18 REEFS & BANKS of the CNMI

18.1 Introduction

Biological, oceanographic, and habitat data of various amounts were collected on Ahyi Seamount, Supply Reef, Zealandia Bank, Marpi Bank, and Esmeralda Bank on the Mariana Arc and on Stingray Shoal, Pathfinder Reef, and Arakane Reef on the West Mariana Ridge during MARAMP 2003, 2005, and 2007. Each of these offshore banks and remote reefs is discussed independently in this chapter along with the corresponding data available for that location. Figure 18.1a shows the locations of these 8 reefs and banks in relation to the islands of the Mariana Archipelago.

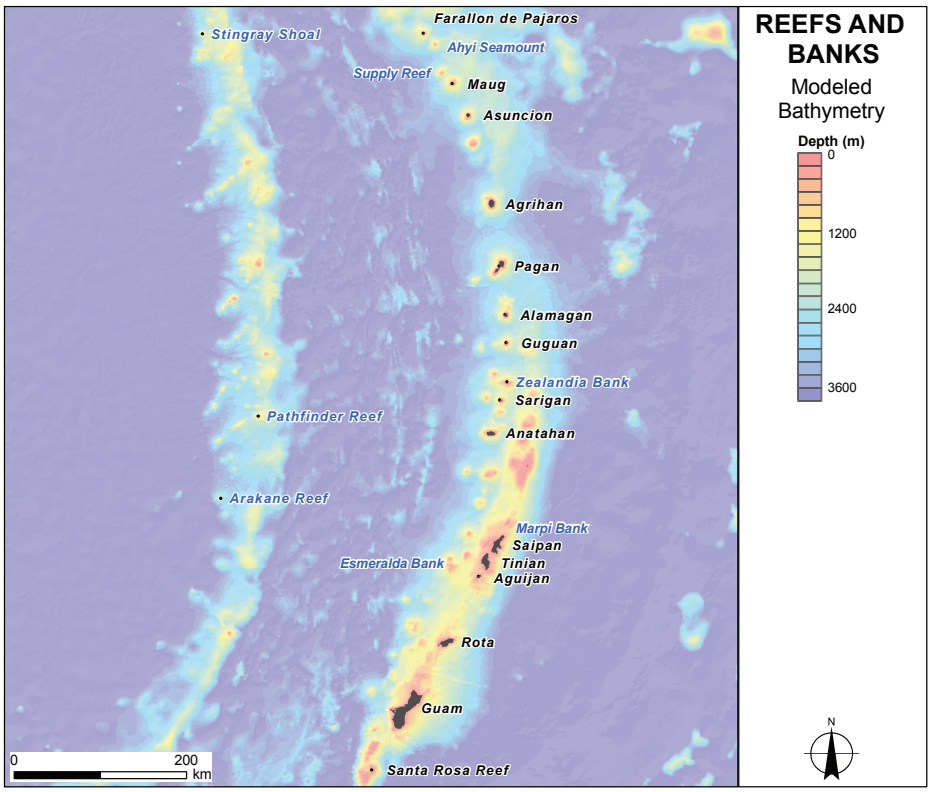


Figure 18.1a. Locations of the offshore banks—Ahyi Seamount, Supply Reef, Zealandia Bank, Marpi Bank, and Esmeralda Bank—and remote reefs—Stingray Shoal, Pathfinder Reef, and Arakane Reef—surveyed in the Mariana Archipelago during MARAMP 2003, 2005, and 2007.

18.1.1 Geologic Setting

The reefs and banks of the Commonwealth of the Northern Mariana Islands (CNMI) can be split into 3 groups based on their geologic history: Mariana active arc, frontal arc of the Mariana arc-trench system, and West Mariana Ridge (for more information on the geologic setting of the Mariana Archipelago, see Chapter 1: "Introduction," Section 1.1.2: "Geologic and Geographic Setting").

Four of the seamounts located on the Mariana Arc are active or dormant volcanoes formed within the past 4 million years as a result of the subduction of the Pacific Plate under the Philippine Plate at the Mariana Trench, which is located ~ 200 km to the east of the Mariana Arc. During MARAMP 2003, 2005, or 2007, 3 of these 4 seamounts were surveyed by the Coral Reef Ecosystem Division (CRED): Ahyi Seamount, Supply Reef, and Zealandia Bank. A fourth active seamount, Esmeralda Bank, located ~ 57 km southwest of Saipan, has been mapped as part of an ongoing series of NOAA Ocean Explorer expeditions.

Esmeralda Bank is one of the southernmost active stratovolcanoes in the Mariana Arc (Stern and Bibee 1984) and has a clear caldera that is breached on the west. Zealandia Bank, located northeast of Sarigan, has a more elongated shape and

is formed by 2 adjacent volcanic pinnacles ~ 1 km apart. Supply Reef and Ahyi Seamount, located between Farallon de Pajaros and Maug, are steeply sloping conical features, the typical morphology for stratovolcanoes. One of Zealandia's pinnacles reaches ~ 1 m above sea level during low tide (Siebert and Simkin 2002–), and it is possible that the shallow summits of Esmeralda Bank (43 m), Supply Reef (~ 10 m), and Ahyi Seamount (~ 80 m) have also emerged during previous sea level stands.

Supply Reef is joined to Maug by a low saddle at a depth of ~ 1800 m, and together these two features form a twin volcanic massif (Siebert and Simkin 2002–). Ahyi Seamount, in contrast, is an isolated conical feature and is thought to be volcanically active. Fishermen in a boat near the seamount in 1979 experienced shocks and observed upwelling of sulfur-bearing water, and, in April 2001, a seismic station detected an explosive eruption somewhere in the vicinity of this summit (Siebert and Simkin 2002–). Fumarolic activity also was detected at Zealandia Bank in 2004 (Siebert and Simkin 2002–). No volcanic activity has been recorded at Supply Reef, while Esmeralda Bank is currently active and frequent surface discoloration and sulfur boils have been seen in the area of this bank (Embley et al. 2004).

Two of the offshore, submerged banks surveyed for MARAMP, Marpi Bank and Tatsumi Reef, are part of the remnant Mariana frontal arc formed during the late Eocene and early Miocene epochs (15–20 million years ago), along with the islands of Farallon de Medinilla, Saipan, Tinian, Aguijan, Rota, and Guam. Data from Marpi Bank, located ~ 11 km north of Saipan, are presented in this chapter. Located only 3 km south of Tinian, Tatsumi Reef is discussed in Chapter 7: "Tinian and Tatsumi Reef." Like the islands on this part of the Mariana Arc, both banks are characterized by a flat top and probably made up of uplifted limestone overlying an older volcanic core.

Three reefs located on the West Mariana Ridge—Stingray Shoal, Pathfinder Reef, and Arakane Reef—were surveyed during MARAMP 2003. This ridge is separated from the Mariana Arc by the Mariana Trough, which continues to spread over time, expanding the distance between the 2 arcs. A remnant volcanic island arc, West Mariana Ridge is of an intermediate age between the modern, active arc and the frontal arc that make up the Mariana Arc. This ridge is now composed of a series of seamounts, none of which break the surface. Shallow summits suggest that some of these seamounts probably formed islands at some time in their history. The 3 reefs visited in 2003 all have minimum depths of 10–13 m.

18.1.2 Environmental Issues

Esmeralda Bank, Zealandia Bank, Ahyi Seamount, and Stingray Shoal are 4 of the 21 seamounts that are part of the Marianas Trench Marine National Monument, which was established by presidential proclamation in January 2009. The Volcanic Unit of the Marianas Trench Marine National Monument includes the submerged lands within 1 nautical mile (or 1.85 km) of 21 designated volcanic sites, and these volcanoes are part of the National Wildlife Refuge System. No waters are included as part of the Volcanic Unit, indicating that fishing is still allowed.

It has been noted that large vessels (9–21 m) in the CNMI that are able to fish on multiday trips focus their efforts from Esmeralda Bank to Zealandia Bank (Western Pacific Fishery Management Council 2011). Aside from this fishing pressure, little is known about the existing or potential effects of human activities on any of the surveyed reefs and banks. Their remoteness from land means that they are less subject to many of the anthropogenic pressures that affect the populated islands of the Mariana Archipelago; however, the extent to which fishing occurs in these remote areas is unknown.

18.2 Ahyi Seamount

18.2.1 Introduction

Ahyi Seamount is a stratovolcano located ~ 17 km south of Farallon de Pajaros on the Mariana Arc (Fig. 18.2.3a). Fishermen in a boat near the seamount in 1979 experienced shocks and observed upwelling of sulfur-bearing water, and, in April 2001, a seismic station detected an explosive eruption somewhere in the vicinity of this summit (Siebert and Simkin 2002–). Ahyi Seamount is designated as part of the Volcanic Unit of the Marianas Trench Marine National Monument.

18.2.2 Survey Effort

During MARAMP 2007, CRED partially mapped Ahyi Seamount with multibeam sonar east and south of this stratovolcano, adding to multibeam data that had been collected by the NOAA VENTS Program during a series of "Submarine Ring of Fire" cruises (Weiss et al. 2008; Embley et al. 2007). To provide a more complete picture of the topography of this reef, among others, these limited multibeam bathymetry data are presented overlying a bathymetry grid with a 30-arcsecond (~ 900-m) resolution and based on a satellite-gravity model calibrated with depth soundings (Becker et al. 2009).

Two towed optical assessment device (TOAD) surveys were conducted on Ahyi Seamount during MARAMP 2003 at depths of ~ 315–375 m, covering a distance of 0.66 km. Subsequent analyses of the video footage obtained from these surveys showed that the camera was too high above the seabed and the quality of the video was insufficient for detailed analyses.

18.2.3 Benthic Habitat Mapping and Characterization

The bathymetry data suggest that Ahyi Seamount is a steep-sided, conical seamount, with a minimum depth of < 80 m. A linear ridge extends southwest of this summit from a depth of ~ 200–300 m. A small number of ridges are shown radiating down the flanks of this seamount, but these flanks otherwise appear relatively smooth (Fig. 18.2.3a). Because of the limited coverage of MARAMP multibeam data, no backscatter analysis was done.

TOAD optical-validation surveys were conducted on the southern flanks of Ahyi Seamount. Analyses of the video footage from both surveys suggest a hard substrate, but further classification of the benthic cover was not possible because of the low quality of much of the video footage obtained. The benthos could be classified in ~ 30% of the video frames from these surveys: no live scleractinian (hard) corals were seen, although some other types of benthic fauna were observed.

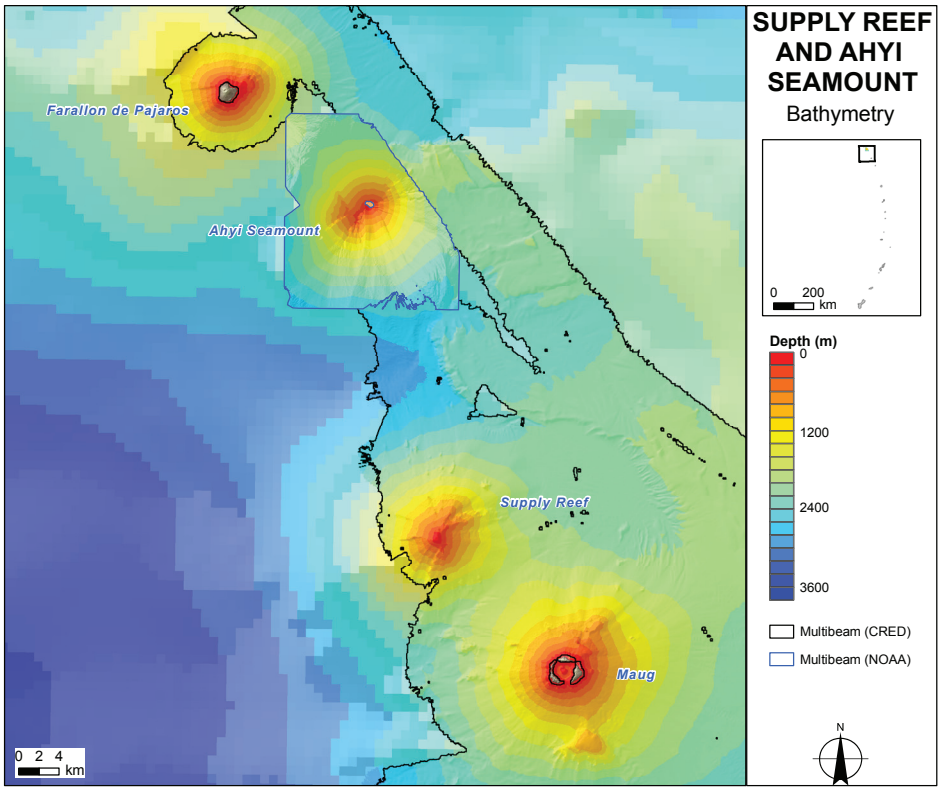


Figure 18.2.3a. Gridded multibeam bathymetry (grid cell size: 60 m, shown outlined in black) collected by CRED during MARAMP 2007 at depths of 10–3000 m using a 30-kHz Kongsberg EM 300 sonar with gridded multibeam bathymetry (grid cell size: 35 m, shown outlined in blue) collected by NOAA in 2003 using a Kongsberg EM 300 sonar (Merle et al. 2003). Shown elsewhere are modeled bathymetry data (grid cell size: 30 arcsecond or ~ 900 m; Becker et al. 2009).

18.3 Supply Reef

18.3.1 Introduction

Supply Reef is a stratovolcano located ~ 25 km north of Maug on the active Mariana Arc (see Figure 18.2.3a in Section 18.2: "Ahyi Seamount"). Supply Reef is joined to Maug by a low saddle at a depth of ~ 1800 m, and these 2 features together form a twin volcanic massif, meaning a single undersea mountain with 2 peaks (Siebert and Simkin 2002–). No volcanic activity has been recorded at Supply Reef.

18.3.2 Survey Effort

Benthic habitat mapping data were collected on Supply Reef using a combination of acoustic and optical survey methods. During MARAMP 2007, Supply Reef was mapped using multibeam sonar, adding to multibeam data that had been collected by the NOAA VENTS Program during a series of "Submarine Ring of Fire" cruises (Weiss et al. 2008; Embley et al. 2007). Multibeam sonar data collected by CRED around Supply Reef, Asuncion, Maug, and Farallon de Pajaros in 2007 covered a total area of 3856 km^2. Optical validation and habitat characterization were completed in 2003 using towed-diver and TOAD surveys that documented live-hard-coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in the next section.

Information on habitat and the composition and distribution of biological communities on Supply Reef was collected using towed-diver and TOAD surveys during MARAMP 2003. Because of the small size of this reef, only a single towed-diver survey was conducted there, covering a distance of 0.98 km at depths of 4–25 m (Table 18.3.2a and Fig. 18.3.2a). Two TOAD surveys were conducted on Supply Reef at depths of 76–171 m, covering a distance of 0.63 km (Fig. 18.3.2a). Results from these surveys are reported in Sections 18.3.3: "Benthic Mapping and Characterization" and 18.3.5: "Biological Characterization." The numbers of surveys conducted are presented in Table 18.3.2a, along with their depth and total area or length.

Table 18.3.2a. Numbers, depth (m), total area (ha), and total length (km) of towed-diver and TOAD surveys conducted on Supply Reef during MARAMP 2003.

Survey Type	Survey Detail	Year
Towed Diver		**2003**
	Number of Surveys	1
	Total Survey Area (ha)	1.0
	Depth (m)	17.4
TOAD		**2003**
	Number of Surveys	2
	Total Length (km)	0.63

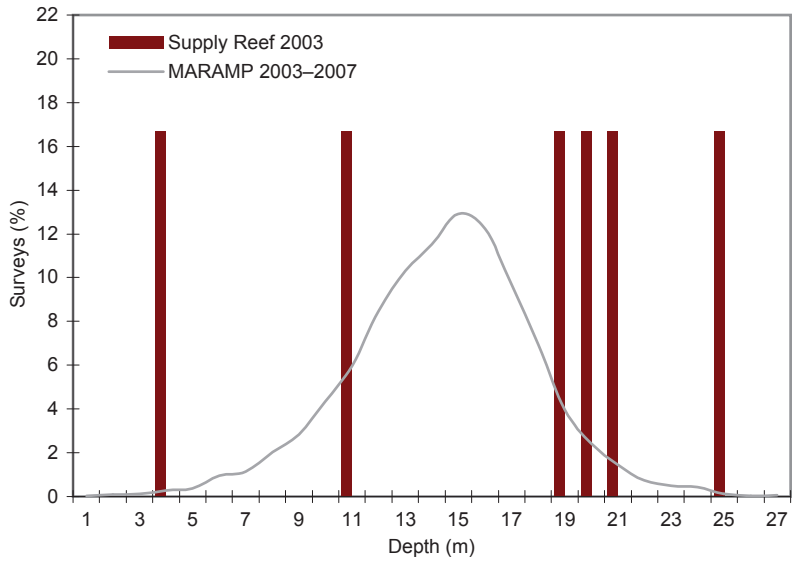


Figure 18.3.2a. Depth histogram plotted from mean depths of 5-min segments of the towed-diver survey conducted on Supply Reef during MARAMP 2003. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005, and 2007.

Temporal observations of key oceanographic parameters influencing reef conditions were collected on Supply Reef using (1) two types of moored instruments designed for long-term observations of high-frequency variability of temperature and wave height and (2) conductivity, temperature, and depth (CTD) profiles of the vertical structure of deepwater properties. A summary of deployed instruments and CTD cast activities is provided in Table 18.3.2b. Data from the wave-and-tide recorder (WTR) are discussed in Section 18.3.4: "Oceanography." Results from deepwater CTD casts performed on Supply Reef are discussed in Chapter 3: "Archipelagic Comparisons." Interpretation of the data from the STR deployed on this reef is beyond the time frame (2003–2007) of this report.

Table 18.3.2b. Numbers of oceanographic instruments deployed and deepwater CTD casts performed on Supply Reef during MARAMP 2003, 2005, and 2007. Deepwater CTD casts were conducted to a 500-m depth. Information on deepwater CTD casts is presented in Chapter 3: "Archipelagic Comparisons."

Observation Type	Year						
Instruments	2003	2005		2007		2009	Lost
	Deployed	Retrieved	Deployed	Retrieved	Deployed	Retrieved	
STR	–	–	–	–	1	1	–
WTR	1	1	1	1	1	1	–
CTD Casts		2005		2007			Total
Deepwater Casts		3		2			5

18.3.3 Benthic Habitat Mapping and Characterization

Supply Reef is steep-sided and conical, with ridges on all flanks and a minimum depth of ~ 10 m (see Figure 18.2.3a in Section 18.2: "Ahyi Seamount"). The bathymetry data also show some blocks of material in deep waters north of Supply Reef, including a small cone-shaped block northeast of this reef.

Sufficient multibeam coverage was obtained over Supply Reef, and these data were used to generate maps of slope, rugosity, and bathymetric position index (BPI) zones. High-resolution multibeam bathymetry data collected on Supply Reef show a steeply sloping, conical bank that arises to a narrow summit at a depth of ~ 10 m (Fig. 18.3.3a). The bathymetry and slope maps of Supply Reef suggest that the topography on the summit of this reef is slightly lumpy in texture and is ~ 300 m in diameter (Figs. 18.3.3a and b). Ridges extend northeast and southeast of this summit, and from them a network of smaller ridges radiate, eventually descending to 800 m, which is the limit of the mapping data. Aside from these ridges, the flanks of this reef are characterized by uniformly steep slopes. The steepest slopes (> 50°) were recorded on the sides of the ridges, while the flattest areas were recorded on the ridge tops and the summit. The rugosity map shows a similar pattern with the lowest rugosity recorded on the summit and ridge tops and elsewhere having moderate to high rugosity (Fig. 18.3.3c). These observations are supported by the BPI terrain analysis, which revealed a landscape dominated by slopes and ridges (Fig. 18.3.3d). The only depression zones identified were on the edge of the data, and the continuous ring of depressions shown on the BPI zone map appears to be an artifact of the data; the low-resolution bathymetry map clearly shows that the flanks continue to descend in a fairly uniform way. No flat zones were identified in the BPI terrain analysis. Backscatter data collected over Supply Reef were affected by steep slopes, which can influence backscatter intensity and, hence, prevent accurate interpretation of data; therefore, no backscatter data analysis for Supply Reef is presented in this report.

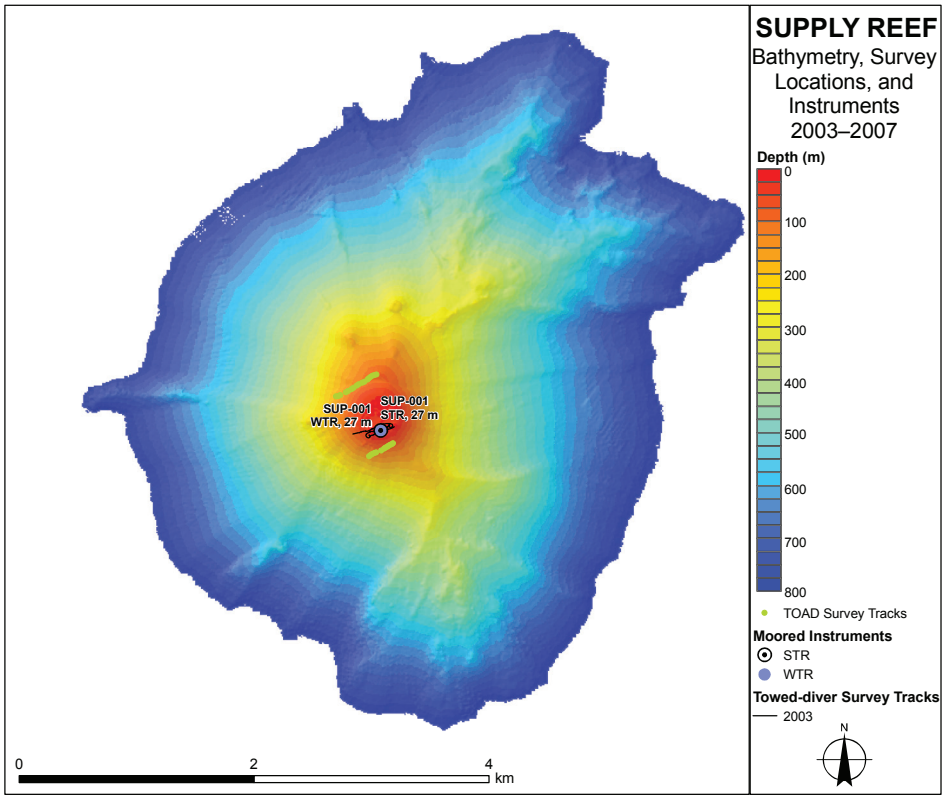


Figure 18.3.3a. High-resolution multibeam bathymetry collected by CRED on Supply Reef using Reson SeaBat 8101 ER and Kongsberg EM 300 sonars during MARAMP 2007. This 10-m bathymetry grid, clipped at 800 m, is used as the basis for slope, rugosity, and BPI derivatives. Also shown are the location and depth of the mooring site for the WTRs and STR deployed and the tracks of the towed-diver and TOAD surveys conducted on Supply Reef during MARAMP 2003, 2005, and 2007.

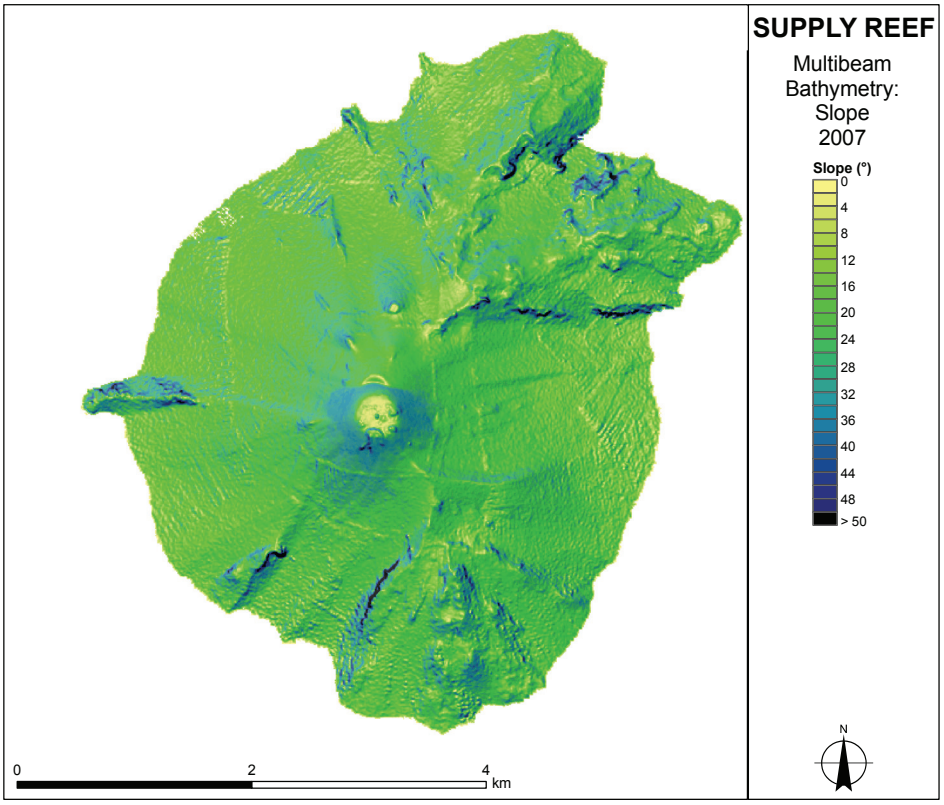


Figure 18.3.3b. Slope (°) of 10-m bathymetric grid on Supply Reef. Derived from data collected during MARMP 2007, this map reflects the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest shades of blue and the flattest areas in yellow shades.

