The State of Coral Reef Ecosystems of the Commonwealth of the Northern Mariana Islands

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INTRODUCTION AND SETTING

The 290 km long Mariana Islands Archipelago encompasses 14 islands of the U.S. Commonwealth of the Northern Mariana Islands (CNMI), the U.S. Territory of Guam, and numerous offshore banks (Figure 15.1). From a geological perspective, the islands can be divided into two groups: a southern and a northern island arc region. Although the islands of the older southern arc, which includes Rota, Tinian, Saipan, and Farallon de Mendinilla (FDM), are volcanic in origin, they are nearly all covered with uplifted limestone derived from coral reefs. The West Mariana Ridge (WMR) is a series of seamounts, lying 145 to 170 km west of and parallel to the main island chains. Some of these mounts rise to within 13 m of the surface. The WMR is intermediate in age, as it is being younger than the southern island arc and older than the northern island arc. The southern arc islands have the oldest and most developed reefs in the CNMI, which are predominantly located along the western (leeward) sides. The majority of the CNMI's residents live on Rota, Tinian, and Saipan, the capital.

Southern Mariana Islands

Rota is 117 km southwest of Saipan and 76 km north of Guam, is the southernmost island in the Mariana Island Chain (Figures 15.1 and 15.2). It has a land area of 85.5 km^2 and is approximately 17 km long and 5 km wide. The principal communities are Sinapalo and SongSong. As Rota was neither developed extensively by the Japanese nor invaded during World War II (WWII), it still has much of its native vegetation. However, the island is becoming more of a tourist destination and development is increasing, which may impact the existing fringing reefs. Fringing reef surrounds the island and modern reef development is most significant on the northwest coast, west of Teteto Beach, and in the Sasanhaya Bay on the southwest coast. Continuous reef is found inside Sasanhaya Bay and an area along the western shore. Erosion along the Talakaya cliffline on the southern coast is causing sedimentation problems on adjacent reefs.

Aguijan (Goat Island) is an uplifted limestone island with a land area of 7.3 km^2 (Figure 15.1). It is presently uninhabited, although it was populated during WWII. The island is now under the management of the Tinian Municipal Council. The neighboring islet, Naftan Rock, was used as a bombing target prior to the U.S. Navy's use of FDM and unexploded ordnance remains in the surrounding waters. The island is now home to nesting seabirds. The reefs just off the northwest coast are the largest and most developed.

Tinian, with a land area of 102 km^2, lies 4.4 km south of Saipan, across the Saipan Channel (Figures 15.1 and 15.2). The principal community is San Jose. Nearly two-thirds of Tinian is leased to the U.S. Military. Tinian's coral reefs are more developed on the western side, most notably in the vicinity of the Tinian Harbor, an area likely to be negatively affected by future development.

Saipan, the largest of the Northern Mariana Islands, has a land area of 122 km^2 and is approximately 20 km long and 9 km wide (Figures 15.1 and 15.2). The island consists of a volcanic core enveloped by younger coral reef-derived limestone formations. The island has the most diverse types of coral reefs and associated habitats in the Commonwealth. A fringing and barrier reef system protects the majority of the beaches along the western and coastal plains. The western side of the island is the most populated and the coral reefs along these areas are negatively affected by human activity. Continuing sediment and nutrient pollution combined with sporadic stressors such as outbreaks of crown-of–thorns starfish (COTS) (*Acanthaster planci*) and temperature-induced bleaching affect many of Saipan's western and southeastern reefs. Furthermore, coral habitat on two large

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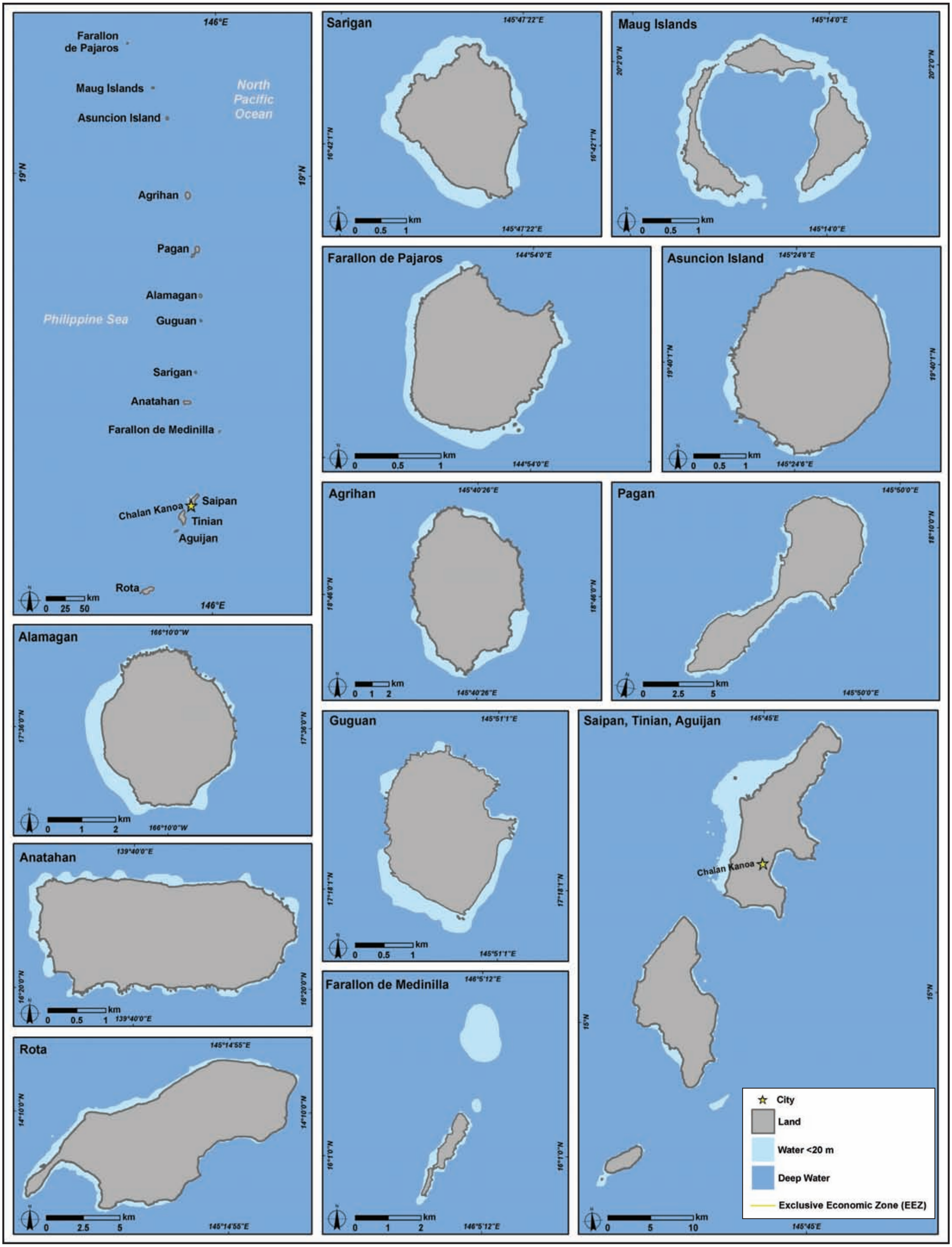

Figure 15.1. Locations in the CNMI mentioned in this chapter. Top left panel shows the spatial distribution of islands and banks in the chain; additional panels provide a closer view of the individual islands and banks. Map: A. Shapiro.

offshore banks (18 km x 22 km) in water depths between 30 m and 60 m on the western side of Saipan are negatively affected by the anchorage of commercial and naval vessels.

FDM is a steep-sided, raised limestone island with a land area of 0.8 km^2 (Figure 15.1). The island supports one of the largest breeding colonies of Masked Boobies (*Sula dactylatra*) in the western Pacific along with several other species of seabirds. The island is surrounded by a fringing reef. Deeper habitat consists of pavement dotted with various sized boulders, some spur and groove formation, and sandy flats. A submerged platform reef with high coral cover exists off the center island lee. Shoal reefs, with a minimum depth of 6 m, occur approximately 1-2 km north of the northern tip of FDM. These reefs consist of complex channels and ridges with a biotic structure similar to that of the windward side of the island.

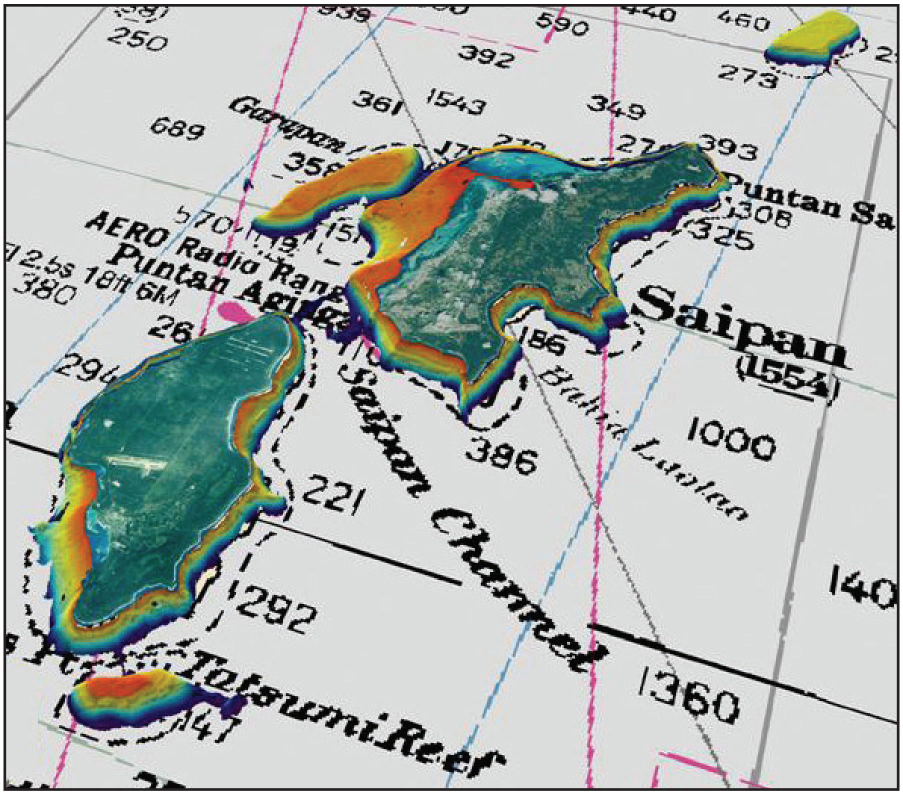

Figure 15.2. Detailed bathymetric map of Saipan, Tinian and Rota in the CNMI. Source: PIFSC-CRED, unpublished data.

FDM is presently leased to the U.S. Military as a bombing range. A significant amount of controversy has arisen, especially in the past 10 years, with regard to the U.S. Navy's use of this island. The effects of bombing are causing accelerated erosion of the landmass.

A variety of fish species that have become uncommon around the populated islands of Saipan and Tinian are more abundant around FDM. Over 350 species of fish have been identified. In addition, survey teams have observed numerous sea turtles (including green and hawksbill) and numerous pods of whitebelly spinner dolphins. In addition, terrestrial wildlife surveys following military live-fire exercises have observed species of whale including Brydes, Sperm, and Humpback whales in the vicinity of FDM.

Northern Mariana Islands

Anatahan is a small volcanic island (32.4 km^2; Figures 15.1 and 15.4). Prior to this island's eruption on May 6, 2003, feral goats were creating severe erosion problems and the resulting sediment runoff was impacting the nearshore environment. A feral animal control program was started by the U.S. Fish and Wildlife Service (USFWS) and the Northern Island Mayor's Office, with financial support from the U.S. Navy. Ash fallout from the 2003 eruption caused extensive damage to nearshore reef habitats, especially on the northern side (Figure 15.3). Although all surveyed locations during the 2003 National Oceanic and Atmospheric Administration (NOAA) Marianas Research and Monitoring Program (MARAMP) cruise contained a layer of ash covering the substrate (Figure 15.3), portions of the south shore and southeastern corner had only a veneer layer. Anatahan provides a unique opportunity to observe recovery and development of reef communities over the next several decades.

Sarigan is an uninhabited volcanic cone with a land area of 4.9 km^2 (Figures 15.1 and 15.4). Sarigan has experienced no terrestrial impacts since the removal of feral animals, although fishery resources continue to be harvested. Since the elimination of feral animals on this island (1997-1998), the vegetation has dramatically recovered, presumably reducing sediment runoff. According to the NOAA MARAMP towed-diver surveys, continuous reef areas along the east and south shores contained roughly 50% live coral cover. The MARAMP dive at Sarigan revealed a layer of sediment that had been deposited from the 2003 Anatahan eruption.

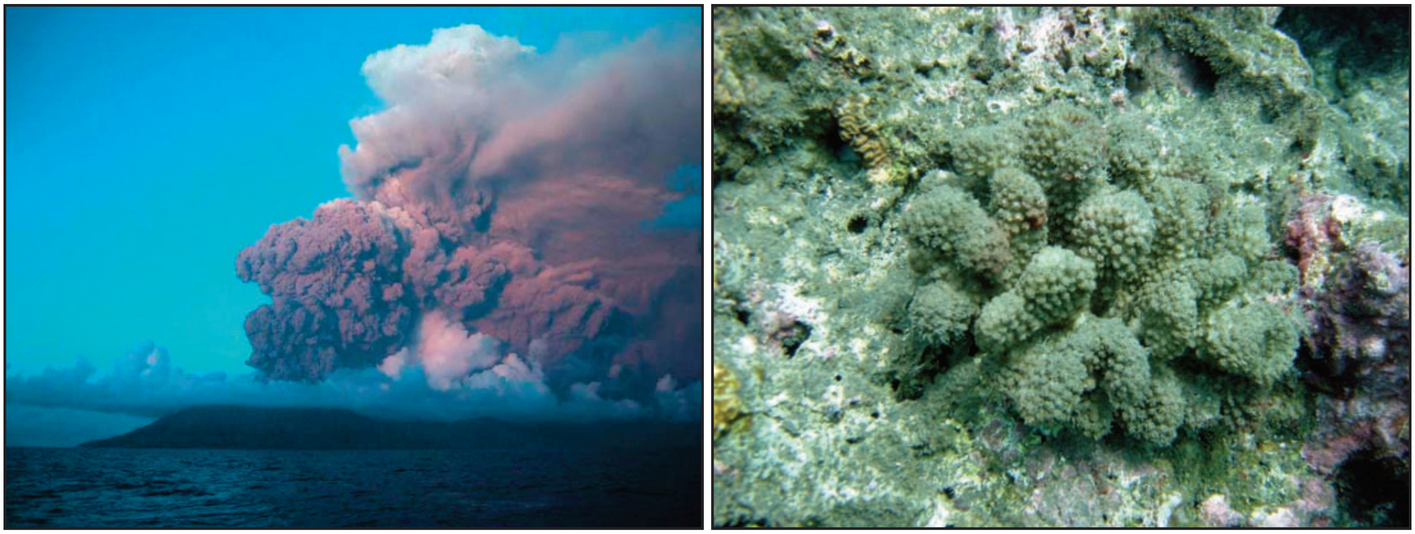

Figure 15.3. Left panel shows Anatahan Volcano eruption, May 11, 2003. Photo: CNMI Emergency Management Office. Right panel shows an ash covered habitat at Anatahan. Photo: S. Holzwarth.

Guguan has a land area of 4.1 km^2 (Figure 15.1) and is an active volcano with two cones, one of which is dormant. It is protected from development by the CNMI Constitution as it has been declared a wildlife conservation area, with large seabird colonies of Sooty Terns (*Sterna fuscata*), Gray-backed Terns (*S. lunata*), Brown Noddies (*Anous stolidus*), Black Noddies (*A. minutus*), and Red-footed Boobies (*Sula sula*). The reef communities observed around most of Guguan are as well developed as any seen in the northern islands, except for Maug. Unlike the exposed southeast shores of other northern islands, Guguan's southeast shore has developed reef communities.

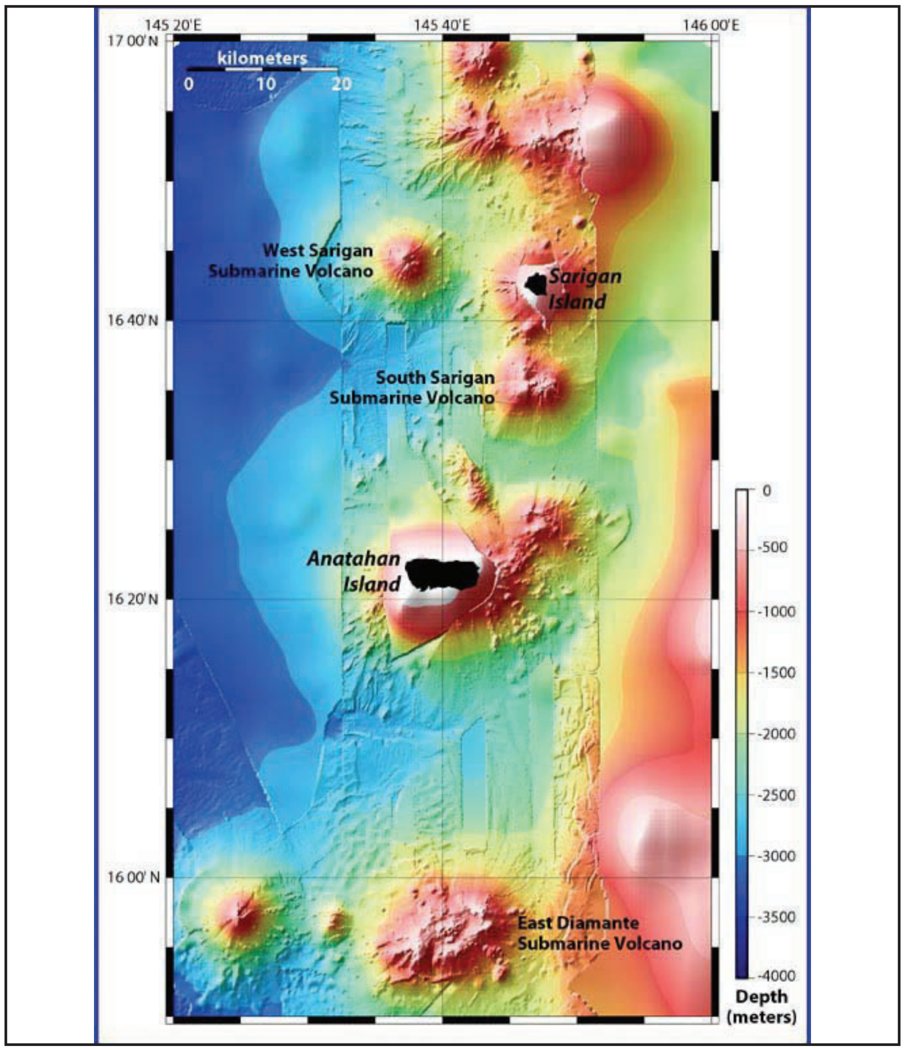

Figure 15.4. Map showing the volcanic islands of Sarigan and Anatahan. Zealandia Bank is also shown approximately 20 km north of Sarigan Island. The bathymetry data are a combination of satellite bathymetry overlaid with EM300 multibeam bathymetry, collected aboard the R/V *Thomas G. Thompson* in 2003 and 2004. Source: R. Embley and NOAA Ocean Exploration.

Alamagan, with a land area of 11.2 km^2, is an active volcano (Figure 15.1). Feral pigs, goats, and cattle are causing extensive damage to terrestrial ecosystems (T. de Cruz, pers. obs.). These terrestrial effects are likely linked to the marine environment through runoff and sedimentation. The reef communities at Alamagan are noticeably less developed than those observed at Guguan Island, which lies only 26 km to the south.

Pagan has a land area of 48.2 km^2 (Figure 15.1) and a volcanically active northern portion that is connected to a dormant southern portion by a narrow isthmus. A major eruption in 1981 caused the evacuation of residents and the ashfall negatively affected reefs (Eldredge and Kropp, 1985). Continuing erosion of unconsolidated ash is having unknown effects on the near shore environment. Large numbers of feral pigs and cattle are present. Cattle have been observed walking on the eastern fringing reef flats (T. de Cruz, pers. obs.). Fish surveys conducted by the CNMI Division of Fish and Wildlife (DFW) in the late 1990s found the nearshore fish resources to be in good condition.

Agrihan is a dormant volcanic cone, with a land area of 47.4 km^2 (Figure 15.1). The impact of feral goats and pigs is most evident on the eastern side of the island where resulting sedimentation and runoff is thought to have a significant effect on the marine environment. This is presently the only northern island that supports a permanent population, which currently stands at seven people.

Ascuncion Island is an active volcanic cone and has a land area of 7.3 km^2, which is protected from development by the CNMI Constitution, as it has been declared a wildlife conservation area (Figure 15.1). It is home to nesting colonies of Sooty and Gray-backed Terns (*Sterna fuscata* and *S. lunata*, respectively).

Maug consists of three small islands (Higashi, Kita, and Nishi), with a total land area of 2.1 km^2 (Figure 15.1) surrounding a flooded caldera that is considered to be a dormant volcano (Figure 15.5). The presence of countless seabirds on the three pinnacles that form the island of Maug provides a steady source of nutrients and organic matter into the caldera waters (Embley, 2004).

Maug is uninhabited and is protected from development by the CNMI Constitution. It has been declared a wildlife conservation area. Fisheries resources are currently harvested, although there has been some interest within the CNMI government to extend conservation to the coastal areas. Results from the 2003 and 2004 NOAA surveys (MARAMP and Ring of Fire) show that Maug, with 73 species recorded, is the most coral-rich island in the northern islands.

