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

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INTRODUCTION AND SETTING

This report is the third in a series of assessments of the current status of coral reef ecosystems in the U.S. Commonwealth of the Northern Mariana Islands (CNMI) and complements other previous assessments. The focus of this report is primarily on data collected during the period 2004 through 2007, with a greater emphasis on oceanographic data than was found in prior reports (Figure 14.1). For general overview of individual islands, please reference Starmer et al., 2005 (http://ccma.nos.noaa.gov/ecosystems/coralreef/coral_report_2005/).

The fourteen islands that make up CNMI lie in the western Pacific basin, stretching approximately 600 km (375 miles) on a north-south axis, with the Pacific Ocean on the east side and the Philippine Sea on the west (Figure 14.2). The southern islands of the archipelago, Saipan, Tinian, Aguijan and Rota, are uplifted limestone whereas the northern islands are volcanic. Active volcanoes exist on Anatahan, Pagan and Agrihan where most recently an eruption was noted on Anatahan in 2003. The archipelago has a peak elevation of 965 m (3,166 ft) on Agrihan.

The primary ocean current that influences this region is the North Equatorial Current, flowing east to west in the tropical Pacific Ocean (Figure 14.1). Persistent trade winds (10-15 mph on average) from the east-northeast create wind driven waves that bathe the exposed shores for the majority of the year. The CNMI has a hot and humid tropical climate, with a mean annual temperature of 83°F (28.3°C) and mean annual rainfall of 84 inches (213 cm). The dryer, winter season generally extends from December through June while the wetter summer season begins in July and ends in November. The seasonality of this region varies from year to year and is influenced by El Niño Southern Oscillation (ENSO) events in the Pacific.

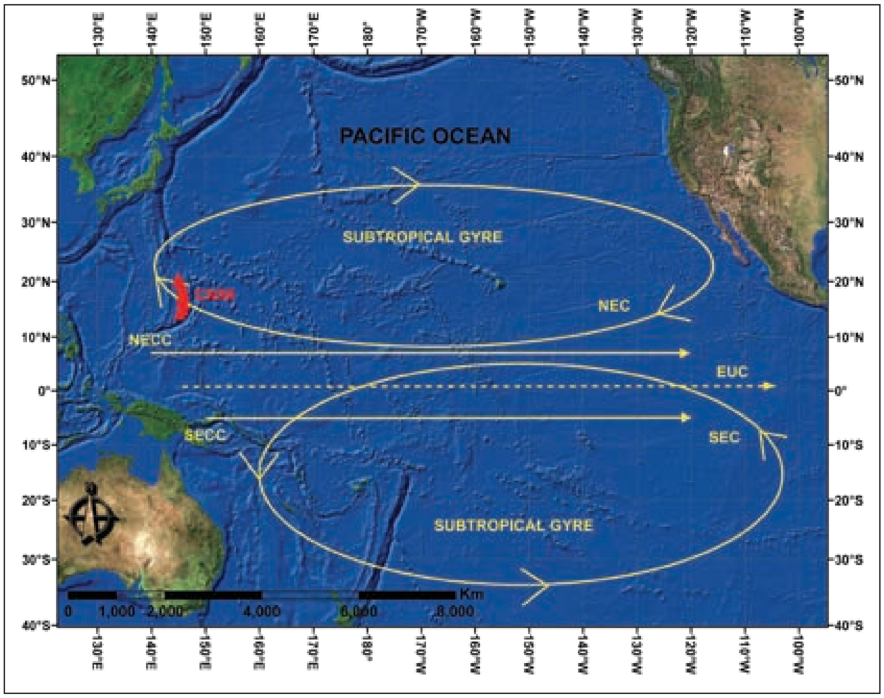

Figure 14.1. Topographic map showing location in Pacific Ocean of the U.S. CNMI and the major ocean currents in the region North Equatorial Current, South Equatorial Current, North Equatorial Counter Current, South Equatorial Counter Current and the Equatorial Under Current. Source: PIFSC-CRED.

1. CNMI Coral Reef Management Office
2. CNMI Department of Environmental Quality
3. University of Mississippi
4. Papahanaumokuakea Marine National Monument
5. Bishop Museum
6. CNMI Division of Fish and Wildlife
7. NOAA Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division
8. Joint Institute for Marine and Atmospheric Research

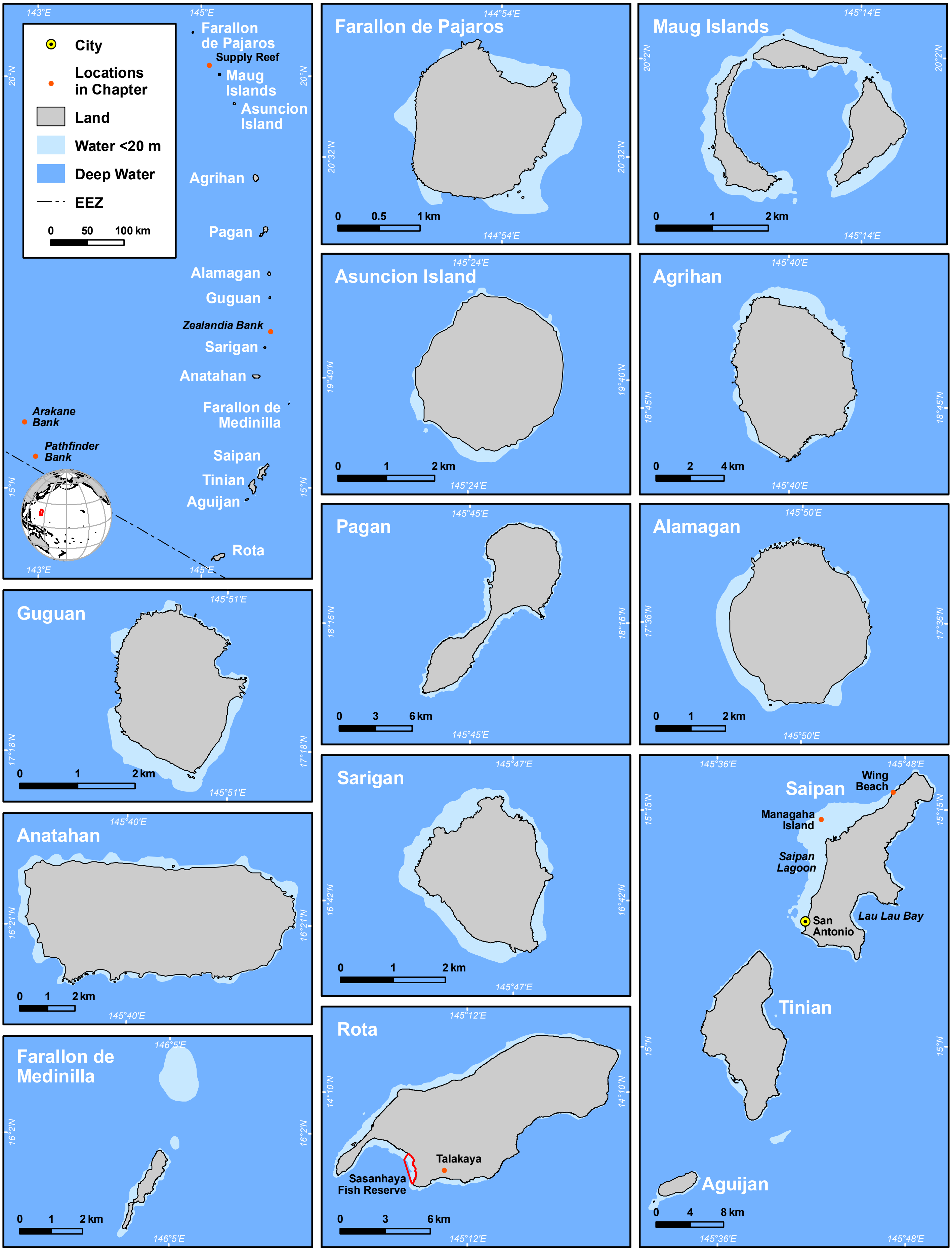

Figure 14.2: A map of CNMI showing the locations mentioned in this chapter. Map: K. Buja.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Concerns over the local effects of global climate change have heightened in CNMI since a 2001 bleaching event affected shallow-water coral assemblages in the southern Mariana Islands. Gathering data relevant to the effects of global warming, such as ENSO related changes and ocean acidification, are among recently identified priorities. CNMI's resource management agencies monitoring programs are building from an ecological monitoring base to increase emphasis on monitoring water quality, oceanographic conditions, and shoreline change. Scientists are actively partnering with regional and global environmental monitoring programs such as NOAA's Integrated Coral Observing Network/Coral Reef Early Warning System (ICON/CREWS) and the National Office for Integrated and Sustained Ocean Observations. NOAA's Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division (PIFSC-CRED) maintains sea surface temperature (SST) buoys at several islands in the archipelago, and the local government also monitors sea temperature at several locations. A notable setback to local data-gathering infrastructure was the removal of a NOAA Coral Reef Early Warning System buoy due to reduced program funding at PIFSC-CRED. The CNMI government now is actively pursuing replacement of this monitoring system's capabilities through the ICON/CREWS program.

Coral Bleaching

The manifestations of ENSO events have been linked to large-scale mortality of reef-building corals due to increased water temperatures and ultraviolet exposure (Hoegh-Guldberg, 1999). The CNMI lies within an ENSO core region in the western North Pacific basin that is linked to interannual variations of rainfall, with the CNMI exhibiting drought-like conditions in years following El Niño events. During El Niño years, there is an increased probability that tropical cyclones will form in the vicinity of the CNMI (http://www.soest.hawaii.edu/MET/Enso/peu/2006_4th/current_conditions.htm). ENSO events also affect local sea levels in the CNMI region with the mean sea level dropping during an El Niño period and rising above normal during a La Niña period. When comparing satellite-derived SST from CNMI with the Multivariate ENSO index, it appears that during a strong El Niño (e.g., 1997-1998), maximum annual temperatures at Maug, Pagan and Saipan are cooler than average when compared to non El Niño years (Figure 14.3).

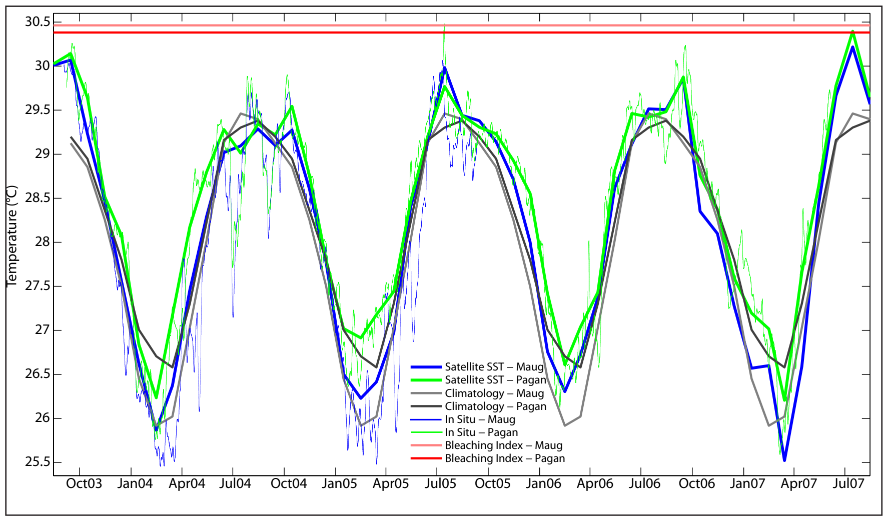

Figure 14.3. Relationship between NOAA Pathfinder derived SST at Maug, Pagan and Saipan (top) and the Multivariate ENSO Index (MEI; bottom) from 1985-2006. Source: PIFSC-CRED.

Ocean Acidification

Another climate change related phenomenon, ocean acidification, is being added to the list of conditions requiring the attention of CNMI's monitoring programs. Uptake of CO_2 by the ocean helps moderate the rising atmospheric concentrations, but associated changes in the oceanic carbonate chemistry lowers the pH along with the carbonate saturation state in oceanic surface waters; this process is referred to as ocean acidification. Coral reef growth depends on the saturation state of carbonate minerals in surface waters. A reduced carbonate saturation state makes it more difficult for marine calcifying organisms, such as corals, to form biogenic carbonate minerals (Orr et al., 2005).

Shoreline Change

The University of Hawaii's (UH) Department of Geology and Geophysics was contracted to assess Managaha Island's shoreline stability and create a projected model of the shoreline in 10 years. Managaha is a small sand cay in Saipan Lagoon which has been showing a rapid rate of erosion from its northeast shore and accretion on the west since 1996 when wreckage was removed from the windward side of the key. Sea level rise would exacerbate the trend. The sand's dynamic shift has covered some coral habitat under sand, but the shift has also exposed new hardbottom habitats to potential colonization.

Scientists used aerial and satellite imagery, beach profiles and current models to complete the study in June 2007. The projected model indicates that the cay's infrastructure is not at risk. However, Shearwater bird habitat is in the path of the erosion. Based on the study's findings UH recommended that coastal managers observe the island for another two years, and if it has not settled into a dynamic equilibrium by that time, hire a coastal engineering firm to design and implement mitigation measures to stabilize the island. Proposed mitigation measures would include construction of groins or artificial reef, which may impact existing coral habitat.

A concurrent study of Saipan's western shore is underway, with quarterly beach profiles being taken from 14 sites around the Garapan district. Findings will be used for planners to test various shoreline management measures (e.g., submerged artificial reefs, beach nourishment, etc.) that may be used to protect infrastructure at risk in the face of sea level rise. Again, the mitigation measures proposed to maintain existing coastal structures may impact reef habitats.

Diseases

Coral Diseases

Coral diseases have received little attention in the CNMI until recently. Various types of coral disease have been observed affecting corals in the CNMI, but they have not been fully characterized. Pending the completion of data analysis, the coral disease survey conducted during the 2007 Mariana Reef Assessment and Monitoring Program (MARAMP) cruise will provide an initial overview of coral disease for the entire archipelago.

Only recently has a standardized method for naming coral diseases become available (Work and Aeby, 2006), so it is difficult to compare disease types observed in Saipan to elsewhere in the Pacific. Certainly, some of the conditions seen in Saipan are commonly found on other Pacific reefs, including pink/purple blemishes, rings and indentations on massive *Porites* and growth anomalies on *Acropora*, *Isopora* and massive *Porites* species. Localized bleaching, focal or multifocal tissue loss, tissue necrosis and discolorations were also frequently observed. These diseases have affected massive, encrusting and branching species in the genera *Acropora*, *Astreopora*, *Favia*, *Goniastrea*, *Leptastrea*, *Montipora*, *Pocillopora*, *Porites*, *Psammacora* and *Stylophora (Figure 14.4)*.

Figure 14.4. Examples of coral diseases. From left to right: a massive Porites *with partial bleaching; submassive* Astreopora *with a band of necrotic tissue; and branching* Isopora *with growth anomalies. Photos: D. Gochfeld.*

Overall prevalence of coral disease increased from 2002 to 2005, and in 2005, diseases were found to be more abundant at sites with high levels of diver activity (e.g., dive entry sites at Obyan and Lau Lau Beaches; (Gochfeld, unpub. data). However, diseases were also observed at offshore sites (e.g., Coral Ocean Point, Outside Grand Hotel and Akino Reef) and at those with high water motion (Wing Beach). The incidence and prevalence of coral diseases in Saipan, as well as their etiology and ecology, warrant further investigation.

Other Coral Reef Diseases

Both coralline lethal orange disease and target syndrome affect coralline algae in the CNMI. A black fungus also affecting coralline algae is reported from Saipan, but has yet to be confirmed histologically. Lesions have been observed on the sea cucumber *Holothuria atra* in Saipan Lagoon. The effects on the animals range from burn-like patches to disintegration of the body wall. The CNMI marine monitoring team is investigating the prevalence of these lesions and possible environmental correlates.