During MARAMP 2003, 1 towed-diver survey and 2 TOAD surveys were conducted on Supply Reef. At 5-min intervals within each towed-diver survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high. Results from this survey suggest habitat of medium-high to high complexity, characterized by very low sand cover (< 5%) and high (30%–50%) live coral cover (Fig. 18.3.3e), compared to

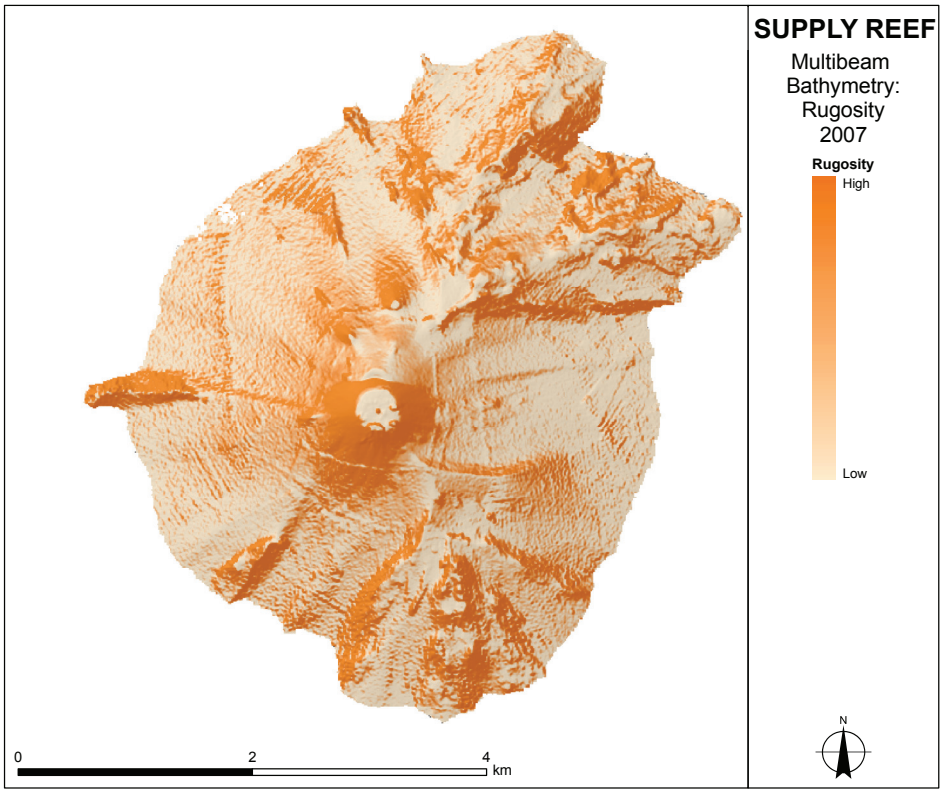


Figure 18.3.3c. Rugosity of 10-m bathymetric grid on Supply Reef. Derived from data collected during MARAMP 2007, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness.

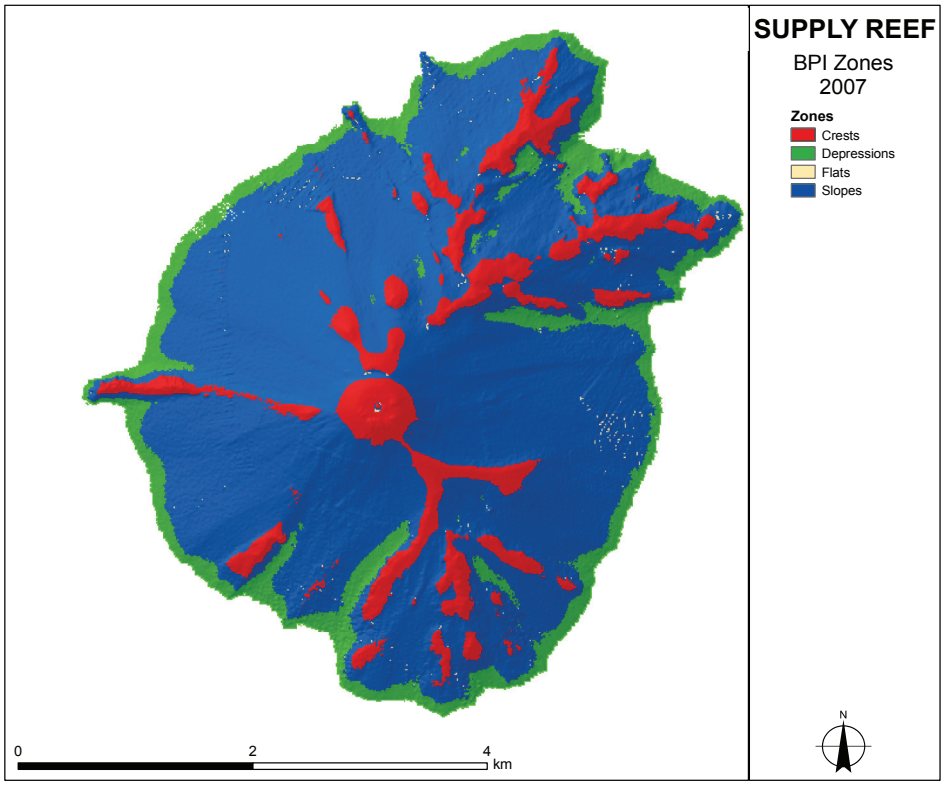
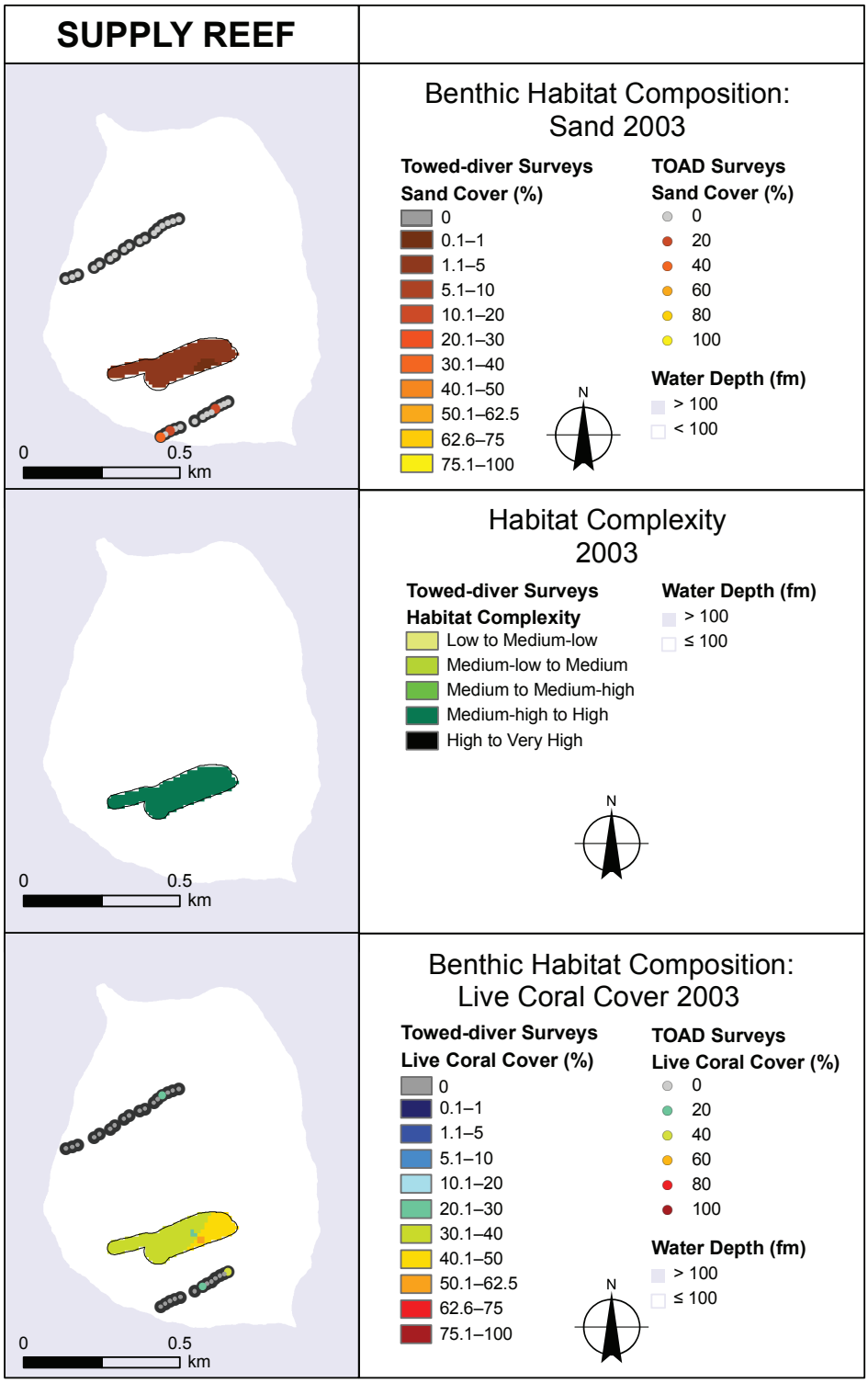


Figure 18.3.3d. BPI zones of 10-m bathymetric grid at Supply Reef derived from data collected during MARAMP 2007. BPI is a second-order derivative of bathymetry that evaluates elevation differences between a focal point and the mean elevation of the surrounding cells within a user-defined circle. Four BPI Zones—crests, depressions, flats, and slopes—have been used in this analysis.

other reef areas surveyed in the Mariana Archipelago. Results from the 2 TOAD surveys conducted on the flanks north and south of the summit of Supply Reef suggest that the substrate there was predominantly hard with only a few small patches having any sand (20%–40% cover). Live corals were rare, and, when observed, coral cover was 20%, based on analyses of the about one-third of the TOAD video footage that could be used to assess benthic cover (Fig. 18.3.3e).

Figure 18.3.3e Observations of (*top*) sand cover (%), (*middle*) benthic habitat complexity, and (*bottom*) cover (%) of live hard corals from the towed-diver survey conducted and analysis of TOAD video collected on Supply Reef during MARAMP 2003. The 100-fm contour shown in white represents potential reef habitat.



18.3.4 Oceanography

Between MARAMP 2003 and 2007, two types of moored instruments were deployed on Supply Reef to collect time-series observations of key oceanographic parameters influencing reef conditions. The time frame and depth of these deployments are provided in Figure 18.3.4a.

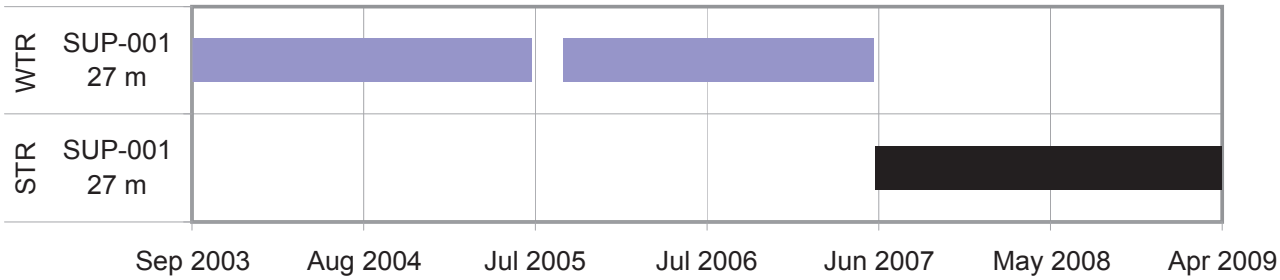


Figure 18.3.4a. Deployment timelines and depths of the WTRs and STR installed at Supply Reef during the period from September 2003 to April 2009. A solid bar indicates the period for which data were collected by a single or a series of instruments that were deployed and retrieved at a mooring site. For more information about deployments and retrievals, see Table 18.3.2b.

Wave heights at Supply Reef, for the period from August 2003 to June 2007, were generally dominated by a seasonal pattern, with the highest ambient wave heights occurring through winter and the lowest heights occurring through summer (Fig. 18.3.4b). Superimposed on these seasonal fluctuations were episodic wave events characterized by brief periods of high (> 4 m) wave heights, which were typically associated with the typhoon season of August–December but also were observed during other time periods. Wave conditions were highly variable from year to year. Wave conditions on Supply Reef in 2004 were characterized by a few large wave events (> 6 m), while only 2 events in the next 3 years (2005–2007) exceeded 6 m. Wave events recorded in 2004 were 1 m smaller on Supply Reef than on Zealandia Bank, which is located farther south on the Mariana Arc and, therefore, more proximate to latitudes of typhoon generation.

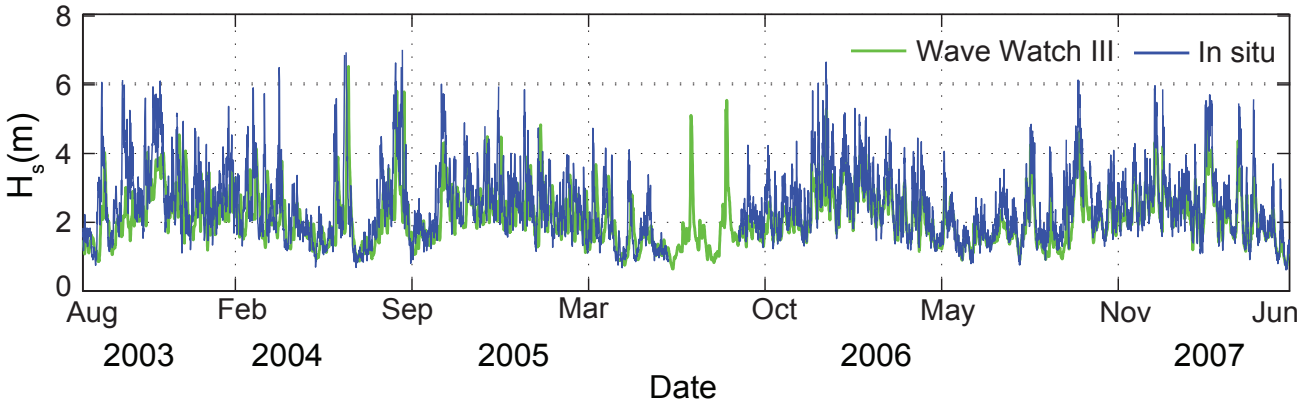


Figure 18.3.4b. Time-series observations of wave height (H_s) for the period from August 2003 to June 2007 using data from WTRs deployed on Supply Reef at a depth of 27 m and from the NOAA Wave Watch III model (see Figure 18.3.3a for mooring location; for information about the Wave Watch III model, see Chapter 2: "Methods and Operational Background," Section 2.3.7: "Satellite Remote Sensing and Ocean Modeling").

18.3.5 Biological Characterization

18.3.5.1 Coral Surveys

From the MARAMP 2003 towed-diver survey, mean cover of live hard corals was 39% (SE 9.2) on Supply Reef (Fig. 18.3.5.1a).

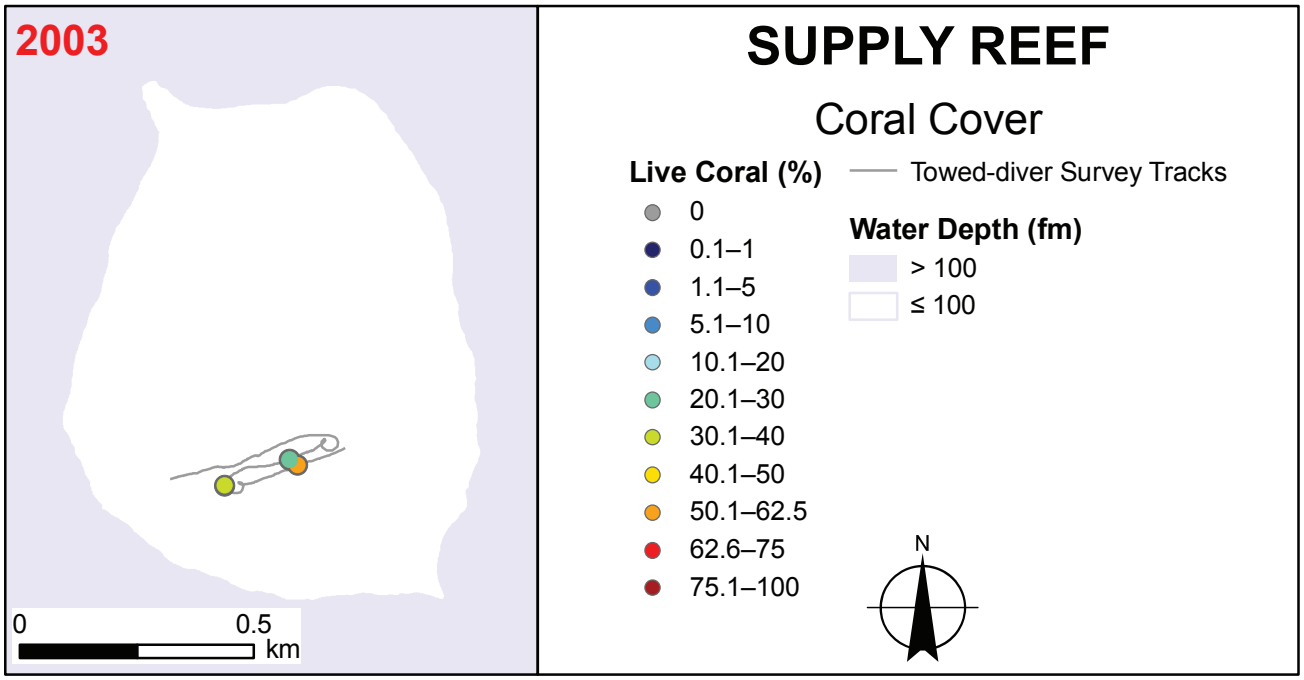


Figure 18.3.5.1a. Cover (%) observations of live hard corals from the single towed-diver benthic survey conducted on Supply Reef during MARAMP 2003. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m^2). The 100-fm contour shown in white represents potential reef habitat.

18.3.5.2 Algal Surveys

From the MARAMP 2003 towed-diver survey, mean macroalgal cover was 19% (SE 5.8), and mean cover of crustose-coralline red algae was 35% (SE 5.8) on Supply Reef (Fig. 18.3.5.2a). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. Habitat complexity was recorded only for the first 3 segments of this survey. Bedrock habitat of high complexity was recorded for each segment.

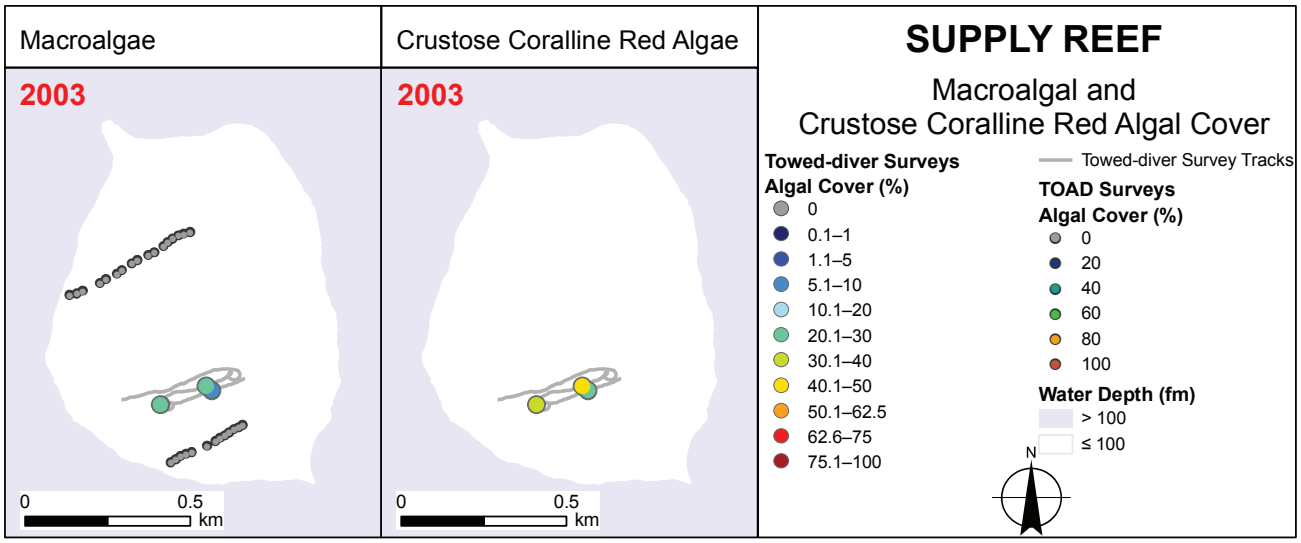


Figure 18.3.5.2a. Cover (%) observations for (*left*) macroalgae and (*right*) crustose coralline red algae from the single towed-diver benthic survey conducted on Supply Reef during MARAMP 2003. Each large, colored point represents an estimate over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m^2). The macroalgal panel shows observations of both macroalgae and turf algae. In this panel, each small, colored point represents an estimate of algal cover from TOAD surveys. The 100-fm contour shown in white represents potential reef habitat.

18.3.5.3 Fish Surveys

During MARAMP 2003, a single towed-diver survey for large fishes (≥ 50 cm in total length [TL]) was conducted on Supply Reef with a mean biomass, calculated as weight per unit area, of 2.99 kg 100 m^{-2}. Jacks accounted for the greatest proportion (49%) or 1.46 kg 100 m^{-2} of estimated large-fish biomass (Fig. 18.3.5.3a). The bluefin trevally (*Caranx melampygus*) accounted for 79% of jack biomass. Reef sharks (Carcharhinidae) accounted for the second-greatest proportion (28%) of observed mean biomass of large fishes. During this survey period, 5 sharks were observed: 3 grey reef shark (*Carcharhinus amblyrhynchos*) and 2 whitetip reef shark (*Triaenodon obesus*), accounting for 57% and 43% of shark biomass. Snappers (Lutjanidae) accounted for 12% of large-fish biomass. The twinspot snapper (*Lutjanus bohar*) contributed 84% of snapper biomass.

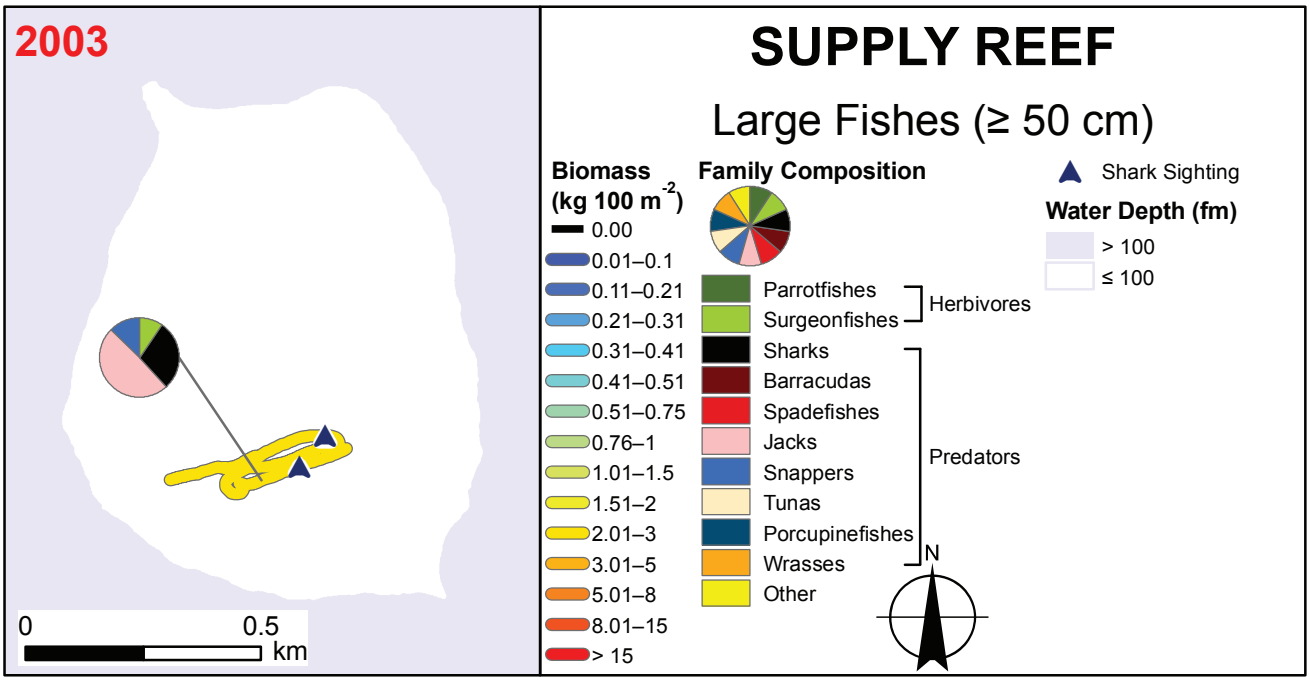


Figure 18.3.5.3a Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and shark sightings from the single towed-diver fish survey conducted on Supply Reef during MARAMP 2003. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown. The 100-fm contour shown in white represents potential reef habitat.

18.4 Zealandia Bank

18.4.1 Introduction

Zealandia Bank is a stratovolcano located ~ 25 km northeast of Sarigan on the active Mariana Arc (Fig. 18.4.3a). Zealandia Bank has an elongated shape and is formed by 2 adjacent volcanic pinnacles ~ 1 km apart. During low tide, 1 of these 2 pinnacles is ~ 1 m above sea level. Fumarolic activity was detected at Zealandia Bank in 2004 (Siebert and Simkin 2002–). Zealandia Bank is part of the Volcanic Unit of the Marianas Trench Marine National Monument.

18.4.2 Survey Effort

Benthic habitat mapping data were collected on Zealandia Bank using a combination of acoustic and optical survey methods. During MARAMP 2007, Zealandia Bank was partially mapped using multibeam sonar, adding to multibeam data that had been collected by the NOAA VENTS Program during a series of "Submarine Ring of Fire" cruises (Weiss et al. 2008; Embley et al. 2007). To provide a more complete picture of the topography of this reef, the combined multibeam bathymetry data are presented overlying a bathymetry grid with a 30-arcsecond (~ 900-m) resolution and based on a satellite-gravity model calibrated with depth soundings (Becker et al. 2009). Multibeam sonar data collected by CRED around Zealandia, Sarigan, Anatahan, Alamagan, and Guguan in 2007 covered a total area of 2228 km^2.

To collect information on the composition of the biological communities on Zealandia Bank, a single TOAD survey was conducted on Zealandia Bank during MARAMP 2003 (Fig. 18.4.3b), covering a distance of 1.17 km at depths of 72–121 m. Results from this survey are reported in the next section. Rapid Ecological Assessment (REA) surveys were attempted, but no data were obtained.

Temporal observations of key oceanographic parameters influencing reef conditions were collected on Zealandia Bank using (1) two types of moored instruments designed for long-term observations of high-frequency variability of temperature and wave height and (2) CTD profiles of the vertical structure of deepwater properties. A summary of deployed instruments and CTD cast activities is provided in Table 18.4.2b. Data from the WTRs are discussed in Section: 18.4.4: "Oceanography." Results from deepwater CTD casts on Zealandia Bank are not presented in this report, since data were collected for only one year. Interpretation of the data from the STR deployed on this bank is beyond the time frame (2003–2007) of this report.

Table 18.4.2b. Numbers of oceanographic instruments deployed and deepwater CTD casts performed on Zealandia Bank during MARAMP 2003, 2005, and 2007. Deepwater CTD casts were conducted to a 500-m depth.

Observation Type	Year						
Instruments	2003	2005		2007		2009	Lost
	Deployed	Retrieved	Deployed	Retrieved	Deployed	Retrieved	
STR	–	–	–	–	1	1	–
WTR	1	1	1	1	1	1	–
CTD Casts		2005		2007			Total
Deepwater Casts		2		–			2

18.4.3 Benthic Habitat Mapping and Characterization

Multibeam data collected around Zealandia Bank provide incomplete coverage of the summit of this seamount (Fig. 18.4.3a). These available data reveal an elongated bank, with ridges radiating from what may be a shallow shelf area on the east. The bathymetry data suggest a longer ridge extending northwards and a conical feature east of this bank. In deeper waters around Zealandia Bank, the bathymetry data identify blocks of material that could be either erosional or volcanic features.

