Chapter 3 Tutuila and Aunu`u Islands

3.1 Geopolitical Context

Tutuila and Aunu`u Islands are highly eroded, volcanic structures bounded by a broad bank extending 3 or more kilometers from the shore in most locations. Of the seven primary islands that make up American Samoa, Tutuila contains the greatest land area (145 km²) and the greatest coral reef habitat area (315 km²). The majority of Tutuila consists of steep mountainous terrain with Matafao Peak (653 m) as the highest point. Two prominent marine protected areas are located around Tutuila Island: Fagatele Bay National Marine Sanctuary and the National Park of American Samoa (Fig. 3.1a). Aunu`u, a small volcanic island located approximately 2 km southeast of Tutuila, has a land area of 1.5 km² that includes Aunu`u Crater and Faimulivai Marsh, the largest marsh wetland in American Samoa.

Tutuila and Aunu`u have a tropical climate with an average year-round temperature of 27°C and an average annual rainfall of ~ 5 m. Climatologically, the heaviest rainfall occurs during the warm Austral summer period from December to March, which also coincides with the peak period for tropical cyclones. The complex mountainous terrain and high rainfall at Tutuila suggest that the nearshore marine ecosystems are influenced by significant freshwater and nutrient inputs from local watersheds (Fig. 3.1a).

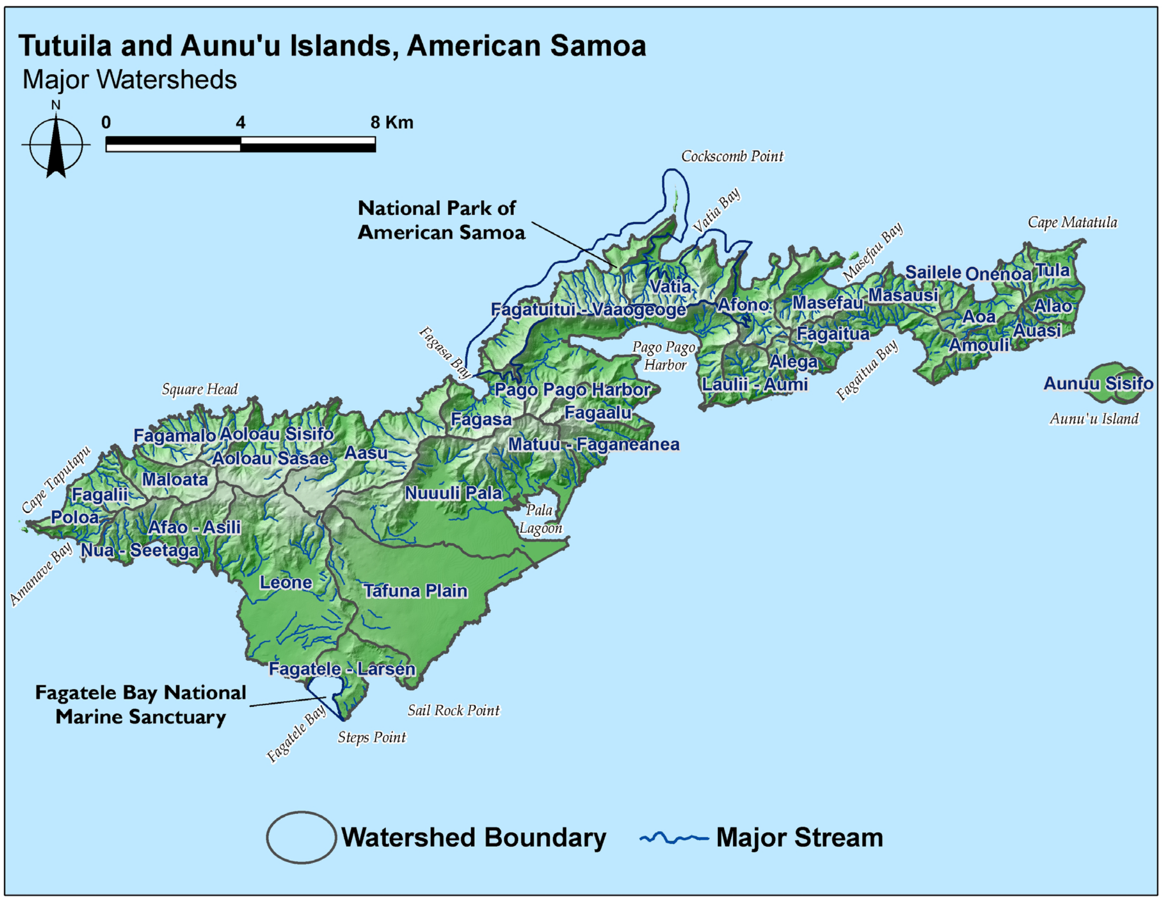

Figure 3.1a. Watershed boundaries, streams, and counties for Tutuila and Aunu`u. Also shown is the boundary of the National Park of American Samoa (American Samoa Department of Commerce, Coastal Management Program).

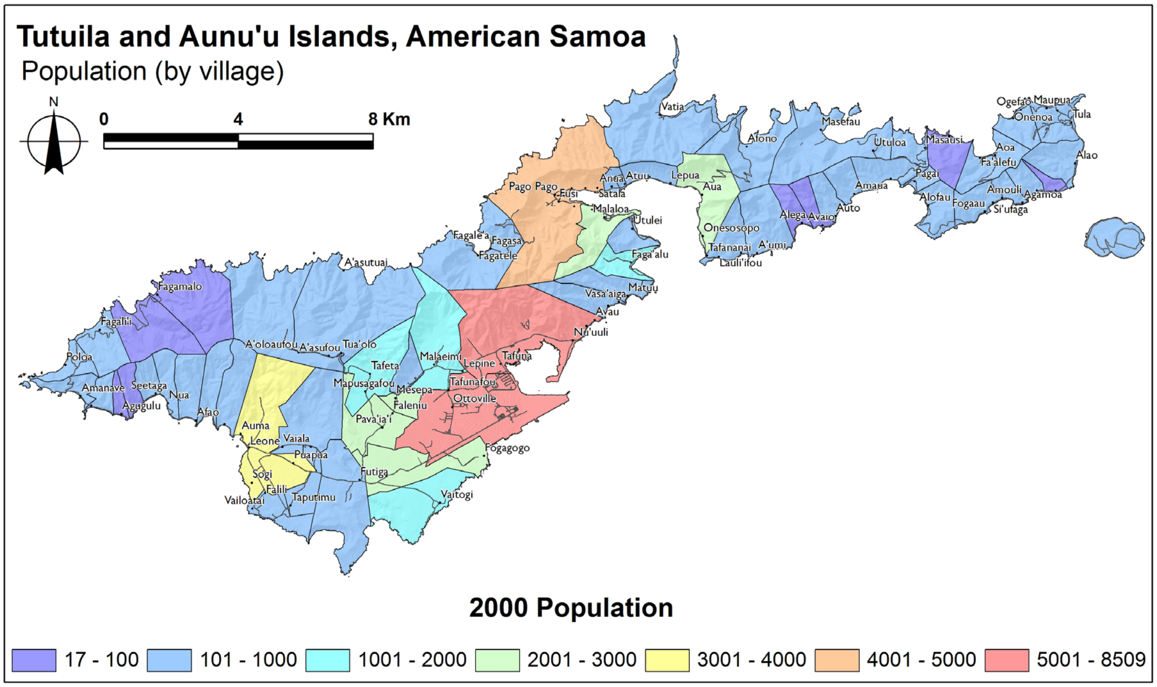

Figure 3.1b. Population density by village for Tutuila and Aunu`u in 2000 (U.S. Census Bureau, 2000).

Tutuila has the largest population of the American Samoan Islands, with 55 876 people counted during the 2000 census, including 476 residents of Aunu`u (Fig. 3.1b). Population density is highest on the Tafuna Plain and the villages surrounding Pago Pago Harbor. The government of American Samoa is the largest employer, followed closely by the tuna canneries located in Pago Pago. Tourism plays a relatively small role in the local economy (Office of Insular Affairs, 2007).

3.2 Survey Effort

A large amount of physical and biological data have been collected around Tutuila and Aunu`u since 2002 as part of the American Samoa Reef Assessment and Monitoring Program (ASRAMP). The extent and timeframe of these survey efforts are discussed below. To aid in the discussion of spatial patterns of ecological and oceanographic observations throughout this chapter, nine geographic regions, which are often exposed to different environmental conditions, are delineated in Figure 3.2a.

Table 3.2a. Total area of benthic habitat surveyed using acoustic multibeam sonar and Towed Optical Assessment Device (TOAD) surveys around Tutuila and Aunu`u during ASRAMP 2002, 2004 and 2006.

Survey Type	2002	2004	2006
Acoustic Multibeam Sonar	0	189 km^2	400 km^2
TOAD	2.6 km (6 tows)	25.6 km (47 tows)	0

Benthic habitat mapping data were collected around Tutuila and Aunu`u using a combination of acoustic and optical survey methods summarized in Table 3.2a. These are further examined in Section 3.3: Benthic Habitat Mapping and Characterization.

Figure 3.2a shows the locations of Rapid Ecological Assessment (REA) and towed-diver survey efforts during 2002, 2004, and 2006. The number of surveys, their mean depth in meters, and area in hectares are presented by year in Table 3.2b.

Depth ranges from towed-diver surveys are presented for each year in Figure 3.5.1a (2002), 3.5.1d (2004), and 3.5.1k (2006). Although the towed-diver survey methodologies are aimed at following specific isobaths, the actual depths surveyed are often quite variable. These figures illustrate the variability of depths observed during towed-diver surveys and can be referenced when further exploring the towed-diver datasets.

Table 3.2b. Number, area, and depth of REA and towed-diver surveys around Tutuila and Aunu`u during ASRAMP 2002, 2004, and 2006.

Year	REA		Towed-diver Survey		
	Number of Surveys	Mean Depth (m)	Number of Surveys	Survey Area (ha)	Mean Depth (m)
2002	14*	13.5 (SD 1.5)	16	38.0	10.4 (SD 3.7)
2004	22*	17.7 (SD 2.0)	43	82.0	11.9 (SD 5.0)
2006	22**	14.3 (SD 1.4)	44	87.5	11.6 (SD 8.3)

** No coral disease surveys were conducted in 2002 and 2004.*
*** Coral surveys were only conducted at 16 of the 22 sites in 2006 because of a logistical problem with one of the REA divers.*

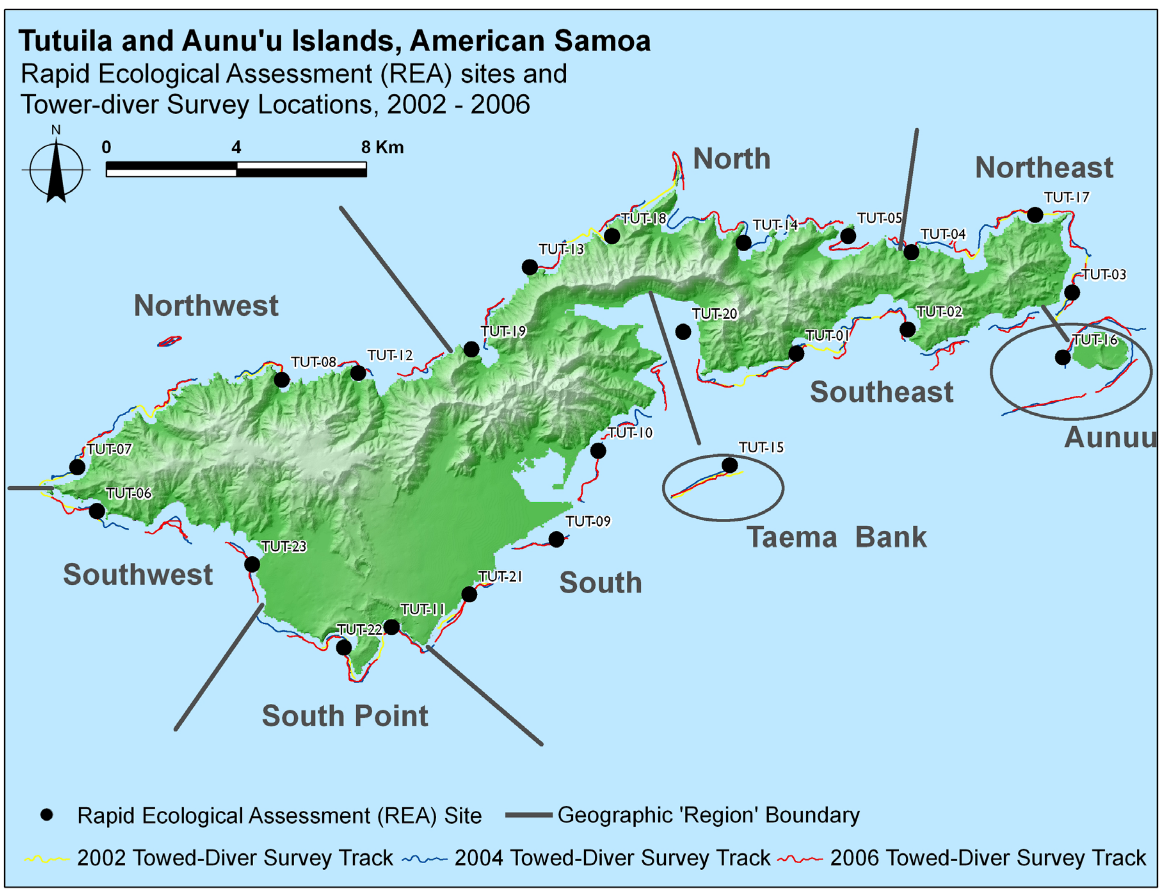

Figure 3.2a. Locations of REA and towed-diver surveys around Tutuila and Aunu`u during ASRAMP 2002, 2004, and 2006. Nine arbitrary geographic regions have been delineated to aid in discussion of spatial

Spatial and temporal observations of key oceanographic and water quality parameters influencing reef conditions around Tutuila and Aunu`u were collected using a diverse suite of long-term moored instrumentation packages and closely spaced conductivity, temperature and depth (CTD) surveys of the vertical structure of water properties during ASRAMP 2002, 2004, and 2006 (Chapter 2, Section 2.3: Oceanography and Water Quality). A summary of deployed instruments/collection activities is provided in Table 3.2c, and are further examined in Section: 3.4: Oceanography and Water Quality.

Table 3.2c. Numbers of oceanographic instrument deployments during 2002-2006 and shallow- and deep-water CTD casts around Tutuila and Aunu`u during ASRAMP 2002, 2004, and 2006. Instrument types include: sea surface temperature (SST) buoys, subsurface temperature recorders (STRs), wave and tide recorders (WTRs), recording current meters (RCMs), and ecological acoustic recorders (EARs). Shallow-water CTD casts were conducted from the surface to a 30-m depth. Deep-water CTD casts were conducted from the surface to a 500-m depth. Deep-water CTD cast information is presented in Chapter 8, Archipelagic Comparisons.

Observation Type	2002	2004	2005	2006
SST	6	0	1	2
STR	0	4	3	7
WTR	0	1	1	1
RCM	1	0	0	0
EAR	0	0	0	4
Shallow-water CTD casts	48	122	0	113
Deep-water CTD casts		8	0	14

3.3 Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization of the nearshore waters around Tutuila and Aunu`u were conducted using acoustic multibeam sonar, underwater video and still imagery, and towed-diver survey observations. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products in depths between ~ 20 and 250 m. Optical validation and benthic characterization via underwater video, still imagery, and diver observations were performed using both shipboard TOAD surveys in depths between ~ 20 and 80 m and towed-diver surveys in depths between 1 and 30 m.

3.3.1 Acoustic Mapping and Optical Validation

Pacific Islands Fisheries Science Center (PIFSC) Coral Reef Ecosystem Division (CRED) collected multibeam acoustic bathymetry and backscatter imagery around Tutuila and Aunu`u between 2002 and 2006, encompassing an area of ~ 589 km^2, with ~ 320 km^2 in water depths less than 100 m. This extensive and generally flat shelf area is hypothesized to be a fossil reef carbonate platform developed during periods of lower relative sea level. Multibeam-derived bathymetry from the shelf around Tutuila reveals a complex system

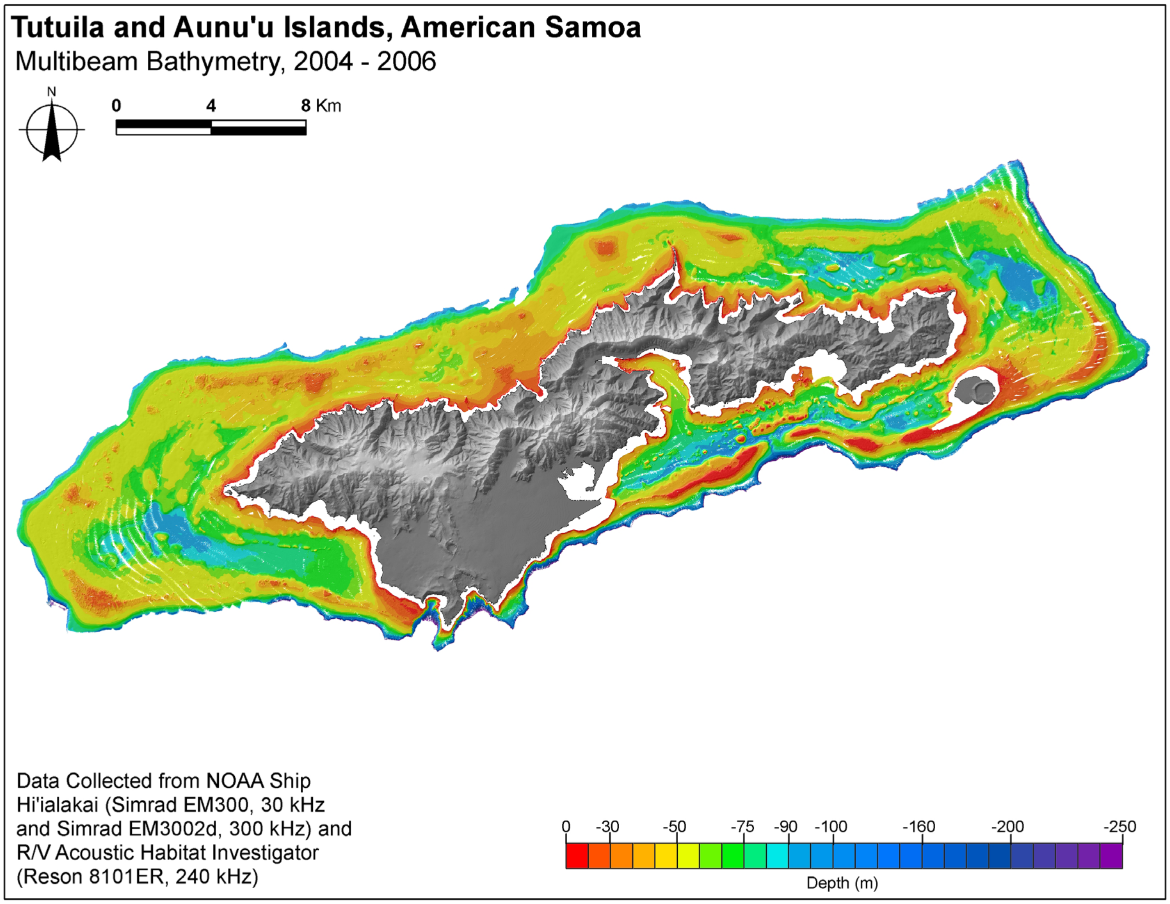

Figure 3.3.1a. Multibeam bathymetry acquisition around Tutuila and Aunu`u was conducted between 10 and 205 m in March 2004 and March 2006 from the R/V *Acoustic Habitat Investigator* (*AHI*) and the NOAA Ship *Hi`ialakai*. Shelves extend from the north shore of Tutuila; offshore banks surround the southeast and west sides, and the bank drops steeply to abyssal depths off the south point region.

of embayments, nearshore habitats, and a number of offshore banks that extend from the seafloor to as shallow as 20 m (Fig. 3.3.1a). What is hypothesized to be a relict barrier reef with ridge-like structures as shallow as 20 m is found around most of the perimeter of the island platform. Multibeam bathymetry collected by a number of university and National Oceanic and Atmospheric Administration (NOAA) vessels in deeper water shows that the bank drops off sharply to abyssal depths immediately outside this relict reef structure. Late stage volcanic eruptions formed Aunu`u and the large flat Tafuna Plain (also known as the Leone Peninsula), as discussed by Stearns (1944). This Tafuna eruption buried a large portion of the southern bank and reef inside the outer barrier. The Tafuna lava flows appear to have been bounded by the outer shoal structure and, where the recent flows cover the bank, there is a steep descent to depths greater than 1000 m. On the banks, but inside of the outermost barrier, depths range from ~ 20 to 100 m, including many isolated high features.

One of the important characteristics of this complex bank structure is a profusion of hard, probably carbonate, structures, particularly around the outer edges of the bank over 1.5 km offshore of Tutuila. Because of their locations and depth, it is speculated that the relict barrier-reef structures may contain significant live coral cover and associated reef communities. A limited number of TOAD survey tracks across these features have confirmed the presence of live scleractinian coral colonies in a number of areas scattered around all sides of the island

and high concentrations of scleractinian coral colonies in a few locations.

Most of the extensive shelf around Tutuila appears to be composed of hard substrate, except for sediment that appears to be washing out of several watersheds (Fig. 3.3.1b). Off the north shore this sediment tends to collect in a shore-parallel band at the base of a gentler slope below the forereef slope of the living reef, ~ 100 m deep. We speculate that the base of this slope may be a paleo shoreline, possibly representing the position of sea level during the last glacial maximum, which ended ca. 18 000 years ago. There are also what appear to be scattered pockets of sediment that have collected in low areas on the offshore shelf. There is an oval-shaped sediment field ca. 2 x 3 km in size in a depression offshore of Masefau Bay near the eastern end of the north shore. Several patch reefs extend up above the sediment field there and are likely capped with coral reef. Interestingly, another large depression approximately 2 km east of Cape Matatula is devoid of significant sedimentary deposits, possibly a result of predominantly westerly currents. On the southern side of Tutuila, the seafloor of Pago Pago Harbor appears to be composed almost entirely of acoustically absorbent sediments which extend out the mouth of the harbor and collect offshore between Taema Bank and the harbor. That sediment field continues several kilometers both east and west of the harbor entrance and appears to be supplemented by sediment washing in from a few smaller watersheds east of the harbor. Late volcanic stage lava flows making up the Tafuna Plain have covered over

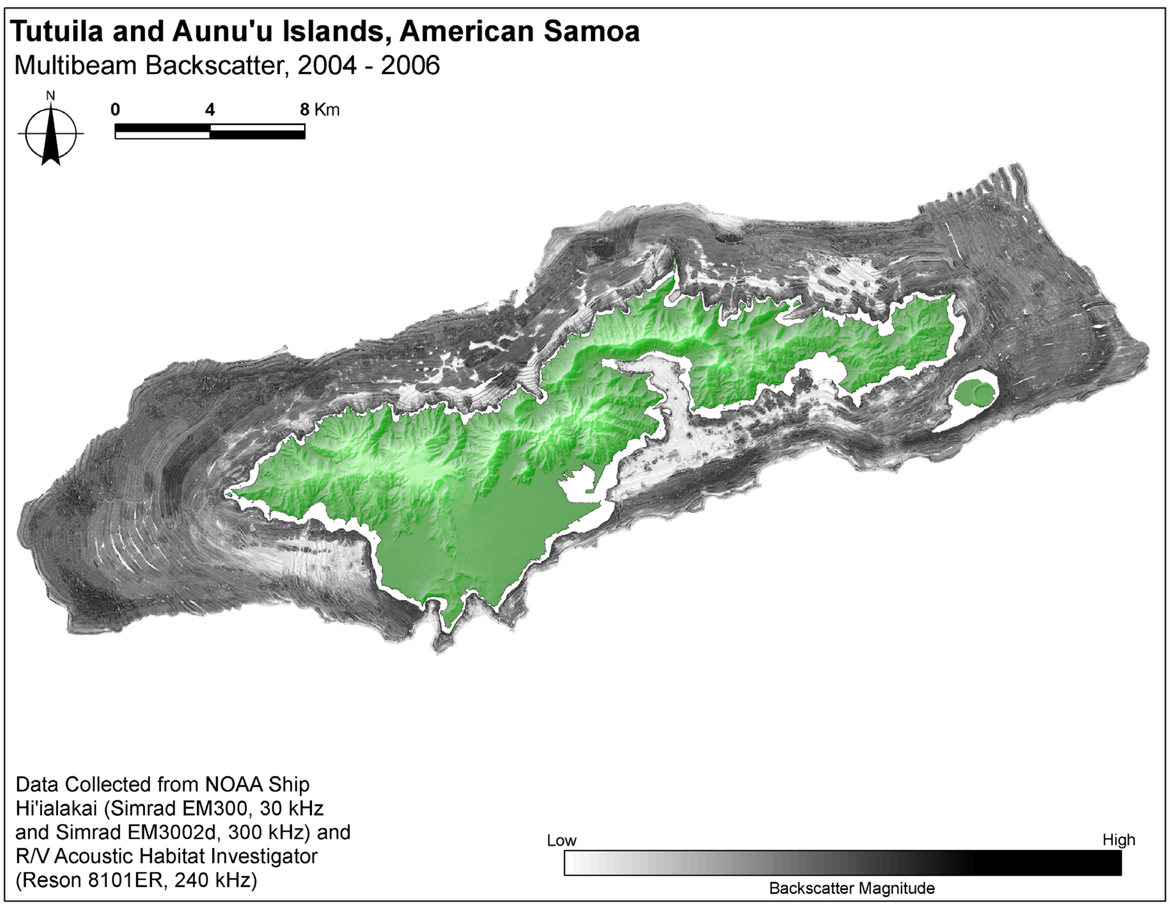

Figure 3.3.1b. Backscatter imagery was acquired in March 2004 and March 2006 during multibeam surveys around Tutuila and Aunu`u from the R/V *AHI*. Lighter shades represent low-intensity backscatter and likely indicate substrates that are acoustically absorbent and typically indicate unconsolidated sediment. Darker shades represent high-intensity backscatter and likely indicate consolidated hard-bottom and coral substrates.

