In addition to coral reefs, mangroves, and seagrass beds, Palau has deep algal beds, mud basins, current swept lagoon bottoms, rich tidal channels, and anoxic basins within the rock islands. Many of these environments contain corals. Additionally, there are more than 70 marine lakes on Palau, many of

1 Palau International Coral Reef Center, Koror, Palau
2 Office of Environmental Response and Coordination, Koror, Palau

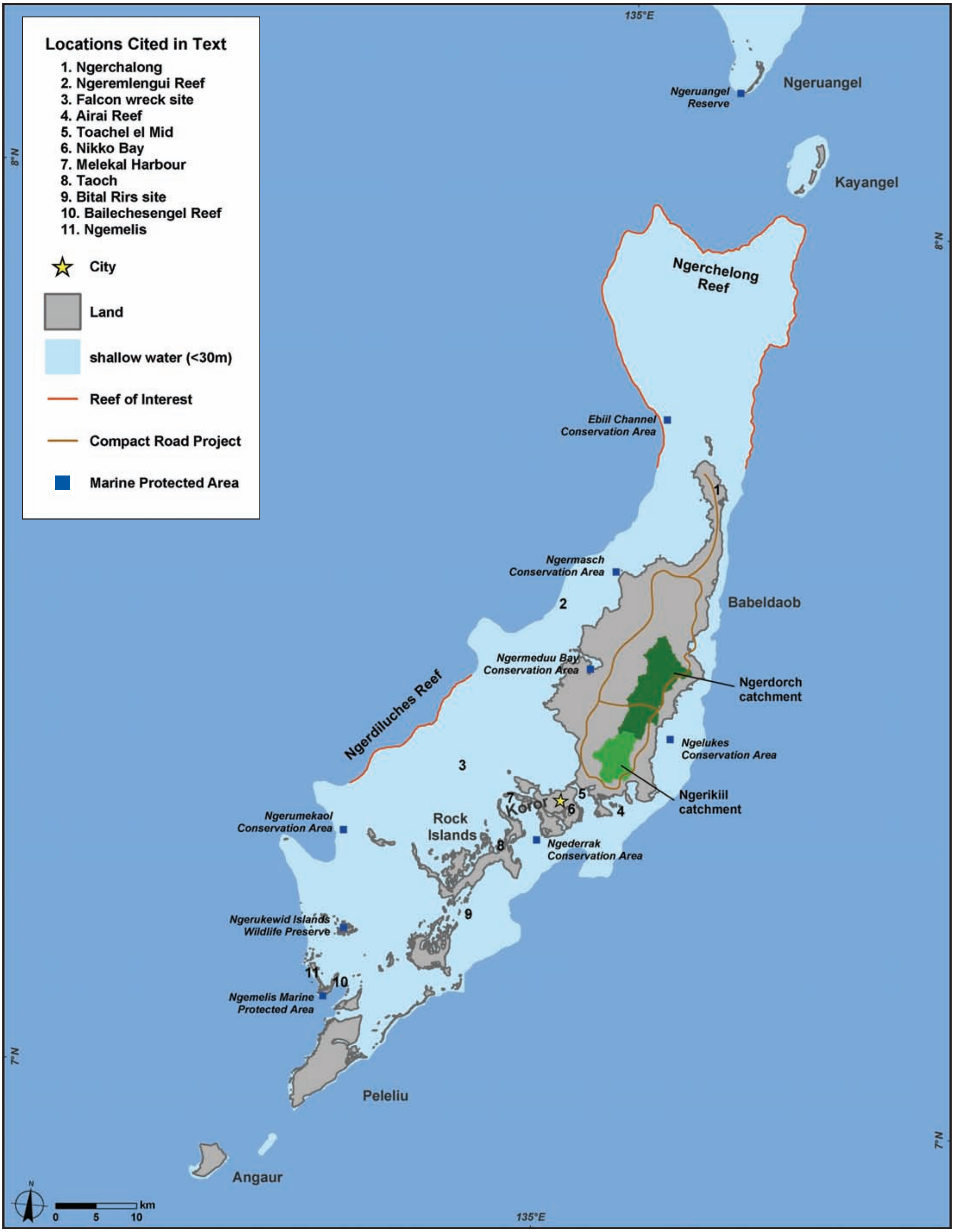

Figure 17.2. A detailed map of Palau's main island cluster, showing the locations referenced in this chapter. Map: A. Shapiro.

which contain scleractinian corals and associated fauna and flora. This high concentration of marine lakes on Palau is unique in the world, and as such, represents a biological treasure which rivals that of the remaining marine environments of Palau.

While no corals are endemic to Palau, the archipelago's coral diversity is comparable to the highest coral diversity areas of the Philippines, Indonesia and Australia. Maragos et al. (1994) estimated Palau's coral diversity at 425 species belonging to 78 genera. Randall (1995) reported a lower number of coral species for Palau at 385 species belonging to 66 genera. The higher estimation by Maragos et al. included observations and a species list, while Randall's lower estimation was based on collections and specimens. Randall noted that greater collecting efforts in Palau are expected to reveal more species since only a relatively small percentage of coral habitats were surveyed.

In addition to corals, fish and other invertebrate groups are highly diverse in Palau. More than 300 species of sponges were documented in Palau (Kelly-Borges and Valentine, 1995), although the total fauna may be as high as 500 if small and burrowing species are included. About 200 species of Cnidarians, other than Scleractinia, are known to exist on Palau, with many smaller species remaining to be documented. The molluscan fauna is not entirely known, but at least 185 species of Opisthobranchs are present on Palau (T. Gosliner, unpublished). Echinoderms are not well documented, but there are at least 21 species of crinoid fauna (Meyer and Macurda, 1980). The ascidian fauna is well over 100 species (P. Colin, pers. comm.). Within Micronesia, Palau has the highest diversity of reef fish with a total of 1,278 known species. Data gaps suggest that reef fish in Palau may number closer to 1,449 species (Myers, 1999).

Endemism is low among Palauan marine organisms. However, true levels of endemism are difficult to estimate because many groups are not well documented. The nautilus, *Nautilus belauensis*, is endemic to Palau and has been the subject of numerous biological studies.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

During the 1997-1998 El Niño event, Palau experienced massive coral bleaching and mortality. Six years after the event, the reefs in Palau have still not fully recovered. The 1997-1998 bleaching event in Palau was widespread and variable among different sites (Bruno et al., 2001). Approximately one-third of Palau's corals died, with coral mortality as high as 90% in some areas. It devastated Acroporid corals, which suffered the highest mortality compared to other coral species. Corals that were found in estuaries closer to shore survived better than corals farther from shore (Golbuu, 2000). Impacts of the elevated water temperature were seen in other habitats such as the famous "Jellyfish Lake," which experienced a complete mortality of the medusa stage of *Mastigias* spp. Presently, coral bleaching is considered one of the greatest threats to Palau's coral reef ecosystems.

Since 1997-1998, Palau has not had a major bleaching event. Localized episodes of coral bleaching have occurred periodically at various sites in Palau, but none as severe or widespread as the 1997-1998 event. The localized bleaching events are probably due to disease or other localized stress at the microhabitat level.

Diseases

In the past few decades, worldwide increases in coral diseases have become one of the major threats challenging the resilience of coral reef communities (Harvell et al., 1999; Willis et al., 2004). Coral disease impacts have increased on reefs worldwide and are emerging as one of the major causes of coral reef deterioration in the Caribbean. Although the Indo-Pacific encompasses more than 80% of the world's coral reefs, very little is known about the ecology and pathology of coral disease in this region (Bryant et al., 1998).

The first assessment of coral disease prevalence on Palau's reefs was conducted in January 2004 as part of the Targeted Coral Reef Research Project by the World Bank/Global Environment Facility . The purpose of these surveys was to identify and establish baseline information for coral disease at sites representative of the major habitat and community types. Results from this initial study indicate that the mean prevalence of coral disease was relatively low, affecting between 1% and 5.28% of colonies at six sites representative of protected, moderately exposed, and exposed communities on Palauan reefs. A total of twelve diseases and syndromes were recorded across thirteen reefs surveyed during preliminary site-selection visits or disease prevalence surveys (Table 17.1). Eight of these syndromes have been previously observed on Indo-Pacific reefs, in particular on the Great Barrier Reef (Willis et al., 2004). However, four syndromes have not been previously recorded: bleached patches, bleached spots, bleached stripe, and yellow spot. At each of the six survey sites, approximately five to nine diseases or syndromes were observed, with the greatest number being recorded at Malakal Harbour (B. Willis, pers. comm.). A more quantitative assessment of coral disease prevalence within Palau requires further research.

Table 17.1. Diseases and syndromes recorded near six transects in Palau in January 2004. Source: B. Willis, unpublished data.

	NIKKO BAY SPAWNING	NIKKO BAY XXIX	MALAKAL HARBOUR SPAWNING	BITAL RIRS	WESTERN BARRIER NGATBANG	WESTERN BARRIER NGEREMLENGUI
Disease States Recorded on Transects						
Black Band Disease						
Brown Band Disease			x	x		
Skeletal Eroding Band	x	x	x	x	x	x
Other Cyanobacterial Infections	x	x	x	x	x	x
Bleached Spots	x	x	x	x	x	x
Bleached Patches	x	x	x	x	x	x
Bleached Stripe	x					
White Syndrome	x	x	x	x		
Patchy Necrosis	x	x				x
Yellow Spot					x	
Tumors			x	x	x	
Disease States Recorded off Transects						
Black Band Disease			x			
Other Cyanobacterial infections	x (red)					
Yellow Spot			x	x		

Prevalence of Coral Disease

Mean prevalence of disease varied considerably across the six sites surveyed, ranging between 1.16 ± 0.62% of coral colonies at the Western Barrier Ngeremlengui site and 5.28 ± 0.97% of colonies at the Malakal Harbour Spawning site (Figure 17.3). Mean prevalence of bleached colonies was much lower at the Nikko Bay Spawning site and the Bital Rirs site, varying between 0.9 ± 0.09% of coral colonies to 1.24 ± 0.47% of colonies, respectively (B. Willis, pers. comm.).