Farallon de Pajaros (*Uracas*) is an active volcano, with a land area of 2.1 km^2 (Figures 15.1 and 15.5). A major eruption and lava flow in 1943 affected coastal habitats. Very steep, sloping, boulder habitats surround Uracas, but provide little suitable habitat for corals. The reef is most developed on the southwest (leeward) side. Uracas was found to have the highest density of large predatory fish in the northern islands based on the MARAMP surveys.

Uracas is protected from development by the CNMI Constitution and has been declared a wildlife conservation area. Although Farallon de Pajaros translates to "the Island of Birds," only those Terns and Noddies that can nest on bare lava have established colonies. Seabird colonies were last surveyed in 1992.

Figure 15.5. NOAA Ship *Oscar Elton Sette* at Uracas Island during the MARAMP cruise in 2003. Photo: R. Schroeder.

Offshore Banks and Reefs

Tatsumi Reef

Tatsumi Reef is a steep-sided, flat-topped submerged bank approximately 2 km southeast of southern Tinian Island and is oriented in a northeast to southwest alignment. It is approximately 5.5 km long by 2 km wide, with a small secondary peak about 1.5 km to the west-southwest (Figure 15.6). The shallowest point on Tatsumi is approximately 6 m. In 2003, Tatsumi was surveyed using multibeam sonar and the R/V *Acoustic Habitat Investigator* (*AHI*; Figure 15.6). Two towed-diver surveys during the NOAA MARAMP cruise showed

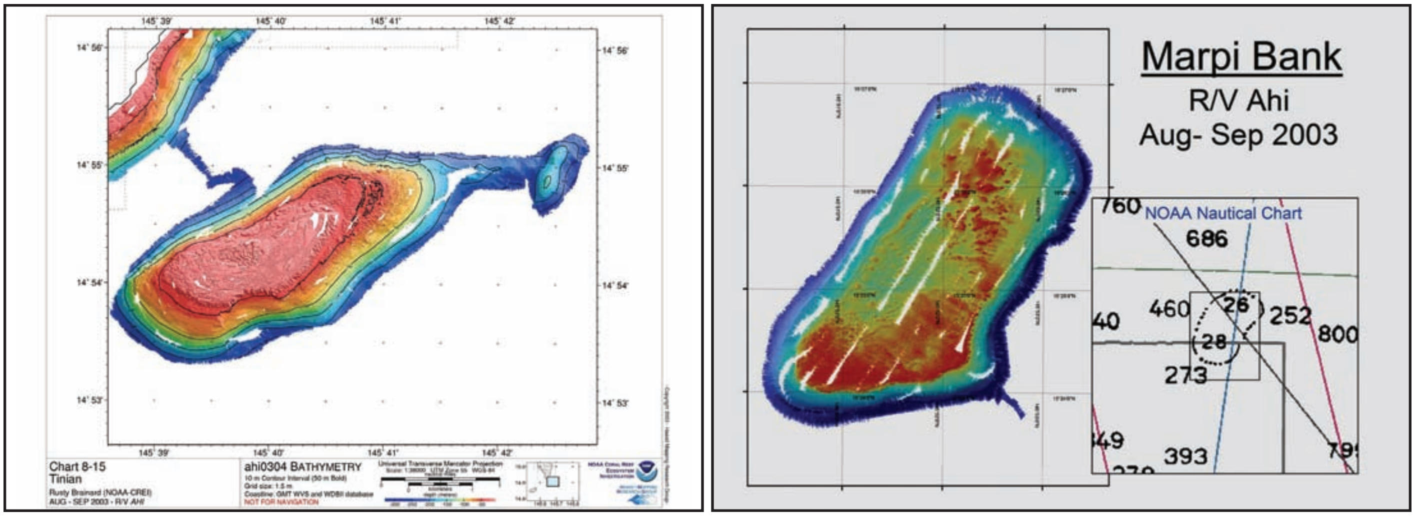

Figure 15.6. Multibeam bathymetric map of Tatsumi Reef, (~2 km southeast of southern Tinian Island; left panel) and Marpi Bank (~28 km north of Saipan; right panel). These field maps were created during the 2003 MARAMP surveys using R/V AHI. Source: PIFSC-CRED, unpublished data.

carbonate pavement to be the dominant habitat with low to moderate coral cover. Tatsumi is a popular fishing location, easily accessible from Tinian.

Esmeralda Bank

Esmeralda Bank is located approximately 37 km west of Tinian. There are two shallow banks plotted near Esmeralda Bank and NOAA's Nautical Chart 81004 shows four soundings less than 80 m in depth. One of these is a kidney-shaped area labeled "Active Sulphur Boil (1945)" with a depth of 30 fathoms (55 m) indicated on the chart. This bank does not exist, while the other bank and Esmeralda Bank are smaller than indicated on the chart. A multibeam survey of Esmeralda Bank was carried out during the NOAA Ring of Fire cruise in April 2004 (NOAA, 2003, 2004). Esmeralda Bank appears to have experienced recent volcanic activity and shows signs of current hydrothermal circulation (Embley, 2004).

Marpi Bank

Marpi Bank is a steep-sided, flat-topped submerged bank approximately 28 km north of Saipan. It is approximately 9 km long by 4 km wide and is oriented in a northeast to southwest alignment similar to Tatsumi Reef; the shallowest point shown on NOAA's Nautical Chart 81067 is 26 fathoms (53 m). Marpi Bank is also a popular fishing location. In 2003, Marpi Bank was surveyed using multibeam sonar and the R/V *AHI* (Figure 15.6).

Arakane Bank

Arakane Bank is located approximately 325 km west-northwest of Saipan. On NOAA's Nautical Chart 81004, it is identified by a single sounding of 5 fm (9 m). It is smaller than indicated on the chart and its true center is approximately 1 km southeast of the center of the charted bank. It was mapped in September 2003 using single-beam sonar and an underwater video camera (Figure 15.7) during the NOAA MARAMP cruise. Encrusting and fleshy algae, hard and soft corals, and sand were seen on hard substrate ridges.

Pathfinder Bank

Pathfinder Bank is located approximately 275 km west of Anatahan in the West Mariana Arc. Pathfinder Bank is 3 km southeast of its plotted position on NOAA's Nautical Chart 81004 and includes areas shallower than 10 m, rather than the 8 fathoms (15 m) shown on the chart. It was mapped in September 2003 using single-beam sonar and an underwater video camera during the NOAA MARAMP cruise (Figure 15.7). Hard and soft corals were found on ridges of carbonate pavement, separated by channels containing rubble.

Zealandia Bank

Zealandia Bank is located approximately 20 km north of Sarigan Island (Figure 15.4). This flat-topped bank with two pinnacles is surrounded by vertical walls. Rhodoliths, calcareous nodular bodies produced by algal accretion, and *Halimeda* algae beds were seen by video camera at depths of 115 m.

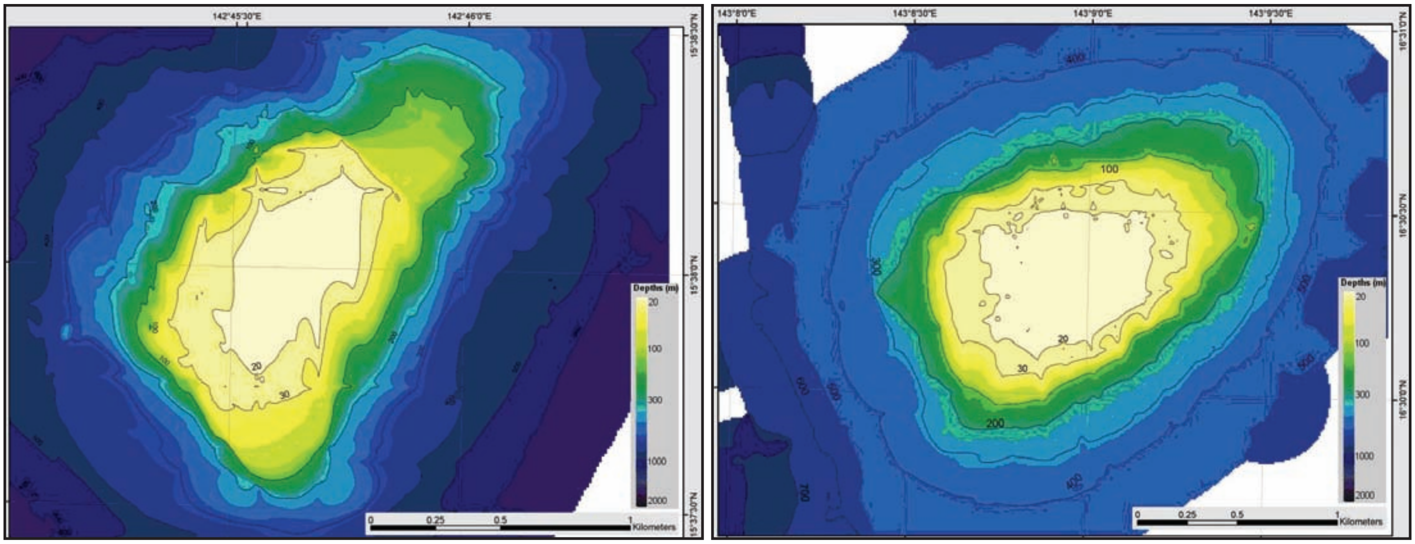

Figure 15.7. Bathymetric maps of Arakane Bank (left) and Pathfinder Bank (right) were made from single-beam soundings taken aboard the NOAA ship *Oscar Elton Sette* in September 2003. Source: PIFSC-CRED, unpublished data.

Supply Reef

Supply Reef is located approximately 18.5 km northwest of Maug Island and identified as two 5 fathom (9 m) soundings on NOAA's Nautical Chart 81004. Brief surveys were conducted from the NOAA ship *Oscar Elton Sette* in 2003. Hard and soft corals and rock were seen at this volcanic pinnacle during a video camera tow.

Stingray Shoals

Stingray Shoals is located approximately 275 km west of Uracas in the West Mariana Ridge. Stingray Shoals is a steep-sided pinnacle that has well-developed continuous reef on the small summit (~300 m x 500 m). Evidence of fishing activity is present, including anchors and long-line gear on the reef.

Socioeconomic Context

Population levels (Figure 15.8), habitation patterns, and the related impacts on reefs have varied tremendously over time. There is evidence of at least temporary settlement on all of the southern Mariana Islands, from Guam to FDM (Fritz, 1986).

In the 17th century, the entire population of the Mariana Islands was removed to Guam and Rota during the Spanish domination of the archipelago. It was not until the end of the 19th and beginning of the 20th century that the foundations of the modern communities in the CNMI returned from Guam and Rota (Spoehr, 2000).

Although some of the islands north of Saipan have held small permanent and seasonal communities, most permanent residents were evacuated in 1981 after the eruption of Pagan. A volcanic eruption also resulted in the evacuation of a small community on Anatahan in 2003. A community of seven individuals remains on Agrihan.

As the population of the CNMI continues to grow and diversify, its effects on adjacent reefs become more pronounced and complex. Fishing appears to have been at subsistence levels until at least the 1950s (Spoehr, 2000). More recently,

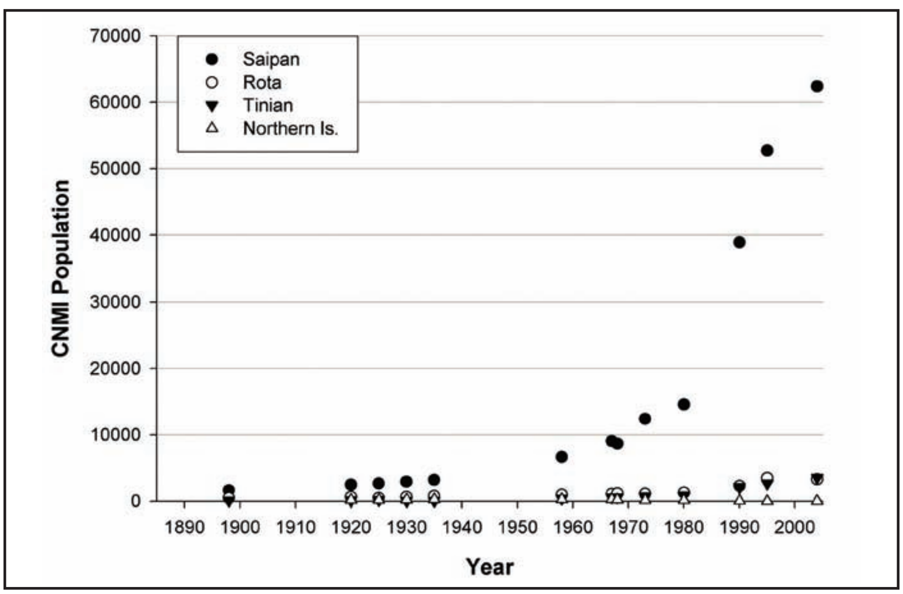

Figure 15.8. Yearly population growth in the CNMI from 1989-2004. Gaps indicate that no data was available. Source: various sources, compiled by J. Starmer.

fishing has grown in importance as a commercial venture with numerous permanent and roadside vendors evident around Saipan.

Tourism experienced a period of explosive growth in the late 1980s. The majority of tourism-related development has occurred along the western Saipan Lagoon. The importance of coral reefs as both a scenic backdrop and a focal point for recreational activities has grown along with the tourism industry. There is a clear recognition of the importance of the marine environment for tourism. However, negative effects have occurred in the adjacent marine ecosystems. Understanding the problems faced by CNMI's coral reefs is the first step in effective management.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Coral bleaching has been noted in the CNMI several times since 1994. However, there has been no quantitative assessment of these events. In 1994, bleached corals were observed in water depths of 16 m at Akino Reef, at the eastern end of the western barrier reef in Saipan, and to a lesser extent in 1995 and 1997 at Unai Bapot in Lau Lau Bay, Saipan and at the site of a vessel grounding in Pagan (Tomokane, 1997). Over the summer of 2001, most shallow water areas (<3 m) on Saipan, Rota, and Tinian appeared to have been affected by bleaching as deep as 18 m. Many encrusting *Montipora* and staghorn *Acropora* corals died as a result. For instance, an *Acropora*-dominated backreef habitat in the Saipan Lagoon exhibited 50-72% mortality (CNMI Inter-Agency Marine Monitoring Team, unpublished data).

The 2003 MARAMP cruise reported 30-50% of relatively mild coral bleaching at the islands north of Pagan and < 30% at some of the more southern islands. The highest percentage of bleached coral was observed at the two northernmost sites surveyed, Uracas Island and Stingray Shoals. Two reefs on Maug and Ascuncion were exceptions to this trend, with no bleaching observed.

Diseases

With the exception of coralline lethal orange disease (CLOD), coral reef diseases are not well documented on CNMI reefs. Recent research by scientists from the University of Mississippi indicates that other diseases are prevalent, but further work is required to understand their ecological significance (D. Gochfeld, pers. comm.).

CLOD is common on most of the southern islands' reefs, but remains at low levels. Another possible disease of coralline algae (Littler and Littler, 2003), which forms concentric circles on live algae, has been recorded by the CNMI Inter-Agency Marine Monitoring Team (MMT) on Saipan and Tinian. The cause of the circular pattern is unknown.

Black-band disease is known from sight records from Tinian, in front of Taga Beach, and from Saipan, just south of Garapan's Lighthouse Channel. Coral tumors have been recorded in a number of species including *Isopora palifera, Acropora robusta, Montipora elschneri, Acropora digitifera, Porites lobata,* and *Astreopora myriophthalma.*

Tropical Storms

Typhoons are a routine part of the annual seasonal cycles in the CNMI (Figure 15.9). These storms can affect coral reefs even when they do not pass directly over an island. Increased swells can cause coral damage through direct wave impact and by shifting loose objects (e.g., coral, debris, grounded vessels) around the reef. The precipitation associated with typhoons also tends to increase sedimentation and nutrient inputs from polluted runoff.

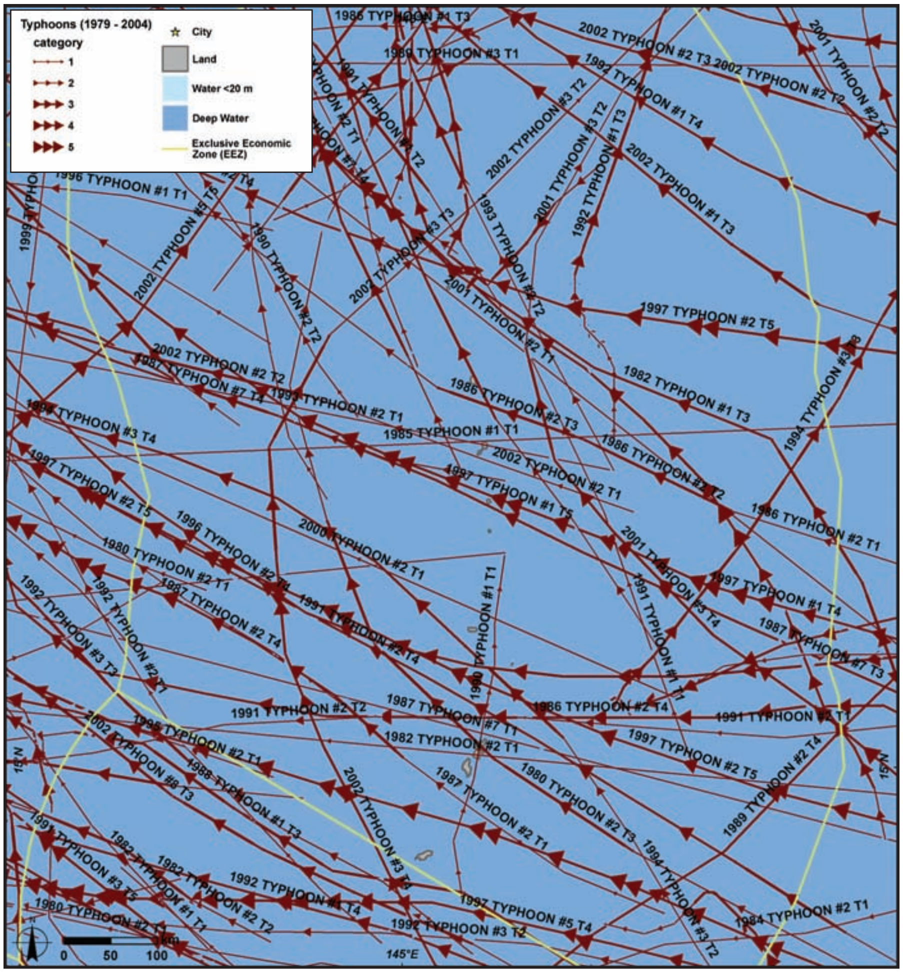

Figure 15.9. The path and intensity of typhoons passing near the CNMI from 1979-2004. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: A Shapiro. Data: UNISYS, http://weather.unisys.com/hurricane.

Coastal Development and Runoff

The boom in rapid urban development in the late 1980s and early 1990s has led to overburdened and failing waste management systems, increased negative effects from sedimentation, and added fishing pressures.

Coastal Pollution

As a whole, CNMI's marine waters meet the high water quality standards designated by the CNMI Division of Environmental Quality (DEQ). The majority of CNMI's marine waters are designated "Class AA" which reflects the highest water quality. Five areas in the CNMI have been designated "Class A" to allow for industrial activities (Table 15.1).

Table 15.1. Class A waters in the CNMI. Source: Houk, 2004.

WATER BODY	REASON FOR CLASS A DESIGNATION
Puerto Rico Industrial, Saipan	Commercial port and municipal waste outfall
Agingan Point, Saipan	Municipal waste outfall
East Harbor, Rota	Commercial port
West Harbor, Rota	Commercial port
San Jose Harbor, Tinian	Commercial port

Nonpoint Source Pollution

The beach warnings posted by the DEQ are, perhaps, one of the most constant reminders of the direct effects of human actions on marine water quality through nonpoint source pollution. In recent years, most microbiological violations occurred in areas with heavy stormwater runoff. Many of these sites were within the highly developed Garapan district, where drainage issues are in the process of being addressed. Other frequent violations occur within Saipan's marinas or in waters surrounding docks.

CNMI's three major inhabited islands have unpaved secondary roads that funnel soil and sediment into nearshore waters during periods of heavy rain, thereby increasing turbidity of nearshore waters. There have been several reports of sedimentation events associated with major construction projects (e.g., the Nikko Hotel, Lau Lau Bay Resort, and Bird Island Road) that were deleterious to nearshore corals. Treatment of secondary roads with crushed limestone without addressing drainage problems created chronic sedimentation problems along Lau Lau Bay and Obyan Beach. On several of the northern islands, deforestation and overgrazing has led to increased nearshore sedimentation. Deforestation from illegal burning has also created an area of eroding badlands on the southern coast of Rota.

Aerial photographs of FDM indicated that the island was eroding at an unprecedented rate. No quantitative studies have been conducted to determine whether bombing has resulted in increased sediment runoff from the island. However, reports of persistent areas of low visibility on the windward side of the island are not reported elsewhere in the CNMI.

Point Source Pollution

Only two sewage outfalls (Agingan and Sadog Tasi, Saipan) exist in the CNMI. Both sewage treatment plants are operated by the Commonwealth Utilities Corporation (CUC) and are designed to provide secondary treatment for an average daily flow of 3 and 4.8 million gallons per day, respectively. The Sadog Tasi's treated effluent is discharged through a marine outfall, approximately 365 m offshore into the Class A receiving waters off Tanapag Harbor, Saipan Lagood at a depth of 15 m. The Agingan plant's treated effluent is discharged at the surf line through an intertidal outfall into the Class A receiving waters of Tinian Channel. Individual National Pollutant Discharge Elimination System permits are issued to each plant. Both plants are presently in violation of local water quality standards (WQS). The U.S. Environmental Protection Agency (EPA) has been working with the CUC to address this. While progress is being made, there is no set deadline for these plants to come into compliance.