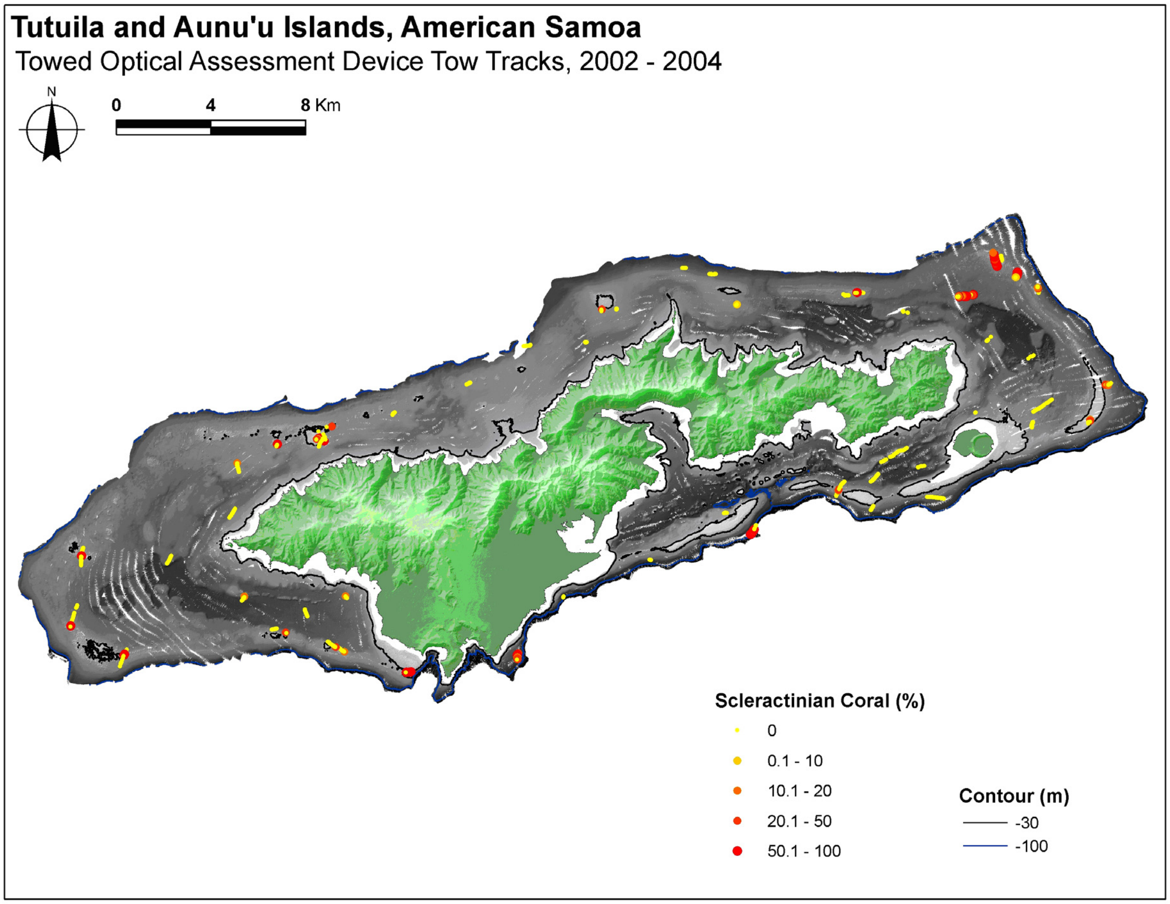

Figure 3.3.1c. TOAD camera sled tracks around Tutuila and Aunu`u collected during ASRAMP 2002 and 2004. The video imagery are post processed to identify substrate type (sand, rock, etc.), living cover (coral, macroalgae, etc.), and other characteristics. The TOAD survey tracks display percentage of live scleractinian coral classified using a point count method with a mean spacing of 20 m along each track. Yellow indicates 0% coral cover, orange colors indicate 0–20% coral cover, and red colors indicate 20–50% and 50–100% coral cover.

much of the insular shelf on the southern side of the island between Pala Lagoon and Leone. West of Fagatele Bay, the insular shelf reappears and rapidly widens, extending approximately 9 km westward of Cape Taputapu, the westernmost point of Tutuila. A large sediment field is located approximately 5 x 2 km off Leone. A large shallow depression on the insular shelf with depths reaching ~ 90–100 m is located farther offshore, about 4 km southwest of Cape Taputapu. Other than the sediment deposits described above, the insular shelf around Tutuila appears to be composed of predominantly hard, and presumably carbonate, substrate.

TOAD photographic and video imagery optical validation surveys were conducted around Tutuila and Aunu`u in 2002 and 2004 (131 still photographs and 52 video segments). Camera sled tracks from ASRAMP 2002 and 2004, shown in Figure 3.3.1c, are color coded to indicate the percentage of the seafloor inhabited by live scleractinian coral. Based on the optical data, coral cover around Tutuila ranged from 0% to > 50% at a few outer bank locations scattered around different sides of the island. These optical data were classified in accordance with a benthic classification scheme which is similar to that used to classify benthic towed-diver survey data in water depths shallower than ~ 30 m, but with a few differences that reflect methodological limitations of the camera sled data.

3.3.2 Habitat Characterization

Towed-diver benthic survey observations around Tutuila and Aunu`u from ASRAMP 2002, 2004, and 2006 were concatenated into mean spatial distributions (see methods Chapter 2, Section 2.2.3: Optical Validation Surveys) of the following benthic components: habitat complexity (Fig. 3.3.2a), percent cover of sand (Fig. 3.3.2b), hard substrate/pavement (Fig. 3.3.2c), rubble (Fig. 3.3.2d), and live coral (Fig. 3.3.2e). For areas where towed-diver survey tracks overlapped between years, the concatenated values represent temporal means; thereby averaging out temporal changes in percent covers of sand, rubble, and live coral cover (actual values of coral cover for each year are shown in coral section).

For areas where towed-diver tracks did not overlap precisely between years, the interpolated values provide additional insights into onshore-offshore gradients. Since these habitat characterization maps represent different complementary components of the same mean habitats, it is useful to analyze them in relation to each other, the local watersheds, and exposure to prevailing oceanographic conditions.

Mean benthic topographic complexity (Fig. 3.3.2a) is a subjective parameter of a three-dimensional structure of the benthic habitat and reflects the ecological complexity of the nearshore environment. As shown, habitat complexity around Tutuila and Aunu`u was

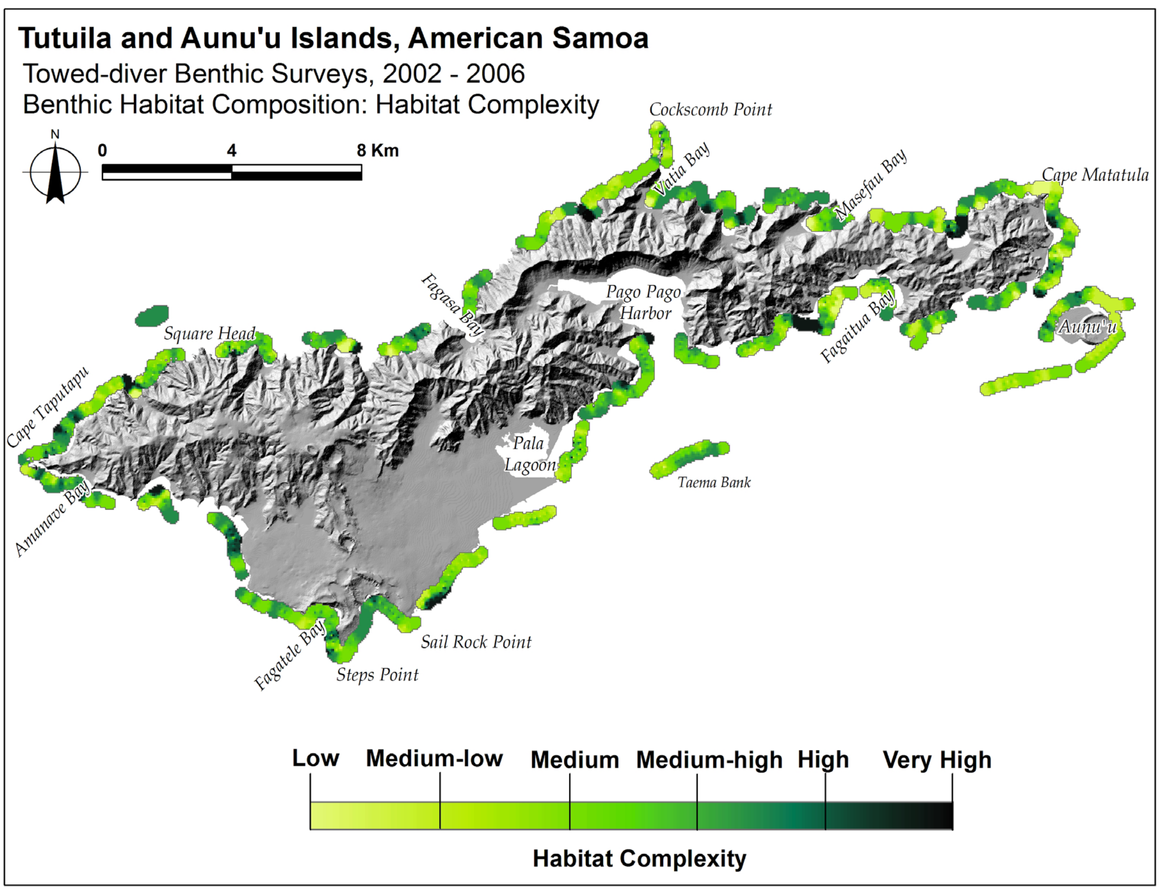

Figure 3.3.2a. Mean benthic habitat complexity concatenated from towed-diver survey observations around Tutuila and Aunu`u during ASRAMP 2002, 2004, and 2006. Habitat complexity was subjectively rated by diver-observers over 5-min ensembles (~ 200 x 10 m) over a 6-point scale representing low (1), medium-low (2), medium (3), medium-high (4), high (5), and very high (6) topographic complexity. Yellow colors indicate low habitat complexity, and dark green colors indicate high habitat complexity.

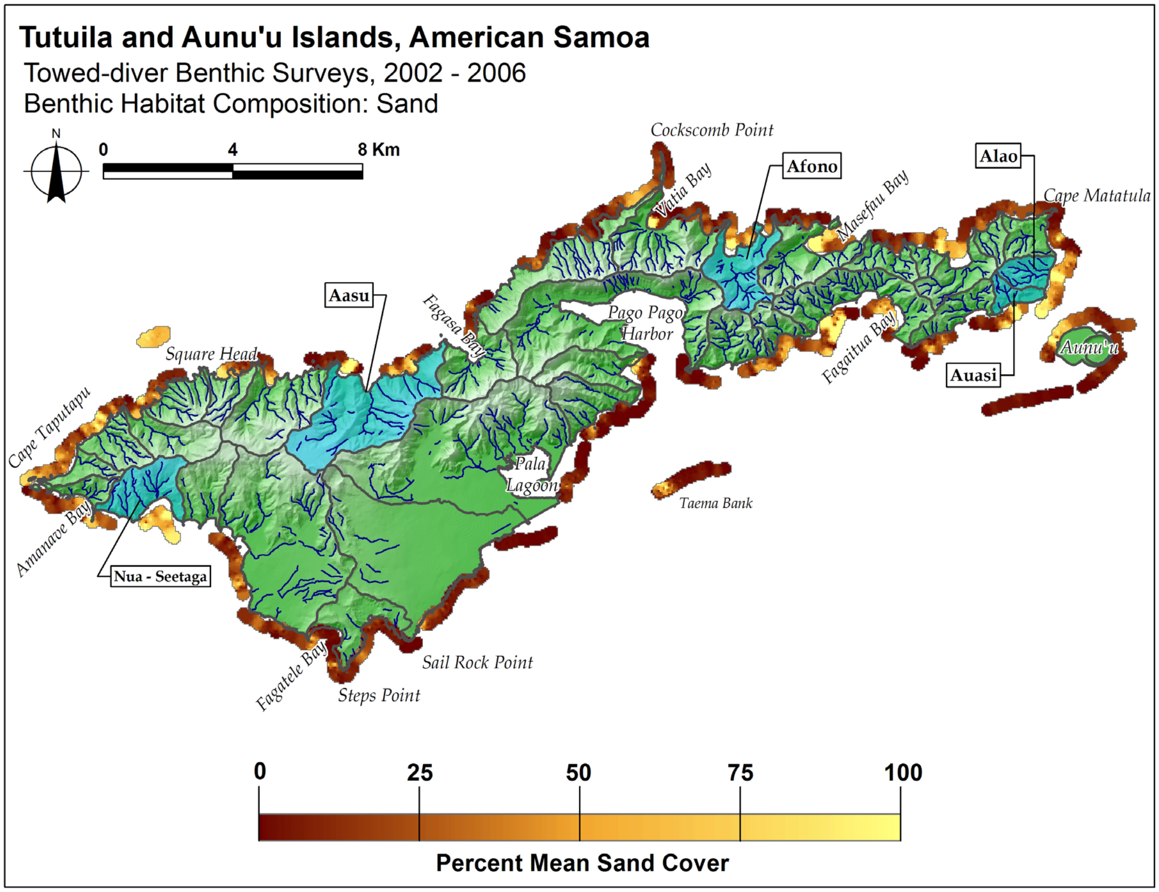

Figure 3.3.2b. Mean percent cover of sand concatenated from towed-diver habitat survey observations around Tutuila and Aunu`u during ASRAMP 2002, 2004, and 2006. Major streams (blue lines) overlay the topographic map of the islands, indicating the location of inputs of freshwater runoff into the marine ecosystem. Selected watersheds (Fig. 3.1a) are highlighted in blue. Sand composition was subjectively rated by diver-observers over 5-min ensembles (~ 200 m x 10 m) over a 1–100% scale. Light shades indicate high percent cover of sand, and dark shades indicate low percent cover of sand.

observed to be highly variable with values ranging across the scale from low to very high scattered around all regions of the island.

The distribution of sand around Tutuila and Aunu`u is shown in Figure 3.3.2b. Regions of high sand cover appear well correlated to the primary watershed discharges around Tutuila, including Nua-Seetagam, Aasu, Afono, Auasi and Alao districts, and Vatia, Masefau, and Fagaitua Bays. These results highlight the role of watersheds in supplying terrigenous sediments to the nearshore habitats. It can be inferred that the inverse of sandy, soft benthic habitat is hard substrate or pavement. Areas of low sand cover appear to correlate with areas of higher benthic complexity (Fig. 3.3.2a) and coral cover (Fig. 3.3.2e), and vice versa.

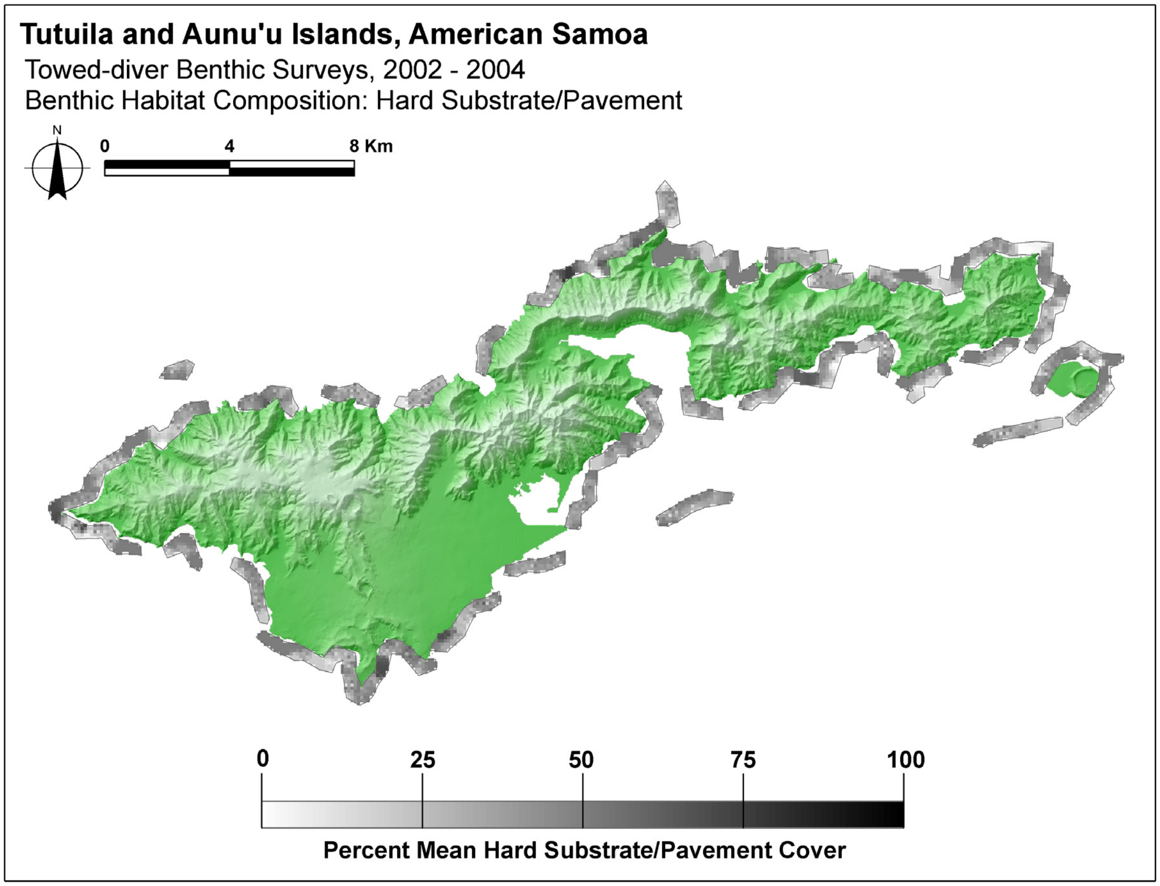

Figure 3.3.2c. Mean percent cover of hard substrate/pavement, concatenated from towed-diver survey observations around Tutuila and Aunu`u during ASRAMP 2002 and 2004. Hard substrate/pavement composition was subjectively rated by diver-observers over 5-min ensembles (~ 200 m x 10 m) over a 1–100% scale. Dark shades indicate high percent cover of hard substrate, and light shades indicate low percent cover of hard substrate.

The distribution of hard substrate/pavement around Tutuila and Aunu`u is shown in Figure 3.3.2c. As described here, hard substrate/pavement includes live and dead coral, rock, and algal covered carbonate pavement. As expected, these hard-bottom habitats were inversely distributed around the islands in comparison to areas of sand cover. In general, the majority of the forereef slopes around Tutuila consisted of hard substrate/pavement habitats, with highest percent cover of hard substrate/pavement often in areas of steep terrestrial topography and low percent cover of hard substrate/pavement often in watershed discharge areas.

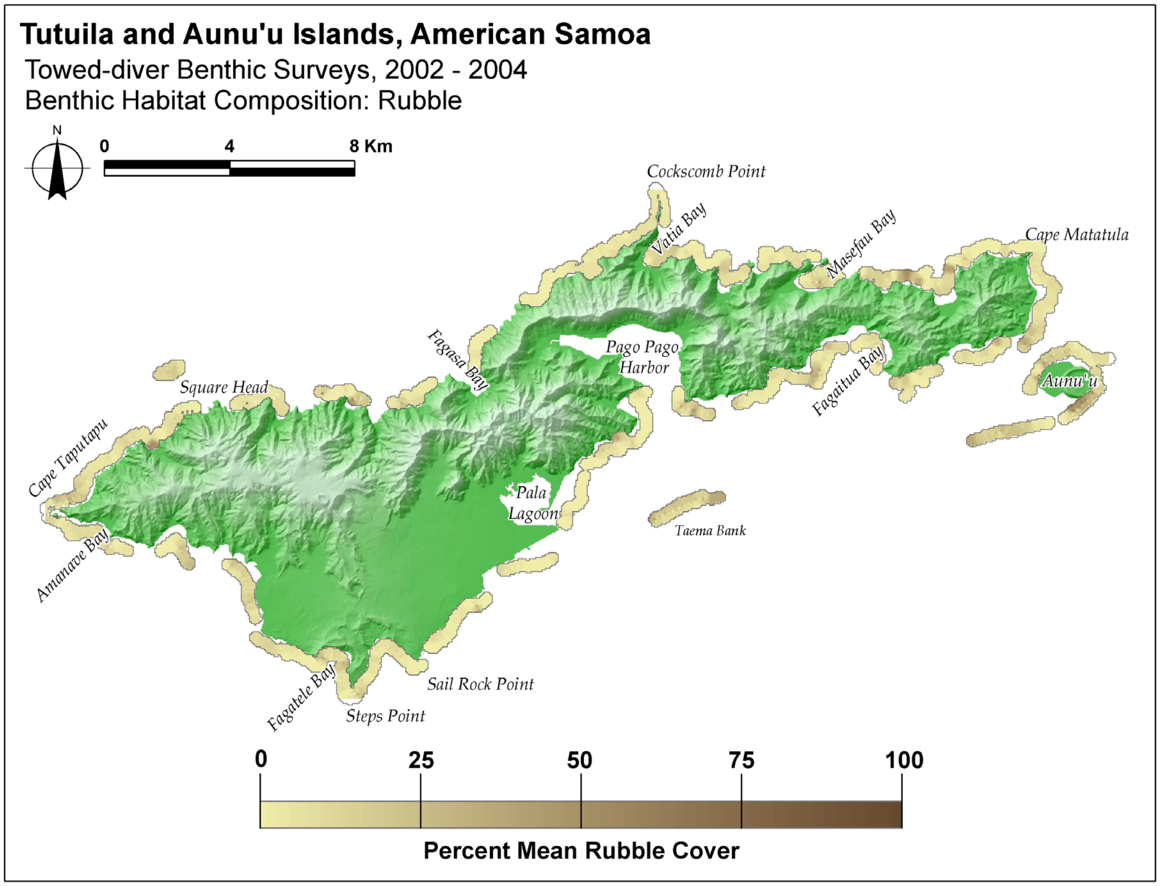

Figure 3.3.2d. Mean percent cover of coral rubble, concatenated from towed-diver survey observations around Tutuila and Aunu`u during ASRAMP 2002 and 2004. Rubble composition was subjectively rated by diver-observers over 5-min ensembles (~ 200 m x 10 m) over a 1–100% scale. Light shades indicate low percent cover of coral rubble, and dark shades indicate high percent cover of coral rubble.

The distribution of percent cover of coral rubble in the nearshore environments around Tutuila and Aunu`u is shown in Figure 3.3.2d. The spatial distribution of coral rubble was variable, with generally low percent cover of rubble dominating most habitats around the islands. Lowest coral rubble values were observed in low complexity sand habitats, and higher coral rubble values were recorded in areas of moderate-to-high complexity and coral cover. Rubble habitats often indicate mechanical or biological erosion, suggesting either exposure to high wave energy forcing or an abundance of bioeroding invertebrates, respectively. In the case of bioeroding invertebrates, percent cover of rubble habitat may serve as a potential indicator of invertebrate biodiversity.

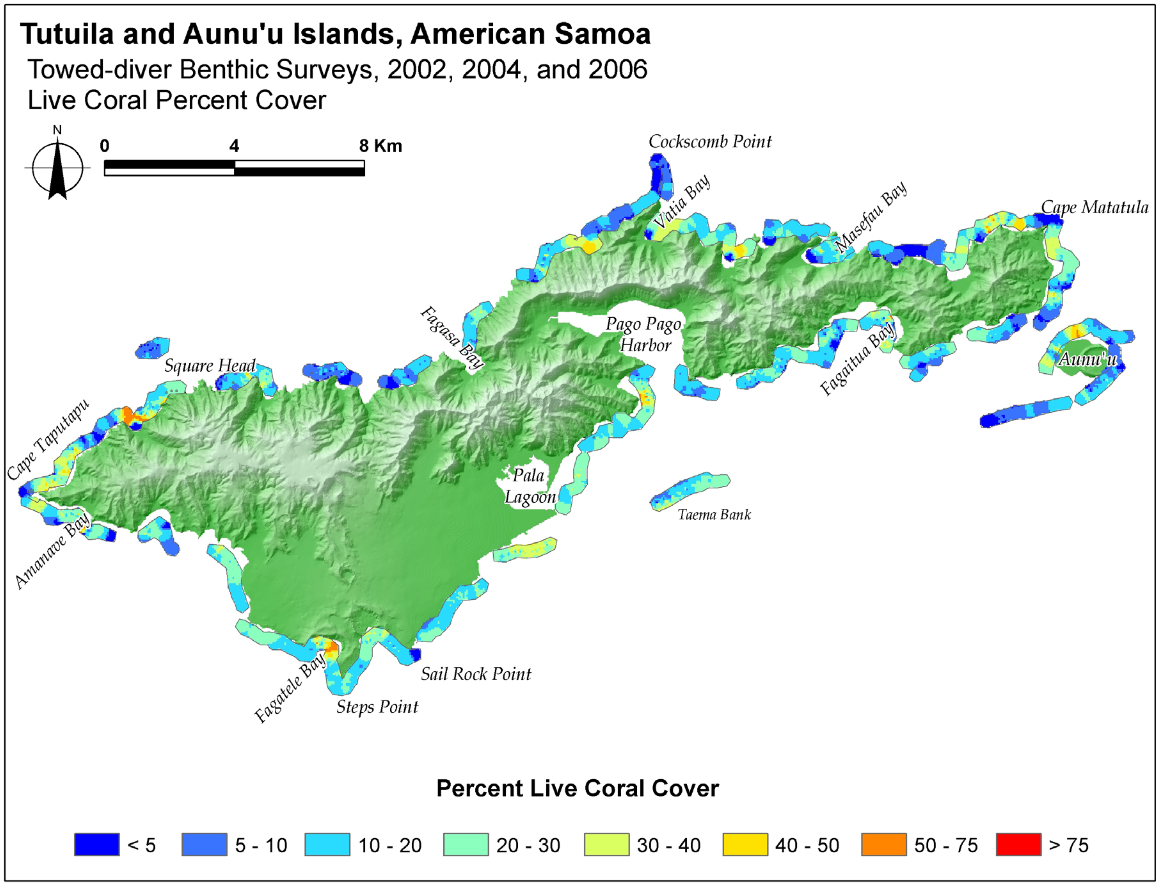

Figure 3.3.2e. Mean percent cover of live scleractinian (stony) coral, concatenated from towed-diver survey observations around Tutuila and Aunu`u during ASRAMP 2002, 2004, and 2006. Live coral cover composition was subjectively rated by diver-observers over 5-min ensembles (~ 200 m × 10 m) over a 1–100% scale. Blue colors indicate low percent cover of coral, and reddish colors indicate high percent cover of coral.