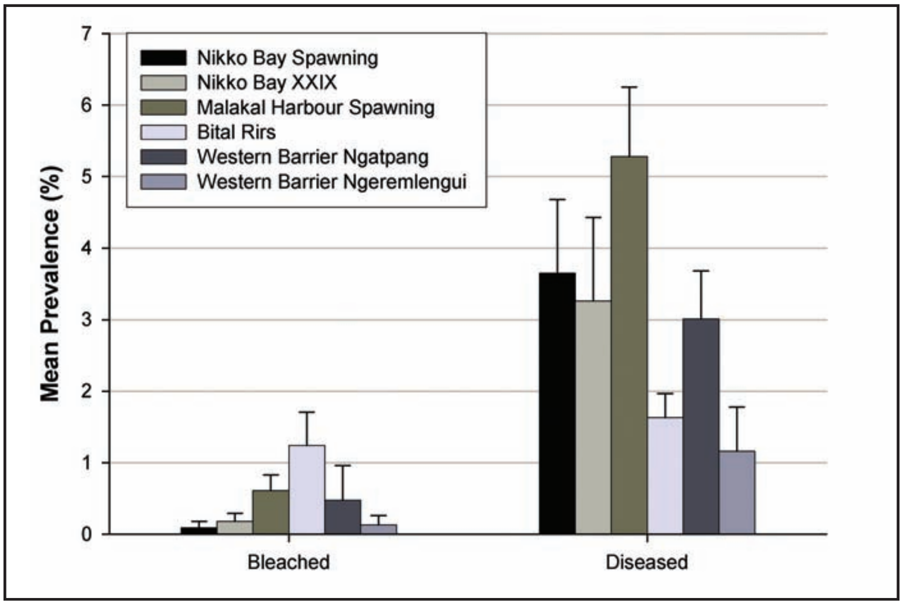

Figure 17.3. Mean prevalence of bleached and diseased coral colonies at six sites surveyed in January 2004. Source: B. Willis, unpublished data.

Tropical Storms

Typhoons, tropical storms, and large waves can affect coral cover. Large waves generated by storms can cause breakage and physical damage. Storm waves can also have beneficial effects on reefs by removing sediments and algae on the reef, thereby making space available for coral recruitment. Palau is outside the typhoon belt and is therefore less likely to experience typhoons compared to other places in Micronesia (Figure 17.4). Areas in Palau that are commonly subjected to high wave energy generally do not have high coral cover and diversity, but the corals that do inhabit these large wave areas are well-adapted to their environment. Encrusting *Montipora*, *Porites*, digitate *Acropora* and massive corals typically dominate the coral fauna in areas exposed to high wave energy.

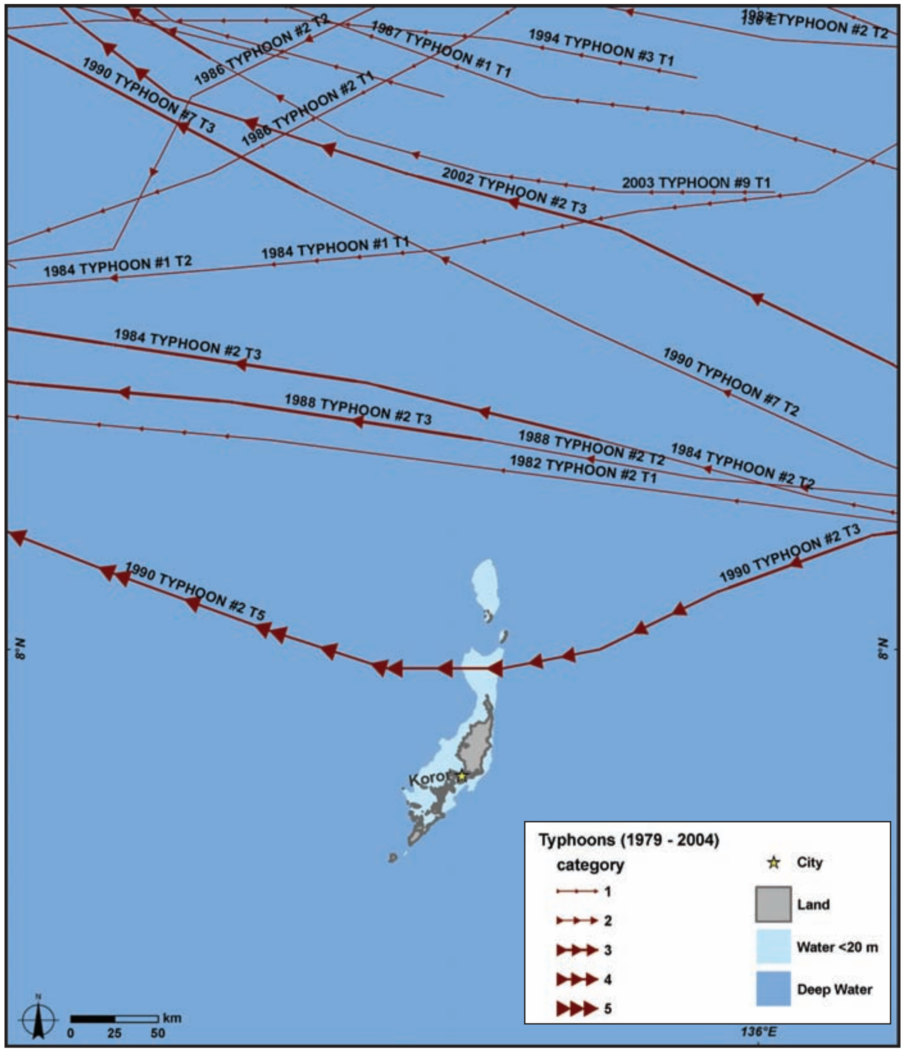

Figure 17.4. The paths and intensities of typhoons passing near Palau from 1979-2004. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: A Shapiro. Data: UNISYS, http://weather.unisys.com/hurricane.

Coastal Development and Runoff

Increased sedimentation is another major threat to coral reef ecosystems worldwide (McCook et al., 2001; Wolanski and Spagnol, 2000; Wolanski et al., 2003), and Palau is no exception. Sedimentation associated with runoff from coastal development poses a serious threat to reefs around Babeldaob, the largest island in the Palau Archipelago.

A study in the Ngerikiil watershed (Figure 17.2) showed an alarming rate of sedimentation (exceeding 1500 mg/L during flood events) which is likely the result of development activities such as road construction and agriculture (Golbuu et al., 2003b). Current sediment monitoring activity in the Ngerdorch watershed shows a direct link between the level of water clarity and runoff from the Compact Road Project (S. Victor, pers. obs.). By comparing the level of activity in the two watersheds (Ngerikiil and Ngerdorch), it is possible to observe a direct correlation between the level of human activity in the area and the observed rate of sedimentation. The Ngerikiil watershed area has experienced an increase in development activity and has a sedimentation rate that is 10 to 19 times higher than Ngerdorch watershed, which is relatively pristine (Victor et al., 2004). These studies also showed that the mangrove systems fringing the estuaries in each watershed can only trap about 30% of the sediment. Increased sedimentation can smother seagrass and coral habitats, causing mortality in some cases (Figure 17.5). Furthermore, sedimentation has the potential to affect coral recovery in Palau by blocking recruitment of coral larvae.

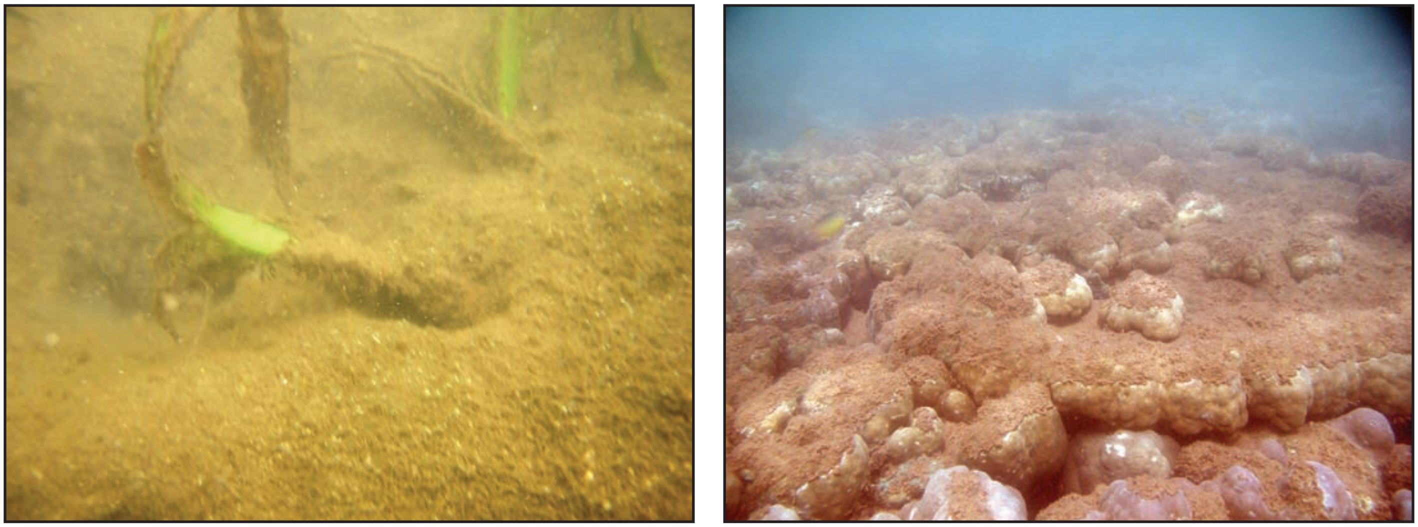

Figure 17.5. Seagrass (left) and corals (right) that are being smothered by sediment. Photos: S. Victor.

