The State of Coral Reef Ecosystems of Guam

Val Porter[1], Trina Leberer[2], Mike Gawel[3], Jay Gutierrez[1], David Burdick[4], Victor Torres[5], and Evangeline Lujan[4]

INTRODUCTION AND SETTING

This report is an assessment of the status of coral reef ecosystems in Guam from 2002 to 2004. Data on coral reef ecosystems were synthesized from assessments and monitoring programs conducted by local and federal organizations. Included in the report are assessments of the environmental and anthropogenic stressors affecting coral reefs, information on data gathering activities and the condition of coral reef ecosystem resources, a description of current conservation management activities, and overall conclusions and recommendations to monitor and manage coral reef ecosystems better in the future.

Guam, a U.S. territory located at 13° 28´N, 144° 45´E, is the southernmost island in the Mariana Archipelago. It is the largest island in Micronesia, with a land mass of 560 km^2 and a maximum elevation of approximately 405 m (Figure 16.1). It is also the most heavily populated island in Micronesia, with a population of about 164,000 people (July 2003 estimate). The northern portion of the island is relatively flat and consists primarily of uplifted limestone. The island's principle source aquifer "floats" on denser sea water within the limestone plateau. It is recharged from rainfall percolating through surface soils (Guam Water Planning Committee, 1998). The average annual rainfall is 218 cm (NOAA National Weather Service, http://www.prh.noaa.gov/guam/normal.html, Accessed 4/17/04). The southern half of the island is primarily volcanic, with more topographic relief and large areas of highly erodible lateritic soils (SCS, 1988). This topography creates a number of watersheds throughout the southern areas which are drained by 96 rivers (Best and Davidson, 1981).

The island possesses fringing reefs, patch reefs, submerged reefs, offshore banks, and barrier reefs surrounding Cocos Lagoon in the south and part of Apra Harbor (Randall and Eldredge, 1976). However, only Apra Harbor has substantial lagoonal habitats deeper than 10 m (Paulay, 2003a). The reef margin varies in width, from tens of meters along some of the windward areas, to over 781 m in Pago Bay (Randall and Eldredge, 1976). The combined area of coral reef and lagoon is approximately 69 km^2 in nearshore waters between 0-3 nmi (5.5 km), and an additional 110 km^2 in U.S. waters greater than 3 nmi offshore (Hunter, 1995). Sea surface temperatures (SSTs) range from about 27-30°C, with higher temperatures measured on the reef flats and in portions of the lagoons (Paulay, 2003a). Although Guam's marine life is not as diverse as the neighboring islands to the south (Palau and the Federated States of Micronesia), it lies relatively close to the Indo-Pacific center of coral reef biodiversity (Veron, 2000). Table 16.1 includes the number of currently documented species for major coral reef taxa on Guam or in some cases for the Mariana Islands as a whole.

Guam's coral reefs are an important component of the island's tourism industry. The reefs and the protection that they provide make Guam a popular tourist destination for Asian travelers. According to the Guam Economic Development Authority, the tourism industry accounts for up to 60% of the government's annual revenues and provides more than 20,000 direct and indirect jobs. Guam's primary tourist market is Asia, with the majority (70-80%) of tourists arriving from Japan. As such, Guam's economy is tied to that of Asia, which has suffered a series of setbacks starting in the early 1990s involving the Asian economic crisis, a massive earthquake and several devastating typhoons, the terrorist attacks on September 11, 2001, the severe acute respiratory syndrome outbreak, and the war in Iraq that began in 2003. Despite these events, Guam still hosted nearly one million visitors in 2003 (GVB, 2004), and expects to host over one million in 2004 (GHRA, 2004).

Traditionally, coral reef fishery resources formed a substantial part of the local Chamorro community's diet and included finfish, invertebrates, and sea turtles (Amesbury and Hunter-Anderson, 2003). Today coral reef resources are both economically and culturally important. Although somewhat displaced from the diet by westernization and declining stocks, reef fish are still found at the fiesta table and at meals during the Catholic Lenten season. Many of the residents from other islands in Micronesia continue to include reef fish as a staple of their diet (Amesbury and Hunter-Anderson, 2003). Sea cucumbers, sea urchins, a variety of crustaceans,

1 Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam
2 The Nature Conservancy, Asia/Pacific Region, Micronesia Program, Kolonia, Pohnpei FM
3 Guam Environmental Protection Agency, Government of Guam, Barrigada, Guam
4 Guam Coastal Management Program, Bureau of Statistics and Plans, Government of Guam, Hagatna, Guam
5 Bureau of Statistics and Plans, Government of Guam, Hagatna, Guam

Figure 16.1. Locator map for Guam. Map: A. Shapiro.

Table 16.1. A recent compendium of over 5,000 species of marine organisms documented in Guam. Source: various authors, *Micronesica* 35-36, 2003.

GROUP	NUMBER OF SPECIES	SOURCES
Seagrasses	3	*Lobban and Tsuda, 2003*
Benthic Macroalgae	237	*Lobban and Tsuda, 2003*
Sponges	110	*Kelly et al., 2003*
Foraminiferan	303	*Richardson and Clayshulte, 2003*
Platyhelminthes	59	*Newman et al., 2003*
Hydroids	42	*Kirkendale and Calder, 2003*
Polychaetes	104	*Bailey-Brock, 2003*
Non-scleractinian Corals	119	*Paulay et al., 2003b*
Scleractinian Coral	377 *	*Randall, 2003*
Hydrozoan Corals	26 *	*Randall, 2003*
Bivalves	339	*Paulay, 2003c*
Prosobranch Gastropods	895	*Smith, 2003*
Opistobranch Gastropods	467	*Carlson and Hoff, 2003*
Cephalopods	21	*Ward, 2003*
Cirripedia	24	*Paulay and Ross, 2003*
Crustaceans	663	*Ahyong and Erdmann, 2003; Paulay et al., 2003a; Castro, 2003; Tan and Ng, 2003; Kensley, 2003*
Echinodermata	196	*Paulay, 2003b; Starmer, 2003; Kirkendale and Messing, 2003*
Ascidians	117	*Lambert, 2003*
Sea Turtles	3	*Eldredge, 2003b*
Marine Mammals	13	*Eldredge, 2003b*
Shorefishes	1019 *	*Myers and Donaldson, 2003*
Total Species	**5137**	

* Number of species is for the entire Mariana Archipelago. The actual number for Guam may be lower.

molluscs, and marine algae are also eaten locally. In addition to the cash and subsistence value of edible fish and invertebrates, reef-related fisheries are culturally important as family and group fishing is a common activity in Guam's coastal waters.

Over 10% of Guam's coastline has been set aside in five marine preserves: Tumon Bay, Piti Bomb Holes, Sasa Bay, Achang Reef Flat, and Pati Point. The preserves were established in 1997 as a response to decreasing reef fish stocks, but were not fully enforced until 2001. Fishing activity is restricted in the preserves with limited cultural take permitted in three of the five areas. The preserves are complemented by the War in the Pacific National Historical Park, Ritidian National Wildlife Refuge, Guam Territorial Seashore Park, Orote Penisula Ecological Reserve Area (ERA), and Haputo ERA. While management practices are enforced in the five marine preserves, there is currently limited management and enforcement in the other areas.

The health of Guam's coral reefs varies considerably, depending on a variety of factors including geology, human population density, level of coastal development, level and types of uses of marine resources, oceanic circulation patterns, and frequency of natural disturbances, such as typhoons and earthquakes. Many of Guam's reefs have declined in health over the past 40 years. The average live coral cover on forereef slopes was approximately 50% in the 1960s (Randall, 1971), but dwindled to less than 25% live coral cover by the 1990s with only a few having over 50% live cover (Birkeland, 1997). In the past, however, Guam's reefs have recovered after drastic declines. For example, an outbreak of the crown-of-thorns starfish (COTS) in the early 1970s reduced coral cover in some areas from 50-60% to less than 1%. Twelve years later, greater than 60% live coral cover was recorded in these areas (Colgan, 1987). A more distressing indicator of the health of Guam's coral reefs is the marked decrease in rates of coral recruitment. In 1979, Birkeland et al. (1982) obtained 0.53 coral recruits per plexiglass fouling panel. The use of similar materials and experimental design in 1989 and 1992 resulted in just 0.004 and 0.009 coral recruits per plexiglass fouling plates, respectively (Birkeland, 1997).

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Large-scale coral bleaching events and associated coral mortality are not common on Guam. Since the establishment of the University of Guam Marine Laboratory (UOGML) in 1970, there have been only two recorded large-scale bleaching events. In 1994, 68% of surveyed taxa bleached on Guam (Paulay and Benayahu, 1999). The event was characterized by considerable inter-species variation in bleaching response and little mortality, and did not appear to be associated with above-average SSTs. In 1996, about half of *Acropora* species showed moderate to heavy bleaching, similar to the response of *Acropora* species to the 1994 bleaching event (G. Paulay, pers. comm.). There was also little mortality, except for a localized die-off on Piti Reef Flat due to extreme tidal conditions (G. Davis, pers. comm.). A recent bleaching event in Pago Bay appears to be linked to freshwater influx from the record rainfall associated with Tropical Storm Tingting in June 2004 (P. Schupp, pers. comm.). Bonito and Richmond (submitted) reported that a UOGML scientist observed cases of coral bleaching on Guam every year for at least the past seven years, but again, they were not accompanied by mass mortality. However, as SSTs continue to rise, coral bleaching events may become more frequent and more deleterious on Guam.

Diseases

Although many common coral diseases have been identified on Guam's reefs, no systematic survey specifically addressing disease has been undertaken. In general, coral disease appears to be much more problematic in the Caribbean and Atlantic than in the Pacific Ocean to date.

Tropical Storms

In the last decade, Guam has been hit directly by four typhoons with sustained winds of greater than 150 miles per hour and suffered high waves and winds from large systems passing close to Guam (Figure 16.2; Guard et al., 2003). These systems have had a tremendous impact on the island. In 2002, Guam was hit with two tropical storms, Typhoon Chata'an and Super Typhoon Pongsona. At Typhoon Chata'an's closest approach, wind speeds of 100-120 mph were recorded. Six months later, Super Typhoon Pongsona passed directly over the island, with wind speeds reaching super typhoon strength at 150 mph (Guard et al., 2003). These types of storms cause considerable damage on land and also impacted the marine environment, especially Guam's coral reefs (Figure 16.3).

According to Guam's Bureau of Statistics and Plans (2002), 175 sites were surveyed by damage assessment teams after Typhoon Chata'an. The surveyors identified problems with erosion, turbidity at river mouths, debris accumulation and debris stag-

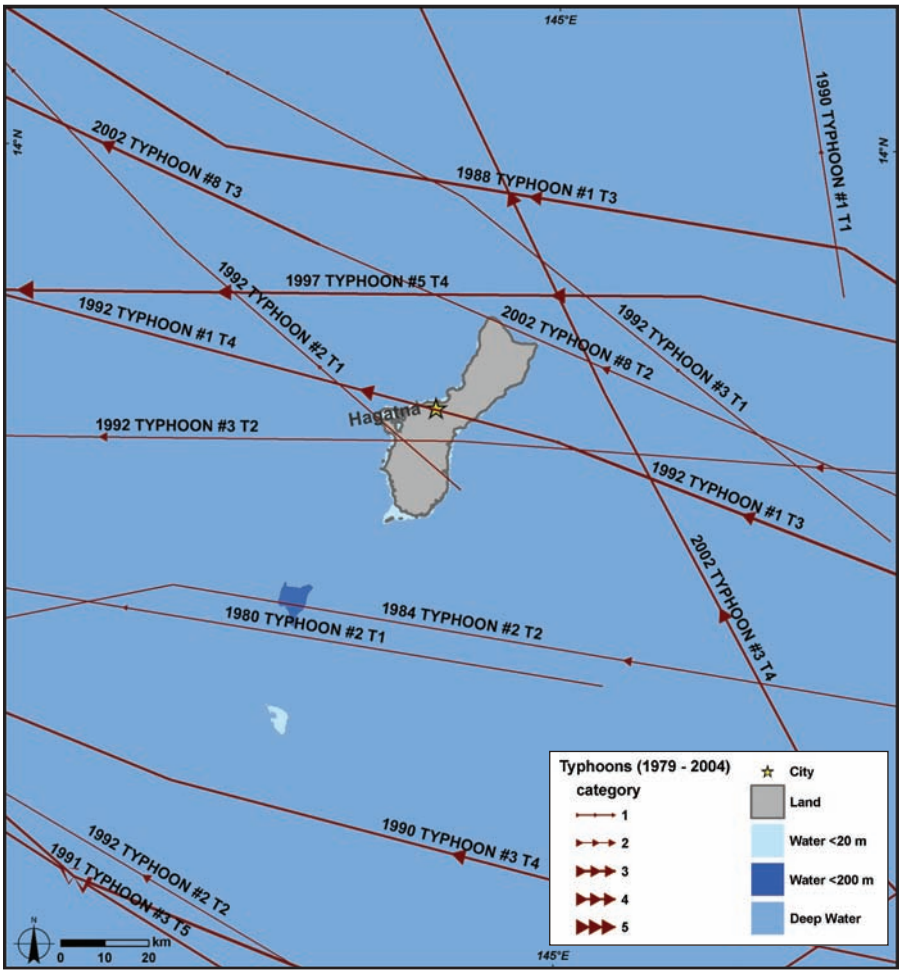

Figure 16.2. The path and intensity of typhoons passing near Guam from 1979-2004. Four major storms (sustained winds >150 mph) have hit Guam in the past 10 years. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: A Shapiro. Data: UNISYS, http://weather.unisys.com/hurricane.

ing sites. Of the sites identified as beach/shore, river, inland, reef, or infrastructure (bridge, drain, road, seawall), 76% showed signs of erosion. Beach and shore erosion were highest in the southern part of Guam with over 20 eroded sites identified.

Figure 16.3. In 1997, Super Typhoon Paka scattered debris across the island, including the reef flats. Photo: Guam Coastal Management Program.

The assessment teams identified many types of debris including a combination of metallic and household trash, natural wood, lumber, bamboo, coconut leaves, coconuts, dead animals, vegetation, tires, and rubber materials. The survey report indicated that the southern part of Guam had the highest concentration of medium to heavy debris from the 10 sites surveyed. A total of 69 pieces of debris were collected from ten sites. The Guam Diving Industry Association assisted with the water/ocean assessment portion of the study. Dive groups observed debris at six popular dive sites and reported that excess trash and debris were believed to be typhoon-related. The debris included cans, leaves, tree fronds, and pieces of plastics. The assessment after Super Typhoon Pongsona suggested that the debris from Typhoon Chata'an was moved off the reef and placed farther offshore by Super Typhoon Pongsona.

The effects of tropical storms are not limited to debris and erosion. Typhoon Chata'an caused waste oil to spill from a U.S. Navy storage waste oil barge into Apra Harbor in July 2002. In December 2002, Super Typhoon Pongsona caused three large fuel storage tanks to catch on fire and burn for six days at the Guam Commercial Port. This fire deposited a large amount of soot in the adjacent harbor. In addition, fire retardants applied to control this fire may have entered the adjacent marine environment.

Coastal Development and Runoff

The resident population of Guam increased 16.3% from 1990 (133,152) to 2000 (154,805) with an associated population density increase from 634.5 to 737.7 individuals/mi^2 (U.S. Census Bureau, 2003). This rate was lower than the population increases observed between 1980 and 1990 (25.6%) and between 1970 and 1980 (24.7%). The population growth rate in 1990 was 2.3 compared to 1.51 in 2000, and predictions estimate the growth rate to steadily decrease over the next 50 years. Nevertheless, the population is expected to reach 203,000 by 2020 and 242,000 by 2050 (U.S. Census Bureau International Programs Center Database, 2003).

Slow economic growth since 2001 has limited new development on Guam. During this time, development has primarily been residential or other small-scale construction. No major building construction projects (e.g., hotels, large office buildings) requiring review by Guam's Application Review Committee (ARC) were undertaken and no new applications for large development were submitted to the ARC in 2003 (DPW, 2004a). However, a small number of large developments that did not require review by the ARC (i.e., proposals that met all of the requirements set forth by Guam's existing rules and regulations) have been completed or are currently underway (DPW, 2004a).

In a recent report to the U.S. Congress on Guam's water quality (GEPA, 2003) the major causes of decline in water quality to marine bays were development (paving and creation of impervious surfaces), encroachment onto the shoreline without the use of pollution management measures, marine debris, mechanical beach sand raking, and construction without the use of management measures. Increased urban runoff associated with greater impervious surface cover and reduced vegetation cover is of particular concern for reefs fringing near

the more densely populated and urbanized northern portion of Guam. Road construction has decreased considerably since the early 1990s and has remained relatively constant over the past six years. Three major road construction projects, totaling approximately 14 km of roadway, have been ongoing during the past two years and are expected to be completed in 2004 (DPW, 2004b). Two of the projects (Rt. 14 in Tumon and Rt. 4 in Yona) are located near the coastline and involve a total of 5 miles of heavily traveled roads. The required use of siltation fences has occurred at the Tumon site, but fences initially installed at the Yona site have not been properly maintained (T. Leberer, pers. comm.). The third project, involving the reconstruction of a section of Rt. 1 in Dededo, is farther from the coastline and is believed to be less of a threat to coral reef systems. In addition to these on-going projects, 17.4 km of highway have been constructed or repaired since 2000. This figure is approximately equal to the miles of road construction/repair that occurred between 1996 and 1999 (17.5 km) and much lower than occurring between 1992 and 1995 (42.25 km) (DPW, 2004b).

Sedimentation, resulting from construction projects and accelerated rates of upland erosion, is commonly considered one of the primary nonpoint source pollution threats to Guam's reefs. In southern Guam, sedimentation is exacerbated by steep slopes and underlying volcanic rock, which allow significant surface water flow and enhanced transport of sediments to coastal waters (Figure 16.4). For example, a road construction project along the southern shores of the island in the early 1990s resulted in the particularly heavy sedimentation of a 10 km section of fringing reef, killing much of the coral (R. Richmond, pers. comm.). A study conducted by the Natural Resources Conservation Service (NRCS; U.S. Department of Agriculture, 1995) examined four types of habitat within the Ugum Watershed in southern Guam. Using the Revised Universal Soil Loss Equation, the NRCS estimated that sediment yield at the mouth of the watershed totaled 5.5 tons per acre. According to the NRCS average estimates ravine forests eroded 12 tons per acre per year (t/a/yr), agricultural lands eroded 20 t/a/yr, savannah grasslands eroded 31 t/a/yr, and unvegetated badlands eroded 243 t/a/yr. Findings indicated that inappropriate road construction, off-road vehicle traffic, and wild land fires accelerated the erosion processes.

Figure 16.4. Sediment plumes due to upland erosion and heavy rainfall lead to serious problems for Guam's coral reef ecosystems. Photo: Guam Forestry and Soil Resources Division.

A recent study by Wolanski et al. (2003) suggested that land erosion in the La Sa Fua River catchment area caused significant sedimentation in Fouha Bay. This problem was exacerbated by the formation of muddy marine snow which has a much higher settling velocity than the unconsolidated clay particles in the river discharge. Wolanski et al. (2003) estimated that approximately 75% of the riverine sediments settle in the receiving bay and may smother juvenile corals. This sediment can become resuspended by storm swells a few times each year, causing high suspended sediment concentrations (1000 mgl/L) in the upper few meters of the bay.

Accelerated rates of upland erosion due to wildfires, clearing and grading forested land, recreational off-road vehicle use, and wild populations of introduced mammals continue to result in increased rates of sedimentation in southern Guam. Estimates suggest that between 1975 and 1999, Guam lost nearly a quarter of its tree cover, while increases in the acreage of badlands (bare soil with extremely high erosion rates) and other erosion-prone surface cover types have been observed (FSRD, 1999). The numerous fires set each year and the popular use of off-road vehicles are believed to be major contributors to the development and persistence

of these erosion-prone surface cover types. According to the Guam Department of Agriculture's Forestry and Soil Resources Division (FSRD), an average of over 750 fires have been reported annually between 1979 and 2001, burning over 404 km^2 during this time period (Figure 16.5). Considering Guam's area is comprised of 560 km^2 and the amount of vegetated land is even less (Table 16.2), the impact of these fires is of great concern.

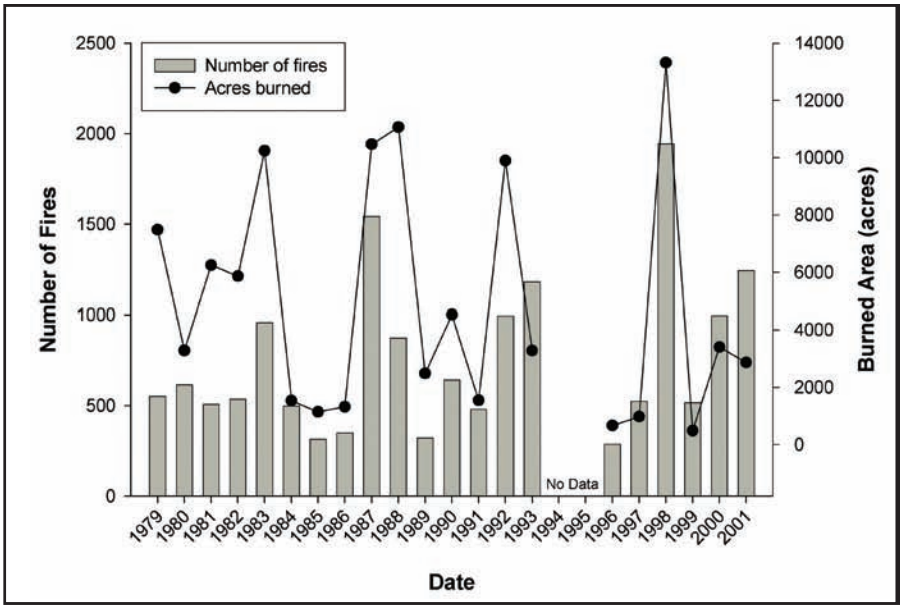

Figure 16.5. The frequency and acreage of wildfires in Guam from 1979-2001 (data unavailable for 1994-1995). Source: D. Limtiaco, unpublished data.

Table 16.2. The current land and water resources of Guam. Source: D. Limtiaco, unpublished data.

RESOURCE	TOTAL ACREAGE
Crop Land	14,227
Pasture Land	11,826
Range Land	21,454
Forest Land	51,058
Urban Areas	36,919
Freshwater	196
Total	**135,680**

It is difficult to regulate the pollution in runoff and infiltration from the many small-scale agricultural activities on Guam. A study by Duenas and Associates (2003) stated that in 1998, only about 262 ha of land were under cultivation and the average farm size was 1.5 ha. Pig and poultry farms (commercial and non-commercial) censused prior to the severe typhoons of 2002 totaled 75 (averaging 30 pigs each) and 42 (with a total of 11,500 birds), respectively. The more significant use of fertilizers and pesticides on Guam's nine golf courses is carefully controlled through requiring GEPA approved turf management plans approved by Guam's Environmental Protection Agency (GEPA) and continuous monitoring through monitoring wells (Figure 16.6). Excluding the two military golf courses for which there are no available data the civilian courses cover over 567 ha (Duenas and Associates, 2003).

