CORAL REEF ECOSYSTEMS OF THE MARIANA ARCHIPELAGO:

a 2003-2007 Overview

PACIFIC ISLANDS FISHERIES
SCIENCE CENTER

CORAL REEF
ECOSYSTEM DIVISION

CORAL REEF ECOSYSTEMS

OF THE MARIANA ARCHIPELAGO:

a 2003-2007 Overview

The PIFSC mission is to conduct high-quality, timely research to support the stewardship of fisheries resources, protected species, and ecosystems in the central and western Pacific Ocean.

To obtain copies of this document, contact PIFSC:

Pacific Islands Fisheries Science Center
2570 Dole Street
Honolulu, HI 96822-2396
(808) 983-5303

An online version is available at http://www.pifsc.noaa.gov/cred.
Unless otherwise indicated, photographs in this publication are in the public domain.

This document may be referenced in the following manner:

Pacific Islands Fisheries Science Center (2010) Coral reef ecosystems of the Mariana Archipelago: a 2003–2007 overview. NOAA Pacific Islands Fisheries Science Center, PIFSC Special Publication, SP-10-002, 38 p.

Front cover: Thysanostoma *jellyfish commonly found throughout the Pacific.* NOAA photo by Kevin Lino

Back cover: The cone-like shapes and colorful, twin, spiral gills of tube-dwelling worms burrowed into this Porites *coral colony have earned them the common name, "Christmas tree worms."* NOAA photo

TABLE OF CONTENTS

This booklet provides the draft executive summary and key findings from the *Coral Reef Ecosystem Monitoring Report of the Mariana Archipelago: 2003–2007* (in review). The full report is a comprehensive analysis of the Pacific Reef Assessment and Monitoring Program research surveys conducted in the Mariana Archipelago in 2003, 2005, and 2007 by the Coral Reef Ecosystem Division (CRED) of the NOAA Pacific Islands Fisheries Science Center (PIFSC) with support from NOAA's Coral Reef Conservation Program.

NAME CODES USED IN TABLE 1 & FIGS. 7, 9, 11, & 12

FDP	FARALLON DE PAJAROS	GUG	GUGUAN	AGU	AGUIJAN
SUP	SUPPLY REEF	ZEA	ZEALANDIA BANK	ROT	ROTA
MAU	MAUG	SAR	SARIGAN	GUA	GUAM
ASC	ASUNCION	ANA	ANATAHAN	SRR	SANTA ROSA REEF
AGR	AGRIHAN	SAI	SAIPAN	STI	STINGRAY SHOAL
PAG	PAGAN	TIN	TINIAN	PAT	PATHFINDER REEF
ALA	ALAMAGAN	TAT	TATSUMI REEF	ARA	ARAKANE REEF

HISTORY & MISSION OF THE CRED

The mission of the Coral Reef Ecosystem Division is to provide high-quality, scientific information about the status of coral reef ecosystems of the U.S. Pacific islands to the public, resource managers, and policy-makers on local, regional, national, and international levels.

National coral reef conservation efforts were formalized in 1998 with a presidential executive order to "preserve and protect the biodiversity, health, heritage, and social and economic value of U.S. coral reef ecosystems and the marine environment." This executive order established the U.S. Coral Reef Task Force (CRTF) and emphasized the need to undertake a comprehensive approach to research, mapping, and monitoring of all U.S. coral reef ecosystems. In 2000, the CRTF developed *The National Action Plan to Conserve Coral Reefs* (U.S. CRTF 2000), and the *Coral Reef Conservation Act* laid out a national framework to address the degradation of U.S. coral reef ecosystems and other coral reef conservation issues (Coral… 2000). The *Coral Reef Conservation Act* also led to the creation of the national Coral Reef Conservation Program under the direction of the Secretary of Commerce. This legislation requires NOAA to conduct scientific research, mitigation, and outreach activities that directly contribute to the conservation of coral reef ecosystems. NOAA, in cooperation with the CRTF, produced *A National Coral Reef Action Strategy* in 2002 with goals and objectives that included mapping, information management, research, and monitoring (NOAA 2002). In response to these mandates and with the support of NOAA's Coral Reef Conservation Program, the NOAA Pacific Islands Fisheries Science Center initiated the Pacific Reef Assessment and Monitoring Program (Pacific RAMP) in early 2000 and established the Coral Reef Ecosystem Division (CRED) in 2001.

To fulfill its mission, the CRED conducts a comprehensive suite of integrated, interdisciplinary research activities, including habitat mapping, oceanographic studies, and long-term monitoring of multiple components of coral reef ecosystems in the U.S. Pacific islands (Fig. 1). The CRED conducts biennial Pacific RAMP

Opposite page: Turbinaria *coral polyps near the island of Asuncion.* NOAA photo by Marie Ferguson

TIMELINE

1998
- Executive order to protect reefs
- U.S. Coral Reef Task Force (CRTF) is formed

1999–2000
- CRTF creates National Action Plan to Conserve Coral Reefs
- Coral Reef Conservation Act of 2000 (CRCA)
- NOAA creates Coral Reef Conservation Program (CRCP)
- 1st Pacific RAMP cruises

2001
- NOAA PIFSC forms Coral Reef Ecosystem Division (CRED)

2002
- NOAA & CRTF produce National Coral Reef Action Strategy

2003
- 1st CRED Mariana Archipelago RAMP (MARAMP) cruise
- Included mapping

2004

2005
- 2nd MARAMP cruise
- Added water-quality sampling

2006

2007
- 3rd MARAMP cruise
- Included mapping
- Added coral-disease surveys
- Added sampling for carbonate chemistry

2008

2009
- 4th MARAMP cruise
- Improved fish surveys: increased number, added stratified random sampling design and expanded depth range to 0–30 m

*2009 data are not included in this document surveys in each study area to improve our understanding of ecosystem variability over climate time scales ranging from several years to decades and across broad spatial scales ranging from individual islands and atolls to entire archipelagoes and the Pacific Basin. Complementary methods are used to assess benthic community composition and abundance and diversity of invertebrates, algae, and fishes in the context of their benthic habitats and associated oceanographic and water-quality conditions. Using consistent methodologies across ~ 50 U.S. Pacific islands, atolls, and shallow banks enables unprecedented comparative analyses of coral reef ecosystems across diverse gradients of biogeography, environmental conditions, and human uses. Results from Pacific RAMP surveys significantly improve our understanding of ecosystem processes and cause-and-effect mechanisms that influence the status and resilience of coral reefs.

CRED STUDY AREA

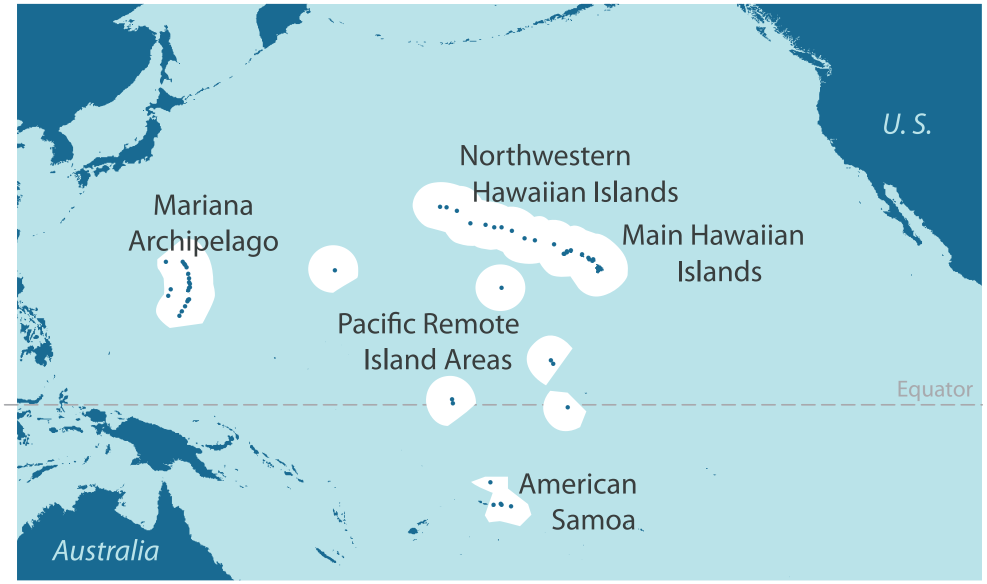


Figure 1. The CRED focuses on a study area that consists of ~ 50 islands, atolls, and shallow banks in American Samoa, the Hawaiian Archipelago, the Mariana Archipelago, and the Pacific Remote Island Areas. White areas represent U.S. Exclusive Economic Zones.

Pacific island communities are economically and culturally dependent on their marine resources. Accurate and up-to-date characterizations of coral reef ecosystems are necessary to develop and evaluate effective strategies for resource management. For a significant majority of the islands, atolls, and banks surveyed through the Pacific RAMP, virtually no prior ecological surveys, bathymetric or habitat maps, or in situ oceanographic observations had been completed. Little or no information was available about what to expect in terms of habitats, biogeographic structure, oceanographic conditions, or species composition, distribution, and abundance. In almost all regards, the initial surveys of the Pacific RAMP in 2000–2003 were exploratory baseline assessments with the purpose of shaping this monitoring program. The logistical and financial challenges presented by the remoteness of the U.S. Pacific islands and the vastness of this region as a whole had a major impact on the initial scope of this program and continue to shape its evolution.

Opposite page: Two batfish (Platax tiera) *near Farallon de Pajaros.* NOAA photo by Chip Young

With the exception of moored oceanographic and bioacoustic instruments that collect data nearly continuously, Pacific RAMP activities do not detect high-frequency (short-term) ecological fluctuations. Instead, biennial Pacific RAMP surveys are designed to examine ecological variability over a longer term of several years or decades, taking periodic "snapshots" of ecosystems when surveys are conducted. As such, many of these biennial ecosystem snapshots are needed before rigorous discussions about changes and trends become possible.

Though changes in survey protocols inherently introduce some inconsistencies in data, the CRED has expanded or added some protocols in response to evolving management priorities and a continually improved understanding of factors that affect coral reef ecosystems, such as ocean acidification (see timeline on Page 3), and has continued to refine survey methods to better limit variability between survey staff members. The CRED conducted its last Pacific RAMP cruise in the Mariana Archipelago in 2009 on the NOAA Ship *Hi`ialakai*, and more information can be found in the cruise reports for this expedition at http://www.pifsc.noaa.gov/library/hiialakai.php. The next cruise in this archipelago is scheduled for 2011.

"...preserve and protect the biodiversity, health, heritage, and social and economic value of U.S. coral reef ecosystems and the marine environment..."

—1998 executive order

THE MARIANA ARCHIPELAGO

The Mariana Archipelago is 890 km long and encompasses 15 islands, located on the Mariana Arc, and numerous offshore banks. The territory of Guam includes the island of Guam and adjacent offshore banks and reefs. All other islands and offshore banks compose the Commonwealth of the Northern Mariana Islands (CNMI). The islands and reefs of the Mariana Archipelago can be divided into 3 geologic groups (Figs. 2 and 3): (1) various offshore banks and submarine volcanoes located on the West Mariana Ridge; (2) the young, volcanic northern islands on the Mariana Arc, including, from south to north, Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, and Farallon de Pajaros; and (3) the old, southern islands located on the Mariana Arc, including Guam, Rota, Aguijan, Tinian, Saipan, and Farallon de Medinilla. The 3 northernmost islands, the Mariana Trench, and several volcanic features between the Mariana Arc and Trough were designated as the Marianas Trench Marine National Monument by presidential proclamation in January 2009.

The islands of the CNMI and Guam differ in size, population, and isolation (Table 1 and Fig. 4). Guam is the largest island in the Mariana Archipelago with a land area of 544 km^2. Saipan is the largest island in the CNMI with a land area of 119 km^2, roughly similar to the combined area of 160 km^2 for the 9 northern islands of the CNMI. Pagan and Agrihan (48 and 44 km^2) are the largest of the northern islands, the majority of which have land areas < 10 km^2, very small relative to the southern islands.

The combined population of Guam and the CNMI in 2009 was estimated at 245,319 by the Secretariat of the Pacific Community, with population centers largely focused on 4 of the 6 southern islands: Guam, with an estimated population of 182,207, as well as Rota, Tinian, and Saipan. The 9 northern islands are sparsely inhabited with total populations on Agrihan, Pagan, and Anatahan fluctuating from 0 to 100 persons since World War II. While

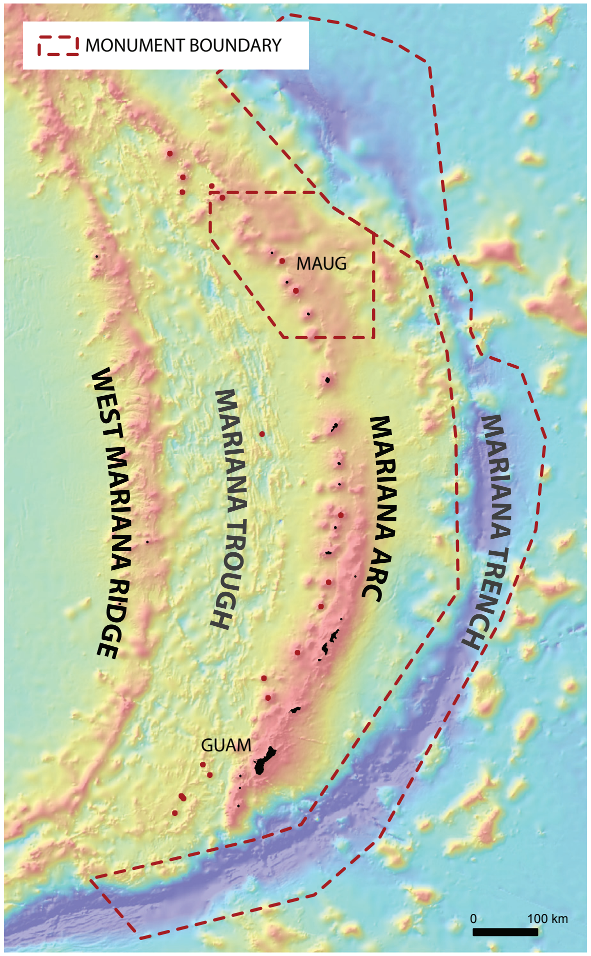


Figure 2. Topography of the Mariana Archipelago and the location of the Marianas Trench Marine National Monument. This monument consists of the Mariana Trench, the 3 northernmost islands of the Mariana Arc, and several volcanic features (see red dots) between the Mariana Trough and Arc.

