10 SARIGAN

10.1 Introduction

The island of Sarigan is located at 16°42′ N, 145°78′ E, in the middle of the Mariana Arc between Anatahan and Guguan. This island is ~ 2.5 km wide and 2.7 km long with a land area of 4.47 km^2, making it the fourth-smallest island of the Mariana Archipelago (Fig. 10.1a). The highest elevation on Sarigan, at 538 m, is on its summit crater. Located south of the center of Sarigan, this summit crater is 750 m wide and surrounded by steep slopes to the south and more gently sloping hills to the north (Fig. 10.1b).

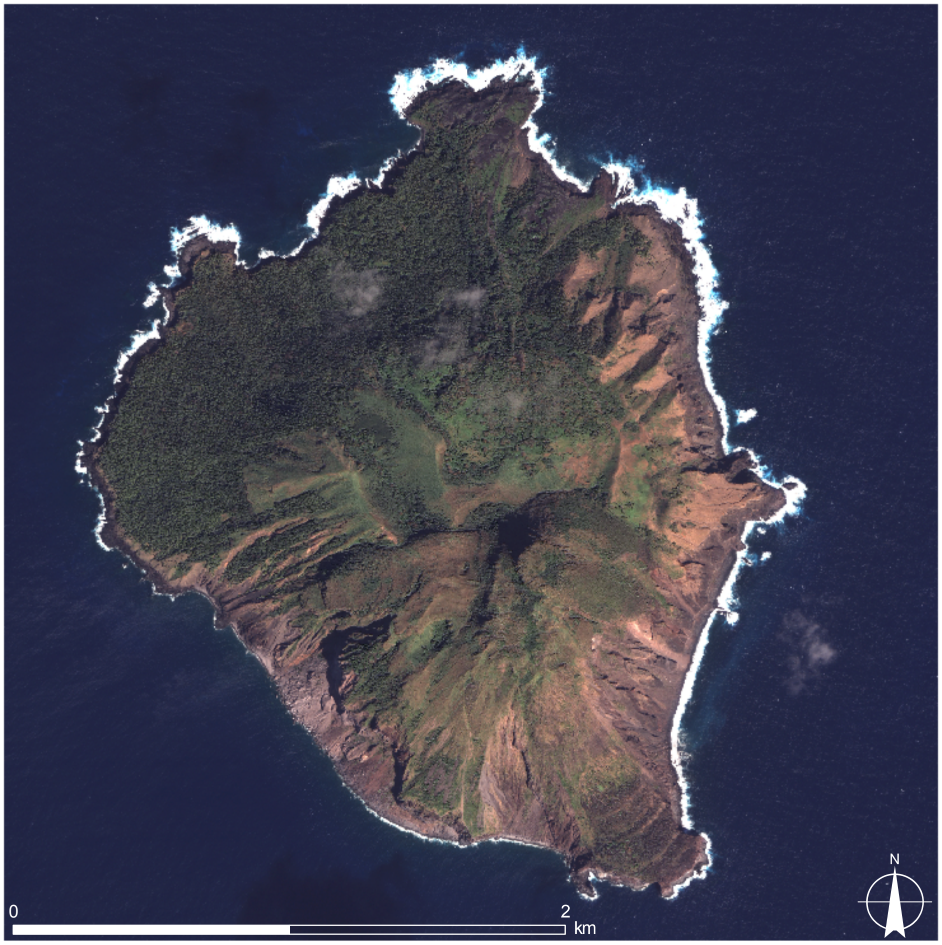


Figure 10.1a. Satellite image of Sarigan (© 2004 DigitalGlobe Inc. All rights reserved).

Figure 10.1b. Sarigan viewed from the south. *NOAA photo*

10.1.1 History and Demographics

Historically, Sarigan was inhabited by the Chamorro people, as suggested by the archaeological artifacts, such as pottery and latte sets, found by the German administrator Georg Fritz in the early 1900s (Spennemann 2006). This island was later used as a penal colony, which was established in 1900 by German administrators. Prisoners of this colony both established and maintained a copra plantation. In 1906, the prisoners were removed when Japanese interests leased the land for commercial copra production (Marianas Avifauna Conservation Working Group 2008). Later, in 1909, the German administration leased Sarigan to the trading association Pagan Gesselschaft for a period of 3 years for the exploitation of bird plumage. During this time, up to 8 Caroline islanders and 6 Japanese bird catchers were resident on this island, and this population was later reduced to 2 persons as a result of low bird counts. The lease to this trading association was terminated early in 1911 because, in violation of the conditions of the lease, no planting of coconut palms had occurred (Spennemann 1999b).

In the 1930s, 10–20 families lived on Sarigan, but all residents were removed after World War II (Marianas Avifauna Conservation Working Group 2008). Sarigan currently is thought to be uninhabited. However, the *Northern Islands Homestead Act of 2008*, which was signed into law by the Governor of the Commonwealth of the Northern Mariana Islands (CNMI) in January 2010, may increase the population in the coming years. This legislation, CNMI Public Law 16-50, recognizes that residents of the “islands north of Saipan” have no formal homesteads, allows residents to have agricultural lots and facilities, encourages resettlement by former residents, and initiates and promotes economic development.

10.1.2 Geography

Sarigan is formed by the exposed portion of a largely submarine volcano with a summit crater containing a small ash cone. Lava flowed from 2 lava domes near the south crater rim, reached the coast, and extended out to sea creating the steep cliffs and irregular shorelines of this island (Siebert and Simkin 2002–). The summit crater is surrounded by very steep slopes to the south, while the slopes around the north of Sarigan are much gentler (Fig. 10.1.2a and b). The slopes of this island are dissected with ravines and end in coastal cliffs. In the center of this island, below the crater, a small plateau is present.

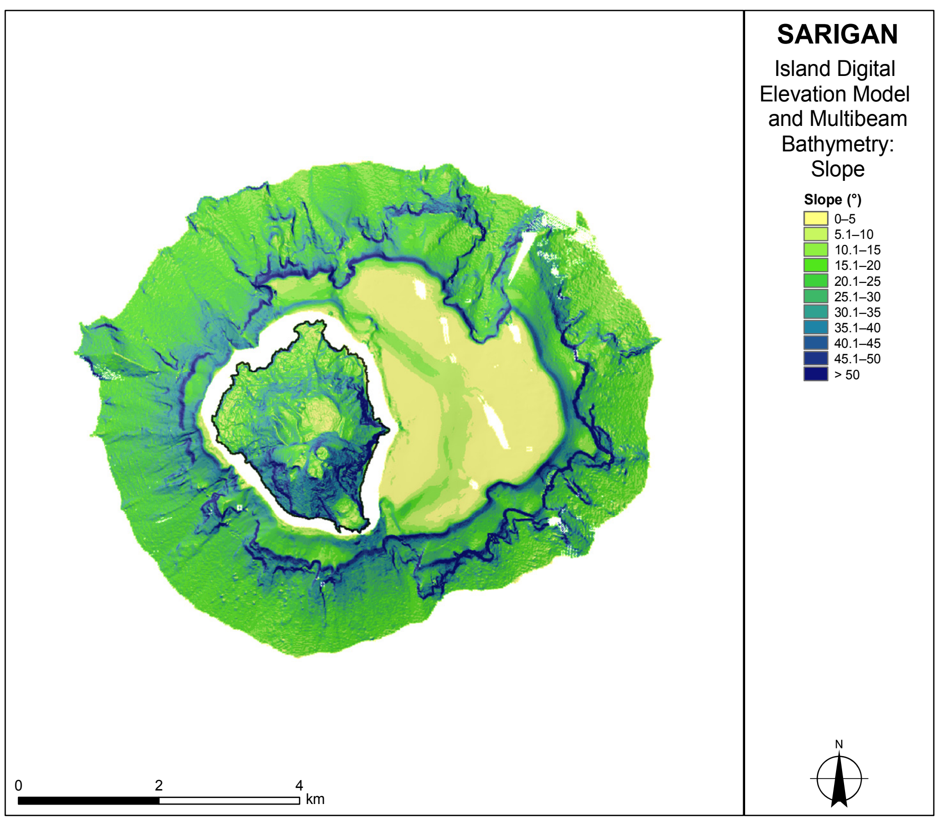


Figure 10.1.2a. Combined slope map using the digital elevation model (grid cell size: 10 m) and multibeam bathymetric data (grid cell size: 10 m) for Sarigan. Values reflect the maximum rate of change in elevation between neighboring cells.

The date of the last eruption of the Sarigan volcano is not known, but the sparse vegetation on the lava flows of this island suggests that the most recent eruption and lava flows occurred during the Holocene Epoch (11,700 years to present; Siebert and Simkin 2002–).

Figure 10.1.2b. Sarigan viewed from the east, showing the summit crater left (or south) of center, steep southern slopes, flat plateau in center, and gentler northern slopes. *NOAA photo by Robert Schroeder*

The steepest slopes of this island, on the east and south sides, are sparsely vegetated with grasses and ferns, while the more gradual slopes on the north and west sides support native and coconut forests (Fig. 10.1.2c). Native forests also are common within the ravines, and patchy stands of trees are present on the plateau. Although native forests have been damaged severely by feral animals, most notably goats, an eradication program managed by the CNMI Division of Fish and Wildlife (DFW) has enabled some recovery to take place in recent years (Martin et al. 2008).

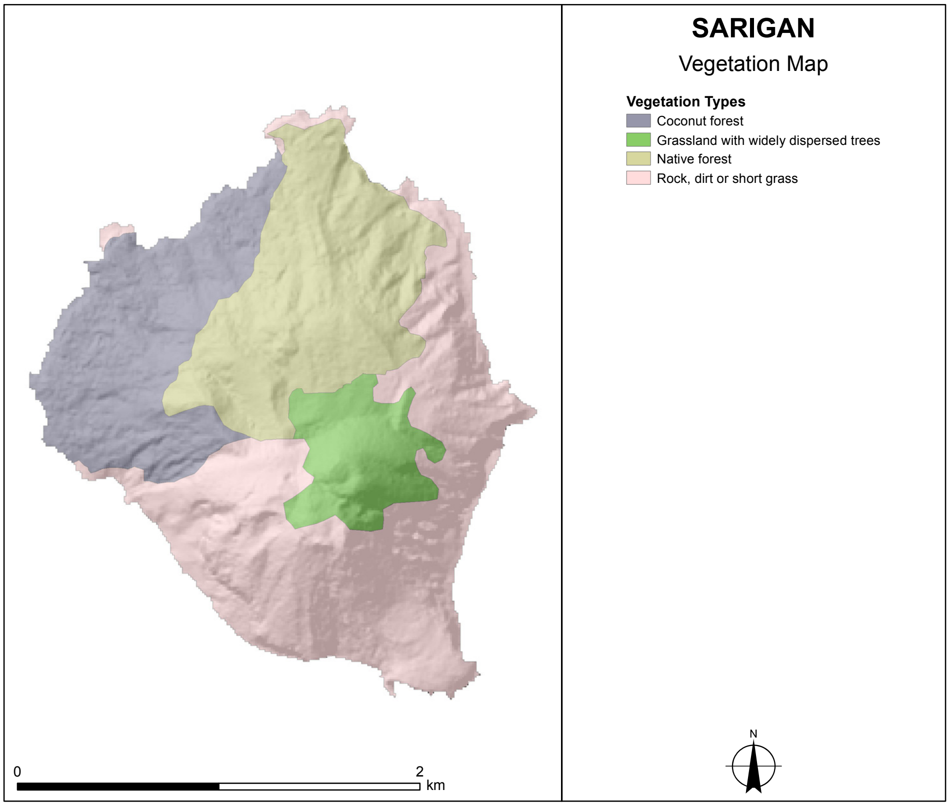


Figure 10.1.2c. Map showing approximate locations of the 4 major vegetation types found on Sarigan, based on surveys conducted in 2006 by the CNMI DFW (Martin et al. 2008).

10.1.3 Environmental Issues on Sarigan

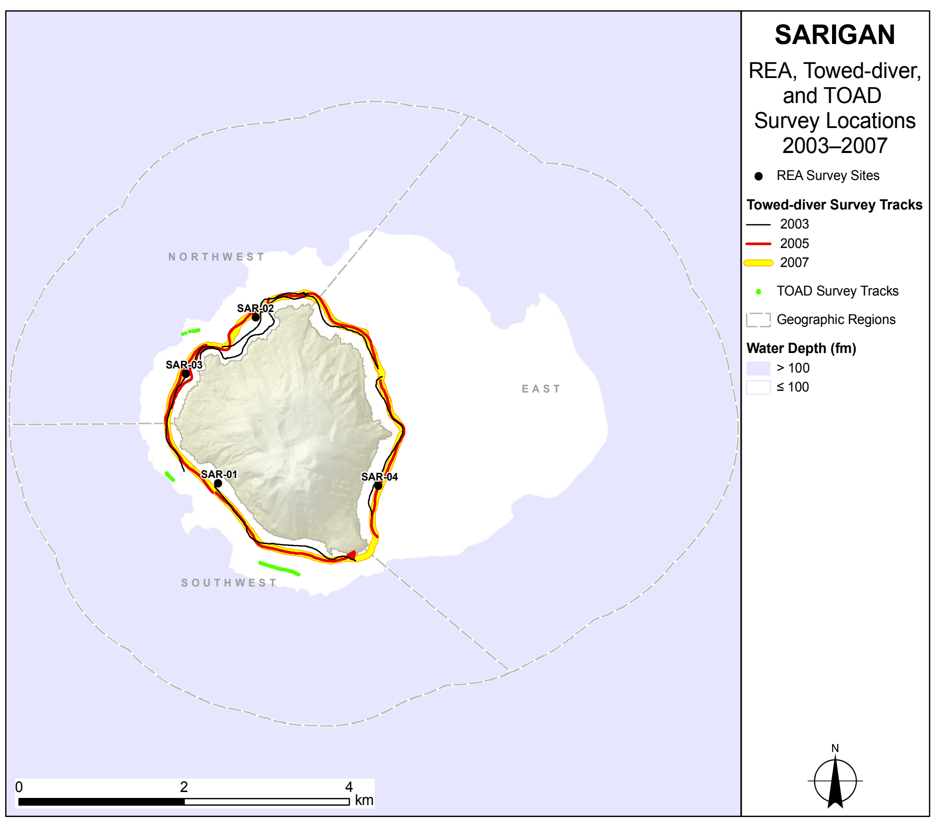
Sarigan supports a number of important species of flora and fauna. Five bird species have been observed during surveys on Sarigan: the endangered Micronesian megapode (*Megapodius laperouse*), a bird listed both as an endangered species federally (U.S. Fish and Wildlife Service) and as a threatened or endangered species locally (Berger et al. 2005) as well as the Micronesian honeyeater (*Myzomela rubrata*), Micronesian starling (*Aplonis opaca*), collared kingfisher (*Halcyon chloris*), and white-throated ground dove (*Gallicolumba xanthonura*), which is locally protected from hunting by regulation (Berger et al. 2005). During surveys conducted in 2006 by the CNMI DFW, the Mariana fruit-dove (*Ptilinopus roseicapilla*), a species federally protected by the *Migratory Bird Treaty Act* (List… 2010) and listed locally as threatened or endangered (Berger et al. 2005), was recorded for the first time on Sarigan (Martin et al. 2008). This island has been selected to receive relocated endemic birds from Saipan, Rota, and Tinian, where they are threatened by the introduced brown treesnake (*Boiga irregularis*), which already has resulted in the extinction of 9 forest birds and 2 native lizards on Guam (Marianas Avifauna Conservation Working Group 2008). Sarigan also supports a small population (~ 150–200) of the Mariana fruit bat (*Pteropus mariannus mariannus*), an endemic subspecies listed federally as threatened and locally as threatened or endangered (Martin et al. 2008; U.S. Fish and Wildlife Service; Berger et al. 2005).

Anthropogenic pressures around Sarigan are relatively few, given its isolated location and lack of inhabitants. Feral animals have caused severe destruction to the natural ecosystems, although some recovery has occurred. The possible establishment of homesteads on Sarigan and the infrastructure development that would come with them could affect the native flora and fauna of this island if these resources go unmanaged. Fishing activity within the CNMI tends to focus around the southern islands of the Mariana Archipelago, with multiday fishing trips on the islands and banks south of Guguan (Western Pacific Fishery Management Council 2009).

10.2 Survey Effort

Biological, physical, and chemical observations collected under the Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) have documented the conditions and processes influencing the coral reef ecosystems around the island of Sarigan since 2003. The spatial reach and time frame of these survey efforts are discussed in this section. The disparate areas around this island often are exposed to different environmental conditions. To aid discussions of spatial patterns of ecological and oceanographic observations that appear throughout this chapter, 3 geographic regions around

Figure 10.2a. Locations of the REA, towed-diver, and TOAD benthic surveys conducted around Sarigan during MARAMP 2003, 2005, and 2007. To aid discussion of spatial patterns, this map delineates 3 geographic regions: northwest, east, and southwest.



Sarigan are delineated in Figure 10.2a; wave exposure and breaks in survey locations were considered when defining these geographic regions. This figure also displays the locations of the Rapid Ecological Assessment (REA) surveys, towed-diver surveys, and towed optical assessment device (TOAD) surveys conducted around Sarigan. Potential reef habitat is represented by a 100-fm contour shown in white on this map.

Benthic habitat mapping data were collected around Sarigan using a combination of acoustic and optical-survey methods. MARAMP benthic habitat mapping surveys conducted around this island with multibeam sonar covered a total area of 2228 km^2 in 2007. Optical validation and habitat characterization were completed using towed-diver and TOAD surveys that documented live coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in Section 10.3: "Benthic Habitat Mapping and Characterization."

Information on the condition, abundance, diversity, and distribution of biological communities around Sarigan was collected using REA, towed-diver, and TOAD surveys. The results of these surveys are reported in Sections 10.5–10.8: "Corals and Coral Disease," "Algae and Algal Disease," "Benthic Macroinvertebrates," and "Reef Fishes." The numbers of surveys conducted during MARAMP 2003, 2005, and 2007 are presented in Table 10.2a, along with their mean depths and total areas or length.

Table 10.2a. Numbers, mean depths (m), total areas (ha), and total length (km) of REA, towed-diver, and TOAD surveys conducted around Sarigan during MARAMP 2003, 2005, and 2007. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys of corals, algae, and macroinvertebrates.

Survey Type	Survey Detail	Year		
REA		**2003**	**2005**	**2007**
Fish	Number of Surveys	3	3	3
	Mean Depth (m)	12.5 (SD 0.5)	12.8 (SD 0.3)	12.8 (SD 0.3)
Benthic	Number of Surveys	3	3	3
	Mean Depth (m)	12.5 (SD 0.5)	12.8 (SD 0.3)	12.8 (SD 0.3)
Towed Diver		**2003**	**2005**	**2007**
	Number of Surveys	6	5	6
	Total Survey Area (ha)	10.6	10.1	12.3
	Mean Depth (m)	12.1 (SD 4.3)	16.3 (SD 1.5)	16.6 (SD 1.8)
TOAD		**2003**		
	Number of Surveys	3		
	Total Length (km)	0.78		

Spatial and temporal observations of key oceanographic and water-quality parameters influencing reef conditions around Sarigan were collected using (1) subsurface temperature recorders (STR) designed for long-term observations of high-frequency variability, (2) closely spaced conductivity, temperature, and depth (CTD) profiles of the vertical structure of water properties, and (3) discrete water samples for nutrient and chlorophyll-a analyses. CTD casts were conducted during MARAMP 2003, 2005, and 2007, and water sampling was performed during MARAMP 2005 and 2007 (see Chapter 2: "Methods and Operational Background," Section 2.3: "Oceanography and Water Quality"). A summary of deployed instruments and collection activities is provided in Table 10.2b. Results are discussed in Section: 10.4: "Oceanography and Water Quality."

Table 10.2b. Numbers of STRs deployed, shallow-water and deepwater CTD casts performed, and water samples collected around Sarigan during MARAMP 2003, 2005, and 2007. One type of instrument, a subsurface temperature recorder (STR) was installed on the seafloor. Shallow-water CTD casts and water samples were conducted from the surface to a 30-m depth, and deepwater casts were conducted to a 500-m depth. Additional deepwater CTD cast information 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	1	1	2	2	–
CTD Casts	2003	2005		2007			Total
Shallow-water Casts	7	9		10			26
Deepwater Casts	–	4		2			6
Water Samples		2005		2007			Total
		1		4			5

Towed-diver Surveys: Depths

Figures 10.2b and c illustrate the locations and depths of towed-diver-survey tracks around Sarigan and should be referenced when further examining results of towed-diver surveys from MARAMP 2003, 2005, and 2007.

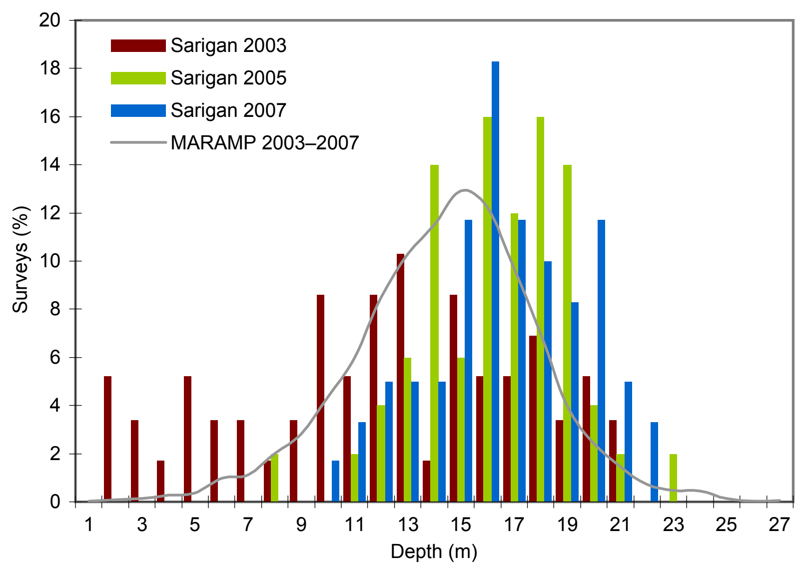


Figure 10.2b. Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted on forereef habitats around Sarigan during MARAMP 2003. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during 2003, 2005, and 2007.

During MARAMP 2003, 6 towed-diver surveys were conducted along the forereef slopes around Sarigan (Figs. 10.2b and c, top panel). The mean depth of all survey segments was 12.1 m (SD 4.3), and the mean depths of individual surveys ranged from 3.8 m (SD 2.5) to 14.9 m (SD 3.5).

During MARAMP 2005, 5 towed-diver surveys were conducted along the forereef slopes of Sarigan (Figs. 10.2b and c, middle panel). The mean depth of all survey segments was 16.3 m (SD 1.5), and the mean depths of individual surveys ranged from 14.3 m (SD 4) to 18.5 m (SD 3.2).

During MARAMP 2007, 6 towed-diver surveys were conducted along the forereef slopes of Sarigan (Figs. 10.2b and c, bottom panel). The mean depth of all survey segments was 16.6 m (SD 1.8), and the mean depths of individual surveys ranged from 14.9 m (SD 2.7) to 19.2 m (SD 3).

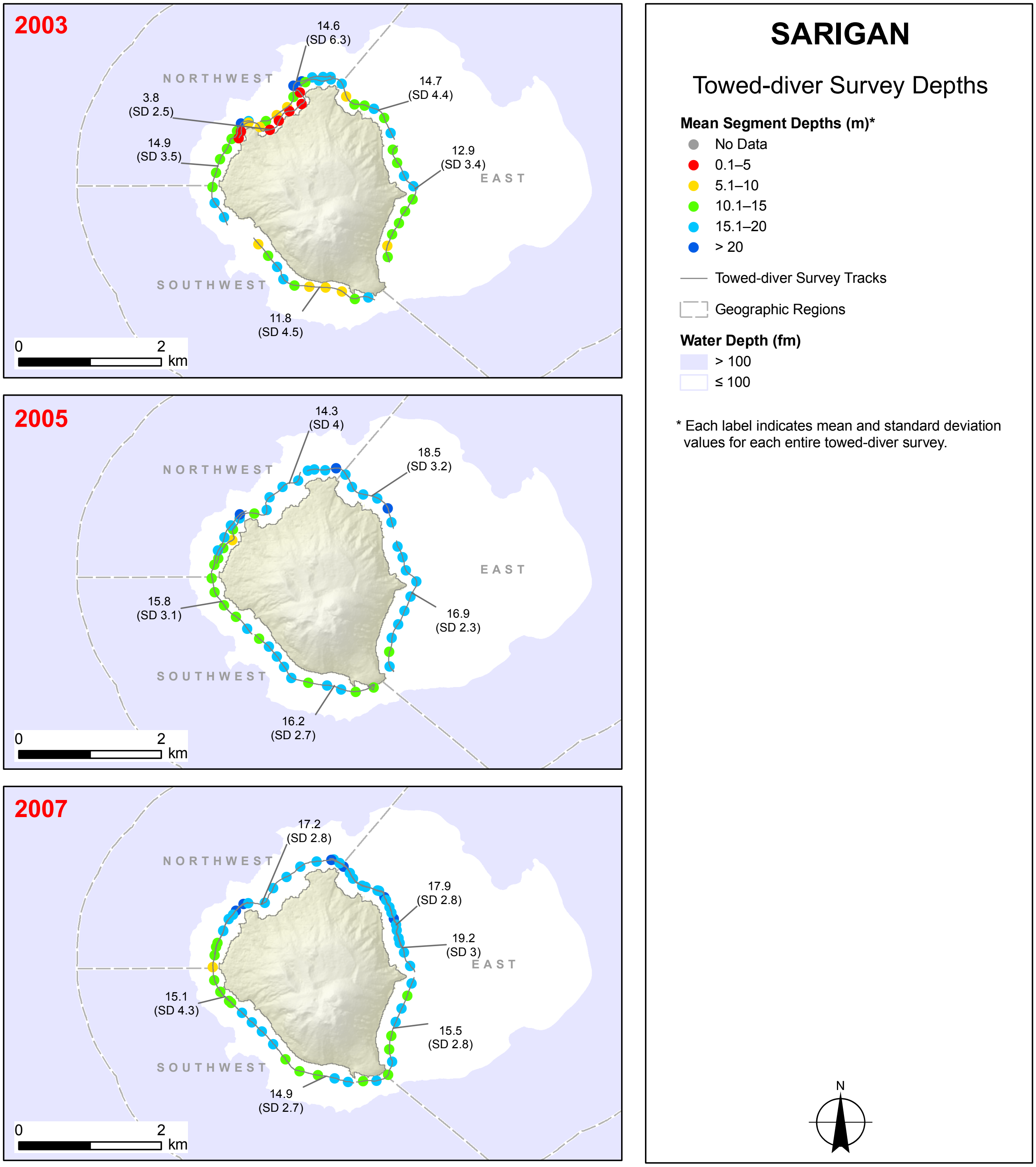


Figure 10.2c. Depths and tracks of towed-diver surveys conducted on forereef habitats around Sarigan during MARAMP 2003, 2005, 2007. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

10.3 Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization surveys around the island of Sarigan were conducted during MARAMP 2003, 2005, and 2007 using acoustic multibeam sonar, underwater video and still imagery, and towed-diver observations. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products over the depth range of ~ 15–1900 m. Optical validation and benthic characterization, via diver observations and both video and still underwater imagery, were performed using towed-diver surveys and TOAD deployments conducted at depths of < 207 m.

10.3.1 Acoustic Mapping

Multibeam acoustic bathymetry and backscatter imagery (Fig. 10.3.1a) collected by the Coral Reef Ecosystem Division (CRED) around the islands of Sarigan, Alamagan, Anatahan, and Guguan, as well as Zealandia Bank, during MARAMP 2007 encompassed an area of 2228 km^2. Near-complete coverage was achieved around Sarigan, with multibeam data obtained in waters down to 1500 m west of Sarigan and to 1900 m east of this island.

Multibeam bathymetry acquired around Sarigan reveals an extensive shallow shelf surrounding this island (Fig. 10.3.1a, top panel). This shelf, at depths of 30–150 m, extends for 2.7 km east of Sarigan. Ridges and canyons radiate from this shelf. West of this island, two large ridges also are shown in the multibeam bathymetry. On the flanks, the multibeam bathymetry reveals blocks of material that may be the result of mass wasting (the movement of soil and surface materials by gravity). North of this island at a depth of 1250 m, a small cone on the flanks rises to a depth of 930 m. A larger cone, south of Sarigan, rises to a depth of 720 m and connects to the main flanks by a ridge at a depth of 880–890 m.