Figure 16.6. Over 560 ha of land in Guam, such as this coastal area in Mangilao, have been converted to golf courses, and chemical run-off is a pressing concern. Source: Guam Division of Aquatic and Wildlife Resources.

Coastal Pollution

The primary pollutants to most waters, and specifically recreational beaches, are microbial organisms, petroleum hydrocarbons, and sediment. The GEPA administers the Water Quality Certification (Federal Clean Water Act Section 401) and National Pollutant Discharge Elimination System (NPDES) permits locally for the U.S. Environmental Protection Agency (EPA). Presently there are 19 active NPDES-permitted on Guam (Table 16.3.) The permitted discharges include treated wastewater from sewage treatment plants (STPs), thermal effluent from the Guam Power Authority power plants, and a number

Table 16.3. Guam EPA currently enforces nineteen NPDES permits on Guam. Facilities include wastewater treatment plants, power plants, and fuel facilities. Source: GEPA, 2003.

FACILITY	PERMITTEE	TYPE	VOLUME (millions of gallons/day)	RECEIVING WATER	MIXING ZONE
Northern District WWTP	Guam Waterworks Authority (GWA)	Municipal Wastewater	12	Philippine Sea	-
Tanguisson Steam Power Plant	Hawaiian Electric, Inc.	Cooling/ Low Volume Wastewater	97.92	Philippine Sea	-
Hagatna WWTP	GWA	Municipal Wastewater	12	Philippine Sea	-
Cabras Power Plant (Units 1-4)	Guam Power Authority (GPA)	Cooling Water	1) 173 2) 65.2	Piti Chanel	Yes
ESSO Eastern Cabras Terminal	ESSO Eastern, Inc. (Guam)	Stormwater	Varies	Apra Harbor	-
Mobil Cabras Terminal	Mobil Oil Guam, Inc.	Stormwater/ Tank Bottom Draws	Varies	Apra Harbor	-
Shell Cabras Island Docking Facility (F-1 Pier)	Shell Guam, Inc.	Stormwater/ Tank Bottom Draws	Varies	Apra Harbor	-
Unitek	Unitek	Stormwater	Varies	Piti Channel	-
Dry Dock	Guam Shipyard	Industrial Wastewater/ Balast	Varies	Inner Apra Harbor	-
GPA Piti Bulk Storage	GPA	Stormwater/Tank Bottom Draws	Varies	Piti Channel	-
Naval Station WWTP	Navy Public Works Center	Municipal Wastewater	4.3	Philippine Sea (Tipalao Bay)	Yes
Agat-Santa Rita WWTP	GWA	Municipal Wastewater	1.5	Philipine Sea (Tipalao Bay)	Yes
Umatac-Merizo WWTP	GWA	Municipal Wastewater	0.391	Toguan River & Philippine Sea	-
Leo Palace WWTP	Leo Palace Resort	Municipal Wastewater	0.100	Irrigation (Yona)	-
GIAA Parking Aprons	Guam International Airport Authority	Stormwater	Varies	Harmon Sink (Tamuning)	-
Continental Aprons	Continental Micronesia Airlines	Stormwater/Tank Bottom Draws	Varies	Harmon Sink (Tamuning)	-
Baza Gardens WWTP	GWA	Municipal Wastewater	0.600	Togcha River (Talofofo)	-
UOG Marine Lab.	University of Guam Marine Laboratory	Sea Water	0.216	Pacific Ocean	-
Shell Agat Terminal	Shell Guam, Inc.	Stormwater/Tank Bottom Draws	Varies	Big Guatali River (Piti)	-

of discharges that could contain minor amounts of oil and other toxic or biological materials. The guidelines for effluent limitations are based on Guam's water quality standards which underwent major revision in 2001 (GEPA, 2001). All permittees are routinely monitored by GEPA staff to verify compliance with applicable permit requirements and compliance schedules.

The 2003 NPDES monitoring reports indicate that shoreline monitoring stations at the Northern and Hagatna STPs did not register fecal coliform counts above the permit standard of 400 fecal coliform units/100 ml. Offshore monitoring stations for these STPs were not sampled. Water samples taken at the shoreline stations at the mouth of the Togcha River, downstream from the Baza Gardens STP, were within the orthophosphates and fecal coliform standards, but exceeded the nitrate-nitrogen standard of 0.10 mg/L half the time. Turbidity at these shoreline stations regularly exceeds water quality standards, but ambient turbidity measured upstream from the discharge likewise exceeded the current permit standards. Monitoring at the Umatac-Merizo (Toguan) STP showed orthophosphates and nitrate levels below standards, but turbidity was usually above

the standard of 1.0 nephelometric turbidity unit (NTU). Turbidity levels were related to rainfall and of 27 recent samples, most registered turbidity less than 2.0 NTU; there were only four samples over 3.0 NTU - two at about 7 NTU, one at 13.6 NTU, and one at 14.2 NTU. It should be noted that when the five-year NPDES permits are renewed in 2006, the new 2001 Guam water quality standards will apply, but these permits are currently monitored according to standards in place when they were issued (GEPA, 2003).

Three of the island's outfall pipes discharge within 200 m of the shallow reef crest, in depths of 20-25 m and in areas where corals are found. These outfalls can be problematic as stormwater leaks into aging sewer lines. During heavy rain, this additional water forces the sewage treatment plants to divert wastewater directly into the ocean outfall pipes. In addition, during 2003 the effluent from the Hagatna STP was partly discharging into a shallow coral reef area due to a break in the outfall line caused by Super Typhoon Pongsona.

Nonpoint source pollutants in the north, such as nutrients from septic tank systems and agricultural or chemical pollutants from urban runoff and illegal dumping, infiltrate basal groundwater, and discharges in springs along the seashore and subtidally on the reefs. A two-year study of spring water discharges from the Northern Guam Aquifer into the marine preserve of Tumon Bay has recently been completed (PCR Environmental, 2002a, 2002b, 2002c). The springs discharge an estimated 64,350 m^3 per day. Chemicals detected in the discharges above GEPA water quality standards included perchloroetene (PCE), trichloroethene (TCE), aluminum, antimony, arsenic, magnesium, sulfate, oil and grease, total coliform bacteria and fecal coliform bacteria. The pesticides dieldrin, alpha-chlordane, and gamma chlordane were also detected in discharges. A recent dye study on water flows from Harmon Sink indicates that the stormwater was drained from the Guam International Airport and surrounding industrial areas, entered a karst formation sinkhole, and discharged through the aquifer to Tumon Bay and East Agana Bay coastal waters (Moran, 2002). Some of the flows reached East Agana Bay within four days of dye injection (traveling 360 to 645 m/day) and Tumon Bay within 17 days (80 to 175 m/day). A new dye study will determine the relation of stormwater discharges from Tiyan, south of Harmon Sink to East Agana Bay and Tumon Bay.

Recent studies of the heavy metals polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs) in newly formed marine sediments and associated food chains in the four main harbor areas of Guam showed a moderate enrichment of contaminants in the harbors, especially Apra Harbor (Denton, et al., 1997; Denton et al., 1999). Sponges, soft corals, sea cucumbers, and fish from Apra Harbor were enriched with PCBs, while invertebrates showed concentrations of arsenic. Oysters showed copper and zinc contamination in Apra Harbor and Hagatna Boat Basin, but none of the fish or shellfish exceeded U.S. Food and Drug Administration food standards or guidance limits (GEPA, 2000b).

The U.S. Navy has been assessing and restoring 15 Comprehensive Environmental Response, Compensation, and Liability Act and Resource Conservation and Recovery Act sites, which could potentially impact coral reefs in Apra Harbor or Agat Bay. In 2001, it was determined that PCBs had entered the food chain offshore from the Orote Landfill site and off Gabgab Beach. The source of the PCBs has yet to be determined. However, PCBs as well as other chemicals are present in buried material at the landfill, which makes the site a potential source, even though it has been capped and contained by a restoration project costing over $15 million. Monitoring wells and other sampling techniques are being used to determine if the Orote Landfill was the source of the contamination. Seafood monitoring has detected PCBs in deep and shallow water reef fishes in the Philippine Sea off Orote Point and the public have been advised on the danger of consuming seafood from this area.

The public landfill located in the village of Ordot has been a source of leachate tentatively entering the Pago Bay reefs via the Lonfit/Pago Watershed. Baseline monitoring of the Pago Bay marine environment is planned by the Water and Environmental Research Institute of the UOG in 2005 to reflect changes related to the closing and capping of the landfill.

Tourism and Recreation

A total of 909,506 people visited Guam in 2003, representing a decrease of 14% from the number of visitors in 2002 (GVB, 2004). Based on visitor data collected from the first two months of 2004, visitor arrivals are expected to exceed one million (GHRA, 2004). According to the December 2003 Visitor's Arrival Statistical Report, 77% of the visitors came to the island for pleasure. A previous exit survey of Japanese visitors noted that the highest rated optional tourism categories were: parasailing, health spas, underwater observation, and jet-skiing (GVB, 2001). This suggests that marine resources are very important to Guam's tourism industry. There are a number of recreational activities that utilize or impact coral reefs, including snorkeling and scuba diving, charter fishing, and jet skiing.

Scuba diving and snorkeling are popular activities for tourists and residents. The Pacific Association of Dive Industry estimates that over 5,000 entry level certifications were issued in Guam last year (J. Bent, pers. comm.). This indicates that there are a large number of newly certified divers visiting Guam's reefs. One of the sites often visited by newly certified divers is the Piti Bomb Holes Marine Preserve. This has led to some negative impacts on the reefs in this area. Tsuda and Donaldson (2004) noted that snorkelers and scuba divers have caused considerable disturbances to the seagrass bed at this site. These disturbances include physical impacts, an increase in turbidity, and decreases in fish abundance and diversity. Other signs of impacts are broken pieces of coral and obviously worn or damaged coral heads (Figure 16.7). A number of other popular sites, including Gun Beach, Tumon Bay, and Ritidian, may also be impacted by reef walking activities.

Figure 16.7. Guam certifies a large number of new divers each year, and even more people try snorkeling in Guam's clear tropical waters. Unfortunately, these new divers and snorkelers often damage the environment by stepping on coral. Photo: D. Burdick.

Charter bottomfishing may also impact the coral reefs. According to an unpublished survey of fishing vessels by the Western Pacific Regional Fisheries Management Council (J. Calvo, unpublished data), there are approximately 10 locally-based charter fishing boats consistently operating in Guam. Most of these have little effect on the reefs as they target pelagic species. However, there are a few operations that offer bottomfishing targeting reef species on a regular, but infrequent basis. One operation offers bottomfishing charters on a daily basis out of the Agat Marina. Such charters normally work in depths of 18 to 110 m. There are an estimated 800 charter trips targeting the shallow water complex each year (Flores, 2003). In 2003, 2.1 metric tons of bottomfish were harvested, up from 1.3 metric tons in 2002, despite the decrease in the number of people participating in this sport (Flores, 2003).

Jet skiing is a popular tourist activity in Guam which may have several impacts on the reef due to jet ski use within the reef margin. These devices are loud, leak fuel, and may damage seagrass beds and corals, especially during low tides. Due to these impacts, jet ski use is limited to four locations within the reef margin: East Agana Bay, Apra Harbor, Cocos Lagoon, and Tumon Bay on a limited scale. A quantitative study on jet ski impacts is scheduled to begin in 2005 to determine the damage these watercraft may cause.

As a tourist destination, the stability and cleanliness of Guam's beaches is an important consideration. Although no known beach nourishment projects occurred in 2003, several of these projects occurred after Typhoon Yuri in 1992 in Cocos Island Resort, Tumon Bay, and Jeff's Pirates Cove in Ypan, Talofofo (G. Davis, pers. comm.). There are also ongoing mechanical beach cleaning operations in Tumon Bay and East Agana Bay.

Fishing

Guam's coral reef fisheries are economically and culturally important. The threat of overfishing is a serious concern that became more apparent in the 1980s. At that time, inshore fisheries data indicated that the number of hours spent fishing almost doubled, from 161,602 hours in 1984 to 300,861 hours in 1987, while the average catch per hour for reef fish declined (Sherwood, 1989). Data from creel that Guam's fisheries have not recovered from this decrease in the 1980s (Figure 16.8). In addition, *in situ* visual surveys have indicated that large reef fish are conspicuously absent from many of Guam's reefs (Figure 16.9; Paulay et al., 2001; Amesbury et al., 2001; R. Schroeder, in review).

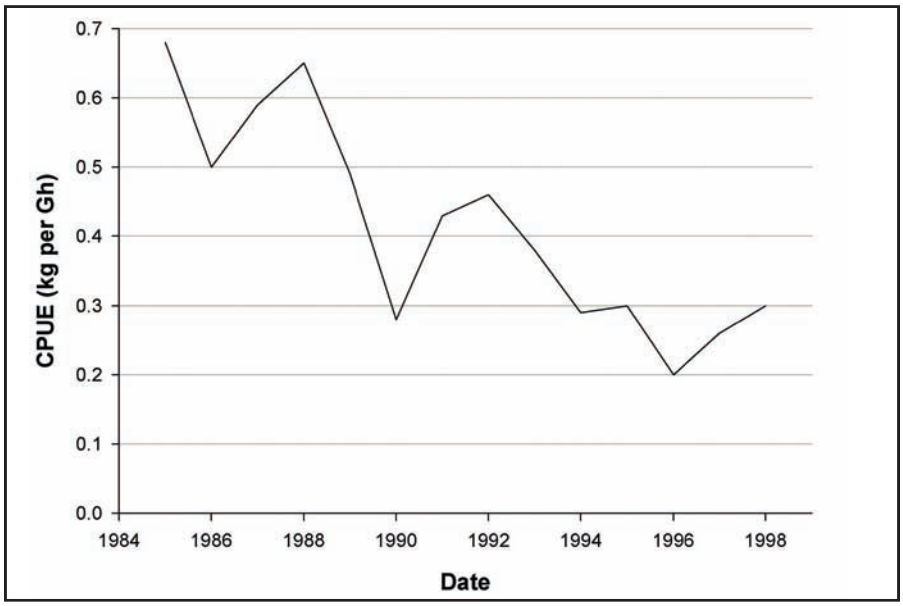

Figure 16.8. Catch per unit of effort (CPUE) declined sharply in the 1980s. Source: Guam Division of Aquatic and Wildlife Resources.

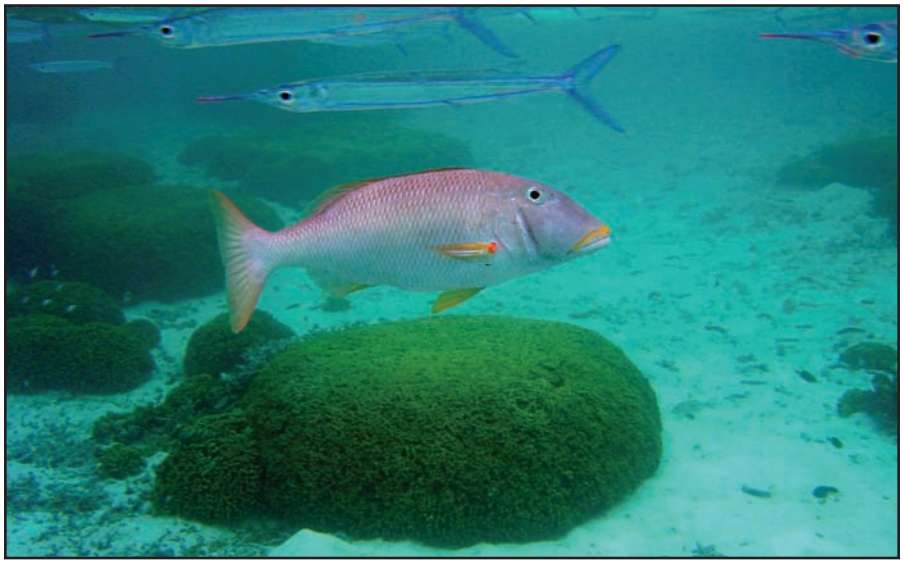

Figure 16.9. Large fish are rarely seen on Guam's coral reefs. This 55-cm yellowlip emperor (*Lethrinus xanthochilus*) has taken up residence in Tumon Bay Marine Preserve. Photo: D. Burdick.

Marine Preserves

Guam established five marine preserves in 1997 to address this concern. The size of the preserves varies, but all preserves extend from 10 m above the mean high tide mark to the 600 ft (183 m) depth contour. The following activities are prohibited in all five marine preserves: dip netting, gill netting, drag netting, surround netting, spear fishing, the use of gaffs, shell collecting, gleaning, and removal of sand or rocks. Trolling may be conducted from the reef margin seaward, but only for pelagic fish. Bottomfishing may be conducted seaward of the 100 ft (30 m) contour in Tumon Bay Marine Preserve.

Limited fishing is allowed in Tumon Bay, Pati Point, and Achang Reef Flat Marine Preserves. In Tumon Bay, hook-and-line fishing from shore and cast net (talaya) fishing from shore and along the reef margin are permitted for certain species. All other fishing methods are prohibited. From shore, catch is limited to rabbitfish (sesyon, mañahak), juvenile goatfish (ti'ao), juvenile jacks (i'e'), and convict tangs (kichu). All other fish must be released immediately. Cast net fishing along the reef margin is allowed for rabbitfish and convict tangs only. There are no species restrictions for fishing in Pati Point Marine Preserve, although fishing methods are limited to hook-and-line from shore. Limited cultural takes are permitted in Achang Reef Flat Marine Preserve for seasonal runs of juvenile rabbitfish (mañahak) and scads (atulai). No fishing is allowed in Piti Bomb Holes and Sasa Bay Marine Preserves.

Despite these laws, Guam Department of Agriculture conservation officers arrest over 40 people per year for fishing illegally in the marine preserves. Infractions range from buckets of sea cucumbers gleaned from the reef flat to large catches of parrotfish, surgeonfish, and other commercially important species taken from the forereef slope (DAWR, unpublished data). Despite these infractions, visual surveys suggest that the marine preserves are functioning as expected. Increases in fish density at Piti Bomb Holes and Achang Reef Flat

Marine Preserves of 113% and 115%, respectively, indicate that fish stocks are recovering in the preserves. Surveys at unprotected sites have shown decreases of 29% (Asan/Cocos) and 4% (Cocos/Pago) during the same period (Gutierrez, 2004).

Reef Fisheries

A number of fishing methods are used on Guam including traditional methods such as hook-and-line, talaya (cast nets), spearfishing, and surround nets (chenchulu), as well as more controversial methods such as the use of mono-filament "throw-away" gill-nets and nighttime scuba spearfishing. Fishing is a popular activity in Guam and is monitored by the Guam Division of Aquatic and Wildlife Resources (DAWR). Creel surveys have been conducted since the early 1970s, with expanded data available for the past two decades. Creel surveys provide valuable insight into fishing activities on Guam and allow the DAWR to estimate total harvest, total time spent fishing, and catch per unit effort (CPUE), which provides insight into the status of fish stocks. Creel surveys are divided into two categories, inshore fisheries and offshore fisheries. Inshore fisheries include shore-based fishing activities, usually involving nearshore casting, netting, and spearfishing. Offshore fisheries include boat-based fishing activities from small boats (3-15 m) such as trolling, bottomfishing, and boat-supported spearfishing (Flores, 2003).

Table 16.4 shows the estimated inshore and offshore coral reef fisheries harvest and CPUE for 2002 and 2003. Among the inshore methods, hook-and-line fishing resulted in the highest harvest for 2002, accounting for 33% of the total harvest. In 2003, snorkel spearing was ranked as the top method for 2003, with 41% of the overall harvest. Although the overall hook-and-line harvest is high, this method had the lowest CPUE of

Table 16.4. Estimated reef fish harvest and CPUE for all inshore and offshore methods from 2002-2003. Reef fish harvest exceeded 100 mt in 2002 and 2003. Inshore data excludes seasonal runs of juvenile siganids and bigeye scads. *CPUE measures for bottom and trolling methods were calculated based on total catch including pelagic and deepwater species. Sources: Gutierrez, 2003; Flores, 2003; DAWR, unpublished data.

	2002					2003				
	INSHORE		OFFSHORE		TOTAL	INSHORE		OFFSHORE		TOTAL
METHOD	Harvest (kg)	CPUE (kg/gr-hr)	Harvest (kg)	CPUE (kg/gr-hr)	Harvest (kg)	Harvest (kg)	CPUE (kg/gr-hr)	Harvest (kg)	CPUE (kg/gr-hr)	Harvest (kg)
Snorkel Spear	12,808	0.81	9,982	1.37	**22,790**	25,844	1.5	10,201	1.96	**36,045**
Hook and Line	20,714	0.1	-	-	**20,714**	20,449	0.12	-	-	**20,449**
Bottom	-	-	18,840	0.44*	**18,840**	-	-	30,087	0.69*	**30,087**
Gill Net	6,053	0.41	11,553	6.45	**17,606**	5,875	0.42	8,924	5.7	**14,799**
Scuba Spear	445	2	15,718	3.01	**16,163**	88	0.24	18,205	5.72	**18,293**
Cast Net	12,015	0.28	711	2.39	**12,726**	8,704	0.18	155	0.65	**8,859**
Surround Net	8,037	3.4	-	-	**8,037**	1,660	2.3	-	-	**1,660**
Trolling	-	-	2,136	1.55*	**2,136**	-	-	5,675	1.97*	**5,675**
Drag Net	1,643	3.3	-	-	**1,643**	-	-	-	-	**0**
Hooks and Gaffs	974	0.34	-	-	**974**	302	0.16	-	-	**302**
Jigging	-	-	757	1.1	**757**	-	-	905	1.1	**905**
Mix Spear	-	-	673	2.58	**673**	-	-	0	0	**0**
Spincasting	-	-	476	0.62	**476**	-	-	495	0.88	**495**
Atulai Jigging	-	-	227	0.99	**227**	-	-	802	0.99	**802**
Other Methods	431	0.14	-	-	**431**	712	0.16	-	-	**712**
Total	**63,120**	**0.21**	**61,073**	**1.34***	**124,193**	**63,634**	**0.24**	**75,449**	**1.67***	**139,083**

all inshore methods for both years. In 2002, surround net and drag net methods produced the highest CPUE of all methods with 3.4 kg/gear-hour (gr-hr) and 3.3 kg/gr-hr, respectively, despite a relatively low amount of effort (2,354 gear-hours and 501 gear-hours, respectively). In 2003, the CPUE for surround nets decreased by 32%. Harvest estimates for drag nets could not be determined for 2003, as no interviews for this method were conducted.

