7 TINIAN

7.1 Introduction

Figure 7.1a. Major locations of human activities (top) on Tinian that have the potential to affect the marine environment (Placenames.com; Bearden 2008; U.S. Geological Survey 2005b) are represented over a population-density map (U.S. Bureau of the Census 2003, 2008). Satellite imagery of Tinian (bottom, includes material © 2006 DigitalGlobe Inc. All rights reserved), labeled with places of interest (U.S. Geological Survey).
The island of Tinian and Tatsumi Reef are adjacent volcanic structures that mostly are overlain by uplifted carbonate rock. Tinian, 6 km south of Saipan, is one of the 14 islands that compose the Commonwealth of the Northern Mariana Islands (CNMI) and, together with Aguijan 8 km to the southwest, forms Tinian County. Located between 15°7’ and 14°53’ N latitude and 145°33’ and 145°43’ E longitude, Tinian is the third largest island in the Mariana Archipelago with a land area of 101.22 km², 52 km of coastline, and a maximum elevation of 187 m. The village of San Jose, located near Tinian Harbor on the southwest coast (Fig. 7.1a), is the principal population center. A casino and hotel in San Jose are the major tourist facilities on this island. In the later part of World War II (WWII), a major U.S. airfield was located on Tinian, and 63% of the land on Tinian is still leased by the U.S. military.

7.1.1 History and Demographics

Tinian was ruled by Spain and Germany before World War I (WWI) and became a major sugarcane growing and processing center while under Japanese control between WWI and WWII. In mid-1944, this island was captured by U.S. forces, who built on the flat terraces of Tinian what were then the world's longest runways. These runways were used to launch U.S. planes for attacks on Japan, including the B-29 bombers that dropped atomic bombs on Hiroshima and Nagasaki. North Field, which encompasses these runways, is a National Historic Landmark maintained by the U.S. Department of Defense.

In 2010, Tinian was the second-most populated island in the CNMI, with a population of 3136, an 11% decrease from 3540 in 2000 but a 262% increase from 866 in 1980 (Fig. 7.1.1a; U.S. Bureau of the Census 2011a; CNMI Department of Commerce 2002a).

7.1.2 Geography

The primary type of rock on Tinian and the other southern islands in the Mariana Archipelago consists of raised limestone (Fig. 7.1.2a) with relatively flat surrounding terraces and steep sea cliffs (Fig. 7.1.2b) that make up more than half of the Tinian coastline. These features are caused by episodic tectonic uplift associated with the subduction of seamounts in the

Figure 7.1.2a. Land use (U.S. Department of Agriculture Forest Service 2006b), a military installation and lease back area (U.S. Geological Survey 2005a; K Herrmann, CNMI Division of Environmental Quality, pers. comm.), a historic site (National Park Service 2001), and a marine protected area (CNMI Public Law 17-14; K Herrmann, pers. comm.) on Tinian are represented over a vegetation cover map (top, Liu and Fischer 2006). Geology, watersheds, and groundwater flows on Tinian (bottom, Gingerich 2002; M Pangelinan, CNMI Department of Land and Natural Resources, pers. comm.).
Isu-Bonin Mariana arc system (Fryer et al. 1992). Much of the limestone on Tinian is covered by thin to moderately thick soils, but some limestone areas exhibit karst topography, which is formed by dissolution of carbonate rocks and characterized by sinkholes, caves, and subterranean passages. Volcanic basement rocks are exposed in only a few areas and cover < 3 km² (Stafford et al. 2005).

Most water consumed on Tinian comes from shallow wells in the karst aquifer (Stafford et al. 2005); Tinian has no perennial streams and very little surface water. Groundwater collects in a subsurface “Ghyben-Herzberg lens” of water and springs, and frequent freshwater seeps occur along the beaches (Gingerich 2002). Groundwater drainage patterns on Tinian are shown as arrows in Figure 7.1.2a. Although an estimated 88%–94% of the rainfall is absorbed into the limestone, effects from runoff into coastal waters still would be expected during periods of heavy rainfall and storms (Gingerich 2002). Severe storm events can cause erosion and pollution, events that are especially problematic for coral reef environments. The major observed source of sediment into nearshore waters has been runoff from unpaved secondary roads (Starmer et al. 2005).

**Figure 7.1.2b.** Combined slope map using the digital elevation model and multibeam bathymetric data for Tinian.

### 7.1.3 Economy

The service sector and local government make up the largest components of Tinian’s resident workforce. Agriculture, tourism, and military spending also contribute to the local economy (Fig. 7.1.3a). Commercial agriculture on Tinian consists of small-scale vegetable and fruit cultivation on the southern part of this island (Fig. 7.1.2a). Produce from these farms is marketed locally and also shipped to Saipan. Commercial cattle grazing on Tinian involves a few small, family-owned ranches.

Under an agreement signed in 1983, the northern two-thirds of Tinian—more than 65 km² or 16,000 acres—was leased to the U.S. military for a period of 50 years (Fig. 7.1.2a). U.S. military training operations are conducted regularly in this area. Any nonmilitary uses within this area, including visits to the North Field National Historic Landmark, must be approved by the Department of Defense. Much of the southern portion of this military-controlled area has been leased back to the CNMI for uses judged to be compatible with the long-term needs of the Department of Defense, uses that primarily include grazing and agriculture (National Park Service 2001). Under this agreement, the leased-back area may be used for training activities that would not be detrimental to ongoing CNMI economic and agricultural activities. The Department of Defense currently is proposing expansion of military training activities on Tinian because of the projected move of 8000 marines to Guam within the next decade (Kan 2012).
In 1997, a casino was constructed adjacent to Tachogna and Taga Beaches near San Jose, Tinian’s only major settlement. A major source of revenue for Tinian comes from tourists who visit on day trips from Saipan via boat or air, although the tourist trade has diminished since flights from Japan to Saipan were reduced in 2005. As shown in Figure 7.1.1a, CNMI visitor trends fluctuate with external events, such as economic downturns and disease outbreaks.

**Figure 7.1.3a.** Employment by sector on Tinian in 2005 (CNMI Department of Commerce 2008).

### 7.1.4 Environmental Issues on Tinian

The native vegetation of Tinian has been highly disturbed, and only small remnants now remain. In the 1920s, the Japanese cleared much of the native limestone forest, which was believed to have covered this island in the late 1700s and 1800s, to plant sugar cane. During WWII, sugar cane plantations were abandoned, and bombing, fires, and military reconstruction further reduced the native limestone forest. Currently, the introduced, weedy tangantangan (*Leucaena leucocephala*), a shrub-like tree also called *haole koa* in Hawai`i that can form dense monospecific thickets and is difficult to eradicate, has replaced both the sugar cane fields and native limestone forest areas. Tangantangan stands dominate most of the level and moderately sloping portions of this island, except for in the few, interspersed non-carbonate regions where guinea grass (*Panicum maximum*) is dominant (Stafford et al. 2005). The remnants of the native limestone forest are now restricted to cliff lines and escarpments around the plateau on the southeast side of Tinian and in a corridor on the central escarpment (National Park Service 2001).

There are 3 wetland areas on Tinian. The largest includes Hagoi, a lake on the northwest part of this island, and the 2 smaller areas are farther south (Fig. 7.1a). At present, these wetlands are effectively protected by both Federal and local laws. In 2007, the CNMI legislature designated a marine reserve area on the southwest side of Tinian through CNMI Public Law 15-90. This area, which CNMI Public Law 17-14 revised in 2010, is bounded from Puntan Carolinas to Tinian Harbor (Fig. 7.1.2a); however, the exact geographic coordinates of the reserve boundary are still undefined. All fishing activities—with the exception of aquaculture and fishing for the seasonal species *atulai* or bigeye scad (*Selar crumenophthalmus*), *i`e* or juvenile jacks (Carangidae), and *ti`ao* or juvenile goatfish (Mullidae)—are prohibited in this reserve for an initial period of 5 years that began in 2007 when Public Law 15-90 became effective. Tinian’s wetlands are essential to the survival of the Mariana common moorhen (*Gallinula chloropus guami*), 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). Small, remnant populations of the Mariana megapode, a pigeon-sized bird of the forest floor, persist on both Tinian and Aguijan.
Current activities to mitigate environmental issues on Tinian (CNMI Department of Commerce 2009):
- Resurfacing of secondary roads to reduce pollution and danger
- Examining alternate energy resources
- Rehabilitating Tinian Harbor, which is in very poor repair
- Upgrading Tinian Airport, including an instrument-landing system and improved fuel storage
- Constructing a wastewater treatment plant (currently septic tanks are used)
- Relocating the sanitary landfill currently located just south of the airport
- Studying impacts of increased military training activities

Projects and proposals for economic improvements and revenue generation on Tinian:
- Creating an interisland super ferry
- Completing Natibu Park
- Building Kastiyu Wildlife Park for ecotourism
- Implementing a Tinian public market
- Creating an aquaculture industry
- Beginning Tangantangan charcoal export
- Building Taga House Museum
- Creating Tinian Botanical Garden

7.2 Survey Effort

Extensive biological, physical, and chemical observations collected under the Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) have documented the conditions and the processes influencing coral reef ecosystems around the island of Tinian and Tatsumi Reef 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, 4 geographic regions around Tinian were delineated in Figure 7.2a; wave exposure and breaks in survey locations were considered when defining these geographic regions. This figure also displays the locations of Rapid Ecological Assessment (REA) and towed-diver surveys conducted around Tinian. Potential reef habitat around this island is represented by a 100-fm contour shown in white on this map.

**Figure 7.2a.** Locations of REA and towed-diver benthic surveys conducted around Tinian Island and Tatsumi Reef during MARAMP 2003, 2005, and 2007. To aid discussion of spatial patterns, this map delineates 4 geographic regions: northeast, southeast, southwest, and northwest.
Benthic habitat mapping data were collected around Tinian using a combination of acoustic and optical survey methods. MARAMP benthic habitat surveys conducted with multibeam sonar around Tinian, Tatsumi Reef, Aguijan, Saipan, and Marpi Bank covered a total area of 210 km² in 2003 and 1800 km² in 2007. Optical validation and habitat characterization were completed using towed-diver surveys that documented live coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in Section 7.3: Benthic Habitat Mapping and Characterization.

Information on the condition, abundance, diversity, and distribution of biological communities around Tinian was collected using REA and towed-diver surveys. The results of these surveys are reported in Sections 7.5–7.8: “Corals and Coral Disease,” “Algae and Algal Disease,” “Benthic Macroinvertebrates,” and “Reef Fishes.” The number of surveys conducted during MARAMP 2003, 2005, and 2007 are presented in Table 7.2a, along with their mean depths and total areas.

Table 7.2a. Numbers, mean depths (m), and total areas (ha) of REA and towed-diver surveys conducted around Tinian Island and Tatsumi Reef 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. REA surveys were conducted only around Tinian.

<table>
<thead>
<tr>
<th>Survey Type</th>
<th>Survey Detail</th>
<th>Year</th>
<th>Year</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2003</td>
<td>2005</td>
<td>2007</td>
</tr>
<tr>
<td>REA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>Number of Surveys</td>
<td>3</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Mean Depth (m)</td>
<td>11.2 (SD 0.6)</td>
<td>10.8 (SD 2.3)</td>
<td>11.7 (SD 0.9)</td>
</tr>
<tr>
<td>Benthic</td>
<td>Number of Surveys</td>
<td>3</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Mean Depth (m)</td>
<td>11.2 (SD 0.6)</td>
<td>10.8 (SD 2.3)</td>
<td>11.7 (SD 0.9)</td>
</tr>
<tr>
<td>Towed Diver</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TINIAN</td>
<td>Number of Surveys</td>
<td>6</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Total Survey Area (ha)</td>
<td>9.8</td>
<td>25.5</td>
<td>20.2</td>
</tr>
<tr>
<td></td>
<td>Mean Depth (m)</td>
<td>12.9 (SD 2.1)</td>
<td>15.8 (SD 1.2)</td>
<td>14.7 (SD 1.6)</td>
</tr>
<tr>
<td>TATSUMI</td>
<td>Number of Surveys</td>
<td>2</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Total Survey Area (ha)</td>
<td>4.8</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Mean Depth (m)</td>
<td>16.4 (SD 2.6)</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Spatial and temporal observations of key oceanographic and water-quality parameters influencing reef conditions around Tinian were collected using (1) subsurface temperature recorders (STR) designed for long-term observations of high-frequency variability of temperature, (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. Results for some casts and water samples are not presented in this report because either the data were redundant or errone-

Table 7.2b. Numbers of oceanographic instruments deployed, shallow-water and deepwater CTD casts performed, and water samples collected around Tinian 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.”

<table>
<thead>
<tr>
<th>Observation Type</th>
<th>Year</th>
<th>Year</th>
<th>Year</th>
<th>Year</th>
<th>Lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instruments</td>
<td>2003</td>
<td>2005</td>
<td>2007</td>
<td>2009</td>
<td></td>
</tr>
<tr>
<td>STR</td>
<td>Deployed</td>
<td>Retrieved</td>
<td>Deployed</td>
<td>Retrieved</td>
<td>Deployed</td>
</tr>
<tr>
<td>CTD Casts</td>
<td>2003</td>
<td>2005</td>
<td>2007</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Shallow-water</td>
<td>9</td>
<td>31</td>
<td>26</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>Deepwater</td>
<td>–</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Water Samples</td>
<td>2005</td>
<td>2007</td>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>5</td>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Towed-diver Surveys: Depths

Figures 7.2b–e illustrate the locations and depths of towed-diver-survey tracks around Tinian and Tatsumi Reef and should be referenced when further examining results of towed-diver surveys from MARAMP 2003, 2005, and 2007.

During MARAMP 2003, 6 towed-diver surveys were conducted along parts of the forereef slopes in the northeast and south regions of Tinian; two additional towed-diver surveys were conducted at Tatsumi Reef off the southeast coast of Tinian (Figs. 7.2b and c). The mean depth for all survey segments around Tinian and Tatsumi Reef was 12.8 m (SD 3.7), and the mean depths of individual surveys ranged from 9.5 m (SD 2.6) to 18.2 m (SD 4.4).

**Figure 7.2b.** Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted on forereef habitats around Tinian and Tatsumi Reef during MARAMP 2003, 2005, and 2007. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005, and 2007.

**Figure 7.2c.** Depths and tracks of towed-diver surveys conducted on forereef habitats around Tinian and Tatsumi Reef during MARAMP 2003. 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.

**Table 7.2b.** Mean segment depths (m) of towed-diver surveys conducted around Tinian and Tatsumi Reef during MARAMP 2003, 2005, and 2007.

<table>
<thead>
<tr>
<th>Region</th>
<th>Mean Depth (m)</th>
<th>SD (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinian 2003</td>
<td>12.8</td>
<td>3.7</td>
</tr>
<tr>
<td>Tinian 2005</td>
<td>12.8</td>
<td>3.7</td>
</tr>
<tr>
<td>Tinian 2007</td>
<td>12.8</td>
<td>3.7</td>
</tr>
<tr>
<td>MARAMP 2003–2007</td>
<td>12.8</td>
<td>3.7</td>
</tr>
</tbody>
</table>

* Each label indicates mean and standard deviation values for each entire towed-diver survey.
During MARAMP 2005, 12 towed-diver surveys were conducted along the forereef slopes around most of Tinian (Figs. 7.2b and d). The mean depth of all survey segments was 15.9 m (SD 2.7), and the mean depths of individual surveys ranged from 12.7 m (SD 1.5) to 17.1 m (SD 2.1).

