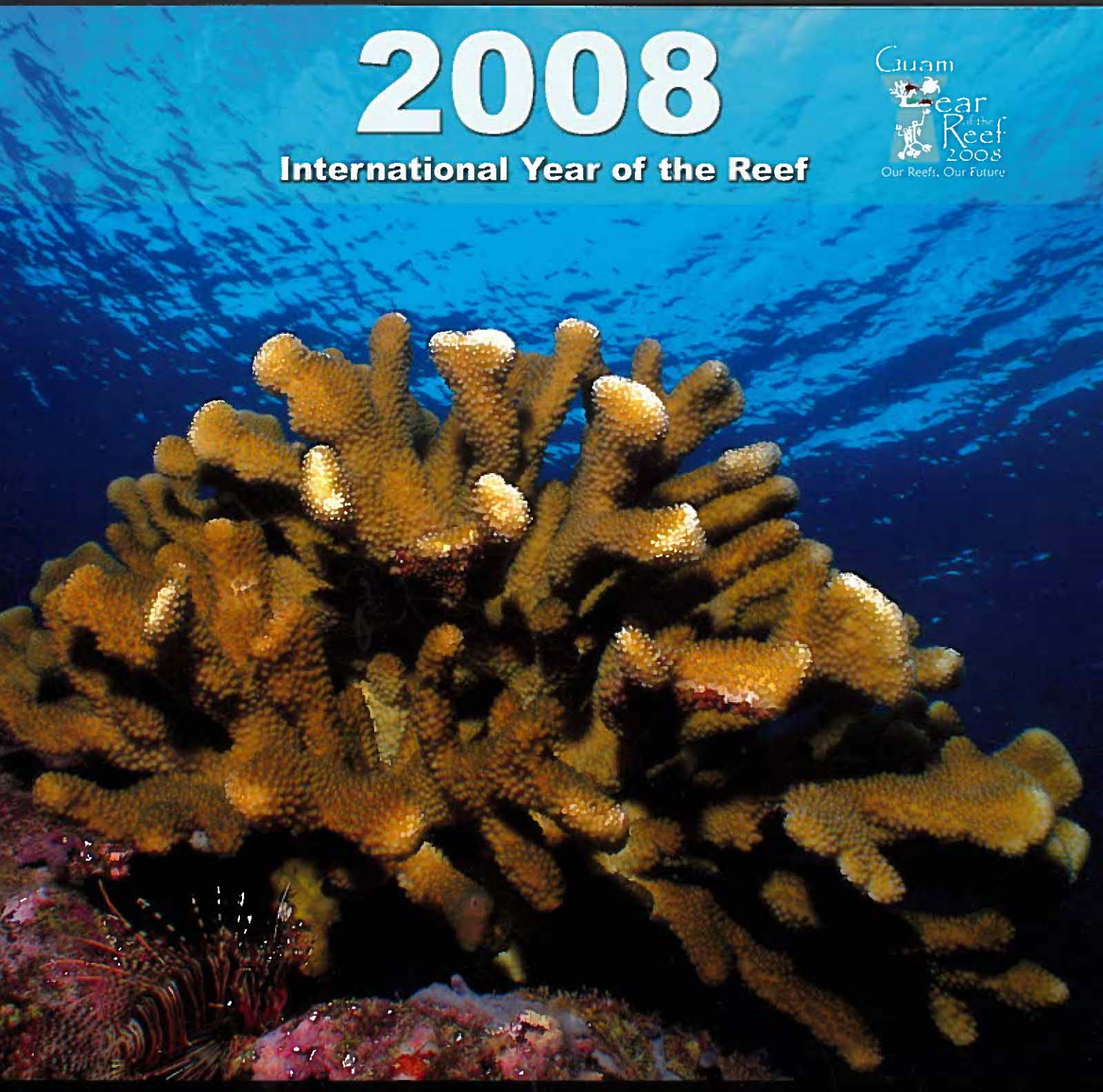
Status of the Coral Reef Ecosystems of Guam



David Burdick, Valerie Brown, Jacob Asher, Ciemon Caballes, Mike Gawel, Lee Goldman, Amy Hall, Jean Kenyon, Trina Leberer, Emily Lundblad, Jenny McIlwain, Joyce Miller, Dwayne Minton, Marc Nadon, Nick Pioppi, Laurie Raymundo, Benjamin Richards, Robert Schroeder, Peter Schupp, Ellen Smith and Brian Zgliczynski

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FOR MORE INFORMATION:
For more information about this report or to request a copy, please contact the Bureau of Statistics and Plans at 472-4201. This report is available in PDF format via a free internet download from http://www.bsp.guam.gov/content/category/6/15/37/. The 2005 Status of the Coral Reef Ecosystems of Guam report is available at http://guammarinelab.com/technicalreports.html. The 2008 NOAA *State of the Coral Reef Ecosystems of the U.S. and the Freely Associated States* report, as well as previous version of that report, are available for free download at http://ccma.nos.noaa.gov/stateofthereefs.

Cover: Design by D. Burdick. Photo by D. Burdick.
Opposite photo: A thriving coral community along the reef margin at Gun Beach. Photo by D. Burdick.

The Status of the Coral Reef Ecosystems of Guam

Status of the Coral Reef Ecosystems of Guam: 2008

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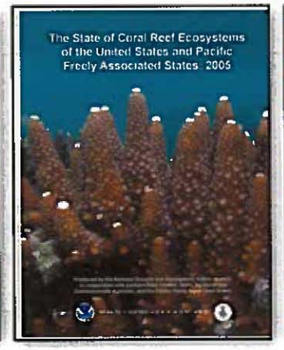
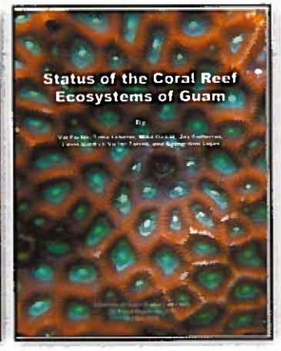
ABOUT THIS DOCUMENT

This report provides an assessment of the status of the coral reef ecosystems of Guam between 2004 and 2007. The findings of various monitoring activities, assessments, and stand-alone investigations conducted by local and federal agencies, educational/research institutions, and government contractors since 2004 were synthesized to obtain an updated, holistic view of the status of Guam's reefs. Where possible, time series data presented in previous reports are updated with the most recently available data. Also included in the report are updated assessments of specific environmental and anthropogenic stressors that have affected the vitality of Guam's reefs since 2004, information on recent data gathering activities, a description of recent and on-going conservation management activities, and overall conclusions and recommendations towards the effective monitoring and management of the coral reef ecosystems of Guam.

This report is the third in an ongoing series of assessments of the condition of Guam's coral reef ecosystem, and the second report to focus specifically on summarizing the quantitative results of coral reef ecosystem monitoring activities carried out by territorial, federal, private, academic, and non-governmental partners. The version of the report provided here is an extended version of the Guam section of the 2008 NOAA *State of the Coral Reef Ecosystems of the U.S. and Freely Associated States* and includes the results of several studies not presented in the national report as well as additional background information for many topics.





The authors of this report represent a number of agencies/institutions directly involved in local efforts to conserve and monitor coral reef ecosystems. In this report, the authors present data describing the status of water quality, benthic habitats, and coral reef-associated biological communities and evaluate the impacts of the major threats to coral reefs identified in the National Coral Reef Action Strategy (NOAA, 2002). The current conservation management activities being implemented on Guam are also discussed, along with recommendations for future action.

Much of the work presented in this document has been funded by NOAA's Coral Reef Conservation Program (CRCP). More information about CRCP activities is available at http://www.coralreef.noaa.gov/. CRCP support complements funding from other federal, territorial, and non-governmental partners who participated in this effort. Thus, this report has been made possible through the collective efforts of many organizations.

Current and previous versions of NOAA's *State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States* report can be downloaded at http://ccma.nos.noaa.gov/ecosystems/coralreef/coral2008/landing.html. The 2005 Status of the Coral Reef Ecosystems of Guam report is available at http://www.guammarinelab.com/technicalreports.html.

EXECUTIVE SUMMARY

Declines in the health of Guam's reef resources and the primary threats causing these declines
Guam's coral reef resources are both economically and culturally important, providing numerous goods and services for the residents of Guam, including cultural and traditional use, tourism, recreation, fisheries, and shoreline and infrastructure protection. Guam's reefs host a large variety of marine organisms; due to its proximity to the Indo-Pacific center of coral reef biodiversity (Veron, 2000), Guam possesses one of the most species-rich marine ecosystems among U.S. jurisdictions. Approximately 108 km² of shallow coral reef area is found within 3 miles of Guam, with an additional 110 km² occurring between 3 and 200 miles.

Despite the critical importance of Guam's coral reefs to so many aspects of life on Guam, Guam's reefs remain under assault from a range of threats, mainly local in origin. As a result, their ability to provide important services to Guam's current and future inhabitants continues to be compromised. Paralleling the decline in the health of coral reefs across the Indo-Pacific (Bruno and Selig, 2007), the vitality of many of Guam's reefs has diminished over at least the last several decades. In the past, Guam's reefs have recovered after drastic declines, but continued degradation of water quality, chronic crown of thorns seastar (COTS) outbreaks, low abundance of major herbivorous (algae-eating) fishes and other persistent stressors make Guam's reefs less resilient to disturbances such as major storms or severe coral bleaching events. A particularly distressing indicator of declining reef resilience is the marked decrease in rates of coral recruitment in the last few decades (Birkeland et al., 1981; Birkeland, 1997; Neudecker, 1981; Porter et al., 2005). In areas without successful coral recruitment, recovery - if it happens at all - will likely be a long process.

The primary threats to Guam's coral reefs continue to include sedimentation, runoff and associated pollutants, and heavy fishing pressure (Burdick et al., 2008). Additional threats include COTS outbreaks, coral diseases, dredging, boat groundings, marine debris, coral bleaching, and recreational misuse and overuse. Guam also experiences a high frequency of storm activity, which can cause direct physical damage to the reef structure and can cause significant reductions in nearshore water quality resulting from stormwater runoff. Coral bleaching is also an emerging threat on Guam, and will likely grow more severe with increasing sea surface temperatures associated with global climate change. Although Guam has yet to experience widespread mortality from a severe bleaching event, recent and regularly-occurring bleaching events that have resulted in minor to moderate coral mortality may portend more severe effects of future bleaching events (Burdick et al., 2008). The direct and indirect impacts of U.S. Department of Defense plans to expand the military presence on Guam, increasing the population by up to 60,000 people and involving numerous construction projects, also pose significant threats to Guam's reefs resources.

Summary of the results from recent monitoring, assessment, and research activities
While Guam possesses one of the most robust long-term reef fisheries monitoring programs in the Pacific, and the Guam Environmental Protection Agency has carried out water quality monitoring for many years, a comprehensive long-term coral reef monitoring program has only recently been initiated. As a result, the overall health of Guam's reefs is generally assessed by integrating the results of individual scientific studies and assessments. The results of island-wide rapid reef assessments conducted by the National Oceanic and Atmospheric Administration (NOAA) in 2003, 2005, and 2007 as part of the agency's Marianas Archipelago Rapid Assessment and Monitoring Program (MARAMP) will also contribute substantially to an understanding of the status and trends in reef health around Guam. A detailed analysis of the multiple years of NOAA MARAMP data is currently underway, so only a limited amount of this data is presented in this report.

Benthic cover
As mentioned above, little data exist to accurately describe long-term changes in the amount of live coral cover, coral species richness, macroalgal cover, and other measures of coral reef health at specific sites on Guam. The data that are available, however, indicates that the amount of living coral on Guam's forereef slopes declined from an average of approximately 50% in the 1960s (Randall, 1971) to less than 25% by the 1990s (Birkeland, 1997). Data gathering efforts have improved significantly in the last few

EXECUTIVE SUMMARY (Cont.)

years, as coral reef monitoring has occurred regularly at permanent sites around the island, with more sites planned in the near future. Towed-diver surveys have also been conducted across large areas of reef biennially since 2003, providing important information about the general status of these reef areas. While an analysis of the data collected across several years at the permanent sites established as part of UOGML's long-term coral reef monitoring program and the NOAA MARAMP, and the towed-diver surveys conducted as part of the NOAA MARAMP, was not available for this report, the baseline data are provided. Coral cover, as measured with rapid ecological assessments (REAs) conducted as part of the NOAA MARAMP at several sites around the island in 2005 ranged from 11.8% on the southwest coast to 38.2% on the west side of the island. Average coral cover for Guam was 26.1% ± 3.6% SE. Towed-diver surveys conducted during the same NOAA MARAMP expedition yielded a similar average coral cover value of 23%. The results of the towed diver surveys indicate that coral cover is similar in the west/northwest, east/northeast, and east/southeast regions of the island (25%, 26%, and 26%, respectively), while coral cover was lowest in the west/southwest region (12%). The comparatively low coral cover along the southwest coast may be a result of extensive coral mortality caused by sedimentation associated with a poorly-planned road construction project in the early 1990s and the continually poor water quality near the many river mouths along that section of coastline.

The results of baseline reef community surveys conducted by the UOGML at five permanent monitoring sites indicate that live coral cover was highly variable between sites and ranged from less than 10% at the Pago Bay site, which has been heavily impacted by poor water quality and crown of thorns predation, to greater than 80% at a site within Apra Harbor characterized by large, monospecific stands of *Porites rus* (Burdick et al., 2008). Continued monitoring of these sites will provide insight into long-term trends in these coral reef communities; additional sites will be established as part of a new comprehensive coral reef monitoring program.

Baseline coral disease assessments conducted in 2006 by the University of Guam Marine Lab (UOGML) at several sites around the island found that disease and syndromes affecting Guam's reefs are largely similar to those reported elsewhere in the region (Burdick et al., 2008; Raymundo et al. 2005; Willis et al., 2004). Coral diseases, as with diseases occurring within communities of other organisms, are a natural part of coral communities. However, human-caused threats, such as excessive nutrient and sediment input, the introduction of sewage-associated pathogens, and an increase in sea-surface temperature associated with climate change, appear to increase the susceptibility of corals to infection by various pathogens. Of the 10 sites surveyed around Guam, three sites exhibited disease prevalence values >10%, which can be considered high and potentially problematic.

Water Quality

Extremely high sedimentation rates continue to be devastating for reefs near river mouths, which account for a significant amount of reef area in southern Guam. A 2005 National Park Service study found that sedimentation rates in Asan Bay were among the highest in the literature. The extremely elevated rate of sediment collection is sufficient to raise serious concerns about the long term health and survival of Guam's reefs. A related National Park Service study that examined the relationship between sedimentation and coral recruitment in Asan Bay over a two-year period observed rates of coral recruitment similar to the low rates reported in previous studies, with an average of only 0.02 recruits per PVC plate (Minton et al., in prep). While it is generally held that rates of coral recruitment are low on reefs in the Mariana Islands as compared to reefs in many other parts of the world, the rates of coral recruitment observed in this study are among the lowest in the literature, and are orders of magnitude lower than recruitment rates reported for Guam in studies conducted in the 1980s.

A 2004 UOGML study in Fouha Bay, in southwestern Guam, correlated terrigenous sediments associated with runoff from heavy rain events with coral community change within the bay (Rongo, 2004). The study found that sedimentation rates were extremely high within the bay, greatly exceeding any of the several published sediment-tolerance thresholds for corals. A comparison of the results of coral community surveys conducted within Fouha bay indicated a steep decline in coral species richness over a 25-yr

EXECUTIVE SUMMARY (Cont.)

period, with more than 100 species reported in 1978 and fewer than 50 found in 2003 (Richmond et al., 2007).

Associated Biological Communities

Guam's coral reef fisheries are both economically and culturally important and target a large number of reef fishes and invertebrates. Despite improvements in gear and technology, Guam's fishery catches have declined over at least the last few decades. Data from creel surveys performed by DAWR suggest that Guam's fisheries have not recovered from a sharp decline in the 1980s. A recent re-estimation of small-scale fishery catches for Guam suggests that catches have declined by up to 86% since 1950 (Zeller et al., 2007). While there are other factors involved in this decline, fisheries impacts are certainly a major contributor. In-water visual surveys have also indicated that large reef fish are still conspicuously absent from many of Guam's reefs (Paulay et al., 2001; Amesbury et al., 2001; Schroeder et al., 2006). Additionally, the results of recent NOAA MARAMP towed diver surveys and REAs indicate that the amount of large reef fish (> 50 cm) is five times greater around neighboring islands in the southern Marianas than around Guam and Santa Rosa Bank and 25 times greater in the more remote northern islands (Burdick et al., 2008).

Particular concern has been raised over the use of SCUBA and artificial light for spear fishing, along with the continued use of monofilament gill nets. These methods have been banned or heavily restricted in most of the Pacific region, including the Commonwealth of the Northern Mariana Islands and American Samoa, but remain legal on Guam. Local fisheries biologists suggest that these methods may have led to a boom and bust harvest of large Napoleon wrasse, the depletion of large groupers, a shift from preferred species (large slow-growing fish) to smaller, faster growing species, and a decrease in the number of other large wrasse, parrotfish, snapper, and grouper caught by other methods (Flores, 2006).

To combat the fishery declines, the Government of Guam created a system of five Marine Preserves. The results of initial surveys conducted by DAWR, and reported to the Guam Legislature in 2003 as required by the law, indicate that the fish stocks in the preserves increased significantly after enforcement began in 2001, indicating that the preserves are working as designed. As reported in 2005, reef fish abundance increased by over 100% in both the Piti and Achang Marine Preserves after only 3 years of protection (Porter et al., 2005). Two additional UOGML studies suggest that the biomass of select reef fish groups is significantly higher inside the preserves than in adjacent non-protected areas (Burdick et al., 2008). Further studies, in conjunction with the regular creel survey monitoring conducted by DAWR, will help determine if the spillover of adult fishes and fish larvae are helping to restore reef stocks around the island.

The results of macroinvertebrate surveys conducted in 2005 and 2007 as part of NOAA's MARAMP indicate that the abundance of conspicuous macroinvertebrates was relatively low around the island, with the exception of high urchin and exceptionally high COTS densities at some sites (Burdick et al., 2008). Manta tow surveys conducted by the UOGML in 2006 at numerous sites around Guam corroborate the results of the NOAA surveys, with large COTS outbreaks and heavy coral mortality evident around the island (C. Caballes, unpub. data).

Socioeconomic Activities

In 2005-2006, an international team of researchers carried out a comprehensive economic valuation of the coral reefs and associated resources of Guam (van Beukering et al., 2007). The researchers estimated that the total economic value of coral reef resources on Guam at that time was between $85-164 million/yr, with a core value of approximately US$127 million/yr. Tourism revenue accounted for nearly 75% of this value, while other non-consumptive uses, such as coastal protection, diving/snorkeling, and amenity value, each accounted for approximately 7% of the total economic value. The contribution of extractive uses (3.1%), such as reef fisheries, was almost negligible compared to the value of non-extractive uses.

EXECUTIVE SUMMARY (Cont.)

What's being done to stop coral reef degradation on Guam?
The Guam Coral Reef Initiative Coordinating Committee and a broad network of local and federal agencies, NGOs, legislators, private enterprises, teachers, students and other concerned citizens continue to partner in the implementation of ambitious and creative ways to address the primary threats to Guam's coral reefs. Re-vegetation efforts, outreach campaigns, enforcement of the marine preserves, development of a comprehensive monitoring strategy, the strengthening of existing policies and the planned implementation of new ones are all examples of Guam's commitment to improving the health of its coral reef resources. Major public works projects, including the extension of sewage outfalls and the closing of Ordot dump, will also contribute to a healthier reef system. Guam's participation in the Micronesia Challenge represents a major step towards effective management of the island's natural resources, setting achievable conservation goals, identifying sustainable financing strategies, and providing an opportunity to further engage the community in natural resource management. An increasing level of community participation in cleanups and erosion control efforts, as well as the success of recent outreach and education activities, indicate that public awareness is increasing.

Many big challenges still remain, but there are solutions...
Despite the progress above-water, the health of Guam's coral reefs continues to decline. Although Guam has made a great deal of progress in coral reef protection, monitoring, and public outreach over the past several years, many challenges still remain. Financial and human resources remain limited compared to the need, and are disproportionate to the value of goods and services generated by coral reefs. Present capacity will be further stretched by the planned military expansion. Global climate change poses a particularly grave and increasingly pressing threat to the vitality of Guam's reefs. The expected increase in incidences of coral bleaching, ocean acidification and the potential for stronger storms will directly affect reef health, challenging even the most resilient reefs.

Policy interventions must be prioritized in an economically sound manner in order to most efficiently allocate the limited financial and human resources available to coral reef managers to address pressing issues of coral reef degradation. Site-based approaches, involving strong community participation and a coordinated network of multiple organizations, could focus resources on management actions that address a spectrum of threats within a specific area. The financial and staff capacity of the resource management community must be significantly increased if current coral reef threats and threats associated with climate change and the anticipated military expansion are to be adequately addressed. Three specific priority projects recommended for immediate implementation include the use of stop-gap measures to greatly reduce soil erosion in southern Guam, the subsequent, rapid, large-scale restoration of southern watersheds, and an island-wide ban on the use of monofilament gillnets and SCUBA for spearfishing. Without a substantial reduction in the amount of sediment reaching the reef and the recovery of reef fish stocks, particularly algae-eating fishes like parrotfishes and surgeonfishes, the recovery of Guam's degraded reefs, and the survival of even the healthiest reefs in the face of climate change is in serious question.

It is clear that the ability of Guam's reefs to cope with climate change must be enhanced significantly if productive reef systems, and the goods and services they provide, are to be available to future generations. To achieve this will require a deep commitment to the rapid, large-scale reduction in the threats currently affecting Guam's reefs. It will also require a vastly improved understanding of reef resilience to climate change and the effective integration of the concept of resiliency into a viable, long-term coral reef management strategy.

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INTRODUCTION AND SETTING

Guam, a U.S. territory located at 13°28' N, 144°45' E, is the southernmost island in the Mariana Archipelago (Figure 1). It is the largest island in Micronesia, with a land mass of 560 km^2, and has a maximum elevation of approximately 405 m and a total shoreline length of 244 km. Guam is a volcanic island completely surrounded by a coralline limestone plateau. The relatively flat northern half of the island, which is primarily comprised of uplifted limestone, is the site of the island's principle aquifer. The southern half of the island has more topographic relief and is comprised mainly of volcanic rock, with areas of highly erodible lateritic soils. The hilly topography creates numerous watersheds drained by 96 rivers (Best and Davidson, 1981).

Guam is the most heavily populated island in Micronesia, with an estimated population in 2007 of about 173,500 (U.S. Census Bureau, 2007). In 2000, the U.S. Census Bureau predicted the population growth rate to steadily decrease over the next 50 years, but this estimate did not take into account the planned movement of roughly 26,000 additional military personnel and dependents to Guam by 2014 (Helber, Hassert and Fee Planners, 2006). Such an influx, coupled with associated migration to Guam by those seeking economic gain from the expansion, would increase the existing population by up to 38% in less than 10 years, potentially pushing the total population to over 230,000 (Guam Civilian Military Task Force, 2007).

The island typically experiences easterly trade wind conditions (10-15 mph and associated east-northeast ocean swell of small (1-2 m), short period (3-10 seconds) waves). The mean annual temperature on Guam is 28°C (82°F), with a mean annual rainfall of approximately 260 cm (102 in) (Lander and Guard, 2003). The dry season extends from December until June, while the wet season falls between July and November. Sea surface temperatures around Guam range from about 27-30°C, with higher temperatures measured on the reef flats and in portions of the lagoons (Paulay, 2003). Guam lies within an El Niño-Southern Oscillation (ENSO) core region, which experiences inter-annual variations of rainfall and drought-like conditions in years following El Niño events. Maximum annual temperatures on Guam during El Niño periods tend to be cooler than average when compared to non El Niño periods (NOAA PIFSC-CRED, unpublished data).

A variety of reef types are represented on Guam, including fringing reefs, patch reefs, submerged reefs, offshore banks and barrier reefs. Fringing reefs are the predominant reef type, extending around much of the island. The shallow (0-2 m) reef flat platform 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 108 km^2 in nearshore waters between 0-5.5 m (0-3 nmi), and an additional 110 km^2 in Federal waters greater than 3 nmi offshore (Hunter, 1995; Burdick, 2006)*. Mangrove growth on Guam is limited to Apra Harbor, which hosts the largest and most developed mangrove forest in any U.S. coastal area in the Pacific (approximately 70 ha), and two smaller areas in the southern villages of Merizo and Inarajan. Over 5,100 marine species have been identified from Guam's coastal waters, including over 1,000 nearshore fish species and over 375 species of scleractinian coral (Paulay, 2003; Porter et al., 2005). Guam lies relatively close to the Indo-Pacific center of coral reef biodiversity (Veron, 2000) and possesses one of the most species-rich marine ecosystems among U.S. jurisdictions.

Guam's reef resources are both economically and culturally important, providing numerous goods and services for the residents of Guam, including cultural and traditional use, tourism, recreation, fisheries, and shoreline and infrastructure protection. A recent economic valuation study estimated that the coral reef resources of Guam are valued at approximately $127 million per year (van Beukering et al., 2007). The aesthetic appeal of the reefs and the protection that they provide for inshore recreational activities help make Guam a popular tourist destination for over one million Asian tourists each year. A recent study

*The revised and substantially larger estimate for the total area of nearshore coral reef and lagoon area (compared to the 69 km^2 figure reported in Porter et al., 2005) was derived from a recent coastal mapping project conducted by the University of Guam Marine Laboratory (Burdick, 2006). Also note that Rohmann et al. (2005) reported a value of 273 km^2 for the area of potential coral reef habitat up to a depth of 183 m (100 fathoms) within the Exclusive Economic Zone (including offshore banks), with 202.8 km^2 associated with the island of Guam directly.

The Status of the Coral Reef Ecosystems of Guam

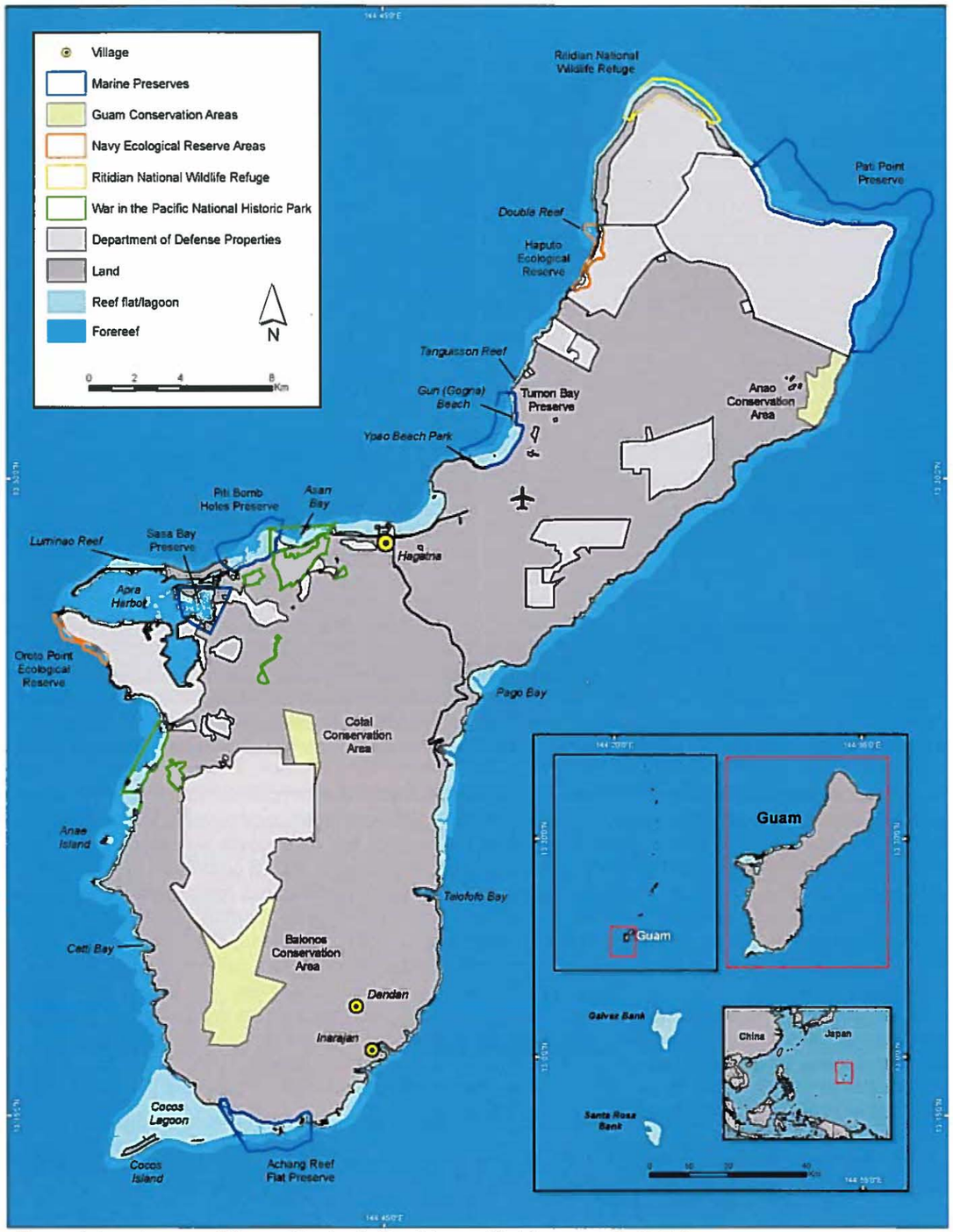

Figure 1. *Locator map of Guam. Map by D. Burdick; modified from map by K. Buja.*

that evaluated the contribution of tourism to Guam's overall economy concluded that the tourism industry accounts for 20% of Guam's GDP (32% of non-governmental GDP) and provides over 15,000 direct and

indirect jobs (Pike, 2007).

Traditionally, coral reef fishery resources formed a substantial part of the local Chamorro community's diet, which included finfish, invertebrates and sea turtles (Amesbury and Hunter-Anderson, 2003). Albeit to a lesser per capita extent than in the past, residents of Guam still use the marine environment for fishing as well as for recreational activities. Despite depleted fish stocks and external influences, fishing is still a popular activity on Guam. Rather than a source of cash or a means of subsistence, fishing activities on Guam's reefs primarily serve as a way to strengthen social bonds and as a source of enjoyment (van Beukering et al., 2007). Many of the residents from other islands in Micronesia continue to include reef fish as a staple part of their diet (Amesbury and Hunter-Anderson, 2003). Sea cucumbers, sea urchins, a variety of crustaceans, molluscs and marine algae are also eaten locally.

In response to declining reef fish stocks, approximately 16.4%* (33.1 km²) of Guam's nearshore (<183 m) waters was set aside in five locally-established Marine Preserves in 1997 (Figure 1). The preserves, which include the Tumon Bay, Piti Bomb Holes, Sasa Bay, Achang Reef Flat and Pati Point Marine Preserves, protect a variety of habitats. Fishing activity is restricted in the preserves, with limited cultural take permitted in three of the five areas and additional hook and line fishing from shore allowed in a fourth. In addition to regulating fishing activities within the preserves, an "eco-permitting" program for regulating non-fishing activities is currently under development. Enforcement of fishing restrictions within these areas began in 2001. The preserves are complemented by the War in the Pacific National Historical Park (WAPA), the Ritidian National Wildlife Refuge, the Orote and Haputo Ecological Reserve Areas and the Guam Territorial Seashore Park, although these areas currently possess only limited management and enforcement.