The distribution of the mean percent cover of live coral around Tutuila and Aunu`u is shown in Figure 3.3.2e. Generally, the spatial distribution of live coral cover was variable, with highest live coral cover often found in sheltered areas, such as bays and leeward coasts, and lowest live coral cover often found in areas exposed to prevailing seas or strong currents, such as major headlands and capes. Close examination shows onshore-offshore gradients of live coral cover, probably associated with changes in depth. For instance, near Maloata in the northwest region, live coral cover was low (< 5%) in shallow water next to the shoreline, high (> 50%) just offshore in intermediate depths, and moderate (0–10%) farther offshore to the north.

3.4 Oceanography and Water Quality

Oceanographic and water quality observations were collected in the waters surrounding Tutuila and Aunu`u between 2002 and 2006. Instrumentation and equipment descriptions, deployment locations, and a subset of the resultant datasets are discussed below. Specific details of deployments and additional data are presented in Appendix II, Table II.i.

3.4.1 Hydrographic Data

2002 Spatial Surveys

During ASRAMP 2002, 48 shallow-water CTD casts were conducted in nearshore waters around Tutuila during the periods February 11–12 and March 3–4 (Figs. 3.4.1a and 3.4.1b). Data from these vertical profiles show that salinity, temperature, and density were closely correlated for all casts; higher temperatures corresponded to lower salinity and density. The most striking feature of these data was a north-south disparity in water properties. The northern shore had a highly stratified water column compared with cooler, less saline, and less stratified (well-mixed) water on the south side of the island. The single cast taken on the east side showed a well-mixed water column of relatively cool water that suggests there was a gradient on the east side between the northern and southern water masses. The less saline waters measured on the south side of the island likely reflect the broad watersheds and large embayments present on the south, compared with those on the north, resulting in increased rainfall runoff.

During the ASRAMP 2002 survey period, temperature and salinity values at a 20-m depth around surveyed portions of Tutuila varied inversely with one another; cooler temperatures were generally associated with higher salinities while warmer temperatures were associated with lower salinities (Fig. 3.4.1c). The highest temperatures and lowest salinities were

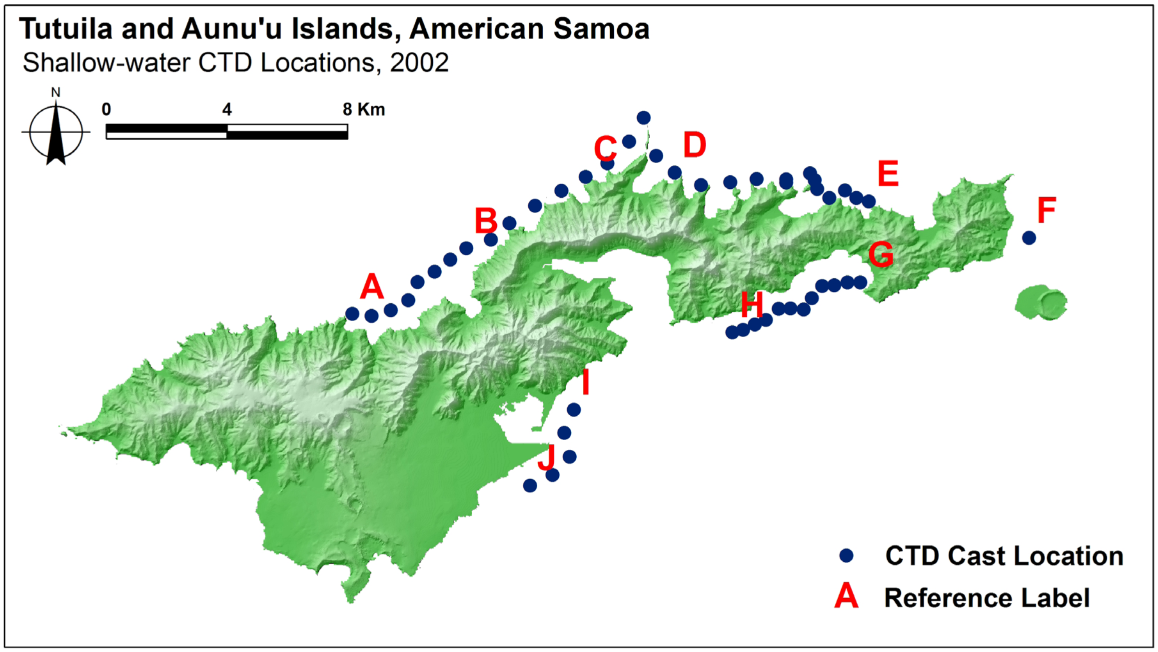

Figure 3.4.1a. Shallow-water CTD cast locations, shown as blue dots, expressed sequentially in a clockwise direction around Tutuila (A–J) during ASRAMP 2002, February 10–11 and March 3–4.

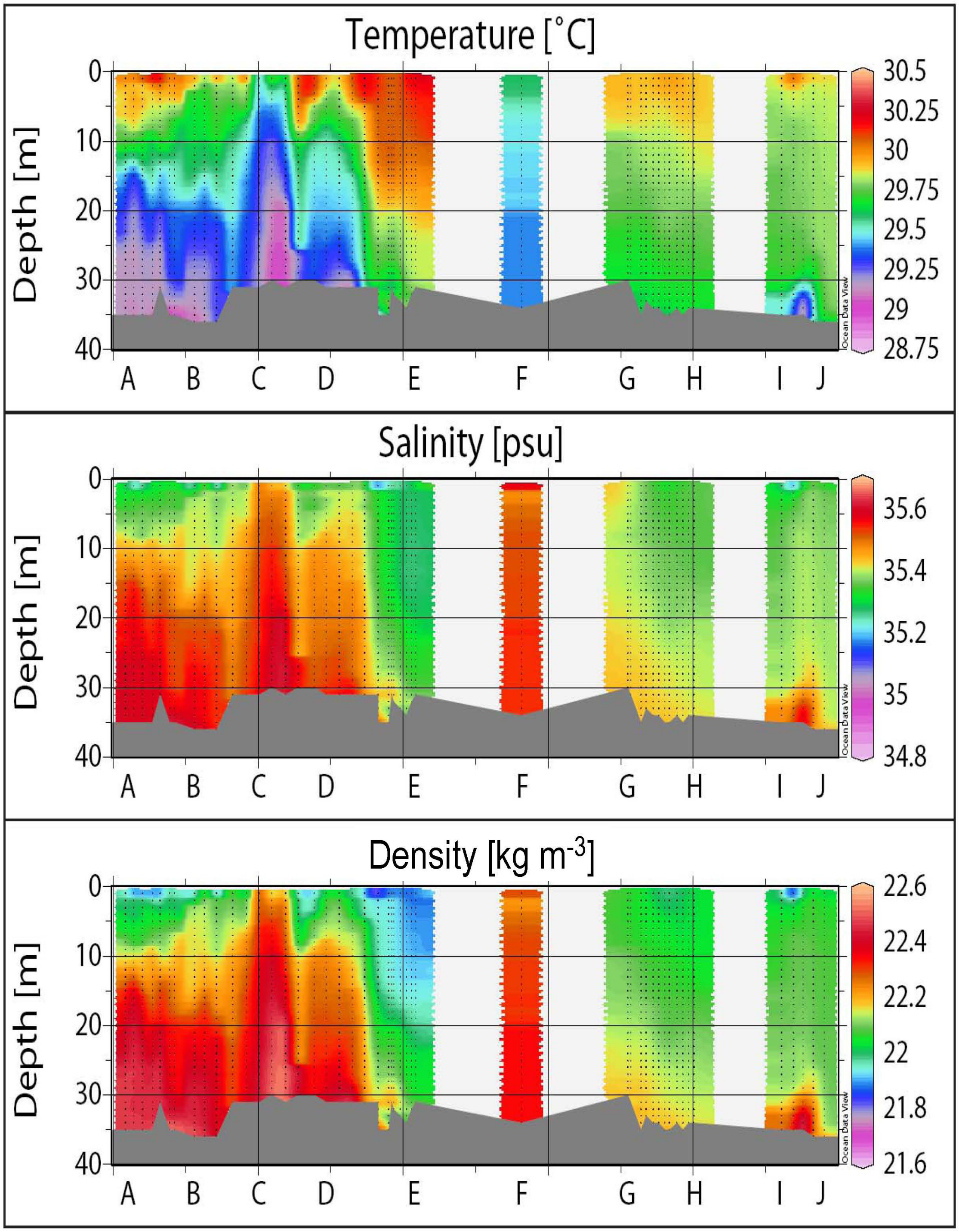

Figure 3.4.1b. Shallow-water CTD cast profiles to a 30-m depth around Tutuila during ASRAMP 2002, February 10–11 and March 3–4, including temperature (°C), salinity (psu), and density (kg m^{-3}). Profiles are shown sequentially in a clockwise direction around the island (A–J), as shown in Figure 3.4.1a.

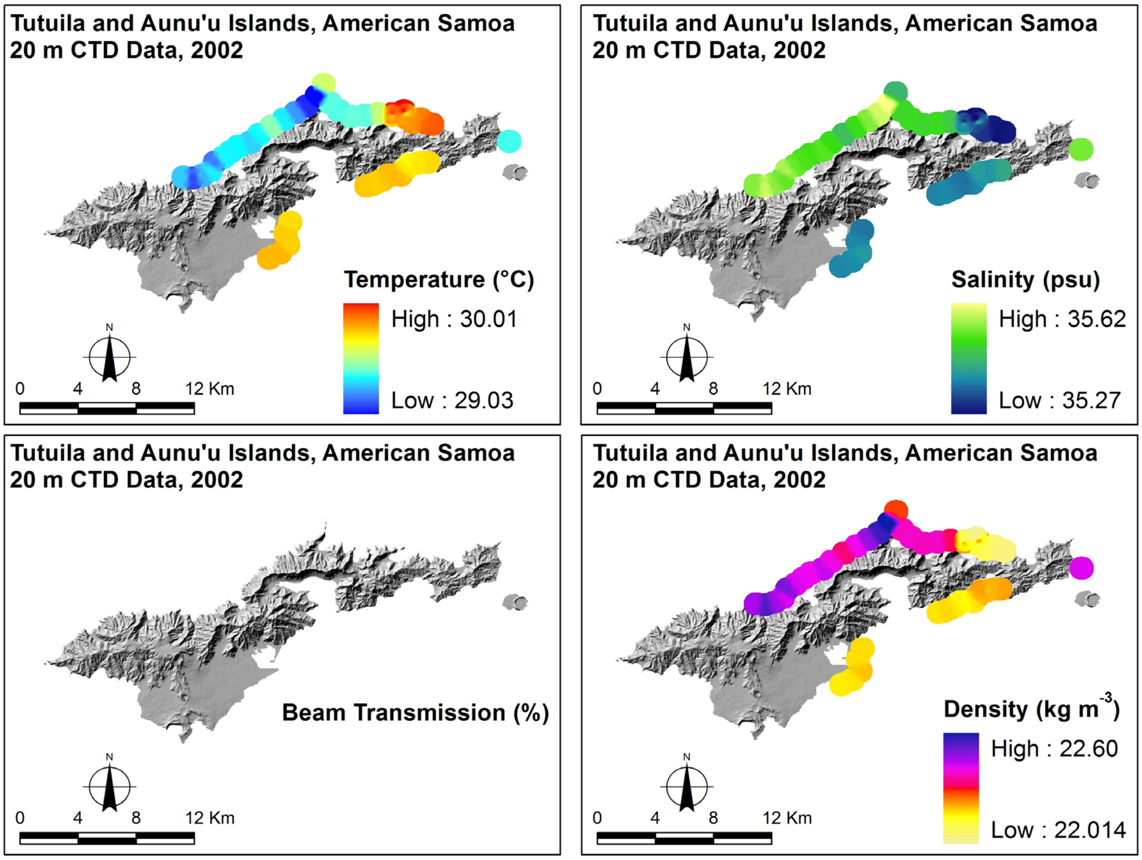

Figure 3.4.1c. Interpolated water temperature (top left), salinity (top right), and density (bottom right) at a 20-m depth derived from shallow-water CTD casts around Tutuila during ASRAMP 2002, February 10–11 and March 3–4. Beam transmission data (bottom left) were not collected.

observed in the northeast region of Tutuila and the coolest, most saline waters were observed off Cockscomb Point in the north region. The south and southeast regions of the island, both east and west of the Pago Pago Harbor, were observed to have similar temperatures and salinities as in the northeast. Since the 2002 observations were conducted over a 3-week period, the assumed synopticity is not likely realistic. As such, it is not possible to determine whether the observed patterns reflect spatial, temporal, or combined shifts.

2004 Spatial Surveys

During ASRAMP 2004, 122 evenly spaced shallow-water CTD casts were conducted in nearshore waters surrounding Tutuila and Aunu`u over the February 19–25 period (Figs. 3.4.1d and 3.4.1e). Data from these vertical profiles show noteworthy spatial differences in water temperature (± 2°C), salinity (± 1 psu) and density during the sampling period (Fig. 3.4.1e). Salinity, temperature, and density changes were typically correlated around the island, with higher temperatures corresponding to lower salinities and densities. There were two main features apparent at Tutuila during this time. The waters in the northwest region were observed to be warm with relatively low salinity and density (A–B). The most striking feature, east of Aunu`u, was a region of strong vertical gradients of temperature, salinity, and density. These observations were suggestive of localized upwelling of cooler, more saline offshore waters encountering the nearshore topography of the eastern bank (Fig. 3.4.1f). A shallow lens (upper 2 m) of relatively fresh water was observed in the southwest region of the island (K–L), suggestive of recent freshwater input from the nearby watersheds. The beam transmission was highest (~ 95%) in both the warm northwest region (A–B) and also at the coldest spike on the east end of Tutuila (E–H).

Analysis of hydrographic data collected at a 20-m depth around Tutuila and Aunu`u during the ASRAMP 2004 survey period shows moderate ranges in temperature (29.03–29.85°C), beam transmission (84.87–94.85%), and computed density (21.78–22.43 kg m^{-3}), and a large range in salinity (34.99–35.51 psu). At all locations around the islands, temperature varied inversely with salinity and density; warmer waters were generally fresher and less dense while cooler waters were more saline and more dense. Waters in the northwest region were warmer, less saline, and less dense compared to the other regions around the islands. Beam transmission, a measure of turbidity, appears to have varied independently of the other observed water properties; the least turbid waters occurred in the southwest region of Tutuila encompassing Leone and Amanave Bays, while the most turbid waters occurred in Pago

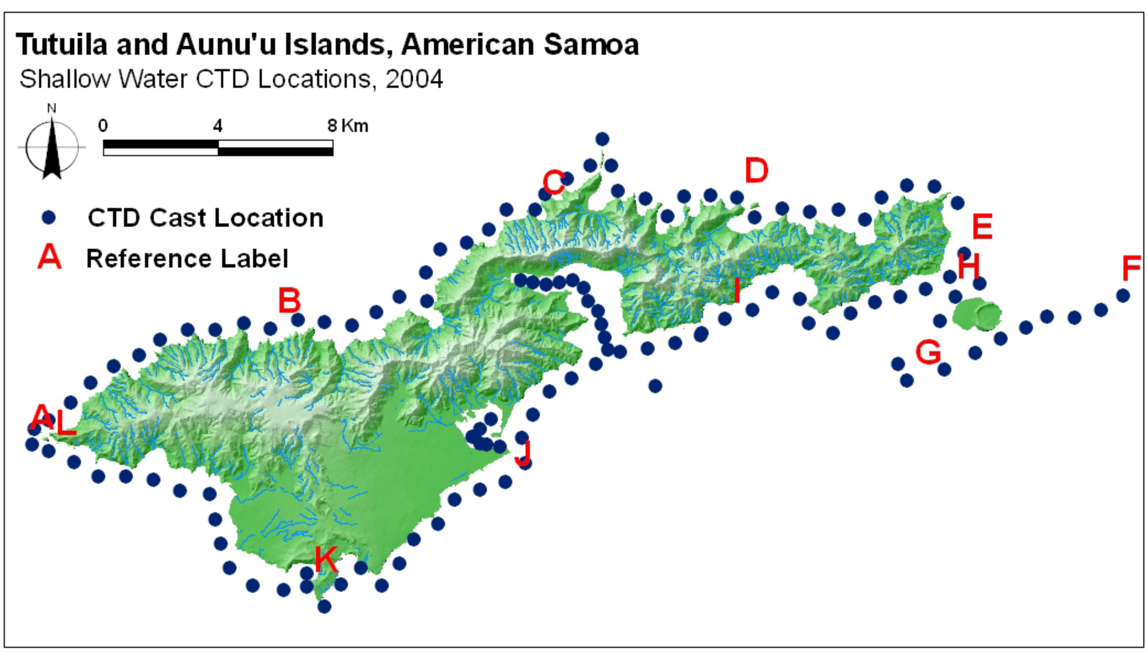

Figure 3.4.1d. Shallow-water CTD cast locations, shown as blue dots, expressed sequentially in a clockwise direction around Tutuila and Aunu`u (A–L) during ASRAMP 2004, February 19–25.

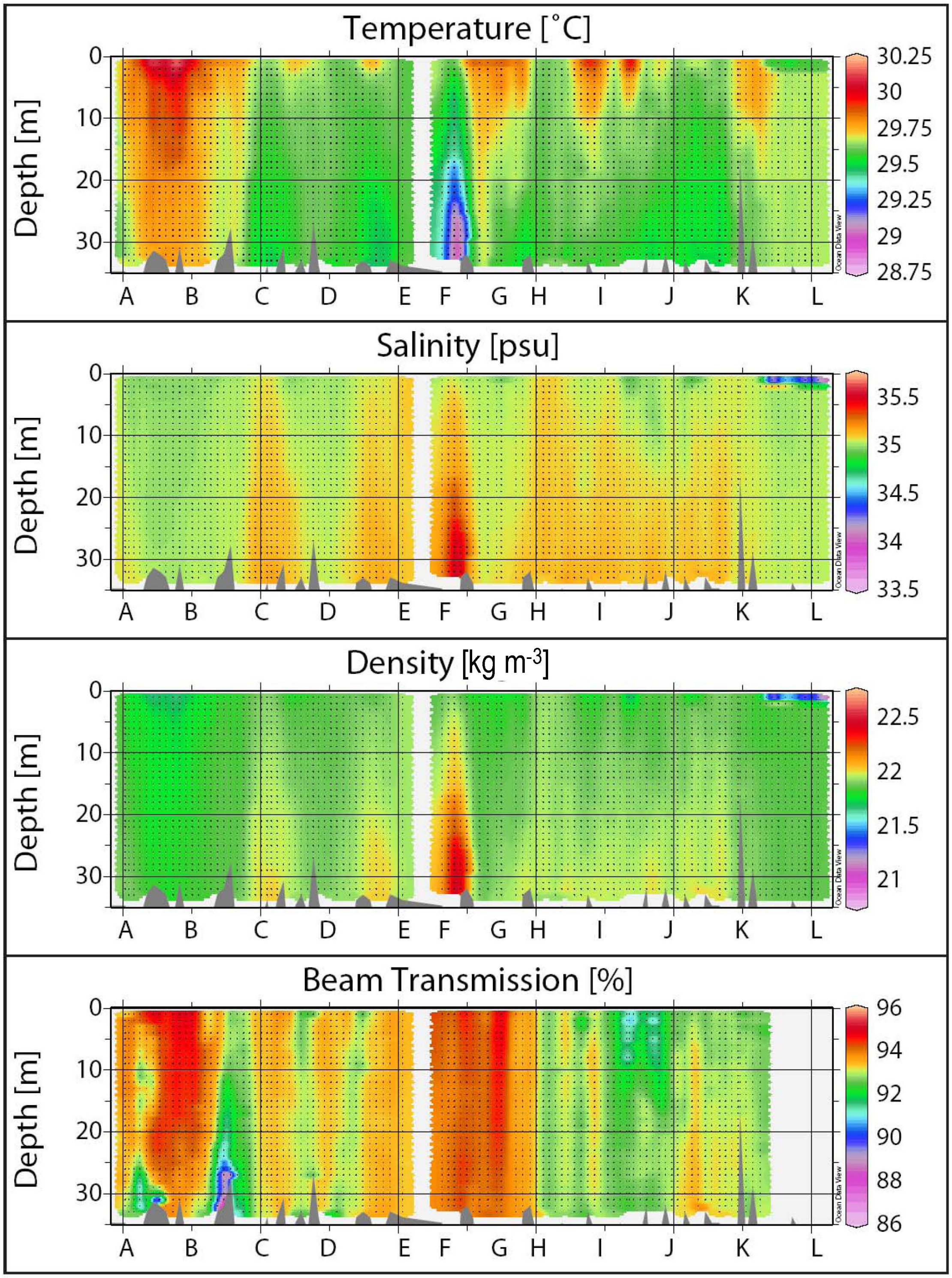

Figure 3.4.1e. Shallow-water CTD cast profiles to a 30-m depth around Tutuila and Aunu`u during ASRAMP 2004, February 19–25, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles are shown sequentially in a clockwise direction around the islands (A–L), as shown in Figure 3.4.1d.

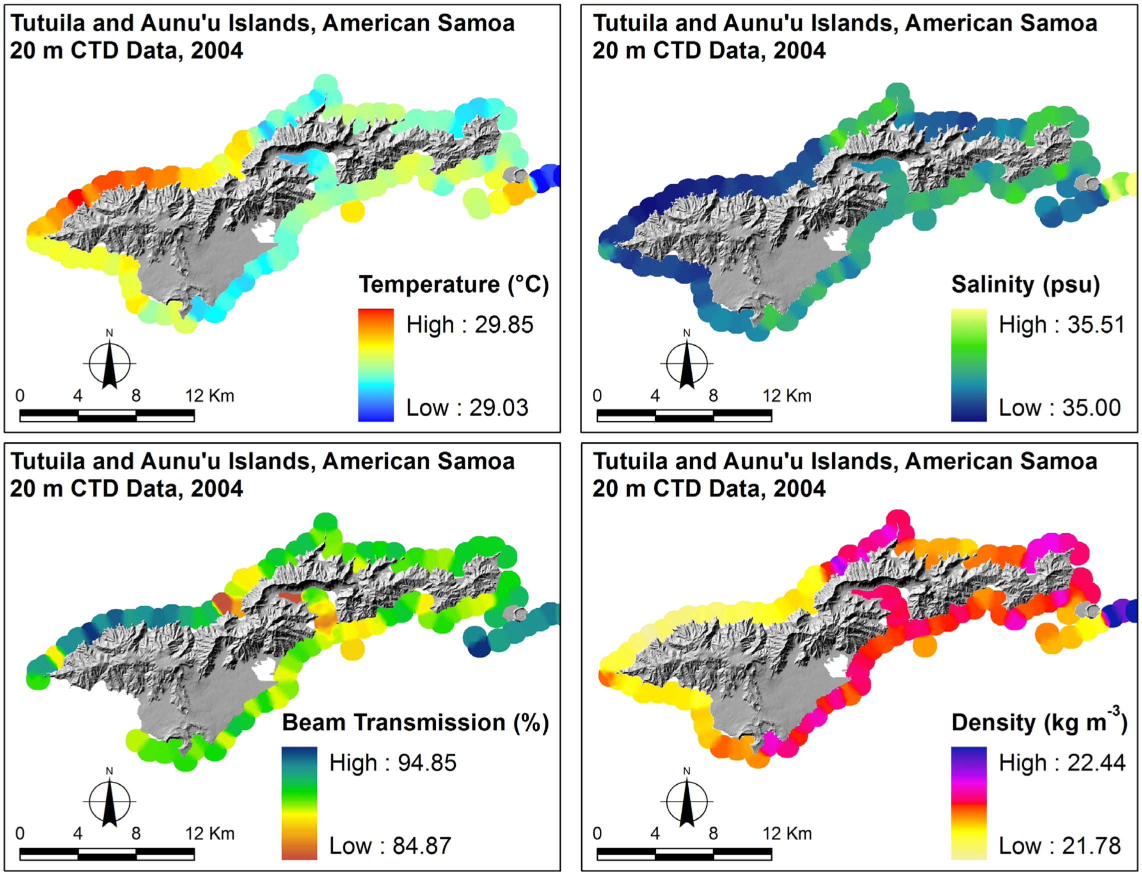

Figure 3.4.1f. Interpolated water temperature (top left), salinity (top right), beam transmission (bottom left) and density (bottom right) at a 20-m depth derived from shallow-water CTD casts around Tutuila and Aunu`u during ASRAMP 2004, February 19–25.

Pago Harbor on the south side and in Fagasa Bay in the north region.

2006 Spatial Surveys

During ASRAMP 2006, 113 evenly spaced shallow-water CTD casts were conducted in nearshore waters surrounding Tutuila and Aunu`u over the February 18–26 period (Fig. 3.4.1g). In addition, water samples for nutrient and chlorophyll-a analyses were collected at water depths of 1, 10, 20, and 30 m, where possible, at 33 of the 113 shallow CTD sites. Dissolved inorganic carbon (DIC) samples were collected at 16 of these sites.

Vertical profiles of temperature, salinity, density, and beam transmission around Tutuila and Aunu`u during ASRAMP 2006 found significant spatial patterns (Fig. 3.4.1h). The most striking feature from these observations was a clear pattern of three distinct and different oceanographic regions. The north coast, all the way from Cape Taputapu at the west end to Cape Matatula at the northeast end (A–E), was characterized by warm (~ 29.5°C), saline, moderately well-stratified (particularly temperature), and relatively turbid waters. The east coast, from Cape Matatula to Aunu`u (E–G) was characterized by colder (~ 28.5°C), less saline, well-mixed, and clear waters. The south coast, from southeast region to Cape Taputapu, was characterized by cooler, fresher, well-stratified, mostly clear waters. There was a strong (1–1.5°C), water column-deep (0–30 m), temperature gradient between the north and south at the eastern end of Tutuila (D–E). There was also an interesting tongue of high beam transmission (low turbidity), relatively warm, low salinity, low density water observed offshore near Pala Lagoon (Fig. 3.4.1i). This was possibly a result of river and estuarine outflow from Pago Pago Harbor (G–H). Density distribution around the islands was largely uniform, with the exception of this same region (G–I). The position of this tongue of low salinity water relative to the inlet suggests that currents on the south shore were traveling east to west during this period. This is consistent with the direction of the southeast trade winds in the region. Beam transmission was generally high (> 90%) around the islands. The highest beam transmission was observed between positions E and F, in the region of the largest temperature gradient, near the eastern tip of Tutuila.