Tropical Storms

The CNMI archipelago is situated in a highly active region of the western Pacific for cyclones and tropical storms sometimes referred to as "Typhoon Alley". An average of three tropical cyclones per year have passed within 300 nautical miles of Saipan since 1970 (Landers, 2004). CNMI storms rapidly develop, and typically, but not exclusively, occur in the more humid summer months (Figure 14.5). Tropical storms in the CNMI region generally propagate from the east-southeast direction with large (2-6 m) short period (3-12 seconds) and long period (11-25 seconds) storm-wind swells propagating from the storm itself and from direction of their origin (typically a distant storm in the high southern or northern latitudes), respectively. Large offshore wave heights associated with high storm driven winds can cause physical damage to the reef, and storm surge and setup from offshore wave inundation can increase mean shoreline water levels (and thus local sea level) by over 40% of the offshore significant wave height (Vetter, 2007). Large influxes of fresh water, including anthropogenic inputs, produced by the heavy rainfall and land runoff from storm conditions can cause a large volume influx of cold, fresh (and often polluted or nutrient enriched) water to the coral reef environment, with prolonged exposure to these conditions resulting in detrimental affects to the coral reef ecosystem (Jokiel, 1993). Problems also arise with associated erosion, turbidity at drainages and seasonal river mouths, debris accumulation and accidental pollutant spills. However, to a certain degree, the coral reef ecosystems in the CNMI have evolved under these annual storm conditions and may benefit from such annual forcing (Becerro, 2006).

Coastal Development and Runoff

Coastal development is managed through the coordinated efforts of the Coastal Resources Management (CRM) Office and CRM board member agencies, with the Department of Environmental Quality (DEQ) taking a leading role in managing earth moving and erosion control and water quality concerns. The declining rates of visitor arrivals and a receding economy have stalled several major proposed development projects. However, much of the existing development was created when weaker protective measures existed in local resource management regulations, resulting in many of today's focal problems. Runoff issues are dealt with in greater detail as coastal and nonpoint source pollution below.

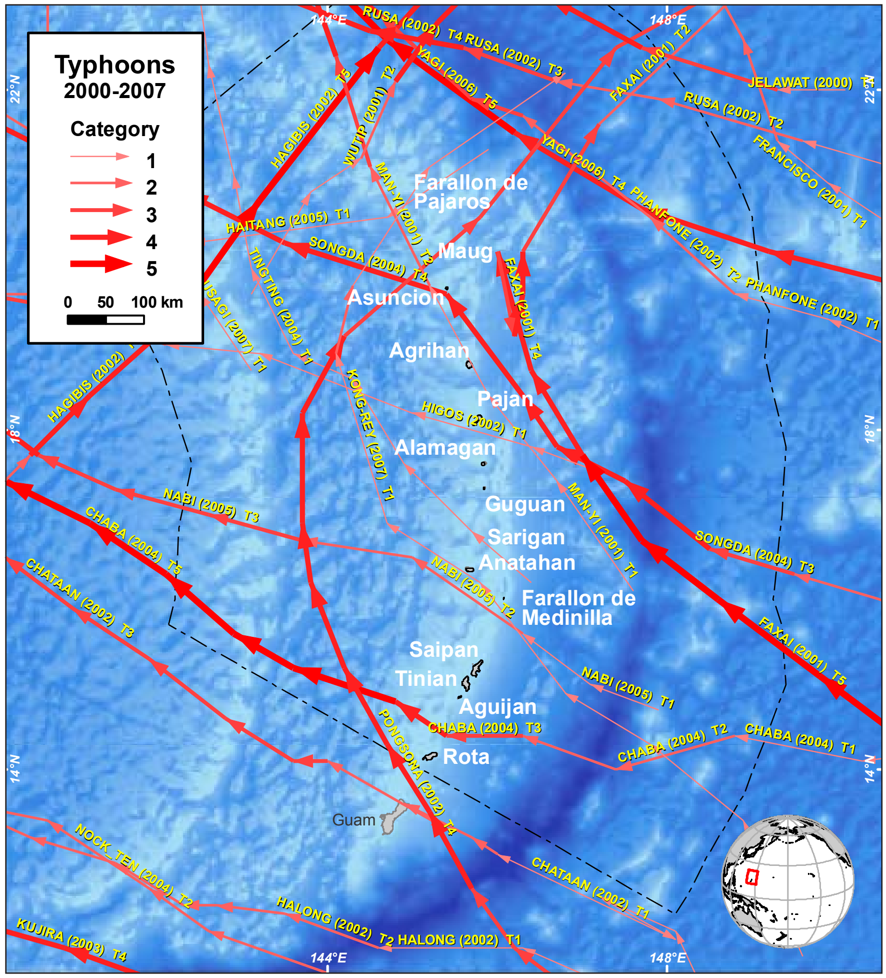

Figure 14.5. The path, intensity and names (when known) of typhoons passing near the CNMI from 2000-2007. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: K: Buja. Source: http://weather.unisys.com/hurricane/.

Coastal Pollution

The health and economic well being of the people of the CNMI depends on good water quality for fishing, recreation, and tourism. Healthy coral reefs require clean water with tested parameters remaining within a narrow range. Given that much of the existing development threatens our nearshore waters, maintaining and improving water quality in the CNMI is a challenge. Both point and nonpoint source pollution are responsible for lowering the quality of the CNMI's surface and ground waters. However nonpoint source pollution (NPS) is a greater source of impairment throughout the CNMI, specifically in the form of failing sewer collection systems, reverse osmosis discharges, urban runoff, sedimentation from unpaved roads and lack of proper erosion control best management practices during road and other construction activities.

Nonpoint Source (NPS) Pollution

NPS pollution remains one of the primary localized threats to coral reefs in the CNMI. In fact, one focus of the CNMI Marine Monitoring Team (MMT) is identifying reefs that are impaired by NPS pollution and prioritizing the limited funding allocated towards mitigation. Since 2000, MMT data demonstrate a steady declining trend in resiliency at "impaired" (defined by territory 305b water quality reports) localities. Specifically, decreases in species richness and recruit abundance, coupled with an increased dominance by one or a few corals, is becoming apparent at sites influenced by watershed pollution, while no such trend exists at other monitored sites (Figure 14.6).

The CRM Office and DEQ have long partnered to monitor and manage NPS in the CNMI. The CRM NPS program was funded by the federal 310 NPS Pollution control program, which was eliminated in fiscal year 2007. This has resulted in the elimination of what was once a highly effective program in the local CRM and has indefinitely stalled several major architectural and engineering best management practices (BMP) from being constructed as well as the implementation of proven local initiatives to combat NPS pollution.

Point Source Pollution

The Commonwealth Utility Corporation is in the process of upgrading sewage transfer and treatment infrastructure. A sewer line replacement project completed in 2006 has eliminated chronic lagoonside sewer line overflows in San Antonio, Saipan. A long overdue repair project at Agingan Point Sewage Treatment Plant on Saipan will relocate the outfall, which presently empties directly into the sea at the waterline. Directional drilling will relocate the outfall to a location approximately 244 m (800 ft) from shore and at a depth of 30 m (100 ft). While the secondary treatment process will not be upgraded to tertiary, the relocation of the outfall will improve nearshore water quality by releasing the treated effluent into ocean currents that will carry it into the open ocean and away from coastal areas.

In 2005, nearly all major hotels were illegally releasing hypersaline and nutrient enriched wastewater from reverse osmosis water purification systems into drainages that directly affected water quality in the Saipan Lagoon. Action by the U.S. Environmental Protection Agency (EPA) resulted in a rapid mitigation effort, and the majority of these systems are now discharging into deep injection wells. While this action has provided short-term improvement in nearshore water quality, it is uncertain what the long-term effects of wastewater injection will be.

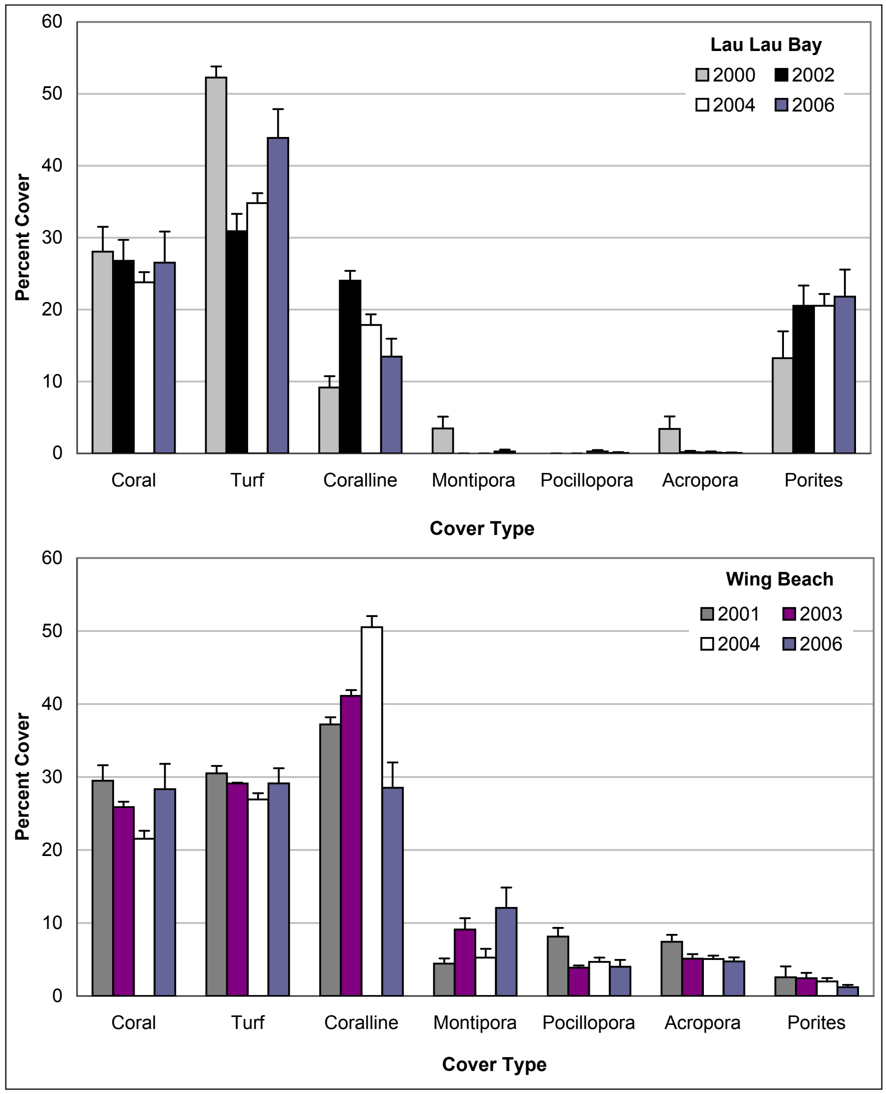

Figure 14.6. Change in percent cover of corals and dominant benthos at an "impaired" site at Lau Lau Bay, Saipan (top) and a "healthy" site at Wing Beach, Saipan (bottom). Notably, change in total coral cover does not differ, however Montipora, Pocillopora, *and* Acropora *corals are being replaced by* Porites *at the "impaired" site (top), yielding a decreased diversity as a result of watershed-based pollution. Source: CNMI MMT.*

Tourism and Recreation

CRM regulates commercial marine recreational sports through its permitting process. Commercial use of a beach front for filming, or the marine environment for SCUBA diving, banana boats, parasailing, submarine tours, commercial and personal jet ski usage, and other motorized marine sports activities must receive a permit from CRM (Table 14.1). The CRM has further designated jet ski exclusion zones near hotels, shallow reefs and seagrass habitat. Recent discovery of seagrass bed propeller scars associated with marine sports concessions has prompted an investigation of the ecological impact of these activities in Saipan Lagoon.

At the same time hotel operators have been seeking permission to remove seagrass beds from their designated swim zones. To date, no operators have applied for a CRM permit, as moving swim zones to areas without seagrass is easier than meeting the requirements of Section 7 of the Endangered Species Act or applying for a U.S. Army Corps Section 401 permit. CRM continues to give presentations to schools, the public and the Chamber of Commerce on the importance of preserving seagrass beds as a nutrient sink for NPS pollution, and as a fisheries nursery and habitat.

Table 14.1. Changes in permitted marine sports activities in CNMI between 2005 and 2007. Source: CNMI CRM.

	SAIPAN		TINIAN		ROTA		TOTAL	
	2005	2007	2005	2007	2005	2007	2005	2007
Jet Ski	12	12	2	1			14	13
Banana Boat	17	20	2	4			19	24
Parasailing	10	8	1	2			11	10
Sea/Aqua Walker	4	3					4	3
Scuba	27	51	2	1	1	3	29	55
Snorkel Tours	2	19					2	19
Waterski/Wakeboard		8						8
Non- Motorized Marine Sports	10	12					10	12

Fishing

While the status of most concerns mentioned in previous reports has not changed, recent enforcement of a ban on gill, drag and surround nets appears to be having positive effects on fisheries resources within the Saipan Lagoon. Cast nets (talaya) are still legal with a permit and exemptions are issued for annual celebrations (fiestas) honoring villages' patron saints. On the whole, however, large nets are no longer used in CNMI, and conversations with local cast net, hook and line, and spear fishermen indicate an increasing abundance and size of food fishes in the lagoon (Starmer, pers. obs.). While there is presently no quantitative assessment of the effect of this net ban, DFW is planning to repeat surveys completed in the Southern Lagoon in 2008.

Trade in Coral and Live Reef Species

This activity is prohibited by local law and is not recognized as a threat in this jurisdiction.

Ships, Boats and Groundings

Recreational anchoring remains a concern, primarily at dive sites that are the focus of marine sports activities. Thirty-six existing moorings in the CNMI have been installed and maintained primarily by the private sector, including Dive Rota around Rota Island and Northern Marianas Dive Operators Association around Saipan and Tinian. However, the number of moorings is recognized to be insufficient, especially at popular diving locations. Further, anchoring is banned within local MPA's, which are among those sites commonly visited by recreational dive charters. To address the issue, NOAA Fisheries grant funding is being used to install at least fifteen additional moorings over a three-year period (2007-2009) to support the protection of reef fish habitat (http://www.cnmicoralreef.net/mooring/mooring.htm).

The current anchoring practices of prepositioned military vessels in coral reef habitat west of Saipan remains a concern as well. Benthic habitat and bathymetric surveys by PIFSC-CRED found high coral cover at sites proposed for additional anchorages.

In June 2003 NOAA's Office of Response and Restoration (NOAA ORR) conducted surveys of 42 abandoned vessels in the CNMI. Of these, 19 vessels were listed as navigational threats and 11 vessels were considered high priority vessels for removal by the CNMI Coral Reef Task Force (CRTF; Table 14.2).

Table 14.2. CNMI's high priority vessels for removal. Source: CNMI CRM.

VESSEL	SPECS	WHERE	THREATS	STATUS
SAIPAN				
Mwaalil Saat (Cost $3,500,000)	93 ft steel trawler	Afloat outside harbor adjacent to the then Puerto Rico dump.	Potential pollution spill, navigational and public health risk	Removed and scrapped September 2004
Samala (Phase I Cost $56,450)	110 ft wood cabin cruiser	Grounded outside of Outer Cove Marina in shallow water	As it disintegrates, debris field moves and causes damage to corals and seagrass beds	Majority of debris removed by Sept 2005. Phase II estimated cost $20,000
Nago No. 15 (Cost $49,100)	53 ft fiberglass longliner	Grounded in 3-5 ft of water in Saipan's lagoon	Movement during storms has scoured seagrass beds	Removed and scrapped February 2006
Charito (In-kind contribution)	97 ft steel longliner	Grounded in 5 ft of water front of a boat ramp in the lower base industrial area	Eyesore, potential threat to other boats in a storm, and public hazard	Scheduled for Spring 2007
ROTA				
#62 Nam Sung (Cost $6,000 and in-kind contribution)	63 ft Steel fishing boat	Grounded on Sasanlago-Tatqua Beach	Extensive debris field damages corals and public health hazard	Scheduled for Spring 2007
TT Gov't 1/1830	106 ft steel M-Boat	Grounded in West Harbor	Public Health hazard	
TT Gov't 2/1831	106 ft steel M-Boat	Grounded in West Harbor	Public Health hazard	
Rota Queen	65 ft Tug boat	Grounded in West Harbor	Public Health hazard	
TINIAN				
Lian Gi	129 ft Steel freighter	Docked in Tinian Harbor	Will eventually sink and impact reef, poses a Public Health hazard	Cleaned and scuttled in Fall 2003
Sun Long No. 8	325 ft Steel freighter	Grounded in Tinian Harbor	Extensive debris field damages corals and public health hazard	
Unk 2578-2579		Grounded Tinian Harbor next to dock	Public Health hazard	

The CNMI CRTF began a Derelict and Abandoned Vessel Program in 2003 to initiate the removal of high priority vessels. Between 2004-2007, over $3.6 million of funding from the CNMI Coral Reef Initiative Management grant, U.S. Congress, FEMA Hazard Mitigation Sub-grant, U.S. Coast Guard (USCG) Oil Spill Liability Response Fund, NOAA Marine Debris Removal Program, and CNMI in kind and local funding have been targeted toward removal of five of the listed vessels. This figure does not include the $137,000 paid by the owner of the derelict vessel, *Lian Gi*, to scuttle her in 2003.