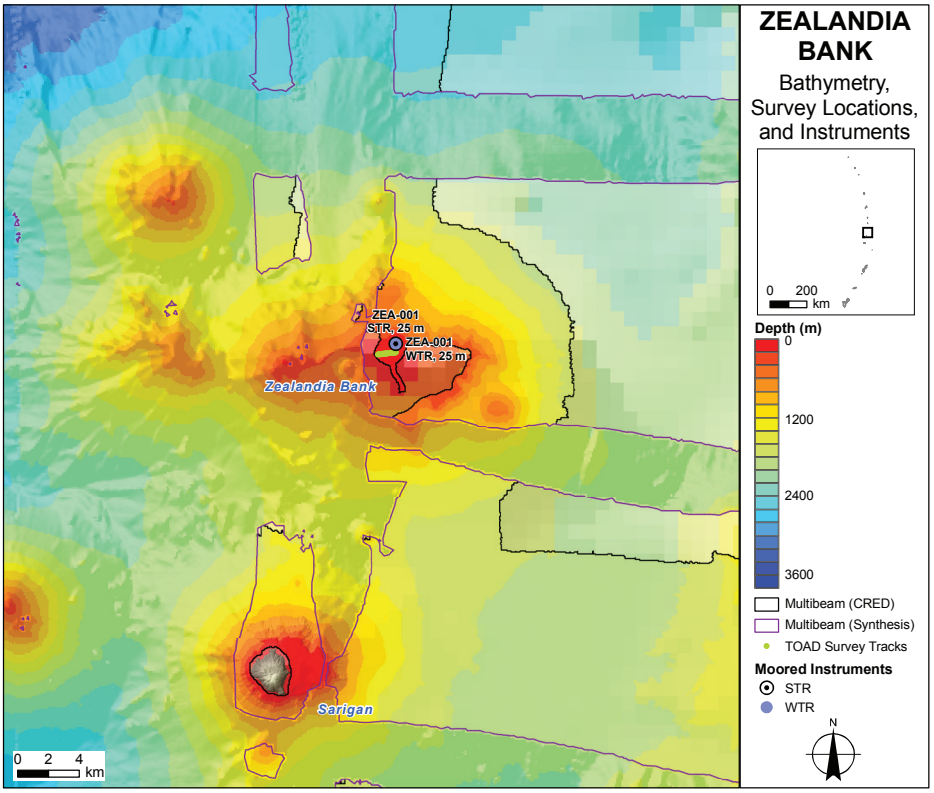


Figure 18.4.3a. Gridded multibeam bathymetry (grid cell size: 60 m, shown outlined in black) collected by CRED on Zealandia Bank during MARAMP 2007 at depths of 25–2500 m using a 30-kHz Kongsberg EM 300 sonar with gridded synthesis of additional multibeam bathymetry data (grid cell size: 100 m, shown outlined in purple) collected on various cruises using multibeam echosounders and compiled from public data available from NOAA's National Geophysical Data Center. Shown elsewhere are modeled bathymetry data (grid cell size: 30 arcsecond or ~ 900 m; Becker et al. 2009). Also shown are the location and depths of the mooring site for the WTRs and STR deployed on Zealandia Bank during MARAMP 2003, 2005, and 2007. The yellow-green bar just south of the mooring site represents the track of the TOAD survey conducted during MARAMP 2003.

During MARAMP 2003, a single TOAD survey was conducted on Zealandia Bank. Analyses of video footage obtained from this survey suggest a variable substrate, with more than a third of the observed benthos classified as hard substrate and the remainder either as sandy or a mixed substrate (Fig. 18.4.3b). No live hard corals were recorded.

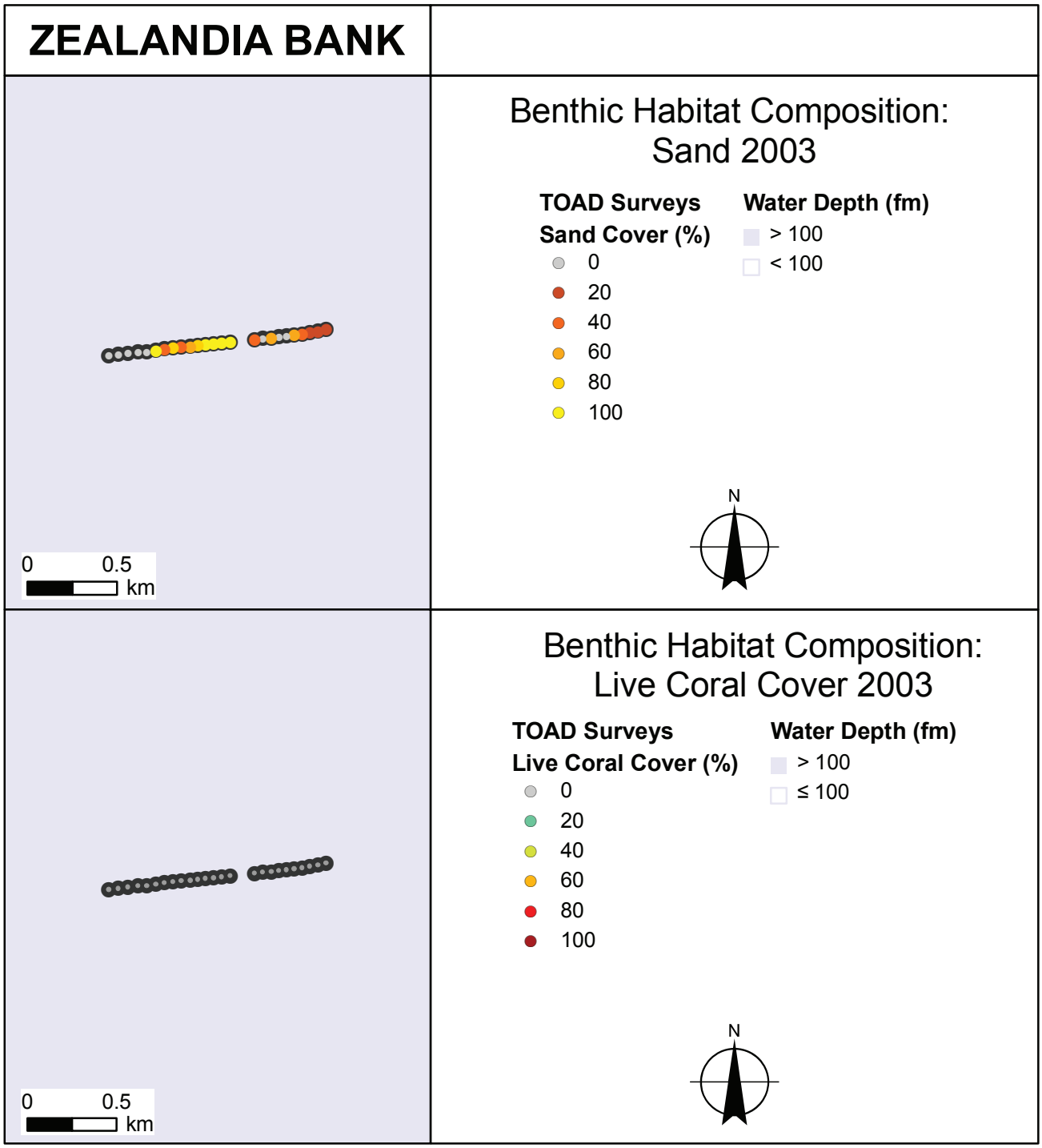


Figure 18.4.3b. Observations of (*top*) sand cover (%) and (*bottom*) cover (%) of live hard corals from analysis of TOAD video collected on Zealandia Bank during MARAMP 2003.

18.4.4 Oceanography

From MARAMP 2003 to 2007, two types of moored instruments were deployed on Zealandia Bank to collect time-series observations of key oceanographic parameters influencing reef conditions. The time frame and depth of these deployments are provided in Figure 18.4.4a.

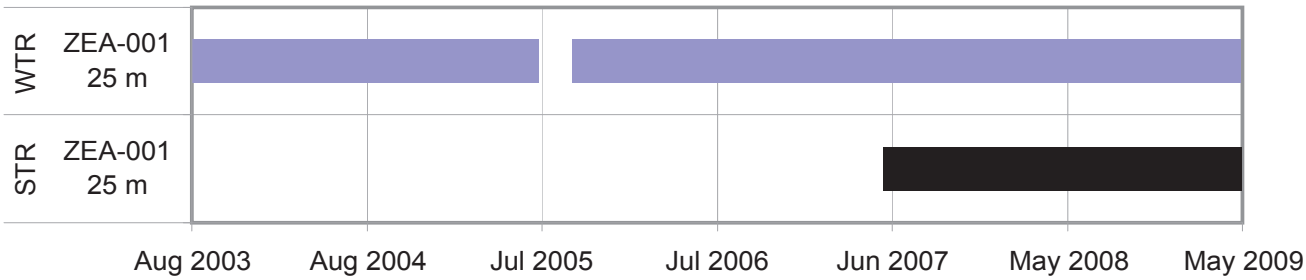


Figure 18.4.4a. Deployment timelines and depth of the WTRs and STR moored at Zealandia Bank during the period from August 2003 to April 2009.

Wave heights at Zealandia Bank, for the period from August 2003 to June 2007, were generally dominated by a seasonal pattern, with the highest ambient wave heights occurring through winter and the lowest heights occurring through summer (Fig. 18.4.4b). Superimposed on these seasonal fluctuations were episodic wave events characterized by brief periods of high (> 4 m) wave heights, which were typically associated with the typhoon season of August–December but also were observed during other time periods. Wave conditions could be highly variable from year to year. Wave conditions on Zealandia Bank in 2004 were characterized by a few large wave events (> 6 m), while no such extreme wave events occurred in the next 3 years (2005–2007). Wave events recorded in 2004 were 1 m larger on Zealandia Bank than on Supply Reef, since Zealandia is located farther south on the Mariana Arc and, therefore, closer to latitudes of typhoon generation.

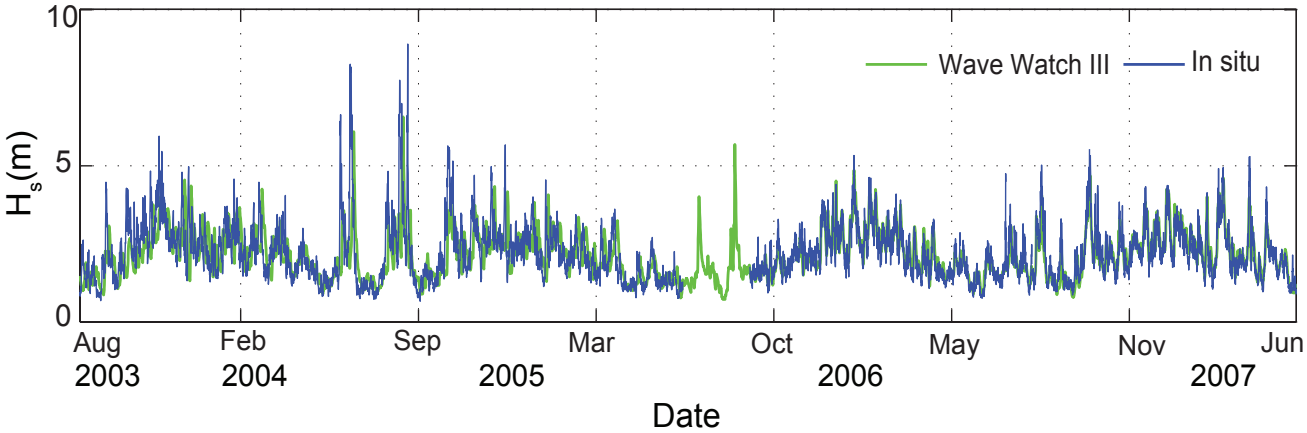


Figure 18.4.4b. Time-series observations of wave height (H_s) for the period from August 2003 to June 2007 using data from WTRs deployed on Zealandia Bank at a depth of 25 m and from the NOAA Wave Watch III model (see Figure 18.4.3a for mooring location; for information about the Wave Watch III model, see Chapter 2: "Methods and Operational Background," Section 2.3.7: "Satellite Remote Sensing and Ocean Modeling").

18.5 Marpi Bank

18.5.1 Introduction

Marpi Bank, located ~ 18 km north of Saipan, is part of the remnant Mariana frontal arc formed during the late Eocene and early Miocene epochs (15–20 million years ago). Like Saipan, Tinian, Tatsumi Reef, Rota, and Aguijan, Marpi Bank has a flat top and is probably made up of uplifted limestone overlying an older volcanic core.

18.5.2 Survey Effort

Benthic habitat mapping data were collected on Marpi Bank using acoustic survey methods. Multibeam sonar data collected by CRED around Marpi Bank, Saipan, Tinian, and Tatsumi Reef in 2003 using the NOAA R/V *Acoustic Habitat Investigator* covered a total area of 213.4 km^2, and data collected by CRED in 2007 using the NOAA Ship *Hi'ialakai* covered a total area of 1800 km^2. These multibeam sonar data are the only data available for Marpi Bank.

18.5.3 Benthic Habitat Mapping and Characterization

Multibeam bathymetry data collected on Marpi Bank suggest a flat-topped bank with a minimum depth of 53 m and an elongated shape that runs in a northeast–southwest direction and is ~ 7 km long and 3 km wide (Fig. 18.5.3a). Bathymetry data suggest that the surrounding seafloor is similar in character to the seafloor around Saipan and Tinian: relatively low slopes punctuated with ridges and fissures and blocks of material that may have resulted from erosional processes.

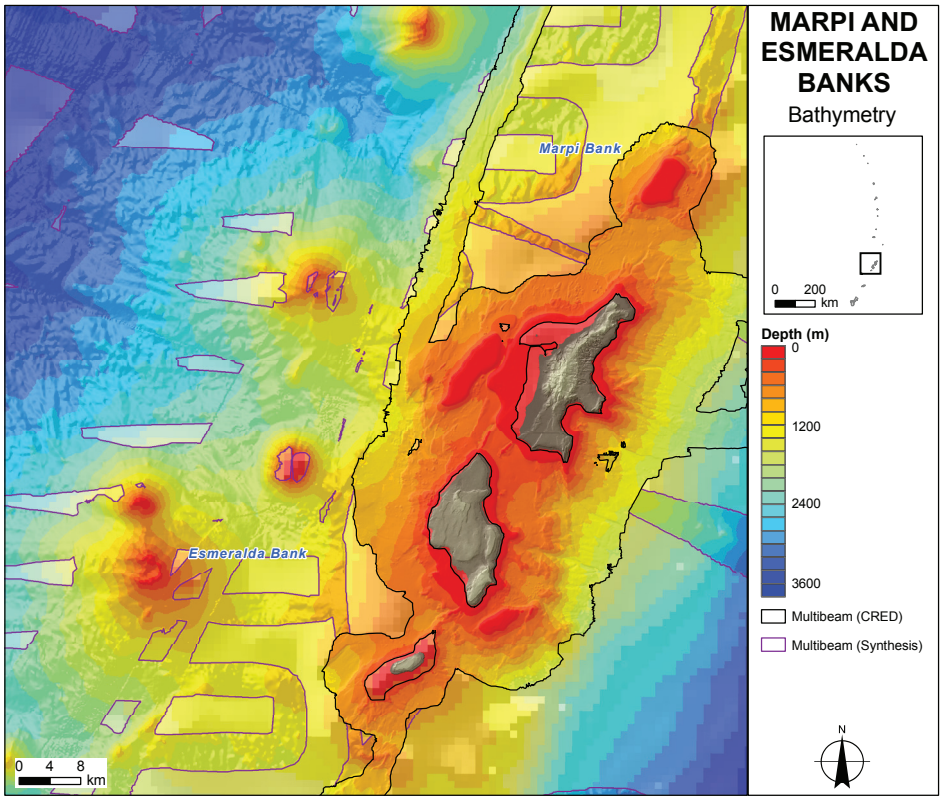


Figure 18.5.3a. Gridded multibeam bathymetry (grid cell size: 60 m, shown outlined in black) collected by CRED during MARAMP 2007 at depths of 60–4000 m using a 30-kHz Kongsberg EM 300 sonar with gridded synthesis of additional multibeam bathymetry data (grid cell size: 100 m, shown outlined in purple) collected on various cruises using multibeam echosounders and compiled from public data available from NOAA's National Geophysical Data Center. Shown elsewhere are modeled bathymetry data (grid cell size: 30 arcsecond or ~ 900 m; Becker et al. 2009).

High-resolution multibeam bathymetry data also were collected on Marpi Bank. These data reveal the texture of this flat-topped bank (Fig 18.5.3b). Various mounds and channels on top of the bank may indicate coral habitat. A depth range of 53–70 m suggests very little depth variation on the bank top, with the shallowest areas shown on the southern part of this bank. The high-resolution data obtained on Marpi Bank were patchy in places because they were collected at survey speeds that were higher than optimal. When bathymetric grids are patchy, artifacts can affect derived products, such as slope and rugosity, and accurate interpretation can be difficult; thus, no derived products are presented for Marpi Bank.

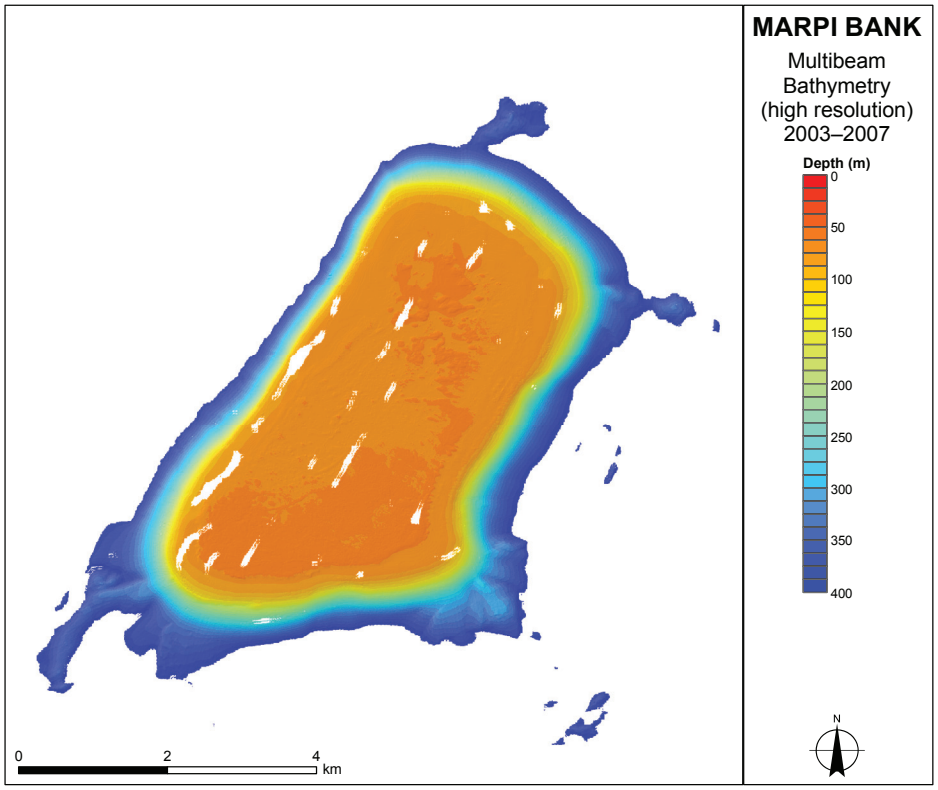


Figure 18.5.3b. High-resolution multibeam bathymetry collected on Marpi Bank using Reson Sea-Bat 8101 ER and Kongsberg EM 300 sonars during MARAMP 2007. This 5-m bathymetry grid has been clipped at 400 m.

18.6 Esmeralda Bank

18.6.1 Introduction

Esmeralda Bank, a stratovolcano located 57 km southwest of Saipan, is one of the southernmost active volcanoes on the Mariana Arc (Stern and Bibee 1984). Hydrothermal activity and venting have been observed on Esmeralda Bank during several NOAA Ocean Explorer cruises (Embley et al. 2004). Esmeralda Bank is part of the Volcanic Unit of the Marianas Trench Marine National Monument.

18.6.2 Survey Effort

CRED has not collected multibeam data on Esmerelda during MARAMP surveys. Multibeam data have been collected as part of an ongoing series of NOAA Ocean Explorer expeditions that have included NOAA VENTS Program "Submarine Ring of Fire" cruises (Weiss et al. 2008; Embley et al. 2007). To provide a picture of the topography of this reef, these multibeam bathymetry data are presented as part of a bathymetry grid with a 100-m resolution that was synthesized from a compilation of public data available from NOAA's National Geophysical Data Center.

Data for optical validation and habitat characterization were collected during MARAMP 2003 using TOAD surveys, which documented live coral cover, sand cover, and habitat complexity. Three TOAD surveys were conducted on Esmeralda Bank, covering a distance of 1.07 km at depths from ~ 63 to > 100 m (exact depth measurements with the sensor on the TOAD is impossible). The results of these efforts are discussed in the next section.

18.6.3 Benthic Habitat Mapping and Characterization

Multibeam data show that the summit of Esmeralda Bank is actually the rim of a crater, which appears to be breached to the west, and from this breach a wide channel runs into deeper water (Fig. 18.6.3a).

During MARAMP 2003, 3 TOAD surveys were conducted on Esmeralda Bank, all of them located on the north crater rim. Analyses of the TOAD video footage obtained from these surveys suggest that the southernmost survey area had predominantly sandy seabeds, while the rest of the areas surveyed mostly had hard substrates (Fig. 18.6.3b). Analyses of video footage from TOAD surveys also suggest that live corals were rare.

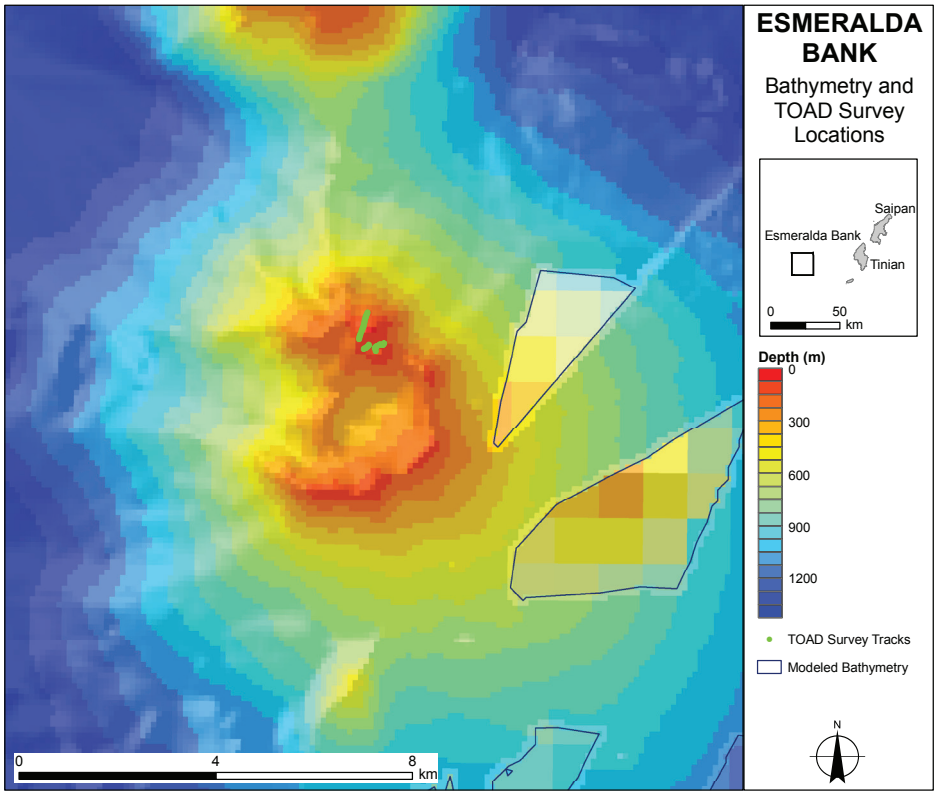


Figure 18.6.3a. Gridded synthesis of multibeam bathymetry data (grid cell size: 100 m) collected on Esmeralda Bank during various cruises using multibeam echosounders and compiled from public data available from NOAA's National Geophysical Data Center. Modeled bathymetry data (grid cell size: 30 arcsecond or ~ 900 m) are shown within the small areas outlined in indigo (Becker et al. 2009). For a different view of these data in a larger context, see Figure 18.5.3a in Section 18.5: "Marpi Bank." Also shown are the tracks of the TOAD surveys conducted on Esmeralda Bank during MARAMP 2003.

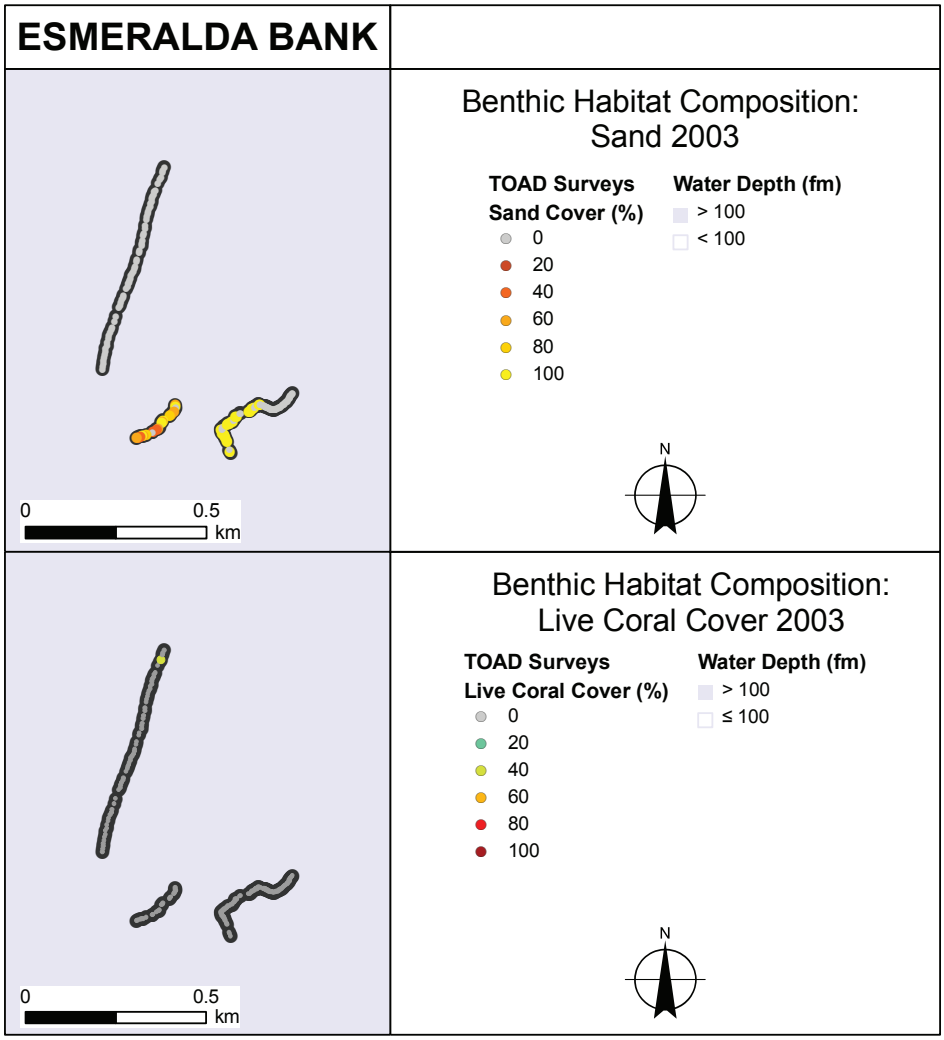


Figure 18.6.3b. Observations of (*top*) sand cover (%) and (*bottom*) cover (%) of live hard corals from analysis of TOAD video collected on Esmeralda Bank during MARAMP 2003.