The spatial patterns of observed physical water properties around Tutuila and Aunu`u at a 20-m depth during ASRAMP 2006 reveal generally warmer waters on the north side of Tutuila (~ 28.88°C) and cooler waters (~ 28.43°C) on the south side, particularly offshore of Aunu`u Island (Fig. 3.4.1i). Patterns from the salinity observations tend to parallel temperature; waters were generally more saline (~ 34.87 psu) on the north side and less saline (~ 34.50 psu) on the south side, particularly in and around Pago Pago Harbor. Density was lowest (21.80 kg m^{-3}) near Pago Pago Harbor, while beam transmission values were low around much of the island.

Water quality, as deduced by the laboratory analyses of key nutrients from the in situ water samples collected at a 20-m depth around Tutuila and Aunu`u during ASRAMP 2006, was

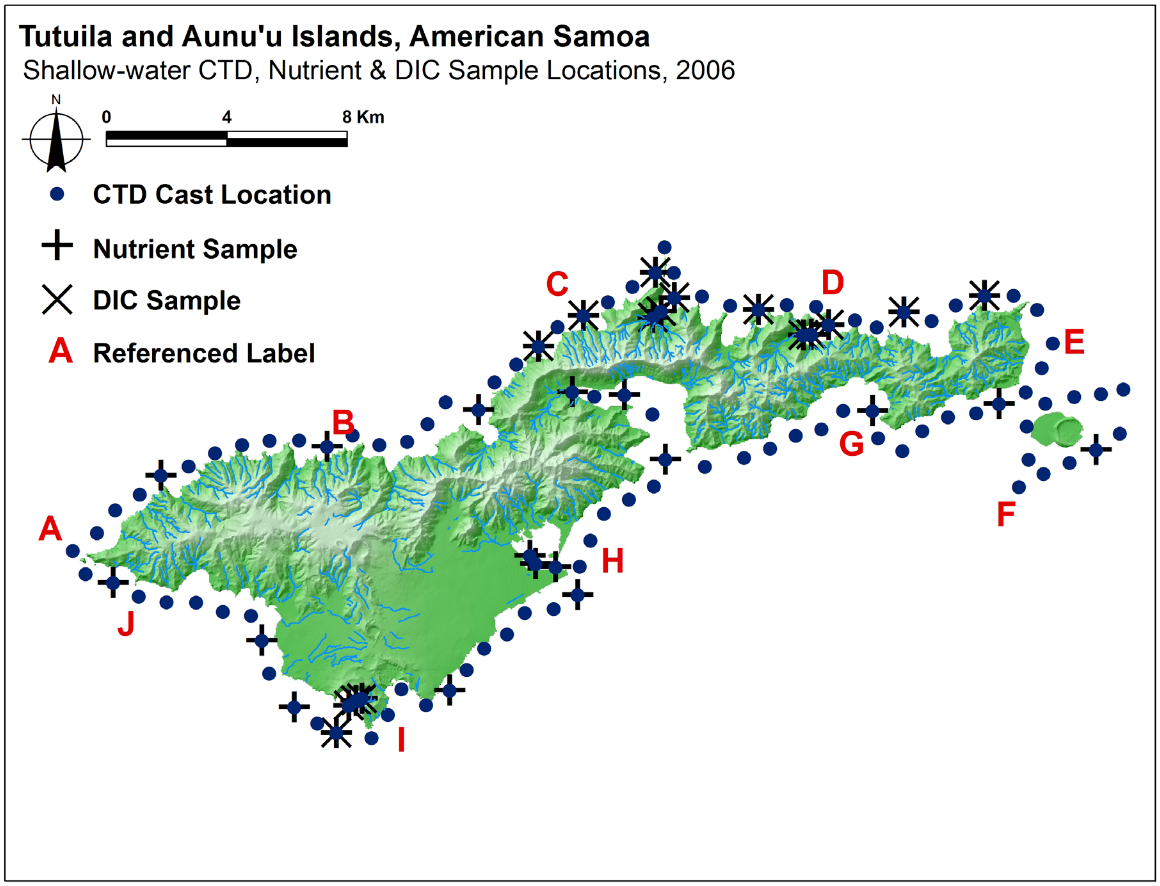

Figure 3.4.1g. Shallow-water CTD cast, nutrient and dissolved inorganic carbon (DIC) water sample locations around Tutuila and Aunu`u (A–J) during ASRAMP 2006, February 18–26.

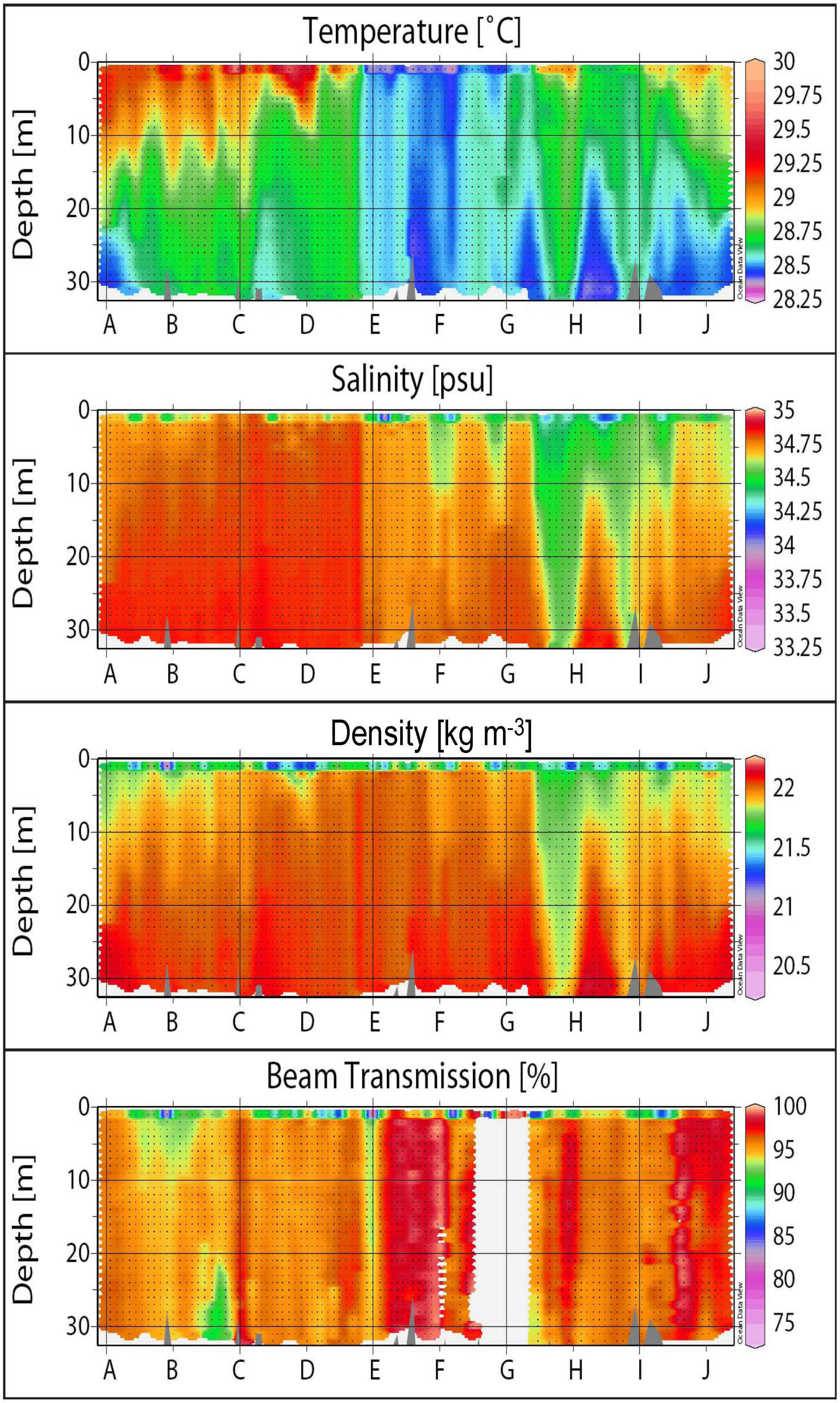

Figure 3.4.1h. Shallow-water CTD cast profiles to a 30-m depth around Tutuila and Aunu`u during ASRAMP 2006, February 18–26, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles are shown sequentially in a clockwise direction around the islands (A–J), as shown in Figure 3.4.1g.

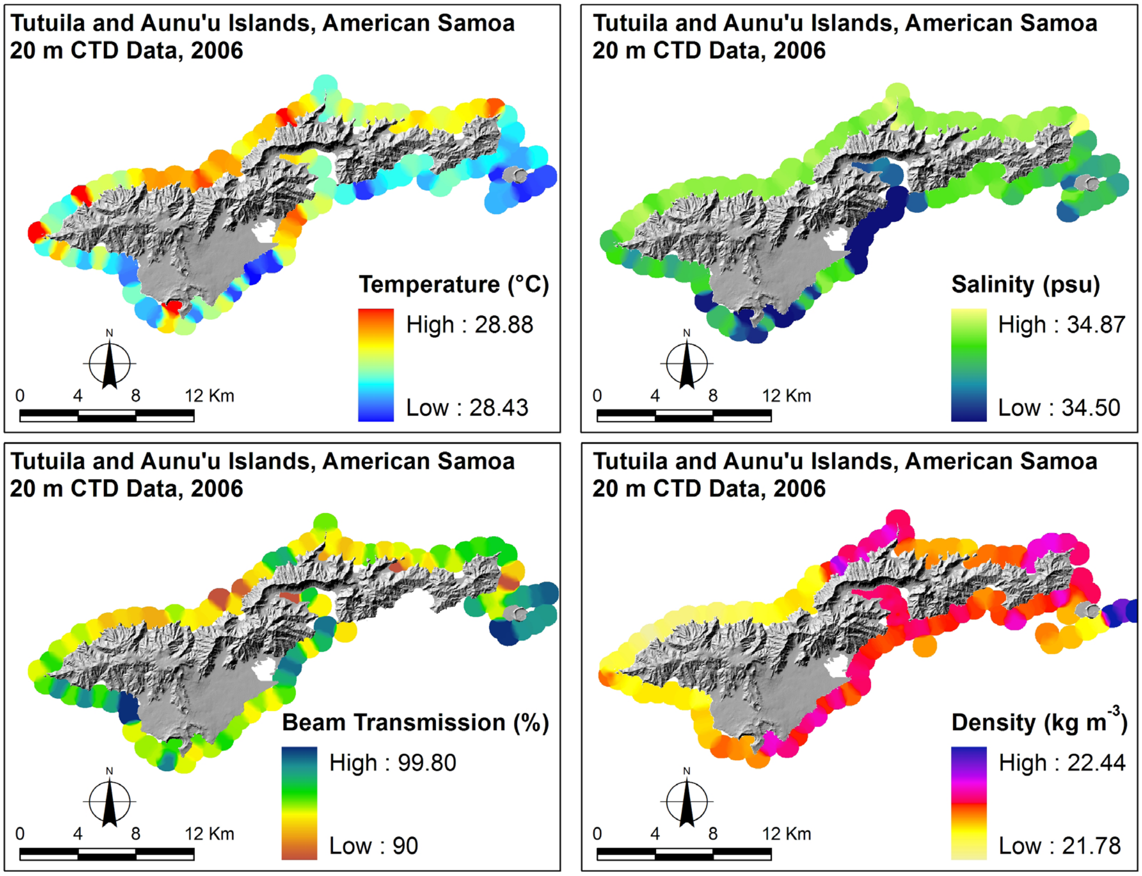

Figure 3.4.1i. Interpolated water temperature (top left), salinity (top right), beam transmission (bottom left), and density (bottom right) at a 20-m depth derived from shallow-water CTD casts around Tutuila and Aunu`u during ASRAMP 2006, February 18–26.

characterized by interesting spatial patterns (Fig. 3.4.1j). The following ranges in water quality parameters were observed around the islands: chlorophyll-a, 0.43–1.66 µg l^{-1}; phosphate (PO_4), 0.09–0.17 µM; silicate (SiO_2), 0.54–2.21 µM; and total nitrogen ($N_{tot} = NO_3 + NO_{2-}$), 0.01–0.48 µM. Nitrogen concentrations on the north side of Tutuila exhibited spatial homogeneity while chlorophyll-a, phosphate, and silicate showed higher spatial variability. Constituent concentrations in the south and southwest regions were more variable spatially, with the highest levels measured in Pago Pago Harbor. It is likely that the relatively high nutrient concentrations observed around parts of the island, such as those visible in the Pago Pago Harbor region, can be attributed to terrestrial runoff.

The rain gauge at the Pago Pago International Airport showed that Tutuila received in excess of 1.5 m of precipitation over the period of January through March 2006, representing the highest 3 month mean rainfall during the 6-year record shown (Fig. 3.4.3d). The substantial amounts of rainfall during the ASRAMP 2006 survey period likely increased suspended sediment, caused reduction in salinity and temperature, and affected nutrient and chlorophyll concentrations in the water column, particularly near waters around Pago Pago Harbor.

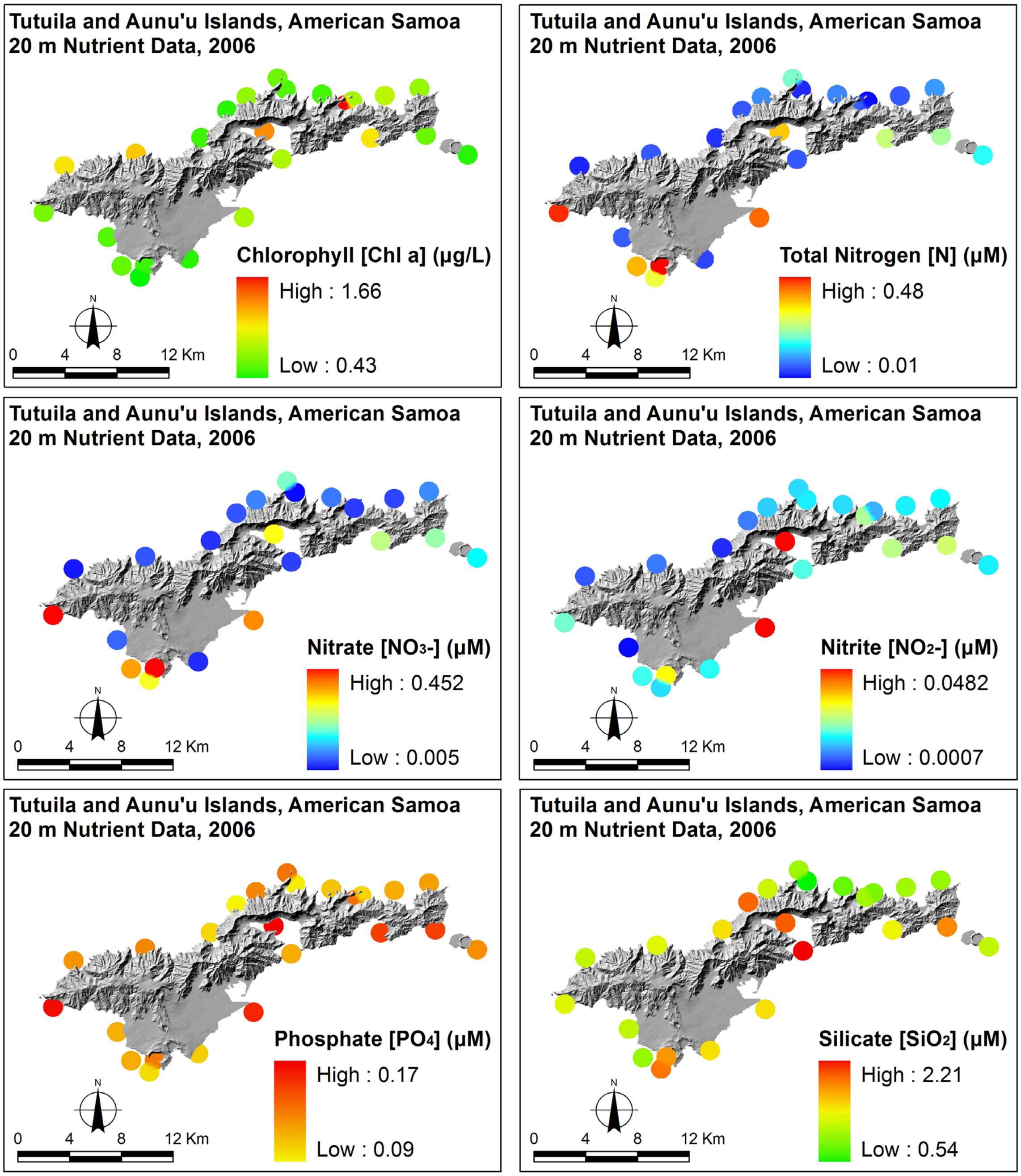

Figure 3.4.1j. Interpolated chlorophyll-a (top left), total nitrogen (top right), nitrate (middle left), nitrite (middle right), phosphate (bottom left) and silicate (bottom right) concentrations, at a 20-m depth derived from water samples collected in concert with shallow-water CTD casts around Tutuila and Aunu`u during ASRAMP 2006, February 18–26.

3.4.2 Temporal Comparison—Hydrographic Data

Nearshore CTD and water quality observations during the ASRAMP surveys in 2002, 2004, and 2006 exhibited noteworthy spatial patterns and temporal differences of survey years. Temperature values varied marginally between survey periods. Salinity showed a north-south, negative gradient in 2002 and 2004 and a positive (low–high) gradient in 2006. A substantial decrease in salinity occurred in 2006 compared to the previous surveys as a result of the record-setting rainfall which coincided with the ASRAMP 2006 survey period. Density values in each of the datasets paralleled salinity rather than temperature. Beam transmission measurements during 2004 and 2006 were low in Fagatele Bay and in Pago Pago Harbor, implying high terrigenous input in these areas. The substantial rainfall that occurred during the 2006 survey period increased the levels of terrestrial runoff into the coral reef ecosystem and likely impacted water quality data. These results will serve as a baseline to compare future nutrient datasets.

3.4.3 Time Series Observations

A suite of moored instruments was deployed around Tutuila and Aunu`u over the 2002–2006 period to collect time series observations of key oceanographic properties influencing reef conditions (Fig. 3.4.3a). Deployment and retrieval dates and time durations of each instrument are detailed Appendix II, Table II.i. Figure 3.4.3b shows a time series of in situ and remotely sensed SST and modeled wave properties from January 2002 to April 2006.

Pathfinder SST and in situ temperature observations around Tutuila show a strong seasonal cycle superposed with moderate intraseasonal and interannual variability. In general, the warmest surface temperatures (~ 30.2°C) were observed during January–March and the coolest temperatures (~ 27.5°C) during June–August (Fig. 3.4.3b, top panel). Over the entire period, Pathfinder-derived SST followed the climatological record relatively closely, with deviations of ~ 0.5–1.0°C. In contrast, all in situ observations from moored instruments, particularly at Fagasa Bay in the north region, indicated warmer temperatures than the

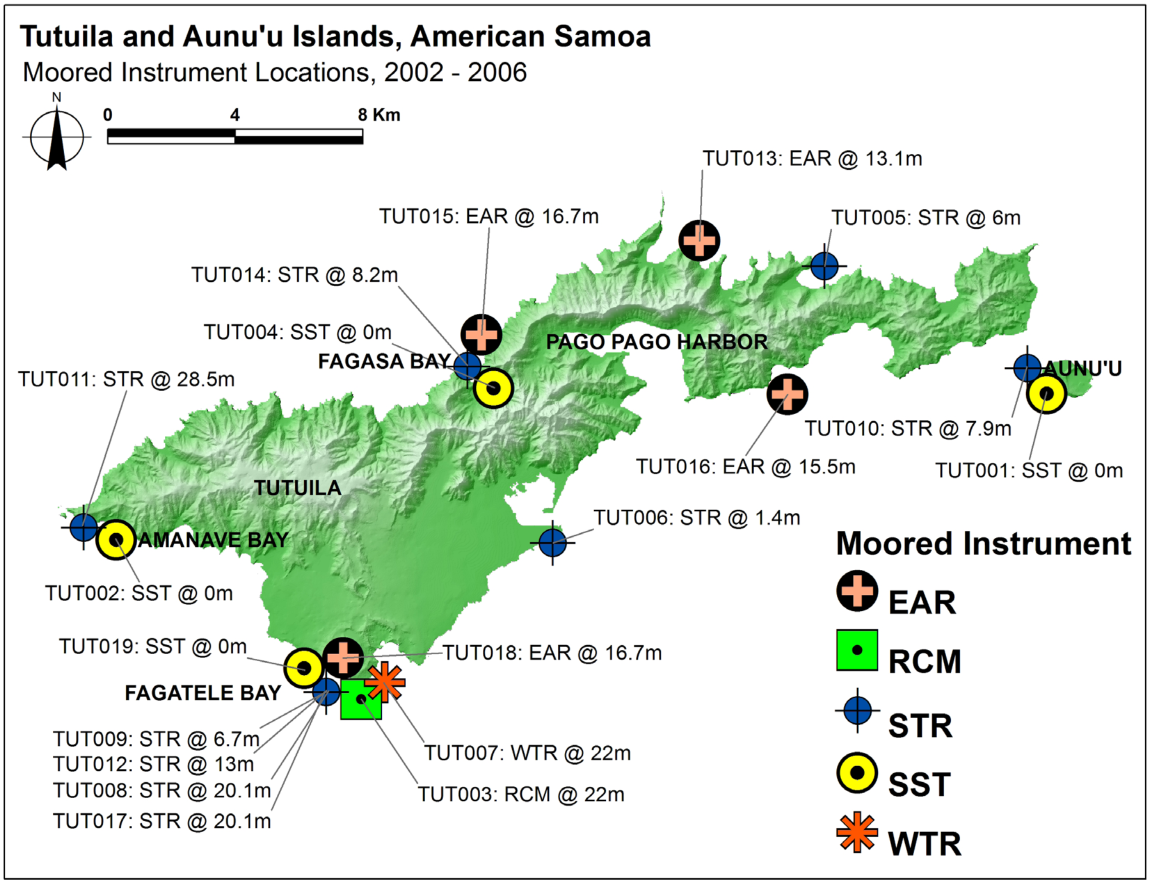

Figure 3.4.3a. Locations and types of oceanographic instrument moorings deployed around Tutuila and Aunu`u between 2002 and 2006. Moored instrument types include: EAR, RCM, STR, SST buoy, and WTR.

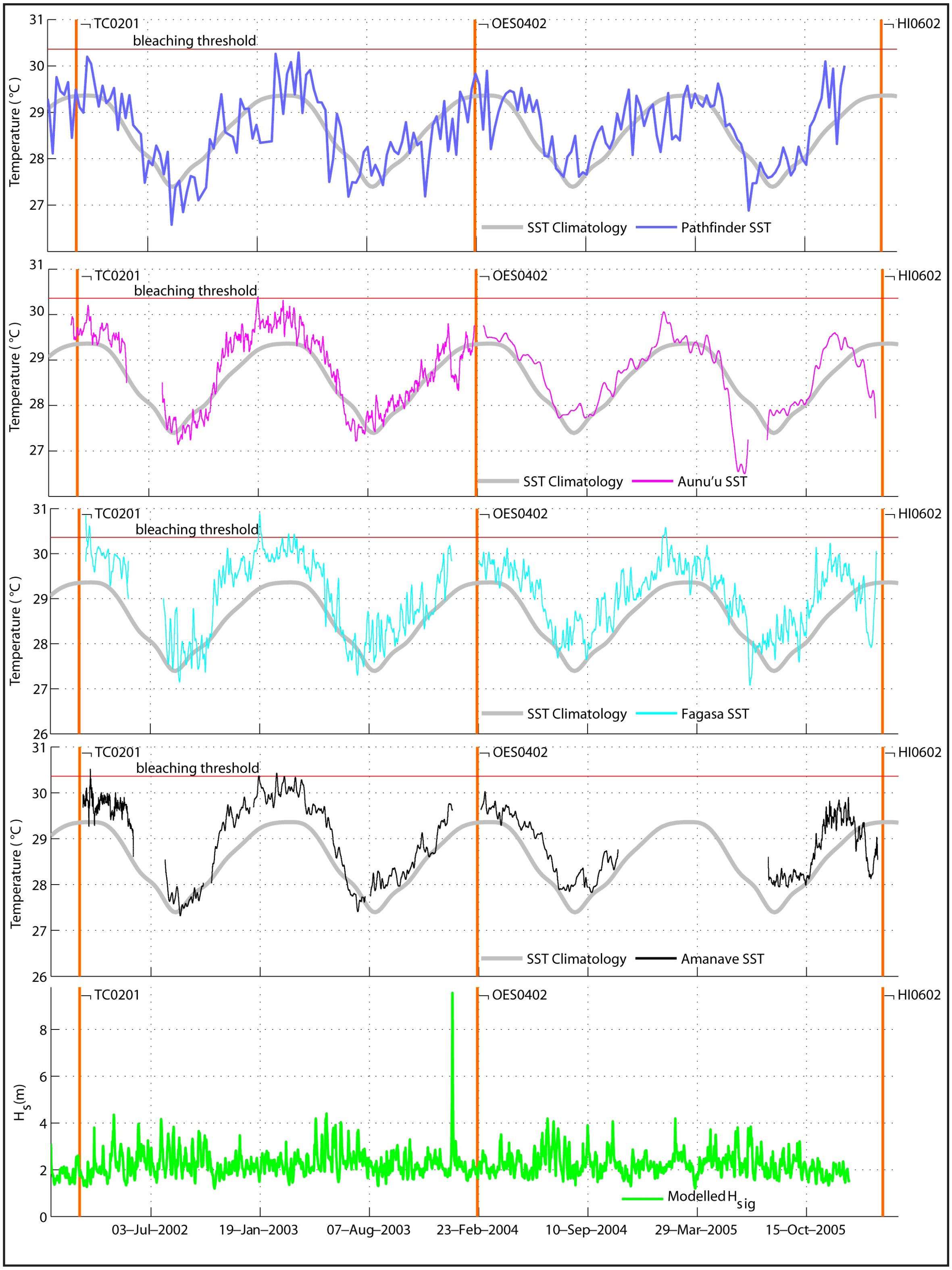

Figure 3.4.3b. SST and wave height time series around Tutuila and Aunu`u between January 2002 and April 2006. Remotely sensed data (SST Climatology and weekly Pathfinder-derived SST) and modeled significant wave-height data derived from Wave Watch III are overlaid with CRED in situ temperature observations from Aunu`u Island, Fagasa Bay, and Amanave Bay (locations shown in Fig. 3.4.3a). The horizontal red and vertical orange bars represent the bleaching threshold and the ASRAMP research cruise dates, respectively. In situ (15-min sampling frequency) and telemetered temperature data (4-hour mean) were used to produce the Aunu`u and Amanave time-series.