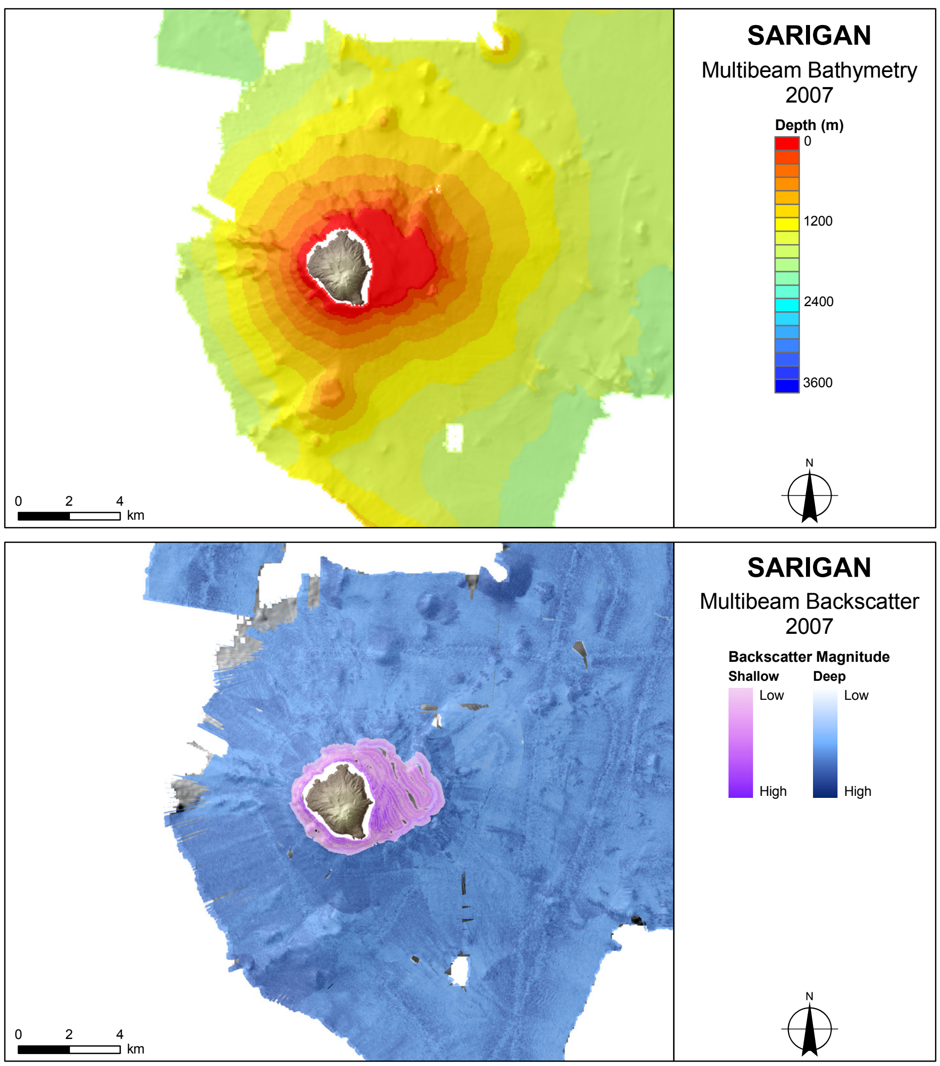


Figure 10.3.1a. Gridded (*top*) multibeam bathymetry (grid cell size: 60 m) and (*bottom*) backscatter (grid cell size: 5 m) collected around Sarigan during MARAMP 2007 in depths of 15–1900 m. Shallow-backscatter data (shown in purple) were collected using a 240-kHz Reson SeaBat 8101 ER sonar, and deep-backscatter data (shown in blue) were collected using a 30-kHz Konsberg EM 300 sonar. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates, such as unconsolidated sediment. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom or coral substrates.

As described in Chapter 2: “Methods and Operational Background,” Section 2.2: “Benthic Habitat Mapping and Characterization,” multibeam backscatter intensity can provide information about the roughness and hardness of the seafloor. Backscatter data aquired around Sarigan have artifacts in some areas, for example, southwest of this island, but patterns in backscatter intensity mainly appear to be related to topographic features. Backscatter intensity on the flanks surrounding the shallow shelf is high, suggestsing that these areas may be characterized by hard substrates (Fig. 10.3.1a, bottom panel). Similarly, high backscatter values were recorded on the cone north of Sarigan and where blocky material is shown along the flanks. In contrast, the larger cone south of Sarigan had low backscatter values, suggesting that this area may be covered with soft sediments.

High-resolution Multibeam Bathymetry and Derivatives

High-resolution multibeam data collected in nearshore (depths of 0–800 m) waters around Sarigan were combined into a grid at 10-m resolution to allow for the identification of fine-scaled features (Fig. 10.3.1b). These high-resolution data were used to derive maps of slope (Fig. 10.3.1c), rugosity (Fig. 10.3.1d), and bathymetric position index (BPI) zones (Fig. 10.3.1e). Together, these maps provide layers of information to characterize the benthic habitats around Sarigan.

The high-resolution bathymetry data (Fig. 10.3.1b) reveal the presence of several terraces rather than just one shelf. The slope map shows that the shallowest mapped seabed has a complex, irregular topography (Fig. 10.3.1c). Below this area, a flat, low-rugosity shelf is located at a depth of 40–60 m and extends for 700 m (Fig. 10.3.1d). This shelf is surrounded by low to moderately steep slopes of 10º–20º with low rugosity levels. A more extensive, low-rugosity shelf, at depths of 100–160 m, is 1.3 km at its widest point. These 2 shelves are delineated clearly through the BPI analysis. The very steep slopes of > 50º that border this deeper shelf continue around this island, although, west of Sarigan, channels and ridges intersect this shelf break. Moderately steep flanks then descend to depths of 250–400 m, whereupon a second steep edge is reached. Below it, the flanks are characterized by higher rugosity levels.

In the shallowest waters surveyed, the BPI analysis identifies reef crests. However, this classification is likely an artifact of the methodology, since no data are available for immediately inshore areas and no comparison can be made to the innermost cells of the grid. Instead, these areas probably should be characterized as slopes.

Overall, the seabed around Sarigan has a fairly complex topography, as revealed by the BPI analysis, which shows that the sloping flanks below the flat zones are interrupted by crests and depressions (Fig. 10.3.1e).

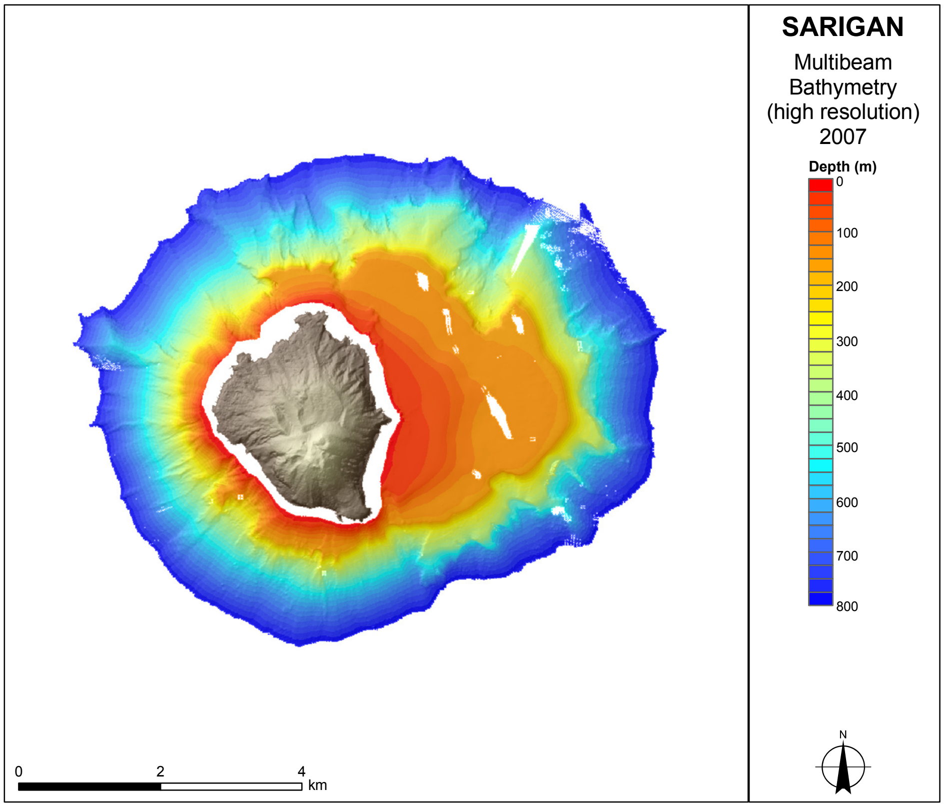


Figure 10.3.1b. High-resolution multibeam bathymetry collected around Sarigan during MARAMP 2007. This 10-m bathymetry grid, clipped at 800 m, is used as the basis for slope, rugosity, and BPI derivatives.

Figure 10.3.1c. Slope (°) of 10-m bathymetric grid around Sarigan. Derived from data collected in 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.

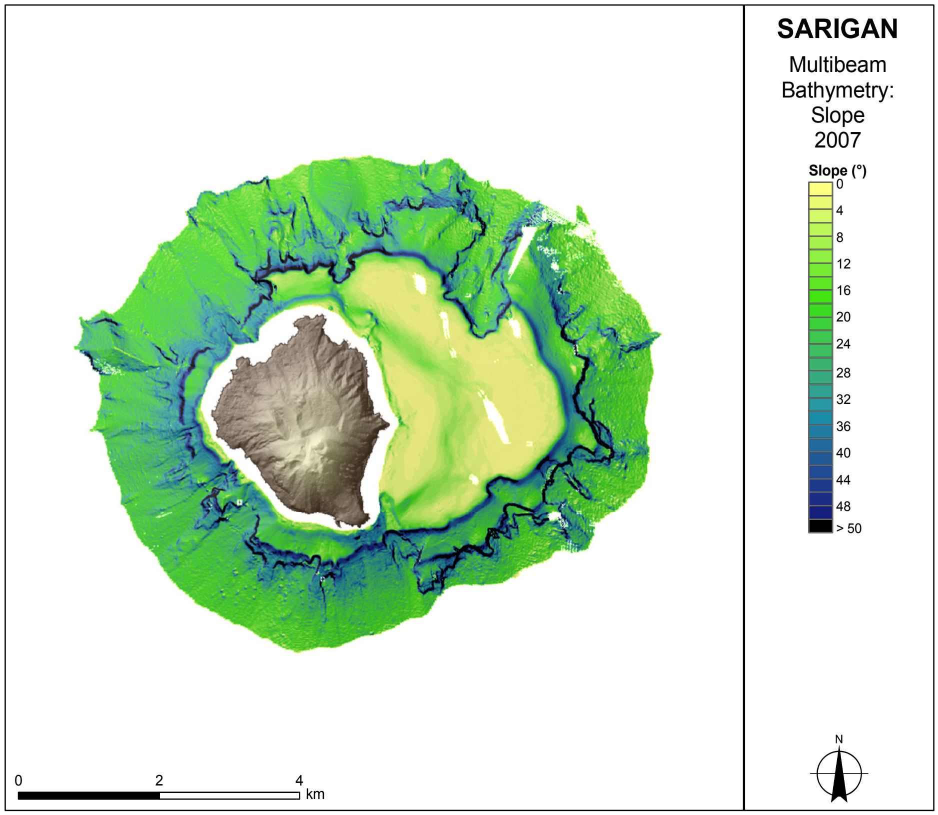
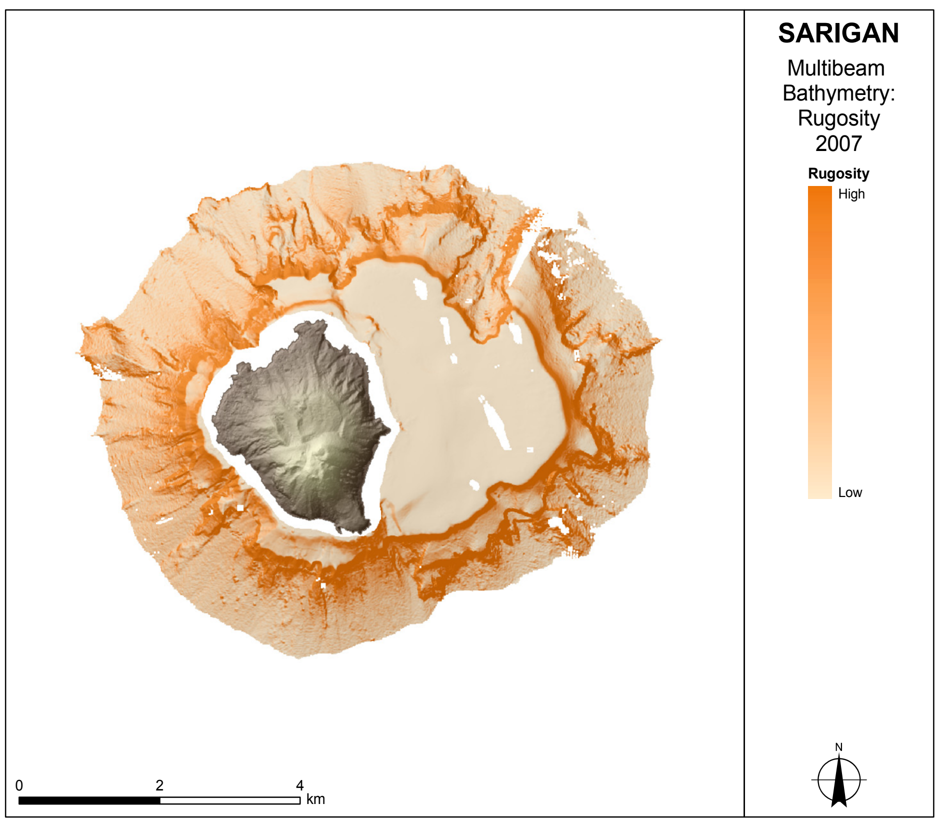


Figure 10.3.1d. Rugosity of 10-m bathymetric grid around Sarigan. Derived from data collected in 2007, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness.



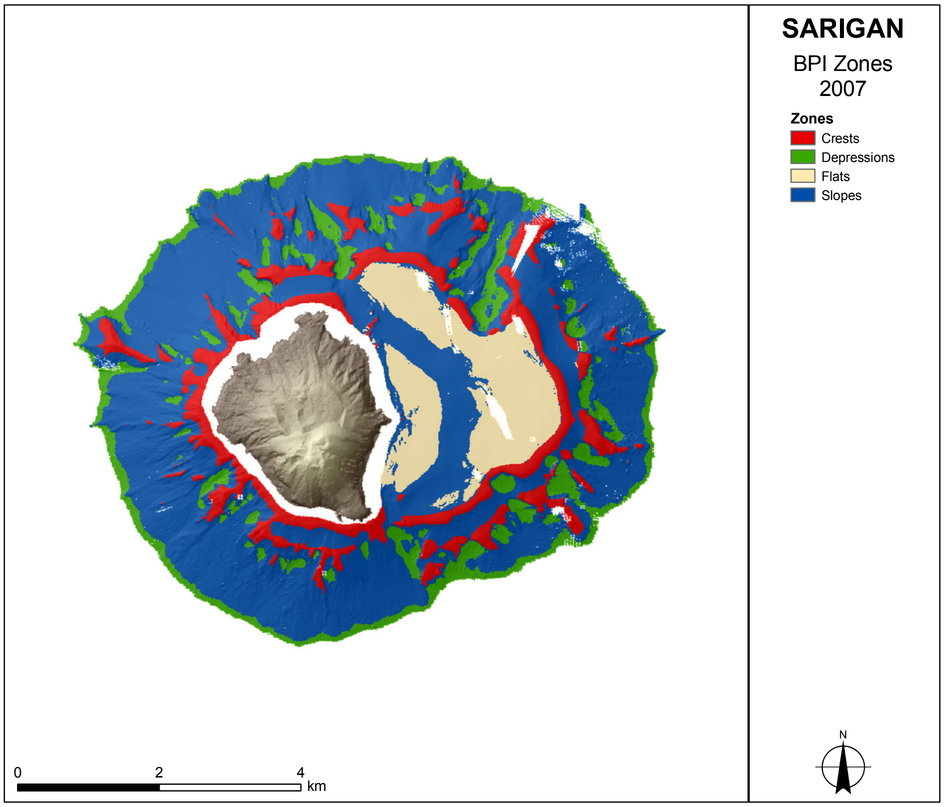


Figure 10.3.1e. BPI zones of 10-m bathymetric grid around Sarigan derived from data collected in 2007. BPI is a second-order derivative of bathymetry that evaluates elevation differences between a focal point and the mean elevation of the surrounding cells within a user-defined circle. Four BPI Zones—crests, depressions, flats, and slopes—were used in this analysis.

High-resolution Multibeam Backscatter and Derivatives

High-resolution backscatter data acquired around Sarigan have some artifacts, such as gaps in the data, and some sharp contrasts between swaths west of this island that did not appear to relate to any topographic features (Fig. 10 3.1f). To reduce the effect of these artifacts on the hard–soft classification, the backscatter data were clipped to a depth of 100 m prior to carrying out the classification. Although the hard–soft analysis is a useful tool to help interpret the seabed character around Sarigan, it should be noted that the ground-truth data underlying the classification was based on other islands with different geological characteristics, and no specific ground-truth data were available from Sarigan to inform the classification. Nevertheless, the classification does provide some indication of the distribution of different substrate types around this island.

East of Sarigan, the more extensive coverage shows some distinct patterns in the recorded backscatter intensity. Most noticeably, linear streaks in the backscatter suggest variation in the acoustic nature of the substrate upon the shelf (Fig. 10.3.1f). These same streaks are highlighted in the hard–soft analysis, which classifies alternating streaks of hard and soft substrate (Fig. 10.3.1g). No topographic features can be seen on the high-resolution bathymetry that associate with this pattern; however, the continuation of this pattern across several adjacent swaths suggest that these streaks are not likely to be artifacts of the data. Rather, the linear streaks may reflect the distribution of soft sediments across the shelf top, with higher backscatter values corresponding to areas where soft sediments are thinner or absent. No optical validation data are available in this area to confirm the nature of the substrate. Elsewhere on the shelf, the distribution of hard and soft substrates appears to be more uniform.

Figure 10.3.1f. Gridded, high-resolution, multibeam backscatter data (grid cell size: 1 m) collected around Sarigan during MARAMP 2007. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom and coral substrates.

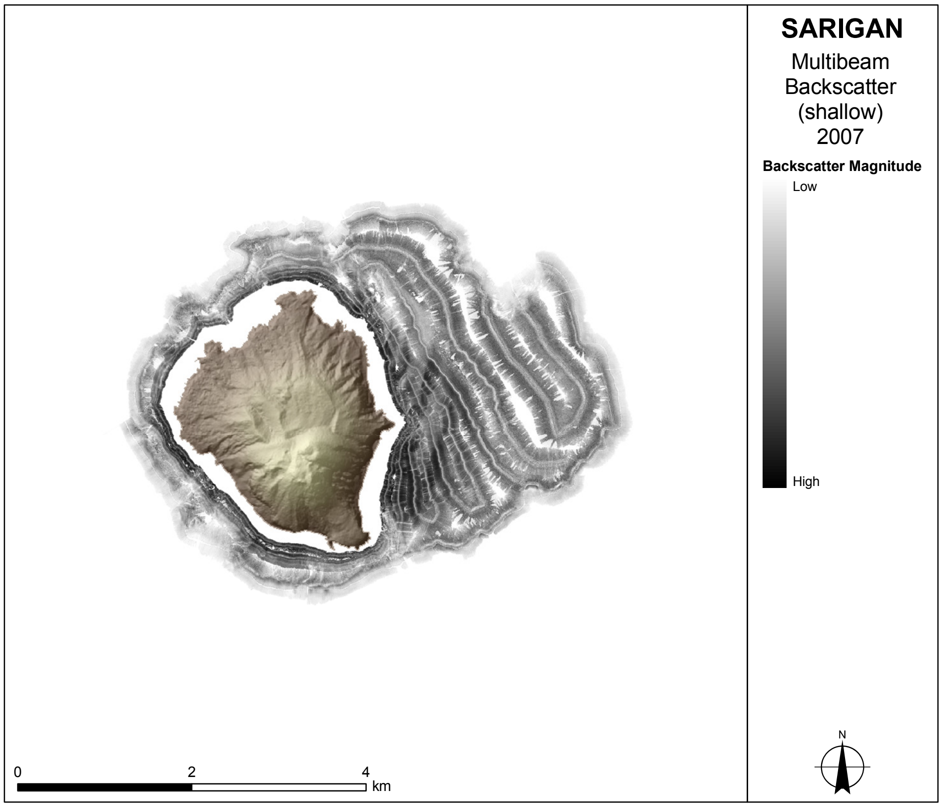
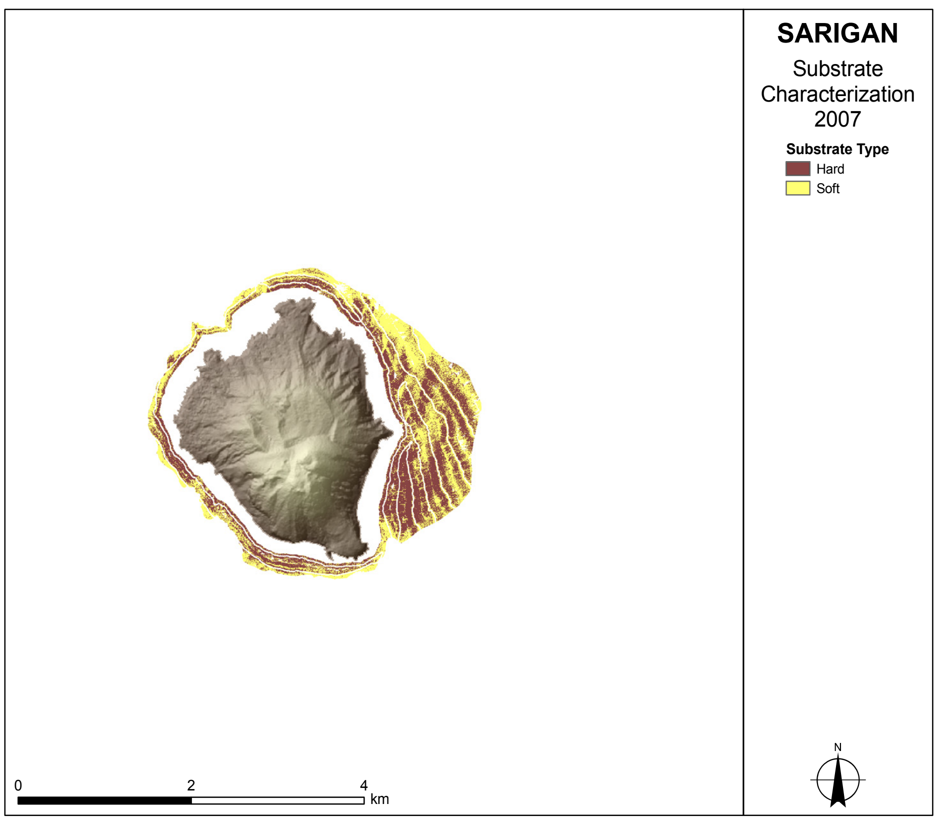


Figure 10.3.1g. Hard and soft substrates (grid cell size: 5 m) at depths < 100 m, based upon an unsupervised classification of multibeam bathymetry and backscatter data acquired around Sarigan in 2007. Data cannot be collected directly under the ship, hence the white lines showing the ship's path.



10.3.2 Optical Validation

During MARAMP 2003, a total of 3 TOAD optical-validation surveys, covering a distance of 0.78 km in depths of 76–207 m, were conducted around Sarigan (Fig. 10.3.2a). Subsequent analyses of video acquired from these surveys provided estimates of the percentages of sand cover and live coral cover.

Covering a distance of 33 km in depths of 2–23 m, 17 towed-diver optical-validation surveys of forereef habitats, were conducted around Sarigan during MARAMP 2003, 2005, and 2007. At 5-min intervals within each 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.

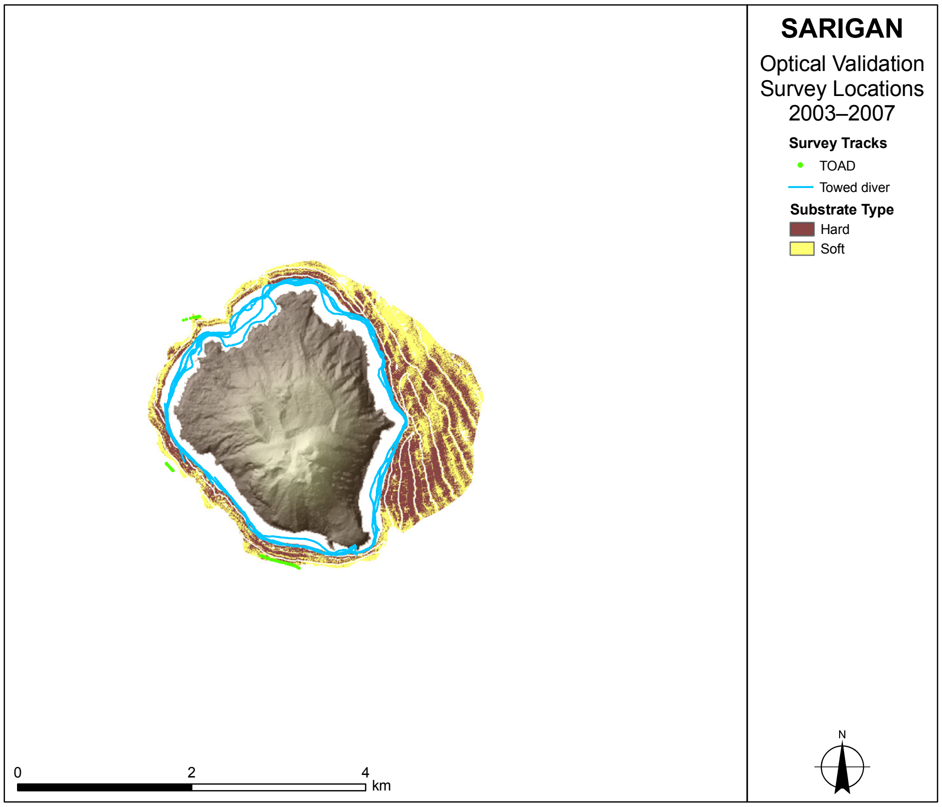


Figure 10.3.2a. Towed-diver tracks from surveys of forereef habitats conducted around Sarigan during MARAMP 2003, 2005, and 2007 and TOAD camera-sled tracks for MARAMP 2003. Survey tracks are displayed over multibeam hard–soft substrate map. Because data cannot be collected right under the ship, white lines are visible.

10.3.3 Habitat Characterization

Sand cover, habitat complexity, and live coral cover around Sarigan are discussed in this section. These descriptions are organized by the 3 geographic regions around Sarigan. Optical-validation surveys conducted around Sarigan during MARAMP 2003, 2005, and 2007 reveal local variability in the distribution of habitats around this island.

Around east Sarigan, sand cover was patchy, with interpolated sand cover ranging from 5.1% to 50% (Fig. 10.3.3a, top panel). Habitat complexity was most frequently recorded as medium to medium-high during towed-diver surveys, although a small number of patches with lower and higher habitat complexity were also observed (Fig. 10.3.3a, middle panel). Within the east region, moderate levels of live coral cover were observed with interpolated cover generally < 20%, although 2 small patches were observed where live coral cover of 20.1%–62.5% was recorded (Fig. 10.3.3a, bottom panel). Habitats observed by towed divers within this region included rocky crags, boulders and pinnacles, and sand with boulder patch reefs.

Habitat complexity, ranging from low to high, was more variable in the northwest region than in the east region. As in the east region, sand cover was locally patchy, ranging from 5.1% to 62.5% and reflecting the variable nature of the seabed. Habitat was characterized as boulder patches, steep walls, and continuous rock reef. Live coral cover appeared to be more consistent, predominantly ranging from 5.1% to 30%. Analyses of TOAD video footage obtained on the flanks at depths of 91–190 m suggested hard substrates with no sand recorded. No live corals were observed in any of the analyzed footage.

In the southwest region, towed-diver surveys recorded habitats of medium to high complexity over boulder reefs and continuous reef with sand patches and live coral cover of 1.1%–40%. Estimates of sand cover from towed-diver surveys were generally < 20%, although a small patch of higher sand cover was observed and appears to associate with a channel between 2 ridges shown in the bathymetry. Two TOAD surveys conducted in this region suggest predominantly hard substrate with only one analyzed video frame showing any sand. No live corals were observed within either of these surveys, although soft corals were noted.

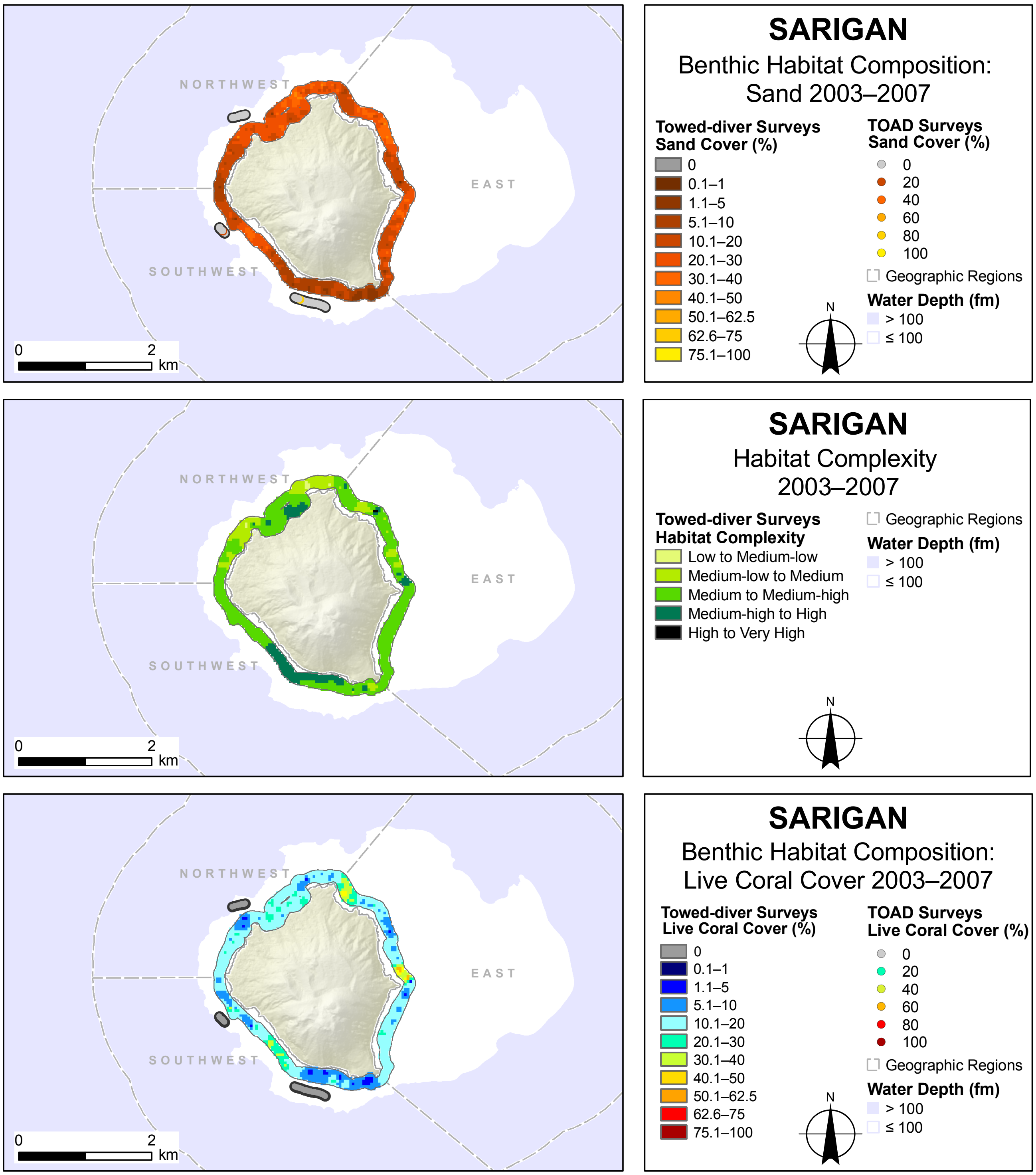


Figure 10.3.3a. Observations of (*top*) sand cover (%), (*middle*) benthic habitat complexity, and (*bottom*) live-hard-coral cover (%) from towed-diver surveys of forereef habitats conducted and analyses of TOAD video collected around Sarigan during MARAMP 2003, 2005, and 2007.