Reverse osmosis units used by hotels and other tourist-related facilities to improve the quality of the public water supply are discharged into the lagoon in several locations. These discharges contain nitrate and phosphate at up to 100 times above DEQ's accepted limits. The EPA issued Administrative Orders to all CNMI dischargers in 2002, resulting in the decision to allow discharges into injection wells. Injection wells have been installed at four of the reverse osmosis facilities, and plans were underway for the remaining facilities to be in compliance before the end of 2004. Once accomplished, all reverse osmosis discharges to Commonwealth waters will cease.

Tourism and Recreation

The Coastal Resources Management Office (CRM) regulates commercial marine sports through its permitting process. Scuba diving, personal watercraft (jet skis), banana boats, parasailing, submarine tours, and other motorized marine sports activities must receive permits from CRM (Table 15.2). The CRM has further designated jet-ski exclusion zones near hotels, shallow reefs and seagrass areas.

Table 15.2. Number of marine sports activity permits issued by CRM in 2003. CRM has implemented a zoning plan and permitting program for several recreational and tourism activities. Source: CNMI, CRM.

PERMITTED ACTIVITY	SAIPAN	ROTA	TINIAN	TOTAL
Jet ski	12	0	2	**14**
Banana Boat	17	0	2	**19**
Parasailing	10	0	1	**11**
Sea/Aqua Walker	4	0	0	**4**
Scuba	27	1	2	**29**
Snorkel Tours	2	0	0	**2**
Misc. Marine Sports	10	0	0	**10**

Fishing

Coral reef fisheries are difficult to manage, as these fisheries are typically multi-species and harvested by a wide variety of gear types. In the CNMI, conventional controls on catch are hard to justify socially while gear restrictions and size limits are virtually impossible to administer. Human pressures on coral reef fisheries combined with developmental perturbations have been detrimental to reef habitats and subsequently to reef fish resources. In short, management of coral reef fisheries in the CNMI has not provided protection against the overexploitation of reef fish resources and degradation of marine habitat by human-induced activities.

The DFW Fisheries Data Section collects commercial landings data through a voluntary vendor invoice system. These data list the pounds sold and the corresponding value, with reef fish typically lumped together under the general heading of "Reef Fish." A confounding factor with this system is that many reef-associated species, such as Lethrinids and Serranids are grouped under "Assorted Bottomfish," and Lutjanids are grouped with "Assorted Reef Fish." The commercial landings of reef fish have been fairly constant over time, averaging about 143,400 lbs, (65,000 kg) although catch per unit effort (CPUE) has steadily decreased from a peak in 1994 (Figure 15.10).

In general, CNMI fisheries are in good condition, although local depletion was determined to exist in the southern islands, especially on the lee aspect of Saipan. Surveys conducted by the University of Guam in 1979 and in collaboration with DFW in 1996 revealed that considerable changes had occurred for some major food fish groups in Saipan Lagoon (Amesbury et al., 1979; Duenas and Associates, Inc., 1997; Figure 15.11).

Additionally, the DFW conducted a sampling program of the reef fish scuba-spear fishery from 1993 to 1996. Data from these surveys resulted in two DFW technical reports (Graham, 1994; Trianni, 1998b) that indicated local depletion for some species of commercially important reef fish. Comparitive analyses of parrotfish landings from a scuba-spear fishery in the northern islands with a scuba-spear fishery in the southern islands revealed a decrease in the percentage of terminal phase males both spatially and temporally (Trianni, 1998b; Table 15.3). Reef fish scuba-spear CPUE was noted to have declined between 1993 and 1996.

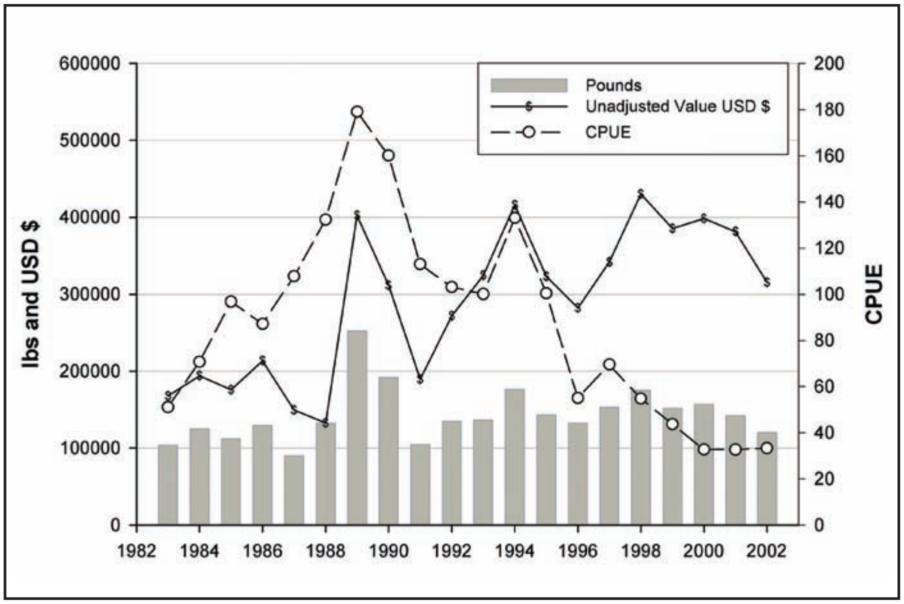

Figure 15.10. Reef fish CPUE, commercial landings and value in USD as estimated from the voluntary invoice system. Source: CNMI DFW, unpublished data.

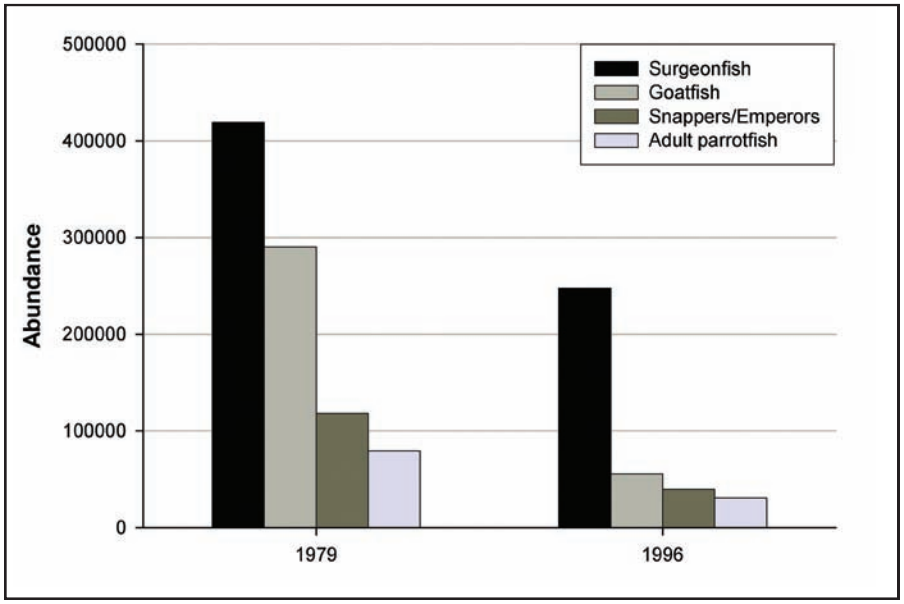

Figure 15.11. Changes in estimated abundance of some commercial reef fish between 1979 and 1996 surveys in Saipan Lagoon. Source: CNMI DFW, unpublished data.

Table 15.3. Percentages of terminal phase parrotfish from the Northern Islands and Southern Islands for two sampling periods. ND = no data. Source: CNMI DFW, unpublished data.

PERIOD/ DATES	NORTHERN ISLANDS	SOUTHERN ISLANDS	SAIPAN	TINIAN
Period 1 (1993-1994)	78	52	48	53
Period 2 (1995-1996)	ND	66	61	68

Over the past several years, the DFW noticed a major increase in the numbers of imported reef fish into the CNMI (Figure 15.12). As a result of these findings, the CNMI Department of Lands and Natural Resources (DLNR) and DFW initiated regulatory changes that restricted the use of gill, drag, and surround-nets, and scuba and hookah spear fishing in the CNMI. Reef fish abundance will be monitored closely over the next several years for signs of recovery in areas where localized depletion was observed.

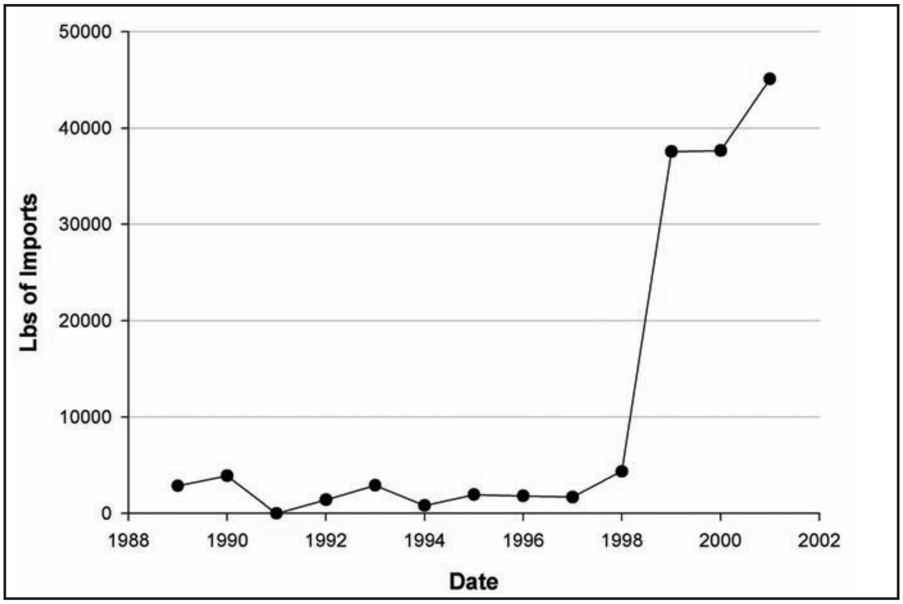

Figure 15.12. Reef fish imports into the CNMI between 1989–2001. Source: CNMI DFW, unpublished data.

DFW regulation prohibits the use of explosives, chemicals, poisons, and electronic shocking devices. The extent of such illegal practices is unclear. There exists no evidence that explosives or electronic shocking devices are currently used for harvesting fish. The use of rotenone, a poison extracted from a plant (*Derris* spp.) has been reported by DFW conservation officers, although the use of other poisons or chemicals has not been verified.

Invertebrate fisheries

A historical fishery for sea cucumbers targeting *Actinopyga mauritiana,* with incidental captures of the black teatfish, *Holothuria whitmaei*, was active from 1995-1996 on Rota and Saipan (Trianni, 2002). The fishery was closed in 1997 due to declining catch. In 1998, a 10-year moratorium was placed on the harvest of sea cucumbers in the CNMI, creating the largest no-take zone for these invertebrates in the world.

The introduced topshell *Tectus niloticus* has been placed in a harvest moratorium since 1981. Although this moratorium is continual, the DLNR Secretary can lift the moratorium and declare an open season following consultation with the DFW Director. This was done in 1996 and a two-month open season ensued (Trianni, 2002). In addition to the state of moratorium, two protected areas for *Tectus* were also established in 1981 - one at Tank Beach on the windward side of Saipan, and the other along a one-mile section of the barrier reef at Saipan Lagoon.

Trade in Coral and Live Reef Species

DFW regulation prohibits the export of live fish for consumption and restricts the export of live fish for the aquarium trade. The collection of reef fish for commercial and personal display is also regulated by the DFW. The number of commercial or personal display permits has been low since 1996, never exceeding five per year. The DFW issues a limited number of permits for the production of slaked lime (locally known as *afuk*) from dead coral for cultural purposes. Lime is traditionally chewed with betel nut (*Arecia* sp.). Much of the lime for this purpose is now being imported from Yap, Federated States of Micronesia, or the Republic of Palau. The number of permits granted from 1996-2004 has ranged from none to four per year.

Ships, Boats and Groundings

Anchoring

Anchor damage is noticeable at some popular fishing and dive sites in the Mariana Islands. At present, there are no restrictions on recreational anchoring outside of marine protected areas (MPAs). Concern over anchoring effects prompted the installation of moorings at most commercial dive sites around Saipan, Tinian, and Rota. The Northern Marianas Dive Operators Association (NMDOA) reports that the installation of these moorings has resulted in noticeable improvement in the corals at these sites and the organization has continued to independently maintain the moorings. U.S. Coral Reef Initiative funds have allowed the purchase of additional mooring maintenance and installation materials. New moorings were installed on Rota thanks to the local efforts of Dive Rota and will be installed with the assistance of NMDOA at sites on Saipan and Tinian in the coming year.

The anchoring of large commercial vessels on the extensive shallow (25-40 m) reef platform to the west of Saipan has been impacting reef coral habitat since the mid-1990s. DFW has obtained some data on vessel anchorage behavior. The number of days at anchor from December 1999 to March 2001 ranged from 3-42. For the same period, the number of pre-positioned vessels at anchorage at any one time ranged from 1-5, with the effective range being 2-4.

DFW Anchoring Study

The DFW Fisheries Research Section undertook dive surveys in May and June 2002 to obtain preliminary data on fish and benthic habitat in high use anchorage zones and control sites (Table 15.4). The sample sizes were relatively small at each site, given the average survey depth of 30 m and the restricted available bottom time.

Table 15.4. Differences in ecological parameters at commercial anchorage and control sites off the west coast of Saipan. Source: CNMI DFW, unpublished data.

	ANCHORAGE (n=6)	CONTROL (n=2)
Fish Density	2.3	2.4
Density Range	0.6 - 4.8	1.1 - 4.5
# Species Range	14 - 29	16 - 31
% Live Coral Cover	9.2	6.3
% Algal Cover	40	35.6
% Abiotic Benthos	50.2	56.6

Methods

Fish stationary point counts (SPCs) involved the identification of all species within 5 m circular areas. Benthic sampling (n=30; n=20), involved documenting 16 random points inside a 0.5 m^2 quadrat.

Results and Discussion

Results from the preliminary fish surveys indicated very little difference between the sites, although the sample size was small. Terminal phase parrotfish, however, were more abundant at control sites (mean of 5.5/5 m diameter) than at anchorage sites (mean of 0.7/5 m diameter). Large snapper and wrasse, as well as schools of fusiliers and unicornfish were observed in the vicinity of a control site.

Benthic surveys indicated a greater percentage of live coral cover and lesser percentage of abiotic benthos at control sites. The overall results of the preliminary survey showed lower fish abundance and diversity as well as lower coral cover. It is noteworthy that recreational fishing activity occurs in this general area.

During the August and September 2003 MARAMP cruise, the R/V *AHI*, used a combination of multibeam echosounder and side-scan sonar to survey the pre-positioned vessel anchorage near Saipan Lagoon. The NOAA ship *Oscar Elton Sette* conducted some underwater video and photographic observations in the anchorage zone during the same period using a tethered optical assessment device (TOAD). In November 2004, NOAA Fisheries, DFW, and DEQ conducted an extensive TOAD survey of the pre-positioned anchorage zone. Following this survey and development of the resulting products, the U.S. Navy plans to expand the number of pre-positioned vessels in the anchorage area.

Abandoned and Grounded Vessels

Nineteen vessels, ranging in size from commercial steamers to canoes, are recorded to have been lost in the CNMI between 1600 and 1940 (Carrell, 1991). Between 1940 and 1946, numerous vessels are recorded to have been sunk in the vicinity of the Mariana Islands (e.g., 38 around Saipan), but only 15 of them appear to have sunk or grounded in nearshore waters (Carrell, 1991). Wreckage of tanks, landing craft, airplanes, and pontoons from WWII are also visible on coral reefs. These craft are considered an important part of the historical record and are unlikely to be removed.

In the past two decades, more than 20 commercial vessels have grounded in the CNMI. The majority of these groundings were typhoon-related and two were the result of operator error. Some of these vessels have since been removed, but nearly half remain in the water. Although these vessels were reportedly cleaned of fuel and oil, they still pose a threat to coral reef habitat as they break apart and their parts are moved across reefs during storms.

Salvage operations of various kinds have also resulted in further disturbance to the marine environment. Salvage operations on Spanish galleons in the CNMI, including the *Nuestra Señora de la Concepción* on Saipan and the *Santa Margarita* on Rota, have caused negative impacts to coral reef environments during the excavation activities.

In addition, small vessels cause damage to the marine environment. One area of seagrass habitat in the Saipan Lagoon was recently discovered by the MMT to contain a mosaic of propeller scars.

CRM intends to coordinate the development of a CNMI Vessel Grounding Action Plan that will guide the CNMI in closing communication gaps, creating or revising laws and regulations, strengthening enforcement, developing preventative measures, and addressing funding and resources limitations. NOAA has provided technical assistance and nominal monetary assistance for grounded vessel inventory and removal.

Marine Debris

While some marine debris washes in from offshore and is deposited on beaches, most of the Southern Mariana Islands have cliffs and limited reef development along the windward (eastern) shores. This limits the opportunity for oceanic marine debris to end up on reefs. A greater problem is debris originating from local, land-based activities. Both the DEQ and CRM have active anti-litter education programs. In addition, the DEQ and several civic groups sponsor monthly beach cleanups. Annual reef cleanups have also been sponsored by local resource management agencies. As a result, marine debris does not generally accumulate on or near local reefs and is considered a minor concern in the CNMI.

Aquatic Invasive Species

Mollusks

The only successful intentional introduction of a marine species in the CNMI has been that of *Tectus niloticus* (locally known as *aliling tulumpo*). *T. niloticus* was introduced as a commercial venture by the Japanese in 1938. Its harvest was essentially unregulated after WWII, prior to the formation of the CNMI. A continual moratorium is presently in effect, although the DLNR Secretary can lift it when the resource is deemed exploitable. Two no-take reserves are established: one at Tank Beach, and the other along the western barrier reef of Saipan Lagoon, called the "Lighthouse Reserve." As an industry, harvests of *Tectus* shells were limited by availability of suitable habitat (Adams et al., 1994). The effects of its introduction on other marine organisms are not known.

The giant clam species, *Tridacna derasa*, was imported from the Micronesian Mariculture Demonstration Center (MMDC) in Palau and released in Saipan in 1988. In 1991, 2,000 *Tridacna derasa* and 2,000 *T. gigas*, as well as some *Hippopus hippopus* and *Tridacna squamosa*, from MMDC were placed in cages in Saipan Lagoon as part of a regional growth study. These introductions failed to produce desired economic benefits and the growth study was hampered by poaching. In 2001, several species of *Hippopus* were found in Saipan Lagoon during surveys by the MMT, although it appears unlikely that the few surviving individuals comprised a reproductively viable population. Currently, there are plans to commence with another aquaculture venture in the CNMI using the same four giant clam species from the renamed Palau Mariculture Demonstration Center. This project is expected to commence in early 2005.

Fish
Red tilapia (*Oreochromis mossambica*) was intentionally introduced to brackish lakes on Saipan, Pagan, Tinian, and Anatahan between 1955 and 1957. It is currently cultivated at the Northern Marianas College (NMC) Aquaculture Center, and is also provided by the NMC as an outreach product for use in private ponds. This species is currently being kept in open-system pools next to the Saipan Lagoon in fully marine water. There is a distinct possibility that these animals could enter the Saipan Lagoon and become established.

Ballast Water
The potential for the introduction of invasive species through the discharge of ballast water exists in the CNMI, but the threat has not been evaluated. As the CNMI is primarily a destination rather than a source of goods, most vessels are more likely to take in rather than discharge ballast. Commonwealth Ports Authority regulations prohibit discharge of ballast water within the commercial port areas.

Security Training Activities

FDM
In 1998, the U.S. Navy completed an environmental impact statement (EIS) as required by Section 102(2)(C) of the National Environmental Policy Act of 1969 (P.L. 91-190). As a result of that process, it was determined that an annual marine survey must be conducted for a three-year period from 1999 through 2001. Subsequently, the Navy decided to continue annual surveys as long as FDM was being used for training activities. The DFW requested that the U.S. Navy continue to fund surveys even after cessation of training activities. The yearly reports stemming from these surveys indicated that damage to the nearshore coral reef environment was minimal. However, it appears that use of live explosives has resulted in accelerated erosion at FDM.

The FDM area serves as prime fishing grounds for large and small vessels from Saipan. The distance from FDM to Saipan (roughly 80 km) makes it relatively inaccessible to boaters except during favorable seas. In addition, the U.S. Navy claims a three-mile exclusion zone around FDM, which is extended to 10 miles during live-fire military training activities, thus further limiting annual fishing effort.

Tinian
During WWII, the island was almost entirely a military base. Waste disposal in the northern part of the island has resulted in several formerly-used defense sites that are awaiting cleanup. Leaching of materials into groundwater is a concern. Debris from both WWII invasions and later dumping activities remains embedded in the reef along the west coast of Tinian.

The U.S. Navy presently leases approximately two-thirds of the northern portion of Tinian for training exercises and maneuvers. Results of qualitative surveys reveal very little damage to the reef structure from these activities. In general, recent military activities on Tinian have been conducted with a high level of sensitivity to the potential impact on the environment. However, because of the large number of personnel and equipment involved in some of the Navy's exercises, the CNMI should continue to monitor these activities.

Offshore Oil and Gas Exploration
Offshore oil and gas exploration are currently not an issue of concern in the CNMI.

Other

COTS
Outbreaks of COTS (*Acanthaster planci)* have occurred in the late 1960s, 1984, and 1990s. Control programs during the 1969-1970 period removed nearly 14,000 of the animals from Rota, Saipan, and Tinian (Tsuda, 1971). An outbreak also occurred at Putan Taipingot, Rota in 1995 (M. Michael, pers. comm.). Presently, the starfish has been noted in low numbers on most surveyed reefs in Aguiguan, Rota, Saipan, and Tinian. Three areas with apparently persistent and dense populations have been identified by the MMT: the eastern side of Puntan

Naftan (near Boy Scout Beach), Lau Lau Bay Site 2 on Saipan, and Unai Babui on the eastern side of Tinian. At Boy Scout Beach, *A. planci* does not appear to have a significant effect on coral cover (Figure 15.13), but may be the causal agent for changes in coral community structure (Figure 15.13).