**Figure 7.2d.** Depths and tracks of towed-diver surveys conducted on forereef habitats around Tinian during MARAMP 2005. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

**Figure 7.2e.** Depths and tracks of towed-diver surveys conducted on forereef habitats around Tinian during MARAMP 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.
During MARAMP 2007, 8 towed-diver surveys were conducted along parts of the forereef slopes around Tinian (Figs. 7.2b and e). The mean depth of all survey segments was 14.7 m (SD 2.8), and the mean depths of individual surveys ranged from 11.8 m (SD 2.5) to 16.7 m (SD 2.8).

7.3 Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization surveys around the island of Tinian and Tatsumi Reef were conducted during MARAMP 2003, 2005, and 2007 using 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 ~2–1750 m with almost complete coverage around Tinian and Tatsumi Reef. Optical validation and benthic characterization via diver observations and both video and still underwater imagery were performed using towed-diver surveys conducted at depths < 25 m.

7.3.1 Acoustic Mapping

Multibeam bathymetry and backscatter imagery (Fig. 7.3.1a) collected by the Coral Reef Ecosystem Division (CRED) around Tinian, Tatsumi Reef, Saipan, Marpi Bank, and Aguijan during MARAMP 2003 and 2007 encompassed an area of 2013.4 km$^2$. The primary multibeam bathymetry was collected by CRED using sonars aboard the NOAA R/V AHI and the NOAA Ship Hi`ialakai. The second data set includes both lidar data and, in waters deeper than ~40 m, multibeam bathymetric data collected by the U.S. Naval Ship Sumner; all of these data were collected in 2001 by the Naval Oceanographic Office (2004). The lidar data were used in areas where no CRED multibeam data were available, primarily in waters shallower than ~20 m. Finally, in shallow areas where neither multibeam nor lidar data were available, “estimated depths” or “derived depths” were calculated from IKONOS imagery data using a modified Lyzenga (1985) method (Hochberg et al. 2007; Hogrefe 2009).

Multibeam bathymetry acquired around Tinian reveals a steeply sloping bank, the flanks of which descend to depths >200 m within 1–2 km of the shore (Fig. 7.3.1a, top panel). This steep slope runs along the east side of Tinian before extending 1.5 km east of Puntan Masalok to form a submerged peninsula (for place-names and their locations, see Figure 7.2a in Section 7.2: Survey Effort). The bathymetry at the base of this slope shows a number of areas of complex topography offshore from southeast Tinian; this topography is caused by erosion and mass wasting (movement of soil and surface materials by gravity) and coincides with onshore margin failure (Stafford et al. 2005). To the south-southeast of Tinian, a shallow bank known as Tatsumi Reef with a minimum depth of ~7 m, is separated from Tinian by a channel nearly 350 m deep. A major feature southwest of Tinian, the anchorage area is composed of a series of 4–6 carbonate platforms forming progressively deeper platforms that extend up to 4 km offshore. The seabed northwest of Tinian, within 1 km of the shore, again slopes steeply to depths of more than 200 m. At the base of this slope, frequently complex topography provides further evidence of mass wasting. An additional feature of note is a series of narrow submerged ridges that extend from the north of Tinian toward Saipan.

Backscatter data reflect signal form and strength and are affected by 3 primary seafloor characteristics—roughness, hardness, and slope. In general, “high” backscatter values usually suggest a hard or rocky seafloor, while “low” backscatter values suggest a soft or sediment-covered seafloor. Backscatter values, however, are also influenced by methodological factors, such as sonar settings and vessel speed. In the case of Tinian, it is important to note that shallow multibeam data collected during MARAMP 2003 were collected at high survey speeds, and this circumstance may also influence results. Thus, it is not possible to directly interpret backscatter into a specific type of seafloor (e.g., hard versus soft); instead backscatter data must be combined with bathymetry derivatives, such as slope or rugosity, to provide an understanding of seafloor characteristics. Nevertheless, backscatter imagery around Tinian does help to elucidate interrelationships between onshore and offshore geology (Fig. 7.3.1a, bottom panel). Maps of groundwater flow patterns and beaches show that carbonate beaches are often located in areas of groundwater discharge. Likewise, considering the offshore backscatter imagery in relationship to these and other factors reveals that areas of low backscatter often associate with the locations of beaches, groundwater discharge, and flow of surface water.

Data acquired around Tinian show high backscatter values in areas where mass wasting has occurred and along the top of many of the ridges around this island. High-intensity backscatter is also observed north of Tinian within the Saipan Channel. High backscatter values around Tinian may suggest hard substrates, but this interpretation must be viewed with caution because of the steep slopes surrounding most of this island.
Figure 7.3.1a. Gridded multibeam bathymetry (top, grid cell size: 60 m) and backscatter (bottom, grid cell size: 5 m) collected around Tinian during MARAMP 2003 and 2007 at depths of 2–1700 m. Shallow-backscatter data (shown in purple) were collected using a 240-kHz Reson SeaBat 8101 ER sonar, and backscatter data (shown in blue) were collected in deeper depths using a 30-kHz Kongsberg 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.
High-resolution Bathymetry and Derivatives

The final Tinian high-resolution depth map is a mosaic with 3 different depth inputs: multibeam sonar, airborne lidar, and estimated depths derived from IKONOS satellite imagery (Fig. 7.3.1b).

**Figure 7.3.1b.** Location of multibeam data collected by CRED (shown in blue), lidar and multibeam data obtained by the National Oceanographic Office (NAV-OCEANO, shown in green), and depths derived from IKONOS satellite imagery (shown in red).

**Figure 7.3.1c.** High-resolution multibeam bathymetry collected around Tinian during MARAMP 2003 and 2007 combined with NAV-OCEANO lidar bathymetry and depths derived from IKONOS satellite imagery. This 5-m bathymetry grid, clipped at 400 m, is used as the basis for slope, rugosity, and BPI derivatives.
Bathymetric data collected in nearshore (depths of 0–400 m) waters around Tinian were combined into a grid at 5-m resolution to allow for the identification of fine-scale features (Fig. 7.3.1c). Because error estimates for the derived depths around Tinian (Hogrefe 2009) are similar in magnitude to the error estimates for both shallow multibeam depths and lidar depths, it is also justifiable to use all 3 of the depth sources (multibeam, lidar, and estimated depths from IKONOS imagery) to derive meaningful slope (Fig. 7.3.1d), rugosity (Fig. 7.3.1e), and bathymetric position index (BPI) zones (Fig. 7.3.1f). Together, these maps provide layers of information to characterize the benthic habitats and describe features of interest around Tinian.

The high-resolution bathymetry further emphasizes the numerous areas of complex topography found around this island, highlighting individual ridges and mounds. In the shallowest areas surveyed, high-resolution bathymetry data also reveal intricate topographic patterns that may represent coral reef formations.

Northeast of Tinian, the slope map (Fig. 7.3.1d) highlights steps in the bathymetry that are not conspicuous in the map of bathymetry (Fig. 7.3.1c) alone and where steep slopes of up to 70° are recorded. Below this steep slope, the seabed continues to deepen but does so more gradually until it reaches a plateau in the Saipan Channel at a depth of ~ 250 m. This plateau is identified as a “flat” zone through the BPI analysis. The highest rugosity values around Tinian are associated with the slopes, suggesting a convoluted and rugged terrain.

East of Puntan Asiga, at depths of 200–300 m, high-resolution bathymetric data and derived slope and rugosity clearly show an area of more complex topography. These slope and rugosity maps (Figs. 7.3.1d and e) show that Asiga Bay has a generally flat bottom with low rugosity, an observation further supported by BPI analysis (Fig. 7.3.1f).

A distinct pattern is shown in the high-resolution bathymetry map (Fig. 7.3.1c) in the shallowest waters, generally < 40 m deep, along the east coast of Tinian: the appearance of linear ridges and mounds that may suggest the presence of spur and groove topography. The slope and rugosity maps also outline these features and help to further elucidate their topography. On the submerged ridge east of Puntan Masalok, this rough topographic character continues to a depth of 80 m (see inset in Figure 7.3.1e), and additional investigation of this area is recommended.
Figure 7.3.1e. Rugosity of 5-m bathymetric grid around Tinian. Derived from data collected between 2001 and 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. Inset map shows complex bathymetry at depths of 20–80 m in the featured area east of Puntan Masalok.

Southeast of Tinian, the slope map reveals steps in the bathymetry similar to those steps found farther north. Very little flat seabed is found in this area, apart from within the small bay south of Puntan Kastiyu. Again, the steepest slopes are associated with the highest rugosity values. The submerged bank Tatsumi Reef, a major bathymetric feature south-southeast of Tinian, has a similar topography to the seabed around Tinian itself, which is composed of a series of platforms. The top of

Figure 7.3.1f. BPI zones of 5-m bathymetric grid around Tinian derived from data collected between 2003 and 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.
the reef has low slope values and is identified from the BPI analysis as being a flat zone with correspondingly low rugosity values. This reef descends steeply, with slope values up to 60°, into the deep channel that separates it from Tinian.

A major feature off the southwest coast is the anchorage area surrounding Tinian Harbor. Here, the seabed is generally flat with low rugosity values. BPI terrain analysis highlights the slopes that separate the successively deeper shelf flats. Three of these platforms are shown clearly in the slope and rugosity maps (Figs. 7.3.1d and e). Such offshore platforms usually indicate previous sea level stands but could also be expressions of faults like those that are seen onshore in the dynamic tectonics of the Mariana Archipelago. This anchorage is one of the few large areas of flats revealed by the BPI terrain analysis, which otherwise shows a seascape dominated by a complex pattern of crests, depressions, and slopes. Within the very shallow waters of Tinian Harbor, rugosity, slope, and bathymetry data also reveal numerous small mounds.

From Puntan Diapblo to the northern tip of Tinian, the seabed is characterized by very steep slopes of up to 70° running parallel to the shore at a distance of less than 500 m. These slopes are associated with high rugosity values, suggesting a relatively rough and convoluted seafloor. BPI terrain analysis (Fig. 7.3.1f) for this region also shows the topographic complexity of a mixture of crests, depressions, and slopes.

**High-resolution Multibeam Backscatter and Derivatives**

High-resolution backscatter data were acquired around Tinian using a 240-kHz Reson SeaBat 8101 ER multibeam echosounder and a 30-kHz Kongsberg EM 300 sonar. As discussed in Chapter 2: “Methods and Operational Background,” Section 2.2.2: “Acoustic Mapping”, because sonars of different frequencies have different backscatter signatures, only data from the SeaBat 8101 ER sonar were used for hard–soft analyses. Also, the backscatter and hard–soft maps in this section use only SeaBat 8101 ER backscatter data because no backscatter was available from either the lidar or IKONOS sensors, although additional bathymetric data were acquired from lidar and IKONOS satellite imagery.

A number of factors aside from substrate characteristics can also affect the measured backscatter intensity, including sonar frequency, settings, and slope (see Chapter 2: “Methods and Operational Background”). In some of the steep nearshore areas, where the depth was close to the maximum range of the 240-kHz sonar (~ 300 m), sonar settings were modified in

![Figure 7.3.1g](image-url)
order to obtain these deep data. These different settings, and the steep slopes themselves, resulted in noticeably different characteristics between the deepest swath collected with the SeaBat 8101 ER sonar and the shallower swaths surveyed with the same sonar (Fig. 7.3.1g). To exclude these artifacts, the backscatter data were clipped to a depth of 150 m prior to deriving the hard–soft substrate map (Fig. 7.3.1h).

The backscatter and hard–soft substrate maps both show a clear pattern of predominantly hard substrate on the east (windward) side of Tinian with soft substrate more common on the west (leeward) side. Tatsumi Reef is almost entirely classified as hard substrate and may be composed of hard carbonate pavement that supports coral reef growth.

A number of interesting exceptions to this general trend are observed. The small bay southwest of Puntan Kastiyu, for example, is both characterized as an area of soft substrate by backscatter data and defined as a flat area by BPI terrain analysis (Fig. 7.3.1f). The anchorage area at Tinian is characterized by a mixture of hard and soft substrate. Two clearly defined patches of soft substrate in the north of this anchorage correspond to areas of low slope and rugosity as shown in Figures 7.3.1d and e. Northwest of Tinian, a narrow band of hard substrate runs close inshore with softer substrate farther offshore. This band coincides with the flat, low-rugosity crests shown in the bathymetry derivatives (Figs. 7.3.1d, e, and f).

**Figure 7.3.1h.** Hard and soft substrates (grid cell size: 5 m) at depths < 150 m based upon an unsupervised classification of multibeam bathymetry and backscatter data acquired around Tinian between 2003 and 2007. Data cannot be collected directly under the ship, hence the white lines showing the ship's path.

### 7.3.2 Optical Validation

Covering a distance of 55 km at depths of 6–26 m, 28 towed-diver optical-validation surveys of forereef habitats were conducted around Tinian and Tatsumi Reef during MARAMP 2003, 2005, and 2007 (Fig. 7.3.2a). 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.
7.3.3 Habitat Characterization

Sand cover, habitat complexity, and live coral cover around Tinian are discussed in this section. These descriptions are organized by the 4 geographic regions around Tinian, beginning with the northeast region and moving clockwise. Towed-

---

**Figure 7.3.2a.** Towed-diver tracks from surveys of forereef habitats conducted around Tinian during MARAMP 2003, 2005, and 2007. Survey tracks are displayed over multibeam hard–soft substrate maps. Data cannot be collected directly under the ship, hence the white lines showing the ship’s path.

---

**Figure 7.3.3a.** Observations of sand cover (%) from towed-diver surveys of forereef habitats conducted around Tinian during MARAMP 2003, 2005, and 2007.
Towed-diver surveys conducted during MARAMP 2003, 2005, and 2007 recorded moderately low sand cover around Tinian (Fig. 7.3.3a), suggesting that the substrate around this island is predominantly hard. This towed-diver finding corresponds well to the prediction of predominance of hard substrate close inshore by the hard–soft analyses (Fig. 7.3.2a). The distribution of habitat complexity (Fig. 7.3.3b) and live coral cover (Fig. 7.3.3c) around Tinian were both varied and in some areas appeared to associate well with each other. Areas with the highest coral cover also had habitat complexity ranging from medium to high, although some areas where medium habitat complexity was recorded, such as south of Puntan Masalok and east of Puntan Diapblo, did not support high coral cover. Other regional distribution patterns were observed, and they are described in relation to the other benthic substrate categories in more detail in the rest of this section.

Towed-diver observations of sand cover (Fig. 7.3.3a) suggest that habitats northeast of Tinian were characterized by predominantly hard substrate with high sand cover recorded only at a small area close to Puntan Tahgong in the northeast region. North of Puntan Asiga, habitat complexity was low, and live coral cover was correspondingly low at < 5%. However, within Asiga Bay, the hard substrate supported a relatively high cover of live corals, particularly in the north part of the bay where interpolated mean cover was observed at 30%–40%. In Asiga Bay, a similarly high level of habitat complexity was also recorded, reflecting the mixture of spur-and-groove formations, boulder fields, and pinnacles observed by divers in this area.

In the southeast region, towed-diver surveys conducted south of Puntan Masalok and in the bay south of Puntan Kastiyu revealed differences in these 2 areas. Sand cover south of Puntan Masalok was low, and this hard substrate supported a low cover of live corals. Habitats observed in this area included rubble flats, rocks and crags, and reef slopes. In contrast, habitats south of Puntan Kastiyu included high-relief, spur-and-groove formations, boulders, and rocky crags. Habitats encountered were characterized by low sand cover of 0%–10% and a high live coral cover of up to 40.1%–50%.