10.4 Oceanography and Water Quality

10.4.1 Hydrographic Data

2003 Spatial Surveys

During MARAMP 2003, 7 shallow-water conductivity, temperature, and depth (CTD) casts were conducted in nearshore waters at the island of Sarigan on August 24. Temperature, salinity, and density values from these casts varied both spatially and vertically (Figs. 10.4.1a and b). Spatial comparisons of water properties at a depth of 10 m suggest a minimal range in temperature (0.15°C) values and moderate ranges in salinity (0.02 psu) and density (0.05 kg m^{-3}) values. Temperature values were slightly higher in the east region (casts 4–5, 6) than in the northwest and southwest regions (casts 1–3, 7; Fig. 10.4.1a). Vertical comparisons of CTD profiles reveal differences in water properties that were larger than the variation seen in spatial comparisons, with broad ranges in temperature (1.5°C) and density (0.7 kg m^{-3}) values and a moderate range in salinity (0.3 psu) values. Well-mixed waters were prominent at Sarigan, except in the northwest region at cast 3, where colder, less saline water was recorded below a depth of 25 m (Fig. 10.4.1b).

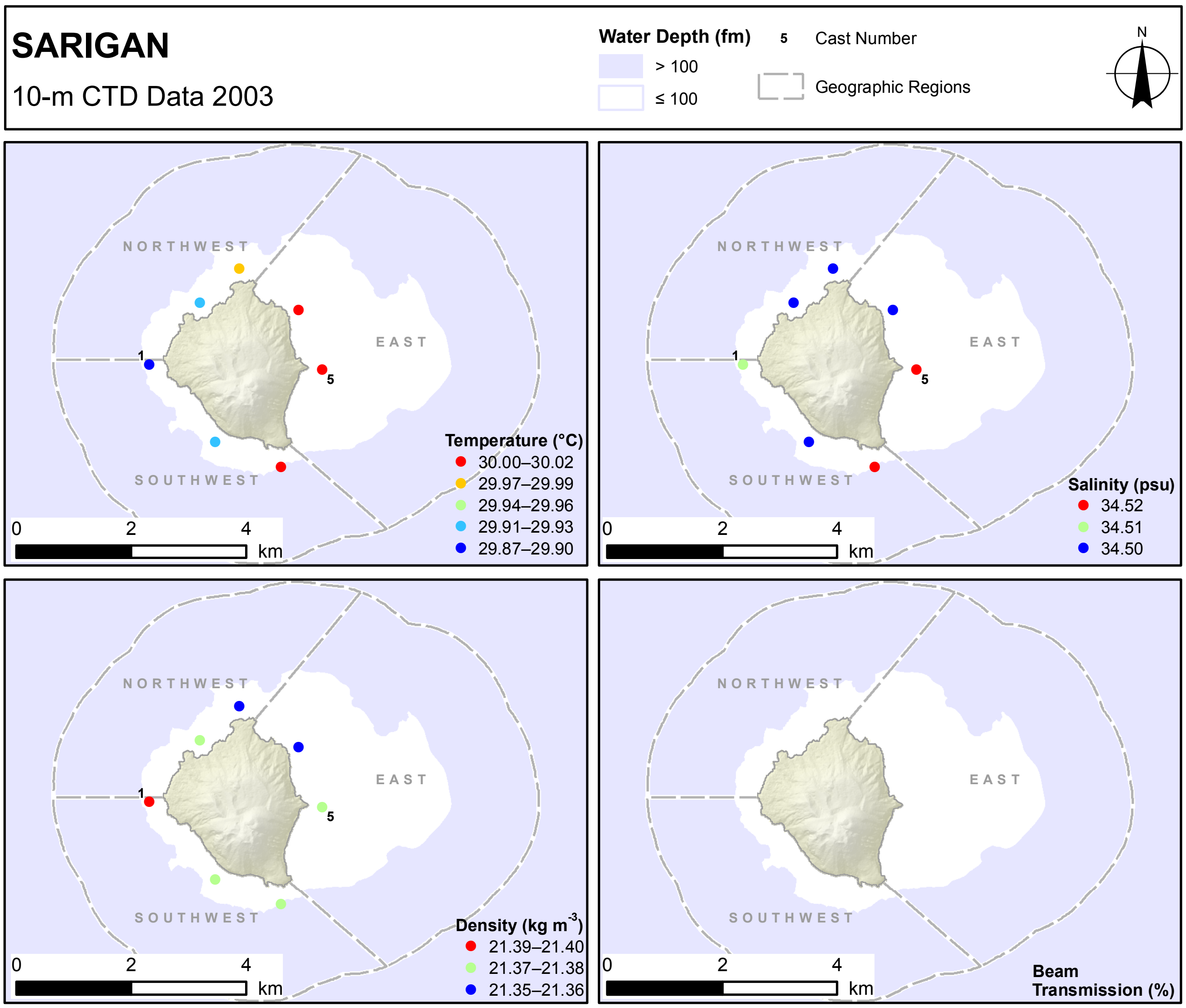
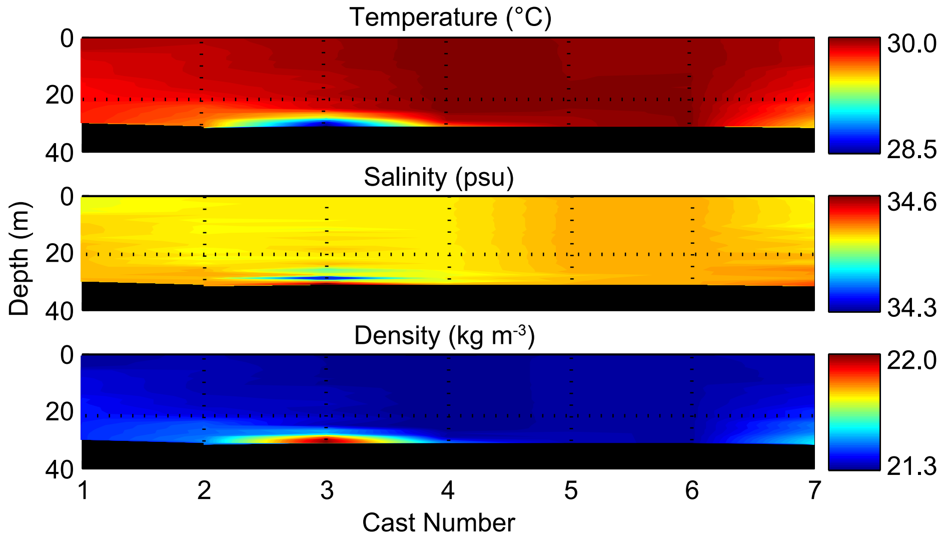


Figure 10.4.1a. Values of (*top left*) water temperature, (*top right*) salinity, and (*bottom left*) density at a 10-m depth from shallow-water CTD casts at Sarigan on August 24 during MARAMP 2003.

Figure 10.4.1b. Shallow-water CTD cast profiles to a 30-m depth at Sarigan on August 24 during MARAMP 2003, including temperature (°C), salinity (psu), and density (kg m^{-3}). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–7 in a clockwise direction around Sarigan. For cast locations and numbers around this island in 2003, see Figure 10.4.1a.



2005 Spatial Surveys

During MARAMP 2005, 9 shallow-water CTD casts were conducted in nearshore waters at Sarigan on September 18. Temperature, salinity, density, and beam transmission values from these casts varied both spatially and vertically (Figs. 10.4.1c and d). Spatial comparisons of water properties at a depth of 10 m suggest small ranges in temperature (0.2°C), salinity (0.02 psu), and beam transmission (< 1%) values and a broad range in density (0.08 kg m^{-3}) values (Fig. 10.4.1c). Vertical comparisons of CTD profiles also reveal small ranges in temperature (0.4°C), salinity (0.1 psu), density (0.2 kg m^{-3}), and beam transmission (< 1%) values (Fig. 10.4.1d). Well-mixed waters were prominent at this island, except for at cast 1, located on the border between the northwest and southwest regions, where colder, less saline water was recorded below a depth of 10 m (Fig. 10.4.1d).

Water samples were collected in concert with shallow-water CTD casts at a single select location in the northwest region in 2005 to assess water-quality conditions (Fig. 10.4.1e). The following values of measured parameters were recorded: chlorophyll-*a* (Chl-*a*), 0.201 µg L^{-1}; total nitrogen (TN), 0.066 µM; nitrate (NO_3^-), 0.044 µM; nitrite (NO_2^-), 0.023 µM; phosphate (PO_4^{3-}), 0.034 µM; and silicate [$Si(OH)_4$], 0.756 µM.

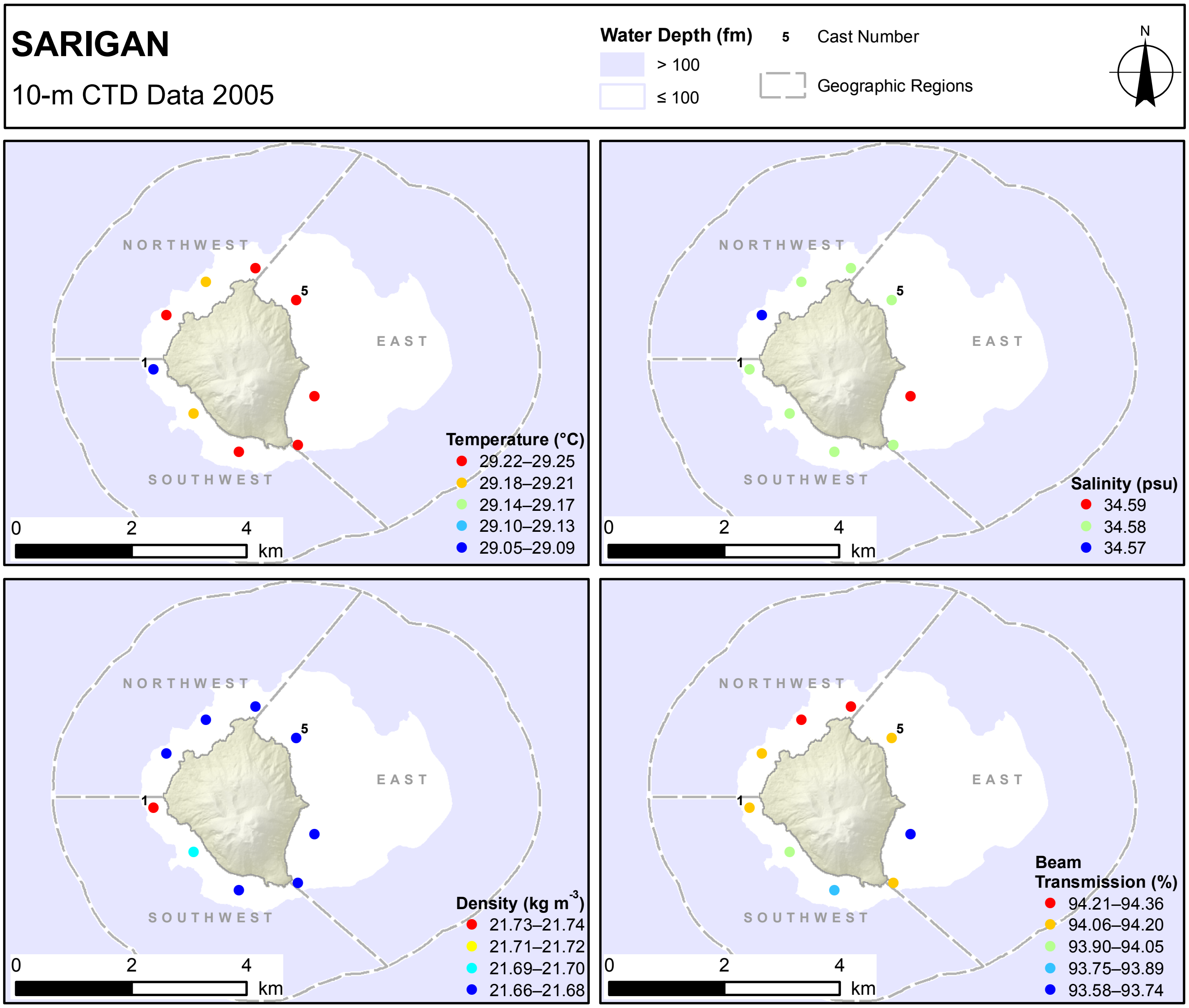


Figure 10.4.1c. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts at Sarigan on September 18 during MARAMP 2005.

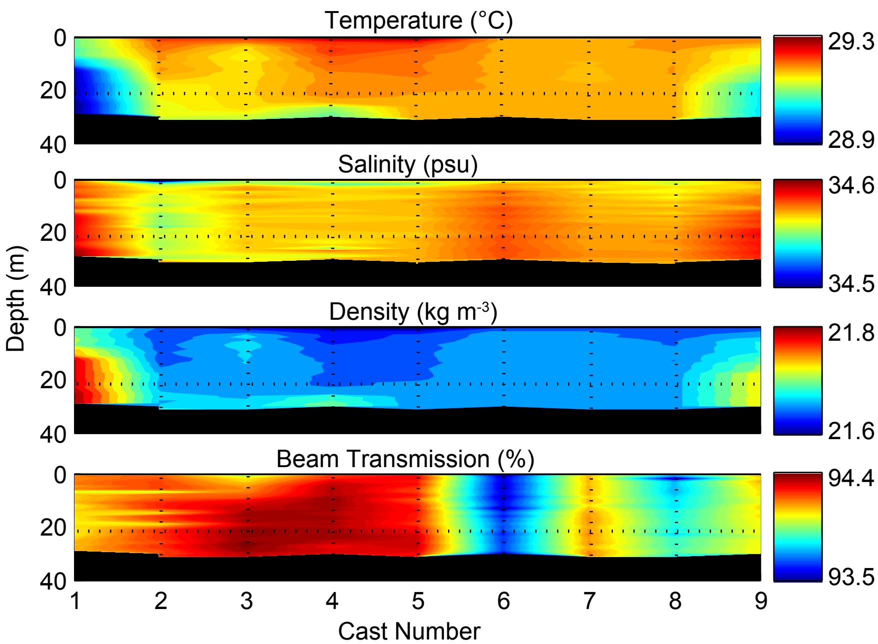


Figure 10.4.1d. Shallow-water CTD cast profiles to a 30-m depth at Sarigan on September 18 during MARAMP 2005, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–9 in a clockwise direction around Sarigan. For cast locations and numbers around this island in 2005, see Figure 10.4.1c.

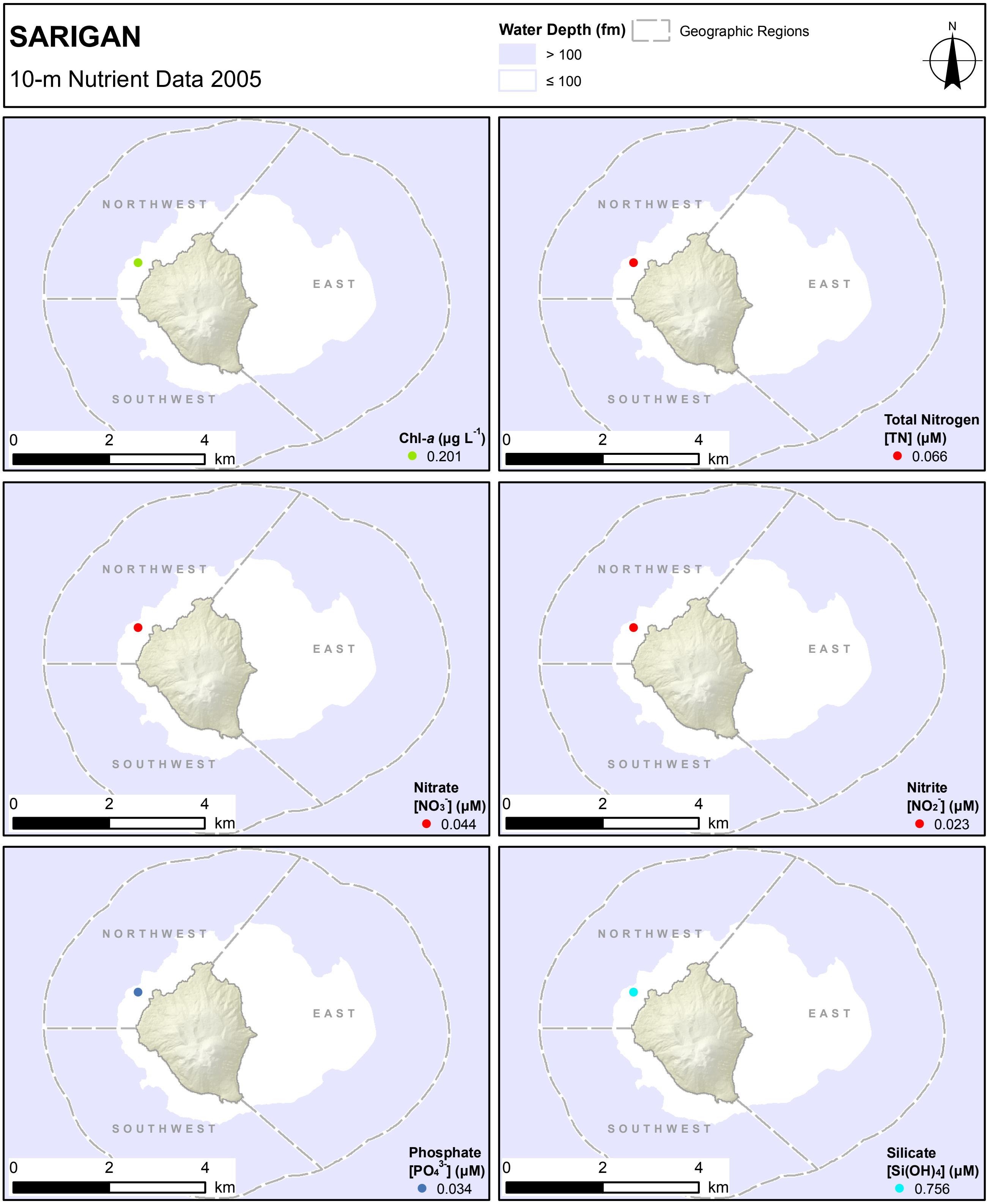


Figure 10.4.1e. Concentrations of (*top left*) chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate, and (*bottom right*) silicate at a 10-m depth from water samples collected at Sarigan on September 18 during MARAMP 2005.

2007 Spatial Surveys

During MARAMP 2007, 10 shallow-water CTD casts were conducted in nearshore waters around Sarigan on May 26. Temperature, salinity, density, and beam transmission values from these casts varied both spatially and vertically (Figs. 10.4.1f and g). Spatial comparisons of water properties at a depth of 10 m suggest a moderate range in temperature (0.45°C) values and small ranges in salinity (0.13 psu), density (0.25 kg m^{-3}), and beam transmission (< 1%) values (Fig. 10.4.1f). Temperatures recorded at cast 10 in the southwest region were anomalously cooler compared to values found at all other cast locations at Sarigan, and data from this cast are the main reason behind the difference recorded in temperatures. Vertical comparisons of CTD profiles reveal water properties with moderate ranges in temperature (0.5°C), salinity (0.2 psu), and density (0.4 kg m^{-3}) values and a small range in beam transmission (1%) values (Fig. 10.4.1g). Differences in mixing and stratification around this island were present. Warm, well-mixed waters were recorded in the east region (casts 4–8), while cooler, more saline subsurface waters were recorded below a depth of 5 m in the southwest region (casts 9–10).

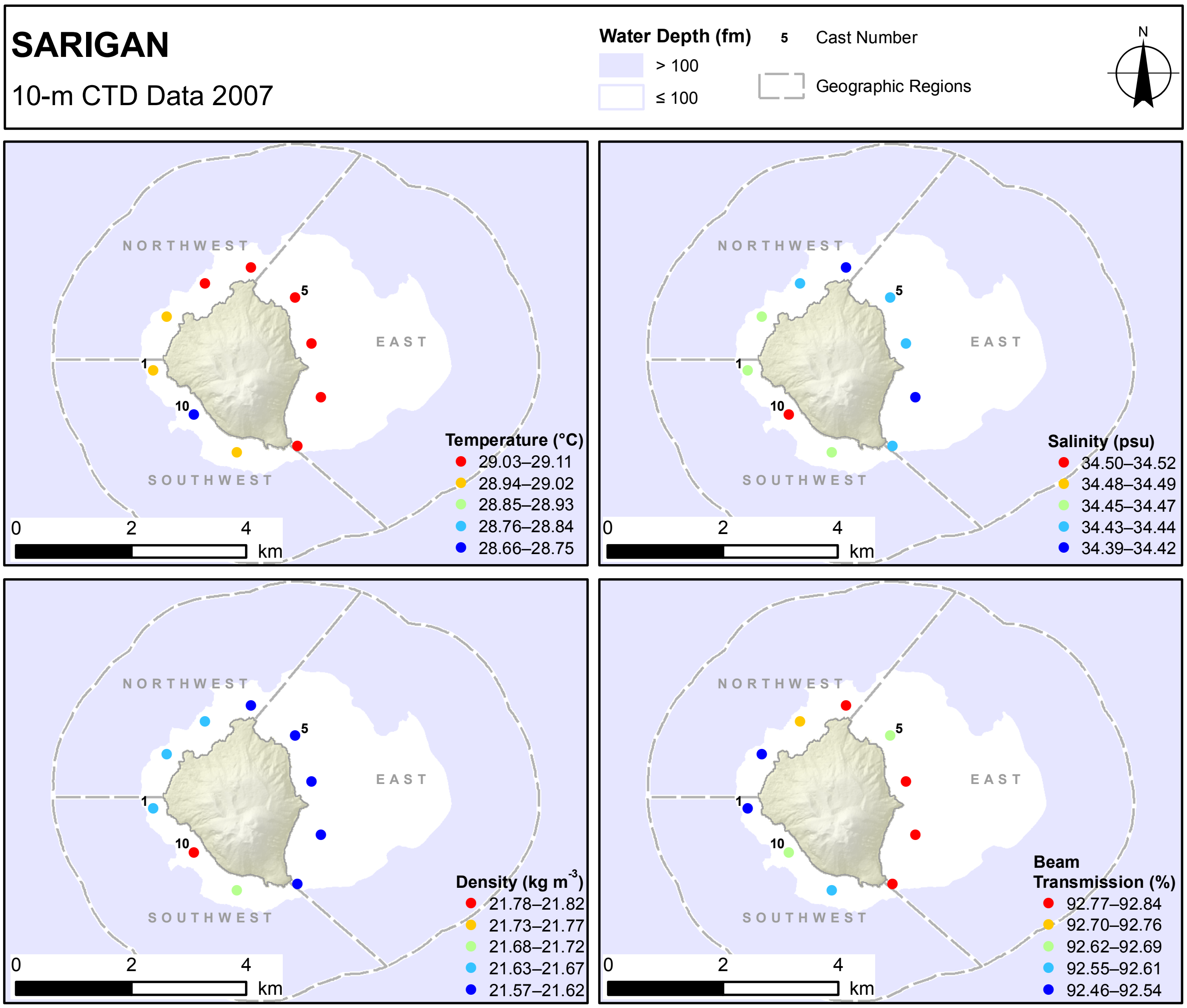
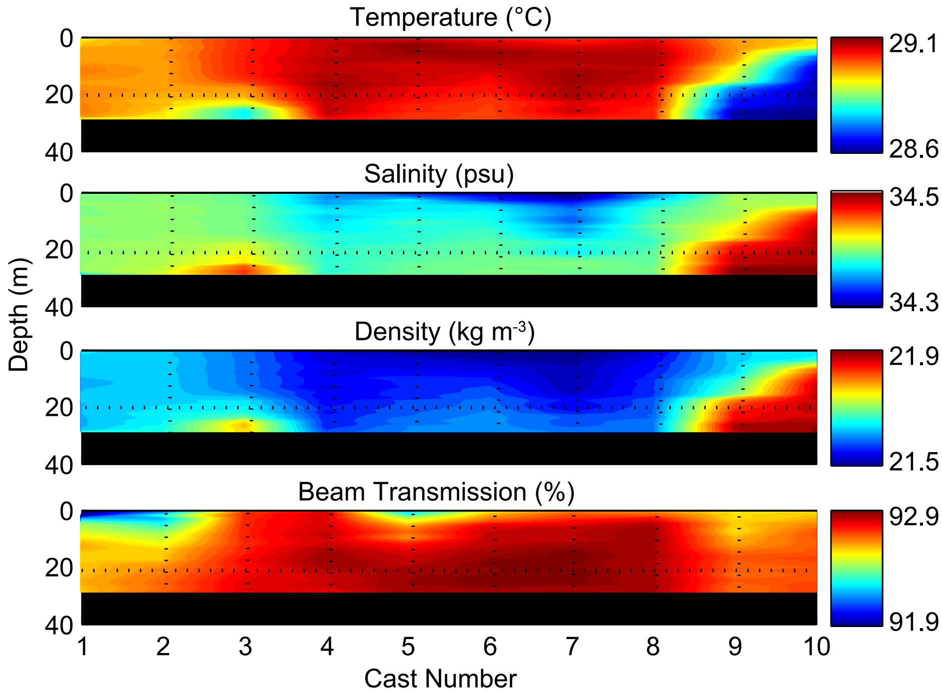


Figure 10.4.1f. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) bean transmission at a 10-m depth from shallow-water CTD casts around Sarigan on May 26 during MARAMP 2007.

Water samples were collected in concert with shallow-water CTD casts at 4 select locations at Sarigan in 2007 (Fig. 10.4.1h). The following ranges of measured parameters were recorded at Sarigan: Chl-*a*, 0.037–0.086 µg L^{-1}; total nitrogen (TN), 0.047–0.101 µM; nitrate (NO_3^-), 0.043–0.083 µM; nitrite (NO_2^-), 0.004–0.018 µM; phosphate (PO_4^{3-}), 0.04–0.065 µM; silicate [$Si(OH_4)$], 1.115–2.561 µM. The highest values of Chl-*a* were recorded in the southwest region, while the highest values of total nitrogen, nitrate, nitrite, phosphate, and silicate were all recorded in the northwest region.

Figure 10.4.1g. Shallow-water CTD cast profiles to a 30-m depth around Sarigan on May 26 during MARAMP 2007, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–10 in a clockwise direction around Sarigan. For cast locations and numbers around this island, see Figure 10.4.1f.



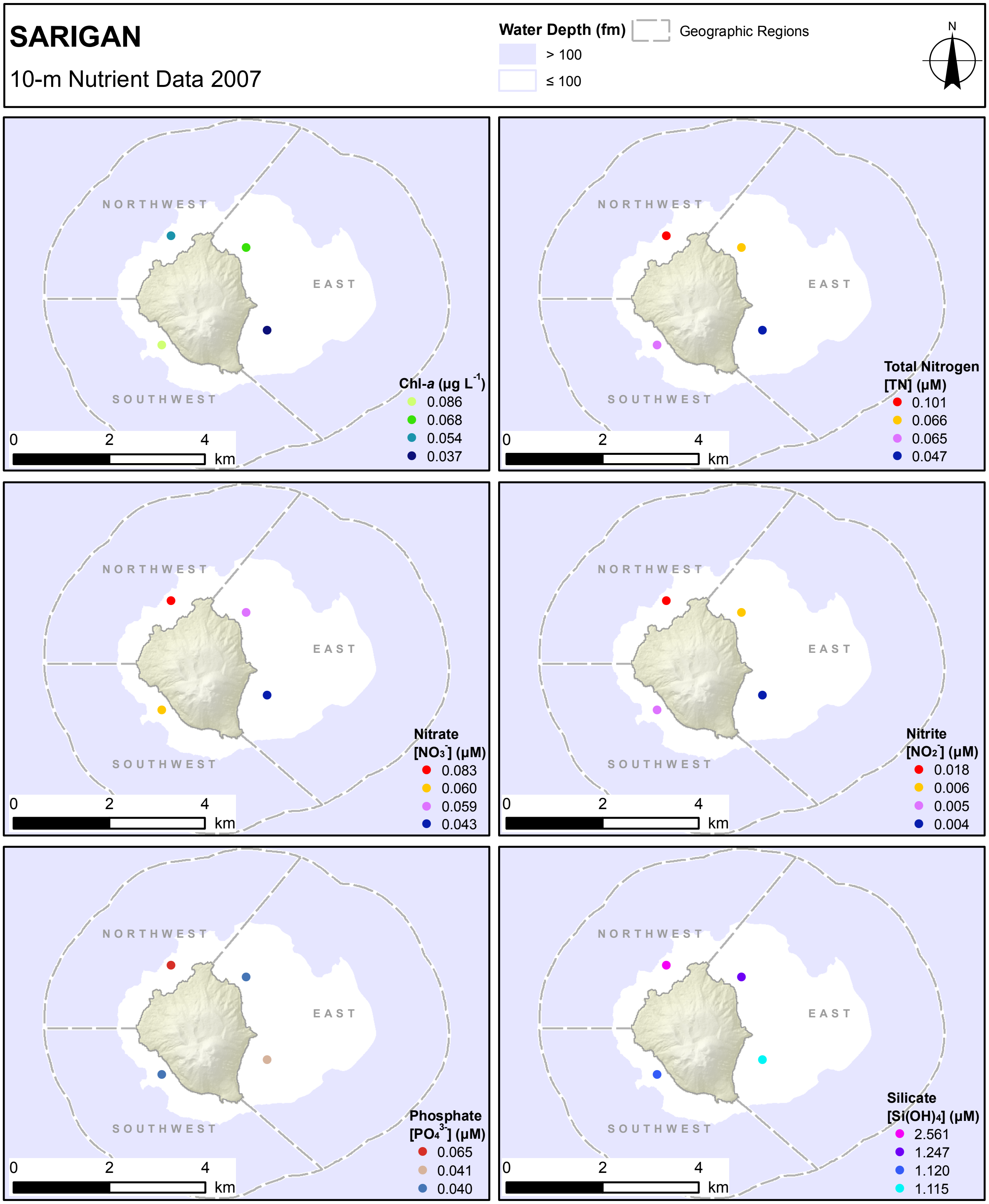


Figure 10.4.1h. Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate, and (*bottom right*) silicate, at a 10-m depth from water samples collected at Sarigan on May 26 during MARAMP 2007.