During the 2003 NOAA MARAMP cruise, towed-divers observed few COTS in the northern islands (Table 15.5). *A. planci* were more prevalent in the southern island arc. Towed-divers recorded 2.2 COTS per km at Tatsumi Reef, 4.2 COTS per km at Saipan, 1.8 COTS per km at Tinian, 6.4 COTS per km at Aguijan, and 10.5 COTS per km at Rota(Figure 15.14).

Volcanic Eruptions

Volcanic eruptions have been sporadic (Table 15.6), but appear to have great influence on the coral communities on some of the geologically active northern islands (Eldredge and Kropp, 1985). Monitoring the recovery of reefs affected by the 2003 eruption of Anatahan will allow an improved understanding of the abilities of coral reefs to recover from these events and the role that volcanic disturbance has played in shaping the reef ecosystems in the northern islands.

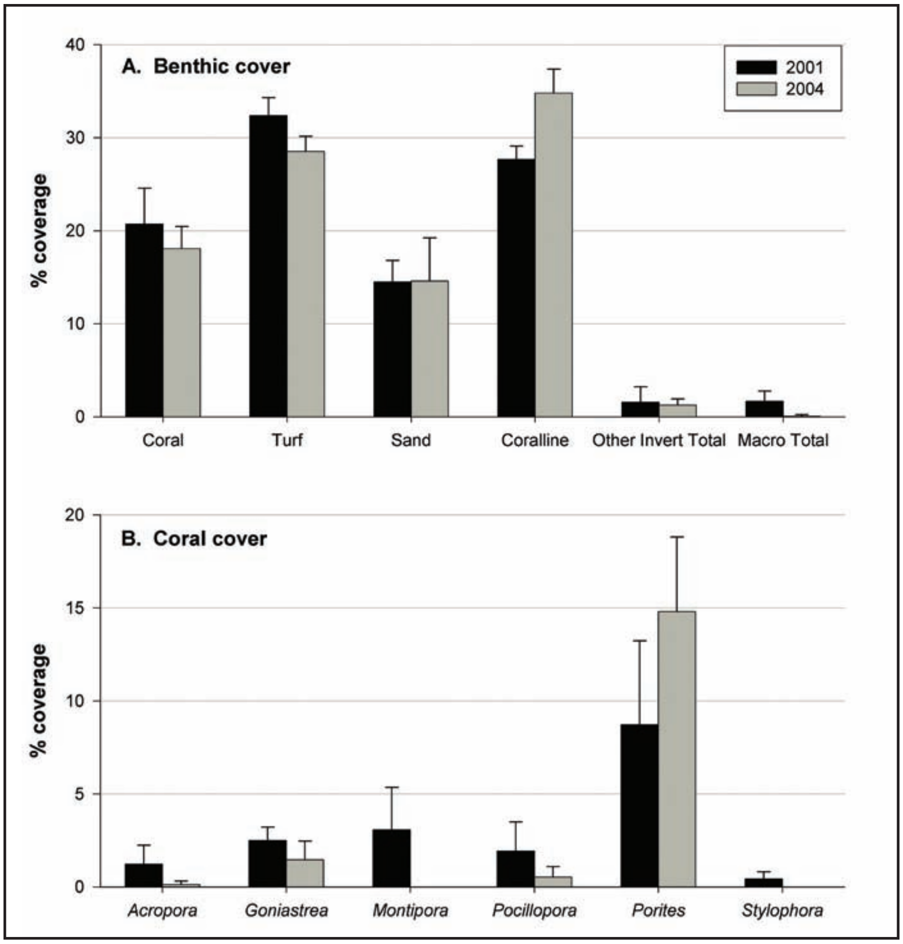

Figure 15.13. Change in benthic cover (A) and coral cover (B) at Boy Scout Beach between 2001 and 2004. Source: CNMI MMT (P. Houk), unpublished data.

Table 15.5. The number and density of COTS recorded during MARAMP 2003 towed-diver surveys. Source: PIFSC-CRED (M. Timmers), unpublished data.

REGION	COTS	TOW LENGTH (KM)	COTS/KM
Northern Islands	18	201.14	0.09
Southern Islands	421	62.88	6.7
TOTAL	**439**	**264.02**	**6.79**

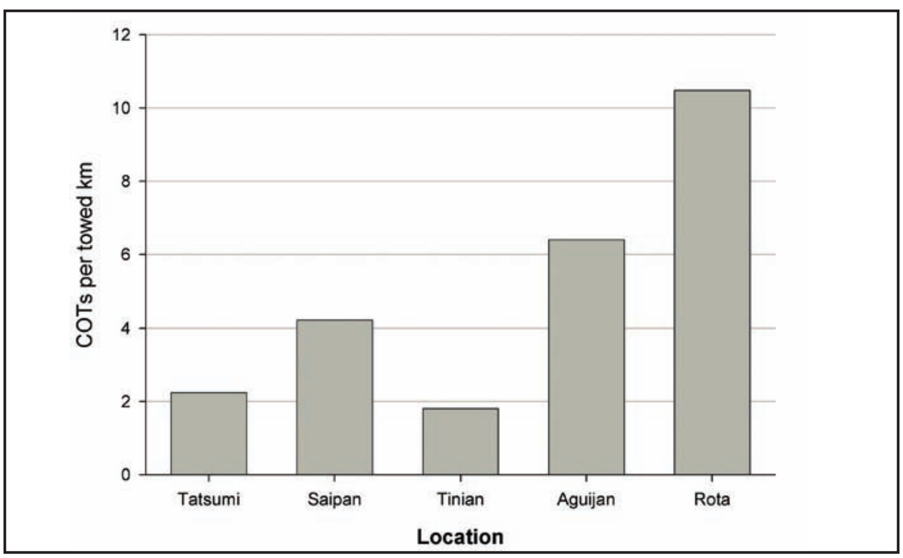

Figure 15.14. Crown-of-thorns densities from towed diver surveys. Source: PIFSC-CRED, (M. Timmers), unpublished data.

Table 15.6. Records of volcano eruptions in the CNMI. * denotes uncertainy of volcano eruption date. Source: Adapted from Sigurdsson et al., 2000.

NAME	TYPE	ELEVATION (m)	ERUPTION DATES
Farallon de Pajaros (Uracas)	Stratovolcano	360	1967, 1952-53, 1951, 1947, 1943, 1941, 1939, 1936, 1934, 1932, 1928, 1925, 1912, 1900-01*, 1874-76*, 1864-76*, 1864
Supply Reef	Submarine Volcano	-8	1989, 1985*, 1969
Ascuncion	Stratovolcano	857	1924*, 1906, 1775*, 1690*
Agrigan	Stratovolcano	965	1917
Pagan	Stratovolcanoes	570	1998, 1998*, 1987, 1993, 1992, 1981-85, 1929-30*, 1925, 1923, 1917, 1909, 1873*, 1864, 1825, 1669
Alamagan	Stratovolcano	744	1887*, 1864*
Guguan	Stratovolcano	287	1883
Anatahan	Stratovolcano	788	2005, 2004
Ruby	Submarine Volcano	-230	1996, 1995
Esmerelda Bank	Submarine Volcano	-43	1987*, 1982*, 1975*, 1970*, 1964*, 1944*

Unexploded Ordnance

The CNMI was a major battlefield during WWII, and war debris and unexploded ordnance is still common in the near shore waters. A moderate, but locally concentrated amount of ordnance has been noted by the MMT south of Agingan Point and the southern end of Lau Lau Bay. Unexploded ordnance was also recorded near Aguijan using towed-diver surveys during the NOAA MARAMP cruise (Figure 15.15). The effects of chemical leaching of ordnance materials, including explosive chemicals and structural metals (e.g., copper, lead, tin, etc.), upon marine life have not been evaluated.

Figure 15.15. Unexploded ordinance observed during NOAA MARAMP towed-diver survey. Photo: S. Holzwarth.

Modern use of explosives for blast fishing occurred until recently (Johannes, 1979). Education regarding long-term environmental effects and enforcement efforts appear to have been effective. Blast fishing is not considered a concern in the CNMI at present, though the practice is difficult to detect near less inhabited parts of the CNMI. In 1996, through the CNMI Governor, the Director of the CNMI Emergency Management Office requested that the U.S. Navy detonate depth charges on a WWII subchaser wreck at the popular Coral Gardens dive site in the Sasanhaya Bay Fish Reserve (SBFR) as it was felt that the charges posed a hazard to recreational divers and fishermen (Worthington and Michael, 1996). The force of the detonation caused significant damage to the SBFR, the oldest of CNMI's MPAs. The blast killed numerous fish, decimated coral, and killed an endangered hawksbill turtle (Trianni, 1998a).

In addition, considerable secondary damage was caused by an extensive sediment plume that resulting from the blast, which blanketed a large area including in and around the Coral Gardens site. Two typhoons subsequently caused further damage, which expanded the impacted area to approximately 29,000 m^2. Estimates based on a value of $2,833/$m^2$ resulted in a total economic impact of $82 million (Richmond and Romano, 1997).

CORAL REEF ECOSYSTEM—DATA GATHERING EFFORTS AND RESOURCE CONDITION

Three main programs within the CNMI currently collect marine monitoring data. The DEQ monitors nearshore marine water quality for bacterial contaminants and a range of standard physical water quality parameters. The DFW Fisheries Research Section monitors fish and benthic parameters in marine preserves. The MMT, which includes staff from DEQ, DFW, and the CRM, monitors fish, invertebrates, and benthic parameters cooperatively at sites around the southern four islands of the CNMI.

In addition, NOAA has been actively involved in geological and ecosystem-based research around the CNMI. NOAA's Office of Ocean Exploration funded two geological cruises in 2003 and 2004 aboard the R/V *Thomas J. Thompson* to study active volcanism and hydrothermal activity in the Marianas Archipelago. These cruises provided invaluable baseline bathymetric data. Results from these cruises can be accessed on-line (NOAA's Office of Ocean Exploration, http://oceanexplorer.noaa.gov/explorations, Accessed 01/07/05).

NOAA's Coral Reef Conservation Program and Pacific Island Fisheries Science Center (PIFSC) funded the first MARAMP cruise on the NOAA ship *Oscar Elton Sette* in 2003. Extensive baseline studies of coral, fish, algae, oceanography, benthic habitats, and bathymetry were conducted from Uracas to Guam. These cruises are planned to continue biennially.

DEQ Activities

The DEQ Surveillance Laboratory was established to provide monitoring data required by the Federal Safe Drinking Water Act (P.L. 93-523) and other environmental programs. The data generated by the laboratory are used to evaluate the quality of drinking water and recreational waters in the Commonwealth. The DEQ has been testing water quality at a number of sites adjacent to the high population centers on Saipan since 1980. More recently, water quality testing has been extended to Tinian and Rota. DEQ posts warnings at local beaches when water quality parameters exceed the acceptable limits for public health.

DFW Activities

The DFW Fisheries Research Section established a Marine Sanctuaries Program (MSP) in 1998 and has been surveying MPAs in the CNMI since 1999. The primary goal of the survey is to monitor annual trends in reef fish abundance and diversity. Secondary goals include monitoring changes in benthic habitat composition, macroinvertebrate abundance, and habitat heterogeneity.

MMT Activities

The MMT - consisting of staff from the DEQ, CRM, and DFW - has also included participation from NMC staff. The MMT was initially established in 1997 to help the CNMI understand the current condition of its coral reefs and coral reef resources. DEQ prepared the first *State of the Reef Reports* for Rota and Saipan (Houk, 2000 and 2001, respectively). These reports documented baseline conditions and will be used for future assessments and regional management recommendations. It is the goal of the MMT to carry out this long-term monitoring program to continually assess our reefs as the CNMI grows. Monitoring locations for the MMT are shown in Figure 15.16.

The DEQ plays a major role in the MMT through its Marine Monitoring Program, Nonpoint Source Pollution Program, and Surveillance Laboratory. Since the previous report on water quality required by Section 305(b) of the Federal Clean Water Act, the DEQ and MMT have initiated two large-scale biocriteria monitoring programs. Both of these are very different from EPA-funded biocriteria monitoring programs in the U.S. mainland. Tropical marine systems are much more dynamic and harbor very different organisms. Biocriteria programs set forth in the U.S. mainland fail to provide useful techniques for the CNMI. One monitoring effort is the Saipan Lagoon Monitoring Program (DEQ and CRM), and the other is the CNMI Nearshore Reef Monitoring Program (DEQ, CRM, and DFW). The goal of these programs is to gather continuous data from marine systems that are affected by water quality concerns (e.g., watershed drainages, sewage pump failures and outfalls, and other sources of point and nonpoint source pollution).

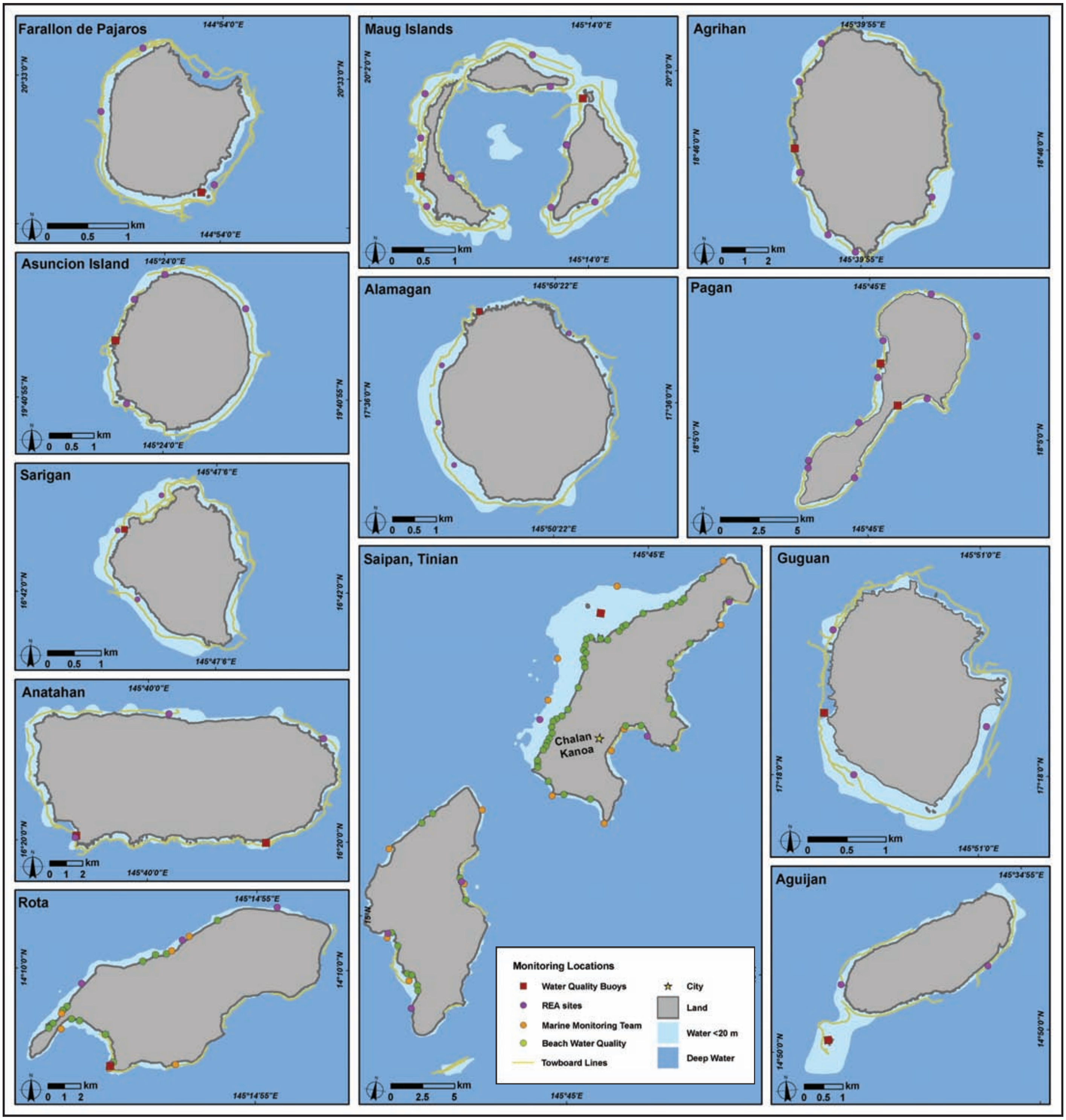

Figure 15.16. Monitoring site locations in the CNMI. Map: A. Shapiro.

Irregular sources of information about the marine environment are site surveys conducted to satisfy local or regional requirements, such as EISs. These surveys provide snapshots of CNMI reefs and can be very informative, but are usually limited to a single reef area. For example, two sites in Lau Lau Bay were surveyed in 1991 and recently re-surveyed in 2001 by the MMT (Houk, 2001). Turf algae was the single most abundant component of benthic cover (47% and 52%). Coral cover represented 28% and 42% on these two reefs. The second site showed a long-term decrease in mean coral diameter and relative frequencies of large branching corals, attributed to the 1983 COTS outbreak. Between 1991 and 2001, the abundance of macroinvertebrates, such as sea urchins and sea cucumbers, decreased at both sites (Houk, 2001).

NOAA MARAMP Cruise

The MARAMP research cruise aboard the NOAA ship *Oscar Elton Sette* from August 22 to September 29, 2003 was led by the PIFSC-Coral Reef Ecosystem Division (CRED) in collaboration with scientists and resource managers from the DFW, DEQ, CRM, Guam Division of Aquatic and Wildlife Resources, NOAA Ocean Service (NOS)-National Geodetic Survey, University of Guam Marine Laboratory, University of Hawaii's Joint Institute for Marine and Atmospheric Research and Hawaii Mapping Research Group, University of Florida, and National Park Service. Other key collaborators assisting and supporting the cruise included NOS' Special Projects Office, NOAA's Center for Coastal Monitoring and Assessment-Biogeography Team (CCMA-BT), NOAA Satellites and Information's Office of Applied Research, NOAA Research-Atlantic Oceanographic and Meteorological Laboratory, Western Pacific Regional Fishery Management Council, USFWS, Bishop Museum, Guam Fisherman's Cooperative, and R/V *Oscar Elton Sette* crew and officers. The cruise was designed to provide an archipelago-wide baseline assessment of the living marine resources, including fish, coral, other invertebrates, and algae, in the context of their benthic and oceanographic habitats. It was the most comprehensive, multi-disciplinary study ever conducted of the coral reef ecosystems in the Marianas Archipelago.

During the cruise, rapid ecological assessments (REAs), benthic habitat mapping, and oceanographic research were conducted at 14 islands (Guam, Rota, Aguijan, Tinian, Saipan, Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, and Uracas) and at many oceanic reefs and banks (Santa Rosa Reef, Galvez Bank, 11 Mile Bank, Esmeralda Bank, Tatsumi Reef, Marpi Reef, Arakane Reef, Pathfinder Bank, Zealandia Bank, Supply Reef, Stingray Shoals, and an unknown bank southeast of Uracas Island). During 29 days of operations in CNMI waters, specialized teams of scientists performed 76 REAs of reef fishes, coral, other invertebrates, and algae; 138 towed diver habitat and fish surveys covering about 265 km of habitat; 76 towed diver turtle and fish surveys covering an estimated 178 km of habitat; 45 bioacoustic surveys of biomass in the water column; 338 oceanographic station visits (using conductivity, temperature, and depth instruments [CTDs]); ocean current profiles along over 664 km of transects; 100 TOAD deployments; 106 single-beam and bottom classification surveys; and high resolution multibeam acoustic mapping of 244.2 km^2 of benthic habitats using the R/V *AHI*. Many of these locations are shown in Figure 15.16. In addition, an array of surface and subsurface oceanographic moorings were deployed as part of NOAA's Coral Reef Watch Program to monitor ocean conditions influencing reef health and to provide resource managers and researchers with coral bleaching and other alerts using the Coral Reef Early Warning System (CREWS).

The MARAMP cruise has provided researchers with a tremendous baseline data set about each of the principal components of these complex coral reef ecosystems. The simultaneous information about the status and diversity of the marine resources along the entire Marianas Archipelago, including their spatial and habitat distributions, provides an opportunity for researchers and resource managers to better understand how these complex ecosystems function. This baseline data set will be used to evaluate temporal changes of these ecosystems as the MARAMP evolves to biennial monitoring cruises. By monitoring the spatial and temporal variability of the marine resources and oceanographic conditions, local and national resource managers will be better equipped to make and apply ecosystem-based management principles to conserve and protect these coral reef ecosystems.

WATER QUALITY

Standard water quality parameters are regularly monitored in nearshore marine waters on Saipan, Tinian, and Rota by the DEQ Surveillance Laboratory. Full information on methods and results are available in the CNMI Integrated 305(b) and 303(d) Water Quality Assessment Report (Houk, 2004; online at: http://www.deq.gov.mp/305b%202004%20Final.pdf, Accessed 01/06/05).

The collaborative efforts of NOAA MARAMP cruises promise to expand the quantity and variety of oceanographic data being collected in the future. PIFSC-CRED deploys oceanographic monitoring systems throughout the archipelago. Information on ocean currents, water temperatures, salinity, and turbidity were collected during the 2003 NOAA MARAMP cruise and will be collected biennially during future cruises.