Coastal Pollution

The population in Palau is small and pollution is relatively low; however, the potential for increased pollution exists as population and development rises in Palau. Sewage can become a source of pollution to the marine environment if proper waste treatment plants are not in place to handle the increase in population and visitation. In Koror, Palau's hub of population and commerce, raw sewage has been observed on the reefs when sewer substations are not able to handle their loads. A new sewage treatment plant is being constructed in Koror to accommodate the increase in population and tourists. Babeldaob, however, has no sewage treatment plants and many of the households use septic tanks. There is a great need for a sewerage treatment plant in Babeldaob to accommodate the expected rise in development that will occur when the capitol is relocated to this island.

Other potential sources of pollution to the marine environment in Palau are animal wastes, pesticides, herbicides, oil spills, and other chemicals. Many of these potential sources are minimal but if left unchecked, they can potentially become major threats to the fragile marine environment in Palau.

Tourism and Recreation

Palau has limited income generation potential. development in hopes that it will generate income and provide a stimulus for other economic activities in Palau. In 1996, Palau derived $67 million or 47% of the Gross Domestic Product (GDP) from its tourism industry. From 1992 to 1997 tourist arrivals doubled from nearly 30,000 to 60,000. However, in 1998 Palau experienced a 3.3% decrease in GDP, which may be attributed to the decline in Palau's coral reef health due to the 1997-1998 coral bleaching event. The numbers of visitors to Palau between 1995 and 2001 are given in Figure 17.6. With the efforts and emphasis placed on tourism development, there is a growing concern that Palau does not have the proper infrastructure to support increased tourism.

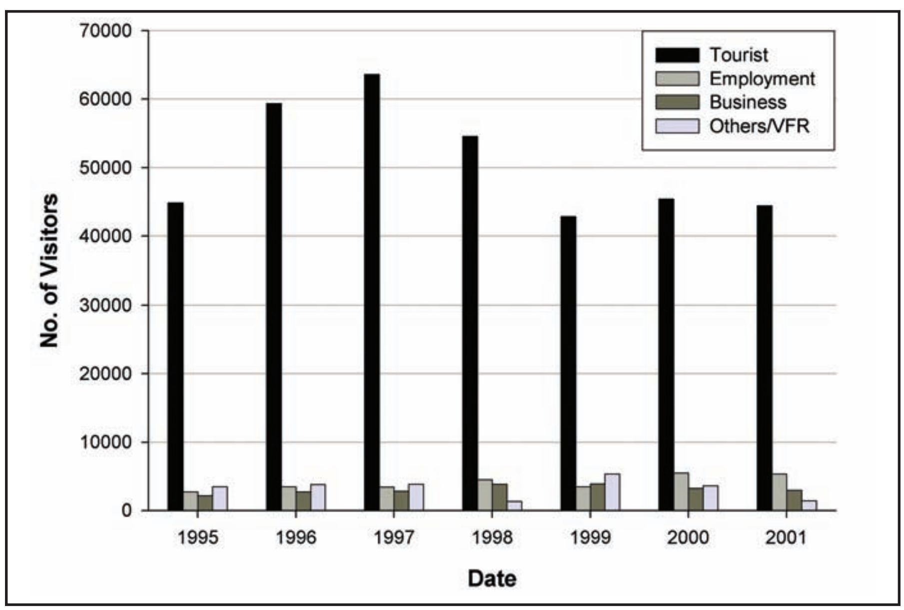

Figure 17.6. Numbers of visitors to Palau from 1995-2001. VFR is 'Visiting Friends or Relatives.' Source: Palau Visitors Authority.

Fishing

Fishing is a popular activity in Palau. In 2001, 835 people (16% of Palau's population) sold their catch to local fish markets at least once during the year (Republic of Palau, Marine Resources Database, 2004). A 2003 survey of subsistence fisheries indicated that 87% of households have someone that fishes either for subsistence or commercial purposes, and often both. Only 13% of Palauan households were not involved in any type of fishing (Palau International Coral Reef Center, unpublished data).

The total annual inshore fisheries production for Palau averaged 1,800 metric tons (mt) over the past 20 years (TEI, 1999). Approximately 360 mt of this total is sold at the local markets, 250 mt is exported, and 1,200 mt is used for direct consumption. Commercial landings data exhibit no significant trend in the amount of catch from 1998 to 2001 (A. Kitalong, pers. comm.). Field surveys (Maragos et al., 1994), fish aggregation studies (Johannes et al., 1999), and observations by fishers all indicate a decline in fish populations (TEI, 1999). In 2002, 31% of fishers and prominent community members perceived that the inshore fisheries were being harvested at unsustainable levels and communities perceived their catch to be at least three times smaller than a decade ago (A. Kitalong, pers. comm.).

Trade in Coral and Live Reef Species

The trade in marine ornamental fish has been rapidly growing worldwide over the past several years. The growing popularity of home aquaria that mimic coral reef ecosystems has made the live fish and marine invertebrate trade a profitable venture in many tropical islands. Many are concerned that this industry can cause reef degradation by targeting important juvenile food fish or species that are ecologically important. The 1994 Palau Marine Act regulates ornamental fisheries through restrictions on the collection of marine resources for aquaria and research, including a prohibition on the export of hard corals, live rock, sponges, and tridacnid clams.

The first ornamental trade company started operation in 1990, changed management in 1994, and went out of business in 1996 due to an unstable market and strict regulation by the Palau Government (Graham, 2001). Prior to 1994, the company traded finfish, tridacnid clams, starfish, rare shrimp, sea slugs, sea urchins, hermit crab with anemone, hard and soft corals, and live rocks. For two years, there was no business in the trade of marine ornamentals until 1998 when Belau Aquaculture was launched. The company originally specialized in the trade of marine invertebrates. In 1999, the company changed management and started trading finfishes as well. In 2000, the company exported 58,000 finfish and 12,000 invertebrates. The top selling finfishes are species of damselfish (Pomacentridae) and the top selling invertebrate is the blue starfish (*Linckia laevigata*; Graham, 2001). Belau Aquaculture is still in operation today, although there are no available statistics on their current export of finfish and invertebrates.

Ships, Boats, and Groundings

In the last several years, there have been several ship groundings on the reefs surrounding Palau. Many of these ship groundings occur on the western barrier reefs and in the southern lagoons. In 2001, the container ship *Falcon* ran aground on the western barrier reef and caused extensive damage to the reef. In 2002, the live-aboard dive vessel *Big Blue Explorer* ran aground and damaged the Bailechesengel Reef, a fringing reef in the Ngemelis complex that is a world renowned dive site (Golbuu et al., 2002). No restoration effort has been undertaken to reclaim these damaged reefs.

Boating is a major recreational activity in the Republic of Palau. Many tourism activities in Palau, including diving, snorkeling, and tours of the Rock Islands, require boat travel. At-sea fishing is a popular activity by locals. The Koror State Government has installed mooring buoys at many dive sites in order to reduce anchor damage to reefs.

The potential effects of motorboat fuel on marine animals have not been studied in Palau. Studies elsewhere have shown that gametes and larvae of many marine animals are susceptible to low levels of pollutants, such as copper, oil, and tributyltin (Heyward, 1988; Negri and Heyward, 2000; Reichelt-Brushett and Harrison, 1999). Many local fishers have complained that increased boating activities around seagrass and mangrove areas may have contributed to the low number of sea urchins (*Tripneustus* spp.) and fish in those areas.

Marine Debris

The impact of marine debris on reefs in Palau has not been documented or studied. The Koror State Government has a regular cleanup program around the Rock Islands to collect marine debris. Currents bring debris originating outside of Palau to the atolls of Ngeruangel and Helen Reef, but these areas do not have a regularly scheduled cleanup. The impact of marine debris on nesting bird and turtle populations in these areas is not known.

Aquatic Invasive Species

Introduction of non-indigenous species is one of the most pervasive and irreversible impacts of human activity on natural ecosystems. In the marine environment, invasive species have been rated as one of the four greatest threats to the world's oceans. Marine ecosystems are particularly vulnerable to alien species invasions. Organisms can spread rapidly in marine environments and are difficult to detect. In addition, control and eradication options used in terrestrial ecosystems often cannot be used in marine environments.

Several marine invasive species have been identified in Palau (Table 17.2; P. Colin, pers. comm.). At present, it appears that none of these invasive species are having a quantifiable effect on fisheries or the marine tourism industry, but marine invasive species do have the potential to become a serious problem in Palau. Relatively little baseline information exists for the groups of marine invertebrates that are invasive species in Palau. Most marine invasive species in Palau belong to a small group of marine invertebrates likely introduced as fouling on ship's hulls or from ballast water pumped out in harbors. The major groups of marine invasive species in Palau are the ascidians or tunicates (Phylum Chordata, Subphylum Urochordata), hydroids and other cnidarians (Phylum Cnidaria), molluscs (Phylum Mollusca), sponges (Phylum Porifera), bryozoans (Phylum Ectoprocta), and other small groups (P. Colin, pers. comm.).