The total harvest of reef fish using offshore methods was similar to the inshore harvest for 2002, but exceeded the inshore harvest for 2003. The top three methods for 2002 harvesting over 75% of the total offshore reef fish catch, were bottomfishing, scuba spearfishing, and gill netting. In 2003, snorkel spearing took over the third spot, followed closely by gill netting. The top three methods for 2003 brought in 77% of the total offshore reef fish catch. Although bottomfishing had the highest harvest, this method had the lowest CPUE of all offshore coral reef fisheries for both 2002 and 2003. In 2002, gill netting produced the highest CPUE with 6.45kg/gr-hr, despite a relatively low amount of effort (1,790 gear-hours). This level decreased slightly in 2003 to a CPUE of 5.7 kg/gr-hr with a slight drop in effort (1,566 gear-hours). Scuba spearfishing produced the highest CPUE of all offshore methods in 2003 with a CPUE of 5.72 kg/gr-hr. This method was very effective, and produced approximately a quarter of the total offshore reef fish catch, while using a relatively low amount of effort (5,225 hours in 2002 and 5,205 hours in 2003).

The top 10 families harvested in 2002 and 2003 are shown in Table 16.5. Harvest composition varied from year to year; for example, Kyphosidae (rudderfish) accounted for 15% of the inshore catch for 2002, but was not a major component of the catch for 2003. Acanthuridae (surgeonfishes) were the most heavily fished inshore family in 2003, as 20% of the total inshore catch. Most of these families were targeted by hook-and-line, however, Kyphosidae were harvested primarily with cast nets. Offshore harvest was dominated by Lethrinidae (emperors) in both 2002 and 2003, with approximately 20% of the catch harvested primarily through bottomfishing. Other key target fish harvested primarily through bottomfishing techniques included Lutjanidae (snappers) and Serranidae (groupers). Acanthuridae, Scaridae (parrotfishes), and Labridae (wrasses) were often harvested using either Scuba spears or snorkel spears. It is interesting to note that scuba spears were used to capture nearly 70% of the scarid harvest. Also, of special concern is the harvest of humphead wrasse (*Cheilinus undulatus*). This valuable species, now listed on Appendix II of the Convention on International Trade in Endangered Species is targeted by fishers using scuba spearfishing methods with 789 kg harvested by this method in 2002 and 1826 kg in 2003. This species made up nearly 60% of the total offshore Labridae catch in 2002 and over 75% of the total offshore Labridae catch in 2002 and over 75% of the total offshore Labridae catch in 2003.

Table 16.5. Estimated harvest of top 10 families for inshore and offshore fisheries during 2002-2003. Inshore data excludes seasonal runs of juvenile siganids and bigeye scads. Sources: Gutierrez, 2003; Flores, 2003; DAWR unpublished data.

INSHORE				OFFSHORE			
2002		2003		2002		2003	
Family	Harvest (kg)	Family	Harvest (kg)	Family	Harvest (kg)	Family	Harvest (kg)
Kyphosidae (Rudderfishes)	9,465	**Acanthuridae** (Surgeonfishes)	12,691	**Lethrinidae** (Emperors)	13,598	**Lethrinidae** (Emperors)	11,632
Siganidae (Rabbitfishes)	8,773	**Carangidae** (Jacks)	9,699	**Acanthuridae** (Surgeonfishes)	9,329	**Serranidae** (Groupers)	10,737
Acanthuridae (Surgeonfishes)	7,786	**Siganidae** (Rabbitfishes)	5,640	**Scaridae** (Parrotfishes)	7,472	**Carangidae** (Jacks)	9,599
Carangidae (Jacks)	6,790	**Mullidae** (Goatfishes)	5,372	**Carangidae** (Jacks)	5,542	**Acanthuridae** (Surgeonfishes)	8,464
Lethrinidae (Emperors)	4,480	**Scaridae** (Parrotfishes)	4,302	**Serranidae** (Groupers)	2,983	**Scaridae** (Parrotfishes)	8,246
Mullidae (Goatfishes)	3,945	**Lethrinidae** (Emperors)	2,352	**Mullidae** (Goatfishes)	2,341	**Scombridae** (Mackerels)	3,431
Lutjanidae (Snappers)	2,712	**Diodontidae** (Porcupinefishes)	1,649	**Sphyraenidae** (Barracudas)	1,587	**Sphyraenidae** (Barracudas)	3,339
Serranidae (Groupers)	2,166	**Scombridae** (Mackerels)	1,307	**Lutjanidae** (Snappers)	1,509	**Lutjanidae** (Snappers)	3,087
Mugilidae (Mullets)	1,990	**Serranidae** (Groupers)	1,284	**Labridae** (Wrasses)	1,391	**Labridae** (Wrasses)	2,377
Belonidae (Needlefishes)	1,968	**Carcharhinidae** (Requiem Sharks)	1,258	**Siganidae** (Rabbitfishes)	1,389	**Carcharhinidae** (Requiem Sharks)	1,632

Invertebrates

The invertebrate harvest varied considerably during 2002 and 2003 for both inshore and offshore fisheries. The top five harvested invertebrate species for 2002 and 2003 are listed in Table 16.6. Inshore invertebrate harvest in 2003 increased 188% from the 2002 harvest. The increase in invertebrate harvest in 2003 correlates with a shift in method; snorkel spear gear-hours and CPUE increased by 11% and 85%, respectively. Although octopus comprised the majority of the top five invertebrate species harvested in 2002 and 2003, harvest of the spiny lobster (*Panulirus pencillatus)* increased 245% between 2002 and 2003. The offshore invertebrate harvest decreased from 2002 to 2003, with catches of the top shell (*Trochus niloticus)* and *Panulirus pencillatus* decreasing 40% and 14%, respectively, over this time period. The conch harvest also decreased over this time period, with over 1,400 kg of conch (*Lambis lambis* and *L. truncata*) harvested in 2002 and no catch recorded in 2003. However, the harvest of venus clams (Veneridae), reef crab (*Zosimus aeneus*), and octopus did increase during this period.

Table 16.6. Estimated harvest of top five invertebrate species during 2002-2003. Sources: Gutierrez, 2003; DAWR, unpublished data.

INSHORE				OFFSHORE			
2002		2003		2002		2003	
SPECIES	HARVEST (kg)	SPECIES	HARVEST (kg)	SPECIES	HARVEST (kg)	SPECIES	HARVEST (kg)
Octopus cyanea	1,052	*Octopus cyanea*	4,772	*Trochus niloticus*	1,525	*Trochus niloticus*	902
Panulirus penicillatus	572	*Octopus* other	3,105	*Lambis lambis*	1,224	*Veneridae*	635
Scylla serrata	508	*Panulirus penicillatus*	1,973	*Panulirus penicillatus*	289	*Panulirus penicillatus*	249
Octopus ornatus	383	*Carpilus maculatus*	145	*Lambis truncata*	218	*Zosimus aeneus*	235
Octopus other	359	*Octopus ornatus*	111	*Zosimus aeneus*	152	*Octopus cyanea*	219

Trade in Coral and Live Reef Species

Guam does not currently export coral or live reef species, but collection for local use does occur. Local pet shops collect approximately 250 ornamental fish per month for Guam's aquarium trade (B. Tibbatts, pers. comm.). In addition, two local aquaria collect approximately 450 local reef fish each month for display in their facilities (L. Goldman, pers. comm.). Guam's corals and live rock are protected by the island's Public Law 24-21. The UOGML is the only entity on the island permitted to harvest coral and live rock. UOGML's permit only allows harvesting in areas not designated as marine preserves and all surviving specimens must be returned to the area from which they were harvested. The UOGML collected 1,008 coral colonies in 2002 and 455 colonies in 2003 for research purposes. Harvested colonies included species of *Acropora, Alveopora, Favia, Goniastrea, Goniopora, Leptoria, Lobophyllia, Platygyra, Pocillopora, Porites,* and *Psammocora*. The colonies collected ranged in size from 2 cm x 2 cm to 40 cm x 20 cm (Amesbury, 2002, 2003; Smith, 2004).

Ships, Boats, and Groundings

Guam's Apra Harbor is the largest U.S. deepwater port in the Western Pacific and the busiest port in Micronesia. The harbor is shared by the Port Authority of Guam and the U.S. Navy. According to Guam's Port Authority (http://www.netpci.com/~pag4, Accessed 8/26/04), the port handled approximately two million tons of cargo and serviced over 2000 vessels in 2002. These vessels are primarily fishing vessels, as well as fuel ships, container ships, tender ships, barges, and cruise ships. The U.S. Naval installation is home to a number of naval vessels including submarines, a submarine tender ship, and two U.S. Coast Guard cutters, and is visited by numerous other vessels including aircraft carriers. The harbor also contains reefs with some of the highest coral cover on the island. Some reef areas have been dredged in the past and other areas (including patch reefs) may be dredged in the future as their growth impedes ship traffic and naval operations. The coral reefs can be damaged not only by such ship traffic and naval operation, but also by anchors, groundings, and illegal vessel discharges.

Commercial ships are not the only concern. According to the boating law administrator in the Guam Police Department's Special Programs Division, there are an estimated 3,000 recreational vessels and an estimated 5,000 commercial vessels under 20 m on Guam. Anchor damage from these ships is a concern due to the lack of operational mooring buoys around the island.

Ship groundings are inevitable due to the frequency of typhoon's affecting Guam. At this time, over 130 vessels are listed in the National Oceanic and Atmospheric Administration's (NOAA) Abandoned Vessel Inventory database for Guam (http://response.restoration.noaa.gov/dac/vessels/vess_main.html, Accessed 4/17/04). During a recent NOAA study, nine of the 31 vessels surveyed (29%) were located on coral reef, hardbottom, or lagoonal fauna (Helton et al., 2004). As these vessels deteriorate or are moved by storms, they may impact the surrounding habitat. Because of limited funding for the removal of these vessels, most of them will remain a threat to the reefs. Navigational buoys also pose a problem as storm swells can drag them onto the reefs, thereby damaging coral and other reef habitat. Such an incidence of this occurred in August 2004 when the storm surge from Typhoon Chaba displaced the navigational buoys outside of Agat Marina (KUAM TV, http://66.129.67.220/news/11022.aspx, Accessed 9/28/2004).

Marine Debris

Marine debris continues to impact Guam's reefs. According to the Guam Coastal Management Program (GCMP), the 2003 International Coastal Cleanup resulted in the collection of 924 bags of debris that weighed 19,640 kg from Guam's beaches and reefs, an increase from 3,252 kg of debris collected in 2002. Additionally, the Micronesian Divers Association, and Guam Marine Awareness Foundation remove 5-10 bags of debris from local reefs each month (M. Barnett, pers. comm.).

Beverage containers are the most common items collected, but other items include appliances, batteries, car parts, and abandoned fishing gear. Over 100 nets were collected during the 2003 cleanup event, along with fishing line, crab and fish traps, buoys, and lures. The DAWR reported that 35 additional nets were removed from coastal waters in 2002-2003. Typhoons are an additional source of debris and can blow objects as large as roofs onto the reefs. Although two powerful typhoons hit Guam in 2002, the debris from these storms appeared to be limited to smaller items such as beverage containers and palm fronds. In contrast, over 14 tons of debris, including tin roofing, auto parts, and dumpsters, were deposited on the reef in 1997 by Super Typhoon Paka (GCMP, 1998).

Aquatic Invasive Species

Although Guam has spent considerable time and resources studying terrestrial invasive species, such as the brown treesnake, little work has been done on invasive marine species (Paulay et al., 2002). Paulay et al. (2002) attempted the first systematic survey of nonindigenous marine species in three study sites on Guam: Apra Harbor, Orote Penisula ERA, and Haputo ERA. They found a total of 85 nonindigenous species on Guam, recognizing that many taxa have yet to be surveyed. Forty-one of those 85 species were catagorized as introduced and 44 as cryptogenic. They found the majority of these species to be sessile (76%) and surmise that they primarily arrived via vessel hulls into Apra Harbor. While further study is warranted, these nonindigenous marine species do not appear to be negatively impacting native species yet. Paulay et al. (2002) found that, although nonindigenous species were abundant on artificial substrates, they were relatively rare on natural reef bottoms.

Security Training Activities

The U.S. Department of Defense regularly carries out military training on Guam, often involving Navy and Marine exercises that impact coastal waters and adjacent reefs (U.S. Department of the Navy, 1998) Although attempts are made to minimize impacts by locating operations away from living corals, the explosions related to marine mine detection and demolition and the stress from landing craft have killed a limited amount of fish and invertebrates, and could threaten marine mammals and endangered sea turtles (DAWR, unpublished incident reports).

Offshore Oil and Gas Exploration

There are currently no oil or gas prospects identified near Guam.

Other

Guam continues to be affected by the COTS (*Acanthaster planci)*. While Guam has not had any large outbreaks of *A. planci*, aggregations of about 500 individuals have been documented (Randall, 1973). Bonito (2002) suggests that the feeding behavior of these aggregations may modify the coral community composition on Guam, as they prefer to feed on *Acropora, Montipora,* and *Pocillopora* species. The coral community at Tanguisson Reef was documented in 1981 and again in 2001; comparison of the data suggests that preferential feeding on these species may have created a shift in the reef community towards *Porites, Favia*, and other non-preferred species.

CORAL REEF ECOSYSTEM MONITORING EFFORTS AND RESOURCE CONDITION

A number of monitoring, research, and assessment activities are conducted on Guam. These include monitoring programs for communities associated with coral reefs, assessment of benthic habitat, and water quality. Table 16.7 describes all recent or ongoing studies related to Guam's coral reefs. Some of these studies are ongoing, while others have just started producing quantitative data. The studies with sufficient data will be discussed further in the next section.

Table 16.7. Summary information for Guam's coral reef monitoring, research, and assessment activities.

ACTIVITY	AGENCY	NO. OF YEARS	FUNDING	OBJECTIVE	DATA COLLECTION	FIT IN LARGER EFFORT
Marine Preserve Monitoring	DAWR	2	NOAA Coral Reef Monitoring Grant, Sportfish Restoration	Assess the effectiveness of Guam's Marine Preserves on Food Fish populations. Visual transects and interval counts are used to assess fish species. Some benthic baseline data has been collected but full-scale benthic monitoring is scheduled to start in 2004.	Every 1-2 years	Provides assessment of fisheries
	Univ. of Guam	2		Assess the effectiveness of Guam's Marine Preserves by looking at focal species abundance, population structure, and recruitment in preserves and adjacent control sites.		
Sedimentation	National Park Service	<1	Dept. of the Interior	Assess the level of sedimentation occurring in the watershed included in the War of the Pacific National Park. Data collected includes total sediment, % organic, % carbonate, sediment size, water temperature, and light penetration. Benthic transect and coral recruitment should be added in near future. Goal of the project is to assess the impacts of wildland fire on sedimentation.	Monthly	Provides sedimentation data and effect on reefs
Erosion	National Park Service	<1	Dept. of the Interior	Land based monitoring of erosion rates in burned vs. non-burned areas. In addition erosion flumes are being used to assess possible badland mitigation techniques.	Weekly	Addresses the land based issues affecting reefs.
	Univ. of Guam	1	EPA, NOAA	Monitoring sediment input in Fouha Bay to create a model of sediment flow and document corresponding changes in coral communities.	Weekly	Provides Water Quality Data affecting corals and marine life
Water Quality	Guam EPA	>20	U.S. EPA	GEPA 305b, Water Quality Report to Congress	Biennially	Provides Water Quality Data affecting corals and marine life
				EMAP, Recreational Water Quality,	Weekly	
			NOAA/US EPA	Denton et al. 1997, 1999, PCR Environmental, 2002 reports,	One time	
			Permittee	Monitoring wells, golf courses and restoration sites	Quarterly	
Benthic Habitat	NOAA Pacific Islands Fisheries Science Center-CRED	<1	NOAA; Dept. of the Interior	Document baseline conditions of the health of coral, algae, and invertebrates, refine species inventory lists, monitor resources over time to quantify possible natural or anthropogenic impacts, document natural temporal and spatial variability in resource community, improve our understanding of the ecosystem linkages between and among species, trophic levels, and surrounding environmental conditions.	Biannually	Provides long-term monitoring of coral reef ecosystem.
	National Park Service			Benthic assessments and establishment of long-term monitoring sites in Orote and Haputo ecological reserves.	Annually (proposed)	

Table 16.7 (con't). Summary information for Guam's coral reef monitoring, research, and assessment activities (continued).

ACTIVITY	AGENCY	NO. OF YEARS	FUNDING	OBJECTIVE	DATA COLLECTION	FIT IN LARGER EFFORT
Fisheries Monitoring	DAWR	>20	Sportfish Restoration	Conduct creel, participation, and boat-based surveys to obtain information including boating activity, fishermen participation, catch per unit effort, and species composition in order to monitor the health of the fisheries resources	Semi-weekly (on average)	
Associated Biological Communities	Univ. of Guam	6	Coral Reef Initiative Management/ Monitoring Grants	Reef Check	Annually	Provides some long-term monitoring at a very broad level
	Univ. of Guam			Assessment of *Acanthaster planci*	One time	Repeated survey from 1980s to assess change over time of benthic community
Recreational Impacts	Univ. of Guam	1	Coastal Zone Management Grant	Assessment of recreational impacts of underwater activities in Cocos and Piti	One time	Provides an initial assessment of recreational impacts and suggests future courses of action

In addition to Guam's efforts, NOAA initiated the Marianas Archipelago Reef Assessment and Monitoring Program (MARAMP) aboard its research vessel *Oscar Elton Sette* in 2003. The cruise lasted 39 days from August 21 to September 28, 2003. The goals of the MARAMP include improving the understanding of coral reef ecosystems, evaluating and reducing adverse impacts, enhancing coral reef ecosystem-based fisheries management and conservation through cooperation with partners (Federal and local agencies and non-governmental organizations), and providing scientific information needed to establish, strengthen, and manage marine protected areas (MPAs; NOAA Pacific Islands Fisheries Science Center - Coral Reef Ecosystem Division, http://www.nmfs.hawaii.edu/crd). The science team for the Guam leg of the cruise (September 23-28) was comprised of staff from the NOAA Coral Reef Ecosystem Investigation Program, DAWR, U.S. National Park Service, and UOGML. The team conducted a variety of ecological and oceanographic assessments, including (Figure 16.10):

- Benthic habitat mapping: multi-beam surveys, single beam QTC surveys, geodetic control, towed diver surveys, and TOAD towed camera surveys;
- Fish, turtle, and marine mammal surveys: belt transects, stationary point counts (SPCs), towed diver surveys, roving diver surveys, and hydroacoustic surveys;
- Benthic surveys (corals, other invertebrates, algae): belt transects, towed diver surveys, roving diver surveys, and TOAD towed camera surveys; and
- Oceanography: closely-spaced conductivity-temperature-depth measurements, drifters, subsurface temperature, acoustic Doppler current profiler transects, CREWS/SST buoys, and current/wave moorings.

The MARAMP is intended to be a long-term monitoring program with research cruises scheduled bi-annually. The next cruise is scheduled to occur in 2005 (R. Brainard, pers. comm.).

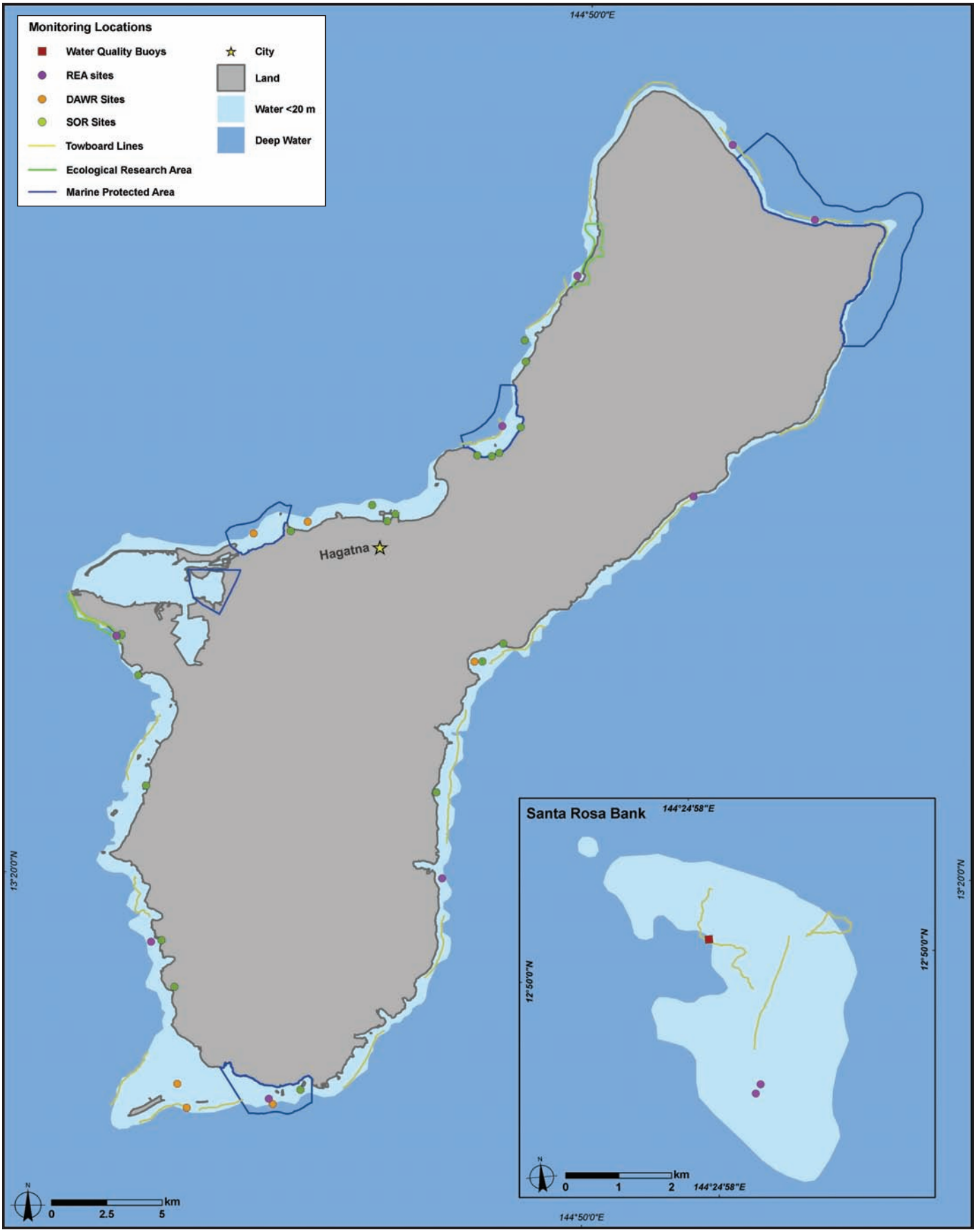

Figure 16.10. The locations of monitoring sites around Guam. Map: A. Shapiro. Sources: DAWR; PIFSC-CRED.

WATER QUALITY

Limited studies have been conducted on water quality indicators important to coral reefs. GEPA regularly monitors point source pollution and tests for *Enterrococcus* indicator bacteria on Guam's beaches, but there is limited information on parameters such as nutrient loads, turbidity, or contaminants. However, this is expected to change in the near future with the implementation of GEPA's Environmental Monitoring and Assessment Program (EMAP).