The health of Guam's coral reefs varies considerably around the island, 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, coral predator outbreaks and natural disasters such as typhoons and earthquakes (Figure 2). Similar to the decline in health of reefs across the Indo-Pacific (Bruno and Selig, 2007), the vitality of many of Guam's reefs has declined over the past 40 years. The average live coral cover on the fore reef slopes was approximately 50% in the 1960s (Randall, 1971), but by the 1990s had dwindled to less than 25% live coral cover, with only a few sites having over 50% live cover (Birkeland, 1997).

In the past, Guam's reefs have recovered after drastic declines. For example, an outbreak of the crown-of-thorns seastar (*Acanthaster planci*; 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). However, continued degradation of water quality, COTS outbreaks, low abundance of target fish species and other persistent stressors currently affecting Guam's reefs make the reefs less resilient. A particularly distressing indicator of declining reef resilience is the marked decrease in rates of coral recruitment in the last few decades (Birkeland et al., 1981; Birkeland, 1997; Neudecker, 1981; Porter et al., 2005). A recent two-year study conducted by the National Park Service in Asan Bay found rates of coral recruitment similar to the low rates reported in previous studies, with an average of only 0.02 recruits per PVC plate (Minton et al., in prep; see p.18, this report). The decrease in resilience to major stress events is of particular concern when the anticipated impacts of global climate change, such as the increased incidence and severity of bleaching events (Hoegh-Guldberg, 1999), ocean acidification (Kleypas et al., 1999; Meehl et al., 2007) and an increase in the strength of cyclones (Emanuel, 2005; Meehl et al., 2007) are considered.

Mangrove growth on Guam is limited to the eastern shore of Apra Harbor, which hosts the largest (approx. 70 ha) and most developed (Moore et al., 1977) mangrove forest in the Mariana Islands, and apparently anywhere in the Pacific on U.S. soil. Two smaller mangrove communities occur in the southern villages of Merizo and Inarajan (Scott, 1993). The mangroves and associated wetlands in the Apra Harbor area were historically much larger, but filling and other disturbances have greatly reduced their size. An estimated 500 ha of land area were filled during the expansion of port facilities by the Navy in the late 1940s, causing the destruction of extensive mangrove communities fringing the eastern harbor (U.S. Department of the Navy, 1978). The construction of a major highway along the eastern shore of Apra Harbor and two oil spills in the 1980s have also impacted mangroves in this area. While mangroves on Guam are protected from un-permitted removal and fill by mechanical means, this legal protection does not adequately protect these wetlands from impacts associated with clearing by hand, upland erosion, contamination by heavy metals and other toxins, or from catastrophic accidents such as oil spills. Some mangroves in Apra Harbor could be impacted by projects associated with the military buildup and the expansion of the commercial port. To the authors' knowledge, no studies of Guam's mangrove communities have been conducted in recent years.

*The 15.5% figure reported in the Guam section of the *NOAA State of the Coral Reef Ecosystems of the United States and the Pacific Freely Associated States: 2008* report is incorrect. The 16.4% value reported here is a more accurate figure arrived at by using a Geographic Information System to calculate the area of the preserves (not including the area 10 m inland of the shoreline). This figure may further be refined as more accurate data becomes available.

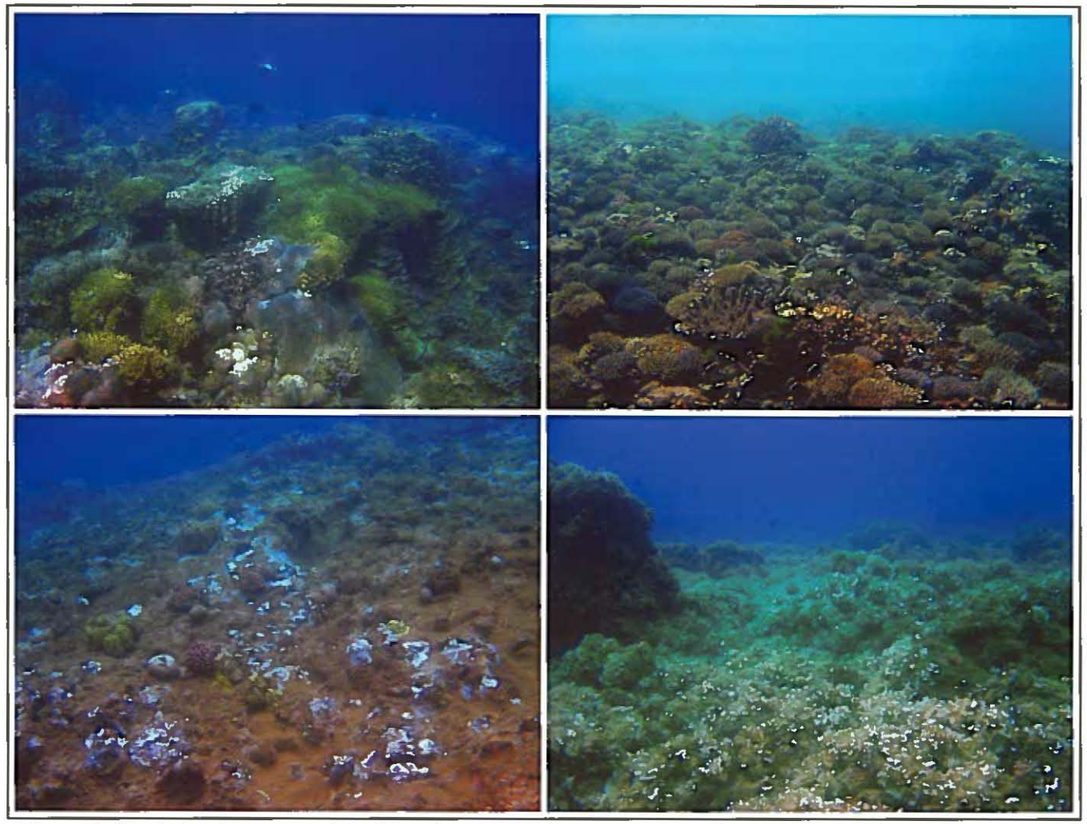

Figure 2. *Clockwise from upper left: Extensive coral growth near Gabgab Beach in Apra Harbor; an Acropora-dominated reef community on a shallow fore-reef terrace off the southeast coast; an extensive macroalgal bloom (Padina sp.) near Apaca Pt. along the southwestern coast; and a reef community near Anae Island on the southwest coast that is heavily impacted by regular sedimentation events. Photos: D. Burdick.*

Guam's seagrass communities are comprised mainly of *Enhalus acoroides*, but *Halophila minor* and *Halodule uninervis* also occur on Guam. According to an island-wide benthic habitat mapping effort conducted by the University of Guam Marine Lab (Burdick, 2006), seagrass beds occupied about 3.1 km², or approximately 2.8%, of Guam's nearshore waters (<40 m water depth). Guam's seagrass communities have generally received little attention by managers and researchers, but the recent completion of the benthic habitat mapping project, a study on the impacts of motorized Personal Water Craft on seagrasses and other marine communities in East Agana Bay, and a UOGML assessment of seagrass health in the Piti Bomb Holes and Achang Reef Flat Marine Preserves are indicative of an emerging commitment to understanding and protecting these valuable ecosystems.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change, Coral Bleaching, and Ocean Acidification

The increase in water temperatures associated with global warming (1-2°C per century) and the regionally specific El Niño-Southern Oscillation (ENSO) events are causing a breakdown in the coral-algal symbiotic relationship, which is critical to the nutrient recycling that is thought to explain the high productivity of coral reefs. Reef-building corals are thought to live near their thermal maxima, making them a good indicator for changing conditions, and the thermal tolerances of reef-building corals are forecasted to be exceeded within the next few decades (Hoegh-Guldberg, 1999). Small increases in water temperature, on the range of 1-2°C, cause stress to the coral host often causing them to expel their symbiotic algae. The algae contain the photosynthetic pigments that often give the corals their distinct color. When the algae have been expelled from the coral tissue, the coral looks white or bleached. If the corals are not able to attain new symbiotic algae in the time period that their nutritional needs require (usually weeks to sometimes months), the bleaching effect of the reef will have resulted in the mortality of the affected live coral.

A major concern is that the accelerating rate of environmental change, including increasing temperatures, could exceed the evolutionary capacity of coral and algal species to acclimate and/or adapt to these changes (Hughes et al., 2003). Corals can die in great numbers immediately following a bleaching event, which can stretch across thousands of square kilometers of ocean, and lead to habitat phase shifts where corals are replaced by macroalgae. Although recent research has documented algal-dominated areas to occur naturally on many healthy Pacific reefs systems (Vroom et al., 2006), algal overgrowth of coral dominated areas as the result of anthropogenically derived activities are indicative of decreased ecosystem health, and may result in decreased accumulation of calcium carbonate, and impacts to the reef fauna that depend on the structural complexity provided by corals. Six major coral bleaching events have occurred since 1979, with massive coral mortality affecting reefs around the globe (Hoegh-Guldberg, 1999). The constantly increasing temperatures associated with global warming are likely to increase the frequency and magnitude of coral bleaching events.

The reefs of Guam have been spared from severe and widespread coral mortality associated with large-scale bleaching events, but observations of bleaching in 2006, 2007, and 2008 suggest that bleaching events in Guam's reefs may become more frequent and severe in the coming decades.

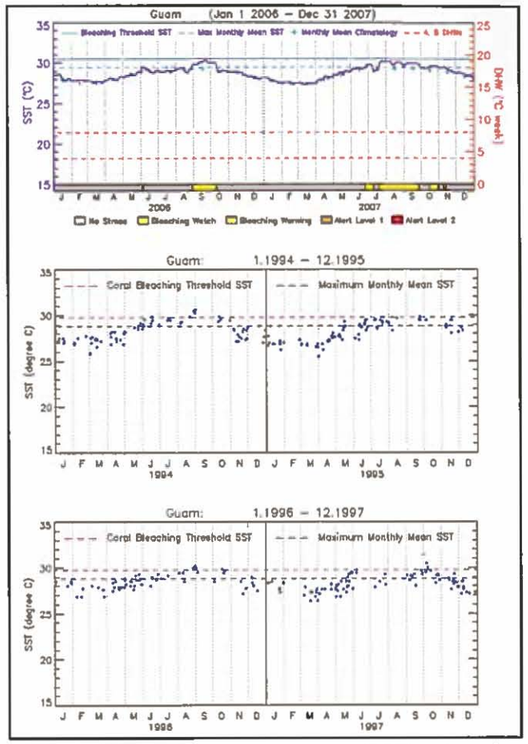

Figure 3. Sea-surface temperature (SST) values for Guam derived from Pathfinder satellite measurements for 2006/2007 (top), 1996/1997 (middle), and 1994/1995 (bottom). Minor to moderate bleaching was observed at several sites around Guam from Sept-Oct 2006, and in Aug 2007, and although sea surface temperature (the solid, dark-blue line) did not reach what is currently regarded as the "Coral Bleaching Threshold" SST (30.5°C), it did exceed the threshold value of 29.9°C used for the 1985-2003 data. Above-average sea surface temperatures were not considered a cause of large-scale coral bleaching events on Guam in 1994 and 1996, but a review of archived Pathfinder SST data (middle and bottom graphs) suggests that sea surface temperatures exceeded the coral bleaching threshold during the time the events were reported to have occurred. The bleaching threshold value is 1°C above the maximum monthly mean; the threshold value for Pathfinder time series data (the 1994/1995 and 1996/1997 data) was calculated from the Pathfinder SSTs and is different from the near-real-time series value used for the 2006/2007, which was calculated using operational SST values. Graphs obtained from http://coralreefwatch.noaa.gov.

The first large-scale bleaching event reported in Guam since the establishment of the University of Guam Marine Laboratory (UOGML) in 1970, was an event in 1994, with another event reported in 1996 (Paulay and Benayahu, 1999). Sixty-eight percent of taxa (51 of 75) surveyed between October and December 1994 were reported bleached. The bleaching in 1996 was believed to have been more severe than in 1994, but a detailed record is not available. It is generally held that neither of these events resulted in significant coral mortality. Paulay and Benayahu (1999) reported that these events were not related to elevated water temperatures, but a recent examination of satellite-derived sea surface temperature (SST) measurements suggests that sustained, higher than average water temperatures may have played a role. The temperatures recorded during the 1994 and 1996 events were very similar to the temperatures that have elicited coral bleaching watches and warnings from NOAA in recent years (Figure 3). The potential role of enhanced exposure to UV radiation in these bleaching events has not been properly examined as cloud cover and wave height data either are not available or have not yet been obtained. A localized bleaching event reported from Pago Bay in 2004 was likely a result of a substantial influx of freshwater (~18 in) from Tropical Storm Tingting. Bonito and Richmond (2004) reported that a UOGML scientist observed cases of coral bleaching on Guam every year for 7 years prior to their report, but these events were localized and were not accompanied by high rates of mortality.

After nearly a decade without reports of large-scale bleaching, coral bleaching was observed in September and October 2006 and August and September 2007 (Figure 4). Both the 2006 and 2007 events appear to have been associated with above-average SSTs and coincided with bleaching watches/warnings issued by the National Oceanic and Atmospheric Administration (NOAA) Coral Watch Program based on satellite measurements of sea surface temperature. During both events, bleaching was observed among numerous species on the reef flat and reef front to a depth of 7 m at several sites around the island (D. Burdick, pers. obs.). Several branching *Acropora* species commonly found in relatively shallow, protected areas were moderately to heavily bleached; *Acropora* species found along the wave-washed reef margin and shallow reef front were also moderately to heavily bleached. *Millepora* spp., *Pocillopora* spp., and various other species also exhibited paling or moderate to heavy bleaching. Observations from other areas around the island, including in the Piti Bomb Holes Marine Preserve, Pago Bay, Hilaan (Shark's Hole), Tanguisson, Ritidian, and in the Achang Reef Flat Marine Preserve, suggest that the 2006 bleaching event may have affected a substantial part of Guam's reef system. The widespread distribution of the 2007 bleaching event was confirmed with observations from an aerial survey carried out in August 2007 (D. Burdick, pers. obs.).

The effects of the 2006 and 2007 events on Guam's reefs were difficult to properly assess, as limited resources and reef access resulted in only a handful of observations and little quantitative data. A survey of *Pocillopora verrucosa* colonies at Anae Island, off Guam's southwest coast, found that 67% of colonies

Figure 4. Bleached Acropora *colonies on the reef margin at Gun Beach in October 2006 (left) and on the reef flat platform at Ypao Beach in August 2007 (right). Turf algae are apparent on some of colonies in the photo on the left, indicating at least partial mortality. Photos: D. Burdick.*

at 1-3 m water depth were pale or full or partially bleached in September 2006 (Chau, unpublished data). Of a total 36 tagged *P. verrucosa* colonies, all appeared to have fully or partially recovered after more than three months. In contrast, about 60% of all coral species surveyed in October 2006 along a single transect on the reef margin in the Tumon Bay Marine Preserve (TBMP) exhibited partial or full mortality (Brown, 2007). Surveys of an arborescent *Acropora*-dominated coral community in Tumon Bay in August 2007 indicated that approximately 60% of the total live coral and >90% of the *Acropora* species along five 25 m transects exhibited paling or partial bleaching (Brown and Burdick, unpublished data). Because this nearly monotypic, *Acropora*-dominated coral community is not common on Guam, observed bleaching rates are not representative of rates island-wide Guam's. A qualitative survey of the north side of Cetti Bay indicated that at least eight scleractinian coral genera were affected to a depth of about 7 m (Brown, unpublished data).

Coral reef calcification depends on the saturation state of carbonate minerals in surface waters. Reduced carbonate saturation state promotes dissolution rather than accretion in reef-building corals, and decreased carbonate concentration makes it more difficult for marine calcifying organisms to form biogenic carbonate minerals (Orr et al., 2005). By the middle of this century, an increased concentration of CO_2 will decrease the saturation state with respect to carbonate minerals in the tropics by 30 percent and biogenic carbonate precipitation by 14 to 30 percent (Kleypas et al., 1999). Coral reefs are particularly threatened, because reef-building organisms secrete metastable forms of carbonate minerals, but the biogeochemical consequences on other calcifying marine ecosystems may be equally severe (Kleypas et al., 1999). The rate of current and projected CO_2 increase, primarily from the burning of fossil fuels, is about 100 times faster than has occurred over the past 650,000 years and the rising atmospheric CO_2 levels are irreversible on human time scales (Kleypas et al., 2005). Uptake of CO_2 by the ocean helps moderate the rising atmospheric concentrations, but the associated change in the oceanic carbonate chemistry system, referred to as "ocean acidification," ultimately results in the increase of CO_2 concentrations in seawater and related decrease in the concentrations of carbonate. If the current rate of fossil fuel combustion continues unabated, the increase in atmospheric CO_2 will result in the reduction of carbonate minerals available to marine calcifying organisms to form biogenic materials (Orr et al., 2005). Coral reefs are particularly threatened by ocean acidification because reef-building organisms, such as corals, many kinds of algae, bivalves, crustaceans, and many other reef inhabitants, utilize carbonate from the water column to build the impressive reef structures, shells, and skeletons for which they are so well known (Kleypas et al., 1999).

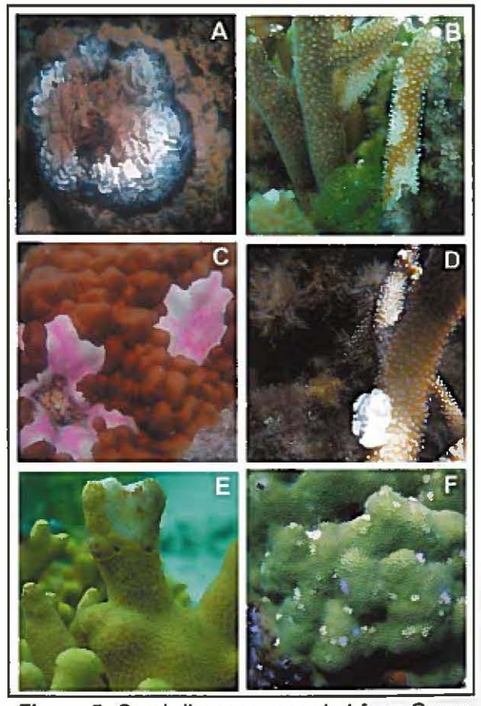

Figure 5. *Coral diseases recorded from Guam reefs. A) black band disease on massive* Porites *(Sella Bay); B) brown band disease on* Acropora *(Luminao Reef); C) growth anomaly on* Porites *(Double Reef); D) growth anomaly on* Acropora *(Cocos Lagoon); E) white syndrome on* Porites *(Luminao Reef); F) ulcerative white spots on massive* Porites *(Pago Bay). Photos: L. Raymundo, University of Guam Marine Lab (UOGML), and D. Burdick.*

Diseases

An interest in establishing a coral disease survey and monitoring program on Guam has arisen in response to known increases in disease prevalence worldwide, and in the appearance of new but poorly characterized diseases and syndromes. Relative to the situation in the Caribbean, little is known about diseases impacting reefs in the Indo-Pacific. However, reefs in this vast region are more widely dispersed, more diverse, and often more impacted by the activities of dense coastal populations. Therefore, developing an understanding of the status of coral disease threats to Guam reefs was considered an important objective of local reef management scientists.

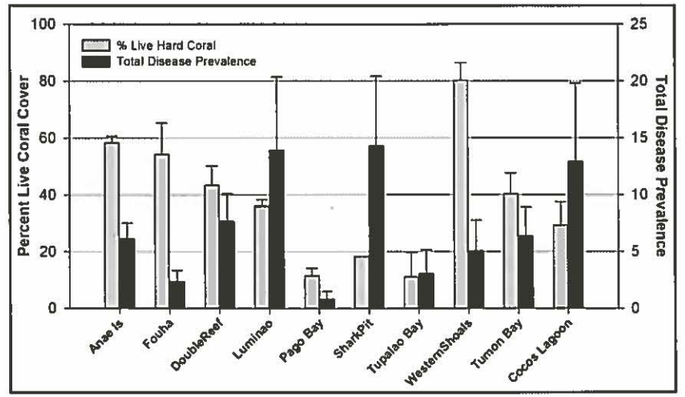

Figure 6. *Live hard coral cover and total disease prevalence for each survey site (mean ± SE; n=3-4 transects/sites). NOTE: the percent live hard coral and total disease prevalence values are measured along different y-axes. Source: L. Raymundo, unpubl. data.*

Coral disease surveys were conducted by the UOGML in 2006 and 2007 to establish baseline levels of coral disease. To date, 10 reefs have been surveyed for benthic composition, coral disease prevalence, and host species range; the survey methodology is described in the "Benthic Habitats" section. Diseases and syndromes affecting Guam reefs are largely similar to those reported elsewhere in the region (Raymundo et al., 2005; Willis et al., 2004), with the addition of a potential syndrome that has not been characterized or described elsewhere. In addition to the diseases described in the literature, other syndromes and signs of ill-health have also been quantified.

Of the diseases reported from the Indo-Pacific region, White Syndrome (Figure 5E) appears to be the most prevalent (observed in 9 out of 10 sites) and the source of greatest tissue mortality. Black Band Disease (Figure 5A), the only documented circumtropical disease, is rare on Guam reefs, and has been observed primarily on massive Porites in Luminao Reef, but has also been observed at Tanguisson and in Sella Bay. The ciliate causal agent of Brown Band Disease (Figure 5B) was identified via microscopy in several species of *Acropora* from reef areas, such as Tumon Bay and Luminao Reef, containing thickets of such species. Growth Anomalies, which were the first diseases to be described from Guam (see Cheney, 1977), are more common, particularly on massive Porites (Figures 5C and 5D). Ulcerative White Spots (Figure 5F), first described from the Philippines (Raymundo et al., 2003), has been verified in Guam, though at very low prevalence. Other signs of compromised health have also been quantified, including Patchy Bleaching (different from temperature-related bleaching) and predation from the crown of thorns starfish, *Acanthaster planci,* and the gastropod snails, *Drupella rugosa* and *Coralliophila violacea*.

Disease prevalence was highly variable within and between sites and did not show a strong relationship with live hard coral cover (Figure 6). Of the 10 surveyed reefs around Guam, three exhibited total prevalence values >10% (Luminao, Cocos Lagoon and Shark Pit Rock). While a baseline figure for total disease prevalence has not been established, using published literature as a guideline, it is reasonable to suggest that prevalence figures greater than 10% can be considered high and potentially problematic. Therefore, it appears from this initial census that disease may be causing at least partial mortality in a significant number of colonies in these reefs.

Tropical Storms

Guam is in a highly active region of the western Pacific for tropical storms, and has been hit by four typhoons with sustained winds greater than 150 mph since 1994. Although Guam has been spared a direct hit by a typhoon-strength storm since Super Typhoon Pongsona (December 2002), Typhoon Tingting brought high winds and record rainfall in June 2004 (Figure 7). While several other tropical cyclones passed close enough to Guam to influence its weather in the last three years, Guam did not experience any major storms in 2005, 2006, or 2007.

Tropical storm systems typically occur in the more humid summer months and can develop rapidly. During El Niño Southern Oscillation (ENSO) years, increased SSTs move the cyclone breeding ground toward the central Pacific, increasing the number of typhoons generated east of the Mariana Islands

(Lander, 2004; Minton and Palmer, 2006). Large offshore waves associated with storm-driven winds can cause physical damage to the reef. Storm surge and wave inundation can increase local sea levels by over 40% of the offshore significant wave height (Vetter, 2007). Large influxes of rainwater laden with sediments, nutrients, debris and other anthropogenic inputs can be detrimental to coral reef ecosystems (Jokiel, 1993).

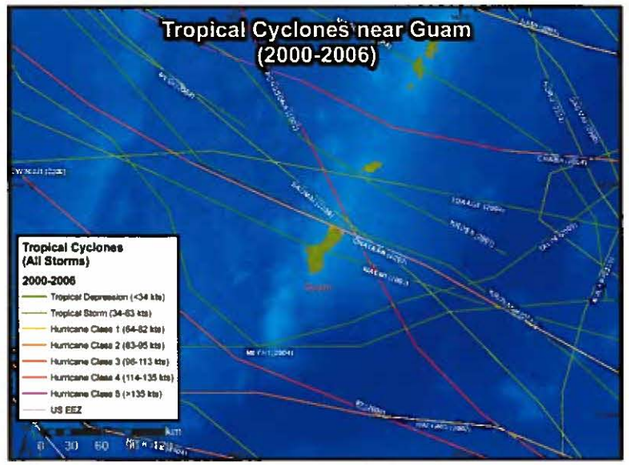

Figure 7. *Path and intensity of tropical cyclones passing near Guam from 2000-2006. The storm name and year are labeled on each track, color-coded by sustained wind speed using the Saffir-Simpson scale. Data from: National Hurricane Center/ Tropical Prediction Center, Central Pacific Hurricane Center, Joint Typhoon Warning Center, http://weaterh.unisys.com/hurricane, and http://www.solar.ifa.hawaii.edu/tropical. Compiled by R. Moffitt.*

ENSO/El Niño

El Niño-Southern Oscillation (ENSO), resulting from the large-scale global coupling of atmospheric and oceanic circulation, is an inter-annual climatic phenomenon (approximately 3-8 years) that creates significant temperature fluctuations in the tropical surface waters of the Pacific Ocean. ENSO events can have a significant impact on coral reef ecosystems due to changing surface winds, ocean currents, water temperatures, nutrient availability, storm frequency and magnitude, etc. The manifestations of ENSO have also been linked to large-scale reef-building coral mortality due to the increased temperatures and UV exposure, as well as decreased nutrient availability (Hoegh-Guldberg, 1999). ENSO is a naturally occurring phenomenon, however, there is uncertainty regarding how global warming and the associated climate changes will impact the frequency and/or magnitude of this cycle and how that will in turn affect coral reef ecosystems.

ENSO has two distinct phases in the Pacific Ocean: El Niño and La Niña. During El Niño conditions, trade winds weaken and occasionally reverse in the equatorial Pacific. This causes eastward surface transport and an anomalously deep thermocline with warm SST's in the central and eastern Pacific and an abnormally shallow thermocline with cool SST's in the western Pacific. During La Niña conditions, trade winds strengthen across much of the equatorial Pacific and push warm surface waters towards the west; this condition results in an anomalously deep thermocline with warm SST's in the western Pacific, and a shallow thermocline with cooler than average SST's in the central and eastern Pacific (McPhaden et al., 1998; Yu and McPhaden, 1999). Guam lies within an ENSO core region, linked to inter-annual variations of rainfall with Guam exhibiting drought-like conditions in years following El Niño events. These drought-like conditions exacerbate the already devastating effects of illegally-set wildfires in southern Guam (see Figure 10 in the "Coastal Development and Runoff Section" below). During El Niño years, there is also an increased probability that tropical cyclones will form in the region (http://www.soest.hawaii.edu/MET/Enso/peu/2006_4th/current_conditions.htm). When comparing satellite derived SST from Guam with the Multivariate ENSO index, it appears that during El Niño periods, maximum annual temperatures at Guam are cooler than average when compared to non El Niño time periods.

COASTAL DEVELOPMENT AND RUNOFF

As reported in the 2005 report, the resident population of Guam grew from 133,152 in 1990 to 154,805 in 2000, a 16.3% increase (U.S. Census Bureau, 2003). The population estimate for 2007, extrapolated from the 2000 Census figures, is estimated at 173,500. The U.S. Census Bureau estimates the population growth rate to steadily decrease over the next 50 years, but this estimate does not take into account the planned movement of a minimum of 40,000 military personnel and dependents beginning in 2010 (Helber

Hassert & Fee, Planners, 2006). An estimated total of 60,000 people, including construction workers and others from nearby islands seeking to gain economically from the expansion, are expected to move to Guam as a result of the expansion (Guam Civilian Military Task Force, 2007). This massive influx, signifying the largest single transfer of military personnel in U.S. history, would increase the existing population by 35%, pushing the total population to over 230,000. The development required to accommodate the additional personnel, including the construction of on-base military facilities, road expansions, and off-base housing developments, has the potential to negatively impact coastal water quality. Of particular concern is the likely concentration of this development above the aquifer in the northern part of the island.

Although most development between 2004 and 2007 has involved residential or other small-scale construction, several major development projects have started recently or are planned for the near future to accommodate the growing tourism sector and planned military expansion. Development associated with the incoming military personnel, their dependents, and support staff, such as construction of military facilities and off-base housing developments and road-building activities, has the potential to negatively impact coastal water quality.

Hotel Okura, situated along the coast of the TBMP (Figure 8), is currently re-developing a section of the coastline for luxury bungalows. Another major development along the preserve is an 8.7 ha development planned for the Gun Beach area, a popular recreational site for both residents and tourists. The infrastructure planned to accommodate this development will likely encourage nearby land owners to develop in this area, which contains some of the last remaining undeveloped land along the bay. Construction activities, the reduction in shoreline vegetation, and the application of fertilizers and pesticides associated with these developments are likely to impact coastal water quality.

Figure 8. *High density development along the Tumon Bay Marine Preserve. Photo: J. Jocson.*

The U.S. Navy has recently undertaken several projects in Apra Harbor that will impact coral reef habitat, with several additional projects planned for the near future. The Alpha/Bravo Wharves' Improvements Project, scheduled for 2007, will involve the removal of 2.9 ha (7.1 ac) of coral reef habitat (Commander Navy Region Marianas, 2006). The military is also expanding the ammunition Kilo wharf, located on Orote Peninsula, in order to accommodate a new class of ammunition ships (Commander Navy Region Marianas, 2007). The Kilo wharf expansion will involve the removal of 1.92 ha (4.75 ac) of coral reef habitat, with sedimentation impacts from dredging operations potentially affecting between 0.68 and 6.02 ha (1.69 and 14.88 ac) of additional coral reef and associated habitat. Of particular concern is the U.S. Navy's proposal to enhance infrastructure and improve waterfront facilities to support transient nuclear aircraft carrier berthing. One of the sites favored for the proposed carrier berthing is at Polaris Point, in Apra Harbor (Helber Hassert & Fee, Planners, 2006). In addition to the impacts to reef habitat during construction of the new 400 m wharf, dredging in the vicinity of nearby shoals popular with tourists and fishermen may be required to provide space for an adequate turning basin.

The Port Authority of Guam's Wharf Improvement and Land Reclamation may also impact coral reef habitat in Apra Harbor, but the future of the plan is unclear with an updated master plan currently pending approval by the Guam Legislature. If the original plan is implemented, it will include the construction of a new 457 x 70 m (1500 x 230ft) wharf to the east of Hotel Wharf and will involve the placement of approximately 726,330 m^3 (950,000 yd^3) of fill material over 3.2 ha (7.9 ac) of submerged lands. An additional 7.3 ha (18.1 ac) of submerged lands at three areas along the east end of Glass Breakwater will

be covered with 383,000 m³ (500,000 yd³) of fill material. The plan will also involve dredging to a depth 17 m (55 ft) in the waters adjacent to the proposed wharf to accommodate large deep draft commercial and military vessels. While the reef habitat in the areas that may be impacted Port Authority projects appears to be somewhat degraded and has not been identified as a coral reef area of "special interest" by NOAA, there is substantial coral growth along some of the coastline. A variety of reef-associated organisms, including the threatened green sea turtle, *Chelonia midas*, and the endangered hawksbill sea turtle, *Eretmochelys imbricata*, are observed in this area. The project will also further limit commercial and recreational activities in the area, placing increased pressure on alternate sites such as the Piti Bomb Holes and Tumon Bay marine preserves.