Opposite page: Since 2003, the CRED has mapped ~ 90% of the coral reef habitats across the Mariana Archipelago and has maintained an ongoing bathymetric data synthesis that combines CRED data with bathymetric data collected by other government and academic groups. Bathymetric and optical data are used for geologic studies, benthic habitat maps, tsunami inundation models, and nautical charts and are routinely provided to management partners in the Commonwealth of the Northern Mariana Islands and Guam to support improved implementation of ecosystem approaches to management of marine resources.

MARIANA ARCHIPELAGO

1 WEST MARIANA RIDGE

- Formed after southern and before northern parts of the main arc
- Remnant volcanic island arc that forms a series of seamounts ~ 145–170 km west of and parallel to the main arc
- Some seamounts rise to within 9 m of the sea surface
- Near-optimal conditions for coral growth due to absence of terrestrially derived sediments, recent volcanic ash, and direct anthropogenic impacts

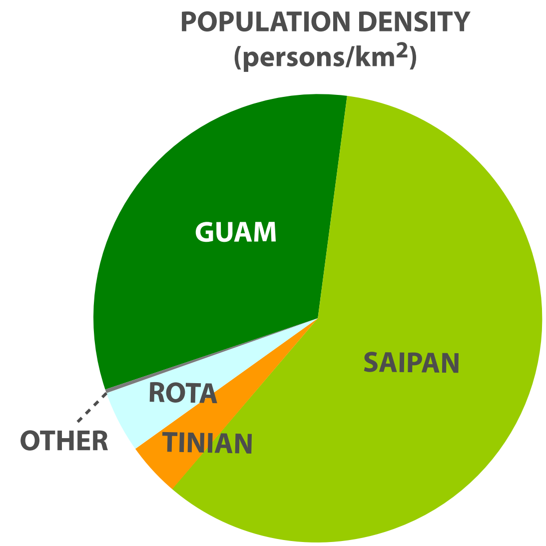
2 NORTHERN ISLANDS OF THE MARIANA ARC

- Formed 0–5 million years ago by the subduction of the Pacific Plate under the Philippine Plate at the Mariana Trench, which lies ~ 130–210 km east of this island chain
- All are active or dormant stratovolcanoes
- Seafloor and land characterized by moderate to steep (10°–45°) slopes and periodic, explosive eruptions and landslides

3 SOUTHERN ISLANDS OF THE MARIANA ARC

- Formed 15–20 million years ago
- Consist of extinct volcanic edifices
- Though volcanic in origin, largely covered by layered, uplifted limestone from ancient coral reefs
- Seafloor and land characterized by low slopes except between uplifted layers

land cover on the southern islands is primarily influenced by population density, land cover on the northern islands is influenced by the shape and activity of volcanoes. Beyond population density and volcanic activity, a major determinant of land cover on all the islands is the presence of feral animals introduced by previous and present human inhabitants. On almost all islands of the Mariana Archipelago, introduced feral goats, pigs, deer, and cows destroy or alter native understory vegetation—typically causing an increase in erosion and, thus, sedimentation and runoff into nearshore waters that could have significant impacts on coral reef ecosystems. Only Guguan and Farallon de Pajaros are thought to have no introduced feral animals at this time (Table 1). Because of their isolated location and lack of inhabitants, the 3 islands within the Mariana Trench Marine National Monument have relatively few direct pressures from human activities.



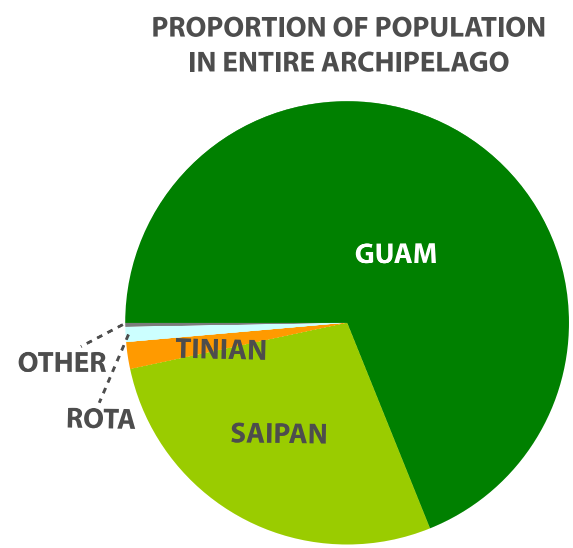


Figure 3 (opposite page). *The islands and reefs of the Mariana Archipelago can be grouped into 3 main geologic groups, shown here with information about their characteristics.*

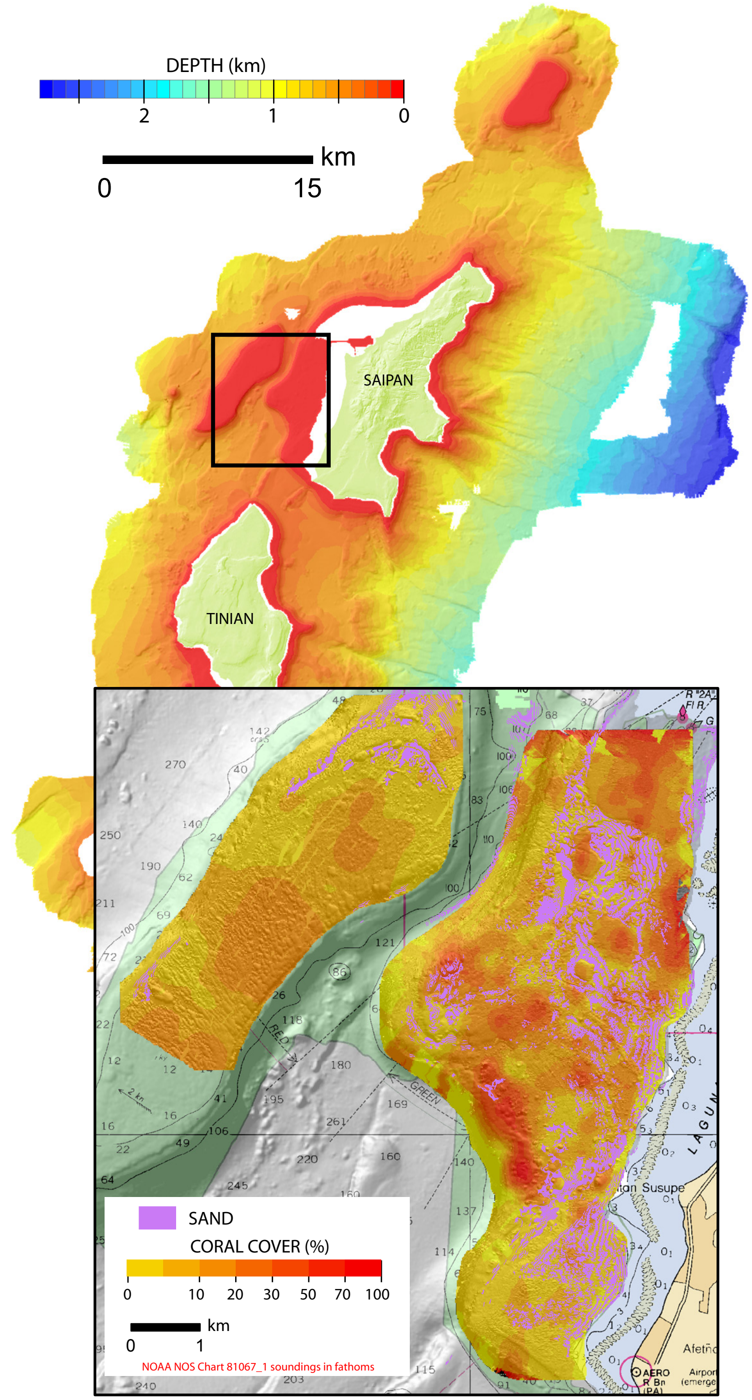
Figure 4 (right). *Guam and Saipan have the largest human populations among the islands of the Mariana Archipelago, accounting for 69% and 28% of the population recorded for this archipelago in the U.S. Census 2000. The population of Saipan is only 40% of the population of Guam; however, because its land area is only 22% of the land area for Guam, Saipan has a higher overall population density. For more details and other island comparisons, see Table 1.*

Table 1 (next page). *Summary table of island parameters across the Mariana Archipelago: land area, proportion of archipelagic population, population density, year of last volcanic eruption, and animal threats. Land areas were calculated using geographic-information-system (GIS) techniques. See page 1 for island codes. Sources: U.S. Bureau of the Census, Smithsonian Institution, U.S. Geological Survey, CNMI Division of Fish and Wildlife, and Pacific Biodiversity Information Forum.*

	SOUTHERN					NORTHERN								
ISLAND CODE	GUA	ROT	AGU	TIN	SAI	ANA	SAR	GUG	ALA	PAG	AGR	ASC	MAU	FDP
AREA (km^2)	544	85	7	101	119	34	4	4	13	48	44	8	2	2
SHARE OF ARCH. POPULATION (% IN 2000)	69	1	0	2	28	0	0	0	<0.1	<0.1	<0.1	0	0	0
POPULATION DENSITY (PERSONS/km^2)	284	39	0	35	524	0	0	0	<1	<1	<1	0	0	0
YEAR OF LAST ERUPTION	—	—	—	—	—	2007	—	1883	1887	2006	1917	1924	—	1967
TREE SNAKES	✓	✓		✓	✓									
CATS	✓	✓		✓	✓		✓		✓					
CATTLE	✓	✓		✓	✓					✓				
GOATS	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓	
PIGS	✓	✓		✓	✓	✓			✓	✓	✓			
RATS	✓	✓	✓	✓	✓				✓		✓	✓	✓	

MESOPHOTIC CORAL REEFS

Bathymetric and optical mapping have revealed extensive and dense coral reefs at depths > 30 m in numerous locations in the Pacific. Although few optical surveys have been carried out in such relatively deep areas in the Mariana Archipelago, those surveys that have been conducted have revealed light-dependent scleractinian (hard) corals. For example, a detailed survey carried out in 2004 at the Garapan Anchorage off Saipan revealed large expanses of corals in the mesophotic range (30–150 m) with reefs predominantly formed by *Euphyllia paraancora*, a hard coral species that was included in a recent petition to list 83 corals under the *Endangered Species Act*. The highest average live-coral cover from this study was observed in the depth range of 61–70 m with cover values > 33%. These results highlight the importance of monitoring at the full range of depths (0–150 m) in which coral communities may be present. More widespread surveys at these depths could define the extent of mesophotic reefs in this archipelago.



Right: Bathymetric and optical data collected by the CRED in 2003 and 2004 were used to create a coral- and sand-cover map of the Garapan Anchorage and to aid management agencies in making decisions related to a proposed expansion of this anchorage into potentially coral-rich areas.