Temporal Comparison

Temporal comparisons of shallow-water CTD data collected during MARAMP 2003, 2005, and 2007 suggest a dynamic oceanographic environment. Data from CTD casts completed in 2005 and 2007 reveal generally minimal to moderate spatial and vertical variability; however, data from 2003 show a greater spatial variance in water properties, as relatively cool water (28.5°C; 1.5°C colder than surface waters) originating from below a depth of 30 m was recorded in the southwest region and may have resulted from upwelling or internal tide activity. When comparing water-quality data between survey years, Chl-*a* concentrations were greater in 2007 than in 2005, and all other parameters measured were much greater in 2007 than in 2005. Data were not collected with respect to a specific tidal cycle, which could be a source of oceanographic variability. Likewise, hydrographic variation between MARAMP survey years is likely a result of differences in season. MARAMP 2007 occurred in May, and MARAMP 2003 and 2005 occurred in September and October. This change was made to avoid the typhoon season and reduce the probability of weather disruptions. Wind and wave conditions are generally higher during the wet season (July–December) with stronger trade winds prominent on the east side of Sarigan. Higher winds and waves likely caused more mixing during MARAMP 2003 and 2005, and calmer weather potentially allowed for increased stratification in 2007. Further investigation will help make these particular results and trends more apparent.

10.4.2 Time-series Observations

Between 2003 and 2007, subsurface temperature recorders (STR) were deployed at Sarigan to collect time-series observations of temperature, a key oceanographic parameter influencing reef conditions (Fig. 10.4.2a). The locations, depths, time frames, and other details about these deployments are provided in Figures 10.4.2a and b.

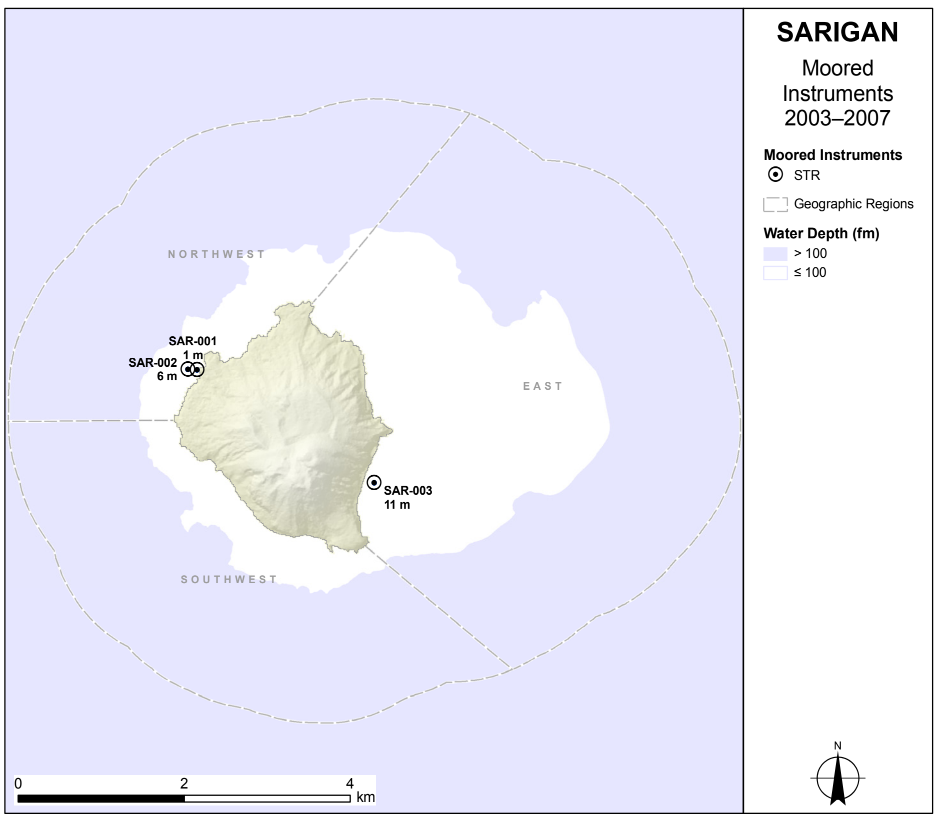


Figure 10.4.2a. Locations and depth of STRs deployed at Sarigan during MARAMP 2003, 2005, and 2007.

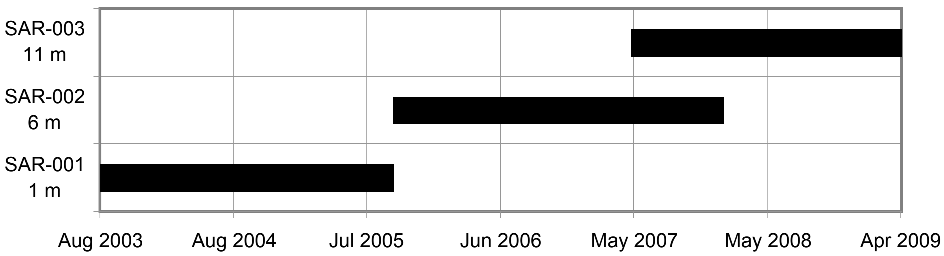


Figure 10.4.2b. Deployment timelines and depths of the STRs moored at Sarigan during the period from August 2003 to April 2009. A solid bar indicates the period for which data were collected by an instrument that was deployed and retrieved at a mooring site. For more information about deployments and retrievals, see Table 10.2b in Section 10.2: "Survey Effort."

Data from 2 STRs deployed at depths of 1 and 6 m at Sarigan show seasonal temperature variability of ~ 4°C (Fig. 10.4.2c). Water temperatures reached 30°C during the months of June–October and fell to a low of ~ 26.5°C during the months of January–May. Intraseasonal temperature variability was prominent throughout this time series, with oscillations of 0.5°C–1.5°C occurring multiple times within a season. The sharpest decline in temperature was recorded in June 2004 at SAR-001 in the northwest region, when temperature dropped ~ 2.5°C for a week before increasing 3.5°C to typical summer temperatures. The cause of this dramatic temperature change is unknown, but transient oceanographic features (e.g., eddies) can lead to abrupt and transitory temperature fluctuations.

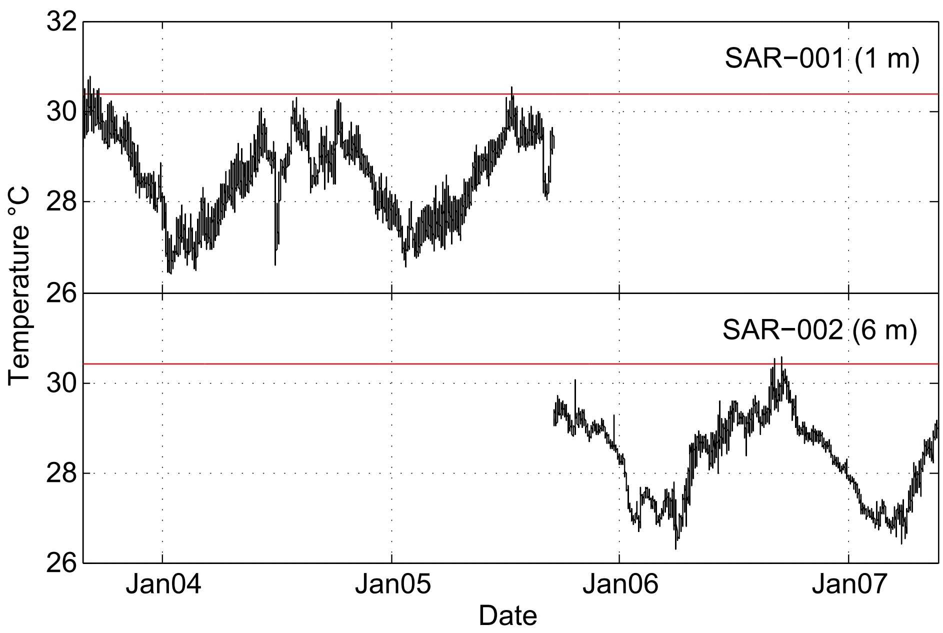


Figure 10.4.2c. Time-series observations of temperature over the period between September 2003 and December 2007 collected from 2 STRs deployed in the northwest region of Sarigan (see Figure 10.4.2a for mooring locations). The red lines represent the satellite-derived coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean.

10.4.3 Wave Watch III Climatology

Seasonal wave climatology for Sarigan was derived using the NOAA Wave Watch III model for the period of January 1997 to May 2008, and seasons were selected to elucidate waves generated by typhoons, which most frequently occur during the period of August–December (Fig. 10.4.3a). In terms of consistency, the wave regime during this period was dominated by trade wind swells characterized by frequent (> 30 d per season), short-period (8–10 s), relatively small (2–2.5 m) wave events originating from the east (~ 80º–90º). Superimposed with these short-period swells were large (> 5 m), long-period (12–16 s) wave events principally from the south (160º–190º). These large, episodic waves were generated primarily by typhoons and occurred on annual to interannual time scales. Additionally, infrequent (~ 5 d per season), long-period (12–14 s) swells with moderate wave heights (2.5–4 m) occurred from any direction, although weighted slightly larger from the south (110º–260º) and likely associated with episodic, moderate-sized, or distant storms. Similar to the wave regime during typhoon season, the wave climate during the period of February–June (outside typhoon season) also was characterized by frequent (> 30 d per season), short-period (~ 8 s) trade wind swells with relatively small wave heights (~ 2 m) originating from the east. Infrequent (< 5 d per season), long-period (12–14 s) swells with moderate wave heights (~ 2–3 m) also occurred during this period and originated from any direction.

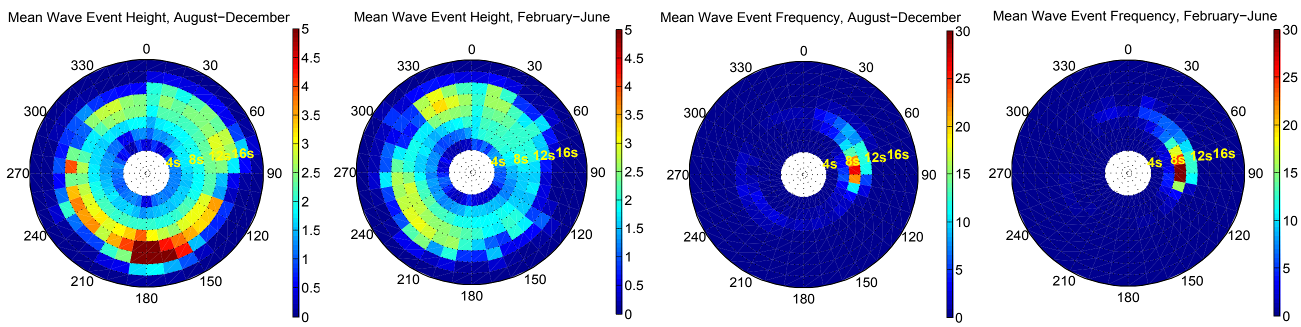


Figure 10.4.3a. NOAA Wave Watch III directional wave climatology for Sarigan from January 1997 to May 2008. This climatology was created by binning (6 times daily) significant wave height, dominant period, and dominant direction from a box (1° × 1°) centered on Sarigan (16° N, 145° E). Mean significant wave height (*far left and left*), indicated by color scale, for all observations in each directional and frequency bin from August to December (typhoon season) and from February to June. The transition months of January and July are omitted for clarity. Mean number of days (*right and far right*) that conditions in each directional and frequency bin occurred in each season, indicated by color scale; for example, if the color indicates 30, then, on average, the condition occurred during 30 of the 150 days of that season.

10.5 Corals and Coral Disease

10.5.1 Coral Surveys

Coral Cover and Colony Density

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on forereef habitats around the island of Sarigan was 18% (SE 2). Localized areas of high coral cover were recorded in the east region over 2 consecutive survey segments with a mean of 63% and in the southwest region over 2 consecutive segments with a mean of 42% (Fig. 10.5.1a, top panel). Generally, coral cover was lowest in the southern part of the southwest region.

From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on forereef habitats around Sarigan was 13% (SE 1.5). Coral cover was highest in the east region, on the border between the east and northwest regions, and within one segment located in the northwest region, with a mean of 33% for 4 segments (Fig. 10.5.1a, middle 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, 0.8% (SE 0.2) of coral cover observed on forereef habitats around Sarigan appeared stressed. Stressed-coral cover was low for the majority of reefs surveyed in 2005 at Sarigan, compared to other areas surveyed in the Mariana Archipelago.

From MARAMP 2007 towed-diver surveys, mean cover of live hard corals on forereef habitats around Sarigan was 14% (SE 1). Coral cover was highest in the northern part of the east region with a mean of 32% for 3 segments (Fig. 10.5.1a, bottom panel). Overall, 0.9% (SE 0.3) of coral cover observed on forereef habitats appeared stressed. Stressed-coral cover was low for the majority of reefs surveyed in 2007 at Sarigan, compared to other areas surveyed in the Mariana Archipelago.

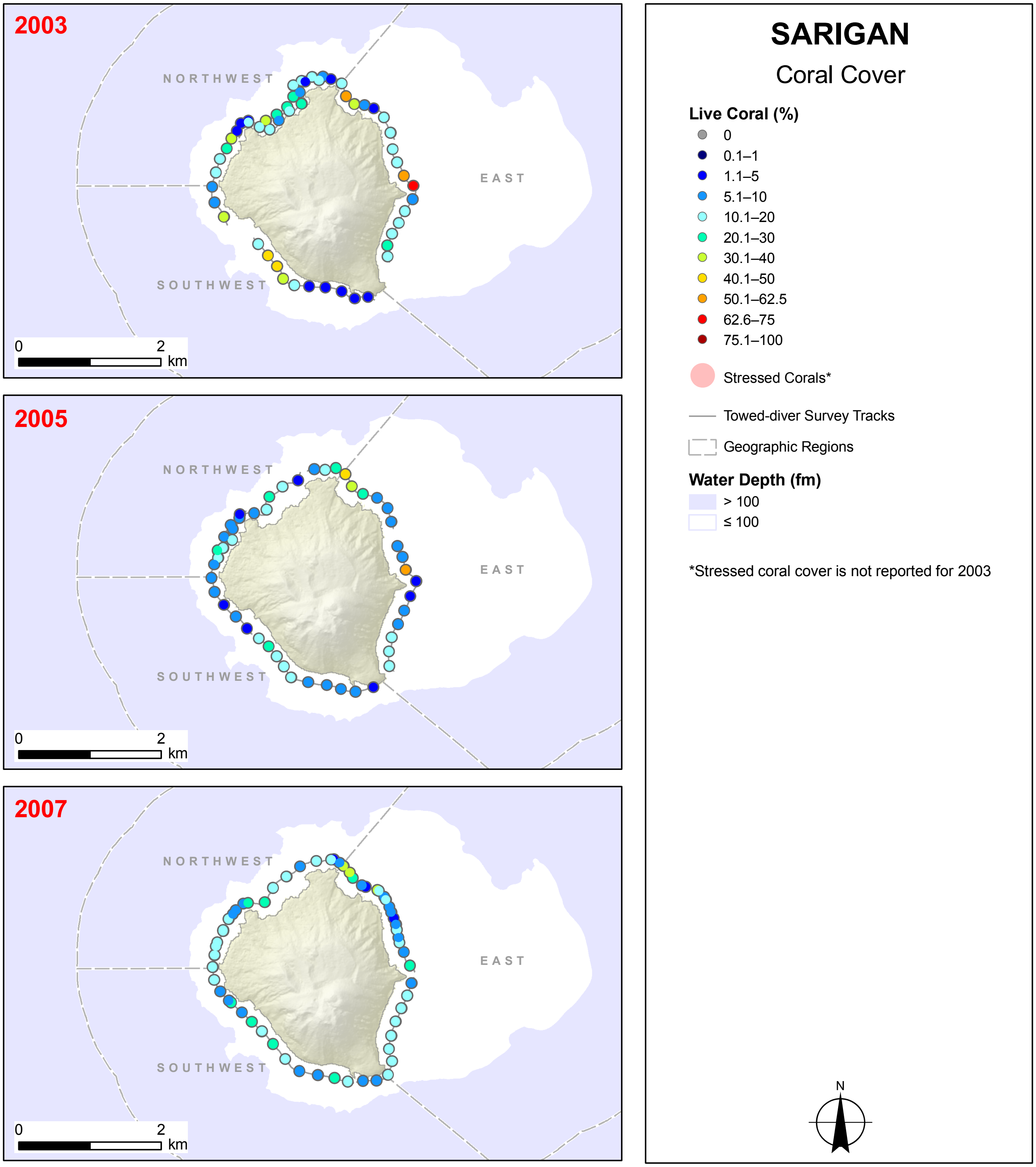


Figure 10.5.1a. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted around Sarigan during MARAMP 2003, 2005, and 2007. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m²). Pink symbols represent segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2005 and 2007.

During MARAMP 2003, 3 REA benthic surveys using the quadrat method on forereef habitats at Sarigan documented 512 coral colonies within a total survey area of 11.25 m^2. Site-specific colony density ranged from 32.8 to 60.5 colonies m^{-2} with an overall sample mean of 45.5 colonies m^{-2} (SE 8.1). The highest colony density was recorded at REA site SAR-01 in the southwest region, and the lowest colony density was observed at SAR-02 in the northwest region (Fig. 10.5.1b, top panel).

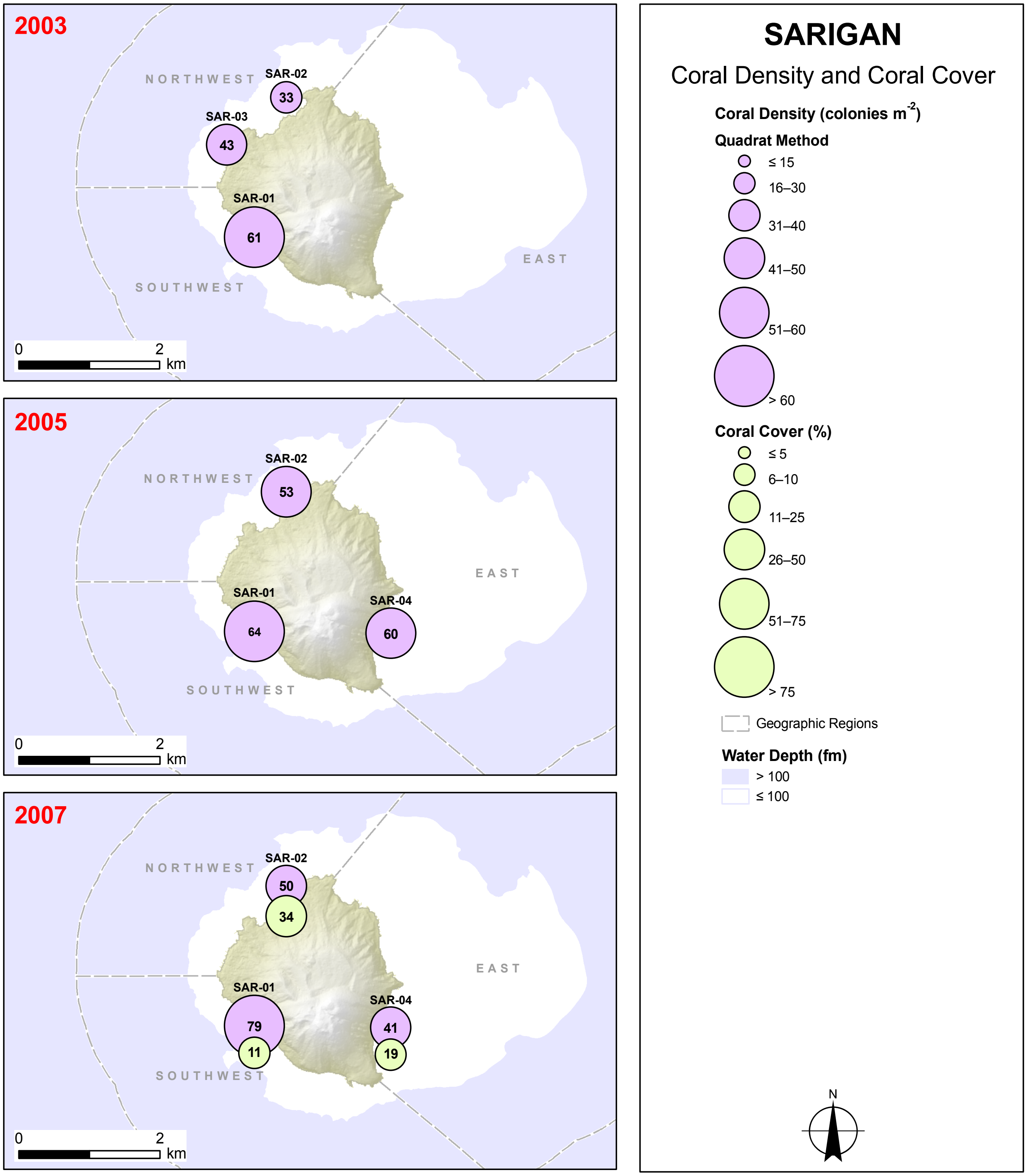


Figure 10.5.1b. Colony-density (colonies m^{-2}) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Sarigan during MARAMP 2003, 2005, and 2007, as well as cover (%) observations of live corals from REA benthic surveys during MARAMP 2007. Values are provided within each symbol. The quadrat method was used in the 3 survey years to assess coral-colony density.

During MARAMP 2005, 3 REA benthic surveys using the quadrat method on forereef habitats at Sarigan documented 705 coral colonies within a total survey area of 12 m^2. Site-specific colony density ranged from 53 to 63.5 colonies m^{-2} with an overall sample mean of 58.3 colonies m^{-2} (SE 3.1). The highest colony density was recorded at SAR-01 in the southwest region, and the lowest colony density was observed at SAR-02 in the northwest region (Fig. 10.5.1b, middle panel).

During MARAMP 2007, 3 REA benthic surveys using the line-point-intercept method were conducted on forereef habitats at Sarigan. Site-specific estimates of live-hard-coral cover from these surveys ranged from 10.8% to 34.3% with an overall sample mean of 21.2% (SE 6.9). Coral cover was highest at SAR-02 in the northwest region and lowest at SAR-01 in the southwest region (Fig. 10.5.1b, bottom panel).

During MARAMP 2007, 3 REA benthic surveys using the quadrat method on forereef habitats at Sarigan documented 520 coral colonies within a total survey area of 10 m^2. Site-specific colony density ranged from 41 to 79 colonies m^{-2} with an overall sample mean of 56.5 colonies m^{-2} (SE 11.5). The highest colony density was recorded at SAR-01 in the southwest region, and the lowest colony density was observed at SAR-04 in the east region (Fig. 10.5.1b, bottom panel).

Islandwide mean cover of live corals estimated from towed-diver surveys of forereef habitats was slightly higher in 2003 than in 2005 and 2007 with overall sample means of 18% (SE 2) in 2003, 12.9% (SE 1.5) in 2005, and 14.2% (SE 1.0) in 2007 (Fig. 10.5.1c). In the 3 MARAMP survey years, observed coral cover was slightly higher in the east region than in other regions at Sarigan. For the 3 sites surveyed using the line-point-intercept method in 2007, coral cover ranged from 10.8% to 34.3%, with an overall sample mean of 21.2% (SE 9.6). Estimates of live coral cover from REA benthic surveys generally exceeded observations from towed-diver surveys because REA surveys target hard-bottom communities whereas towed-diver surveys include more variable substrate.

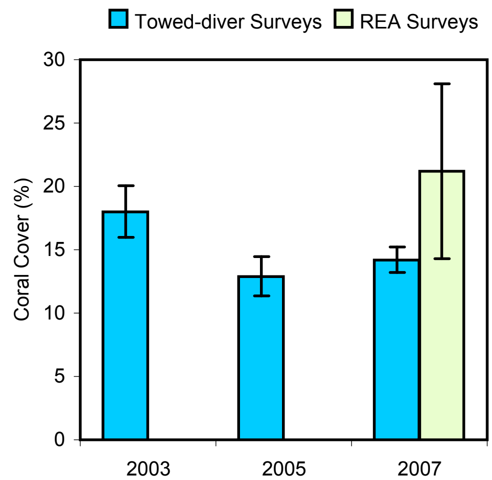


Figure 10.5.1c. Temporal comparison of mean live-coral-cover (%) values from REA and towed-diver benthic surveys conducted on forereef habitats around Sarigan during MARAMP 2003, 2005, and 2007. No REA coral-cover surveys using the line-point-intercept method were conducted at Sarigan in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

Overall mean coral-colony density from REA benthic surveys of forereef habitats at Sarigan did not vary substantially between the 3 MARAMP survey years witih overall sample means of 45.5 colonies m^{-2} (SE 8.1) in 2003, 58.3 colonies m^{-2} (SE 4.3) in 2005, and 56.5 colonies m^{-2} (SE 11.5) in 2007 (Fig. 10.5.1d). Increased colony density could be a result of increased recruitment, fragmentation of existing colonies, or both.

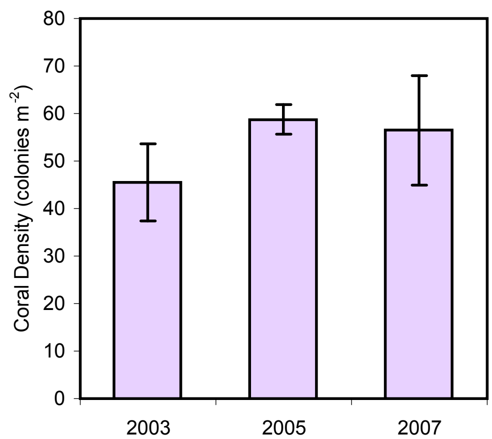


Figure 10.5.1d. Temporal comparison of mean coral-colony densities (colonies m^{-2}) from REA benthic surveys conducted on forereef habitats at Sarigan during MARAMP 2003, 2005, and 2007. The quadrat method was used in all survey years to measure coral-colony density. Error bars indicate standard error (± 1 SE) of the mean.

Coral Generic Richness and Relative Abundance

Three REA benthic surveys were conducted using the quadrat method at Sarigan during MARAMP 2003. At least 16 coral genera were observed at Sarigan. Generic richness ranged from 14 to 16 with a mean of 15.3 (SE 0.7) coral genera per site. Generic diversities were similar at all sites with 2 more genera recorded at SAR-01 and SAR-02, in the southwest and northwest regions, than at SAR-03 in the northwest region (Fig. 10.5.1e, top panel).

Pavona, Leptastrea, *Astreopora, Favia,* and *Porites* were the most numerically abundant genera, contributing 16.7%, 14.5%, 11%, 10.9%, and 10.5% of the total number of colonies enumerated at Sarigan in 2003. All other genera individually accounted for < 10% of the total number of colonies. *Leptastrea* dominated the coral fauna at SAR-01, contributing 27.8% of the total number of colonies recorded at that site. *Favia* dominated at SAR-02, accounting for 20.3% of the total number of colonies. *Pavona* dominated at SAR-03, contributing 15.4% of the total number of colonies.