GEPA Water Quality Sampling

According to U.S. EPA requirements, the GEPA samples coastal recreational waters at 39 stations around the island every week for *Enterococcus* bacteria. A public advisory is issued when an instantaneous measurement of bacterial levels exceeds 104 units per 100 ml of water. In fiscal year 2003, 27% of 2,028 samples exceeded this standard, resulting in 551 advisories. In 2002, GEPA weekly monitoring of the 39 stations resulted in 1,055 advisories (Table 16.8). Despite the apparent improvement in recreational water quality from 2002 to 2003, it is important to consider that water quality in 2002 was unusually poor, with 51% of samples resulting in advisories. Previous years had rates similar to those observed in 2003. However, the validity of basing advisories on *Enterococcus* as a bacterial indicator of sewage pollution is questionable, as it exists in the tropical soils of Guam, independent of sewage pollution. Following rains and stormwater runoff, *Enterococcus* readings always increase in Guam's coastal recreational waters, as the bacteria wash out of the soil (Collins, 1995).

Table 16.8. Water quality advisories issued for recreational areas due to unacceptable *Enterococcus* levels in 2002-2003. Quarters are by fiscal year. Source: GEPA.

REGION	NUMBER OF ADVISORIES PER QUARTER				TOTAL NUMBER OF ADVISORIES
	1ST	2ND	3RD	4TH	
2002 Northern Guam Subtotal	117	124	66	128	**435**
2002 Southern Guam Subtotal	83	70	98	369	**620**
2002 Total	200	194	164	497	**1055**
2003 Northern Guam Subtotal	76	29	63	78	**246**
2003 Southern Guam Subtotal	81	26	77	121	**305**
2003 Total	**157**	**55**	**140**	**199**	**551**

According to PCR Environmental Inc. (2002a, b, c), freshwater springs in Tumon Bay discharge an estimated 64,350 m^3 of freshwater each day. In 2002, samples from eight of these springs were tested for a broad range of pollutants. Of the 35 volatile organic compounds that were measured only methylene chloride was present in amounts exceeding drinking water standards (5 µ/L). Eight different organophosphate pesticide compounds and 25 carbamate pesticide compounds were not detected or were below standards. Of 23 metals tested including mercury, only one metal in one sample exceeded drinking water standards (selenium at 0.0957mg/l, with the standard at 0.05 mg/l). Despite meeting the drinking water standards, the contaminants discharged by the freshwater springs may affect organisms found in the shallow marine waters of Tumon Bay (PCR Environmental, 2002a, b, c).

Other chemical and physical parameters of coastal waters were not tested regularly during 2002 and 2003 due to a shift to the new EMAP system, impacts from typhoons to the GEPA laboratory, and the need to prioritize increased testing of drinking water following the disasters. Sampling results of marine water quality from previous years by GEPA provided the following results.

From June 1997 to November 1998, 57 surface marine water quality samples were tested from San Vitores Beach, Dai Ichi Beach and Ypao Beach in the shallow waters of Tumon Bay (Table 16.9). In the rainy season of 2001 from July to October, GEPA took 89 surface water samples from sites throughout Tumon Bay (Table 16.10). In addition, 30 samples from four surface water stations in Tumon Bay were tested in the rainy season and the dry season from July to December 2001 (Table 16.11).

Table 16.9. Summary of 57 water quality samples from Tumon Bay, 1997-98. Source: GEPA.

	Temp (°C)	DO (mg/L)	pH	Sal. (ppt)	Secchi Disc - Horiz. (meters)	Enterococ. (CFU/100mL)	Ttl Susp. Solids (mg/L)	Turb. (NTU)	Cond. (mmho)	NO_2-N (mg/L 0.000)	NO_3-N (mg/L 0.000)	P-Tot (mg/L)	O-P (mg/L)	N P-Tot (mg/L)S
Mean	28.4	7.08	8.29	34	11.7	11.1	19.7	0.54	43.7	0.002	0.102	0.007	0.003	0.007
Med	28.4	7.35	8.3	35	11	1	20	0.41	42.7	0.001	0.046	0.007	0.002	0.007
Max	30.7	12.08	8.68	37	27	264	40	1.7	65.8	0.006	0.98	0.017	0.025	0.017
Min	26	2.76	7	30	3	1	4	0.15	33.2	0	0.003	0	0	0
Mode	27	7.4	8.5	35	11	1	20	0.3	#N/A	0	0.036	0	0.002	0

Table 16.10. Summary of 89 water quality samples from Tumon Bay, July to October 2001. Source: GEPA.

	Temp (°C)	DO (mg/L)	pH	Sal. (ppt)	Secchi Disc - Horiz. (meters)	Enterococ. (CFU/100mL)	Ttl Susp. Solids (mg/L)	Turb. (NTU)	Cond. (mmho)	NO_2-N (mg/L) 0.000	NO_3-N (mg/L) 0.000	P-Tot (mg/L)	O-P (mg/L)	N P-Tot (mg/L)S
Mean	30.5	6.63	8.20	34.4	0.120	0.33	48.70	0.003	0.077	0.037	0.003	0.003	0.007	0.003
Med	30.5	6.0	8.22	35.0	0.105	0.28	44.70	0.003	0.026	0.013	0.003	0.002	0.007	0.002
Max	32.5	11.8	8.71	35.0	0.463	1.50	431	0.008	0.99	0.321	0.011	0.025	0.017	0.025
Min	28.5	4.6	7.83	23.0	0.027	0.15	30.9	0.001	0.001	0.001	0.001	0	0	0
Mode	31.0	5.5	8.26	35.0	0.064	0.20	45.4	0.003	0.007	N/A	0.002	0.002	0	0.002

Table 16.11. Summary of 30 water quality samples from four locations in Tumon Bay, 2001. Source: GEPA.

	Temp (°C)	DO (mg/L)	pH	Sal. (ppt)	SiO2	Turb. (NTU)	Cond. (mmho)	NO2-N (mg/L)0.000	NO3-N (mg/L)0.000	NH4-N (mg/L)0.000	O-P (mg/L)	O-P (mg/L)	N P-Tot (mg/L)S
Mean	29.82	6.55	8.19	34.8	0.104	0.998	50.78	0.003	0.0376	0.002	0	0.003	0.007
Med	29.75	6.29	8.21	35	0.093	0.425	52	0.003	0.0155	0.002	0	0.002	0.007
Max	32	9.14	8.39	35	0.18	16	53.2	0.008	0.155	0.002	0	0.025	0.017
Min	28	4.57	7.91	33	0.061	0.21	43.4	0.003	0.002	0.002	0	0	0
Mode	29.5	5.9	8.15	35	0.078	0.35	52	0.003	0.004	N/A	0	0.002	0

BENTHIC HABITATS

A number of studies have looked at benthic habitats in Guam's nearshore waters. These studies include studies sponsored by the U.S. Navy at two compensatory mitigation sites, Orote Peninsula ERA and Haputo ERA (Amesbury et al., 2001; Paulay et al., 2001), a thesis study on the effects of *Acanthaster planci* infestations on coral community structure (Bonito, 2002), and the initial interpretation of the macroalgae surveyed during the 2003 *Oscar Elton Sette* cruise to Guam (Vroom, in review).

Orote Peninsula Ecological Reserve Area

The Orote Peninsula ERA contains a diverse assemblage of habitats, including a highly exposed, current-swept point; a silty bay; intertidal fringing reefs; and deep, steep dropoffs and caves. To capture this diversity, the area was divided into 58 representative sub-zones (Figure 16.11). The area was examined using a manta tow and divided into 17 zones based on topography and bottom-type. These zones were then sub-divided based on depth. For the qualitative diversity surveys, divers surveyed each sub-zone and recorded all visible fish, macroinvertebrate, and coral species (Paulay et al., 2001).

Methods

For the quantitative surveys, 10 permanent monitoring stations were established representing the main habitat types found in the ERA. Due to the steep forereef topography in most of the study area, eight stations were located at the 15 m depth contour where the forereef slope is less steep. The other two stations were located in Agat Bay, which has a more traditional forereef slope which allowed for two stations at a depth of 5 m. At each monitoring station, five 50-m transects laid end to end (5-10 m apart) were used to survey an area approximately 270-290 m long. Four types of surveys were conducted along each transect: 1) a benthic cover survey, 2) a coral population survey, 3) a fish survey, and 4) a macroinvertebrate survey.

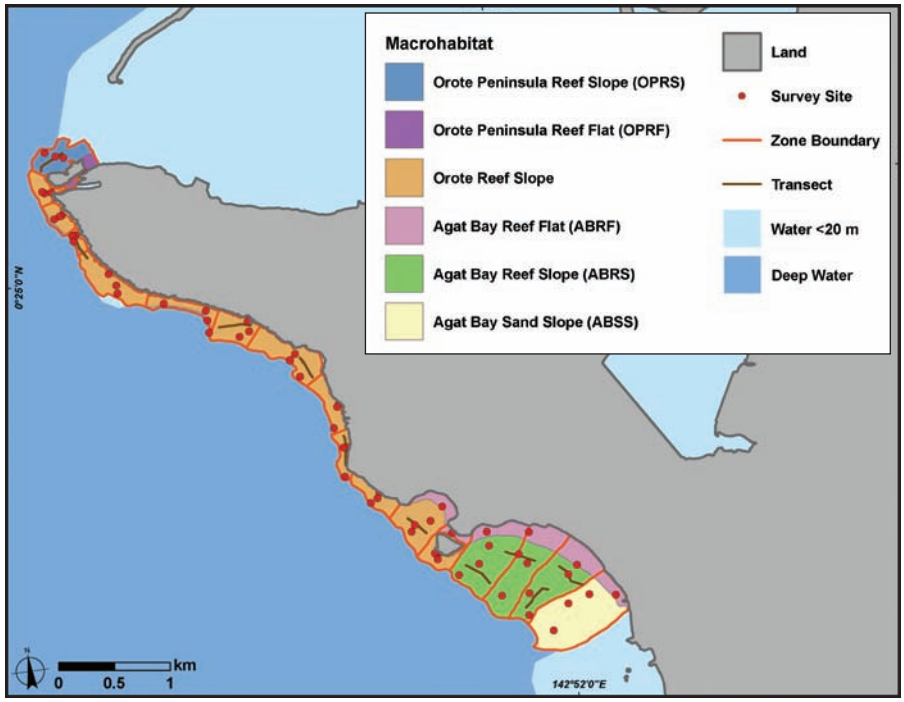

Figure 16.11. Macrohabitat zones, transect sites, and survey sites in the Orote Peninsula ERA. Map: A. Shapiro. Source: Paulay et al., 2001.

Quantitative surveys used both the video protocol recommended by English et al. (1997) and point quarter methods used by Birkeland and Lucas (1990). For the video transects, the camera was held 25 cm away from the bottom to record a 25 cm swath along each transect. Five points from 60 equally spaced frames were analyzed for each transect, providing a total of 1,500 points per station. The point quarter method was used to survey one to three transects at each station. Sixteen points were haphazardly selected on each transect. The distance to the center of the closest coral colony center, the length and width of the colony, and the species were recorded in each quadrant.

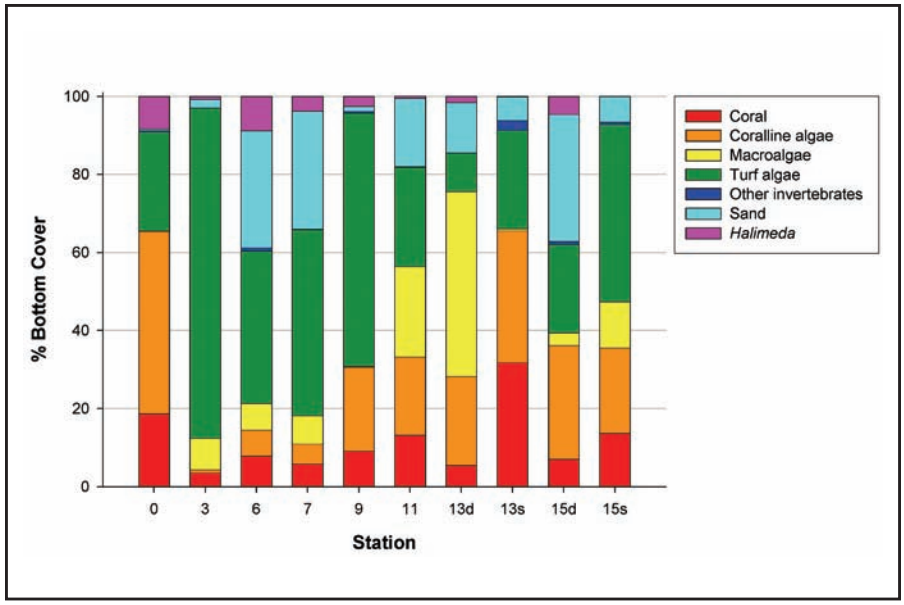

Figure 16.12. The relative composition of each coral cover class at 10 stations in Orote ERA. Coral cover was relatively, with percent coral cover ranging from 4-19%, except at one site dominated by *Porites rus*, which had 32% cover. Other cover types included turf algae, macroalgae, *Halimeda*, and coralline algae. Source: Paulay et al., 2001.

Results and Discussion

During these surveys, 1,252 species of marine animals were reported, including 156 species of scleractinian corals. Two of the coral species documented (*Leptoseris spp.* and *Favia rotundata*) were new records for Guam. Coral cover was relatively low at most Orote Point stations surveyed, ranging between 4 and 19%. One site dominated by *Porites rus* had 32% coverage. Bottom cover varied across the study area (Figure 16.12), and included coral, coralline algae, the green algae *Halimeda*, other macroalgae, turf algae, other invertebrates and sand. Coral demographics also varied by site, with colony size exceeding colony density at only the site dominated by *Porites rus* (Figure 16.13).

Haputo Ecological Reserve Area

The Haputo ERA is located along the northwest coast of Guam, from just south of Haputo Beach to just north of Double Reef. This area is bounded by narrow, supratidal benches or unprotected rock faces, although the study area contains two small, localized reef flats near Haputo Beach and Double Reef. Double Reef, an incipient barrier reef, is a unique feature in this area that creates highly heterogeneous habitat, including a distinct backreef community. Unlike the Orote Peninsula ERA, this study area lacked large-scale transitions along the shore, thus 31 sites were distributed evenly along the coast and along the depth gradient for the qualitative surveys (Figure 16.14). The fauna at each site were surveyed for at least one hour by a team of four or five divers. Two divers focused on corals and fish, which were surveyed during 30 minute diversity surveys. Two to three divers surveyed both exposed and cryptic macroinvertebrates.

Methods

For the quantitative surveys, six permanent monitoring stations were established in areas that provided relatively homogeneous benthic communities and maximal geographic coverage within the study area. Three stations were set at 8 m and three were set at 15 m. At each station, five 50-m transects were laid end to end (5-10 m apart), covering an area 270-290 m long. If there was not sufficient homogeneity for 250+ m of transects, two groups of 2-3 transects were laid, with the second group placed 10 m seaward of the first. Four types of surveys were conducted along each transect: 1) a benthic cover survey, 2) a coral population survey, 3) a fish survey, and 4) a macroinvertebrate survey. Quantitative surveys followed the same protocols discussed in the previous section.

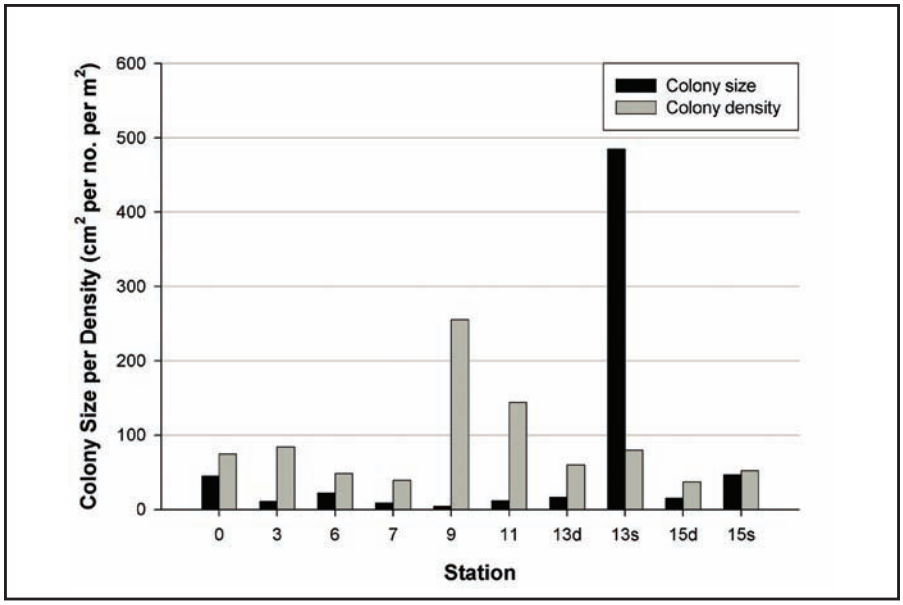

Figure 16.13. Coral demographics at 10 stations in the Orote ERA. Colony density was greater than colony size at all but one site. Source: Paulay et al., 2001.

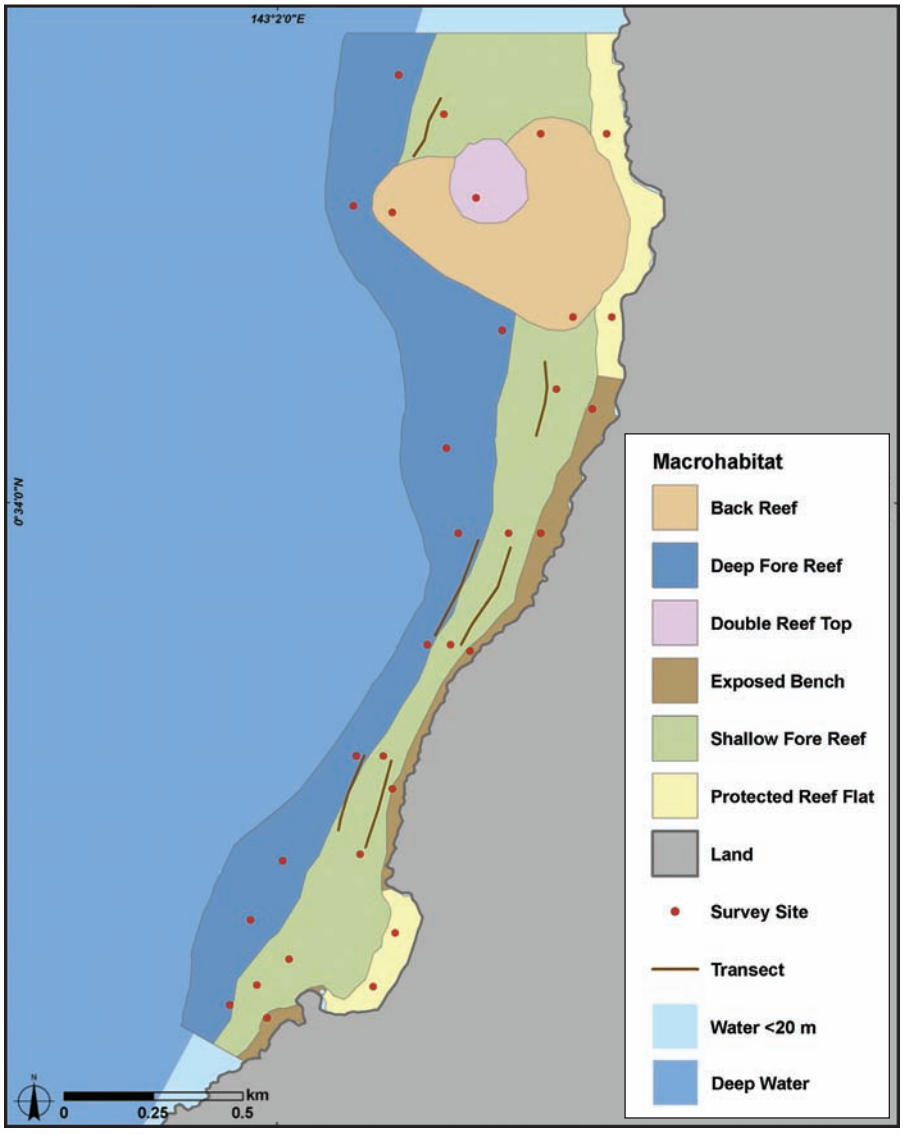

Figure 16.14. Macrohabitat zones, transect sites, and survey sites in the Haputo ERA. Map: A. Shapiro. Source: Amesbury et al., 2001.

Results and Discussion

During these surveys, 944 species of marine animals, including 154 species of scleractinian corals, were recorded. The quantitative studies indicated that coral cover was relatively high at most Haputo stations surveyed, ranging between 37% and 64%. This is higher than most locations in Guam's waters. *Montipora* and *Porites* were the dominant corals at all stations (Figure 16.15). *Montipora* was common at the shallow stations (1-3), but *Porites* dominated in deeper stations (4-6). Station 1 had 64% coral coverage, which was dominated by a diverse assemblage of *Montipora* colonies. In general, the data from this area suggest that the coral communities are thriving. Bottom cover varied across the study area (Figure 16.16), and included coral, coralline algae, macroalgae, turf algae, other invertebrates, and sand/pavement. Corals were the dominant cover, followed by turf algae. It is interesting to note that the coral killing sponge, *Terpios hoshinota,* was an important cover at Station 6 (coded as other invertebrates).

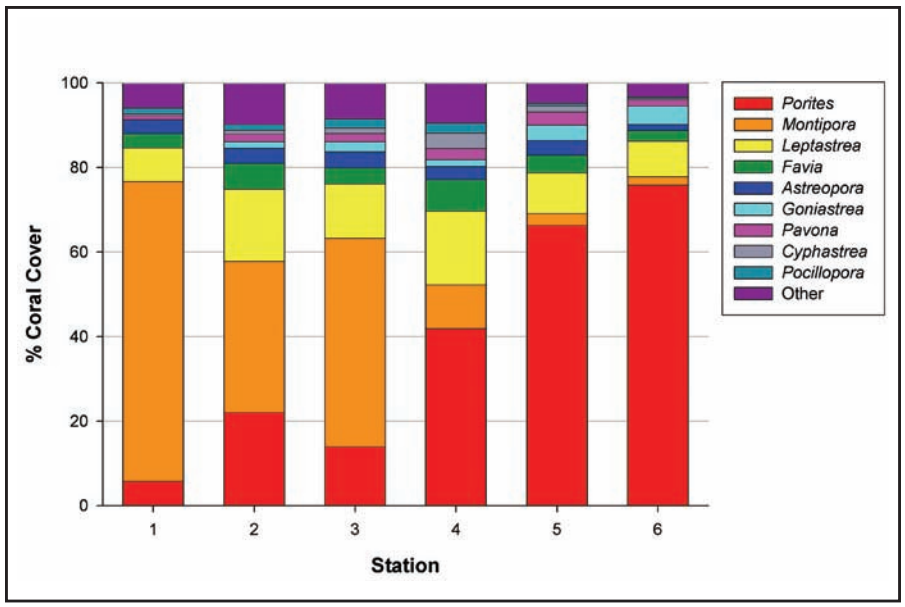

Figure 16.15. Over 150 species of scleractinian coral were documented in the Haputo ERA. Coral cover was dominated by *Montipora* and *Porites* at most of the six sites. Source: Amesbury et al., 2001.