METHODS OVERVIEW

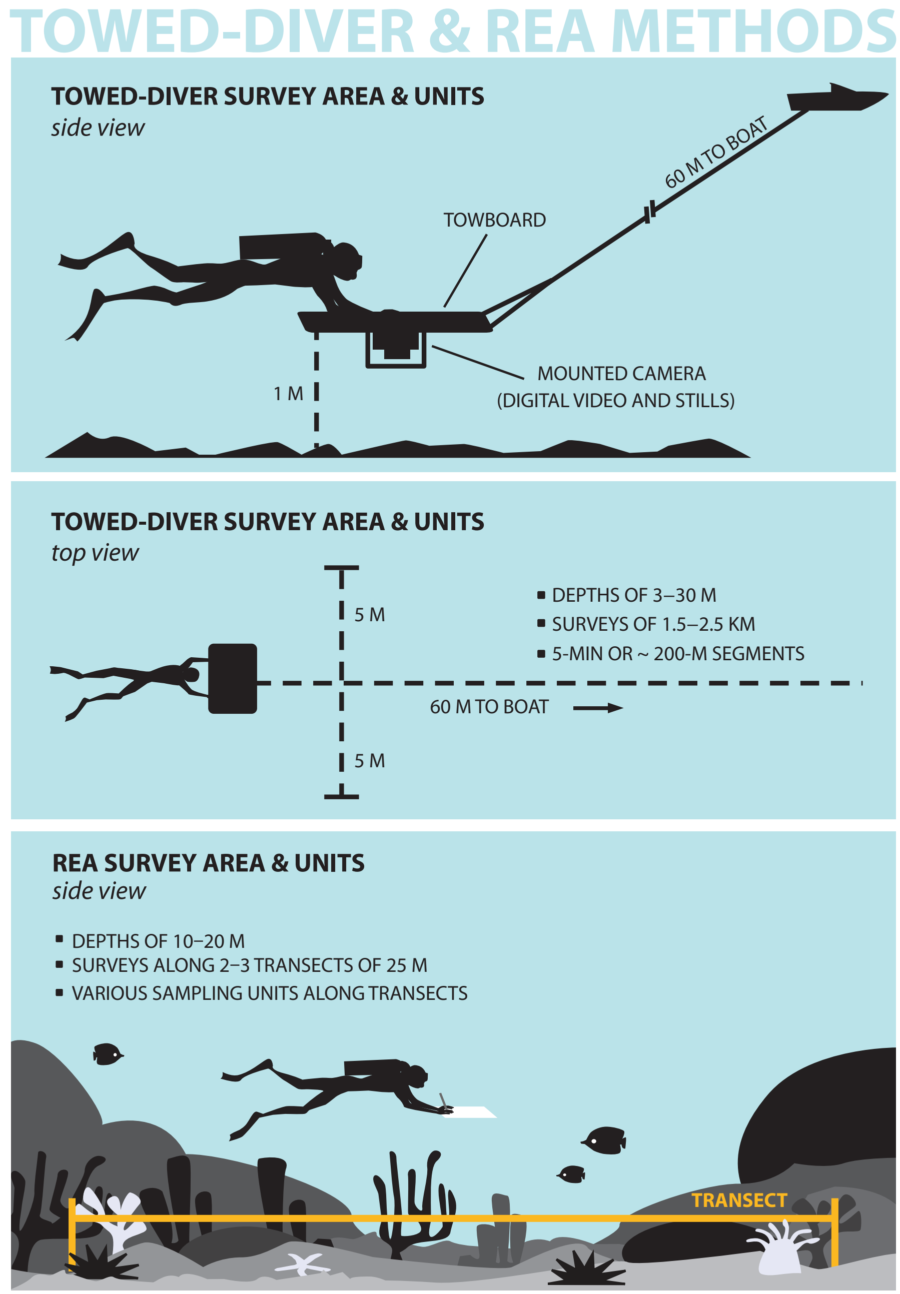
SUMMARY OF METHODS

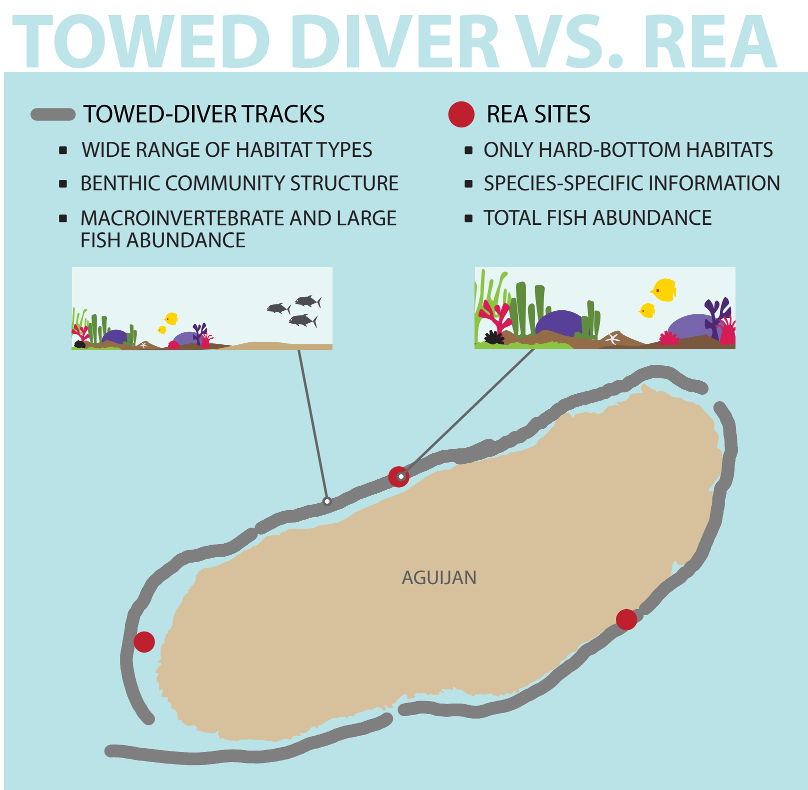
BIOLOGICAL	TOWED DIVER - broad surveys of benthic and fish communities REA - detailed view of benthic and fish community structure TOAD - optical validation and habitat characterization
PHYSICAL/ CHEMICAL	MOORED INSTRUMENTS - collect continuous oceanographic data CTD CASTS - measure conductivity, temperature, and depth WATER SAMPLES - measure nutrients and Chl-*a*
MAPPING	MULTIBEAM SONAR - bathymetry, habitat characterization

The CRED conducted its first Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) cruise in 2003, with subsequent cruises in 2005, 2007, and 2009. Partners from Guam (Division of Aquatic and Wildlife Resources, Bureau of Statistics and Plans, Guam Environmental Protection Agency, and University of Guam) and the CNMI (Department of Environmental Quality, Department of Fish and Wildlife, and Coastal Resources Management) worked alongside CRED scientists to develop and implement a comprehensive monitoring program. Extensive biological, physical, and chemical surveys were conducted to document the conditions of and processes influencing the coral reef ecosystems around the islands of the Mariana Archipelago. Benthic habitat mapping data were collected using multibeam sonar surveys. Spatial and temporal observations of key oceanographic and water-quality parameters were collected using (1) a diverse suite of moored instruments designed for long-term observations; (2) closely spaced conductivity, temperature, and depth profiles of the vertical structure of water properties; and (3) discrete water samples for nutrient and chlorophyll-*a* analyses. Information on the condition, abundance, diversity, and distribution of biological communities around islands and on offshore reefs was collected using Rapid Ecological Assessment (REA), towed-diver, and towed optical assessment device (TOAD) surveys (Fig. 5). Towed-diver surveys, conducted on the forereef slopes of islands and banks loosely following the depth contour of ~ 15 m and encompassing various substrates, generate a broad overview of substrate types and associated large-fish and benthic communities. REA surveys, carried out at selected forereef locations at islands or banks at similar depths, produce more detailed, site-specific information on fishes of all sizes and community structure of hard substrate. TOAD surveys and a subset of towed-diver-survey data were used for optical validation and habitat characterization, documenting cover of live scleractinian (hard) corals, sand cover, and habitat complexity. The forthcoming *Coral Reef Ecosystem Monitoring Report of the Mariana Archipelago: 2003–2007* provides detailed information on all methods used.

Opposite page: CRED diver conducting a REA survey for coral disease. NOAA photo by Russell Moffitt

Figure 5. Schematic diagrams of (below) *the main differences between towed-diver surveys and Rapid Ecological Assessment (REA) surveys,* (top & middle right) *1 of 2 divers conducting a towed-diver survey, and* (bottom right) *a diver conducting a REA survey along a 25-m transect line (the full report provides details about these methods).*





To compare the coral reef ecosystems across the Mariana Archipelago, the CRED developed 3 composite metrics based on towed-diver visual observations from 2005 and 2007 (Fig. 6). The overall *Coral Reef Condition Index* has equally weighted benthic and fish components. The *Benthic Condition Index* was calculated using data for live-coral cover, stressed-coral cover, crustose-coralline-red-algal cover, macroalgal cover, and density of crown-of-thorns seastars (*Acanthaster planci*). The *Fish Condition Index* was calculated using data for density and biomass of large fishes (≥ 50 cm in total length). These indices were calculated at 2 scales for this report: (1) archipelagic level for comparisons among 13 islands of the CNMI and Guam and (2) island scale for comparisons among only the 4 populated, southern islands of Guam, Rota, Tinian, and Saipan. The ranks in these condition indices, for the purposes of discussion and visual representation, are grouped as high, medium, or low. A high rank means superior condition relative to (a), in the archipelagic indices, other geographic regions in the Mariana Archipelago or (b), in the island-level indices, other survey areas in the 4 populated, southern islands. The *Archipelagic Coral Reef Condition Index* is used in the next section as a basis for comparing the ecosystems around the southern islands to the ones around the northern islands. The *Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan* is used later in the discussion of the reef conditions observed around individual southern islands.

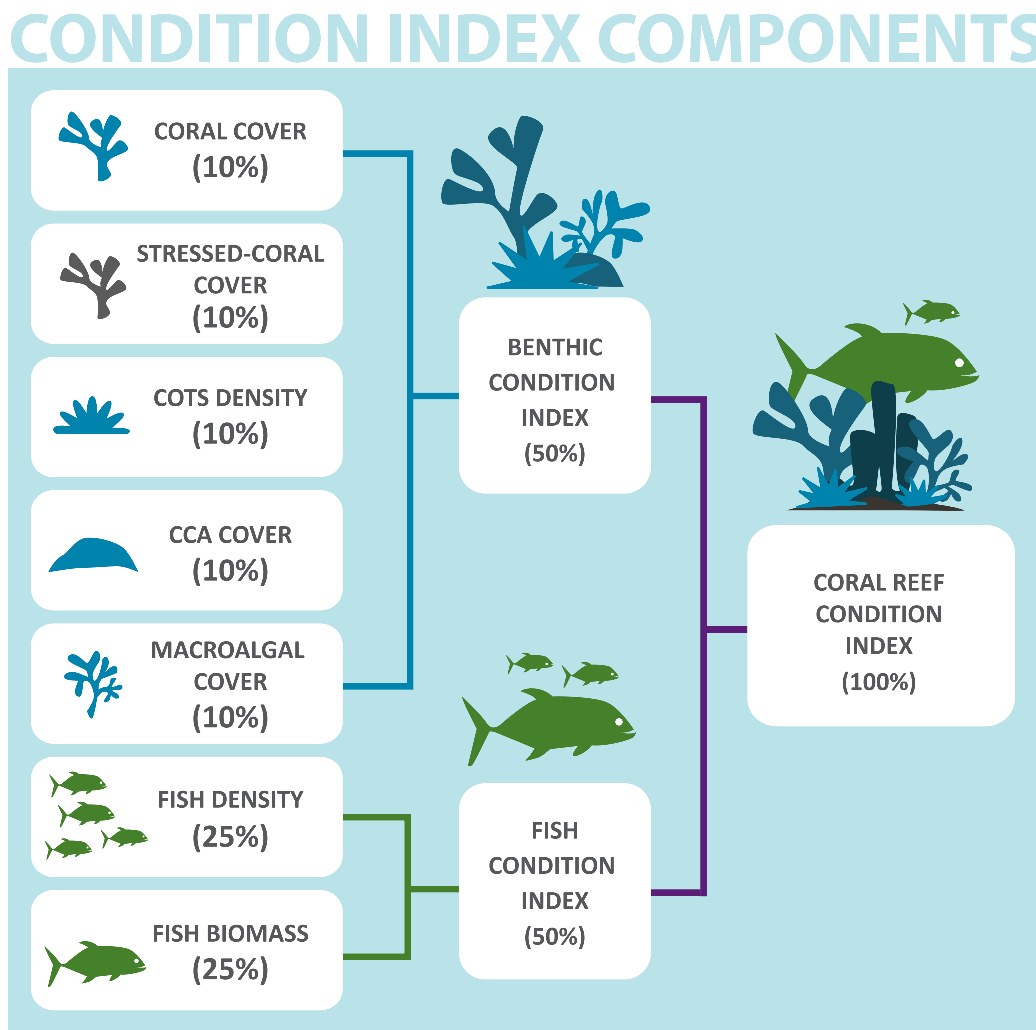


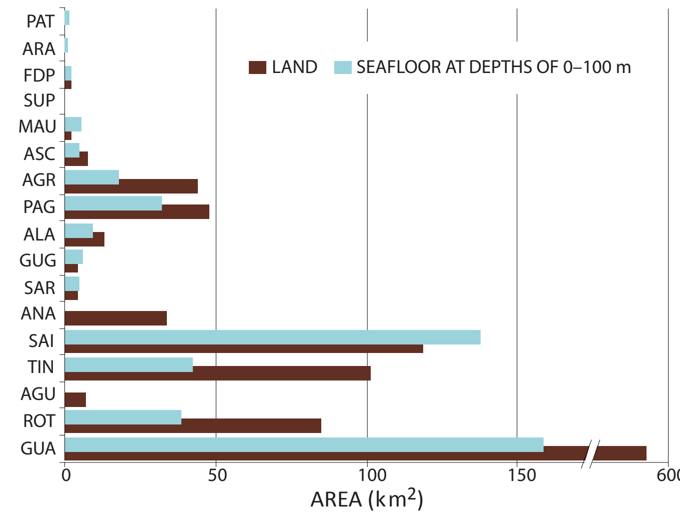
Figure 6. Conceptual diagram of the calculation of the 3 condition indices, which are based on data from towed-diver surveys conducted on forereef habitats during MARAMP cruises in 2005 and 2007. CCA stands for crustose coralline red algae and COTS for crown-of-thorns seastar.

SOUTHERN VS. NORTHERN ISLANDS

Differences in the geologic histories of these islands, which result in large differences in land area and slope, have been identified as a major factor shaping the coral reef ecosystems of the Mariana Archipelago (Burdick et al. 2008; Houk and Van Woesik 2010; Riegl et al. 2008). The 6 southern islands are, in general, significantly larger than the northern islands and have uplifted calcium carbonate terraces with mostly low slopes (0°–10°) both onshore and offshore, resulting in a substantial amount of total potential reef area. In contrast, the 9 small, northern islands are active or dormant volcanoes with steep onshore and offshore slopes, narrow ridges, and few offshore terraces, resulting in total potential reef areas that are much smaller relative to the southern islands (Fig. 7). Other factors likely influencing coral reef conditions include the anthropogenic stressors of coastal sedimentation and pollution, fishing pressure, and land use that in the populated, southern islands are associated with increasing population, tourism, and development. In the northern, largely uninhabited islands, the frequency, duration, and magnitude of active volcanism can severely affect coral reef ecosystems.

MARAMP surveys found differences in several key oceanographic indicators between the southern and northern islands. The north–south orientation of the Mariana Archipelago results in latitudinal gradients in sea-surface temperatures (SST), wind conditions, currents, and chlorophyll-*a* (Chl-*a*) and nutrient concentrations across this archipelago. The southern islands exhibited warmer SSTs, stronger wind conditions and surface currents, lower salinities, and less productive waters (Fig. 8). Additionally, episodic volcanic eruptions, ash discharge, and landslides on the northern islands can significantly modify the quality and chemistry of surrounding coastal waters over short (days to weeks) and medium (months to years) time frames. As a result of such natural and human-induced coastal processes, the nearshore waters around the southern islands exhibited considerable spatial and temporal variability in water-quality parameters, including inorganic nitrogen and Chl-*a*, particularly around Guam.

*Opposite page: A blacktip grouper (*Epinephelus fasciatus*).* NOAA photo by Chip Young



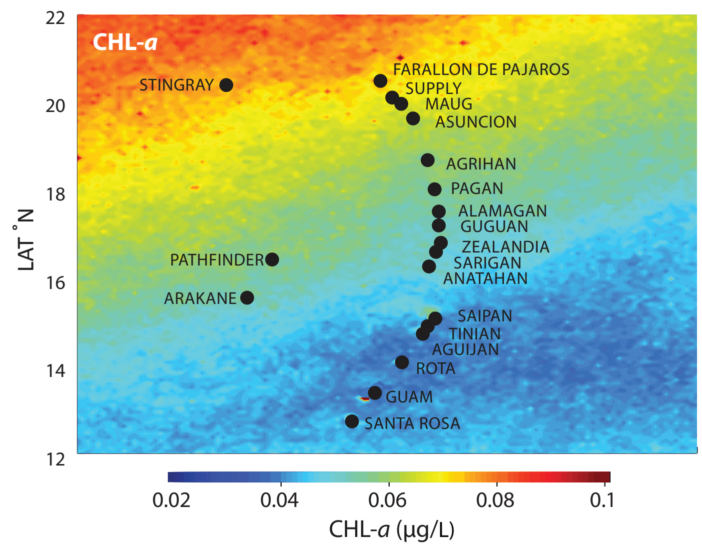


Figure 7 (top). *Land and potential reef area per island.*

Figure 8 (bottom). *Latitudinal gradients of seasonal Chl-*a *concentrations in the Mariana Archipelago for January–March using National Aeronautics and Space Administration SeaWiFS imagery (12°–22° N, 140°–150° E; http://oceancolor.gsfc.nasa.gov/SeaWiFS).*

BLEACHING & STORM EVENTS AROUND GUAM

Corals bleach when the ocean temperature increases 1°C–2°C above the maximum monthly mean for ocean temperatures in their area. Satellite-derived sea-surface temperatures (SST) and in situ observations from subsurface temperature recorders (STRs) deployed around Guam show that water temperatures reached a maximum (29.5°C) in late August or September and a minimum (27.1°C) in February. These SST and STR data show that water temperatures around Guam in August and September 2006 surpassed the coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean. David Burdick of the Guam Coastal Management Program reported field observations of bleaching occurring among numerous species at several sites around Guam to a depth of 7 m (Burdick et al. 2008). Follow-up observations in October 2006 showed that some coral species had recovered whereas others exhibited partial to full mortality (Brown 2007). MARAMP data show that estimates of coral cover were lower in 2007 than in 2005 from both towed-diver and REA surveys.