Sedimentation of nearshore habitats, primarily a result of severe upland erosion, continues to be one of the most significant threats to Guam's reefs (Figure 9). Sedimentation is most prevalent in southern Guam, where steep slopes, underlying volcanic rock, barren areas and areas with compromised vegetation contribute large quantities of the mostly lateritic, clay-like soils to coastal waters. According to one estimate, the sediment yield of unvegetated "badlands" is more than 20 times that of ravine forests (243 tons/acre/yr versus 12 tons/acre/yr), while savannah grasslands, which also cover large areas of southern Guam, produce more than 2.5 times as much sediment as ravine forests (U.S. Dept. of Agriculture, NRCS, 1995). The excess sediment flows into coastal waters, where it combines with organic matter to form "marine snow," falling to the seafloor and smothering corals and other sessile organisms (Wolanski et al., 2003). Sediment, along with excess nutrients and freshwater, can also interfere with or inhibit coral gamete production, release, and viability, and larval survival, settlement and recruitment (Hodgson, 1990;

Figure 9. *Clockwise from top-left: View of exposed soil along southwestern coast of Guam; concentrated plume of clayey soils deposited into coastal waters near same area; a wildfire in southern Guam; and a Quickbird satellite image from 2005 depicting large expanses of exposed soil and recently-burned areas in southwestern Guam. Quickbird satellite image provided by DigitalGlobe. Photos: D. Burdick and DAWR.*

Tomascik, 1991; Wittenberg and Hunte, 1992; Ward and Harrison, 1997; 2000; Gilmour, 1999). While it is generally held that Guam's southern reefs have evolved under a regime characterized by larger sediment loads than at northern reefs, an increase in destructive anthropogenic activities, including wildland arson, clearing and grading of forested land, inappropriate road construction methods and recreational off-road vehicle use, as well as grazing by feral ungulates, have accelerated rates of sedimentation and appear to have exceeded the sediment tolerance of coral communities in these areas, resulting in highly degraded reef systems. For example, a 2004 UOGML study in Fouha Bay, in southwestern Guam, correlated terrigenous sediments associated with runoff from heavy rain events with coral community change within the bay (Rongo, 2004). The study found that sedimentation rates were extremely high within the bay, greatly exceeding any of the several published sediment-tolerance thresholds for corals. A comparison of the results of coral community surveys conducted within Fouha Bay indicate a steep decline in coral species richness over a 25-yr period, with more than 100 species reported in 1978 and fewer than 50 found in 2003 (Richmond et al., 2007).

Wildfires set by poachers are believed to be the main cause of badlands development and persistence (Minton, 2005). Despite being illegal, intentionally-set fires continue to burn vast areas of southern Guam. According to figures from the Department of Agriculture's Forestry and Soil Resources Division (FSRD), an average of over 700 fires have been reported annually between 1979 and 2006, burning over 46.5 ha (115,000 acres) during this period (Figure 10). The devastating effects of illegally-set wildfires in southern Guam are exacerbated by the drought-like conditions associated with El Niño events.

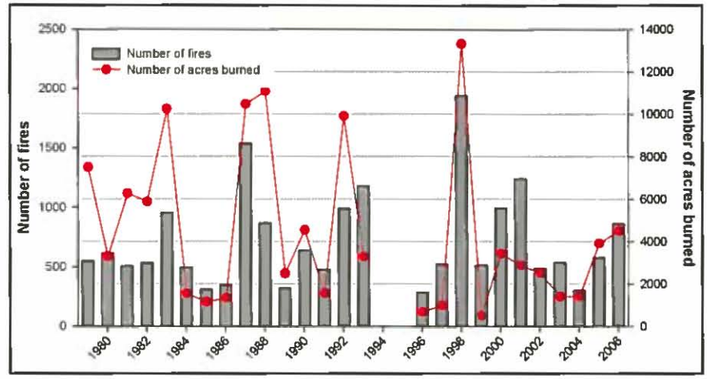

Figure 10. *Frequency (no. of fires/yr) and extent (acres burned) of wildfires in Guam from 1979-2006. Note the steep increase in the number and extent of fires during El Nino periods (1982/83, 1987/88, 1992/93 and 1997/98). Wildfire data was not available for 1994 and 1995. Source: Guam Dept. of Agriculture, Forestry and Soil Resources Division, unpub. data.*

No major road construction projects between 2004 and 2007 are believed to have significantly impacted nearshore coastal ecosystems. Road construction projects are of particular concern on Guam, especially after a project along the southern shore of the island in the early 1990s killed much of the coral along a 10 km stretch of fringing reef (Turgeon et al., 2002).

According to the Guam Department of Agriculture, there are approximately 1,300 farms on Guam; about 200 are considered commercial farms, while the remainder are comprised of small ventures of less than a few acres (Borja, pers. comm.). There are little available data on the quantity and types of fertilizers, pesticides and herbicides used on these farms. The use of fertilizers and pesticides on Guam's nine civilian golf courses, which occupy a total of approximately 566.6 ha (1,400 acres), is regulated and monitored by the Guam Environmental Protection Agency (Guam EPA) under approved turf management plans. Still, there is no regular monitoring of nearshore water quality and benthic habitat or associated biological community health adjacent to courses situated near the coast.

Coastal Pollution

The primary pollutants to most waters around Guam – and specifically to recreational beaches – are microbial organisms, petroleum hydrocarbons and sediment. The Guam EPA locally administers the Water Quality Certification permits (Clean Water Act Section 401) and coordinates the National Pollutant Discharge Elimination System (NPDES) permits for the U.S. EPA. Presently there are 19 active NPDES

permits on Guam (see Porter et al., 2005, for a list of permitted facilities) to regulate discharges of treated wastewater from the sewage treatment plants (STP), thermal effluent from the Guam Power Authority power plants, and a number of other discharges which could contain minor amounts of oil and other toxic or biological materials. The guidelines for effluent limitations are based on the Guam water quality standards which underwent major revision in 2001 (Guam Environmental Protection Agency, 2001). All permittees are routinely monitored by Guam EPA staff to verify compliance with applicable permit requirements and compliance schedules. The new 2001 Guam water quality standards were applied when the five-year NPDES permits were renewed in 2006, but monitoring before that time utilized the standards in place when they were issued. Violations reported in the 2005 and 2006 NPDES monitoring reports are summarized in Table A.

Offshore monitoring stations for the Hagåtña STP registered settleable solids and suspended solids violations every quarter and biochemical oxygen demand (BOD) violations five quarters. Offshore monitoring stations for the Northern STP registered settleable solids violations in six quarters, suspended solids violations every quarter and BOD violations in four quarters. However, fecal coliform counts above the permit standard of 400 fecal coliform units/100 ml were not recorded at these two major sewage outfall offshore sites. Water samples taken downstream from the Baza Gardens STP exceeded the orthophosphates and nitrate-nitrogen standard of 0.10 mg/L and the fecal coliform standard all eight quarters. Turbidity was exceeded seven quarters; BOD, six quarters; and suspended solids three quarters. Ambient turbidity measured upstream from the discharge likewise exceeded the current permit standards of 1.0 nephelometric turbidity unit (NTU). Monitoring at the Umatac-Merizo (Toguan) STP showed nitrate levels below standards, but turbidity, BOD, suspended solids, *E. coli*, *Enterococcus*, and orthophosphates exceeded standards one quarter in 2004. The Inarajan and Pago Bay STP NPDES permits registered no violations.

Three of the island's STP outfall pipes continue to discharge within 200 m of the shallow reef crest, in

Table A. *Number of quarters between 2005 and 2006 in which allowable pollutant limits were exceeded at NPDES-permitted facilities. NPDES facilities that did not register violations during this period are not included in this list. Note: The absence of a value for a particular pollutant does not necessarily indicate that levels of the pollutant are within acceptable levels, as the pollutant may not be monitored as part of the NPDES permit for a given facility. Source: Guam Environmental Protection Agency.*

NPDES-PERMITTED FACILITY	POLLUTANT																					
	BOD	Sus	SeS	EC	EN	FC	PO_4-P	NO_3-N	TB	N	Fe	Cu	Ni	NO_3	BZ	Pb	Zn	Al	pH	Mn	P	CR
Agana STP	5	8	8																			
Baza Gardens STP	6	3		8			8	3	8	1				4								
Agat/Santa Rita STP	7	7			8	8						8	1				5	8				
Umatac/Merizo STP	1	1		1	1		1		1													
Northern District STP	4	8	6																			
Tanguisson Power Plant		2								8	8	7										
Piti Tank Farm															2							
South Pacific Petroleum															1	1						
Guam Int'l Airport							3												1			
Naval Station STP	1	6			3	1			1			8	7					8		1		
Continental Air Micronesia																2					6	
Leo Palace STP																						1
Mobil Cabras Terminal																1			3			
Dry Dock (AFDM8)		2										2										

Pollutant: BOD = Biochemical oxygen demand; SuS = Suspended Solids; SeS = Settleable Solids; EC = E. coli; EN = Enterococcus; FC = Fecal coliform; PO_4-P = orthophosphate; NO_3-N = Nitrate-Nitrogen; TB = Turbidity; N = Nitrogen; Fe = Iron; Cu = Copper; Ni = Nickel; NO_3 = Nitrate; BZ = Benzene; Pb = Lead; Zn = Zinc; Al = Aluminum; pH = pH; Mn = Manganese; P = Phosphorous; CR = Chlorine Residual

depths of 20-25 m and in areas where corals are found. Stormwater leakage into aging sewer lines during heavy rains forces the sewage treatment plants to divert untreated wastewater directly into the ocean outfall pipes. Additionally, since Super Typhoon Pongsona impacted Guam in 2003, effluent from the Hagåtña STP has been partly discharging into a shallow coral reef area due to a break in the outfall line.

When the five-year NPDES permits were renewed in 2006, the new 2001 Guam water quality standards were applied, but these permits had been monitored before then, according to standards in place when they were issued.

Nonpoint source pollutants in the north can infiltrate basal groundwater, which discharges into springs along the seashore and subtidally on the reefs. Pollutants include nutrients from septic tank systems, sewage spills, and livestock and agricultural areas, as well as chemical discharge from urban runoff, farms and illegal dumping. Several studies have detected chemicals from the Northern Guam Aquifer in spring water discharges to Tumon Bay that exceeded Guam EPA water quality standards (PCR Environmental, Inc., 2002a, 2002b, 2002c), while another study determined that stormwater draining from the Guam International Airport and surrounding industrial areas entered Tumon Bay and East Agana Bay through the aquifer within four and 17 days, respectively (Moran, 2002). Previous studies have also found moderate enrichment of contaminants, including polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in newly formed marine sediments and associated food chains in the four main harbor areas of Guam (Denton et al., 1997; Denton et al., 1999; see Porter et al., 2005).

The U.S. Navy has recently completed restoration (under the Comprehensive Environmental Response, Compensation, and Liability Act and the Resource Conservation and Recovery Act) of five sites contaminated with toxic chemicals from operations dating to World War II (WWII) on Guam and continues to assess and restore another 15 sites. Most of these sites are on or near shorelines. 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 identified, but PCBs and other chemicals present in buried material at the landfill make the site a potential source, even though it has been capped and contained by a restoration project costing over $15 million (M. Wolfram, pers. comm.). Monitoring wells and other sampling techniques undertaken in 2006 seemed to indicate that other sources of the contamination may be upstream of the landfill (Commander Navy Regional Marianas, 2005). Seafood monitoring has detected PCBs in deep and shallow water reef fishes in the Philippine Sea off Orote Point, and the public has been advised on the danger of consuming seafood from this area (Agency for Toxic Substances and Disease Registry, 2002). Investigations into the former Coast Guard Long Range Navigation station on Cocos Island suggested that the lagoon may have been contaminated by PCBs as a result of dumping activity that occurred during the station's active use between 1944 and 1963. Sediment sampling of the intertidal zone has not yielded any detectable toxins, but a number of fish species near the site exhibited PCB concentrations above the recommended limit for subsistence fishers (Element Environmental, 2006). The Coast Guard is currently engaged in site remediation and is considering additional testing for biota.

Guam's only public dump, which is located in the village of Ordot, has been utilized for over fifty years. The site has been a source of leachate that could impact Pago Bay reefs via the Lonfit/Pago Watershed (Denton et. al., 2005a). Baseline monitoring of the Pago Bay marine environment completed in 2006 by the University of Guam's Water and Environmental Research Institute (WERI), however, indicates that the pollutants are not having significant impacts on biological communities in the bay (Denton et al., 2006). A Federal Court Consent Decree with the Government of Guam required the closing of this dump by September 2007, but this date could not be met.

In 2000-2001, researchers from WERI investigated the potential causes of intertidal blooms of the filamentous green algae, *Enteromorpha clathrata*, in Tumon Bay (Denton et al., 2005b). Measurements of nitrogen, phosphorous, and silica levels from nearshore water samples and from emergent groundwater seeps and springs at intertidal sites in Tumon Bay indicated that nitrogen was abundant in this region of the bay, while phosphorus levels were frequently limiting. The data also indicated that the northern freshwater aquifer was not the only source of phosphorus for the bay, suggesting that small anthropogenic inputs of phosphorus, such as from fertilizers used on hotel grounds, could influence the abundance and

distribution of *E. clathrata* in the bay. A detailed description of this study is provided on page 34.

Tourism and Recreation

The number of visitors to Guam grew from 1.16 million visitors in 2004 to 1.21 million in 2006, indicating continued growth after a 10-year low of approximately 910,000 in 2003 (Guam Visitors Bureau, 2006). The marine resources of Guam have been consistently identified as an important draw for tourists. A tourist exit survey conducted during a recent economic valuation of Guam's coral reefs shows that, on average, 28.5% of tourist sector revenues depend on healthy marine ecosystems (van Beukering et al., 2007). Coral reefs play an important role in the creation and protection of the beaches that draw tourists and in the protection of the infrastructure that support their visits to the island. The coral reef environment of Guam also offers an attractive environment for activities such as scuba diving, snorkeling, SNUBA, SCUBA BOB, charter fishing, and personal watercraft operation. However, the coastal development required for sustaining and enhancing Guam's tourism economy, and the overuse and misuse of the island's coral reef habitat for recreational and commercial activities, has the potential to degrade the very resources that a substantial part of the tourism industry is dependent upon for sustained, long-term viability.

SCUBA diving, snorkeling and related activities continue to be very popular for both tourists and residents. According to a recent coral reef economic valuation study conducted on Guam, an estimated 300,000 dives are performed on Guam each year (van Beukering et al., 2007). Official Pacific Association of Dive

Figure 11. *Clockwise from upper left: A dive guide instructs clients to hold on to a large* Porites *sp. colony in the Piti Bomb Holes Marine Preserve; a snorkeling guide observes his clients while standing atop a colony of* Porites cylindrica *at Ypao Beach in the Tumon Bay Marine Preserve; "reef graffiti" carved into a large* Platygyra daedalea *colony at Faifai Beach, in the Tumon Bay Marine Preserve; a snorkeler feeding fish at Ypao Beach in the Tumon Bay Marine Preserve; . Photos: D. Burdick.*

Industry statistics cited in this study indicate that around 6,000 open water certifications were provided in 2004; the number of certifications provided by other organizations is not known. The number of divers and snorkelers visiting Guam's reefs will likely increase significantly with the additional military personnel, their dependents and others associated with the military expansion.

While the contribution of recreational users to the degradation of Guam's coral reefs is likely considerably less than sedimentation, overharvesting of reef fish, and runoff and associate pollutants, the overuse and misuse of certain high-profile reef areas for recreational activities continues to be a serious concern (Figure 11). These impacts tend to be focused on relatively small, but exceptionally valuable, reef areas, and can have a direct impact on the long-term viability of the businesses that depend on these sites to draw tourists. Of particular concern is the extraordinary number of divers, snorkelers, swimmers, and SeaWalker and SCUBA customers that continue to utilize relatively small areas in the Piti Bomb Holes and TBMP. The number of divers in the Piti Bomb Holes Marine Preserve increased considerably after access to another popular beginner-diver site in Apra Harbor was restricted and access to a third site was eliminated by a road fortification project. An estimated 50-200 dives occur daily within a popular 0.25 ha (0.6 acre) "bomb hole" (i.e., solution hole) in the Piti Bomb Holes Marine Preserve (Brown, pers. obs.). Even a conservative estimate based on these observations suggests that the number of dives that occur at this small site each year (>18,000) vastly exceeds the 4,000-6,000 diver per year threshold value above which coral cover loss and coral colony damage levels may increase rapidly (Hawkins and Roberts, 1997; Hawkins et al., 1999).

Most of the divers at easily accessible, shallow, protected sites are open water students or resort divers. Reef habitat at popular dive sites is often adversely impacted when numerous inexperienced divers visit the site within a short period. Broken pieces of coral and colonies damaged by kicking, grabbing and standing are often observed in these areas. Other impacts, such as trampling of coral and other benthic organisms, increased turbidity and alterations of fish behavior from fish feeding are also regularly observed. For example, a study conducted by Tsuda and Donaldson (2004) noted that snorkelers and scuba divers walking across the shallow reef flat to the popular "bomb hole" have detrimentally impacted the sea grass community at this site through direct physical damage, an increase in turbidity, and decreases in fish abundance and diversity. These behaviors and associated damage are also routinely observed at popular boat diving sites, such as Blue Hole, Hap's Reef, Finger Reef and Western Shoals. Many operators display a lack of awareness or disregard for their impact to the reef and regularly encourage their clients to grab or sit on coral colonies and feed fish. This behavior has been documented by resource agency personnel at several sites (Figure 11).

Unfortunately, these behaviors were still observed regularly even after the Guam Coastal Management Program and DAWR conducted a workshop in 2005 aimed at raising awareness among commercial and recreational reef users about their potential impact on the coral reefs of Guam. A marine eco-permitting program is currently being developed to regulate non-fishing activities within the marine preserves. Such a program would provide coral reef managers with the permitting tools necessary to limit potentially destructive activities within these important areas.

The operation of motorized personal watercraft (PWC) is restricted to four reef flat/lagoon areas around Guam under the Recreational Water Use Master Plan, including limited areas within East Agana Bay, Apra Harbor, Cocos Lagoon and Tumon Bay, to reduce conflict with other water-based activities. PWC use is not restricted beyond the reef margin. Although these craft are loud, known to leak fuel and have the potential to scour seagrass beds and corals, the results of a 2006 study by PCR Environmental, Inc., of the direct, cumulative and secondary impacts of PWCs in heavily used East Agana Bay showed no significant effect on water quality or biological communities (PCR Environmental, Inc., 2006).

Mechanical beach cleaning equipment is still utilized by the Guam Visitor's Bureau (GVB) to remove trash and other material from Tumon Bay and East Agana Bay beaches. There is concern about the impact of this activity on the stability of the beach and on the health of intertidal biota and associated biological communities. Previous recommendations, such as requiring contractors to shake out as much sand and dead coral as possible from algae and place the material back onto the beach, are rarely followed. Piles

of dead coral and sand left on the beach along with the large amounts of beach material brought to the Ordot dump serve as evidence. The recommendation to implement an adopt-a-beach program, in which hotels pledge to manually rake the algae from beaches on their property, has not yet been carried out. The Department of Agriculture's Division of Aquatic and Wildlife Resources has recently taken steps to phase out the use of mechanical beach raking in the TBMP, with the use of beach cleaning equipment being completely prohibited beginning in January 2009. No known beach nourishment projects occurred between 2004 and 2007.

Fishing

Guam's coral reef fisheries are both economically and culturally important and target a large number of reef fishes and invertebrates. Reef-related fishing methods currently used on Guam include hook and line, cast net (*talaya*), spear fishing with snorkel and SCUBA, gill net (*tekken*), surround net, trolling, drag net (*chenchulu*), hooks and gaffs, jigging, spincasting and bottom fishing. Despite improvement in gear and technology, Guam's fishery catches have declined over the last few decades. A recent re-estimation of small-scale fishery catches for Guam suggests that catches have declined by up to 86% since 1950 (Zeller et al., 2007).

While there are other factors involved in this decline, fisheries impacts are certainly a major contributor. This is supported by offshore catch experiments conducted by the Guam Division of Aquatic and Wildlife Resources (DAWR) at three offshore banks that experience different levels of fishing pressure. The data indicated that the number of high level predators decreased with fishing pressure while the number of small groupers increased. Using *Lethrinus rubrioperculatus* as an indicator species, the data also indicate a shift in size frequency with increased fishing pressure (Tibbatts, 2006). Additionally, data from creel surveys performed by DAWR suggest that Guam's fisheries have not recovered from a sharp decline in the 1980s. For a number of methods, including hook and line and cast net, the harvest has continued to decline despite increasing effort. While the catch per unit effort (CPUE) for spear fishing has remained relatively stable, the species composition of the catch has changed over time (Flores, 2006a). *In situ* visual surveys have also indicated that large reef fish are conspicuously absent from many reefs (Paulay et al., 2001; Amesbury et al., 2001; Schroeder et al., 2006).

Two fishing methods used on Guam have raised particular concern: the use of SCUBA and artificial light for spear fishing and the use of monofilament gill nets. These methods have been banned or heavily restricted by many countries, including the Commonwealth of the Northern Mariana Islands and American Samoa. In Guam, local fisheries biologists suggest that these methods may have led to a boom and bust harvest of large Napoleon wrasse, the depletion of large groupers, a shift from preferred species (large slow-growing fish) to smaller faster growing species and a decrease in the number of other large wrasse, parrotfish, snapper and grouper caught by other methods (Flores, 2006a). Abandoned gill nets also cause physical damage to the reef and DAWR regularly removes nets from nearshore reefs (Figure 12).

Figure 12. *A monofilament gill-net on a coral. Photo: V. Brown.*

To combat the fishery declines, the government of Guam created a system of five marine preserves designed to increase fish stocks by establishing areas where limited or no harvest of marine species is permitted (Figure 1). Initial surveys indicate that the fish stocks in the preserves have increased and appear to be working as designed. Unfortunately, the large fish in the preserve areas are targets for

fishermen who disregard the marine preserve designation. Guam DAWR law enforcement officers have made more than 140 arrests related to illegal fishing within the preserves since they began enforcing the regulations in January 2001. Arrests are highest in the Tumon Bay and Piti Bomb Holes Marine Preserves, but infractions have been documented in all five of the preserves.

Trade in Coral and Live Reef Species

Guam does not currently export coral or live reef species, but collection for local use does occur. Guam's corals and live rock are protected by local law (5 Guam Code Annotated Chapter 63). The UOGML is currently the only entity on the island permitted to harvest coral and live rock. The 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. According to the UOGML, 1,067 coral colonies were collected in 2004, 227 in 2005 and 57 in 2006 for research purposes. The majority (>80%) of colonies collected in 2004 and 2005 were colonies of *Leptastrea purpurea* and *Pocillopora damicornis*, both of which are abundant on Guam. Over 50% of the corals collected in 2006 were *L. purpurea*. According to catch records turned in to DAWR, a total of 3,132 fish and invertebrates were collected for aquariums on Guam in 2006. The most frequently caught fish families were damselfish and surgeonfish (Table B). Sea anemones were formerly the most frequently collected invertebrates, but since 2006 have been protected by Public Law 28-107.

Table B. *Number of fish, by family, collected for aquariums on Guam.*

Family	No. of Fish
Pomacentridae (Damselfishes)	1440
Acanthuridae (Surgeonfishes)	410
Chaetodontidae (Butterflyfishes)	178
Labridae (Wrasses)	140
Apogonidae (Cardinalfishes)	121
Pomacanthidae (Angelfishes)	97
Lutjanidae (Snappers)	85
Siganidae (Rabbitfishes)	53
Zanclidae (Moorish Idols)	46
Scaridae (Parrotfishes)	43

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 also contains reefs with some of the highest coral cover on the island. Some of these reef areas may be dredged in the future as their growth impedes ship traffic and naval operations. They are also threatened by anchoring, grounding events and illegal vessel discharges. The harbor is shared by the Port Authority of Guam and the U.S. Navy. According to the Port Authority (http://www.portofguam.com/, accessed 9/13/2007), the port handled an average of approximately two million tons of cargo a year and serviced an average of approximately 1,600 vessels a year between 2002 and 2006. These vessels are primarily fishing vessels, but also include 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 and associated tender ships, and is visited by aircraft carriers and other vessels. The number of both military and commercial vessels is expected to increase with the planned military expansion.

Ship groundings on Guam's reefs are inevitable due to the frequency of typhoons affecting the island. At this time, over 130 vessels are listed in NOAA's 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). Navigational buoys also pose a problem as storm swells can drag them onto the reef, causing damage to coral and other habitats. In addition, since 2004, several vessels have grounded on Guam's reefs. The October 2004 grounding of a foreign longliner at Western Shoals, a popular dive site, caused substantial damage to an area of high coral cover (Figure 13); the other two groundings caused minor damage. A vessel carrying illegal immigrants from Saipan caused an unknown amount of damage in May 2007 when it was abandoned at the Guam National Wildlife Refuge. In December 2007, a 260' barge used for work on the extension of the sewage outfall at the Hagatna STP broke loose from it's mooring lines and grounded on the reef margin south of the treatment plant. Although detailed surveys of the affected site were not possible due to ocean conditions, the grounding was estimated to have impacted roughly 2700 m^2 (~0.67 acres) of reef area (B. Tibbatts, pers. comm.). In an incident that occurred in March 2008, a 70' vessel grounded on the reef margin near Falcona Beach, in northwestern Guam, while transporting illegal immigrants. Local government biologists noted some damage to coral

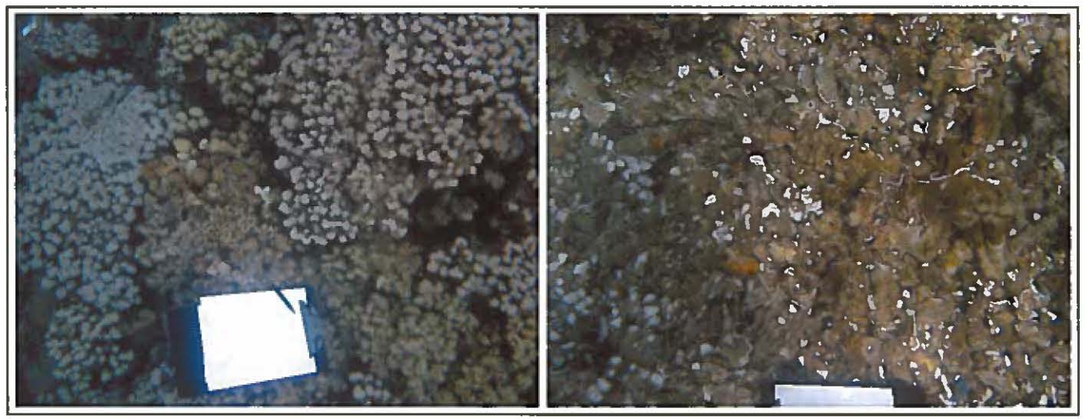

Figure 13. *Undamaged (left) and damaged (right) reef at the site of a 2004 grounding of a foreign longliner on Western Shoals, a popular dive. Photos: V. Brown.*

colonies and reef structure in the vicinity of the grounding, but the vessel appeared to have rested on an area of the reef with little live coral. As of the publication of this report, the vessel near Falcona Beach remains on the reef. However, the Navy has recently hired a contractor to remove the vessel, with pre- and post-removal environmental surveys being conducted by local natural resource agencies to ensure minimal further impact to the reef.

Marine Debris

While not a major threat, marine debris continues to impact Guam's reefs. According to the Guam Coastal Management Program (GCMP), over 2,500 bags of debris weighing nearly 12 metric tons were collected during the 2007 International Coastal Cleanup, while 1,800 bags weighing about 11.5 metric tons were collected in 2005 and about 900 bags weighing 5.6 metric tons were collected in 2004. As in previous years, beverage containers were the most common items collected in 2004 and 2006, with cigarette filters, plastic bags and cups, plates and food wrappers also collected in high numbers. Car batteries, appliances, tires, car parts and abandoned fishing gear were also collected during both events. The Coastal Cleanup data indicate that most of the marine debris found on the beaches and in the coastal waters of Guam is generated locally. The majority of this debris is from land-based activities, such as barbecues, festivals, sports and days at the beach (The Ocean Conservancy, 2007). Litter washed from streets, parking lots and storm drains also contributes to the debris found on Guam's shores.

Discarded fishing nets are occasionally found wrapped around coral colonies (Figure 12), with partial or full colony mortality apparently a result of abrasion and smothering. Nearly 200 fishing nets were collected during the 2006 International Coastal Cleanup. DAWR has also removed numerous abandoned fishing nets since 2004. There were three cases of marine debris recorded by towed-divers participating in the 2005 Marianas Archipelago Reef Assessment and Monitoring Program (MARAMP) expedition, including a single large trawl or seine net off of Cocos Island, a trawl net near Togcha Bay and an old automobile off of Asan Point.

Aquatic Invasive Species

No additional work on aquatic invasive species has been conducted since the 2005. However, there is concern that the expected increase in military and commercial shipping activity in Apra Harbor as a result of the military expansion will increase the risk of impact to Guam's reefs by aquatic invasive species. Previous work conducted on Guam found a total of 85 non-indigenous species, 41 of which were characterized as introduced (Paulay et al., 2002). Most of these species were sessile and likely arrived via vessel hulls into Arbor Harbor. The researchers found that non-indigenous species were abundant on artificial substrates but relatively rare on natural bottoms. Although diverse tropical systems appear to

be more resistant to impacts from introduced species (Hutchings et al., 2002), such impacts, particularly from invasive algae species, have occurred elsewhere and have the potential to significantly alter native ecosystems (Russell, 1992).

Security Training Activities

The Department of Defense continues to carry out training activities on Guam that have the potential to impact coastal waters and adjacent reefs. The frequency of these activities, including underwater demolition and landing craft exercises, appears to have lessened since 2004, but their cumulative impact remains a concern. The impacts of multiple training activities in the W-517 Warning Area, which encompasses Santa Rosa and Galvez Banks, are not known. An increase in the type and frequency of security training activities is expected in association with the overall military expansion. The Navy is currently preparing separate environmental impact statements to address current levels of training activity and potential impacts of enhanced training activity proposed for the Marianas Islands Range Complex and additional training required for the marine relocation.

Offshore Oil and Gas Exploration

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

Offshore Dredge Spoil Disposal

A new site for offshore dredge spoil disposal west of Guam is being proposed for U.S. EPA designation, following National Environmental Policy Act review in 2008. Guam policy calls for beneficial use of dredge spoils, but the anticipated sudden production of large quantities of material due to urgent military projects in Apra Harbor has triggered the plan for non-beneficial disposal in deep offshore waters.

Crown-of-thorns seastar (Acanthaster planci)

Guam has been affected by widespread outbreaks of the crown-of-thorns sea star (COTS) since at least 2004. According to the definition used for surveys on the Great Barrier Reef, a local COTS population is considered in "active outbreak status" when densities reach or exceed 30 individuals/hectare (CRC Research Center, 2003). Manta tow surveys (English et al., 1997) conducted by the UOGML between February and October 2006 at numerous sites around Guam indicated widespread COTS outbreaks and large-scale coral mortality (C. Caballes, unpublished data). Large aggregations, ranging from approximately 100 to over 1,600 individuals per 20-minute tow, were observed at six of 17 survey sites (Figure 14). Preferred prey species, including *Montipora* spp. and *Acropora* spp., were almost wiped out at most sites, and COTS had begun feeding on less-preferred corals such as massive *Porites* spp. and *Goniopora* spp. Estimated COTS densities of 50-61 individuals per hectare were observed on tows at three of the 17 survey sites and between 14-26 individuals/hectare at three additional sites. Most striking, however, were observations of densities greater than 450 individuals/hectare in Pago Bay and nearly 1,500 individuals per hectare at Tanguisson Point.