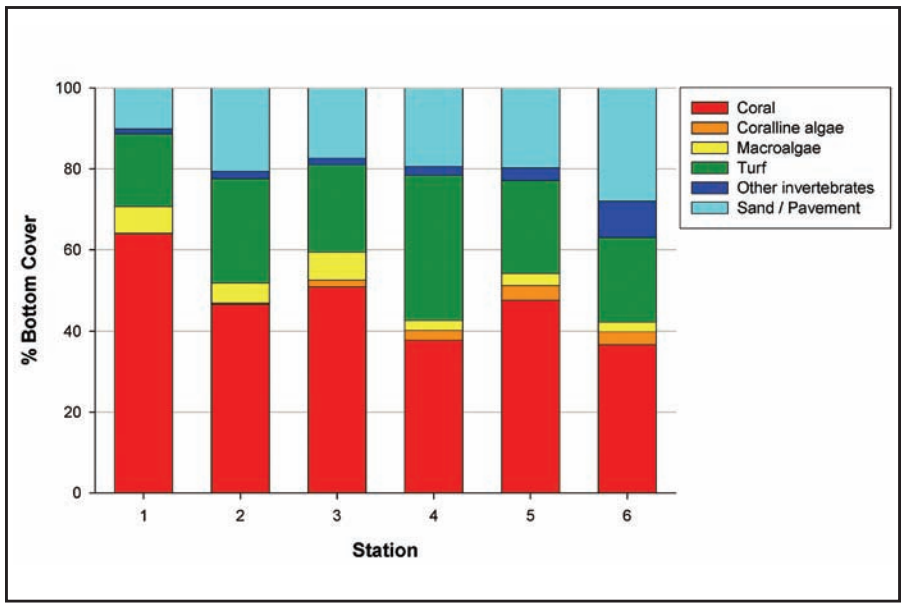

Figure 16.16. Bottom cover within the Haputo ERA. Corals emcompass 37-64% of bottom coer at the six sites. Other cover included turf algae, macroalgae, and coralline algae. There was a high incidence of *Terpios hoshinota*, the coral-killing sponge at site six. Source: Amesbury et al., 2001.

Effects of *Acanthaster planci* on Coral Community Structure

Tanguisson Reef has been studied since the early 1970s, when Randall (1973) monitored the recovery from a 1967 outbreak of COTS (*Acanthaster planci)*. The study indicated that coral coverage increased after the infestation through new coral recruitment and growth of existing corals. By 1980-81, the coverage of corals had increased until it was similar to neighboring reefs unaffected by the outbreak (Colgan 1981a,b; Colgan, 1987). This study also indicated that the community was dominated by *Acropora* and *Montipora* species. Since that time, a number of smaller *A. planci* outbreaks have been reported. Bonito and Richmond (submitted) studied the community again in 2001 to determine if the community structure had changed since the 1980s.

Methods

Tanguisson Reef is located on the northwest coast of Guam and can be divided into three physiographic zones. The reef front is a well-developed spur and groove system in depths of 1-6 m and ranges in width from 50-70 m. Relief in this area can be greater than 3 m, but tapers off at the end of this zone. The submarine terrace covers areas that are 6-18 m in depth. This zone has lower relief and ranges from 40-110 m in width. It is followed by the seaward slope, which ranges from 18-40 m in depth. This zone has an intermediate relief of 1-2 m.

Transects in the 1970s and 1980s were laid perpendicular to shore across the reef to a depth of 10 m. In 1970, 1971, and 1974, Randall (1973) used a quadrat method at 10 m intervals along each transect (Jones et al., 1976). This method measured the width and length of each colony at least 50% within the quadra, and recorded the growth form of each colony. This information was used to determine the live coral cover, colony abundance, small colony abundance, and species frequency. Colgan resurveyed the transects in 1980 using the point-quarter method at 2 m intervals and in 1981 using the quadrat method. The most recent study in 2000 and 2001 used the quadrat method used by Randall in the 1970s; however, the original transects could not be located. Twenty stations were sampled on the reef front, 22 on the submarine terrace, and 15 on the seaward slope. Three additional dives were conducted in each zone to assess overall species richness.

The researchers also studied the feeding preferences of *A. planci* on northwestern reefs. Twelve sites were chosen on the western side of the island. At each site, coral species abundance was surveyed and the site was searched for *A. planci*. Researchers recorded the number of *A. planci* present and the number of freshly eaten colonies of each coral species.

Results and Discussion

The researchers found that *A. planci* preferentially feed on *Acropora, Montipora,* and *Pocillopora* species. *Astreoopora, Cyphastrea, Goniastrea, Pavona,* and *Stylophora* were considered medium-preference corals. *Acanthastrea, Favia, Favites, Galaxea, Goniopora, Leptastrea, Leptoseris, Millepora, Platygyra, Porites, Psammocora,* and *Stylocoeniella* were considered non-preferred corals. They observed that diet depended on relative abundance of corals. If the preferred species were relatively abundant, they were the predominant food source, while medium-preference corals were eaten when preferred species were not abundant. Non-preferred corals were only eaten when the others were relatively rare.

Colgan's study in 1980-81 found that the submarine terrace was dominated by several species of *Montipora*. *Acropora* and *Montipora* species were the second and third most dominant species in the reef front and seaward slope. The newest survey of this area found that *Porites* is now the dominant genus on the submarine terrace and seaward slope, with only negligible contributions from *Montipora* and *Acropora*. The reef front is now dominated by other genera and *Acropora* is only an insignificant contributor. This study found no change in total percent coral cover on the submarine terrace and a slight decrease on the seaward slope. The researchers suggest that this change in community composition may be due to feeding by *A. planci*, as non-preferred corals had significantly greater cover than preferred or medium-preference corals on the seaward slope and submarine terrace. Non-preferred corals are the most abundant in all zones. Preferred corals increased slightly in cover and abundance on the reef front, but not as much as the other preference groups.

This study suggests that large-scale changes in the coral communities at Tanguisson Reef over the last 20 years may have been driven by selective feeding by *A. planci*. The study also identifies seasonal algal blooms as an additional stressor that may impact the settling of larvae produced by *Acropora, Montipora,* and *Pocillopora* species that spawn in the summer. This combination of effects seems to be exacerbated by nutrient influx into Guam's coastal waters and depletion of herbivorous fish stocks due to overfishing. Nutrient influx may be directly affecting the survivorship of *A. planci* larvae, which are dependent on planktonic food supply and can directly assimilate dissolved organic matter. Declines in the herbivorous fish stocks may impact larval settling of corals as algal blooms cover most of the suitable substrate during the summer months when these species spawn. Better land management is suggested as the best means to protect Guam's reefs from future shifts in coral communities.

Algal Communities

Guam's algal communities were surveyed as a part of the MARAMP in September 2003 using a rapid ecosystem assessment (REA) protocol developed specifically for remote island ecosystems (Preskitt et al., 2004). One component of this protocol, a rapid method of analysis using presence/absence and ranked data, was employed for this preliminary assessment (Vroom, in review). These data provide information on prevalence and relative abundance of algae in Guam at the genus level. Prevalence was defined as the percentage of quadrats in which a genus occurs at each site and relative abundance was defined as the abundance of a genus (i.e., the rank) in relation to other algal genera occurring in the same quadrat (Vroom, in review).

Methods

Benthic REAs were conducted at nine sites around Guam, including one site on Santa Rosa Bank, just southeast of Guam. Three 25-m transect lines were set in a single-file row at a constant depth, with each transect separated by 10 m. Ranked abundance of algal genera was collected from a total of 12 quadrats (0.18 m^2) at each site (1 being the most abundant, 2 being the next most abundant, etc.; Vroom et al., in review). Additionally, samples of macroalgae present within each quadrat were collected as voucher specimens (Preskitt et al., 2004).

Results and Discussion

According to Vroom (in review), algae from 28 genera or functional groups (i.e., crustose coralline algae, upright branched coralline algae, turf algae, cyanophytes) were found in quadrats at sites sampled around Guam and Santa Rosa Bank. In addition to the functional groups of turf, cyanophytes, branched coralline algae, and crustose coralline algae, the most prevalent genera found around Guam included green algae (*Halimeda* and *Neomeris)*, brown algae (*Padina*), and red algae (*Trichleocarpa* and an unknown gelid rhodophyte). At the Santa Rosa Bank site, species in the genera *Dictyosphaeria, Halimeda, Udotea,* and the green algal species *Microdicyton okamurai* Setchell were most prevalent. Turf and the gelid rhodophyte were also extremely prevalent. Relative abundance of genera was similar among sites.

Benthic Habitat Mapping

NOAA's Center for Coastal Monitoring and Assessment - Biogeography Team initiated a nearshore benthic habitat mapping project for Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands (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. The project, which was completed in 2004, mapped 104.7 km^2 of nearshore habitat in these islands and produced a series of 42 maps that are currently being distributed via a print atlas, CD-ROM, and on-line at: http://biogeo.nos.noaa.gov/products/us_pac_terr/. The benthic habitat maps for Guam are depicted in Figure 16.17.

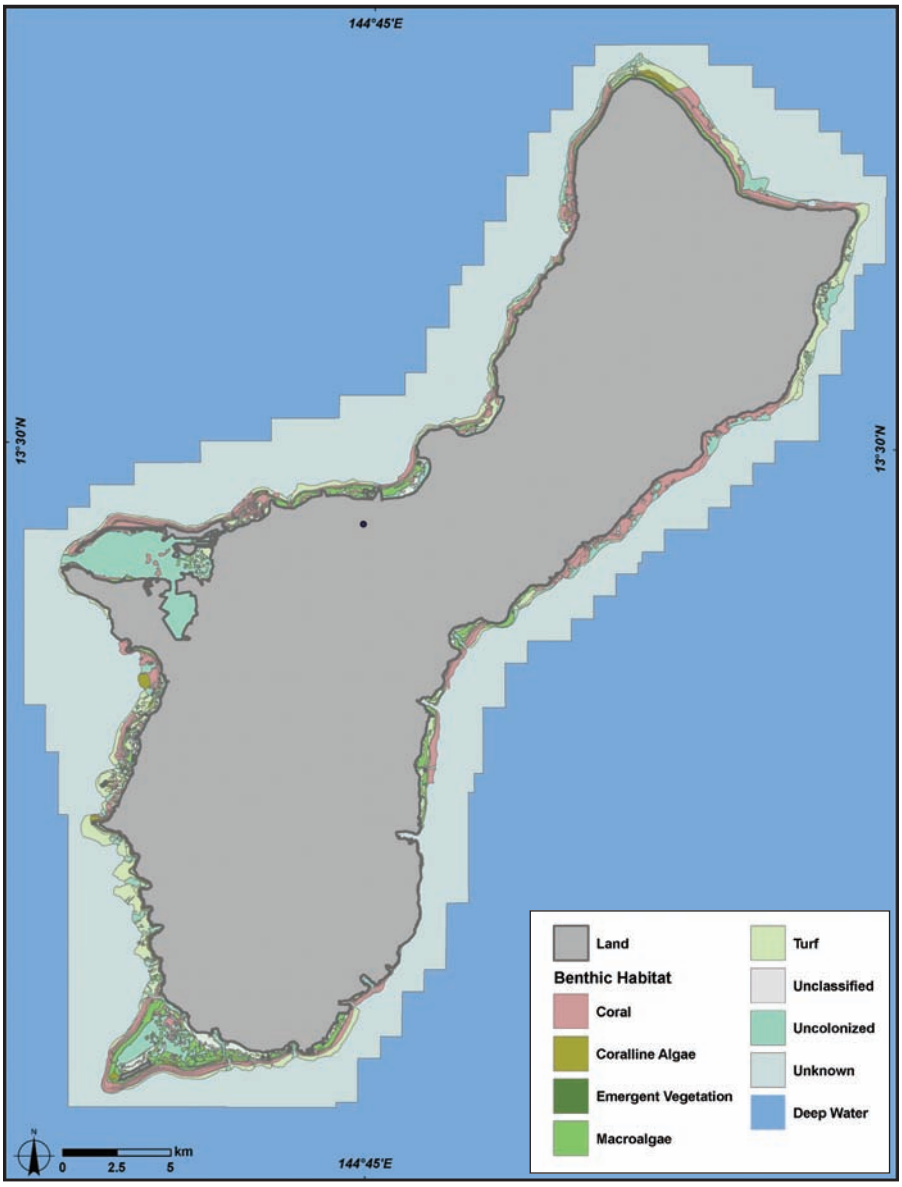

Figure 16.17. Nearshore benthic habitat maps were developed in 2004 by CCMA-BT based on visual interpretation of IKONOS satellite imagery. For more info, see: http://biogeo.nos.noaa.gov. Map: A. Shapiro.

ASSOCIATED BIOLOGICAL COMMUNITIES

Many recent studies on Guam have examined the biological communities associated with coral reefs. The most detailed studies have examined the fish communities. These include the marine preserve monitoring by the DAWR (Gutierrez, in prep.) and UOGML (Tupper, in prep.). The U.S. Navy-sponsored studies at Orote Peninsula and Haputo ERAs discussed in the previous section also examined fish communities and macroinvertebrate populations at the survey sites. Preliminary data for fish communities collected during the MARAMP are included below, although data for other communities are not yet available.

DAWR Marine Preserve Monitoring

In 1997, Guam established five marine preserves around the island, covering 11.8% of the island's shoreline. DAWR sampled the fish populations in two of the preserve areas and suitable control sites prior to the start of full enforcement on January 1, 2001, and has since monitored the fish communities at these sites to determine the effectiveness of the preserve system. These studies focus on fish species targeted for consumption and indicator species such as butterflyfish.

Methods

The Piti Bomb Holes and Achang Reef Flat Marine Preserves are the experimental sites for the stock assessment surveys. Cocos Lagoon and the Asan forereef slope serve as the control sites for the Piti Bomb Holes Marine Preserves, while Pago Bay reef flat and Cocos forereef slope serve as the control sites for the Achang Reef Flat Marine Preserve.

Prior to full enforcement in 2001, 66 permanent belt transects (50 m x 5 m) were surveyed on the reef flats and forereef slopes of two preserve sites, Piti Bomb Holes and Achang Reef Flat Marine Preserves, and three control sites, Asan Bay, Cocos Lagoon, and Pago Bay. Two sets of transects were placed on the forereef slope at the 6, 9, 12 and 15 m depth contours. Eight transects were placed on the reef flat at each site, representing distinct microhabitats (seagrass, coral/algal/rubble, and sandy bottom).

Fish communities were surveyed using two different visual survey techniques along each transect. Density was assessed using a visual fish census along a strip transect. Two fish counters followed the 50 m long permanent transect, each counting all target fish within 2.5 m of the side of the transect. All target fish within this 250 m^2 area were scored on data sheets based on their species and size class. Three size classes were used based on the fork length of the fish (<15 cm, 15 cm-30 cm, >30 cm). The strip transect method was complemented by a timed visual survey in the same area. At each site, fish counters recorded the species and size class of all fish encountered in the area during a 30-minute interval.

Fish surveys were conducted at all sites prior to full enforcement of the preserves and then repeated within two years. Because of poor weather conditions and lack of a boat, only four transects on the forereef slope of Achang Reef Flat Marine Preserve were repeated (one at each depth of 6, 9, 12 and 15 m). Data were analyzed using Statview 4.5 for PC published by Abacus Concepts Inc. A two-tailed paired t-test was used to compare fish densities and diversity over time within each study site (Sokal and Rohlf, 1995). The Shannon-Weiner diversity index was used to calculate an index number for species diversity and evenness at each site for both pre- and post-implementation data. A higher index number indicated greater diversity. When the assumptions of analysis of variance (ANOVA) were not met, even after transformations, a nonparametric test was conducted (Sokal and Rohlf, 1995).

Results and Discussion

The data from the belt transect surveys suggest that fish stocks in the preserve areas are starting to recover, while some non-preserve areas are still declining. Data also indicate that within the Piti Bomb Holes and Achang Reef Flat Marine Preserves, there were significant increases of 113% ($p<0.001$) and 115% ($p<0.001$) respectively, in the number of individuals within the transects after the preserve protections were implemented (Figure 16.18). At non-preserve control sites, significant to minor decreases detected (29% at Asan/Cocos ($p<0.005$) and 4% at Cocos/Pago ($p>0.05$)) in the total number of individuals within the transects (Figure 16.19).

The largest increase appeared to be in the smallest size class. There were significant increases of 123% and

138% within the Piti Bomb Holes Marine Preserve ($p<0.001$) and Achang Reef Flat Marine Preserve ($p<0.001$), respectively, for individuals <15 cm after the preserve protections were implemented. In the non-preserve areas, there were significant to minor decreases of 27% at Asan/Cocos ($p<0.001$) and 5% at Cocos/Pago ($p>0.05$) for individuals <15 cm during the same period. For larger fish (>15 cm to <30 cm), results were more variable, with an increase of 44% within the Piti Bomb Holes Marine Preserve after preserve implementation and a 10% decrease in the Achang Reef Flat Marine Preserve. However, in the non-preserve areas, there were decreases of 75% (Asan/Cocos) and 33% (Cocos/Pago) in the number of individuals between >15 cm and <30 cm during the same period of time.

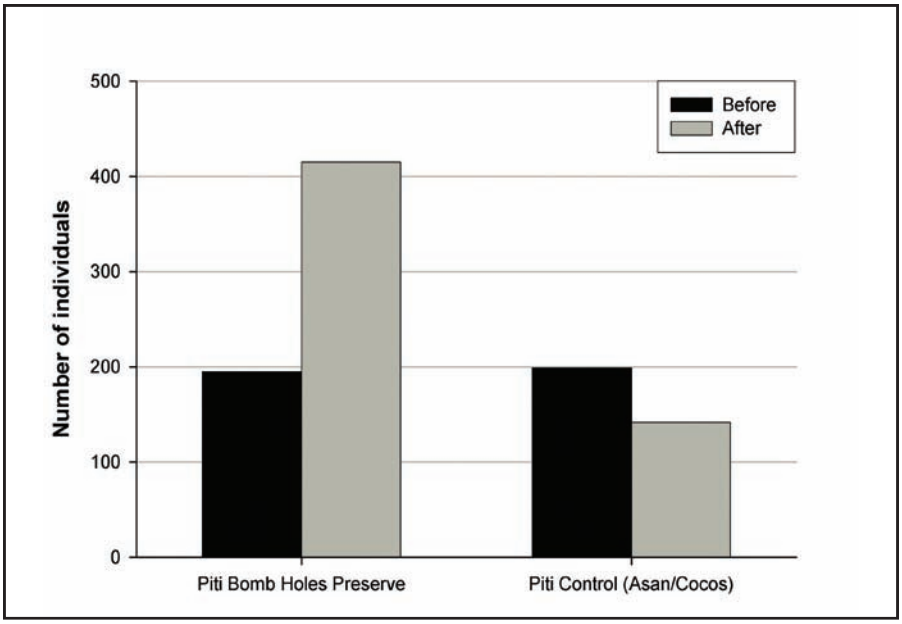

Figure 16.18. Number of individuals counted by DAWR on 16 transects in the Piti Bomb Holes Preserve and control site before and after full enforcement of the preserves. Source: Gutierrez, 2003.

Timed interval surveys indicated that the number of species observed at the study sites after preserve implementation increased by 14% within the Piti Bomb Holes Marine Preserve and 3% at the Asan/Cocos control sites. During the study period, diversity increased significantly (38%) in the Piti Bomb Holes Marine Preserve. Although diversity increased in the Asan/Cocos control sites, the increase was not significant (3%). Diversity indices have not yet been calculated for Achang Reef Flat Marine Preserve and the Pago/Cocos control sites.

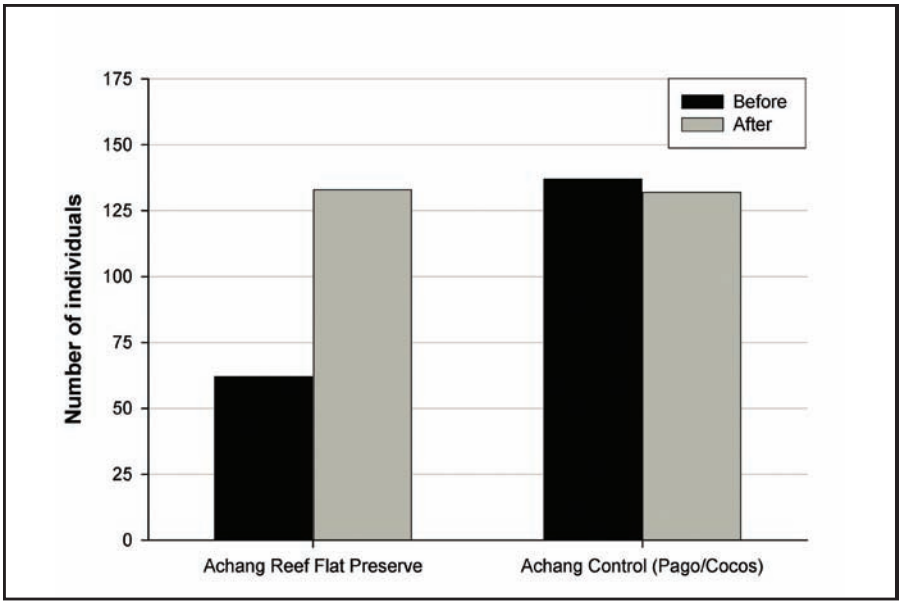

Figure 16.19. Number of individuals counted by DAWR on 16 transects in the Achang Reef Flat Preserve and control site before and after full enforcement of the preserves. Source: Gutierrez, 2003.

After only two years of implementation, there have been significant increases in fish density within the preserves. The majority of fish recruiting into the preserves are smaller than 15 cm. Within the non-preserve areas, fish density has remained the same or has decreased significantly within the same period of time. Preliminary data show that larger size fish (>15 cm) are being observed within the preserve while their numbers are decreasing within the non-preserve areas. Within one preserve, diversity also increased significantly.

University of Guam Marine Laboratory Marine Preserve Effectiveness

The UOGML is also involved with assessing the effectiveness of Guam's marine preserves. Tupper (in prep.) studied the effectiveness of three marine preserves - Achang Reef Flat, Piti Bomb Holes, and Tumon Bay - as compared to adjacent, unmanaged control sites - Cocos Lagoon, Asan Bay, and Agana Bay, respectively. The biophysical indicators chosen for this study were focal species abundance, population structure, and recruitment success.