18.7 Stingray Shoal

18.7.1 Introduction

Stingray Shoal is a remnant volcanic seamount located on the northern end of the West Mariana Ridge. Stingray Shoal is part of the Volcanic Unit of the Marianas Trench Marine National Monument.

18.7.2 Survey Effort

No multibeam acoustic bathymetry data were collected over Stingray Shoal. Single-depth soundings were obtained from a small boat using a handheld depth sounder and handheld GPS over Stingray Shoal during MARAMP 2003.

REA, towed-diver, and TOAD surveys were conducted on Stingray Shoal during MARAMP 2003 to collect information on habitat and the composition and distribution of biological communities. No data were obtained from REA surveys, and the results of towed-diver and TOAD surveys are reported in Section 18.7.3: "Benthic Mapping and Characterization" and Section 18.7.5 "Biological Characterization." The numbers of these surveys are presented in Table 18.7.2a, along with their mean depth and total area or length. Two TOAD surveys were conducted on Stingray Shoal at depths of ~ 20–110 m, covering a distance of 0.94 km. Subsequent analyses of the video acquired from these surveys provided estimates of sand cover and live coral cover. Four towed-diver surveys were conducted along parts of the forereef slope of Stingray Shoal at depths of 6–26 m (mean depth 12.8 m), covering a distance of 4.95 km.

Table 18.7.2a. Numbers, mean depth (m), total area (ha), and total length (km) of towed-diver and TOAD surveys conducted on Stingray Shoal during MARAMP 2003.

Survey Type	Survey Detail	Year
Towed Diver		**2003**
	Number of Surveys	4
	Total Survey Area (ha)	5.0
	Mean Depth (m)	12.8
TOAD		**2003**
	Number of Surveys	2
	Total Length (km)	0.94

18.7.3 Benthic Habitat Mapping and Characterization

Single-depth soundings collected over Stingray Shoal revealed an apparently conical seamount with an estimated minimum depth of 13 m (Fig. 18.7.3a).

During MARAMP 2003, 4 towed-diver surveys and 2 TOAD surveys were conducted. At 5-min intervals within each towed-diver survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high. Both observations from towed-diver surveys conducted and analyses of TOAD video footage collected over Stingray Shoal suggested a predominantly hard substrate with very few areas exhibiting sand cover of > 5%. Towed-diver surveys completed on the summit of Stingray Shoal recorded habitat of medium-high to high complexity supporting consistently high cover of live hard corals, compared to other areas surveyed in the Mariana Archipelago, over continuous, well-developed reef (Fig. 18.7.3b). Live coral cover of 40.1%–100% was observed for all but 2 survey segments. Analyses of video footage obtained from TOAD surveys revealed that these high levels of live coral cover were seen more sporadically in the deeper waters of the northern and southern parts of this reef.

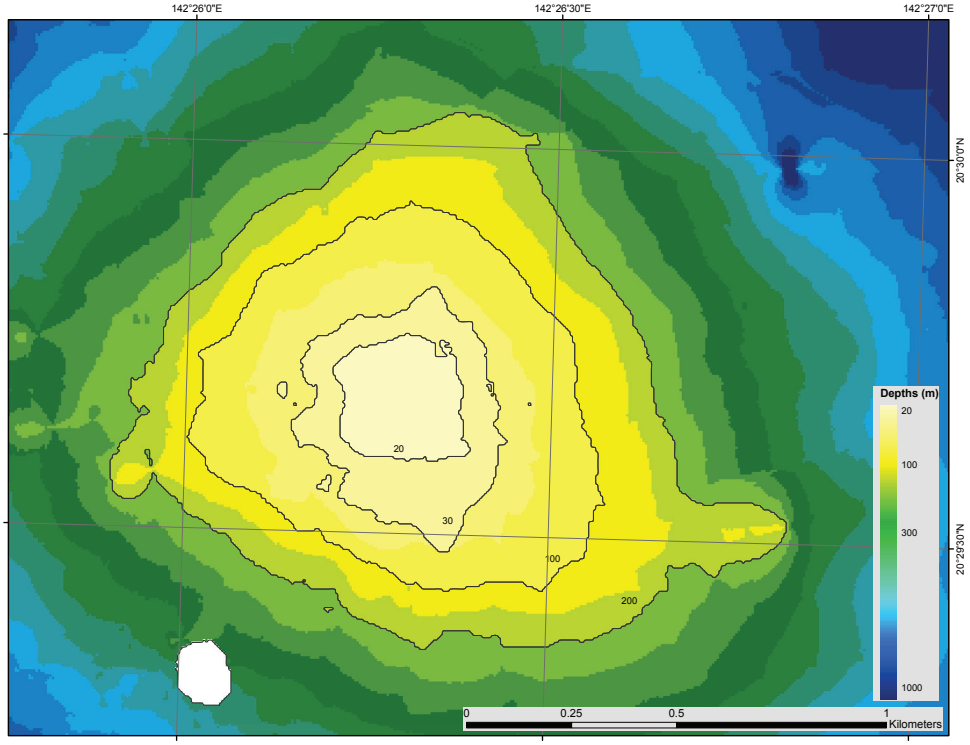
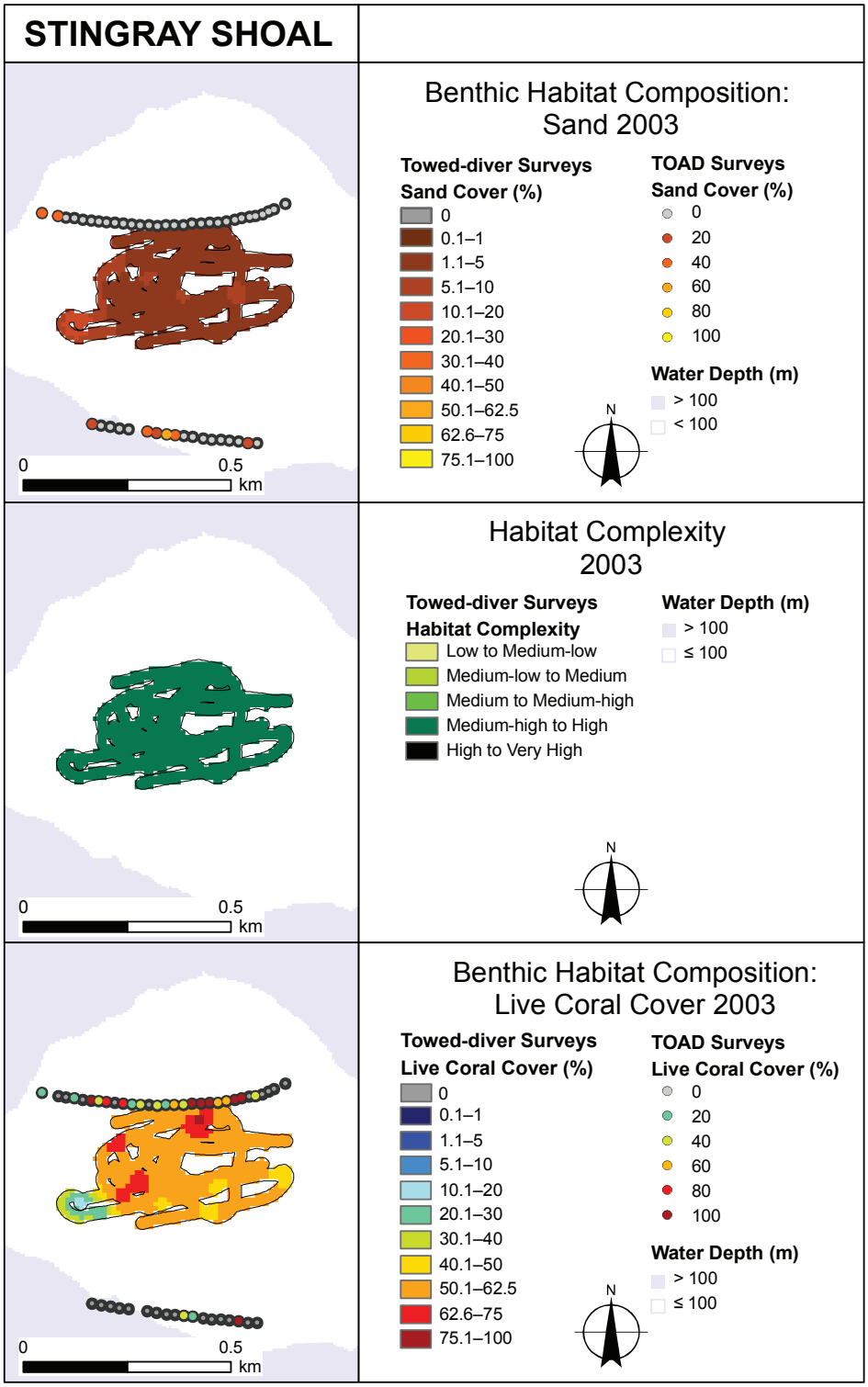


Figure 18.7.3a. Contoured map derived from single-depth soundings collected using a handheld depth sounder on Stingray Shoal during MARAMP 2003.

Figure 18.7.3b. Observations of (*top*) sand cover (%), (*middle*) benthic habitat complexity, and (*bottom*) cover (%) of live hard corals from towed-diver surveys conducted and analysis of TOAD video collected on Stingray Shoal during MARAMP 2003.



18.7.4 Biological Characterization

During MARAMP 2003, towed-diver surveys conducted on Stingray Shoal were short in duration (5 or 7 segments instead of the typical 10 segments) because of deep depths.

18.7.4.1 Coral Surveys

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals was 55% (SE 2.7) on Stingray Shoal (Fig. 18.7.4.1a), the highest level recorded for an island or bank in the Mariana Archipelago during any of the 3 MARAMP survey years. For all but 2 survey segments, live coral cover was 40.1%–100%. The highest coral cover was observed in the north and west, with segment means of 75% and 76%.

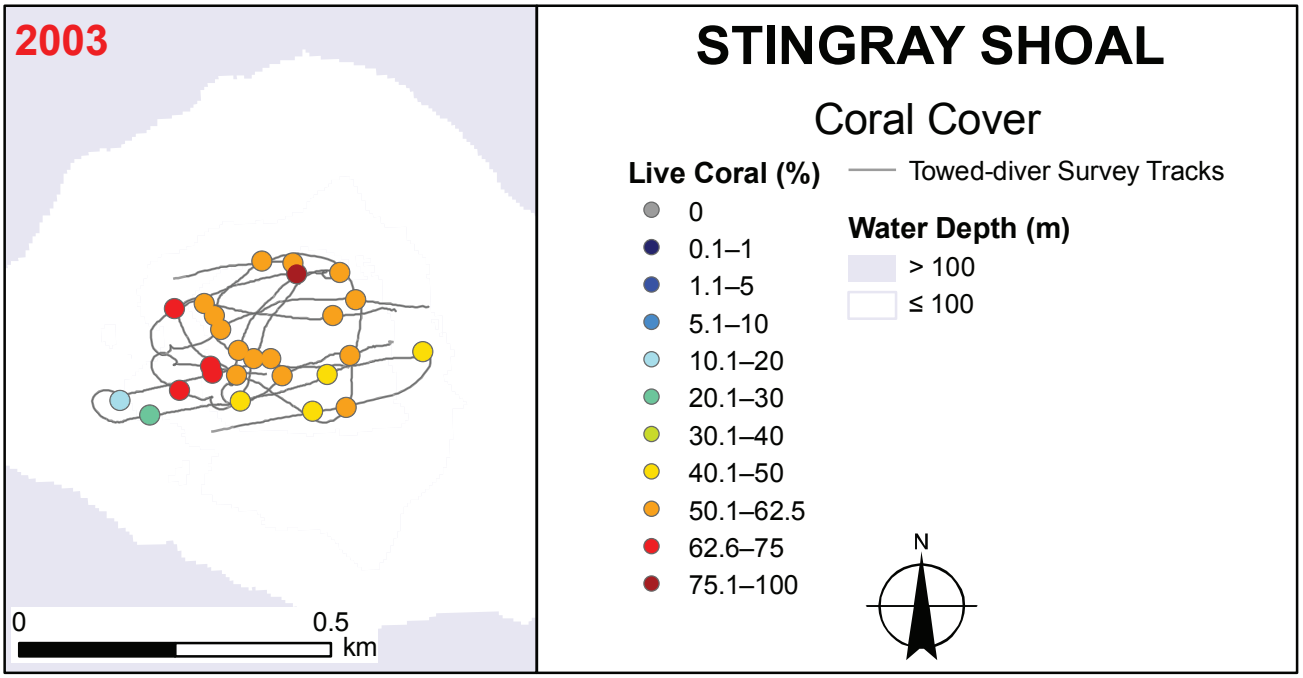


Figure 18.7.4.1a. Cover (%) observations of live hard corals from towed-diver benthic surveys conducted on Stingray Shoal during MARAMP 2003. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m^2). The 100-fm contour shown in white represents potential reef habitat.

18.7.4.2 Algal Surveys

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on Stingray Shoal was 34% (SE 1.9), with mean values for the 4 surveys of 21%, 32%, 35%, and 44% (Fig 18.7.4.2a). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. The overall estimated mean for cover of crustose coralline red algae was 2% (SE 0.4), with survey means of 0%, 0%, 3%, and 5%. Continuous reef was the most commonly reported habitat type and complexity was high and medium high.

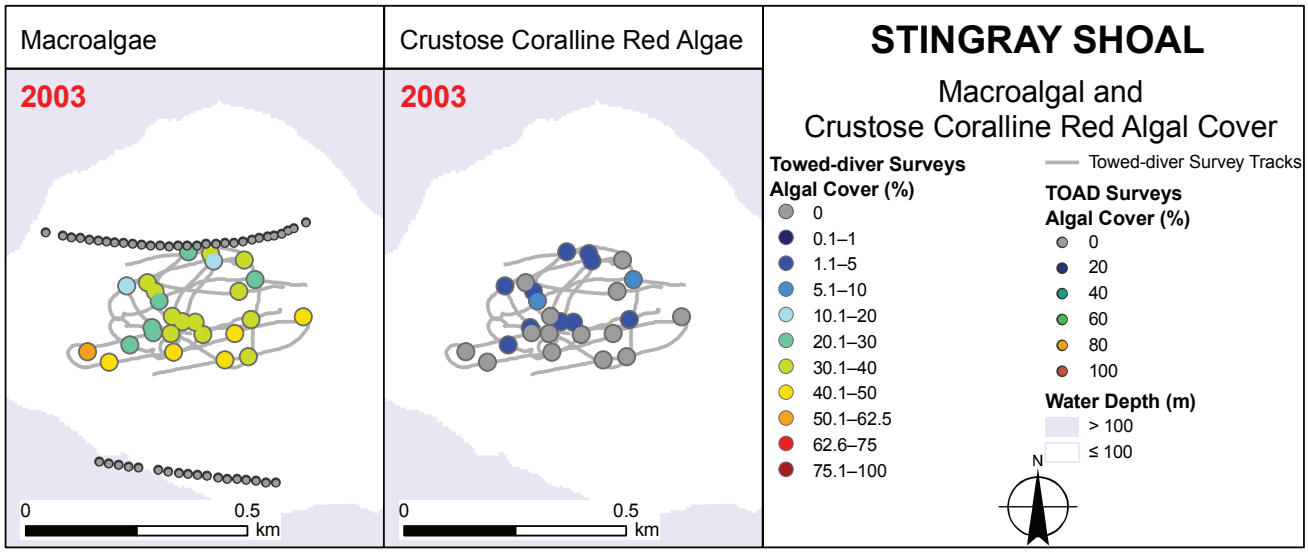


Figure 18.7.4.2a. Cover (%) observations for (*left*) macroalgae and (*right*) crustose coralline red algae from towed-diver benthic surveys conducted on Stingray Shoal during MARAMP 2003. Each large, colored point represents an estimate over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m²). The macroalgal panel shows observations of both macroalgae and turf algae. In this panel, each small, colored point represents an estimate of algal cover from TOAD surveys. The 100-fm contour shown in white represents potential reef habitat.

18.7.4.3 Benthic Macroinvertebrate Surveys

During MARAMP 2003, species of *Tridacna* giant clams were observed in 1 of the 4 towed-diver surveys conducted on Stingray Shoal, with an overall mean density of 0.002 organisms 100 m^{-2}. Giant clams were seen over only 1 survey segment, which had a density of 0.053 organisms 100 m^{-2} (Fig. 18.7.4.3a).

Crown-of-thorns seastars (*Acanthaster planci*) were not observed on Stingray Shoal in 2003 during towed-diver surveys.

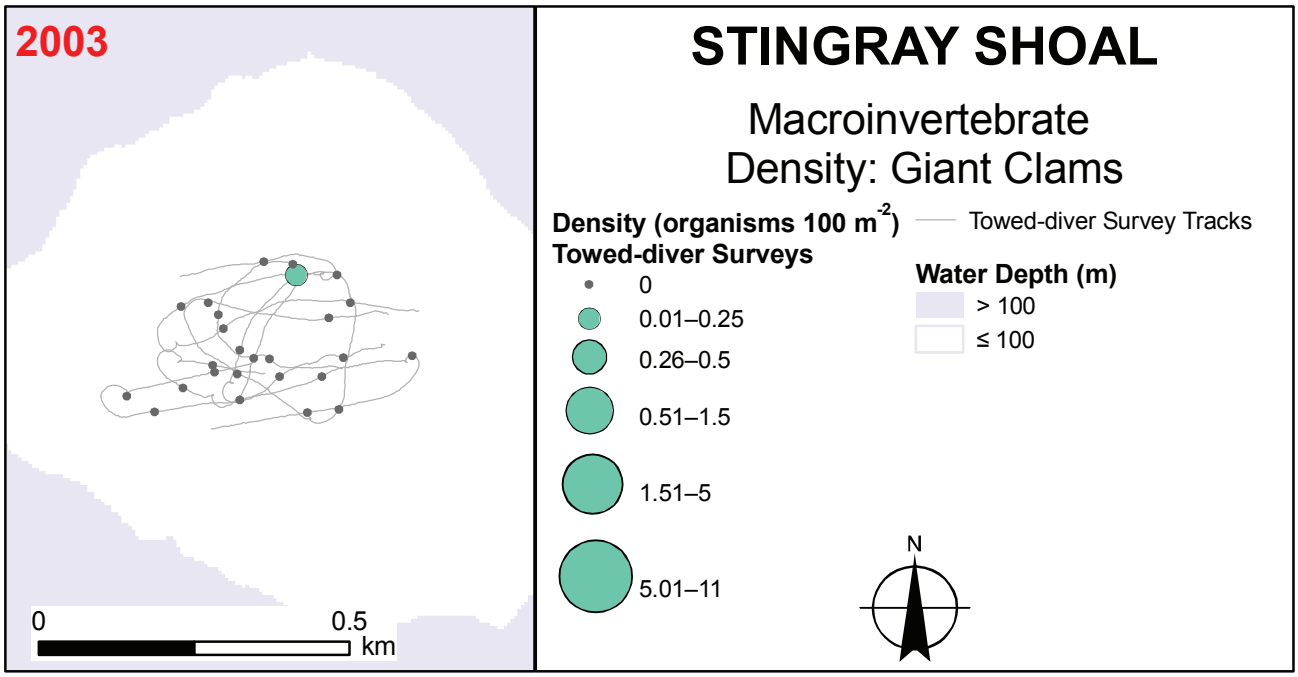


Figure 18.7.4.3a. Densities (organisms 100 m^{-2}) of giant clams from towed-diver benthic surveys conducted on Stingray Shoal during MARAMP 2003. The 100-fm contour shown in white represents potential reef habitat.

Sea cucumbers were observed in 2 of the 4 towed-diver surveys conducted on Stingray Shoal in 2003, with an overall mean density of 0.006 organisms 100 m^{-2}. Between the 2 surveys, the higher mean density of sea cucumbers was 0.018 organisms 100 m^{-2}; sea cucumbers were observed during only 1 segment, which had a density of 0.089 organisms 100 m^{-2}.

Sea urchins were observed in all 4 towed-diver surveys conducted on Stingray Shoal in 2003, with an overall mean density of 0.84 organisms 100 m^{-2}. The greatest mean density from a towed-diver survey was 1.55 organisms 100 m^{-2}; segment densities ranged from 0 to 3.64 organisms 100 m^{-2} (Fig. 18.7.4.3b).

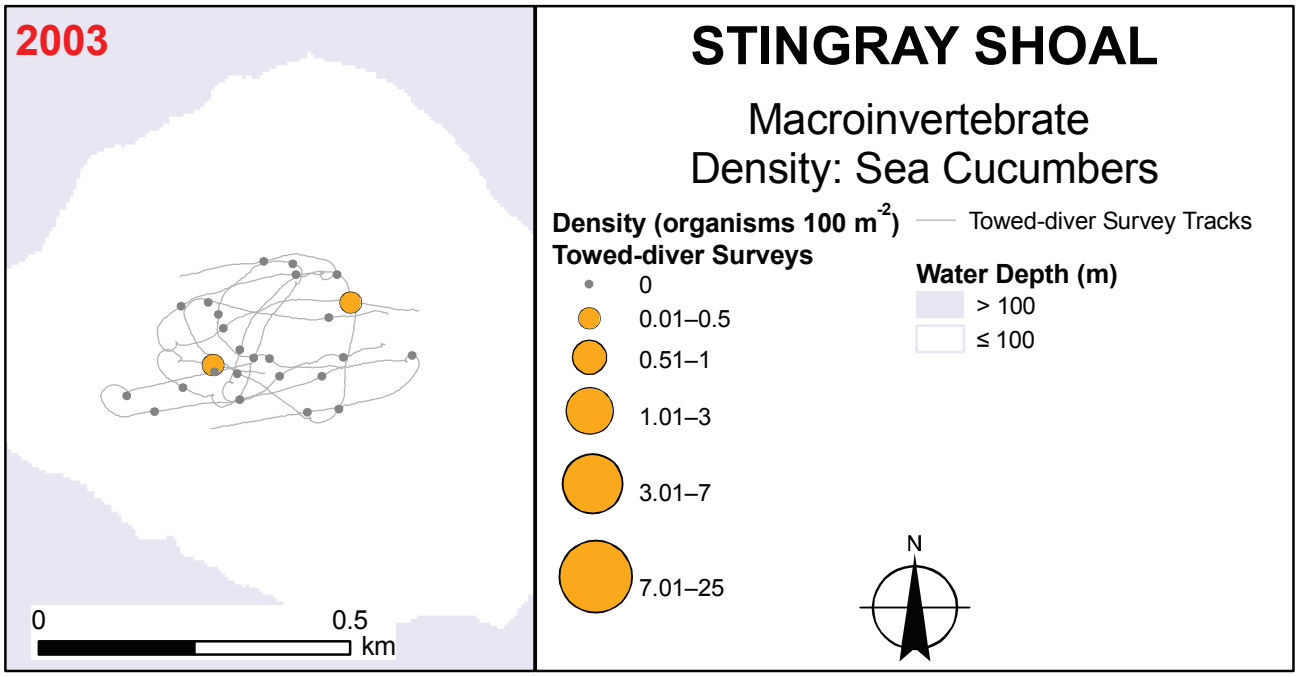


Figure 18.7.4.3b. Densities (organisms 100 m^{-2}) of sea urchins from towed-diver benthic surveys conducted on Stingray Shoal during MARAMP 2003. The 100-fm contour shown in white represents potential reef habitat.

18.7.4.4 Fish Surveys

During MARAMP 2003, 4 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted on Stingray Shoal (Fig. 18.7.4.4a.). The overall estimated mean biomass, calculated as weight per unit area, was at 5.15 kg 100 m^{-2} (SE 1.08), a high value compared to other areas surveyed in the Mariana Archipelago. Reef sharks accounted for the highest proportion (52%) or 2.67 kg 100 m^{-2} of large-fish biomass. The grey reef shark accounted for 88% or 2.36 kg 100 m^{-2} of shark biomass. During this survey period, 71 sharks, with a mean length of 103.4 cm TL, were observed: 65 grey reef shark and 6 whitetip reef shark. Surgeonfishes (Acanthuridae) accounted for the second-greatest proportion (31%) of overall biomass of large fishes, with the sleek unicornfish (*Naso hexacanthus*) and the bulbnose unicornfish (*Naso tonganus*) making up the majority of surgeonfish biomass, at 0.92 kg 100 m^{-2} and 0.56 kg 100 m^{-2}. Snappers also were commonly observed and accounted for 13% of the overall large-fish biomass. The twinspot snapper contributed 94% of snapper biomass.