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Sarigan during MARAMP 2005. At least 20 coral genera were observed at Sarigan. Generic richness was similar at all sites, ranging from 15 to 16 with a mean of 15.3 (SE 0.3) coral genera per site. One extra genus was recorded at SAR-02 in the northwest region than at SAR-01 and SAR-04 in the southwest and east regions (Fig. 10.5.1e, middle panel). *Porites, Pavona, Astreopora,* and *Favia* were the most numerically abundant genera, contributing 22%, 21.2%, 12.7%, and 9.9% of the total number of

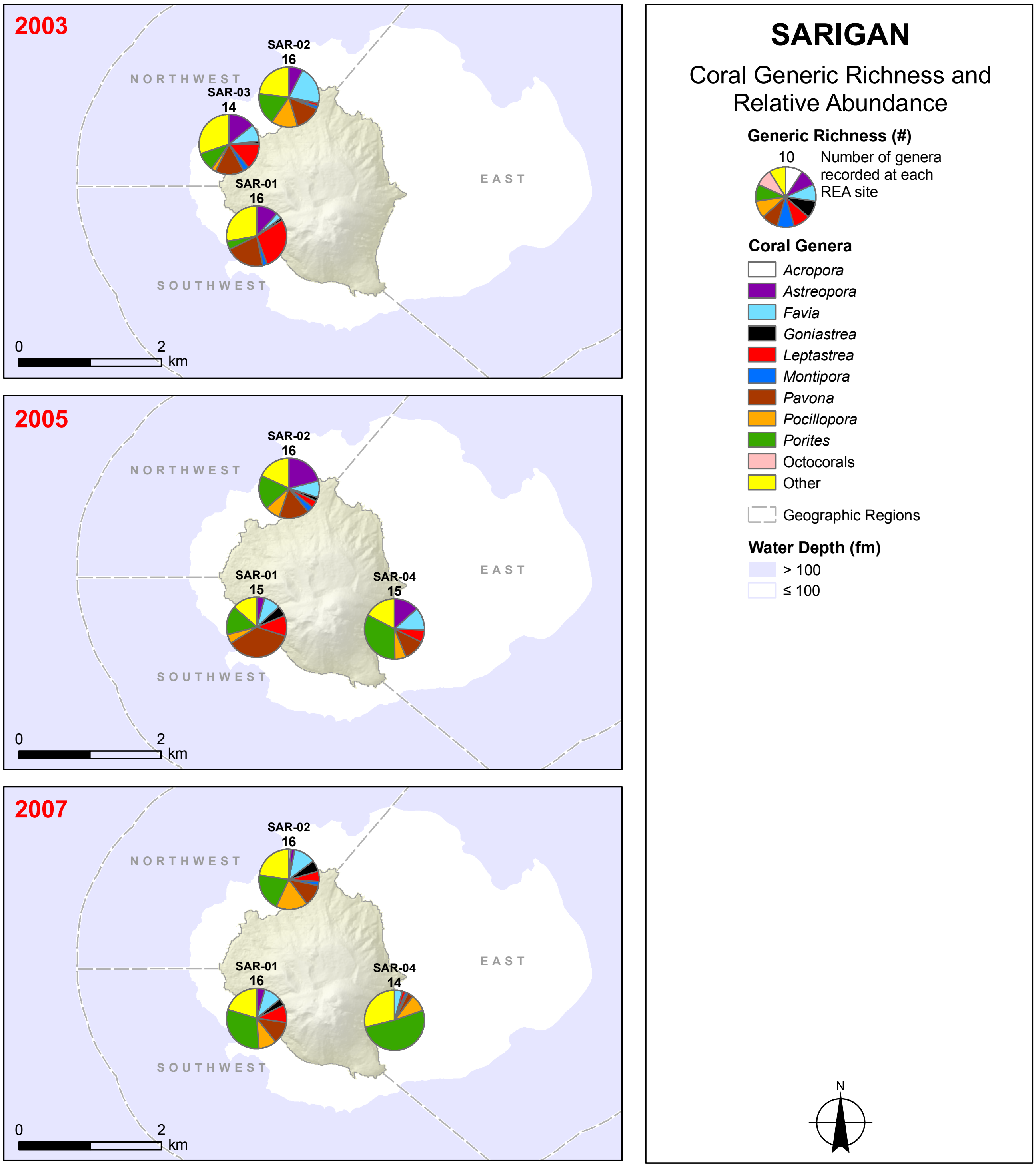


Figure 10.5.1e. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Sarigan during MARAMP 2003, 2005, and 2007. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in all survey years to survey coral genera.

colonies enumerated at Sarigan in 2005. All other genera individually accounted for < 10% of the total number of colonies. *Pavona* dominated at SAR-01, contributing 36.2% to the total number of colonies at that site. *Astreopora* dominated the coral fauna at SAR-02, accounting for 20.8% of the total number of colonies. *Porites* dominated at SAR-04, contributing 32.2% of the total number of colonies.

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Sarigan during MARAMP 2007. At least 19 coral genera were observed at Sarigan. Similar to the results from 2003 and 2005, little variation was observed between sites in generic richness, which ranged from 14 to 16 with a mean of 15.3 (SE 0.7) genera per site. The highest generic diversities were recorded at SAR-01 and SAR-02 in the southwest and northwest regions, and the lowest generic diversity was recorded at SAR-04 in the east region (Fig. 10.5.1e, middle panel). *Porites* and *Pocillopora* were the most numerically abundant genera, contributing 34.1% and 11.9% to the total number of colonies enumerated at Sarigan in 2007. All other genera individually accounted for < 10% of the total number of colonies. *Porites* dominated the coral fauna at all 3 REA sites (SAR-01, SAR-02 and SAR-04), contributing 31%, 20.2%, and 51.2% of the total number of colonies recorded at those sites.

Site-specific estimates of generic richness across the 3 MARAMP survey years ranged from 14 to 16 on forereef habitats at Sarigan. Site-specific and overall mean generic richness values were similar in the 3 years with means in a range of 15.3–15.5 genera per site (Fig, 10.5.1f). At each individual site, generic richness varied at most by one genus between successive survey periods. The quadrat method was used in the 3 survey years to assess generic richness.

Across the 3 MARAMP survey years, 25 coral genera were observed on forereef habitats at Sarigan. *Pavona* was the most abundant component of the coral fauna in 2003 surveys, contributing 16.7% of colonies enumerated at Sarigan and the second-most abundant taxon in 2005, accounting 21.2% of the total number of colonies. *Porites* contributed 22% in 2005 and 34.1% in 2007 to the total number of colonies enumerated. *Astreopora* was the third-most abundant taxon in 2003 and 2005, accounting for 11% and 12.7% of the total number of colonies. *Leptastrea* contributed 14.5% of the total number of colonies enumerated in 2003. *Favia* was the fourth-most numerically abundant taxon in 2003 and 2005, accounting for 11% and 10% of the total number of colonies enumerated. All other taxa contributed < 10% of the total number of colonies across the 3 survey years.

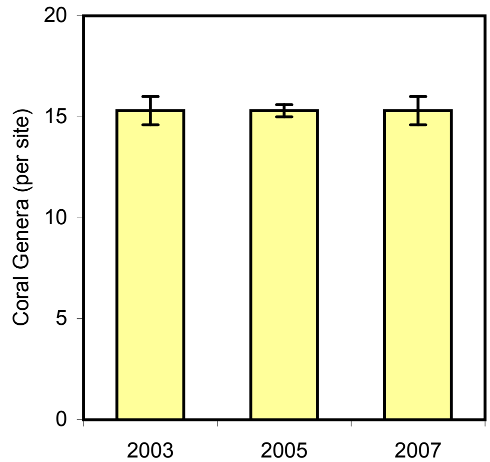


Figure 10.5.1f. Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on forereef habitats at Sarigan during MARAMP 2003, 2005, and 2007. The quadrat method was used in the 3 survey years to survey coral genera. Error bars indicate standard error (± 1 SE) of the mean.

Coral Size-class Distribution

During MARAMP 2003, 3 REA benthic surveys of forereef habitats were conducted at Sarigan using the quadrat method. The coral size-class distribution from these surveys shows that the majority (78.4%) of corals had maximum diameters ≤ 5 cm (Fig. 10.5.1g, top panel). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 15.7%, 4.6%, and 1.4% of colonies recorded. No colonies measuring > 40 cm maximum diameter were recorded. At all REA sites a majority (> 60%) of corals were in the smallest size class (0–5 cm).

During MARAMP 2005, 3 REA benthic surveys of forereef habitats were conducted at Sarigan using the quadrat method. The coral size-class distribution from these surveys shows that the majority (76.9%) of corals had maximum diameters ≤ 5 cm (Fig. 10.5.1g, middle panel). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 16.4%, 5.1%, and 1.7% of colonies recorded. No colonies measuring > 40 cm maximum diameter were recorded. At all REA sites a majority (> 70%) of corals were in the smallest size class (0–5 cm).

During MARAMP 2007, 3 REA benthic surveys of forereef habitats were conducted at Sarigan using the quadrat method. The coral size-class distribution from these surveys shows that the majority (69.4%) of corals had maximum diameters ≤ 5 cm (Fig. 10.5.1g, bottom panel). The next 4 size classes (6–10, 11–20, 21–40, and > 40 cm) accounted for 22.3%, 6.0%, 1.9%, and 0.4% of colonies recorded. At all REA sites a majority (> 60%) of corals were in the smallest size class (0–5 cm).

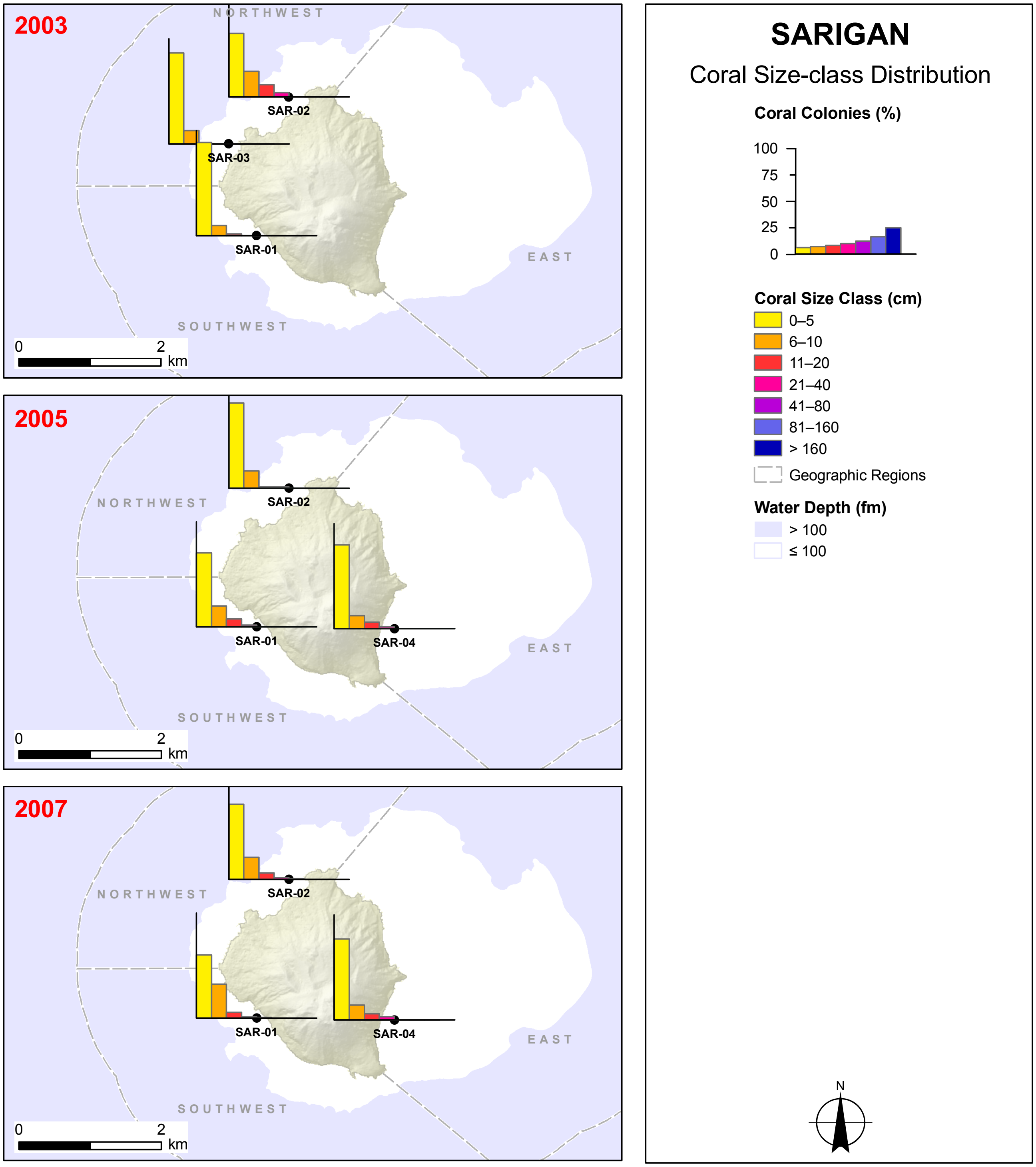


Figure 10.5.1g. Size-class distribution of hard corals from REA benthic surveys of forereef habitats conducted at Sarigan during MARAMP 2003, 2005, and 2007. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in all survey years to size corals.

Site-specific and overall distributions of estimated coral size classes on forereef habitats at Sarigan are affected by inherent biases in the method used to census and size corals. Corals whose center fell within the borders of a quadrat (50 × 50 cm) were tallied and measured in 2 planar dimensions to the nearest centimeter. Fewer large colonies than small colonies can fall within a quadrat. This bias can contribute to higher counts of colonies in the smallest size classes and lower counts of colonies in the largest size classes compared to the actual relative colony densities. At each site, 15 or 16 such quadrats were examined (total survey area = 3.75 or 4 m^2), enabling observers to closely inspect and record each coral colony within the quadrat. For more on this survey method, see Chapter 2, "Methods and Operational Background," Section 2.4.5: "Corals and Coral Disease."

In the 3 survey years, the majority of coral colonies were in the smallest size class (≤ 5 cm; Fig. 10.5.1h). The overall sample mean proportion of colonies in the smallest size class decreased slightly from 2003 to 2005 (78.4% and 76.9%, respectively), with a further small decrease by 2007 (69.4%). Variable patterns of change in the proportion of colonies in the smallest size class existed among sites surveyed in successive years. At SAR-01 in the southwest region, the observed proportion decreased between 2003 and 2005 and again in 2007. At SAR-02 in the northwest region, the proportion increased from 2003 to 2005 and then decreased in 2007. At SAR-04 in the east region, the proportions were nearly the same in 2005 and 2007. An increase in the proportion in the smallest size class may be a result of recruitment, fragmentation of existing colonies, or both, while a shift toward higher proportions in the larger size classes may reflect growth coupled with the absence of compensatory recruitment or fragmentation. Minor variations between years in size-class distribution likely derive from chance differences in the placement of individual quadrats. Thus, it appears from these data that variable dynamics of recruitment, fragmentation, and growth occurred among the 3 sites that were surveyed in more than one year.

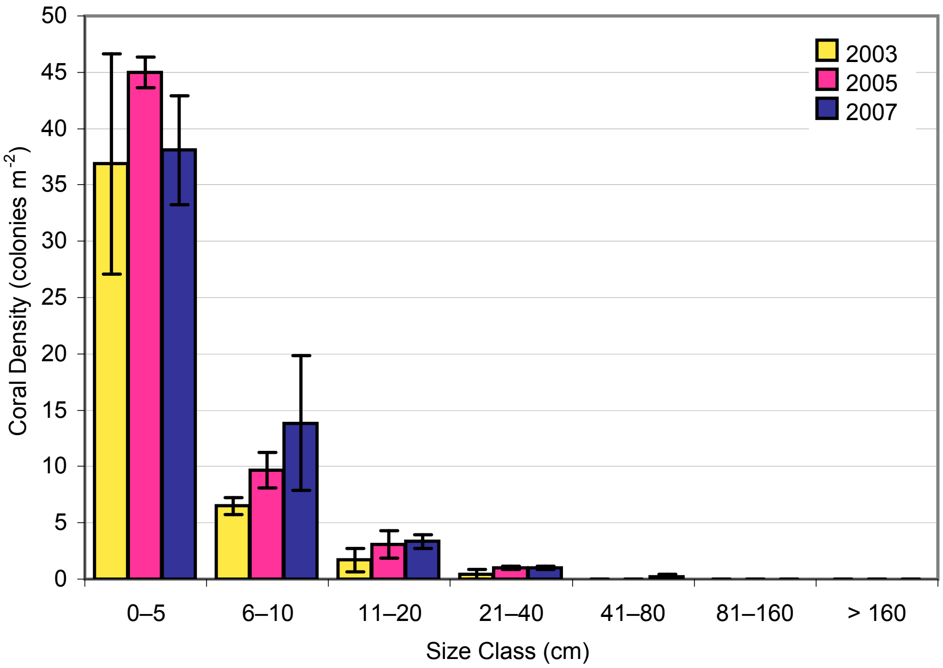


Figure 10.5.1h. Mean coral-colony densities (colonies m^{-2}) by size class from REA benthic surveys of forereef habitats conducted at Sarigan during MARAMP 2003, 2005, and 2007. The quadrat method was used in each of the 3 survey years to size corals. Error bars indicate standard error (± 1 SE) of the mean.

10.5.2 Surveys for Coral Disease and Predation

During MARAMP 2007, REA benthic surveys for coral disease and predation were conducted at 3 sites on forereef habitats at Sarigan, covering a total area of 900 m^2. Surveys detected 14 cases of disease, translating to an overall mean prevalence of 0.04% (SE 0.02). Coral-colony counts at all REA sites at Sarigan were conducted using the quadrat method, resulting in high coral-colony densities and, therefore, low disease prevalence values, relative to the levels found at sites at other islands surveyed using the belt-transect method.

Three disease conditions were observed at Sarigan: fungal infection, an infestation by the encrusting sponge *Terpios,* and bleaching. All 3 sites contained disease, however in low prevalences (Fig. 10.5.2a and b). Eight cases of fungal infection were recorded at Sarigan, with over 50% occurring at SAR-04, particularly on corals of the genus *Cyphastrea*. Cases of fungal infection were also present at SAR-01 and SAR-02. *Terpios* infestations were noticeable at SAR-04 and SAR-01 on a variety of coral genera including *Turbinaria*, *Porites*, *Montipora*, *Astreopora*, and *Pavona*. Finally, one case of bleaching was observed at SAR-02 in the northwest region. No signs of the crown-of-thorns seastar (*Acanthaster planci)* or corallivorous snail predation scars were noticed at the sites surveyed.

Figure 10.5.2a. Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys conducted at Sarigan during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site. The color-coded portions of the pie chart indicate disease-specific prevalence.

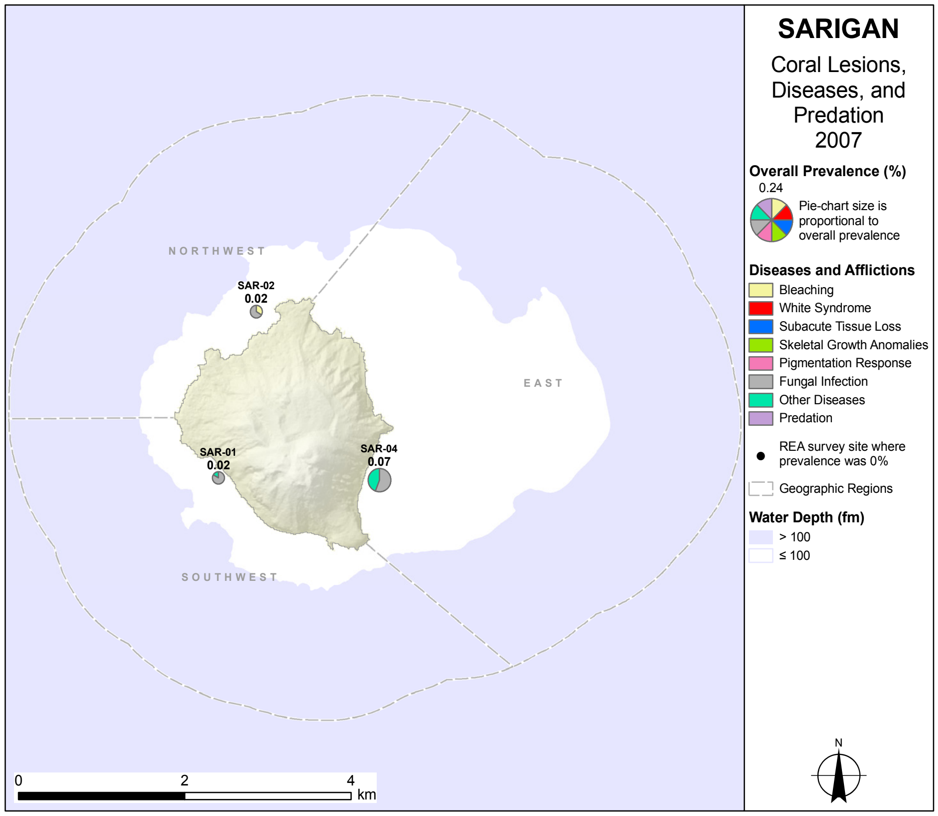
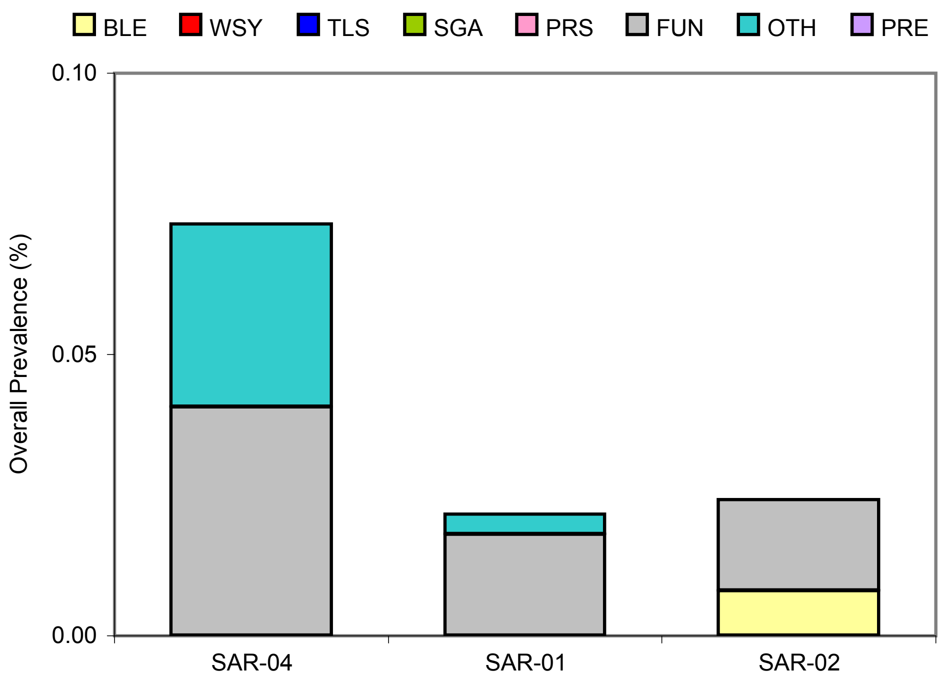


Figure 10.5.2b. Overall prevalence (%) observations of coral diseases and predation from REA surveys conducted at Sarigan during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site. The order of conditions presented in the bars is the same as the order in the legend. BLE: bleaching; WSY: white syndrome; TLS: subacute tissue loss; SGA: skeletal growth anomalies; PRS: pigmentation response; FUN: fungal infection; OTH: algal and cyanophyte infections and other lesions of unknown etiology; PRE: COTS or corallivorous snails.



10.6 Algae and Algal Disease

10.6.1 Algal Surveys

Algal Cover: Macroalgae and Turf Algae

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on forereef habitats around the island of Sarigan was 42% (SE 2.1). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. Two surveys had the highest mean macroalgal cover of 49%, within a range of 30.1%–75%. The first of these surveys was completed on a track that straddled the southwest and northwest regions, over predominantly pavement and rock boulder habitat of medium-high complexity for 7 survey segments and low to medium-low complexity for 3 segments (Fig. 10.6.1a, top left panel). The second survey traversed the border of the northwest and east regions, beginning near the northern tip of this island. The lowest mean macroalgal cover from a towed-diver survey with was 33.7%, within a range of 20.1%–50%, recorded in the northwest region, also near the northern tip of Sarigan.

TOAD surveys completed at Sarigan during MARAMP 2003 were conducted at depths of 78–207 m. Analyses of TOAD video footage obtained from a survey conducted south of Sarigan, in the southwest region at depths of 78–100 m, suggested that macroalgal cover was high with 60%–100%, at least as observable from a majority of images (Fig. 10.6.1a, top left panel). Two short surveys, 1 in the northwest region and 1 in the southwest region, were less successful with only 9 video frames successfully classified; no macroalgae were observed within these images.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on forereef habitats around Sarigan was 24% (SE 2.3). The survey with the highest mean macroalgal cover of 40.1%, within a range of 30.1%–62.5%, occurred along the west side and crossed the border between the southwest and northwest regions (Fig. 10.6.1a, middle left panel). Habitat of medium complexity was found throughout this survey. The lowest mean macroalgal cover from a towed-diver survey was 3.1%, within a range of 1.1%–10%, recorded along the northern shoreline and across the border between the east and northwest regions.

From MARAMP 2007 towed-diver surveys, mean cover of macroalgae on forereef habitats around Sarigan was 16% (SE 1.1). The survey with the highest mean macroalgal cover of 24.2%, within a range of 5.1%–40%, occurred in the northwest region (Fig. 10.6.1a, bottom left panel). Habitat in the middle of this survey was characterized by a steep wall; however, the remaining survey area had habitat of medium complexity over continuous reef strewn with boulders. The lowest mean macroalgal cover from a towed-diver survey was 11.5%, within a range of 10.1%–30%, recorded on the west coast, crossing the border between the southwest and northwest regions. This survey recorded medium-complexity habitat of large boulders on one half and continuous reef on the other half, with cyanobacteria found in the middle of this survey.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats at Sarigan were conducted using the line-point-intercept method. Site-specific estimates of macroalgal cover ranged from 0% to 15.7% with an overall sample mean of 5.9% (SE 4.9). The survey with the highest macroalgal cover occurred at REA site SAR-02 in the northwest region (Fig. 10.6.1b). No macroalgae were recorded in the east region at SAR-04. Macroalgal cover was low at 2% at SAR-01 in the southwest region.

Turf-algal cover from these REA benthic surveys ranged from 31.4% to 45.1% with an overall sample mean of 39.5% (SE 4.2). The highest turf-algal cover was observed at SAR-01 in the southwest region (Fig. 10.6.1b). The survey with the lowest turf-algal cover occurred in the northwest region at SAR-02.

Algal Cover: Crustose Coralline Red Algae

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Sarigan was 11% (SE 1.1). The survey with the highest mean crustose-coralline-red-algal cover of 19%, within a range of 10.1%–30%, occurred in the southwest region (Fig. 10.6.1a, top right panel) over rock boulder and pavement habitat of medium-high complexity. The lowest mean cover of crustose coralline red algae from a towed-diver survey was 3.5%, within a range of 1.1%–10%, recorded along the northern coast across the border between the east and northwest regions.

From MARAMP 2005 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Sarigan was 3% (SE 0.7). The survey with the highest mean crustose-coralline-red-algal cover of 6.8%, within a range of 0.1%–

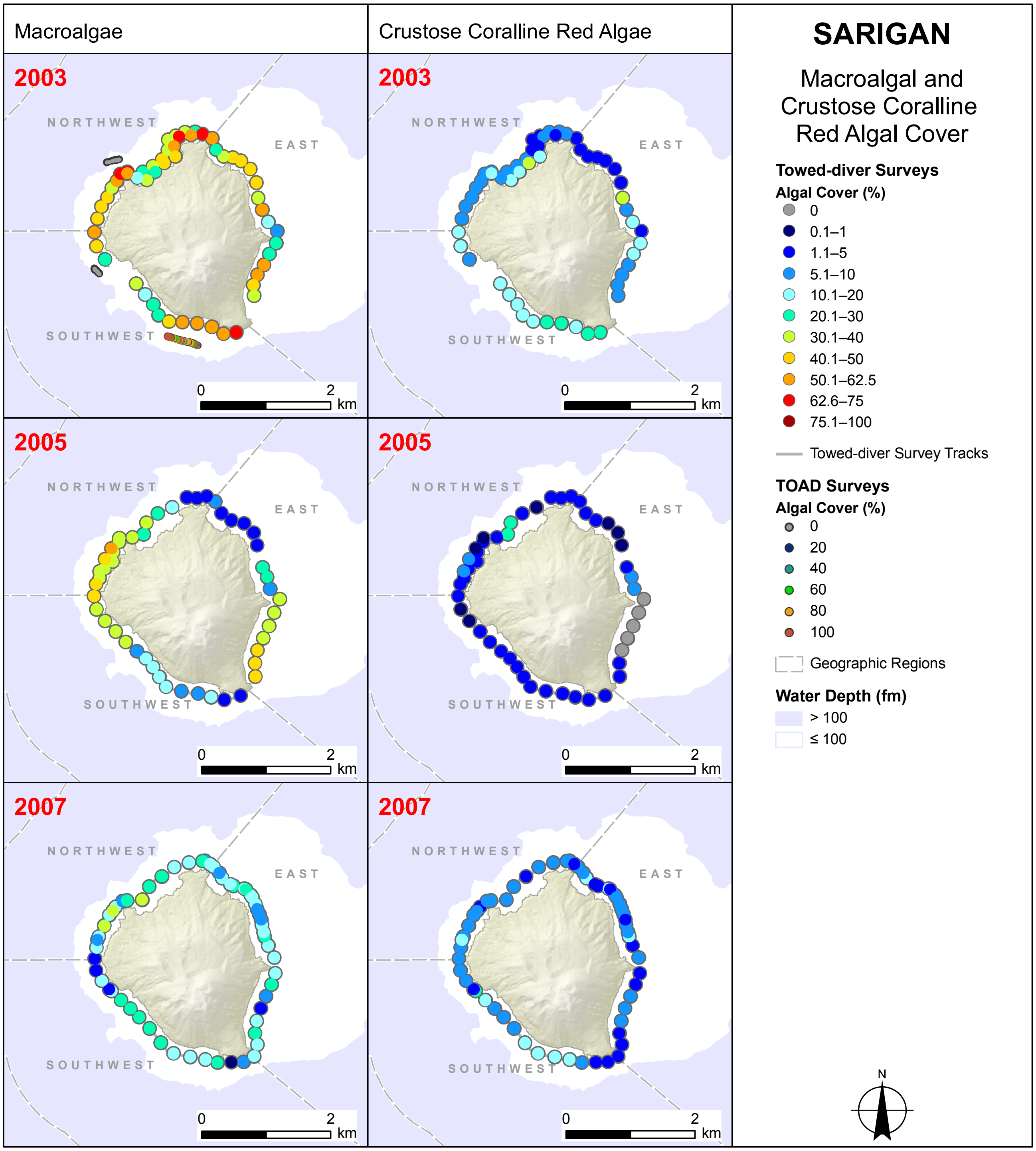


Figure 10.6.1a. Cover (%) observations for macroalgae and crustose coralline red algae from towed-diver benthic surveys of forereef habitats conducted around Sarigan during MARAMP 2003, 2005, and 2007. Each large, colored point represents an estimate over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m²). The 2003 macroalgal panel shows observations of both macroalgae and turf algae (towed-diver surveys included turf algae only during MARAMP 2003). In this panel, each small, colored point represents an estimate of algal cover from TOAD surveys.