Three high priority vessels have been removed from Saipan's shores since 2004, including: the *Mwaalil Saat* (scuttled 2004- $3,500,000), *Samala* (scrapped 2005 - $56,450), and the *Nago No. 15* (scrapped 2006 - $49,100). Discussions are now underway with the USCG and U.S. Navy to scuttle the *Charito*, which grounded in Saipan Lagoon as part of ongoing military exercises. The CRM Office on Rota is presently removing the #62 *Nam Sung* wreckage from Tatqua Beach.

The CRM Office, DEQ, the CNMI Attorney General's Office, and USCG in conjunction with the CNMI Department of Public Safety (DPS) Division of Boating Safety, are discussing ways to prevent vessels from grounding or from being abandoned by their owners. Solutions include creating derelict and abandoned vessel legislation and creating an emergency fund to allow for the removal of vessels at risk before they go aground or sink. Other possible solutions include expanding the DPS annual inspections to include vessel integrity as part of the boat safety inspection requirements, and requiring vessels owners who use moorings or slips to obtain insurance to cover possible removal and mitigation costs.

Marine Debris

There has been no change in the overall status of this threat for the CNMI. Observations during exploratory dives by the CNMI MMT indicate that there is a smattering of vessel debris ranging from anchors to machinery components to unidentifiable metal scraps scattered along the west coast of Saipan from Tanapag Channel to Agingan Point and along Tinian from Unai Babui to the San Jose. Accumulations of metal debris, including unexploded ordinance that has been dumped from cliffs, can be found at Agingan and Naftan Points, Saipan and at Faibus Point (Dump Coke), Tinian. A PIFSC-CRED towed-diver survey at Tinian reported helicopter fragments and large tires at Faibus Point. Marine debris was not commonly encountered during PIFSC-CRED towed-diver surveys in the Marianas Archipelago. Infrequent sightings included isolated monofilament line (at Alamagan) or other types of fishing line (at Uracus and Tinian), miscellaneous rope or line (at Maug and Sarigan) and an anchor line (at Arakane).

Aquatic Invasive Species

There has been no change in the overall status of this threat for the CNMI. A commercial attempt to introduce several non-native species of *Tridacna* from Palau failed after the clams died of unspecified causes.

Security Training Activities

The status of concerns mentioned in previous reports has not changed. The U.S. military is currently proposing a build up of personnel in the neighboring U.S. Territory of Guam that may number in the tens of thousands. If this occurs, the CNMI will likely see an increasing frequency of training exercises in coming years.

Offshore Oil and Gas Exploration

Offshore oil and gas exploration is not occurring nor has it been proposed for the CNMI.

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Several local and federal coral monitoring and mapping programs have been collecting data to characterize, define trends, and approach causal relations between CNMI's coral reef assemblages and driving environmental variables (Table 14.3; Figure 14.7). Local efforts supported by the NOAA monitoring and EPA water quality monitoring grants provide for the most spatially and temporally encompassing characterization of the reefs systems in the southern, populated islands. These efforts are focused upon the Saipan Lagoon and nearshore coral reefs around Rota, Aguijan, Tinian and Saipan. The structure of the local monitoring program follows the above noted blueprint (characterization-trends-causal relations) and aims to translate scientific findings for management activities such as Local Action Strategies, EPA waterbody assessments and prioritizations and the Micronesia Challenge. CNMI's efforts have benefited through numerous collaborations with federal partners, notably from NOAA's Biogeography Branch, which has conducted habitat mapping and reef characterization activities and manages the National Coral Reef Ecosystem Monitoring Program grants. Collaboration with the NOAA PIFSC-CRED has provided an opportunity for CNMI's local marine monitoring team to participate in data collection efforts in the volcanic northern islands and other remote areas (Figure 14.7). Collaboration with PIFSC-CRED brings many otherwise unattainable resources to examine coral reef assemblages and gather water quality and environmental data throughout the CNMI.

Table 14.3. Monitoring programs in the CNMI. Source: CNMI MMT.

PROGRAM	VARIABLES	LOCATIONS	DATES	FREQUENCY	AGENCY
Coral Reef Early Warning Buoy	Enhanced: temperature (1 m), conductivity (salinity), wind, atmospheric pressure, ultraviolet radiation, photosynthetically available radiation	Saipan	2003-2006	Continuous	PIFSC-CRED
Deepwater CTDs*	Conductivity, temperature, depth, dissolved oxygen, chlorophyll to depth of 500 m	All Islands	2003-present	Continuous	PIFSC-CRED
MARAMP REA	Coral, Fish, Algal and Invertebrate abundance and diversity, benthic cover	All Islands	2003-present	Biennial	PIFSC-CRED
Marine Monitoring Program	Benthic cover, Coral Community Structure, Benthic Biodiversity, Coral Recruitment, Fish Abundance	Saipan, Rota, Tinian, Agijuan	2000-present	Annual	CRM DEQ
Nearshore Water Quality Monitoring	Coliform Bacteria, Nitrate, Phosphate, Temperature, Salinity, PH, dissolved oxygen	Saipan (and Managaha), Rota, Tinian	1995-present	Biweekly	CRM DEQ Environmental Surveillance Laboratory
Sanctuary Program	Fish abundance and diversity, invetebrate abundance, rugosity	Saipan, Rota, Tinian	2000-present	Annual	DFW
Sea Surface Temperature	Temperature at 0.5 m	Maug, Pagan, Rota	2003-present	Continuous	PIFSC-CRED
Shallow-water CTDs*	Temperature, conductivity, turbidity	All Islands	2003-present	Continuous	PIFSC-CRED
Subsurface Temperature Recorders	Temperature between 0.5 and 30 m	All Islands	1995-1996, 2001-present	Continuous	PIFSC-CRED, CNMI MMT
Water Samples	Chlorophyll, nitrate, nitrite, silicate, phosphate concurrent with deep and shallow-water CTDs* at selected depths	All Islands	2003-present	Continuous	PIFSC-CRED
Wave and Tide Recorders	Wave and Tidal Height	Supply Reef and Zelandia Bank	2003-present	Continuous	PIFSC-CRED
Ocean Data Platform	Temperature, conductivity (salinity), spectral waves, current profiles	Santa Rosa Reef	2003-present	Continuous	PIFSC-CRED

*CTD stands for a sensor that measures conductivity, temperature and depth.

Within the Mariana Archipelago the most notable broad-scale reef-community zonation pattern exists between the northern volcanically active islands and the southern raised limestone islands. Examinations of 40 fringing reefs throughout the northern islands found that while coral diversity and colony surface area are significantly lower on the northern islands than the southern (mean of 62 species per site and 206 cm^2, mean of 82 species, 312 cm^2, respectively (Houk and Starmer, unpub. data), population density is similar (mean of 144 and 139 colonies per site, respectively). This suggests that recruitment is not limiting, rather that harsh environmental conditions select against species settlement and growth (Randall, 1985; Houk, 2006). The failure of much of the coastline around the northern islands to form into fringing reefs is attributed to: 1) unfavorable bathymetry, 2) a lack of favorable substrate upon which corals can settle and grow, 3) high exposure to wave energy, 4) the re-suspension of volcanic ash, and 5) volcanic eruptions. In the southern, raised limestone islands local efforts have provided enhanced characterizations of the coral reefs in areas where reef growth has not been uniform throughout the late Holocene. In some places, spur-and-groove reef types exist, while others are devoid of deposition entirely.

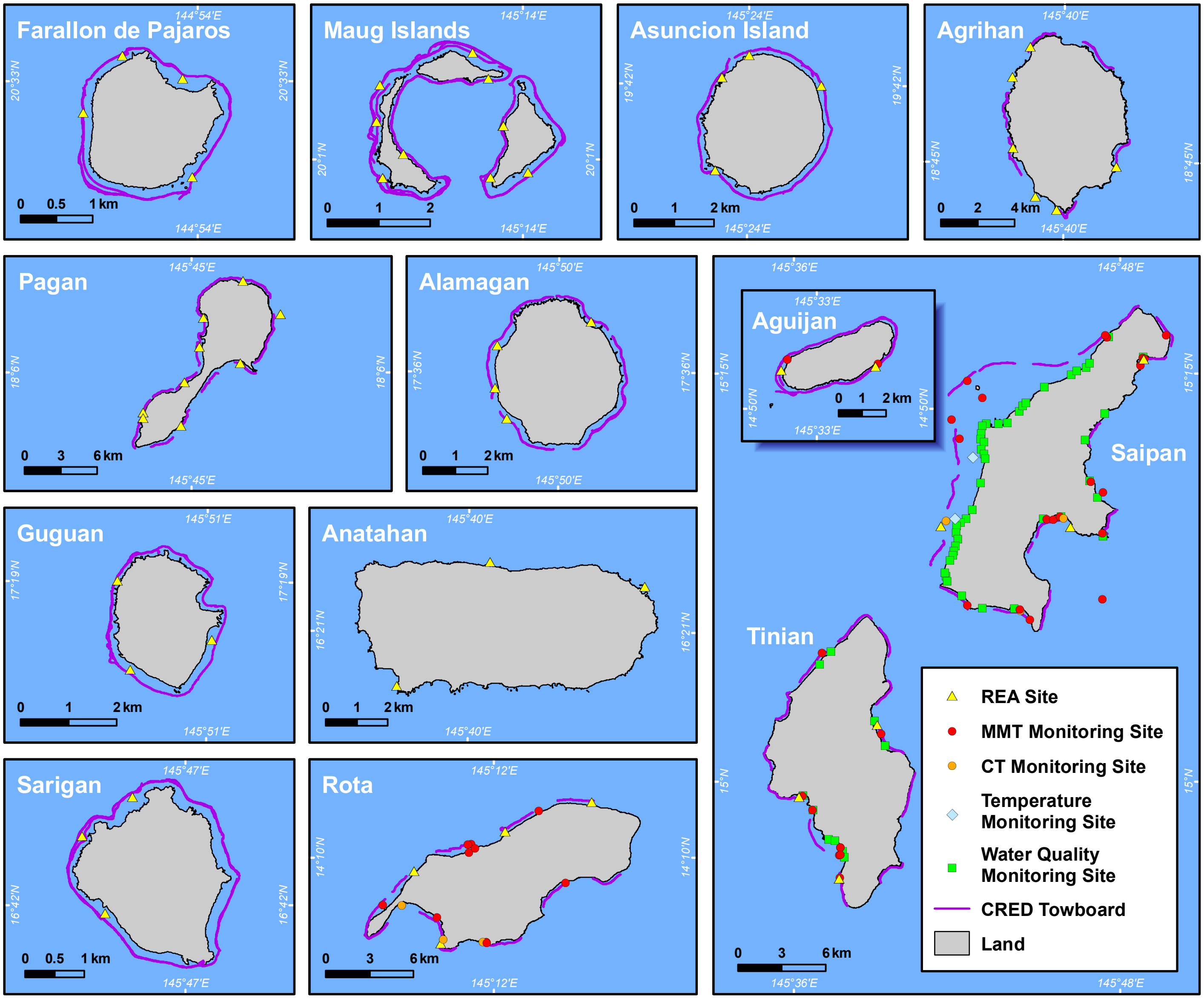

Figure 14.7. Monitoring locations sampled throughout the CNMI. Map: K. Buja.

Houk and van Woesik (2008) identified four distinct geomorphological settings that hold significantly different modern coral assemblages: 1) Holocene "spur and groove", 2) Rota Holocene "slope", 3) unconsolidated Holocene, and 4) Pleistocene. By developing this understanding of overarching environmental constraints to coral reef community development, monitoring efforts are better able to distinguish anthropogenic from environmental changes in the marine environment. Building from these characterizations monitoring efforts are now moving into detecting trends that improve our understanding of cause. A summary of current progress and future directions are presented below.

WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

As with reefs globally, the health, functioning and biogeography of CNMI's coral reef ecosystems are influenced by the regional oceanographic conditions, such as waves, temperature, salinity, turbidity, nutrients, and other measures of water quality. As these conditions change, so do the physical condition, distribution, abundance, and species diversity of each reef community. NOAA PIFSC-CRED efforts have just begun to characterize oceanographic conditions in the CNMI, and future data analyses will provide more detailed insight.

Local water quality monitoring efforts are focused upon the southern islands. Of the 83 locations that are monitored for water quality by the DEQ Environmental Surveillance Lab, 37.3% were classified as "impaired" due to excess nutrient and bacteria levels in 2006 (Table 14.4; Houk, 2006). Unsurprisingly, most microbiological violations were recorded at beaches near storm water discharges (Figure 14.8), especially during rain events (Figure 14.8). Many of these beaches are associated with the Saipan Lagoon, representing CNMI's most developed coastline, however, impaired waters exist on all islands except Managaha. In total, 42% of Saipan's beach shoreline was classified as "impaired", while only 28.2% of Tinian's and 8.7% of Rota's beach shoreline were similarly classified.

The dynamic nature of water quality data makes it very difficult to properly assess an area without spatially comprehensive and frequent sampling. An alternative approach towards understanding water quality is to examine the biological communities that are bathed by the waterbody in question. In tropical marine waters, these communities change in response to nutrients, sediment loads, turbidity, and other parameters (Valiela, 1995; Fabricius, 2005; Houk et al., 2005). Building upon habitat maps that characterize the Saipan Lagoon, significant relationships have been reported between the extent and integrity of seagrass beds and watershed size and development (Houk and van Woesik, 2008). The two ubiquitous seagrass-dominated habitats, *Enhalus acoroides* and *Halodule uninervis*, responded differently to proxies of watershed pollution. Habitats dominated by the former show expansion with increasing watershed development, while high proxies to pollution were related to increased macroalge growth inside the *Halodule* beds, which shade out seagrass and indirectly decrease its abundance. Current and future efforts will continue to examine causal relations by monitoring permanently marked seagrass beds associated with watersheds of varying size and level of development. These studies aim to identify how change occurs and the ecological indicators of negative change.

Table 14.4. Statistics associated with the CNMI Division of Environmental Quality's beach monitoring results from 2006. Source: Houk, 2006.

ISLAND	# BEACH MONITORING SITES	% WITH IMPAIRED WATER	% BEACH COASTLINE WITH IMPAIRED WATERS
Saipan	50	48.2	42
Managaha	11	0	0
Tinian	10	40.1	28.2
Rota	12	25	8.7
Overall	**83**	**37.3**	**28.8**

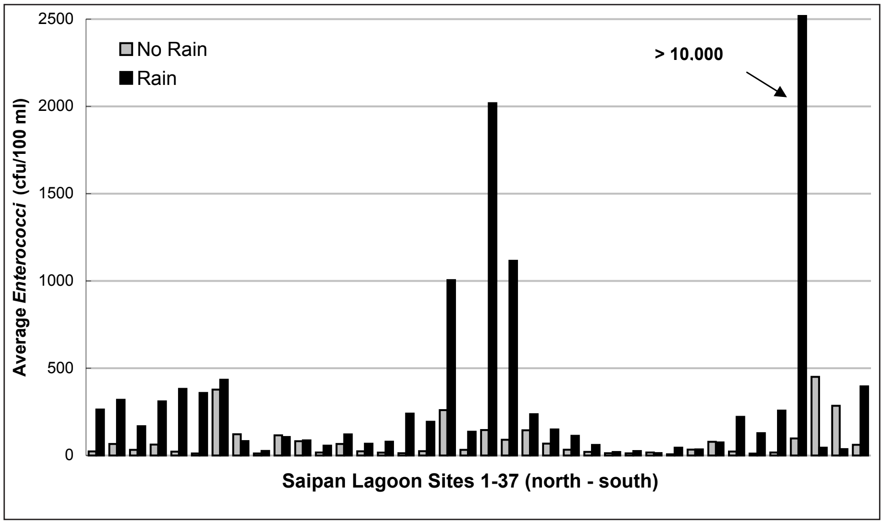

Figure 14.8. Average Enterococci *bacteria levels for 2006 at monitoring stations on the west coast of Saipan Island. Source: CNMI DEQ.*

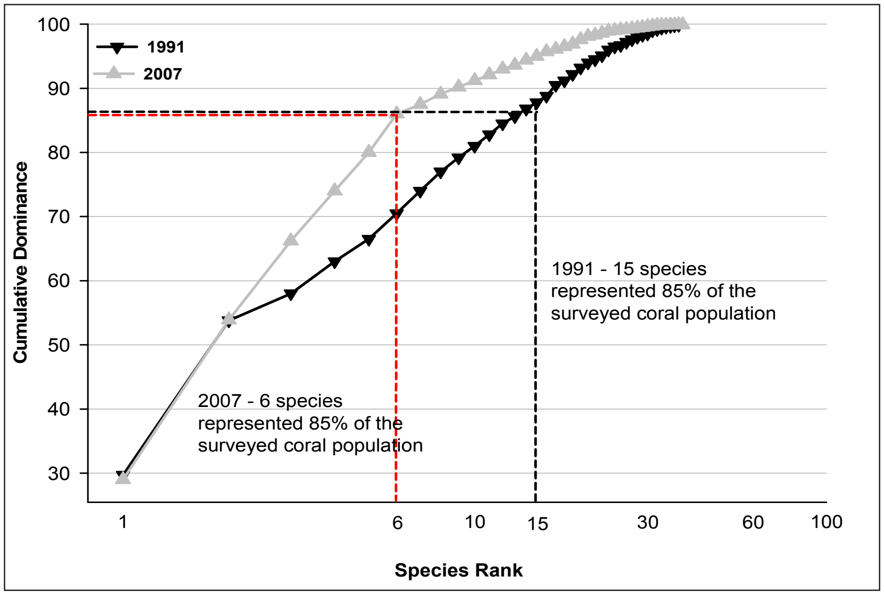

Figure 14.9. Coral species accumulation curves for reef-slope assemblages in Lau Lau Bay from 1991 and 2007. Source: CNMI DEQ.