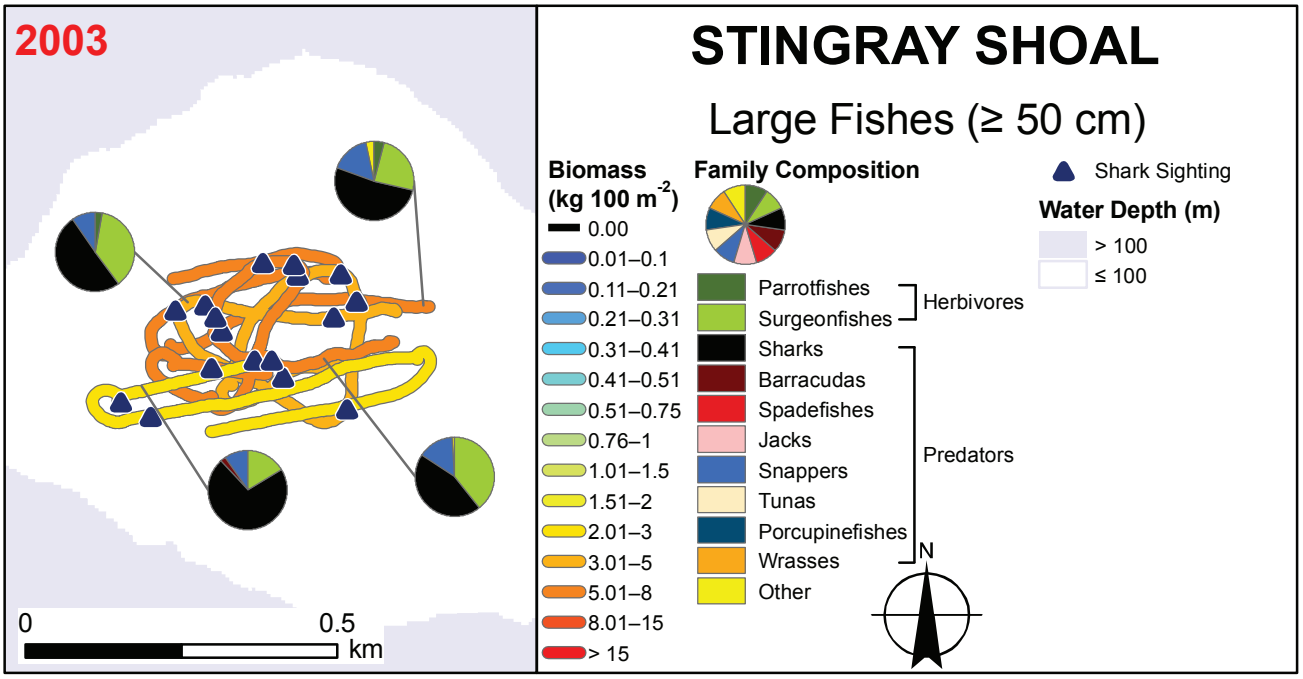


Figure 18.7.4.4a Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and shark sightings from towed-diver surveys conducted on Stingray Shoal during MARAMP 2003. Each blue triangle represents a sighting of one or more sharks recorded inside or outside the survey area over which it is shown. The 100-fm contour shown in white represents potential reef habitat.

18.8 Pathfinder Reef

18.8.1 Introduction

Pathfinder Reef is a remnant, volcanic, submerged ridge located ~ 150 km west of Saipan on the southern end of the West Mariana Ridge with a minimum depth of 10 m.

18.8.2 Survey Effort

No multibeam acoustic bathymetry data were collected over Pathfinder Reef. To provide some indication of the minimum depth, single-depth soundings were obtained from a small boat using a handheld depth sounder and handheld GPS over Pathfinder Reef during MARAMP 2003.

REA, towed-diver, and TOAD surveys were conducted on Pathfinder Reef during MARAMP 2003 and 2005 to collect information on habitat and the condition, abundance, diversity, and distribution of biological communities. Results from these surveys are discussed in Section 18.8.3: "Benthic Mapping and Characterization" and Section 18.8.4 "Biological Characterization." The numbers of these surveys are presented in Table 18.8.2a, along with their mean depths and total areas or length. Two TOAD surveys were conducted on Pathfinder Reef during MARAMP 2003 at depths of ~ 12–34 m, covering a distance of 2.21 km. Subsequent analyses of the video acquired from these surveys provided estimates of the percentages of sand cover and live coral cover.

For both MARAMP survey years combined, 7 towed-diver surveys were conducted on Pathfinder Reef at depths of 0–22 m, covering a distance of 13.68 km. The mean depths of individual surveys ranged from 16.4 m (SD 2.9) to 17.4 m (SD 3.2) in 2003 and from 15.7 m (SD 1.9) to 16.7 m (SD 1.9) in 2005. Figures 18.8.2a and b illustrate the locations and depths of towed-diver-survey tracks on Pathfinder Reef and should be referenced when further examining results of the towed-diver surveys from MARAMP 2003 and 2005.

Survey Type	Survey Detail	Year	
REA		**2003**	**2005**
Fish	Number of Surveys	2	2
	Mean Depth (m)	17 (SD 2.8)	17 (SD 2.8)
Benthic	Number of Surveys	2	2
	Mean Depth (m)	17 (SD 2.8)	17 (SD 2.8)
Towed Diver		**2003**	**2005**
	Number of Surveys	4	3
	Total Survey Area (ha)	7.5	6.2
	Mean Depth (m)	17 (SD 0.5)	16.3 (SD 0.5)
TOAD		**2003**	
	Number of Surveys	2	
	Total Length (km)	2.21	

Table 18.8.2a. Numbers, mean depths (m), total areas (ha), and total length (km) of REA, towed-diver, and TOAD surveys conducted at Pathfinder Reef during MARAMP 2003 and 2005. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys for corals, algae, and macroinvertebrates.

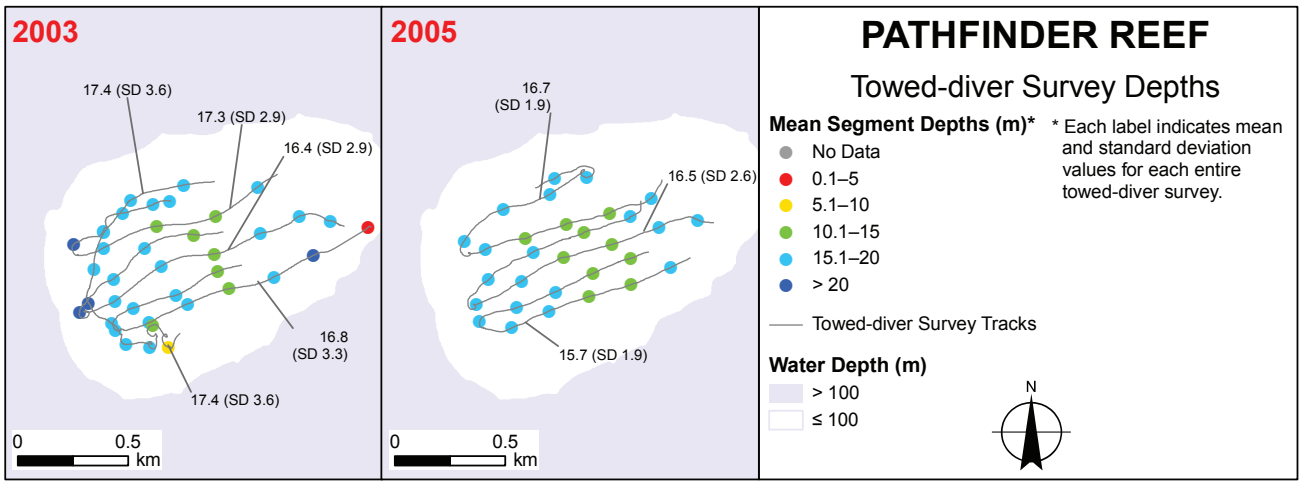


Figure 18.8.2a. Depths and tracks of towed-diver surveys conducted on Pathfinder Reef during MARAMP 2003 and 2005. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate. The 100-fm contour shown in white represents potential reef habitat.

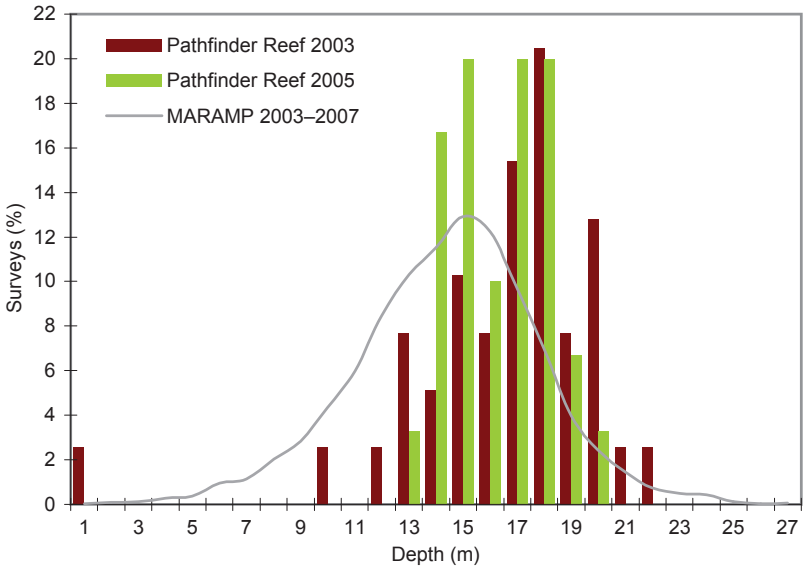


Figure 18.8.2b. Depth histogram plotted from mean depths of 5-min segments of the towed-diver surveys conducted on Pathfinder Reef during MARAMP 2003 and 2005. Mean segment depths are derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005, and 2007.

18.8.3 Benthic Habitat Mapping and Characterization

Figure 18.8.3a presents a contoured map of the handheld depth soundings collected on Pathfinder Reef.

During MARAMP 2003, 4 towed-diver surveys and 2 TOAD surveys were conducted, and, during MARAMP 2005, 3 towed-diver surveys were completed. At 5-min intervals within each towed-diver survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high. Both observations from towed-diver surveys conducted and analyses of TOAD video footage collected over Pathfinder Reef revealed a predominantly hard substrate with sand cover of 100% observed in only 3 video frames (Fig. 18.8.3b). Habitat complexity was lower here than at Stingray Shoal and ranged from medium-low to medium high. Habitats on Pathfinder Reef were described as atypical spur-and-groove reef with gently sloping mounds of coral interspersed with hard pavement channels. Estimates of live coral cover from towed-diver surveys were consistent, with means of 10.1%–40% recorded in all but 1 survey segment. Results for live coral cover from analyses of video footage obtained from TOAD surveys were more variable and ranged from 0% to 100%. These results reflect the differences between the 2 survey methods, with TOAD surveys providing snapshots of the seabed in a restricted area and towed-diver surveys covering a larger area, with observations averaged by survey segment.

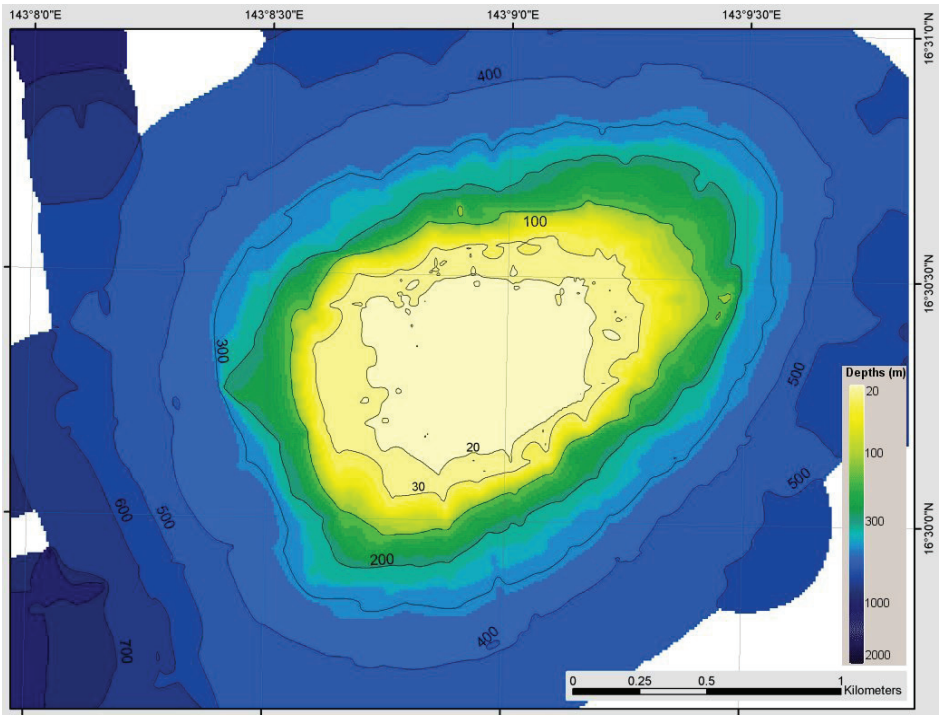


Figure 18.8.3a. Contoured map derived from single-depth soundings collected using a handheld depth sounder on Pathfinder Reef during MARAMP 2003.

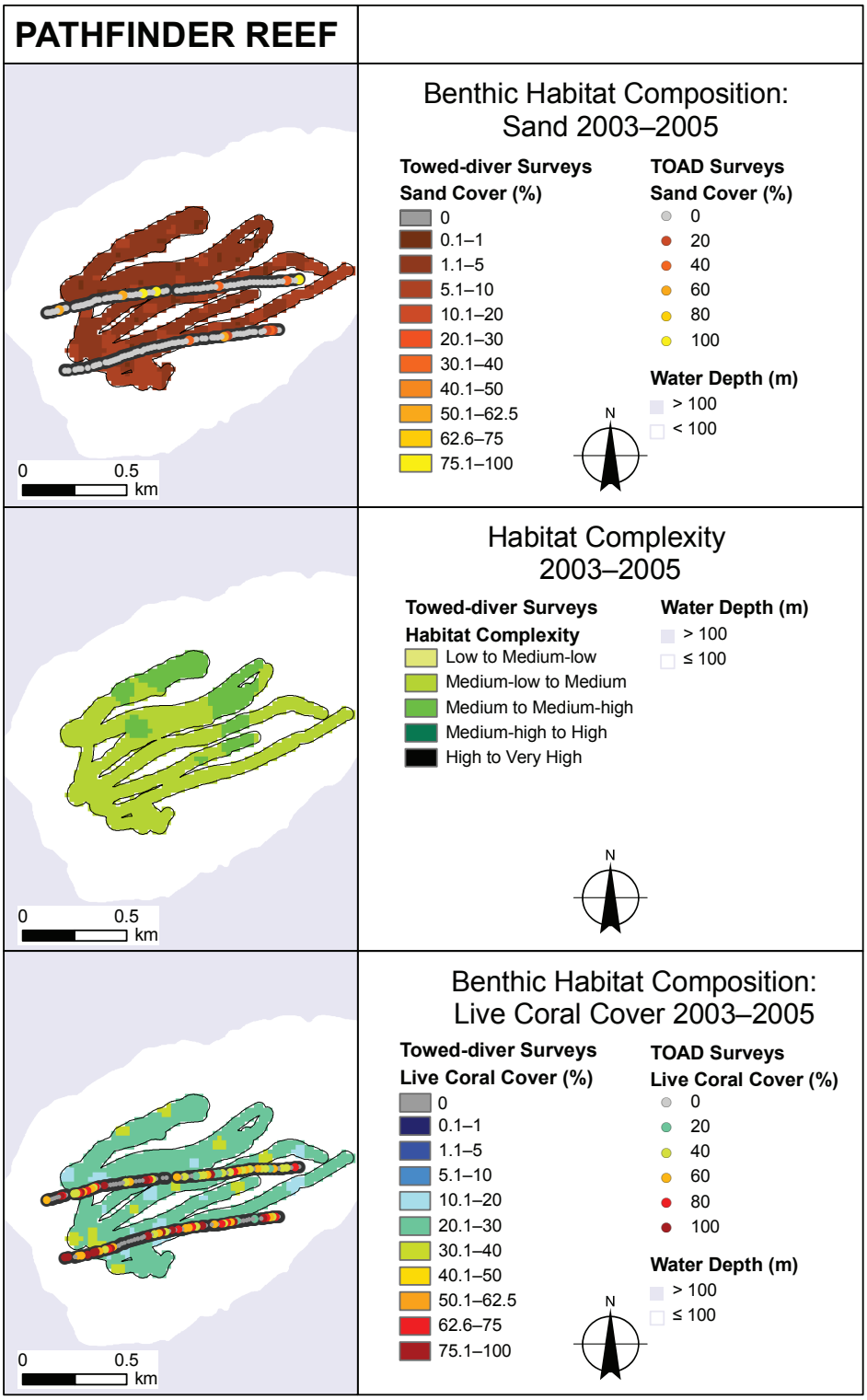


Figure 18.8.3b. Observations of (*top*) sand cover (%), (*middle*) benthic habitat complexity, and (*bottom*) cover (%) of live hard corals from towed-diver surveys conducted and analysis of TOAD video collected on Pathfinder Reef during MARAMP 2003 and 2005. The 100-fm contour shown in white represents potential reef habitat.

18.8.4 Biological Characterization

18.8.4.1 Coral Surveys

Coral Cover and Colony Density

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on Pathfinder Reef was 24% (SE 0.9). Coral cover was relatively uniform, with means of 10.1%–30% recorded for a majority of survey segments. The highest coral cover was observed along the western edge of Pathfinder, with a mean of 35% over 4 segments (Fig. 18.8.4.1a, left panel).

From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on Pathfinder Reef was 25% (SE 1.4). Coral cover remained relatively uniform, again with the majority of survey segments having means of 10.1%–30%. The highest coral cover was observed along the interior, western edge, and northern border of Pathfinder, with a mean of 35% for 8 segments (Fig. 18.8.4.1a, right panel).

Towed divers during MARAMP 2005 recorded estimates of stressed-coral cover, including coral that was fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease"). Overall, < 1% of coral cover observed on Pathfinder Reef appeared stressed in 2005.

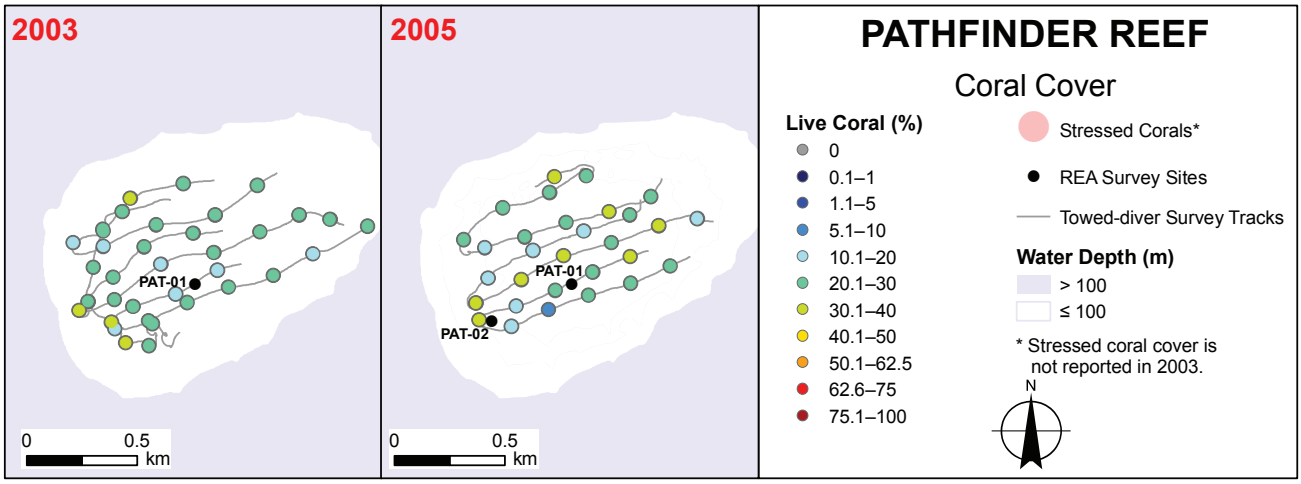


Figure 18.8.4.1a. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys conducted on Pathfinder Reef during MARAMP 2003 and 2005. Each colored point represents an estimate of live coral over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m²). Pink symbols are not shown here, since they represent only segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2005. The 100-fm contour shown in white represents potential reef habitat.

During MARAMP 2003, 1 REA benthic survey using the quadrat method on Pathfinder Reef documented 77 coral colonies within a survey area of 3.75 m^2, yielding a site-specific colony density of 20.5 colonies m^{-2} (Table 18.8.4.1a).

During MARAMP 2005, 2 REA benthic surveys using the quadrat method on Pathfinder Reef documented 280 coral colonies within a survey area of 8 m^2. Site-specific colony density ranged from 28 to 42 colonies m^{-2} with a sample mean of 35 colonies m^{-2} (SE 7). The higher colony density was recorded at REA site PAT-02 on the western edge of this reef (Table 18.8.4.1a).

Between MARAMP survey years, little difference was seen in overall mean coral cover at Pathfinder Reef, as estimated from towed-diver surveys. At the single REA site surveyed in both years, PAT-01 in the center of this reef, observed coral-colony density increased from 20.5 to 28 colonies m^{-2}. The increase in estimates of colony density between 2003 and 2005 could reflect increased recruitment, fragmentation of existing colonies, or both, or could simply reflect sampling variation.

Coral Generic Richness and Relative Abundance

One REA benthic survey was conducted using the quadrat method on Pathfinder Reef during MARAMP 2003, and 11 coral genera were observed (Table 18.8.4.1a). Two REA benthic surveys were conducted using the quadrat method during MARAMP 2005. Generic richness in 2005 ranged from 11 genera at PAT-01 to 15 genera at PAT-02, with a mean of 13 (SE 2) coral genera per site.

Across the 2 MARAMP survey years, 16 coral genera were observed. *Pocillopora*, *Montastrea*, and *Psammocora* were important components of the coral fauna at Pathfinder Reef, contributing > 10% of the total number of colonies enumerated in both survey years. *Pocillopora* was the most numerically abundant taxon at PAT-01 in 2003 (Table 18.8.4.1a), contributing 40.3% of the total number of colonies observed at that site. *Montastrea* and *Psammocora* were the two next-most abundant taxa, contributing 18.2% and 10.4% of the total number of colonies. *Pocillopora* also was the most abundant taxon in 2005, contributing 36% of the total number of colonies enumerated. *Psammocora* and *Montastrea* were the next-most abundant taxa in 2005, contributing 16.5% and 10.1% of the total number of colonies recorded. All other taxa contributed < 10% of the total number of colonies enumerated in both survey years.

Table 18.8.4.1a. Observations of colony densities (colonies m^{-2}), coral generic richness, size-class distribution (%), and relative abundance of coral genera from REA benthic surveys conducted using the quadrat method on Pathfinder Reef during MARAMP 2003 and 2005.

Year	Site	Density (colonies 100 m^{-2})	Generic Richness (#)	Size-class Distribution (%)							Abundance (%)										
				0–5 cm	6–10 cm	11–20 cm	21–40 cm	41–80 cm	81–169 cm	> 160 cm	*Acropora*	*Astreopora*	*Favia*	*Goniastrea*	*Leptastrea*	*Montipora*	*Pavona*	*Pocillopora*	*Porites*	Octocorals	Other
2003	PAT-01	21	11	41.6	33.8	19.5	3.9	1.3	0	0	0	1.3	2.6	0	3.9	0	2.6	40.3	7.79	0	41.6
2005	PAT-01	28	11	54.5	27.7	13.4	3.57	0.89	0	0	0	0	0.89	0	2.68	3.57	3.57	50	5.36	0	33.9
2005	PAT-02	42	15	63.7	17.9	13.7	4.76	0	0	0	0	5.95	5.36	0	1.19	1.19	4.17	22	12.5	0	47.6

Coral Size-class Distribution

During MARAMP 2003, the coral size-class distribution at PAT-01 showed that no single size class contained the majority of corals. The greatest proportion of corals (41.6%) belonged to the smallest size class (≤ 5 cm; Table 18.8.4.1a). The next 4 size classes (6–10, 11–20, 21–40, and 41–80 cm) accounted for 33.8%, 19.5%, 3.9%, and 1.3% of colonies recorded. No colonies with maximum diameters > 80 cm were recorded.

During MARAMP 2005, the coral size-class distributions on Pathfinder Reef showed that the majority (59.1%) of corals had maximum diameters ≤ 5 cm (Table 18.8.4.1a). The next 4 size classes (6–10, 11–20, 21–40, and 41–80 cm) accounted for 22.8%, 13.5%, 4.2%, and 0.4% of colonies recorded. No colonies with maximum diameters > 80 cm were recorded.

At the single site surveyed in both MARAMP survey years, PAT-01, the proportion of colonies in the smallest size class (≤ 5 cm) increased from 41.5% to 54.6% between 2003 and 2005, and the proportion of colonies in all other size classes decreased. This shift towards the smallest size class may reflect recruitment, fragmentation of existing colonies, or both.

18.8.4.2 Algal Surveys

Algal Cover

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on Pathfinder Reef was 37% (SE 1.3), with mean values for the 4 surveys of 30%, 38%, 38%, and 45% (Fig. 18.8.4.2a, left top panel). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. The overall estimated mean for cover of crustose coralline red algae was 6% (SE 0.8), with survey means of 0%, 4%, 7%, and 10% (Fig. 18.8.4.2a, right top panel). Spur-and-groove reef of medium-low complexity was the most commonly noted habitat type throughout these surveys.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on Pathfinder Reef was 29% (SE 1.1), with mean values for the 3 surveys of 24%, 28%, and 35% (Fig. 18.8.4.2a, bottom left panel). The overall estimated mean for cover of crustose coralline red algae was 10% (SE 1.2), slightly higher than the overall mean for 2003; means for individual surveys were 3%, 13%, and 13% (Fig. 18.8.4.2a, right bottom panel). Habitat complexity was most frequently noted as medium, except one survey had a higher incidence of medium-high complexity.