30%, occurred in the northwest region (Fig. 10.6.1a, middle right panel). The lowest mean cover of crustose coralline red algae from a towed-diver survey was 1.8%, within a range of 0.1%–5%, recorded in the east region.

From MARAMP 2007 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Sarigan was 8% (SE 0.6). The survey with the highest mean crustose-coralline-red-algal cover of 13%, within a range of 5.1%–30%, occurred in the southwest region (Fig. 10.6.1a, bottom right panel). Habitat consisted primarily of medium to medi-

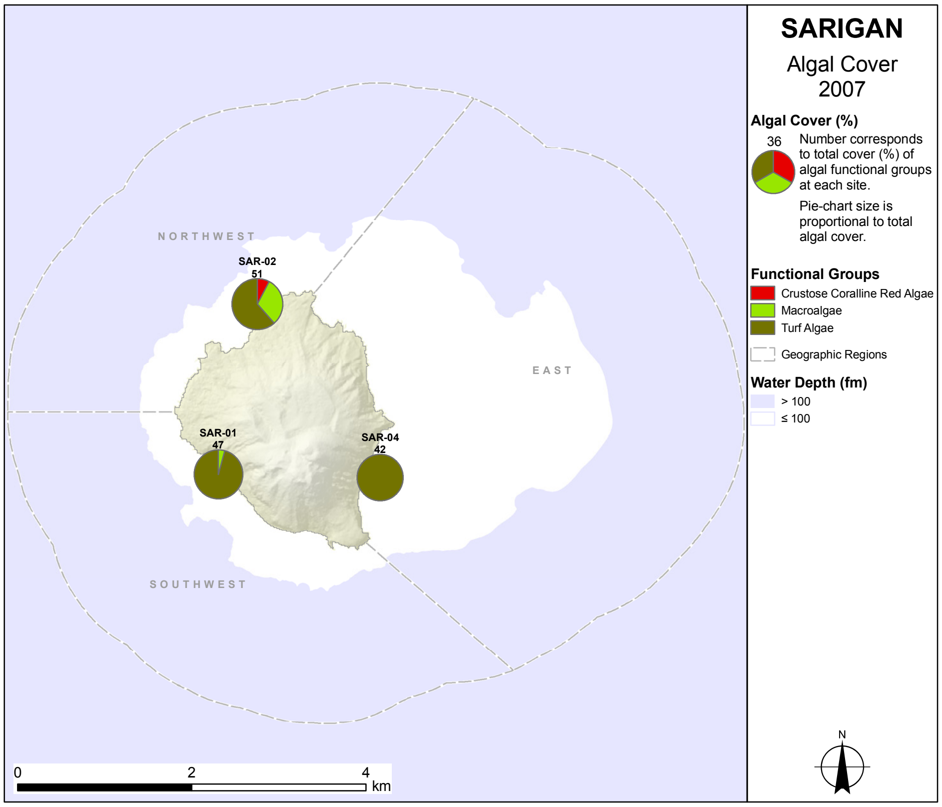


Figure 10.6.1b. Observations of algal cover (%) from REA benthic surveys of forereef habitats conducted using the line-point-intercept method at Sarigan during MARAMP 2007. The pie charts indicate algal cover by functional group, and values of total algal cover are provided above each symbol.

um-high complexity boulder reef on moderately sloped habitat, shifting to continuous reef and boulders in sand (boulder patch reef). The lowest mean cover of crustose coralline red algae from a towed-diver survey was 2.7%, within a range of 0.1%–10%, recorded in the northwest region.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats at Sarigan were conducted using the line-point-intercept method. Site-specific estimates of crustose-coralline-red-algal cover ranged from 0% to 3.9% with an overall sample mean of 1.3% (SE 0.9). The survey with the highest crustose-coralline-red-algal cover occurred at SAR-02 (Fig. 10.6.1b). No crustose coralline red algae were recorded at SAR-01 in the southwest region or SAR-04 in the east region.

Algal Cover: Temporal Comparison

Between MARAMP 2005 and 2007, islandwide mean cover of macroalgal populations around Sarigan, based on towed-diver surveys of forereef habitats, was lower in 2007 than in 2005 with means of 24% (SE 2.3) in 2005 and 16% (SE 1.1) in 2007 (Fig. 10.6.1c). When considering survey results, keep in mind that turf algae were included, along with macroalgae, in towed-diver surveys of macroalgal cover only in 2003. Other factors, such as a change in season between survey periods, could have contributed to differences in algal cover (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Between MARAMP survey years, no area at Sarigan consistently had the highest or lowest macroalgal cover recorded during towed-diver survey. A survey area that crossed the border between the southwest and northwest regions had the highest levels of macroalgal cover recorded in both 2003 and 2005 with means of 49% and 40.1%, but the survey

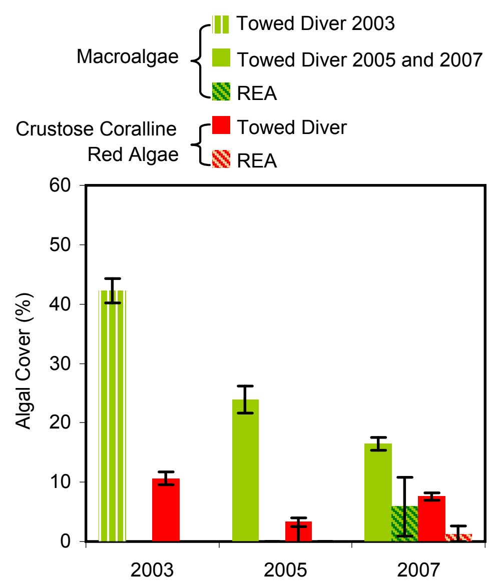


Figure 10.6.1c. Temporal comparison of algal-cover (%) values from surveys conducted on forereef habitats around Sarigan during MARAMP 2003, 2005, and 2007. Values of macroalgal cover from towed-diver surveys include turf algae only in 2003. No REA surveys using the line-point-intercept method were conducted in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

completed in that same area in 2007 had the lowest macroalgal cover for that survey year with a mean of 11.5%.

Crustose-coralline-red-algal populations around Sarigan, based on towed-diver surveys of forereef habitats, varied by as much as 8% in average cover of the benthos between MARAMP survey years, with islandwide means of 11% (SE 1.1) in 2003, 3% (SE 0.7) in 2005, and 8% (SE 0.6) in 2007. During MARAMP 2003 and 2007 survey years, the highest mean crustose-coralline-red-algal cover occurred in the southwest region. In each of the 3 survey periods, the lowest cover of crustose coralline red algae was found near the northern tip of Sarigan in either the northwest or east regions.

REA surveys using the line-point-intercept method were conducted only in 2007. Values for both macroalgal and crustose-coralline-red-algal cover from these surveys were lower than results from towed-diver surveys.

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 is about 90% complete for the northern islands of the Mariana Archipelago with hundreds of species identified so far. Ultimately, based on this microscopic analysis, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2003, REA benthic surveys were conducted at 3 sites on forereef habitats at Sarigan. In the field, 5 macroalgal genera (1 red and 4 green), containing at least 7 species, as well as 2 additional algal functional groups—turf algae and cyanobacteria—were observed. SAR-02 in the northwest region had the highest macroalgal generic diversity with 4 genera, containing 6 species, documented in the field. The lowest macroalgal diversity was found at SAR-03, also located in the northwest region, with 1 species representing 1 genus recorded.

Species of the green algal genus *Boodlea* were common at every site surveyed at Sarigan in 2003, occurring in 22.2% of sampled photoquadrats, and this genus was the only one to occur at all sites. Species of the calcified, red algal genus *Amphiroa* and 3 species of the calcified, green algal genus *Halimeda* were equally abundant, each occurring in 16.7% of sampled photoquadrats (Fig. 10.6.1d, top panel). However, species of *Amphiroa* and *Halimeda* did not occur at SAR-03 in the northwest region, where species of *Boodlea* were the only macroalgae observed. Two other green algal genera were recorded in 2003, *Chlorodesmis* and *Valonia* (previously recognized as *Ventricaria*); they were found in low abundance compared to *Boodlea*, occurring in only 8.3% of the photoquadrats sampled at the sites where they were observed.

Turf algae were exceptionally common in 2003, occurring in 94.4% of photoquadrats sampled at Sarigan (Fig. 10.6.1d, top panel). Crustose coralline red algae were absent at all sites. Cyanobacteria were less common compared to turf algae, occurring in 19.4% of sampled photoquadrats. Turf-algal communities were ubiquitous and extremely common at all sites, and although cyanobacteria also were observed at all sites, this functional group was much more abundant in the northwest region at SAR-03, where it occurred in 41.7% of sampled photoquadrats, than in the southwest and northwest regions, where cyanobacteria occurred in only 8.3% of photoquadrats sampled at SAR-01 and SAR-02.

During MARAMP 2005, REA benthic surveys were conducted at 3 sites on forereef habitats at Sarigan. In the field, 11 macroalgal genera (4 red, 5 green, and 2 brown), containing at least 12 species, as well as 2 additional algal functional groups—turf algae and crustose coralline red algae—were observed. SAR-01 in the southwest region had the highest macroalgal generic diversity with 8 genera, containing 8 species, documented in the field. The lowest macroalgal generic diversity was found at SAR-02 in the northwest region and SAR-04 in the east region, each with 6 genera representing 6 species recorded.

Of the 11 different genera identified in the field at Sarigan in 2005, 7 occurred in > 10% of sampled photoquadrats. Species of the red algal genus *Jania* were common at all 3 sites surveyed, occurring in 52.8% of sampled photoquadrats (Fig. 10.6.1d, middle panel). This genus was observed in particularly high abundance at SAR-04 in the east region and SAR-01 in the southwest region, occurring in 75% and 58.3% of sampled photoquadrats, but was found in only 25% of photoquadrats sampled at SAR-02 in the northwest region. At SAR-02, 4 genera—*Jania*, *Amphiroa, Chlorodesmis*, and *Halimeda*—were seen in 25% of sampled photoquadrats. The only other genus observed at all sites was the brown algal genus *Dictyota*, recorded in 19.4% of photoquadrats sampled at Sarigan. Another brown algal genus, *Lobophora*, occurred in a greater percentage of sampled photoquadrats than did *Dictyota*, even though it was only found at 2 sites and only in high abundance (75%) at SAR-01. The green algal genus *Bryopsis* occurred in 22.2% of sampled photoquadrats; however, this genus was only observed at SAR-04, where it occurred in 66.7% of sampled photoquadrats, second to *Jania* at that site. The genera *Chlorodesmis, Amphiroa,* and *Halimeda* occurred in 16.7%, 11.1% and 11.1% of sampled photodquarats and were the only genera to occur at SAR-01 and SAR-02 in 2005.

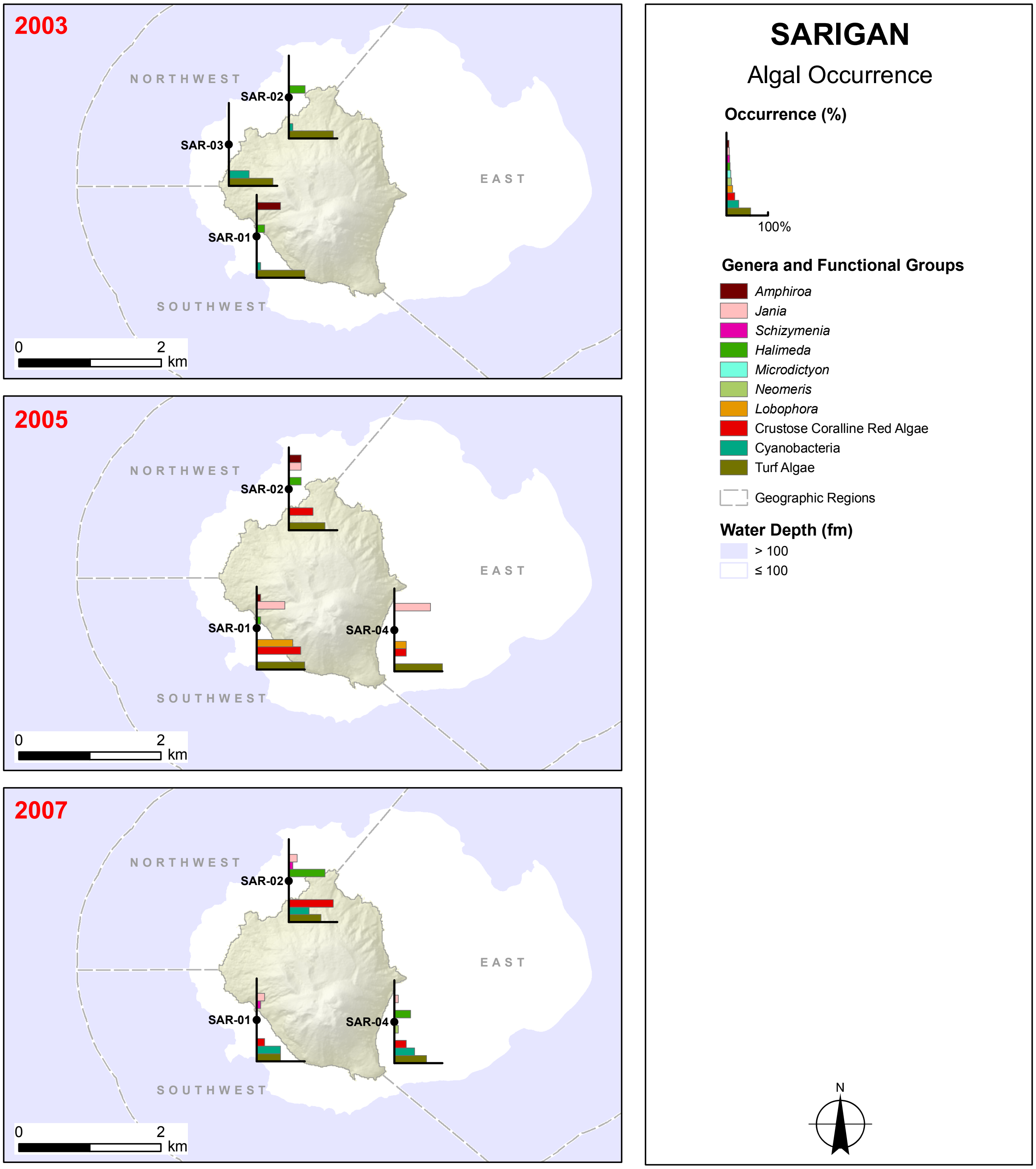


Figure 10.6.1d. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA algal surveys of forereef habitats conducted at Sarigan during MARAMP 2003, 2005, and 2007. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

Turf algae and crustose coralline red algae were both common in 2005, occurring in 91.7% and 55.6% of photoquadrats sampled at Sarigan (Fig. 10.6.1d, middle panel). Turf-algal communities, ubiquitous at all sites, were found in 75%–100% of sampled photoquadrats. Also observed at all sites, crustose coralline red algae were present in 25%–91.7% of sampled photoquadrats. The absence of cyanobacteria in MARAMP 2005 surveys conducted at Sarigan is peculiar; however, an alga unidentifiable to the scientist completing REA benthic surveys at Sarigan was recorded at roughly the same abundance levels observed for cyanobacteria in 2003 (occurrence values of 8.3%–16.7%), and it is possible that this "mystery alga" was cyanobacteria.

During MARAMP 2007, REA algal surveys were conducted at 3 sites on forereef habitats around Sarigan. In the field, 9 macroalgal genera (3 red, 4 green, and 2 brown), containing at least 9 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanobacteria—were observed. SAR-02 in the northwest region and SAR-04 in the east region each contained 5 distinct macroalgal genera, representing 5 species. A slightly lower algal diversity was found at SAR-01 with 4 species representing 4 genera.

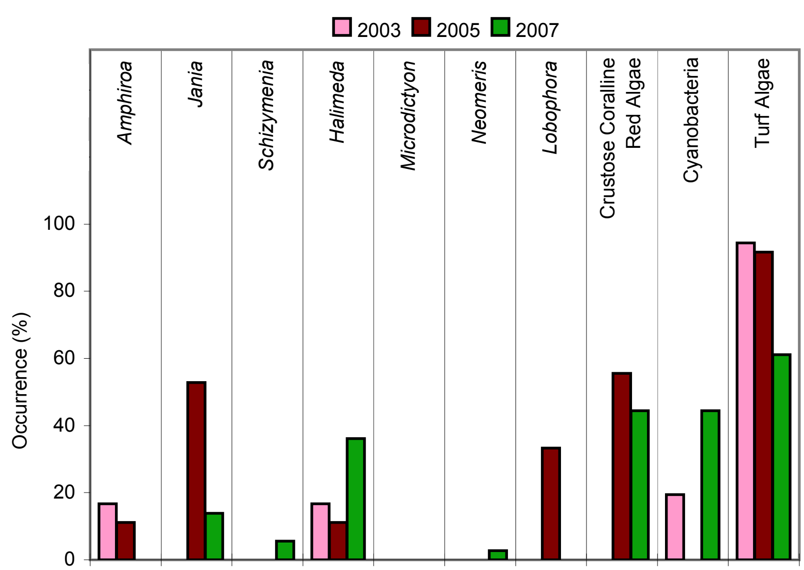
The genus *Halimeda* was the most common macroalgal genus at Sarigan in 2007, occurring in 36.1% of sampled photoquadrats (Fig. 10.6.1d, bottom panel). This genus was recorded in high abundance at SAR-02 and SAR-04 in the northwest and east regions, seen in 75% and 33.3% of sampled photoquadrats, but was not found at SAR-01 in the southwest region. A similar pattern was observed for the genus *Boodlea,* which also was recorded only at SAR-02 and SAR-04; this genus occurred in 50% of photoquadrats sampled at each of these sites. The genus *Jania* was the only algal genus observed in the field at all 3 sites, occurring in 13.9% of sampled photoquadrats islandwide with site-specific occurrence values of 8.3%–16.7%.

Turf algae, crustose coralline red algae, and cyanobacteria were all common in 2007, occurring in 61.1%, 44.5%, and 44.4% of photoquadrats sampled at Sarigan (Fig. 10.6.1d, bottom panel). Crustose-coralline-red-algal communities were ubiquitous at all sites, although occurrence values varied substantially within a range of 16.7%–91.7%. Turf algae and cyanobacteria, also prominent components of the algal community at all sites, were observed in 50%–66.7% and 41.7%–50% of sampled photoquadrats.

The number of macroalgal genera recorded on forereef habitats around Sarigan increased from 5 in 2003 to 11 in 2005 but decreased to 9 in 2007. The substitution of SAR-04 in the east region for SAR-03 in the northwest region after MARAMP 2003 may account for some of this change in algal diversity. In both 2005 and 2007, 5 macroalgal genera were found at SAR-04, compared to observations of just a single genus and species at SAR-03 in 2003. Macroalgal diversity at SAR-01 and SAR-02 was lower in 2003 and 2007 than in 2005. The genus *Halimeda* was the only taxon that was observed in each of the 3 MARAMP survey years, suggesting that the diversity of the marine flora at Sarigan may be influenced by seasonal variability. Subsequent surveys may provide additional insight into this hypothesis.

Turf algae was recorded in 61.1%–94.4% of photoquadrats sampled at Sarigan during MARAMP 2003, 2005, and 2007, with the greatest occurrence recorded in 2003 and the lowest in 2007 (Fig. 10.6.1e). Because identical site locations were

Figure 10.6.1e. Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional groups conducted on forereef habitats at Sarigan during MARAMP 2003, 2005, and 2007.



surveyed in both 2005 and 2007, the reduction in occurrence from 91.7% to 61.1% could indicate loss of benthic turf-algal cover; however, it is important to consider seasonal variability as a potential explanation since MARAMP 2005 surveys were conducted in September and MARAMP 2007 surveys were conducted in May. No trends showing increasing or decreasing abundance of the functional groups crustose coralline red algae or cyanobacteria were obvious.

10.6.2 Surveys for Coralline-algal Disease

During MARAMP 2007, REA benthic surveys for coralline-algal disease were conducted in concert with coral-disease assessments at 3 sites on forereef habitats at Sarigan. These surveys covered a total reef area of ~ 900 m^{-2} and detected no cases of coralline-algal disease.

10.7 Benthic Macroinvertebrates

10.7.1 Benthic Macroinvertebrates Surveys

Four groups of benthic macroinvertebrates—sea urchins, sea cucumbers, giant clams, and crown-of-thorns seastars (COTS)—were monitored on forereef habitats around the island of Sarigan through benthic REA and towed-diver survey methods during MARAMP 2003, 2005, and 2007. This section describes by group the results of these surveys. A list of additional taxa observed during REA invertebrate surveys is provided in Chapter 3: "Archipelagic Comparisons."

Monitoring these 4 groups of ecologically and economically important taxa provides insight into the population distribution, community structure, and habitats of the coral reef ecosystems of the Mariana Archipelago. High densities of the corallivorous COTS can affect greatly the community structure of reef ecosystems. Giant clams are filter feeders that are sought after in the Indo-Pacific for their meat, which is considered a delicacy, and for their shells. Sea cucumbers, sand-producing detritus foragers, are harvested for food. Sea urchins are important algal grazers and bioeroders.

In 2003, 3 REA benthic surveys and 6 towed-diver surveys were conducted around Sarigan, and, in 2005, 3 REA surveys and 5 towed-diver benthic surveys were performed. In 2007, 3 REA surveys and 6 towed-diver benthic surveys were completed around Sarigan. When considering survey results from towed-diver surveys, keep in mind that cryptic or small organisms can be difficult for divers to see, so the density values presented in this report, especially of giant clams and sea urchins, may under-represent the number of individuals present.

Overall, both REA and towed-diver surveys revealed low daytime macroinvertebrate abundance on forereef habitats around Sarigan. Minor fluctuations in densities between MARAMP survey periods occurred with all target groups. Temporal patterns of islandwide mean macroinvertebrate density on forereef habitats around Sarigan—from towed-diver benthic surveys during MARAMP 2003, 2005, and 2007—are shown later in this section (Figs. 10.7.1b, d, f, and h).

Giant Clams

During MARAMP 2003, species of *Tridacna* giant clams were observed at all 3 REA sites surveyed and in 4 of the 6 towed-diver surveys conducted around Sarigan (Fig. 10.7.1a, top panel). The overall sample mean density of giant clams from REA surveys was 5.67 organisms 100 m^{-2} (SE 1.4), and the islandwide mean density from towed-diver surveys was 0.03 organisms 100 m^{-2} (SE 0.01). Survey results suggest giant clams were most abundant along the western half of this island. The highest density among REA sites at Sarigan, at 8 organisms 100 m^{-2}, was recorded at REA site SAR-01 in the southwest region. Among all towed-diver surveys around this island, the survey completed in the northwest region had the highest mean density of giant clams with 0.09 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.3 organisms 100 m^{-2}.

During MARAMP 2005, giant clams were observed at 2 of the 3 REA sites surveyed and in 4 of the 5 towed-diver surveys conducted around Sarigan (Fig. 10.7.1a, middle panel). The overall sample mean density of giant clams from REA surveys was 1.67 organisms 100 m^{-2} (SE 1.20), and the islandwide mean density from towed-diver surveys was 0.097 organisms 100 m^{-2} (SE 0.01). The highest density among REA sites, at 4 organisms 100 m^{-2}, was recorded at SAR-01. Among all towed-diver surveys around this island, the surveys completed in the northwest region had the highest mean density of giant clams with 0.17 and 0.13 organisms 100 m^{-2}; segment densities from these surveys ranged from 0 to 0.56 organisms 100 m^{-2}.

During MARAMP 2007, giant clams were observed at all 3 REA sites surveyed and in all 6 towed-diver surveys conducted around Sarigan (Fig. 10.7.1a, bottom panel). The overall sample mean density of giant clams from REA surveys was 1.47 organisms 100 m^{-2} (SE 0.59), and the islandwide mean density from towed-diver surveys was 0.05 organisms 100 m^{-2} (SE 0.01). The highest density among REA sites, at 2.33 organisms 100 m^{-2}, was recorded at SAR-04 in the southeast. Among all towed-diver surveys around this island, the survey completed across the border between the southwest and northwest regions had the highest mean density of giant clams with 0.13 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.29 organisms 100 m^{-2}.

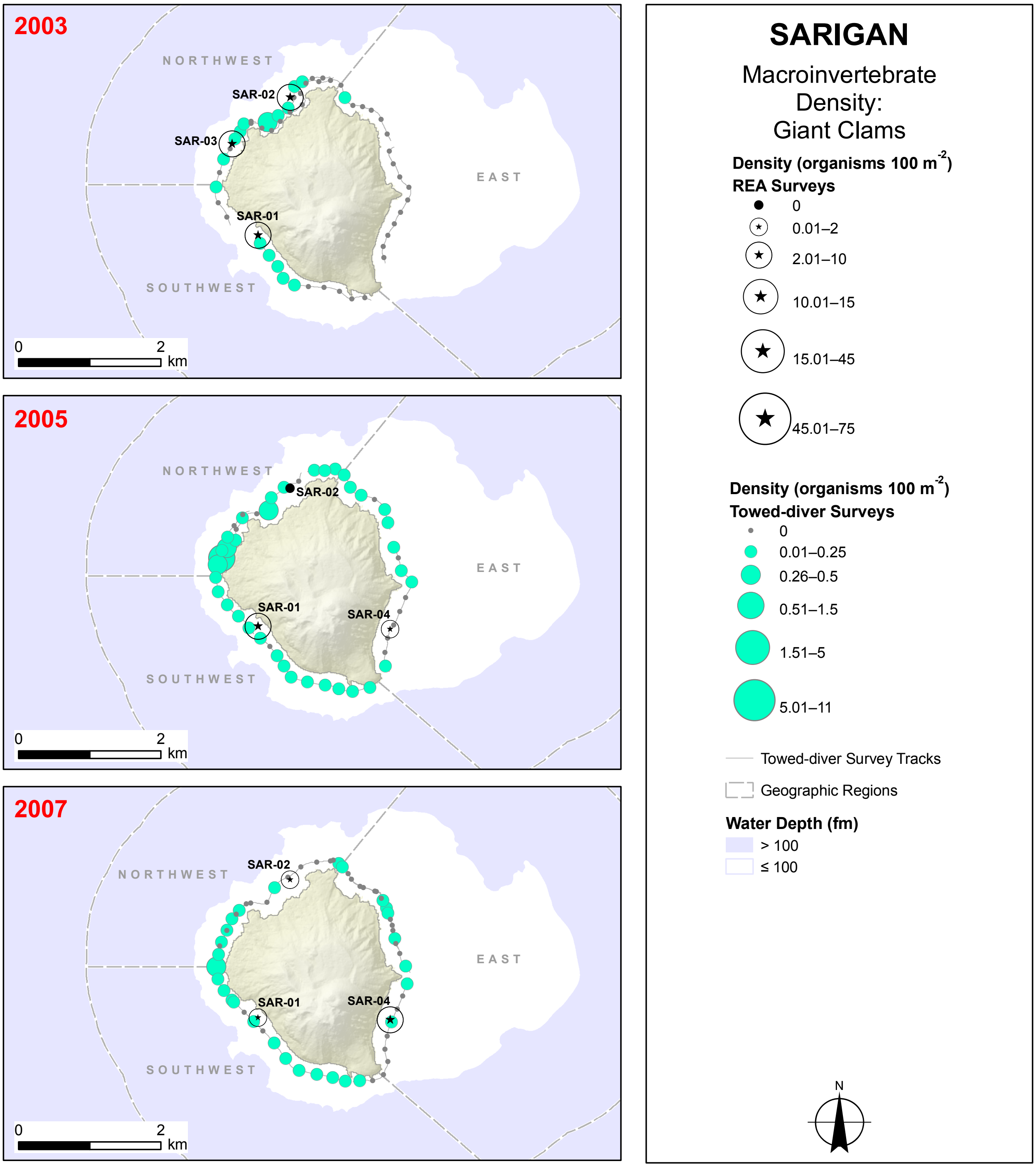


Figure 10.7.1a. Densities (organisms 100 m^{-2}) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Sarigan during MARAMP 2003, 2005, and 2007.

Towed-diver surveys suggested low abundance of giant clams around Sarigan during the 3 MARAMP survey periods. In each survey year, densities of giant clams were greater along the western half of this island than on the east side. The overall observed mean density of giant clams was higher in 2005 than in 2003 and 2007 (Fig. 10.7.1b). Minor fluctuations in density are not necessarily indicative of changes in the population structure of giant clams (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

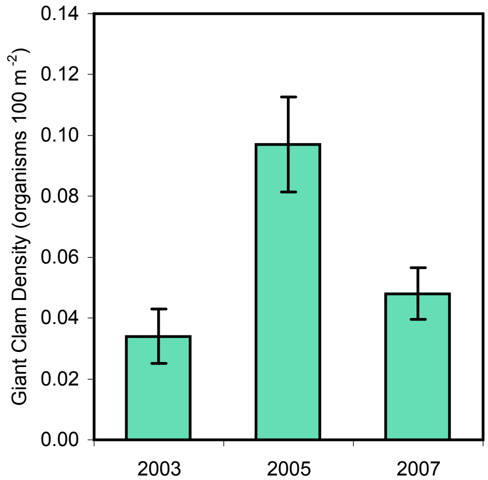


Figure 10.7.1b. Temporal comparison of mean densities (organisms 100 m^{-2}) of giant clams from towed-diver benthic surveys conducted on forereef habitats around Sarigan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Crown-of-thorns Seastars

During MARAMP 2003, no crown-of-thorns seastars (*Acanthaster planci*) were observed at the 3 REA sites surveyed at Sarigan, and only 1 of the 6 towed-diver surveys had recordings of COTS (Fig. 10.7.1c, top panel). This towed-diver survey in the southwest region had a mean density of 0.002 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.05 organisms 100 m^{-2}.