Building upon geomorphological and environmental characterizations of CNMI's nearshore reefs, Houk and van Woesik (2008) found significant relationships between watershed development, human population density, and several ecological measures of coral reef communities that were most responsive to proxies of pollution. Coral species richness and abundance of recruits were the most sensitive indicators to land based pollution, while not being significantly altered by large-scale natural disturbances. In support, monitoring trends show decreased coral species richness in Lau Lau Bay where water quality has been declining due to land-based pollution (Figure 14.9). Ecological measures are currently being used as indicators to evaluate the "status" of nearshore reefs. A major informational gap is the current understanding of the fate and magnitude of watershed discharge to the marine environment. The raised, karst nature of the populated Mariana Islands makes visual estimations of the location and quantity of freshwater discharge (a proxy to pollution) insufficient. CNMI's goals are to create detailed maps of nearshore marine water quality using continuously-recording, water quality testing instruments integrated with positional data (global positioning system data), that together will yield Geographic Information System (GIS) layers for interpretive and modeling purposes (Figure 14.10). These results would estimate the spatial boundaries of watershed influence, and compliment the existing long-term biological monitoring that examines patterns, causes and processes that alter our coral reef ecosystem.

While DEQ's attended monitoring continues to provide a robust data set on populated islands, collecting water quality data throughout the entire CNMI is a daunting task that is gradually being met through the application of *in situ* data logging instrumentation (Table 14.3). The PIFSC-CRED program has enhanced coverage of data logging and satellite-linked water quality instrumentation since 2003 (Figure 14.11; Maug and Pagan, PIFSC-CRED), budget constraints already have impacted this program, as evidenced by the removal of a CREWS buoy in 2007.

However, local efforts, supported primarily through the Territorial Monitoring Grant Program, have been gradually expanding. The majority of monitoring stations presently measure temperature and salinity with basic loggers, but multi-parameter data sondes have recently been procured to characterize other parameters of CNMI's nearshore water quality (Figure 14.12). Further, efforts are underway to bring the NOAA ICON/CREWS program to Saipan in 2008, with direct support from CRM and the Territorial Monitoring Grant.

Most of the water quality data are analyzed on a site-specific basis, with future efforts aiming to produce spatial connections. For instance, unattended water quality instruments are now being used to characterize the effects of a newly established breakwater on SST in Rota's west harbor. The breakwall has isolated one portion of the lagoon and the alteration of water flow has increased temperature variability and appears to be hampering ecological recovery of benthic assemblages.

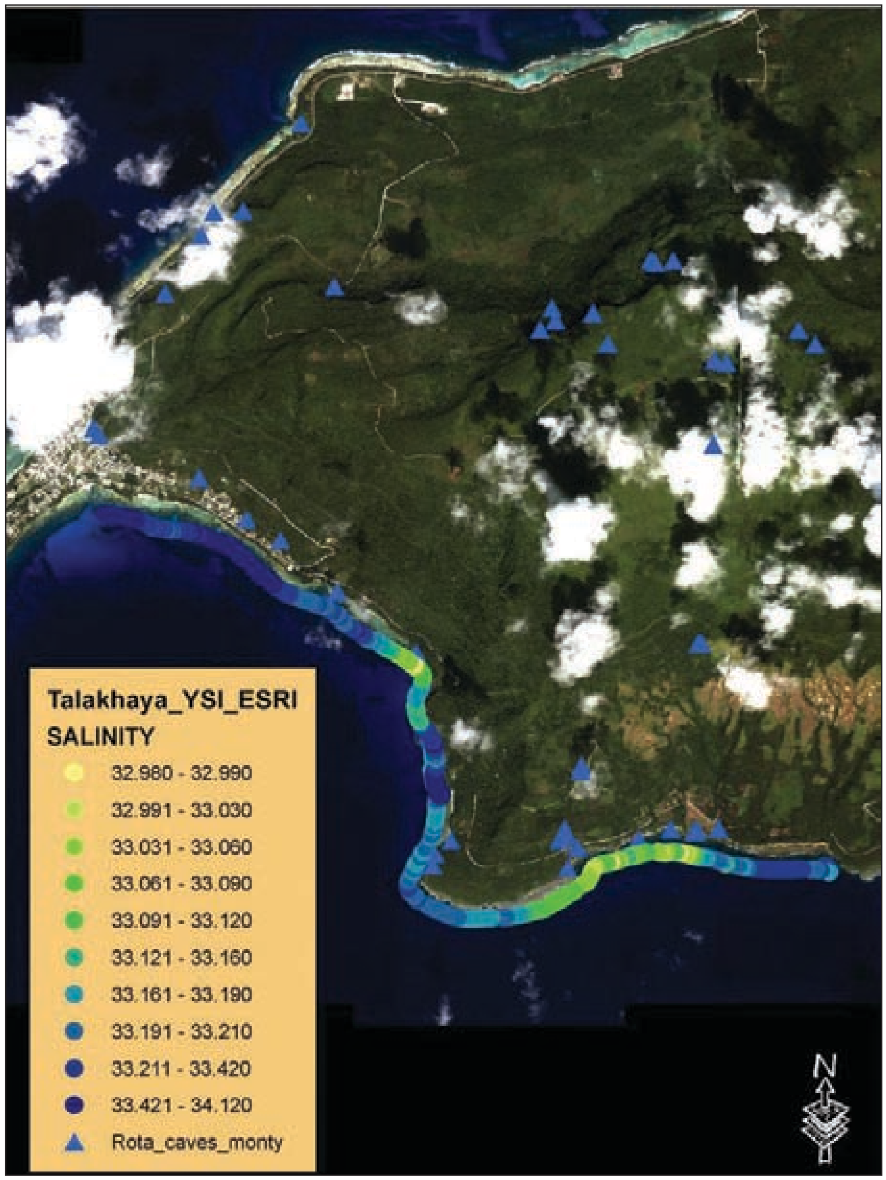

Figure 14.10. The coast of southern Rota showing variation in salinity at 1 m depth in relation to cave features. Source: CNMI MMT and Monty Keel.

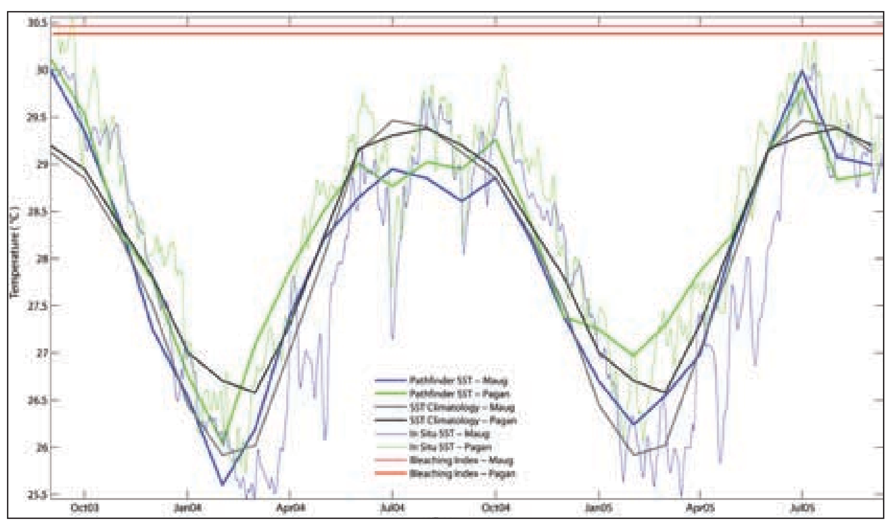

Figure 14.11. Satellite and in situ temperatures at Maug and Pagan. Throughout the three year time series, satellite derived SST shows mostly seasonal oscillations. Coral Reef Watch bleaching threshold of maximum monthly mean SST plus 1°C are included for reference. Source: PIFSC-CRED,unpub. data.

BENTHIC HABITATS

As stated earlier, the most extensive habitat mapping products have been created by the NOAA (2005). These products provide basic geological and ecological characteristics for the entire CNMI. Building from these products, the Saipan Lagoon was mapped in greater ecological detail using ground-based techniques (Houk and van Woesik, 2008). Changes over the past 50 years were assessed by comparing temporary habitat occurrences with those evident in the late 1940s (Cloud, 1959). There have been declines in the occurrences and extent of coral habitats (particularly staghorn *Acropora*), and increases in seagrass and algae habitats that were correlated with watershed characteristics (discussed above in the water quality section). Anomalous increases in SSTs evident in 2000 and 2006 caused high mortality (up to 50%) within back reef coral assemblages. It appears that nearshore seagrass habitats are most impacted by land-based pollution, while offshore back reefs suffer greatest from natural disturbances. Expanding from these characterizations and preliminary trends, a Saipan Lagoon monitoring effort has been established to continue to document and understand change over time at 28 permanent locations.

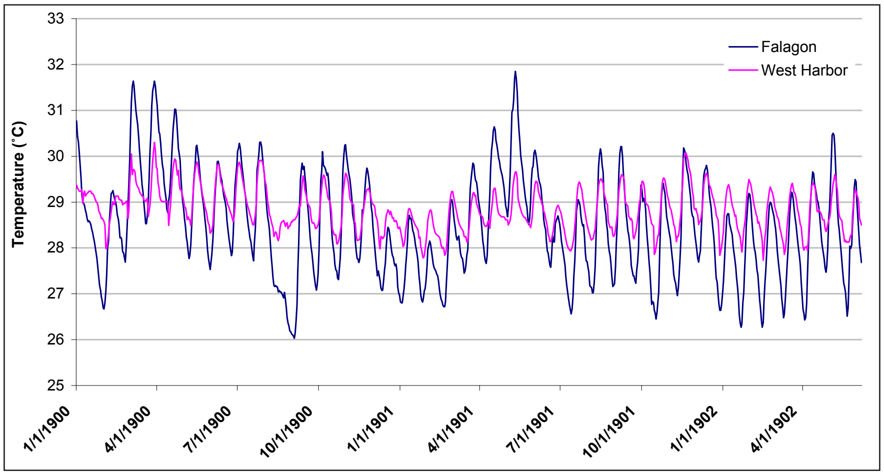

Figure 14.12. Temperature variation on the lagoon side (Falagon) and harbor side of a constructed breakwater at West Harbor, Rota. Source: CNMI MMT.

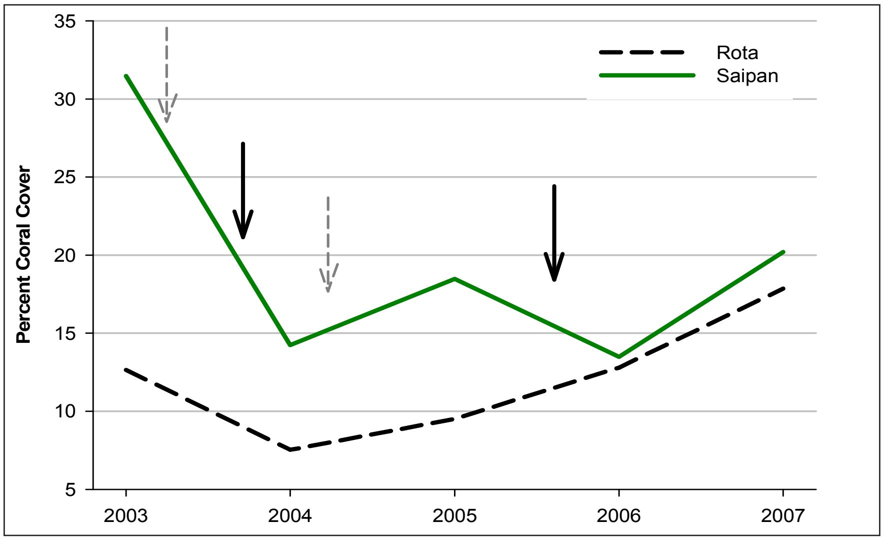

Figure 14.13. Trends in coral abundance on Saipan and Rota. Dashed arrows indicate high coral-eating sea star populations. Solid arrows indicated climate-induced coral bleaching. Source: CNMI MMT.

Described in the introductory section, the nearshore reefs assemblages can initially be characterized by their geological and environmental setting, and trends over the past six years are best understood by comparing similar reef types (e.g., stratification). The most influential disturbances that have occurred in the CNMI since monitoring by the MMT was initiated in 2000 were high populations of crown-of-thorns sea stars (COTS, *Acanthaster planci)* in 2003 and 2004 (Houk et al., 2007). Differences in resilience to these events have been noted at the island level (Figure 14.13), and among differing sites within islands (Figure 14.14). Declines in coral abundance were evident at most of the 30 monitoring locations during these disturbances; however, recovery of fast growing *Acropora* and *Pocillopora* corals varied, perhaps due to watershed and/or other oceanographic conditions. CNMI's marine monitoring program aims to analyze the rates of change in accordance with driving variables.

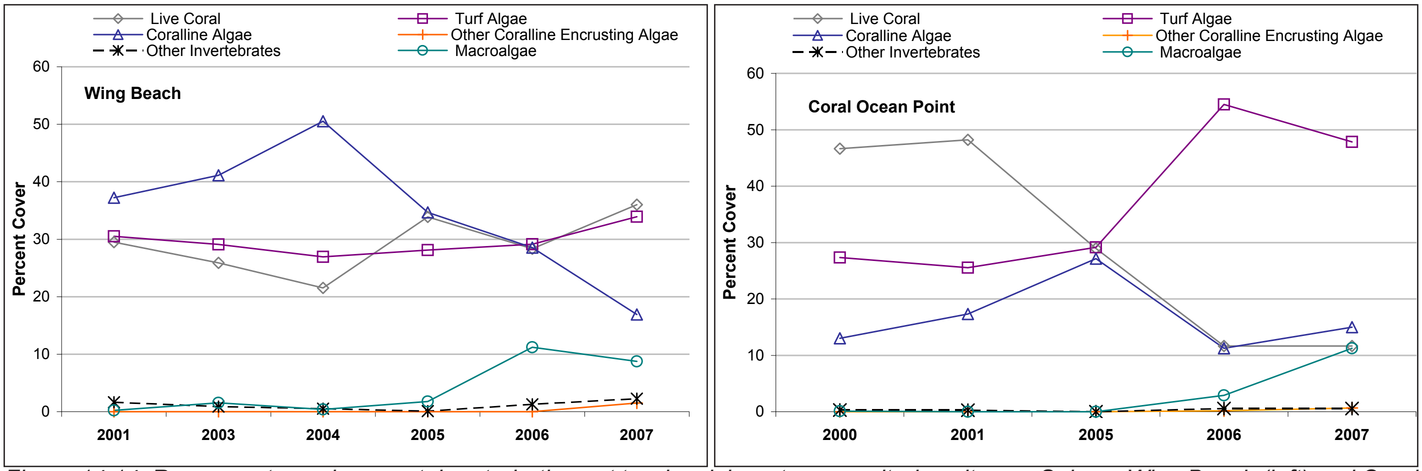

Figure 14.14. Response to environmental perturbations at two local, long-term monitoring sites on Saipan: Wing Beach (left) and Coral Ocean Point (right). Source: CNMI MMT.