DEQ Beach Water Quality Monitoring Program

Methods

The DEQ Surveillance Laboratory was established by the CNMI to provide monitoring data required by the Safe Drinking Water Act, and other environmental programs. Salinity (‰), dissolved oxygen (% DO), temperature (°C), pH, turbidity (NTU), orthophosphate (PO_4), nitrates (NO_3), and *Enterococci* spp. bacteria (cfu/100ml) are monitored weekly at 84 fixed sites around Saipan, Rota, and Tinian. The data collected by this program comprise the longest consistently-collected set of marine water quality data available for the CNMI.

Development of the CNMI WQS was largely based upon the review of WQS from other tropical islands (Houk, 2004). Due to the potential important influence of water quality on coral reef ecosystems and the lack of existing data, stringent WQS for nutrients were adopted for the CNMI. DEQ recently initiated the collection of nutrient data. It has not yet been determined whether the nutrient concentrations recorded are due to anthropogenic sources. At all islands, PO_4 levels exceeded WQS more than 50% of the time, with the exception of Managaha Island, which has no major sources of terrestrial input (Houk, 2004).

The goal of the DEQ's Surface Water Quality Monitoring Program is to assess CNMI's waterbodies for compliance with recreational uses and aquatic life uses. EPA guidance material was used to classify each waterbody as 1) non-supportive, 2) partially supportive, or 3) fully supportive for use (Table 15.7).

Table 15.7. Criteria for waterbody classification. Source: Houk, 2004.

DEGREE OF AQUATIC LIFE USE SUPPORT	CRITERIA
Fully Supporting	For any one pollutant, WQS was exceeded in ≤10% of measurements
Partially Supporting	For any one pollutant, WQS was exceeded in 11-25% of measurements
Not Supporting	For any one pollutant, WQS was exceeded in >25% of measurements

Results and Discussion

Recreational use classifications were based upon elevated counts of *Enterococcus* bacteria. Saipan Island has the largest number of waterbodies that were classified as non-supportive for recreational use. Rota, Tinian, and Managaha Islands each had only one non-supportive waterbody. For Saipan Island, regression analysis was used to examine the relationship between rainfall and *Enterococcus* bacteria counts. Rainfall explained a significant amount ($p<0.05$) of the variance in bacteria levels at the majority of non-supportive waterbodies (Table 15.8).

Observations have shown that storm events quickly inundate many of the sewage lift stations around Saipan, and the overflow enters the marine environment through drainages, leading to elevated bacteria levels at many beach locations. Other known causes of excessive bacterial contamination include urban runoff from the heavily populated Garapan district. Only one site among the remaining islands - a site adjacent to the relatively highly populated village of Song Song, Rota - was classified as non-supportive (Houk, 2004). PO_4 levels exceeded the WQS at all waterbodies on Saipan, Rota, and Tinian Islands (Houk, 2004). This suggests that the water quality criterion (0.025 mg/L) is not appropriate for the CNMI, and that the WQS should be updated in the next review cycle to account for this. The only exception to this finding was for Managaha, which is a small (~0.5 km^2) island situated away from terrestrial input.

DO measurements followed similar trends as for microbiological data (Houk, 2004). Most non-supportive sites are associated with drainage regions on Saipan especially areas where observations show frequent sewage lift station overflow or heavy urban runoff. DO readings are influenced by wave activity, and waterbodies protected from rough oceanographic conditions naturally have lower levels. As a result, all monitoring locations in the Saipan Lagoon consistently had DO readings below the water quality criterion. This also suggests that during the next WQS review the DO criterion should also be evaluated.

Table 15.8. Summary of DEQ beach monitoring locations for which data were available for regression analysis of rainfall (Y) on *Enterococcus* levels (X). Waterbody ranking of 1= non-supportive, 2= partially supportive, and 3= fully supportive based on WQS for recreational and aquatic life uses. Regression analysis results are presented as p-values at a significance level of * p <0.05, ** p <0.01, ***p <0.001. Source: adapted from Houk, 2004.

DEQ BEACH IDENTIFIER	BEACH NAME	NUMBER OF SAMPLES IN 2003 (*Enterococcus*)	PERCENT VIOLATIONS (*Enterococcus*)	WATERBODY RANKING	SAMPLES SIZE FOR HISTORICAL REGRESSION	P VALUE FOR REGRESSION ANALYSIS
WB 1	Wing Beach	52	11.54	2	84	0.619
WB 2	PauPau Beach	52	19.23	2	84	0.63
WB 3	Nikko Hotel	52	23.08	2	84	0.617
WB 4	San Roque School	52	50	1	84	0.179
WB 5	Plumeria Hotel	52	23.08	2	84	< .01 **
WB 6	Aqua Resort Hotel	52	19.23	2	84	< .01 **
WB 7	Tanapag Meeting Hall	48	54.17	1	84	< .001 ***
WB 8	Central Repair Shop	39	61.54	1	84	< .001 ***
WB 9	Sea Plane Ramp	46	17.39	2	84	< .05 *
WB 10	DPW Channel Bridge	46	93.48	1	84	0.068
WB 11.1	N. Puerto Rico Dump	6	33.33	1	57	0.805
WB 11.2	S. Puerto Rico Dump	36	47.22	1	9	0.069
WB 12	Smiling Cove Marina	46	36.96	1	62	< .001 ***
WB 12.1	American Memorial Park	45	44.44	1	45	< .001 ***
WB 13	Outer Cove Marina	46	17.39	2	74	0.622
WB 14	Micro Beach	52	15.38	2	74	< .001 ***
WB 15	Hyatt Hotel	52	21.15	2	84	0.115
WB 16	Dai-Ichi Hotel	52	34.62	1	84	0.074
WB 17	Drainage #1	46	71.74	1	57	< .01 **
WB 18	Samoan Housing area	52	38.46	1	76	< .001 ***
WB 19	Hafa-Adai Hotel	52	51.92	1	76	< .001 ***
WB 20	Drainage #2	41	51.22	1	44	0.212
WB 21	Garapan Fishing Dock	46	82.61	1	75	< .001 ***
WB 22	Garapan Beach	52	55.77	1	62	< .001 ***
WB 23	Drainage #3	46	54.35	1	59	< .001 ***
WB 24	Chalan Laulau Beach	52	11.54	2	66	< .01 **
WB 25	San Jose Beach	52	13.46	2	78	0.885
WB 26	Civic Center Beach	52	19.23	2	76	0.845
WB 27	Diamond Hotel	52	17.31	2	84	0.616
WB 28	Grand Hotel	52	9.62	3	86	0.195
WB 29	Community School Beach	52	19.23	2	71	0.251
WB 30	Sugar Dock	46	69.57	1	76	0.937
WB 31	CK District #2 Drainage	46	36.96	1	68	< .001 ***
WB 32	CK District #4 Lally Beach	52	15.38	2	80	< .001 ***
WB 33	Chalan Piao Beach	52	15.38	2	80	< .001 ***
WB 34	Hopwood School Beach	48	29.17	1	46	0.121
WB 35	San Antonio Beach	52	5.77	3	73	< .001 ***
WB 36	Pacific Islands Club (PIC)	52	23.08	2	81	< .001 ***
WB 37	San Antonio Lift Station	46	52.17	1	50	< .001 ***

CRM Marine Temperature Monitoring

A shallow-water bleaching event in 2001 prompted the CRM to reinstate its Temperature Monitoring Pogram, which began and ceased operation in 1999.

Methods

Continuous data on temperature were recorded using data loggers installed at 6 m depths at the Lau Lau #2, Outside Grand, and Sasanhaya MMT reef monitoring sites. In addition, a recorder was placed at a 1 m depth in the Saipan Lagoon just north of the Outside Grand site.

Results and Discussion

Temperature data collected for this project, such as those presented in Figure 15.17, will assist managers in understanding the causes of differential bleaching phenomena among the lagoon and reef sites in the southern Mariana Islands.

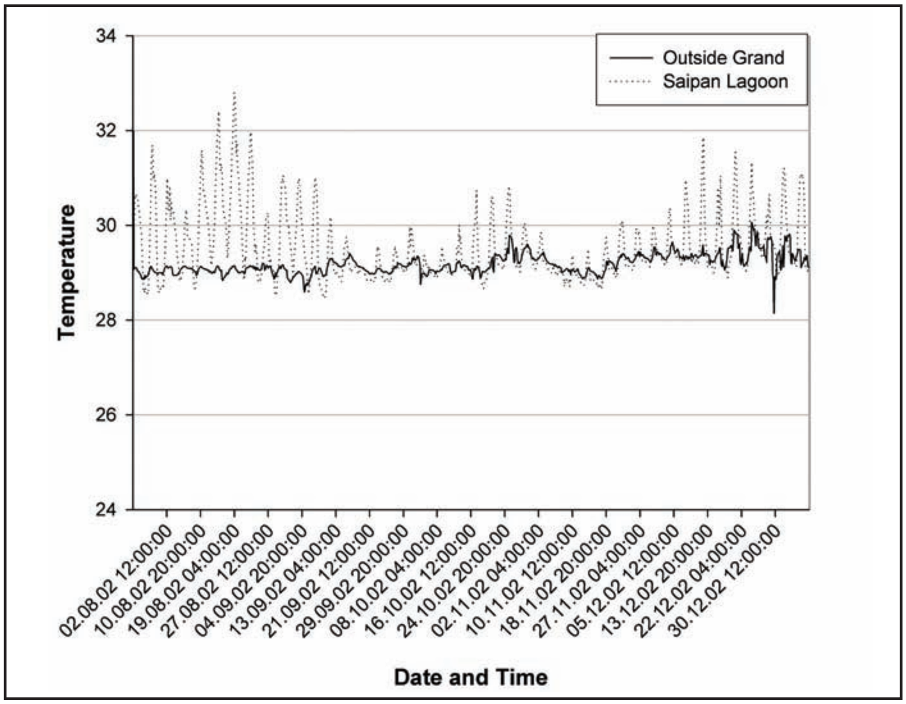

Figure 15.17. Hourly water temperature data within the Saipan Lagoon (1 m) and the adjacent fore reef (6 m) over five months, illustrating the differences in temperature changes. Source: CNMI CRM, unpublished data.

NOAA MARAMP, Study of Water Quality and Oceanographic Conditions

The volcanic island arc/subduction zone topography and associated extremely steep slopes of the Marianas Archipelago greatly modify the oceanography of the nearshore waters of the islands. Localized upwelling and the associated nutrient enrichment of surface waters, nutrient enrichment and seawater chemistry changes due to volcanic seeps and vents, freshwater inputs, and anthropogenic impacts all have poorly understood effects on the nearshore ecosystems. The effects of seasonal and climatic changes on the islands' marine ecosystems, as well as changes due to episodic events such as typhoons and volcanic eruptions, are also poorly understood. In order to better understand the linkages between oceanography and ecology, NOAA's PIFSC-CRED is taking a two-pronged approach: 1) intensive assessment of oceanographic conditions and ecological assessments at each island and 2) establishment of long-term oceanographic monitoring. Intensive oceanographic assessments at each island are accomplished by continuous recording of water temperatures as a function of depth during all towing operations, shallow-water CTDs (e.g., turbidity and chlorophyll measurements) at regular intervals around the islands, and deep water CTDs and acoustic doppler current profiler (ADCP) transects. During the 2003 MARAMP cruise, 40 deep-water (500 m) CTD casts and 271 shallow-water (30 m) CTD casts were deployed along with four surface velocity profile (SVP) drifters, one CREWS buoy, 11 subsurface temperature recorders (STRs), two SST buoys, and two wave and tide recorders (WTRs; Figure 15.16).

Methods

Long-term oceanographic monitoring is accomplished by deploying a variety of both internally recording and near-real-time telemetered instrument platforms and oceanic drifters. These instruments include CREWS buoys, SST buoys, WTR buoys, ocean data platforms (ODPs), STRs, and satellite drifters. Telemetered data is being recorded and analyzed by PIFSC-CRED, but the WTR, ODP, and STR data will only be available after recovery of the instruments during the MARAMP cruise scheduled for 2005.

Results and Discussion

A number of generalizations can be made about the oceanographic conditions of the Marianas Archipelago from preliminary analysis of 2003 MARAMP cruise data. All measured SSTs were 0.5-0.8°C degrees warmer than NOAA's Pathfinder SST monthly climatology data for the region. Relatively strong cross-island chain currents exist, and they accelerated at the northern and southern tips of the islands, presumably due to tides. Oxygen concentrations appear to increase at deeper depths towards the northern end of the chain. Several areas of hydrothermal seeps have been noted. CTD measurements of these areas at Maug have shown temperature increases of up to 3°C from surrounding waters, as well as large salinity and other (e.g., transmissometry) anomalies. Large plumes of extremely turbid water were noted at Anatahan. These plumes may be associated with hydrothermal vents, or with volcanic ash runoff from Anatahan's recent eruption. Transmissometry values within these plumes are several orders of magnitude greater than other locations surveyed. Depending on their number and distribution, these features may contribute significantly to local circulation, nutrient loading, and, particularly in the case of Anatahan, are likely to have deleterious effects, such as increased sedimentation and runoff, on reef ecosystems.

BENTHIC HABITATS

DEQ Lagoon and Coral Reef Biocriteria Monitoring Programs

Methods

The CNMI's biocriteria monitoring programs assess marine community shifts in response to nutrient loads, sediment loads, temperature, turbidity, and other water quality parameters (Rogers, 1990; Telesnicki and Goldberg, 1995). The CNMI uses weekly water quality data combined with other benthic community data to evaluate waterbodies. Biocriteria monitoring occurs at the Saipan Lagoon and at various nearshore coral reefs. Information on methods and results is available in the CNMI Integrated 305(b) and 303(d) Water Quality Assessment Report (DEQ, http://www.deq.gov.mp/305b%202004%20Final.pdf, Accessed 01/12/05).

Ecological surveys were completed to evaluate each waterbody's ability to support aquatic life in comparison to a control site. Based on EPA guidance each site was given an aquatic life use support (ALUS) classification of: 1) non-supportive, 2) partially supportive, or 3) fully supportive. All waterbodies assessed are adjacent to areas with development on land, and have experienced anthropogenic pollution. As a result, there is no ideal reference or control site. Biocriteria monitoring programs, however, were designed to sample sites along a disturbance gradient. A degree of measure was established for each variable based upon relative site comparisons (mean and standard deviations) (Table 15.9).

Table 15.9. A description of how relative measures were used to assign appropriate Aquatic Life Use Support designations. Source: Houk, 2004.

BIOLOGICAL COMMUNITY MEASURE	AQUATIC LIFE USE SUPPORT DESIGNATION
Less than one standard deviation below the mean	Not Supporting
Not different from the mean	Partially Supporting
Greater than one standard deviation above the mean	Fully Supporting

Results and Discussion

There were three regions in the Saipan Lagoon identified as non-supportive for aquatic life use. The largest is in the vicinity of Garapan, with high levels of bacteria and nutrients, and low DO associated with urban runoff. As a result, macroalgae (*Caulerpa* spp.) dominates benthic communities. Another large, non-supportive waterbody in the lagoon is adjacent to Beach Road, at the southern end of Garapan. These waters receive large inputs of stormwater during rainfall events due to adjacent topography, and are also associated with relatively high bacteria and nutrient levels. The last small, non-supportive waterbody is located adjacent to Chalan Kanoa village, presumably due to frequent sewage lift station failures. Water quality results agree with benthic data showing high bacteria and nutrient levels.

Twenty coral reef monitoring locations were used for waterbody evaluation (Table 15.10). Only sites with appropriate reef development can be used to evaluate water quality, since at other locations, environmental factors such as exposure, reef slope, and prior geological development have a larger influence on the benthic community than water quality.

Of the 20 locations surveyed, one was non-supportive, five were fully supportive, and the remaining 14 were partially supportive of aquatic life use (Table 15.10). Rankings were calculated using two measures: the benthic community and the coral community. The final ALUS ranking is based upon EPA guidance stating if any one measure of the community is non-supportive, it is classified as such, and both must be fully supportive for such a classification. The suggested explanation for most sites resulting in a partially supportive classification is the larger distances that impaired waters would have to travel to reach the reef monitoring locations compared with the lagoon monitoring locations.

Fully supportive reefs are present only in relatively unpopulated watersheds or barrier reef locations not heavily influenced by stormwater runoff. In general, the results of REAs based upon relative measures are less desirable than data analysis from long-term studies and monitoring programs, which better elucidate small changes with greater statistical power. However, the present evaluation serves to fill an important role for regulatory agencies.

Table 15.10. Results from the CNMI coral reef biocriteria monitoring program for aquatic life use support (ALUS): a ranking of 1= non-supportive, 2= partially supportive, and 3= fully supportive. The final ALUS ranking is based on EPA guidance material where if any one measure of the community is non-supportive, it is classified as such, and both must be fully supportive for such classification. Source: Adapted from Houk, 2004.

SITE NAME	CORAL COMMUNITY DATA							BENTHIC COMMUNITY DATA		ALUS
	Coral Community Evenness (Margalef's D-Statistic)	Rank	Coral Species Richness	Rank	Average Coral Geometric Diameter	Rank	Coral Community Ranking	Ratio of Benthic Substrate Health	Benthic Community Ranking	
Aguijan - 2	10.6	3	82	3	9.1	3	3	1.28	3	Fully
Akino	7.3	2	53	2	7.4	2	2	0.93	2	Partially
Barcinas Bay	4.6	1	45	2	8.7	3	2	0.3	1	Partially
Boy Scout	9.7	2	74	2	5.8	2	2	0.81	2	Partially
Coral Gardens	4.4	1	42	1	5.2	2	1	0.75	2	Partially
Coral Ocean Point	8.8	2	72	2	9.2	3	2	0.68	2	Partially
Iota N	4.6	1	21	1	6.5	2	1	0.84	2	Partially
Iota S	5.7	1	28	1	4.6	1	1	0.39	1	Non
Lau Lau Bay #1	8.9	2	50	2	7.3	2	2	0.29	1	Partially
Lau Lau Bay #2	6.6	2	59	2	5	2	2	0.77	2	Partially
Obyan	11.7	3	76	3	8	2	3	0.97	2	Fully
Outside Garapan	8	2	66	2	5.3	2	2	0.17	1	Partially
Outside Grand	8.4	2	79	3	8.8	3	3	1.18	3	Fully
Outside Managaha	8.5	2	77	3	6.1	2	2	1.32	3	Fully
Rota - 6	6.9	2	61	2	3.9	2	2	no data	no data	Partially
Rota - 5	7.3	2	69	2	5.4	2	2	no data	no data	Partially
Saipan - 1	9.2	2	47	2	8.7	3	2	0.84	2	Partially
Tinian - 1	11.4	3	65	2	6	2	2	no data	no data	Partially
West Harbor	8.5	2	49	2	4.5	1	2	0.32	1	Partially
Wing Beach	7.7	2	73	2	6	2	2	1.41	3	Fully
Average	**7.9**		**59.4**		**6.6**			**0.78**		
Standard Deviation	**2**		**16.7**		**1.7**			**0.37**		

MMT Nearshore Coral Reef Monitoring Program

Methods

This program complements to the DEQ Biocriteria Monitoring Program discussed above. In many cases, sites and methods show close overlap. However, the primary goal of this data collection program is to understand the ecological condition of coral reefs in regions that are associated with potential water quality disturbances (e.g., runoff, sewage outfalls, urban development) as well as reference sites with low anthropogenic influence. Three to five 50-m transects were used based on standard coral reef survey techniques. Methods are described in detail in Houk (2000, 2001).

Results and Discussion

The majority of MMT survey sites showed no significant differences within sites over the two to four years of monitoring (Figure 15.18). When combined with available historical data, however, differences become much more obvious.

Lau Lau Bay was the location of some of the oldest scientifically valid coral reef surveys using methods comparable to those of current MMT survey protocols (PBEC, 1984; Randall, 1991). It thus serves as an exemplar for the utility of monitoring to understand long-term trends in ecological trajectories. Unlike most other MMT sites, variation in yearly surveys at Lau Lau #1 (southeastern Lau Lau Bay) and Lau Lau #2 (northeastern

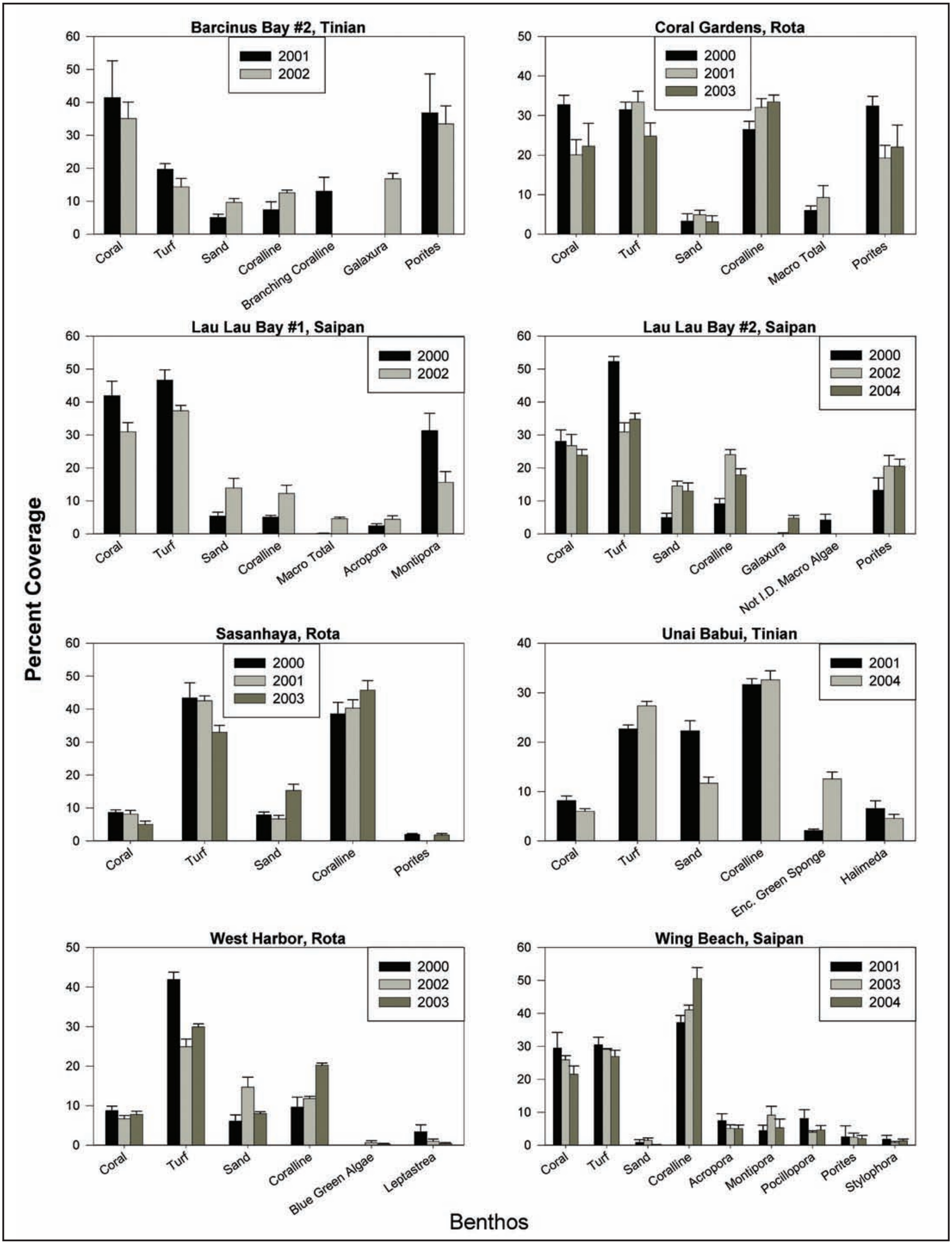

Figure 15.18. Percent cover of the benthos recorded between 2000 and 2004 at selected long-term monitoring sites on Tinian, Rota, and Saipan. Source: CNMI MMT (P. Houk), unpublished data.