Towed-diver data from the 2003, 2005 and 2007 NOAA MARAMP expeditions provide further indication of COTS outbreaks at numerous locations around Guam over the last several years, with an increase in outbreak intensity observed with each subsequent research cruise. COTS aggregations and extensive COTS-related coral mortality have also been observed at several other sites not surveyed by the UOGML or during the MARAMP expedition (D. Burdick, pers. obs.). The widespread, persistent nature of these outbreaks, as well as observations of mortality among less-preferred coral species, suggest that these outbreaks have had, and are continuing to have, a severe impact on many of Guam's reefs.

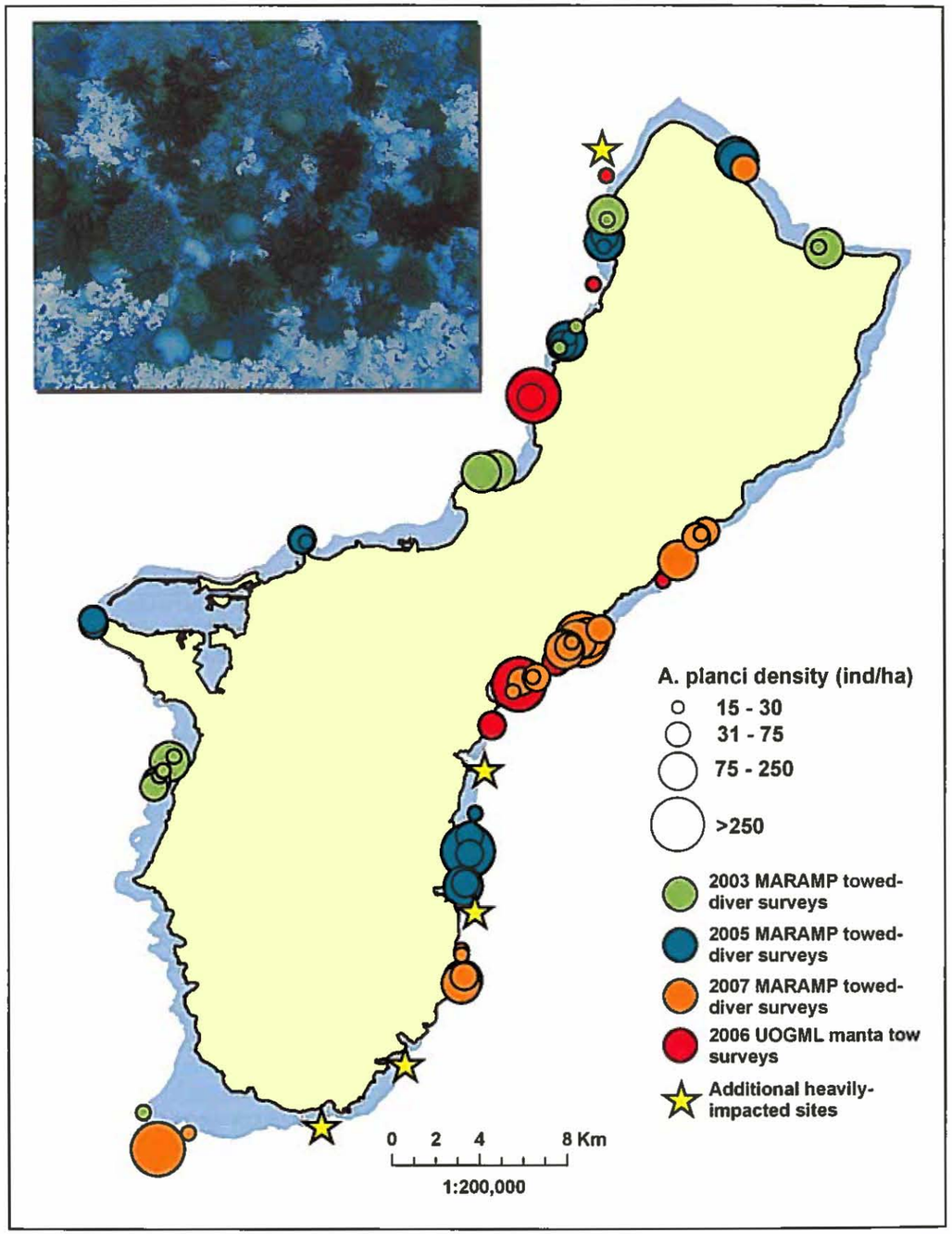

Figure 14. *Crown of Thorns (*Acanthaster planci*) starfish densities around Guam recorded during manta tow surveys carried out by the UOGML in 2006 and MARAMP towed-diver surveys in 2003, 2005, and 2007. UOGML manta tow transect length was recorded, but width was not specified; a conservative width estimate of 40 m was used in density calculations.* Acanthaster *density for MARAMP towed diver surveys was calculated using the known 10-m transect width and an average tow segment length of 0.2 km. Sites where additional observations indicated high levels of* A. planci *predation since 2005 are marked by yellow stars. The photo is of a high-density* A. planci *aggregation near Tanguisson Point in April 2006. Source: NOAA PIFSC-CRED, unpub. data; C. Caballes, unpub. data. Photo: P. Schupp.*

DATA GATHERING ACTIVITIES AND CORAL REEF RESOURCE CONDITION

Several monitoring, assessment, and research activities have been conducted on Guam since 2004. These activities measure several aspects of Guam's reef community that are important to coral reef management, including benthic habitat, water quality, biological communities associated with coral reefs (e.g., fishes and macroinvertebrates) and socioeconomic information. A comprehensive list of all recent or ongoing studies related to Guam's coral reefs is provided in Table C, and the locations of monitoring sites are shown in Figure 15. Two additional MARAMP research cruises were conducted since the September 2003 expedition, including one from October 3-9, 2005, and another from May 12-15, 2007 (NOAA PIFSC-CRED; http://www.nmfs.hawaii.edu/cred). The science teams for the Guam leg of MARAMP cruises have included staff from the NOAA Pacific Islands Fisheries Science Center (PIFSC) Coral Reef Ecosystem Division (CRED), the NOAA Pacific Islands Regional Office, Guam DAWR, the National Park Service (NPS) and the UOGML. Most of the ecological and oceanographic assessments conducted during the 2003 expedition were repeated at the same sites in later years. Santa Rosa Bank was not surveyed during the 2007 expedition due to time constraints. Most of the 2007 assessment results were not available for this report, but will be provided at a later date.

Table C. *Summary information for Guam's coral reef monitoring, research, and assessment activities. Source: D. Burdick and V. Brown.*

ACTIVITY CATEGORY	AGENCY	NO. OF YEARS	ACTIVITY DESCRIPTION	DATA COLLECTION
Marine Preserve Monitoring	DAWR	7	Assessment of the effectiveness of Guam's Marine Preserves on Food Fish populations. Visual transects and interval counts are used to assess fish species.	Every 1-2 years
	UOGML	1	Investigation of the connectivity between Marine Preserves and exploited reefs using larval tracking methods	One-time
		1	Assessment of spillover of adult target fish species from Marine Preserves into adjacent areas	One-time
		1	Assessment of abundance of target fish groups in Marine Preserves and adjacent control sites; part of larger investigation of relationship between herbivorous fish, algae , and nutrient interactions within marine preserves	One-time
		1	Investigation of role of soft coral as fish habitat within a Marine Preserve	One-time
Sedimentation	NPS	4	Assess the level of sedimentation and its affect on reefs in the War of the Pacific National Park. Data collected include total sediment, %organic, %carbonate, sediment size, water temperature, light penetration, benthic cover, and coral recruitment.	Monthly
Erosion	NPS	4	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
Oceanography and Water Quality	Guam EPA	>20	GEPA 305b, Water Quality Report to Congress	Biennially
			Recreational Water Quality (microbial)	Weekly
			Monitoring wells, golf courses and restoration sites	Quarterly
		3	Environmental Monitoring and Assessment Program	Biennially
	NOAA PIFSC-CRED	5	Monitoring of: 1) conductivity, temperature, depth, dissolved oxygen, and chlorophyll to a depth of 500m using deepwater CTDs; 2) temperature, salinity, and temperature at multiple sites using shallow-water CTDs; 3) chlorophyll and nutrients (nitrate, nitrite, silicate, phosphate) concurrent with the deep and shallow-water CTDs; 4) temperature at 0.5m using two SST buoys; and 5) temperature at depths between 0.5 and 30m using three subsurface temperature recorders	Biennially
	UOGML	3	Evaluation of the effectiveness of using soft corals as bioindicators of water quality	One-time
		1	Acquisition of monthly measurements of NOx, RP, Si, and salinity at 11 reef flat sites; part of larger investigation of relationship between herbivorous fish, algae , and nutrient interactions within marine preserves	One-time
	UOG WERI	1	Investigation of relationship between nutrients and *Enteromorpha clathrata* blooms in Tumon Bay in relation to (Denton et al., 2005)	One-time

Oceanography and Water Quality (cont.)	UOG WERI	1	Determination of impacts of leachate from Ordot dump on marine communities in Pago Bay (Denton et al., 2006)	One-time
	NPS/U.S. Geological Service	1	Development of detailed hydrodynamic model for the Asan Beach Unit of the WAPA. Data collected for 5 locations within Asan Bay include 1) current speed and direction throughout the water column 2) wave height, wave period, wave direction, and tide level 3) near-bed water temperature, salinity, turbidity, and PAR; and 4) near-surface water temperature, salinity, and turbidity. The water level in Asan River as well as wind speed, wind direction, air temperature, rainfall, and incident PAR will also be monitored.	One-time
Benthic Habitat	NOAA-PIFSC-CRED	5	Documentation of 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.	Biennially
	UOGML	1	Baseline assessment and long-term monitoring of benthic community at five permanent reef sites	Tri-monthly for 1st year; then biannually or annually
Coral Disease	UOGML	1	Baseline assessment of coral disease prevalence at 10 sites; benthic composition, coral species richness, bleaching, predation, and other signs of compromised health were also assessed.	One-time
		1	Monitoring of coral disease prevalence, coral community, signs of stress and disease, and water temperature at four of the 10 baseline assessment sites.	Quarterly
Fisheries Monitoring	DAWR	>20	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)
	NPS	1	Assessment of impacts of fishing within the WAPA	One-time
	UOGML	1	Characterization of previously identified reef fish spawning aggregations and sites in Piti Marine Preserve and Asan	One-time
Associated Biological Communities	UOGML	1	Baseline assessment and long-term monitoring of fish and macroinvertebrate communities at five permanent reef sites	Tri-monthly for 1st year; then biannually or annually
	NOAA PIFSC-CRED	6	Monitoring of reef fish communities using Rapid Ecological Assessments (Belt Transects, Stationary Point Counts, and Roving Diver surveys) and towed-diver surveys.	Biennially
	UOGML/ DAWR	6	Monitoring of specific Reef Check sites using community volunteers	Annually, when possible
	UOGML	1	Assessment of *A. planci* outbreaks using manta-tow surveys	One-time
Recreational Impacts	GCMP	1	Assessment of impacts of motorized personal watercraft on water and sediment quality, benthic habitat, and fish communities in East Agana Bay	One-time
Socioeconomic Information	UOGML	1	Assessment of economic value of Guam's coral reefs and associated resources; the underlying motives and mechanisms behind the total economic value were also investigated by focusing on people's relationship with the marine ecosystems, local "willingness to pay" for coral reef conservation, and the spatial variation of reef-associated economic values and threats.	One-time
		1	Determination of the non-extractive value of coral reef icon species	One-time
	UOG	1	Assessment of perceptions, values, and level of awareness among Micronesian populations on Guam regarding coastal resources, particularly with regard to the marine preserves and differences in management systems (e.g., traditional marine tenure vs. open access)	One-time
	GCMP	<1	Evaluation of the effectiveness of GCMP's various public outreach activities and to identify the environmental issues of most concern to the public	Every 3-5 years

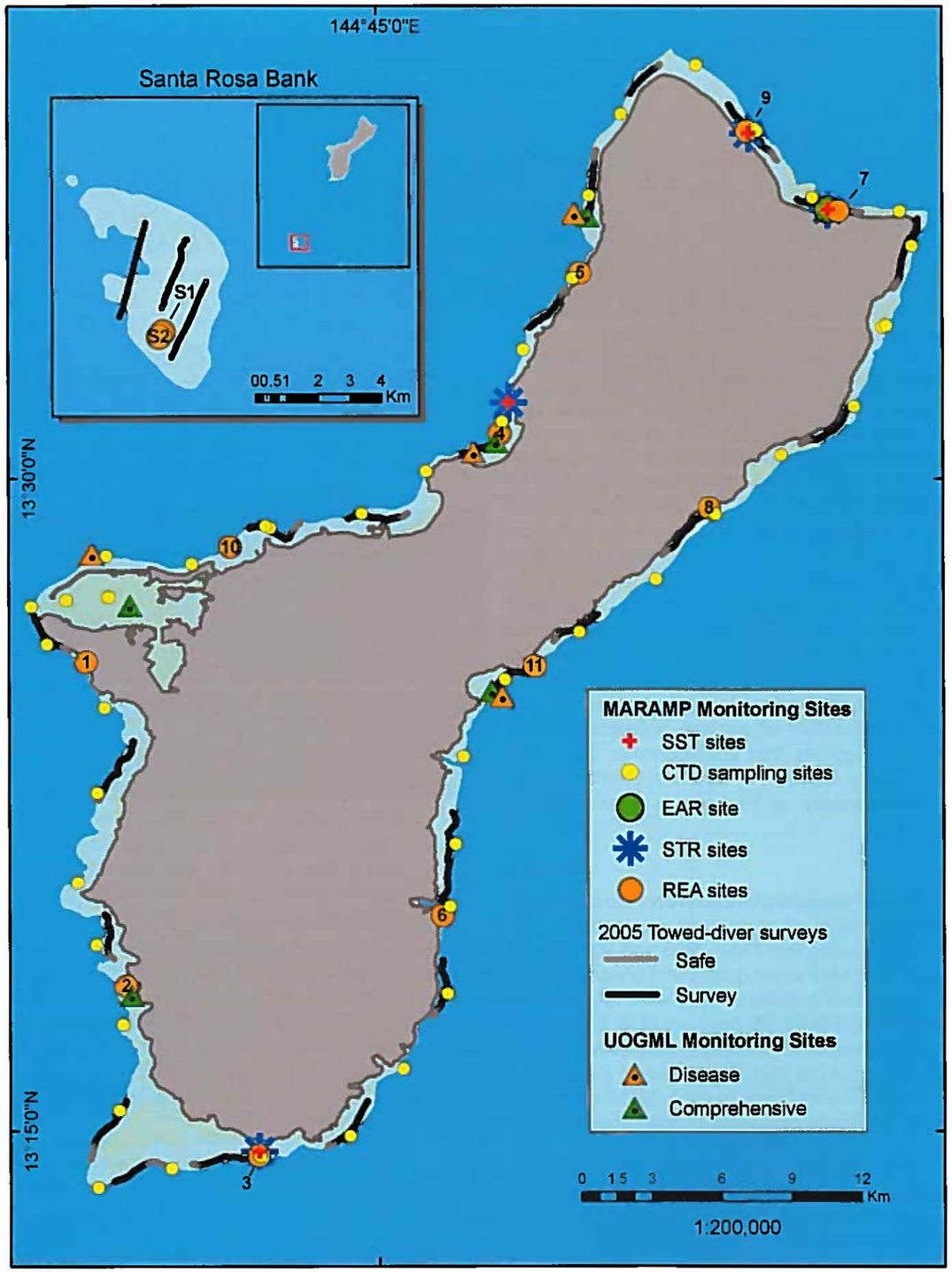

Figure 15. *The location of monitoring sites around Guam. Map: D. Burdick.*

WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

Efforts to obtain water quality data relevant to coral reef management have increased in recent years, with biennial sampling of multiple parameters around the island occurring with Guam EPA's Environmental Monitoring and Assessment Program (EMAP). EMAP sampling was carried out in 2005 and 2006, but data analysis is not yet complete and the results will be presented at a later date. A summary of the results of Guam EPA sampling efforts prior to switching to the EMAP program is available in Porter et al. (2005). Included below are the latest results of two long-term water quality monitoring efforts, including Guam EPA's recreational beach water quality monitoring and water quality sampling activities conducted during the 2005 and 2007 NOAA MARAMP cruises. The results of an ongoing NPS study to determine the impact of sedimentation on the coral community within the Asan Unit of the WAPA are also discussed below.

Guam EPA Water Quality Sampling

The Guam EPA continues to sample coastal recreational waters at more than 40 stations around the island every week, testing for *Enterococcus* bacteria, according to U.S. EPA requirements. A public advisory is issued when an instantaneous reading of bacteria exceeds 104 units per 100 ml of water. In fiscal year (FY) 2005, 27% of 2,055 samples exceeded these levels, resulting in 556 advisories (Table D); there were 604 advisories from 2,196 samples (28%) in FY 2006. Using *Enterococcus* as a bacterial indicator of sewage pollution, water quality has not improved since 2003, when 27% of samples exceeded standards and 551 advisories were issued. However, as mentioned in Porter et al.(2005), the use of *Enterococcus* as a bacterial indicator of sewage pollution may not be appropriate for tropical islands such as Guam, since it naturally occurs in the island's soil (independent of sewage pollution). Collins (1995) suggests that *Enterococcus* levels will predictably increase in Guam's coastal waters after rain events, as the bacteria are washed out of the soil.

Table D. *Summary of recreational water quality monitoring sampling from 2005 to the third quarter of 2007. Source: Guam EPA.*

NUMBER OF ADVISORIES PER QUARTER					TOTAL NO. OF ADVISORIES
REGION	1st	2nd	3rd	4th	
2005 Northern Subtotal	66	34	12	88	200
2005 Southern Subtotal	114	65	75	112	366
2005 Total	**180**	**99**	**87**	**200**	**566**
2006 Northern Subtotal	50	36	29	133	248
2006 Southern Subtotal	99	50	55	152	356
2006 Total	**149**	**86**	**84**	**285**	**604**
2007 Northern Subtotal	76	30	21	-	127
2007 Southern Subtotal	182	77	69	-	328
2007 Total	**258**	**107**	**90**	**-**	**455**

MARAMP Oceanographic/Water Quality Data

Measurements of chlorophyll and nutrient concentrations, conductivity temperature and depth, were obtained during the 2003, 2005 and 2007 MARAMP expeditions at numerous sites around the island. A list of MARAMP water quality and oceanographic data collecting activities is provided in Table C; methods are described in detail at http://www.nmfs.hawaii.edu/cred. The locations of monitoring around Guam are provided in Figure 15. Analysis of *in situ* water samples collected around Guam revealed relatively low spatial variability in measured nutrients during the sampling period. The highest nutrient concentrations were in the Apra Harbor region and increased with depth. There also appeared to be slightly elevated nutrient concentrations in the surface waters north of the Pago Bay region and increased levels in total nitrogen (nitrate plus nitrite) concentrations at all depths in the TBMP.

National Park Service Sedimentation and Coral Recruitment Studies

Since October 2003, War in the Pacific National Historic Park (WAPA), a unit of the NPS, has been monitoring sediment collection rates on park coral reefs in Asan Bay (Minton, 2005; Minton et al., 2005). The goal of this work has been to increase understanding of the spatial and temporal dynamics of sediments onto the park's coastal reefs, in order to better assist the park staff with their coral reef management efforts.

Methods

Spatially intensive surveys, covering 25 sites spaced across the roughly 3.5 km-long Asan Bay, were conducted for one year (October 2003-November 2004), and continuous long-term monitoring (November 2004-present) has continued at selected sites (Figure 16). At each sampling site, two sediment samplers, each comprised of three PVC tubes, were deployed, one each at 10 and 20 meters depth. After three weeks, the collectors were retrieved and sediments were processed in the laboratory to measure total dry weight, percent organic material and percent $CaCO_3$. A grain size analysis was also conducted to determine the proportion of coarse, fines and silts in the sediment samples. Coral recruitment to settling plates at eight of the sediment study sites was also examined during this period to see if a link existed between coral recruitment and coastal sediments (Lundgren and Minton, 2005; Minton and Lundgren, 2006; Minton et al., in prep). Coral recruitment arrays, comprised of both PVC and terra cotta settlement plates, were deployed at eight sites at 20 m depth.

Figure 16. *Sediment and coral recruitment study sites in Asan Bay, Guam. Coral recruitment study sites (circled) were a subset of locations where War in the Pacific NHP conducted three years of sediment monitoring. Each lettered sediment site was comprised of two sediment collectors, one placed at 10 m and second at 20 m. Coral recruitment arrays were placed only at the deepwater locations (C20, D20, K20, L20, O20, P20, Q20, and R20). AR=Asan River outlet through Asan Cut; DP=Runoff drainage pipe; FR=Fonte River outlet. Source: Minton and Lundgren 2006).*

Results and Discussion

Both spatial and temporal patterns were apparent in the sediment collection rates in Asan Bay. Sediment collection rates were best explained by proximity to a sediment point source, such as a river mouth or a drainage pipe (Figure 17). Additionally, heavy rainfall events were found to be more important than total rainfall. The seasonal nature of rain events on Guam resulted in significantly higher sediment collection rates during the wet season (July-December). A significant sediment flushing event was observed at the start of the wet season, following the first large storm event of the summer. This large rain event presumably moved sediments that had collected in the watershed or streams during the low intensity rain events common during Guam's dry season (January-June) into the coastal waters. Flushing events may be particularly harmful to Guam's coastal reefs because they occur coincident with the annual coral mass spawning. Coral gametes and larvae have been shown to experience high mortality when exposed to Guam's sediment-laden water

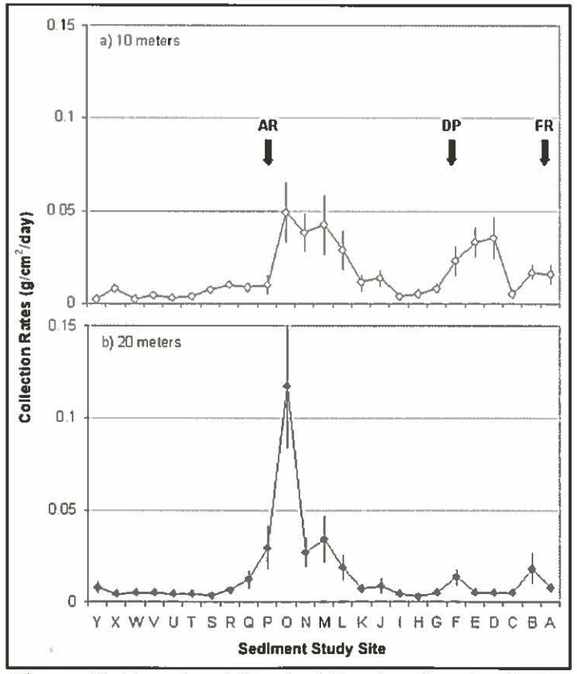

Figure 17. *Mean (= ±1 Standard Error) sediment collection rates (g/cm²/day) at a) 10 m and b) 20 m-deep sediment study sites in Asan Bay. Site reference letters correspond with site locations in Figure 16. Arrows represent the approximate location of three sediment point sources. Data are for October 2003-November 2004. Source: Minton (2005).*

(Richmond, 1993).

Over the course of the two year study, recruitment rates across Asan Bay were found to be low, with an average of approximately three coral recruits/m^2. Recruitment rates were independent of sediment collection rates, and did not appear to be a result of post-settlement mortality. Instead, low recruitment may have been the result of pre-settlement factors, including poor larval supply to the bay, poor water quality conditions within the bay and/or poor benthic conditions that interfered with successful larval settlement. This study highlights a trend of declining coral recruitment on Guam's leeward reefs. In studies conducted prior to 1981 (Neudecker, 1976; Birkeland et al., 1981; Neudecker, 1981), a two-order of magnitude higher recruitment rate was observed compared to 1989 studies using nearly identical methodologies (Birkeland and Sakai in Birkeland, 1997; Chirichetti in Birkeland, 1997). The results for Asan Bay are consistent with these later studies, further suggesting that this trend is not the result of annual variation but a real decline in successful coral recruitment on Guam's reefs.

Investigation of *Enteromorpha clathrata* blooms in Tumon Bay (UOG WERI)

In 2005, researchers from the University of Guam's Water and Environmental Research Institute investigated the potential causes of intertidal blooms of the filamentous green algae, *Enteromorpha clathrata*, in Tumon Bay, Guam's premier tourist destination (Denton et al., 2005). Local hoteliers in this area consider the algae unsightly and as a potential threat to tourism. *Enteromorpha clathrata* typically occurs along beaches as a result of groundwater intrusion, with blooms commonly believed to be associated with high levels of nitrate (NO_3) that occur naturally in Guam's groundwater (2-3 mg/l). The change in the distribution and abundance of *E. clathrata* in Tumon Bay, however, appears to have paralleled commercial development in the area, suggesting that there may be other important factors in causing the algal blooms. The detection of reactive phosphorous (RP) approaching 500 ug/l in the surface runoff from a major hotel fronting Agana Bay led the study authors to hypothesize that similar releases from gardens along the Tumon Bay waterfront may account for the algal bloom problem.

The WERI researchers measured the level of nitrogen (N), phosphorous (P), and silica ($SiCO_2$) in emergent groundwater seeps and springs from 9 intertidal sites in Agana Bay and 70 sites in Tumon Bay. RP levels ranged from 12.7-30.6 ug/l in Agana Bay, with the highest level recorded near the hotel mentioned above. The highest levels of NO_3-N (1.3-4.0 mg/l) and SiO_2 (2.7-5.5 mg/l) were also found at that site. RP, NO_3-N, and SiO_2 levels in Tumon Bay ranged from 1.3-31.9 ug/l, <0.01-7.9 mg/l, and 0.42-3.8 mg/l, respectively. Greater than 90% of the total P in all samples was in the form of RP, while NO_3-N comprised the majority of dissolved inorganic nitrogen (DIN = NO_3-N + NO_2-N + NH_4-N). NO_3-N concentrations tended to decrease with increased salinity, while SiO_2 tended to increase with increased salinity. No significant correlation was found between RP and salinity. The levels of all three nutrients were far more variable in seeps than springs.

The levels of P, N, and Si in the Tumon Bay seeps and springs were compared with those found in groundwater from 96 drinking water production wells located further inland. A comparison of frequency distribution histograms, which showed that the measure of central tendency for RP in seep and spring samples were displaced to the right of that for the wells, suggested that the aquifer was not the only source of P into the bay. The reverse was true for NO_3-N, which is likely a result of conservative mixing in the transition zone. The measures of central tendency for Si were the same for both the springs/seeps and the well samples.

The study also involved the daily collection of nearshore water samples from nine sites in Tumon Bay over a three-month period. The researchers found that NO_3-N and RP behaved conservatively in the surf zone and were rapidly diluted and dispersed. Nearly 70% of all samples taken ~50 m offshore contained RP levels that were below the threshold concentration (~3 ug/l) estimated to be required to promote macroalgal blooms, while only 20% of the samples were below the estimated threshold concentration for DIN (~70 ug/l). The results indicate that N was abundant, and indeed in oversupply, in this region of the bay, while P levels were frequently limiting.

The findings of this study suggest that relatively small anthropogenic inputs of RP could have a dramatic effect on the abundance and distribution of *E. clathrata* in the bay. The researchers urge hotel managers and government regulators to pay close attention to the level of irrigation and pesticide use for hotel lawns and gardens.

BENTHIC HABITATS

Significant progress has been made in assessment, monitoring and mapping of benthic habitats on Guam since 2004. The first island-wide coral disease assessment was conducted in 2006 and 2007, with long-term disease monitoring continuing for established sites. Coral- and algae-focused Rapid Ecological Assessments (REAs), as well as extensive towed-diver benthic surveys were conducted during 2005 and 2007 MARAMP cruises, but with the exception of the algae REA surveys conducted in 2007, only the results of the 2005 surveys were available for inclusion in this report. The mapping of nearshore (0-30 m) benthic habitats was conducted by the UOGML in 2006, building upon the 2003 mapping efforts of the NOAA Center for Coastal Monitoring and Assessment, Biogeography Branch (CCMA-BB), while multibeam bathymetry and backscatter data were collected for deeper waters (>20 m) around the island during the 2007 MARAMP cruise.

Coral Disease Prevalence and Long-Term Monitoring (UOGML)

The coral disease monitoring program continued from the initial baseline surveys in 2006 that established disease prevalence on Guam reefs. A total of 10 reefs around Guam have been surveyed for benthic composition, coral species richness, coral disease prevalence, bleaching, predation and other signs of compromised health. Of these 10 sites, four sites, including Luminao and Tumon Bay (shallow reef flat communities) and Pago Bay and Double Reef (deeper reef slope/shelf communities), were selected for long-term monitoring of the coral community, signs of stress and disease and water temperature (Figure 15).

Methods

Sites were surveyed using a minimum of three 20 x 2 m belt transects laid perpendicular to shore at depths ranging from 2 m-7 m. At sites with several distinct coral communities, such as Tumon Bay and Double Reef, additional transects were laid within each distinct reef zone. The Line Intercept method (English et al., 1997) was used to characterize benthic composition along each transect; all hard coral colonies were counted within each belt. Colonies were examined individually for signs of disease, predation, bleaching, algal overgrowth, silt damage and lesions of unknown cause. Photographs were taken of representative diseases, and corals were sampled when an underwater diagnosis could not be made or needed to be verified microscopically. All colonies exhibiting disease or compromised health were counted and identified to species. Permanent transect markers were established at the sites mentioned above in August 2006, and temperature data loggers were deployed at each site. Monitoring of the parameters mentioned above has taken place quarterly along these transects since then, and is expected to continue indefinitely.

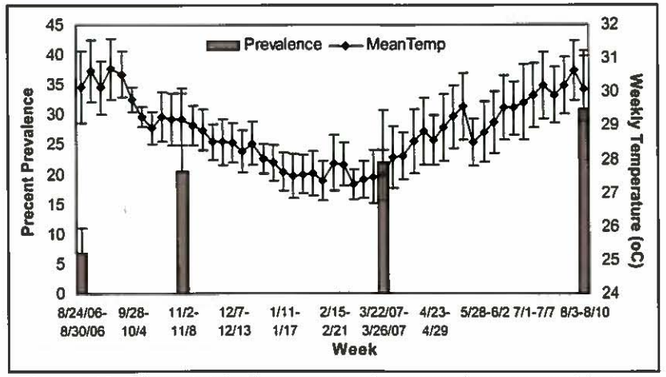

Figure 18. *Mean total disease prevalence and mean weekly temperature, Luminao Reef (Mean ± SD; n=3 transects). Source: L. Raymundo, unpubl. data.*

Results and Discussion

The prevalence of diseases within each coral family was examined in order to determine how coral diseases were distributed taxonomically. Guam showed a strong link between disease prevalence and abundance per family (regression of generic abundance on total disease prevalence: R^2=0.89; p<0.0001). *Porites*, the most abundant

coral genus on Guam reefs, was also the most impacted by a number of diseases; five out of the six diseases described previously affect various species within the genus. Because this genus represents the primary reef builder in Guam reefs, coral diseases that result in partial or full colony mortality have the potential to significantly affect community structure.