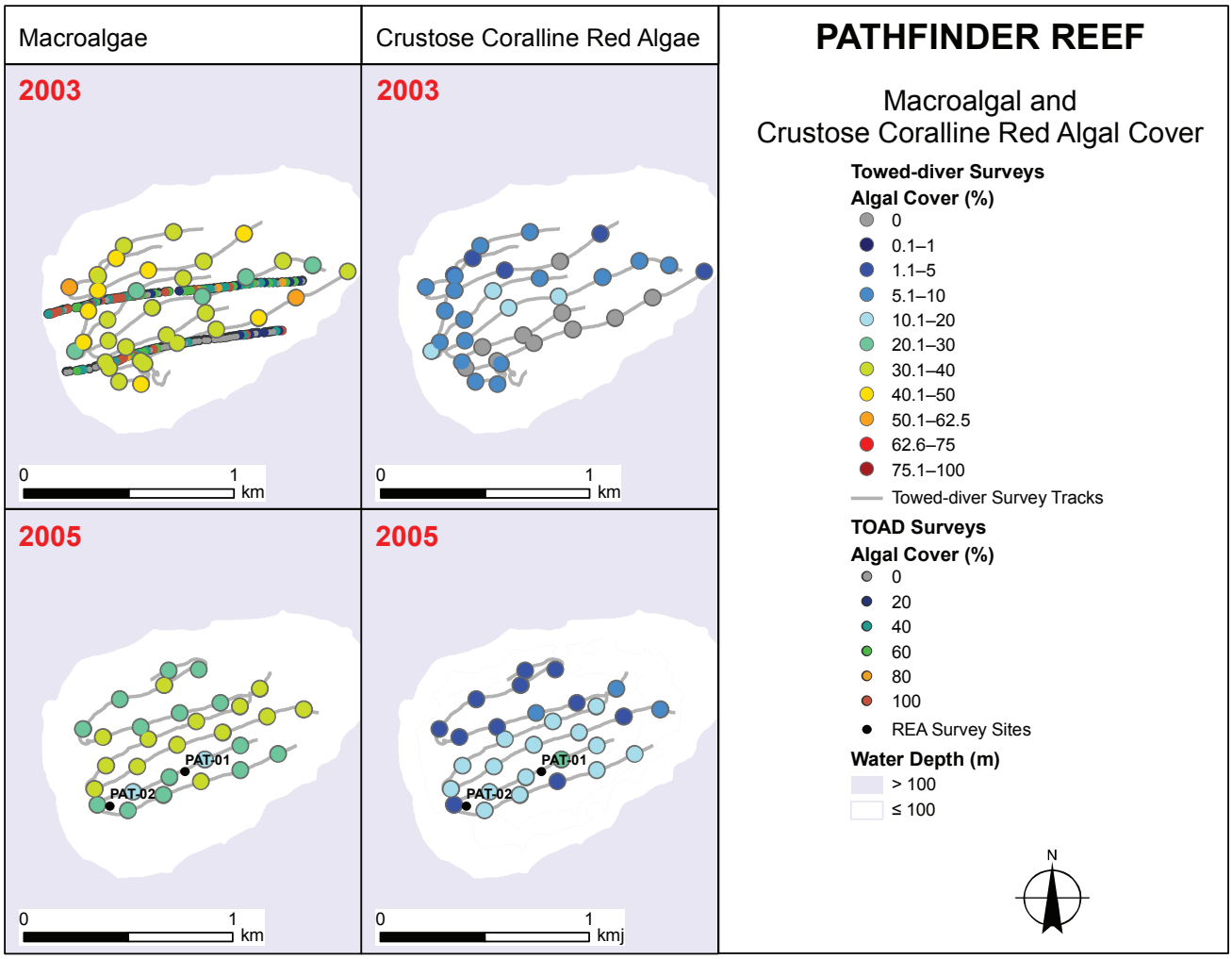


Figure 18.8.4.2a. Cover (%) observations for (*left*) macroalgae and (*right*) crustose coralline red algae from towed-diver benthic surveys conducted on Pathfinder Reef during MARAMP 2003 and 2005. Each large, colored point represents an estimate over a 5-min observation segment with a towed-diver survey swath of ~ 200 × 10 m (~ 2000 m^2). The 2003 macroalgal panel shows observations of both macroalgae and turf algae (turf algae were included in towed-diver surveys only during MARAMP 2003).In this panel, each small, colored point represents an estimate of algal cover from TOAD surveys. The 100-fm contour shown in white represents potential reef habitat.

Macroalgal Genera and Functional Groups

In the field, because of their small size or similarity in appearance, turf algae, crustose coralline red algae, cyanophytes (blue-green algae), and branched, nongeniculate coralline red algae were lumped into functional group categories. The generic names of macroalgae from field observations are tentative, since microscopic analysis is necessary for proper taxonomic identification. The lengthy process of laboratory-based taxonomic identification of all algal species collected at REA sites on the West Mariana Ridge has not been undertaken yet. Ultimately, based on microscopic analysis that may occur in the future, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2005, REA benthic surveys were conducted at 2 sites on Pathfinder Reef. In the field, 10 macroalgal genera (2 red, 7 green, and 1 brown), containing at least 10 species, as well as 3 additional algal functional groups—turf

algae, crustose coralline red algae, and cyanophytes—were observed. Macroalgal generic diversity was approximately equal at both sites with 7 genera, each containing 1 species, observed at each site. However, the macroalgal generic composition varied slightly between sites with *Caulerpa, Dictyosphaeria*, and *Neomeris* observed only at PAT-01 and *Actinotrichia*, *Dictyota*, and *Rhipidosiphon* recorded only at PAT-02.

The most widely distributed algal genera on Pathfinder Reef in 2005 were chlorophytes. Species of the genera *Halimeda* and *Chlorodesmis* were the most common component of algal communities (Table 18.8.4.2a), occurring in 87.5% and 70.8% of photoquadrats sampled at both sites. Species of the algal genera *Actinotrichia, Caulerpa, Dictyosphaeria, Dictyota, Jania, Neomeris, Rhipidosiphon* and *Valonia* also were present, occurring in < 12.5% of the sampled photoquadrats.

Turf algae and crustose coralline red algae were both exceptionally common in 2005, occurring in 95.8% and 62.5% of photoquadrats sampled at both sites on Pathfinder Reef. Turf-algal communities, ubiquitous at both sites, were found in 91.7%–100% of sampled photoquadrats (Table 18.8.4.2a). Crustose coralline red algae also were observed at both sites, in 50%–75% of photoquadrats sampled.

	Occurrence (%)									
Site	*Amphiroa*	*Jania*	*Schizymenia*	*Halimeda*	*Microdictyon*	*Neomeris*	*Lobophora*	*Crustose Coralline Red Algae*	*Cyanobacteria*	*Turf Algae*
PAT-01	0	8.33	0	75	0	8.33	0	50	8.33	100
PAT-02	0	16.7	0	100	0	0	0	75	33.3	91.7

Table 18.8.4.2a. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys conducted on Pathfinder Reef during MARAMP 2005. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed.

18.8.4.3 Macroinvertebrate Surveys

During MARAMP 2003, species of *Tridacna* giant clams were observed in all 4 towed-diver surveys conducted on Pathfinder Reef (Fig. 18.8.4.3a, left panel), with an overall mean density of 0.094 organisms 100 m^{-2}. The greatest mean density from a towed-diver survey was 0.12 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.308 organisms 100 m^{-2}.

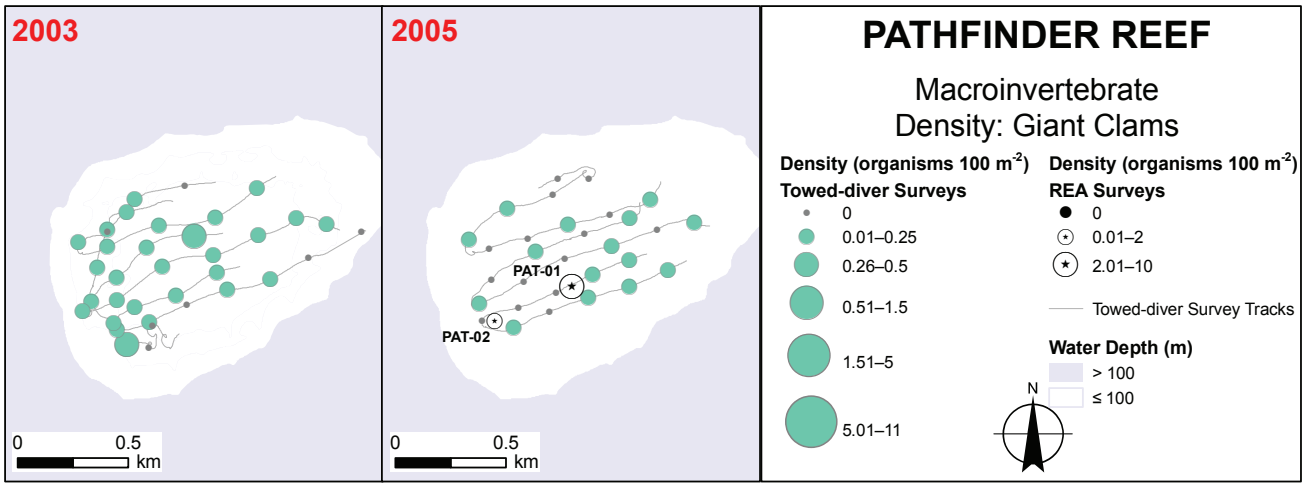


Figure 18.8.4.3a. Densities (organisms 100 m^{-2}) of giant clams from towed-diver benthic surveys conducted on Pathfinder Reef during MARAMP 2003 and 2005. The 100-fm contour shown in white represents potential reef habitat.

During MARAMP 2005, giant clams were observed in all 3 towed-diver surveys conducted on Pathfinder Reef (Fig. 18.8.4.3a, right panel), with an overall mean density of 0.052 organisms 100 m^{-2}. The greatest mean density from a towed-diver survey was 0.064 organisms 100 m^{-2}; segment densities ranged from 0 to 0.159 organisms 100 m^{-2}.

Crown-of-thorns seastars were not observed on Pathfinder Reef during MARAMP 2003 and 2005.

During MARAMP 2003, sea cucumbers were observed in 1 of the 4 towed-diver surveys conducted on Pathfinder Reef, with a mean density of 0.005 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.132 organisms 100 m^{-2} (Fig. 18.8.4.3b, left panel). During MARAMP 2005, sea cucumbers were recorded in 1 of the 3 towed-diver surveys conducted on Pathfinder Reef, with a mean density of 0.002 organisms 100 m^{-2}. Sea cucumbers were observed during only 1 segment from that survey, at a density of 0.069 organisms 100 m^{-2} (Fig. 18.8.4.3b, right panel).

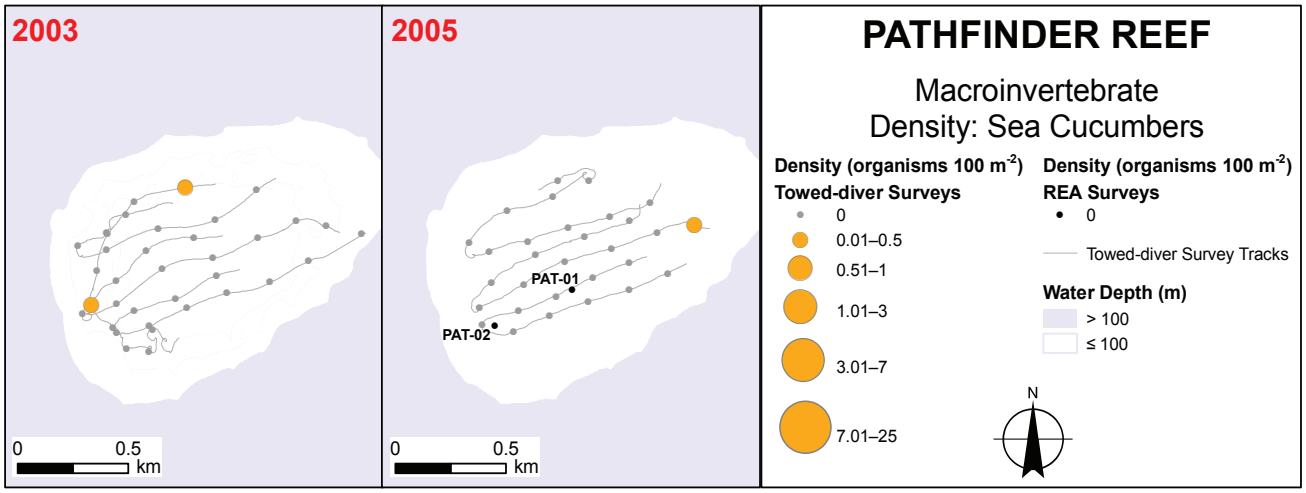


Figure 18.8.4.3b. Densities (organisms 100 m^{-2}) of sea cucumbers from towed-diver benthic surveys conducted at Pathfinder Reef during MARAMP 2003 and 2005. The 100-fm contour shown in white represents potential reef habitat.

During MARAMP 2003, sea urchins were observed in all 4 towed-diver surveys conducted on Pathfinder Reef, with an overall mean density was 9.92 organisms 100 m^{-2} (Fig. 18.8.4.3c, left panel). The greatest mean density from a towed-diver survey was 14.11 organisms 100 m^{-2}; segment densities from this survey ranged from 5.82 to 29.11 organisms 100 m^{-2}.

During MARAMP 2005, sea urchins were observed in all 3 towed-diver surveys conducted on Pathfinder Reef, with an overall mean density of 5.10 organisms 100 m^{-2} (Fig. 18.8.4.3c, right panel). The greatest mean density from a towed-diver survey was 6.83 organisms 100 m^{-2}; segment densities ranged from 2.06 to 19.63 organisms 100 m^{-2}.

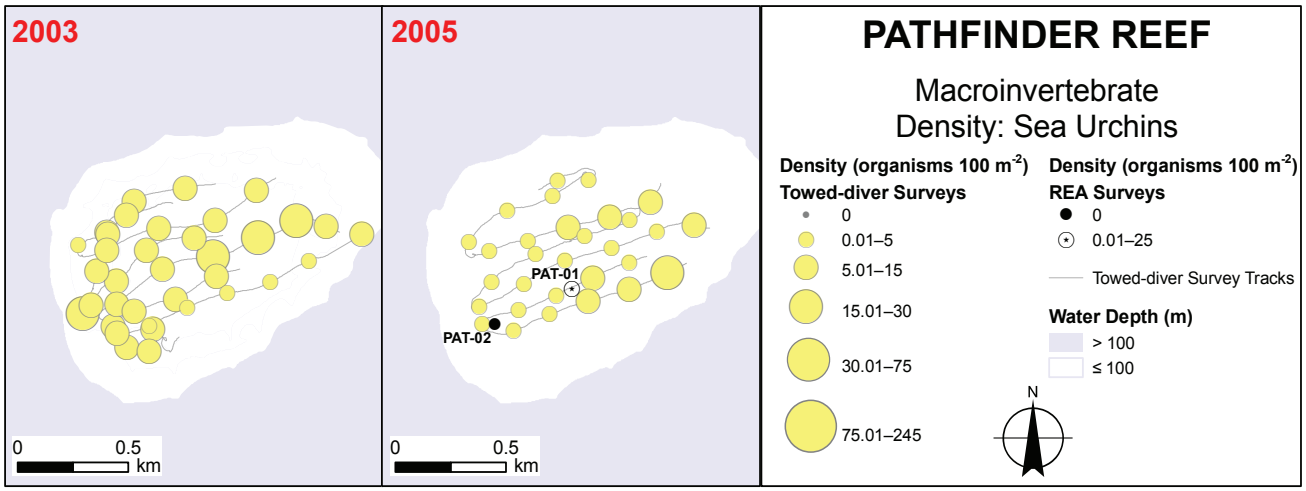


Figure 18.8.4.3c. Densities (organisms 100 m-^{2}) of sea urchins from towed-diver benthic surveys conducted at Pathfinder Reef during MARAMP 2003 and 2005. The 100-fm contour shown in white represents potential reef habitat.

18.8.4.4 Reef Fish Surveys

During MARAMP 2003, 4 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted on Pathfinder Reef. The overall estimated mean biomass, calculated as weight per unit area, was 1.44 kg 100 m^{-2} (SE 0.41). Observed large-fish biomass was highest in the northern part of this reef where jacks, snappers, and sharks were common (Fig. 18.8.4.4a, left panel). Reef sharks and jacks each accounted for the highest proportion (21%) or 0.30 kg 100 m^{-2}of overall large-fish biomass. The whitetip reef shark accounted for 44% of reef shark biomass. During this survey period, 19 sharks were observed: 11 whitetip reef sharks and 8 grey reef sharks. The bigeye trevally (*Caranx sexfaciatus*) accounted for 94% of jack biomass. Snappers and surgeonfishes also were commonly observed, accounting for 21% and 23% of overall estimates of large-fish biomass. The twinspot snapper made up 99% of snapper biomass. The bulbnose unicornfish and sleek unicornfish were the 2 surgeonfish species encountered, contributing 0.17 and 0.16 kg 100 m^{-2} to overall large-fish biomass.

During MARAMP 2005, 3 towed-diver surveys for large-fishes (≥ 50 cm in TL) were conducted on Pathfinder Reef (Fig. 18.8.4.4a, right panel.). The overall estimated mean biomass was 0.54 kg 100 m^{-2} (SE 0.12), lower than the level observed in 2003 (Fig. 18.8.4.4b). Reef sharks accounted for the highest proportion (46%) or 0.25 kg 100 m^{-2} of reef-wide large-fish

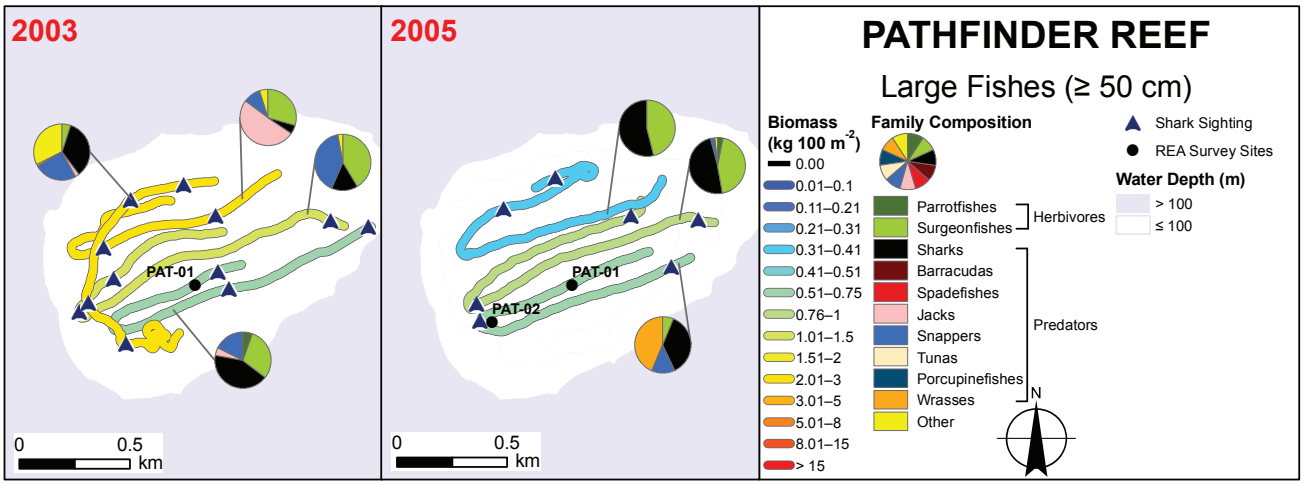


Figure 18.8.4.4a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and shark sightings from towed-diver fish surveys conducted on Pathfinder Reef during MARAMP 2003 and 2005. Each blue triangle represents a sighting of one or more sharks recorded inside or outside the survey area over which it is shown. The 100-fm contour shown in white represents potential reef habitat.

biomass. Consistent with observations made in 2003, whitetip reef sharks were the most abundant shark species. During this survey period, 13 sharks were observed: 8 whitetip reef shark and 5 grey reef shark. Surgeonfishes accounted for 32% of overall large-fish. As seen in 2003, the bulbnose unicornfish and sleek unicornfish were the 2 major surgeonfishes by biomass, contributing 0.11 kg 100 m^{-2} and 0.04 kg 100 m^{-2} to overall mean biomass of large fishes. A notable sighting was a single large (100 cm in TL) humphead wrasse (*Cheilinus undulatus*).

Total fish biomass for the single REA site surveyed for fishes of all sizes and species on Pathfinder Reef during MARAMP 2003 was 4.72 kg 100 m^{-2} (Table 18.8.4.4a). Snapper accounted for the highest proportion (46%) or 2.15 kg 100 m^{-2} of total fish biomass. The twinspot snapper was the only snapper species observed with 10 individuals seen in total. Jacks accounted for the second-greatest proportion (32%) of total fish biomass. The bluefin trevally accounted for 87% or 1.31 kg 100 m^{-2} of jack biomass.

From the single REA survey conducted on Pathfinder Reef during MARAMP 2003, species richness was 23.7 species 100 m^{-2}, and 38 species in total were observed (Table 18.8.4.4a). Wrasses (Labridae) and damsel-

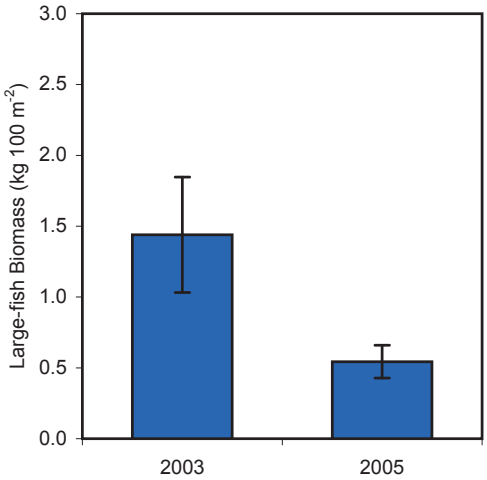


Figure 18.8.4.4b. Temporal comparison of mean values of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}) from towed-diver surveys conducted on Pathfinder Reef during MARAMP 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

fishes (Pomacentridae) were the 2 most diverse families, each with 7 species recorded. The bluntheaded wrasse (*Thalassoma amblycephalum*) was the most abundant species overall, with 45 individuals 100 m^{-2}, and the Pacific gregory (*Stegastes fasciolatus*) was the most abundant damselfish species.

Table 18.8.4.4a. Observations of total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method on Pathfinder Reef during MARAMP 2003 and 2005.

Year	Site	Richness (species 100 m^{-2})	Biomass (kg 100 m^{-2})												
			Total	Parrotfishes	Surgeonfishes	Sharks	Soldierfishes	Groupers	Jacks	Fusiliers	Snappers	Triggerfishes	Wrasses	Damselfishes	Other
2003	PAT-01	23.7	4.72	0.26	0.17	0	0	0.01	1.5	0	2.15	0.08	0.36	0.05	0.13
2005	PAT-01	19.5	9.11	0.06	1.05	0	0	0.05	1.22	0	5.88	0.09	0.42	0.1	0.23
2005	PAT-02	29.5	5.24	0	0.48	0.76	0.05	0.8	0.79	0	1.6	0.23	0.37	0.07	0.1

Total fish biomass for the 2 REA sites surveyed on Pathfinder Reef during MARAMP 2005 was slightly higher than observations made in 2003, with an overall sample mean of 7.18 kg 100 m^{-2} (SE 1.93). Estimated fish biomass was higher at PAT-01, located in the center of this reef, at 9.11 kg 100 m^{-2} (Table 18.8.4.4a). Similar to the results from surveys in 2003, snapper accounted for around half or 3.74 kg 100 m^{-2} of total fish biomass. The twinspot snapper again was the only snapper species seen, with 22 individuals recorded in 2005. Jacks accounted for the second-greatest proportion (14%) of total fish biomass, with the black jack (*Caranx lugubris)* accounting for 78% or 0.78 kg 100 m^{-2} of jack biomass. Surgeonfishes also were commonly observed, accounting for 11% of total fish biomass. The bulbnose unicornfish contributed more than half or 0.41 kg 100 m^{-2} of surgeonfish biomass. During this survey period, 2 reef sharks were observed; both were small (75 cm in TL) grey reef shark.

From the 2 REA surveys conducted during MARAMP 2005, species richness on Pathfinder Reef ranged between 19.5 and 29.5 species 100 m^{-2}, with the higher species richness found at PAT-02 on the western edge of this reef (Table 18.8.4.4a). As in 2003, wrasses and damselfishes were the 2 most diverse families, with 10 and 11 species recorded. The bluntheaded wrasse was the most abundant species overall with 21 individuals 100 m^{-2}, but Katherine's wrasse (*Cirrhilabrus katherinae*) was nearly as abundant with 20 individuals 100 m^{-2}. The midget chromis (*Chromis acares*) was the most abundant damselfish species.

There were insufficient REA surveys at Pathfinder Reef to attempt to discern meaningful spatial or temporal trends. When compared with the rest of the Mariana Archipelago, total fish biomass was moderately high with the mean for the 2 MARAMP survey periods at 5.95 kg 100 m^{-2}. Snappers accounted for the greatest proportion of total fish biomass, with the twinspot snapper alone contributing about half of total fish biomass in both survey years. Jacks also were commonly observed, accounting for the second-greatest proportion of total fish biomass. Two grey reef shark were observed in 2005; no other reef sharks were observed during REA fish surveys conducted on Pathfinder Reef.

For both MARAMP survey periods, wrasses and damselfishes were the 2 most diverse families, averaging 8.5 and 9 species per family. Wrasses were the most abundant fishes tallied for both survey years, and the bluntheaded wrasse was the most abundant species overall with > 20 individuals 100 m^{-2} observed in both survey periods.

18.9 Arakane Reef

18.9.1 Introduction

Part of the West Mariana Ridge, Arakane Reef is a small (~ 1.8 × 1 km), shallow bank located ~ 110 km southwest of Tinian.

18.9.2 Survey Effort

Benthic habitat mapping data were collected on Arakane Reef using a combination of acoustic and optical survey methods. During MARAMP 2003, depth soundings were obtained from a small boat using a handheld depth sounder and handheld GPS to provide guidance for locating subsequent diving operations. Optical validation and habitat characterization were completed using towed-diver and TOAD surveys that documented live-hard-coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in the next section.

REA, towed-diver, and TOAD surveys were conducted on Arakane Reef during MARAMP 2003 and 2005 to collect information on habitat and the condition, abundance, diversity, and distribution of biological communities. Results from these surveys are discussed in Section 18.9.3: "Benthic Mapping and Characterization" and Section 18.9.4 "Biological Characterization." The numbers of these surveys are presented in Table 18.9.2a, along with their mean depths and total areas or length. Three TOAD surveys were conducted on Arakane Reef during MARAMP 2003 at depths of 20–280 m, covering a distance of 1.33 km. Subsequent analyses of the video acquired from these surveys provided estimates of the percentages of sand cover and live coral cover.

For both MARAMP survey years combined, 9 towed-diver surveys were conducted on Arakane Reef at depths of 13–23 m, covering a distance of 17.13 km. The mean depths of individual surveys ranged from 14.9 m (SD 2.4) to 20.7 m (SD 2.5) in 2003 and from 15.6 m (SD 1.9) to 18.1 m (SD 1.6) in 2005. Figures 18.9.2a and b illustrate the locations and depths of towed-diver-survey tracks on Arakane Reef and should be referenced when further examining results of the towed-diver surveys from MARAMP 2003 and 2005.

Survey Type	Survey Detail	Year	
REA		**2003**	**2005**
Fish	Number of Surveys	2	2
	Mean Depth (m)	18 (SD 2.8)	18 (SD 2.8)
Benthic	Number of Surveys	2	2
	Mean Depth (m)	18 (SD 2.8)	18 (SD 2.8)
Towed Diver		**2003**	**2005**
	Number of Surveys	6	3
	Total Survey Area (ha)	10.7	6.5
	Mean Depth (m)	16.9 (SD 2.1)	16.8 (SD 1.2)
TOAD		**2003**	
	Number of Surveys	3	
	Total Length (km)	1.33	

Table 18.9.2a. Numbers, mean depths (m), total areas (ha), and total lengths (km) of REA, towed-diver, and TOAD surveys conducted at Arakane Reef during MARAMP 2003 and 2005. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys of corals, algae, and macroinvertebrates.