Tatsumi Reef showed a gradient of habitat complexity and live coral cover with complexity and coral cover highest at its shallowest point and decreasing with depth. The maximum observed live coral cover of 20.1%–30% was recorded at the center of this reef.

Tinian anchorage in the southwest region was observed to have a relatively low habitat complexity and support low (< 10%) cover of live corals. Areas of high and low sand cover were seen, suggesting a mixed substrate. This area was described by towed divers as consisting of rock flats with rocks and boulders.
Southeast of Puntan Diapblo in the north of the anchorage, relatively high levels of habitat complexity were observed during towed-diver surveys. Sand cover was low, representing a predominantly hard-bottom substrate that supported high coral cover of 40.1%–50%, relative to other areas surveyed around Tinian. Towed divers encountered a range of habitat types, including reef with sand channels, rubble fields, and rocky walls, crags, and boulders.

In the northwest region, medium to medium-high habitat complexity was observed, and, similarly, high mean coral cover was recorded at several locations. Between Puntans Lamanibot Sampapa’ and Lamanibot Sanhilo, high coral cover of 40.1%–50% was found in an area characterized as spur-and-groove habitat of medium complexity. The remainder of this survey was characterized by pavement flats, and low sand cover was recorded there. Northeast of Puntan Lamanibot Sanhilo, along the northwestern coast, high coral cover of 40.1%–50% also was recorded. Although the hard–soft map shows numerous soft substrate patches in this area (Fig. 7.3.2a), towed divers saw very low sand cover. This observation could result from this survey running closer inshore and missing the sand patches; divers were probably towed along the top of the carbonate shelf, the edge of which is shown in the combined bathymetry (Fig. 7.3.1b).

### 7.4 Oceanography and Water Quality

#### 7.4.1 Hydrographic Data

**2003 Spatial Surveys**

During MARAMP 2003, shallow-water conductivity, temperature, and depth (CTD) casts were conducted in nearshore waters around the island of Tinian over the period of August 22–23. Temperature, salinity, and density values from 8 of these casts varied both spatially and vertically (Figs. 7.4.1a and b). Spatial comparisons of water properties at a depth of 10 m suggest a moderate range in temperature (0.43°C) and a small range in salinity (0.08 psu) values (Fig. 7.4.1a). Cooler temperatures and higher salinities, and associated higher densities were recorded around the northeast end of Tinian (casts 3 and 4) relative to other areas of this island. Vertical comparisons of CTD profiles (Fig. 7.4.1b) reveal a prominent north–south gradient. To the south of Tinian (casts 6–8), water temperatures were warmer and profiles show higher stratification compared to those obtained in the north, where waters were cool and well mixed. This observation is likely because of mixing of deep waters or localized upwelling, which may be caused by vigorous tidal flows around the north tip of this island.
Figure 7.4.1a. Values of (top left) water temperature, (top right) salinity, and (bottom left) density at a 10-m depth from shallow-water CTD casts around Tinian on August 22–23 during MARAMP 2003.

Figure 7.4.1b. Shallow-water CTD cast profiles to a 30-m depth around Tinian on August 22–23 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 1–8 in a clockwise direction around Tinian. For cast locations and numbers around this island in 2003, see Figure 7.4.1a.
During MARAMP 2005, shallow-water CTD casts were conducted in nearshore waters around Tinian over the period of September 25–27. Temperature, salinity, density, and beam transmission values from 28 of these casts varied both spatially and vertically around this island (Figs. 7.4.1c and d). Spatial comparisons of water properties at a depth of 10 m suggest an east–west gradient in water properties, with warmer, more saline, less dense, and less turbid waters along the western half of the island compared to the eastern half (Fig. 7.4.1c). Vertical comparisons of CTD profiles (Fig. 7.4.1d) reveal well-mixed waters with a broad range in water properties with temperature differences as large as 1.6°C at the southeast side close to the channel between Tinian and Tatsumi Reef. The east side of Tinian (casts 10–21) exhibited slightly lower temperatures, slightly higher salinities, and associated higher densities compared to the west side of Tinian (casts 21–28; 1–7). This difference may be caused by greater wind and wave mixing with deep waters compared to the west (leeward) side of this island. Two profiles (casts 19 and 20) on the southeast end of this island suggest enhanced mixing with deep waters or localized upwelling, relative to other areas of this island. Turbidity was low with beam transmission > 93% at all cast locations; all temperature, salinity, and water-clarity data show no obvious signs of terrestrial runoff.

Water samples were collected in concert with shallow-water CTD casts at 6 select locations around Tinian in 2005 to assess water-quality conditions (Fig. 7.4.1e). Three successive samples were obtained at the northern site in the southwest region. The following ranges of measured parameters were recorded around Tinian during MARAMP 2005: chlorophyll-$a$

**Figure 7.4.1c.** 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 around Tinian on September 25–27 during MARAMP 2005.
(Chl-a), 0.163–0.387 μg L⁻¹; total nitrogen (TN), 0.213–1.046 μM; nitrate (NO₃⁻), 0.198–0.990 μM; nitrite (NO₂⁻), 0.015–0.056 μM; phosphate (PO₄³⁻), 0.011–0.040 μM; and silicate (Si(OH)₄), 0.692–0.937 μM. Based on data from the 6 sample locations, all parameters measured showed higher concentrations at the southern sample site in the southwest region; total nitrogen was 4 times higher at this site compared to all other locations from around this island. Chl-a and nutrient concentrations were lower in the northwest region compared to other regions. The succession of 3 samples at the northern site in the southwest region exhibited a wide range of values, suggesting a dynamic oceanographic environment.

**Figure 7.4.1d.** Shallow-water CTD cast profiles to a 30-m depth around Tinian on September 25–27 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 1–27 in a clockwise direction around Tinian. In the southwest region, 2 casts were performed at essentially the same location, but only 1 vertical profile is shown in this graph. For cast locations and numbers around this island in 2005, see Figure 7.4.1c.
10-m Nutrient Data 2005

Figure 7.4.1e. 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 around Tinian on September 25–27 during MARAMP 2005.
2007 Spatial Surveys

During MARAMP 2007, 26 shallow-water CTD casts were conducted in nearshore waters around Tinian over the period of May 18–19 (Fig. 7.4.1f). Temperature, salinity, density, and beam transmission values varied both spatially and vertically around this island (Figs. 7.4.1f and g). Spatial comparisons of water properties at a depth of 10 m suggest an east–west gradient in oceanographic conditions, with warmer, slightly less saline, less dense waters along the western half of this island compared to the eastern half. Beam transmission values were low at select sites (cast 17 and 21), but were generally homogenous around much of this island (Fig. 7.4.1f). Vertical comparisons of CTD profiles (Fig. 7.4.1g) reveal distinct intraisland variability. Greater cold-water intrusions were found along the east coast of Tinian with generally lower temperatures, higher salinities, and associated higher densities than in other areas around this island. This interpretation may result from greater wind and wave mixing with deep waters compared to the west (leeward) side of this island. Both the northeast (casts 7–10) and southeast (casts 13–17) corners of Tinian, relative to other areas of this island, show signs of greater mixing with deep waters or localized upwelling. These areas were potentially influenced by strong tidal flows across the Marianas Ridge, and between the islands on the ridge. Another area of cooler, more saline water, similar to the areas at the northeast and southeast corners of this island, can be seen near the harbor (cast 25).

**TINIAN**

10-m CTD Data 2007

![Maps showing temperature, salinity, density, and beam transmission at a 10-m depth from shallow-water CTD casts around Tinian on May 18–19 during MARAMP 2007.]

*Figure 7.4.1f. 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 around Tinian on May 18–19 during MARAMP 2007.*
Water samples were collected in concert with shallow-water CTD casts at 5 select locations around Tinian in 2007 to assess water-quality conditions (Fig. 7.4.1h). The following ranges of measured parameters of 4 out of 5 water samples were recorded around Tinian during MARAMP 2007: Chl-$a$, 0.059–0.123 μg L$^{-1}$; total nitrogen (TN), 0.009–0.044 μM; nitrate (NO$_3^-$), 0.002–0.035 μM; nitrite (NO$_2^-$), 0.006–0.010 μM; phosphate (PO$_4^{3-}$), 0.050–0.056 μM; and silicate (Si(OH))$_4$, 0.792–1.198 μM. Based on data from the 4 sample locations, the highest concentrations of nutrients were found in the northeast and northwest regions, while the highest Chl-$a$ values were in the southwest region.

Figure 7.4.1g. Shallow-water CTD cast profiles to a 30-m depth around Tinian on May 18–19 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 1–26 in a clockwise direction around Tinian. For cast locations and numbers around this island in 2005, see Figure 7.4.1f.
Figure 7.4.1h. 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 around Tinian on May 18–19 during MARAMP 2007.
**Temporal Comparison**

Results from shallow-water CTD casts taken during MARAMP 2003, 2005, and 2007 suggest a complex oceanographic environment around Tinian. Intersurvey comparisons show a similarity in the 3 MARAMP survey years of high water clarity or low turbidity with > 93% beam transmission for all profiles for the 3 survey years. Maximum water temperature decreased with each subsequent MARAMP survey period, while the greatest range in temperature (1.6°C) values was observed in 2005. Spatial and vertical variability was greatest during the 2007 survey, when pronounced, localized, deepwater mixing tongues were observed. A similar pattern of cooler temperatures and higher salinities on the east side (windward) of Tinian compared to the west (leeward) existed in both 2005 and 2007 surveys. 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 August and September. This change was made to avoid the typhoon season and reduce the probability of weather disruptions. Wind and waves conditions are generally higher during the wet season (July–December), with stronger trade winds prominent on the east side. This seasonal variation could explain some of the differences seen between survey years, with higher winds and waves causing more mixing during MARAMP 2003 and 2005, and calmer weather potentially allowing for the east-west gradient recorded in 2007. Further investigation will help make these particular results and patterns more apparent.

Water-quality data obtained during MARAMP 2005 and 2007 suggest that chl-α, total nitrogen, nitrate, and nitrite concentrations were much lower in 2007 than in 2005, while phosphorus and silicate concentrations were much higher. Differences between the two survey years are likely because of seasonal effects. Precipitation data show that MARAMP 2005 occurred during a period of seasonally high precipitation, while MARAMP 2007 occurred during a period of seasonally low precipitation (Fig. 7.4.2d). The comparatively high nitrogen and chl-α concentrations measured in 2005 versus 2007 are likely related to an increase in terrigenous run-off associated with increased precipitation during the sampling period. Future water sampling efforts will help constrain what appears to be a dynamic coastal environment.

### 7.4.2 Time-series Observations

Between MARAMP 2003 and 2007, subsurface temperature recorders (STRs) were deployed at 2 mooring locations at Tinian to collect time-series observations a key oceanographic parameter. The locations, depths, time frames, and other details about these deployments are provided in Figures 7.4.2a and b.

**Figure 7.4.2a.** Locations and depths of the STRs deployed at Tinian during MARAMP 2003, 2005, and 2007. For information about deployments and retrievals, see Figure 7.4.2b in this section and Table 7.2b in Section 7.2: “Surve Effort.”
Figure 7.4.2b. Deployment timelines and depths of the STRs installed at Tinian during the period from September 2005 to April 2009. A solid bar indicates the period for which temperature data were collected by a series of STRs that were deployed and retrieved at a mooring site.

An STR mooring site was established in 2005 at Tinian (Fig. 7.4.2a). Data from the STRs deployed at a depth of 7 m at this site in the northeast region show seasonal temperature variability of 3°C–4°C (Fig. 7.4.2c). Water temperatures reached ~ 30.5°C during the months of June–October and fell to a low of ~ 27°C during the months of January–May. Temperatures briefly exceeded the coral bleaching threshold of 30.5°C in September 2006. Diurnal temperature fluctuation was ~ 0.3°C throughout this time series.

Figure 7.4.2c. Time-series observations of temperature over the period between September 2005 and May 2007 collected from 1 STR mooring site on the east side of Tinian at depth of 7 m. The red line indicates the satellite-derived coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean (see Figure 7.4.2a for mooring locations).

Precipitation at Tinian from 2002 to the middle of 2008 was highly seasonal with the greatest rainfall occurring in the months of July–September and the lowest occurring in the months of February–April (Fig. 7.4.2d). MARAMP 2003 and 2005 cruises were conducted in September and October, which are months characterized by seasonally high precipitation. In contrast, MARAMP 2007 was conducted in May when rainfall was seasonally low.

Figure 7.4.2d. Average monthly rainfall (m) from the Tinian Airport from January 2002 to July 2008. The cyan line indicates precipitation climatology (1987–2008) and vertical red bars indicate MARAMP cruise periods. Source: National Weather Service, Honolulu, Hawaii (http://www.prh.noaa.gov/hnl/).
7.4.3 Wave Watch III Climatology

Seasonal wave climatology for Tinian was derived using the NOAA Wave Watch III model for the period of January 1997 to May 2008 (Fig. 7.4.3a), and seasons were selected to elucidate waves generated by typhoons, which most frequently occur during the period of August–December (for information about the Wave Watch III model, see Chapter 2: “Methods and Operational Background,” Section 2.3.7: “Satellite Remote Sensing and Ocean Modeling”). 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 (2–3 m) wave events originating from the east (~ 75°). Superimposed with these short-period swells were large (> 4 m), long-period (12–16 s) wave events principally from the southeast (135°), although they could originate from a broad directional source (90°–200°). These large, episodic waves primarily were generated via typhoons and occurred on annual to interannual time scales. Also, infrequent (~ 5 d per season), long-period (12–14 s) swells with moderate wave heights (2.5–3.5 m) occurred from the southwest (~ 240°) and were likely associated with episodic storms. Similar to the wave regime during typhoon season, the wave climate during the period of February–June (outside the typhoon season) also was characterized by frequent (> 30 d per season) and short-period (~ 8 s) trade wind swells with relatively small wave heights (~ 2 m) originating from the east. Infrequent (< 5 days per season) and long-period (12–14 s) swells with slightly larger wave heights (~ 3 m) also occurred during this time and originated from the southwest (~ 240°).

Figure 7.4.3a. NOAA Wave Watch III directional wave climatology for Tinian 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 Tinian (15° N, 145°35′ E). Mean significant wave height (top), 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 (bottom) that conditions in each directional and frequency bin occur in each season, indicated by color scale; for example, if the color indicates 30, then, on average, the condition occurred during 30 out of 150 days of that season.

7.5 Coral and Coral Disease

7.5.1 Coral Surveys

Coral Cover and Density

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on forereef habitats was 13% (SE 1.4) at the island of Tinian and 8% (SE 1.8) at Tatsumi Reef. The spatial coverage of surveys was limited, but, among the areas surveyed, coral cover was lowest within Tinian Harbor, with a mean of 5% for 20 survey segments, and highest within Asiga Bay, with a mean of 28% for 15 segments (Fig. 7.5.1a; for place-names and their locations, see Figure 7.2a in Section 7.2: Survey Effort). The 2 parallel towed-diver surveys conducted at Tatsumi Reef recorded relatively low coral cover (0%–10%) along the ends of this reef with an area of higher coral cover (10%–30%) within 4 segments in the center of this reef.
Figure 7.5.1a. Cover (%) observations of live hard corals from towed-diver benthic surveys of forereef habitats conducted at Tinian and Tatsumi Reef during MARAMP 2003. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~200 × 10 m (~2000 m²).

During MARAMP 2003, the 2 REA benthic surveys using the quadrat method on forereef habitats at Tinian documented 234 coral colonies within a total survey area of 7.5 m². Colony density was 25.6 colonies m⁻² at REA site TIN-02 in the southwest region and 36.8 colonies m⁻² and TIN-01 in Asiga Bay (Fig. 7.5.1b) with a mean of 31.2 colonies m⁻² (SE 5.6).