Expanding on the existing MMT efforts, monitoring on the reef flats on Saipan, Tinian and Rota has recently begun. While most sites have only been visited a single time at present, two sites at Laulau Bay have been surveyed four times over two years (Figure 14.15). These surveys demonstrate a greater variability on reef flats than in fore reef environments, and indicate that the persistence of specific macroalgae may result from watershed-based pollution. Further information on local monitoring efforts is available online (http://www.cnmicoralreef.net/monitoring.htm).

In the remote northern islands, quantitative benthic surveys have been conducted on three occasions, led by NOAA's PIFSC-CRED and supported by several partner agencies in CNMI. The rapid ecological assessment (REA) data are currently being processed, however, initial analyses indicate that geology, water discharge patterns, and island size are the best predictors of modern coral assemblages. Unlike the southern islands, the relationship between the amount of vegetation in the watershed and the adjacent reef assemblage is weak, suggesting higher operating controls regulate coral reef populations.

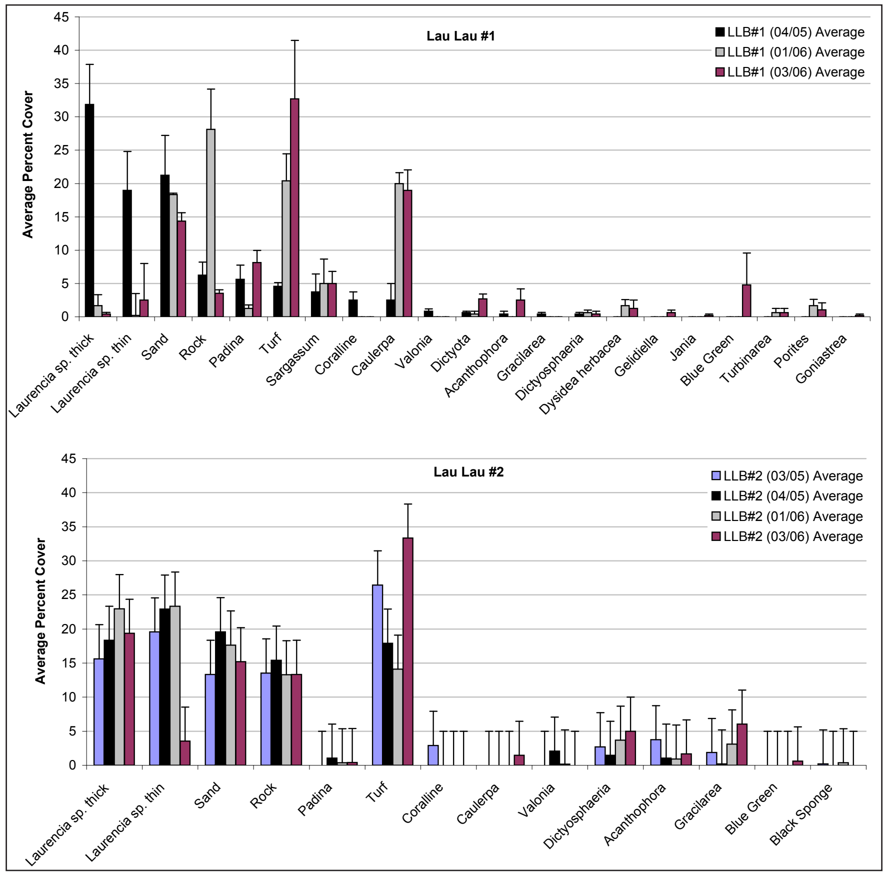

Figure 14.15. Annual and seasonal differences in benthic cover at two reef flat sites on Saipan: (top) Lau Lau #1 and (bottom) Lau Lau #2. Source: CNMI MMT.

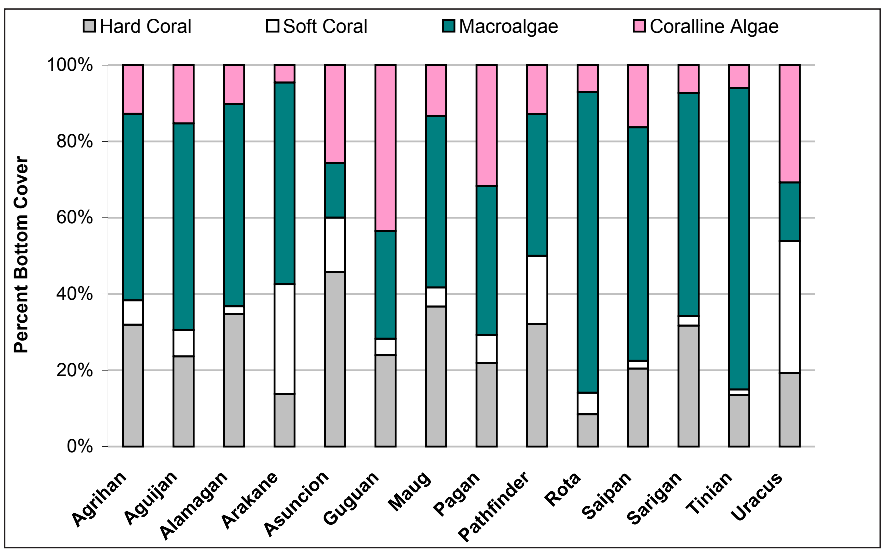

Figure 14.16. Dominant benthic cover categories for CNMI, including selected offshore reefs at fore reef sites. Source PIFSC-CRED, unpub. data.

MARAMP surveys also include a towed-diver approach that provides for broad coverage of island environments. A total of 110 towed-diver surveys were completed during the 2005 MARAMP, covering nearly 216 linear km of habitat and providing an initial overview of CNMI's benthic cover. These surveys revealed highly variable levels of coral and algal cover between islands (Figure 14.16). The highest overall hard coral cover was found at Pathfinder (average 25%, range 10.1–40%) and Maug (average 22%, range 0–75%). Maug had the highest coral cover for any single towed-diver survey conducted in CNMI, located along the western fore reef (average 55%, range 41.5–75%; Figure 14.16). Notable areas of soft coral cover were observed on Agrihan, where soft coral was dominant during several time segments along the western coast. Some of the vertical walls in the west had up to 90% coral cover. Arakane had the highest overall soft coral cover with an average of 25% and range of 1.1–62.5%. Algal cover was nearly as dominant as hard or soft coral cover on some islands: Rota had the highest overall macroalgae cover (average 56%, range 20.1–100%), followed by Tinian (average 53%, range 20.1–100%) and Arakane (average 46%, range 30.1– 75%). The highest overall coralline algae cover was recorded at Guguan (average 20%), followed by Pagan (average 13%).

The percent cover of hard coral with a loss of pigment from bleaching, predation, etc. is also assessed by towed-diver surveys as an indicator of coral stress. High levels of overall coral stress were recorded at Agrihan (average 5%, range 0.1–100%). The highest level of coral stress was located along the northeastern corner of Agrihan's fore reef (average 24%, range 0.1–100%; Figure 14.16). Pagan recorded the next highest overall coral stress level (average 3%, range 0–62.5%). The highest level of coral stress was located during a towed-diver survey along the northeast coast in the vicinity of Hira Rock and Baranka. In addition, at this site there were signs of COTS predation, along with higher numbers of COTS recorded during the survey than in any other area of Pagan, with 85 recorded within 50 minutes. Saipan had relatively low overall coral stress, with an average of 2% and a range of 0–40%. High levels of coral stress were recorded during towed-diver surveys completed between Puntan Obyan and Puntan Agingan in the south (average 13%, range 1.1–40%). Divers described certain sections of the survey as a “graveyard of *Pocillopora* on pavement”. During the 50-minute survey, 99 COTS were counted, which represents the highest concentration (60 individuals) in any 60-second period surveyed in CNMI in 2005.

Data from 2003 and 2005 MARAMP surveys were used to examine spatial and temporal changes in relative abundance of macroalgae across the Mariana archipelago to test the usefulness of common and abundant algae as indicators of ecosystem condition (Tribollet and Vroom, 2007). Genus-level algal data showed abundance patterns that indicated distinct dichotomies between carbonate versus volcanic islands, populated versus unpopulated islands, and small versus large islands. The diversity of macroalgal genera was generally highest at the southern end of the archipelago, probably because of increased habitat heterogeneity around these larger islands. Relative abundance of macroalgae showed significant variability at the local scale (between sites within an island) and over time. The environmental heterogeneity in the CNMI provides for remarkable overall diversity. A joint effort between the PIFSC-CRED and the Bishop Museum is addressing algal biodiversity of the CNMI based on 2003 collections. Preliminary findings have tentatively identified 327 species, of which 110 are new records (Tsuda et al., unpub. data; Table 14.6).

Table 14.6. Number of marine benthic algal species identified on each island, bank, shoal and remote reef in the CNMI (north to south) during the August and September 2003 cruise. Source: PIFSC-CRED; Tsuda et al., unpub. data.

ISLANDS, BANKS, SHOALS OR REEFS	NUMBER OF SPECIES				
	Cyanophyta	Rhodophyta	Phaeophyta	Chlorophyta	Total
Uracas	1	29	6	14	50
Stingray Shoals	1	6	3	1	11
Supply Reef	2	1	2	3	8
Maug	12	61	11	27	111
Asuncion	2	45	6	20	73
Agrihan	7	59	9	19	94
Pagan	11	91	11	37	150
Alamagan	6	51	8	20	85
Guguan	4	38	6	12	60
Zealandica Bank	2	9	1	6	18
Sarigan	8	31	5	12	56
Anatahan	2	28	2	10	42
Pathfinder Bank	3	14	2	6	25
Arakane Bank	2	8	4	7	21
Saipan	8	57	9	20	94
Tinian	7	41	9	17	74
Aguijan	8	31	6	23	68
Tatsumi Reef	1	3	0	1	5
Rota	9	82	12	39	142
CNMI (number of species)	23	192	21	91	327

Benthic Mapping

In support of the U.S. Coral Reef Task Force's mission to "produce comprehensive digital maps of all shallow (<30 m) coral reef ecosystems in the United States and characterize priority moderate-depth reef systems by 2009," NOAA's CRCP has developed a comprehensive mapping program for the Pacific Islands region. As documented in Starmer et al. (2005), NOAA's Center for Coastal Monitoring and Assessment, Biogeography Branch (CCMA-BB) produced shallow water benthic habitat map products from IKONOS satellite imagery (Figure 14.17; http://ccma.nos.noaa.gov/ecosystems/coralreef/us_pac_mapping.html) and CRED conducted multibeam and optical validation mapping around Saipan and Tinian in 2003 (http://www.soest.hawaii.edu/pibhmc/pibhmc_cnmi.htm).

In addition to CRCP's benthic habitat mapping program, other major mapping and scientific initiatives are being sponsored by the U.S. in CNMI. NOAA's Ocean Exploration program conducted geologic and water chemistry surveys in the remote Northern Mariana chain in 2003 and 2006 as documented at http://oceanexplorer.noaa.gov/explorations/06fire/ and http://oceanexplorer.noaa.gov/explorations/03fire/. A 2007 NOAA-sponsored cruise aboard a U.S. Naval Oceanographic Office vessel the *U.S.N.S. Bowditch* mapped deeper waters of the western insular margin in order to better define the U.S. Exclusive Economic Zone.

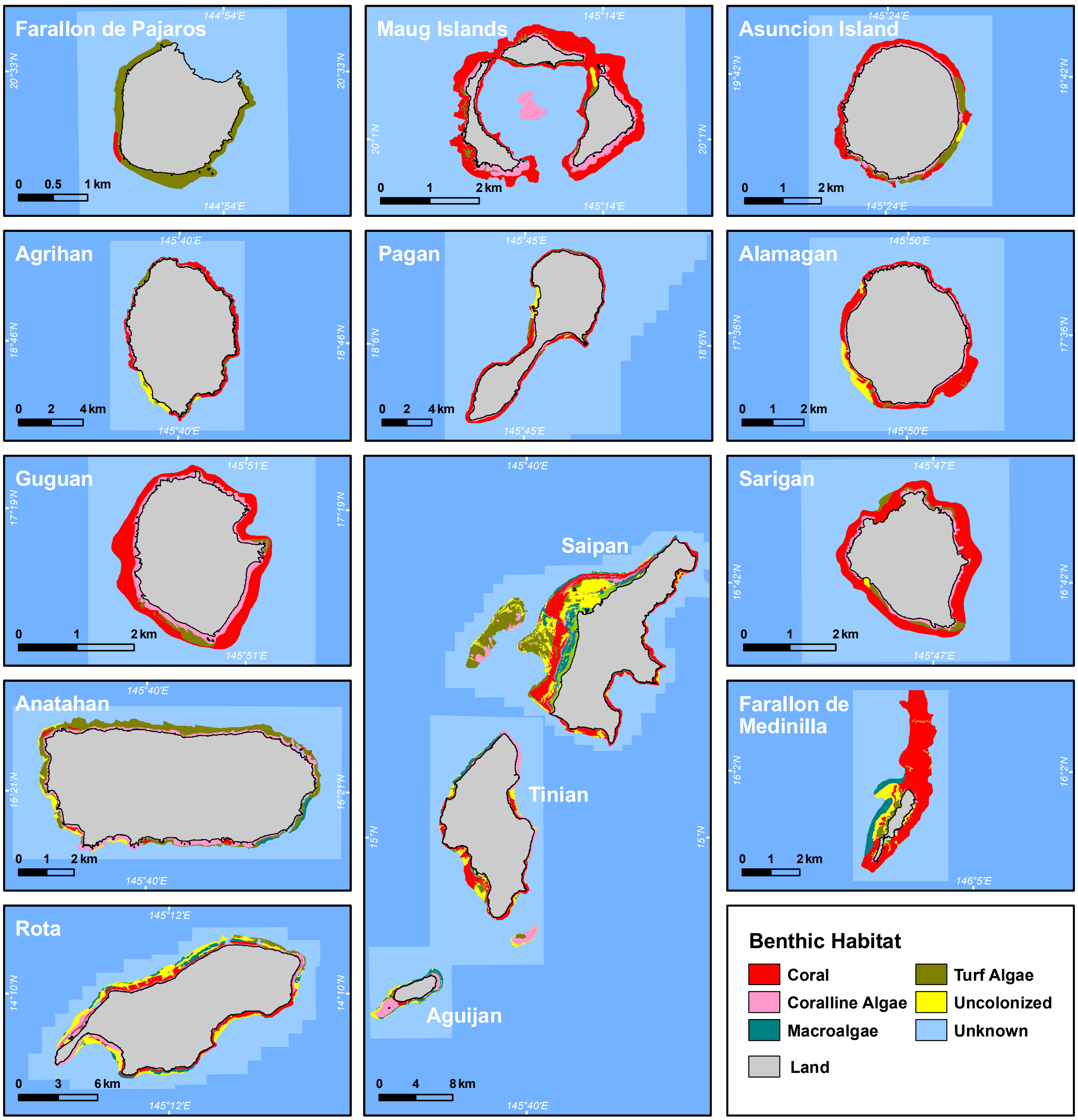

Figure 14.17. Nearshore benthic habitat maps were released in 2005 by CCMA-BB based on visual interpretation of IKONOS satellite imagery. Source: CCMA-BB, 2005. Map: K. Buja.

In late 2004 PIFSC-CRED scientists worked in Saipan to collect optical validation data in the Garapan anchorage as part of an assessment of bottom types in the area, and produced a report documenting this work (PIFSC-CRED, 2005). A towed camera system was deployed to collect 123 linear km (75 miles) of video footage. Figure 14.18 presents the results of an analysis of these video data in terms of coral cover percentage along the video tracks. Analysis of the optical validation data has produced GIS shape files that contain information on substrate types and other parameters. Findings are available for download from the Pacific Islands Benthic Habitat Mapping Center Web site at http://www.soest.hawaii.edu/pibhmc/pibhmc_cnmi.htm.

Using these processed multibeam and optical validation data, analyses of sand versus non-sand habitats and percent coral cover in non-sand habitats were conducted (Figure 14.19). The interpolated percent coral cover values were derived by kriging the classified optical validation (video) data. The yellow/red color gradient in this figure represents percent coral cover on the reef, and purple areas indicate sand substrate, and therefore 0% coral cover. The underlying base (gray) layers are hillshades derived from multibeam bathymetry on top of NOAA nautical charts.