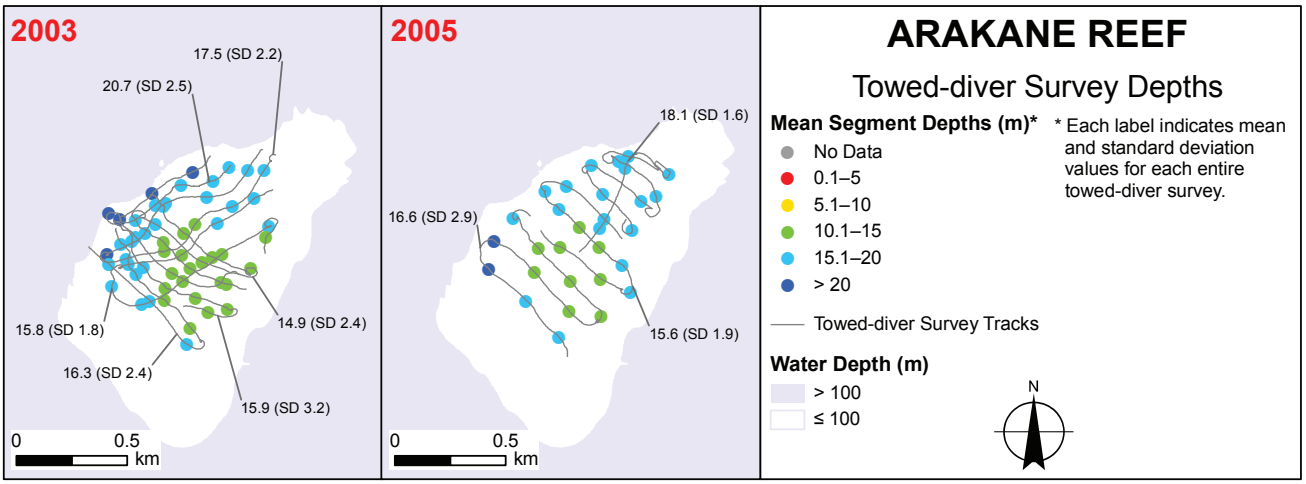


Figure 18.9.2a. Depths and tracks of towed-diver surveys conducted on Arakane Reef during MARAMP 2003 and 2005. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate. The 100-fm contour shown in white represents potential reef habitat.

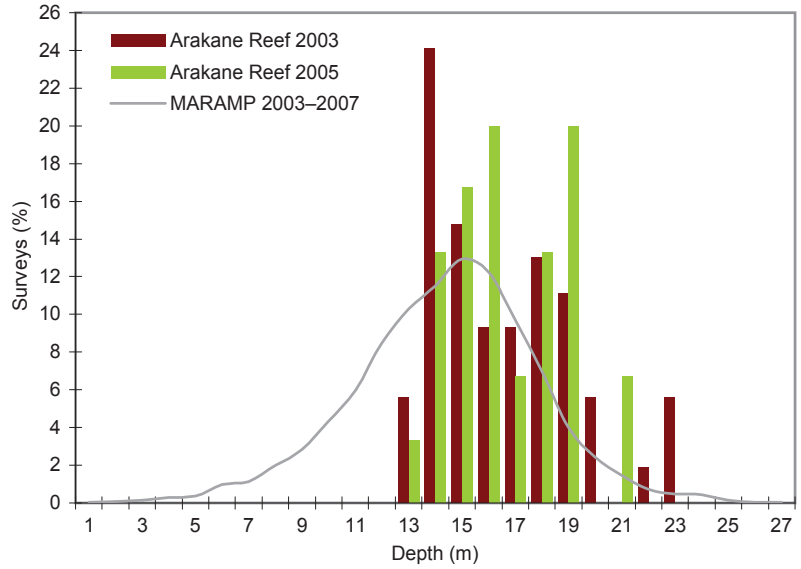


Figure 18.9.2b. Depth histogram plotted from mean depths of 5-min segments of the towed-diver surveys conducted on Arakane Reef during MARAMP 2003 and 2005. Mean segment depths are derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005, and 2007.

18.9.3 Benthic Habitat Mapping and Characterization

Figure 18.9.3a presents a contoured map of the handheld depth soundings collected on Arakane Reef.

During MARAMP 2003, 6 towed-diver surveys and 3 TOAD surveys were conducted, and, during MARAMP 2005, 3 towed-diver surveys were completed. At 5-min intervals within each towed-diver survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high. Habitats on Arakane Reef were found to have uniformly medium-low to medium habitat complexity (Fig. 18.9.3b). As with the 2 other reefs surveyed on the West Mariana Ridge, the substrate of the surveyed area was predominantly hard; however, some small patches of sand were observed during both towed-diver surveys and analyses of TOAD video. Cover of live hard corals at Arakane Reef, based on towed-diver surveys was the lowest level observed among the reefs on the West Mariana Ridge, with segment means of 1.1%–50% and a majority of them at 10.1%–30%. Results for live coral cover from analyses of video footage obtained from TOAD surveys ranged from 0% to 100%, with live coral cover higher for the southernmost survey than for the other survey. Divers surveying Arakane Reef described a high abundance of soft and fire corals, which are not represented in the maps showing only cover of hard corals.

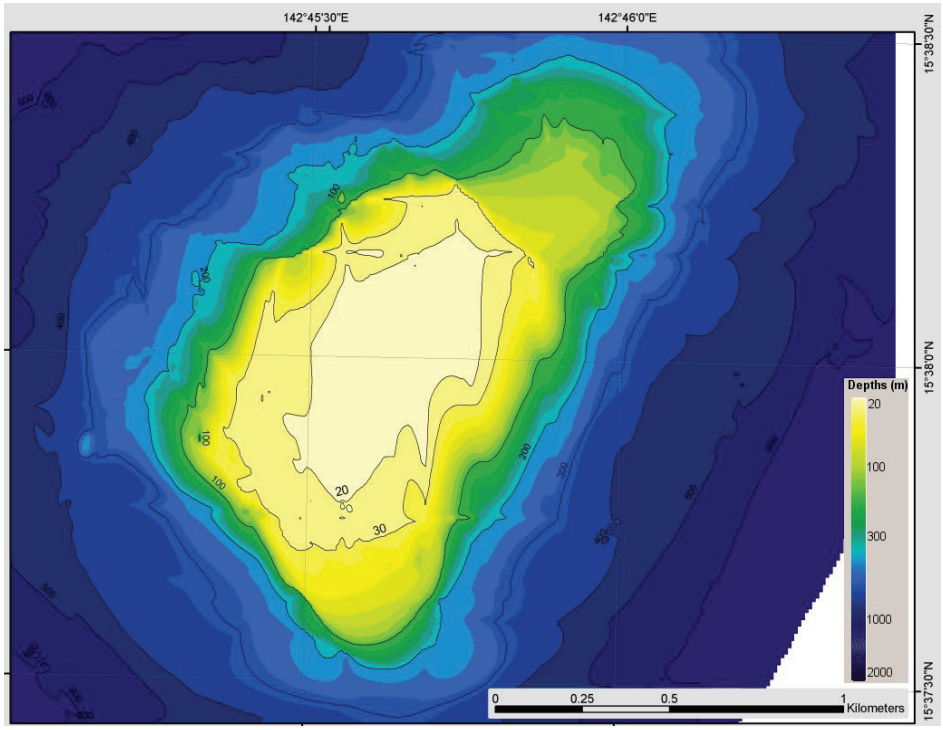


Figure 18.9.3a. Contoured map derived from depth soundings collected using a handheld depth sounder on Arakane Reef during MARAMP 2003.

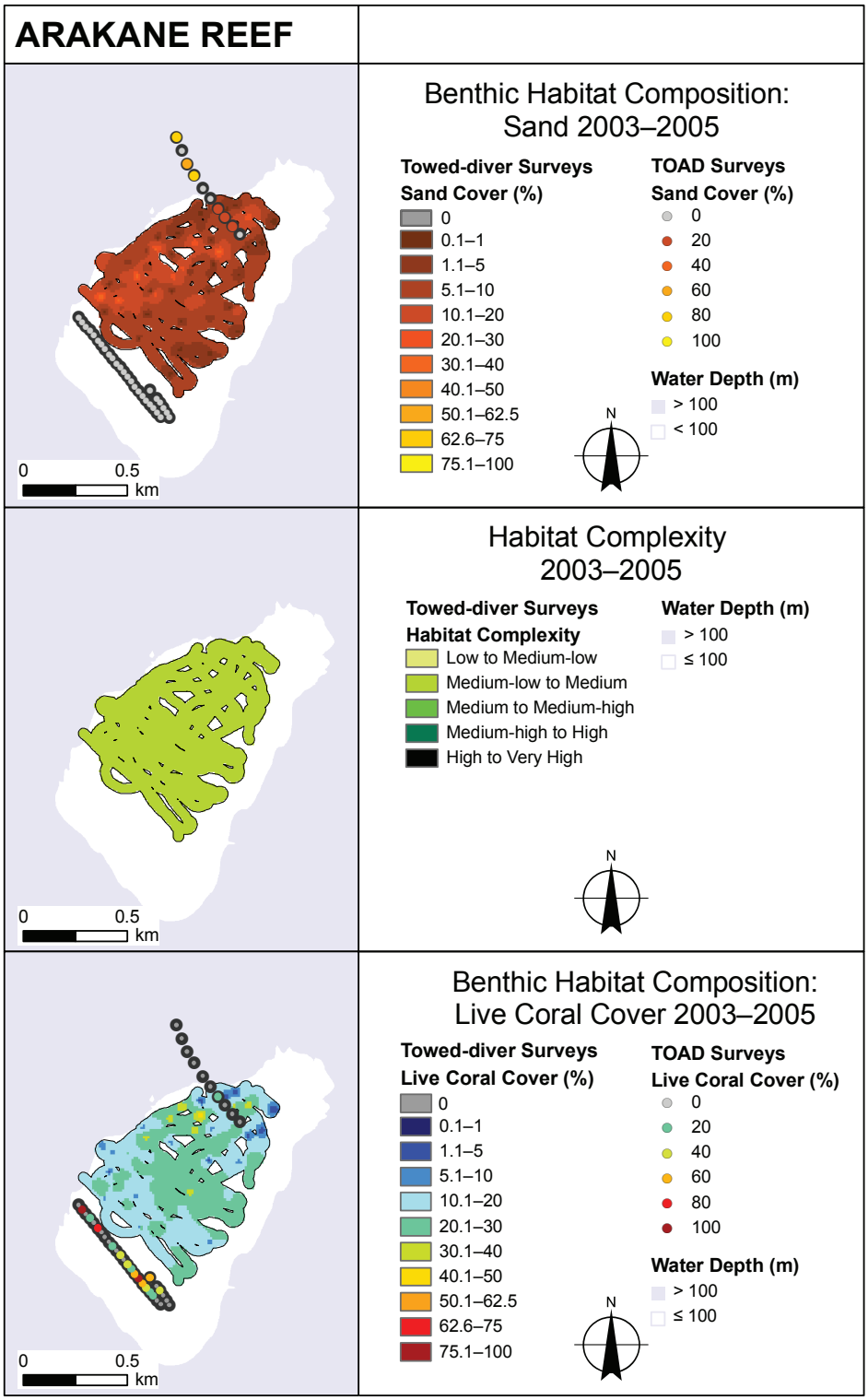


Figure 18.9.3b Observations of (*top*) sand cover (%), (*middle*) benthic habitat complexity, and (*bottom*) cover (%) of live hard corals from towed-diver surveys conducted and analysis of TOAD video collected on Arakane Reef during MARAMP 2003 and 2005. The 100-fm contour shown in white represents potential reef habitat.

18.9.4 Biological Characterization

18.9.4.1 Coral Surveys

Coral Cover and Colony Density

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on Arakane Reef was 24% (SE 1.1). For a majority of segments (45 of 53 segments) coral cover was 10.1%–30%. The highest coral cover was observed on the northern part of this reef, with a mean of 39% over 6 segments (Fig. 18.9.4.1a, left panel).

From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on Arakane Reef was 12% (SE 1.6). Over all survey segments coral cover was 1.1%–30%. The highest coral cover was recorded on the center of this reef, with a mean of 25% over 6 segments (Fig. 18.9.4.1a, right panel).

Towed divers during MARAMP 2005 recorded estimates of stressed-coral cover, including corals that were fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease"). Overall, < 1% of coral cover observed on Arakane Reef in 2005 appeared stressed.

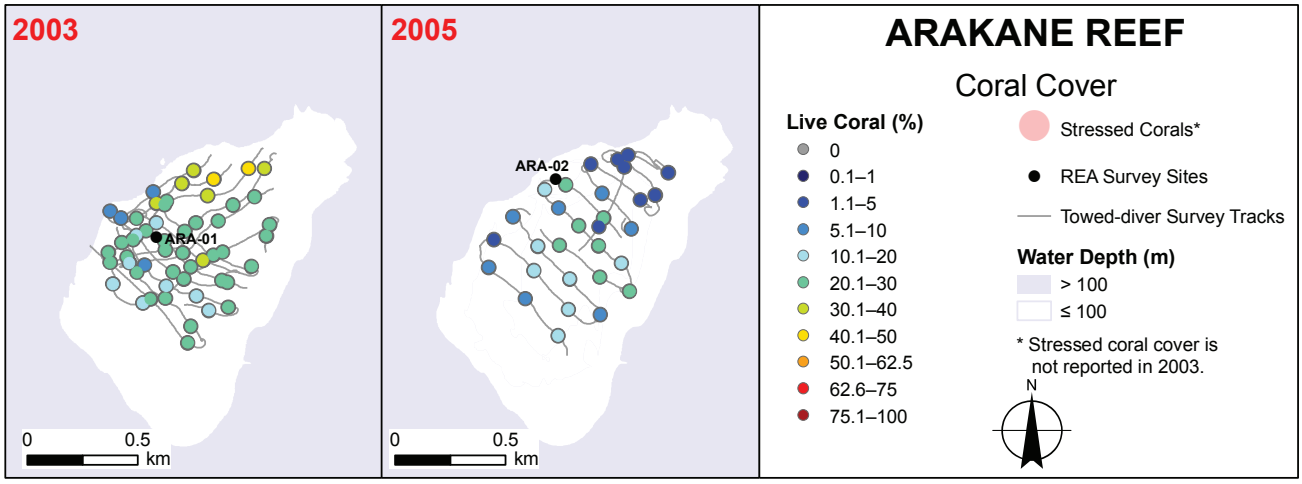


Figure 18.9.4.1a. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys conducted on Arakane Reef during MARAMP 2003 and 2005. Each colored point represents an estimate of live coral over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m^2). Pink symbols are not shown here, since they represent only segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2005. The 100-fm contour shown in white represents potential reef habitat.

During MARAMP 2003, 1 REA benthic survey using the quadrat method at Arakane Reef documented 90 coral colonies within a survey area of 3.75 m^2, yielding a site-specific colony density of 24 colonies m^{-2} (Table 18.9.4.1a).

During MARAMP 2005, 1 REA benthic survey using the quadrat method at Arakane Reef documented 121 coral colonies in a survey area of 4 m^2, yielding a site-specific colony density of 30.3 colonies m^{-2} (Table 18.9.4.1a).

Between MARAMP survey years, overall mean coral cover estimated from towed-diver surveys decreased from 24% (SE 1.1) in 2003 to 12% (SE 1.6) in 2005. The comparable depth strata surveyed in both years and a visible drop in coral cover in the north, where elevated coral cover was previously reported in 2003, suggest that this decrease in estimated coral cover was genuine rather than an artifact of environmental heterogeneity or variable locations of survey tracks (Figs 18.9.2a and b; for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Coral Generic Richness and Relative Abundance

One REA benthic survey was conducted using the quadrat method at Arakane Reef during MARAMP 2003, and 9 coral genera were observed (Table 18.9.4.1a). One REA benthic survey was conducted using the quadrat method at Arakane Reef during MARAMP 2005, and 10 coral genera were observed.

Across the 2 MARAMP survey years, 11 coral genera were observed. *Montastrea, Pocillopora, Leptastrea,* and *Favia* were important components of the coral fauna at Arakane Reef, contributing > 10% of the total number of colonies enumerated in both survey years (Table 18.9.4.1a). *Montastrea* was the most numerically abundant taxon at ARA-01 in 2003, contributing 32.2% of the total number of colonies enumerated at that site. *Pocillopora*, *Favia* and *Leptastrea* were the next-most abundant taxa, accounting for 25.6%, 13.3%, and 10% of the total number of colonies. *Montastrea* was the most numerically abundant taxon at ARA-02 in 2005, contributing 21.5% of the total number of colonies enumerated at that site. *Porites*, *Leptastrea*, *Pocillopora* and *Favia* were the next-most abundant taxa, contributing 18.2%, 17.4%, 10.7%, and 10.7%, respectively, of the total number of colonies recorded. All other taxa contributed < 10% of the total number of colonies enumerated in both survey years.

Table 18.9.4.1a. Observations of colony densities (colonies m^{-2}), coral generic richness, size-class distribution (%) and relative abundance of coral genera from REA benthic surveys using the quadrat method conducted at Arakane Reef during MARAMP 2003 and 2005

				Size-class Distribution (%)							Abundance (%)										
Year	Site	Density (colonies 100 m^{-2})	Generic Richness (#)	0–5 cm	6–10 cm	11–20 cm	21–40 cm	41–80 cm	81–169 cm	> 160 cm	*Acropora*	*Astreopora*	*Favia*	*Goniastrea*	*Leptastrea*	*Montipora*	*Pavona*	*Pocillopora*	*Porites*	Octocorals	Other
2003	ARA-01	24	9	37.8	41.1	14.4	5.56	1.11	0	0	0	0	13.3	0	10	0	0	25.6	5.56	0	45.6
2005	ARA-02	30	10	71.9	15.7	8.26	4.13	0	0	0	0	0.83	10.7	0	17.4	0.83	0	10.7	18.2	0	41.3

Coral Size-class Distribution

During MARAMP 2003, the coral size-class distribution at ARA-01 showed that no single class contained the majority of corals. The greatest proportion of corals (41.1%) belonged to the second-smallest size class (6–10 cm; Table 18.9.4.1a). The other 4 size classes (0–5, 11–20, 21–40, and 41– 80 cm) accounted for 37.8%, 14.4%, 5.6%, and 1.1% of colonies recorded. No colonies with maximum diameters > 80 cm were recorded.

During MARAMP 2005, the coral size-class distribution at ARA-02 showed that the majority (71.9%) of corals had maximum diameters ≤ 5 cm (Table 18.9.4.1a). The next 3 size classes (6–10, 11–20, and 21-40 cm) accounted for 15.7%, 8.3%, and 4.1% of colonies recorded. No colonies with maximum diameters > 40 cm were recorded.

18.9.4.2 Algal Surveys

Algal Cover

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on Arakane Reef was 52% (SE 1.6), with mean values for the 6 surveys of 35%, 47%, 55%, 5%, 60%, and 62% (Fig. 18.9.4.2a, left top panel). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. The overall estimated mean cover of crustose coralline red algae was 5% (SE 0.7), with survey means of 2%, 2%, 2%, 4%, 10%, and 13% (Fig. 18.9.4.2a, right top panel). The levels of habitat complexity most frequently noted during towed-diver surveys were medium and medium-low.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on Arakane Reef was 46% (SE 2.3), with mean values for the 3 surveys of 34%, 43%, and 60% (Fig. 18.9.4.2a, left bottom panel). The overall estimated mean for cover of crustose coralline red algae was 4% (SE 0.6), similar to the overall mean for 2003; means for individual surveys were 1%, 4%, and 5% (Fig. 18.9.4.2a, right bottom panel). For the 3 surveys, the substrate was frequently covered in red algae and cyanobacteria.

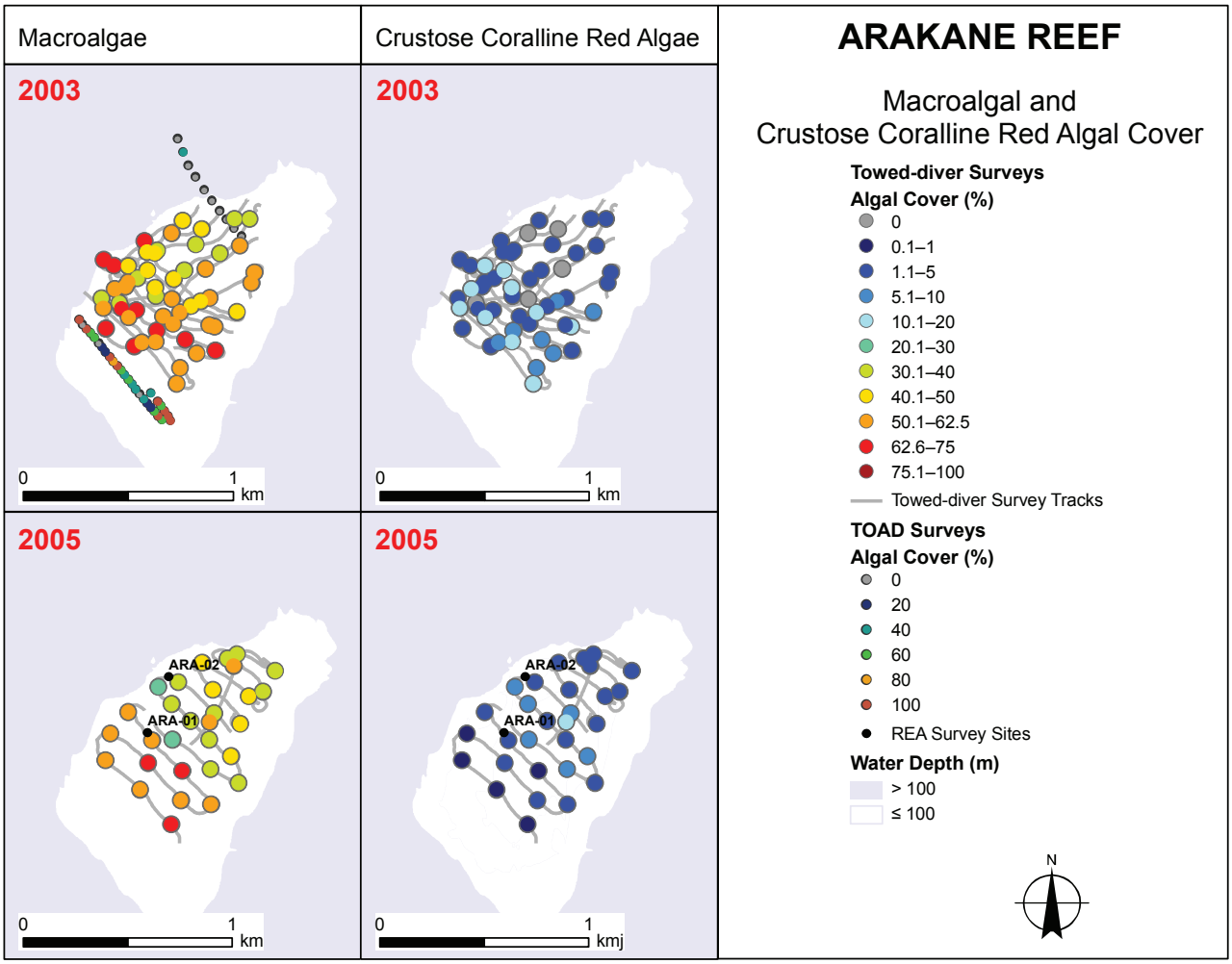


Figure 18.9.4.2a. Cover (%) observations for (*left*) macroalgae and (*right*) crustose coralline red algae from towed-diver benthic surveys conducted on Arakane Reef during MARAMP 2003 and 2005. Each large, colored point represents an estimate over a 5-min observation segments with a survey swath of ~ 200 × 10 m (~ 2000 m^2). The 2003 macroalgal panel shows observations of both macroalgae and turf algae (turf algae were included in towed-diver surveys only during MARAMP 2003). In this panel, each small, colored point represents an estimate of algal cover from TOAD surveys. The 100-fm contour shown in white represents potential reef habitat.

Macroalgal Genera and Functional Groups

In the field, because of their small size or similarity in appearance, turf algae, crustose coralline red algae, cyanophytes (blue-green algae), and branched, nongeniculate coralline red algae were lumped into functional group categories. The generic names of macroalgae from field observations are tentative, since microscopic analysis is necessary for proper taxonomic identification. The lengthy process of laboratory-based taxonomic identification of all algal species collected at REA sites on the West Mariana Ridge has not been undertaken yet. Ultimately, based on microscopic analysis that may occur in the future, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2005, REA benthic surveys were conducted at 2 sites on Arakane Reef. In the field, 9 macroalgal genera (2 red, 6 green, and 1 brown), containing at least 9 species, as well as 3 additional algal functional group—turf algae, crustose coralline red algae, and cyanophytes—were observed. Macroalgal generic diversity varied slightly with 7 genera observed at site ARA-01 and 5 genera recorded at site ARA-02. The macroalgal genera *Boodlea, Liagora, Neomeris* and *Rhipidosiphon* were observed only at ARA-01, while *Dictyota* and *Valonia* were observed only at ARA-02.

The most widely distributed algal genera on Arakane Reef in 2005 were chlorophytes. Species of the genera *Halimeda* and *Microdictyon* were the most common components of algal communities (Table 18.9.4.2a), occurring in 83.3% and 91.7%

of photoquadrats sampled at both sites. Species of the genera *Jania* occurred in 16.7% of photoquadrats sampled at both sites. Species of the algal genera *Neomeris*, *Boodlea, Dictyota, Liagora, Rhipidosiphon*, and *Valonia* also were present, occurring in < 8.4% of sampled photoquadrats.

Turf algae and cyanobactera were both exceptionally common in 2005, occurring in 100% and 95.8% of photoquadrats sampled at Arakane Reef (Table 18.9.4.2a). Turf-algal communities were found in 100% of sampled photoquadrats at both sites, and cyanobacteria were observed in 91.7%–100% of sampled photoquadrats.

	Occurrence (%)									
Site	*Amphiroa*	*Jania*	*Schizymenia*	*Halimeda*	*Microdictyon*	*Neomeris*	*Lobophora*	*Crustose Coralline Red Algae*	*Cyanobacteria*	*Turf Algae*
ARA-01	0	25	0	75	100	16.7	0	0	100	100
ARA-02	0	8.33	0	91.7	83.3	0	0	16.7	91.7	100

Table **18.9.4.2a.** Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys conducted on Arakana Reef during MARAMP 2005. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed.

18.9.4.3 Macroinvertebrate Surveys

During MARAMP 2003, species of *Tridacna* giant clams were observed in all 6 towed-diver surveys conducted on Arakane Reef (Fig. 18.9.4.3a, left panel), with an overall mean density of 0.1 organisms 100 m^{-2}. The greatest mean density from a towed-diver survey was 0.156 organisms 100 m^{-2}; segment densities ranged from 0 to 0.542 organisms 100 m^{-2}.

During MARAMP 2005, giant clams were observed in all 3 towed-diver surveys conducted on Arakane Reef (Fig. 18.9.4.3a, right panel), with an overall mean density of 0.078 organisms 100 m^{-2}. The greatest mean density from a towed-diver survey was 0.172 organisms 100 m^{-2}; segment densities ranged from 0 to 0.408 organisms 100 m^{-2}.