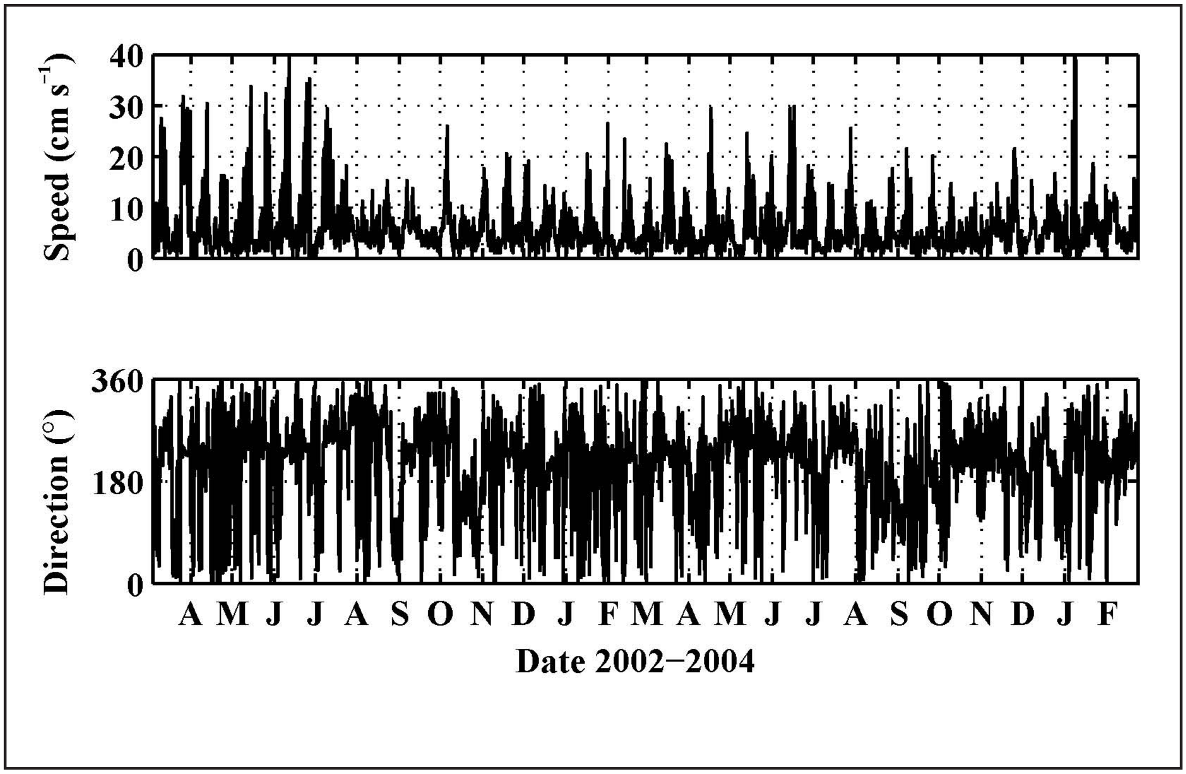

Figure 3.4.3c. Data from an Aanderaa RCM9 current meter deployed at a 22-m depth off Steps Point (TUT003), from March 2002 to February 2004. Top panel: Current speed (cm s^{-1}). Bottom panel: direction (^{0} from north).

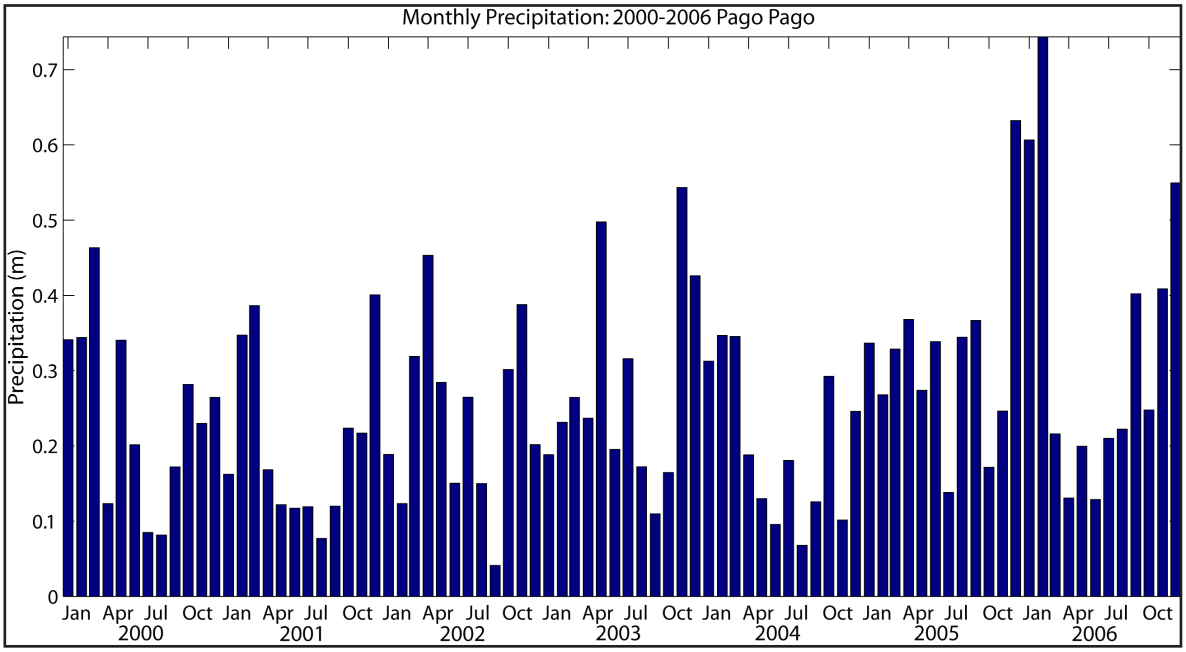

Figure 3.4.3d. Average monthly rainfall from Pago Pago International Airport from January 2000 to December 2006 (SOURCE: National Weather Service, Honolulu, Hawaii: http://www.prh.noaa.gov/hnl/). Note the unusually high rainfall during the ASRAMP 2006 survey period in February.

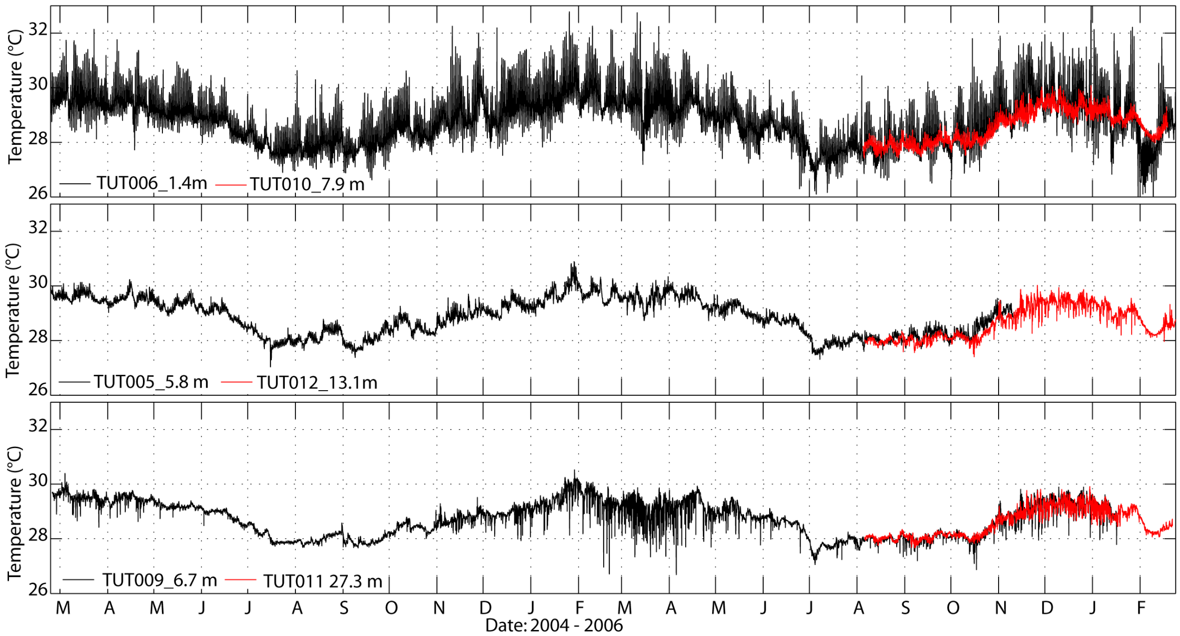

Figure 3.4.3e. Time series observations of temperature from March 2004 to February 2006 collected from six STRs deployed at different locations and depths around Tutuila. See Figure 3.4.3a for mooring locations.

climatological mean with periodic temperature drops. Warm temperatures were observed in each of the moored instrument temperature datasets during the austral summer of 2002–2003. Maximum observed temperatures at Fagasa Bay reached 1.5°C above the climatological mean (0.5°C degree above the bleaching threshold). In situ observations and Pathfinder SST at Aunu`u were anomalously cooler (~ 1.5°C and ~ 1.0°C, respectively) than climatological values during June 2005.

Modeled significant wave-height data for Tutuila shows weak seasonal variation superposed with episodic, cyclone-induced extreme wave events. Large wave heights (> 3 m) typically occurred during winter months compared to smaller wave heights (~ 2 m) during the summer months. One extreme swell event (> 8 m), produced by tropical cyclone Heta, was observed in January 2004 (Fig. 3.4.3b, bottom panel).

An Aanderaa RCM9 current meter was deployed in 22 m of water off Step's Point, on the southernmost point of Tutuila (TUT003) in the south point region. The objective of this 2-year deployment was to determine current flow in the region. The median current direction at Step's Point was ~ 230°, indicating south-westward flow (Fig. 3.4.3.c). Mean current speed was ~ 5 cm s^{-1} with strong diurnal tidal forcing. The westward skew of the observations suggests that wind forcing from the east is a possible contributor to the flow regime (Fig. 3.4.3c). The prevailing wind conditions and currents measured during the deployment suggest that water movement along the south shore of Tutuila was generally east to west.

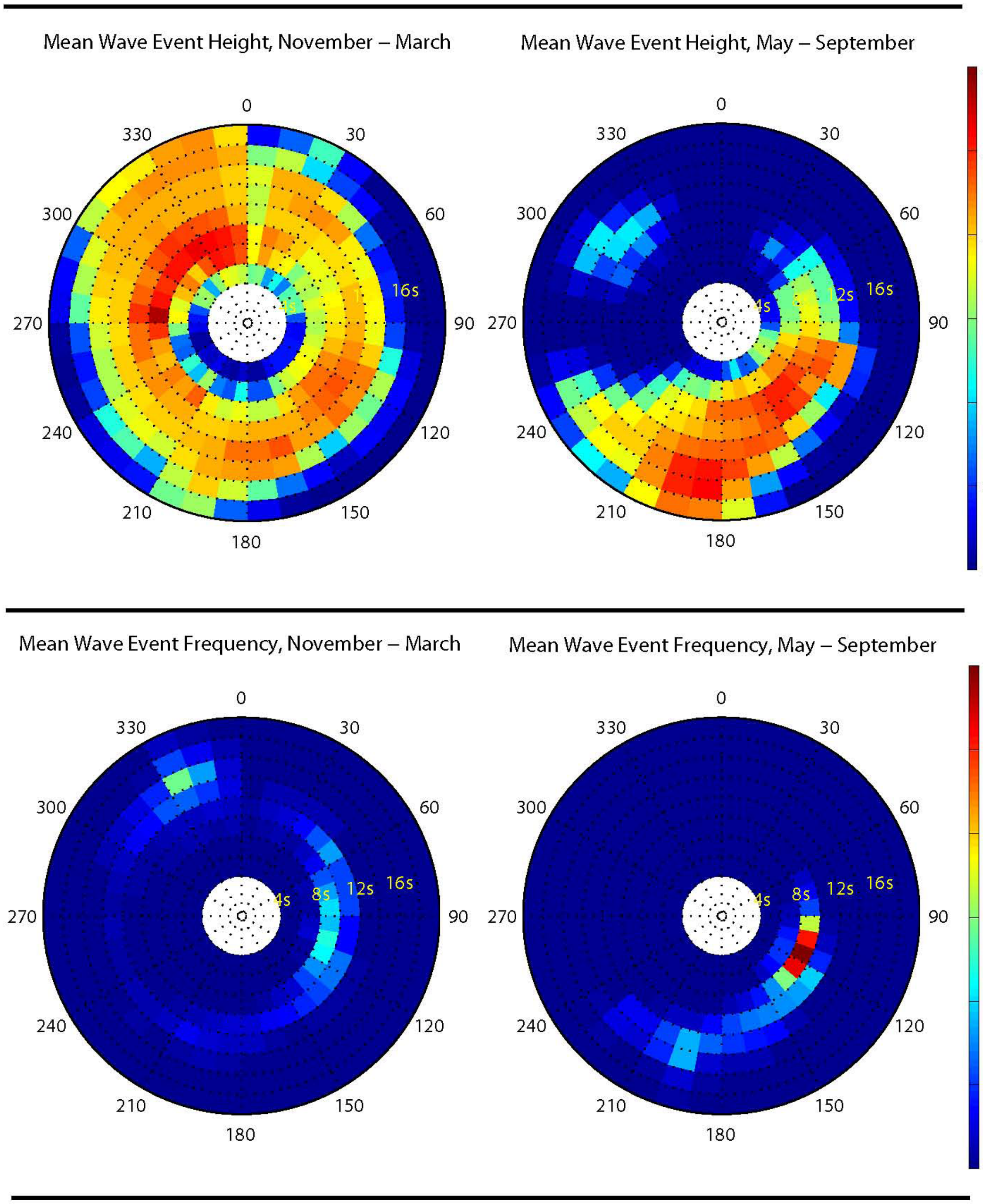

Figure 3.4.3f. NOAA Wave Watch III directional wave climatology for American Samoa from January 1, 1997 and April 1, 2007. The climatology was created by binning (six times daily) significant wave height, dominant period, and dominant direction from a 1° × 1° box centered on the Manu`a group (14.2° S, - 169.5° W). Top panel: mean significant wave height for all observations in each directional/frequency bin from November to March and from May to September. The months of April and October, transition months, are omitted for clarity. Bottom panel: mean number of days conditions in each directional/frequency bin occur in each season; e.g., if the color indicates 30, then, on average, the condition occurs on 30 out of 150 days each season (or 30 out of 365 days each year).

3.4.4 Bioacoustic Observations

In 2006, four EARs were deployed in nearshore waters around Tutuila (Appendix II, Table II.I.i). Two EARs were located in the National Park of American Samoa in the north region, while the remaining two were deployed in Fagatele Bay National Marine Sanctuary in the south point region and in Alega Bay in the southeast region (Figs. 3.4.4a and 3.4.4b). These units were programmed to record ambient sounds at frequencies up to 12.5 kHz for 30 seconds every 15 minutes and set to activate on vessel generated sounds. To date, only preliminary data exist from the EAR deployed at the eastern end of the National Park of American Samoa because it was recovered for preventative maintenance (and replaced) after only 7 weeks of data collection.

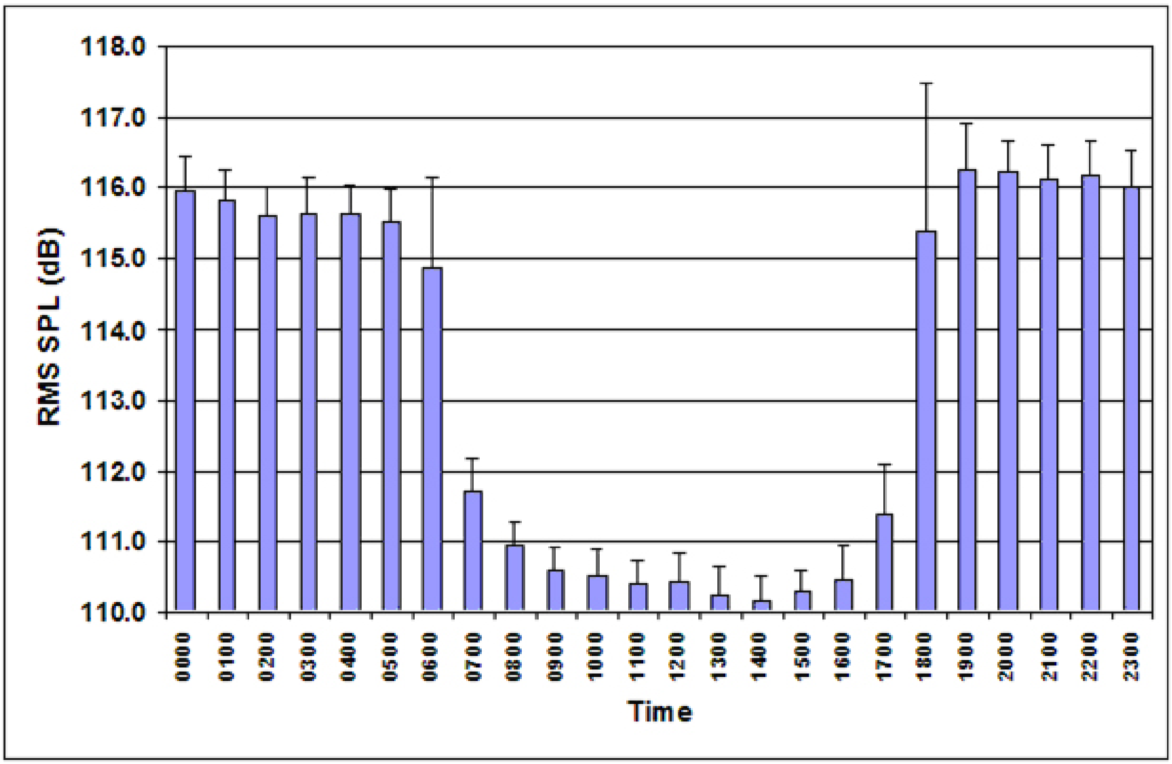

Figure 3.4.4a. Hourly averaged acoustic energy over the 7-week period from an EAR deployed in the National Park of American Samoa. Dominant sounds were produced by snapping shrimp.

The EAR recovered from the National Park of American Samoa contained sounds from a variety of sources, including fish, snapping shrimp, whales, rain showers, and vessels. The predominant sound was produced by snapping shrimp, which had a distinct diel pattern with higher levels occurring at night than during the day (Fig. 3.4.4a). This diel pattern is significant because there is nearly a doubling of acoustic energy (6 dB difference) between noon and midnight.

Snapping shrimp exhibited longer-term patterns of acoustic variability. Over the 7-week deployment period, a distinct periodicity was observed in the nighttime levels examined. This periodicity appears to be correlated with the lunar cycle, with higher levels occurring during the new moon and lower levels during the full moon (Fig. 3.4.4b). Both the diurnal and lunar cycles indicate that snapping shrimp produce significantly more sound during periods of increased darkness.

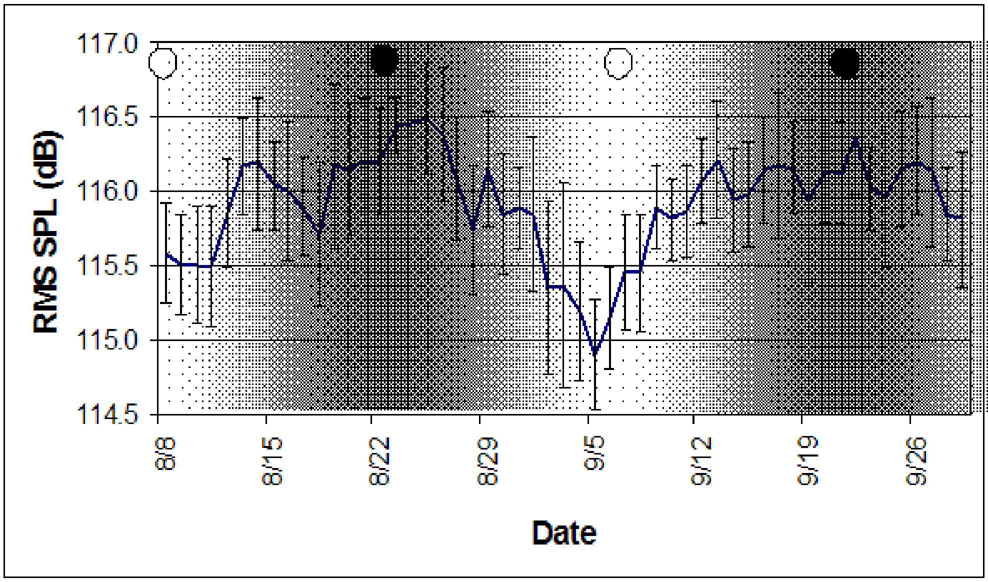

Figure 3.4.4b. Periodicity in the nighttime acoustic energy produced by snapping shrimp during the EAR deployment period superimposed by the lunar cycle. The shaded circle and darker-shaded sections of the graph signify a new moon and increased nighttime darkness, while the open-white circle and lighter areas signify a full moon and increased nighttime luminosity.

The EAR's vessel detection trigger was activated 34 times during the deployment period, providing a minimum estimate of vessel traffic that occurred in the area. This is a minimum estimate because vessels transiting farther away may not have produced enough acoustic energy at the unit to trigger it to record. Of interest is the timing of the vessel traffic that was observed. The majority of vessel detections (23/35–65.7%) occurred during periods of dusk or nighttime between 1800 hr and 0600 hr (Fig. 3.4.4c).

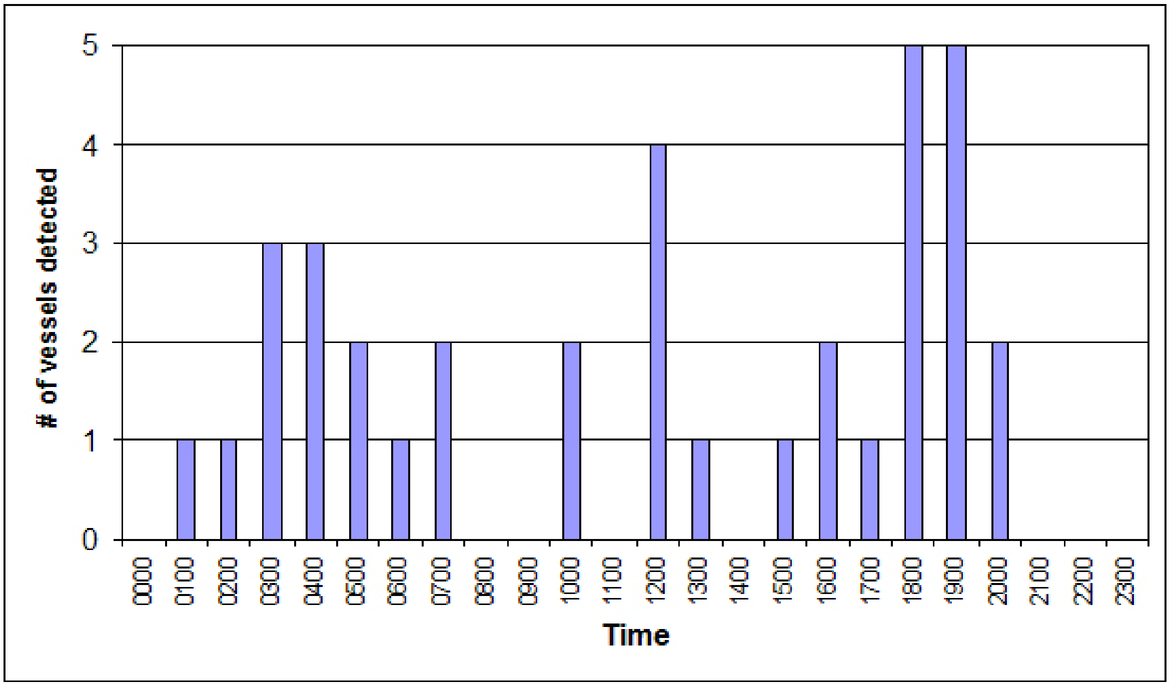

Figure 3.4.4c. The number of vessels detected during a 7-week record from an EAR deployed in the National Park of American Samoa during each hour of the day.

3.5 Coral and Coral Disease

3.5.1 Coral Surveys

2002 Spatial Surveys

Sixteen towed-diver surveys were conducted along the forereef slopes of Tutuila during ASRAMP 2002 (Fig. 3.5.1a), with a mean depth of 10.5 m (SD 3); individual tow tracks varied in depth from 8 m (SD 3) to 14 m (SD 3). An island-wide mean of live scleractinian (stony) coral percent cover of 28.9% (SE 2.5) was observed (Fig. 3.5.1b). The island-wide mean dead coral percent cover was 2.3% (SE 0.8), which was assessed as an independent component of the benthic habitat (Fig. 3.5.1c).