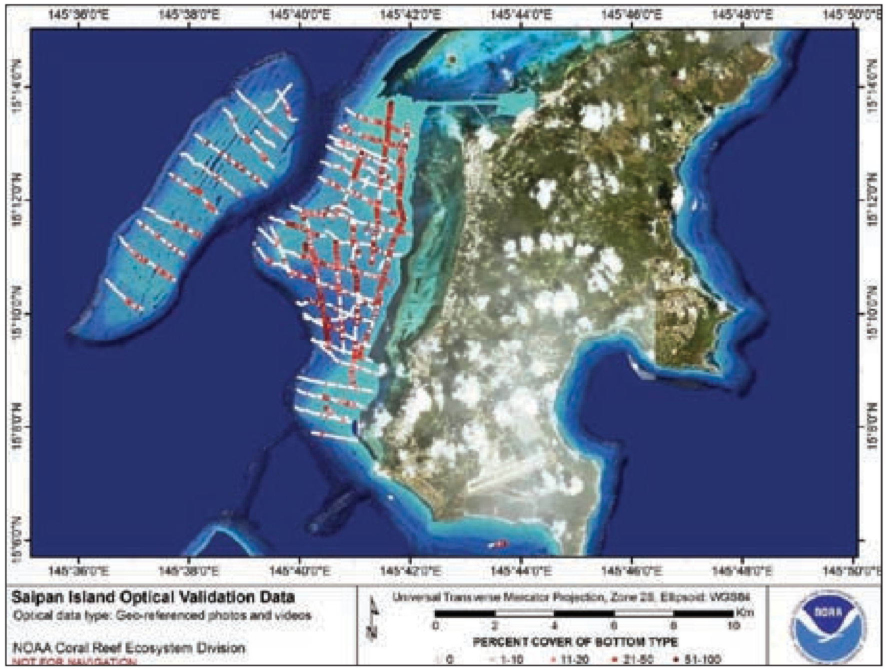

Figure 14.18. Video data (123 km) were collected and classified according to percent cover of bottom type. Source: PIFSC-CRED.

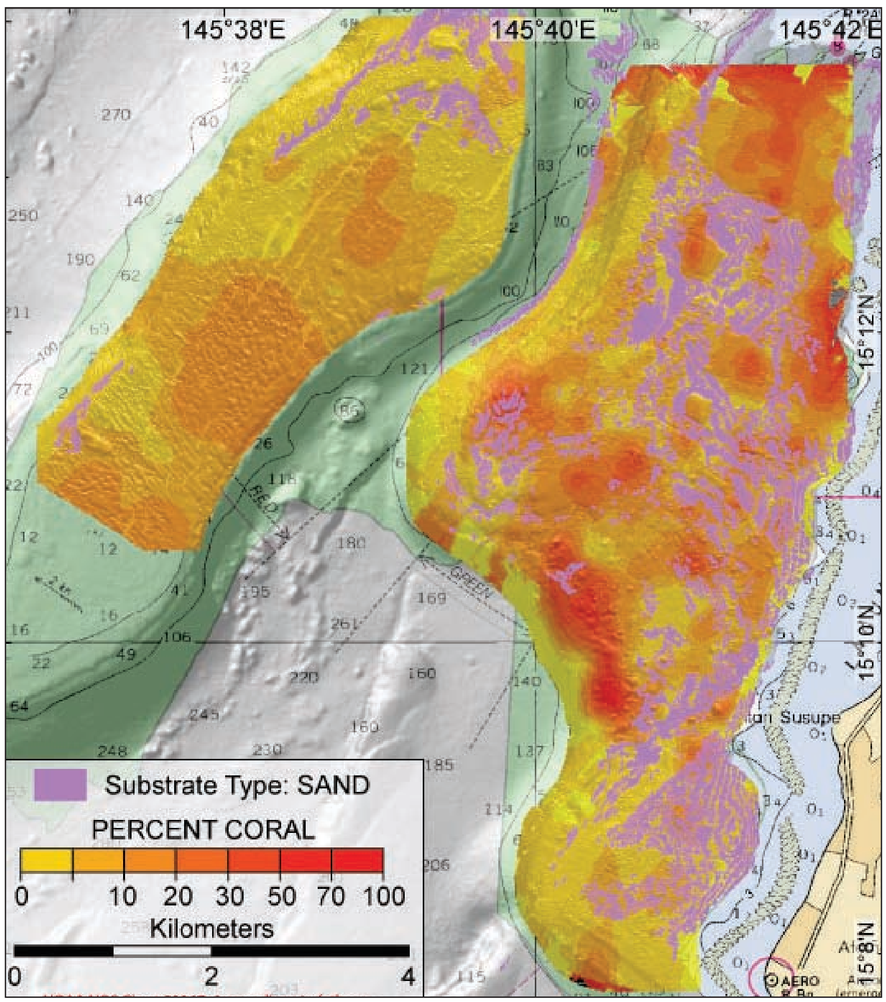

Figure 14.19. Sandy basins and interpolated values of live coral cover in the Saipan Anchorage. Source: PIFSC-CRED.

In 2007 during the biennial MARAMP cruises HI0702 and HI0703, multibeam bathymetry and backscatter data were collected around Rota (Figure 14.20), Tinian, Aguijan, Saipan (Figure 14.21), Sarigan, Zealandia Bank, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, Supply Reef, and Uracas (Figure 14.22). Shallow sonar data (10-300 m, 30-1,000 ft) were collected using the R/V *Acoustic Habitat Investigator (AHI)*, while overlapping and deeper sonar data (200-3,000 m, 650-9,850 ft.) were collected using the NOAA Ship *Hi'ialakai*. All maps shown here are in draft form because only preliminary processing was completed aboard ship; further processing is underway. In addition to the data shown here, which was collected primarily for coral ecosystem habitat analysis, the R/V *AHI* was also used by scientists from PIFSC-CRED in collaboration with personnel from NOAA's Office of Coast Survey to survey and update nautical charts for Saipan, Tinian and Rota harbors. The 2007 data are also being integrated into a project by NOAA's Ocean Exploration program to synthesize all available data in the Mariana Archipelago to produce a consistent bathymetric data set for the region.

Local mapping efforts have concentrated on habitat mapping within Saipan Lagoon. These activities have received support through funding from EPA and NOAA's National Coral Reef Ecosystem Monitoring Program grants and General Coral Reef Conservation grants. The mapping project was started in 2001 and fieldwork was completed in 2005. Ground based mapping methods and results of these efforts are reported in Houk and van Woesik (2008). While final map products for the southern lagoon are now being finalized, an interactive Web site provides an introduction to habitats in the northern lagoon (http://www.cnmicoralreef.net/sl/northlagoon.htm). Habitat classifications are now being used by the MMT to guide placement of monitoring sites within the lagoon using a stratified random sampling approach.

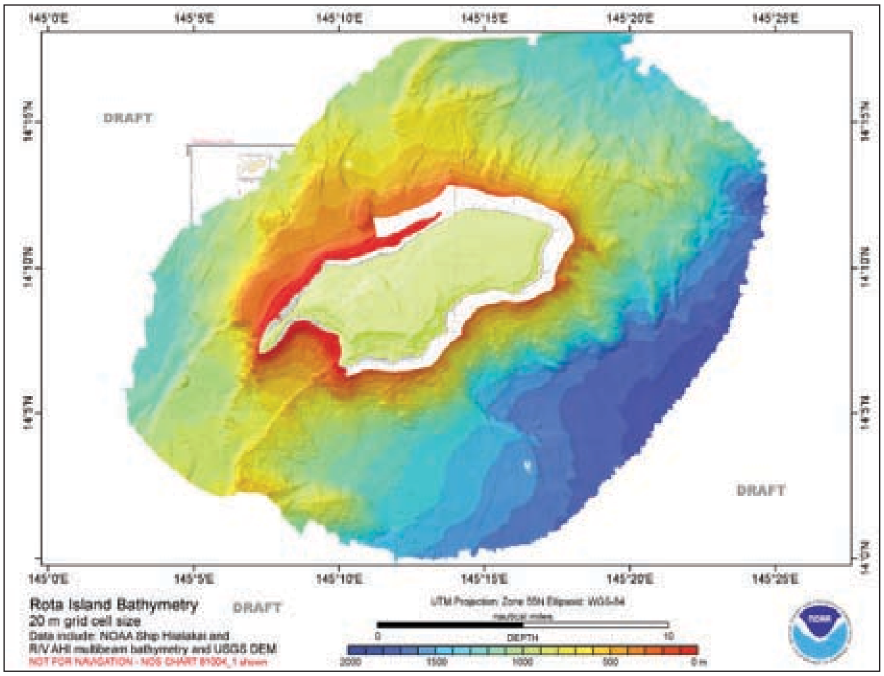

Figure 14.20. Multibeam data collected for Rota. Source: PIFSC-CRED.

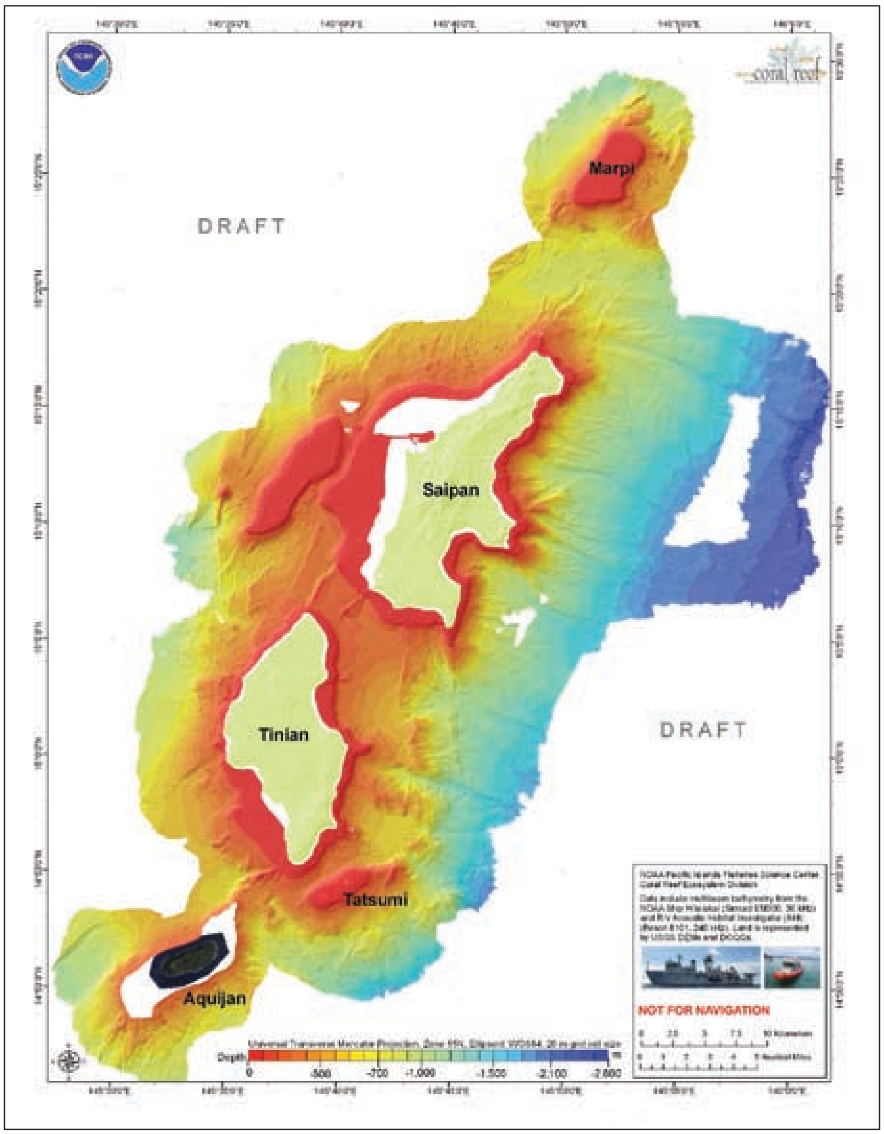

Figure 14.21. Multibeam data collected for Saipan, Tinian and Agijuan. Source: PIFSC-CRED.

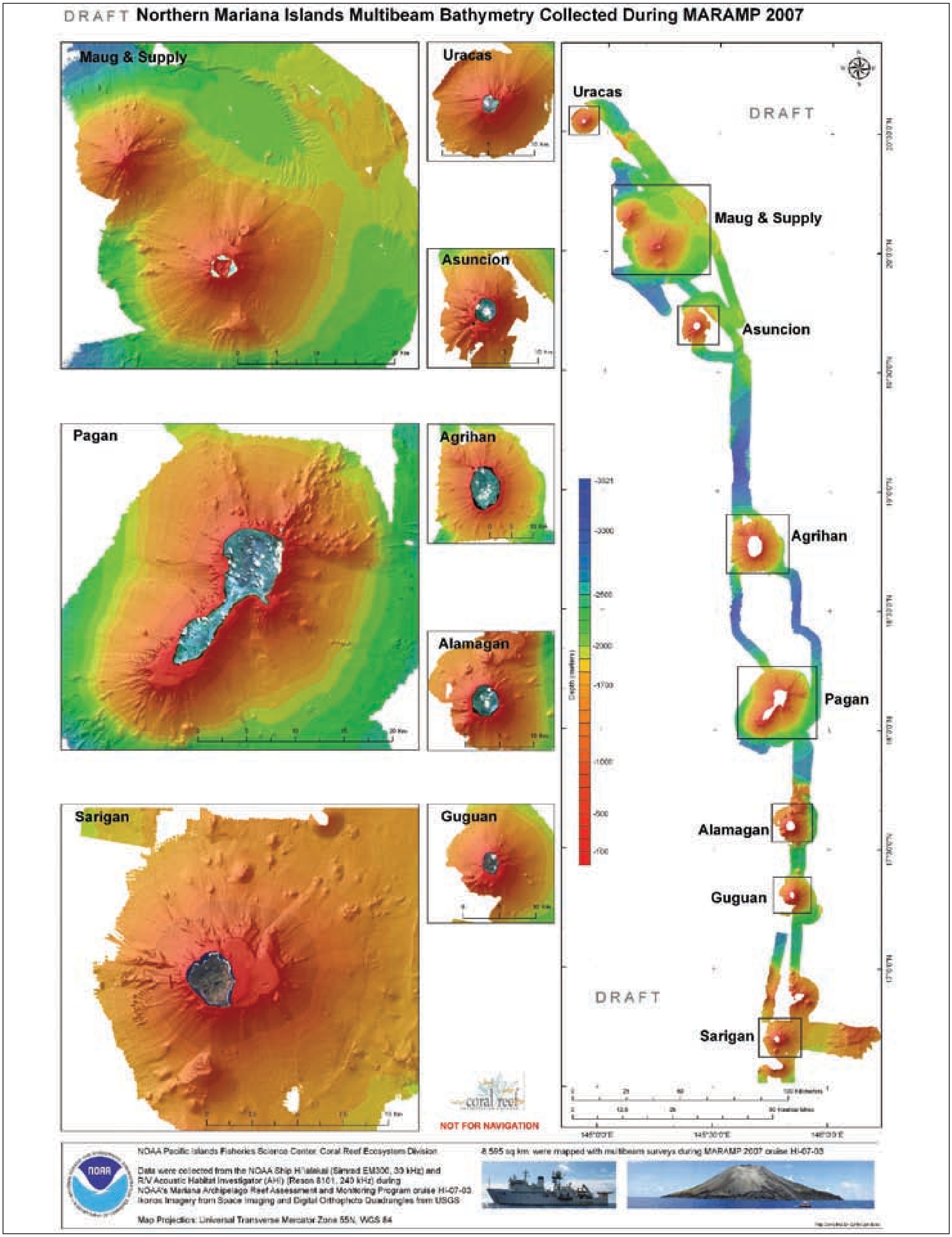

Figure 14.22. A composite of all PIFSC-CRED multibeam data available in the remote Northern Mariana Islands. Source: PIFSC-CRED.

ASSOCIATED BIOLOGICAL COMMUNITIES

Coral Reef Fishes

Three programs currently conduct in-water fish monitoring surveys in the CNMI. The DFW Fisheries Research Section has conducted annual surveys of two marine protected areas, Managaha Marine Conservation Area (MMCA) on Saipan and Sasanhaya Bay Fish Reserve (SBFR) on Rota, since 2000. The CNMI Marine Monitoring Team (MMT) has included annual fish surveys as part of their long-term monitoring protocol since 2000 at sites around Rota, Tinian, Saipan and Aguijan. The NOAA PIFSC-CRED began fish surveys throughout the archipelago during the initial MARAMP cruise in 2003 and has repeated surveys on a two-year cycle. In addition to in-water surveys, the DFW Fisheries Data Section collects monthly commercial fish catch data provided by fish vendors, which provides a direct measure of fisheries pressure on local coral reef fish resources. In the following sections, data from DFW and PIFSC-CRED are provided.