Focal Species Abundance

Focal species abundance was determined for four species: bullethead parrotfish (*Chlorurus sordidus*), yellowstripe goatfish (*Mulloidichthys flavolineatus*), orangespine unicornfish (*Naso lituratus*), and bluespine unicornfish (*Naso unicornis*). Two sites were chosen within each of the three marine preserves and the three control sites. All sites were near the edge of the reef flat at depths of 2-5 m. Four replicate 50 m x 2 m transects were surveyed at each site to determine the density of each species per 100 m^2 area. The results were analyzed using a nested ANOVA. Location and status were used as model factors with location nested within status.

Densities for all four species were significantly higher in the MPAs than in the control sites, and in some cases, density was an order of magnitude higher in the preserves (Figure 16.20). Further analysis indicated that there were also significant differences among the preserve sites and among the control sites. Density of *Chlorurus sordidus* was highest at Piti Bomb Holes Marine Preserve, possibly due to fish feeding by divers and snorkelers. *Mulloidichthys flavolineatus* density was five to nine times higher in the preserves than in the control sites, with the highest density documented in Tumon Bay. Achang Reef Flat Marine Preserve had the highest densities of *Naso lituratus* and *Naso unicornis*.

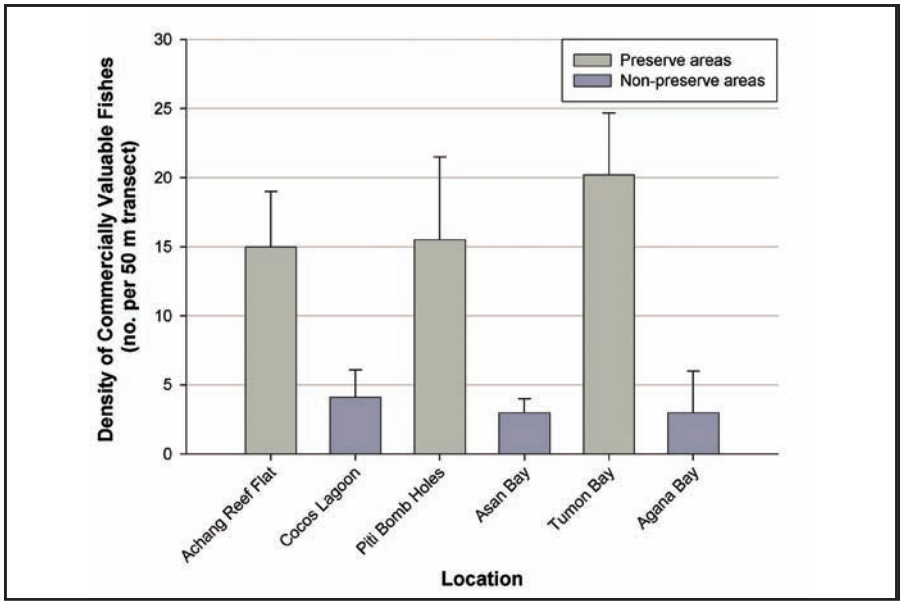

Figure 16.20. Density of commercially valuable food fishes along a 50 m transect at preserve and non-preserve sites following two years of enforcement at preserve areas. Food fish density was noticeably greater in preserve sites. Source: Tupper, in prep.

Population Structure

Population size structure was determined by counting fish and estimating their fork length in situ. As described in the previous section, fish were surveyed on four replicate 50 m x 2 m transects. Eight size classes were used for size estimation: 10-12.5 cm, 12.5-15 cm, 15-17.5 cm, 17.5-20 cm, 20-22.5 cm, 22.5-25 cm, 25-27.5 cm, and 27.5-30 cm. Fish less than 10 cm were not counted. As these small transects did not provide enough data, the method was modified to use a single 100 m x 4 m transect. However, this prevented statistical comparison between sites. The results indicated that *C. sordidus*, particularly the larger size classes, were more abundant at all preserve sites than control sites. *M. flavolineatus* were more abundant in the preserves than the control sites; however, small-medium sized *M. flavolineatus* were less abundant in Achang Reef Flat Marine Preserve than at the control sites in Cocos Lagoon.

The length and abundance data were used to determine the spawning biomass (the weight of the spawning adult fishes per unit area). The length data were used to estimate weight values using published length-weight regressions. Biomass for *C. sordidus* and *M. flavolineatus* was significantly higher in the preserve sites than the control sites (nested ANOVA, $F=8.49$, $p=0.006$, $F=15.7$, $p<0.001$).

Recruitment Success

Two aspects of recruitment success were studied: settlement and recruitment. Four replicate 25 m x 2 m transects were used to enumerate newly settled fish in March 2002. *C. sordidus* were recorded as newly settled if they were 10-15 mm long. *M. flavolineatus* were recorded as newly settled if they were 6-7 mm long. *C. sordidus* had the highest settlement in Cocos Lagoon; however, overall mean settlement was higher in the preserves than the control sites (nested ANOVA, $F=4.1$, $p<0.01$). *M. flavolineatus* settlement was similar across all sites with no significant differences between preserve areas and the control sites (nested ANOVA, $F=0.04$, $p=0.840$).

Transects were revisited three months later to determine the survival rates of the settled fish. On the second visit, the expected length for the previously recorded settlers was recorded: *C. sordidus* at 25-50 mm long and *M. flavolineatus* at 90-120 mm long. The pattern of recruitment changed during the three months that elapsed between surveys. Despite the high settlement in Cocos Lagoon, the second survey indicated that recruitment success was 50% less than in the Achang Reef Flat Marine Preserve. In general, *C. sordidus* recruitment in the marine preserves was significantly higher than in the control sites (nested ANOVA, $F=64.8$, $p<0.001$). *M. flavolineatus* recruited less successfully in the control sites, despite similar settlement (nested ANOVA, $F=9.5$, $p=0.004$). This was expected due to fishing pressure on newly-settled *M. flavolineatus* in the control sites.

Discussion

The results of this study suggest that the marine preserves in Guam have a positive effect on local reef fish populations. Species abundance for four species indicated significant differences between the protected areas and adjacent control sites. Large sizes of *C. sordidus* and *M. flavolineatus* were more common in the preserve areas; however, smaller sizes were more abundant in some of the control sites. Spawning mass was significantly higher in the marine preserves than in the control sites, thus indicating that the marine preserves may function as "egg banks" and provide higher production potential.

Orote Peninsula ERA Fish and Macroinvertebrate Surveys

As described above in the 'Benthic Habitat' section, the U.S. Navy sponsored biodiversity studies and baseline reef monitoring surveys at Orote Peninsula ERA (Paulay et al., 2001). Both qualitative biodiversity surveys and quantitative baseline monitoring were conducted for fish and macroinvertebrates.

Methods

Fish and macroinvertebrates were qualitatively surveyed at a site in each of the subzones identified in the study. At least one diver surveyed each category for the duration of one dive. Deep dives occurred at a depth of 27-30 m for 25 minutes, deeper dives were shorter (at least 10-15 minutes), and all other dives were 40 minutes or longer.

Fish surveys were conducted along the three central transects (50 m x 5 m) laid out for the benthic surveys described above. Quantitative surveys were conducted following the methods described in English et al. (1997). The fish surveyor started the transect at least 10 minutes after the transects were laid and before any other surveyor. Large fish within 2.5 m of the transect and within 5 m of the bottom were recorded first. For highly abundant fish, a logarithmic scale was used for estimates of abundance. Abundance statistics were calculated for species, family, and total population at each station. The Shannon-Weiner diversity index and the number of species encountered were also calculated for each station.

Quantitative surveys of macroinvertebrates were conducted along all five belt transects (50 m x 1 m). Surveys included all large, exposed macrofauna. The primary taxa studied were larger mollusks and echinoderms, as cryptic fauna and small species could not be effectively sampled. Abundance was recorded in five 10-m^2 quadrats per transect, which were lumped into 50 m^2 quadrats for analysis. The mean and standard deviation were calculated for each of the transects.

Results and Discussion

The survey recorded 1,252 species of marine animals based only on the exposed macrofauna identified during the limited dives. Fish recorded included 339 species, approximately 37% of the 920 known species from Guam. Macroinvertebrates accounted for 657 species encountered during the qualitative surveys. Diversity appears to be related to habitat, with areas such as the reef flat between Neye Island and the coast, and the patch reefs in North Agat Bay, exhibiting high levels of diversity. In general, diversity declines from Orote Point southeastward and then increases again in the Agat area (Figure 16.21).

The quantitative surveys were conducted at 10 stations. Orote forereef sites had a higher abundance of fish than Agat Bay. Twenty-five fish families were recorded during the quantitative studies. The most abundant family was the Pomacentridae (69%), followed by the Acanthuridae (10.2%), Labridae (4.4%), Chaetodontidae

(3.8%), Scaridae (3.2%), and Balistidae (2.2%), while all other fish species comprised 7.2% (Figure 16.22).

During the quantitative surveys, a total of 26 species of macroinvertebrates were identified. This included 19 echinoderms, six mollusks, and one crustacean. The maximum number of species observed at a single station was 13, with the highest diversity occurring towards Agat Bay (Figure 16.23). These surveys only captured the large, diurnal, exposed species and did not capture the many cryptic and nocturnal species resident at these areas. The most commonly encountered species were: echinoids (*Echinostrephus aciculatus* and *Echinothrix* spp.), the giant clam (*Tridacna maxima)*, and the sea cucumber (*Holothuria edulis)*.

The study indicates that diversity and species composition of Orote Peninsula reefs are strongly influenced by physical factors such as wave exposure, currents, riverine influence, and bottom topography. A number of unique microhabitates and macrohabitats exist in this area, with very different assemblages found within each of them. The researchers indicate that the Blue Hole, Orote Boulder Fields, and Orote Point reef slope were biologically important due to unique species and high biodiversity.

Haputo ERA Fish and Macroinvertebrate Surveys

As described above in the 'Benthic Habitat' section the U.S. Navy sponsored biodiversity studies and baseline reef monitoring surveys at Haputo ERA (Amesbury et al., 2001). Both qualitative biodiversity surveys and quantitative baseline monitoring were conducted for fish and macroinvertebrates.

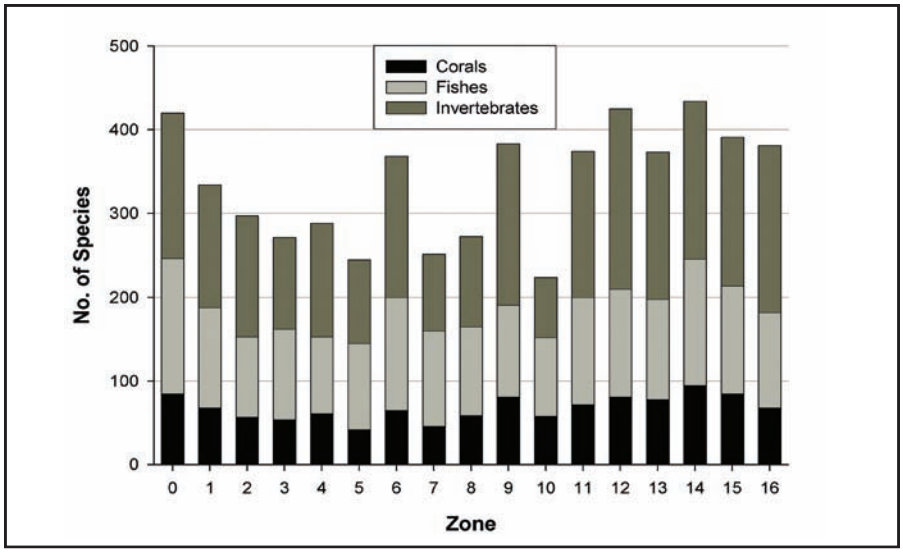

Figure 16.21. 1252 species were recorded during a survey in the Orote Peninsula ERA. Richness varied greatly between subzones. Source: Paulay et al., 2001.

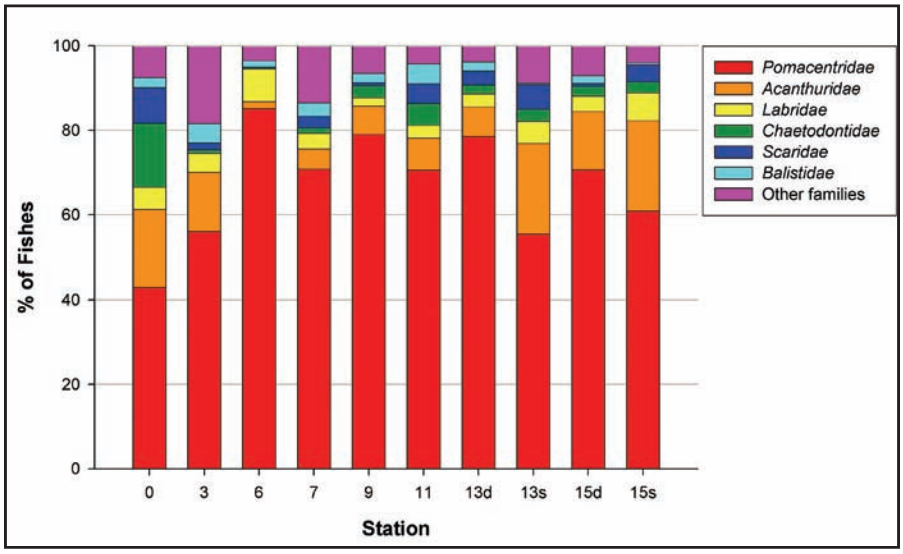

Figure 16.22. Fish family composition in the Orote Peninsula ERA. Source: Paulay et al., 2001.

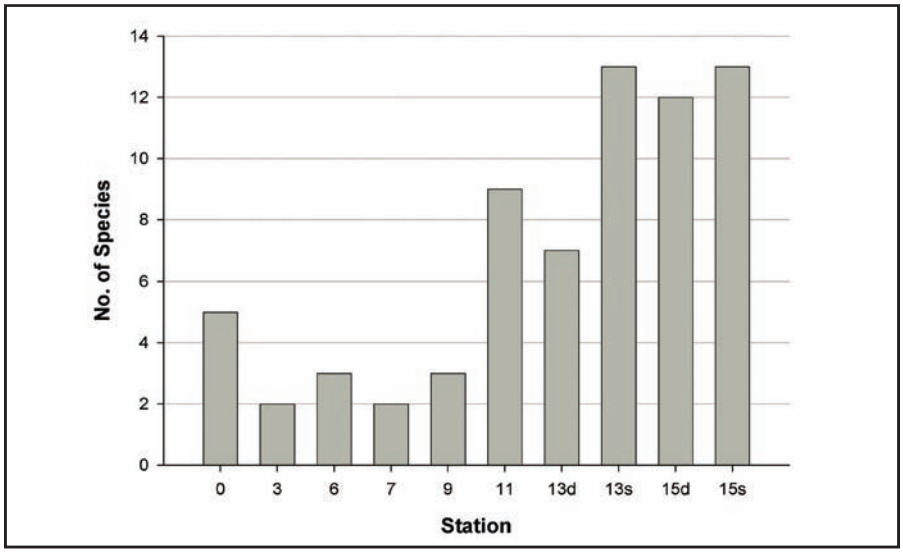

Figure 16.23. Number of macroinvertebrate species at 10 sites in the Orote Peninsula ERA. Macroinvertebrate communities varied greatly over the study sites. Cryptic species were not included in the survey. Source: Paulay et al., 2001.

Methods

Fish and macroinvertebrates were qualitatively surveyed at each of the sites identified in the study using timed surveys (30 minutes) to assess fish diversity and abundance and a timed search (one hour) for large macroinvertebrates. The survey team followed the same methodology for fish as described above in the Orote Point section, but used 2 m-wide transects for macroinvertebrates.

Results and Discussion

This survey recorded 944 species of marine animals. This included only the exposed macrofauana identified during the limited dives. Fish recorded included 207 species, approximately 22% of the 920 known species from Guam. Macroinvertebrates accounted for 583 species encountered during the qualitative surveys. A comparison of surveyed biodiversity between Orote Peninsula and Haputo ERAs showed some interesting results (Table 16.12). Researchers identified a similar number of corals at the two sites; however, they found more species of fish and invertebrates at Orote Peninsula than at Haputo sites. The researchers noted that while the corals are thriving at Haputo, the fish community is not. Large piscivores and herbivores were rare.

Table 16.12. A comparison of coral species in the Orote and Haputo ERAs indicated that both areas exhibited similar coral species richness, but different levels of fish and invertebrate species richness. Source: Amesbury et al., 2001.

SURVEY AREA	CORALS	OTHER INVERTEBRATES	FISHES
Orote-Agat	156	757	339
Haputo-Double Reef	154	583	207
Ratio	1.01	1.3	1.64

The researchers also noted differences among the six macrohabitats identified in the survey. The forereef sites are more diverse than the shallow sites. The shallow sites had fewer coral, fish, and other invertebrate species than the medium to deep macrohabitats (Figure 16.24).

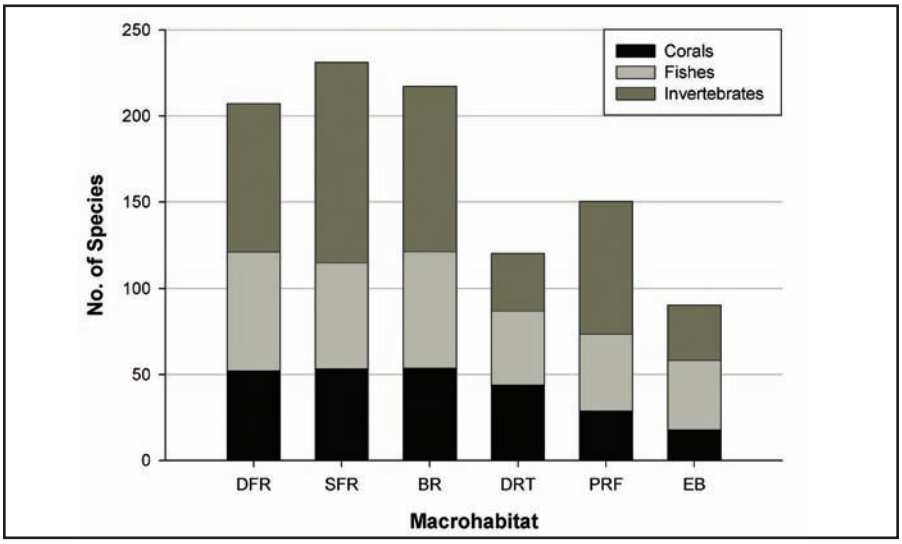

Figure 16.24. Mean number of species in six microhabitats in the Haputo ERA: Exposed Bench (EB), Protected Reef Flat (PRF), Double Reef Top (DRT), Back Reef (BR), Shallow Fore Reef (SFR), and Deep Fore Reef (DFR). Note the large variation in species richness among the six sites. Source: Amesbury et al., 2001.

The quantitative surveys were conducted at six stations. Twenty-one fish families were recorded during the quantitative studies. The most abundant family was the Pomacentridae (74%), followed by the Acanthuridae (10.1%), Labridae (6.7%), Lethrinidae (3.1%, *Gnathodentex aurolineatusa* only), Gobiidae (2.7%), Scaridae (1.2%) and Chaetodontidae (1.1%), while all other fish species comprised 3.4% (Figure 16.25).

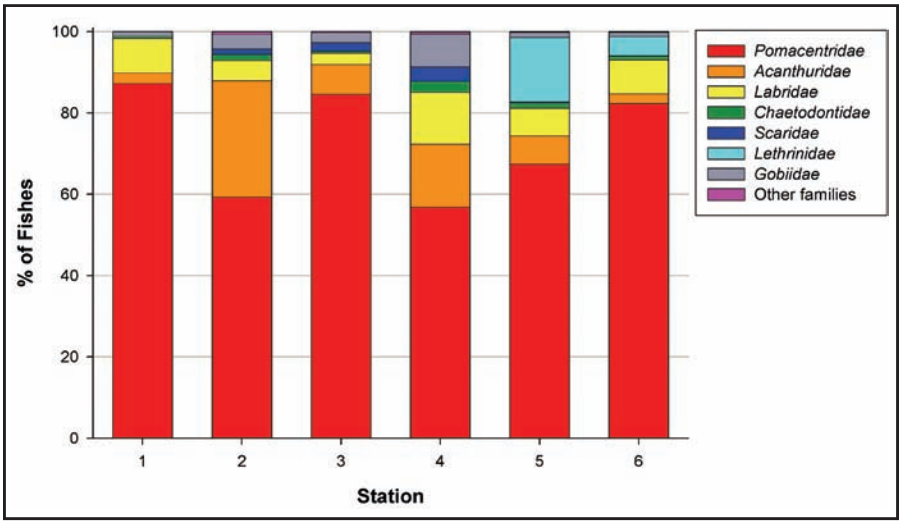

Figure 16.25. Fish family composition in the Haputo ERA. Source: Amesbury et al., 2001.

During the quantitative surveys a total of 24 species of macroinvertebrates were identified. This included 16 echinoderms and eight mollusks. The maximum number of species observed at a single station was 13, with the highest diversity occurring in the shallow stations (1-3) (Figure 16.26). The most commonly encountered species were sea urchins in the genera *Echinometra* and *Echinostrephus*. Giant clams (*Tridacna maxima)*, were found at five of the six sites, but were less common than sea urchins.

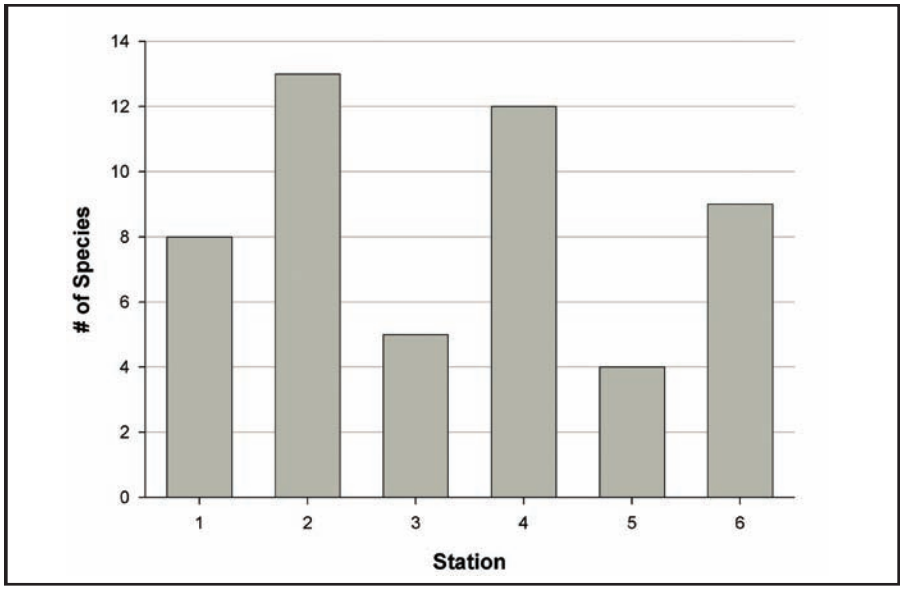

Figure 16.26. Number of macroinvertebrate species in the Haputo ERA. Macrovertebrate communities varied greatly and included 16 echinoderms and eight mollusks. Cryptic species were not included in the survey. Source: Amesbury et al., 2001.