Relief from temperature increases that can cause bleaching sometimes comes from storms, since they typically mix cool, deep waters with warmer, shallow waters. The waters around Guam are dominated by trade wind swells, characterized by frequent (6–10 s), relatively small waves (2–3 m), originating from the east. Typhoons are a common occurrence around Guam and generate large (> 4 m), mid-to-long-period (10–16 s) wave events, generally from the southeast (110º) and typically between August and December. Infrequent long-period swells with moderate wave heights (2.5–3.5 m) occur from the west-southwest and are associated with distant storms. While several tropical cyclones have passed close enough to Guam to influence its weather since 2003, the only large wave event (> 4 m) observed during the period of 2003–2007 occurred during the summer of 2004 with the passages of Typhoons Tingting and Chaba. Damage from these wave events did not appear to be extensive.

Left: Partially bleached Acropora *coral near Guam.* Photo by Dave Burdick (www.guamreeflife.com)

BENTHIC COMPOSITION AND DIVERSITY

Based on towed-diver surveys of forereef habitats for each of the 3 MARAMP cruises in 2003, 2005, and 2007, estimates of mean macroalgal cover generally were higher and estimates of mean coral cover were lower around the southern islands than around the northern islands (Fig. 9). These differences in ecosystem conditions for the southern islands may result from differences in human impacts (for example, variation in levels of nutrient input and harvest of herbivorous fishes). It is important to note, however, that macroalgae are a normal and necessary part of reef ecosystems. The southern carbonate islands may naturally experience conditions that promote higher macroalgal growth than the growth seen in the northern, volcanic islands. Without a sufficient number of time-series observations, it is difficult to conclude that macroalgal populations are increasing or coral populations are decreasing around the southern islands, thus, underscoring the importance of the kind of long-term monitoring conducted by the CRED.

Data from towed-diver surveys conducted on forereef habitats in 2005 and 2007 are integrated in the *Archipelagic Benthic Condition Index* by geographic region in the Mariana Archipelago. Based on these analyses, the benthic condition was generally better in the northern islands compared to the southern islands. Ranks in this index indicate that the benthic conditions for Maug, Alamagan, Guguan, and Sarigan were superior to the conditions for other islands in the Mariana Archipelago, a result of high or increasing coral cover, low stressed-coral cover, and low densities of crown-of-thorns seastars (COTS). Index ranks for the southern islands of Saipan, Tinian, Aguijan, Rota, and Guam were low in or decreasing between

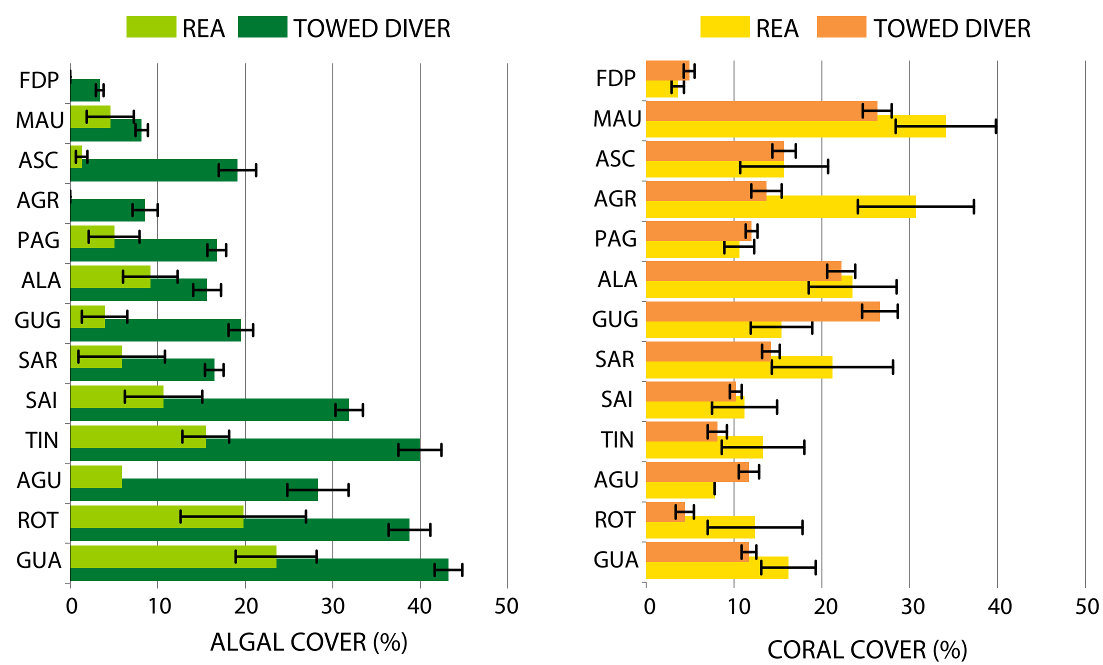


Figure 9. Comparisons of mean (left) algal cover (%) and (right) coral cover (%) from REA and towed-diver surveys of forereef habitats conducted in the Mariana Archipelago in 2007. Error bars indicate standard error (±1 SE) of the mean.

2005 and 2007, except for a few geographic regions of Tinian and Saipan and the north coast of Aguijan. The low ranks for these 5 islands in this condition index resulted from relatively high levels of stressed-coral cover and macroalgal cover and low levels of coral cover. Particularly around Rota, some of the lowest coral-cover values in the Mariana Archipelago were observed (Fig. 9). Around the southern islands, compared to the northern islands, the occurrence of bleaching and coral disease was higher and COTS densities were found more often at levels of a potential outbreak.

REA benthic surveys of hard-bottom habitats conducted in 2007 found that mean coral cover was moderate and similar around all southern islands. Conversely, around the young, sparsely inhabited or uninhabited, volcanic northern islands, coral cover was more variable, and both the highest and the lowest levels in the Mariana Archipelago were recorded there, with overall mean coral cover of 34.1% (SE 5.7) at Maug and 3.6% (SE 0.7) at Farallon de Pajaros (SE stands for standard error of the mean). Macroalgal-cover estimates from REA surveys reveal a clear spatial pattern with high algal cover in the southern islands compared to the northern islands (Fig. 9).

The diversity of benthic communities, measured as mean richness of coral genera and of macroalgal genera per island, was greater in the southern islands than in the northern islands (richness was computed as the maximum number of coral genera or macroalgal genera recorded at a REA site). This difference is probably a result of the southern islands having greater potential habitat areas at shallow-water depths of < 100 m, compared to the northern islands (Fig. 7). These large areas in the southern islands support a wider range of habitat types and oceanographic conditions that result in a greater number of niche environments. The notion that the size of islands and disturbance frequency (predominantly volcanic activity) are likely predictors of taxonomic richness (Houk and Starmer 2010) is supported by data from MARAMP surveys (Tribollet and Vroom 2007). The greatest overall mean generic richness of corals for an island was recorded around Saipan (17.3 [SE 1.1]), and the highest overall mean generic richness of macoalgae was observed around Rota (13.1 [SE 0.74]) and Guam (13 [SE 0.68]). In this context, some coral and algal taxa were restricted to or particularly widespread around the southern islands, including the hard corals *Diploastrea*, *Plesiastrea*, *Alveopora*, and *Coscinaraea* and the red algae *Amansia*, *Crouania*, *Gelidiella*, *Haloplegma*, *Halymenia*, and *Predaea*. The lowest diversity was found around Farallon de Pajaros with a mean richness of 7.6 (SE 1.4) for coral genera and a mean richness of 6 (SE 0.47) for macroalgal genera. Farallon de Pajaros has a land area of a mere 2.3 km^2 and experienced frequent volcanic activity during the 19th century and recurrent eruptions from the 1940s to the 1960s.

CROWN-OF-THORNS SEASTAR DENSITIES

With the exception of Pagan, the northern islands had low islandwide mean densities of crown-of-thorns seastars (COTS). These corallivorous seastars oscillate in a boom-and-bust population cycle with natural fluctuations in food availability and successful recruitment events. Using a threshold of 0.15 organisms/100 m^2, towed-diver surveys of forereef habitats in 2005 recorded potential outbreaks at Pagan with a mean islandwide COTS density of 0.24 organisms/100 m^2, the greatest density value recorded for any island in the Mariana Archipelago. This high COTS density may have caused the observed decline in coral cover from 19% (SE 0.8) in 2003 to 10% (SE 0.8) in 2005. By 2007, COTS densities had decreased threefold at Pagan, and coral cover appeared to be recovering slightly with an islandwide mean of 12% (SE 0.7). At all of the southern islands, with the exception of Tinian, localized outbreaks were observed during towed-diver surveys in 2003 and 2005. By 2007, however, COTS populations declined sharply around all of these islands except Guam. There, the islandwide mean density almost doubled from 0.1 organisms/100 m^2 (SE 0.03) in 2005 to 0.16 organisms/100 m^2 (SE 0.03) in 2007, with the highest densities recorded along the south and east coasts of Guam (Fig. 10). Across the Mariana Archipelago in 2007, signs of predation by COTS or snails were observed on a total of 14 genera of hard corals, belonging to 7 families, with more than 96% of all scars found on members of the families Faviidae, Acroporidae, Poritidae, and Pocilloporidae. Of these coral genera, *Goniastrea*, *Porites*, and *Astreopora* hosted 60% of all cases. Interestingly, around the northern islands of Asuncion and Maug, colonies of *Goniastrea* hosted 50% of all scars islandwide, whereas colonies of *Astreopora*, *Porites*, *Pocillopora*, and *Stylophora* hosted more than 60% of cases around the inhabited Guam and Saipan.

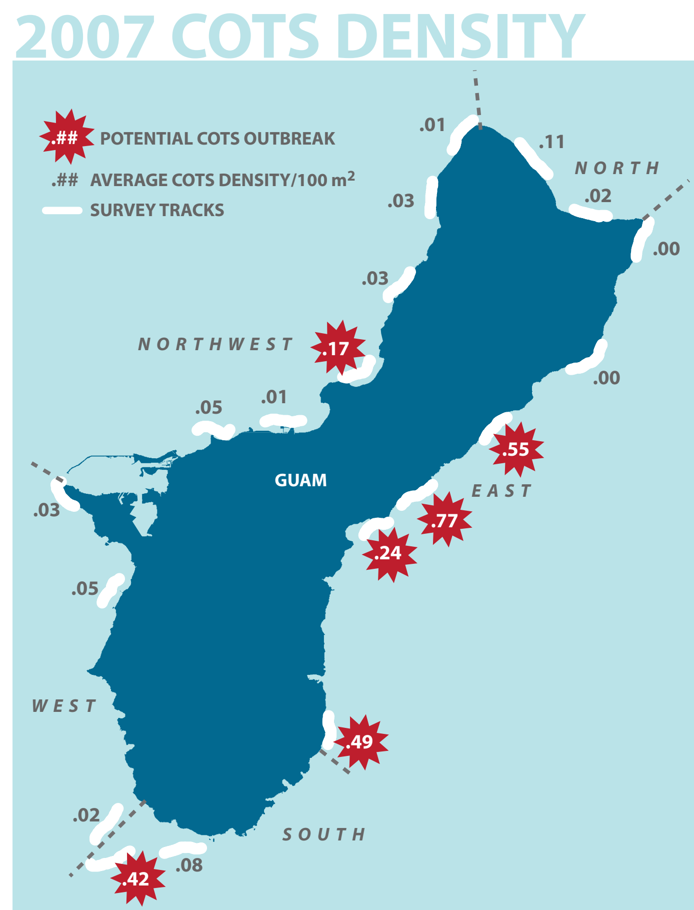


Figure 10. Densities (organisms/100 m^2) of crown-of-thorns seastars (COTS) from towed-diver surveys of forereef habitats conducted around Guam in 2007.

OCEAN ACIDIFICATION AROUND MAUG

During the CRED's MARAMP cruise in 2003, a hydrothermal vent system (depth of ~ 10 m and seafloor area of ~ 400 m^2) was observed within the caldera of Maug. In 2007, area-wide and near-vent water samples were collected to gain insight into the biogeochemistry of hydrothermal vents. Divers collected (1) gas bubbles for analysis of carbon dioxide (CO_2) and hydrogen sulfide concentrations; (2) water samples for dissolved inorganic carbon, total alkalinity, pH, iron, manganese, trace metals, and nutrient concentrations; and (3) water temperatures from multiple locations within and around the area of this vent system. The seafloor within this vent system was composed of boulders and sand, layered with accumulations of iron-rich, orange-tinted flocculent material. *Spatoglossum* sp. was the dominant alga within this vent system, covering every hard surface. No calcium-carbonate-producing organisms were observed within this vent system. However, a REA survey conducted only 15 m south of this vent revealed live-coral cover of 67% in 2007, reaching close to 100% cover of *Porites rus* within one part of this REA site. Water temperatures were 45°C–63°C at the vent openings, 16°C–34°C above the surrounding subsurface water temperatures. Gas bubbles collected consisted of CO_2 and probably contributed to pH values of 6.07 in this vent system, much more acidic than the pH of 8.13 of surrounding waters. Calculated states of calcite and aragonite saturation of undiluted vent waters were < 1, demonstrating that these waters were highly corrosive to calcifying organisms (calcium carbonate generally dissolves in waters with saturation states of < 1). The unique temperature and pH values for this vent system clearly regulated the benthic community structure there, but they had only a very local impact on coral growth as nearby water temperatures (29°C) and pH (8.13) reflected levels typical for this region. These preliminary results provide the only known example of present day ocean acidification within a coral reef ecosystem.