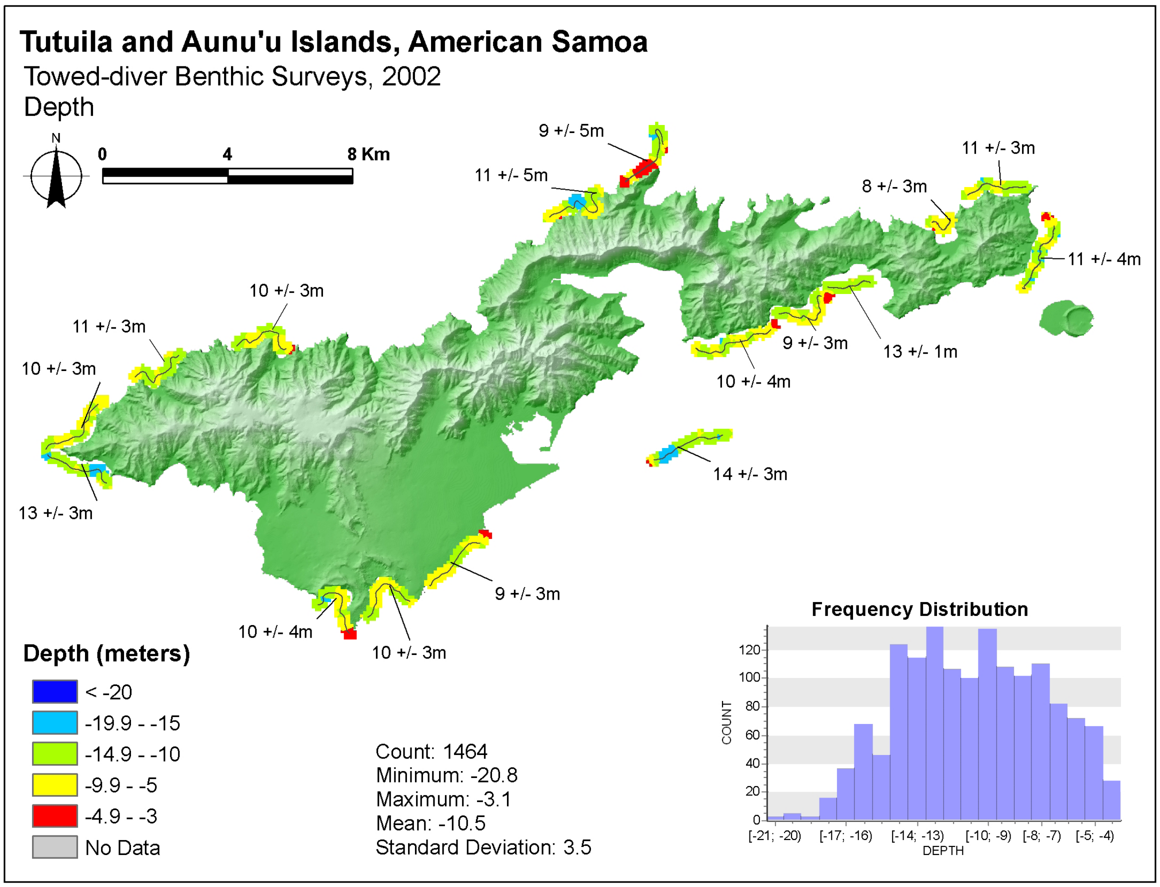

Figure 3.5.1a. Towed-diver survey tracks around Tutuila and Aunu`u during ASRAMP 2002. Towed-diver survey tracks are color coded with mean depths for each 5-min segment. Mean depths and standard deviations for each towed-diver survey are shown in black text. Depth histogram and statistics (counts, minimum depth, maximum depth, mean, and standard deviation) from 30-sec depth recordings during towed-diver surveys are included.

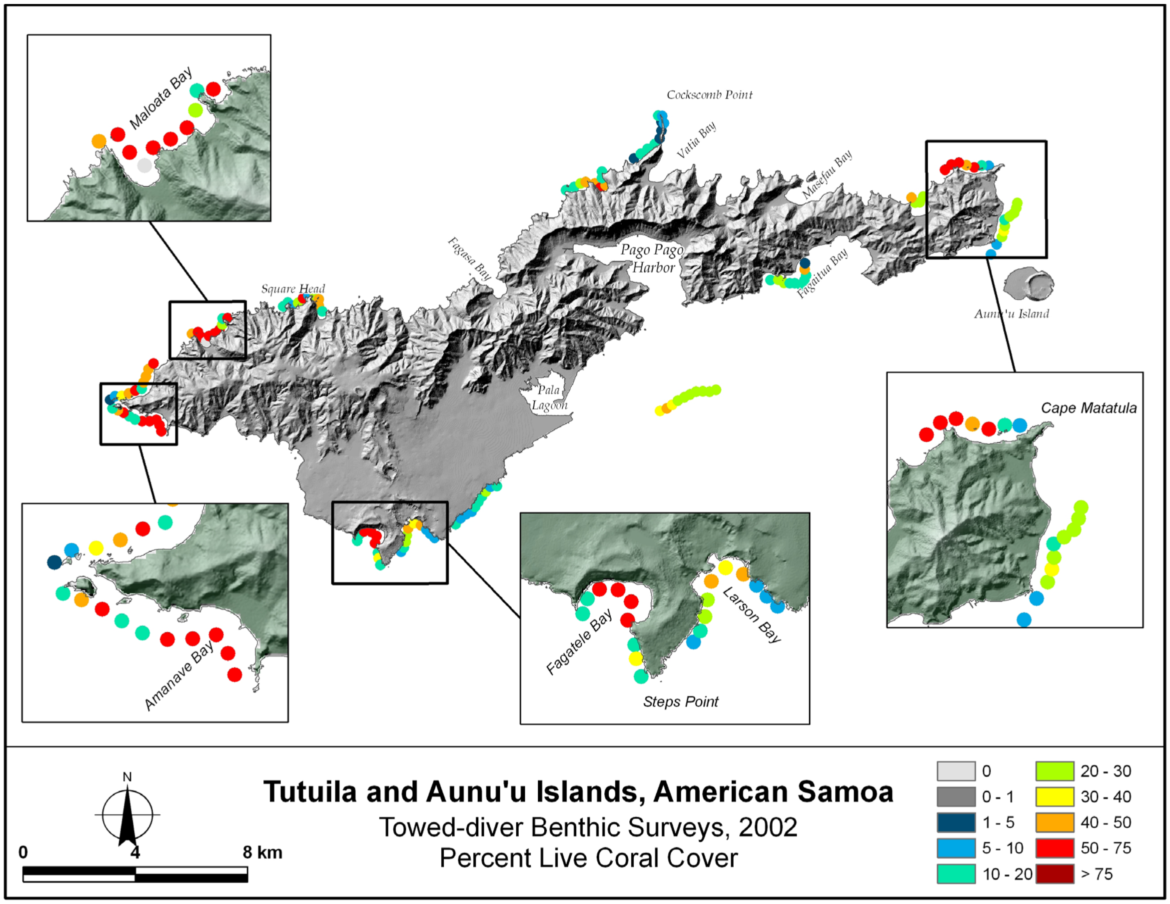

Figure 3.5.1b. Towed-diver benthic survey observations of live scleractinian (stony) coral cover around Tutuila during ASRAMP 2002. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2). Symbol size represents the percent live coral cover on the benthic habitat. Note that coral cover was measured as a direct percentage of overall benthic cover in 2002.

Although representing only a small fraction of the total reef area around Tutuila (~ 20% of the coastline was surveyed), the areas of highest live coral cover observed during the towed-diver surveys were in Fagatele Bay (4 tow segments; mean: 57.5%), Amanave Bay (5 tow segments; mean: 60.0%), Maloata Bay in the northwest region (7 tow segments; mean: 46.4%), and off Onenoa in the northeast region (5 tow segments; mean: 52.2%). Estimates of recently dead coral from the towed-diver surveys were highest in the areas over Taema Bank (7 tow segments; mean: 10.0%), off Alega Beach in the southeast region (3 tow segments; mean: 10.0%), and in Aoa Bay in the northeast region of Tutuila (3 tow segments; mean: 10.0%). Although the 2002 observations of recently dead coral do not indicate the cause of the mortality, the open exposure of Taema Bank to south swell suggests the possibility of wave energy damage, and the relatively closed circulation in Aoa and Alega Bays suggests the possibility of coral bleaching.

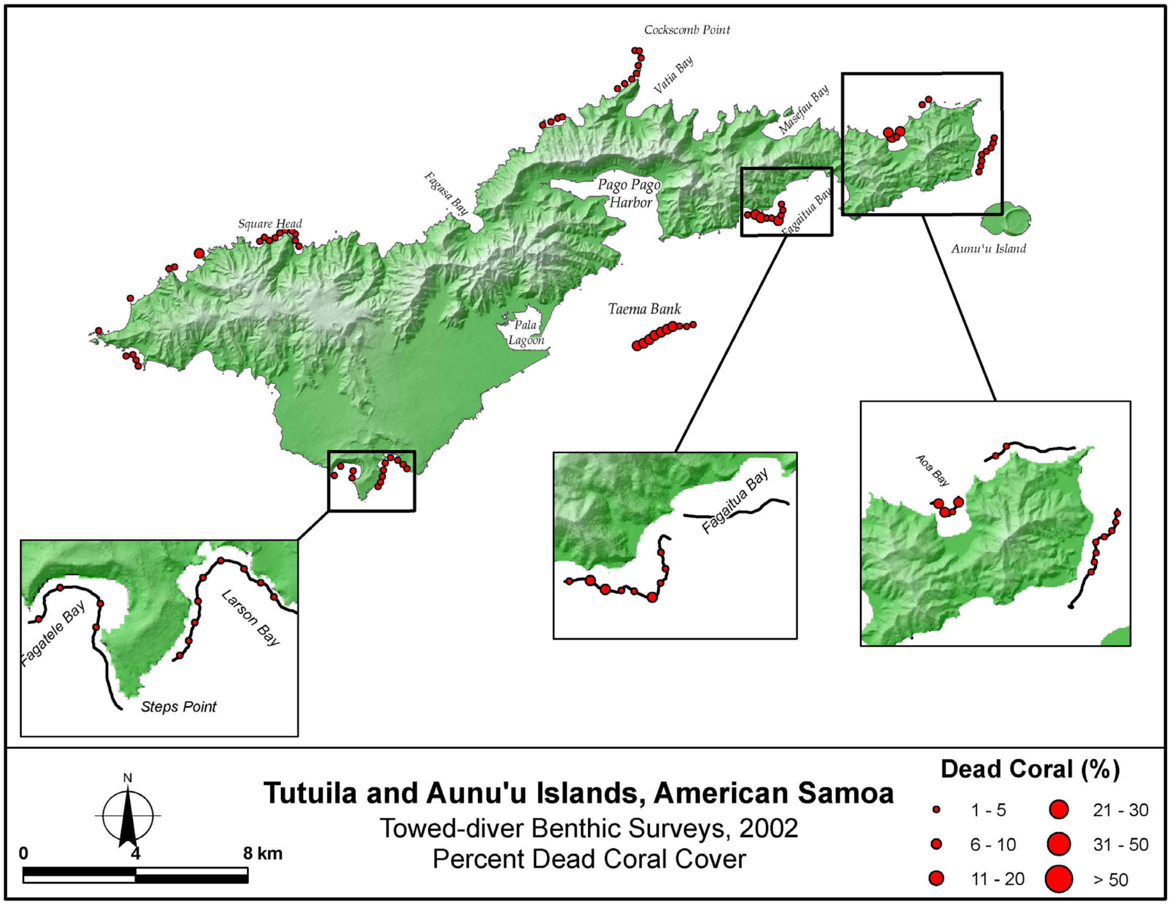

Figure 3.5.1c. Towed-diver benthic survey observations of dead coral cover around Tutuila during ASRAMP 2002. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2). Symbol size represents the percent dead coral cover on the benthic habitat.

ASRAMP REA coral surveys in 2002 were the first surveys conducted in American Samoa by CRED. Although five sites were surveyed around Tutuila by a CRED coral biologist, much of the focus of those surveys was to explore different coral monitoring methodologies. An additional nine sites were surveyed by a CRED partner who focused on expanding the coral species list for Tutuila. Since both of these survey efforts were exploratory and qualitative in nature, no data are presented in this more quantitative report.

2004 Spatial Surveys

A total of 43 towed-diver benthic surveys were conducted along the forereef slopes around most of Tutuila and Aunu`u during ASRAMP 2004 (Fig. 3.5.1d), with a mean depth of 12.1 m (SD 4.8); individual tow tracks varied in depth from 5 m (SD 2) to 21 m (SD 2). An island-wide mean percent live scleractinian coral cover of 20.9% (SE 1.1) was observed (Fig. 3.5.1e). It should be noted that the 2004 towed-diver surveys were generally conducted in deeper waters than during 2002 because of a change in NOAA diving safety protocols, allowing for the use of dive computers and hull-mounted fathometers. Generally, higher live coral cover was observed along the southern regions of Tutuila. Areas of the highest live coral cover were observed along the northern side of Aunu`u (4 tow segments; mean: 43.5%), west of Pago Pago Harbor near Niuloa Point (3 tow segments; mean: 55.0%), as well as numerous tow segments along the southern coast of Tutuila and within the sheltered portions of bays along the northeast region.

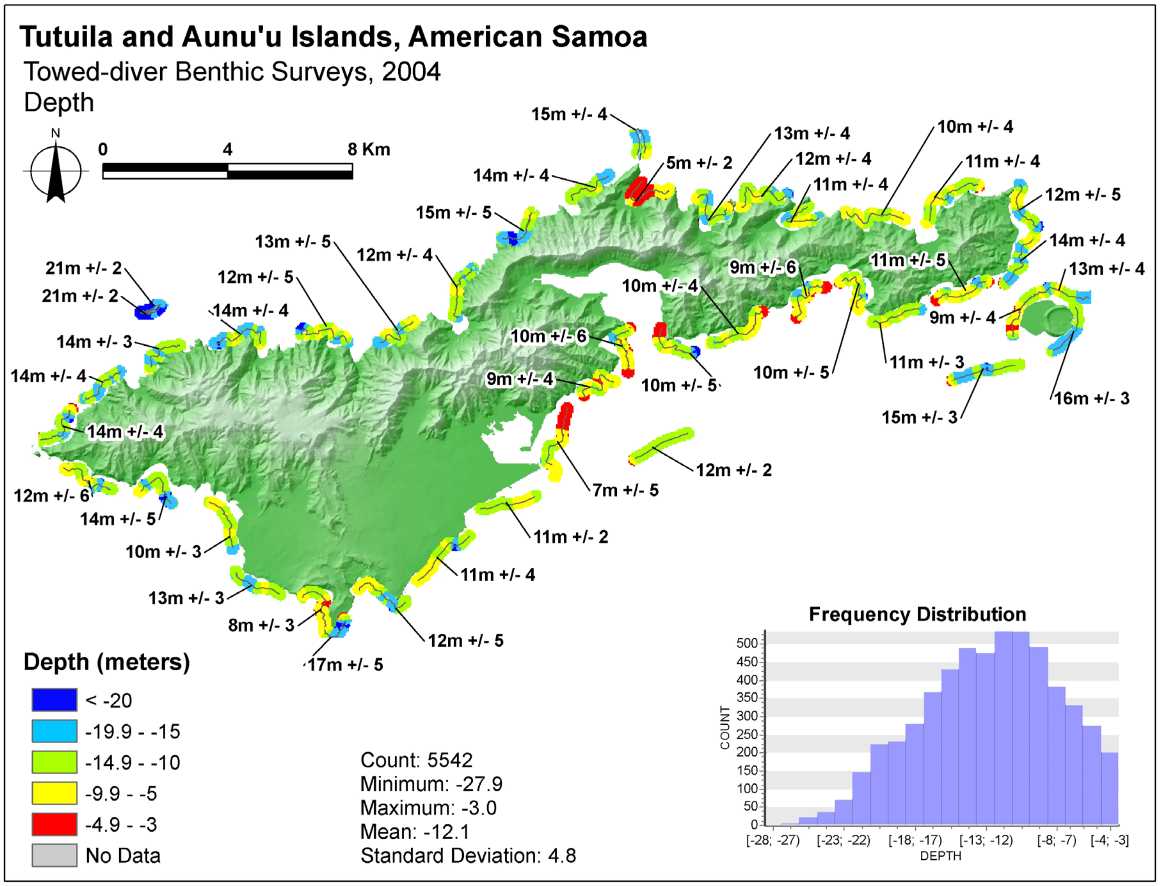

Figure 3.5.1d. Towed-diver survey tracks around Tutuila and Aunu`u during ASRAMP 2004. Towed-diver survey tracks are color coded with mean depths for each 5-min segment. Mean depths and standard deviations for each towed-diver survey are shown in black text. Depth histogram and statistics (counts, minimum depth, maximum depth, mean, and standard deviation) from 30-sec depth recordings during towed-diver surveys are included.

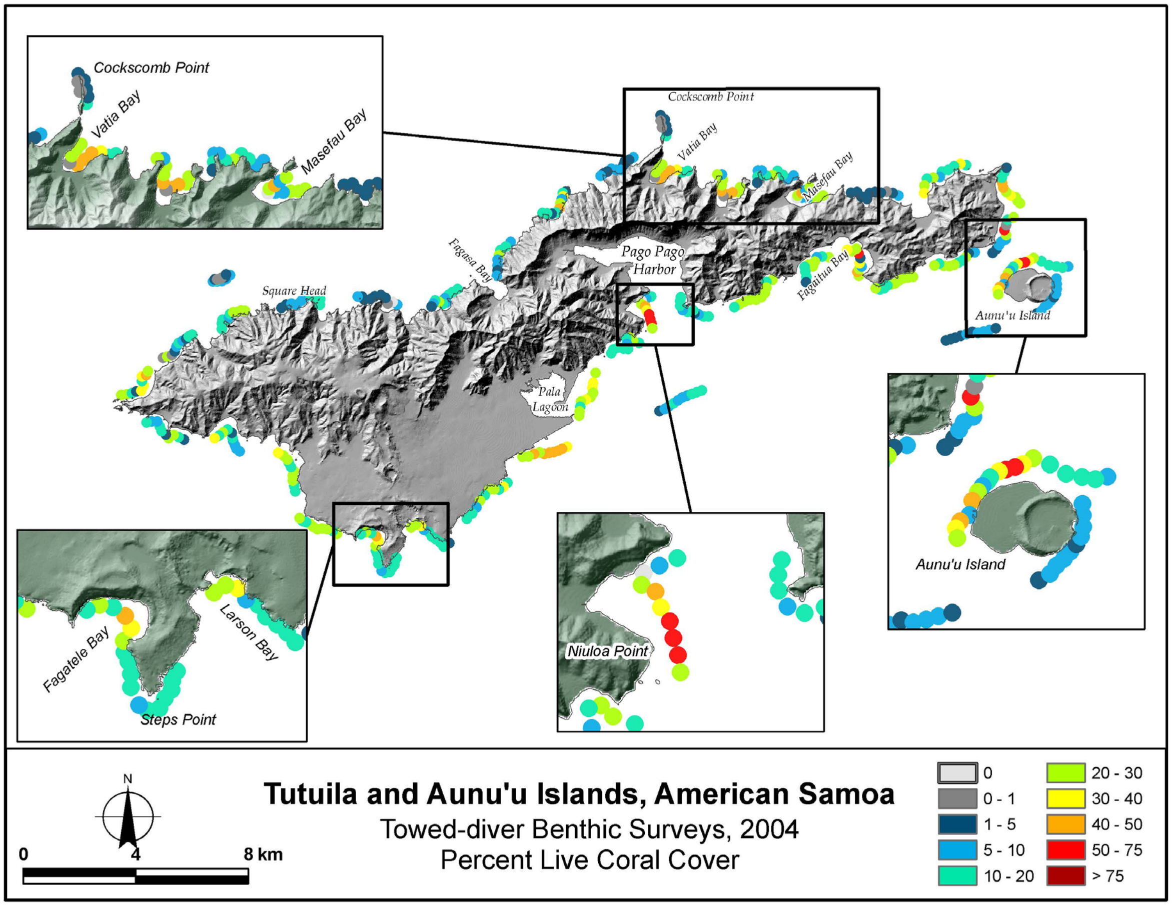

Figure 3.5.1e. Towed-diver benthic survey observations of live scleractinian (stony) coral cover around Tutuila and Aunu`u during ASRAMP 2004. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2). Symbol size represents the percent live coral cover on the benthic habitat.

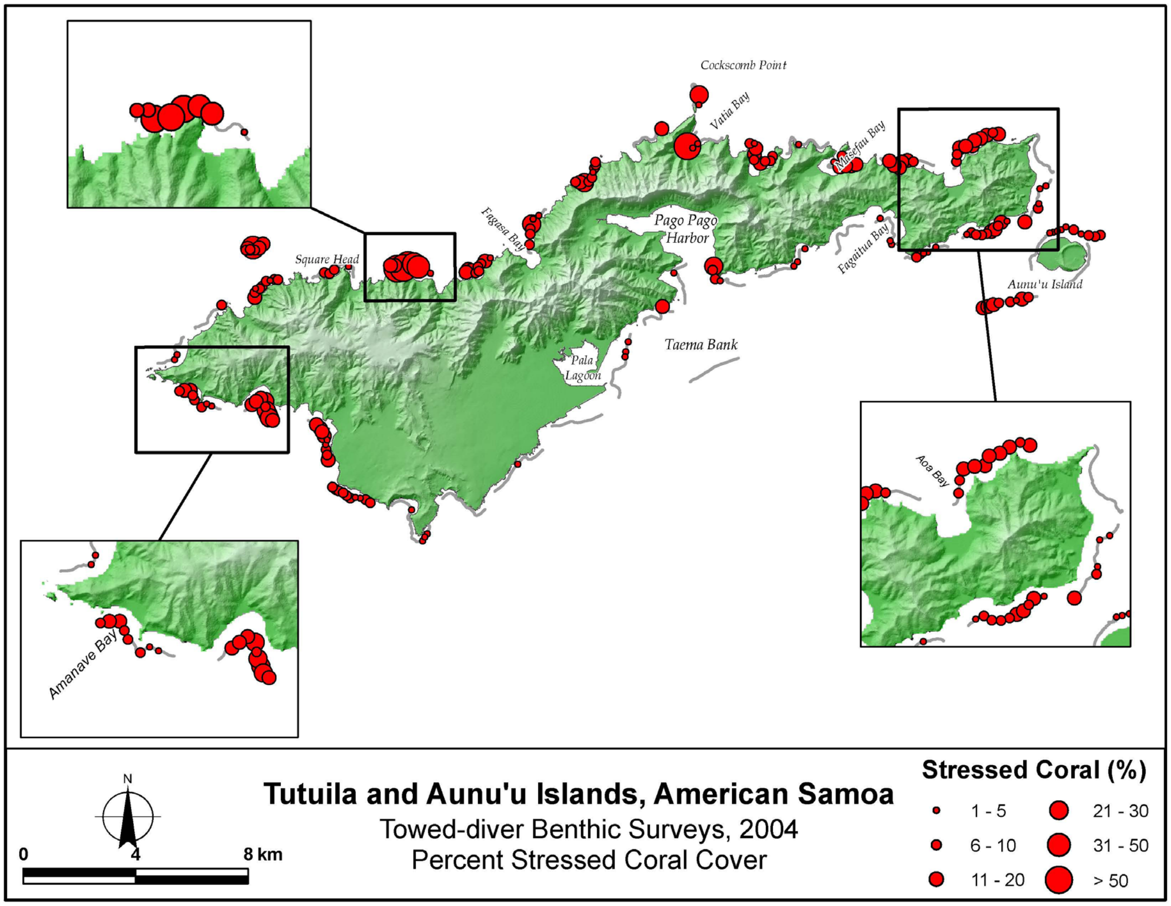

Figure 3.5.1f. Towed-diver benthic survey observations of stressed coral cover around Tutuila and Aunu`u during ASRAMP 2004. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2). Symbol size represents the percent of stressed coral cover of the total coral benthic coverage. Note that stressed coral cover was measured as a percentage of overall coral cover in 2004.

Rather than documenting recently dead coral, as was done during ASRAMP 2002 surveys, towed-diver surveys during ASRAMP 2004 recorded observations of stressed coral, which included fully bleached (white), pale or discolored, malformed or tumored corals (Fig. 3.5.1f). Overall, the mean of stressed coral cover estimates from towed-diver surveys around Tutuila and Aunu`u was 4.9% (SE 0.7). Relatively high estimates of coral stress were observed at numerous locations along the southwest, northwest, north, and northeast regions of Tutuila. Estimates of coral stress were generally low along the south and southeast regions, with one notable exception. A relatively high observation of coral stress (28%) was recorded during a tow segment just inside the Pago Pago Harbor entrance near Breaker Point. The highest percent coral stress (mean: 53.4%) was observed during 5 tow segments west of Massacre Bay within the northwest region of Tutuila.