On an archipelagic scale, PIFSC-CRED found that fish assemblages around the CNMI in 2005 were essentially similar to that found during the MARAMP cruise two years prior (Starmer et al., 2005). The general trend recorded by towed-diver surveys indicates a greater biomass of larger fish in the northernmost islands (0.25 ton ha^{-1}) compared to the middle section of the island chain (0.13 ton ha^{-1}) and the heavily populated southern islands (0.05 ton ha^{-1}; Figure 14.23). Large fish biomass was moderately abundant on the western banks (0.10 ton ha^{-1}). A similar pattern was observed by the REA team conducting stationary point count surveys at monitoring sites (Figure 14.24) In general, sharks were scarce throughout the archipelago, but slightly more common at Asuncion, Zealandia, Agrihan and Pathfinder. The most common fishes were damsels and small wrasses, especially in the southern islands, and many species exhibited good recruitment pulses (e.g., *Chromis acares*, *C. vanderbilti*, *Pomacentrus vaiuli*). A few individual Napoleon wrasse (*Cheilinus undulatus*), including some large ones, were seen around the mid-chain and in the southern islands. Bumphead parrotfish (*Bolbometopon muricatum*) were not seen in 2005, although several were seen in the archipelago in 2003. The size class distribution of targeted species (snappers, jacks, groupers and sharks) showed low numerical density in Guam and the Southern Islands, especially for fish larger than 20 cm (Figure 14.25).

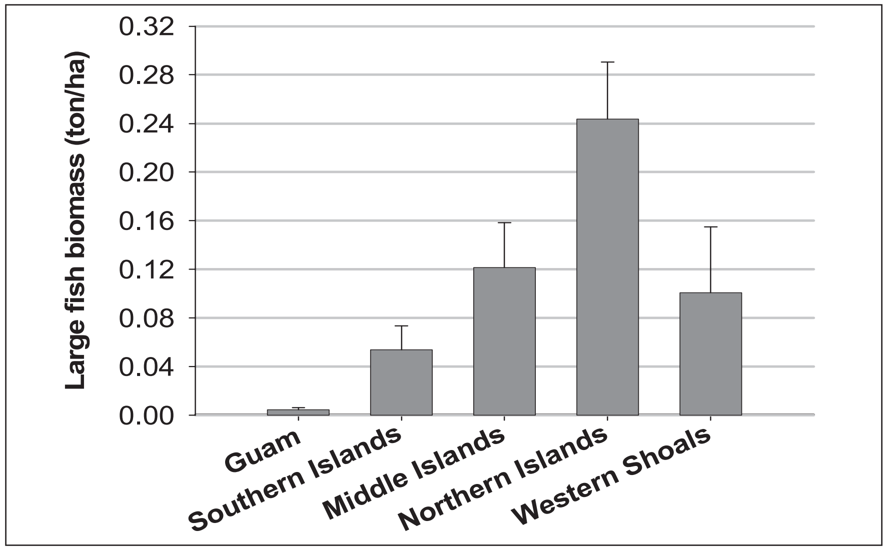

Figure 14.23. Large (>50 cm) fish biomass as observed in towed-diver surveys across the Marianas Archipelago. Source: PIFSC-CRED, unpub. data.

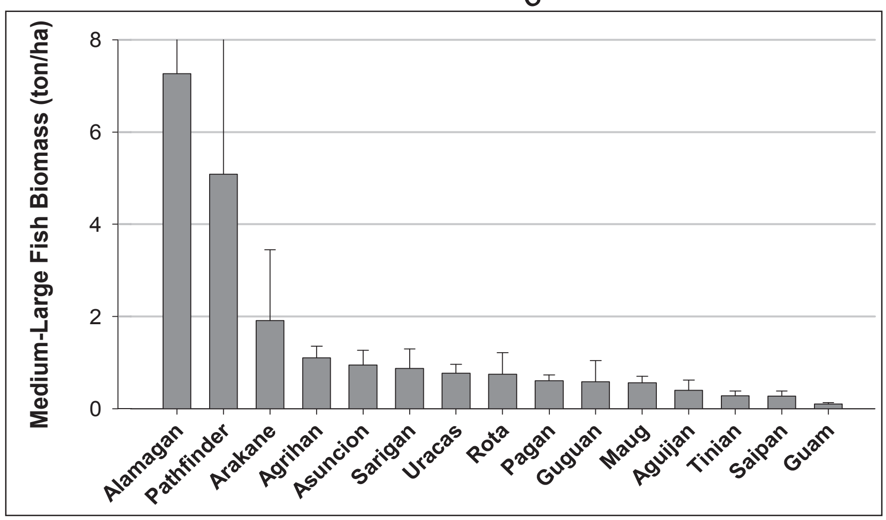

Figure 14.24. Medium-large (>25 cm) fish biomass recorded in Stationary Point Counts across the Marianas Archipelago. Source: PIFSC-CRED, unpub. data.

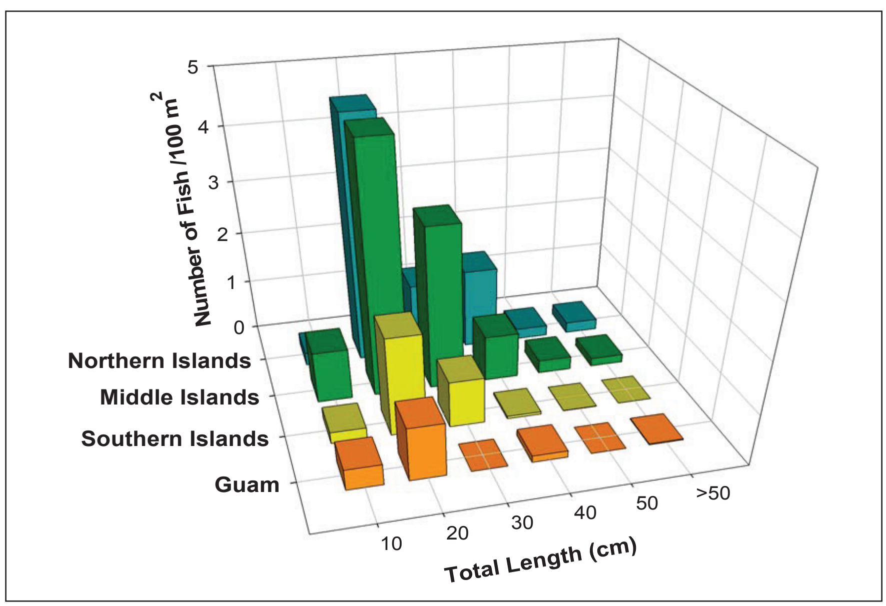

Figure 14.25. Numerical density of targeted families (snappers, jacks, groupers, and sharks) by size class measured on belt transects across the Marianas Archipelago. Source: PIFSC-CRED, unpub. data.

Within the MMCA and SBFR, DFW belt transect surveys identified generally positive trends in surveyed fish populations. The data shown in Figure 14.26 show relative population estimates of 12 food fish groups over time in the MMCA and SBFR. Data collection was allocated according to a stratified random sampling approach using the four primary habitats where transect data has been demonstrated to be useful; the reef slope, lagoon deep patch reef, lagoon shallow patch reef/*Acropora* zone, and the mixed area. For SBFR, the graphs of relative population over the 2000-2006 survey period indicate positive upward trends for the Lutjanidae, Mullidae, Nasinae, Serranidae, roving Acanthuridae, and initial and terminal phase Scaridae. No trends are evident among Balsitidae, Holocentrinae, Myripristinae, Lethrinidae and sedentary Acanthuridae. Within the MMCA, Lutjanidae and Nasinae did not exhibit a detectable trend, but all other surveyed groups exhibited populations increases, especially over the last two survey years.

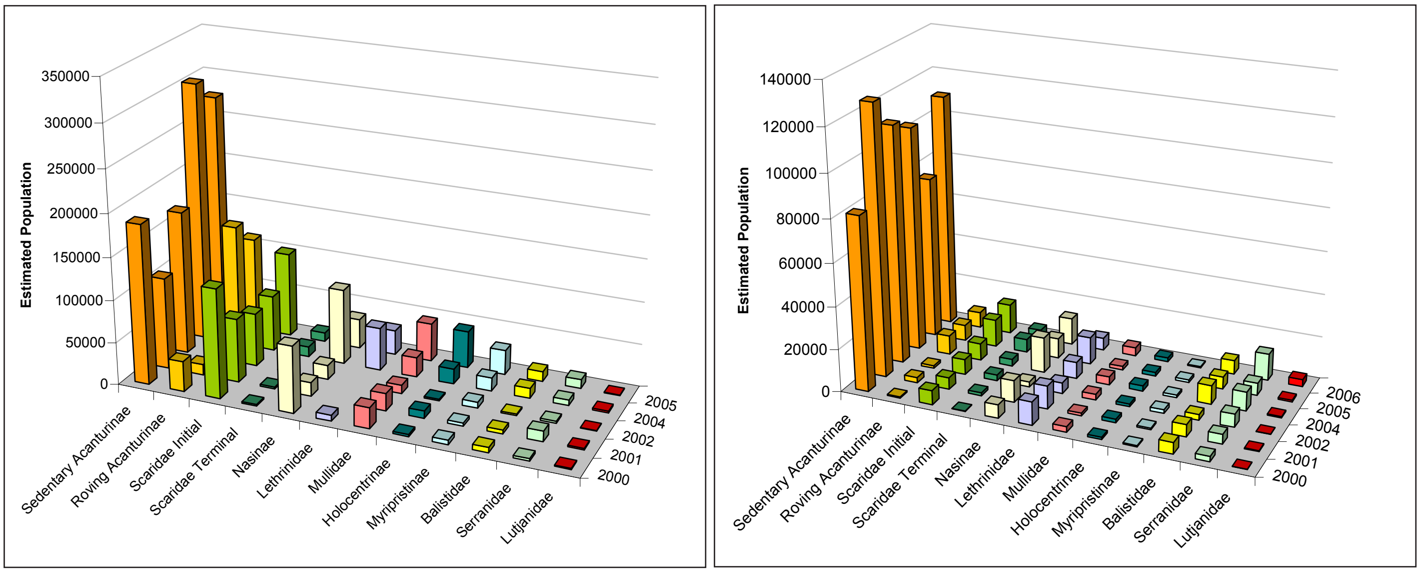

Figure 14.26. Belt transect survey data from stratified random sampling at MMCA (left) and SBFR (right), agglomerated from the primary habitats where transect data has been demonstrated to be useful. Source: CNMI DFW.

Regular enforcement began in late 2002, which DFW believes to be directly attributable to the enhancement of reef fish resources within the MMCA. The institution of regulatory restrictions on the use of gill, drag and surround nets in 2003 have also enhanced the MMCA and probably the entire lagoon in general, as these methods of harvest were most prevalent in the Saipan Lagoon. In addition, the ban on the use of SCUBA spear fishing on Saipan in 2003 has also improved the abundance of food fish groups. As an example, relative population estimates of Lethrinidae in Figure 14.27 indicate a positive trend over the past two years, which are attributable to *Gnathodentex aurolineatus* and *Lethrinus harak* becoming more abundant since the inception of prohibitions on use of scuba spear and nets. Both species were landed in high numbers during the scuba spear fishery (Graham, 1994; Trianni, 1998), and *L. harak* has comprised as much as 40% of recent exemptions to the net prohibition (DFW, unpub. data). It can be considered that the increase in abundance of *L. harak* was due not only to the MMCA but also to the scuba spear and net prohibitions, as this species travels widely throughout the lagoon, whereas the increase in *G. aurolineatus* is more likely due to the MMCA and the scuba spear ban.

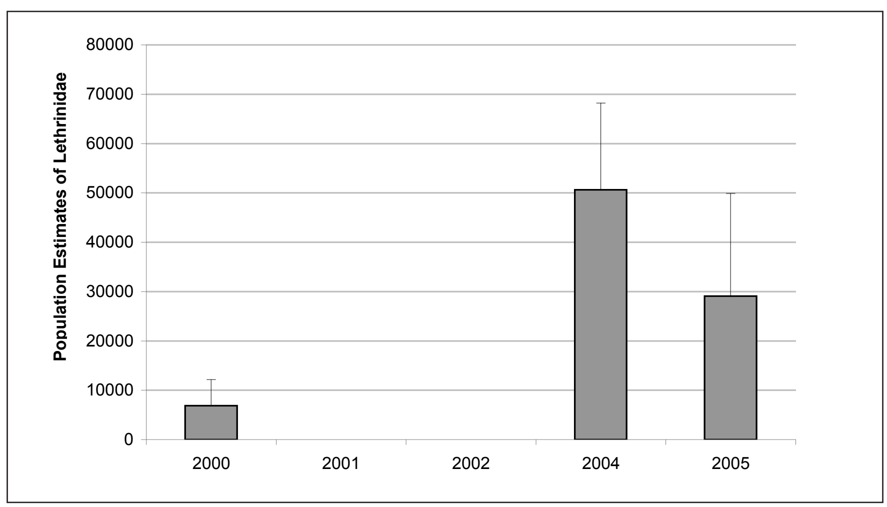

Figure 14.27. Belt transect data for Lethrinidae in MMCA on Saipan from a set of pooled sampling strata. Source: CNMI DFW.

Although the SBFR was created in 1994, little management action occurred until March 2000, when the DFW formally demarcated the boundaries with marker buoys. Even with the lack of adequate enforcement in the SBFR, seven of the twelve groups surveyed demonstrate an upward trend over time. More importantly, no groups indicated a negative trend. There is no clear indication of the reasons for either trend, although there may have been a self-governed harvest restraint practiced by some percentage of the Rota fishing community. The lack of real trends in nearly half of the groups may be indicative of a relatively stable fish community, with observed increasing trends merely natural variability.

The DFW Fisheries Data Section provides monthly catch data to NOAA PIFSC's WPacFin program, which maintains fisheries data across the Pacific and is available at http://www.pifsc.noaa.gov/wpacfin/cnmi/Pages/cnmi_data_1.php. These data are provided by Saipan fish vendors to DFW. The robustness and coverage of the data, especially in early years of the program, was less than complete. As a result, catch data are adjusted to 100% and reported as estimates. Figure 14.28 illustrates the importance of reef fish to the fisheries industry on Saipan. While most reef fish are reported as management units and combined with non-reef associated taxa, rabbitfish, parrotfish and spiny lobster (Figure 14.29) are reported individually.

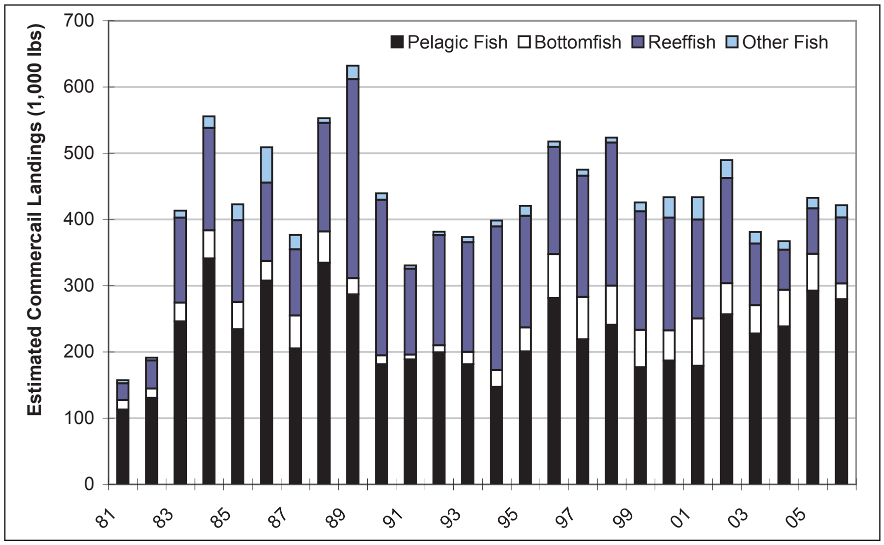

Figure 14.28. Annual estimated commercial landings of fish for Saipan, 1981-2006. Source: WestPacFin.