Left: Vents release gas bubbles and warm water west of East Island, one of the 3 islands that make up the Maug island group. The seafloor is covered by "fluffy" orange silt. NOAA photo by Ellen Smith

INFORMING RESOURCE MANAGEMENT

Climate change and the anticipated expansion of the military presence on Guam are primary factors affecting coral reefs around Guam and the Commonwealth of the Northern Mariana Islands (CNMI), as outlined in the NOAA Coral Reef Conservation Program (CRCP) Management Priority Setting documents for Guam and the CNMI, along with impacts of fisheries and land-based sources of pollution, especially around populated areas.

The population of military personnel and their dependents on Guam is expected to increase 160% from 15,000 persons in 2009 to more than 39,000 by 2020—a change expected to directly affect this territory's coral reef ecosystems. Resource managers on Guam have explicitly expressed a need for baseline data, which they view as crucial to measuring the effects of the military buildup and potential mitigation activities. Continuing ecosystem monitoring, along with examination of existing data from previous CRED research activities, will provide valuable guidance for setting future priorities for coral reef management and research tied to the CRCP's National Goals and Objectives.

Interdisciplinary data from the CRED are presented in detail in the *Coral Reef Ecosystem Monitoring Report of the Mariana Archipelago: 2003–2007*. Since 2003, the CRED has been conducting a broad range of surveys of the coral reef ecosystems around Guam, including nearshore waters adjacent to the Piti-Asan and Geus-Manell watersheds. These watersheds, which discharge into ocean areas that include the Piti Bomb Holes Marine Preserve and Achang Reef Flat Marine Preserve, along with other Pacific RAMP survey areas, such as the Tumon Bay and Pati Point Marine Preserves, have been identified as priority management sites by the CRCP and local Guam resource management agencies.

Similarly, Pacific RAMP surveys have been conducted in priority management sites and marine protected areas around the more populated areas of the CNMI, including around Saipan, the Bahia Laolao Sea Cucumber Reserve, Managaha Marine Conservation Area, Lighthouse Reef Trochus Reserve, Bird Island Marine Sanctuary, and Forbidden Island Marine Sanctuary; at Rota, the Sasanhaya Fish Reserve and Talakhaya Watershed Revegetation Area; and a marine reserve designated on the southwest coast of Tinian.

The CRED will continue to monitor these and other areas through the Pacific RAMP and other collaborative opportunities. Improved techniques implemented in 2009 will yield enhanced data about nearshore fish communities, data that are important in developing stock assessments and annual catch limits for commercially important reef-fish species. In 2009, the CRED performed some limited studies and established a permanent benthic Rapid Ecological Assessment site within Apra Harbor. In 2010, a PIFSC-led fisheries cruise in this archipelago focused on filling gaps in mapping data and improving studies of coral reef fishes. These projects were designed to respond to questions, interests, and information gaps presented by local scientists, managers, and fisheries groups in the CNMI and Guam.

To find out more about the information available from the CRED or to make suggestions for future research and outreach activities, please contact the CRED at nmfs.pic.credinfo@noaa.gov.

Right: School of breams (Gnathodentex aureolineatus). Photo by Dave Burdick (www.guamreeflife.com)

FISH BIOMASS AND DIVERSITY

The *Archipelagic Fish Condition Index*, based on towed-diver surveys, demonstrates a north–south pattern of ranks declining from high to low. The highest values of biomass of large fishes (≥ 50 cm in total length), calculated as weight per unit area, in the Mariana Archipelago were observed around Farallon de Pajaros and Asuncion in 2005 and 2007. Around the southern islands, where human populations and exposure to anthropogenic stressors are greater than in the northern islands, towed-diver surveys of forereef habitats recorded generally lower levels of large-fish biomass in 2005 and 2007, compared to the northern islands, or decreasing values between these survey years. Observations from these surveys of large fishes (Fig. 11) were dominated by jacks and sharks, both piscivores (fishes that prey primarily on other fishes), with mean large-fish biomass estimates more than 4 times higher around the northern islands than around the southern islands: 0.92 kg/100 m^2 (SE 0.18) versus 0.22 kg/100 m^2 (SE 0.04). The density of sharks encountered during towed-diver surveys was nearly 10 times higher around the northern islands than around the southern islands: 174.5 individuals/km^2 versus 17.6 individuals/km^2.

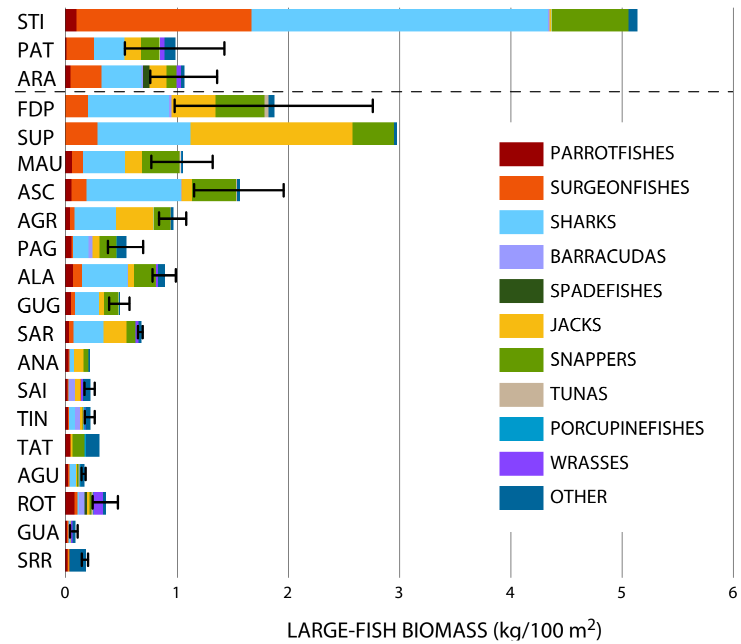


Figure 11. Estimates of islandwide mean biomass (kg/100 m^2) of large fishes (≥ 50 cm in total length) based on pooled data from the 3 MARAMP cruises in 2003, 2005, and 2007. Large-fish biomass is derived from towed-diver surveys of forereef habitats and divided into taxonomic family groups. The dotted line distinguishes the West Mariana Ridge from the Mariana Arc. See Page 1 for island codes. Error bars indicate standard error (±1 SE) of the mean.

Site-specific results from REA surveys that included all fishes of all sizes indicate that the overall mean total fish biomass for the 9 northern islands was more than 3 times higher than the total fish biomass for the 5 surveyed southern islands: 12 kg/100 m^2 (SE 2.37) versus 3.63 kg/100 m^2 (SE 0.53). Biomass values from REA fish surveys were higher around the northern islands for all trophic groups, but these south–north differences were greatest for piscivores (Fig. 12), for which mean total fish biomass around the northern islands with 4.04 kg/100 m^2 (SE 1.38) was more than 13 times the value recorded around the southern islands with 0.30 kg/100 m^2 (SE 0.03). Fish assemblages at the southern islands were dominated by herbivores (54% of total biomass), including surgeonfishes and parrotfishes. These patterns in total fish biomass and trophic composition are consistent with the patterns found along anthropogenic gradients in other archipelagoes in the central Pacific (Williams et al. 2008; Stevenson et al. 2007; Friedlander et al. 2008; Friedlander and DeMartini 2002).

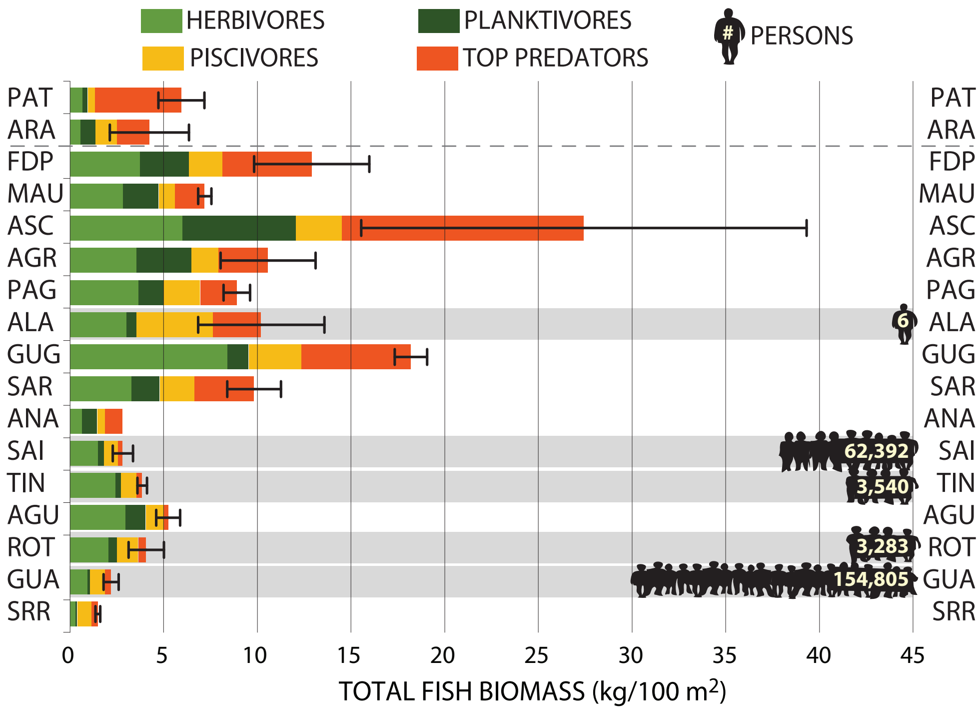
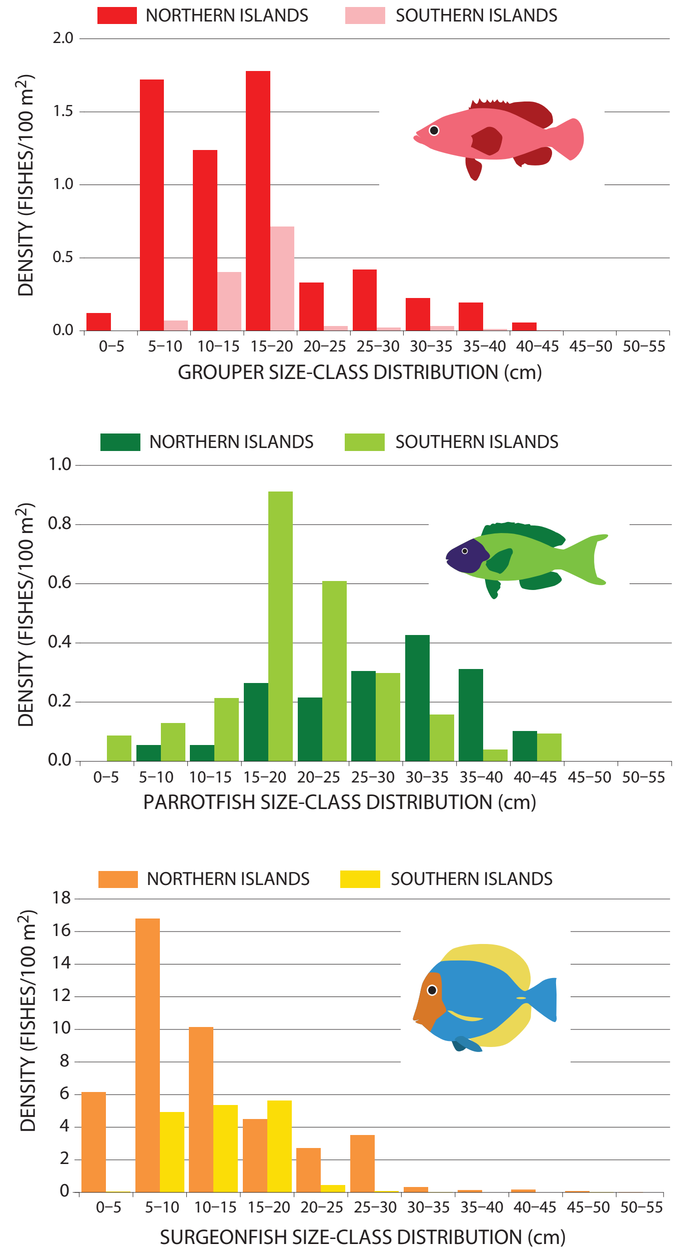


Figure 12 (above). *Estimates of* (right axis) *human population from the U.S. Census 2000 (not to scale) and* (left axis) *mean total fish biomass (kg/100 m*^{2}*). Values of total fish biomass from REA fish surveys were pooled from the 3 MARAMP cruises in 2003, 2005, and 2007 and divided into 4 trophic groups. The dotted line distinguishes the West Mariana Ridge from the Mariana Arc. See Page 1 for island codes. Error bars indicate standard error (±1 SE) of the mean.*

Figure 13 (right). *Size-class distribution (length in cm) for* (top) *groupers,* (middle) *parrotfishes, and* (bottom) *surgeonfishes from REA fish surveys conducted in 2007 on forereef habitats around the northern and southern islands of the Mariana Archipelago.*