Figure 7.5.1b. Colony-density (colonies m⁻²) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Tinian during MARAMP 2003. Values are provided within each symbol. The quadrat method was used in 2003 to assess coral-colony density.
From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on forereef habitats around Tinian was 9% (SE 1.1). Coral cover was < 10% for the majority (78%) of the 115 segments surveyed around Tinian (Fig. 7.5.1c). A long, continuous stretch of high coral cover, compared to other areas surveyed at Tinian, was observed in the northwest region over 9 segments with a mean of 35%. Localized areas of high coral cover were observed south of Puntan Diapblo for 1 segment with 45%, near Puntan Kastiyu with a mean of 35% for 2 segments, and in the northwest region between Puntans Lamanibot Sanhilo and Lamanibot Sampapa' with a mean of 35% for 4 segments.

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, 0.6% (SE 0.1) of coral cover observed on forereef habitats around Tinian appeared stressed in 2005, with very low values of stressed-coral cover recorded in most survey segments (Fig. 7.5.1c). However, levels of stressed-coral cover for 2 segments in the northeast region fell in the range of 5%–10%.

During MARAMP 2005, the 5 REA benthic surveys using the quadrat method on forereef habitats at Tinian documented 638 coral colonies within a total survey area of 20 m². Site-specific colony density ranged from 28.5 to 38.3 colonies m⁻² with an overall sample mean of 32 colonies m⁻² (SE 1.8). The highest colony density was recorded at TIN-02 in the southwest region, and the lowest colony densities were recorded at TIN-03, east of Puntan Diapblo in the southwest region, and at TIN-06 in the northwest region (Fig. 7.5.1d).

From MARAMP 2007 towed-diver surveys, mean cover of live hard corals on forereef habitats around Tinian was 8% (SE 1.1). The spatial coverage for surveys was more limited in 2007 than in 2005, with 4 fewer surveys. No towed-diver surveys were conducted in the area that had the longest stretch of continuous high coral cover in 2005. Coral cover in 2007 was < 10% within the majority (80%) of 80 segments. Similar to results from MARAMP 2005, localized areas of high coral cover were observed within the northwest region between Puntans Lamanibot Sanhilo and Lamanibot Sampapa’ over 3 segments with a mean of 38%, south of Puntan Diapblo with 45% for 1 segment, and near Puntan Kastiyu over 5 segments with a mean of 23% (Fig. 7.5.1e).
Overall, 3% (SE 0.6) of coral cover observed on forereef habitats around Tinian appeared stressed in 2007 (see Chapter 2: “Methods and Operational Background,” Section 2.4.5, “Corals and Coral Disease”). Stressed-coral cover was highest south of Tinian Harbor over 9 segments with a mean of 12% (Fig. 7.5.1e). Stressed-coral cover was also noted in the northwest region between Puntans Lamanibot Sanhilo and Lamanibot Sampapa’ with a mean of 5% over 9 segments and in the northeast region with a mean of 6% over 7 segments.

Figure 7.5.1d. Colony-density (colonies m$^{-2}$) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Tinian during MARAMP 2005. Values are provided within each symbol. The quadrat method was used in 2005 to assess coral-colony density.

Figure 7.5.1e. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted around Tinian during MARAMP 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 m$^2$). 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 2007.
During MARAMP 2007, 5 REA benthic surveys using the line-point-intercept method were conducted on forereef habitats around Tinian. Site-specific estimates of live-hard-coral cover from these surveys ranged from 5.9% to 31.4% with an overall sample mean of 13.3% (SE 4.7). The highest coral cover was observed at TIN-03 in the southwest region, and the lowest level was found at TIN-04 in the southeast region (Fig. 7.5.1f).

During MARAMP 2007, 5 REA benthic surveys using the belt-transect or quadrat method on forereef habitats around Tinian documented 1464 coral colonies within a total survey area of 204 m$^2$. For the 4 REA sites surveyed using the belt-transect method, site-specific densities ranged from 4.5 to 9 colonies m$^{-2}$ with an overall sample mean of 6.7 colonies m$^{-2}$ (SE 1); a colony density of 28.8 colonies m$^{-2}$ was recorded near Puntan Kastiyu at TIN-04, which was surveyed with the quadrat method (Fig. 7.5.1f).

**Figure 7.5.1f.** Cover (%) and colony-density (colonies m$^{-2}$) observations of live hard corals from REA benthic surveys of forereef habitats conducted around Tinian during MARAMP 2007. Values are provided within each symbol. In 2007, the quadrat method was used only at TIN-04, and the belt-transect method was used to assess coral-colony density at the other 4 of the 5 REA sites surveyed.
Temporal comparison of mean live coral cover (%) from REA and towed-diver benthic surveys conducted on forereef habitats around Tinian during MARAMP 2003, 2005, and 2007. No REA surveys using the line-point-intercept method were conducted around Tinian in 2003 or 2005. Error bars indicate standard error (± 1 SE) of the mean.

Islandwide mean cover of live corals, estimated from towed-diver surveys of forereef habitats, was 13% (SE 1.4) in 2003, 9% (SE 1.1) in 2005, and 8% (SE 1.1) in 2007 (Fig. 7.5.1g). This variation in overall mean values of live coral cover between MARAMP survey years does not necessarily reflect actual changes in overall coral cover (for information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”). Estimates of live coral cover from REA surveys generally exceeded levels recorded in towed-diver surveys; REA surveys target hard-bottom communities, whereas towed-diver surveys include a wider array of substrate types. Site-specific estimates of coral cover averaged 13.3% (SE 4.7) for the 3 REA sites surveyed in 2007 (Tinian was not surveyed for coral cover using the line-point-intercept method in 2003 or 2005).

Overall mean coral-colony density from REA surveys conducted on forereef habitats at Tinian were similar during MARAMP 2003 and 2005, when the quadrat method was used, with 31.2 colonies m\(^{-2}\) (SE 5.6) and 31.9 colonies m\(^{-2}\) (SE 1.8, Fig. 7.5.1h). Site-specific coral-colony densities appeared substantially lower in 2007, as did the overall mean density with 6.7 colonies m\(^{-2}\) (SE 1), excluding TIN-04 in the southeast region. However, this apparent decline is likely an artifact of the use of a different method to assess colony density during MARAMP 2007. The placement of quadrats used in 2003 and 2005 was highly biased towards surveying hard-bottom substrate where coral was present, whereas the belt-transect method used at 4 of the 5 sites in 2007 sampled benthos that fell within the transect belt regardless of the nature of the substrate. TIN-04, the fifth REA site surveyed in 2007, was assessed with the quadrat method. At this site near Puntan Kastiyu, observed colony density was 28.8 colonies m\(^{-2}\), nearly 4 times greater than the density recorded at other sites surveyed with the belt-transect method. This considerable difference strengthens the supposition that the quadrat method yielded higher density values than the belt-transect method.

**Coral Generic Richness and Relative Abundance**

Two REA benthic surveys of forereef habitats were conducted using the quadrat method at Tinian during MARAMP 2003. At least 21 coral genera were observed at Tinian. Generic richness was 15 at TIN-02 in the southwest region and 20 at TIN-01 in Asiga Bay in the northeast region with a mean of 17.5 (SE 2.5) coral genera per site (Fig. 7.5.1i).
Leptastrea, Favia, and Astreopora were the most numerically abundant genera, contributing 18.5%, 14.6%, and 13.3% of the total number of colonies enumerated at Tinian during MARAMP 2003. All other genera individually accounted for < 10% of the total number of observed colonies. Leptastrea dominated the coral fauna at TIN-02, accounting for 31.3% of the total number of colonies, while Favia dominated at TIN-01, accounting for 16.7% of the total number of colonies. Porites, in addition to Leptastrea, Favia, and Astreopora, accounted for more than 10% of the total number of colonies at TIN-02.

Porites, Favia, Leptastrea, and Montipora were the most numerically abundant genera, contributing 23.8%, 13.5%, 12.8%, and 10.5% of the total number of colonies enumerated at Tinian during MARAMP 2005. All other genera individually accounted for < 10% of the total number of colonies. Porites dominated the coral fauna at TIN-03 and TIN-05 in the southwest region, accounting for 71.9% and 29.8% of the total number of colonies enumerated at those sites. Favia dominated at TIN-04 near Puntan Kastiyu and at TIN-06 in the northwest region, accounting for 21.5% and 30.4% of the total number of colonies at those sites. Montipora dominated at TIN-02 in the southwest region, accounting for 32% of the total number of colonies.
Figure 7.5.1j. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Tinian during MARAMP 2005. The pie charts indicate the percentages of relative abundance of key coral genera. The quadrat method was used in 2005 to survey coral genera.

Five REA benthic surveys of forereef habitats were conducted around Tinian during MARAMP 2007. The belt-transect method was used to survey 4 sites, while the quadrat method was used at TIN-04 in the southeast region near Puntan Kastiyu. At least 29 coral genera were observed, including the following 11 genera that had not been recorded at Tinian in 2003 and 2005: Coscinaraea, Cycloseris, Goniopora, Heliopora, Lobophyllia, Lobophytum, Montastrea, Plesiastrea, Octocorals, Other.

Figure 7.5.1k. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted around Tinian during MARAMP 2007. The pie charts indicate the percentages of relative abundance of key coral genera. In 2007, the quadrat method was used only at TIN-04, and the belt-transect method was used to assess coral-colony density at the other 4 of the 5 REA sites surveyed.
Sinularia, Turbinaria, and Zoanthus. Generic richness ranged from 16 to 25 with a mean of 19 (SE 1.6) coral genera per site (Fig. 7.5.1k). The highest generic diversity was seen at TIN-01 in the northeast region, and the lowest generic diversity was recorded at TIN-03 in the southwest region near Puntan Diablo.

Goniastrea, Porites, Favia, and Leptastrea were the most numerically abundant genera, contributing 16.5%, 15.6%, 13.2, and 10.6 % of the total number of colonies enumerated around Tinian during MARAMP 2007. All other genera individually accounted for < 10% of the total number of colonies. Porites dominated the coral fauna at TIN-03 in the southwest region, contributing 39.7% of the total number of colonies enumerated at that site, and co-dominated farther south at TIN-02 with Leptastrea and Astreopora, each genus accounting for 17.3%, 17.7%, and 17%, respectively, of the total number of colonies. Favia dominated at TIN-01 and TIN-04 on the east side, accounting for 16.8% and 20.9% of the total number of colonies observed at those sites, and co-dominated with Goniastrea and Porites at TIN-06 in the northwest region, with each genus accounting for 12.7%, 13.8%, and 12.4%, respectively, of the total number of colonies.

Site-specific estimates of generic richness across the 3 MARAMP survey years ranged from 10 to 25 on forereef habitats at Tinian. Site-specific and overall mean generic-richness values in 2007 with a mean of 19 genera per site (SE 1.6) were higher than estimates in 2005 with a mean of 14.2 genera per site (SE 1.4) and were comparable to values in 2003 with a mean of 17.5 (SE 2.5) genera per site (Fig. 7.5.1l). Note the difference in the size of the area in which corals were censused: the survey area at 4 of the 5 sites surveyed in 2007 was 50 m² per site, an area much larger than the 3.75 m² and 4 m² per site surveyed at TIN-04 in 2003 and 2005 (see Chapter 2: “Methods and Operational Background,” Section 2.4.5, “Corals and Coral Disease”). Additionally, the only octocoral genus assessed in 2003 and 2005 was Heliopora, whereas all octocoral genera were assessed at 4 of the 5 sites surveyed in 2007.

Across the 3 MARAMP survey years, 36 coral genera were observed on forereef habitats at Tinian. Porites, Favia, Leptastrea, Astreopora, Montipora, and Goniastrea were important components of the coral fauna. Porites was the most numerically abundant taxon in 2005 and the second-most abundant in 2007, accounting for 23.8% and 15.6% of the total number of colonies enumerated at Tinian. Favia and Leptastrea were also important components of the coral fauna, accounting for > 10% of the total number of colonies enumerated in the 3 MARAMP survey years. Astreopora, Montipora, and Goniastrea accounted for > 10% of the total number of colonies in 2003, 2005, and 2007, respectively.

Figure 7.5.11. Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on forereef habitats at Tinian during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to survey coral genera, but in 2007 the belt-transect method was used at 4 of 5 survey sites and the quadrat method at 1 site. Error bars indicate standard error (± 1 SE) of the mean.

Coral Size-class Distribution

During MARAMP 2003, 2 REA benthic surveys of forereef habitats were conducted at Tinian using the quadrat method. The coral size-class distribution from these surveys shows that the majority (68.8%) of corals had maximum diameters ≤ 5 cm (Fig. 7.5.1m). The next 4 size classes (6–10, 11–20, 21–40, and 41–80 cm) accounted for 19.6%, 8.2%, 2.5%, and 0.9% of colonies recorded. At both TIN-01 in Asiga Bay and TIN-02 in the southwest region, high proportions (86.2% and 90.6%) of colonies were small (≤ 10 cm) and low proportions (13% and 8.3%) of colonies were midsize (11–40 cm).
Figure 7.5.1m. Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Tinian during MARAMP 2003. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in 2003 to size corals.

During MARAMP 2005, 5 REA benthic surveys of forereef habitats were conducted at Tinian using the quadrat method. The coral size-class distribution from these surveys shows that the majority of corals (72.1%) had maximum diameters ≤ 5 cm (Fig. 7.5.1n). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 19.2%, 5.3%, and 2.3% of colonies recorded, and colonies with maximum diameters > 40 cm accounted for only 1% of colonies recorded. A high proportion (> 80%) of small (≤ 10 cm) colonies was found at all sites and a low proportion (< 17%) of colonies was midsize (11–40 cm).

Figure 7.5.1n. Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Tinian during MARAMP 2005. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in 2005 to size corals.
During MARAMP 2007, 4 REA benthic surveys of forereef habitats were conducted around Tinian using the belt-transect method. The coral size-class distribution from these surveys shows that the majority (81.3%) of corals had maximum diameters ≤ 10 cm (Fig. 7.5.1). The first 4 size classes (0–5, 6–10, 11–20, and 21–40 cm) accounted for 37.9%, 43.4%, 10.5%, and 5.4% of colonies recorded, and colonies with maximum diameters > 40 cm accounted for only 2.7% of colonies observed. At TIN-04 near Puntan Kastiyu, the only site surveyed with the quadrat method, 79.1% of colonies had maximum diameters ≤ 5 cm, 16.5% occurred in the next size class (6–10 cm), and only 4.3% had maximum diameters > 10 cm.

Site-specific and overall distributions of estimated coral size classes on forereef habitats at Tinian are affected by inherent biases in the methods used to census and size corals. During MARAMP 2003 and 2005, 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 m²), enabling observers to closely inspect and record each coral colony within the quadrant. During MARAMP 2007, corals whose center fell within a belt transect (1 × 25 m) were tallied and binned into 1 of 7 size classes based on visual estimates of maximum colony diameter. This method is better suited to capturing large colonies, but the larger census area likely reduces the number of very small colonies (≤ 5 cm) that are observed and recorded. For more on these survey methods, see Chapter 2, “Methods and Operational Background, Section 2.4.5: “Corals and Coral Disease.”