The study indicated that while corals were thriving, the fish targeted by the local fisheries were less diverse and less abundant than expected. The low abundance of large individuals of these species suggests that overfishing may also be a problem in this area.

MARAMP Fish Surveys

Fish surveys were directed in September 2003 as part of the Guam leg of the MARAMP. Objectives of the surveys included: 1) creating a fish baseline to measure MPA effectiveness; 2) monitoring size-frequency assemblages; 3) assessing the status of target, indicator or keystone species; 4) assessing response by the fish community to possible ecosystem impacts (e.g., overfishing, habitat damage, sedimentation, prey size changes); and 5) assessing species composition and diversity by area and effectiveness of temporal monitoring of managed areas (R. Schroeder, unpublished data).

Methods

Fish were surveyed around the island of Guam and at Santa Rosa Bank. Several types of surveys were conducted, including: 1) REAs to document species diversity at a site; 2) belt transects to estimate densities of relatively small-bodied and abundant fishes; 3) SPCs to estimate densities of relatively larger (≥25 cm total length (TL)) and more mobile fish species; and 4) towed-diver/video surveys to estimate densities of relatively large-bodied (≥50 cm TL), wide-ranging fishes over a broad-spatial scale, in conjunction with a towed-diver/habitat video. Fish length-class was estimated for all quantified fishes to provide an estimate of numerical size structure and biomass density by taxa.

Results and Discussion

Schroeder (unpublished report) provided the following preliminary results. Data from 11 belt transects showed that large fish (≥20 cm) were not abundant, averaging about 2/100 m^2 (compared with over 14/100 m^2 at Uracas and Maug, the two northernmost islands in the Mariana Archipelago). Results from 11 SPC surveys were similar. Medium-sized fish were only common along the north and northeast sides of the island. Densities of larger fish (>50 cm TL) from towboard surveys were also quite low for both Guam and Santa Rosa (less than 0.1/100 m^2). No sharks were observed by the fish census team, although the fish tow-team did see black-tip and white-tip sharks. About 232 species were sighted during the five-day survey. Few juvenile fish were present, unlike the northernmost Mariana Islands, where recruitment for several species was higher. The highest diversity of fish was found at Jinapsan Beach on the northern tip of Guam. Common species observed included brown surgeonfish (*Acanthurus nigrofuscus*), red ribbon wrasse (*Thalassoma quinquevittatum*), bullethead parrotfish (*Chlorurus sordidus*), and orangespine unicornfish (*Naso lituratus*).

Guam sustains a large human population and its waters are heavily fished. Habitat damage and loss may also contribute to these preliminary findings on the status of coral reef fish assemblages. Ongoing analysis of the 2003 data, together with planned biennial monitoring, should help determine the effectiveness of Guam's recently established MPAs, as well as provide the scientific basis for other management initiatives.

Overall Condition/Summary of Analytical Results

Guam's northern reefs are generally in better condition than those affected by erosion and sedimentation in the south, due to the primarily limestone composition of northern Guam. Coral cover and diversity are generally highest in an area beginning roughly at Falcona Beach on the northwest coast, continuing clockwise around the northern coast, and extending down to Pagat Point on the eastern side of the island (Figure 16.27). The areas between Tanguisson Point and Falcona Beach also have high coral cover and diversity; however, they are heavily fished and have higher recreational use than the reefs to the north (Amesbury et al., 2001).

The eastern reefs along the central and southern portions of the island are heavily affected by sedimentation and freshwater runoff near the mouths of rivers that drains Guam's largest watersheds, especially during the rainy season. However, some very diverse and relatively healthy reefs lie adjacent to these heavily impacted spots, especially the forereef slopes off of Achang Reef Flat Marine Preserve and the south side of Cocos Lagoon. Most of the fringing reefs along the southwestern shores are in poor to fair condition, again depending on their proximity to river mouths. Water quality impacts caused by coastal development, wildland arson, and runoff are a serious concern in these areas; however, there are limited water quality data available. GEPA, DAWR, and UOGML hope to address this issue through future monitoring efforts such as increasing water quality monitoring and studying sedimentation of southern reefs in conjunction with upland restoration projects.

Although Apra Harbor is home to the busiest port in Micronesia, a large U.S. Navy base, and numerous recreational facilities, it contains both patch and fringing reefs with some of the highest coral cover on the island (i.e., Jade Shoals, Western Shoals, and Finger Reef). Both hawksbill and green sea turtles frequently forage in the protected waters of the harbor, and the extensive mangroves of Sasa Bay Marine Preserve are also located there. However, corals and reefs near the northeastern part of the harbor have been impacted by thermal discharges from the Guam's main power generation facilities (G. Davis, pers. comm.). The reefs from Orote Point south to Agat include many different microhabitats for a diverse assemblage of reef organisms. The fishing advisory for the areas near the Orote Dump has resulted in a de facto fishing preserve, allowing some stocks to rebound from fishing pressure. Chemicals leaching from the dumpsite do not appear to have significantly impacted the resources (Paulay et al., 2001).

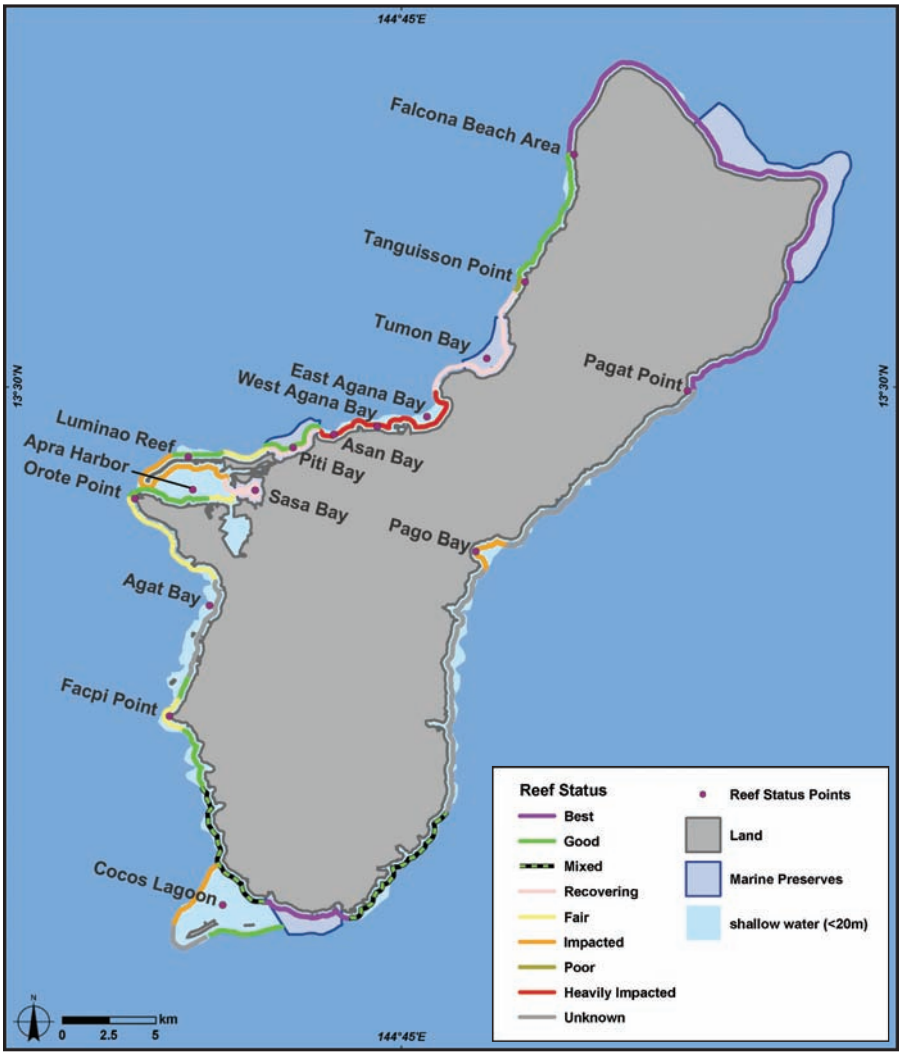

Figure 16.27. Summary map showing the overall condition of Guam's coral reef ecosystems. Map: A. Shapiro. Source: DAWR.

Several large bays - Piti, Asan, West and East Agana, and Tumon - are located along the central western coastline an area that experiences calm conditions for most of the year. According to Gutierrez (in prep.) and Tupper (in prep.), Asan Bay is heavily impacted by fishing, and fish stocks have decreased in this area since monitoring began in 2001. Piti and Tumon Bays were selected to be marine preserves due to their wide diversity of habitat types. Since full implementation of the preserves in January 2001, increases in herbivorous fish densities appear to have better controlled the growth of palatable macroalgae in the two preserves, resulting in healthier looking reefs (T. Leberer, pers. obs.). A study to assess algal abundance and composition in relation to herbivore stocks inside and outside the marine preserves has been proposed for funding in fiscal year 2005.

The overall scarcity of reef fish, especially larger individuals, despite the persistence of some relatively healthy and diverse coral communities around the island, is a serious concern (Schroeder, unpublished report). The exceptions to this are within the marine preserves, where significant increases in fish density and diversity have been observed (Gutierrez, in prep.). Continued fish and habitat assessment surveys within Guam's marine preserves will provide an effective means to monitor their status. In addition, two recently funded projects will assess the amount of spillover - both from larval recruitment and adult migration - occurring into areas adjacent to the marine preserves. This information is crucial to help Guam's resource managers determine whether current MPAs are an effective management tool for restoring depleted coral reef fishery resources island-wide.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Guam recognizes the important benefits that coral reefs provide, and has developed a diverse assortment of laws, regulations, permits, policies, plans and education programs to serve as mechanisms for the management of human activities that impact Guam's coral reefs (Gawel, 1999). Many of these, such as the environmental impact assessment requirements, were not created specifically to protect coral reef ecosystems, but now serve that purpose. Guam continues to expand and improve its management activities to address the threats identified above.

This process has been facilitated by the creation of the Guam Coral Reef Initiative Coordinating Committee (GCRICC) in 1997 by Executive Order 97-10. This committee prioritized the 13 threats identified in the National Coral Reef Action Strategy and selected the top five on which to focus for the next three years. By February 2003, the GCRICC had identified local navigators and drafted local action strategies (LAS) regarding for the prioritized focus areas of land-based sources of pollution, fisheries management, outreach and education, recreational area misuse and overuse, and climate change and coral bleaching. These LAS have provided a guiding framework for local resource agencies and have facilitated improved management and coordination among agencies. Current conservation management activities can be grouped according to the threat that they address (Figure 16.28).

The LAS process has also served to broaden the network of stakeholder groups working on coral reef issues. Members of the Guam Watershed Planning Committee (WPC), a group of local, Federal, and non-governmental agencies involved primarily with watershed restoration, have become involved in LAS development; members of the GCRICC now participate in the WPC as well. In addition, the UOGML and UOG's Water and Environmental Research Institute, guided by the needs of the local natural resource agencies, have shifted much of their focus toward management-driven research. Recently, another crucial stakeholder group has been engaged. The Guam Visitors Bureau (GVB) and Guam's tourism industry are now working with natural resources agencies to market Guam's coral reefs, and in particular the marine preserves, to the one million visitors that come to the island annually. This new awareness of the economic value of Guam's coral reef resources is beginning to create a sense of stewardship which was absent during the economic boom of the 1980s and recession of the 1990s.

Land-Based Sources of Pollution

Guam identified land-based sources of pollution as its number one priority focus area in 2002 and local and Federal stakeholders have developed a three-year LAS to address this threat. This is the most difficult threat

Current Conservation Management Activities in Guam

Land-Based Sources of Pollution

- Guam Seashore Protection Plan
- Soil Erosion and Sediment Control Regulations of 2000
- GEPA enforcement of Section 401 and NPDES permits
- Watershed Restoration (DoAg)
- Watershed Planning Group
- Permit Conditions to Limit disturbance during coral spawning (DPW/GEPA)

Fisheries Management

- Marine Preserve Areas (DAWR)
  - Enforcement
  - Education
  - Monitoring
- Creel Surveys (DAWR)
- School Presentations

Lack of Public Awareness

- Coral Awareness Campaign
  - Video
  - PSAs
  - Hotel Tent Cards
  - Coloring Books
- Island Pride Campaign
  - Trash Collections
  - Tree Planting
  - Snorkeling

Recreational Overuse and Misuse

- Informational campaign for Tumon Bay (GCMP/GVB)
- Beach Cleaning Permit Conditions (GVB)
- Eco-Permit for Marine Preserves (DAWR)

Land-Based
Bleach-

to address as it involves a large number of stakeholders and is complicated by the lack of cooperation from some key Guam governmental agencies.

One of the most effective outlets has been the WPC which was recently strengthened by Executive Order 2004-04. This committee is carrying out a comprehensive watershed planning process to address pollution in each Guam watershed by assessing pollution, determining the total maximum daily loads of particular pollutants that the watershed can withstand and still meet water quality standards, identifying potential pollution sources, and then initiating projects to control or prevent the pollution. In addition, Guam's Clean Marina Advisory Committee has developed an action plan identifying specific projects to manage nonpoint source pollution in Guam's marinas.

This is complemented by recent revisions to Guam's soil erosion and sediment control regulations in 2000. These are applied through clearing and grading permits, which are processed through Guam's Department of Public Works and GEPA. These permits provide protection during coral spawning periods by limiting activities during these times. One of the major topics of Guam's upcoming 2005 land use conference will be the control of pollution, especially stormwater runoff, through better land use planning. A manual for stormwater management is being produced for Guam in 2004, and recently the GCMP funded a workshop for contractors and builders on Guam's soil erosion and sediment control regulations, under GEPA oversight. To address the illegal burning of natural grasslands on mountain slopes carried out by deer hunters, an anti-arson campaign coordinator will be funded in 2005. In the meantime, the FSRD, NRCS, and UOG are working to restore badlands using erosion control fabric and nitrogen-fixing plants and trees such as acacia (Figure 16.30).

The GEPA has a number of permit processes to limit the impacts of nonpoint source pollution. Landfills, including construction material hardfills, must receive GEPA permits and be designed to protect all waters from polluting discharges. A new landfill for public solid waste is being planned and its site will be determined soon, with its construction following an accelerated schedule determined by a Federal court-ordered consent

Figure 16.30. Erosion control fabric and nitrogen-fixing acacia trees shown here are being used to re-vegetate nutrient depleted, highly erodible lands damaged by wildfires in southern Guam. Source: Forestry and Soil Resources Division.

decree. Baseline monitoring is being performed to assess the impacts of leachate that pollutes coastal and river waters below Guam's old landfill, which must be closed when the new one is operable. In addition, injection of stormwater runoff through dry wells is regulated by GEPA underground injection control permits to prevent pollution from entering groundwater and subsequently being discharged to beaches and reefs. The GEPA Water Resources staff also requires golf courses to monitor the quality of their groundwater through monitoring wells. GEPA also locally administers the Water Quality Certification (Federal Clean Water Act Section 401) and NPDES permits for the U.S. EPA. Through its Water Pollution Control Program and in coordination with its Environmental Planning and Review Division, GEPA is responsible for certifying all permit applications, recommending the conditions and abatement schedules for each permit, and providing oversight for the implementation and compliance with the conditions. All permittees are routinely monitored by the GEPA staff to verify compliance with applicable permit requirements and compliance schedules. The Guam Waterworks Authority (GWA), responsible for Guam's public water supply and wastewater systems, is restructuring and improving its facilities and operations in response to U.S. District Court stipulated orders. Required activities include improving the Northern and Agana STPs and building new, deeper outfalls in order for both STPs to meet NPDES requirements.

These improvements to Guam's sewage systems involve major expenses - well over $40 million - that are far beyond GWA's current budget. These costs and similar high unbudgeted costs for public facilities for stormwater management and solid waste pollution control are not only a problem for Guam, but also are shared with other U.S. island territories and commonwealths that are members of the U.S. Coral Reef Task Force. At its October 2003 meetings, the Task Force passed a Pacific Islands Water Quality Resolution, directing its attention to seeking a solution to funding the capital improvement needs to provide the infrastructure necessary to manage water pollution in order to protect the islands' coral reefs. Guam's estimate for basic funding for these projects is close to a $100 million. Pacific Islands members of the Task Force await urgent action on this resolution.

The Guam Seashore Protection Commission (GSPC) has review and approval authority over construction projects proposed within the area from 10 m inland of the mean high tide mark out to a depth of 18 m (an area defined in law as the "seashore reserve"). The Application Review Committee, comprised of a large number of Guam's governmental agencies, reviews all project applications, to identify potential impacts. The Committee's comments are submitted to a seven-member commission appointed by the Governor for consideration of approval or rejection.

Presently, the Guam Seashore Reserve Plan Task Force, comprised of several of Guam's governmental agencies, is developing the Guam Seashore Reserve Plan to better guide the decisions of the GSPC. The plan will limit development in the areas designated as the seashore reserves. Zones were designated to identify what types of development, if any, are allowed. The zones were determined based on sensitivity of areas adjacent to the shoreline and the effects of development on the coral reefs. While this task is taking longer than desired, the end product should help Guam make good decisions about future development along its coasts.

In addition to local activities, the U.S. Department of Defense (DoD) has started restoration activities on DoD base sites, cleaning up scores of old dumps and hazardous or toxic pollutants with impacts on the coastal waters of Guam. Contaminated sites, including ammunition dumps on coral reefs that were formerly used by the military but are not on current DoD property, are being identified through the DoD and State/Territorial Memorandum of Agreement program with GEPA, which is the first step to their cleanup.

Fisheries Management

A three-year LAS for coral reef fishery management that focuses on increasing the effectiveness of Guam's marine preserves was developed by DAWR and reviewed by fishers, resource managers, and other stakeholders. The strategy addressed three main issues: the lack of enforcement and prosecution, lack of public awareness and support, and need to assess the effectiveness of the preserves in increasing reef fish stocks. Specific management actions proposed to address these issues include the purchase of vehicles, a vessel, and equipment for conservation officers; implementing a reserve officer program to expand enforcement coverage; hiring of a natural resource prosecutor; implementing a multi-media education and outreach campaign; and funding studies that focus on assessing fish biomass increases and spillover effects.

This has been one of the more successful strategies for Guam. A number of the tasks have been accomplished: the conservation officers have purchased new vehicles and equipment to facilitate better enforcement; the GCRICC has continued education efforts at all levels, from elementary to the territorial legislature and administration; monitoring programs are underway in three preserves; and Guam's legislature recently passed Public Law 27-87 which requires a permit for certain non-fishing activities in the preserves. In addition, the GCRICC is in the process of hiring a natural resource prosecutor to be based in the Office of the Attorney General and DAWR is working on a citation system for marine preserve violators.

Guam has laws (5 GCA, Chapter 63) that regulate the taking of coral and identify penalties for damages inflicted on corals during fishing activities. Coral can only be taken with a permit issued by the Guam Department of Agriculture. The law has provisions for both personal and commercial take, but limits such permits to five days and requires that specific collecting locations be identified. However, no personal or commercial permits have been issued since 1982. The UOGML has been issued a collection permit for scientific research. This law also regulates fishing net mesh sizes used in coastal waters and the use of illegal chemicals and explosives for fishing. In addition, Guam's legislature also delegated the authority and responsibility of management and oversight for all aquatic and wildlife resources to the Guam Department of Agriculture. In 1997, Guam's Department of Agriculture's DAWR used its regulatory authority to amend and expand the existing fishing regulations. Title 16 of the law includes size and gear restrictions for aquatic fauna. Also contained in these regulations is the creation of marine preserves. The penalty for violating both the law and associated regulations is a petty misdemeanor, with a fine of up to $500. The DAWR is currently in the process of converting to a magistrate court system in which citations can be issued rather than requiring a court hearing to collect misdemeanor penalties.

Lack of Public Awareness

In 2003, as part of its Education and Outreach LAS, the GCRICC launched a multi-media coral reef awareness campaign featuring a clownfish character in an educational video and shown on incoming flights, movie theater slides, hotel room tent cards, coloring books, advertisements, and streetside banners (Figure 16.31). An island-wide contest seeking a name from children for the clownfish character was held in conjunction with Earth Week activities from April 17-24, 2004. The Environmental Education Committee selected the top 10 entries from over 600 entries. On April 24, at the Earth Week Island Pride Festival, the public selected 'Professor Kika Clearwater' as the character's name.

GCRICC members have also teamed up for the Island Pride Campaign. This program combines educational and environmental activities with fun events to teach children to love the island's resources and instill a sense of stewardship. Events have included the 2004 Earth Week festival, a trash collection and snorkel tour at Tumon Bay Marine Preserve, a trash collection and kid's fishing derby at the War in the Pacific National Park, and a tree-planting at Paseo combined with the Fishermen's Festival at the Guam Fishermen's Cooperative. The events have been a great success, attracting families from all over the island. The campaign has also

strengthened ties among the GCRICC and GVB as well as the private sector which have helped sponsor these events.

Figure 16.31. Guam's new multimedia Coral Reef Awareness Campaign includes billboards, print ads, public service announcements, tourism literature, and an upcoming video to be shown on all flights to Guam. Source: GEPA.

Recreational Misuse and Overuse

The GCRICC decided that recreational misuse and overuse were serious threats to Guam's coral reefs. With jet ski users, recreational boaters, scuba divers and snorkelers all using the reef zone, the impacts can multiply. The Committee decided that it is important to address these issues before they cause severe damage to the reefs. While this strategy is still being developed through meetings with stakeholders, positive steps have already been taken to limit recreational impacts in the marine preserves. Public Law 27-87, which was passed in May 2004, creates a marine preserve eco-permitting system to be administered by DAWR, to address non-fishing activities in Guam's marine preserves. The DAWR is currently working with a large group of stakeholders to draft the rules and regulations for this new permitting system.

Other actions have worked to limit the impact of recreational watercraft. The impacts of jet skis have been addressed through the Recreational Water Use Master Plan, which currently limits these watercraft to three locations within reef areas: East Agana Bay, Apra Harbor, and Cocos Lagoon. A study to examine the impacts of jet skis is underway. In 1999, DAWR installed 35 shallow water mooring (SWM) buoys at popular sites on the western side of the island and in Apra Harbor. While the goal of these buoys was to avoid anchor damage from recreational boaters and fishers only seven of these buoys are still in the water due to storms, theft, and age. DAWR did not have the staff to replace these buoys, so they have teamed up with the Guam Marine Awareness Foundation (GMAF) to replace the missing buoys. DAWR will acquire the buoys and GMAF will use volunteer divers to install them.