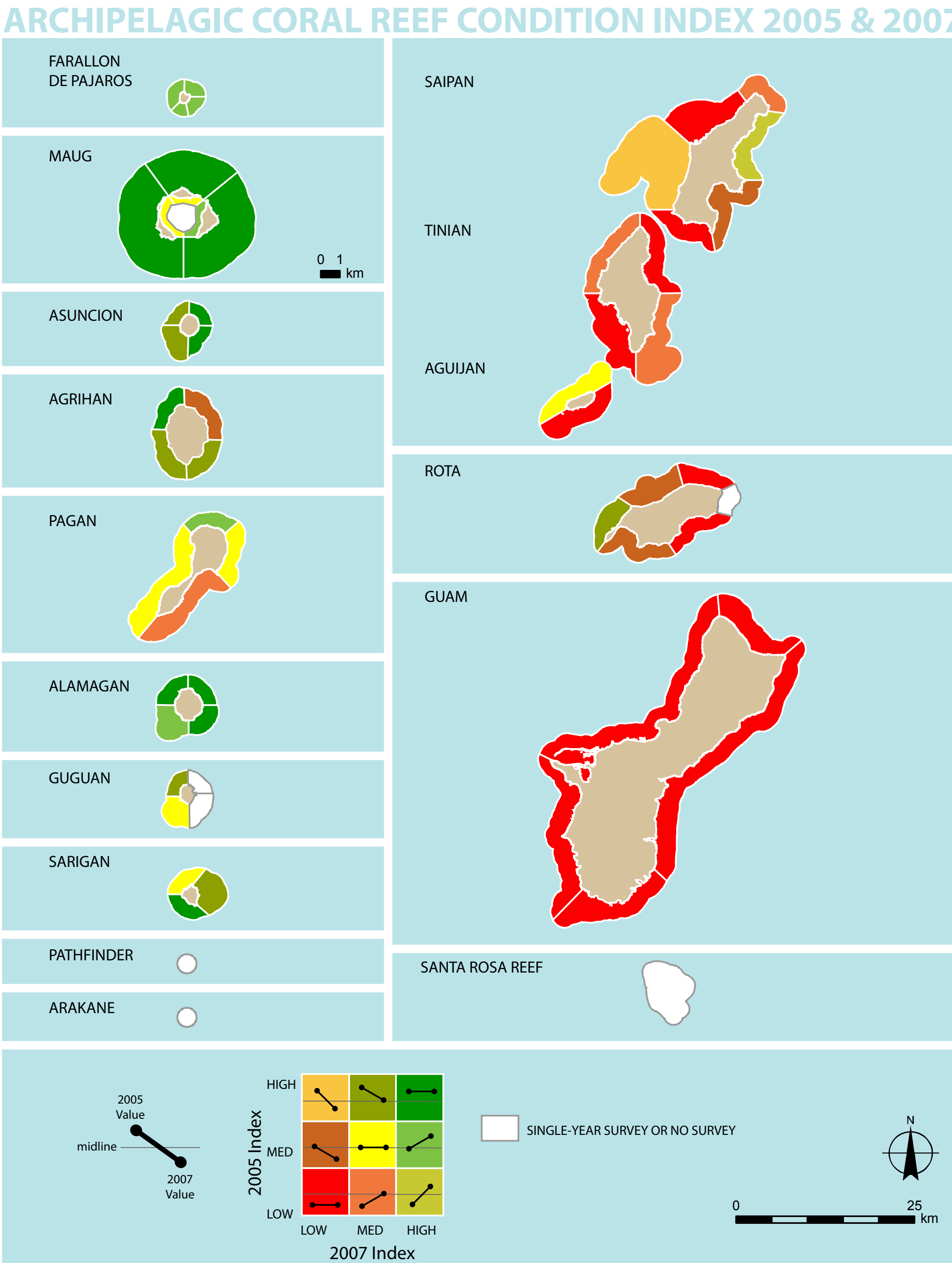
Levels of species richness, measured as the number of fish species encountered per 100 m^2, were averaged across the 3 survey years of 2003, 2005, and 2007. Species richness was higher at all northern islands with a range of 30.6–43.6 species/100 m^2, except for Anatahan with 14.1 species/100 m^2, than at any of the southern islands with a range of 20.2–30 species/100 m^2. The low species richness and biomass around Anatahan was likely a consequence, at least partially, of the low visibility encountered as a result of ash and debris in the water column from volcanic eruptions in 2003 and may also reflect low sampling effort there (just 3 REA sites were surveyed there during the MARAMP cruise in 2003).

Observations of size-class distribution for 3 families of fishes from REA surveys show that densities of large size classes were higher in the northern islands of the Mariana Archipelago than in the southern islands (Fig. 13). Groupers of all size classes were more abundant in the northern islands. Large size classes (≥ 25 cm) were commonly encountered in the northern islands, but these size classes were rare in the southern islands. Parrotfishes displayed more of a bimodal distribution with large individuals more common in the northern islands and small individuals more common in the southern islands. While the surgeonfish community was dominated by small size classes, its overall size range was greater around the northern islands, where densities were higher in all but the size class of 15–20 cm.

INTEGRATING ECOSYSTEM COMPONENTS

The Archipelagic Coral Reef Condition Index provides a simple tool to compare the general conditions of coral reef ecosystems across the Mariana Archipelago. This index illustrates striking differences in the conditions of both benthic and fish communities: conditions become lower moving from the northern islands to the southern islands (Figs. 14 and 15). These spatial patterns coincide with gradients in several potential causative factors, including human population, latitude, and geologic age and structure. A comparison of the 2005 and 2007 ranks for geographic regions in the Archipelagic Coral Reef Condition Index demonstrates that the index ranks (high, medium, or low) for about two-thirds of the geographic regions in this archipelago did not change between years. The other one-third of geographic regions, then, are identified as areas of change by the shift in their index ranks between years. With continued long-term monitoring, and additional years of data beyond 2005 and 2007, changes illustrated with these condition indices will reveal ecologically relevant patterns.

This analysis of MARAMP survey data shows that our observations are in agreement with other studies that suggest higher levels of macroalgal cover, lower fish biomass, smaller fish sizes, and lower percentage of coral cover are likely to occur in association with high densities of human population and high use of resources. In addition, the overall abundance of marine debris was greater around the southern islands compared to the rest of the Mariana Archipelago, with the greatest number of sightings of derelict fishing gear and other man-made objects, such as anchors, ground tackle, mooring blocks, and metal scrap, found around Guam and Tinian.



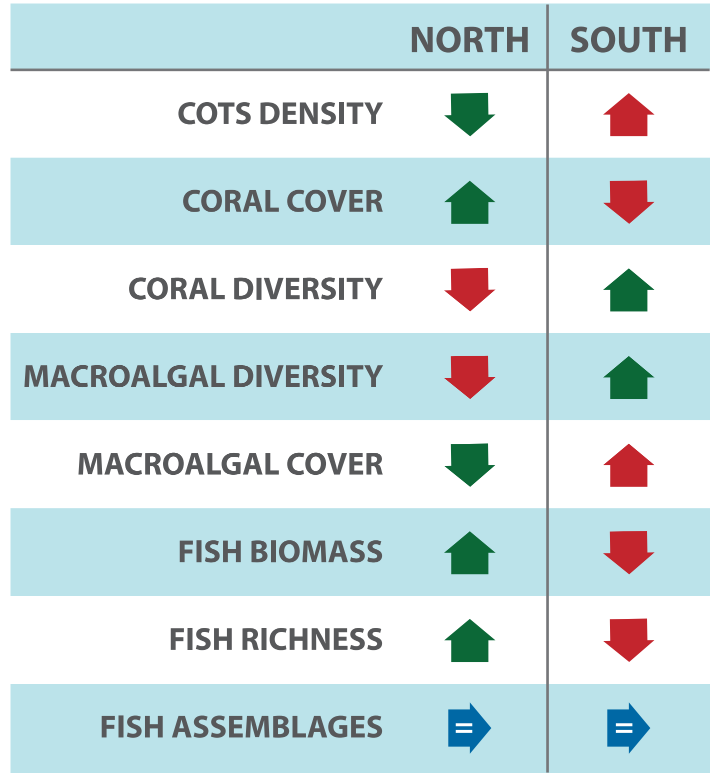
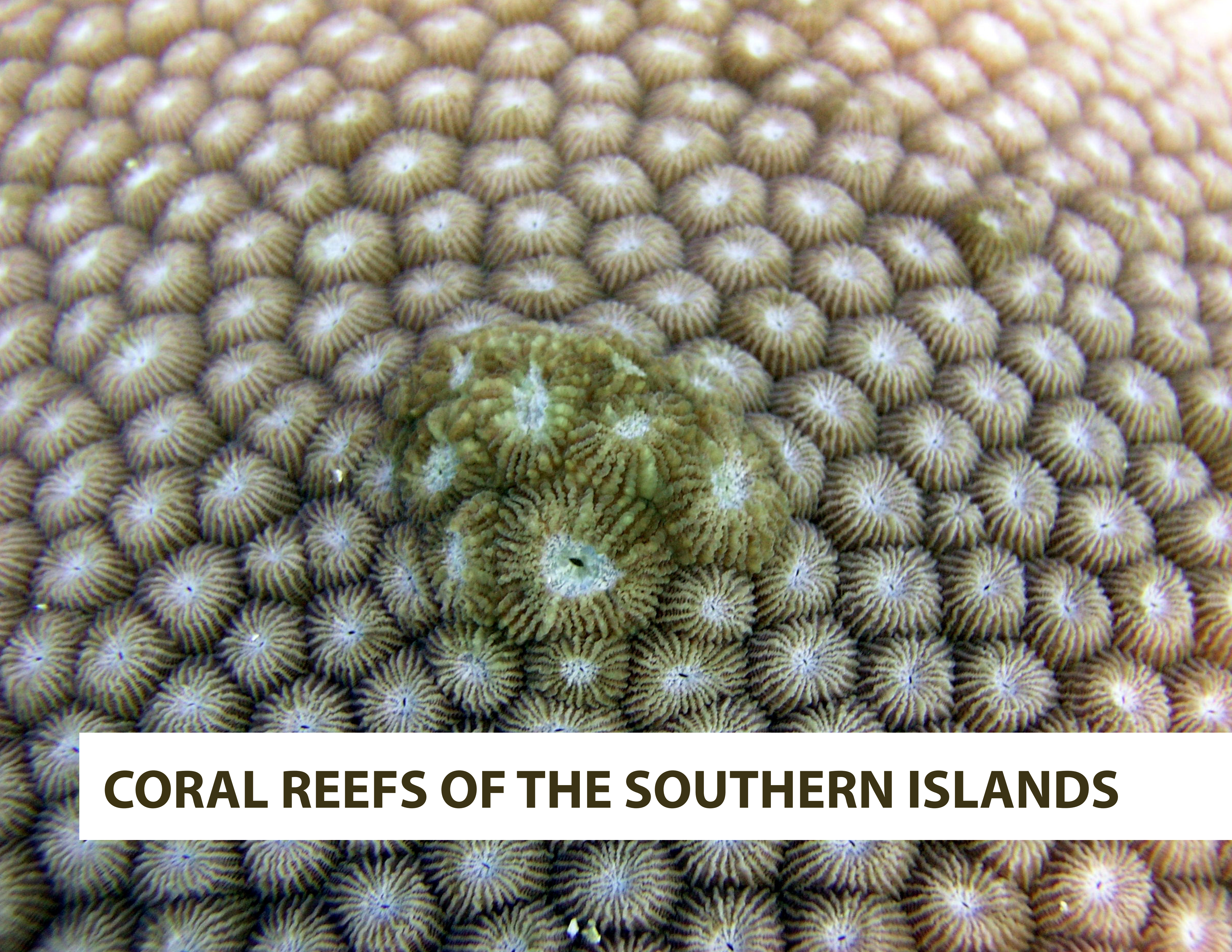


Figure 14 (left). *The Archipelagic Coral Reef Condition Index, based on towed-diver surveys conducted in 2005 and 2007, reflects the integrated condition of the benthic and fish communities for each geographic region, relative to other regions across the Mariana Archipelago. The regions around Maug, for example, have high index ranks for both 2005 and 2007. Thus, they are all assigned the bright-green color that corresponds to the top-right square in the legend. The position of the horizontal bar above the midline in this square also reflects that those geographic regions maintained a high rank for both 2005 (y-axis) and 2007 (x-axis).*

Figure 15 (above). *General comparison of parameters between the 9 northern islands and 5 southern islands. A green arrow indicates superior condition, a red arrow represents inferior condition, and the direction of an arrow shows whether a condition was higher or lower relative to the other island group. The blue arrows indicate that conditions were similar.*



CORAL REEFS OF THE SOUTHERN ISLANDS

This section includes management-relevant analyses from observations collected in the southern islands of the Mariana Archipelago, where human populations are more concentrated and there is high interest in issues of marine resource management.

BENTHIC COMPOSITION

The southern islands and nearby reefs include Guam, Rota, Aguijan, Tinian, and Saipan as well as Santa Rosa Reef, near Guam, and Tatsumi Reef, close to Tinian. The composition of the benthos around these islands was dominated by macroalgae. Mean macroalgal cover from towed-diver surveys conducted on forereef habitats in 2005 and 2007 was 47% with islandwide mean values ranging from 31% (SE 1.2) around Saipan to 50% (SE 1.5) around Tinian. The highest macroalgal cover in the Mariana Archipelago was recorded on Santa Rosa Reef with 70.5% (SE 3.1). Mean live-coral cover, from towed-diver surveys conducted during the 3 MARAMP cruises in 2003, 2005, and 2007, was 11% with values ranging between 7% (SE 0.5) around Rota and 19% (SE 0.6) around Guam. A mean coral cover of 7.7% (SE 0.2) was recorded for the 2 nearby offshore reefs, Tatsumi and Santa Rosa. Cover of crustose coralline red algae did not vary much among the southern islands, with mean cover ranging from 8% (SE 0.4) to 12.3% (SE 1.3) and the highest mean values recorded around Aguijan. At Santa Rosa Reef and Tatsumi Reef, crustose-coralline-red-algal cover was slightly lower with 4.9% (SE 1.2). Looking specifically at hard-bottom areas, results from REA surveys conducted only in 2007 show lower estimates of macroalgal cover (6%–24%) and similar values of coral cover (8%–16%) compared to islandwide estimates from towed-diver surveys encompassing all substrate types. Size-class distribution of coral colonies did not vary substantially among the southern islands in 2007.

Coral and coralline-algal diseases were observed around all 5 of the surveyed southern islands. The highest prevalence of coral disease of 1.4% (SE 0.4) was recorded at Guam, and the lowest prevalence of 0.1% (SE 0.03) was observed at Rota. Many of the cases of coral disease observed around these 5 islands disproportionately affected important reef-building taxa, including hard corals in the families Poritidae, Acroporidae, and Faviidae, as well as the carbonate-producing crustose coralline red algae. Excluding Aguijan, where only one site was surveyed, islandwide mean density of coralline-algal diseases was greatest at Tinian with 2.8 cases/100 m^2 (SE 1.5). Although prior field surveys (Starmer et al. 2008; Goreau J, pers. comm.) have identified the presence of coralline-algal disease in this region, the results from MARAMP surveys conducted in 2007 represent the first attempt to quantitatively evaluate the occurrence of these diseases across the Mariana Archipelago. In this context, patterns of coralline-algal disease indicate that some disease states were abundant and widespread and others were uncommon and rare. Of the 124 coralline-algal disease cases enumerated during MARAMP surveys in 2007, > 87% of cases corresponded to coralline lethal orange disease.