Monitoring along permanent transects has also revealed changes over time, but at present, only the Luminao data set has been analyzed. Transects at both Double Reef and Tumon Bay required re-positioning after transect markers were lost. Although less than one year of monitoring data have been collected to date, preliminary results suggest that long-term monitoring is likely to be very useful. Temperature loggers have been in place at Luminao continually since August 2006 and reveal a seasonal decline in water temperature beginning in September.

March temperatures appeared to level off, and water temperatures were predicted to begin warming. Total disease prevalence increased greatly between August and November 2006, though values between transects were highly variable (Figure 18); this was attributed to an increase in observations of a white syndrome, which was affecting both branching and massive *Porites*. In general, disease prevalence at Luminao appears to be increasing over time; the initial assessment showed a mean prevalence of 6%, increasing to 30% by the following year. The data also suggest some correlation between temperature and disease; the highest prevalence values correspond to the period of warmest temperatures. This monitoring, combined with an examination of between-site differences, should allow an analysis of long-term trends, links with water temperature seasonality and changes in the coral community at each site.

UOGML Long Term Monitoring: Benthic Community

In 2006, the UOGML established permanent transects at five long-term monitoring sites around Guam. Although Guam's coral reefs have been studied since the early 1970s, no permanent sites were successfully established with the explicit objective of studying long-term change in coral communities. While temporary transects were used for a number of studies, a lack of permanent transects and long-term baseline data have made it difficult to examine the effects of multiple natural and anthropogenic impacts. In addition, few studies have assessed the reef community in its entirety or examined interactions between components. It is anticipated that the sampling design outlined below will result in the collection of robust baseline data in order to assess the potential impacts of future natural and anthropogenic disturbances on Guam's reefs and to quantify their recovery. The monitoring of these sites will continue indefinitely, resulting in a reef monitoring database. The methods and results of baseline benthic habitat surveys conducted in 2006 are presented below.

Methods

In consultation with DAWR, five sites were selected for monitoring, including Pago Bay, Fouha Bay, Western Shoals, Tumon Bay and Double Reef (Figure 15). Four permanent 50 m transects were established at each site within a depth range of 3-10 m. Each site will be surveyed every three months until mid-2008, after which monitoring will be conducted on a biennial or annual basis.

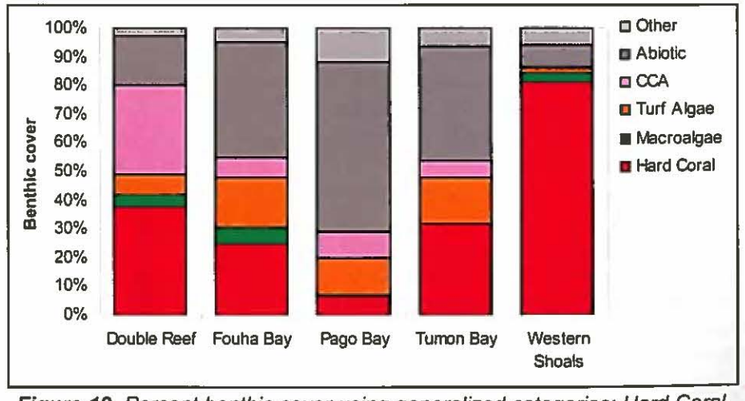

Figure 19. *Percent benthic cover using generalized categories: Hard Coral, Macroalgae, Turf Algae, Crustose Coralline Algae (CCA), Abiotic (all non-living categories, such as reef substrate) and Other (e.g., sponges, soft coral, anemones). Source: P. Schupp, unpubl. data.*

The benthos associated with each transect was filmed using an under-water video camera. The video footage was analyzed using CORALID software (M. Claereboudt, unpublished). For each transect, total percent cover was determined for every benthic category. For the purposes of this report, these were subsequently pooled into six general categories: Hard Coral (scleractinian corals), Macroalgae, Turf Algae, Crustose Coralline Algae (CCA), Abiotic (all non-living categories, such as reef substrate) and Other (sponges, soft corals, anemones). The data presented below were collected from the first sampling period of the monitoring program; only two of the four transects were surveyed at each site during this time. The full survey regime will be carried out during subsequent sampling periods.

Results and Discussion

Percent cover data is consistent with field observations of other benthic organisms collected at the same time. For example, Pago Bay has a high percentage of dead coral, which is in accordance with an increase in the size of the COTS population over the past few years. It is possible that much of the observed coral mortality has been the result of COTS predation. Fouha Bay, which receives a large input of land-based sediment (and possible nutrient influx), exhibited the second lowest coral cover. Western Shoals, on the other hand, had the highest hard coral cover (about 85%) but the least number of coral species (Figures 19 and 20). Like the rest of Apra Harbor, Western Shoals is dominated by large stands of *Porites rus*. Coral cover and species richness in Tumon Bay were similar to that of Double Reef. While the Tumon Bay site does not appear to be impacted by sedimentation, it has, like Pago Bay, experienced high numbers of COTS in recent years.

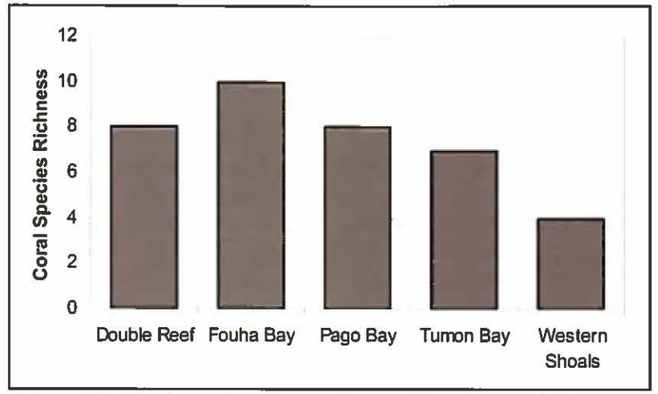

Figure 20. *Coral species richness for each for each monitoring site. Source: P. Schupp, unpubl. data.*

MARAMP Coral and Algae REA and Benthic Towed-Diver Surveys

Coral Community REA

Methods

REA surveys of coral communities were conducted at several sites around Guam and two sites at Santa Rosa Bank (Figure 15) in October 2005 by NOAA PIFSC-CRED using methods that have been applied at numerous other Pacific reef locations by CRED since 2002 (detailed methodology can be found at http://www.nmfs.hawaii.edu/cred). Several parameters were calculated from recorded data that collectively describe community structure, including coral percent cover, biodiversity, relative abundance, colony density and size-frequency distribution.

Results and Discussion

Twenty-six genera of scleractinian corals, as well as several taxa of octocorals, including *Heliopora coerulea*, were recorded within belt transects. *Porites* dominated the coral

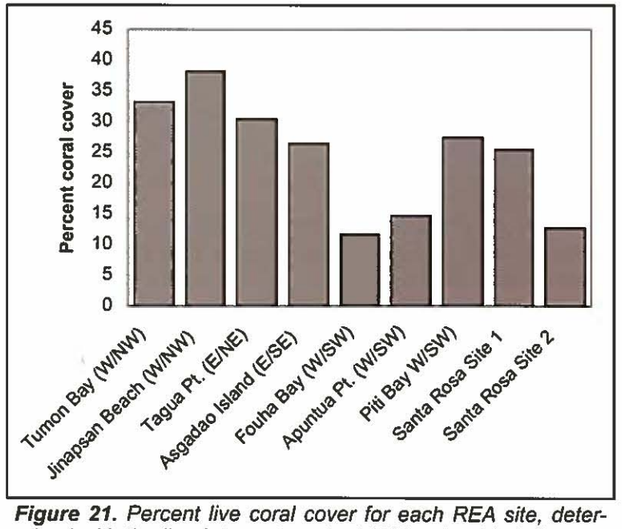

Figure 21. *Percent live coral cover for each REA site, determined with the line-intercept method (102 points/site). Source: NOAA PIFSC-CRED, unpubl. data.*

fauna at Guam, while *Favia*, *Montastrea*, *Pocillopora* and *Porites* dominated the two sites surveyed at Santa Rosa Bank. Coral cover ranged from 11.8% on the southwest side of Guam to 38.2% on the west side of Guam (Figure 21). Average coral cover at Guam was 26.1% ± 3.6% standard error (SE). Average coral cover at Santa Rosa Bank was 19.1% ± 6.4% SE. Size frequency distributions from Guam and Santa Rosa Bank are highly similar. Colonies measuring <20 cm maximum diameter characterized the coral community structure at both Guam (83.4% of colonies) and Santa Rosa Bank (87.9% of colonies).

Algal Community REA

Methods

Quantitative algae community surveys were conducted at nine of the 11 established REA sites around Guam in 2005 and 10 of the sites in 2007 (Figure 15) using an REA protocol developed specifically for remote island ecosystems (Preskitt et al., 2004). The two REA sites established at Santa Rosa Bank were not surveyed in 2007. Photographs of 12 quadrats sampled at each site were taken for percent cover analysis. Additionally, relative abundance of macroalgal genera or functional groups and voucher specimens were collected from each photo-quadrat.

Results and Discussion

Guam has a relatively diverse algal flora, with more genera than other islands in the Mariana Archipelago. A total of 16 green algae genera, 21 red algae genera and four brown algae genera were recorded inside sampled photo-quadrats around Guam and Santa Rosa Bank during the 2005 MARAMP expedition. *Padina* sp., rarely seen at the other islands, was locally abundant, especially on the southwest side of the island. Santa Rosa Bank was dominated by macroalgae, particularly from the genera *Caulerpa*, *Avrainvillea*, *Dictyosphaeria*, *Halimeda*, *Microdictyon* and *Udotea*. Turf algae and cyanobacteria were also common, while very little crustose coralline algae was observed. A total of 11 green algae genera (22 species), 16 red algae genera (19 species) and four brown algae genera (five species) were recorded during the 2007 expedition. Some algal communities exhibited monotypic dominance, while others were very diverse. The most conspicuous macroalgae at many of the sites were *Halimeda* spp. and *Padina* spp. Turf algae and cyanobacteria dominated most sites, and crustose coralline algae were also present. Relative abundance of macroalgae at several sites around Guam differed between 2003 and 2005 sampling periods (Tribollet and Vroom, 2007), although the causal factors are not clear.

Benthic Towed Diver Survey

Methods

A total of 23 benthic towed-diver surveys were completed around Guam in 2005 (Figure 15). Hard coral cover averaged 23% island-wide (range 0-75%), corresponding well with average coral cover estimated from the REA surveys (26.1% ± 3.6% SE; Figure 22). When divided into general regions (west/southwest, west/northwest, east/northeast, east/southeast), average coral cover was similar in the W/NW, E/NE and E/SE regions (25%, 26%, and 26%, respectively; Figure 22A). Coral cover was lowest in the W/SW region (12%).

Results and Discussions

Additional coral observations included:

- West/southwest: The highest coral cover (average 49%, range 30.1-62.5%) was at southern reefs of Cocos Island;
- West/northwest: The highest coral cover (average 49%, range 30.1-62.5%) was found during a towed-diver survey between Hila'an Point and a location 1.1 km to the southwest of Haputo Point. Divers noted massive *Porites* spp. dominated the reef, which was also marked by low levels of COTS predation (54 recorded during the 50-minute survey);
- East/northeast: The highest coral cover (average 37%, range 30.1-62.5%) was noted in an area 2.7-5.2 km west of Pati Point;
- East/southeast: The highest coral cover (average 39%, range 10.1-62.5%) was noted on a survey near Togcha Bay.

Stressed coral was recorded at an average of 4% for all of Guam (range 0-40%). The majority of surveys recorded average stress levels of between 0-4%; however, certain areas, particularly in the east/southeast, exhibited significantly higher stress levels. Additional observations of stressed corals included:

- The survey in the vicinity of Togcha Bay recorded high levels of coral stress (average 19%, range 1.1-40%). Divers noted the presence of increased sedimentation, diseased coral and dead encrusting coral;
- A subsequent survey further south (ending at Talofofo Bay) recorded an average of 5% stressed coral (range 0-30%). Divers noted COTS predation, abnormal/diseased massive *Porites* spp. and *Diploastrea heliopora* colonies that showed signs of disease (yellow blotches);
- The towed-diver survey completed between Asiga Point and Jalaihai Point recorded the highest levels of coral stress in Guam (average 24%, range 10.1-50%);
- The towed-diver survey completed between Agfayan Point and Aga Point also recorded high levels of coral stress (average 12%, range 1.1-40%). Divers noted *Pocillopora* spp. that showed signs of disease, along with live coral that appeared to be overgrown with algae; The towed-diver survey completed near Asgadao Island, towards the eastern tip of Babe Island, also recorded an average of 12% coral stress (range 1.1-40%);
- In the northeast, a towed-diver survey off of Jinapsan Beach recorded an average of 8% coral stress (range 0-30%). Divers noted *Pocillopora*, *Astreopora* and other species appeared white, apparently from COTS predation.

Macroalgae cover for Guam averaged 51% (range 0-100%; Figure 22B), while coralline algae averaged 7% (range 0-100%; Figure 22D). The highest algal cover was noted during the towed-diver survey completed between Agfayan Point and Aga Point (average 86%, range 75-100%). Soft coral cover was low around Guam, with an average of 1% recorded island-wide (range 0-20%; Figure 22C). The highest level of soft coral cover (6%) was noted during the survey in the northwest region, north of Achae Point.

Santa Rosa Bank

Three towed-diver surveys over 7.1 km were completed at Santa Rosa Bank in 2005 (Figure 15). The following observations were recorded:

- Hard coral cover averaged 8% (range 1.1-30%); this was similar to coral cover recorded in 2003 (average 8%, range 2-18%);
- Stressed hard coral remained low, averaging 0.27% (range 0 -1%);
- Soft coral cover was also low, averaging 0.23% (range 0-1%);
- Macroalgae dominated the reef community (average 71%, range 1.1-100%), and was higher than macroalgae cover recorded in 2003 (average 43%, range 3-75%);
- Coralline algae cover was low (average 0.55%, range 0-5%), and was lower than coralline cover recorded in 2003 (average 7%, range 0-15%).

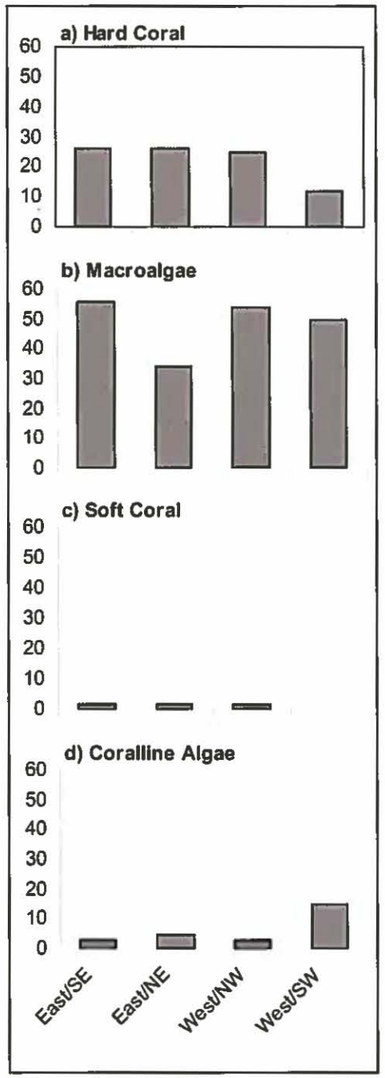

Figure 22. *Benthic cover by region from 2005 MARAMP towed-diver surveys. Total benthic cover measured by benthic towed-diver surveys consisted of a biotic component (coral, algae), along with an abiotic component (sand, rubble). Turf algal cover, carbonate pavement and rock were not recorded. Source: NOAA PIFSC-CRED, unpubl. data.*

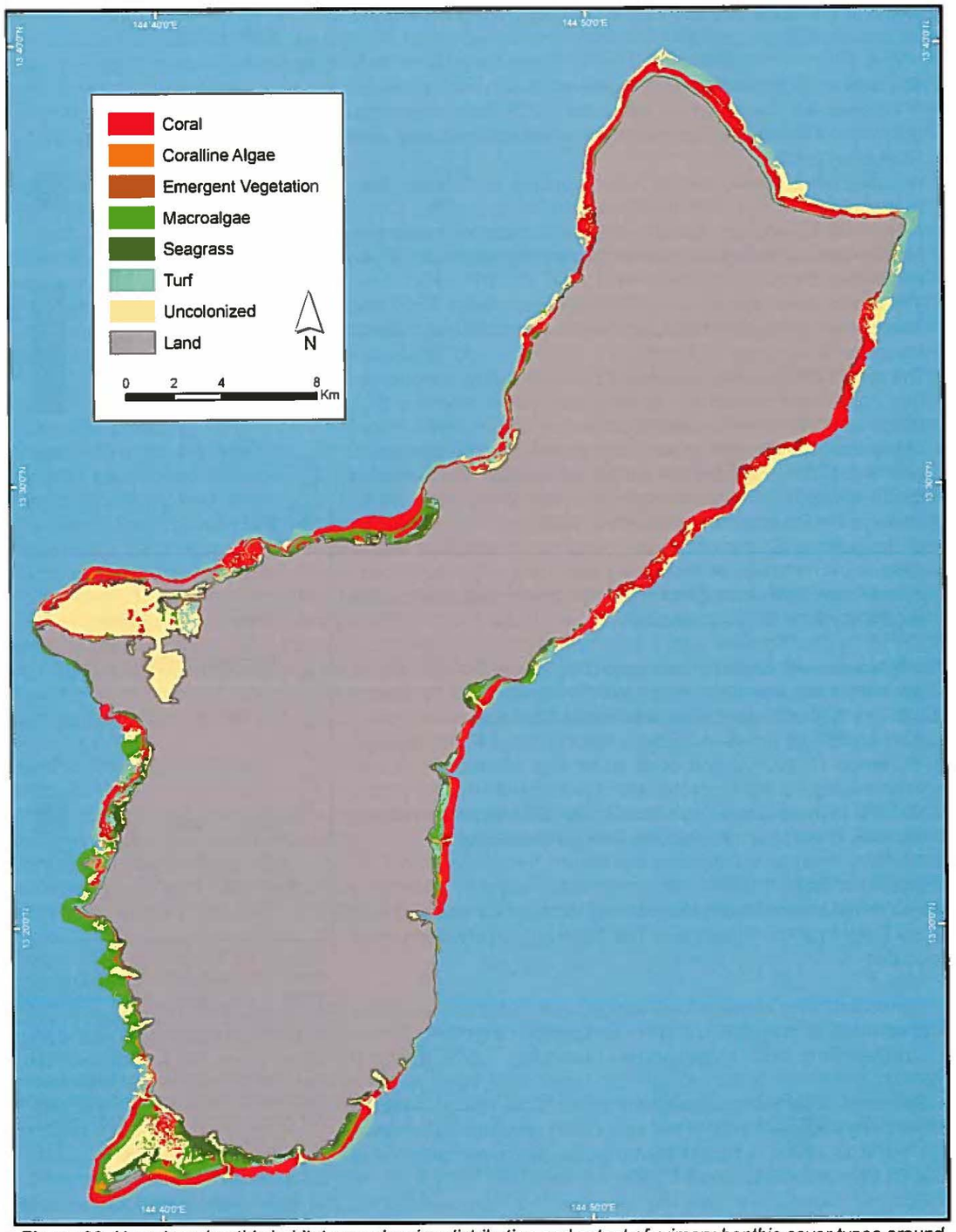

Figure 23. *Nearshore benthic habitat map showing distribution and extent of primary benthic cover types around Guam. Data developed by D. Burdick. Map: D. Burdick. Source: Burdick (2005).*

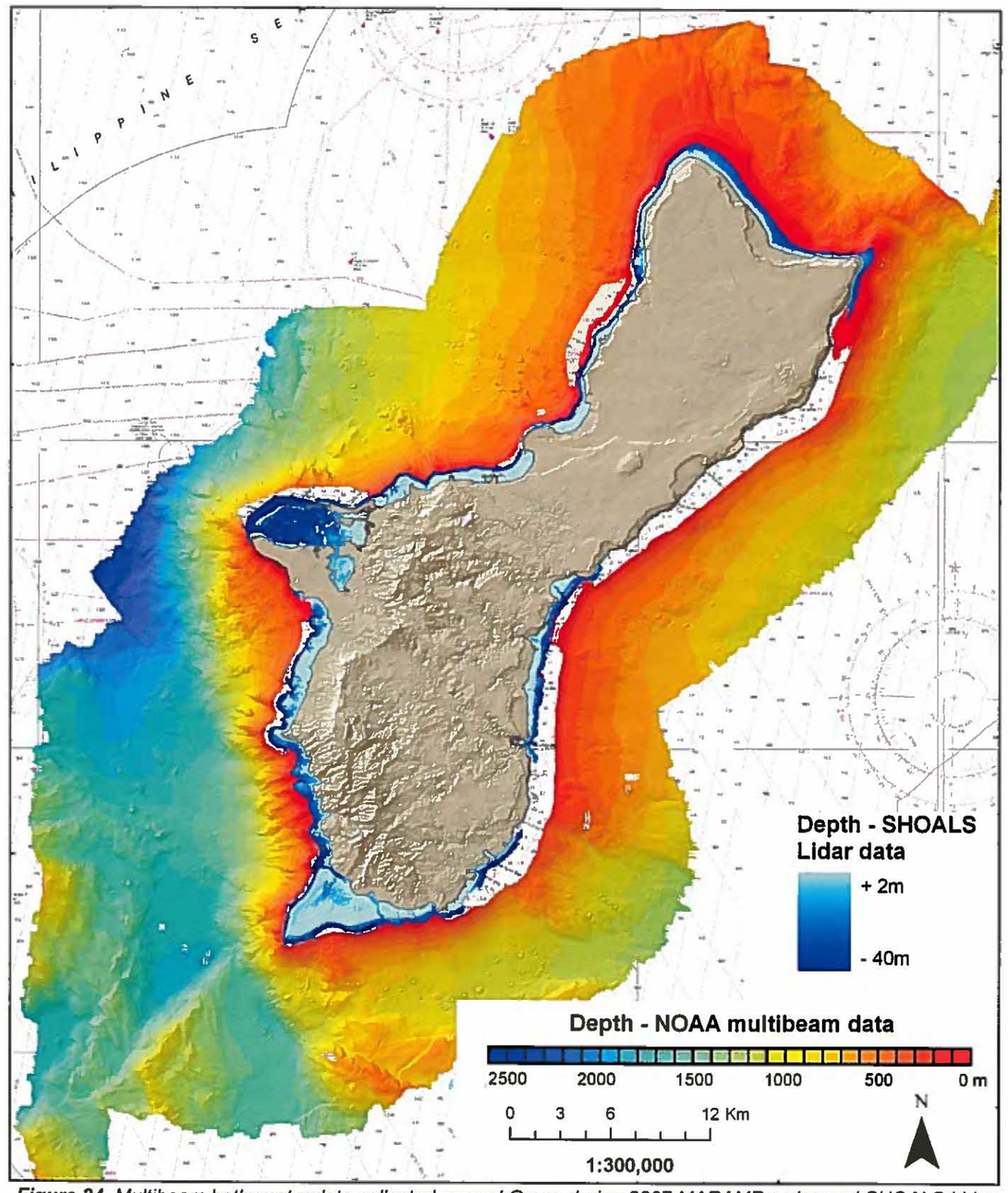

Figure 24. *Multibeam bathymetry data collected around Guam during 2007 MARAMP cruise and SHOALS Lidar data collected in 2001. The multibeam bathymetry data cover much of the deeper waters around Guam, while the SHOALS Lidar data cover much of the shallow waters (0-30m) around the island. Sources: NOAA PIFSC-CRED and the Guam Bureau of Statistics and Plans. Map: D. Burdick; modified from map by NOAA PIFSC-CRED.*

Benthic Habitat and Bathymetric Mapping

NOAA's Mapping Activities

NOAA's CCMA-BB produced a shallow water benthic habitat atlas in 2005 based on visual analysis of IKONOS satellite imagery (NOAA National Centers for Coastal Ocean Science, 2005; Figure 23); the maps, derived products, and associated digital data are available from: http://ccma.nos.noaa.gov/ecosystems/coralreef/us_pac_mapping.html. PIFSC-CRED conducted limited multibeam and optical validation mapping around Guam during the MARAMP cruise in 2003. Additional multibeam data collection was carried out in 2007 by PIFSC-CRED. When combined with shallow-water LIDAR data, the bathymetric information provides a nearly complete picture of Guam's nearshore marine bathymetry (Figure 24). The data are available for download from http://www.soest.hawaii.edu/pibhmc/pibhmc_cnmi.htm.

Guam Coastal Atlas

The UOGML, with support from the NOAA Pacific Islands Technical Assistantship program, developed an updated nearshore benthic habitat data set for Guam in 2006 based on the benthic habitat atlas developed by the NOAA's CCMA-BB in 2005 (Figure 25). The updated data set was developed using the most recent, pan-sharpened IKONOS image mosaic available. 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. By using a significantly smaller minimum mapping unit (0.05 ha or 0.125 ac) and additional ground-truthing data, this effort provided a higher level of detail for benthic habitats at selected areas of the coastline, including four of the five marine preserves and three focus areas. The updated benthic habitat data set was incorporated into the Guam Coastal Atlas (Burdick, 2006; http://www.guammarinelab.com/coastal.atlas/index.htm), which was developed to provide updated, relevant coastal information for managers, researchers, teachers, fisherman, and the general public. The atlas provides full-color, 1:15,000-scale maps for the entire coastline of Guam, and 1:4,000-scale maps for four of the five marine preserves and the three "focus areas." Two maps are provided for each section of the coastline, with one map containing only the pan-sharpened IKONOS satellite imagery and another map depicting benthic habitat data overlaying the satellite imagery.

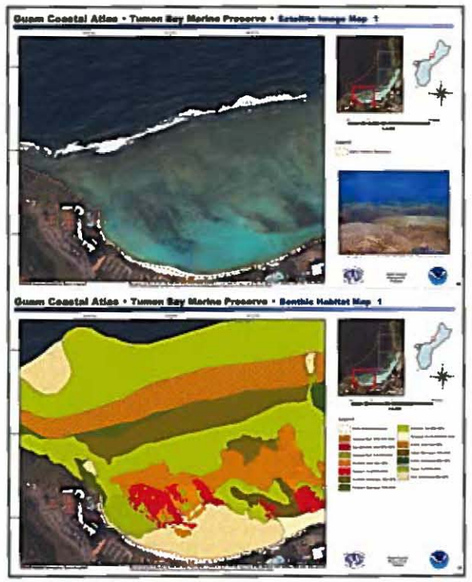

Figure 25. *Example of maps presented in the Guam Coastal Atlas. A map containing satellite imagery, along with underwater or above-water photos of features from the area depicted (top), as well as a map depicting benthic habitat data overlaying satellite imagery (bottom) are provided for each section of the coastline. Source: Burdick (2005).*

ASSOCIATED BIOLOGICAL COMMUNITIES

Several studies have examined the biological communities associated with coral reefs since the 2005 report. As before, most of these studies were focused on reef fish communities. Additional data collected by DAWR as part of their creel survey program is provided in this section. Also provided are the results of REAs for fish and towed-diver surveys for fish and macroinvertebrates conducted during the 2005 MARAMP cruise, as well as macroinvertebrate data collected with towed-diver surveys during the 2007 cruises. Two stand alone studies of fish communities were also conducted since 2004, including an examination of the impacts of artisanal fishing on the reef fish communities within the WAPA, and preliminary findings from an investigation into the role of Marine Preserves in controlling herbivory levels and the effect on algae communities. Descriptions of these studies and their findings are presented below.

Guam Division of Aquatic and Wildlife Resources Creel Surveys

The Guam DAWR, Fisheries Section has collected one of the largest, most continuous data sets on marine fisheries in the Pacific. The DAWR started collecting creel data in the early 1970s and has continued to refine its survey techniques and expand its scope over the years. The creel surveys are broken into two distinct categories: boat-based (or offshore) fisheries and shore-based (or inshore) fisheries. Boat-based fisheries primarily rely on small boats (3.6-14.6 m) for trolling and bottom fishing trips lasting up to two days. The majority of the boat based fishery catch consists of pelagic fish; however, reef fish are also an important component. Shore-based fisheries consist of fishing methods used from shore without a boat, and include methods such as nearshore casting, netting and spear fishing. The data collected by these surveys are entered into a database, quality controlled by DAWR staff and then expanded through a Visual FoxPro database application developed by the Western Pacific Fisheries Information Network, (WPacFIN) and DAWR to get the total estimated effort and harvest for the island. Table E provides a summary of reef fish harvest and CPUE by method for the period between 2003 and 2006. For more information about this program: http://www.pifsc.noaa.gov/wpacfin/guam/dawr/Pages/.

Shore-based Fisheries

Methods

Each month, DAWR Fisheries staff randomly select four days for shore-based catch surveys. These survey days are divided into a day survey (0630-1200 hours) and a night survey (1900-2400 hours). For each survey day, one of three survey areas is selected for the day's efforts. DAWR staff then conducts fishermen-intercept interviews to determine the amount of effort, fishing method, species composition and the amount caught. Surveyors also note location, reef zone, and weather and tide conditions. These catch surveys are complemented by participation surveys that are conducted four times a month on randomly selected days. During participation surveys, the surveyor records all in-progress shore-based fishing participation. This includes time of day, locations, number of people, number of gear units, fishing method, reef zone fished, and weather and surf conditions. The surveyor drives through all three survey areas beginning at a randomly selected region. The direction of the survey, clockwise versus counter-clockwise, is alternated each survey day. Participation surveys are conducted during the day and at night. The participation survey is supplemented by an island-wide aerial survey. Aerial surveys are conducted twice a month, simultaneous with one weekday and one weekend participation survey. The aerial survey collects the same information as the participation survey, but surveys the entire coastline. The participation survey assesses total fishing effort, which is then expanded based on the creel data through the WPacFIN database to get the total estimated effort and harvest for shore-based fisheries.

Table E. *Estimated reef fish harvest and catch per unit effort (CPUE) for all shore based and boat based methods between 2003 and 2006. Reef fish harvest exceeded 100 metric tons in both years. Shore based 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. **SCUBA spear measures are based on a limited number of interviews and may be underestimated. Source: DAWR unpublished data.*

METHOD	SHORE BASED		BOAT BASED		TOTAL
	Harvest (kg)	CPUE (kg/gr-hr)	Harvest (kg)	CPUE (kg/gr-hr)	Harvest (kg)
Bottom*			34,633	0.80	34,633
Cast Net	20,189	0.4451	1,745	2.60	21,934
Snorkel Spear	9,725	0.5771	5,804	0.82	15,529
Hook and Line	13,731	0.104			13,731
Gill Net	7,286	0.4677	3,227	5.66	10,513
Trolling*			6,204	2.00	6,204
SCUBA Spear*	1,209	1.7286	2,885	1.83	4,094
Hooks and Gaffs	2,473	0.3829			2,473
Surround Net	2,446	3.1972			2,446
Atulai Jigging			752	0.99	752
Spincasting			468	0.42	468
Jigging			360	1.10	360
Aquarium Fish			16	1.00	16
Longline			12	1.00	12
Mix Spear					0
Drag Net					0
Other	1,097	0.5312			1,097
Total	58,156		56,106		114,262

Results and Discussion

The trends in catch per unit effort, total es-

timated harvest and total estimated effort from 1985 to 2006 for four of the common shore-based fishing methods (e.g., gill net, snorkel spear, cast net and hook and line) are illustrated in Figure 26. These graphs indicate that overall harvest and CPUE have declined over the last twenty years for all of these primary methods. Although hook and line is the major contributor to the total catch and is the most common method used by fishermen, it also has the lowest CPUE. Snorkel spear and gill net methods have the highest CPUE and are important contributors to total harvest, although the data indicate that gill net effort has declined.