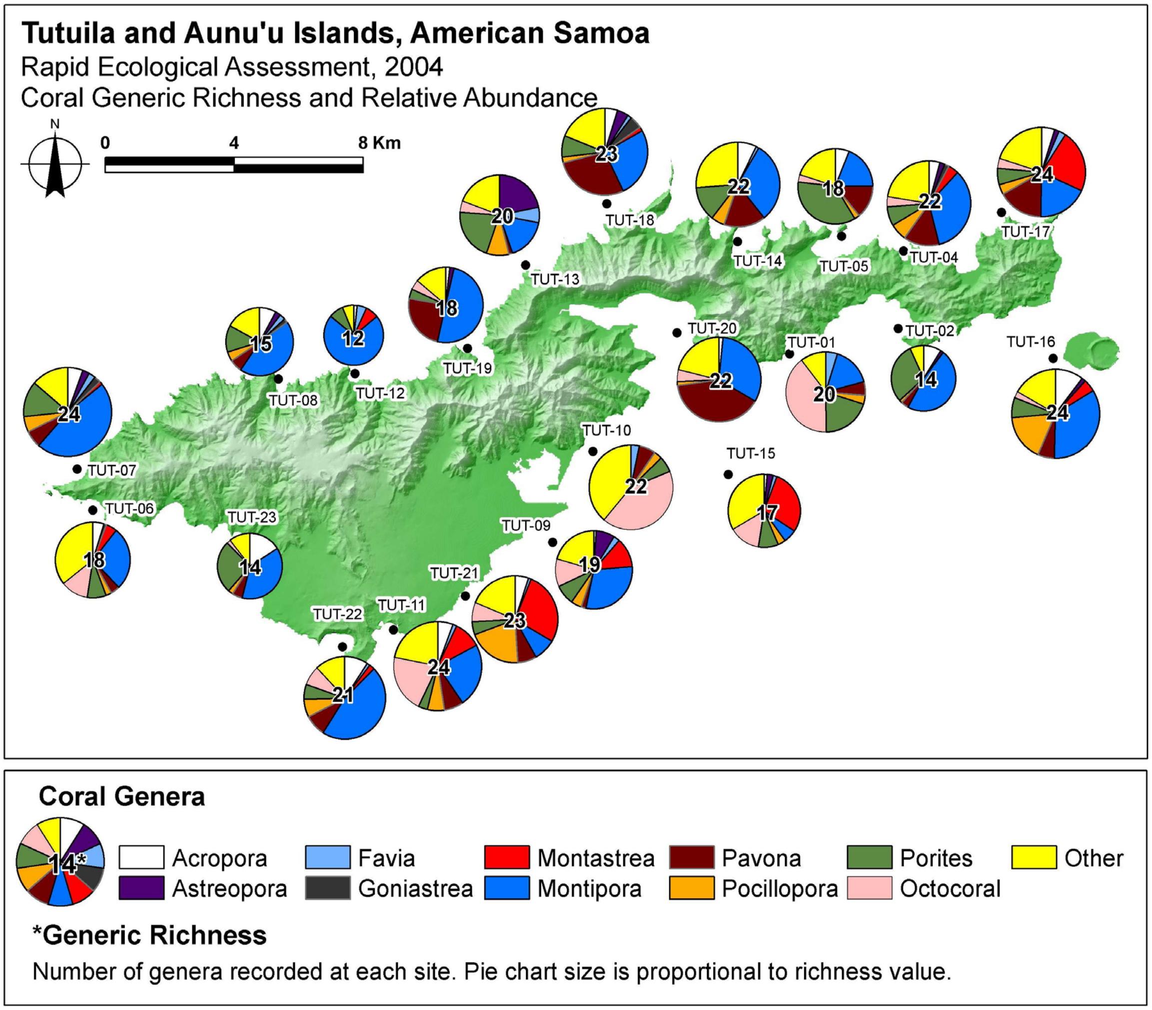

Figure 3.5.1g. Relative abundance of coral genera and generic richness from REA surveys around Tutuila and Aunu`u during ASRAMP 2004. Percent relative abundance of key coral genera are indicated by color-coded portions of the pie charts. Size of the pie charts and black numbers in the center of the pie charts indicate the number of coral genera observed at each REA site.

Twenty-two coral REA surveys were conducted around Tutuila and Aunu`u during ASRAMP 2004. At least 37 anthozoan/hydrozoan genera were recorded around Tutuila and Aunu`u with members of *Montipora*, *Porites*, and octocorals (*Sinularia/Lobophytum/Sarcophyton*) each contributing more than 10% of the total number of colonies recorded at the islands (Fig. 3.5.1g). *Montipora* was the most common coral genus at most sites around the island, comprising on average 30% of the coral community. Octocorals were more common at sites in the southeast region of Tutuila, especially at sites TUT-10 and TUT-01 where they were the dominant coral making up 42% and 39% of the coral community, respectively. Other genera were locally abundant, especially *Lobophyllia* at TUT-09, *Echinopora* at TUT-06, and *Astreopora* at TUT-13 and TUT-09 (Fig. 3.5.1g). Site-specific relative abundance of corals, shown as the percentage by taxon of total number of coral colonies, is presented in Appendix III, Table III.i.

Generic richness was relatively high around the islands, with a mean of 19.8 coral genera (SE 0.8) recorded per site (Fig. 3.5.1g). Relatively high coral richness (22–24 coral genera) was observed at several north and northeast region sites (TUT-18, -14, -04, and -17), at Aunu`u (TUT-16), and in the south and southeast regions of Tutuila (TUT-11, -21, -10, and -20). A`ua

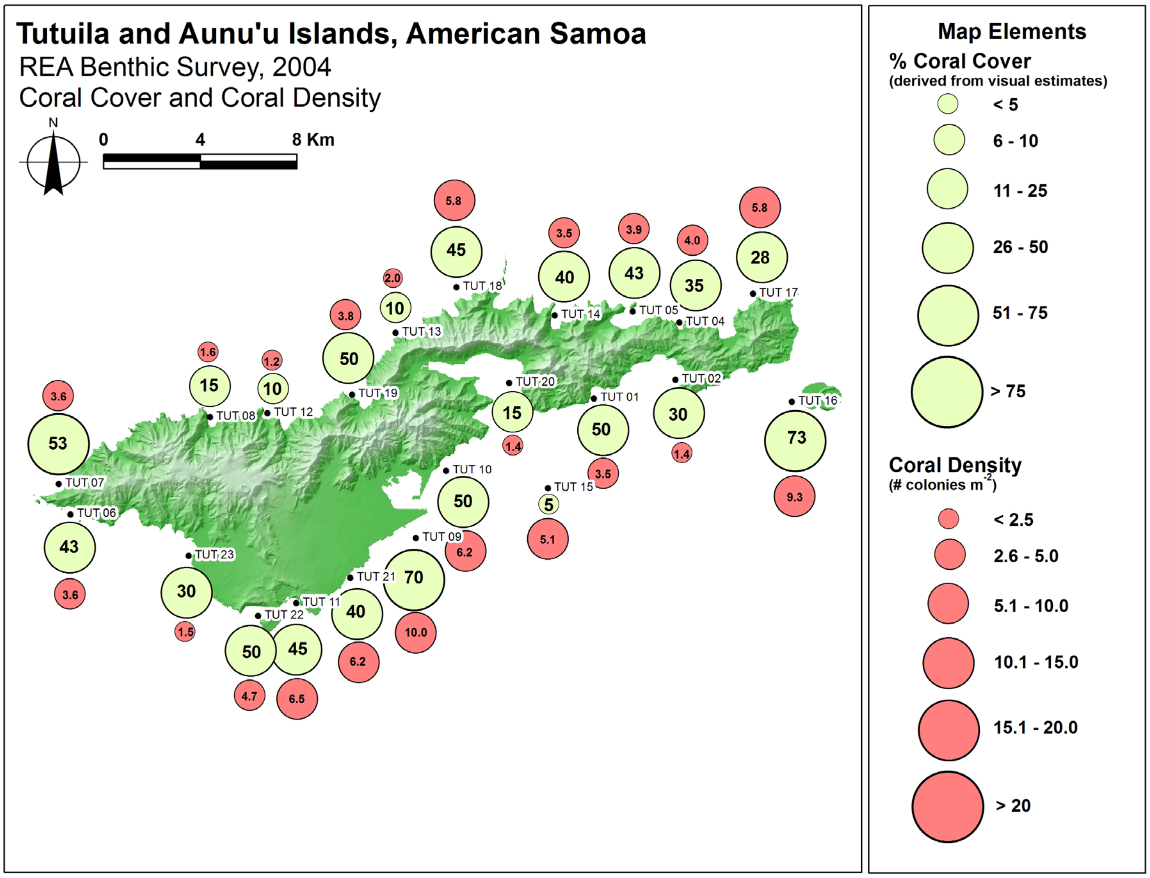

Figure 3.5.1h. Live scleractinian (stony) coral cover and coral colony density from REA surveys around Tutuila and Aunu`u during ASRAMP 2004. The size of the symbol is proportional to the value of each parameter. It is important to note that coral percent cover was determined by qualitative visual estimates.

reef (TUT-20), inside nutrient-subsidized Pago Pago Harbor, was found supporting a few genera not common elsewhere, which contributed to the site's high coral diversity (22 coral genera). Coral richness was relatively lower at two sites within the northwest region (TUT-12 and TUT-08) where 12 and 15 coral genera were recorded, respectively.

During the ASRAMP 2004 REA coral surveys, visual estimates of coral cover around Tutuila and Aunu`u were variable (Fig. 3.5.1h), with an island-wide mean of 37.7% (SE 3.9). Coral cover was highest at TUT-16 off Aunu`u and TUT-09 in the south region (73% and 70%, respectively). Estimates of coral cover were relatively low (5–15%) in the north and northwest regions at sites TUT-08, TUT-12, and TUT-13, at Taema Bank at site TUT-15, and outside Pago Pago Harbor at site TUT-20 (Fig. 3.5.1h).

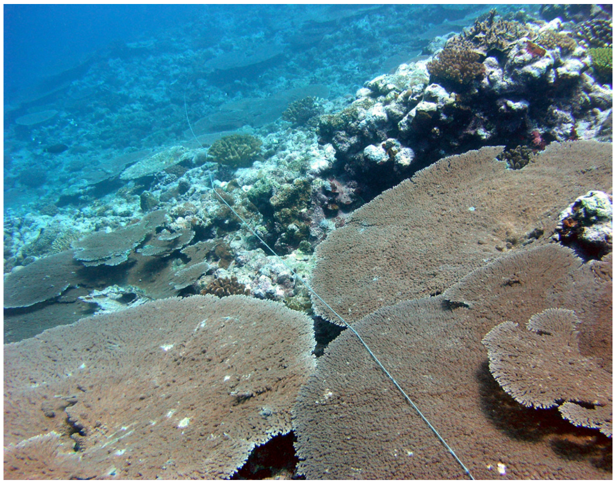

Figure 3.5.1i. Numerous large, mature table corals (*Acropora* sp.) along belt transect at Tutuila. (*Photograph provided by NOAA PIFSC CRED; J Kenyon, JIMAR*)

During ASRAMP 2004 surveys around Tutuila and Aunu`u, a total of 8219 coral

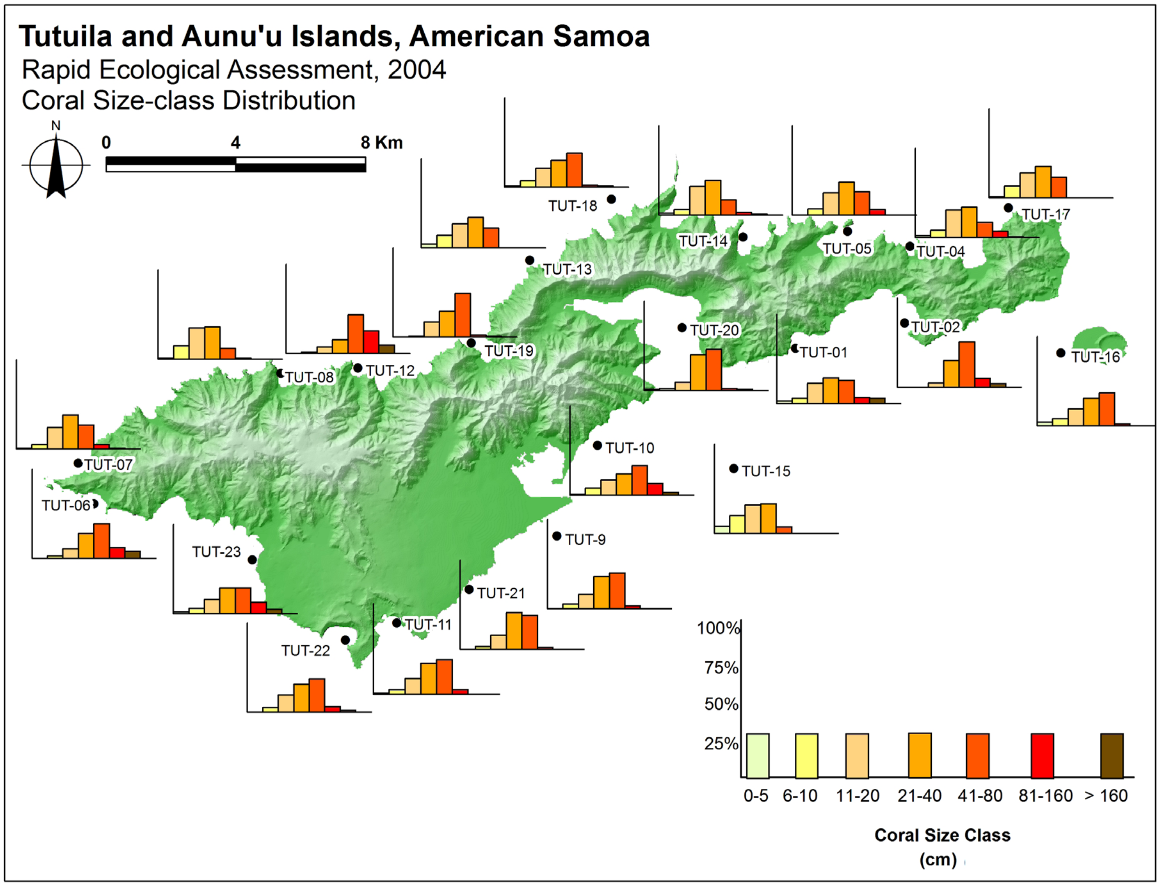

Figure 3.5.1j. Scleractinian coral size-class distribution around Tutuila and Aunu`u from REA surveys during ASRAMP 2004. The height of the ***y***-axis in each size class chart represents 100%. The seven observed size classes (0–5, 6–10, 11–20, 21–40, 41–80, 81–160, and > 160 cm), are color coded in size frequency diagrams at each REA site.

colonies were counted within a total survey area of 2030 m^2. Mean coral densities per site around Tutuila and Aunu`u were variable with 4.3 colonies $m^{-2}$ (SE 2.4) reported (Fig. 3.5.1h). The highest coral density values (9.3 and 10.0 colonies $m^{-2}$) were recorded off Aunu`u at site TUT-16 and in the south region at TUT-09, respectively. Relatively low coral densities (1.2 to 2 colonies m^{-2}) were generally reported in the northwest and north regions at sites TUT-07, TUT-08, TUT-12, and TUT-13, and inside Pago Pago Harbor at site TUT-20. The highest coral cover and colony densities observed around Tutuila and Aunu`u in 2004 occurred at the same two sites: TUT-09 and TUT-16.

During ASRAMP 2004 surveys around Tutuila and Aunu`u, size-class distributions of scleractinian (stony) corals showed the majority of corals (63.2%) had diameters between 20 cm and 80 cm (Fig. 3.5.1j). Sites with more than 25% of corals having maximum diameters greater than 40 cm were mostly located within southern regions of Tutuila: southwest (TUT0-6, -23), South Point (TUT-22), south (TUT-10,-11), southeast (TUT-01), and Aunu`u (TUT-16), while only site TUT-12 in the northwest region had abundant large corals (Fig. 3.5.1j). Only site TUT-15 at Taema Bank had more than 10% of coral colonies in the smallest (< 5 cm) size class.

2006 Spatial Surveys

During ASRAMP 2006, large swells made towed-diver surveys difficult, leading to deeper and less consistent sampling than in previous years (Fig. 3.5.1k). Towed-diver surveys around Tutuila and Aunu`u in 2006 had a mean depth of 16.1 m (SD 4.7); individual tow tracks varied in depth from 10 m (SD 4) to 24 m (SD 3). For the 44 towed-diver benthic surveys completed in 2006, the overall mean scleractinian (stony) coral cover was 13.7% (SE 0.7) (Fig. 3.5.1l), while the associated mean stressed coral cover was 3.2% (SE 0.4; Fig. 3.5.1m).

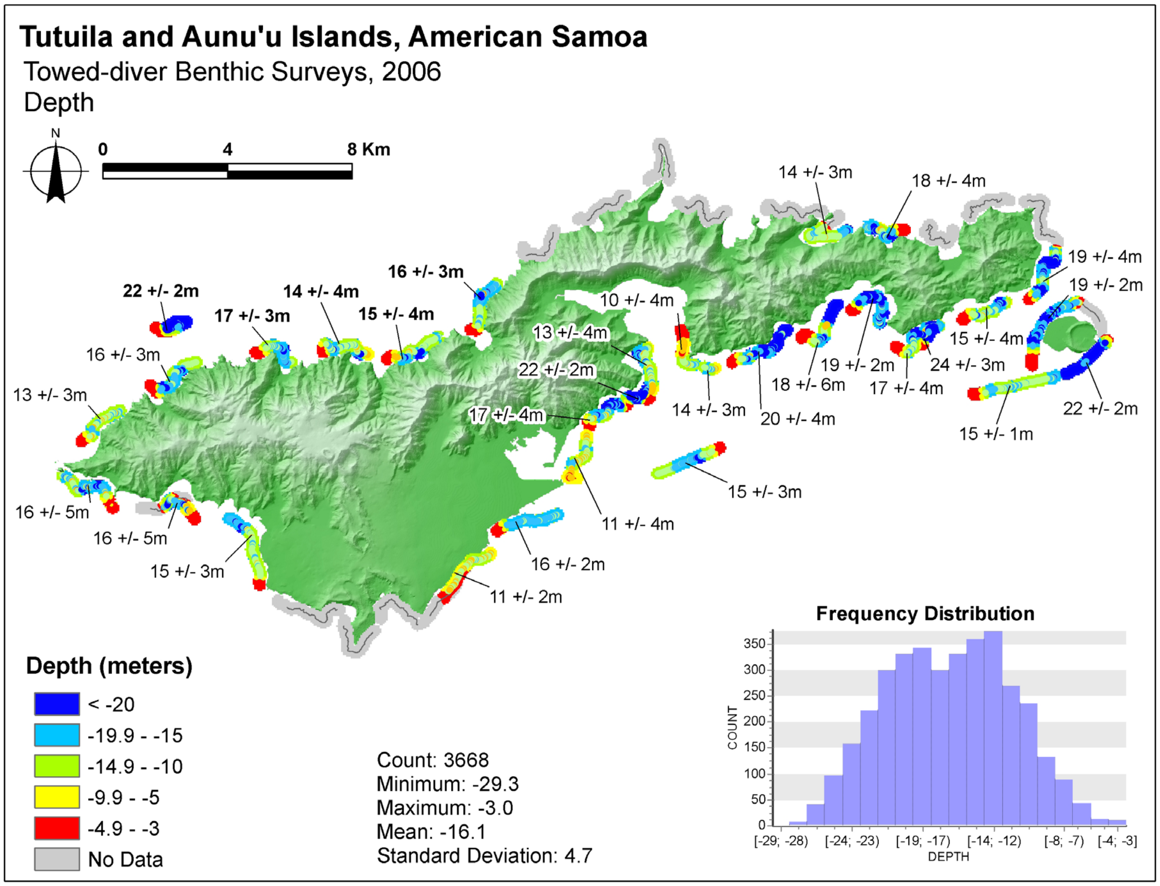

Figure 3.5.1k. Towed-diver survey tracks around Tutuila and Aunu`u during ASRAMP 2006. Towed-diver survey tracks are color coded with mean depths for each 5-min segment. Mean depths and standard deviations for each towed-diver survey are shown in black text. Depth histogram and statistics (counts, minimum depth, maximum depth, mean, and standard deviation) from 30-sec depth recordings during towed-diver surveys are included.

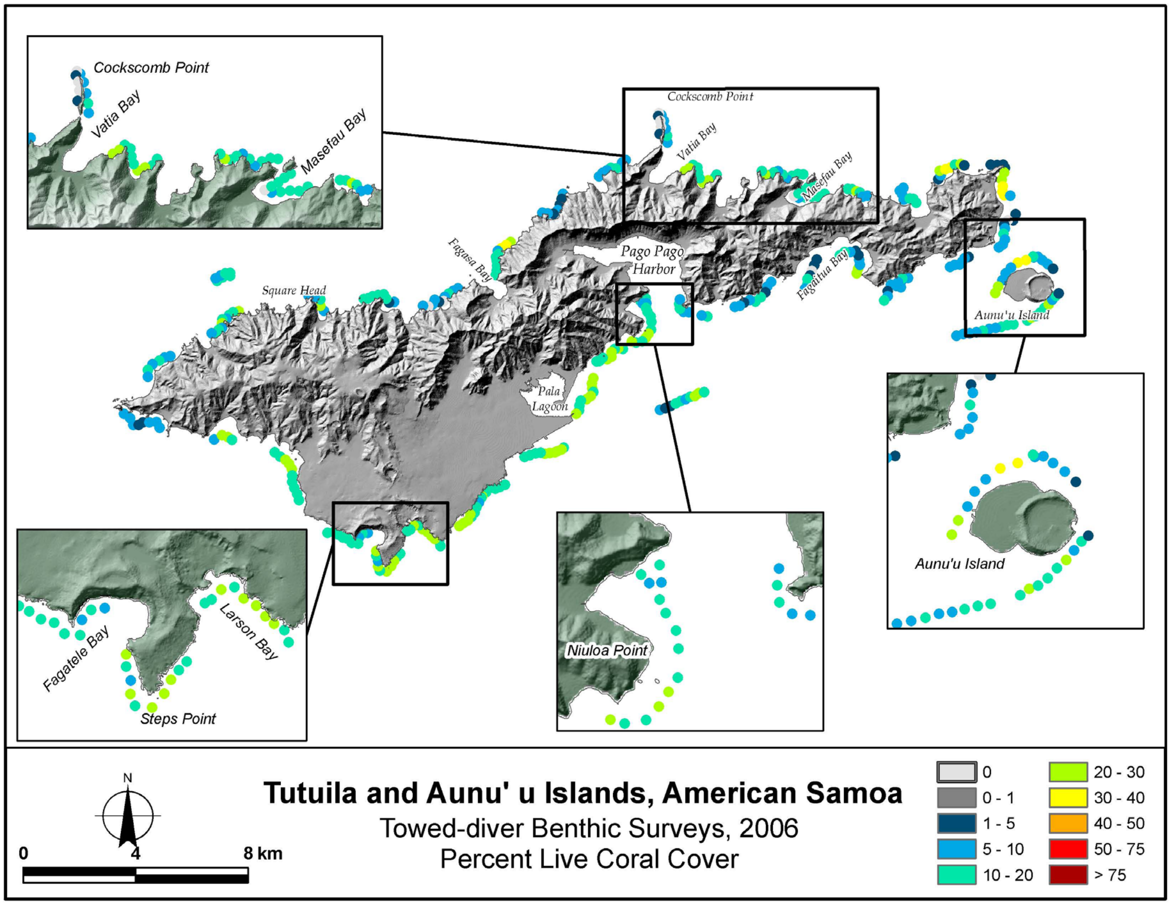

Figure 3.5.11. Towed-diver benthic survey observations of live scleractinian (stony) coral cover around Tutuila and Aunu`u during ASRAMP 2006. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2). Symbol size represents the percent live coral cover on the benthic habitat. See Chapter 2, Table 2.4.2b for more information on benthic towed-diver binning categories during ASRAMP 2006.

Areas of high coral cover included the forereef near the airport runway and Matautuotafuna Point (5 tow segments; mean: 25%) in the south region, the northern side of Aunu`u (2 tow segments; mean: 35%), and 3 tow segments near Papuloa Point east of Aoa Bay in the northeast region (mean: 31.7%; Fig. 3.5.11).

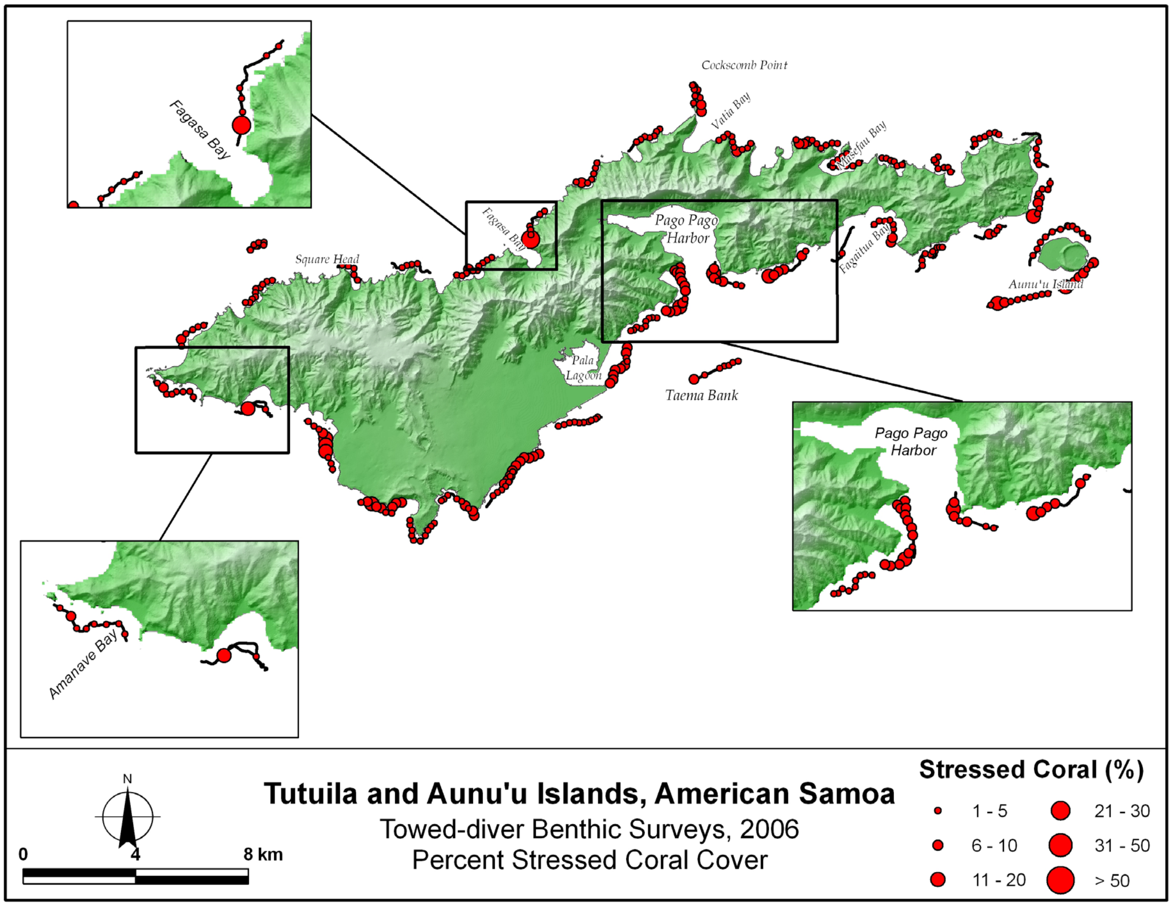

Figure 3.5.1m. Towed-diver benthic survey observations of stressed coral cover around Tutuila and Aunu`u during ASRAMP 2006. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2). Symbol size represents the percent of stressed coral cover of the total coral benthic coverage. See Chapter 2, Table 2.4.2b for more information on benthic towed-diver binning categories during ASRAMP 2006.