Opposite page: A massive Diploastrea heliopora *colony with enlarged corallites. The cause of this skeletal growth anomaly is unknown.* NOAA photo by Jean Kenyon

REEF FISHES

Mean large-fish biomass, estimated from towed-diver surveys conducted on forereef habitats in 2003, 2005, and 2007, was highest around Rota with 0.4 kg/100 m^2 (SE 0.1) and lowest around Guam with 0.1 kg/100 m^2 (SE 0.03). Mean total fish biomass, estimated from REA surveys conducted in 2003, 2005, and 2007, was highest around Aguijan with 5.2 kg/100 m^2 (SE 0.6) and Rota with 4.1 kg/100 m^2 (SE 0.9) and lowest around Santa Rosa Reef with 1.5 kg/100 m^2 (SE 0.1).

INTEGRATED OVERVIEW OF SAIPAN & GUAM

The *Coral Reef Ecosystem Monitoring Report of the Mariana Archipelago: 2003–2007* devotes individual chapters to Guam and 13 islands of the CNMI, discussing results from each of several interdisciplinary surveys. For the 4 populated, southern islands of Guam, Rota, Tinian, and Saipan, this report also provides comparisons of the benthic and fish communities around each island relative to the conditions around only these 4 islands. This overview section focuses on Saipan and Guam, which have the largest human populations in this archipelago.

Despite the lower levels of live-coral cover along the east coast of Saipan relative to the west coast, the general condition of the benthic communities in most survey areas around Saipan appeared above average compared to other survey areas in the 4 populated, southern islands in 2005 and 2007, based on the calculated *Benthic Condition Index for Guam, Rota, Tinian, and Saipan*. The relatively low coral cover on the east coast may reflect the natural character of the reef, including geologic, topographic, and oceanographic factors, rather than the impact of human activities. Integrating towed-diver benthic and fish data with modeled wave conditions reveals that coral cover was higher along Saipan's sheltered west coast than in other areas, but large-fish biomass was relatively constant around this island (Fig. 16).

Ranks for survey areas in the Coral Reef Condition Index for Guam, Rota, Tinian and Saipan, as well as in the associated Benthic Condition Index, varied around Guam. The survey area near the Guam National Wildlife Refuge on the northwest corner of this island had coral cover of 11%–20% (Fig. 17) and a high rank in the Benthic Condition Index in 2005, but this rank declined to medium in 2007. The large population near and frequent use of Tumon Bay on the northwest coast of Guam and the numerous associated stressors that can impact high-use areas may have resulted in deteriorating conditions of the benthic communities on the forereef off Tumon Bay: the rank for this survey area in the Benthic Condition Index changed from medium in 2005 to low in 2007. It should be pointed out that many possible land-based impacts likely take place predominantly on the shallow backreef that was not surveyed as part of the MARAMP. Within the Tumon Bay Marine Preserve, regulations pro-

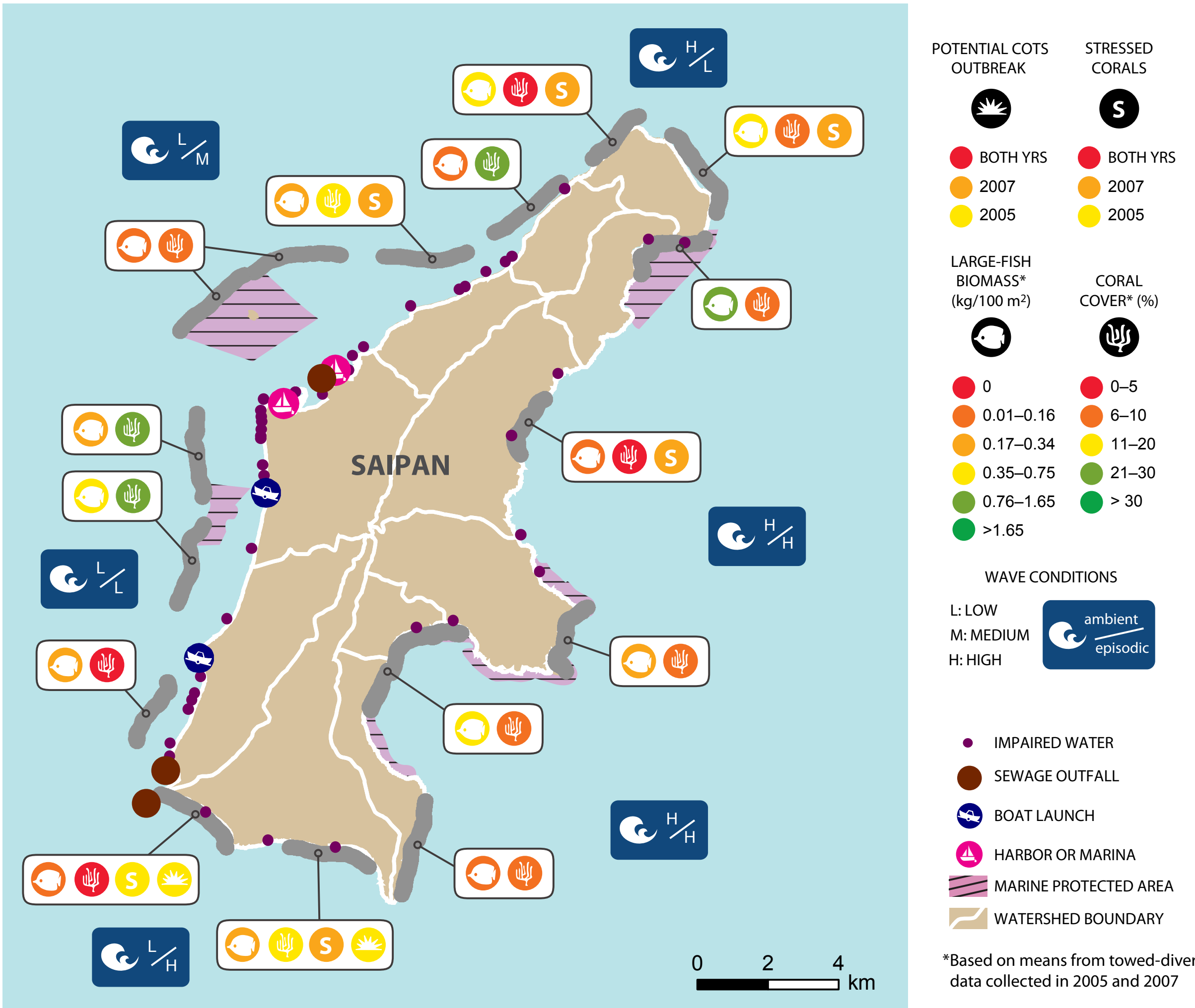
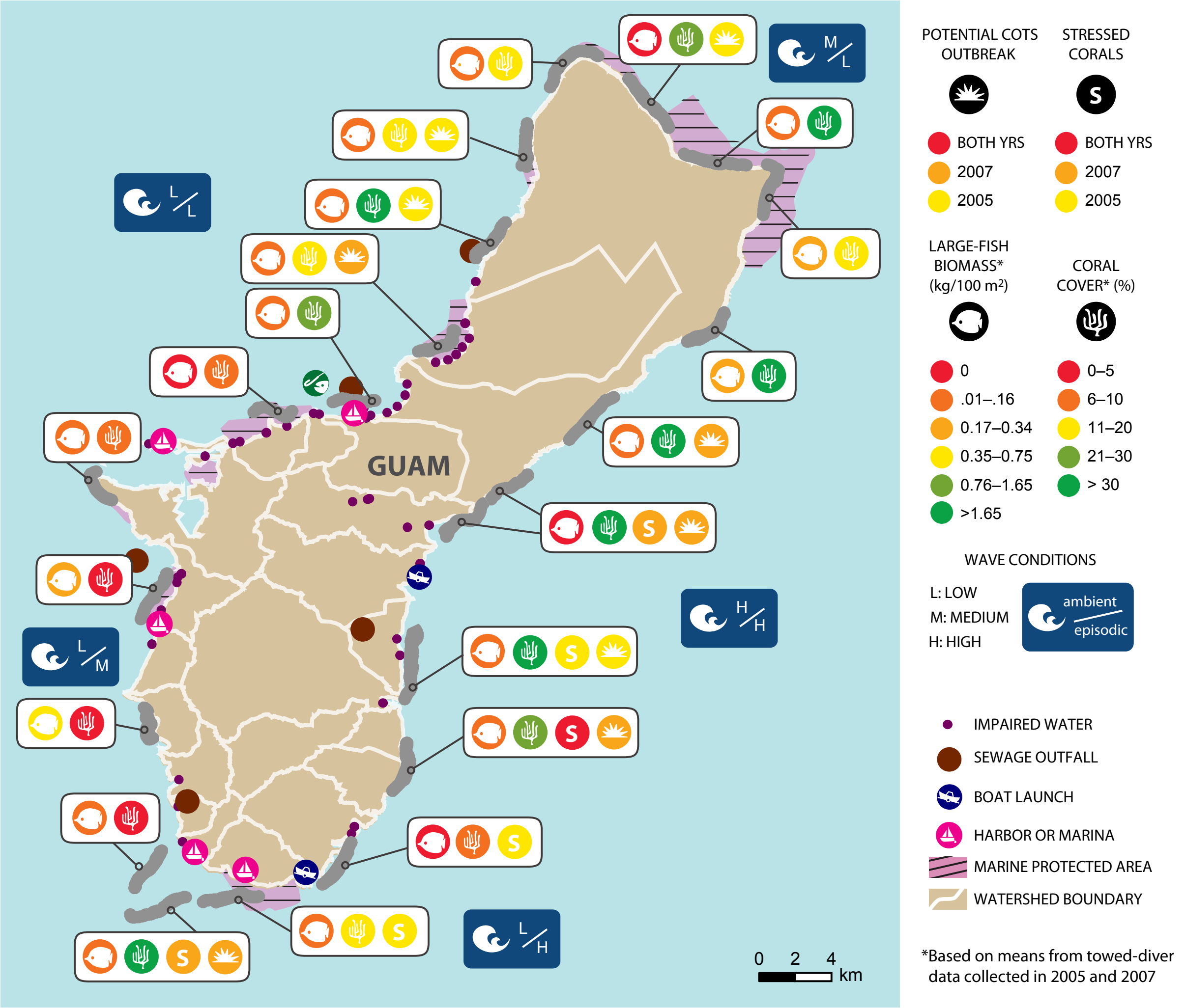


Figure 16. Integrated overview of benthic and fish communities around Saipan, illustrated with various human and natural factors that may influence their condition.

hibit various fishing activities, yet towed-diver surveys of the forereef habitats of Tumon Bay recorded very low biomass of large fishes (≥ 50 cm in total length) in all 3 survey years, with generally only a few individuals recorded per survey (the low values from 2005 and 2007 are illustrated in Fig. 17). Around southwest Guam, where very low levels of coral cover (0%–5%) were observed (Fig. 17), factors exerting a potential negative influence on reef communities included poor water quality along portions of the coastline, a lack of favorable substrate for reef development,

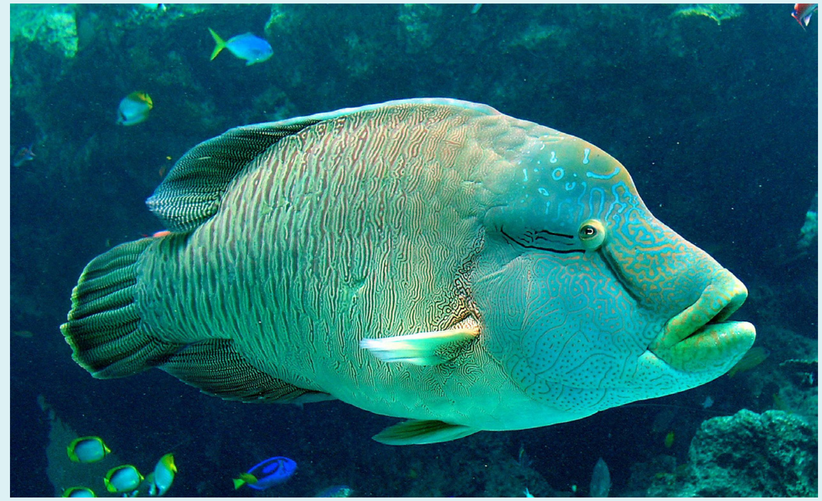
Figure 17. Integrated overview of benthic and fish communities around Guam, illustrated with various human and natural factors that may influence their condition.



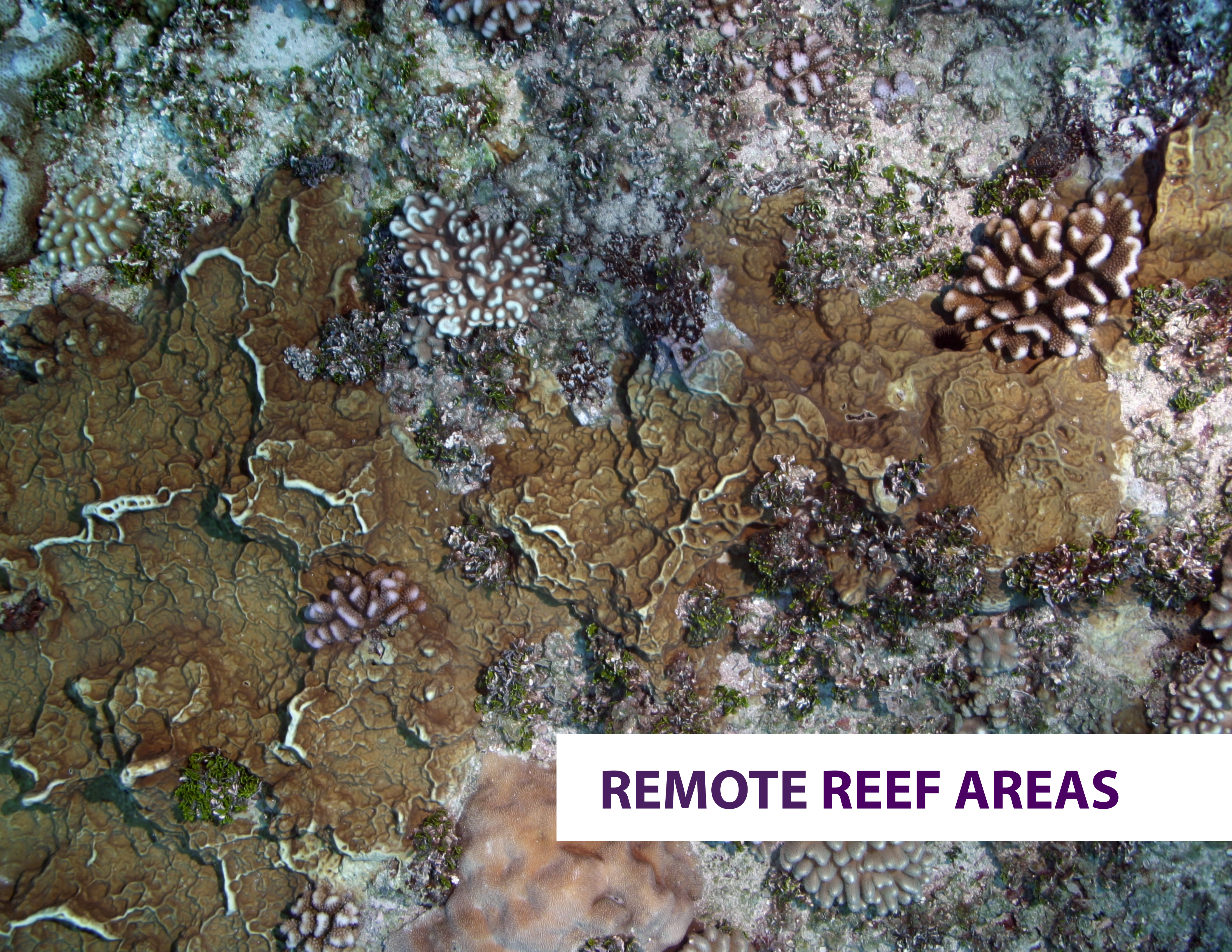
and elevated sediment input. The conditions of the reef in the Pati Point Marine Preserve, located around the northeast corner of Guam, were among the best observed around the 4 populated, southern islands. Ranks for the survey area closest to the northeastern tip of Guam were high in the Coral Reef Condition Index and Benthic Condition Index for 2005 and 2007. The highest numbers of large fishes around Guam, from towed-diver surveys conducted in 2007, were recorded in this area.