GVB, in association with GCMP, is launching a new campaign to educate tourists about Tumon Bay's unique habitat and diverse assemblage of marine creatures. The project will include three educational kiosks placed in northern, central, and southern Tumon Bay and accompanied by underwater guides. The goal is to reduce the impacts of recreational activities by educating divers about the resources and how they can prevent damage. GVB has also assisted with the incorporation of changes for beach cleaning permits in the tourist areas of Tumon and East Agana Bays. These included: 1) requiring contractors to find ways to shake out as much sand and dead coral as possible from algae and place the sand and dead coral back onto the beach and 2) implementing an adopt-a-beach program, in which hotels manually rake the algae from the beach in front of their property. Unfortunately, not all of these changes have currently been implemented. However, GVB is again consulting with DAWR in developing a new request for proposals for beach cleaning and maintenance of Tumon and Agana Bays.

Climate Change and Coral Bleaching

This LAS has had the least development, as it is the most difficult to solve at the local level. Addressing the issue of climate change requires policy decisions at the national and international levels. Locally, current management efforts are focusing on addressing additional anthropogenic stresses on coral reefs such as overfishing and land-based sources of pollution through the development and implementation of the three-year LAS. Outreach and education efforts include the development of posters, pamphlets, public service announcements, and videos addressing the importance of coral reefs and ways to better protect them. One of the greatest challenges facing resource managers in Guam is the reality that, given current regulatory pro-

cesses, management decisions cannot happen in as timely a manner as that dictated by a bleaching event. At the 10th U.S. Coral Reef Task Force Meeting in CNMI and Guam, the steering committee was directed to consider the opportunities to include mass coral bleaching in natural disaster relief efforts. Task Force members endorsed a resolution to address emergency response for environmental impacts of natural disasters. Federal members of the Task Force were also directed to engage the states, territories, and commonwealths of the U.S. and the Freely Associated States, as appropriate, in developing partnership response plans for environmental impacts to coral reef ecosystems following natural disasters, and developing strategies to support implementation of the plans.

While natural disasters can not be managed, responses can be. A hazard mitigation plan is currently being developed for Guam. The intent of the plan is not only to reduce the damages caused by natural disasters to buildings and infrastructure, but also to protect the environment by limiting the effects of flooding on property and subsequent depositing of debris on Guam's coral reefs. Better protection of coral reefs and other natural resources from impacts of Guam's frequent natural disasters is also being sought through development of an environmental emergency response plan. This plan will provide appropriate steps for government agencies to take following a natural disaster, in terms of conducting both damage assessments and debris removal efforts.

OVERALL STATE/TERRITORIAL CONCLUSIONS AND RECOMMENDATIONS

The health of Guam's coral reefs vary significantly. Reefs unaffected by sediment and nutrient loading, such as those in the northern part of the island and in between river outflows in the south, have healthy coral communities. Guam's reefs have been spared from large-scale bleaching events and coral diseases which are prevalent in so many parts of the world. Unfortunately, a number of Guam's reefs are impacted by land-based sources of pollution and heavy fishing pressure. Sedimentation, algal overgrowth due to decreased fish stocks, and low recruitment rates of both corals and fish are important issues that must be addressed.

The GCRICC has made great strides in identifying ways to understand and address these issues, from funding watershed restoration efforts, to conducting innovative education and outreach efforts, expanding monitoring, and increasing support for the five marine preserves. Working groups have been created for each of the five LAS (land-based sources of pollution, fisheries management, outreach and education, recreational area misuse and overuse, and climate change and coral bleaching).

Although Guam has made a great deal of progress in the past two years in terms of coral reef protection, monitoring, and public outreach, many challenges still remain. Wildland arson is still a problem in many watersheds in Southern Guam. STPs in Toguan, West Agana, and Tanguisson discharge primary treated wastewater into coastal waters of 18 m or less. Leaks from aging infrastructure and an increase in impervious surfaces, especially near the coast, have exacerbated the problem of stormwater runoff. In response to the Pacific Water Quality Resolution passed by the U.S. Coral Reef Task Force at its 10th Meeting in CNMI and Guam in October 2003, the GCRICC asked the GEPA to compile a list of priority capital improvement projects that would have direct implications for improved water quality and subsequent coral reef ecosystem health. The estimated cost of the eight identified projects totals more than $90 million and includes such infrastructure improvements as closing the island's municipal dump and replacing it with a fully functioning landfill, renovating and expanding several STPs (including extending their ocean outfalls), and eliminating the discharge of stormwater into Tumon and Agana Bays.

Gaps in Guam's monitoring efforts have been identified and will begin to be addressed in the next few years. However, despite the presence of the UOG (in particular the Marine Laboratory and Water and Environmental Research Institute), Guam still suffers from a lack of capacity to fully implement all of the monitoring gaps. The lack of capacity is not entirely due to a lack of available staff. For example, Guam would benefit greatly from a more streamlined and stable Federal grant process for coral reef effort, in order to secure contractual monitoring assistance (i.e., three year block grants). Local resource agencies would also be better served in their partnerships with valuable Federal programs, such as NOAA's REA research cruises, by a faster turnaround time on data availability and analysis. In addition, although Federal sources of funding have been utilized to

support enforcement efforts, local support for additional full-time conservation officers is still nonexistent. To rectify this, local resource agencies have recently spent a great deal of time escorting local policymakers and members of the private sector on snorkel tours of the marine preserves in order to show them the island-wide value of the reef resources. A new economic valuation study commencing in fiscal year 2005 will also provide an effective means to garner support for coral reef protection. With successes like the recently launched Island Pride Campaign, there is certainly reason to hope for an increased awareness of the value of coral reefs to the people of Guam.

REFERENCES

Ahyong, S. and M.V. Erdmann. 2003. The stomatopod Crustacea of Guam. Micronesica 35-36: 315-352

Amesbury, S. 2002. Annual Report for Coral Collection Permit for University of Guam Marine Laboratory. Guam Division of Aquatic and Wildlife Resources.

Amesbury, S. 2003. Annual Report for Coral Collection Permit for University of Guam Marine Laboratory. Guam Division of Aquatic and Wildlife Resources.

Amesbury, S., V. Bonito, R. Chang, L. Kirkendale, C. Meyer, G. Paulay, R. Ritson-Williams and T. Rongo. 2001. Marine biodiversity resource survey and baseline reef monitoring survey of the Haputo Ecological Reserve Area, COMNAV-MARIANAS. U.S. Dept. of the Navy.

Amesbury, J.R. and R.L. Hunter-Anderson. 2003. Review of archaeological and historical data concerning reef fishing in the U.S. flag islands of Micronesia: Guam and the Northern Mariana Islands. Western Pacific Regional Fishery Management Council. Final Report. 147 pp.

Bailey-Brock, J.H. 2003. Coral reef polychaetes of Guam and Saipan, Mariana Islands. Micronesica 35-36: 200-217

Barnett, M. 2004. Guam Marine Awareness Foundation, Micronesian Divers Association. Piti, Guam. Personal communication.

Bent, J. 2004. Pacific Association of Dive Industry, Guam Tropical Dive Station. Anigua, Guam. Personal communication.

Best, B.R. and C.E. Davidson. 1981. Inventory and atlas of the inland aquatic ecosystems of the Marianas Archipelago. University of Guam Marine Laboratory, Technical Report 75. 226 pp.

Birkeland, C. 1997. Status of coral reefs in the Marianas. pp. 91-100. In: Dollar, R., and C. Birkeland. (eds.) Status of coral reefs in the Pacific. Hawaii: Sea Grant College Program, School of Ocean and Earth Science and Technology, University of Hawaii.

Birkeland, C., D. Rowley and R.H. Randall. 1982. Coral recruitment patterns at Guam. pp. 2: 339-344. In: Proceedings of the Fourth International Coral Reef Symposium, Manila.

Birkeland, C. and J. Lucas, 1990. *Acanthaster planci*: Major management problem of coral reefs. CRC Press, Boca Raton. 257 pp.

Bonito, V. 2002. Tanguisson reef: Changes in coral community structure driven by *Acanthaster planci* predation? Masters Thesis. University of Guam, Mangilao, Guam. 82 pp.

Bonito, V and R. Richmond. Submitted. Long-term changes in coral community structure and correlations with *Acanthaster planci* feeding preferences on Guam. 29 pp.

Brainard, R. National Oceanic and Atmospheric Administraion, National Marine Fisheries Center, Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division, Honolulu. Personal communication.

Calvo, J. 2004. Western Pacific Regional Fisheries Management Council. Tamuning, Guam. Personal communication.

Carlson, C., and P.J. Hoff. 2003. The opisthobranchs of the Mariana Islands. Micronesica 35-36: 271-293

Castro, P. 2003. The trapeziid crabs (Brachyura) of Guam and Northern Mariana Islands, with the description of a new species of *Trapezia latreille*, 1828. Micronesica 35-36: 440-455

Colgan, M. 1981a. Succession and recovery of a coral reef after predation by *Acanthaster planci*. pp. 333 -- 338. In: Proceedings of the Fourth International Coral Reef Symposium, Volume 2, Manila.

Colgan, M. 1981b. Long-term recovery process of a coral community after a catastrophic disturbance. University of Guam Marine Lab Technical Report 76.

Colgan, M. 1987. Coral reef recovery on Guam (Micronesia) after catastrophic predation by *Acanthaster planci*. Ecology 68(6): 1592-1605

Collins, J.M. 1995. Occurrence and fate of fecal pollution indicator bacteria in sediments of Tumon Bay, Guam. Masters Thesis for the University of Guam Marine Laboratory. 75 pp.

Davis, G. Guam Department of Agriculture, Division of Aquatic and Wildlife Resources. Mangilao, Guam. Personal communication.

Denton, G.R.W., H.R.Wood, L.P. Concepcion, H.G. Siegrist, Jr., V.S. Eflin, D.K. Narcis and G.T. Pangelinan. 1997. Analysis of in-place contamination in marine sediments from four harbor locations on Guam. Water and Environmental Research Institute, University of Guam. Technical Report 81. 120 pp.

Denton, G.R.W., H.R.Wood, L.P. Concepcion, V.S. Eflin and G.T. Pangelinan. 1999. Heavy metals, PCBs and PAHs in marine organisms from four harbor locations on Guam. Water and Environmental Research Institute, University of Guam. Technical Report 87. 158 pp.

DPW (Department of Public Works). 2004a. Building permits and inspections. 2003 Annual Report. Department of Public Works, Government of Guam.

DPW (Department of Public Works). 2004b. Completed highway projects report: 2003. Government of Guam, Department of Public Works, Highway Planning Section.

Duenas and Associates. 2003. Guam Nonpoint Source Pollution Management Program (Draft). Guam Coastal Management Program.

Eldredge, L.G. 2003a. A retrospective look at Guam's marine biodiversity. Micronesica 35-36: 26-37

Eldredge, L.G. 2003b. The marine reptiles and mammals of Guam. Micronesica 35-36: 653-660

English, S., C. Wilkinson and V. Baker. 1997. Survey manual for tropical marine resources. 2nd Edition. Australian Institute of Marine Science, Townsville.

Flores, T. 2003. Offshore Fisheries Survey. 2003. Annual Report. Government of Guam, Department of Agriculture, Division of Aquatic and Wildlife Resources. Annual Report. 11 pp.

FSRD (Forestry and Soil Resources Division). 1999. Five Year Plan. Department of Agriculture, FSRD.

Gawel, M.J. 1999. Protection of marine benthic habitats in the Pacific Islands. A case study of Guam. Oceanologica Acta 22: 721-726

Goldman, L. Guam Department of Agriculture, Division of Aquatic and Wildlife Resources. Mangilao, Guam. Personal communication.

GCMP (Guam Coastal Management Program). 1998. Super Typhoon Paka: Deep Water Clean-Up. Governement of Guam, Bureau of Planning, Guam Coastal Management Program. Final Report. 30 pp.

GEPA (Guam Environmental Protection Agency). 2000a. Guam Soil Erosion and Sediment Control Regulations. Public Law 25-152. 39 pp.

GEPA (Guam Environmental Protection Agency). 2000b. Management of contaminated harbor sediments of Guam. CZMA Section 309, Guam Harbor Sediment Project Phase III Final Report. 57 pp.

GEPA (Guam Environmental Protection Agency). 2001. Revised Guam Water Quality Standards. Public Law 26-32. 122 pp.

GEPA (Guam Environmental Protection Agency). 2003. Water Quality Report to Congress, Section 305b. 56 pp.

GHRA (Guam Hotel and Restaurant Association). 2004. Hospitality Guahan monthly. Pacific Daily News insert (March). 12 pp.

Guam Bureau of Statistics and Plans. 2002. Coastal environmental damage-a preliminary survey of impacts of Typhoon Chata'an on Guam's natural environment. Government of Guam, Technical Report.

Guam Water Planning Committee. 1998. Clean water action plan for Guam: unified watershed assessment. 28 pp.

Guard, C., A.N.L. Chiu and M.A. Lander. 2003. National Oceanic and Atmospheric Administration, National Weather Service meteorological assessment for Typhoon Pongsona in: Pohnpei State, FSM; Chuuk State, FSM; Guam; and Rota, CNMI. NOAA/NWS, Tiyan, Guam. 59 pp.

Gutierrez, J.T. 2003. Fisheries participation, effort, and harvest surveys. Government of Guam, Department of Agriculture, Division of Aquatic and Wildlife Resources. 24 pp.

Gutierrez, J.T. 2004. In preparation. Visual Stock Assessment Surveys of Marine Preserves and Control Sites. Government of Guam, Department of Agriculture, Division of Aquatic and Wildlife Resources.

GVB (Guam Visitors Bureau). 2001. Japanese Exit Survey August 2001.

GVB (Guam Visitors Bureau). 2004. Guam Visitors Arrival Monthly Statistic Report, January 2002 – Present.

Helton, G., I. Zelo, C. Lord and C. Plank. 2004. Surveys of Abandoned Vessels: Guam and the Commonwealth of the Northern Mariana Islands.

Hunter, C.L. 1995. Review of coral reefs around American flag Pacific islands and assessment of need, value, and feasibility of establishing a coral reef fishery management plan for the western Pacific region. Western Pacific Regional Fishery Management Council. Final Report. 30 pp.

Jones, R.S., R.H. Randall, and M.J. Wilder. 1976. Biological impact caused by changes on a tropical reef. U.S. Environmental Protection Agency, US EPA-600/3-76-027.

Kelly, M., J. Hooper, V. Paul, G. Paulay, R. van Soest and R. de Weerdt. 2003. Taxonomic inventory of the sponges (Porifera) of the Mariana Islands. Micronesica 35-36: 100-120.

Kensley, B. 2003. Axioid shrimps from Guam (Crustacea, Decapoda, Thalassinidea). Micronesica 35-36: 359-384.

Kirkendale, L. and D.R. Calder. 2003. Hydroids (Cnidaria: Hydrozoa) from Guam and the Commonwealth of the Northern Marianas Islands (CNMI). Micronesica 35-36: 159-188.

Kirkendale, L. and C.G. Messing. 2003. An annotated checklist and key to the Crinoidea of Guam and the Commonwealth of the Northern Marianas Islands. Micronesica 35-36: 523-546.

Lambert, G. 2003. Marine biodiversity of Guam: the Ascidiacea. Micronesica 35-36: 584-593.

Leberer, T. Guam Department of Agriculture, Division of Aquatic and Wildlife Resources. Mangilao, Guam. Personal communication.

Lobban, C.S. and R.T. Tsuda. 2003. Revised checklist of benthic marine macroalgae and seagrasses of Guam and Micronesia. Micronesica 35-36: 54-99.

Moran, D. C. 2002. Qualitative groundwater dye trace of the Harmon Sink and Guam International Airport Authority. M.S. Thesis for the University of Guam. 55 pp.

Myers, R.F. and T.J. Donaldson. 2003. The fishes of the Mariana Islands. Micronesica 35-36: 594-648.

Newman, L.J., G. Paulay and R. Ritson-Williams. 2003. Checklist of polyclad flatworms (Platyhelminthes) from Micronesian coral reefs. Micronesica 35-36: 189-199.

Paulay, G. 2003a. Marine Biodiversity of Guam and the Marianas: overview. Micronesica 35-36: 3-25.

Paulay, G. 2003b. The Asteroidea, Echinoidea, and Holothuroidea (Echinodermata) of the Mariana Islands. Micronesica 35-36: 563-583.

Paulay, G. 2003c. The Bivalvia (Mollusca) of Guam. Micronesica 35-36: 218-243

Paulay, G. 2004. University of Guam Marine Laboratory. Mangilao, Guam. Personal communication.

Paulay, G. and Y. Benayahu. 1999. Patterns and consequences of coral bleaching in Micronesia (Majuro and Guam) in 1992-1994. Micronesica 32 (1): 109-124.

Paulay, G., L. Kirkendale, C. Meyer, P. Houk, T. Rongo and R. Chang. 2001. Marine biodiversity resource survey and baseline reef monitoring survey of the Southern Orote Peninsula and North Agat Bay area. Commander Naval Forces Marianas.

Paulay, G., L. Kirkendale, G. Lambert and C. Meyer. 2002. Anthropogenic biotic interchange in a coral reef ecosystem: a case study from Guam. Pacific Science 56 (4): 403-422.

Paulay, G., R. Kropp, P.K.L. Ng and L.G. Eldredge. 2003a. The crustaceans and pycnogonids of the Mariana Islands. Micronesica 35-36: 456-513.

Paulay, G., M.P. Puglisi, and J.A. Starmer. 2003b. The non-scleractinian Anthozoa (Cnidaria) of the Mariana Islands. Micronesica 35-36: 138-155.

Paulay, G., and A. Ross. 2003. An annotated checklist of the shallow water Cirripedia of Guam. Micronesica 35-36: 303-314.

PCR Environmental, Inc. 2002a. Sampling of Tumon Bay springs for chemical analysis. Guam Environmental Protection Agency. 125 pp.

PCR Environmental, Inc. 2002b. Sampling of Tumon Bay springs for chemical and bacterial analysis. Guam Environmental Protection Agency. 145 pp.

PCR Environmental, Inc. 2002c. Summary Report of Tumon Bay springs sampling for chemical analysis. Guam Environmental Protection Agency. 141 pp.

Preskitt, L.B., P.S. Vroom and C.M. Smith. 2004. A rapid ecological assessment (REA) quantitative survey method for benthic algae using photoquadrats with scuba. Pacific Science 58: 201-209.

Randall, R.H. 1971. Tanguisson-Tumon, Guam coral reefs before, during and after the crown-of-thorns starfish (*Acanthaster*) predation. M.S. Thesis for the University of Guam, Department of Biology. 119 pp.

Randall, R.H. 1973. Distribution of corals after *Acanthaster planci* infestation at Tanguisson Point, Guam. Micronesica. 9 (2): 213-222.

Randall, R.H. 2003. An annotated checklist of hydrozoan and scleractinian corals collected from Guam and other Mariana Islands. Micronesica 35-36: 121-137.

Randall, R.H., and L.G. Eldredge. 1976. Atlas of the reefs and beaches of Guam. University of Guam Marine Laboratory. Technical Report 19: 1-191.

Richardson, S.L. and R.N. Clayshulte. 2003. An annotated checklist of Foraminifera of Guam. Micronesica 35-36: 38-53.

Richmond, R. Professor, University of Hawaii, Kewalo Marine Lab. Former professor, University of Guam. Personal communication.

Schroeder, R., M. Triani, K. Moots, B. Zgliczynski, J. Laughlin, B. Tibbatts and M. Capone. In Review. Status of the Fishery Target Species on Coral Reefs of the Marinas Archipelago. In: Proceedings of the 10th International Coral Reef Symposium, Okinawa.

Schupp, P. University of Guam Marine Laboratory. Mangilao, Guam. Personal communication.

SCS (Soil Conservation Service). 1988. Soil Survey of Territory of Guam. United States Department of Agriculture May 1988. Washington, DC. 166 pp.

Sherwood, T. 1989. Establishing Permanent Marine Conservation Areas in Guam. pp. 110-118. In: Project Progress Report. Division of Aquatic and Wildlife Resources Annual Report Fiscal Year 1989.

Sokal, R. and F. Rolff. 1995. Biometry. Third Edition, W.H. Freeman and Company, New York.

Smith, B.D. 2003. Prosobranch gastropods of Guam. Micronesica 35-36: 244-270

Smith, B.D. 2004. Annual Report for Coral Collection. Permit for the University of Guam Marine Laboratory. Government of Guam, Department of Agriculture, Division of Aquatic and Wildlife Resources.

Starmer, J.A. 2003. An annotated checklist of ophiuroids (Echinodermata) from Guam. Micronesica 35-36: 547-562

Tan, S.H. and P.K.L. Ng. 2003. The Parthenopinae of Guam (Crustacea: Decapoda: Brachyura: Parthenopidae). Micronesica 35-36: 385-416

Tibbatts, B. Guam Department of Agriculture, Division of Aquatic and Wildlife Resources. Mangilao, Guam. Personal communication.

Tsuda, R. and T. Donaldson. 2004. Cumulative and Secondary Impacts: Seawalker, Scuba Bob and the Fish Eye Underwater Observatory, Piti and Cocos Lagoon, Guam. University of Guam Marine Laboratory. Technical Report 108. 85 pp.

Tupper, M. In preparation. Piti Bomb Holes Preserve, Achang Reef Flat Preserve, and Tumon Bay Marine Preserve WCPA-Marine / WWF MPA Management Effectiveness Initiative Draft Preliminary Report

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

U.S. Census Bureau (USCB). 2003. 2000 Census of population and housing: social, economic, and housing characteristics PHC-4-GUAM, Guam. USCB, Washington, D.C.

U.S. Census Bureau International Program Center Database. 2003. U.S. Census Bureau population predictions for Guam. Available from the internet URL: http://www.census.gov/ipc/www/idbnew.html.

U.S. Department of Agriculture (USDA), Natural Resources Conservation Service, Pacific Basin, Guam. 1995. DeMeo, R.A., Z.R. Sims, R.W. Wescom, and R. White (eds.). Draft Resource Assessment, Ugum Watershed, Guam. USDA, Guam. 92 pp. + appendices.

U.S. Department of the Navy. 1998. Draft Environmental Impact Statement for Military Training in the Marianas. 306 pp. + Appendices.

Veron, J.E.N. 2000. Corals of the world, Volume 3. Australian Institute of Marine Science and CRR Qld Pty Ltd. Queensland, Australia. 490 pp.

Vroom, P.S. In review. Rapid Ecological Assessments of Algal Genera on reefs in the Mariana archipelago (Guam and CNMI).

Vroom, P.S., K.N. Page, K.A. Peyton and J.K. Kukea-Shultz. In review. Marine algae of the French Frigate Shoals, Northwestern Hawaiian Islands: a multivariate analysis of benthic cover on a relatively unpolluted tropical atoll.

Ward, L. 2003. The cephalopods of Guam. Micronesica 35-36: 294-302.

Wolanski, E., R.H. Richmond, G. Davis and V. Bonito. 2003. Water and fine sediment dynamics in transient river plumes in a small, reef-fringed bay, Guam. Estuarine Coastal Shelf Science 56: 1029-1043.