During MARAMP 2005, no COTS were observed at the 3 REA sites surveyed at Sarigan, and only 1 of the 5 towed-diver surveys had recordings of COTS (Fig. 10.7.1c, middle panel). This towed-diver survey in the southwest region had a mean density of 0.001 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.06 organisms 100 m^{-2}.

During MARAMP 2007, no COTS were observed at the 3 REA sites surveyed or in any of the towed-diver surveys conducted around Sarigan (Fig. 10.7.1c, bottom panel).

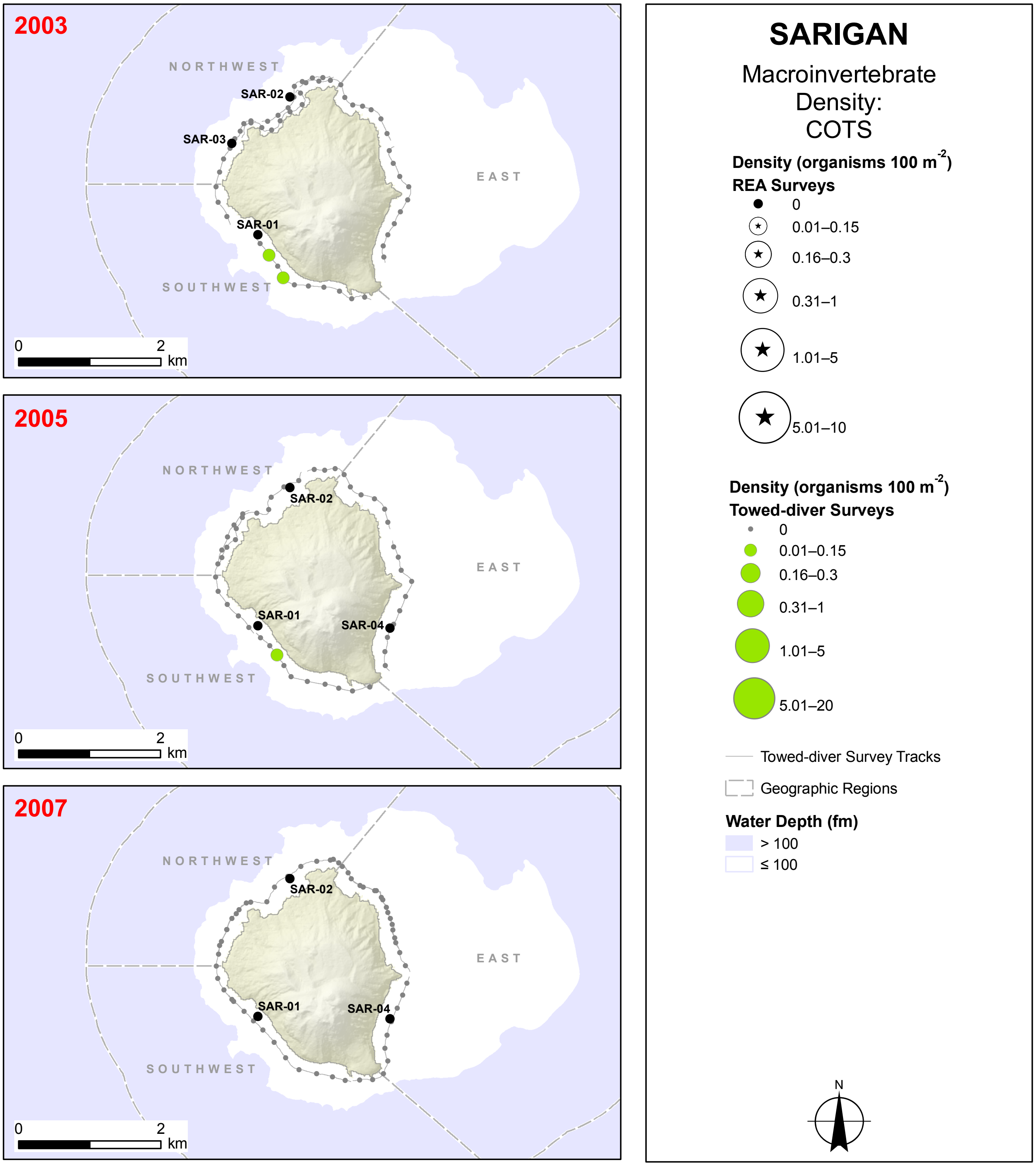


Figure 10.7.1c. Densities (organisms 100 m^{-2}) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted around Sarigan during MARAMP 2003, 2005, and 2007.

Towed-diver benthic surveys revealed virtually no COTS at Sarigan during the 3 MARAMP survey years (Fig. 10.7.1d). In 2003 and 2005, COTS were observed only in the southwest region at very low densities.

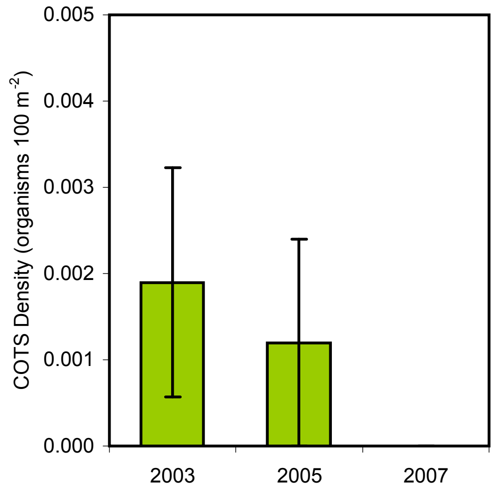


Figure 10.7.1d. Temporal comparison of COTS mean densities (organisms 100 m^{-2}) from towed-diver benthic surveys conducted on forereef habitats around Sarigan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Sea Cucumbers

During MARAMP 2003, sea cucumbers were observed at 2 of the 3 REA sites surveyed and in 5 of the 6 towed-diver surveys conducted around Sarigan (Fig. 10.7.1e, top panel). The overall sample mean density from REA surveys was 0.67 organism 100 m^{-2} (SE 0.33), and the islandwide mean density of sea cucumbers from towed-diver surveys was 0.55 organisms 100 m^{-2} (SE 0.22). Species from 2 genera were observed during REA surveys: *Stichopus* and *Actinopyga.* Among all towed-diver surveys around Sarigan, the survey completed in the northwest region had the highest mean density of sea cucumbers with 2.02 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 10.94 organisms 100 m^{-2}. The second-greatest mean density of sea cucumbers from a towed-diver survey was 1.09 organisms 100 m^{-2}, recorded along the north shore; segment densities from this survey ranged from 0.23 to 4.16 organisms 100 m^{-2}.

During MARAMP 2005, sea cucumbers were observed at 2 of the 3 REA sites surveyed and in 4 of the 5 towed-diver surveys conducted around Sarigan (Fig. 10.7.1e, middle panel). The overall sample mean density from REA surveys was 2 organisms 100 m^{-2} (SE 1.53), and the islandwide mean density of sea cucumbers from towed-diver surveys was 0.22 organisms 100 m^{-2} (SE 0.07). The highest density of sea cucumbers was observed at SAR-01 in the southwest region with 5 organisms 100 m^{-2}—all of which were from the genus *Stichopus*. During REA surveys at Sarigan, *Stichopus* and *Holothuria* were the only observed genera. Among all towed-diver surveys around Sarigan, the survey conducted across the border between the southwest and northwest regions had the highest mean density with 0.85 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 1.91 organisms 100 m^{-2}.

During MARAMP 2007, sea cucumbers were observed at 2 of the 3 REA sites surveyed and in all 6 towed-diver surveys conducted around Sarigan (Fig. 10.7.1e, bottom panel). The overall sample mean density from REA surveys was 1.33 organisms 100 m^{-2} (SE 0.88), and the islandwide mean density of sea cucumbers from towed-diver surveys was 0.4 organisms 100 m^{-2} (SE 0.09). Similar to results from 2005, the highest density of sea cucumbers was recorded at SAR-01 in the southwest region with 3 organisms 100 m^{-2}—89% of which were from the genus *Stichopus* and 11% from the genus *Pearsonothuria.* During REA surveys around Sarigan, *Stichopus, Pearsonothuria,* and *Holothuria* were the 3 observed genera. Among all towed-diver surveys around Sarigan, the survey conducted across the border between the southwest and northwest regions had the highest mean density with 1.22 organisms 100 m^{-2}; segment densities from this survey ranged from 0.37 to 4.24 organisms 100 m^{-2}.

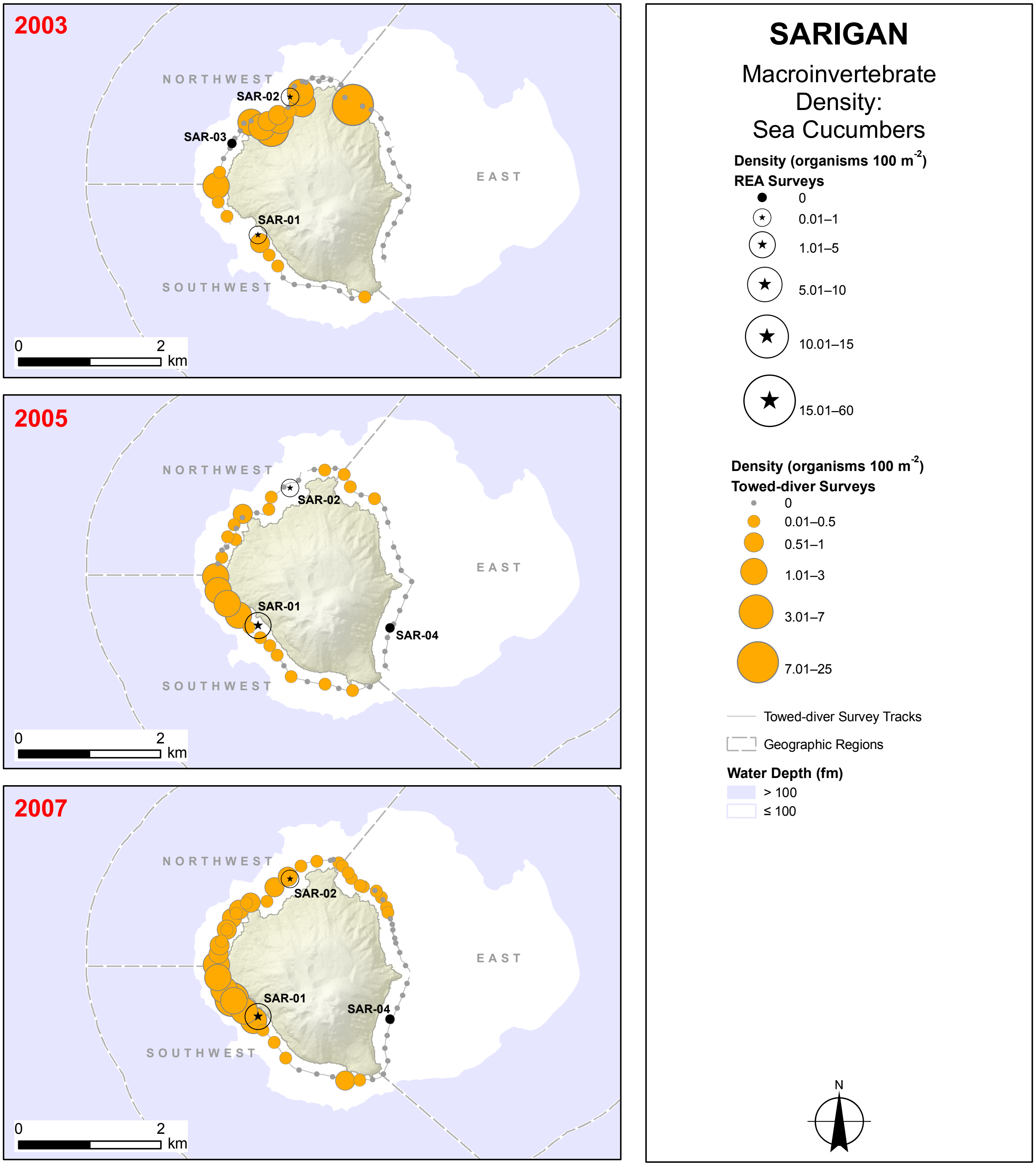


Figure 10.7.1e. Densities (organisms 100 m^{-2}) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Sarigan during MARAMP 2003, 2005, and 2007.

Both towed-diver surveys and REA surveys suggested low daytime abundance of sea cucumbers around Sarigan during the 3 MARAMP survey years (Fig. 10.7.1f). In each survey year, observed densities of sea cucumbers were greater along the western part of this island. Minor fluctuations in densities are not necessarily indicative of changes in the population structure of sea cucumbers (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

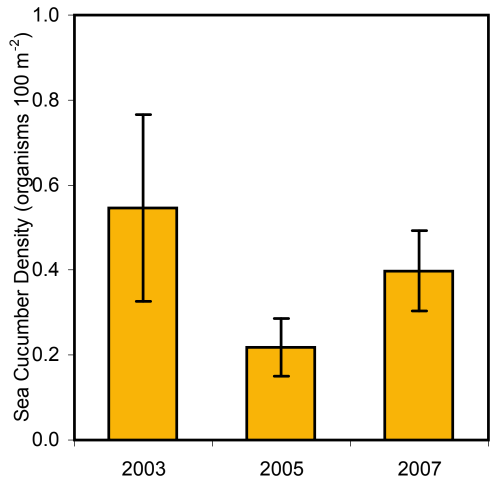


Figure 10.7.1f. Temporal comparison of mean densities (organisms 100 m^{-2}) of sea cucumbers from towed-diver benthic surveys conducted on forereef habitats around Sarigan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Sea Urchins

During MARAMP 2003, sea urchins were observed at all 3 REA sites surveyed and in 5 of the 6 towed-diver surveys conducted around Sarigan (Fig. 10.7.1g, top panel). The overall sample mean density from REA surveys was 91.33 organisms 100 m^{-2} (SE 57.37), and the islandwide mean density of sea urchins from towed-diver surveys was 0.35 organisms 100 m^{-2} (SE 0.1). The highest density of sea urchins was recorded at SAR-03 in the northwest region with 206 organisms 100 m^{-2}. Four genera were observed at this REA site: *Echinostephus*, *Echinometra*, *Echinothrix*, and *Diadema.* The rock-boring urchin, *Echinostrephus*, was the dominant urchin genus at all sites, accounting for 95% of recorded urchins. Among all towed-diver surveys around Sarigan, the survey completed in the northwest region had the highest mean density at 0.84 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 2.5 organisms 100 m^{-2}.

During MARAMP 2005, sea urchins were observed at 1 of the 3 REA sites surveyed and in 4 of the 5 towed-diver surveys conducted around Sarigan (Fig. 10.7.1g, middle panel). The density for this REA survey was 3 organisms 100 m^{-2}, and the islandwide mean density of sea urchins from towed-divers surveys was 0.09 organisms 100 m^{-2} (SE 0.05). All observed sea urchins at SAR-02 in the northwest region were from the genus *Echinostrephus.* Among all towed-diver surveys around Sarigan, the survey completed in the east region had the highest mean density of 0.26 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 2.28 organisms 100 m^{-2}. The towed-diver survey conducted had the second-greatest density of sea urchins from a towed-diver survey was 0.12 organisms 100 m^{-2}, recorded in the southwest region; segment densities ranged from 0 to 0.9 organisms 100 m^{-2}.

During MARAMP 2007, sea urchins were observed at 2 of the 3 REA sites surveyed and in 4 of the 6 towed-diver surveys conducted around Sarigan (Fig. 10.7.1g, bottom panel). The overall sample mean density from REA surveys was 1.22 (SE 1.06), and the islandwide mean density of sea urchins from towed-diver surveys was 0.15 organisms 100 m^{-2} (SE 0.06). The highest density of sea urchins, at 3.33 organisms 100 m^{-2}, was recorded at SAR-02. All observed urchins from REA surveys were from the genus *Echinostrephus.* Among all towed-diver surveys around Sarigan, the survey completed across the border between the southwest and east regions had the highest mean density at 0.41 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 2.18 organisms 100 m^{-2}. The second-greatest mean density from a towed-diver survey was 0.2 organisms 100 m^{-2}, recorded in the east region; segment densities ranged from 0 to 1.91 organisms 100 m^{-2}.

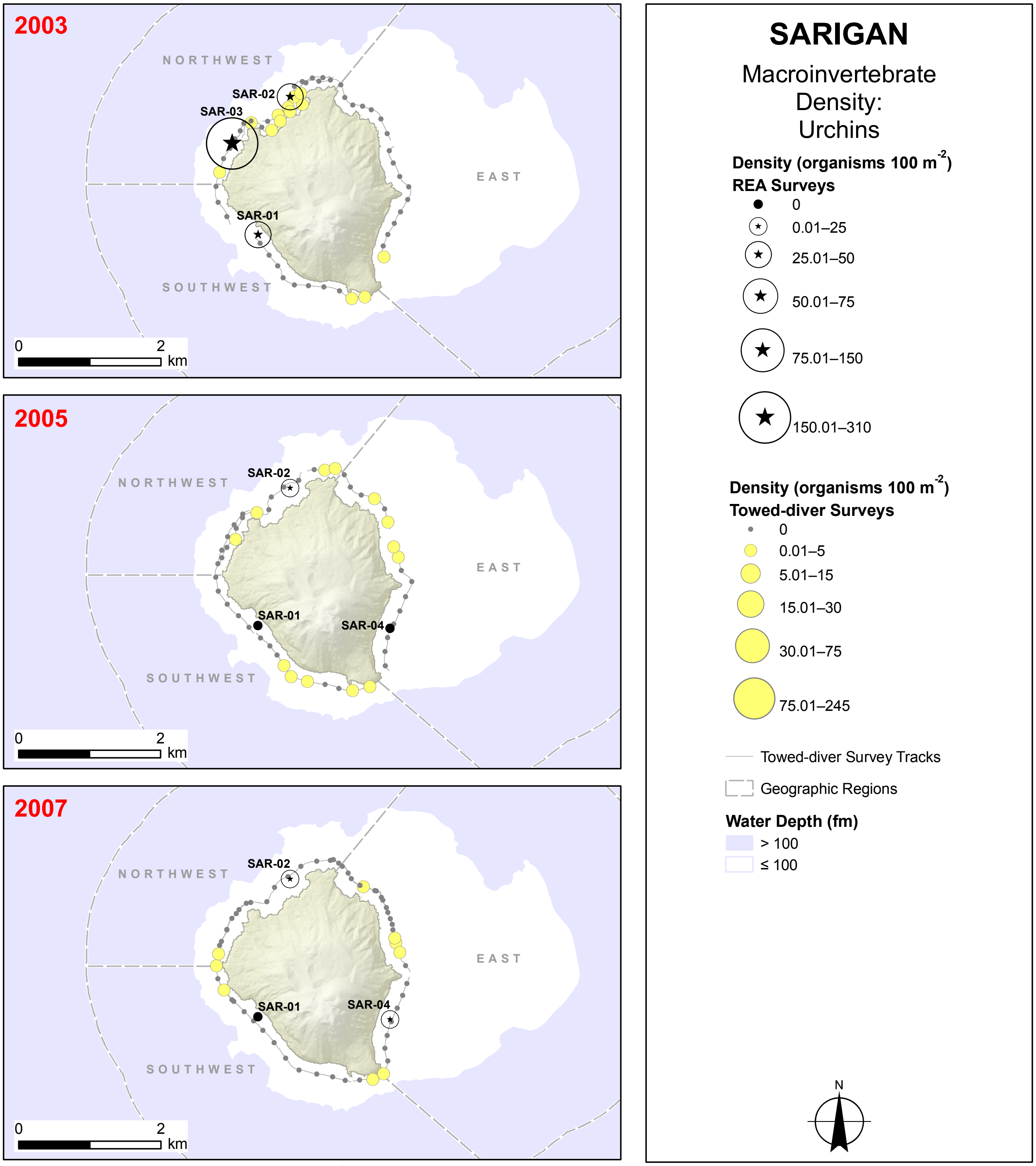


Figure 10.7.1g. Densities (organisms 100 m^{-2}) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Sarigan during MARAMP 2003, 2005, and 2007.

The overall observed mean density of sea urchins around Sarigan was higher in 2003 than in 2005 and 2007 (Fig. 10.7.1h). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of sea urchins (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys"). Although sea urchins were not recorded to the genus level during towed-diver surveys, REA surveys suggested that the majority of the sea urchin species observed at Sarigan were rock-boring urchins from the genus *Echinostrephus*.

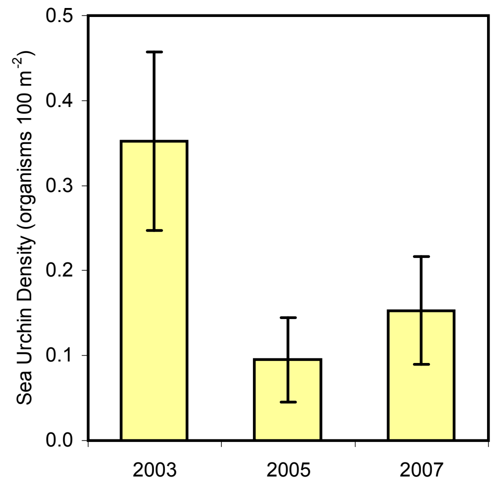


Figure 10.7.1h. Temporal comparison of mean densities (organisms 100 m^{-2}) of sea urchins from towed-diver benthic surveys conducted on forereef habitats around Sarigan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

10.8 Reef Fishes

10.8.1 Reef Fish Surveys

Large-fish Biomass

During MARAMP 2003, 6 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted in forereef habitats around the island of Sarigan. The overall estimated mean biomass of large fishes around this island calculated as weight per unit area, was 0.72 kg 100 m^{-2} (SE 0.25). Observed large-fish biomass was highest in the east region where sharks were common (Fig. 10.8.1a, top panel). Reef sharks (Carcharhinidae) and nurse sharks (Ginglymostomatidae) accounted for 53% (0.38 kg 100 m^{-2}) of overall large-fish biomass. During this survey period, 5 sharks were observed: 2 whitetip reef sharks (*Triaenodon obesus*) and 3 tawny nurse sharks (*Nebrius ferrugineus*). Snappers (Lutjanidae) and jacks (Carangidae) were also common, contributing 12% and 9% of overall mean biomass of large fishes. The twinspot snapper (*Lutjanus bohar*) contributed 0.05 kg 100 m^{-2}, while the giant trevally (*Caranx ignobilis*) contributed the next greatest proportion to overall large-fish biomass with 0.04 kg 100 m^{-2}.

During MARAMP 2005, 5 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Sarigan. The overall estimated mean biomass of large fishes was 0.64 kg 100 m^{-2} (SE 0.19). Observed large-fish biomass was highest in the southwest region, where a large school of bigeye trevally (*Caranx sexfaciatus*) was observed during a single survey (Fig. 10.8.1a, middle panel). Jacks, reef sharks, and nurse sharks accounted for 69% of overall large-fish biomass. The bigeye trevally contributed the greatest proportion of overall mean biomass of large fishes with 0.19 kg 100 m^{-2}. During this survey period, 6 sharks were observed: 2 whitetip reef sharks, 2 tawny nurse sharks, and 2 blacktip reef sharks (*Carcharhinus melanopterus*).

During MARAMP 2007, 6 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Sarigan. The overall estimated mean biomass for large fishes was 0.69 kg 100 m^{-2} (SE 0.26). The observed large-fish biomass was highest in the east and southwest regions, where sharks and jacks were common (Fig. 10.8.1a, bottom panel). Consistent with observations made in 2005, jacks, reef sharks, and nurse sharks contributed the greatest proportion (75%) of overall large-fish biomass. A large (~ 100) school of bigeye trevally was observed in the southwest region, making the bigeye trevally the major jack species by biomass, accounting for 94% (0.26 kg 100 m^{-2}) of jack biomass. Reef sharks and nurse sharks accounted for 35% of overall mean biomass of large fishes with the tawny nurse shark contributing the greatest proportion of shark biomass. During this survey period, 7 sharks were observed: 4 grey reef sharks (*Carcharhinus amblyrhynchos*), 2 tawny nurse sharks, and 1 whitetip reef shark.

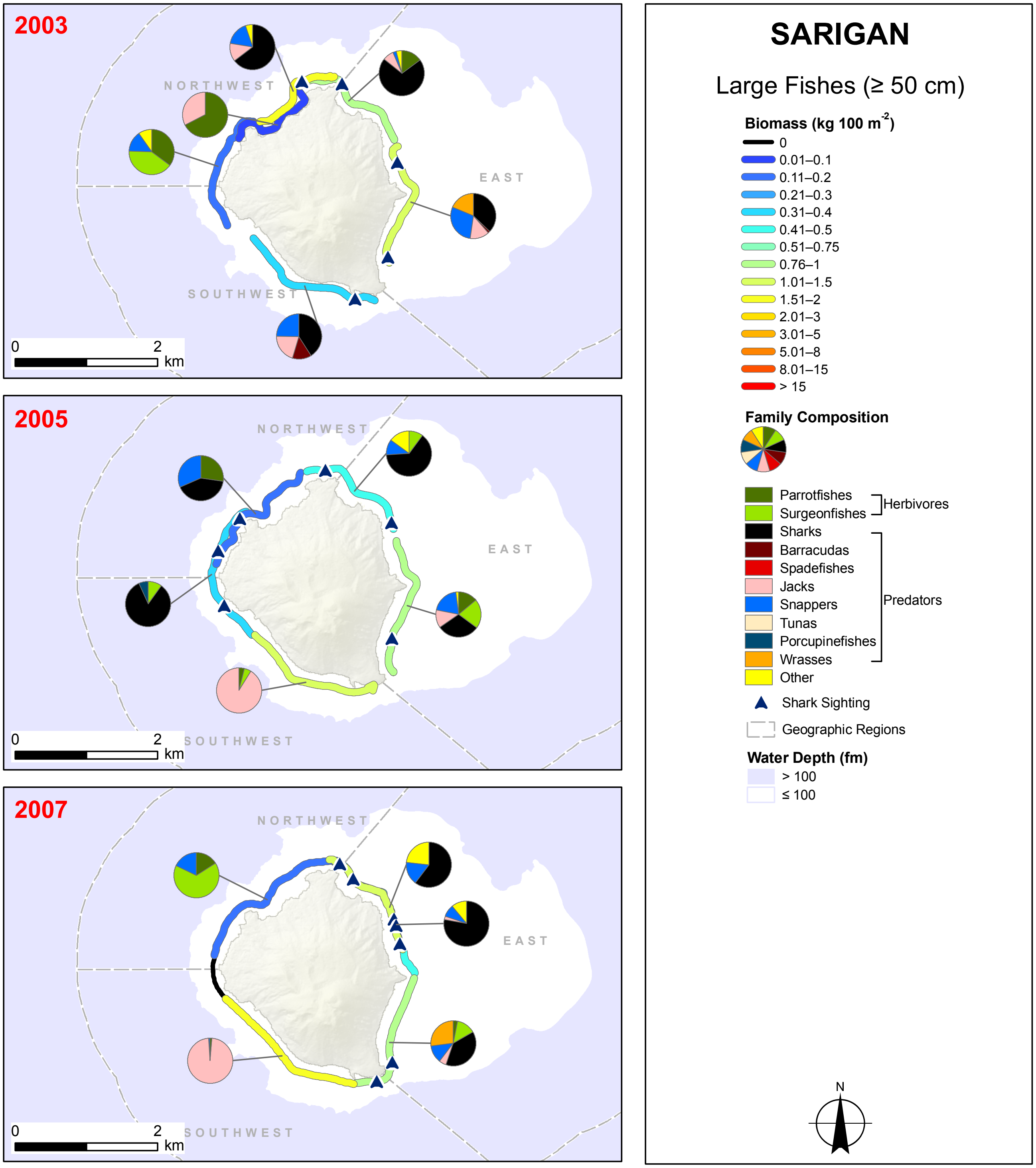


Figure 10.8.1a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and individual shark sightings from towed-diver fish surveys of forereef habitats conducted around Sarigan during MARAMP 2003, 2005, and 2007. Each blue triangle represents a sighting of one or more sharks recorded inside or outside the survey area over which it is shown.

Large-fish biomass from towed-diver surveys of forereef habitats was moderate compared to the archipelago-wide mean biomass and was observed at fairly consistent levels in the 3 MARAMP survey periods (Fig. 10.8.2b). Large-bodied predatory fishes, such as jacks, reef sharks, and nurse sharks accounted for 65% or more of overall estimated large-fish biomass across the 3 survey periods. Of note was the observation of a large school of bigeye trevally in the southwest region in both 2005 and 2007. No consistent spatial patter in large-fish biomass was observed during the 3 survey periods; however, the highest large-fish biomass in 2005 and 2007 was recorded in the southwest region, where, in each year, a school of bigeye trevally was observed. Other notable observations included 3 sightings of the humphead wrasse (*Cheilinus undulatus*), with 2 sightings in 2007 and 1 sighting in 2003.