Lau Lau Bay recreational dive site) was clearly present. However, after four years of surveys, it is still not apparent if the data are depicting clear trends in population trajectories for coral taxa. In comparison to decadal changes, year-to-year changes from 2000-2004 at either site are minimal (Figure 15.19). The implications of these results are that continued negative effects from sedimentation, *Acanthaster planci* predation, bleaching, recreational use, and storm damage have significantly changed the composition of the coral community at Lau Lau Bay. Information on community change allows regulatory agencies to more effectively target ecological baseline conditions for restoring such environments.

While recent surveys have not detected major changes in community composition, comparison of community evenness between 1991 and 2003-2004 provides additional information. Evenness is a measure of how equitably coral cover is distributed among taxa sampled within a transect. The decrease in evenness over this time period is the result of an increased dominance of disturbance-resistant taxa such as *Porites* spp. (Figure 15.20).

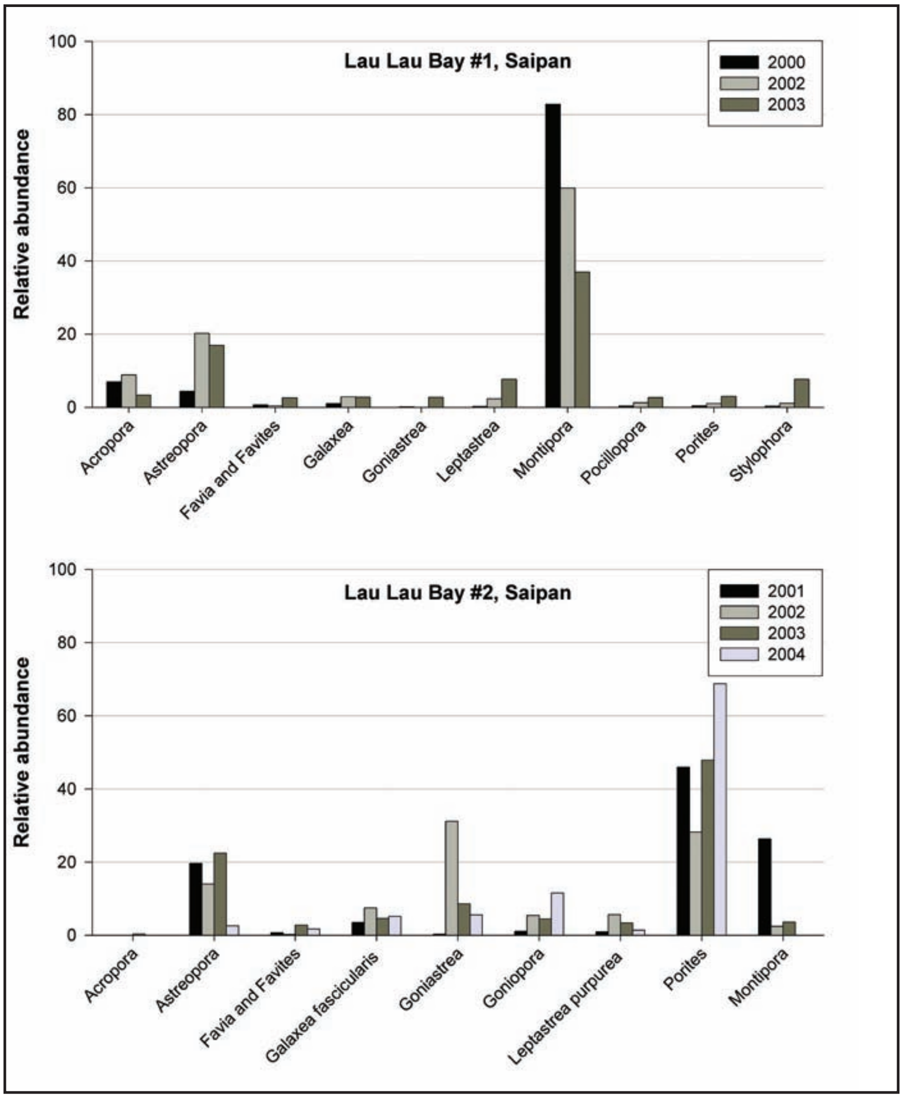

Figure 15.19. Changes in relative abundance of corals over a four year period at two long term monitoring sites in Lau Lau Bay, Saipan. Source: CNMI MMT (P. Houk), unpublished data.

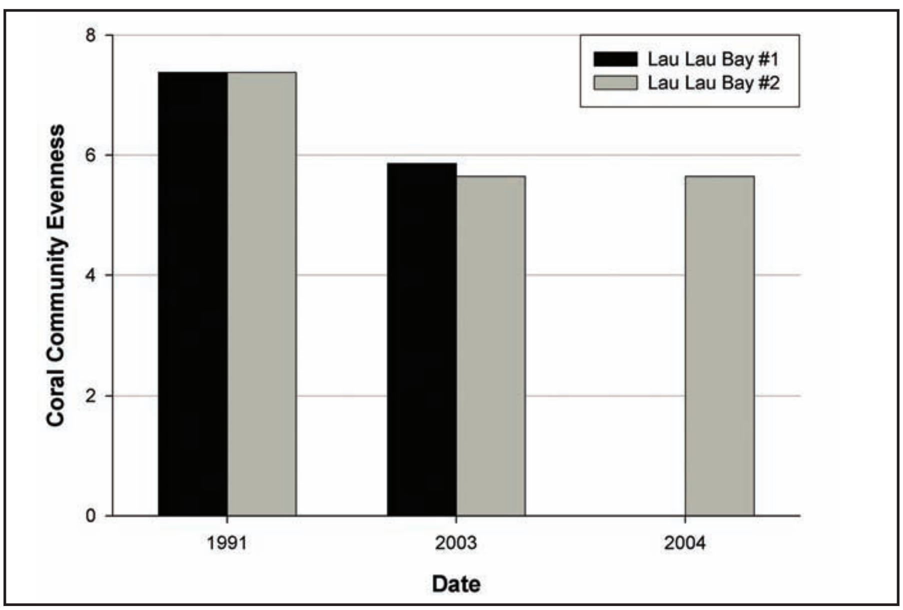

Figure 15.20. Change in community evenness at two long-term monitoring sites. Source: CNMI MMT (P. Houk), unpublished data.

NOAA MARAMP Coral Community Structure Study

Methods

Coral abundance, distribution, condition, biodiversity, and population structure in the CNMI were surveyed at 53 sites during the 2003 MARAMP cruise. Several techniques were used: towed-diver video surveys each averaging about 2 km in length; REAs each covering between 1000-5000 m^2 and consisting of a quadrat-based coral community survey; direct observations for species diversity, coral disease, and bleaching; and video benthic surveys at three 50-m transects.

Results and Discussion

A moderately high prevalence (30-50%) of mild coral bleaching was found at the islands north of Pagan, while a lower prevalence was found at more southerly islands. The highest percentages of coral bleaching were observed at the two northernmost sites surveyed, Uracas Island and Stingray Shoals. Coral species diversity was greatest in the southern islands and lowest in the northern islands. The coral cover of oceanic banks varied along the extent of the archipelago. Stingray Shoals in the north had high coral cover. Arakane, Pathfinder, and Santa Rosa Banks primarily exhibited spur and groove and carbonate formations. Species diversity of corals, algae, and fishes was generally low at the oceanic banks due to limited habitat diversity.

NOAA MARAMP Algae Community Structure Study

Methods

Algal surveys using photoquadrats, field observations, and specimen collection were conducted along the same transect lines used for fish surveys (Vroom, in review).

Results and Discussion

Over 45 genera, representing up to 198 species, were recorded. Macroalgae, with the exception of algal turf, contained 60% of the total number of algal species known for the Marianas Archipelago (198 out of 332; Vroom, in review). Large standard deviations of prevalence for most genera indicated that algal composition differed substantially among individual islands.

BENTHIC HABITAT MAPPING

NOAA CCMA-BT Benthic Habitat Atlas

Methods

NOAA's CCMA-BT initiated a nearshore benthic habitat mapping program for Guam, American Samoa, and the CNMI in 2003. IKONOS satellite imagery was purchased from Space Imaging, Inc. for all three jurisdictions, and used to delineate habitat polygons in a geographic information system (GIS). Habitat polygons were defined and described according to a hierarchical habitat classification system consisting of 18 distinct biological cover types and 14 distinct geomorphological structure types.

Results and Discussion

The project was completed in 2004 and resulted in maps of 158.5 km^2 of nearshore habitat in the CNMI. A series of 96 maps are currently being distributed as a print atlas, on a CD-ROM, and are available on-line (CCMA-BT, http://biogeo.nos.noaa.gov/products/us_pac_terr/, Accessed 01/12/05). The benthic habitat maps are depicted in Figure 15.21.

CNMI DEQ and CRM Mapping of the Saipan Lagoon

Detailed habitat maps for the Saipan Lagoon have been developed through a collaborative project between the DEQ and CRM. Cross-lagoon transects were used to delineate habitats, which were validated using video transect data. Habitats were mapped in a GIS using orthorectified aerial photography. GIS-based spatial analysis of maps using IKONOS imagery is also being tested. As this method is refined, prior habitat maps are being revised for consistency. Preliminary results of this project are currently available (CNMI DEQ, http://www.deq.gov.mp/mmt/lagoon.htm, Accessed 01/10/05).

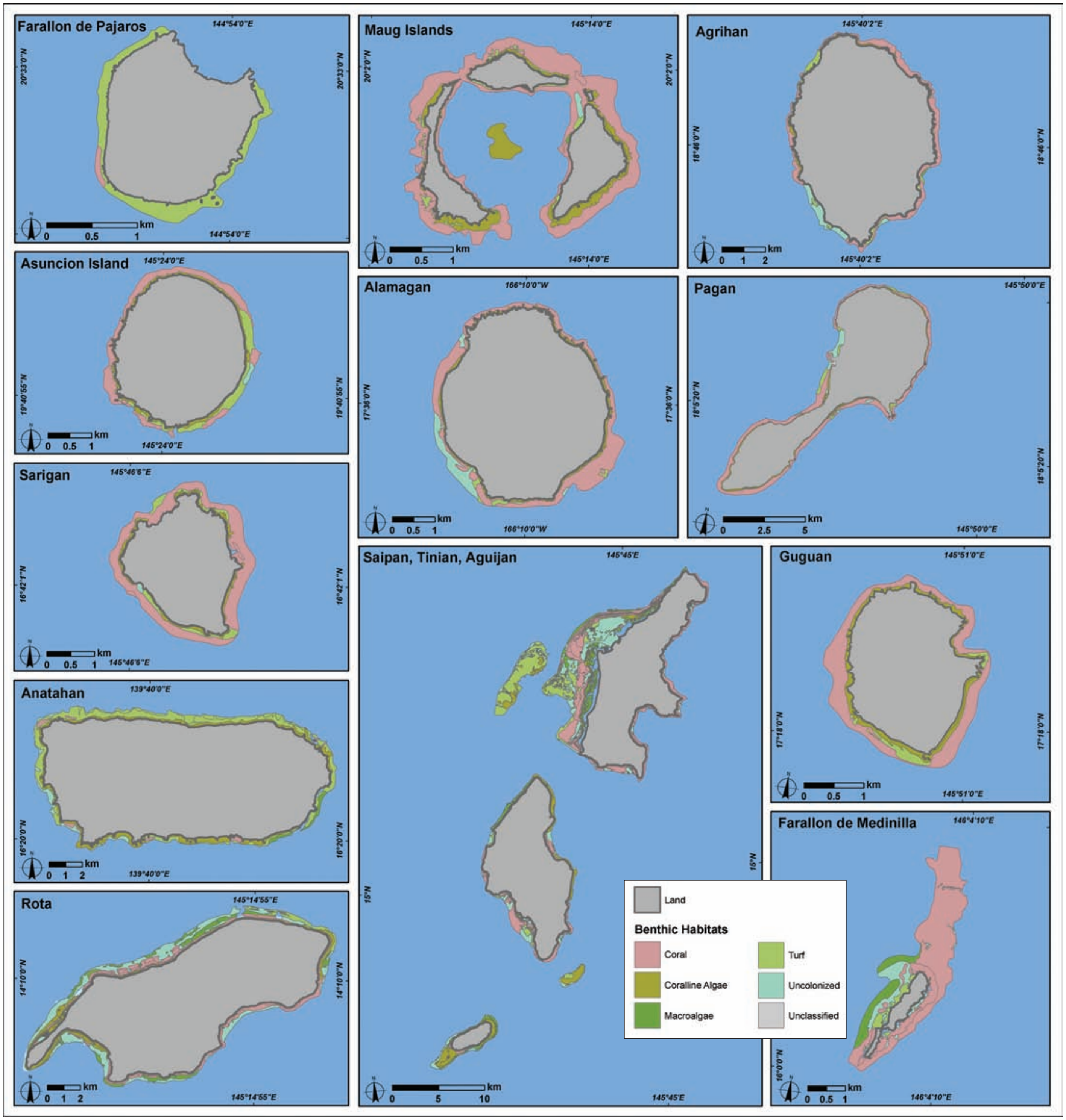

Figure 15.21. Nearshore benthic habitat maps were developed in 2004 by CCMA-BT based on visual interpretation of IKONOS satellite imagery. For more info, see: http://biogeo.nos.noaa.gov. Map: A. Shapiro.

NOAA MARAMP Benthic Habitat and Multibeam Mapping

During the 2003 MARAMP cruise, PIFSC-CRED scientists conducted numerous benthic habitat mapping activities including multibeam bathymetric surveys, drop video camera surveys, Quester-Tangent bottom classification surveys, and diver surveys in water depths to 30 m. All but the last method are discussed below.

Multibeam Mapping Methods

The R/V *AHI*, a new PIFSC-CRED vessel, was deployed in the southern islands of the CNMI and Guam in August and September 2003. The 8 m launch was equipped with a RESON multibeam echosounder and a POS/MV motion sensor, and produced high resolution depth and backscatter data across a 150 degree swath of the seafloor. These data have been used to develop many of the high resolution bathymetric maps and images shown in the 'Introduction' section of this chapter; approximately 120 km were surveyed in southern CNMI. With tremendous support from the DFW, including use of the DFW research vessel, high quality surveys were completed in water depths ranging from 20 m to greater than 250 m in almost all areas visited. Backscatter imagery from the multibeam data is being processed and will be combined with other data to create benthic habitat maps.

Results and Discussion
Multibeam data collected by the R/V *AHI* were used to prepare gridded bathymetric maps and images of Rota, Tatsumi Reef, Tinian, Saipan, and Marpi Bank. Bathymetric data processing has been completed, and the 5-m resolution grids with comprehensive metadata are available on-line (PIFSC-CRED, http://pifsc.noaa.gov/cred/hmapping/datadownload.html#mariana Accessed: 01/10/05). All gridded data sets are also being submitted to the NOAA Coral Reef Information System, and multibeam data will be submitted to the NOAA's National Geophysical Data Center for general distribution when all processing has been completed. Processed backscatter imagery, seafloor texture, and video from the towboard and TOAD vehicle surveys will be integrated in a geographic information system GIS to further characterize benthic habitats.

Integration of multibeam data and other information from the NOAA Ring of Fire cruises with data from the 2003 MARAMP cruise is underway and is scheduled to be complete before the MARAMP cruise in fall 2005. This collaborative work will synthesize deep and shallow bathymetric data into a coherent ecosystem-wide view of the Marianas Archipelago. PIFSC-CRED scientists are also working closely with scientists from CCMA-BT and Analytical Labs of Hawaii (ALH) to integrate shallow-water benthic habitat information derived from visually interpreted IKONOS imagery with the extensive multibeam and video data collected during MARAMP cruises.

As a top priority, PIFSC-CRED scientists are working to synthesize data collected at the Saipan anchorage site near Saipan Lagoon for use by CNMI resource managers as well as and commercial and military users of the anchorage. Bathymetric data processing is complete; backscatter imagery processing, seafloor texture analysis, and analyses of 10 existing video tapes are underway. Scientists from PIFSC-CRED and ALH returned to Saipan in fall 2004 to collect hundreds of additional video clips that will be used to refine the benthic habitat maps in this and other important anchorage areas and to develop a method to integrate and cross-reference the map products being developed independently by PIFSC-CRED, CCMA-BT, and ALH scientists. It is important that analyses of potential impacts to the anchorage areas be completed and evaluated prior to increasing either the size of the designated anchorage or the number of vessels permitted to use the area.

TOAD Optical Data and Quester Tangent Corp. Bottom Classification
The TOAD is an undersea tethered vehicle that is deployed from the R/V *Oscar Elton Sette* during night operations in depths ranging from 20 m to 140 m. Still images and video footage collected via the TOAD are used to ground-truth data and produce benthic habitat maps. Ninety-five TOAD deployments have resulted in 69 photographs, 93 video segments, and 109 Quest Tangent Corp. (QTC) files. Analyses of the video data are underway by the PIFSC-CRED.

Bioacoustics Surveys
During the 2003 MARAMP expedition, a 38-kHz Simrad echosounder was used to record water column scattering data for bioacoustics surveys. Sound scattering layers (SSLs) are vertically migrating 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. The observed horizontal migration of the Hawaiian community towards shore at night also suggests SSLs may play a significant role in the coral reef ecosystem through input of biomass and nutrient cycling.

These bioacoustic surveys indicate that the SSL off Rota Island is present during both daylight and nighttime hours at depths between approximately 50 m and 100 m. Aside from Maug Island, which features a persistent SSL inside the crater, all of the islands surveyed in the CNMI presented an active mesopelagic community which exhibited diurnal migration.

ASSOCIATED BIOLOGICAL COMMUNITIES

FISH

DFW Marine Sanctuaries Program

Methods

The DFW MSP conducts annual surveys to assess reef fish abundance within designated marine sanctuaries. Using a habitat-based stratified sampling method, data are collected along 25 m by 4 m transects located haphazardly within habitat types. Methods are described in detail in DFW technical reports (Trianni, 1999a,b).

Results and Discussion

Abundance results for select foodfish groups from the Managaha Marine Conservation Area (MMCA) are presented in Figure 15.22. These data indicate a general decline in abundance for most of the depicted fish groups from 2000-2002. The one exception is for Labridae which shows a spike in 2001, a trend that was also observed in other parts of the CNMI for some groupers. Although the MMCA was enacted into law in 2000, enforcement of regulations did not commence until 2002. Enforcement benefited significantly from the use of U.S. Coral Reef Initiative Management Grant funds, and has been successful in the past two years. Therefore, the first three years of the survey are viewed as preliminary results.

Data collected from 2000-2002 from the SBFR in Rota are depicted for a range of abundant select reef fish groups in Figure 15.22. The abundance estimates for the SBFR show mostly insignificant variability among all three years for the groups depicted. The most notable exceptions are decreases in the Lethrinidae and Nasinae, and increases in the Labridae (Figure 15.22) and terminal phase Scaridae (Figure 15.23).