Invertebrates

As with fishes, the MMT, DFW and PIFSC-CRED have conducted invertebrate surveys in CNMI. DFW concentrates monitoring efforts on finfish and has paid sporadic attention to specific taxa of fisheries interest, sea cucumbers and *Trochus*, but does not consistently monitor these resources. Inconsistencies in the application of PIFSC-CRED's REA survey methods, used during MARAMP cruises, hamper the use of this program's invertebrate data for monitoring trends in abundance. However, the PIFSC-CRED towed-diver surveys provide an overview of areas of notable COTS abundance, as described in the benthic status section above. MMT data have also identified peaks in COTS abundance at long-term monitoring sites: Barcinas Bay at Tinian in 2003 and Wing Beach at Saipan in 2005 (Figure 14.30).

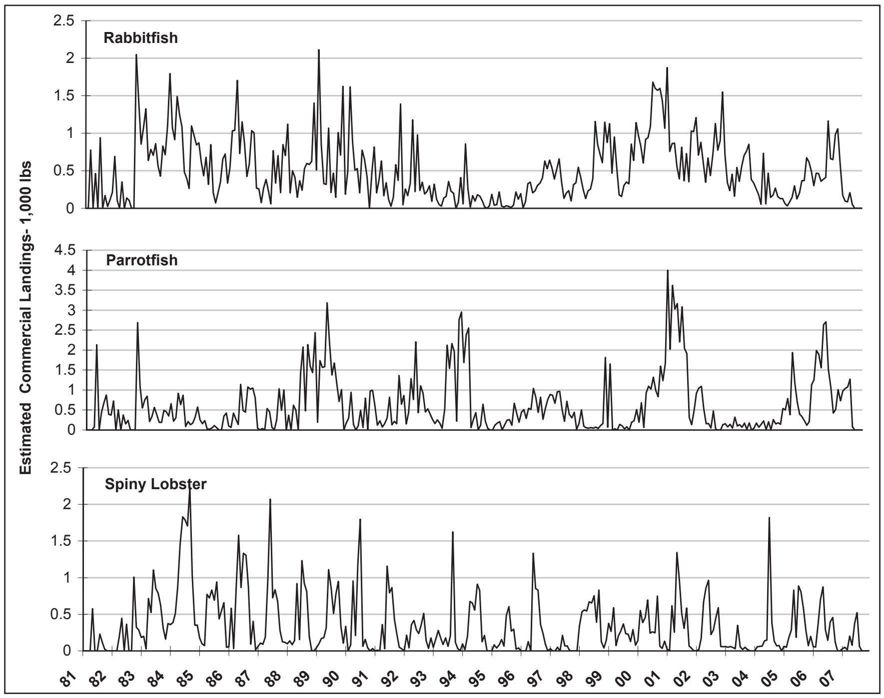

Figure 14.29. Estimated commercial landings from Saipan, 1981-2008. Source: WestPacFin.

The CNMI's long-term monitoring program has collected data on macroinvertebrate abundances on an annual basis at most fore reef survey sites. Most sites have exhibited remarkable year-to-year variation in invertebrate abundances (Figure 14.30). Unfortunately, even abrupt changes in species composition, as were observed in 2005-2006 at Rota's Sasanhaya and West Harbor do not to have obvious environmental correlates. With the exception of *Tridacna* clams, the majority of taxa included in the study are not harvested at survey sites, so the variation may simply be the result of stochastic variation in recruitment.

The MMT is further extending its invertebrate monitoring effort to reef flats, deeper fore reefs and habitats within the Saipan Lagoon to gain an improved understanding of invertebrate spatial distribution. While few of these novel sites have been revisited and none have sufficient temporal coverage to provide trend data, these habitats are proving to be less diverse than fore reef habitats, though abundances of some taxa, especially sea cucumbers, are exceedingly high in lagoon habitats.

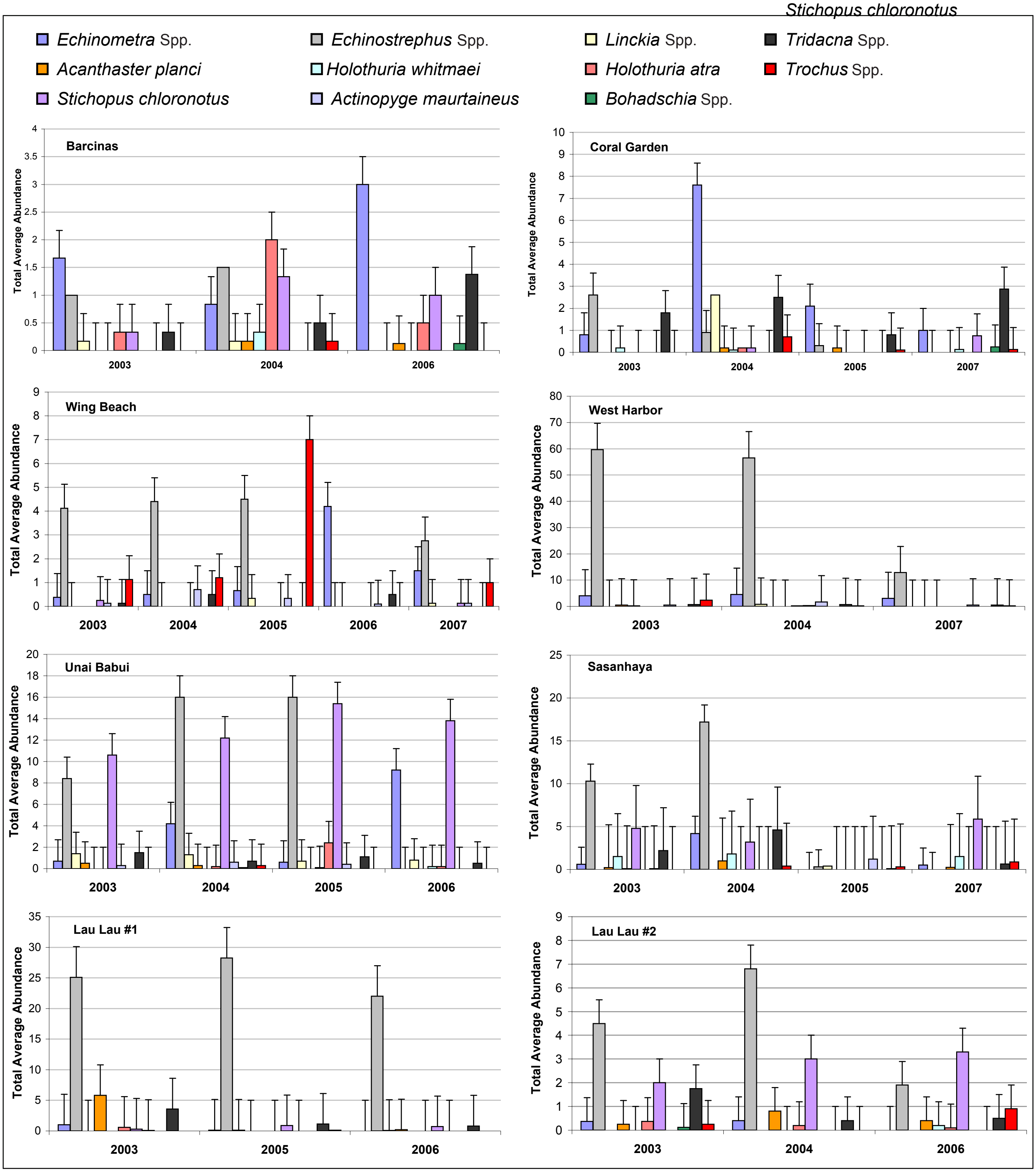

Figure 14.30. Abundance of macroinvertebrates expressed as average per 100 m² at 8 m depth fore reef MMT long-term monitoring sites. Source: CNMI MMT.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Micronesia Challenge

In March 2006, the President of Palau launched the Micronesia Challenge (MC) at the Eighth Conference of Parties to the Convention of Biological Diversity to promote efforts to effectively conserve 30% of marine resources and 20% of the terrestrial resources by 2020. Five political entities of Micronesia, including the CNMI Governor, signed on to the MC Declaration of Commitment. The MC is designed to build on ongoing conservation work in each jurisdiction and increase access to critically needed resources, regional coordination and cooperation. Local environmental agency representatives attended an organizational meeting in Palau later that year. While most other signatory jurisdictions are focusing efforts on Marine Protected Area designations, the CNMI's approach is more general and is focusing on marine resource status and NPS pollution issues along with consideration of place-based management efforts.

U.S. Coral Reef Initiative (CRI)

The CNMI continues to actively participate in U.S. Coral Reef Initiative (CRI) activities. Interagency management efforts have been focused more clearly through the LAS development and implementation. Since its development in 2003, the LAS have been in an implementation stage. The LAS process has been important in identifying management gaps and providing tangible benchmarks to address those gaps. CNMI continues to utilize the LAS to address problems affecting coral reefs, and is in the process of developing a new round of LAS to further address current threats. The 2003 CNMI Coral Reef LAS are currently being evaluated and revised. The CNMI LAS focus on fisheries management, land-based sources of pollution, public use and misuse, public awareness and involvement and coral reef resource management. The LAS has been the primary guide for design of implementation projects. One major by-product of the LAS was the directive issued by the governor establishing an interagency coordinating structure for the local CRI programs. This structure includes a director-level policy committee, and interagency coordination and science advisory committees. Further information about the CNMI CRI efforts and LAS is available at http://www.cnmicoralreef.net.

In addition to local government participation in federal grant programs, such as the Coral Reef Management and Coral Reef Ecosystem Monitoring Grants, several General Coral Reef Conservation grants have been awarded to local non-governmental organizations (NGOs). These grants have provided a remarkable boost to local coral reef conservation capacity over the past six years. The local marine sanctuary enforcement program is almost entirely funded through these programs (see next section below), and the entire CRM coral monitoring program is similarly supported by CRI funds.

Marine Protected Area Programs

The Marine Protected Areas (MPA) program, managed by DFW, continues to make strides in building its capacity to effectively manage CNMI's MPAs, in large part due to the support provided by the Coral Reef Management Grants. The no-take Mañagaha Marine Conservation Area (MMCA) is the most commonly recognized MPA in the CNMI because it is a very popular tourist attraction. MMCA lies in the protected Saipan Lagoon and is an important part of the cultural history of the CNMI's Carolinian inhabitants. Although it was established in August 2000, effective enforcement required additional staff and equipment. Starting in September 2002, the NOAA Coral Reef Conservation Program provided the necessary funds for enforcement staff and equipment. The federal funding was used to hire three local agency marine conservation officers to enforce the MPA laws on Saipan, and they began to hand out citations for violations in 2003. At the same time, education efforts were initiated, including ads in local magazines, publication of brochures, educational signs, school presentations, and fishermen's forums to discuss fishery issues, such as MPAs.

In contrast, the no-take Sasanhaya Bay Fish Reserve (SBFR) in Rota was established in 1994, and additional enforcement staff were never made available for the site. Outreach efforts were also limited. Unpublished research from DFW's Fisheries Research Section suggests a possible difference in fishery recovery rates between the two MPAs. Fisheries biologists began seeing positive trends in the size of certain fish species in the MMCA, while such trends have not been observed in the SBFR. Although it is difficult to account for all of the variables that may have caused this disparity, DFW suggests the difference in enforcement presence, enforcement actions, and education efforts account for much of the difference between the recovery rates at the two sites.

CNMI now has nine MPAs, including the recent addition of a sizeable MPA (9 km, 2,200 acre) on Tinian. The CRI management grant funded the development of management plans for Bird Island and Forbidden Island Sanctuaries, which were recently approved. The plans include provisions to charge visitors fees to sustainably fund associated management programs. Nearly three years of support by a NOAA Coral Reef Fellow have provided additional capacity to the MPA program for community outreach and education on Saipan. In Rota, another NOAA Coral Reef Fellow has similarly built local support for the single MPA there. Efforts are underway to engage the community in fisheries management with the Pacific Islands Marine Protected Area Communities (PIMPAC) partnership. A recent peer learning exchange with Hawaiian and Pohnpeian fisherman in Rota and Saipan encouraged the fishing community and local agencies to work together.

Nonpoint Source (NPS) Pollution Programs

NPS pollution has long been recognized as the major anthropogenic stressor of coral reef ecosystems in the CNMI. The NPS programs in CNMI have been collaboratively run by DEQ (funded by EPA) and CRM (funded by NOAA). The removal of all funding for the NOAA 310 grant program in the 2007 federal budget has eliminated CRM's program. However, efforts are being made to address the shortfall locally through other funding sources.

Despite this substantial setback to the CNMI NPS program, a number of major NPS projects continue to progress, primarily through EPA and LAS funds. The LAS strategies addressing land based sources of pollution focus on priority watersheds on CNMI's three most populated islands. Collaborative efforts by local government agencies and communities have revegetated areas of eroding badlands. In Talakhaya, the first two-year phase of the project focused on revegetation, which included planting of 25,000 grass and tree seedlings by local volunteers, students, and local agency staff from DLNR and DEQ. A water quality monitoring plan is in effect to determine the environmental impact the grass and tree seedlings will have on the adjacent marine area. In addition, a request was submitted the to the CNMI legislature to include the project area, estimated over 400 acres, into the existing Sabana Conservation Area. This request has been granted and the Talakhaya watershed is now a conservation area, which protects the entire watershed from extractive and illegal activities.

In Lau Lau Bay, Saipan, architectural and engineering designs have been completed to improve stream crossings along Lau Lau Bay Road to address sedimentation and runoff from badlands and secondary dirt roads. Another component of the Lau Lau Bay project is the revegetation of badlands with the assistance of hundreds of community volunteers and a Know-Your-Watershed project that educates households within the watershed about their environment. The project also recruited numerous volunteers to assist in other related activities. Other land-based pollution efforts include a completed architectural and engineering design for Obyan Beach to capture sediment runoff in five terraced ponds before it reaches the drainage overflow and the ocean. Ongoing marine water quality sampling by DEQ and nearshore and reef flat monitoring by the CNMI MMT will assess the eventual success of these efforts in mitigating NPS stressors at these sites.

A steady increase in 4x4 motor vehicle sales since the economic boom of the late 1980s has led to an increase in vehicular traffic on CNMI beaches, especially around Saipan. The steady beach traffic has resulted in compacted sand, destroyed turtle nesting sites, introduction of petroleum products to the nearshore environment, and destroyed beach vegetation leading to increased erosion and uncontrolled runoff from upland watersheds. In response, natural resources agencies began the "Walk it, Don't drive it" beach campaign in late 2001. The campaign has educated the community about the importance of beach vegetation and the harmful impacts of vehicular traffic on the nearshore environment and aquatic ecosystems. The campaign has successfully gained community support for closing two area beaches to vehicular traffic, the first in 2004 and the second in 2007. Both efforts were funded through a grant from the U.S. Fish and Wildlife Service. The beaches have since recovered, and once again nests of threatened green sea turtles have successfully hatched on their shores (Figure 14.31).

Figure 14.31. Photographs of Wing Beach, Saipan prior to installing bollards and a gate in 2004 (left) and a year after closing access to vehicles (right). Photo: K. Yuknavage.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

Largely thanks to funding provided by the U.S. Coral Reef Initiative (CRI), the CNMI's capacity to manage its coral reef ecosystem resources effectively has grown substantially over the past seven years. The overall understanding of CNMI's coral reef ecosystems is just approaching the point where management activities can be quantitatively evaluated through monitoring and other assessment programs. The CNMI's capacity to assess, monitor, educate and enforce coral reef management policy has grown substantially through an increase in both personnel and the development of locally applicable management tools.

Local and federal monitoring and assessment programs have made remarkable strides in addressing gaps in bathymetric and benthic mapping as well as assessment and monitoring of large and small scale habitat variability. While monitoring protocols continue to improve, capacity to carry out *in situ* surveys remains a limiting factor given the size of the Commonwealth and the limited number of trained personnel and transport options available in the CNMI. Support continues to grow for validating remote sensing tools such as satellite and video habitat assessment and monitoring and for the development of an integrated system of unattended environmental monitoring stations for the archipelago.

As the CNMI moves toward identifying and addressing gaps in knowledge and management capacity, the local CRI program will continue to ensure activities remain relevant to coral reef management. The CNMI's critical goals are the development of justifiable performance indicators and programmatic self-sufficiency. The LAS have played a large part in the development of performance indicators, but the programmatic self-sufficiency is just beginning to be realized through activities associated with fulfilling the Micronesia Challenge.

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