These methodological biases are reflected in the size-class data by survey year. During MARAMP 2003 and 2005, a high number of coral colonies (> 20 colonies m⁻²) observed at Tinian were in the smallest size class (Fig. 7.5.1). In 2003 and 2005, more than half (68.8% and 72.1%) of all colonies censused at Tinian had maximum diameters ≤ 5 cm, but in 2007 only 37.9% of colonies were in this smallest size class, excluding TIN-04 in the southeast region, the one site where the quadrat method was used in 2007. Comparing size-class data between survey years when different methods were used is, therefore, inappropriate. Only TIN-02 in the southwest region was surveyed with the same quadrat method in 2 different survey years (2003 and 2005). At this site, the minor changes in size-class distribution between years likely reflect chance variation in the placement of individual quadrats.
Figure 7.5.1p. Mean coral-colony densities (colonies m⁻²) by size class from REA benthic surveys of forereef habitats conducted at Tinian during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to size corals, but in 2007 the belt-transect method was used at 4 of 5 survey sites and the quadrat method at 1 site. Error bars indicate standard error (± 1 SE) of the mean.

7.5.2 Surveys for Coral Disease and Predation

During MARAMP 2007, REA benthic surveys for coral disease and predation were conducted using the belt-transect and quadrat methods at 5 sites on forereef habitats around Tinian, covering a total area of 1430 m². Surveys detected 20 cases of disease. Two different methods were used to collect coral-colony counts: 2 belt transects (1 × 25 m), at TIN-01, TIN-02, TIN-03, and TIN-06, and 16 haphazardly placed quadrats (50 × 50 cm) at TIN-04 (see Chapter 2, “Methods and Operational Background, Section 2.4.5: “Corals and Coral Disease). The biases of each method are reflected in colony-density and disease-prevalence estimates: the quadrat method resulted in higher coral-colony densities and, therefore, lower-than-expected disease-prevalence values. For the purpose of this report, however, site-specific overall prevalence values obtained using differing methods are combined to produce mean overall disease prevalence. As such, the mean overall disease prevalence for Tinian was low, amounting to 0.2% (SE 0.1). Four major disease conditions were observed at Tinian—bleaching, subacute tissue loss, skeletal growth anomalies, and pigmentation response—all of which were recorded at TIN-03 north of Tinian Harbor in the southwest region. This site also had the greatest number of cases (50% of total) and overall disease prevalence (0.7%) of all sites. Overall prevalence of disease at the other 4 REA survey sites was quite low with a range of 0.01%–0.17% (Fig. 7.5.2a; the values of overall prevalence shown in this figure include predation).

Lesions involving pigmentation response were the most common disease condition encountered, accounting for 60% of disease cases. Bleaching contributed 20% of disease cases, and subacute tissue loss and skeletal growth anomalies combined accounted for 15% of cases. Overall, pigmentation response was the most prevalent disease condition with 0.13% (SE 0.08) of the surveyed population at Tinian affected (Fig. 7.5.2b). Bleaching was uncommon and, when present, mild and focal (i.e., concentrated in one area of an affected colony); overall prevalence of bleaching only amounted to 0.06% (SE 0.02). Cases of bleaching were observed on the genera Goniastrea and Astreopora. Corals of the genus Porites hosted all other disease states recorded at Tinian.

Cases of coral predation attributable to crown-of-thorns seastars (Acanthaster planci) or corallivorous snails, such as snails from the genus Drupella, were observed at all sites except for TIN-02 in the southwest region. Active predation and predation scars were most numerous and prevalent at TIN-03 north of Tinian Harbor. The genera Porites, Astreopora, Goniastrea, and Montipora were the main prey of crown-of-thorns seastars (COTS) and snails. For more about COTS around Tinian, see Section 7.7.1: “Benthic Macroinvertebrates Surveys.”
Figure 7.5.2a. Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted around Tinian 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 charts indicate disease-specific prevalence. In 2007, the quadrat method was used only at TIN-04, and the belt-transect method was used to estimate colony density and disease prevalence at the other 4 of the 5 REA sites surveyed.

Figure 7.5.2b. Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted around Tinian 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. In 2007, the quadrat method was used only at TIN-04, and the belt-transect method was used to estimate colony density and disease prevalence at the other 4 of the 5 REA sites surveyed. 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 infections; OTH: algal and cyanophyte infections and other lesions of unknown etiology; and PRE: predation by COTS or corallivorous snails.
7.6 Algae and Algal Disease

7.6.1 Algal Surveys

Algal Cover: Macroalgae and Turf Algae

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on forereef habitats at the island of Tinian and Tatsumi Reef was 47% (SE 1). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. The survey with the highest mean macroalgal cover of 78%, within a range of 40.1%–100%, occurred on Tatsumi Reef, offshore of the southeast region of Tinian and where pavement habitat of low to medium-low complexity was the dominant structural feature (Fig. 7.6.1a, top left panel). Other moderately dense areas of macroalgal cover were found along Tinian Harbor in the southwest region and the area between Puntans Chiget and Asiga in the northeast region (for place-names and their locations, see Figure 7.2a in Section 7.2: Survey Effort). Pavement or boulder habitats of medium to medium-low complexity were the dominant observed habitats.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on forereef habitats around Tinian was 56% (SE 1.5). Macroalgae were abundant islandwide, but estimates of cover were especially high in the northeast region between Puntans Asiga and Masalok and in the southwest region in the vicinity of Tinian Harbor (Fig. 7.6.1a, middle left panel). Species of *Halimeda*, a calcified, jointed green alga, were recorded covering extensive areas in low to medium-low complexity habitats along the coast near Puntan Tahgong in the northeast region.

From MARAMP 2007 towed-diver surveys, mean cover of macroalgae on forereef habitats around Tinian was 40% (SE 2.5). The survey with the highest mean macroalgal cover of 76%, within a range of 62.6%–100%, occurred along a 3.2-km towed-diver survey that ended near Puntan Masalok in the northeast region (Fig. 7.6.1a, bottom left panel). This area was characterized by continuous, moderately sloping reef areas that contained occasional rubble flats, rock slabs, clefts, crags, and pillars. Species of the siphonous alga *Halimeda*, the brown alga *Padina*, and the red alga *Liagora* dominated the benthos with several survey segments exhibiting macroalgal cover of 75.1%–100%. Species of the red alga *Asparagopsis* and the green alga *Microdictyon* were also recorded as lesser benthic components.

During MARAMP 2007, 5 REA benthic surveys of forereef habitats around Tinian were conducted using the line-point-intercept method. Site-specific estimates of macroalgal cover ranged from 7.8% to 23.5% with an overall mean of 15% (SE 2.7). The survey with the highest macroalgal cover occurred in the northeast region at TIN-01 (Fig. 7.6.1b). Macroalgal cover was also high, compared to other sites surveyed at Tinian, in the northwest region at TIN-06 and in the southwest region at TIN-02: 17.6% and 16.7%. The lowest macroalgal cover was recorded in the southwest region at TIN-03.

Turf-algal cover from these REA surveys in 2007 ranged from 44.1% to 57.8% with an overall mean of 52% (SE 2.9). The highest turf-algal cover was found at 2 sites, both with 57.8%: TIN-01 in the northeast region and TIN-02 in the southwest region (Fig. 7.6.1b). The survey with the lowest turf-algal cover occurred in the southwest region at TIN-03.

Algal Cover: Crustose Coralline Red Algae

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats at Tinian was 6% (SE 0.7). The survey with the highest mean crustose-coralline-red-algal cover of 13.3%, within a range of 0%–30%, occurred in the vicinity of Punatan Chiget in the northeast region on spur-and-groove habitat of medium to medium-high complexity (Fig. 7.6.1a, top right panel). All other surveys reported relatively low cover values for crustose coralline red algae.

From MARAMP 2005 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats at Tinian was 5% (SE 0.4). Crustose coralline red algae appeared to favor boulder and pavement habitats of medium to medium-high complexity near Puntans Chiget and Asiga in the northeast region, where its cover was 10.1%–20% over 4 survey segments (Fig. 7.6.1a, middle right panel).

From MARAMP 2007 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Tinian was 16% (SE 1.1). The survey with the highest mean cover of crustose coralline red algae of 25%, within a range of 20.1%–40%, occurred along the northwest corner of Tinian, rounding Puntan Tahgong (Fig. 7.6.1a, bottom right panel).
Areas near Puntans Kastiyu and Diapblo also exhibited high cover averages. All survey areas were characterized habitats of medium-high to high complexity.

During MARAMP 2007, 5 REA benthic surveys of forereef habitats around Tinian were conducted using the line-point-intercept method. Site-specific estimates of crustose-coraline-red-algal cover ranged from 2.9% to 12.7% with an overall mean of 6.7% (SE 1.7). The survey with the highest crustose-coraline-red-algal cover occurred in the southeast region at TIN-04 (Fig. 7.6.1b). The lowest crustose-coraline-red-algal cover was recorded in the southwest region at TIN-02.

Figure 7.6.1a. Cover (%) observations for macroalgae and crustose coralline red algae from towed-diver benthic surveys of forereef habitats conducted around Tinian during MARAMP 2003, 2005, and 2007. Each 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).
Figure 7.6.1b. Observations of algal cover (%) from REA benthic surveys of forereef habitats conducted using the line-point-intercept method around Tinian during MARAMP 2007. The pie charts indicate algal cover by functional group, and values of total algal cover are provided above each symbol.

Algal Cover: Temporal Comparison

Between MARAMP 2005 and 2007, islandwide mean cover of macroalgal populations around Tinian, based on towed-diver surveys of forereef habitats, varied by 16.4% (Fig. 7.6.1c). The most common habitat for macroalgae was low-to-medium complexity pavement. 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”).

Macroalgal cover near Tinian Harbor in the southwest region and north of Puntan Masalok in the northeast region was higher in 2005 than in 2003. Surveys recorded lower macroalgal cover in 2007 than in 2005 for several survey areas around the island, particularly for west-facing reefs. The greatest changes between MARAMP 2005 and 2007 occurred in survey areas north of Puntan Carolinas, the southernmost tip; south of Puntan Diapblo in the southwest region; and south of Puntan Lamanibot Sanhilo in the northwest region.

Populations of crustose coralline red algae around Tinian, based on towed-diver surveys on forereef habitats, varied as much as 11% in average cover of the benthos between MARAMP survey years. The greatest changes in cover of crustose coralline red algae between surveys in 2003 and 2005 were observed along the east side of Tinian, where cover was lower near Puntans Asiga and Kastiyu. Cover was higher in 2007 than in 2005 in the majority of surveys, except along...
the central portion of the east side of this island. The greatest differences between MARAMP 2005 and 2007 occurred in surveys southwest of Puntan Tahgong in the northwest region, south of Puntan Kastiyu in the southeast region, and south of Puntan Diapblo in the southwest region.

**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 are 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 has not been undertaken yet for the southern islands of the Mariana Archipelago. Ultimately, based on microscopic analysis that may be done in the future, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2003, REA algal surveys were conducted at 3 sites on forereef habitats at Tinian. In the field, 8 macroalgal genera (4 red and 4 green), containing at least 11 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. TIN-01, located in Asiga Bay in the northeast region, had the highest macroalgal generic diversity with 7 genera, containing 10 species, documented in the field. The lowest macroalgal generic diversity was found in the southwest region at TIN-02 with 2 species representing 2 genera recorded.

Species of *Halimeda* were some of the most common components of algal communities at Tinian in 2003 (Fig. 7.6.1d), occurring in 66.7% of sampled photoquadrats. Species of the calcified, red algal genus *Amphiroa* were also extremely common, although these algae were seen more often in the southwest region at TIN-02 and TIN-03, where they were found in 41.7% and 50% of sampled photoquadrats, than in the northeast region at TIN-01, where they were seen in 16.7% of sampled photoquadrats. At the species level, most of the remaining 7 taxa tentatively identified were observed only at 1 or 2 sites, making distinctive spatial patterns of distribution difficult to determine for most macroalgae at Tinian.

Turf algae and crustose coralline red algae were exceptionally common in 2003, occurring in 88.9% and 47.2% of photoquadrats sampled at Tinian in 2003. Turf-algal communities were ubiquitous at each site. Although crustose coralline red algae were recorded at all sites, the occurrence of this functional group at individual sites varied between 8% and 100%. Cyanobacteria, found in 8%–17% of sampled photoquadrats, were less common.

![Figure 7.6.1d. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted at Tinian during MARAMP 2003. 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.](image)
During MARAMP 2005, REA algal surveys were conducted at 6 sites on forereef habitats around Tinian. In the field, 23 macroalgal genera (9 red, 10 green, and 4 brown), containing at least 23 species, as well as 4 additional algal functional groups—turf algae, crustose coralline red algae, nongeniculate coralline red algae, and cyanophytes—were observed. TIN-01 in Asiga Bay, TIN-03 in the southwest region north of Tinian Harbor, and TIN-06 in the northwest region had the highest macroalgal generic diversity with 12 genera, each containing 1 species, documented in the field at each site. The lowest macroalgal generic diversity was found at TIN-02, the southernmost site in the southwest region, with 8 species representing 8 genera recorded.

Species of the green algae *Halimeda* and *Neomertis*, the red algae *Amphiroa* and *Jania*, and the brown alga *Dictyota* were common at every site surveyed around Tinian in 2005 (Fig. 7.6.1e), occurring in 59.7%, 33.3%, 40.3%, 30.6%, and 30.6% of sampled photoquadrats. At the genus level, most of the 23 taxa tentatively identified occurred only at 1 or 2 sites, making distinctive spatial patterns of distribution difficult to determine for most macroalgae at Tinian. However, species of the red alga *Peyssonnelia* were a major component of 3 sites on the west side of this island: TIN-03, TIN-05, and TIN-06, where they were observed in 83%, 50%, and 67% of sampled photoquadrats. A species of *Padina* commonly occurred at TIN-01 in Asiga Bay and on the southern coasts at TIN-02, TIN-05, and TIN-04, and species of both the red alga *Galaxaura* and green alga *Caulerpa* were common at TIN-01, TIN-03, TIN-04, and TIN-06. Species of *Amphiroa* were found along the west side at TIN-02, TIN-03, TIN-05, and TIN-06 but were missing from both of the sites on the east side.

Turf algae, crustose coralline red algae, and cyanobacteria were all exceptionally common in 2005, occurring in 97.2%, 50%, and 65.3% of photoquadrats sampled around Tinian. Turf-algal communities were found in 83%–100% of sampled photoquadrats, and crustose coralline red algae were observed in 25%–83% of sampled photoquadrats. Cyanobacteria were a prominent component of the algal community at all sites, excluding TIN-06 in the northwest region, occurring in 58%–83% of sampled photoquadrats. At TIN-06, located southwest of Puntan Tahgong, the northernmost point of Tinian, cyanobacteria were seen in 8% of sampled photoquadrats. Nongeniculate, calcified, branched red algae were a minor component of the algal community at 4 of the 6 sites surveyed, occurring in 8%–33% of photoquadrats sampled at TIN-01 in the northeast region and on the west side at TIN-03, TIN-05, and TIN-06.

**Figure 7.6.1e.** Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted around Tinian during MARAMP 2005. 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.

During MARAMP 2007, REA benthic surveys were conducted at 5 sites on forereef habitats around Tinian. In the field, 20 macroalgal genera (12 red, 6 green, and 2 brown), containing at least 28 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed in the field. TIN-01 in Asiga Bay had...
the highest macroalgal generic diversity with 13 genera, containing 15 species, documented in the field. The lowest macroalgal generic diversity was found in the southwest region at TIN-02 with 5 species representing 5 genera recorded.