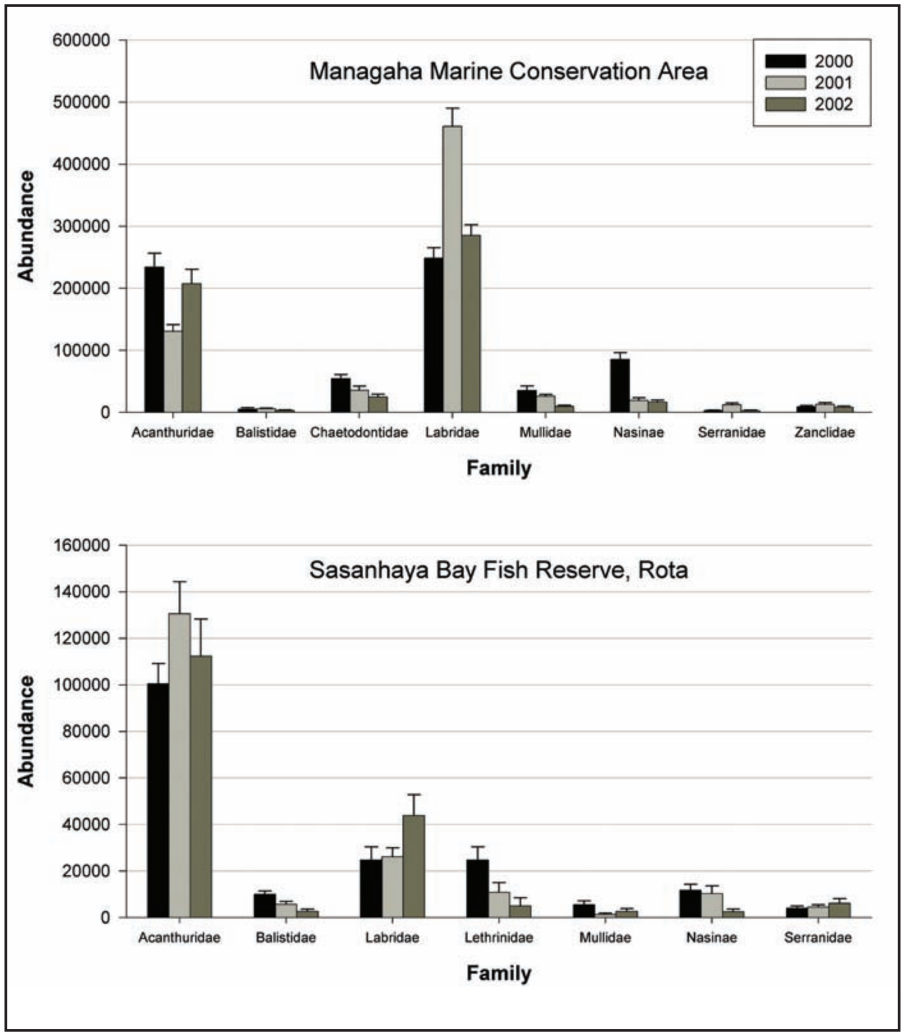

Figure 15.22. Abundance estimates from the MMCA (upper panel) and SBFR (lower panel) for various reef fish families. Source: Trianni, in prep.

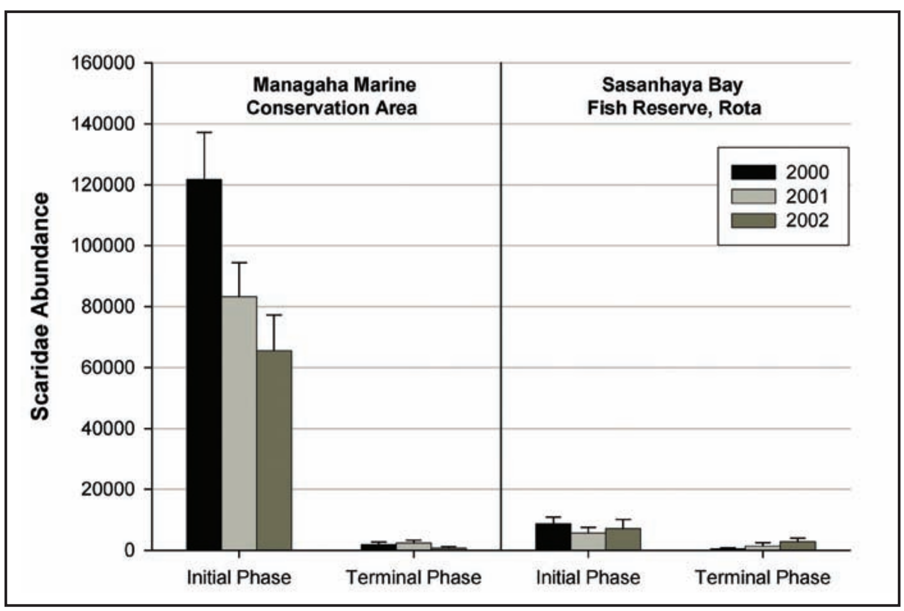

Figure 15.23. Abundance of initial and terminal phase Scaridae in the MMCA and SBFR, 2000-2002. Source: Trianni, in prep.

NOAA MARAMP

Methods

REAs, belt transects (BLTs), SPCs, and towed-diver/video surveys (TDVSs) were used to census diurnally active shallow-water reef fish assemblages. Each method was replicated at sites within or among the various habitat types. Fish length-class was estimated for all fish to provide an estimate of numerical size structure and biomass densities by taxa.

Results and Discussion

Preliminary results from the CNMI are presented here because full analysis of the data from these assessments is ongoing.

In general, all three methods (BLT, SPC, and TDVS) recorded the highest densities of large fish (all taxa pooled) at the northernmost islands (Asuncion, Maug, and Uracas) and banks (Stingray Shoals and Supply Reef; Figure 15.24). High to moderate densities occurred throughout the central part of the chain (to Sarigan). Densities of the largest jacks (Figure 15.25) and groupers (Figure 15.25) were highest at the northern end of the archipelago, as observed by TDVSs. Moderate densities occurred through the central part of the chain, a pattern supported when smaller fish were measured using the SPC (≥25 cm total lenght [TL]) and BLT (≥20 cm TL) methods. The largest (i.e.,≥50 cm TL) snappers occurred at the northernmost islands, with high to moderate densities south to Anatahan (Figure 15.26). The largest surgeonfish occurred at Stingray Shoals in the far northwest, with moderate densities extending from the northern islands to the central part of the chain (Figure 15.26). Other target families (e.g., parrotfish, wrasses, and emperors) also exhibited the same trends found in surgeonfish. However, there were some exceptions, such as shark which occurred in low densities in the north. Overall, the 2003 PIFSC-CRED fish surveys found that common fishery target species in the Marianas Archipelago were most abundant in the northern islands, although less abundant than about a decade ago, particularly around the southern populated islands. However, these results, together with REAs surveys, found highest fish diversity at the southern islands (especially for emperors, wrasses, squirrelfish, and parrotfish), moderate fish diversity at the western banks, and lowest fish diversity at the northern islands.

High densities of recently recruited young juveniles were present for a number of species at many of the northern reefs, with very high densities of the red-toothed triggerfish (*Odonus niger*) at Rota. In contrast, fish at Anatahan were nearly absent along some transect lines due to the major volcanic eruption of this island only four months earlier. Visibility was very poor (average 1-2 m) around much of the island due to suspended ash in the water column, which also buried much of the reef.

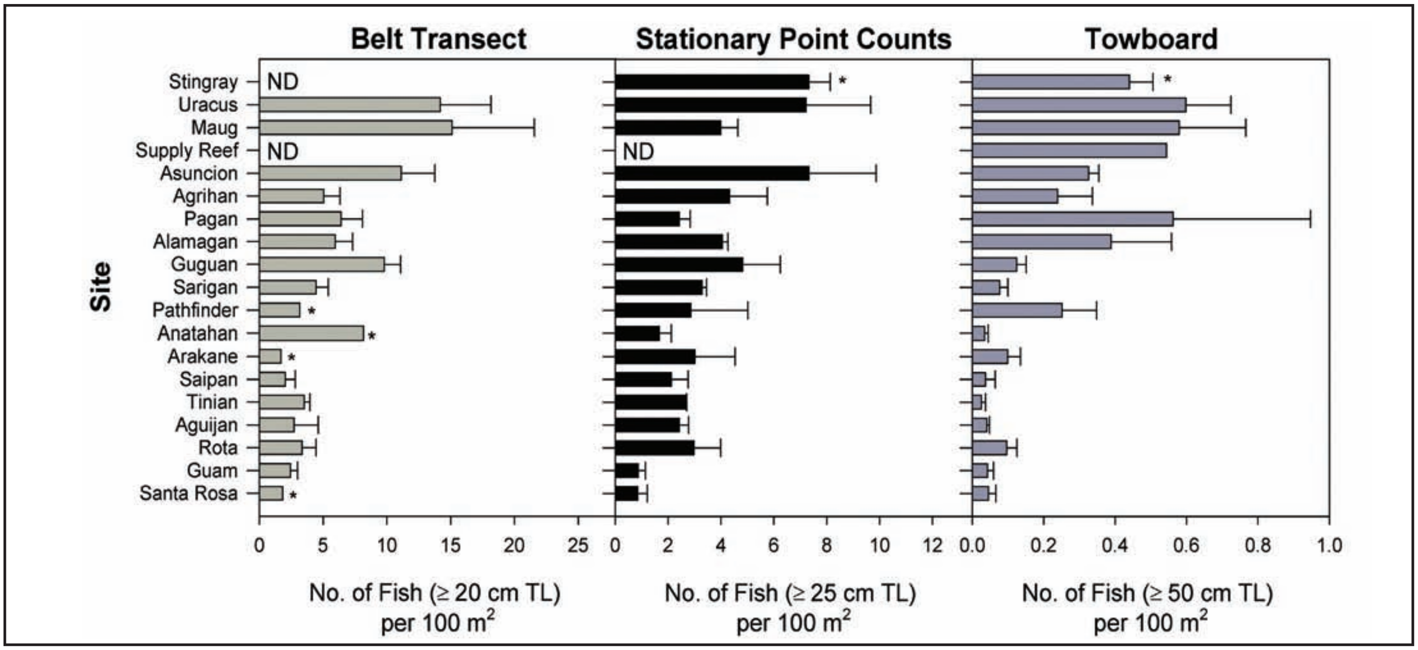

Figure 15.24. All three fish survey methods used during the NOAA MARAMP cruise documented a high abundance of large fish (all taxa pooled) at the northern islands and banks in the Marianas Archipelago. Source: PIFSC-CRED (R. Schroeder), unpublished data.

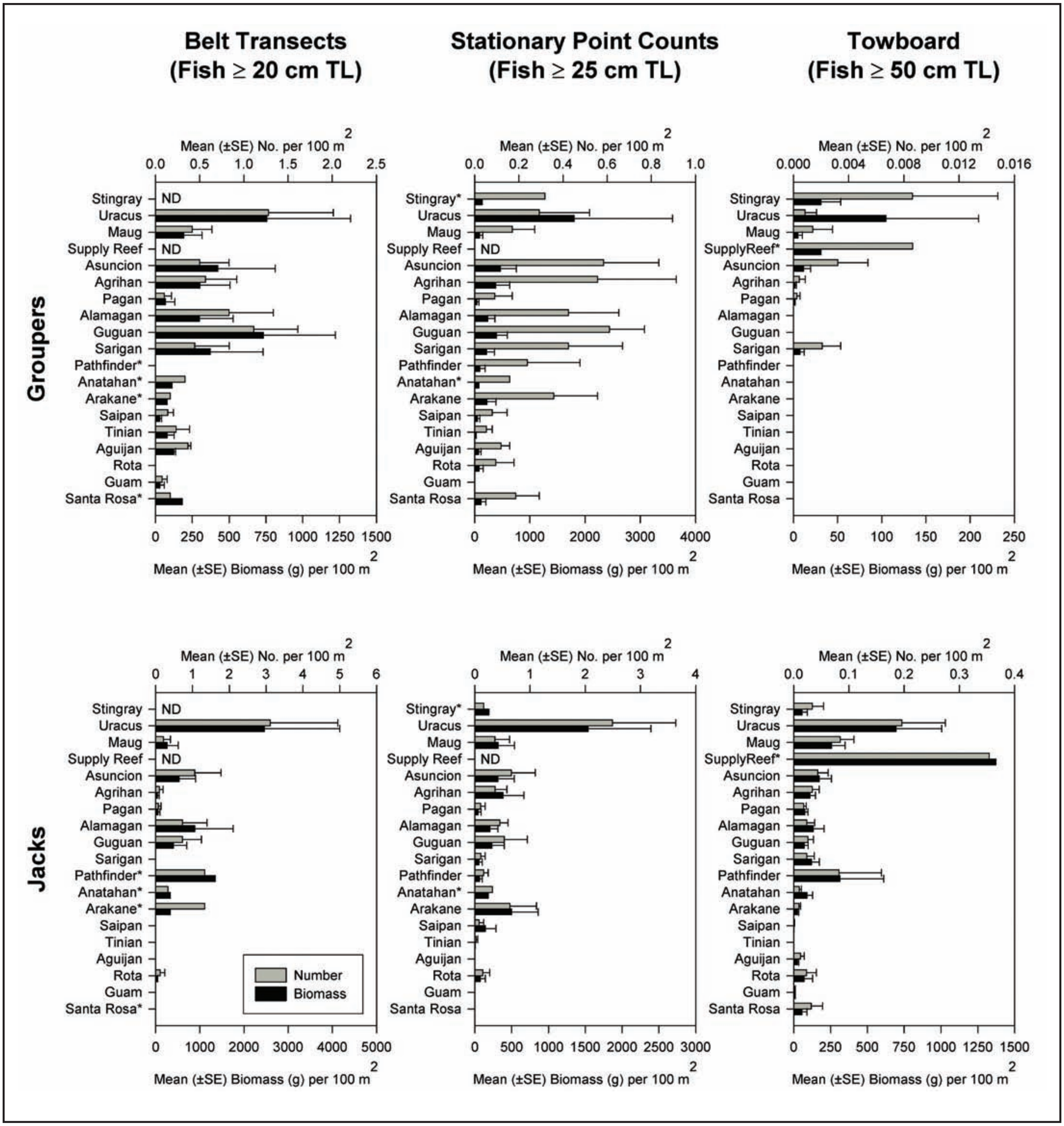

Figure 15.25. Number and biomass of Jacks and Groupers observed in the CNMI by sampling method. Source: PIFSC-CRED (R. Schroeder), unpublished data.

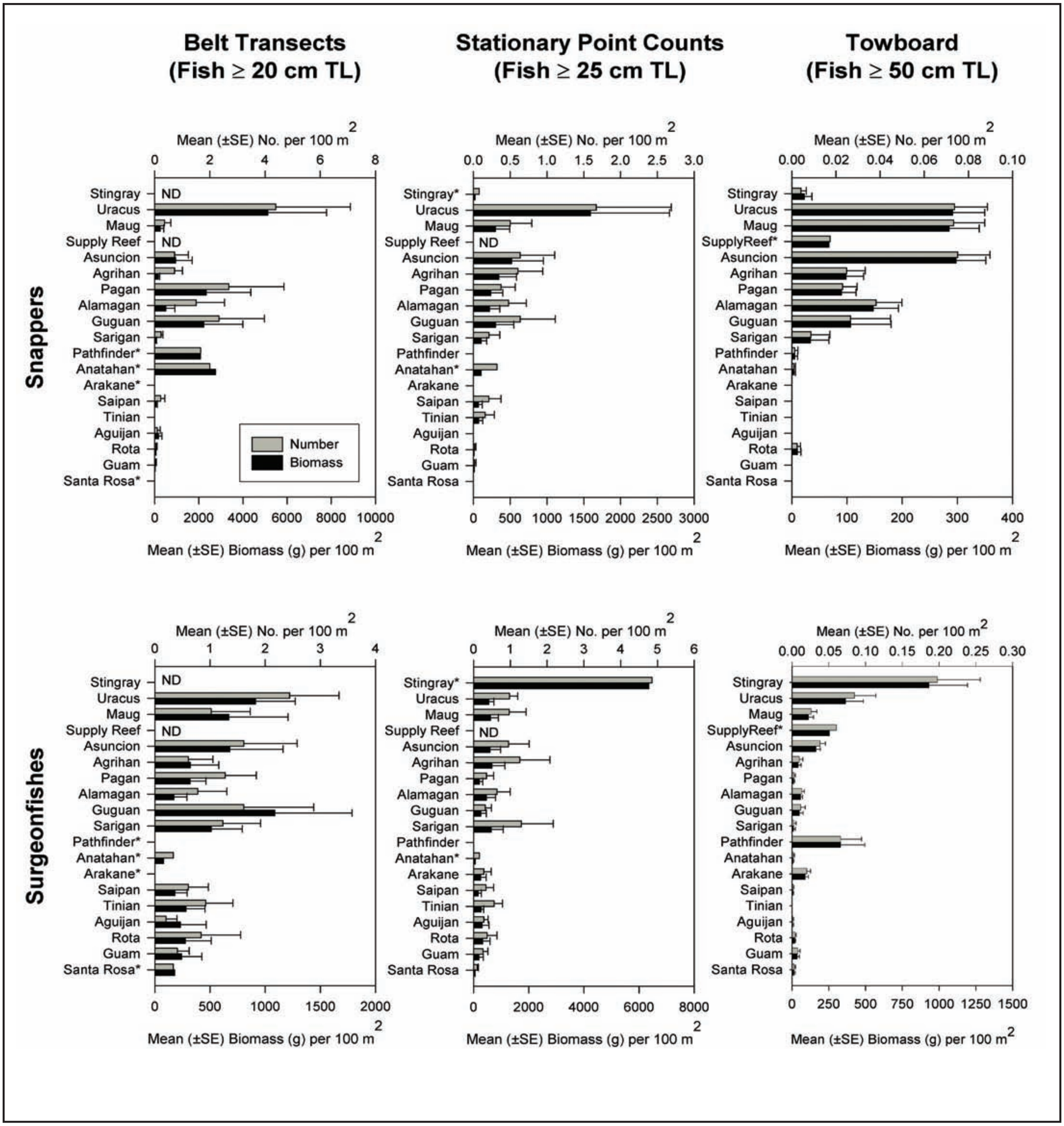

Figure 15.26. Number and biomass of Snappers and Surgeonfish observed in the CNMI by sampling method. Source: PIFSC-CRED (R. Schroeder), unpublished data.

INVERTEBRATES

NOAA MARAMP Invertebrate Surveys

Methods

Surveys focusing on marine invertebrates other than corals were performed in conjunction with surveys of coral and macroalgae, collectively termed the benthic survey. Two types of data on the benthic macroinvertebrate fauna of the CNMI were obtained: 1) quantitative data on the abundance of conspicuous species using BLTs and 2) qualitative information on the occurrence of other invertebrate species at each site.

Results and Discussion

The dominant invertebrate groups observed throughout the CNMI were sponges and echinoids. All sites had a diverse assemblage of encrusting and boring species of sponges. *Terpios hoshinota*, a coral killing sponge, was observed in Guguan and Uracas. The most common echinoid throughout the northern Mariana Islands was the small black-spined sea urchin, *Echinostrephus aciculatus*, with densities of up to 2-3/m^2. The most abundant sea star observed was the fissiparous *Linckia multifora*, with high densities that reached up to 0.75/m^2. The coral-predatory COTS, *acanthaster planci*, was present in Agrihan, Pagan, Anatahan, Saipan, and Rota but was not observed at densities more than 0.06/m^2.

The dominant genera of alcyoniid soft corals were *Sarcophyton, Lobophytum, Sinularia,* and *Cladiella*; soft corals were present at all of the islands and shoals, except in Uracas, where soft corals were almost completely absent. Among the mollusks, the giant clam *Tridacna maxima* was present at all CNMI islands and was especially abundant in Guguan and Maug Islands. The maximum density recorded was along the interior slope of the eastern end of the northern island, where densities reached 0.5-1/m^2.

MMT Nearshore Coral Reef Monitoring Program

Methods

This program was previously described in this chapter and the data presented here are based on replicate 50 m by 2 m transects. Methods are described in detail in Houk (2000, 2001).

Results and Discussion

Variables measured at the majority of MMT monitoring sites showed no significant within-site differences in invertebrate abundances during the two to four years of monitoring. Several sites showed significant variation in sea urchin abundance (Figure 15.27). Despite the magnitude of these changes, they are not consistent among or within sites. These data are being further analyzed to examine relationships with other parameters monitored by the MMT. It is more likely that an understanding of this variation will depend on the collection of additional, long-term data to clarify the nature of the population dynamics for these animals.

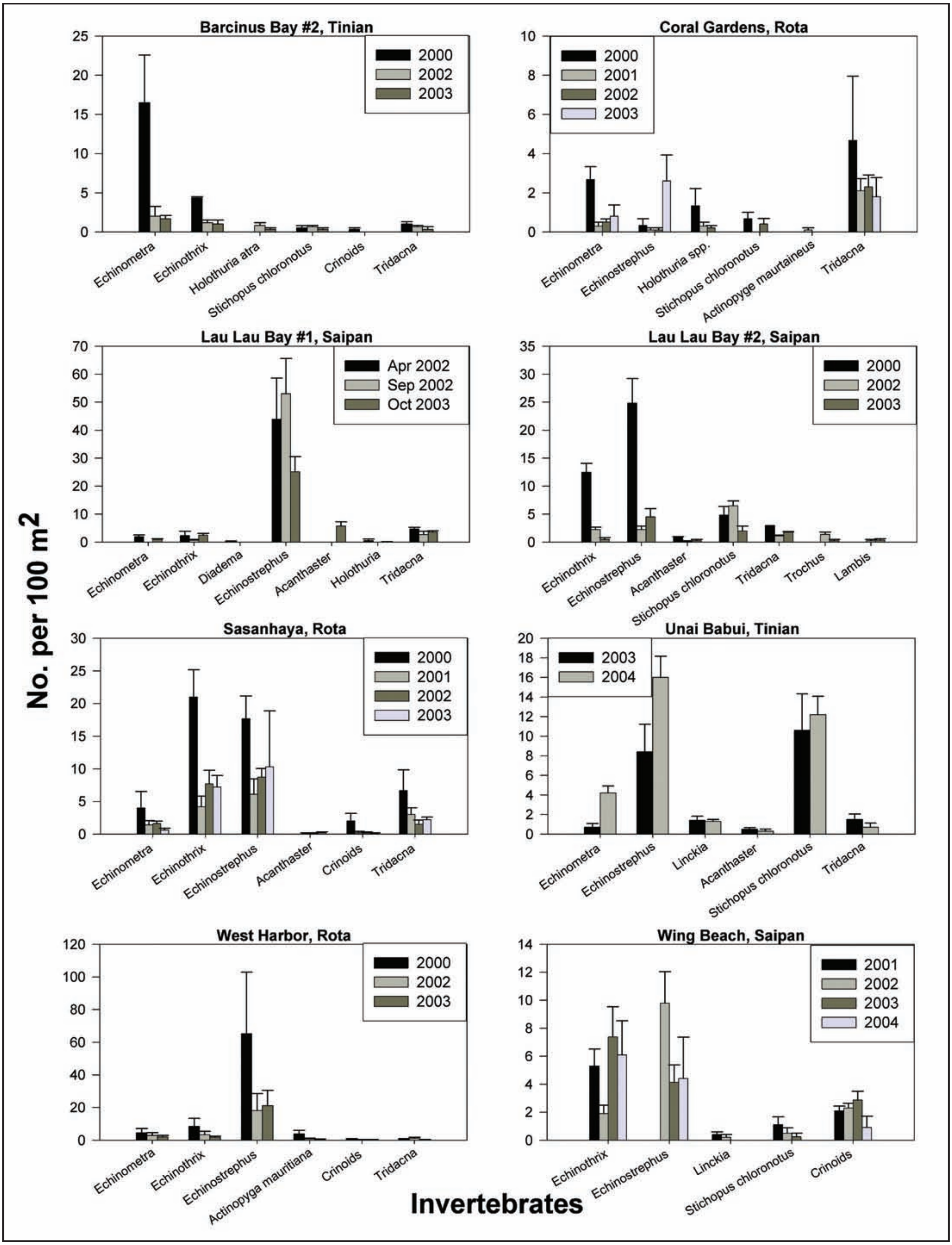

Figure 15.27. Invertebrate abundance at selected long-term monitoring sites at Tinian, Rota, and Saipan. Source: CNMI MMT (P. Houk), unpublished data.