Presently only one marine invasive species, the hydroid, *Eudendrium cameum*, has the potential for becoming a "pest" organism in Palau. This hydroid is a rapid growing species and has been found growing in at least three channels of Palau. *E. carneum* prefers rocky bottom substrates with particularly high currents, and often forms a tangle of branches that tends to accumulate sediment, making it a fairly unattractive "weed." The masses of *E. carneum* tend to make rocky surfaces on the reef less visible, and make the reef look "dirty." As with any marine invasive species, *E. carneum* has the potential to

Table 17.2. Marine species introduced in Palau. Source: P. Colin, pers. comm.

PHYLUM	CLASS	SPECIES
Cnidaria	**Hydrozoa**	*Eudendrium carneum*
		Thyroscyphus fruticosus
Chordata (Subphylum Urochordata)	**Ascidiacea**	*Didemnum perlucidum*
		Diplosoma listerianum
		Lissoclinum fragile
		Ascidia aperta
		Ascidia archaia
		Botryllus tyreus
		Ecteinascidia diaphanis
		Eusynstyela hartmeyeri
		Herdmania insolita
		Herdmania momus
		Microcosmus helleri
		Microcosmus pupa
		Perophora mutliclathrata
		Phallusia philippinensis
		Polyclinum nudum
		Pyura curvigona
		Pyura honu
		Pyura vittata

spread throughout the marine environments (e.g., rocky bottoms) of Palau. *E. carneum* could potentially interfere with the feeding of grazers, such as parrotfishes and surgeonfishes, which scrape algae from rock surfaces. At present, the current knowledge on the status and distribution of *E. carneum* in Palau is unknown.

Security Training Activities

Security training activities do not occur in Palau.

Offshore Oil and Gas Exploration

Offshore oil and gas exploration activities do not occur in Palau.

CORAL REEF ECOSYSTEM—DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

Various data gathering efforts have contributed to the general understanding of coral reef ecosystems in Palau. Table 17.3 provides a tabular summary of the monitoring and assessment activities that have been undertaken in recent years.

Table 17.3. Monitoring and assessment activities occurring in Palau.

AGENCY	PLANNING/ MANAGEMENT	RESEARCH	MONITORING	EDUCATION/ OUTREACH	TRAINING	ENFORCEMENT
Bureau of Natural Resources and Development	X	X	exports and fish markets			
Coral Reef Research Foundation		X	temperature, marine lakes			
Environmental Quality Protection Board			water quality	X		X
Koror State Department of Conservation and Law Enforcement	X	X	marine lakes, rock islands	X	X	X
Palau Conservation Society			MPAs	X		
Palau International Coral Reef Center		X	fish, coral, MPAs, watersheds	X	X	
The Nature Conservancy	X	X			X	

WATER QUALITY

Methods

The Environmental Quality Protection Board of Palau (EQPB) conducts monthly water quality monitoring of marine waters around most of Palau. Turbidity, pH, salinity, dissolved oxygen, fecal coliform, and temperature are collected monthly at 32 permanent sites (Table 17.4). Sampling sites were selected because they are either a popular recreational site or in close proximity to a drinking water station. Results from the monitoring program are added to a database that dates back to the early 1980s.

Table 17.4. Water quality parameters measured by the EQPB of Palau.

PARAMETER	UNITS	COLLECTION METHOD
Fecal Coliform	bacteria/100 ml	Obtain near surface water sample for laboratory analysis
Turbidity	NTU	*In situ* hydrolab multi parameter meter: near surface
pH	scale of 1-14	*In situ* hydrolab multi parameter meter: near surface
Temperature	°C	*In situ* hydrolab multi parameter meter: near surface
Dissolved Oxygen	mg/L	*In situ* hydrolab multi parameter meter: near surface
Salinity	parts per thousand (ppt)	*In situ* hydrolab multi parameter meter: near surface

Results and Discussion

EQPB issues an 'unsafe for swimming' warning for when the fecal coliform count at a site exceeds 20 bacteria per 100 mL. Most of the sites sampled had fecal coliform counts less than this threshold (Figure 17.7). However, in April, May, and August of 2002, at least one-quarter of the monitoring sites had fecal coliform counts over 20 bacteria per 100 mL.

In 2002, the average turbidity was below 4 Nephlometric Turbidity Units (NTU), except in April and September when it exceeded 5 NTU (Figure 17.8). The increase in turbidity in April and September could be the result of increased land earth moving activities or more rain during those months.

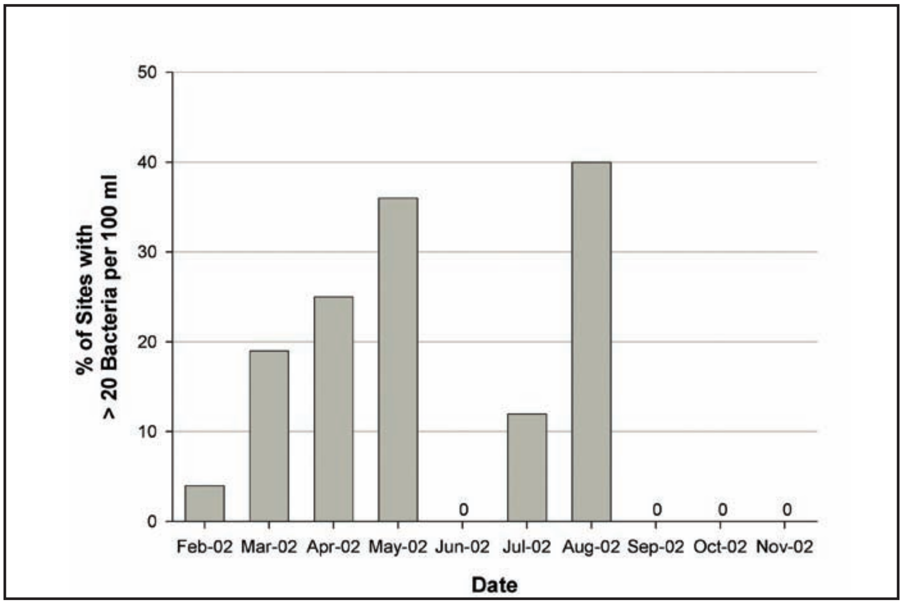

Figure 17.7. Fecal coliform sampling in 2002 at 32 sites around Palau. Source EQPB.

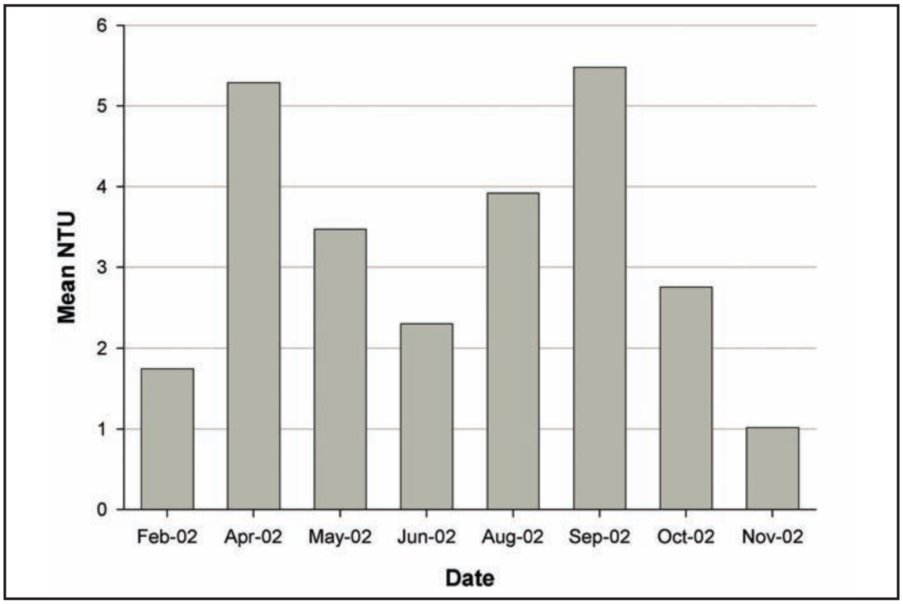

Figure 17.8. Mean turbidity in 2002 at 32 permanent sites around Palau. No samples were collected in March or July 2002. Source: EQPB.

BENTHIC HABITATS

Methods

The Palau International Coral Reef Center (PICRC) launched a nationwide coral reef monitoring program for Palau in 2001. The objectives of the program are to: (1) establish permanent monitoring sites; (2) determine status of Palau's reefs; (3) assess changes to the benthic and fish communities at each site over time; and (4) examine the recovery process from the 1997-1998 bleaching event at each site. The program consists of a rapid assessment of reef habitats using the spot check method and a detailed monitoring survey of benthic organisms, fish size and abundance, and coral recruitment.

The spot check method is a rapid qualitative assessment of bottom substrates, coral cover, and dominant life forms. In 2001-2002, 217 spot checks were performed in Palau (Figure 17.9). Spot check surveys were conducted by making qualitative observations during a 15-minute snorkel survey at each site. Two to three representative pictures of the site were also taken during the survey. Estimated coral cover was classified as *Acropora* or "other" and grouped into one of four density categories: 0-5%, 6-25%, 26-50%, and >50%. Spot check sites were chosen haphazardly along the reef front every few kilometers. While the spot check method provides a good qualitative overview of the condition of Palau's reef, it cannot be used for quantitative analysis.