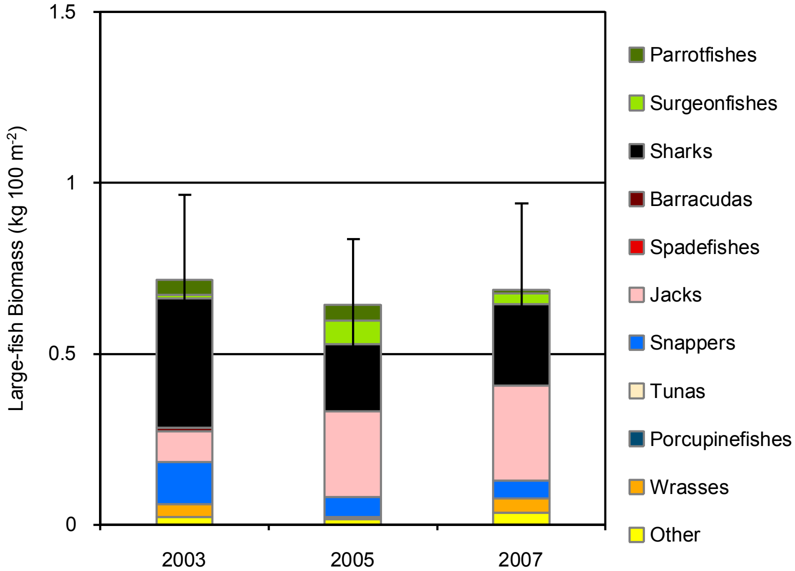


Figure 10.8.1b. Temporal comparison of mean values of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}) from towed-diver fish surveys of forereef habitats conducted around Sarigan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Total Fish Biomass and Species Richness

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Sarigan during MARAMP 2003 was high compared to other sites in the Mariana Archipelago, with an overall sample mean of 11.54 kg 100 m^{-2} (SE 6.42). The highest biomass of 24.23 kg 100 m^{-2} was observed at REA site SAR-02 in the northwest region, and the lowest biomass of 3.5 kg 100 m^{-2} was found at SAR-01 in the southwest region (Fig. 10.8.1c, top panel). A large (200 cm in TL) tawny nurse shark was observed at SAR-02, contributing 47% (5.44 kg 100 m^{-2}) of total fish biomass at . No other species of sharks were observed during this survey period. Surgeonfishes (Acanthuridae) accounted for the second greatest proportion (15%) or 1.78 kg 100 m^{-2} of total fish biomass. The orangespot surgeonfish (*Acanthurus olivaceus*) dominated surgeonfish biomass, accounting for 34% (0.61 kg 100 m^{-2}) of surgeonfish biomass. Parrotfishes (Scaridae) were also fairly common, contributing 0.97 kg 100 m^{-2} to total fish biomass.

Based on REA surveys conducted during MARAMP 2003, species richness at Sarigan was high with a range of 36–44 species 100 m^{-2}, compared to the archipelago-wide mean for this survey period (31.1 species observed 100 m^{-2}). The highest diversity was observed at SAR-03 in the northwest region (Fig. 10.8.1c, top panel). Wrasses (Labridae) and surgeonfishes were the 2 most represented families with 18 and 14 species observed. The fivestripe wrasse (*Thalassoma quinquevittatum*) was the most abundant wrasse species, and the orangespine unicornfish (*Naso lituratus*) was the most abundant surgeonfish species. Damselfishes (Pomacentridae) were the most numerically abundant family overall, and the midget chromis (*Chromis acares*) dominated counts with 41 individuals 100 m^{-2} observed.

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Sarigan during MARAMP 2005 was moderate compared to other sites in the Mariana Archipelago, with an overall sample mean of 6.98 kg 100 m^{-2} (SE 0.62). The highest biomass of 7.82 kg 100 m^{-2} was observed at SAR-01 in the southwest region (Fig. 10.8.1c, middle panel). Surgeonfishes accounted for the greatest proportion (31%) or 2.2 kg 100 m^{-2} of total fish biomass. Surgeonfish biomass was spread across several species with no single species dominating biomass (8 species contributed between 8% and 16% each of surgeonfish biomass). Eagle rays (*Aetobatus narinari*), observed at SAR-01, accounted for the second-greatest proportion (16%) of total fish biomass. No sharks were observed during this survey period.

Based on REA surveys conducted during MARAMP 2005, species richness was moderate, compared to other sites surveyed in the Mariana Archipelago, with a range of 27–32 species 100 m^{-2}. The highest diversity was observed at SAR-01 in the southwest region (Fig. 8.1c, middle panel). Consistent with observations made in 2003, wrasses and surgeonfishes were the 2 most represented families with 16 and 14 species recorded. The ornate wrasse (*Halichoeres ornatissimus*) was the most numerically abundant wrasse species observed, while the brown surgeonfish (*Acanthurus nigrofuscus*) was the most numerically abundant surgeonfish species. Damselfishes dominated counts, and the midget chromis was the most

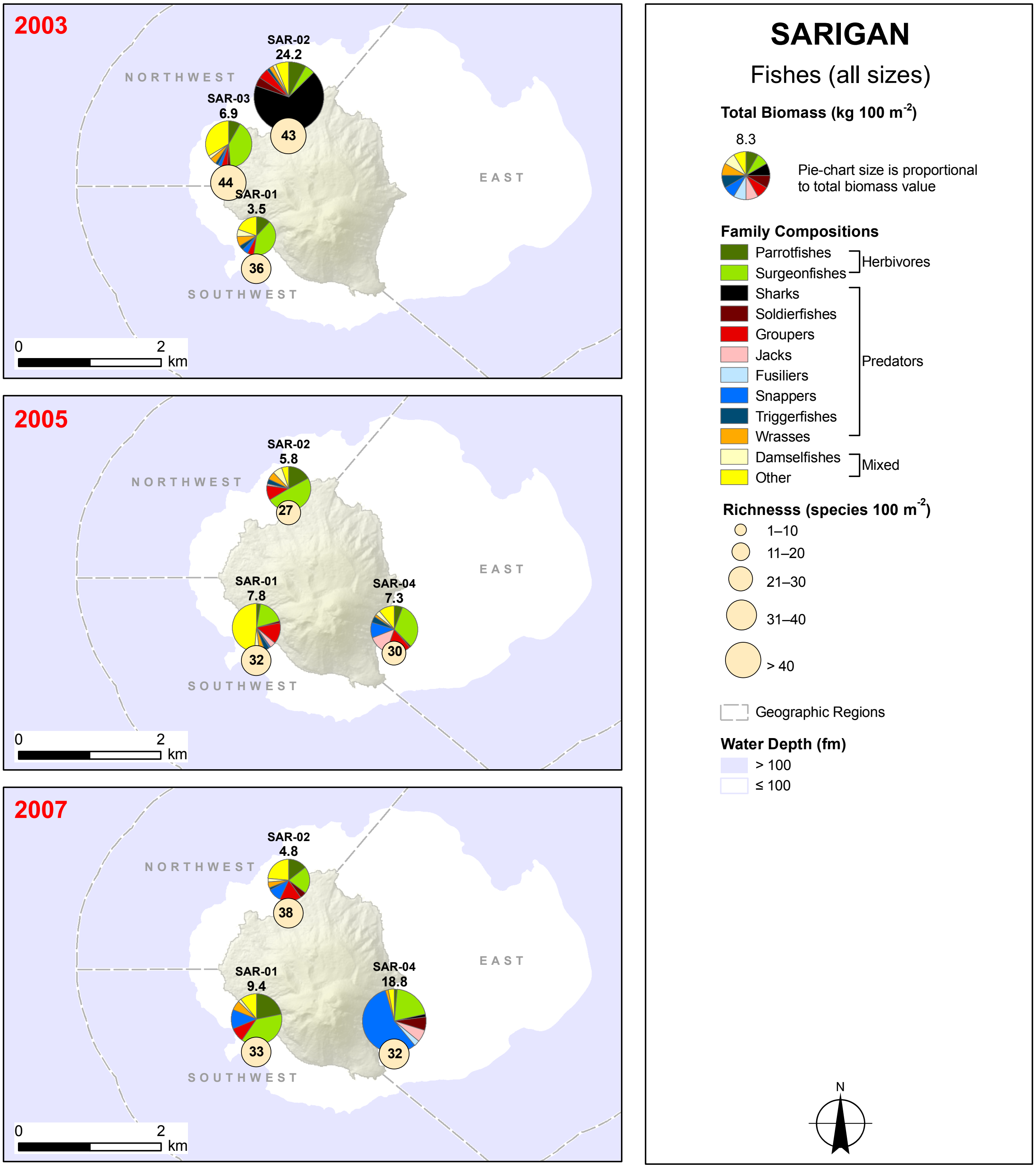


Figure 10.8.1c. Observations of total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method in forereef habitats at Sarigan during MARAMP 2003, 2005, and 2007.

abundant species with more than 29 individuals 100 m^{-2}. The amethyst anthias (*Pseudanthias pascalus*) was the second most numerically abundant species with 20 individuals 100 m^{-2} observed.

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Sarigan during MARAMP 2007 was high compared to other sites surveyed in the Mariana Archipelago, with an overall sample mean of 10.97 kg 100 m^{-2} (SE 4.13). The highest biomass of 18.79 kg 100 m^{-2} was observed at SAR-04 in the east region (Fig. 10.8.1c, bottom panel). Snappers and surgeonfishes accounted for the greatest proportions of total fish biomass with 4.03 kg 100 m^{-2} (37%) and 2.75 kg

100 m^{-2} (25%). The midnight snapper (*Macolor macularis*), black and white snapper (*Macolor niger*), and twinspot snapper dominated snapper biomass, contributing 2 kg 100 m^{-2}, 1.05 kg 100 m$^{-2,}$ and 0.55 kg 100 m^{-2} of total fish biomass. The orangespine unicornfish dominated surgeonfish biomass, accounting for 39% or 1.07 kg 100 m^{-2} of surgeonfish biomass.

Based on REA surveys conducted during MARAMP 2007, species richness at Sarigan was moderate compared to other sites surveyed in the Mariana Archipelago with a range of 32–38 species 100 m^{-2}. The highest diversity was observed at SAR-02 in the northwest region. Wrasses and surgeonfishes were the 2 most represented families with 21 and 14 species recorded. Damselfishes were the most numerically abundant family overall, and the midget chromis dominated counts with 86 individuals 100 m^{-2} observed.

No persistent spatial patterns were observed for the total fish biomass in forereef habitats at Sarigan between the 3 MARAMP survey periods. When compared with the rest of the Mariana Archipelago, the overall total fish biomass for Sarigan was high, but it was close to the average biomass for the northern islands. The overall sample mean of total fish biomass was highest in 2003, at 11.54 kg 100 m^{-2} (SE 6.42), when a large (200 cm in TL) tawny nurse shark contributed half of total fish biomass. Estimated total fish biomass was lower in 2005 than in 2003 and 2007 (Fig. 10.8.1d). Surgeonfishes generally accounted for a large proportion of total fish biomass with 15%–31%. The orangespot surgeonfish and orangespine unicornfish tended to dominate surgeonfish biomass.

Mean species richness ranged from 30 to 41 species 100 m^{-2} for the 3 MARAMP survey periods, with no clear spatial pattern in species richness observed at the island level. Wrasses and surgeonfishes were consistently the 2 most represented families with an average of 18 and 14 species recorded. Damselfishes were the most numerically abundant fish species with the midget chromis dominating counts in each of the 3 survey periods.

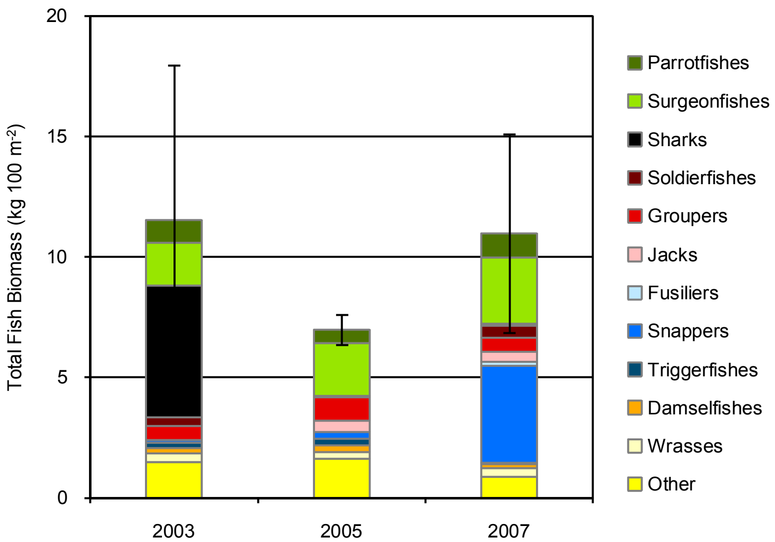


Figure 10.8.3d. Temporal comparison of mean values of total fish biomass (all species and size classes in kg 100 m^{-2}) from REA fish surveys of forereef habitats conducted at Sarigan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

10.9 Marine Debris

10.9.1 Marine Debris Surveys

During MARAMP 2003, no marine debris was found in the 6 towed-diver surveys conducted on forereef habitats around the island of Sarigan. During MARAMP 2005, only 1 sighting of derelict fishing gear, in the northwest region, was recorded in the 5 towed-diver surveys conducted. No additional descriptive information regarding this sighting was documented. During MARAMP 2007, in the southwest region, only 1 sighting of derelict fishing gear, consisting of fishing line, was recorded in the 6 towed-diver surveys conducted around Sarigan. No munitions, wrecks, or other man-made objects were identified in the 3 MARAMP survey years.

Observations of debris are positive identifications, but absence of reports does not imply lack of debris. Since methods for observing marine debris varied between MARAMP surveys in 2003, 2005, and 2007, temporal comparisons are not appropriate. Debris sightings were recorded differently—with sightings in 2003 recorded as a direct part of diver observational methods and sightings in 2005 and 2007 recorded solely as incidental observations by the towed divers in their observer comments.

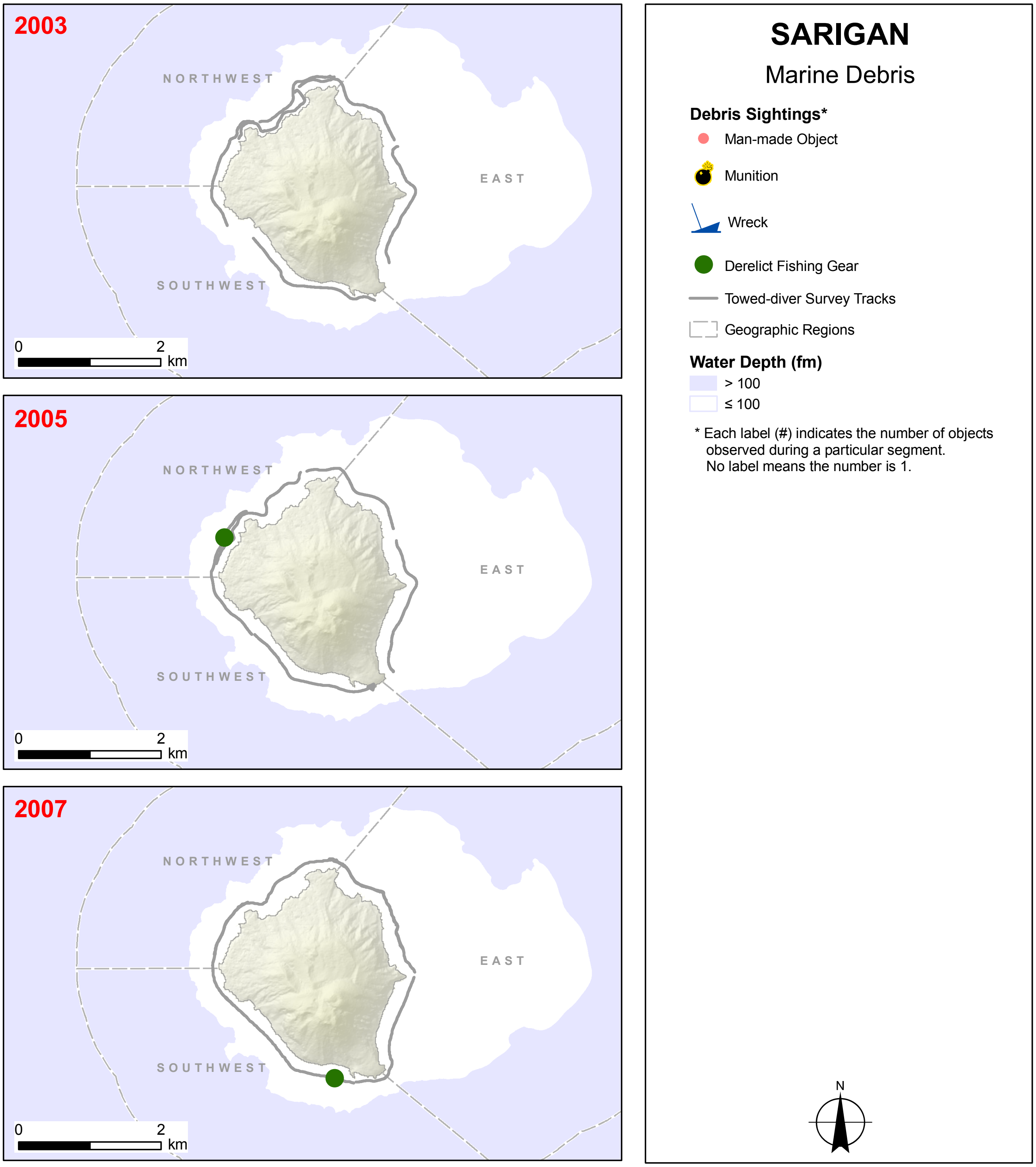


Figure 10.9.1a. Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted around Sarigan during MARAMP 2005 and 2007. No debris sightings were recorded in 2003. Symbols indicate the presence of a specific debris type.

10.10 Ecosystem Integration

The spatial distributions and temporal patterns of individual coral reef ecosystem components around the island of Sarigan are discussed in the discipline-specific sections of this chapter. In this section, key ecological and environmental aspects are considered concurrently to identify potential relationships between various ecosystem components. In addition to this island-level analysis, evaluations on an archipelagic scale of different ecosystem elements and their potential relationships across the entire Mariana Archipelago are presented in Chapter 3: "Archipelagic Comparisons," including archipelago-wide reef condition indices with ranks for Sarigan as well as the other 13 islands covered in this report.

Sarigan, located between Anatahan and Guguan in the middle of the Mariana Arc, is the fourth-smallest island of the Mariana Archipelago. Like other northern, volcanic islands, Sarigan has an onshore topography characterized by steep slopes, particularly on the south and east sides of this island.

The main feature of Sarigan's seascape is the extensive shelf area that extends east for 2.7 km. This shelf, at depths of 30–150 m, is composed of at least 2 terraces (Fig. 10.10a). A very shallow shelf may extend farther around this island, although the absence of bathymetry data at depths < 15 m means it is not possible to confirm this possibility (Fig. 10.3.1b in Section 10.3.1: "Acoustic Mapping").

In the northwest and southwest regions, multibeam bathymetry suggested a seafloor shaped by numerous ridges and canyons that radiate away from Sarigan. The substrate encountered was predominantly hard with < 30% sand cover (Fig. 10.3.3a in Section 10.3.3: "Habitat Characterization"). This hard substrate formed steep walls and boulders, and continuous reef was observed in some places.

Cover of live hard corals, based on towed-diver surveys, in the northwest and southwest regions of Sarigan was generally low in 2005 and 2007, compared to the levels observed in the east region, with most recorded values < 20% and some areas with cover of 20.1%–30% (Fig. 10.10a; see also Fig. 10.5.1a in Section 10.5.1: "Coral Surveys"). In 2003, the observed distribution of live corals was more variable with cover of 40.1%–50% recorded for 2 survey segments in the southwest region. Corals in survey areas appeared healthy: no stressed-coral cover was observed during towed-diver surveys, and very low prevalence of coral disease was found during REA surveys (Fig. 10.5.2a in Section 10.5.2: "Surveys for Coral Disease and Predation").

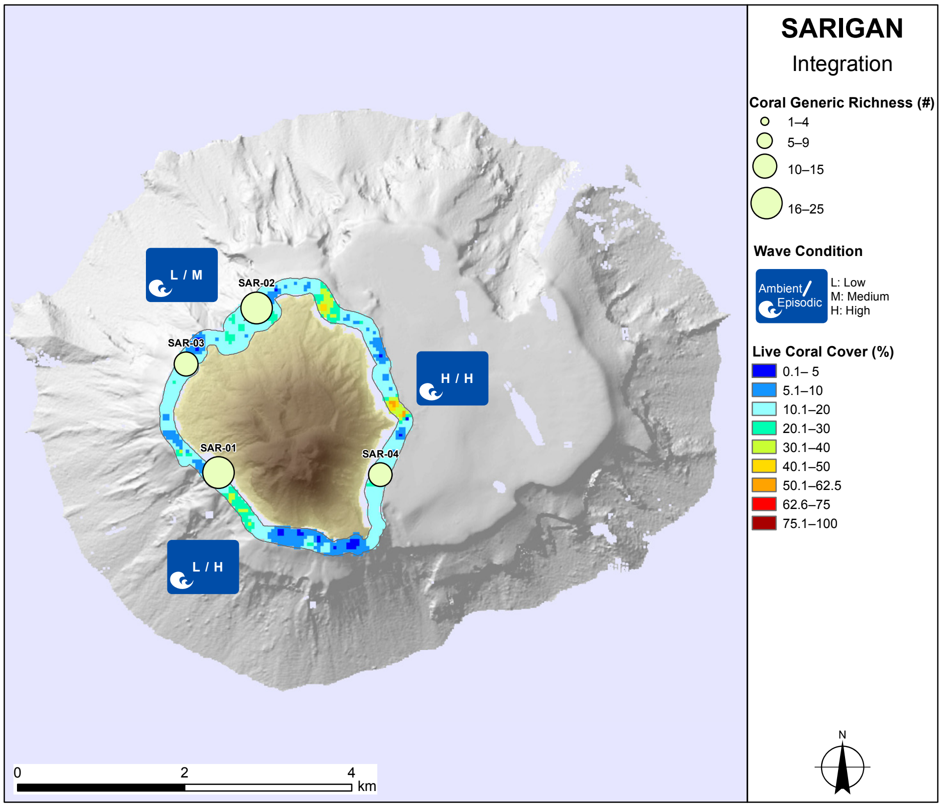


Figure 10.10a. Cover (%) observations of live hard corals from towed-diver surveys and generic richness from REA surveys conducted on forereef habitats around Sarigan during MARAMP 2003, 2005, and 2007. Values of coral cover represent interpolated estimates from the 3 MARAMP survey years, and values of generic richness represent averages of data from the 3 survey years. A large, blue icon indicates the level of ambient and episodic wave exposure for each geographic region. Underlying these data in grey scale is the hillshade bathymetry.

Densities of sea cucumbers, particularly of *Stichopus chloronotus*, were much higher on non-shelf areas around Sarigan than on the shelf area (Fig. 10.7.1e in Section 10.7.1: Benthic Macroinvertebrate Surveys"), and overall abundance of sea cucumbers around Sarigan was high compared to densities seen at other northern islands of the Mariana Archipelago (Fig 3.6.1c in Chapter 3: Archipelagic Comparison," Section 3.6.1: "Density Distribution: Giant Clams, Sea Urchins, and Sea Cucumbers"). Giant clams also were more abundant on the west side of Sarigan than in the east region (Figs. 10.10b and 10.7.1a).

Despite the markedly different topography revealed by multibeam bathymetry east of Sarigan, the benthic communities around this island appeared fairly alike in character, based on observations from towed-diver surveys. The proportion of sand to hard substrate, the levels of habitat complexity, and descriptions of habitats observed in the east region were similar to the conditions recorded in the southwest and northwest regions. The distribution of benthic macroinvertebrates, particularly of sea cucumbers and giant clams, differed greatly on different sides of this island. Cover of live hard corals, based on towed-diver surveys, was slightly higher in the east region than in the northwest and southwest regions, with coral cover of 10.1–30% recorded for most survey segments. Two distinct survey areas in the east region had coral cover of 30.1%–75%: one in a bay east of the northern tip of Sarigan and another just north of the easternmost point of this island.

Figure 10.10b. A giant clam (*Tridacna* sp.) on a western reef at Sarigan. *NOAA photo by Danny Merritt*

Figure 10.10c. Diver observing sharks at Sarigan. *NOAA photo*

The fish communities observed around Sarigan had moderately high diversity, compared to the fish communities seen at other islands of the Mariana Archipelago (Fig. 10.8.1f in Section 10.8.1: “Reef Surveys”). Values of total fish biomass and species richness from REA surveys varied fairly widely between the 3 MARAMP survey years, but they were among the highest recorded at any island in the Mariana Archipelago in 2003. Sharks were observed frequently during towed-diver surveys (Figs. 10.10c and 10.8.1f), and other notable observations included 3 sightings of the humphead wrasse (*Cheilinus undulatus*): 2 sightings in 2007 and 1 sighting in 2003.

10.11 Summary

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 around Sarigan. 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 Sarigan chapter are included in the relevant discipline sections. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter. The conditions of the fish and benthic communities and the overall ecosystem around Sarigan, relative to the ecosystems around all the other islands in the Mariana Archipelago, are discussed in Chapter 3: “Archipelagic Comparisons.”

This section presents an overview of the status of coral reef ecosystems around the island of Sarigan as well as some of the key natural processes influencing these ecosystems:

- Sarigan is positioned in the center of the Mariana Arc, between Anatahan and Guguan, and is the fourth-smallest island of the Mariana Archipelago with a land area of 4.9 km^2.

- Like other islands of the CNMI, Sarigan is formed by the exposed portion of a largely submarine volcano. A summit crater is located on southern part of this island. Steep cliffs and irregular shorelines were created by lava flows that reached the coast and extended out to sea from 2 lava domes near the southern crater rim. Sparse vegetation on these lava flows indicates that the last eruption may have occurred in the Holocene age, although the exact date is not known.

- Sarigan is thought to have been uninhabited since the last residents were removed after WWII. However, legislation encouraging repatriation was signed into law in 2010 and may result in repopulation of this island in the future. Because of its lack of inhabitants and isolated location, Sarigan has relatively few anthropogenic pressures on its marine environment, although multiday fishing trips around the islands and banks south of Guguan potentially may affect fish stocks and associated habitats around Sarigan.

- An extensive, shallow shelf that extends east for 2.7 km at depths of 30–150 m surrounds Sarigan. The very steep slopes that border the deepest part of this shelf continue around this island, and, west of this island, this shelf break is intersected by channels and ridges.

- Overall, the seabed around Sarigan, based on the high-resolution bathymetry data, has a fairly complex topography, and BPI analysis reveals that sloping flanks below flat zones are interrupted by crests and depressions.

- In the east region, habitat complexity was predominantly medium to medium-high. Towed-diver surveys documented patchy sand cover and habitats that included rocky crags, boulders and pinnacles, and sand with boulder patch reefs.

- In the northwest region, habitat complexity ranged from low to high. The seabed was variable, with patchy sand cover and habitats ranging from boulder patches to steep walls and continuous rock reef. Analyses of TOAD video footage obtained on flanks at depths of 91–190 m suggested hard substrates with no sand cover or live-hard-coral cover observed.

- In the southwest region, boulder reef and continuous reef with sand patches were recorded during the 2 towed-diver surveys conducted in this region, suggesting predominantly hard substrate with no live coral cover and sparse, localized sand cover.

- Wave model output shows ambient trade wind swells impacting the east region. Episodic wave energy from storm tracks impacts the east and southwest regions and to a lesser extent the northwest region.

- CTD casts revealed mostly well-mixed waters, except in 2003, when results from a single cast location in the northwest region showed a 1.5˚C reduction in temperature between waters at depths > 25 m and surface waters. Time-series data from 2 STRs deployed in the northwest region at depths of 1 and 6 m show large variation (~ 4°C) in temperature values on intraseasonal time scales, indicating a dynamic thermal environment.

- The overall sample mean for live coral cover at Sarigan was 22.6%, based on REA surveys conducted using the line-point-intercept method during MARAMP 2007. Islandwide estimates of coral cover from towed-diver surveys ranged from 13%–18% across the 3 MARAMP survey years, a moderate level compared to values seen at other islands in the Mariana Archipelago.

- At the 3 REA sites surveyed using the belt-transect method in 2007, 14 cases of coral disease were found, resulting in an overall mean prevalence of 0.04%. Three disease states were recorded at Sarigan, including, in order of numerical abundance, fungal infection, infestation by the encrusting sponge genus *Terpios*, and bleaching. No signs of predation scars from the crown-of-thorns seastar (*Acanthaster planci*) or corallivorous snails were reported at these 3 sites. Densities of COTS from towed-diver surveys were extremely low in 2003 and 2005, and no COTS were observed in 2007.

- Results from towed-diver surveys conducted in the 3 MARAMP survey years reveal that both *Tridacna* giant clams and sea cucumbers were more common along the west side of Sarigan than along the east side. Also, both towed-diver and REA surveys in 2003 showed that sea urchins were more common on the west side than on the east side. Abundance of sea cucumbers was high, compared to values found at other northern islands in the Mariana Archipelago.

- Islandwide mean cover of macroalgae from towed-diver surveys conducted around Sarigan was lower in 2007 than in in 2005. In each of the 3 survey years, the lowest cover of crustose coralline red algae was found near the northern tip of this island during towed-diver surveys in either the northwest region or east region. No signs of coralline-algal disease were observed.

- Across the 3 MARAMP survey periods, overall estimated mean biomass of large fishes was stable and moderate, relative to levels seen at other northern islands in the Mariana Archipelago. Observed large-fish biomass was highest in 2003 with an islandwide mean of 0.72 kg 100 m^{-2}. Large-bodied, predatory species such as jacks (Carangidae), reef sharks (Carcharhinidae), and nurse sharks (Ginglymostomatidae) accounted for 65% or more of large-fish biomass in each of the 3 survey periods. A large school of bigeye trevally (*Caranx sexfaciatus*) was seen in the southwest region in 2005 and 2007. Also of note were 3 sightings of the humphead wrasse (*Cheilinus undulates*), with 1 sighting in 2003 and 2 sightings in 2007.

- Total fish biomass around Sarigan, based from REA surveys for fishes of all sizes and species, was similar to the average for the northern islands. Estimated total fish biomass was highest in 2003, with an overall sample mean of 11.54 kg 100 m^{-2}. A large (200 cm in TL) tawny nurse shark (*Nebrius ferrugineus*) contributed almost half of this overall biomass in 2003.

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