According to DAWR's FY06 annual report, Guam's shore-based fish stocks may be overfished. This concern is based on historical catch data and information from long-time fishermen (Flores, 2006b). The estimated harvest for the top five families of reef fish caught using shore-based fishery methods over the last three years is presented in Table F. Acanthuridae (surgeonfishes) and Carangidae (jacks) continue to be the top two families targeted by shore-based fisheries.

Table F. *Estimated harvest for the top five families of reef fish caught using shore based fishery methods between 2004 and 2006. Data excludes seasonal runs of juvenile siganids and bigeye scads. Source: DAWR, unpub. data.*

SHORE-BASED FISHERIES HARVEST					
2004		2005		2006	
FAMILY	HARVEST (kg)	FAMILY	HARVEST (kg)	FAMILY	HARVEST (kg)
Acanthuridae (Surgeonfishes)	10,315	**Carangidae** (Jacks)	8,657	**Acanthuridae** (Surgeonfishes)	13,010
Carangidae (Jacks)	6,395	**Acanthuridae** (Surgeonfishes)	5,522	**Carangidae** (Jacks)	10,339
Siganidae (Rabbitfishes)	4,242	**Mullidae** (Goatfishes)	4,142	**Kyphosidae** (Rudderfishes)	5,645
Mullidae (Goatfishes)	1,785	**Siganidae** (Rabbitfishes)	2,468	**Mullidae** (Goatfishes)	5,373
Lutjanidae (Snappers)	1,696	**Lethrinidae** (Emperors)	1,468	**Siganidae** (Rabbitfishes)	5,219

Table G. *Estimated harvest of the top five marine invertebrate species harvested using shore based fishing methods between 2004 and 2006. Source: DAWR, unpubl. data.*

SHORE-BASED INVERTEBRATE HARVEST					
2004		2005		2006	
SPECIES	HARVEST (kg)	SPECIES	HARVEST (kg)	SPECIES	HARVEST (kg)
Octopus other	10,315	*Octopus cyanea*	8,657	*Octopus* other	13,010
Tripneustes gratilla	6,395	*Octopus* other	5,522	*Octopus cyanea*	10,339
Octopus ornatus	4,242	*Scylla serrata*	4,142	*Toxopneustes pileolus*	5,645
Panulirus penicillatus	1,785	*Trochus niloticus*	2,468	*Octopus ornatus*	5,373
Octopus cyanea	1,696	*Tripneustes gratilla*	1,468	*Parribacus antarcticus*	5,219

The estimated harvest of the top five marine invertebrate species harvested using shore-based fishing methods over the last three years is presented in Table G. Octopus continues to be the most popular invertebrate species collected using shore-based fishing methods.

Boat-based Fisheries

Methods

The boat-based survey is conducted on eight randomly selected days each month and covers the three primary launching sites: Agana Boat Basin, Agat Marina and Merizo Pier. Agana, the busiest site, is surveyed two weekdays and two weekend days each month, while Agat and Merizo are each surveyed on one weekday and one weekend day each month. Surveys are conducted during two shifts [AM: 0500-1200 hours (Agana), 0530-1200 hours (Agat), 0600-1100 hours (Merizo); and PM: 1600-2400 hours]. At the start of each survey day, the AM surveyor starts a boat log for the site. Surveyors record boat identification, departure and return times and report fishing method information on this log. The log is used to keep track of participation during the survey day and is the main priority for the surveyors. During the survey period, all returning vessels are approached and asked to provide information about their trip. Their participation is voluntary and surveyors are trained to get as much information as possible in the time available. Information collected includes: fishing method, number of fish, length of fish, fish species, amount of time spent fishing, gear used, area fished and meteorological/ocean conditions. In addition,

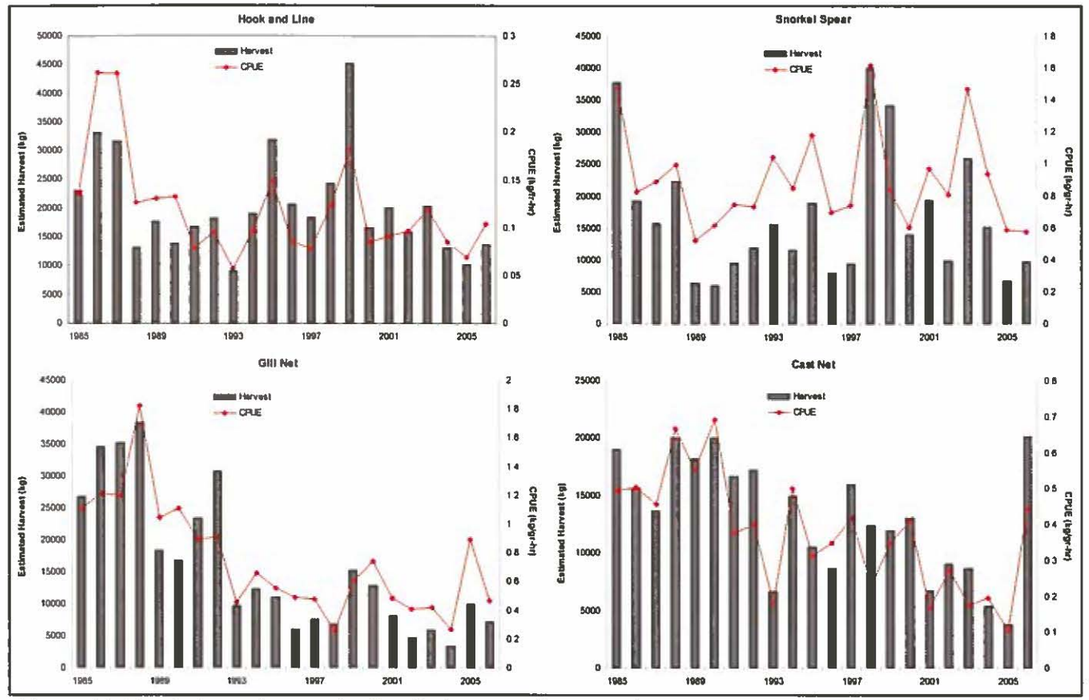

Figure 26. *Trends in catch per unit effort (kg harvested/gear-hour) and total estimated harvest (kg) from 1985 to 2006 for four of the common shore-based fishing methods: gill net, snorkel spear, cast net, and hook and line. The data are from the expanded estimates calculated by the WPacFIN database from the DAWR shore based survey data. Source: DAWR, unpub. data.*

a vehicle-trailer census is conducted during the shore-based participation survey, in order to record participation at all other sites around the island. The information from all three surveys is entered into the WPacFIN database, checked for quality, and then expanded to determine total effort and harvest for the entire island.

Results and Discussion

The trends in CPUE and total estimated harvest in kilograms for four of the common boat-based fishing methods, including bottom fishing, SCUBA spear, snorkel spear and gill net, are depicted in Figure 27 and Table E. These graphs indicate that overall harvest and CPUE have declined over the last twenty years for most of these primary methods. Bottomfishing is the most popular boat based method targeting reef fisheries. The CPUE for this method has declined over the period from 1982-2006. In addition, the numbers of trips and fishermen in the fishery have declined over the last five years, possibly due to poor catch rates or fuel costs (Flores, 2006a). Despite the decline in effort, the CPUE for bottomfishing has increased

Table H. *Estimated harvest for the top five families of reef fish caught using boat- based fishery methods over the last three years. Source: DAWR, unpub. data.*

BOAT-BASED FISHERIES HARVEST					
2004		2005		2006	
FAMILY	HARVEST (kg)	FAMILY	HARVEST (kg)	FAMILY	HARVEST (kg)
Acanthuridae (Surgeonfishes)	18,751	**Lutjanidae** (Snappers)	13,062	**Lutjanidae** (Snappers)	9,668
Carangidae (Jacks)	18,247	**Acanthuridae** (Surgeonfishes)	8,481	**Carangidae** (Jacks)	11,193
Lutjanidae (Snappers)	10,925	**Carangidae** (Jacks)	8,319	**Scombridae** (Mackerels)	6,360
Lethrinidae (Emperors)	8,974	**Lethrinidae** (Emperors)	5,446	**Sphyraenidae** (Barracudas)	5,257
Scaridae (Parrotfishes)	8,603	**Scaridae** (Parrotfishes)	3,954	**Lethrinidae** (Emperors)	4,804

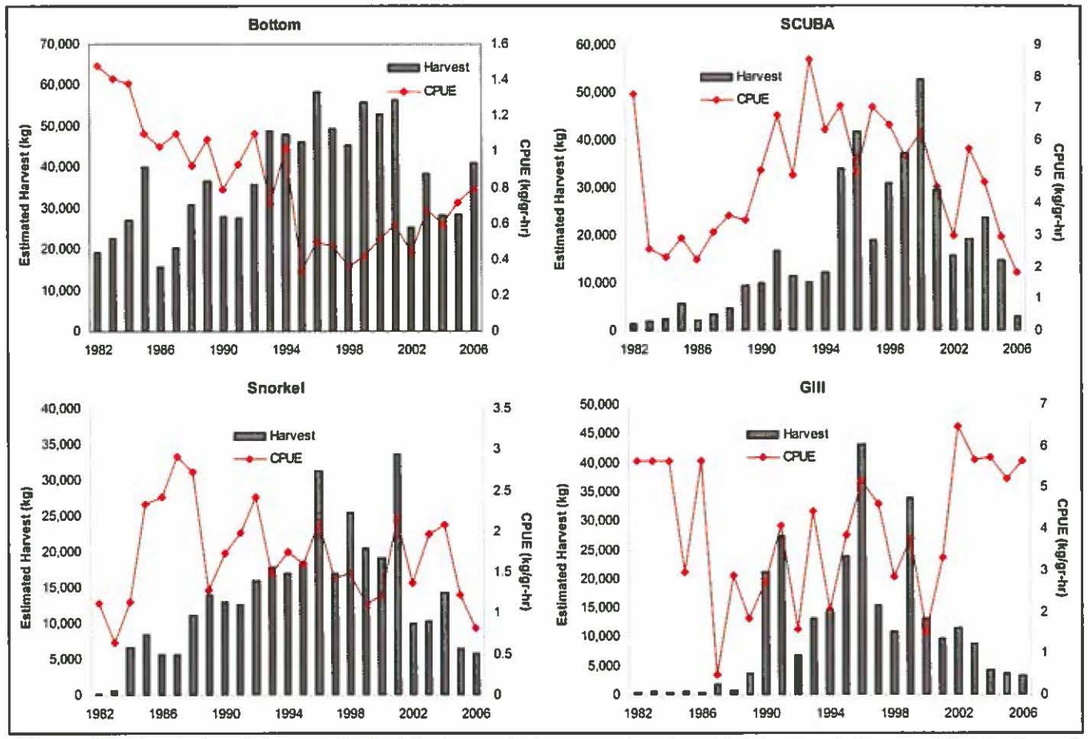

Figure 27. *Trends in catch per unit effort (kg harvested per gear-hour) and total estimated harvest (kg) for four of the common boat-based fishing methods: Bottom Fishing, SCUBA Spear, Snorkel Spear, and Gill Net. The data are from the expanded estimates calculated by the WPacFIN database from the DAWR boat based survey data. Source: DAWR, unpub. data.*

slightly over the last five years.

Another popular method is spearfishing using SCUBA. This method became a major fishery in the 1990s. During this time, the catch regularly consisted of large grouper, wrasse and parrotfish and the CPUE was very high, approaching 9 kg per gear-hour in 1993. DAWR has documented a recent shift from these large species to smaller, faster growing species such as surgeonfish. According to the database, the CPUE for this method has greatly decreased over the last five years; it is important to note, however, that many of the fishermen using this method have refused to participate in the surveys. This prohibits the accurate documentation of this fishery, and DAWR expects that the values are underestimated (Flores, 2006a). Snorkel spear and gill net methods are the two other most popular methods targeting reef fish. Harvest and CPUE using these methods have decreased over the last five years. Gill net has consistently had the highest CPUE for all of the boat-based methods over the past five years (five year average=6.7),

Table I. *Estimated harvest of the top five marine invertebrate species harvested using boat-based fishing methods between 2004 and 2006. Source: DAWR, unpub. data.*

BOAT-BASED INVERTEBRATE HARVEST					
2004		2005		2006	
SPECIES	HARVEST (kg)	SPECIES	HARVEST (kg)	SPECIES	HARVEST (kg)
Trochus niloticus	1,711	*Octopus cyanea*	113	*Trochus niloticus*	2,139
Panulirus penicillatus	132	*Panularis versicolor*	27	*Octopus cyanea*	423
Octopus teuthoides	103	*Parribacus antarcticus*	12	*Panulirus penicillatus*	205
Lambis truncata	87	–	–	*Octopus ornatus*	13
Sepioteuthis lessoniana	65	–	–	*Parribacus antarcticus*	10

raising concerns about the sustainability of this method (Flores, 2006a).

The estimated harvest for the top five families of reef fish caught using boat-based fishery methods over the last three years is presented in Table H. The top five families have changed, but there is no clear trend. Top families have included the Lethrinidae (emperors), Acanthuridae (surgeonfish) and Lutjanidae (snappers).

The estimated harvest of the top five marine invertebrate species harvested using boat-based fishing methods are provided in Table I. *Trochus* was the most popular invertebrate species for four of the last five years. Octopus and lobster species also contributed regularly to the boat-based invertebrate harvest. *Trochus* and lobster are primarily harvested using SCUBA. Due to the low level of survey participation by fishermen using SCUBA, the estimated harvest values for these species are probably underestimated (T. Flores, pers. comm.).

UOGML Long-term Monitoring Program: Fish Communities

Fish communities were surveyed in 2006 along permanent transects established for the UOGML's long-term monitoring program.

Methods

At each transect, species from 11 fish families (Serranidae, Lutjanidae, Lethrinidae, Nemipteridae, Mullidae, Chaetodontidae, Pomacanthidae, Labridae, Scaridae, Siganidae and Acanthuridae) were counted in a 5 m wide band (2.5 m either side of the transect center line). In order to minimize disturbance to the fish, the counts took place as the observer laid each 50 m tape. The same observer returned along the transect and counted all species of Pomacentridae in a 1 m wide band.

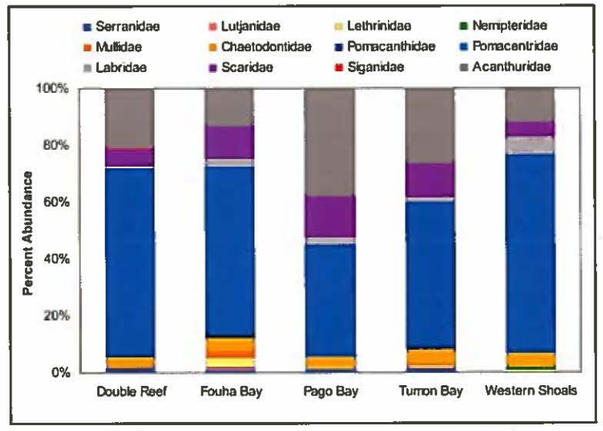

Figure 28. *Percent total abundance of each fish family at five permanent monitoring sites. Source: J. McIlwain, unpubl. data.*

Results and Discussion

A summary of the total abundance of each fish family based on the limited baseline data reveals similar patterns across all five sites, despite one site's (Tumon Bay) marine preserve status (Figure 28). The most abundant family (numerical abundance) is Pomacentridae followed by the Acanthuridae and Scaridae. Interestingly, the families Lutjanidae and Lethrinidae, which include the popular food fish *Lethrinus harak* (*mafute*), are poorly represented at all sites, although they are most abundant at Fouha Bay. The piscivorous fish in the family Serranidae, which are heavily targeted by fishermen, were completely absent from one of the five sites. The lack of rabbitfish (Siganidae) may have been a direct result of the position of the transects on the reef slope (average depth 5 m), which is not typical habitat for this family. Similarly, fish in the families Pomacanthidae and Mullidae were absent from all sites, with

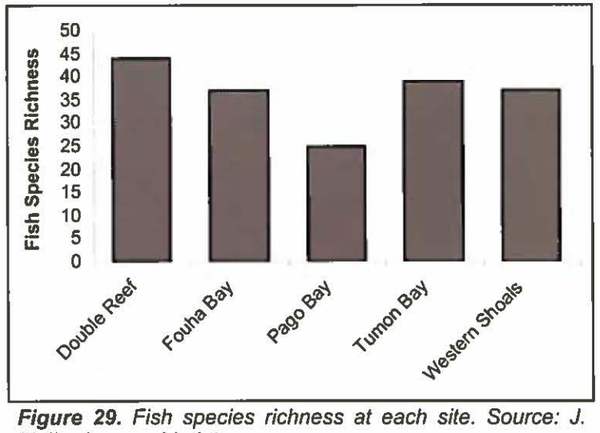

Figure 29. *Fish species richness at each site. Source: J. McIlwain, unpubl. data*

the exception of a few individuals from the Mullidae family that were recorded at Fouha Bay. Four of the five sites were similar in terms of total fish species (presented as species richness). However, Pago Bay recorded nearly 50% fewer species than Double Reef, which is not surprising given it also had the lowest hard coral cover (Figure 29; Figure 19).

MARAMP Fish REAs and Towed-Diver Surveys

Methods

Fish were resurveyed by NOAA PIFSC-CRED from October 3-9, 2005, at the nine REA stations around Guam and two at Santa Rosa Bank (Figure 15). Quantitative belt transects, stationary point counts and towed-diver surveys were conducted at these sites, which had also been visited during the first CRED cruise in 2003, using standard protocols summarized in Porter et al., 2005.

Results and Discussion

In general, fish diversity and abundance were relatively low around Guam, although both were slightly higher along the north and east shores, which are characterized by relatively good habitat rugosity and higher live coral cover. Medium-large fish (total length >25 cm) were very rare along the leeward (west) side of the island. Sharks were rare; only one white-tip and one black-tip were seen. No Napoleon wrasse; (*Cheilinus undulatus*) or bumphead parrotfish (*Bolbometopon muricatum*) were observed. Slightly more fish were seen in the marine preserve areas (snappers, emperors, unicornfish, parrotfish, goatfish). The north side of Guam revealed a moderate diversity and abundance of medium-large fish (e.g., *Lethrinus xanthochilus*, *Caranx melampygus*, *Macolor niger*, *Aphareus furca*, *Kyphosus cinerascens*). Other taxa of medium-large size, such as parrotfish, *Lethrinus* spp. *Monotaxis grandoculis*, *Aprion virescens* and *Lutjanus* spp., were also of fair abundance. Other common taxa included wrasses, surgeonfish and rabbitfish. The most common fish found on belt transects along the west side of Guam were damselfish (*Pomacentrus vaiuli*, *Stegastes fasciolatus*), wrasse (*Halichoeres margaritaceus*, *Thalassoma quinquevittatum*) and surgeonfish (*Acanthurus nigrofuscus*, *Ctenochaetus striatus*). These same three families were also common along the north and east sides, while additional taxa (angelfish, butterflyfish, snappers, groupers and goatfish) were also better represented. Planktivorous damselfish were also more abundant at these sites (e.g., *Pomachromis guamensis*, *Chromis acares*, *C. vanderbilti*, *Dascyllus reticulatus*).

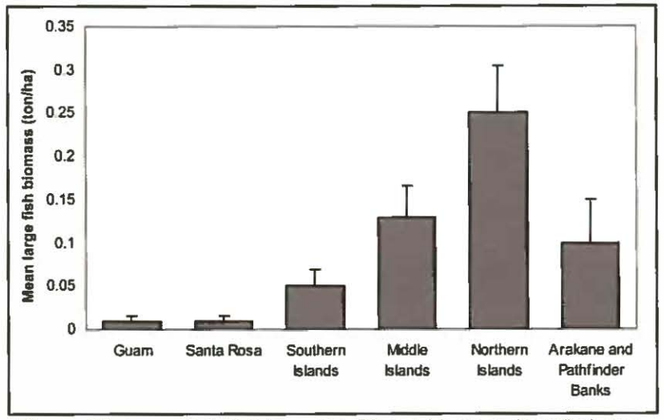

Figure 30. *Large fish (total length >50 cm) biomass (tons/ha) measured on towed-diver surveys in the Mariana Islands. Source: NOAA PIFSC-CRED, unpubl. data.*

Large fish (total length >50 cm) biomass for both Guam and Santa Rosa Bank recorded during towed-diver surveys, was very low at around 0.01 to/ha, compared to the 0.13 ton/ha average for the "middle" Mariana Islands (Sarigan, Guguan, Alamagan, Pagan and Agrihan), and the 0.25 ton/ha average for the "northern" islands (Asuncion, Maug, and Uracas; Figure 30). Medium to large fish (total length >25 cm) biomass was also very low around Guam compared to the rest of the Mariana Islands (0.1 ton/ha versus 1.7 ton/ha; see Starmer et al., 2008, for more information).

MARAMP Macroinvertebrate Surveys

Methods

Conspicuous macroinvertebrates were recorded by towed-divers along 10 m-wide transects at depths of

15-25 m during the 2005 and 2007 MARAMP expeditions. Echinoids, Holothuroids, COTS and *Tridacna* spp. (giant clams) were recorded at numerous sites around the island. Both Guam and Santa Rosa Bank were surveyed in 2005, while only Guam was surveyed in 2007.

Results and Discussion

Macroinvertebrates were in relatively low abundance around Guam, with the exception of high urchin and COTS densities at some sites (Figure 31). Echinoid abundance was generally low around the island, with the greatest abundances observed on the north-east corner of the island. COTS were observed in both 2005 (449 total observed, mean of 8.24 individuals/ha) and 2007 (648 total observed, mean of 14.60 individuals/ha). These numbers represent a 100% and 200% increase, respectively, over the number of COTS observed in 2003 (n=215). COTS outbreak densities were observed on 24 out of a total of 107 individual, five-minute tows (22%) in 2007, with densities greater than 100 individuals per hectare observed on seven of these tows (Figure 14). A further 28 tows (26%) exhibited moderately high densities of between 15-25 individuals per hectare. The highest COTS densities were found along the eastern coastline near Fadian Point and near Cocos Island during the 2007 cruise. Relatively high COTS densities were also observed at Ypao Pt., Nomna Pt., and north of Taguan Pt. As expected, high densities of COTS coincided with areas that exhibited high percentages of stressed coral. No COTS were observed on Santa Rosa Bank in 2005.

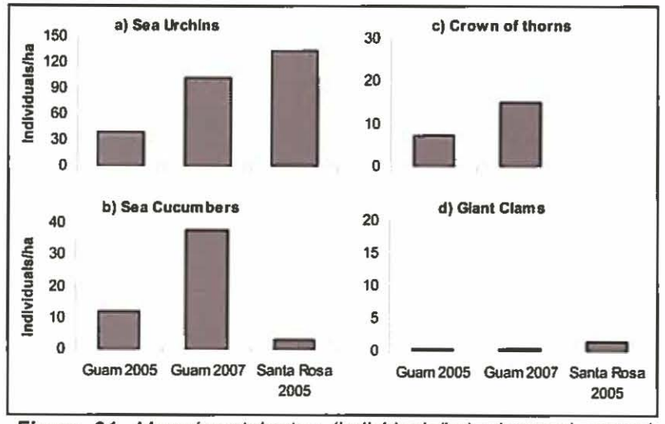

Figure 31. *Macroinvertebrates (individuals/ha) observed around Guam (2005, 2007) and Santa Rosa Bank (2005). Source: NOAA PIFSC-CRED, unpubl. data.*

The Role of Marine Protected Areas in Controlling Herbivory Levels and the Impact on Local Algal Communities (UOGML)

The goals of this study were to compare algal communities inside and outside marine preserves and test for any evidence of top-down effects as well as other differences in communities in terms of composition and abundance of algal species, including "bottom-up" effects caused by increased nutrient availability (Pioppi, in prep). Presented here are the preliminary results of the fish surveys conducted for this study. The final report for the overall study should be available in 2008.

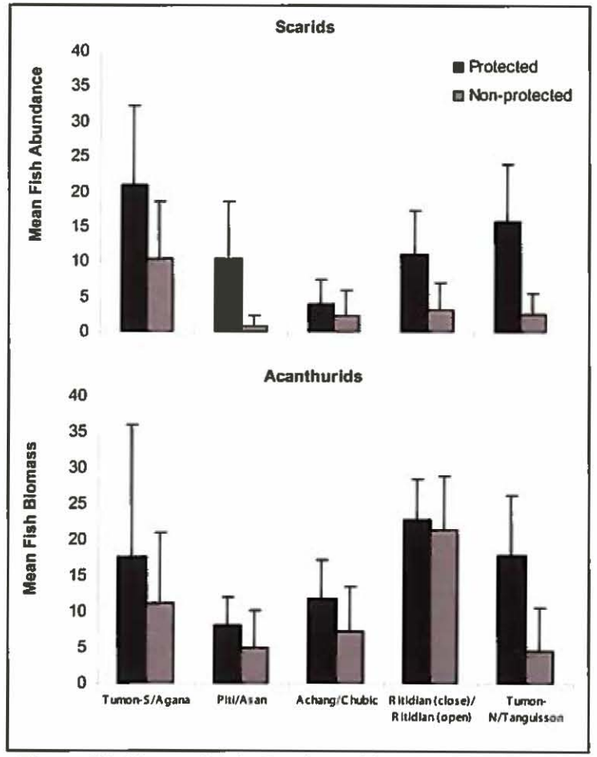

Figure 32. *Mean adult (> 6 cm) scarid and acanthurid abundance (± SD) observed in protected and non-protected areas between January and December 2006 (n = 12). Source: N. Pioppi, unpubl. data.*

Methods

Ten reef sites around Guam were surveyed monthly from January to December 2006. Five of these sites have no fishing restrictions; the remaining five sites prohibit most or all fishing according to Guam law and, in one case (Ritidian Point), federal law. Five pairs of protected/non-protected sites were chosen based on proximity, and members of pairs were surveyed on consecutive days. The pairs included (protected/unprotected): Piti/Asan, Tumon South/Agana, Tumon North/Tanguisson, Ritidian Closed (East Side)/Ritidian Open (West Side) and Achang/Chubic Beach. At each site, two permanent 50 m transects were installed on the reef flat parallel to the shoreline. Transects at each site were surveyed consecutively, starting with the same transect each sampling period. At the beginning of each survey, a 50 x 5 m fish count with size estimations was performed for target species in the following families: Acanthuridae, Scaridae and Siganidae. Benthic cover was estimated every five meters along each transect using a 16-point quadrat count method. Macroalgae were identified to species when possible; other categories recorded included sand, cyanobacteria and crustose coralline algae. Environmental data, such as temperature and water height, were also collected.

Results and Discussion

Mean adult (>6 cm) abundance for fish from the families Scaridae and Acanthuridae for each pair of protected and non-protected sites is provided in Figure 32. These preliminary data indicate that the protected sites tended to have a greater abundance of individuals from these families than in the non-protected sites. The greater abundance of Scaridae in protected sites is clearly evident in four of the five site pairs, despite the relatively high degree of seasonal variation in abundance observed at most sites. While monthly counts of Acanthuridae were consistently higher at most protected sites compared to non-protected sites, the high variation of seasonal abundance observed at most sites tends to obscure differences between protected and non-protected sites. Comparative statistical analysis is being performed on both the fish and the algal data; multivariate ordination techniques will be used to examine the effect of herbivorous fish on algae community structure and percent cover.

Impacts of Fishing on Coral Reef Resources in the War in the Pacific National Historic Park

In 2005, researchers from the UOGML examined the impacts of fishing on the coral reef resources in the WAPA (Tupper and Donaldson, 2005). The investigation had several objectives, including: 1) determining the spatial and temporal pattern of fishing in park waters; 2) identifying the species exploited in the fishery; 3) determining the CPUE of different fishing methods; and 4) conducting population assessments of key fishery species within the park and comparing no-take marine protected areas (e.g., Piti Bomb Holes Preserve) to adjacent areas open to fishing.

Methods

Effort-hours, number of fish landed, mean length of fish landed and CPUE were obtained through interviews with 63 fishers at six locations within the park. *In situ* fish surveys were also conducted; live fish biomass was estimated by visual estimation of total length and abundance along 50 x 5 m transects. Four replicate transects were surveyed at Piti Bomb Holes Marine Preserve and Asan Bay sites. Published length-weight regressions for each species were applied to length and abundance data to estimate biomass for each species.

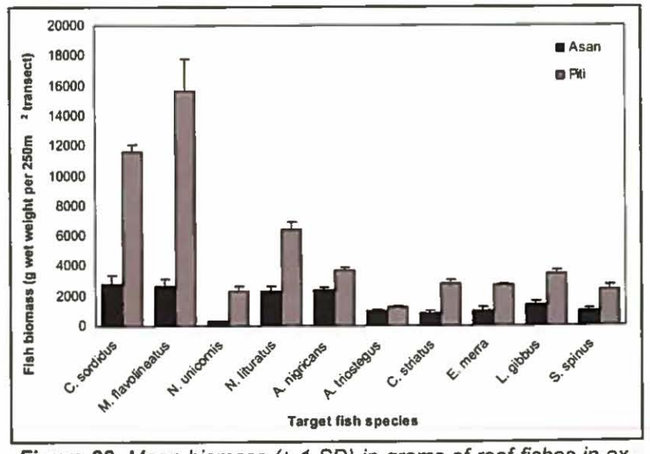

Figure 33. *Mean biomass (± 1 SD) in grams of reef fishes in exploited vs. protected areas of WAPA. Source: modified from Tupper and Donaldson, 2005.*

Results and Discussion

Fish biomass was significantly higher within the Marine Preserve than in Asan Bay (one-way ANOVA, $p<0.01$ for all species except *Acanthurus triostegus* (Figure 33), indicating that the preserve is producing more and larger fish than the adjacent exploited area of Asan Bay. Most fishing effort (measured in effort-hours) involved either rod and reel (75 hours) or sling (59 hours), followed by gill net, cast net, straight spear and spear gun (Table J). Slings landed the greatest number of fish, followed by rod and reel. However, cast nets exhibited the highest CPUE, followed by gill net, sling, rod and reel, and straight spear. No catch was reported by fishers using spear guns from the shore. The researchers concluded that WAPA is subject to considerable fishing pressure, evidenced by the lower biomass of nine out of 10 common reef fishes in the exploited Asan Bay as compared to the adjacent marine preserve. The heavy fishing pressure also results in degradation of the reef through discarded gear and trampling of corals, but further research is needed to determine the extent of physical impacts of fishing on the park's submerged resources.

Table J. *Number of fishers, numbers of fish caught, mean fish length, hours of effort, and Catch Per Unit Effort (CPUE) from creel surveys at War in the Pacific National Historic Park, Guam. Source: modified from Tupper and Donaldson, 2005.*

Gear Type	No. of fishers	No. of Fish	Mean Total Length (cm)	Effort (hrs.)	CPUE
Cast net	6	53	16.8	11.5	4.61
Gill net	8	67	9.9	19.5	3.44
Sling	6	139	12.4	59	2.36
Rod & reel	34	116	20.7	75	1.55
Straight spear	6	3	--	9.5	0.32
Spear gun	3	0	--	2.5	0

SOCIOLOGICAL AND ECONOMIC MONITORING ACTIVITIES

The importance of sociological and economic assessment and monitoring activities in effective management strategies is becoming more widely recognized. The causes of coral reef degradation and the solutions necessary to reverse these trends are often, at their root, economic and social in nature. The lack of sociological studies in the past has limited the effectiveness of coral reef management activities, as the relationship between humans and the reef, and the motivations for particular detrimental or beneficial behaviors, are not fully understood or are disregarded. The lack of economic assessments, such as coral reef valuation studies, has lead to underestimations of the economic and cultural importance of coral reefs. As a result, short-term economic gains from destructive activities are often pursued over more sustainable economic activities that are considerably more profitable in the long-term.