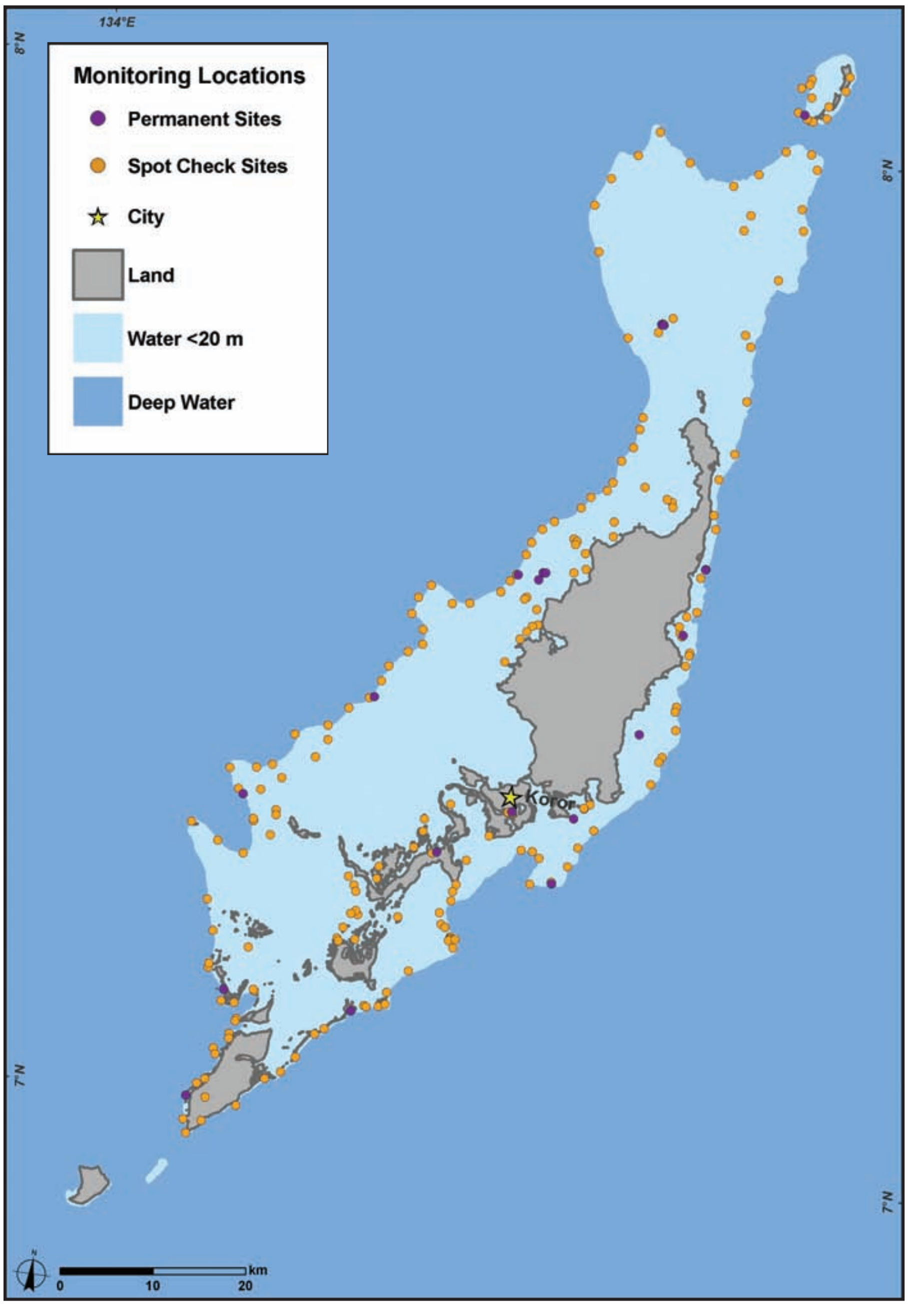

Figure 17.9. Locations of spot checks (orange dots) and permanent monitoring sites (purple dots). Map: A. Shapiro.

In addition to the spot checks, a quantitative assessment examining temporal and spatial changes was conducted at 14 permanent monitoring sites around Palau (Figure 17.9). The monitoring sites utilized in these detailed surveys were representative of Palau's geomorphologic reef types and localities, ranging from sheltered fringing reefs to oceanic atolls. The potential level of human impacts on the health of coral reefs was also taken into account in the selection of sites. Currently the permanent sites are stratified and replicated within habitats, sites, depths and transects. Four sites were surveyed on the western barrier reefs and Rock Island fringing reefs, two sites on the east coast fringing reefs and patch reefs, and one site at the atoll and east coast barrier reefs, for a total of 14 permanent monitoring sites around Palau.

Detailed surveys of benthic communities were conducted using video transects. At each site, five replicate benthic cover surveys were conducted at 3 m and 10 m depths along a 50 m transect. The observer swam approximately 70 cm above the transect line at a constant speed and videotaped the transect for approximately five minutes. Recruitment surveys were conducted using a belt transect (0.30 m wide x 10 m long) along the same transects. Any coral that was smaller than 5 cm in diameter was considered a recruit and its size was recorded. A minimum of three transects were completed for the recruitment surveys; additional transects were surveyed at sites with few recruits.

Results and Discussion

Spot check results shows that 87% of the sites surveyed had low *Acropora* cover in the range of 0-5% (Figure 17.10). 68% of the sites surveyed had coral other than *Acropora* covering less than 25%. Overall, percent coral cover was generally low to moderate; only 1% of spot check sites had *Acropora* cover greater than 50% and only 9% of the sites had non-*Acropora* coral cover greater than 50%.

The quantitative surveys at the permanent monitoring sites show that coral cover was highest along the 3 m depth belt transect at Nikko Bay, a fringing reef site within the Rock Islands (Figure 17.11). Nikko Bay and Ngemelis western barrier reef exhibited the highest coral cover at the 10 m depth. Airai fringing reef on the east coast of Palau and Ngaremlengui patch reef on the west coast had the lowest coral cover at both 3 m and 10 m depths (Figure 17.11). Both Airai and Ngaremlengui are dominated by sandy bottom substrates and experience high levels of sediment resuspension during windy conditions.

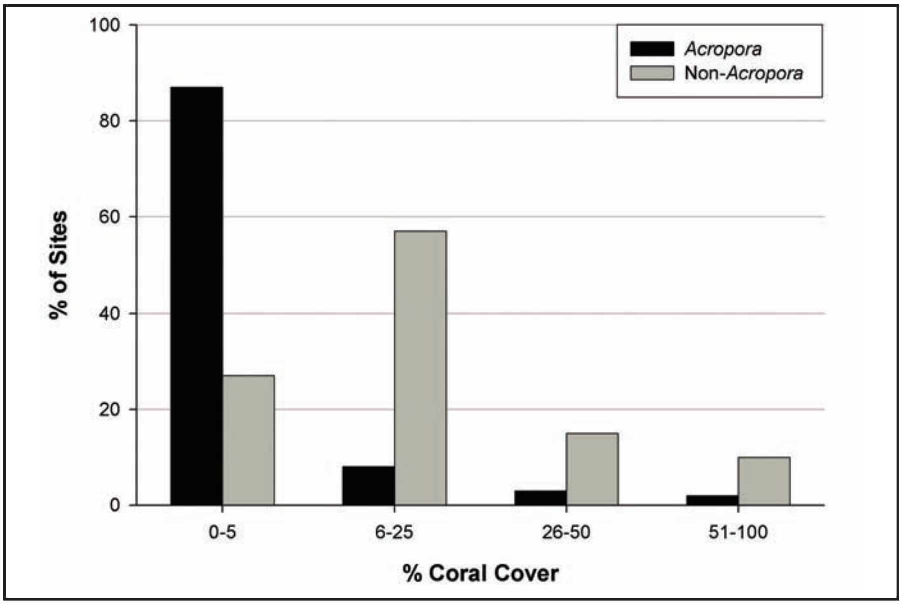

Figure 17.10. Coral cover of reefs at 217 sites around Palau that were surveyed by spot checks. Source: Golbuu et al., 2003a.

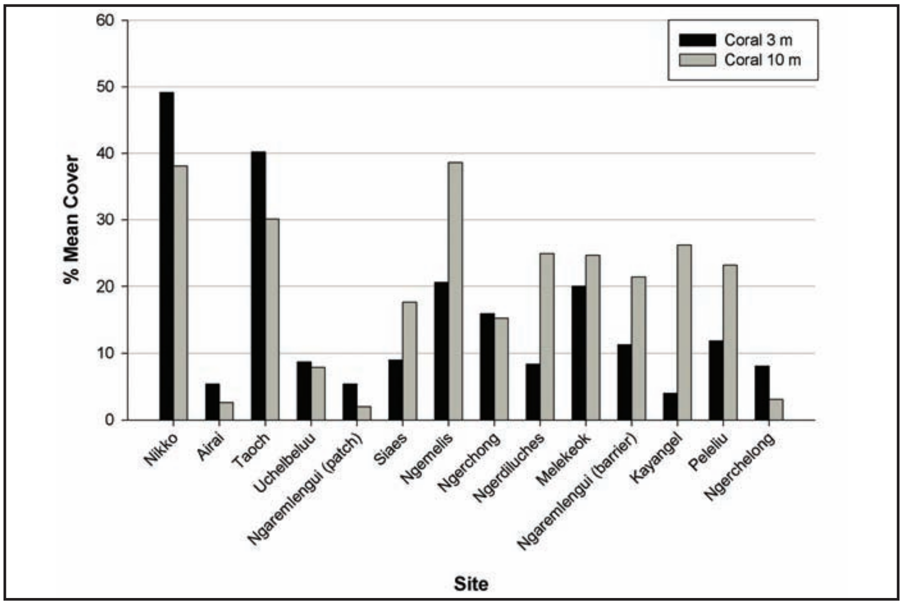

Figure 17.11. Coral cover at established permanent monitoring sites at 3 m and 10 m depths. Source: Golbuu et al., 2003a.