SIGHTINGS OF RARE WRASSE

Although large-bodied fish species generally were encountered more frequently around the northern islands, an exception was the rare humphead wrasse (*Cheilinus undulatus*), also known as the Napoleon Wrasse. This fish species is one of the largest coral reef fishes, reaching up to 2 m and 190 kg. It occurs patchily throughout much of the Indo-Pacific region, and its life-history characteristics make it more vulnerable than most other species of coral reef fishes to overexploitation. Although this species is not common, the CRED recorded 48 sightings of humphead wrasse around the southern islands, with a mean density of 10.9 individuals/km^2 (SE 7.3), but only 7 sightings around the northern islands, with 2.2 individuals/km^2 (SE 1.1), over 3 survey years. The sizes of individual fish were similar with an average length of 92.8 cm (SE 9.9) in the northern islands and 90.7 cm (SE 4.1) in the southern islands. Three of the individuals seen at the remote banks on the West Mariana Ridge were slightly larger with a mean length of 115.8 cm (SE 9.3).



*The humphead wrasse (*Cheilinus undulatus*) was seen more frequently around the southern islands compared to the northern islands.* NOAA photo



REMOTE REEF AREAS

Before the CRED initiated MARAMP surveys, little information was available on the benthic composition and geologic structure of the remote reefs and banks located on the West Mariana Ridge (Fig. 18). The CRED conducted limited reconnaissance surveys at Arakane Reef, Pathfinder Reef, and Stingray Shoal in 2003 and at Arakane and Pathfinder Reefs in 2005. Results show, in general, that cover percentages for corals and crustose coralline red algae were fairly high (Table 2) at these 3 remote reef areas, relative to other survey areas in the Mariana Archipelago. Estimates of coral cover and large-fish biomass were higher at Stingray Shoal with 54.9% and 5.2 kg/100 m^2 than at any other area surveyed in the Mariana Archipelago, and macroalgal cover was highest on Arakane Reef with 52.3% (Table 2).

Table 2. Overview of benthic composition and fish biomass at 3 remote, submerged reefs on the West Mariana Ridge.

	ARAKANE REEF				PATHFINDER REEF				STINGRAY SHOAL	
	2003		2005		2003		2005		2003	
	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
MACROALGAL COVER (%)	52.3	1.6	45.8	2.3	37.3	1.3	29.0	1.1	33.9	1.9
CRUSTOSE CORALLINE RED ALGAL COVER (%)	5.3	0.7	3.6	0.6	5.6	0.8	10.0	1.2	1.5	0.4
CORAL COVER (%)	24.1	1.1	11.8	1.6	24.2	0.9	24.8	1.4	54.9	2.7
STRESSED-CORAL COVER (%)	–	–	0.0	0.0	–	–	0.1	0.0	–	–
LARGE-FISH BIOMASS (kg/100m^2)	0.8	0.5	1.4	1.1	1.4	0.4	0.5	0.1	5.2	1.1
TOTAL FISH BIOMASS (kg/100m^2)	2.1	N/A	6.4	2.8	4.7	N/A	7.2	1.9	–	–

Opposite page: Benthic composition at Arakane Reef captured during a towed-diver survey. NOAA Photo

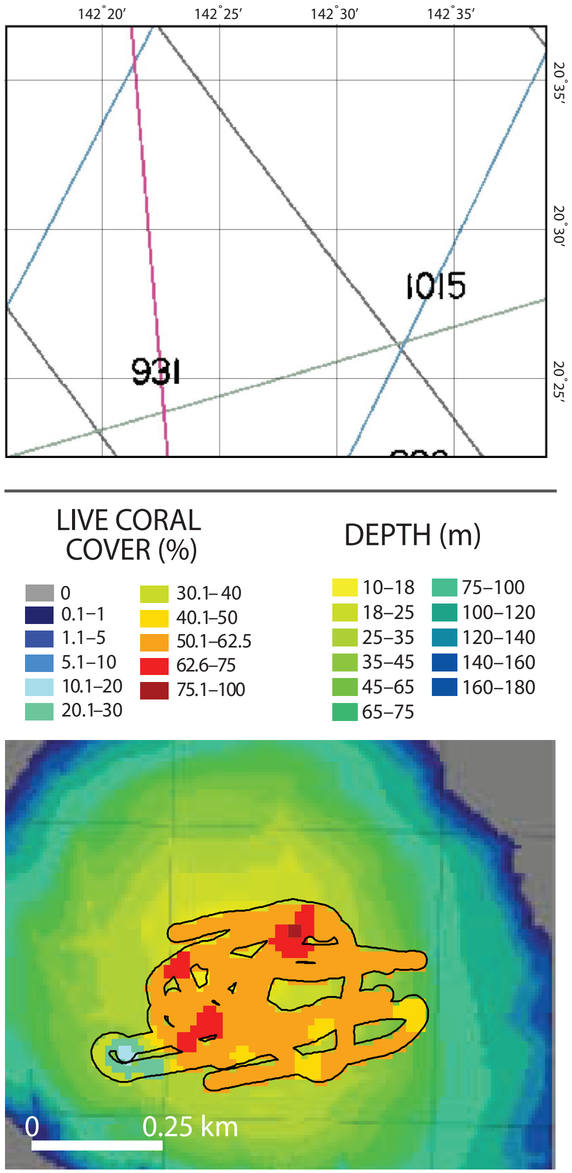
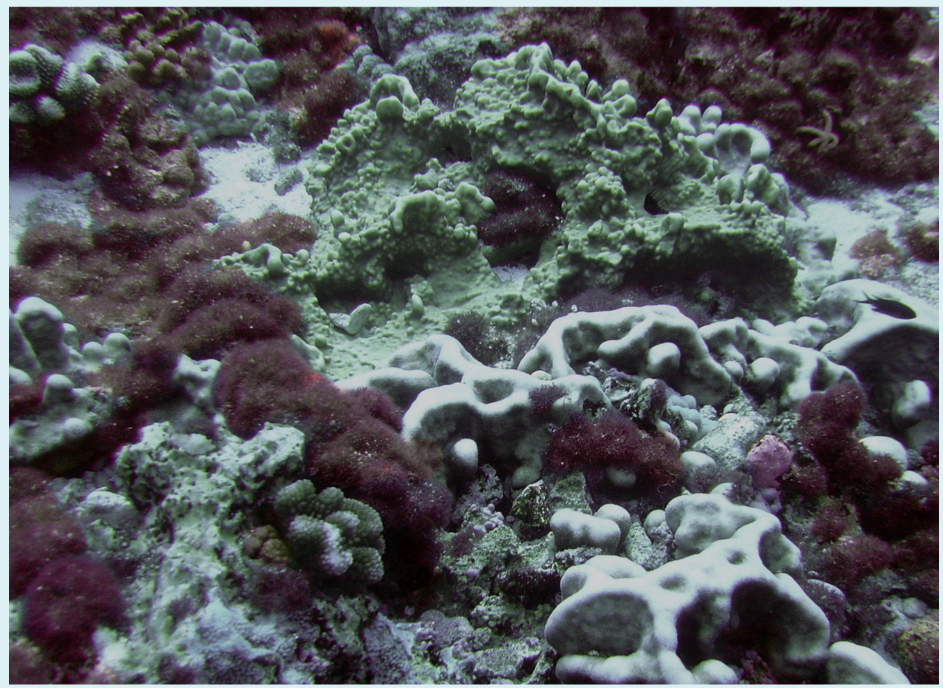


Figure 18. Information about Stingray Shoal (top) *prior to Pacific RAMP surveys and* (bottom) *live-coral cover (%) from towed-diver surveys and depths (m) from sonar mapping conducted by the CRED in 2003.*

NEWLY MAPPED REEFS: STINGRAY SHOAL

Though there were undocumented reports from fishermen about Stingray Shoal, the best available nautical charts in 2003 indicated shallowest water depth in this area of 931 fm (1703 m), with no suggestion of a shallow-water coral reef ecosystem. Using shipboard and handheld single-beam sonars, the CRED located this little-known, submerged seamount and mapped a minimum depth of only 13 m. Ensuing diver-based biological surveys found predominantly hard substrate with high-complexity habitats supporting live-coral cover of 40%–100% (Fig. 18). The coral reefs of Stingray Shoal were found to support a high-density reef-fish community, with large-fish biomass levels of > 5 kg/100 m^2 almost 5 times the values observed for the northern islands and 23 times the values found around the southern islands. Reef sharks accounted for the highest proportion (50%) of large-fish biomass with the greatest contribution from the grey reef shark (*Carcharhinus amblyrhynchos*). Though biomass was high, towed-diver surveys discovered derelict fishing gear and other man-made objects, clearly indicating that these reefs had been fished.



The reef at Stingray Shoal, part of the West Mariana Ridge. NOAA photo

REFERENCES

Brown VA (2007) Guam coral bleaching event September–October 2006. NMFS/PIRO/HCD Incident Report, NMFS Pacific Islands Regional Office, Habitat Conservation Division, Honolulu, HI. December 2006 (updated July 2007).

Burdick D, Brown V, Asher J, Gawel M, Goldman L, Hall A, Kenyon J, Leberer T, Lundblad E, McIlwain J, Miller, J, Minton D, Nadon M, Pioppi N, Raymundo L, Richards B, Schroeder R, Schupp P, Smith E, Zgliczynski B (2008) The state of the coral reef Ecosystems of Guam. In: Waddell JE, Clarke AM (eds) The state of the coral reef ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team, Silver Spring, MD. p. 465–509.

Coral reef conservation: purposes. 16 U.S. Code § 6401 (2000).

Friedlander AM, DeMartini EE (2002) Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian islands: the effects of fishing down apex predators. Mar Ecol Progr Ser 230:253–264.

Friedlander A, Aeby G, Balwani S, Bowen B, Brainard R, Clarke A, Kenyon J, Maragos J, Meyer C, Vroom P, Zamzow J (2008) The state of coral reef ecosystems in the northwestern Hawaiian islands. In: Waddell JE, Clarke AM (eds) The state of coral reef ecosystems of the United States and Pacific freely associated states: 2008. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. p. 263–306.

Houk P, Starmer J (2010) Constraints on the diversity and distribution of coral-reef assemblages in the volcanic Northern Mariana Islands. Coral Reefs 29(1):59–70

Houk P, Van Woesik R (2010) Coral assemblages and reef growth in the Commonwealth of the Northern Mariana Islands (Western Pacific Ocean). Mar Ecol 31(2):318–329.

NOAA (2002) A National Coral Reef Action Strategy. Report to Congress on implementation of the Coral Reef Conservation Act of 2000 and the National Action Plan to Conserve Coral Reefs in 2002–2003, produced by NOAA, U.S. Department of Commerce, in cooperation with the U.S. Coral Reef Task Force. Silver Spring, MD. 122 p.

Riegl BM, Purkis SJ, Houk P, Cabrera G, Dodge RE (2008) Geologic setting and geomorphology of coral reefs in the Mariana Islands (Guam and Commonwealth of the Northern Mariana Islands). In: Riegl BM, Dodge RE (eds) Coral reefs of the USA, Springer-Verlag, Berlin. p. 695–718.

Starmer J, Asher J, Castro F, Gochfeld D, Gove J, Hall A, Houk P, Keenan E, Miller J, Moffit R, Nadon M, Schroeder R, Smith E, Trianni M, Vroom P, Wong K, Yuknavage K (2008) The state of coral reef ecosystems of the Commonwealth of the Northern Mariana Islands. In: Waddell JE and Clarke AM (eds.), The state of coral reef ecosystems of the United States and Pacific freely associated states: 2008. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. p. 437–464.

Stevenson C, Katz LS, Micheli F, Block B, Heiman KW, Perle C, Weng K, Dunbar R, Witting J (2007) High apex predator biomass on remote Pacific islands. Coral Reefs 26(1):47–51.

Tribollet AD, Vroom PS (2007) Temporal and spatial comparison of the relative abundance of macroalgae across the Mariana Archipelago between 2003 and 2005. Phycologia 46:187–197.

U.S. Coral Reef Task Force (2000) National Action Plan to Conserve Coral Reefs. U.S. Coral Reef Task Force, Washington, D.C. Online at http://coralreef.gov/about/CRTFAxnPlan9.pdf. Accessed on August 31, 2009.

Williams ID, Walsh WJ, Schroeder RE, Friedlander AM, Richards BL, Stamoulis KA (2008) Assessing the importance of fishing impacts on Hawaiian coral reef fish assemblages along regional-scale human population gradients. Environ Conserv 35(3):261–272.

PACIFIC ISLANDS FISHERIES SCIENCE CENTER

CORAL REEF ECOSYSTEM DIVISION