An earlier attempt to value the ecological services, tourist-related industries and coastal protection from Guam's reefs concluded that the island's reefs were worth $85 million a year (Richmond, 2000). Although this study was an important step in the direction of valuing the economic importance of Guam's reefs, it was limited by its use of secondary data sources and its exclusion of the cultural importance of reefs, which can be expressed in monetary terms. A comprehensive study was conducted in 2005-2006 to determine the economic value of Guam's coral reefs and associated resources by collecting primary data and incorporating cultural value through special survey methods. Another study evaluated the effectiveness of GCMP's various public outreach activities and identified the environmental issues of most concern to the public.

Guam Coral Reef Economic Valuation Study

In 2005-2006, an international team of researchers contracted by the UOGML carried out a comprehensive economic valuation of the coral reefs and associated resources of Guam (van Beukering et al., 2007). The aim of the study was to provide much-needed information about the economic importance of Guam's reefs, allowing decision makers to formulate more effective policies utilizing limited funds. The study assessed the value of five main coral reef uses on Guam: 1) extractive uses, such as fisheries; 2) non-extractive uses, such as recreation/tourism; 3) cultural/traditional uses; 4) education and research; and 5) indirect uses, such as shoreline and infrastructure protection. In addition to estimating the total economic value, the researchers also investigated the underlying motives and mechanisms behind the total economic value by focusing on people's relationship with the marine ecosystems, local "willingness to pay" (WTP) for coral reef conservation, and the spatial variation of reef-associated economic values and threats.

Methods

The researchers gathered existing data from a variety of sources, including tourist exit surveys, real estate databases, and DAWR creel surveys. To supplement these data, they conducted a household survey of 400 Guam residents to assess the cultural value of coral reefs. For households that fish, a supplemental survey about fishing was conducted. At the end of the survey, the researchers conducted a Discrete Choice Experiment (DCE) to determine individuals WTP for services that do not have market values. These data were analyzed to determine the total economic value of Guam's reefs, representing a more comprehensive estimate of the economic importance of Guam's marine environment. The researchers used a variety of techniques to determine the value of six uses: tourism, diving and snorkeling, fishing, amenity value, coastal protection and biodiversity; they also used Geographic Information System tools to determine the spatial variation of reef-associated economic values and threats.

Results and Discussion

Household Survey

The results of the survey indicated that several recreational activities link local residents to marine ecosystems. Over 92% of the population uses Guam's nearshore resources, such as beaches and reef flats, for recreational activities (Table J). According to the survey results, fishing has not declined in popularity (between 35% and 45% of respondents were active fishermen) despite depleted fish stocks. The survey found that the majority of fishermen fished because they enjoyed it and because it strengthens social bonds. Despite external influences, freshly-caught fish is still an essential part of local diets. At the time of the study, more than half of all consumed fish was obtained from stores and restaurants, while about 40% came from immediate or extended family or friends. Fishermen spent around $165 a month to fish; only a small number of fishermen on Guam sell part of their catch, indicating that fishing in Guam is neither a subsistence, nor a commercial, activity. The survey showed that most local residents have witnessed a degradation of the marine environment in recent decades, with declines in water quality and fish abundance being the most cited concerns (Table K). Residents identified increased runoff, poor development practices and leakage from broken sewage pipes as the three main causes. Residents were also asked for solutions and suggested improvements to the sewer system, increased environmental education and stricter law enforcement.

Table J. *Respondents' participation in various reef-related recreational activities. Source: van Beukering et al., 2007*

Rank	Activity	Days per household/yr	Share of active respondents
1	Swimming/wading	17.01	87%
2	Beach picnic/barbecue	13.26	92%
3	Fishing	9.05	45%
4	Snorkeling	7.4	44%
5	Kayaking/paddling	2.73	21%
6	Scuba diving	2.65	19%
7	Body boarding/surfing	1.75	12%
8	Jet skiing	1.73	14%
9	Windsurfing/kiteboarding	0.25	5%

Table K. *Perception of causes of environmental change in Guam's marine environment. The score represents the average importance that residents give to each of the proposed causes of environmental change in the marine ecosystems of Guam. Source: van Beukering et al., 2007*

Rank	Perceived cause of environmental degradation	Importance
1	Increased runoff and storm water	20.70%
2	Sedimentation due to poor development practices	20.60%
3	Leakage from broken sewage pipes	18.40%
4	Use of improper fishing methods (gillnets, fishing with scuba gear)	9.50%
5	Increased pesticide fertilizer outflows from golf courses and hotels	7.60%
6	Sedimentation due to intentionally lit fires	6.30%
7	Too many fishermen	5.70%
8	Too many jet skis, banana boats	5.10%
9	Too many divers and snorkelers	1.90%
10	Other, specify	4.20%

Discrete Choice Experiment (DCE)

The results of the DCE indicate that significant economic values are associated with three non-market benefits evaluated in the survey: local recreational use, abundance of culturally significant fish species, and noncommercial fishery values. Guam's residents appeared to place a similar value on the reefs' ability to provide local recreational benefits and supply culturally significant fish species. The results also indicated that maintaining reef fish and seafood stocks at a level that can support the culture of food sharing was very important. Interestingly, the DCE revealed that WTP for fish catches sufficient to share with family and friends was nearly triple the WTP for a catch large enough for the sale of fish ($92 versus $32), implying that the sharing of fish was more important than earning additional income. The DCE also revealed residents' attitudes towards management. Guam's residents generally supported a ban on some of the more exploitative fishing methods (e.g., night SCUBA spear fishing), but they were more concerned about managing the threat of pollution. The concern about pollution revealed in the DCE is not surprising considering pollution negatively affects both fishing and recreational beach uses, which were identified as two of the most important reef-related activities for Guam's residents.

Table L. *Total Economic Value of coral reefs in Guam. Source: modified from van Beukering et al., 2007.*

Type of reef-related value	Economic value (million $/yr)	Economic value (% of total)
Tourism	94.63	74.30%
Diving and snorkeling	6.69	6.80%
Fishery	3.96	3.10%
Amenity	9.6	7.50%
Coastal protection	8.4	6.60%
Biodiversity	2	1.60%
Total Economic Value	**127.28**	

Total Economic Value (TEV)

The researchers determined that the TEV of Guam's reefs is between $85-164 million/year with a core value of $127 million/year. Table L shows the breakdown by type of reef-related value. The tourism industry in general accounts for nearly three-quarters (74%) of the TEV, followed by amenity (e.g., property values) at 7.5% and diving and snorkeling at 6.8%. As is expected for a tourism-dependent island economy, the market value of the fishery sector (3.1%) is almost negligible compared to the value provided by non-consumptive goods and services.

Spatial Variation Analysis

A map of TEV was developed by aggregating individual maps of fisheries, tourism, recreation, amenity, biodiversity and coastal protection (Figure 34). The average value per square kilometer was $2 million/year, with the highest value area valued at nearly $15 million/year. The highest value reef area measures only 200 m^2, and is host to the most popular diving and snorkeling sites. A threat map was developed by aggregating maps of various

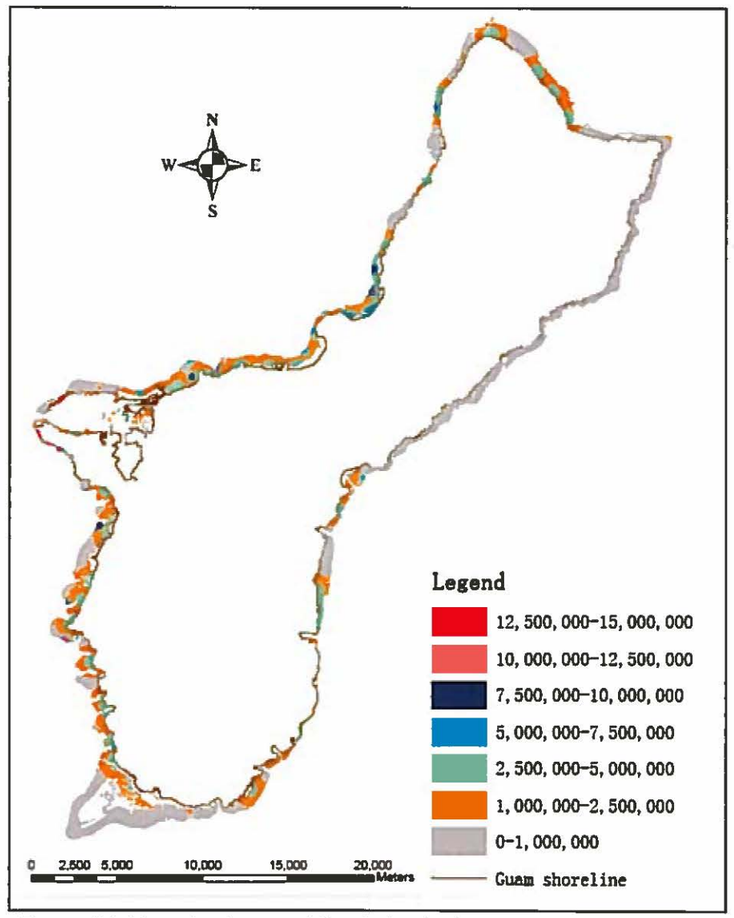

Figure 34. *Map showing spatial variation in the Total Economic Value of coral reefs and associated resources in Guam. Source: van Beukering et al., 2007*

threats, including sedimentation, eutrophication, freshwater runoff, overharvest and tourist overuse to build a map depicting the spatial variation in threats to Guam's reefs.

The results of the spatial analysis indicated that the most economically valuable reefs are, typically, the most threatened. The most valuable reefs are located within 200 m of the most popular diving and snorkeling spots. Corals adjacent to tourism areas in Tumon, Agana and Piti are also valuable due to their high level of use. Reefs in the southern part of the island have relatively high value due to tourism use, but are highly threatened due to sedimentation. The northern reefs are in better condition, but besides a few exceptions, their value is relatively low.

While the study helped identify the most valuable and most threatened reefs on Guam, and to some degree identified the type of threats endangering specific reefs, the authors suggest that, in order to provide the most economically-sound guidance to reef managers and policy-makers, the benefits and costs of various management interventions must be evaluated and sustainable sources of funding for these actions must be identified. Still, they were able to provide several policy recommendations based on the outcomes of the study, including: 1) making use of the cultural importance residents place on marine ecosystems to improve coral reef management; 2) actively involving the tourism industry in the development of sustainable coral reef management; 3) limiting the commercial consumptive use of coral reefs by prioritizing stronger enforcement of marine protected areas in Guam; and 4) prioritizing potential policy interventions in an economically sound manner.

Guam Coastal Management Program Outreach Effectiveness/Public Issue Priority Assessment

The GCMP contracted QMark Research and Polling in 2005 to conduct a quantitative study with Guam residents to evaluate the effectiveness of the Program's various public outreach activities and to identify the environmental issues of most concern to the public (QMark Research and Polling, 2005). This study, which involved 387 telephone interviews conducted in August 2005, was one of the more comprehensive assessments of public awareness concerning environmental issues on Guam.

The results of the survey indicated that a large majority (88%) of respondents considered the island's environment and natural resources a very important part of their lives. When asked to identify the level of responsibility that residents should bear in preserving Guam's natural environment, a majority (81%) agreed that they shared a large responsibility in the preservation and upkeep of Guam's natural environment. The local government and the community-at-large were identified as the two primary partners in the protection of the local environment. A majority of respondents indicated that trash/landfill issues are of primary concern, with concerns about drinking water quality/supply and pollution ranking a distant second and third, respectively. Interestingly, coral reef/marine issues and ocean/coastlines issues were not of great concern compared to trash/landfill, water quality/supply and pollution; this could be a result of the relatively high percentage of residents who don't snorkel or SCUBA dive and who may not be aware of the deteriorating state of some of Guam's reefs. The results suggest that future outreach activities should focus on informing citizens not only of the importance of Guam's reefs, but also about the poor condition of parts of the reef ecosystem.

The study also provided an opportunity to identify the primary sources of environmental-related information for Guam residents. The responses indicated that the Pacific Daily News, a local newspaper, and KUAM, a local television station, are the primary sources of environmental information for the largest number of respondents (89% and 78%, respectively), while 38% of the respondents obtained environmental-related information from GCMP's Man, Land and Sea television show or newsletter. The annual International Coastal Cleanup and Island Pride events (e.g., an annual festival, clean-ups, other events) were also a source of information for approximately a quarter of the respondents.

The researchers also sought to identify incentives preferred by residents for participating in the conservation of Guam's natural resources. New laws with penalties for violations were cited most often as a policy that would get residents to more actively participate in the care and upkeep of Guam's environment. About half of respondents felt that in-home demonstrations and having children asking adults to behave in a certain manner would be a successful strategy.

OVERALL REEF CONDITION/SUMMARY OF ANALYTICAL RESULTS

The health of Guam's reefs remains highly variable, with some reefs showing signs of degradation due to multiple stressors and others supporting diverse, relatively healthy reef communities. Since long term monitoring efforts have only recently begun, however, it is difficult to objectively assess the health of Guam's reefs. Still, it is clear from the data presented in this report that the stressors affecting Guam's reefs have increased and are likely to continue to increase in the future unless major action is taken. Poor water quality, the paucity of large herbivorous fish and low coral recruitment may severely decrease the resiliency of Guam's reefs to recover from future disturbance events. With this in mind, reefs described in this section as "healthy" should be considered so only relative to other, more degraded reefs on Guam, and relative to reefs of the past few decades as described by relatively limited data sets.

The data presented in this report suggest that the overall scarcity of reef fish, especially larger individuals, despite the persistence of some relatively healthy and diverse coral communities, continues to be a serious concern (Schroeder et al., 2006). The biomass of medium-to-large fish on Guam and Santa Rosa Bank rank as the lowest in the archipelago and is also quite low compared to other islands in the U.S. Pacific. In contrast, fish abundance has increased significantly in Guam's Marine Preserves (Gutierrez, 2003). Recent studies further demonstrate the effectiveness of the marine preserves in maintaining consistently greater target fish abundance than unprotected areas, and other ongoing studies appear to indicate adult fish and larvae are exported from the preserves to nearby reefs, potentially enhancing fish catches in these areas (Tupper, in prep (a) and (b)). Coral disease, bleaching and COTS outbreaks have emerged as more serious threats since the last report in 2005. Coral diseases have been documented across the island's reefs, minor to moderate bleaching has affected the shallow reef systems annually since at least 2006, and COTS populations have bloomed. Still, these threats do not affect all of Guam's reefs and a broad range of reef conditions have been documented.

The northern reefs are generally considered to be in better condition than reefs in the south, and although they may be exposed to elevated nutrient levels through groundwater discharge, northern reefs are not affected by the intense levels of sedimentation experienced by many southern reefs. In general, the highest coral cover and diversity on Guam is found 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. The abundance of medium-to-large fish is slightly higher on northern reefs compared to reefs in other parts of the island, possibly due to the relatively better habitat quality and restricted fishing access. COTS outbreaks may have significantly altered the coral communities in the northwestern part of the island in the last few years, however, including at least some of the reef extending north from Falcona Beach to Ritidian Point. The reef tract between Tanguisson Point and Falcona Beach, which was also reported to have high coral cover and diversity (Porter et al., 2005), has since been the site of the largest COTS densities recorded in the last few years (approximately 1,500 individuals/ha; C. Caballes, unpublished data).

The health of reefs along the central and southern portions of the east coast is highly variable; some reefs adjacent to large river mouths have been degraded by sedimentation and freshwater runoff, while other reefs appear relatively healthy. Some of the areas in the east-central and southeastern part of the island reported as relatively healthy in Porter et al. (2005), including the forereef slope off Achang Reef Flat Marine Preserve and the south side of Cocos Lagoon, have since experienced outbreak densities of COTS. Other areas previously known to have relatively high coral cover and diversity, such as near the UOGML in the northern part of Pago Bay and at sites south of Agfayan Bay and south of Talofofo Bay, have also been heavily impacted by COTS predation.

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 (>80%) on the island. The reefs along the northern side of the peninsula and the many patch reefs and shoals throughout the harbor provide habitat for a significant number of invertebrate species and are an important foraging area for resident sea turtles. Coral growth along the south side of Orote Peninsula is limited, with much of the reef comprised of turf and macroalgae-dominated pavement scattered with small

coral colonies. While the harbor reefs appear to be doing relatively well, the impacts of the increased turbidity, pollution, and invasive species associated with the area's use as a port and naval base have not been fully assessed. Approximately 1.2 ha (3 acres) of patch reef were removed from the entrance of the Inner Harbor by the Navy in 2006 and 2007 in order to meet the operational needs of the base. Additional areas are expected to be lost or degraded due to other planned construction and dredging activities in the harbor. In contrast to many other reef areas around Guam, COTS have been rarely observed within Apra Harbor.

Most of the fringing reefs and patch reefs along the southwestern shore remain in poor to fair condition, depending on their proximity to river mouths. MARAMP benthic towed diver surveys conducted in 2005 suggest that these reefs had the lowest average coral cover on the island. This is supported by the REA and UOGML data from this region. A 10 km stretch of reef in this area was reportedly heavily impacted by sedimentation from a poorly planned coastal road project in the early 1990s; the reefs in this area continue to experience high levels of sedimentation from erosion caused by wildland arson, off road vehicle use and other activities.

Several large bays, including Piti, Asan, West and East Agana, and Tumon, are located along the central western coastline. This area generally experiences calm conditions for most of the year and is readily accessed by fishermen and other recreational users. Both Piti and Tumon Bays host a wide diversity of habitats, and possess areas with vibrant reef communities. Since their designation as marine preserves in 2001, fish abundance within the bays has increased significantly. The increase in herbivorous fish densities appears to have better controlled the growth of palatable macroalgae in the two preserves, resulting in healthier looking reefs (T. Leberer, pers. obs.). Asan Bay is heavily impacted by fishing, with fish stocks decreasing in this area since monitoring began in 2001. The reef communities in Asan Bay are also heavily impacted by sediment- and nutrient-laden river and stormwater discharges. The health of coral communities in West and East Agana Bays varies; coral cover is relatively high, especially along the shallow reef front and forereef slope, but fish abundance is low.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

A broad network of agencies, educational/research institutions and non-governmental organizations continue to carry out a range of activities aimed at mitigating the threats to Guam's coral reefs, improving public awareness of coral reef issues and monitoring the vitality of Guam's coral reef resources. Progress towards short- and long-term increases in human capacity to effectively carry out these activities has been made with the establishment of two scholarship programs for graduate study in marine biology/ natural resource management, the NOAA Coral Management Fellowship, the Pacific Islands Technical Assistantship program, the NOAA Pacific Islands Regional Office (PIRO) Guam Field Office and various training opportunities for managers, technicians and teachers.

The goals and objectives of the various coral reef management projects on Guam are linked to the goals of the U.S. National Action Plan to Conserve Coral Reefs (2000) through locally-driven priorities enabled by the Local Action Strategy Initiative. In 2002, the Guam Coral Reef Initiative Coordinating Committee (GCRICC) identified the top five priority threats impacting Guam's coral reefs: land-based sources of pollution, overfishing, lack of public awareness, recreational misuse and overuse and climate change/ coral beaching/disease. By 2003, LAS were drafted to address each of these priority areas. The five priority focus areas of the first round of LAS will continue into the next three-year LAS cycle. An additional LAS is currently being developed to address the impacts of the military expansion.

Land-Based Sources of Pollution LAS

Land-based sources of pollution remain among the greatest threats to the vitality of Guam's coral reef ecosystem, and are perhaps the most challenging to address. Still, significant progress has been made in addressing this threat. The Watershed Planning Committee (WPC), comprised of representatives from local and federal agencies and NGOs, has continued in the development of a comprehensive watershed planning process to address pollution in each of Guam's watersheds. The committee previously

developed restoration strategies for the Northern and Ugum priority watersheds and has since implemented restoration activities using a combination of federal (EPA, NOAA and U.S. Forest Service) and local funds and resources, as well as volunteer time. The development of a suite of measures to control nonpoint source pollution from watershed degradation, agriculture, development, marinas, and other sources led to the recent federal approval of Guam's Coastal Nonpoint Source Pollution Control Program, bringing Guam into compliance with the requirements of Section 6217 of the Coastal Zone Management Act Reauthorization Amendments of 1990.

Current Management Activities
Land-based Sources of Pollution

- Federal approval of Guam's Nonpoint Source Pollution Control Program
- Re-vegetation efforts in Ugum and Fouha watersheds
- Extension of sewage outfalls at Hagatna and Northern STPs
- Adoption of Guam EPA Stormwater Management Manual
- Hiring of Arson Campaign Coordinator
- Hiring of consultant to develop management plan for Asan-Piti watershed
- Guam EPA's EMAP
- Wash-down facility and hazardous waste disposal containers at Agana Boat Basin
- Development of Seashore Reserve Plan

Guam's Department of Agriculture's Forestry and Soil Resource Division (FSRD), the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) and UOG are continuing work to restore grasslands and unvegetated areas (e.g., badlands) using erosion control fabric and nitrogen-fixing plants and trees such as *Acacia*. Between 2004 and 2005, approximately 52.6 ha (130 acres) of badlands and grasslands in the Ugum Watershed and the Coastal Conservation Reserve were converted to *Acacia* stands. Unfortunately, the success of these efforts was hindered by frequent wildfires and land ownership issues. The UOG, NPS, and the U.S. Navy are exploring the use of a variety of vetiver grass (e.g., *Vetiveria zizanoides*) as a means to reduce erosion in the southern watersheds. The watershed restoration efforts provide an opportunity for community members and groups to participate directly in the improvement of natural resources on Guam. Well over 1,500 volunteers have planted more than 75,000 trees in 86.6 ha (214 acres) since 2004 (Figure 35). The NPS is also focusing attention on watershed restoration and erosion prevention with an investigation into how off-road vehicles impact native vegetation and contribute to the persistence on badlands within the park and a project to evaluate the effectiveness of techniques for restoring native grasslands and reducing soil erosion.

Guam's resource agencies are pursuing additional reforestation projects throughout the island. Currently planned projects include the Masso Reservoir restoration and the Piti Conservation Action Planning (CAP) project (discussed below). The local agencies, in coordination with the federal resource trustee agencies, are also working to facilitate the use of watershed restoration as mitigation for coral reef losses due to dredging and other development projects. The first of these mitigation plans is presented in the final EIS for the Kilo Wharf Expansion (Commander Navy Region Marianas, 2007).

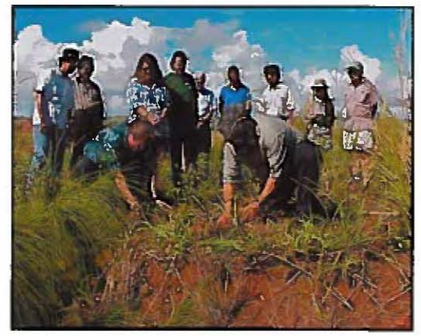

Figure 35. *Volunteers participating in a tree-planting event led by the Guam FSRD. Photo: Guam FSRD.*

The biggest challenge to watershed restoration efforts is the threat of wildland fires, most of which are set by poachers to promote the growth of young, tender plants preferred by deer. Wildland fire control efforts, which are also headed by the Guam Department of Agriculture, involve fuel reduction and the construction and maintenance of firebreaks and green breaks. During the dry season, the southern watersheds are patrolled and wildland fires are suppressed as effectively as possible. An arson campaign coordinator was hired by the FSRD in March 2007 to conduct outreach and education activities in an attempt to prevent illegal burning of natural grasslands.

Guam EPA has a number of permit processes in place to limit the impacts of nonpoint source pollution, including the Water Quality Certification (Federal Clean Water Act Section 401) and NPDES programs. Through its Water Pollution Control Program, Guam EPA is responsible for certifying all permit applications, recommending condition and abatement schedules for each permit, and providing oversight for the

implementation of and compliance with the conditions. The Guam EPA also regulates the injection of stormwater runoff into dry wells in order to prevent contamination of groundwater and the pollution of nearshore marine waters through subsequent discharge. In 2006, Guam updated its *Guidance for Best Practices in the Preparation of Soil Erosion and Sediment Control Plan* and the *Storm Drainage Manual* into a combined *Stormwater Management Manual*. All developments larger than 0.4 ha (about one acre) are required to adhere to the manual, which establishes as best practices the reduction in impervious surfaces, the maintenance of natural drainage patterns, the preservation of vegetation, the control of 80% of total suspended solids and maintenance of post-development runoff rates equal to pre-development levels. Major public works projects will also contribute to improved nearshore water quality. A new municipal solid waste landfill conforming to U.S. EPA and Guam EPA requirements is planned for a site in Dandan, Inarajan, and concrete steps towards the closing of Ordot dump and the construction of the new landfill were recently made with the signing of Executive Order 2007-2009, which outlines actions towards achieving compliance with the consent decree. In response to U.S. District Court orders, the Guam Waterworks Authority (GWA) is extending the sewage outfalls at the Northern (Tanguisson) and Hagåtña STP sites into deeper water in order to meet NPDES requirements. The outfall extensions will be constructed using directional-drilling technology to bore under the fringing reefs with minor disturbance to the coral communities. The Guam Seashore Reserve Plan Task Force, comprised of representatives from several of Guam's governmental agencies, developed a Guam Seashore Reserve Plan to better guide decisions of the Guam Seashore Protection Commission (GSPC). The 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 18.3 m (an area defined by law as the "seashore reserve"). The Plan will revise interim rules and regulations that have been in place since the passing of the Seashore Reserve Act in 1974 and provide clearer definitions and guidelines for managing development along the coast.

Fisheries Management LAS

The fisheries management LAS, developed by DAWR and reviewed by fishermen, resource managers and other stakeholders, originally focused on increasing the effectiveness of Guam's marine preserves. The strategy addresses three main issues: lack of enforcement and prosecution, lack of public awareness and support and the need to assess the ability of the preserves to increase reef fish stocks. The fisheries management LAS has been one of the more successful LASs for Guam, as most of the tasks outlined in the original plan were completed (Figure 36). Through CRI funding, four vehicles and other equipment were purchased to facilitate better enforcement; DAWR has also obtained funding from NOAA to purchase a pair of jet skis in 2008, and efforts are underway to procure a patrol vessel to improve marine preserve enforcement. As part of this effort, DAWR has produced a user-friendly fisheries regulations booklet, printed updated marine preserve brochures and is currently working on a multimedia educational campaign for the marine preserves. In addition, monitoring programs are underway in three preserves, and DAWR has developed regulations to implement Public Laws 27-87 and 27-30, which establish a permitting system for non-fishing activities in Marine Preserves and create the Conservation Officer Reserve Program. With the addition of a dedicated natural resource attorney hired by DAWR, the Division hopes to improve prosecution of marine preserve violations and gain legal approval for DAWR's citation system and eco-permit system. The GCRICC has continued to convey the importance of Marine Preserves to all parts of the community, from elementary schools to the territorial legislature, and undertake research focusing on the assessment of fish biomass increases within the preserves and associated spillover effects.

Current Management Activities
Fisheries Management

- Strengthening of statutory laws
- Creation of Conservation Officer Reserve Program
- Development of eco-permitting program
- Purchase of 4 vehicles, 2 jet-skis, and equipment for enforcement
- Production of user-friendly fisheries regulation booklet
- Development of multi-media campaign for Marine Preserves
- Hiring of natural resources prosecutor
- Development of new goals for LAS

Several legislative advancements were designed to bolster the original three-year local action strategy for coral reef fishery management. The statutory laws regulating Guam's reef resources were strengthened in 2006 through Public Law 28-107. This law updated and expanded the definition of terms used within the regulations, closing a number of loopholes in the regulations for the marine preserves by defining

Guam's Marine Preserves: Preserving our Marine Resources for the Future

"The purpose of the marine preserve is to protect, preserve, manage, and conserve aquatic life, habitat, and marine communities and ecosystems, and to ensure the health, welfare and integrity of marine resources for current and future generations." – 5 GCA, Title 16, Chapter 63, §63116.1

In 1997, the government of Guam passed Guam Public Law 24-21, establishing five marine preserves around the island to restore Guam's fishery resources. In 2006, Public Law 28-107 expanded the purpose of the preserves to include the protection and preservation of aquatic life, habitat, and marine communities and ecosystems and strengthened the protection of the preserves by making all forms of fishing and the taking or altering of aquatic life, coral, and any other resources within a preserve unlawful unless specifically permitted by DAWR through regulations.

The preserves vary in size from 3-20 km² and protect a variety of habitats from 10 m above mean high tide to the 183 m (600 ft) depth contour, including an ecologically valuable mangrove area in Sasa Bay. The preserves are managed and enforced by the Guam DAWR.

Enforcement of the preserve regulations began in 2001. Current regulations allow limited take using specific methods or limited species, such as trolling for pelagic fish, shoreline hook and line fishing in the Pati Point Preserve for unrestricted species, and limited traditional take in the Tumon Bay Preserve for four species using specific hook and line or cast net methods. The department also issues special permits in the Achang Reef Flat and Piti Bomb Holes Preserves for traditional harvest of seasonal runs of juvenile rabbitfish (*mañahak*), juvenile jacks (*I'e*) and scads (*atulai*).

Preserve	Area (km²)
Achang Reef Flat	4.85
Sasa Bay	3.12
Piti Bomb Holes	3.63
Tumon Bay	4.52
Pati Point	20.00
Total:	**36.12**

The Tumon Bay and Piti Bomb Holes Preserves are popular recreational sites, but the high level of use appears to have a detrimental effect on the marine ecosystems. DAWR is currently developing "eco-permitting" regulations that will allow the agency to place limitations on certain activities within the preserves and require a permitting process for all commercial uses of the preserve. DAWR hopes to involve the community in developing these limits.

Studies by DAWR and UOGML have indicated a substantial increase in the abundance of fish found within the preserves (Gutierrez, 2003; Tupper, in prep (a) and (b); Pioppi, in prep) and initial results of a study on larval transport and spillover suggest that the beneficial effects are extending outside of the preserve boundaries (M. Tupper, pers. comm.). Unfortunately, these improvements are hampered by illegal fishing within the preserves. To address this problem, DAWR has purchased equipment necessary for enforcement and developed a Conservation Officer Reserve Program to increase the number of officers patrolling the marine preserves as well as to educate the public about Guam's fisheries regulations. They have also launched a new educational campaign entitled "Marine Preserves are good for Guam. Marine Preserves are good for you," to help residents understand the benefits of marine preserves.

the Chamoru terms for certain fish life stages such as i'e (juvenile jacks) and tiao (juvenile goatfish). It also strengthened the marine preserves by inserting two new sections into the 5 GCA, Chapter 63, defining the purpose of the Marine Preserves and the activities allowed in the marine preserves. Public Law 28-107 also expanded the definition of coral to include, "any live or dead member or part thereof of the Phylum Cnidaria that form calcareous skeletons, spicules or sclerites (including soft and hard corals both hermatypic and ahermatypic) or exist as sessile, solitary, or colonial polyps." In 2005, the

legislature passed Public Law 28-30, which created a Conservation Officer Reserve Program designed to expand enforcement coverage by the addition of ten part-time civilian officers. Through CRI funding, DAWR has created the regulations governing this program, developed training modules, and procured equipment for the reserve officers. The program is scheduled to begin in early 2008, pending final approval. As most of the original goals were met by 2005, DAWR developed a new set of goals for the fisheries management LAS. The new goals include identifying non-sustainable fishing practices, developing sustainable alternatives and developing demand schedules to reduce overharvest. The specific objectives for this new LAS effort include: research on the structure of reef fish communities around the island; increased water quality monitoring in coastal areas; identification of fishing methods that have a disproportional effect on reef fish and an examination of alternatives that could ease the impact on reefs; provision of educational materials about reef fish biology and ecology to facilitate better harvest choices; and the identification of spawning periods and aggregation sites for key species.