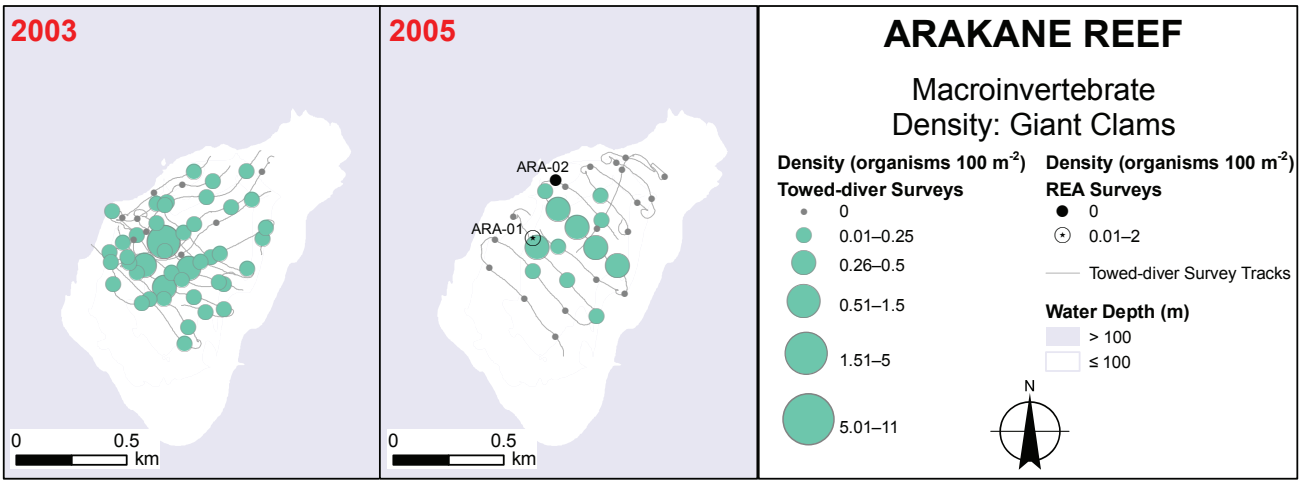


Figure 18.9.4.3a. Densities (organisms 100 m^{-2}) of giant clams from towed-diver benthic surveys conducted on Arakane Reef during MARAMP 2003 and 2005. The 100-fm contour shown in white represents potential reef habitat.

Crown-of-thorns seastars were not observed on Arakane Reef during MARAMP 2003 or 2005.

During MARAMP 2003, sea cucumbers were observed in only 1 of the 6 towed-diver surveys conducted on Arakane Reef. The mean density was 0.003 organisms 100 m^{-2}; segment densities ranged from 0 to 0.061 organisms 100 m^{-2}. Sea cucumbers were not observed in towed-diver surveys conducted during MARAMP 2005.

During MARAMP 2003, sea urchins were observed in all 6 towed-diver surveys conducted on Arakane Reef (Fig. 18.9.4.3b, left panel), with an overall mean density of 12.41 organisms 100 m^{-2}. The greatest mean density from a towed-diver survey was 17.39 organisms 100 m^{-2}; segment densities ranged from 4.38 to 26.97 organisms 100 m^{-2}.

During MARAMP 2005, sea urchins were observed in all 3 towed-diver surveys conducted on Arakane Reef (Fig. 18.9.4.3b, right panel), with an overall mean density of 8.83 organisms 100 m^{-2}. The greatest mean density from a towed-diver survey was 11.44 organisms 100 m^{-2}; segment densities ranged from 3.15 to 36.31 organisms 100 m^{-2}.

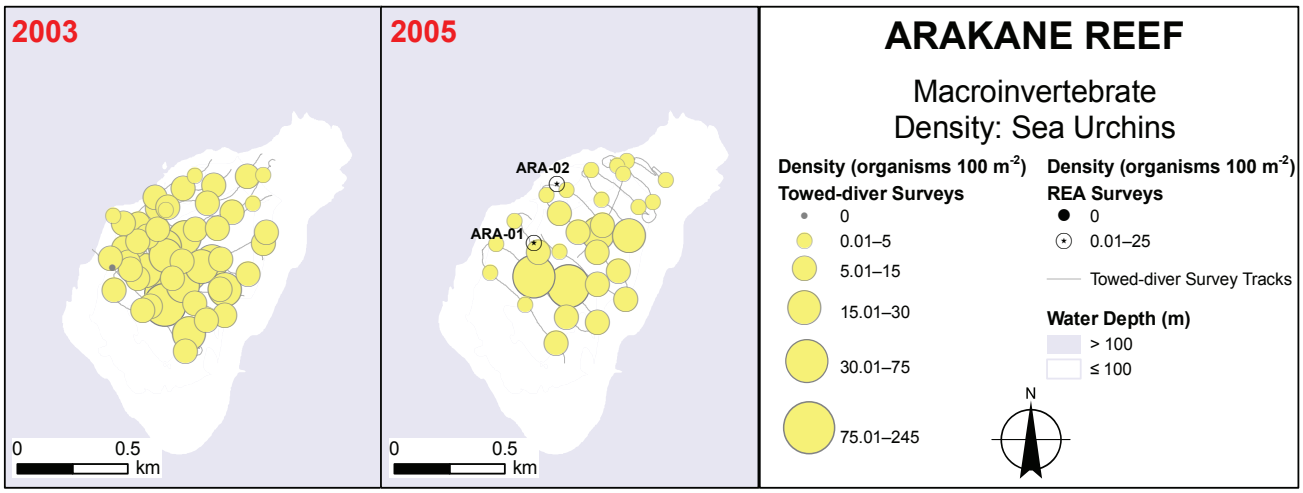


Figure 18.9.4.3b. Densities (organisms 100 m^{-2}) of sea urchins from towed-diver benthic surveys conducted at Arakane Reef during MARAMP 2003 and 2005. The 100-fm contour shown in white represents potential reef habitat.

18.9.4.4 Reef Fish Surveys

During MARAMP 2003, 6 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted on Arakane Reef. The overall estimated mean biomass, calculated as weight per unit area, was 0.77 kg 100 m^{-2} (SE 0.46). Observed

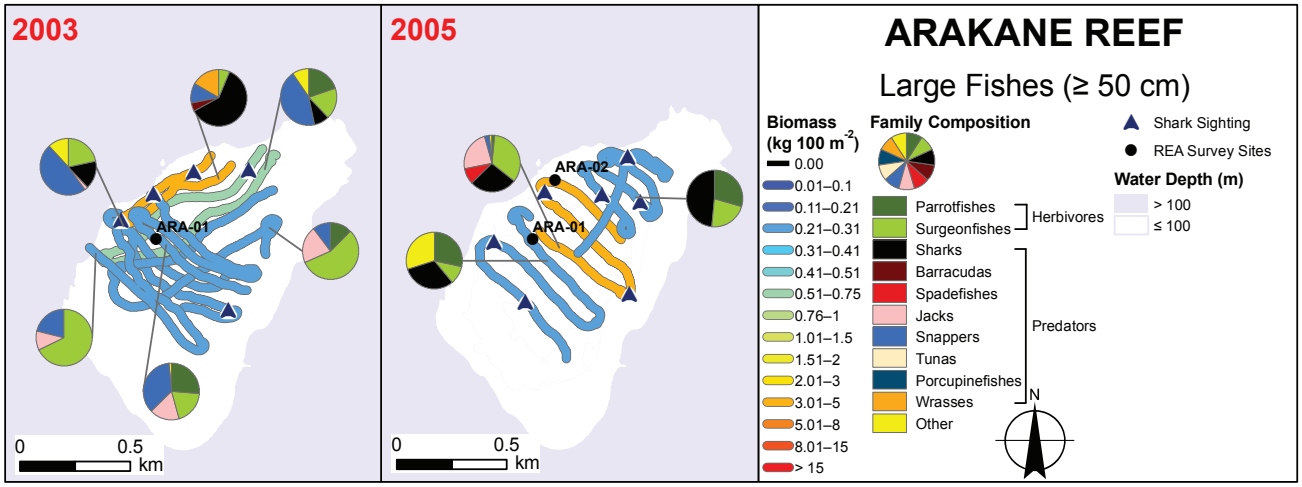


Figure 18.9.4.4a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and shark sightings from towed-diver fish surveys conducted on Arakane Reef during MARAMP 2003 and 2005. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of survey area over which it is shown. The 100-fm contour shown in white represents potential reef habitat.

large-fish biomass tended to be higher along the northern region of the reef (Fig. 18.9.4.4a, left panel). Reef sharks and nurse sharks (Ginglymostomatidae) accounted for 42% or 0.33 kg 100 m^{-2} of overall large-fish biomass. Nurse sharks alone contributed to the greatest proportion of overall mean biomass of large fishes, with a single large (200 cm in TL) tawny nurse shark (*Nebrius ferrugineus*) contributing 65% of shark biomass. During this survey period, 6 sharks were observed: 4 whitetip reef sharks, 1 grey reef shark, and 1 tawny nurse shark. Snappers accounted for the second-greatest proportion (19%) of overall large-fish biomass. The twinspot snapper was the only snapper species recorded, with 31 individuals seen. Notable observations included 2 sightings of the humphead wrasse.

During MARAMP 2005, 3 towed-diver surveys for large-fishes (≥ 50 cm in TL) were conducted on Arakane Reef (Fig. 18.9.4.4a, right panel) The overall estimated mean biomass was 1.37 kg 100 m^{-2} (SE 1.14). Reef sharks and surgeonfishes accounted for 32% and 29%, or 0.44 kg 100 m^{-2} and 0.39 kg 100 m^{-2}, of overall large-fish biomass. During this survey period, 8 sharks were observed: 7 whitetip reef sharks and 1 grey reef shark, with those species making up 43% and 57% of shark biomass. The sleek unicornfish accounted for 73% or 0.32 kg 100 m^{-2} of surgeonfish biomass, with > 40 individuals observed during a single survey. Jacks also were commonly observed in 2005, contributing 21% of overall large-fish biomass, 98% of which was made up of a school of bigeye trevally seen during a single survey.

Overall, large-fish biomass on Arakane Reef was similar to the average of other northern reef areas in the Mariana Archipelago (Fig. 18.9.4.4b). Reef sharks and nurse sharks accounted for the largest proportions of large-fish biomass for the 2 MARAMP survey periods, and the whitetip reef shark was the most abundant shark species.

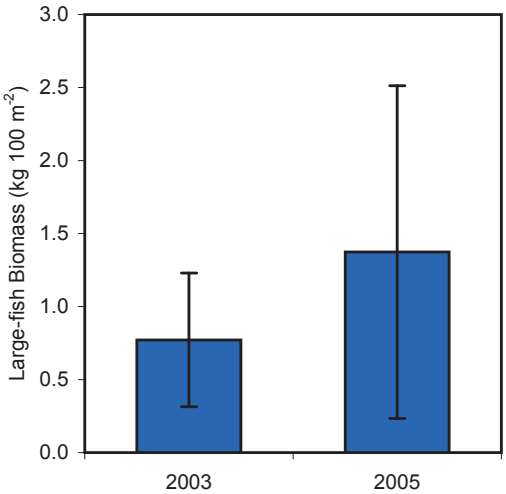


Figure 18.9.4.4b. Temporal comparison of mean values of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}) from towed-diver fish surveys conducted at Arakane Reef during MARAMP 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

Total fish biomass for the single REA site surveyed for fishes of all sizes and species on Arakane Reef during MARAMP 2003 was 2.11 kg 100 m^{-2} (Table 18.9.4.4a). Wrasses accounted for the greatest proportion (49%) or 1.03 kg 100 m^{-2} of total fish biomass. The bluntheaded wrasse alone accounted for more than 80% or 0.84 kg 100 m^{-2}of wrasse biomass. Jacks accounted for the second-greatest proportion (16%) of total fish biomass. The bluefin made up 69% or 0.24 kg 100 m^{-2} of jack biomass. No sharks were encountered during the single REA survey conducted in 2003.

From the single REA survey conducted on Arakane Reef during MARAMP 2003, species richness was 25.3 species 100 m^{-2}, and 42 species in total were observed (Table 18.9.4.4a). Wrasses and damselfishes were the 2 most diverse families with 7 and 6 species observed. The Johnston Island damselfish (*Plectroglyphidodon johnstonianus*) was the most abundant damselfish species, and the bluntheaded wrasse was the most abundant species overall, with 88 individuals 100 m^{-2} observed.

Table 18.9.4.4a. Total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method on Arakane Bank during MARAMP 2003 and 2005.

Year	Site	Richness (species 100 m^{-2})	Biomass (kg 100 m^{-2})												
			Total	Parrotfishes	Surgeonfishes	Sharks	Soldierfishes	Groupers	Jacks	Fusiliers	Snappers	Triggerfishes	Wrasses	Damselfishes	Other
2003	ARA-01	25.3	2.11	0.11	0.12	0	0	0.1	0.34	0	0.01	0.07	1.03	0.08	0.24
2005	ARA-02	20.5	9.14	0	0.39	5.39	0	0.03	0	0	0	0.13	0.25	0.2	2.74
2005	ARA-01	23	3.57	0.53	0.34	0.35	0	0.06	0	0	0	0.4	1.18	0.51	0.2

Mean total fish biomass for the 2 REA sites surveyed on Arakane Reef during MARAMP 2005 was 6.36 kg 100 m^{-2} (SE 2.78). Reef sharks accounted for the greatest proportion (45%) of total fish biomass (Table 18.9.4.4a), and the whitetip reef shark was the only shark species encountered. The 3 whitetip reef sharks observed contributed 2.87 kg 100 m^{-2} of total fish biomass. Stingrays (Dasyatidae) accounted for the second-greatest proportion (18%) of total fish biomass, with a single blotched fantail ray (*Taeniura meyeni*) contributing 1.17 kg 100 m^{-2} to total fish biomass. Wrasses and surgeonfishes also were commonly observed, contributing 0.71 kg 100 m^{-2} and 0.37 kg 100 m^{-2} to total fish biomass.

From the 2 REA surveys conducted during MARAMP 2005, species richness was similar among sites surveyed on Arakane Reef (Table 18.9.4.4a), with a 33 species observed at ARA-01 and 28 species seen at ARA-02. As in 2003, wrasses and damselfishes were the 2 most diverse families with 11 and 10 species observed. Wrasses again dominated counts, and the bluntheaded wrasse was the most abundant species overall, with 97 individuals 100 m^{-2} recorded. The midget chromis was the most abundant damselfish species.

For both MARAMP survey years, wrasses and damselfishes were the 2 most diverse families, with an average of 9 and 8 species observed. Wrasses were the most abundant fishes, and the bluntheaded wrasse dominating counts during both survey periods.

18.10 Summary

This section presents an overview of the status of coral reef ecosystems on the reefs and banks of the CNMI and some of the key natural processes influencing coral reefs on these banks. This summary of the integrated ecosystem observations collected by the CRED and its partners during biennial MARAMP cruises in 2003, 2005, and 2007 provides sound scientific information about the conditions of the coral reef ecosystems on CNMI's reefs and banks to enable resource managers, policymakers, scientists, and other key stakeholders to make more informed decisions about the long-term conservation of the coral reef ecosystems on these areas.

MARAMP integrated ecosystem observations provide a broad range of information: bathymetry and geomorphology, oceanography and water quality, and biological observations of corals, algae, fishes, and benthic macroinvertebrates along the forereef habitats of the reefs and banks of the CNMI. Methodologies and their limitations are discussed in detail in Chapter 2: "Methods and Operational Background," and specific limitations of the data or analyses presented in this chapter are included in the appropriate discipline sections. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter.

This section highlights key attributes of the coral reef ecosystems on the reefs and banks of the CNMI:

Ahyi Seamount

- Ahyi Seamount is a stratovolcano located ~ 17 km south of Farallon de Pajaros on the active Mariana Arc. It is part of the Volcanic Unit of the Marianas Trench Marine National Monument.
- In 2001, the detection by a seismic station of an explosive eruption in the vicinity of this summit suggests that this seamount may still be volcanically active.
- During MARAMP 2007, Ahyi seamount was partially mapped using multibeam sonar, adding to multibeam data that had been collected by the NOAA VENTS program. These data reveal that Ahyi Seamount is a steep-sided, conical seamount, with a minimum depth of < 80 m.
- Limited optical data collected during TOAD surveys conducted on the southern flanks of this seamount revealed a hard substrate. No hard corals were observed.

Supply Reef

- Supply Reef is a stratovolcano located ~ 25 km north of Maug on the active Mariana Arc and joined to Maug by a low saddle at a depth of ~ 1800 m. Together these 2 features form a twin volcanic massif.

- No volcanic activity has been recorded at Supply Reef.

- During MARAMP 2007, Supply Reef was mapped using multibeam sonar, adding to multibeam data that had been collected by the NOAA VENTS program. These data reveal that Supply Reef is steep-sided and conical, with ridges along the flanks and a minimum depth of ~ 10 m.

- The summit of this reef is ~ 300 m in diameter, with a lumpy topography. The flanks on Supply Reef have uniformly steep slopes, with the highest slopes (> 50°) recorded on the sides of ridges.

- The towed-diver survey conducted on and near the summit during MARAMP 2003 suggested habitat of medium-high to high complexity, characterized by low sand cover (< 5%) and high (30–50%) live-hard-coral cover, compared to levels observed at other areas in the Mariana Archipelago. The overall mean live-hard-coral cover from this survey was 39%. TOAD surveys conducted on the flanks north and south of the summit indicated similarly hard substrates.

- Wave model output shows seasonal variation with the highest ambient wave heights occurring through winter and the lowest through summer. Episodic wave events of high (> 4 m) wave heights, associated with the typhoon season of August–December also were recorded by a WTR deployed at Supply Reef.

- Mean cover of macroalgae from the single towed-diver survey conducted in 2003 was 19%, and crustose-coralline-red-algal cover was 35%.

- Mean biomass of large fishes, based on the single towed-diver survey in 2003, was 2.99 kg 100 m^{-2}. Jacks and reef sharks contributed the greatest proportions (49% and 28%) to large-fish biomass.

Zealandia Bank

- Zealandia Bank is a stratovolcano located ~ 25 km northeast of Sarigan Island on the active Mariana Arc. It is part of the Volcanic Unit of the Marianas Trench Marine National Monument.

- Zealandia Bank is elongated in shape and formed by 2 adjacent volcanic pinnacles ~ 1 km apart. During low tide, 1 of 2 pinnacles is ~ 1 m above sea level. Ridges radiate from the north and east of this bank. In 2004, fumarolic activity was detected at Zealandia Bank, suggesting that this area is still volcanically active.

- Wave model output shows seasonal variation with the highest ambient wave heights occurring through winter and the lowest through summer. Episodic wave events of high (> 4 m) wave heights, associated with the typhoon season of August–December also were recorded by WTRs deployed at Zealandia Bank from 2003 to 2007. Wave events in 2004 were 1 m higher than similar events at Supply Reef, because Zealandia has a more southerly location and is closer to the latitudes where typhoons are generated.

- Analyses of video footage obtained from the single TOAD survey conducted at depths of ~ 70–120 m on Supply Reef suggested a variable substrate, and no live hard corals were seen.

Esmeralda Bank

- Esmeralda Bank is a stratovolcano that is located 57 km southwest of Saipan and is one of the southernmost active volcanoes in the Mariana Arc. Esmeralda Bank is one of 21 seamounts protected within the Volcanic Unit of the Marianas Trench Marine National Monument.

- Multibeam data obtained over Esmeralda Bank show that the summit of the bank is formed by the rim of a crater, which appears to be breached to the west by a wide channel that runs into deeper water.

- No dive surveys were conducted on Esmeralda Bank but three TOAD surveys were conducted on the north crater rim. Only 1 of the 189 analyzed video frames revealed any live hard coral.

Marpi Bank

- Marpi Bank is located ~ 18 km north of Saipan and is part of the remnant Mariana frontal arc formed during the late Eocene and early Miocene epochs (15–20 million years ago).

- Multibeam data acquired over Marpi Bank reveal a flat-topped bank, ~ 7 km long by 3 km wide, elongated in a northeast-southwest direction, with a minimum depth of 53 m. Like Saipan, Tinian, Rota, Aguijan, and Tatsumi Reef, Marpi Bank probably is made up of uplifted limestone overlying an older volcanic core.

- High-resolution multibeam bathymetry acquired on the bank-top reveals mounds and channels, which may indicate coral habitat.

Stingray Shoal

- Stingray Shoal is a remnant volcanic seamount located on the northern end of the West Mariana Ridge, with a minimum depth of 13 m. Stingray Shoal is part of the Volcanic Unit of the Marianas Trench Marine National Monument.

- During MARAMP 2003, observations from both towed-diver surveys and TOAD video analyses revealed a predominantly hard substrate on Stingray Shoal, with very few areas exhibiting sand cover of > 5%. Towed-diver surveys on Stingray Shoal recorded habitat of medium-high to high complexity with consistently high cover of live hard corals (all but 2 survey segments had cover 40%–100%) over what was described by divers as continuous, well-developed reef. Mean live-hard-coral cover over this reef, from towed-diver surveys, was 55%, the highest level recorded for an island or bank during any of the 3 MARAMP survey years.

- Estimated macroalgal cover from the 4 towed-diver surveys conducted on Stingray Shoal averaged 34%, and overall mean cover of crustose coralline red algae was 2%.

- Deep depths limited the duration of towed-diver surveys on Stingray Shoal, and macroinvertebrates were observed in low densities there, relative to levels found at other surveyed areas in the Mariana Archipelago. Giant clams, sea cucumbers, and sea urchins were observed with mean densities of 0.002, 0.006, and 0.84 organisms 100 m^{-2}. No crown-of-thorns seastars were observed.

- Estimated biomass of large fishes on Stingray Shoal, based on towed-diver surveys conducted in 2003, was high compared to other reef areas in the Mariana Archipelago, with an overall mean of 5.15 kg 100 m^{-2}. Reef sharks accounted for the highest proportion (52%) of large-fish biomass, with the greatest contribution coming from the grey reef shark.

Pathfinder Reef

- Pathfinder Reef is a remnant volcanic ridge located on the southern part of the West Mariana Ridge, with a minimum depth of 10 m. It is located ~ 150 km west of Saipan.

- Towed-diver and TOAD surveys conducted over Pathfinder Reef revealed a predominantly hard substrate and habitat complexity characterized as medium-low to medium-high.

- Estimates of live-hard-coral cover from towed-diver surveys conducted during MARAMP 2003 and 2005 were high compared to levels seen at other reef areas surveyed in the Mariana Archipelago, with overall means of 24% and 25%.

Coral cover was consistent, with a range of 10.1%–40% for all but a single survey segment. Analyses of video footage obtained from TOAD surveys suggested that live coral cover was more variable with values in a range of 0%–100%.

- Stressed-coral cover, recorded on Pathfinder Reef during towed-diver surveys in 2005, was < 1%. Based on the 3 REA benthic surveys conducted in 2003 and 2005, coral generic richness ranged from 11 to 15 genera per site.

- Mean macroalgal cover from towed-diver surveys on Pathfinder Reef was 37% in 2003 and 29% in 2005. Mean cover of crustose coralline red algae in 2003 and 2005 was 6% and 10%.

- In both 2003 and 2005, giant clams were observed on Pathfinder Reef at moderate densities, with means of 0.093 and 0.052 organisms 100 m^{-2}. As on Stingray Shoal and Arakane Reef, densities of sea cucumbers were low on Pathfinder Reef, relative to levels found at other areas surveyed in the Mariana Archipelago, with means of 0.019 and 0.007 organisms 100 m^{-2} in 2003 and 2005. In contrast, densities of sea urchins were high compared to results from other reef areas in the Mariana Archipelago, with means of 9.79 and 5.10 organisms 100 m^{-2} in 2003 and 2005. No crown-of-thorns seastars were observed.

- Mean biomass of large fishes, from towed-diver surveys conducted on Pathfinder Reef in 2003, was moderately high compared to the levels observed at other reef areas in the Mariana Archipelago, with an overall estimated mean of 1.44 kg 100 m^{-2}. In 2005, observed biomass was much lower with an overall mean of 0.54 kg 100 m^{-2}. Across both years pooled, the greatest contribution to biomass was made by reef sharks. A notable sighting in 2005 was a single large (100 cm in TL) humphead wrasse.

- Based on the limited number of REA surveys for fishes of all sizes and species conducted on Pathfinder Reef, total fish biomass was moderate in 2003, with a sample mean of 4.72 kg 100 m^{-2}, but somewhat higher in 2005 with a sample mean of 7.18 kg 100 m^{-2}. In both survey years, the greatest contribution to overall biomass was made by snapper. Only 1 species, the twinspot snapper, was observed. Species richness ranged from 19.5 to 29.5 species 100 m^{-2} over the 2 MARAMP survey years.

Arakane Reef

- Arakane Reef is a small (~ 1.8 x 1 km), shallow bank on the West Mariana Ridge and located ~ 110 km southwest of Tinian.

- Towed-diver surveys conducted on this reef during MARAMP 2003 and 2005 suggested habitat was dominated by hard substrate and uniformly of medium-low to medium complexity.

- Overall mean cover of live hard corals, estimated from towed-diver surveys, was 24% in 2003 but only 12% in 2005. Analyses of video footage obtained from TOAD surveys suggested live coral cover within a range of 0%–100% cover, with live coral cover higher in the southern survey than in the other two surveys on this reef. Divers surveying Arakane Reef described a high abundance of soft and fire corals.

- Coral generic diversity was measured during a single REA survey at different REA sites in 2003 and 2005, with 9 and 10 genera observed.

- Mean macroalgal cover from towed-diver surveys on Arakane Reef was 52% in 2003 and 46% in 2005. Mean cover of crustose coralline red algae in 2003 and 2005 was 5% and 3%.

- In both 2003 and 2005, giant clams were observed on Arakane Reef at moderate densities, with means of 0.098 and 0.078 organisms 100 m^{-2}. As on Stingray Shoal and Pathfinder Reef, densities of sea cucumbers were low on Arakane Reef, relative to levels found at other areas surveyed in the Mariana Archipelago, with a mean of 0.029 organisms 100 m^{-2} in 2003 and none observed in 2005. In contrast, densities of sea urchins were high compared to results from other reef areas in the Mariana Archipelago, with means of 12.25 and 8.83 organisms 100 m^{-2} in 2003 and 2005. No crown-of-thorns seastars were observed.

- Mean biomass of large fishes, from towed-diver surveys conducted on Arakane Reef in 2003 and 2005, was moderate compared to levels observed at other northern reefs in the Mariana Archipelago, with overall estimated means of 0.77 and 1.37 kg 100 m^{-2}. The greatest contribution to biomass was made by reef sharks and nurse sharks in 2003 and surgeonfishes in 2005.

- Based on the limited number of REA surveys for fishes of all sizes and species conducted on Arakane Reef, estimated total fish biomass was 2.11 and 6.36 kg 100 m^{-2} in 2003 and 2005. Observed species richness was fairly consistent between the 2 MARAMP survey years, with 25 species 100 m^{-2} observed at a single site in 2003 and 28 and 33 species 100 m^{-2} recorded at the 2 REA sites surveyed in 2005.