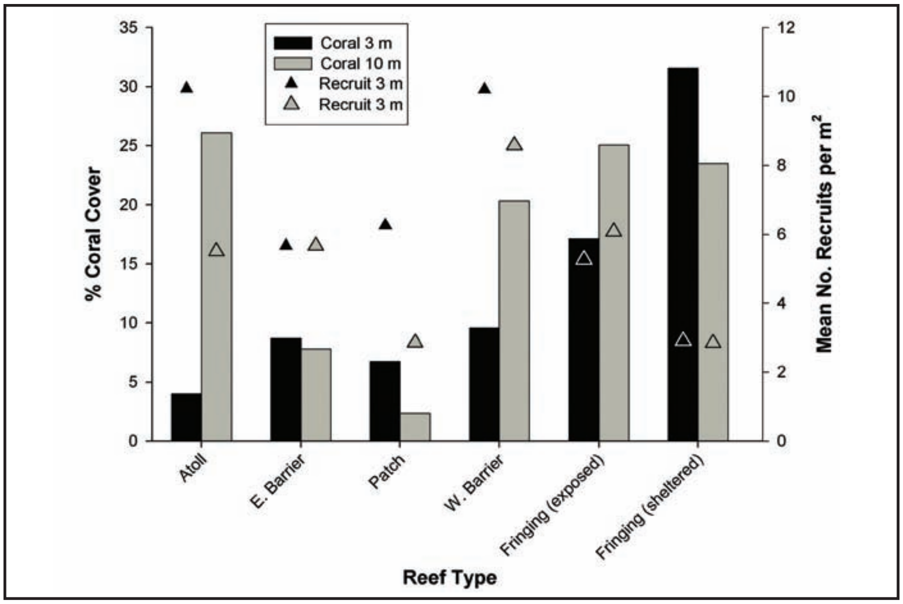

Figure 17.12. Mean coral cover and coral recruitment by reef type at 3 m and 10 m depths. Source: Golbuu et al., 2003a.

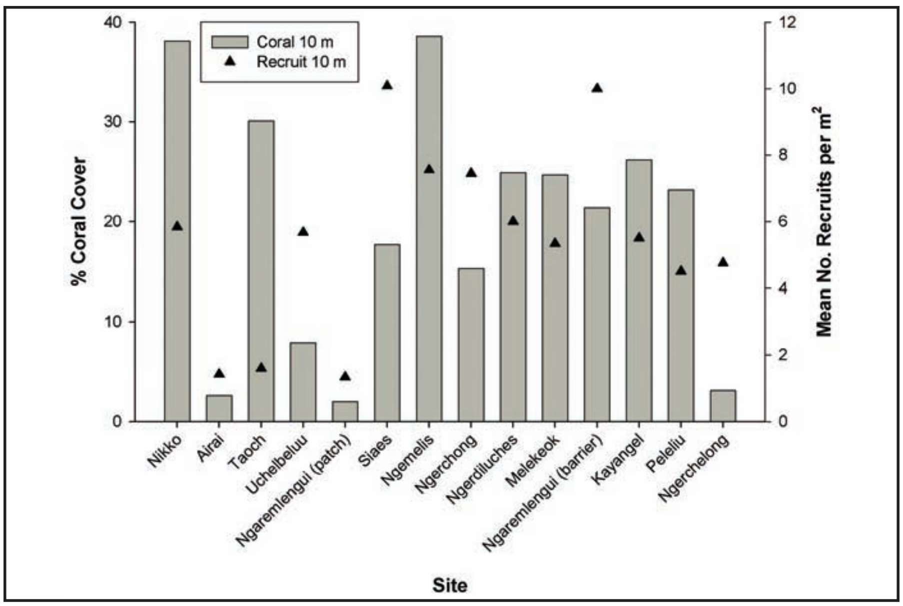

Figure 17.13. Coral cover and recruitment rate at the permanent monitoring sites. Source: Golbuu et al., 2003a.

The monitoring sites were selected to represent the various types of Palauan reefs: Atoll; east coast barrier (east barrier); patch reefs (patch); west coast barrier (west barrier); fringing reefs that are not protected by other reef or land (fringing exposed); fringing reefs that are protected by reef or island (fringing sheltered). There are significant differences in coral cover among reef types and depths. At 10 m depth, coral cover on patch reefs was significantly lower than all other reef types except for east barrier (Figure 17.12). In contrast, at 3 m, both exposed and sheltered fringing reefs had coral cover that was significantly higher than other reef types (Figure 17.12).

Mean coral recruitment varied significantly among the different reef types at both 3 m and 10 m depths (Figure 17.12). West barrier reefs had the highest number of recruits at both 3 m and 10 m depths. At the 3 m depth, the number of recruits at west barrier reefs was significantly different than the number of recruits at both exposed and sheltered fringing reefs. The only significant difference in coral recruitment among reef types at the 10 m depth was between west barrier reefs and sheltered fringing reefs (Figure 17.12).

There was no correlation between coral cover and recruitment at 10 m depths (Figure 17.13). For example, Nikko Bay and Taoch had high coral cover, but low coral recruitment. In contrast, Ngemelis and Kayangel have high coral cover and high recruitment. Airai and Ngeremlengui had low coral cover and low coral recruitment. Other sites, such as Ngerchelong, had low coral cover, but a high number of recruits.

Recruitment patterns can be better explained by the characteristics specific to each of the monitoring sites. In Nikko Bay, low recruitment was due to the lack of available substrates since all suitable substrate was covered by benthic organisms. Even though Ngemelis and Kayangel had high coral cover, there was still suitable substrate available for recuitment. Airai and Ngaremlengui sites have low coral cover and low recruitment because both sites are dominated by sandy bottoms and rubble, which are not suitable for coral recruitment.

The presence of recruits and young juvenile corals at many of the monitoring sites suggests that reefs are recovering. However, percent cover and species diversity remain lower than reef conditions prior to 1998.

ASSOCIATED BIOLOGICAL COMMUNITIES

Methods

Detailed surveys of fish communities were conducted by visual census at each permanent monitoring site. The surveys were conducted at 3 m and 10 m depths along five 50 m transects at each site. An observer swam along the transect line, counting the number of fish within 2.5 m of each side of the transect. Size was also estimated for each observed fish.

Results and Discussion

At the 3 m depth, the greatest number of fish (mean of 80 fish per 250 m^2) was observed at Ngerdiluches (Figure 17.14). Surgeonfishes (Acanthuridae) were the most common fish at all monitoring sites (Figure 17.15). Parrotfish, rabbitfish, and snappers were also found in high abundance. The lowest number of fish was recorded at Nikko for both the 3 m and 10 m depths (Figure 17.14).

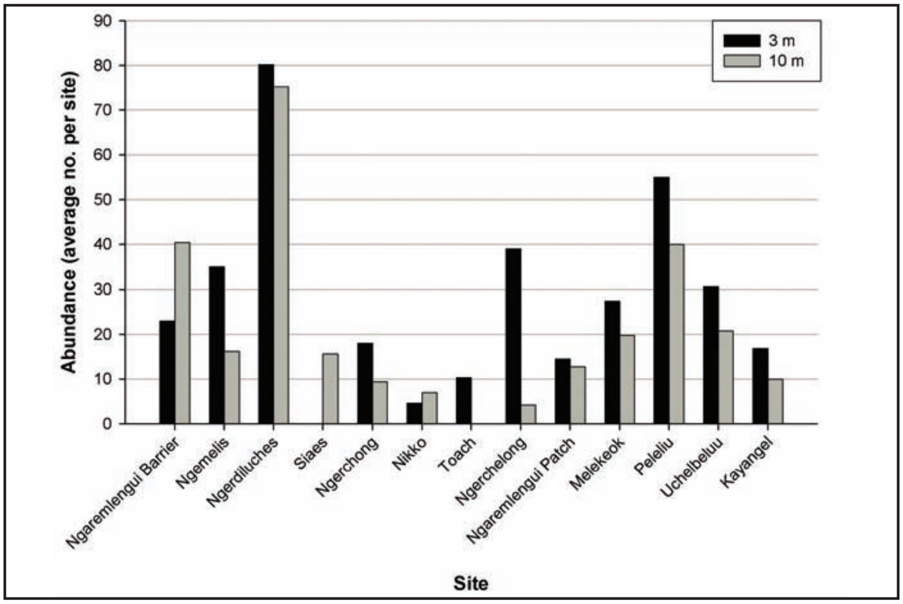

Figure 17.14. Average number of fish at the permanent monitoring sties around Palau. Source: PICRC, unpublished data.