Figure 36. *A school of yellowstripe goatfish, (Mulloidichthys flavolineatus), known locally as satmoneti, in the Tumon Bay Marine Preserve. Goatfish, which are abundant in the preserves, are one of most often targeted reef fish outside of these protected areas. Photo: D. Burdick.*

Lack of Public Awareness LAS

The lack of public awareness LAS has been one of the more active and successful of Guam's LAS strategies. The coordination of multiple partners and the implementation of innovative social marketing techniques have increased the effectiveness of outreach efforts on Guam. The development of an engaged, active outreach coordinating body and a comprehensive coral reef outreach strategy, improved capacity, and the movement towards regularly conducted public awareness surveys all contributed to improved coral reef outreach and education activities. A promising sign is the significant increase in community participation in cleanups, tree plantings, recycling drives, and other events. The government of Guam has sought to further encourage environmental participation and leadership by establishing annual awards, such as the Environmental Steward of the Year and the Governor's Green School Award.

The Guam Environmental Education Committee (GEEC), comprised of representatives from a wide array of government agencies, private businesses and community groups, has made significant strides towards a comprehensive environmental education and outreach program that involves many partners and utilizes multiple products and media outlets. The GEEC developed an environmental education strategy to provide guidance to government agencies regarding environmental outreach efforts. The work of the GEEC has been coordinated with and supplemented by the Guam Environmental Education Partners, Inc. (GEEPI), which serves as a non-governmental partner in outreach and education efforts. Numerous island pride events have also been carried out since 2004. The Island Pride Program, which was developed by GCRICC members, combines educational and environmental activities with fun events designed to instill a sense of stewardship among the island's youth. Island Pride events conducted since 2004 include annual Island Pride/Earth Day festivals, beach clean ups, an annual kid's fishing derby at the WAPA, tree planting, and recycling drives at parades and other events. Public participation in these events has grown considerably in recent years. The campaign has also strengthened ties among the GCRICC and GVB, as well as with the private sector, which has helped sponsor these events. A series of environmental education and outreach products was developed to promote coral reef awareness as part of the campaign. The campaign prominently features Professor Kika Clearwater, a cartoon spokesperson, on a variety of products (Figure 37). Products include a video played on the

Current Management Activities ***Lack of Public Awareness***
• Island Pride events • Development of school curriculum • Marketing survey to evaluate effectiveness of outreach efforts • Guardian's of the Reef program • International Coastal Cleanup • Marine debris campaign • International Year of the Reef activities

Visitor's Channel, posters, hotel tent cards, a quarterly newsletter, calendars, movie theater intermission slides, a recycling guide, marine life identification slates, and public service announcements for radio, newspaper and television. Teacher guides and school curricula are also under development.

The Guardians of the Reef project, developed by the NOAA Coral Fellow for Guam and the GCMP, utilizes local 11th and 12th grade students to provide coral reef-focused educational opportunities to 3rd grade students. In 2007, 20 pairs of high school students each developed a one-hour program, which was presented to about half of the 3rd grade classrooms in public schools around the island. The success of the Guardians of the Reef project has encouraged other high schools to participate; the program may be expanded to all public and private schools on Guam in 2008.

Figure 37. *Professor Kika Clearwater, mascot of the Island Pride campaign, is featured in a variety of products, including a video played on flights from Japan and on a local tourism TV channel.*

Several other campaigns planned for 2008 by partner organizations will further increase public awareness of coral reef issues. The GCMP, GEEPI and NOAA PIRO will be spearheading a year-long campaign to coincide with the International Year of the Reef in 2008 (IYOR08). The signing of an Executive Order declaring 2008 as International Year of the Reef will kick off the campaign, followed by dozens of activities planned throughout the year. The first Guam Coral Reef Symposium, which will feature presentations from managers, researchers, educators, and others working on CRI-funded projects, will also be introduced with the IYOR08 campaign. NOAA's PIRO obtained funding from the NOAA Marine Debris Program for a marine debris education campaign for Guam designed to increase residents' awareness of marine debris impacts and promote stewardship for coastal and marine resources. This program will be supplemented by a community-based marine debris education and prevention campaign designed by Micronesian Divers Association, a local dive shop, in coordination with the Guam Marine Awareness Foundation and funded by the NOAA Marine Debris Program Community-based Marine Debris Prevention and Removal Grants.

Recreational Misuse and Overuse

While the impacts of recreational misuse and overuse are not as pervasive as threats such as sedimentation, stormwater runoff and overfishing, the impacts of recreational users can cause localized degradation to high value reef habitat. Several steps have been made to address the threat of recreational misuse and overuse under the Recreational Misuse and Overuse LAS.

With the passing of Public Law 27-87 in May 2004, which creates a marine preserve eco-permitting system administered by DAWR to address non-fishing activities in Guam's Marine Preserves, DAWR developed a fee schedule and a permitting plan for carrying out its new regulatory authority. The rules and regulations are awaiting legal review before they can be approved. A workshop was conducted in May 2005 to receive input from stakeholders regarding the eco-permitting plan. The workshop also provided information to commercial operators and recreational users regarding the impact of recreational users on Guam's coral reefs.

A study of the effects of personal watercraft use on marine communities in East Agana Bay was completed in 2006 (PCR Environmental, Inc., 2006). The results of the study, which indicate little or no observable impact on the marine

Current Management Activities ***Recreational Misuse/Overuse***
• Development of eco-permitting plan to regulate non-fishing activities in Marine Preserves • Recreation impacts workshop • Informational kiosks along Tumon Bay • In-flight video for tourists arriving from Japan • Study to identify alternate introductory scuba sites • Study evaluating impacts of PWC on marine communities in East Agana Bay • Update of Recreational Water Use Master Plan

communities in the study areas, will be used to help update the Recreational Water Use Master Plan. A study to identify alternative sites for beginning SCUBA divers will be carried out in 2008. This study, which will also examine possible modifications of existing sites, should provide resource mangers with options for reducing the high level of recreational use, and the associated impacts on the ecosystem, in the Piti Bomb Holes and TBMP. Natural resource management agencies have continued to engage stakeholders within the tourism sector, including the GVB and the Guam Hotel and Restaurant Association, in marketing Guam's coral reefs and marine preserves to the one million visitors that arrive annually. An on-going campaign launched by GVB, in association with GCMP, involves a range of projects aimed at educating tourists about the value of Tumon Bay's marine community and ways to reduce their physical impacts. The campaign is comprised of a range of activities, such as the installation of four education kiosks along Tumon Bay, the development and distribution of waterproof marine life identification slates, the development and local use of school curricula and teacher guides, and screening of an educational video on the Visitor's Channel to educate tourists about how to avoid damaging coral reefs.

Coral Bleaching and Disease

The Coral Bleaching and Disease LAS continues to be one of the most challenging to address at a local scale. Previous activities under this LAS primarily involved management efforts covered by other LAS to reduce local anthropogenic stressors, raise public awareness, and improve coordination among resource agencies with regard to reef resiliency and climate change. Recent activities under the coral bleaching and disease LAS have more directly addressed the threats of coral bleaching and disease by improving our understanding of how coral diseases and bleaching affect Guam's reefs, increasing the ability of the natural resource agencies and UOGML to respond to bleaching and disease events, and improving protected area design and management through the incorporation of resiliency to climate change.

Current Management Activities
Coral Bleaching and Disease

- Baseline assessment of coral disease prevalence
- Long-term monitoring of coral disease
- Coral disease workshop
- Development of bleaching response plan

As described in the "Benthic Habitats" section, a baseline coral disease assessment was carried out in 2006 and 2007, and a long term program for monitoring coral diseases was initiated. In addition, a coral disease workshop was conducted at the UOGML to improve local capacity in responding to disease events. Several representatives from Guam also attended a workshop conducted by NOAA and the Great Barrier Reef Marine Park Authority entitled, *Responding to Climate Change: a Workshop for Coral Reef Managers* in August 2007. The workshop was geared toward managers and biologists from various Pacific jurisdictions and provided information about the threat of coral bleaching and training in the use of NOAA's satellite monitoring tools. The workshop also prompted the development of a coral bleaching response plan for Guam as part of a larger coral reef response plan, which will provide protocols for predicting and monitoring bleaching events as well as guidance for incorporating reef resiliency into coral reef management efforts.

Military Expansion on Guam

The GCRICC has identified as a priority the potential threat of the planned military expansion on Guam's coral reef ecosystem and is currently developing a LAS to address it. Projects under this LAS may include: the development of a comprehensive natural resource management strategy; independent assessments of the environmental impacts of certain military activities; assistance in the development of a compensatory mitigation policy; a review of current legislation; an update of the building code to include the U.S. Green-Building Council's Leadership in Energy and Environmental Design recommendations; the development of a model for determining the cumulative and secondary impacts of various land use activities on the northern aquifer; public outreach efforts; and invasive species-related projects.

Guam Coral Reef Monitoring and Response Plans

Guam has made great strides since 2004 in addressing gaps in monitoring efforts. The multi-agency Guam Coral Reef Monitoring Group (GCRMG) developed an island-wide monitoring strategy that incorporates existing monitoring programs, including Guam EPA's EMAP and Status and Trends Monitoring programs, DAWR's Marine Preserve Monitoring, UOGML's long-term monitoring program and NPS monitoring

activities. The territorial monitoring program, which will also include the establishment of additional long-term monitoring sites, will provide data for a number of parameters useful in assessing coral reef ecosystem health and identifying specific stressors. The monitoring program will allow resource managers to evaluate the effectiveness of specific management strategies and serve as an early warning system for changes in reef health. The implementation of a three-year block grant, as recommended in the 2005 report, provided an important foundation for the long-term monitoring strategy, and the significant expansion of monitoring sites, the procurement of a central monitoring data server, and the development of a web-based data entry and automated report-generation application.

Guam is also developing coral reef response plans for coral bleaching, disease, COTS outbreaks, groundings, spills and storm damage. The plans will establish protocols for responding to a number of disturbance events including the assessment of vessel grounding and spill impacts to determine compensatory mitigation, rapid response for coral disease outbreaks (e.g., identifying the disease(s)), assessing prevalence and coral mortality and collecting tissue samples), assessment and control of COTS outbreaks, and post-storm coral community assessments and cleanup efforts. The response plans will also outline the development of community watch programs for COTS, bleaching and disease.

New Approaches to Coral Reef Management

Conservation Action Planning

In preparation for the next iteration of Guam's local action strategies, members of the GCRICC explored the use of a process developed by The Nature Conservancy (TNC) called Conservation Action Planning (CAP) to develop a site-based local action strategy for the Piti Bomb Holes Marine Preserve and adjacent watershed. As part of the process, the GCRICC developed a preliminary list of focal conservation targets with an assessment of their viability, and identified and ranked critical threats affecting the focal targets. The group also developed a preliminary list of strategic objectives and actions to either abate the critical threats or enhance the viability of the targets, and practical indicators to measure success. Finally, the group conducted a self-assessment of their capacity to implement this conservation action plan.

The group identified certain benefits of using a site-based approach in developing their next round of LAS, including compatibility with Guam's watershed planning process, the ability to more objectively prioritize targets, threats, actions, and resources, as well as the strengthening of the GCRICC by bringing together members with diverse technical expertise to holistically address multiple threats at one site, allowing for the prioritization of sites versus projects. In early 2007, the GCRICC began coordinating with the Piti Mayor's office to engage the community in the process of implementing actions identified in the Piti LAS/CAP. A consultant from the Center for Watershed Protection will assist in the development of watershed management plan for the Piti-Asan watershed. Funding has been secured for large scale re-vegetation efforts in the watershed beginning in 2008.

The Micronesia Challenge

In January 2006, Governor Felix P. Camacho signed the Micronesia Challenge (MC), a commitment by the Chief Executives of Guam, the Commonwealth of the Northern Mariana Islands, the Federated States of Micronesia, the Republic of the Marshall Islands and the Republic of Palau to effectively conserve at least 30% of nearshore marine resources and 20% of terrestrial resources across Micronesia by 2020.The MC is the result of a process that began at the 7th Conference of the Parties to the Convention on Biological Diversity (CBD) in 2004 in Kuala Lumpur, Malaysia where world leaders committed to an increase in protected areas around the globe. At the 2005 Mauritius International Meeting High Level Event, the Presidents of Palau and the Seychelles called for the establishment of a Global Island Partnership. In November 2005 at the US Coral Reef Task Force Meeting, Palau President Tommy E. Remengesau, Jr. invited the other chief executives from Micronesia to join him in committing to the MC. The MC was then officially announced to the international community by President Remengesau at the 8th Conference of the Parties held in March 2006 in Curitiba, Brazil.

The MC was conceived as a result of the deep commitment of these five leaders to ensure a healthy future for their people, protect their unique island cultures, and sustain the livelihoods of their island communities, by sustaining the island biodiversity of Micronesia. The MC also contributes to global and

national targets set out in the Millennium Development Goals, the Johannesburg Plan of Implementation for the World Summit on Sustainable Development, the Mauritius Strategy for Small Island Developing States, the U.S. Coral Reef Task Force National Plan of Action and the relevant Programmes of Work of the Convention on Biological Diversity.

To begin the process of implementing the Micronesia Challenge, 80 representatives from the 5 jurisdictions participated in a regional action planning meeting in Palau in early December 2006. This meeting resulted in a comprehensive set of recommendations that were endorsed by the Chief Executives in 2007 and will be presented to the Presidents of the FSM and the RMI at the upcoming Presidents' Summit. Recommendations included the following:

- The establishment of a Steering Committee, comprised of a focal point from each of the jurisdictions;
- The budgeting for and recruitment of a regional coordinator and support staff;
- The development of an annual report process;
- The development of a regional fundraising strategy in coordination with national strategies for public and private funds to support the MC;
- The proposal that the Micronesia Conservation Trust house a single endowment in support of the MC; and
- The commitment that each jurisdiction takes the appropriate steps to institutionalize the MC, including the engagement of traditional and community leaders.

Guam and each of the other four jurisdictions are designing their own strategies to implement the MC involving partnerships between Government agencies, NGOs and local communities. The MC Steering Committee, made up of government focal points from each jurisdiction, provided regional coordination and recently hired a Regional Coordinator to advance MC activities across the region.

The MC Regional Support Team, with representatives from NOAA, Department of Interior, the Secretariat of the Pacific Regional Environment Program, Rare (formerly RARE Center for Tropical Conservation), the Micronesia Conservation Trust, the Locally Managed Marine Area Network, the Community Conservation Network, the Pacific Islands Forum, The Nature Conservancy, Conservation International, and the local conservation NGOs in each of the jurisdictions has been formed to provide strategic assistance and external resources required for effective implementation of the MC.

Along with the other jurisdictions, Guam has developed a strategy to implement the MC, involving partnerships between government agencies, NGOs and local communities. One of the first actions Guam is undertaking is the development of a sustainable financing plan to be completed in early 2008. The plan will identify the level and sources of funding needed to effectively manage Guam's natural resources and meet the goals of the MC. The plan will also identify key strategies, from internal and external sources, to secure the necessary funding, including the building of an endowment.

CONCLUSIONS AND RECOMMENDATIONS

Similar to what was reported in 2005, the health of Guam's coral reefs varies significantly across the island. In general, reefs in the northern part of the island and southern reefs at sufficient distances from rivers are relatively healthy, while large sections of reef in the south, particularly those near river mouths, are in poor to fair condition. Chronic COTS outbreaks have affected numerous reefs around the island in the last few years, including some reefs previously characterized by relatively high coral cover and diversity. Individual fish >25 cm are uncommon to rare on Guam, and while their numbers are slightly higher on northern reefs, medium and large fish abundance is still very low compared to other islands in the Mariana Archipelago. The ability of some reefs on Guam to recover from their current degraded state and from acute disturbance events such as COTS outbreaks, storms and bleaching events, is likely hindered by poor water quality, low target herbivorous fish abundance and low coral recruitment.

The GCRICC and a broad network of local and federal agencies, NGOs, legislators, private enterprises, teachers, students and other concerned citizens continue to partner in the implementation of ambitious and creative ways to address the primary threats to Guam's coral reefs. Re-vegetation efforts, outreach campaigns, enforcement within marine preserves, development of a comprehensive monitoring strategy, the strengthening of existing policies and the planned implementation of new ones are all examples of Guam's commitment to improving the health of its coral reef resources. Major public works projects, including the extension of sewage outfalls and the closing of Ordot dump, will also contribute to a healthier reef system. Guam's participation in the MC represents a major step towards effective management of the island's natural resources, setting achievable conservation goals and providing an opportunity to further engage the community in natural resource management. The increasing level of community participation in cleanups and erosion control efforts, as well as the success of outreach and education activities like the Island Pride Campaign and the Guardians of the Reef Program, indicates that public awareness is increasing.

Although Guam has made a great deal of progress in coral reef protection, monitoring and public outreach over the past several years, many challenges still remain. Financial and human resources remain limited compared to the need, and are disproportionate to the value of goods and services generated by coral reefs. Present capacity will be further stretched by the planned military expansion and by the additional responsibilities required to carry out new programs. The military expansion presents a direct threat to coral reef resources through dredging and filling of reef areas, as well as an indirect threat stemming from the consumption, recreational and housing demands that the tens of thousands of new residents will place on Guam's reef resources. Wildland arson is still a major problem in many watersheds in southern Guam, and stormwater runoff and aquifer discharge continue to contribute excessive volumes of freshwater, nutrients, heavy metals and other pollutants to nearshore waters, impacting high-value reef systems such as Tumon Bay.

Global climate change poses a particularly grave and increasingly pressing threat to the vitality of Guam's reefs. The expected increase in incidences of coral bleaching, ocean acidification and the potential for stronger storms will directly affect reef health, challenging even the most resilient reefs. Expected economic and social changes at the global, regional, and national levels are likely to strain resources devoted to coral reef management as priorities shift to cope with the impacts of migration, poverty and disease associated with climate instability (Stern, 2006).

Policy interventions must be prioritized in an economically sound fashion in order to most efficiently allocate the limited financial and human resources available to coral reef managers to address pressing issues of coral reef degradation in a timely manner. The use of extended cost-benefit analyses would help identify management actions that provide the most benefit for the lowest cost. Site-based approaches, facilitated by the CAP or similar tools and involving strong community participation and a coordinated network of multiple organizations, would focus resources on management actions that address a spectrum of threats within a specific area. In order to more effectively address current threats to Guam's coral reefs and to prepare for threats associated with the planned military expansion, local and federal agencies must actively push to ensure that important plans and programs, including the Eco-Permitting Program, the Seashore Reserve Plan and the Conservation Officer Reserve Program are implemented immediately. The financial and staff capacity of the resource management community must be significantly increased if current coral reef threats and threats associated with the anticipated military expansion are to be adequately addressed.

It is crucial to expand and expedite re-vegetation efforts and eliminate the threat of wildland fires in order to restore watershed integrity and nearshore water quality, allowing the recovery of once-productive reef systems and enhancing their capacity for long-term survival. Stop-gap measures to prevent soil erosion should be implemented broadly as soon as possible, followed by restoration of native vegetation. Additional funding and active community involvement will be needed to achieve success on an island-wide scale. The disproportionate contribution of a small number of poachers to large-scale watershed degradation must be addressed through aggressive and creative enforcement, application of steep penalties that are proportionate to the damage that results and intense outreach to communities affected by the fires.

Although fish abundance has increased within the marine preserves and spillover is becoming apparent, additional fisheries management tools are necessary to address the severe depletion of key reef fisheries on Guam. Species-specific regulations, such as size and catch limits or closures during spawning seasons, and limits on exploitative fishing practices are required to restore populations of large, slow-growing species that aren't effectively protected by the preserves. Particular attention should be placed on protecting large herbivorous fish and iconic species such as napoleon wrasse, possibly including a ban on the take of these species. The results of surveys conducted for the economic valuation study indicate that there is support among the public for a ban on scuba spearfishing and the use of monofilament gill-nets. The involvement of the community, and fishermen in particular, will be crucial in addressing these concerns. Following the lead of American Samoa, the Commonwealth of the Northern Mariana Islands, and numerous other nations around the world, Guam should consider banning particularly exploitative, non-traditional fishing methods immediately to help to restore vulnerable reef fish populations, preserve cultural fishing practices and improve overall coral reef ecosystem health.

Future environmental outreach and education efforts should continue to build on the success of efforts such as the Island Pride Campaign and the Guardians of the Reef Program, encouraging even greater participation in these events and further engaging the public through community-based monitoring and management efforts. The effectiveness of outreach and education activities can be improved by further implementing social marketing techniques and by utilizing information obtained through regularly-conducted socioeconomic surveys. There is a great need in Guam for more community-driven action; the natural resource management agencies and partnering organizations and institutions can help facilitate this through internships, training, and other opportunities for future environmental leaders and enable the development of community-based, environmentally-focused NGOs, which are lacking on Guam.

Natural resource management agencies must actively involve the tourism industry and the community in the development of sustainable coral reef management policies to address the impacts of tourism on Guam's reefs. Recreational misuse and overuse at highly valued sites, such as Tumon and Piti Bays, requires immediate attention. The Eco-permitting Program, once approved, will provide the mechanism through which non-fishing activities can be limited within the preserves, but more information is required to achieve sustainable levels of recreational use without further damaging the resource or jeopardizing the viability of responsible commercial operations.

It is clear that the ability of Guam's reefs to cope with climate change must be enhanced significantly if productive reef systems, and the goods and services they provide, are to be available to future generations. Since it is appears that even immediate global action to reduce greenhouse gas emissions will not prevent some further climate change, our main course of action should be to significantly reduce local impacts to Guam's coral reefs. These actions must be undertaken with a new sense of urgency. Addressing the most severe local impacts will increase the likelihood that Guam's coral reefs will survive through a difficult few decades. To achieve this will require a deep commitment by political leaders, coral reef managers, researchers, and the citizens of Guam to dedicating resources for the rapid, large-scale reduction in the threats currently affecting Guam's reefs. It will also require a vastly improved understanding of reef resilience to climate change and the effective integration of the concept of resiliency into a viable, long-term coral reef management strategy.

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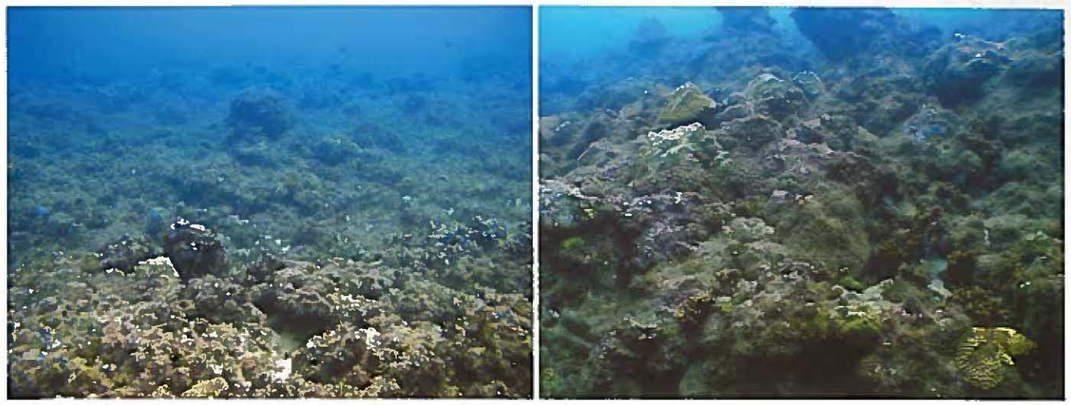
Left: A lush Pocillopora- *and* Stylophora*-dominated coral community at 11-mile reef, a relatively deep (~ 25m) reef occurring off the southwest coast (Sept. '08). Right: A diverse, healthy coral community near Tarague Beach, along the northern coast (Aug. '08). Photos: D. Burdick.*

Left: The forereef near Asgadao Bay, in the Achang Reef Flat Marine Preserve (Aug. '07). While possessing a relatively robust reef fish community, the coral community in this area appears to have been recently impacted by Acanthaster *predation. Right: A* Porites*-dominated coral community in Cetti Bay, southwestern Guam (Dec. '07). Photos: D. Burdick.*

Left: Dense growth of Porites rus *and massive* Porites *species on the forereef slope in Agana Bay, near Adelup Point (June '08). Right: A similar coral community at the northern reaches of Agana Bay, near Alupat Island (Jan. '08). While the coral communities along much of this large bay appear to be relatively healthy, medium to large fish are uncommon. Photos: D. Burdick.*



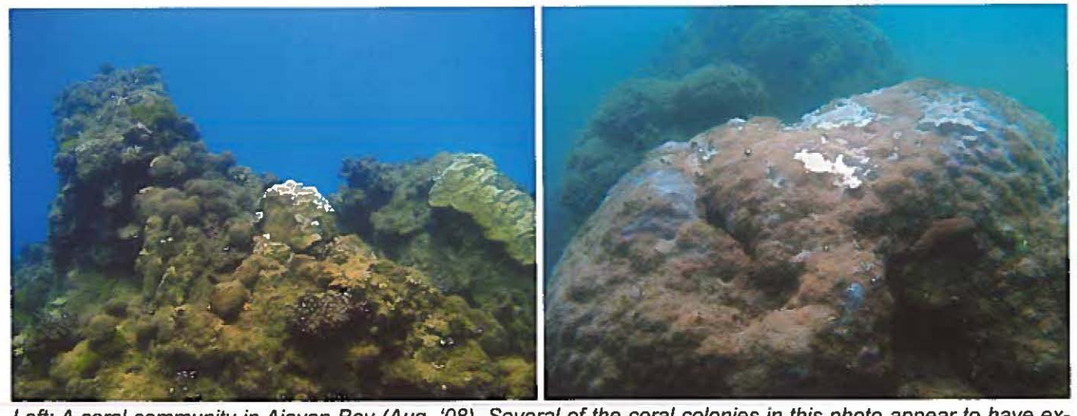
Left: A highly degraded reef community near Apaca Pt., Agat (Oct. '08). Little living coral can be found in this area, and a thick algal mat laden with sediment covers much of the substrate. Right: A reef community between Toguon and Bile bays, in southwestern Guam (Nov. '07). The reefs in this area appear to have once hosted robust, diverse coral communities, but poor water quality, Acanthaster *predation, depauperate reef fish communities, and perhaps other factors have likely contributed the degradation of these reefs. Photos: D. Burdick.*

Left: A Porites rus*-dominated coral community near Gabgab Beach, Apra Harbor (Sept. '07). Right: The intact skeletons of* Acropora *sp. at Western Shoals, Apra Harbor (June '07). It's not clear what caused the mortality of* Acropora *thickets in this area, a combination of coral bleaching and disease is suspected. Photos: D. Burdick.*

Left: The forereef slope near Urunao Pt., in northwestern Guam, with evidence of extensive, and fairly recent (< 5 yrs), Acanthaster *predation (May '08). Right: The forereef slope near Ajayan Bay, in southeastern Guam, also with evidence of recent* Acanthaster *predation (Aug. '08). Photos: D. Burdick.*

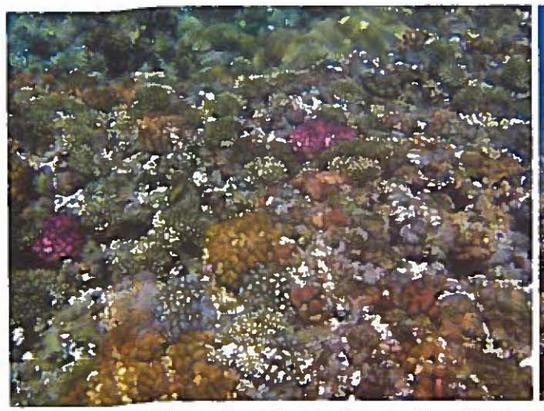
Left: The forereef slope near Ga'an Pt., Agat (Dec. '07). The reefs in this area are heavily degraded, with low coral cover, low diversity, and extensive algal growth covering much of the substrate. Right: A relatively rich coral community south of Agfayan Bay, Inarajan (May '07). Chronically elevated Acanthaster *populations appear to have reduced living coral cover in this area in recent years. Photos: D. Burdick.*

Left: A rich reef community on the forereef slope of eastern Cocos Lagoon (Jan. '06). Numerous coral colonies in this area appear to have been recently impacted by Acanthaster *predation. Right: a typical, relatively barren reefscape on the forereef along the western side of Cocos Lagoon (Jan. '06). Photos: D. Burdick.*



Left: A coral community in Ajayan Bay (Aug. '08). Several of the coral colonies in this photo appear to have experienced full or partial mortality relatively recently, perhaps by Acanthaster *predation, but the sediment-crusted substrate also suggests stress as a result of poor water quality. Right: A massive* Porites *colony near Nimitz Park clearly impacted by poor water quality (Sept. '04). Photos: D. Burdick.*


Left: A coral community along the reef margin at Gun Beach dominated by Acropora digitifera *(Mar. '08). Right: A* Porites rus*-dominated coral community on the forereef slope near Gun Beach (Jan. '08). Photos: D. Burdick.*




Left: Dense coral growth on the shallow reef front in Haputo Bay, in northwestern Guam (July '07). Right: A similar coral community near Adelup Pt. (June '08). The coral communities in the wave-washed reef front around much of Guam host Guam's more diverse, apparently healthy coral communities. The abundance of small coral colonies suggest sustainable levels of coral recruitment, perhaps aided by the high wave energy, which limits the growth of nuisance algae species and prevents sediment from accumulating on the colonies. Photos: D. Burdick.


Left: A coral community on the shallow (<10m) reef shelf at Pati Pt., dominated by relatively small, sparse Acropora *spp. and* Pocillopora *spp. colonies (Aug. '08). Right: Limited coral growth near Blue Hole, on the south side of the Orote Peninsula (Nov. '07). Several of the* Pocillopora *colonies in this photo appear to have been recently preyed upon by* Acanthaster. *Photos: D. Burdick.*


Left: Dense, vibrant coral growth on the reef flat in Tumon Bay (Feb. '06). Right: Extensive Acropora *sp. thickets on the reef flat at Luminao Reef (May '04). Photos: D. Burdick.*


Left: An Acropora *sp. thicket in Piti Bomb Holes Marine Preserve (Mar. '08). Right: Highly eroded* Acropora *spp. rubble on the reef flat in the Piti Preserve (Oct. '07). While some* Acropora *spp. thickets still remain in the preserve, mainly in protected "bomb holes" scattered across the reef flat, the vast amount of* Acropora *spp. rubble suggests much more extensive* Acropora *growth in the recent past. Photos: D. Burdick.*


Left: The reef margin in the Piti Bomb Holes Marine Preserve, dominated by the alcyonacean, Asterospicularia randalli *(Mar. '08). Right: The forereef slope in the Piti Bomb Holes Marine Preserve (Dec. '07). Few living scleractinian corals have colonized the skeletons of corals that appear to have been killed in the last few decades, possibly as a result of catastrophic* Acanthaster *predation in the 1970s and/or acute sedimentation events associated with upland development and dredging. Photos: D. Burdick.*