Species of *Halimeda*, seen in 68.3% of sampled photoquadrats overall, were common at every site surveyed around Tinian in 2007 (Fig. 7.6.1f), occurring in 42%–100% of photoquadrats sampled at individual sites. At the genus level, most of the 20 taxa tentatively identified only occurred at 1 or 2 sites, making distinctive spatial patterns of distribution difficult to determine for most macroalgae around Tinian. However, species of *Jania* occurred as a minor component of the algal community with 8%–17% occurrence at TIN-01 in Asiga Bay, TIN-02 in the southwest region, TIN-04 near Puntan Kasitiyu, and TIN-06 in the northwest region. Except for TIN-01, species of *Amphiroa* were observed at all sites, where they exhibited 17%–100% occurrence.

Turf algae, crustose coralline red algae, and cyanobacteria were all exceptionally common in 2007, occurring in 43.8%, 45.8%, and 75% of photoquadrats sampled around Tinian. Communities of crustose coralline red algae were ubiquitous at all sites. Although turf algae were observed at all sites, the occurrence of this functional group at individual sites varied between 17% and 67%. Cyanobacteria were a prominent component of algal communities around Tinian, occurring at all sites and in 58%–83% of sampled photoquadrats.

The number of macroalgal genera recorded on forereef habitats around Tinian increased from 7 to 23 between MARAMP 2003 and 2005 but decreased to 20 during MARAMP 2007. Estimates of macroalgal biodiversity may have been higher in 2005 and 2007 than in 2003 because of the increased number of REA sites surveyed (for information on data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”). The overall occurrence of macroalgal genera did not fluctuate greatly between 2003, 2005, and 2007. Species of *Halimeda* consistently exhibited the highest occurrence during the 3 MARAMP survey years, ranging from 59.7% to 68.3% (Fig. 7.6.1g). Species of *Amphiroa*, with occurrence of 36.1%–41.7%, were the second-most prevalent components of algal communities, steadily increasing in occurrence between survey years. Other common genera included the green algae *Neomeris* and *Caulerpa*; the red algae *Dichotomaria, Tricleocarpa, Galaxaura, Gelidiella*, and *Jania*; and the brown alga *Dictyota*. Species of *Jania* exhibited greater variation in occurrence between survey years than did other species. Not recorded at all in 2003, species of *Jania* occurred in 30.6% and only 8.3% of photoquadrats sampled in 2005 and 2007.
Turf algae and crustose coralline red algae occurred in 16.7%–100% and 8.3%–100% of photoquadrats sampled at sites around Tinian during MARAMP 2003, 2005, and 2007. No patterns in abundance of these functional groups were obvious in survey results.

**Figure 7.6.1g.** Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional groups conducted on forereef habitats around Tinian during MARAMP 2003, 2005, and 2007.

### 7.6.2 Coralline-algae-disease Surveys

During MARAMP 2007, REA benthic surveys for coralline-algal disease were conducted in concert with coral-disease assessments at 5 sites on forereef habitats around Tinian. These surveys covered a total reef area of 1430 m² and detected 33 cases. These numbers translate to a high overall mean density of 2.8 cases 100 m⁻² (SE 1.7), compared to other areas surveyed in the Mariana Archipelago. Disease in coralline algae was found at 4 sites, and 2 major types of diseases were observed: coralline lethal orange disease and coralline white band syndrome. Cases of coralline lethal orange disease represented nearly 60% of all cases recorded at Tinian. Site-specific density of disease was the highest with 8.3 cases 100 m⁻² at TIN-02 in the southwest region; the other sites registered much lower disease densities (Figs. 7.6.2a and b).

**Figure 7.6.2a.** Densities (cases 100 m⁻²) of coralline-algal diseases from REA benthic surveys conducted on forereef habitats around Tinian during MARAMP 2007. The color-coded portions of the pie charts indicate disease-specific density.
7.7 Benthic Macroinvertebrates

7.7.1 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 Tinian through REA and towed-diver benthic surveys 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 surveys and 6 towed-diver benthic surveys were conducted around Tinian. Also, 2 towed-diver surveys were performed along Tatsumi Reef, located ~ 4 km southeast of Tinian. In 2005, 6 REA surveys and 12 towed-diver benthic surveys were completed. In 2007, 1 REA survey and 12 towed-diver benthic surveys were conducted around Tinian. 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 underrepresent the number of individuals present.

Overall, both the REA and towed-diver surveys suggested low daytime macroinvertebrate abundance on forereef habitats around Tinian compared to the rest of the Mariana Archipelago. Minor fluctuations in observed densities between MARAMP survey periods occurred with all target groups. For each target organism, temporal patterns of islandwide mean macroinvertebrate density around Tinian—from towed-diver benthic surveys during MARAMP 2003, 2005, and 2007—are shown later in this section (Figs. 7.7.1d, h, l, and p). Because of the variable REA survey effort, with 3 surveys in 2003, 6 in 2005, and 1 in 2007, temporal comparisons of REA data are not presented.

**Giant Clams**

During MARAMP 2003, species of *Tridacna* giant clams were observed at 2 of the 3 REA sites surveyed and in 4 of the 6 towed-diver surveys conducted at Tinian (Fig. 7.7.1a). The sample mean density of giant clams from REA surveys was 1.66 organisms 100 m$^{-2}$ (SE 1.2), and the overall mean density from towed-diver surveys was 0.013 organisms 100 m$^{-2}$ (SE 0.004). Results from REA surveys suggest giant clams were most abundant in the northeast region between Puntans Asiga and Masalok (Fig. 7.7.1a; for place-names and their locations, see Figure 7.2a in Section 7.2: Survey Effort). TIN-01, the...
only REA site in the northeast region, had the highest density with 4 organisms 100 m\(^{-2}\). Also recorded in the northeast region, the second-greatest mean density of giant clams from a towed-diver survey was 0.028 organisms 100 m\(^{-2}\) along Punta Asiga; segment densities from this survey ranged from 0 to 0.16 organisms 100 m\(^{-2}\). Among all towed-diver surveys at Tinian, the survey completed just south of Punta Kastiyu in the southeast region had the highest mean density of giant clams with 0.03 organisms 100 m\(^{-2}\); segment densities from this survey ranged from 0 to 0.11 organisms 100 m\(^{-2}\).

As part of MARAMP 2003, 2 towed-diver surveys were conducted along Tatsumi Reef. The overall mean density of giant clams on this reef was extremely low at 0.005 organisms 100 m\(^{-2}\), compared to the rest of the Mariana Archipelago. Giant clams were observed during only 1 survey and occurred in only 2 of 18 segments in this survey. The densities from these 2 segments were 0.07 and 0.03 organisms 100 m\(^{-2}\).

**Figure 7.7.1a.** Densities (organisms 100 m\(^{-2}\)) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted at Tinian during MARAMP 2003.

During MARAMP 2005, giant clams were observed at 3 of the 6 REA sites and in 8 of the 12 towed-diver surveys conducted around Tinian (Fig. 7.7.1b). With the increase in coverage by towed-diver surveys in 2005, giant clams were detected sporadically around much of Tinian but not in the southwest region. Also in this region, no giant clams were observed at the 3 REA sites surveyed there. The overall mean density of giant clams from REA surveys was 0.5 organisms 100 m\(^{-2}\) (SE 1.2), and the islandwide mean density from towed-diver surveys was 0.02 organisms 100 m\(^{-2}\) (SE 0.004). Among all towed-diver surveys around Tinian, the survey completed just south of Punta Kastiyu in the southeast region had the highest mean density of giant clams with 0.11 organisms 100 m\(^{-2}\); segment densities from this survey ranged from 0 to 0.26 organisms 100 m\(^{-2}\). The second-greatest mean density of giant clams from a towed-diver survey was 0.04 organisms 100 m\(^{-2}\), recorded in the northeast region just north of Punta Masalok; segment densities ranged from 0 to 0.19 organisms 100 m\(^{-2}\).

During MARAMP 2007, giant clams were observed at the 1 REA site surveyed and in 6 of the 8 towed-diver surveys conducted around Tinian (Fig. 7.7.1c). Density of giant clams at TIN-04, the single REA site surveyed in 2007, was 1.33 organisms 100 m\(^{-2}\), and the overall mean density of giant clams from towed-diver surveys was 0.008 organisms 100 m\(^{-2}\) (SE 0.002). Among all towed-diver surveys around Tinian, the survey completed just north of Punta Masalok in the northeast region had the highest mean density of giant clams with 0.02 organisms 100 m\(^{-2}\); segment densities from this survey ranged from 0 to 0.09 organisms 100 m\(^{-2}\). The second-greatest mean density of giant clams from a towed-diver survey was 0.015 organisms 100 m\(^{-2}\), recorded in the northwest region between Puntans Lamanibot Sampapa˚ and Lamanibot Sanhilo; segment densities ranged from 0 and 0.11 organisms 100 m\(^{-2}\).
Figure 7.7.1b. Densities (organisms 100 m$^{-2}$) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Tinian during MARAMP 2005.

Figure 7.7.1c. Densities (organisms 100 m$^{-2}$) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Tinian during MARAMP 2007.
Towed-diver benthic surveys suggested low abundance of giant clams around Tinian during the 3 MARAMP survey periods, relative to the rest of the Mariana Archipelago. The overall observed mean density of giant clams was lower in 2007 than in 2005 (Fig. 7.7.1d). Minor fluctuations in densities 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”).

**Crown-of-thorns Seastars**

During MARAMP 2003, COTS (*Acanthaster planci*) were observed at 1 of the 3 REA sites surveyed and in 5 of the 6 towed-diver surveys conducted at Tinian (Fig. 7.7.1e). COTS density at TIN-02 was 0.33 organisms 100 m\(^2\), and the overall mean density from towed-diver surveys was 0.018 organisms 100 m\(^2\) (SE 0.007). Among all towed-diver surveys at Tinian, the survey completed in the northeast between Puntans Asiga and Masalok had the highest mean density of COTS with 0.04 organisms 100 m\(^2\); segment densities from this survey ranged from 0 to 0.31 organisms 100 m\(^2\). The second-greatest mean density of COTS from a towed-diver survey was 0.03 organisms 100 m\(^2\), recorded just north of Tinian Harbor in the southwest region; segment densities ranged from 0 to 0.14 organisms 100 m\(^2\).

![Figure 7.7.1d. Temporal comparison of mean densities (organisms 100 m\(^2\)) of giant clams from towed-diver benthic surveys conducted on forereef habitats around Tinian during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.](image)

![Figure 7.7.1e. Densities (organisms 100 m\(^2\)) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted at Tinian during MARAMP 2003.](image)

![Map of Tinian showing geographic regions and towed-diver survey tracks.](image)
The 2 towed-diver surveys conducted on Tatsumi Reef in 2003 recorded COTS densities with an overall mean density of 0.02 organisms 100 m². The second survey, moving southwest, had the greater mean density at 0.03 organisms 100 m²; segment densities from this survey ranged from 0 to 0.15 organisms 100 m².

During MARAMP 2005, COTS were observed at 1 of the 6 REA sites surveyed and in 7 of 12 towed-diver surveys conducted around Tinian (Fig. 7.7.1f). COTS density at TIN-01 was 0.33 organisms 100 m², and islandwide mean density from towed-diver surveys was 0.02 organisms 100 m² (SE 0.005). The majority of COTS recorded during towed-diver surveys were observed in the northeast region between Puntans Asiga and Masalok. Among all towed-diver surveys around Tinian, the survey heading north around Puntan Asiga had the highest mean density of COTS with 0.13 organisms 100 m²; segment densities from this survey ranged from 0 to 0.39 organisms 100 m². The second-greatest mean density of COTS from a towed-diver survey was 0.06 organisms 100 m², recorded just north of Puntan Masalok; segment densities ranged from 0 to 0.19 organisms 100 m².

During MARAMP 2007, COTS were observed at the 1 REA site surveyed and in 4 of the 8 towed-diver surveys conducted around Tinian (Fig. 7.7.1g). COTS density at TIN-04, the single REA site surveyed in 2007, was 0.33 organisms 100 m², and the islandwide mean density from towed-diver surveys was 0.008 organisms 100 m² (SE 0.004). Among all towed-diver surveys around Tinian, the survey completed in the southeast region near and around Puntan Kastiyu had the highest mean density of COTS with 0.05 organisms 100 m²; segment densities from this survey ranged from 0 to 0.22 organisms 100 m².

Towed-diver surveys suggested low daytime densities of COTS around Tinian during MARAMP 2003, 2005, and 2007, relative to the rest of the Mariana Archipelago. The overall observed mean density of COTS was lower in 2007 than in 2003 and 2005 (Fig. 7.7.1h). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of COTS (for information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys†”). The density of this corallivorous seastar naturally fluctuates with food availability and variation in recruitment success.
During MARAMP 2003 and 2005, the greatest mean density of COTS from a towed-diver survey was recorded in the northeast region between Puntans Asiga and Masalok. The overall mean density of COTS in this region was 0.017 organisms 100 m² from 3 surveys in 2003, 0.096 organisms 100 m² from 2 surveys in 2005, and 0.003 organisms 100 m² from 1 survey in 2007. The observed density in this area increased fivefold between 2003 and 2005 even though fewer surveys were conducted there in 2005. The sharp reduction in observed density in 2007 was more likely a result of a population die off or exodus to shallower or deeper depths in search of food rather than a result of lower survey effort.

**Sea Cucumbers**

During MARAMP 2003, sea cucumbers were observed at 2 of the 3 REA sites surveyed and in all 6 towed-diver surveys conducted at Tinian (Fig. 7.7.1i). The sample mean density of sea cucumbers from REA surveys was 1 organism 100 m² (SE 0.58), and the overall mean density from towed-diver surveys was 0.73 organisms 100 m² (SE 0.201). Species from 3 genera were observed during REA surveys: *Pearsonothuria*, *Stichopus*, and *Holothuria*. Among all towed-diver surveys at Tinian, the survey performed to the north of Puntan Masalok had the highest mean density of sea cucumbers with 2.38 organisms 100 m²; segment densities from this survey ranged from 0 to 5.05 organisms 100 m². Just a little farther north, the
towed-diver survey completed between Puntans Masalok and Asiga had the second-greatest mean density of sea cucumbers from a towed-diver survey with 1.44 organisms 100 m\(^2\); segment densities ranged from 0 to 3.87 organisms 100 m\(^2\).

The 2 towed-diver surveys conducted on Tatsumi Reef in 2003 recorded densities of sea cucumbers with an overall mean density of 0.41 organisms 100 m\(^2\). The second survey, moving southwest, had the greater mean density with 0.79 organisms 100 m\(^2\); segment densities from this survey ranged from 0.37 to 1.34 organisms 100 m\(^2\).

**Figure 7.7.1j.** Densities (organisms 100 m\(^2\)) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted at Tinian during MARAMP 2003.

During MARAMP 2005, sea cucumbers were observed at 3 of the 6 REA sites surveyed and in all 12 towed-diver surveys conducted around Tinian (Fig. 7.7.1j). The overall mean density of sea cucumbers from REA surveys was 1.66 organisms 100 m\(^2\) (SE 1.12), and the islandwide mean density from towed-diver surveys was 0.16 organisms 100 m\(^2\) (SE 0.03). Survey results suggest that sea cucumbers were most abundant at TIN-06 in the northwest region with a mean density of 7 organisms 100 m\(^2\)—all of which consisted of animals from the genus *Stichopus*. During REA surveys at Tinian, *Stichopus* and *Holothuria* were the only 2 genera observed.