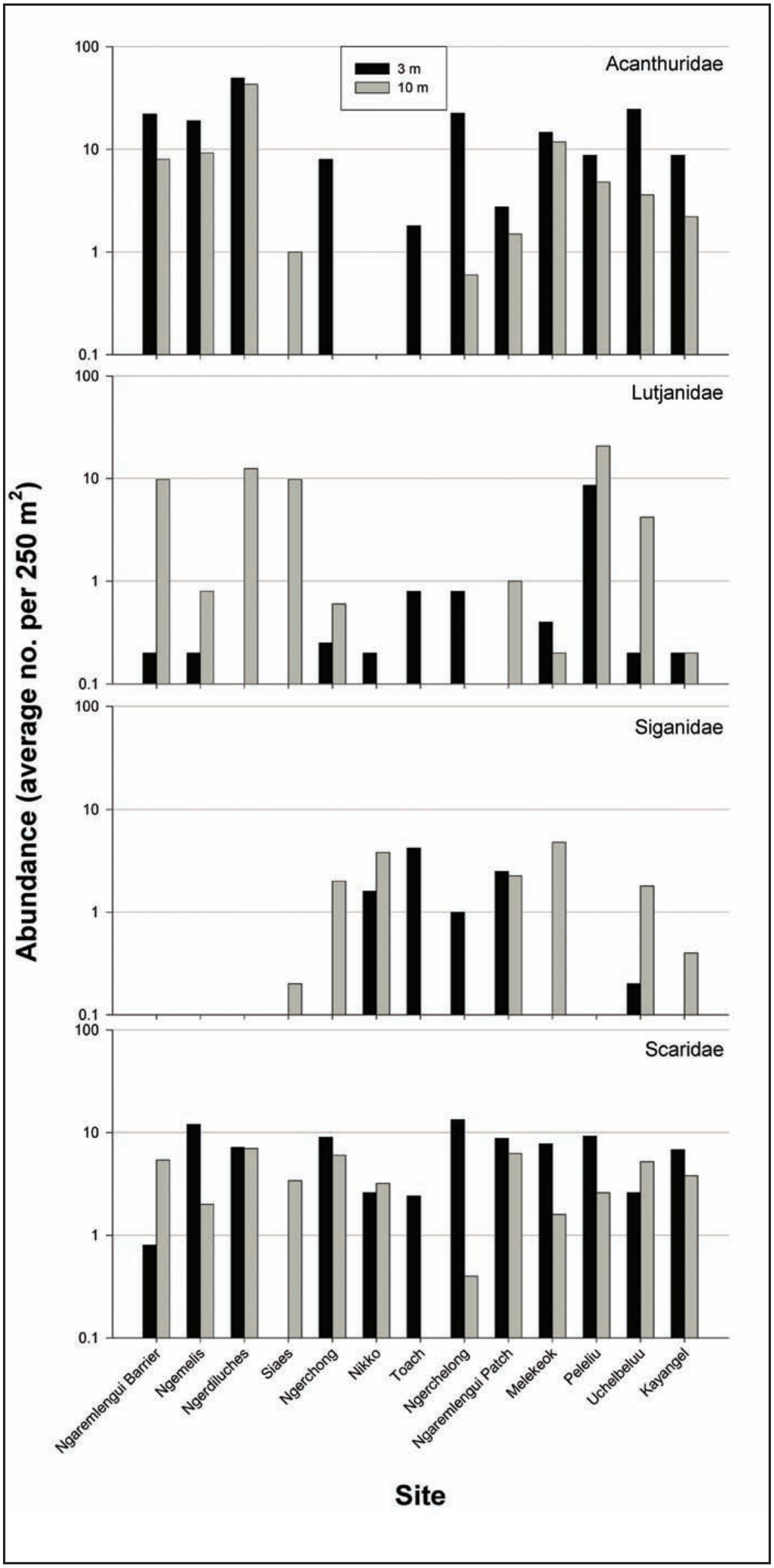

Figure 17.15. Abundance of Acanthuridae, Lutjanidae, Siganidae and Scaridae at the permanent monitoring sites around Palau. Source: PICRC, unpublished data.

Figure 17.15 shows the abundance of four main fish families observed at the permanent monitoring sites in Palau. Sites were grouped by reef type to demonstrate the differences in fish communities at different habitat types. Surgeonfish (Acanthuridae) are the most abundant fish found at the monitoring sites. Sites that are exposed, such as barrier reefs (i.e., Ngaremlengui, Ngemelis, Ngerdiluches, Siaes, and Uchelbeluu) and exposed fringing reefs (i.e., Ngerchong, Melekeok, and Peleliu) have high numbers of surgeonfish, while sheltered fringing reefs (i.e., Nikko and Taoch) have lower numbers (Figure 17.15).

Barrier reefs have high numbers of snappers (Lutjanidae), but few were found on sheltered fringing reefs and patch reefs (i.e., Ngerchelong and Ngaremlengui patch; Figure 17.15). Rabbitfish of the family Siganidae show a pattern opposite to that of snappers. Fringing and patch reefs had high numbers of rabbitfish but none were found on barrier reefs (Figure 17.15). Parrotfishes (Scaridae) were evenly distributed at all sites (Figure 17.15).

Kayangel, the only atoll site, had moderate concentrations of all four of the main fish families surveyed.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The Palau Ministry of Resources and Development has overlapping jurisdiction with each of Palau's 16 state governments for all marine areas within 12 nm of the hightide watermark. Various governmental and non-governmental organizations have conducted research and monitoring projects to aid in the management of Palau's coral reef ecosystems. National and state agencies, in coordination with locally based non-governmental organizations, have put a variety of management tools in place to address issues such as fishing, recreational use, and land-based sources of pollution in order to protect the marine resources of Palau.

Marine Protected Areas

Several marine protected areas (MPAs) have been established throughout Palau to provide measures of protection for marine resources tailored to the management goals and intended purpose of the individual MPAs (Table 17.5). Several more of these protected areas have been designated over the years, thereby providing protection for a greater percentage of coral reef ecosystems (Figure 17.1).

Most of Palau's MPAs have been designated by the states and management of these areas falls under the authority of the local governments. In addition, there are MPAs designated by the national government for the purpose of protecting biodiversity and significant habitats. The designation of a MPA by the local governments is initiated by the implementation of a traditional moratorium, or 'bul', on the area, prohibiting all use for a restricted time period (usually one to three years). The majority of these MPAs were designated to address local concerns of decreased commercial reef fish populations. The Palau Conservation Society and The Nature Conservancy have been working in partnership with these state governments to implement community-level monitoring programs within the MPAs and to produce management plans for these areas which will be in effect after the moratorium period has expired. In the last several years, more of these MPAs have also been designated through legislation by the state governments to provide a legal basis for management action.

Table 17.5. Marine Protected Areas of Palau.

MARINE PROTECTED AREAS	OBJECTIVES	MANAGEMENT AUTHORITY	PROTECTED HABITATS
Ngerukeuid Preserve	Preservation of marine habitat biodiversity	National government	Rock islands, inner reef flats, lagoon, patch reefs
Ngerumkaol	Protection of reef fish aggregations	State government	Outer reef wall, reef flat, reef channel
Ngemelis	Protection of marine habitat diversity	State government	Rock island, inner reef flats, lagoon, patch reefs
Sardine Sanctuary	Protection of sardine aggregations	State government	Inner patch and fringing reefs
Ngederrak	Protection of commercial reef fish and invertebrate species populations	State government	Reef flats, inner reef slope, seagrass beds, lagoon
Ngermeduu Bay	Protection of marine habitat biodiversity	State government	Mangroves, mudflats, seagrass beds, fringing reefs, reef channel, inner reef flats, reef slope
Ngelukes	Protection of locally important fish and invertebrate species populations	State government	Patch reef, seagrass beds
Ngermasech	Protection of important nursery areas for fish and invertebrate species	State government	Seagrass beds, fringing reefs
Ebiil Channel	Preservation of grouper spawning aggregations	State government	Reef slopes, reef flats, channel, patch reefs, lagoons
Ngaruangel	Protection of marine habitats and locally important marine species populations	State government	Atoll

Protected Area Network Act

The Protected Areas Network Act of 2003 aims to support Palauan state government efforts directed at protecting marine resources. This law creates a nationally sanctioned framework by which non-governmental organizations and local governments can coordinate marine reserve conservation initiatives through a system of protected areas, which collectively preserve marine biodiversity. It is hoped that the Act will encourage the designation of new MPAs by state governments. Until recently, state governments have designated MPAs, but there was no system for collaboration and support from the national government in identifying appropriate areas, as well as designating and maintaining these resources. The Protected Area Network Act was seen as the necessary tool to ensure that areas representative of the full range of biodiversity in Palau are preserved. A Protected Areas Network coordinator will be appointed to facilitate the implementation of this law. With technical assistance from The Nature Conservancy in the form of a Protected Area Network counterpart, the state governments will have access to technical expertise and financial resources that are often lacking at the local level to properly develop MPAs.

MPA Effectiveness

The Palau International Coral Reef Center (PICRC) is currently conducting research to assess the efficacy of several MPAs in Palau. MPAs will be selected based on the level of management, geographic distribution, size, the protection timeframe, and willingness of managers and community members to be evaluated. The main objective is to improve the management of MPAs in Palau, thereby making MPAs more effective in meeting their goals and objectives.

The Palau Conservation Society, in partnership with The Nature Conservancy, has also established several monitoring sites in four community-designated MPAs in Babeldaob. The monitoring program tracks the abundance of locally important fish and invertebrate species (Table 17.6).

Table 17.6. Community-designated Conservation Areas.