TURTLES

Methods

Sea turtles have been surveyed in the nearshore waters of CNMI southern arc islands (Kolinski et al., 2001, 2004). During the 2003 MARAMP cruise, methods were modified for use in the northern arc islands (Kolinski et al., in prep.) and at isolated bank and reef systems (Kolinski et al., in press). A combination of towed-diver, dive, and surface surveys were employed to assess turtle presence.

Results and Discussion

Resident Turtles

Previous surveys suggest roughly 1,000 to 2,000 mainly immature green turtles (*Chelonia mydas*) reside in CNMI southern arc waters (Kolinski et al., 2004; Figure 15.28). Hawksbill turtles (*Eretmochelys imbricata*) have been infrequently sighted in these waters, and transitory visits by leatherbacks (*Dermochelys coriacea*) and olive ridleys (*Lepidochelys olivacea*) are known. Extensive examination of seven shallow-water (≤ 40 m) isolated reef systems within the Marianas Archipelago identified only two immature and one juvenile/adult green turtles, suggesting that these habitats support minimal numbers of this species, perhaps for transitory periods of time (Kolinski et al., in press). Data analysis of turtle observations from northern arc waters is in progress. For the nine surveyed islands (Figure 15.28), 166 green, four hawksbill, and three unidentified turtle observations were made. A projected upper boundary for the resident green turtle population size throughout the CNMI portion of the Marianas Archipelago is not likely to exceed 2,700 turtles (Kolinski et al., in prep). Hawksbill numbers likely do not exceed 50 individuals.

Nesting

Small numbers of green turtles are known to nest on the southern arc islands of the CNMI (Wiles et al., 1989, 1990; Pultz et al., 1999; McCoy, 1997; Kolinski et al., 2001; Ilo and Manglona, 2001). There are no reports of turtles nesting at northern arc island locations. Available northern arc beach substrate is limited and consists mainly of black volcanic sands and ash, although beaches at Maug and Pagan also include calcareous sands (Kolinski, pers. obs.).

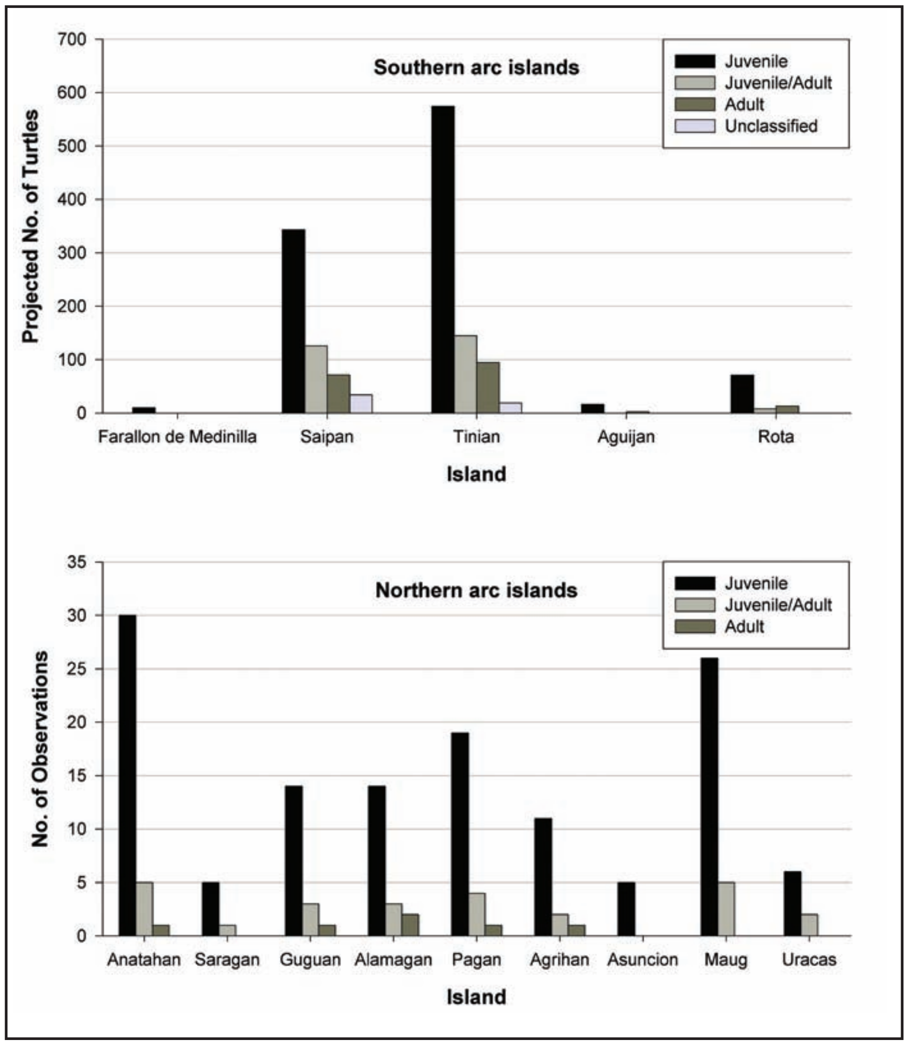

Figure 15.28. Upper panel shows projected population structures of *Chelonia mydas* at surveyed CNMI southern-arc islands. Source: Kolinski et al., 2004. Lower panel shows the numbers of observations of *Chelonia mydas* at surveyed CNMI northern-arc islands. Source: Kolinski et al., in prep.

Overall Condition and Summary of Analytical Results

Coral reef ecosystems in the CNMI are, on the whole, reasonably healthy. However, it must be recognized that coral reef ecosystems in the CNMI cannot be realistically treated as a single entity since the geology, oceanography, ecological history, and human activities vary widely across the 14 islands and associated reef shoals and banks. Biological diversity, across coral reef taxa, is variable among islands and isolated reefs, with limited data indicating that offshore banks and reefs support lower diversity, probably due to lower habitat diversity.

Anthropogenic effects, such as nonpoint source pollution and fishing pressure, have clearly affected areas in proximity to the populated southern islands. While these stressors are actively being managed by local government agencies, some solutions, such as the replacement of sewer infrastructure, exceed locally available funding. From a fisheries perspective, the northern islands and more distant banks and reefs appear to be in better condition than those closer to population centers.

Environmental stressors such as volcanic ashfall, elevated SST, and *Acanthaster* predation have clearly had localized negative effects on coral reefs in the Marianas. Anthropogenic stressors also create an additive, if not synergistic, increase in coral reef degradation. It is imperative to support and expand monitoring programs that provide information to managers which helps them address both natural and anthropogenic sources of coral reef degradation.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Saipan Lagoon and Tinian Marine Management Areas

Activities within the Saipan Lagoon fall under the general jurisdiction of several CNMI government agencies. The CRM has designated the lagoon as part of an Area of Particular Concern and is involved in protecting the lagoon's environment by preventing and reducing user conflicts. One of CRM's primary activities in the lagoon is the regulation of commercial marine sports. The Commonwealth Ports Authority further regulates the Tanapag Harbor and Harbor Channel. Management of these areas also falls under the jurisdiction of DFW, DEQ, and Marianas Public Lands Authority.

Marine Protected Areas

Current opinion supports the need for permanent spatial and temporal reef fish sanctuaries in the hope that they will act as insurance against fishery "collapse." Setting aside MPA to serve as spawning stock areas and to ensure habitat integrity, not only for coral reef fish but for food organisms as well, may be the most effective management tool available to maintain levels of spawning stock biomass necessary to replenish or sustain coral reef fisheries.

In 1985, the concept of the establishment of marine parks in the CNMI was explored when the CRM studied whether to propose marine parks on the populated southern islands of Saipan, Tinian, and Rota to promote and enhance tourism (PBEC, 1985). More recently, concern over declining catch rates around Saipan, Tinian, and Rota raised concern over management protocols for coral reef fisheries (Trianni, 1998b).

In 1998, the DFW MSP commenced a project with funding from the Sportfish Restoration Act (16 USC § 777-777k) administered by the USFWS. The goal of the project was to provide funding for the monitoring and assessment of coral reef fish in existing no-take MPAs (nMPAs) in the CNMI, as well as to conduct surveys of all CNMI islands for the designation of additional nMPAs. When the project commenced, the SBFR in Rota was the only nMPA in existence, as it was designated in 1994. Shortly after the DFW MSP project commenced, a bill was introduced to create the Tinian Marine Sanctuary (TMS; Tinian Island) and MMCA (Saipan Lagoon). Geographic placement of these nMPAs generally followed the suggestions of the 1985 CRM-funded study, although the "no-take" provisions were added. The MMCA was subsequently passed into law in August 2000, while the TMS has yet to be enacted. Law enforcement of the SBFR did not begin until late 2000, while MMCA rules and regulations are being developed. DFW enforcement activities have increased over the past two years with the increased funding provided by a Coral Reef Initiative Management Grant. The funds have provided for two boats, dive gear, dive training, and workshops and support two conservation officer positions. Monitoring of the MMCA has resulted in several arrests for illegal spearfishing and use of rotenone, a poison derived from the naturalized plant *Derris* sp. In addition to enforcement activities, DFW has initiated an education and outreach program to promote compliance with MPA and fisheries regulations.

Education and Outreach

Support for educational efforts is increasing with recognition that education has an important role in marine conservation. The DFW has a dedicated education specialist to visit schools and educate students about endangered species issues. MPA pamphlets were produced and distributed by DFW on Rota and Saipan, and these pamphlets are currently being updated and translated into Chammoro, Carolinian, Mandarin, Tagalog, Japanese, and Korean in an attempt to educate all CNMI population sectors about MPAs. In addition, the Saipan DLNR erected educational signs at entrances to the Bird and Forbidden Island MPAs.

The DEQ has a strong education program targeting nonpoint source pollution and coral reef water quality issues. DEQ's Nonpoint Source Program also coordinates with EPA, NOAA, and CRM to implement the requirements of EPA's Coastal NonPoint Source Pollution Control Program (pursuant to Section 6217 of the Coastal Zone Reauthorization Amendments of 1990). NOAA funding recently supported the short-term hiring of a coral reef education specialist to assist DEQ, DFW, and CRM to build the coral reef education components of their outreach programs.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

The recent expansion of coral reef assessment, mapping, and monitoring in the CNMI is, in part, driven by funding from the U.S. Coral Reef Initiative to provide important baseline data. Without a firm understanding of the actual condition and ecological trends on local coral reefs, CNMI managers are forced to follow precautionary measures, rather than base decisions on locally reliable data. While this is changing with the maturation of local monitoring and assessment programs and the initiation of the NOAA MARAMP, understanding of Mariana Island coral reefs is far from complete. Long-term monitoring of fisheries, water quality, and other ecological parameters will be necessary to support management efforts.

Through an extensive process of stakeholder meetings, the CNMI has developed local action strategies that identify those areas of greatest concern for the continued effective management of local coral reefs. These strategies provide a blueprint for how the CNMI hopes to address the identified areas of concern. Nonpoint source pollution, fishing pressure, and improvement of reef-related education and outreach were identified as the three areas of highest priority. While these areas have been the management focus even before the formation of the Commonwealth, the boom in development and concomitant population growth have outpaced the ability of local government to effectively manage them. The U.S. Coral Reef Initiative, through NOAA, EPA, USFWS, and other organizations, has provided tremendous support to build local capacity to effectively manage coral reef ecosystems.

REFERENCES

Adams, A.T., C.V. Alfred, B.L. Bukurrou, A.J. Cruz, T. Ilo, L. Rasa, R. Seman, Taitano, J. Taman, T. Mendiola, D. Santos and H. King. 1994. Assessment of the Northern Marianas *Trochus* resource and recommendations for management of the fishery. Draft report of the CNMI/SPC Fisheries Survey Team to the Chief of the Division of Fish and Wild Life, Saipan. 36 pp.

Amesbury, S.S., D.R. Lassuy, R.F. Myers and V. Tyndzik. 1979. A survey of the fish resources of Saipan Lagoon. Marine Lab Technical Report 52. University of Guam. 58 pp.

Carrell, T. 1991. Submerged Cultural Resources Assessment of Micronesia. Southwestern Cultural Resources Center Professional Papers 36. Southwestern Cultural Resources Center, Santa Fe, New Mexico. 624 pp.

Duenas and Associates, Inc. 1997. Saipan lagoon use management plan, Survey of sea cucumbers and fish in the Saipan lagoon, Northern Mariana Islands (NMI). Duenas and Associates, Inc. Report 97-6F. Prepared for NMI Coastal Resources Management Office.

Eldredge, L.G and R.K. Kropp. 1985. Volcanic ashfall effects on intertidal and shallow-water coral reef zones at Pagan, Mariana Islands. pp. 4: 195-200. In: Proceedings of 5th International Coral Reef Congress.

Embley, R.W. 2004. Explorations of Mariana Arc Volcanoes Reveal New Hydrothermal Systems. EOS Transactions American Geophysical Union 85 (4): 37-44.

Fritz, G. 1986. The Chamorro: A history and ethnography of the Marianas. Translation by E. Craddock. CNMI Division of Historic Preservation, Saipan. 59 pp.

Gochfeld, D. 2004. University of Mississippi, School of Pharmacy. Personal communication.

Graham, T. 1994. Biological Analysis of the Nearshore Reef Fish Fishery of Saipan and Tinian. CNMI Department of Fish and Wildlife, Saipan, CNMI. DFW Tech. Report. 98-02. 64 pp.

Houk, P. 2000. State of the reef report for five sites on Rota Island, CNMI. CNMI Division of Environmental Quality.

Houk, P. 2001. State of the reef report for Saipan Island, Commonwealth of the Northern Mariana Islands. CNMI Division of Environmental Quality. 59 pp.

Houk, P. (ed.) 2004. Commonwealth of the Northern Mariana Islands Integrated 305(b) and 303(d) Water Quality Assessment Report. Commonwealth of the Northern Mariana Islands, Division of Environmental Quality. 60 pp.

Ilo, L.I. and J.M. Manglona. 2001. Rota turtle assessment report. Report prepared for the Division of Fish and Wildlife, Commonwealth of the Northern Mariana Islands. 22 pp.

Johannes, R.E. 1979 Improving shallow water fisheries in the Northern Mariana Islands. Unpublished Report. 25 pp.

Kolinski, S.P., D.M. Parker, L.I. Ilo and J.K. Ruak. 2001. An assessment of the sea turtles and their marine and terrestrial habitats at Saipan, Commonwealth of the Northern Mariana Islands. Micronesica 34: 55-72.

Kolinski, S.P., L.I. Ilo and J.M. Manglona. 2004. Green turtles and their marine habitats at Tinian and Aguijan, with projections on resident turtle demographics in the southern arc of the Commonwealth of the Northern Mariana Islands. Micronesica 37: 95-116.

Kolinski, S.P., R.K. Hoeke, S.R. Holzwarth and P.S. Vroom. In press. Sea turtle abundance at isolated reefs of the Mariana Archipelago. Micronesica 37: 287-296.

Kolinksi, S.P., S.R. Holzwarth, R.K. Hoeke and R. O'Conner. In preparation. Sea turtle demographics in the northern-arc islands of the Mariana Archipelago.

Littler, D. S. and M.M. Littler. 2003. South Pacific Reef Plants: A Divers' Guide to the Plant Life of South Pacific Coral Reefs. OffShore Graphics Inc., Washington, D.C. 331 pp.

McCoy, M.A. 1997. The traditional and ceremonial use of the green turtle (*Chelonia mydas*) in the Northern Mariana Islands with recommendations for its use in cultural events and education. Unpublished Report for the Western Pacific Regional Fishery Management Council and the University of Hawaii Sea Grant College Program. 87 pp.

Michael, M. 2004. Dive Rota. Rota, CNMI. Personal communication. NOAA. 2003. Submarine Ring of Fire 2003. Available from the internet URL: http://oceanexplorer.noaa.gov/explorations/03fire/welcome.html.

NOAA (National Oceanic and Atmospheric Administration). 2004. Submarine Ring of Fire 2004. Available from the internet URL: http://oceanexplorer.noaa.gov/explorations/04fire/welcome.html.

PBEC (Pacific Basin Environmental Consultants, Inc.) 1984. Final Report: Biological and physical survey of Bahia Laulau, Saipan. CNMI Planning/Energy Office. 159 pp.

PBEC (Pacific Basin Environmental Consultants, Inc.). 1985. CNMI Marine Parks Management Plan. CNMI Coastal Resource Management Office. 88 pp.

Pultz, S., D. O'Daniel, S. Krueger, H. McSharry and G. Balazs. 1999. Marine turtle survey on Tinian, Marianas Islands. Micronesia 32: 85-94.

Randall, R.H. 1991. Community structure of the corals along the fringing reefs bordering Unai Laolao Kattan, Unai Baput, and Unai Laolao, Saipan, CNMI. Cheenis Pacific Company.

Richmond, R.H. and S. Romano. 1997. Survey of the Coral Gardens, Rota, CNMI. Report to the CNMI Coastal Resources Management Office. 12 pp.

Rogers, C.S. 1990. Responses of coral reefs and reef organisms to sedimentation. Marine Ecology Progress Series 62: 185-202.

Sigurdsson, H., B. Houghton, S. McNutt, H. Rymer and J. Stix (eds.). 2000. Encyclopedia of volcanoes. Academic Press, San Diego. 1417 pp.

Spoehr, A. 2000. Saipan: Ethnology of a War-Devastated Island, Second Edition. CNMI Division of Historic Preservation, Saipan. 365 pp.

Telesnicki, G.J. and W.M. Goldberg. 1995. Effects of turbidity on the photosynthesis and respiration of two South Florida reef species. Bulletin of Marine Science 57(2): 527-539.

Tomokane, J. 1997. Marine Monitoring Team Survey Report: Nago 16 Vessel Grounding Unpublished Report. Coastal Resources Management Office. 3 pp.

Trianni, M.S. 1998a. Qualitative Assessment Surveys of World War II Ordinance Sites in Coral Reef Habitats at the Island of Rota: A Historical Record. Division of Fish and Wildlife Technical Report 98-02. Commonwealth of the Northern Mariana Islands, Saipan. 17 pp.

Trianni, M.S. 1998b. Summary and further analysis of the nearshore reef fishery of the Northern Mariana Islands. Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife Technical Report 98-03, Saipan. 64 pp.

Trianni, M.S. 1999a. Estimation of reef fish abundance and benthic habitat composition in the proposed Managaha Marine Conservation Area. Commonwealth of the Northern Marinan Islands, Saipan. Division of Fish and Wildlife Technical Report 99-03. Commonwealth of the Northern Mariana Islands, Saipan. 16 pp.

Trianni, M.S. 1999b. Estimation of reef fish abundance and benthic habitat characteristics in the proposed Tinian Marine Sanctuary. Commonwealth of the Northern Marinan Islands, Saipan. Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife Technical Report 99-02, Saipan. 21 pp.

Trianni, M.S. 2002. Summary of data collected from the sea cucumber fishery on Rota, CNMI. SPC Beche-de-mer Information Bulletin 16: 5-11.

Trianni, M.S. In preparation. Determining Reef Fish Abundance in Marine Protected Areas in the Northern Marinana Islands.

Tsuda, R.T. (ed.) 1971. Status of *Acanthaster planci* and Coral Reefs in the Mariana and Caroline Islands, June 1970 to May 1971. Technical Report No. 2. University of Guam Marine Lab.

UNISYS. 2004. Typhoon data for the Western Pacific Ocean. Available from the internet URL: http://weather.unisys.com/hurricane.

Wiles, G.J, A.B. Amerson, Jr. and R.E. Beck, Jr. 1989. Notes on the herpetofauna of Tinian, Mariana Islands. Micronesica 22: 107-118.

Wiles, G.J., G.H. Rodda, T.H. Fritts and E.M. Taisacan. 1990. Abundance and habitat use of reptiles on Rota, Mariana Islands. Micronesica 23: 153-166.

Worthington, D. and M. Michael. 1996. An assessment of the unexploded ordinance operations conducted on Rota by the Department of the Navy and the CNMI Emergency Management Office in May and June 1996. Report for the Administrative Record of the CNMI Emergency Management Office, Saipan. 9 pp.