Overall, sea cucumbers were seen predominantly along the shores of the northern half of this island during towed-diver surveys in 2005. As in the REA surveys, the towed-diver survey that had the highest density, with a mean of 0.9 organisms 100 m\(^2\), was completed in the northwest region, specifically just south of Puntan Tahgong; segment densities from this survey ranged from 0.26 to 2.07 organisms 100 m\(^2\). The second-greatest mean density of sea cucumbers from a towed-diver survey was 0.66 organisms 100 m\(^2\), recorded just north of Puntan Masalok in the northeast region; segment densities ranged from 0 to 1.64 organisms 100 m\(^2\).

During MARAMP 2007, no sea cucumbers were observed at the 1 REA site surveyed at Tinian, but sea cucumbers were recorded in all 8 of the towed-diver surveys conducted (Fig. 7.7.1k), with an islandwide mean density of 0.14 organisms 100 m\(^2\) (SE 0.029). Among all towed-diver surveys around Tinian, the survey completed to the north of Puntan Masalok in the northeast region had the highest mean density of sea cucumbers with 0.61 organisms 100 m\(^2\); segment densities from this survey ranged from 0.08 to 1.49 organisms 100 m\(^2\). The second-greatest mean density of sea cucumbers from a towed-diver survey was 0.13 organisms 100 m\(^2\), recorded just south of Puntan Tahgong in the northwest region; segment densities ranged from 0 to 0.41 organisms 100 m\(^2\).
Figure 7.7.1j. Densities (organisms 100 m$^{-2}$) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Tinian during MARAMP 2005.

Figure 7.7.1k. Densities (organisms 100 m$^{-2}$) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Tinian during MARAMP 2007.
Towed-diver surveys suggested low daytime abundance of sea cucumbers around Tinian during MARAMP 2003, 2005, and 2007, relative to the rest of the Mariana Archipelago. The overall observed mean density of sea cucumbers was much lower in 2005 and 2007 than in 2003 (Fig. 7.7.1l). Although the overall number of surveys increased around Tinian during MARAMP 2005 and 2007, the number of surveys conducted in the area that had the greatest density of sea cucumbers in 2003—between Puntans Asiga and Masalok in the northeast region—decreased to 2 surveys in 2005 and 1 survey in 2007 from 3 surveys in 2003 (for information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”).

**Sea Urchins**

During MARAMP 2003, sea urchins were observed at all 3 of the REA sites surveyed and in 4 of the 6 towed-diver surveys conducted at Tinian (Fig. 7.7.1m). The sample mean density of sea urchins from REA surveys was 11.67 organisms 100 m\(^{-2}\) (SE 5.17), and the overall mean density from towed-diver surveys was 2.05 organisms 100 m\(^{-2}\) (SE 0.43). Survey results suggest that sea urchins were most abundant at TIN-02, in the southwest region north of Puntan Carolinas, with a mean density of 22 organisms 100 m\(^{-2}\). Four genera were observed overall during REA surveys at Tinian: *Echinostrephus*, *Echinometra*, *Echinothrix*, and *Diadema*. The rock-boring urchins *Echinostrephus* and *Echinometra* were the dominant macroinvertebrate taxa at all sites; together, they accounted for 91% of recorded urchins, and the genus *Echinostrephus* alone composed 84% of boring urchins. TIN-03, east of Puntan Diapblo, had the greatest species diversity with representatives from the genera *Echinostrephus*, *Echinometra*, and *Diadema*.

Among all towed-diver surveys conducted at Tinian in 2003, the survey completed just north of Puntan Masalok in the northeast region had the highest mean density of sea urchins in 20037 with 4.69 organisms 100 m\(^{-2}\); segment densities from this survey ranged from 0 to 11.34 organisms 100 m\(^{-2}\). The second-greatest mean density from a towed-diver survey was 3.5 organisms 100 m\(^{-2}\), recorded during the survey completed around Puntan Asiga in the northeast region; segment densities ranged from 0 to 5.31 organisms 100 m\(^{-2}\). The next-highest mean density of 3.2 organisms 100 m\(^{-2}\) was from the towed-diver survey performed in the southeast region near Puntan Kastiyu; segment densities ranged from 0 to 9.9 organisms 100 m\(^{-2}\). No sea urchins were recorded during the 2 surveys conducted near Tinian Harbor.

The 2 towed-diver surveys conducted on Tatsumi Reef in 2003 recorded densities of sea urchins with an overall mean density of 2.13 organisms 100 m\(^{-2}\). The first towed-diver survey, moving southwest, had the greater mean density with 6.55 organisms 100 m\(^{-2}\); segment densities from this survey ranged from 3.61 to 9.25 organisms 100 m\(^{-2}\). The second towed-diver survey had a mean density of 3.92 organisms 100 m\(^{-2}\); segment densities ranged from 2.37 to 6.44 organisms 100 m\(^{-2}\).

During MARAMP 2005, sea urchins were observed at all 6 of the REA sites surveyed and in 10 of the 12 towed-diver surveys conducted around Tinian (Fig. 7.7.1n). The overall mean density of sea urchins from REA surveys was 10.22 organisms 100 m\(^{-2}\) (SE 3.78), and the islandwide mean density from towed-diver surveys was 4.48 organisms 100 m\(^{-2}\) (SE 1.05). Survey results suggest that sea urchins were most abundant at TIN-04 near Puntan Kastiyu with a mean density of 22 organisms 100 m\(^{-2}\). The second-greatest density, recorded at TIN-01 in Asiga Bay, was 20 organisms 100 m. Species from 2 genera were observed during REA surveys: *Echinometra* and *Diadema*. 
Figure 7.7.1m. Densities (organisms 100 m$^{-2}$) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted at Tinian during MARAMP 2003.

Sea urchins were most abundant along the western shore, around Puntan Atigidon and east of Puntan Diapblo, as well as in the southeast region around Puntan Kastiyu during towed-diver surveys in 2005. Among all towed-diver surveys around Tinian, the survey completed near Puntan Diapblo had the highest mean density of sea urchins with 23.38 organisms 100 m$^{-2}$; segment densities from this survey ranged from 0 to 57.13 organisms 100 m$^{-2}$. The second-greatest mean density of sea cucumbers from a towed-diver survey was 8.3 organisms 100 m$^{-2}$, recorded near Puntan Kastiyu; segment densities ranged from 0 to 47.5 organisms 100 m$^{-2}$.

Figure 7.7.1n. Densities (organisms 100 m$^{-2}$) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Tinian during MARAMP 2005.
During MARAMP 2007, sea urchins were observed at the 1 REA site surveyed and in all 8 of the towed-diver surveys conducted around Tinian (Fig. 7.7.1o). The density of sea urchins at TIN-04, the single REA site surveyed in 2007, was 20.33 organisms 100 m\(^2\), and the islandwide mean density from towed-diver surveys was 6.37 organisms 100 m\(^2\) (SE 1.20). Only the rock-boring urchins, *Echinostrephus* and *Echinometra*, were observed during the REA survey, with 98% of observations belonging to the genus *Echinostrephus*. Among all towed-diver surveys around Tinian, the survey completed near Puntan Diaphlo had the highest mean density of sea urchins with 19.91 organisms 100 m\(^2\); segment densities from this survey ranged from 0 to 48.58 organisms 100 m\(^2\). The second-greatest mean density from a towed-diver survey was 10.12 organisms 100 m\(^2\), recorded south of Puntan Masalok in the southeast region; segment densities ranged from 2.55 to 23.28 organisms 100 m\(^2\).

With the exceptions of the surveys near Puntans Diaphlo and Kastiyu, towed-diver surveys suggested low daytime abundance of sea urchins around Tinian, compared to the rest of the Mariana Archipelago. The overall observed mean density of sea urchins was lower in 2003 than in 2005 and 2007 (Fig. 7.7.1p). 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”). During both MARAMP 2005 and 2007, the greatest mean density of sea urchins from towed-diver surveys was recorded on the west side of Tinian in areas that were not surveyed in 2003.

**Figure 7.7.1o.** Densities (organisms 100 m\(^2\)) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Tinian during MARAMP 2007.

**Figure 7.7.1p.** Temporal comparison of mean densities (organisms m\(^{-2}\)) of sea urchins from towed-diver benthic surveys conducted on forereef habitats around Tinian during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.
7.8 Reef Fishes

7.8.1 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 at the island of Tinian, primarily in the southwest and northeast regions; 2 additional surveys were completed near Tatsumi Reef. The overall estimated mean biomass of large fishes at Tinian, calculated as weight per unit area, was 0.20 kg 100 m$^{-2}$ (SE 0.09), a low value compared to other survey areas in the Mariana Archipelago. Reef sharks (Carcharhinidae) accounted for the greatest proportion (50%) or 0.10 kg 100 m$^{-2}$ of overall mean large-fish biomass. Three reef sharks, all of them whitetip reef sharks (*Trienodon obesus*), were observed at Tinian, 1 near Puntan Masalok in the northeast region and 2 south of Puntan Kastiyu in the southeast region (Fig. 7.8.1a; for place-names and their locations, see Figure 7.2a in Section 7.2: Survey Effort).

Figure 7.8.1a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m$^{-2}$), family composition, and shark sightings from towed-diver fish surveys of forereef habitats conducted at Tinian during MARAMP 2003. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.

During MARAMP 2005, 12 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Tinian. The islandwide estimated mean biomass of large fishes was 0.17 kg 100 m$^{-2}$ (SE 0.07). Stingrays (Dasyatidae) contributed the greatest proportion (45%) of islandwide mean large-fish biomass. No clear spatial patterns in the distribution of large-fish biomass or families were evident in 2005. One reef shark, a whitetip reef shark, was observed near Puntan Kastiyu in the southeast region (Fig. 7.8.1b).

During MARAMP 2007, 8 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Tinian. The overall estimated mean biomass of large fishes around this island was 0.31 kg 100 m$^{-2}$ (SE 0.15), a level higher than the islandwide values observed in the previous MARAMP survey years. Barracudas (Sphyraenidae) and sharks accounted for the largest proportion of islandwide large-fish biomass, contributing 0.11 and 0.07 kg 100 m$^{-2}$ of overall mean biomass. Mean large-fish biomass was somewhat higher along the east side of this island, compared to other areas surveyed at Tinian (Fig. 7.8.1c). In 2007, 11 sharks were observed. Whitetip reef sharks were the most common with 8 individuals encountered. The remaining sharks were 2 black tip reef sharks (*Carcharhinus melanopterus*) and 1 tawny nurse shark (*Nebrius ferrugineus*). A majority of these sharks were seen along the east coast, 3 of them north of Puntan Barangka.
**Figure 7.8.1b.** Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m\(^{-2}\)), family composition, and shark sightings from towed-diver fish surveys of forereef habitats conducted around Tinian during MARAMP 2005. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.

**Figure 7.8.1c.** Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m\(^{-2}\)), family composition, and shark sightings from towed-diver fish surveys of forereef habitats conducted around Tinian during MARAMP 2007. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.
Islandwide mean biomass of large fishes from towed-diver surveys of forereef habitats around Tinian ranged from 0.17 kg 100 m$^{-2}$ (SE 0.07) in 2005 to 0.31 kg 100 m$^{-2}$ (SE 0.15) in 2007 (Fig. 7.8.1d). Sharks were sighted more frequently on the east side of Tinian, with the fewest sharks observed during MARAMP 2005, when only one shark was sighted. Large-fish biomass from towed-diver surveys was higher on the east side of Tinian in 2007.

**Figure 7.8.1d.** Temporal comparison of mean values of large-fish ($\geq 50$ cm in TL) biomass (kg 100 m$^{-2}$) from towed-diver fish surveys of forereef habitats conducted around Tinian during MARAMP 2003, 2005, and 2007. Error bars indicate standard error ($\pm 1$ SE) of the mean.

**Total Fish Biomass and Species Richness**

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Tinian during MARAMP 2003 was low compared to other sites in the Mariana Archipelago, with an overall sample mean of 3.33 kg 100 m$^{-2}$ (0.96 SE). The highest biomass of 5.22 kg 100 m$^{-2}$ was observed at TIN-03 in the southwest region, and the lowest biomass of 2.09 kg 100 m$^{-2}$ was found at TIN-02 farther south along the southwest coast (Fig. 7.8.1e). Surgeonfishes (Acanthuridae) and parrotfishes (Scaridae) together accounted for about half of the total mean biomass, contributing 1.14 and 0.47 kg 100 m$^{-2}$ of biomass.

**Figure 7.8.1e.** 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 Tinian during MARAMP 2003.
Based on REA surveys conducted during MARAMP 2003, species richness at Tinian did not vary much with a small range of 32–38 species 100 m$^2$. Damselfishes (Pomacentridae), surgeonfishes (Acanthuridae) and wrasses (Labridae) were common. No large fishes (≥ 50 cm TL) were recorded during REA surveys.

Total fish biomass for the 6 REA sites surveyed in forereef habitats around Tinian during MARAMP 2005 remained low with an overall sample mean of 4.04 kg 100 m$^2$ (SE 0.88). The highest biomass of 6.27 kg 100 m$^2$ was observed in the southeast region at TIN-04 near Puntan Kastiyu, and the lowest biomass (1.22 kg 100 m$^2$) again was found in the southern part of the southwest region, this time at TIN-05 just south of Tinian Harbor (Fig. 7.8.1f). Surgeonfishes and parrotfishes together accounted for 64% of the total mean biomass, a proportion that was dominated by the striated surgeonfish (*Ctenochetus striatus*) and the orange-spine unicornfish (*Naso lituratus*).

Based on REA surveys conducted during MARAMP 2005, species richness around Tinian, with a range of 24–37 species 100 m$^2$, was broadly similar to data recorded in 2003. Damselfishes, most of them juveniles, composed the most abundant family with 3 species that were particularly common: princess damsel (*Pomacentrus vaiuli*), jewel damsels (*Plectroglyphidodon lacrymatus*), and midget chromis (*Chromis acares*). Wrasses and surgeonfishes were also common.

Total fish biomass at the 5 REA sites surveyed in forereef habitats around Tinian during MARAMP 2007, with an overall sample mean of 4.16 kg 100 m$^2$ (0.73 SE), was above the average observed at the southern islands but moderately low compared to survey results from other islands in the Mariana Archipelago. The highest biomass of 5.68 kg 100 m$^2$ was observed at TIN-04 in the southeast region, and the lowest biomass of 2.04 kg 100 m$^2$ was found in the northwest region at TIN-06 southwest of Puntan Tahgong (Fig. 7.8.1g). Parrotfishes and surgeonfishes together accounted for the largest proportion (62%) of total fish biomass around Tinian, contributing 1.58 and 0.99 kg 100 m$^2$ of biomass.

Based on REA surveys conducted during MARAMP 2007, species richness around Tinian was similar to results from previous survey years with a range of 21–36 species 100 m$^2$. The highest diversity was observed at TIN-02 in the southwest region.
Figure 7.8.1g. Observations of total fish biomass (all species and size classes in kg 100 m²), family composition, and species richness (species 100 m²) from REA fish surveys using the belt-transect method in forereef habitats around Tinian during MARAMP 2007.

The lack of consistent survey effort made it difficult to identify clear spatial patterns for total fish biomass in forereef habitats around Tinian between the 3 MARAMP survey periods. During the 3 survey years, parrotfishes and surgeonfishes were major contributors to biomass. Overall mean values of total fish biomass from REA surveys conducted at Tinian varied from 3.33 kg 100 m⁻² in 2003 to 4.16 kg 100 m⁻² in 2007 (Fig. 7.8.1h). Across the 3 MARAMP survey years combined, mean total fish biomass around Tinian was 3.85 kg 100 m⁻² (SE 0.26).