MARINE PROTECTED AREA	STATE GOVERNMENT	INDICATORS
Ngelukes Conservation Area	Ngchesar State	Reef fish and invertebrate species abundance (rabbitfish, snappers, surgeonfish, giant clams, and sea cucumbers)
Ngermasech Conservation Area	Ngardmau State	Reef fish and invertebrate species abundance (rabbitfish, snappers, surgeonfish, giant clams, and sea cucumbers)
Ebiil Channel Conservation Area	Ngarchelong State	Abundance of groupers at spawning aggregation sites
Ngaruangel Reserve	Kayangel State	Fish abundance, occurrence of nesting sea turtle and sea bird poplulations

Other Management Tools

The Palau Bureau of Marine Resources has deployed fish aggregating devices in territorial waters around Palau in order to take fishing pressure off the reefs and promote a shift to pelagic fishes. Mooring buoys have been installed throughout the state of Koror as a management tool to decrease recreational impacts on coral reefs. Mooring buoys are well used by dive operators, recreational fishers and boaters. Outside the MPAs and other managed areas with very specific regulations, fishing is nationally regulated. Size restrictions exist for the humphead wrasse, bumphead parrotfish, and lobster. The harvest of grouper is restricted to non-peak spawning months and the season is well established. Additionally, the commercial export of reef fish and crustaceans is prohibited. Other restrictions are in place such as a closed season on harvesting sea turtles and full protection for the dugongs in Palau.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

Collaboration and coordination among the different agencies and groups involved in coral reef monitoring, management and conservation are important. Interagency working groups (e.g., National Environmental Protection Council, Marine Resources Pacific Consortium, etc.) should be strengthened to ensure the inclusion of local agencies and interest groups and to increase communication and cooperation when addressing priorities and actions outlined in nationally adopted strategies (e.g., National Biodiversity Strategy Action Plan). Information beginning to emerge from studies of important watersheds in Palau suggests that collaboration between land management authorities, legislative bodies, and traditional leadership will be required to develop effective land use regulations. An integrated and transparent approach that recognizes the complexities of managing the coastal zone is considered crucial to this effort. In addition, the incorporation of coral reef ecosystem issues into local education programs will further promote marine conservation. Forming partnerships among relevant agencies that deal with outreach and education in Palau should be initiated to maximize the use of limited resources. The main objective of this effort should be to raise public awareness and appreciation for coral reef ecosystems through targeted and focused communication campaigns.

Specialized advice, technical assistance, and additional data are required in several areas. Most of the work being done in Palau has focused on biological and physical aspects of coral reefs and marine resources. Social, cultural, economic, and political factors, however, are also extremely important to the success of management strategies. Currently, Palau has limited expertise and capacity to address socio-economic issues, and therefore technical assistance and expertise in this area are needed.

Palau recently passed the Protected Areas Network Act which provides a framework for the establishment of an MPA network in Palau. Much of the work on the design, criteria, and regulations are under development, and expertise and technical assistance are needed to assist in implementation. Furthermore, in order to ensure efficiency in resource management, managers require accurate information on ecosystem change. Activities such as monitoring of coral reefs, as well as site selection and monitoring of MPAs require detailed habitat maps. Currently, Palau does not have maps of sufficient detail to support the necessary research and monitoring work. However, nearshore benthic habitat mapping has been initiated by NOAA's Center for Coastal Monitoring and Assessment, Biogeography Team, and preliminary products for approximately 75% of the main island cluster will be available by the end of 2005. In addition, fisheries managers in Palau urgently need reliable information on catch per unit of effort and trends in the population structure of target fish.

REFERENCES

Bruno, J.F., C.E. Siddon, J.D. Witman, and P.L. Colin. 2001. El Nino related bleaching in Palau, Western Caroline Islands. Coral Reefs 20: 127-136.

Bryant, D., L. Burke, J. McManus and M. Spalding. 1998. Reefs at risk: a map-based indicator of threats to the world's coral reefs. World Resources Institute, Washington, DC.

Colin, P. Coral Reef Research Foundation. Koror, Palau. Personal communication.

Golbuu, Y. 2000. Status of the coral reefs of Palau. PCC-CRE Publication 19/00.

Golbuu, Y., D. Idip Jr., S. Victor, J. Kloulechad, and K. Okaji. 2002. Environmental Assessment for the Big Blue Explorer Grounding, Koror State, Republic of Palau. PICRC Publication 02-001.

Golbuu, Y., S. Victor, E. Wolanski, and R.H. Richmond. 2003a. Trapping of fine sediment in a semi-enclosed bay, Palau, Micronesia. Estuarine, Coastal and Shelf Science 57: 941-949.

Golbuu, Y., L. Penland, D. Idip, S. Victor, C. Emaurois, J Kloulechad, and K. Okaji. 2003b. Status of Palau's Coral Reefs. In: Proceedings of Palau coral reef conference, Koror, Palau. PICRC Publication 04-001.

Gosliner, T. California Academy of Sciences, San Francisco. Personal communication.

Graham, T. 2001. The live reef fisheries of Palau: history and prospect for management. Asia Pacific Coastal Marine Program Report 0103. The Nature Conservancy, Hawaii. 85 pp.

Harvell, C., K. Kim, J. Burkholder, R. Colwell, P. Epstein, D. Grimes, E. Hofmann, E. Lipp, A. Osterhaus, R. Overstreet, J. Porter, G. Smith, and G. Vasta. 1999. Emerging marine diseases: Climate links and anthropogenic factors. Science 5433: 1505-1510.

Heyward, A.J. 1988. Inhibitory effects of cooper and zinc on fertilization in corals. pp. 2: 299-303. In: Proceedings of the 6th International Coral Reef Symposium.

Johannes, R.E., L. Squire, T. Graham, Y. Sadovy, and H. Renguul. 1999. Spawning aggregations of groupers (Serranidae) in Palau. The Nature Conservancy Marine Research Series Publication No.1, 144 pp. Available from the internet URL: http://www.tnc.org/asiapacific.

Kelly-Borges, M. and C. Valentine. 1995. The sponges of the tropical island region of Oceania: A taxonomic status review. pp. (1) 83-120. In: J. Maragos, M.N.A. Peerson, L.G. Eldredge, J.E. Bardach, and H.F. Takeuchi (eds.) Marine and Coastal Biodiversity in the Tropical Island Pacific Region. Species Systematics and Information Management Priorities. East-West Center, Honolulu. 424 pp.

Kitalong, A. The Environmental, Inc. Airai, Palau. Personal communication.

Maragos, J.E., C. Birkeland, C. Cook, K. Des Rochers, R. Di Rosa, T.J. Donaldson, S.H. Geermans, M. Guilbeaux, H. Hirsh, L. Honigman, N. Idechong, P.S. Lobel, E.Matthews, K.J. McDermid, K.Z. Meier, R. Myers, D. Otobed, R.H. Richmond, B. Smith, and R. Smith. 1994. Marine and coastal areas survey of the main Palau Islands: Part 2. Rapid Ecological Assessment Synthesis Report. Republic of Palau, Ministry of Resources and Development.

McCook, L., E. Wolanski, and S. Spagnol. 2001. Modelling and visualizing interactions between natural disturbances and eutrophication as causes of coral reef degradation. pp. 113-125. In: E. Wolanski (ed.), Oceanic processes of coral reefs, Physical and biological links in the Great Barrier Reef. CRC Press, Boca Raton, FL. 356 pp.

Meyer, D.L. and D.B. Macurda, Jr. 1980. Ecology and Distribution of the Shallow-Water Crinoids of Palau and Guam. Micronesica 16: 59-99.

Myers, R.F. 1999. Micronesian reef fishes: a comprehensive guide to the coral reef fishes of Micronesia. Coral Graphics, Barrigada, Guam. 330 pp.

Negri, A.P. and A.J. Heyward. 2000. Inhibition of coral fertilization and larval metamorphosis by tributyltin and cooper. Marine Environmental Research 51: 17-27.

Randall, R.H. 1995. Biogeography of reef-building corals in the Mariana and Palau Islands in relation to back-arc rifting and the formation of the eastern Philippine Sea. Natural History Research 3 (2): 193-210.

Reichelt-Brushett, A.J. and P.L. Harrison. 1999. The effects of cooper, zinc, and cadmium on fertilization success of gametes from scleractinian reef corals. Marine Pollution Bulletin 38 (3): 182-187.

Republic of Palau. 2004. Marine Resources Database. Bureau of Marine Resources.

TEI (The Environment, Inc.). 1999. Palau Inshore Fisheries Profile. A report submitted to: Palau Conservation Society.

UNISYS. 2004. Typhoon data for the Western Pacific Ocean. Available on-line at: http://weather.unisys.com/hurricane.

Victor, S. Palau International Coral Reef Center, Koror, Palau. Personal communication.

Victor, S., Y. Golbuu, E. Wolanski, and R.H. Richmond. 2004. Wetland Ecology and Management. 12: 277 - 283.

Willis, B. 2004. James Cook University, Townsville, Australia. Personal communication.

Willis, B.L., C.A. Page, and E.A. Dinsdale. 2004. Coral disease on the Great Barrier Reef. pp. 69 – 104. In: E. Rosenberg and Y. Loya (eds.) Coral Health and Disease. Springer-Verlag, Berlin.

Wolanski, E. and S. Spagnol. 2000. Environmental degradation by mud in tropical estuaries. Regional Environmental Change 1 (3-4): 152-162.

Wolanski, E., R.H. Richmond, G. Davis, and V. Bonito. 2003. Water and fine sediment dynamics in transient river plumes in a small reef-fringed bay, Guam. Estuarine, Coastal and Shelf Science 56: 1029-1040.