No clear patterns for species richness were seen between sites or MARAMP survey years. The average diversity of fish species around Tinian was 29.9 species 100 m⁻² (SE 2.3) across all REA surveys conducted during MARAMP 2003, 2005, and 2007.

Figure 7.8.1h. Temporal comparison of mean values of total fish biomass (all species and size classes in kg 100 m²) from REA fish surveys of forereef habitats conducted around Tinian during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.
7.9 Marine Debris

7.9.1 Marine Debris Surveys

During MARAMP 2003, 15 man-made objects were recorded in the 6 towed-diver surveys conducted on forereef habitats at the island of Tinian. Debris sightings were recorded only in the southwest region (Fig. 7.9.1a). Outside of the Tinian Harbor break-wall, 2 anchors, 2 pipes, and 4 cables were identified (for place-names and their locations, see Figure 7.2a in Section 7.2: Survey Effort). No additional descriptive information was recorded during towed-diver surveys, and no derelict fishing gear, munitions, or wrecks were identified.

During MARAMP 2005, 3 sightings of derelict fishing gear and 2 sightings of other man-made objects were recorded in the 12 towed-diver surveys conducted on forereef habitats around Tinian (Fig. 7.9.1b). In the southwest region near Puntan Carolinas, one of the sighting of derelict fishing gear consisted of lost lines and weights at a depth of 14–15 m. In the northwest region, a trawl or seine net was observed at a depth of 16–18 m in the vicinity of Puntan Atgidon, and a small net was noted north of Puntan Lamanibot Sanhilo. Finally, a dump site that included helicopter components and wheels was recorded just off Puntan Lamanibot Sanhilo. No munitions or wrecks were identified.

During MARAMP 2007, 1 sighting of derelict fishing gear, 15 sightings of munitions, 1 wreck, and 35 other man-made objects were recorded in the 8 towed-diver surveys conducted on forereef habitats around Tinian (Fig. 7.9.1c). No additional descriptive information was recorded for the derelict fishing gear, which was located in the northeast region near Puntan Masalok. In the southeast region South of Puntan Kastiyu, an estimated 15 bombs (unexploded ordinances), each ~110 kg, were noted at 14°56′ N, 145°39′ E, and a possible airplane wheel strut was observed during the same survey. As in observations made in 2005, a dump site was recorded in the northwest region near Puntan Lamanibot Sanhilo. This time at that site, 35 man-made objects were counted within the survey swath, including helicopter components, airplane and vehicle parts, and many unidentifiable metal objects.
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, 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. Still, the location of an apparent dump site in the vicinity of Puntan Lamanbot Sanhilo was the same in 2005 and 2007.
7.10 Ecosystem Integration

The spatial distributions and temporal patterns of individual coral reef ecosystem components around the island of Tinian 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. Biological information from towed-diver surveys was integrated to derive 3 composite indices that provide assessments of the relative ecological conditions of forereef habitats in the 4 populated, southern islands of Tinian, Saipan, Rota, and Guam.

The Benthic Condition Index for Guam, Rota, Tinian, and Saipan was derived by equally weighting observations of the following 5 parameters from towed-diver benthic surveys around these 4 islands: cover of live hard corals, stressed corals, macroalgae, and crustose coralline red algae and density of crown-of-thorns seastars (COTS). The Fish Condition Index for Guam, Rota, Tinian, and Saipan was derived from 2 equally weighted parameters from towed-diver fish surveys: density and biomass of large fishes (≥ 50 cm in TL). The overall Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan was derived from an equal weighting of these benthic and fish indices. These condition indices were calculated using ranks assigned to the biological variables from towed-diver surveys conducted around Tinian, relative to all surveys performed around the 4 populated, southern islands of Tinian, Saipan, Rota, and Guam for each survey year. To indicate changes in these ranks between survey years, these indices were visualized on a map within survey areas, which are represented by color-coded and irregular polygonal buffers derived from towed-diver-survey tracks that overlapped in 2005 and 2007 (towed-diver-survey tracks were often similar but not exactly the same in each survey year). For more details about the methodology behind these indices, see Chapter 2: “Methods and Operational Background,” Section 2.5: “Ecosystem Integration.” Each of these 3 condition indices for Tinian is presented on a map in Figure 7.10a. Reef condition indices for the entire Mariana Archipelago are presented in Chapter 3: “Archipelagic Comparisons,” providing ranks for Tinian as well as the other 13 islands covered in this report.

Tinian sits atop a steeply sloping bank that is primarily composed of carbonate terraces that overlie a volcanic core. Hard–soft analysis and towed-diver observations suggest that the substrate on these terraces is predominantly hard. West of Tinian, areas of softer sediment were observed, mainly associated with sand patches within shallow bays and the anchorage and on the shelf slope. At various points around this island, the submarine bank extends away from the coast, forming ridges. Tatsumi Reef, a popular fishing bank, lies ~ 2 km south-southeast of Tinian, and the uninhabited island of Aguijan is located ~ 5 km to the southwest.

Immediately offshore in the southwest region of Tinian, the anchorage area is formed by 4–6 carbonate platforms of progressively deeper shelves and characterized by a mixture of hard and soft substrate. The anchorage area, which extends 2 km offshore, was one of the few areas of flats around Tinian suggested by BPI terrain analysis. Based on towed-divers surveys of forereef habitats, estimates of habitat complexity and live coral cover were low in the 3 MARAMP survey years in this area, relative to other areas surveyed around Tinian. High levels of macroalgal cover were observed near Tinian Harbor compared to most other areas surveyed around this island (for place-names and their locations, see Figure 7.2a in Section 7.2: Survey Effort). From the anchorage area south to Puntan Carolinas, towed divers characterized habitat complexity as high to medium. The rank for this area in the Benthic Condition Index for Guam, Rota, Tinian and Saipan was high in 2005 and medium in 2007 (Fig. 7.10a). Observed coral cover was low there in 2005 and 2007 compared to other areas surveyed around Tinian, and stressed-coral cover was > 10% for several survey segments in 2007 (Fig. 7.10b), suggesting some level of declining condition in this area.
Figure 7.10a. The Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan, as well as the associated Benthic Condition Index and Fish Condition Index, reflects the condition of the benthic and fish communities and their integrated ecosystem for each towed-diver-survey area, relative to other survey areas around the 4 populated, southern islands. These maps indicate changes in index ranks between MARAMP 2005 and 2007 for towed-diver-survey areas around Tinian. Survey areas are represented by irregular polygonal buffers derived from towed-diver-survey tracks that overlapped in 2005 and 2007. No index value is calculated for areas with only one year of survey data. A high rank means superior condition relative to other survey areas around the 4 populated, southern islands. The survey area in the southeast region south of Puntan Kastiyu, for example, has a high rank for both 2005 (y-axis) and 2007 (x-axis) and, thus, is assigned the bright-green color that corresponds to the top-right square in the legend. The position of the horizontal bar above the midline in this square also reflects that this survey area maintained a high rank in both years.
The northwest region of Tinian was characterized by a steep sloping bank with high habitat complexity composed of hard and soft substrates interspersed with channels and sharp ridges. This region is popular for recreational scuba diving, a status that can be attributed to the dynamic habitat and greater amount of corals there relative to other regions of this island. A large dump site with military debris was observed off Puntan Lamanibot Sanhilo in this region during towed-diver surveys in both 2005 and 2007 (Fig. 7.10c); 35 man-made objects were counted within the survey swath in 2007, including helicopter components, airplane and vehicle parts, and many unidentifiable metal objects. The survey area around and south of Puntan Lamanibot Sanhilo stands out with benthic conditions that are among the best when compared in the Benthic Condition Index to other areas surveyed around the populated, southern islands.
Waters east of Tinian were cooler and more saline than waters west of this island. This interpretation may result from the greater wind and wave mixing with deep waters that occur on the east side of Tinian. This difference, combined with varying habitat along the eastern coast of Tinian, results in a variety of reef conditions. East of Puntan Masalok, a submerged ridge was characterized by a rough and complex topography to a depth of 80 m, suggesting that coral reefs may exist in this area (no benthic surveys were conducted there). South of Puntan Masalok, habitat complexity varied from high to low, but coral cover in this forereef area was moderate compared to other forereef habitats surveyed at Tinian. Farther south, the survey area between Puntans Kastiyu and Carolinas, had a high rank in the Coral Reef Condition Index in both 2005 and 2007, suggesting reef conditions there are among the best of the areas surveyed around the populated, southern islands. During towed-diver surveys in this area, moderate levels of coral cover were recorded and no indications of stressed corals were recorded, including COTS predation, coral bleaching, or coral disease. In addition to these benthic observations, during the 3 MARAMP survey years, high levels of large-fish biomass were observed in this area compared to other areas surveyed around Tinian (Fig. 7.10d), and shark sightings were more common on the east side. The single REA site surveyed in the southeast region, TIN-04, had the largest biomass of reef fishes of all sizes, among all sites surveyed at Tinian, in both 2005 and 2007.

**Figure 7.10d.** Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m²) from towed-diver surveys and species richness from REA fish surveys conducted on forereef habitats around Tinian during MARAMP 2005 and 2007, presented over a map of human population density (U.S. Bureau of the Census 2003, 2008). Biomass and richness values represent averages of data from both survey years, but, if surveys were conducted during one year only, then values represent data from that single year. Towed-diver-survey areas combine overlapping survey tracks for both MARAMP survey years; survey tracks are often similar but not necessarily the same between survey years.

### 7.11 Summary

This section presents an overview of the status of coral reef ecosystems around the island of Tinian and some of the key natural processes and anthropogenic activities influencing them. 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 Tinian. 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 Tinian chapter are included in the appropriate discipline sections. One noteworthy limitation, for example, is the focus of MARAMP observations on forereef habitats to the exclusion of the shallow backreef flats around Tinian. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter.
To simplify interpretation of ecosystem conditions around Tinian, a Benthic Condition Index, a Fish Condition Index, and an integrated Coral Reef Condition Index were developed to reflect ecosystem conditions at specific locations around Tinian, relative to locations around the 4 populated, southern islands of Guam, Rota, Tinian, and Saipan and based on MARAMP 2005 and 2007 surveys only (see Section 7.10: “Ecosystem Integration”). By synthesizing large amounts of complex, interdisciplinary information, these reef condition indices assist resource managers in identifying potential relationships between various ecosystem components. The conditions of the fish and benthic communities and the overall ecosystem around Tinian, relative to all the other islands in the Mariana Archipelago, are discussed in Chapter 3: “Archipelagic Comparisons.”

The following summary highlights key attributes of the coral reef ecosystems around Tinian (for place-names and their locations, see Figure 7.2a in Section 7.2: “Survey Effort”):

• With a land area of 102 km$^2$, Tinian is the second-largest island in the CNMI. After Saipan, Tinian has the second-highest human population in the CNMI with 3540 or ~ 5% of the total CNMI population in 2000.

• The topography of Tinian is formed by a series of uplifted carbonate platforms bounded by steep faults. Although this island has no streams, during periods of heavy rainfall, runoff into the ocean from unpaved secondary roads on Tinian has been reported.

• Wave model output shows trade wind swells from the east and high wave energy from storm tracks from the southeast and, to a lesser extent, the southwest.

• A similar pattern of cooler temperatures and higher salinities on the east (windward) side of Tinian compared to the west (leeeward) side existed during both MARAMP 2005 and 2007. This interpretation may result from greater wind and wave mixing with deep waters on the east side compared to the west side of this island. The northeast (in 2007 only) and southeast (in 2005 and 2007) corners of Tinian, relative to other areas of this island, show signs of greater mixing with deep waters or localized upwelling. These areas were potentially influenced by strong tidal flows across the Mariana Ridge and between the islands on the ridge.

• Temperature data from the STRs deployed at a depth of 7 m in the northeast region briefly exceeded the coral bleaching threshold of 30.5˚C in September 2006.

• This island sits atop a steeply sloping bank that in many places is composed of carbonate terraces. Hard–soft analysis and observations from towed-diver surveys suggest that the substrate on these terraces is predominantly hard. At various points around Tinian, the submarine bank extends away from the coast, forming ridges. East of Puntan Masalok, a submerged ridge was characterized by a rough and complex topography to a depth of 80 m, suggesting that coral reefs possibly exist there.

• In the southwest region, the anchorage area at Tinian is composed of 4-6 carbonate platforms forming progressively deeper shelves and is characterized by a mixture of hard and soft substrate. The anchorage area was one of the few areas of flats suggested by BPI terrain analysis.

• Site-specific estimates of cover of live hard corals from REA surveys conducted at 5 sites during MARAMP 2007 ranged from 5.9% to 31.4%. The overall mean from these surveys was 13.3%, a level similar to survey results at the other populated, southern islands of Guam, Rota, and Saipan. The islandwide means for coral cover from towed-diver surveys of forereef habitats varied from 13% in 2003 to 9% in 2005 and 8% in 2007.

• In 2007, the mean overall prevalence of coral disease at Tinian was low (0.22%). Four major disease states were observed around Tinian: pigmentation response (60% of cases), bleaching (20% of cases), and subacute tissue loss and skeletal growth anomalies (15% of cases combined). Lesions involving pigmentation response were the most prevalent disease state with 0.13% of the surveyed population at Tinian affected.

• Mean macroalgal cover around Tinian varied as much as 16.4% between MARAMP survey years. Near Tinian Harbor and north of Puntan Masalok, observed macroalgal cover was higher in 2005 than in 2003. For several survey areas around this island, particularly for west-facing reefs, macroalgal cover was lower in 2007 than in 2005.

• Mean cover of crustose coralline red algae varied as much as 11% between MARAMP survey years. The greatest differences in observed cover between 2003 and 2005 were along the east coast, where cover was lower near Puntans Asiga and Kastiyu. Observed cover was higher in 2007 than in 2005 with the greatest differences occurring southwest of Puntan Tahgong in the northwest region, south of Puntan Kastiyu in the southeast region, and south of Puntan Diapblo in the southwest region.
Two major types of coralline-algal diseases were observed around Tinian: coralline lethal orange disease and coralline white band syndrome. Cases of coralline lethal orange disease represented nearly 60% of all cases recorded at Tinian.

Large-fish biomass, from towed-diver surveys conducted on forereef habitats during MARAMP 2007, tended to be higher on the east side than on the west side of Tinian. Sharks were sighted more frequently on the east side of Tinian in 2007.

Total fish biomass was moderately low at the REA sites surveyed at Tinian with an overall mean of 3.85 kg 100 m$^{-2}$ across the 3 MARAMP survey years, a level close to the average for the populated, southern islands. TIN-04, near Puntan Kastiyu in the southeast region, had the highest mean biomass observed at Tinian in both of the years in which it was surveyed (2005 and 2007), but biomass levels were only marginally higher there than at other sites.

Abundance of giant clams from towed-diver surveys conducted around Tinian was low during the 3 MARAMP survey years, relative to the rest of the Mariana Archipelago. Estimates of daytime abundance of crown-of-thorns seastars (COTS), sea cucumbers, and sea urchins also were low.

In the northwest region, the survey area around and south of Puntan Lamanibot Sanhilo stands out with benthic conditions that are among the best when compared to other areas surveyed using the Benthic Condition Index for Guam, Rota, Tinian, and Saipan.

The survey area between Puntans Kastiyu and Carolinas in the southeast region had high ranks in the overall Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan in both 2005 and 2007. The highest biomass of large fishes at Tinian in 2007 was recorded during this survey, and the rank for this survey area was high in the Fish Condition Index in both 2005 and 2007.

At Tatsumi Reef, a popular fishing spot, a gradient of habitat complexity and coral cover was observed. Complexity and coral cover were highest at this reef’s shallowest point at its center and decrease with depth.