Stressed coral (Fig. 3.5.1m) was found in a number of locations, including the area near Breakers Point entering the eastern side of Pago Pago Harbor (3 tow segments; mean: 10.0%), the area on the southeastern side of Aunu`u (5 tow segments; mean: 9.0%), and within Leone Bay near Logologo Point (3 tow segments; mean: 15%) in the southwest region. A high level of stressed coral (25%) was also recorded during a single 5-min tow segment near Fagasa Bay in the north region; however, no additional information regarding the type or potential cause of the stress was noted.

A total of 16 coral REA surveys were conducted around Tutuila and Aunu`u during ASRAMP 2006. Coral population parameters (density, richness, and size classes) were not recorded at REA sites TUT-06, -07, -08, -12, -19, and -23 because of logistical diving problems. At least 35 anthozoan/hydrozoan genera were recorded during surveys around Tutuila and Aunu`u. Coral community composition varied greatly at sites around the islands, with no single coral genus showing dominance throughout (Fig. 3.5.1n). *Montipora*, *Pavona*, *Porites*, and octocorals were the most common corals seen, each accounting for 10–20% of the coral community. *Porites* was more common at sites off the north coast of Tutuila, making up on average 22% of the coral community compared to only 3.5% of the coral community for the rest of the island. Octocorals were most common at sites TUT-01, -10, and -15 in the southeast, south, and Taema Bank regions, where they accounted for more than 40% of colonies. Other genera were locally abundant, especially *Lobophyllia* at TUT-10 in the south region, *Echinopora* at TUT-06 in the southwest region, and *Astreopora* at TUT-13 and -09 in the north and south regions. Site-specific relative abundance of corals, shown as the percentage by taxon of total number of coral colonies, is presented in Appendix III, Table III. ii.

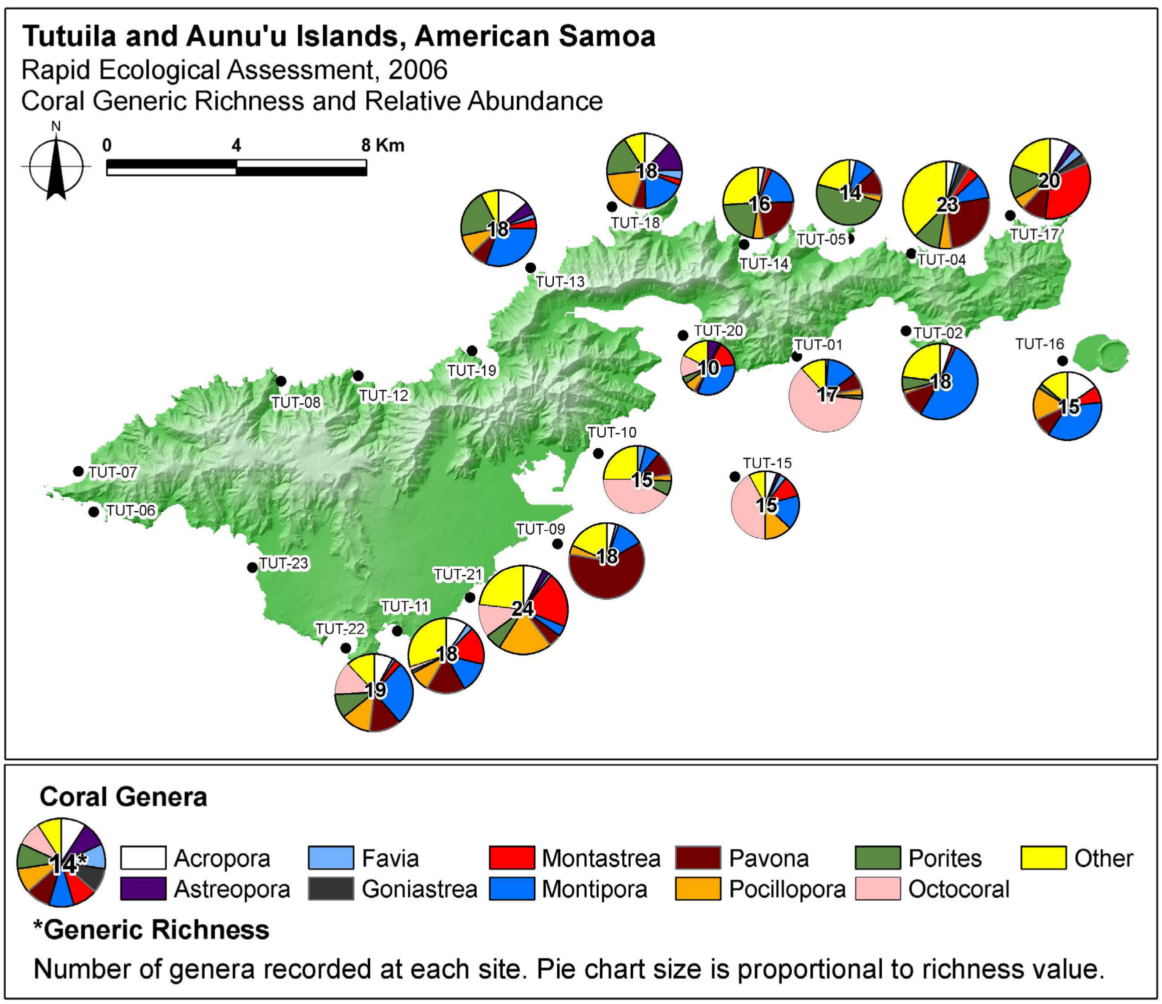

Figure 3.5.1n. Relative abundance of coral genera and generic richness from REA surveys around Tutuila and Aunu`u during ASRAMP 2006. Percent relative abundance of key coral genera are indicated by color-coded portions of the pie charts. Size of pie charts and black numbers in the center of the pie charts indicate the number of coral genera observed at each REA site. Data were not recorded at REA sites TUT-06, -07, -08, -12, -19, and -23 because of logistical diving problems.

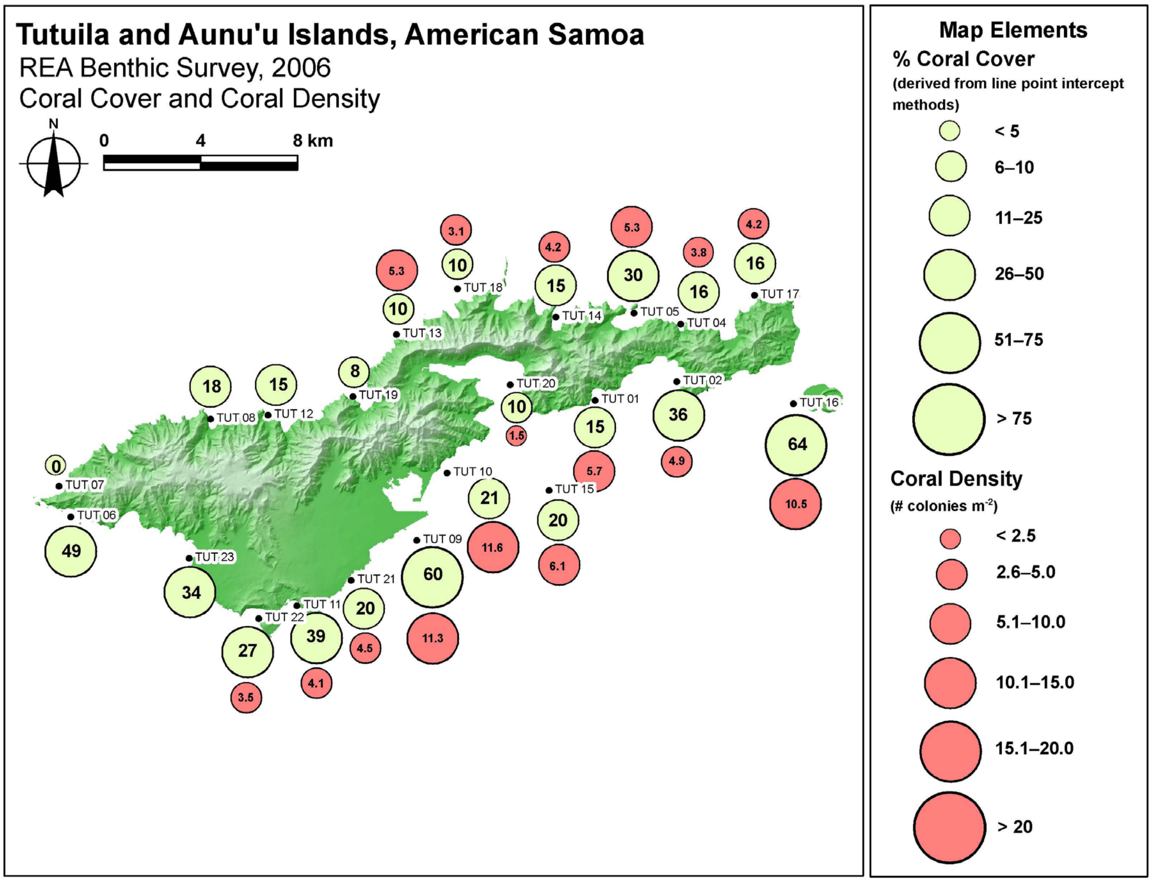

Figure 3.5.1o. Live scleractinian (stony) coral cover and coral colony density from REA surveys around Tutuila and Aunu`u during ASRAMP 2006. The size of the symbol is proportional to the value of each parameter. Data were not recorded at REA sites TUT-06, -07, -08, -12, -19, and -23 because of logistical diving problems.

Generic richness was variable with a mean of 17.4 coral genera per site (SE 0.8) (Fig. 3.5.1n). High richness (20–24 coral genera) was found at sites TUT-04 and -17 in the northeast region and also at site TUT-21 in the south region. Coral richness was relatively low inside Pago Pago Harbor at site TUT-20, with only 10 coral genera being recorded.

During ASRAMP 2006 surveys, a total of 4251 coral colonies were counted within belt transects covering 875 m^2. Mean coral densities per site around Tutuila and Aunu`u were variable with 5.6 colonies $m^{-2}$ (SE 2.4) reported (Fig. 3.5.1o). The highest coral densities (10–12 colonies $m^{-2}$) were recorded at sites TUT-09 and TUT-10 in the south region and at site TUT-16 off Aunu`u. Low coral densities (3.1–5.3 colonies m^{-2}) were generally reported at north-facing sites (TUT-17, -04, -05, -14, -18, and -13) while the lowest coral density (1.5 colonies m^{-2}) was found inside the Pago Pago Harbor (TUT-20).

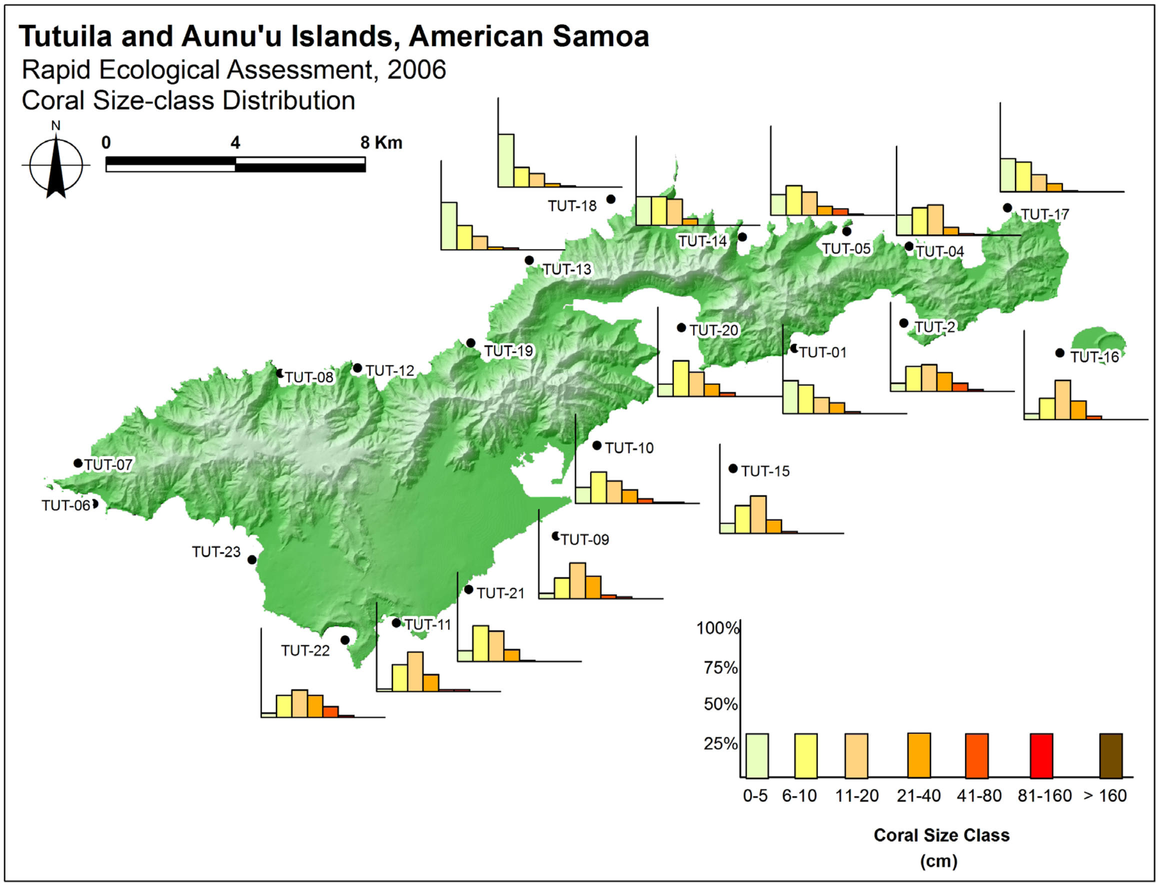

Figure 3.5.1p. Scleractinian coral size-class distribution around Tutuila and Aunu`u from REA surveys during ASRAMP 2006. The height of the *y*-axis in each size class chart represents 100%. The seven observed size classes (0–5, 6–10, 11–20, 21–40, 41–80, 81–160, and > 160 cm), are color coded in size frequency diagrams at each REA site. Data were not recorded at REA sites TUT-06, -07, -08, -12, -19, and -23 because of logistical diving problems.

Size-class distributions of scleractinian corals showed the majority of corals (80.1%) had diameters less than 20 cm (Fig. 3.5.1p). Only at site TUT-22 in Fagatele Bay in the south point region were greater than 25% of the corals observed to have diameters greater than 40 cm. Generally, corals were smaller off the north coast, with most sites having a relatively high percentage of corals with diameters less than 10 cm. Sites TUT-13 and TUT-18 in the north region each had more than 50% of corals with maximum diameters less than 5 cm.

3.5.2 Coral Disease Surveys

2006 Spatial Surveys

Coral diseases were first surveyed around Tutuila and Aunu`u during ASRAMP 2006; disease surveys covered 9100 m^2 of reef habitat. Within this survey area a total of 73 cases of disease, predation, and other types of lesions were enumerated. Of the 22 sites visited, 13 (59%) contained disease and visible signs of predation (Fig. 3.5.2a, b). The mean overall prevalence of bleaching, disease, and 'other lesions', excluding predation, was 0.12% (SE 0.03). Sites TUT-18, TUT-14, and TUT-17 in the north and northeast regions exhibited the greatest occurrence of disease (> 80% of cases; Fig. 3.5.2a).

The most common disease state at Tutuila and Aunu`u was 'other lesions', which involved coral hyperpigmented irritations (Fig. 3.5.2b). This condition was observed predominantly on corals of the genera *Montipora* and *Porites*, but also on *Astreopora* and *Leptoria*. Skeletal growth anomalies were the second most common type of lesion; mean prevalence values for this disease state were as high as 0.24% at site TUT-08 in the northwest region, where 56 growth anomalies were enumerated on one single colony of *Acropora abrotnoides*. Skeletal

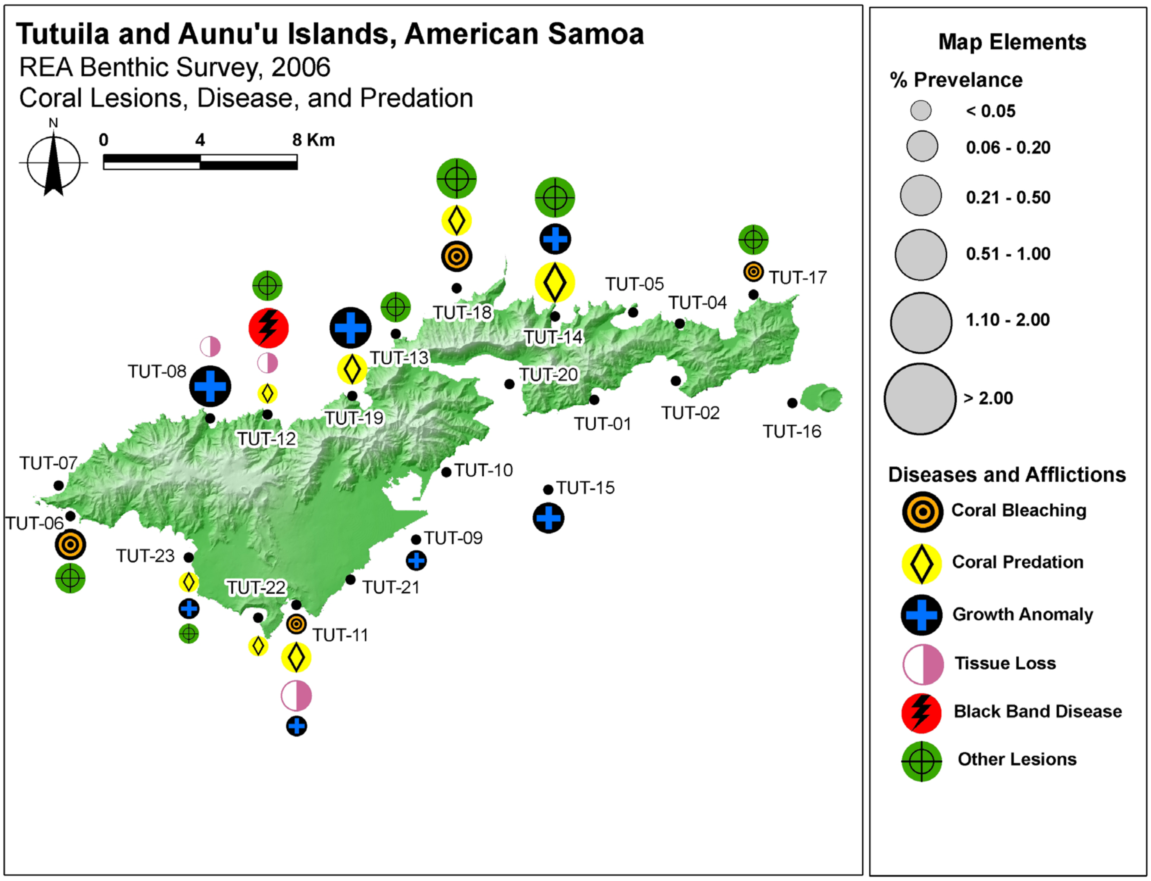

Figure 3.5.2a. Prevalence of predation, bleaching, growth anomalies, tissue loss, black band disease, and other lesions at Tutuila and Aunu`u during ASRAMP 2006. Prevalence was calculated relative to the average colony density estimates and is indicated by the size of the respective disease symbols. Colony density data were not recorded at REA sites TUT-06, -07, -08, -12, -19, and -23 because of logistical diving problems. Percent prevalence for those sites was estimated using the mean colony density for the entire island.

growth anomalies were also detected on corals of the genera *Astreopora*, and *Favites*. Coral bleaching was observed in low prevalence at sites TUT-18, TUT-17, TUT-11, and TUT-06 in the north, northeast, south point, and southwest regions; bleaching was generally mild and focal. Scleractinian genera that exhibited bleaching included: *Porites*, *Montastrea*, and *Leptoria*. Other disease states present on corals around Tutuila and Aunu`u included tissue loss (0.07%), all on colonies of *Acropora cytherea*, and one case of black band disease on *Porties* cf. *lobata* (0.04%).

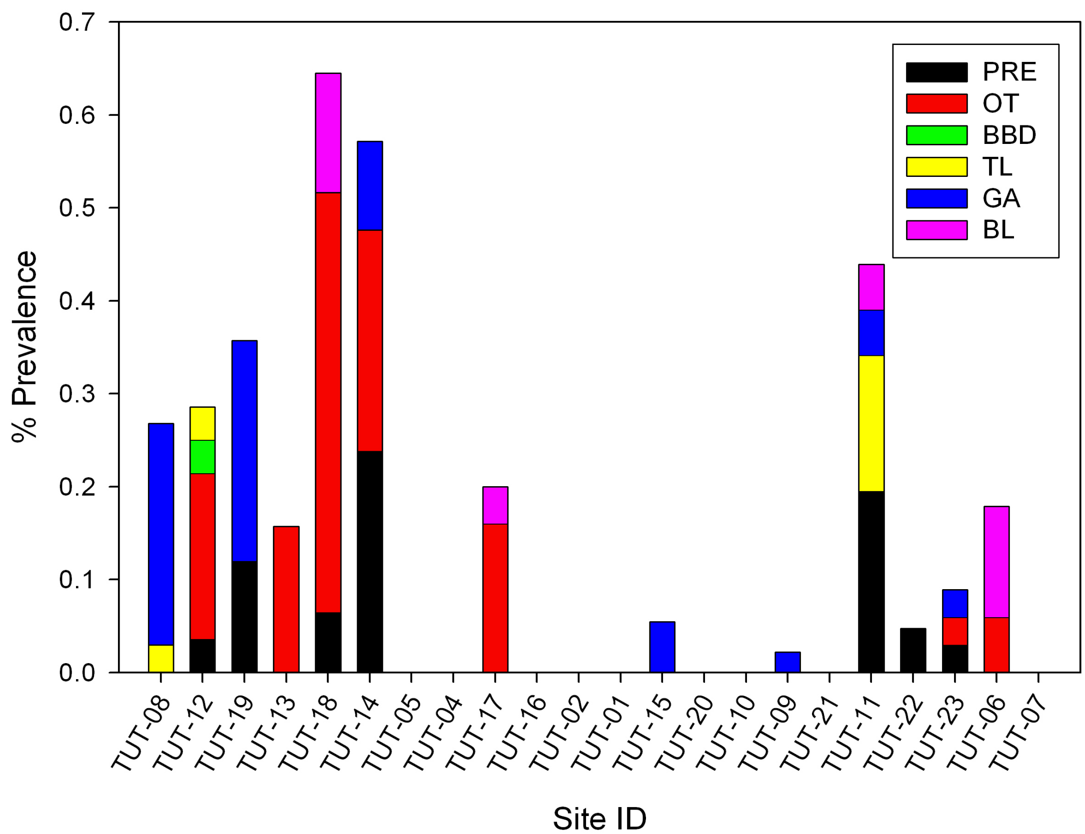

Figure 3.5.2b. Prevalence of predation, bleaching, growth anomalies, tissue loss, black band disease, and other lesions at Tutuila and Aunu`u during ASRAMP 2006. Prevalence was calculated relative to the average colony density estimates. Colony density data were not recorded at REA sites TUT-06, -07, -08, -12, -19, and -23 because of logistical diving problems. Percent prevalence for those sites was estimated using the mean colony density for the entire island. PRE—*Acanthaster* and/or *Drupella* predation; OT—other lesions, including hyperpigmented irritations; BBD— black band disease; TL— tissue loss; GA—skeletal growth anomalies; and BL— bleaching.

3.5.3 Temporal Comparison—Coral and Coral Disease

Mean percent live scleractinian coral cover, as derived from towed-diver surveys, declined from 28.9% (SE 2.5) in 2002, to 20.9% (SE 1.1) in 2004, to 13.7% (SE 0.7) in 2006 (Fig. 3.5.3a). Coral cover values from the towed-diver surveys were consistently lower than REA coral cover values. This result is expected, based on the difference in methodologies: towed-diver surveys record benthic cover along all habitat types (i.e. hard-bottom and soft-bottom substrates), while REA surveys tend to focus on hard-bottom substrate. Generally, soft-bottom habitats have lower coral cover than hard-bottom habitats, likely explaining the higher coral cover reported by REA surveys. It is interesting to note that despite the inherent differences between the two methods of estimating coral cover, estimates of the relative percent decline of coral cover between 2004 and 2006 were similar for both methods (36% and 34%, respectively, for REA and towed-diver surveys).

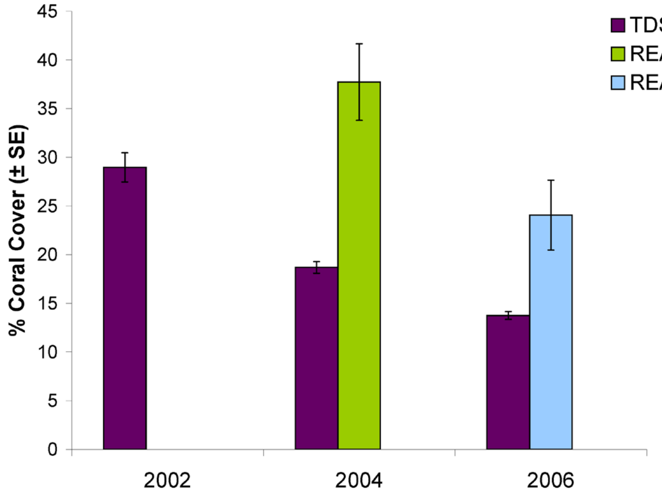

Figure 3.5.3a. Temporal comparison of mean percent live coral cover from REA surveys and towed-diver surveys around Tutuila and Aunu`u during ASRAMP 2002, 2004, and 2006. The purple bars represent observations collected during towed-diver benthic surveys. The green bar represents REA data collected by visual estimates during REA surveys and the blue bar represents data collected by the line point intercept technique during REA surveys. See Chapter 2, Section 2.4: Reef Benthic (Coral, Algae, Macroinvetebrate) and Fish Surveys for considerations when comparing the results of these methodologies.

Total live coral cover declined in REA surveys (2004–2006) as well as towed-diver surveys (2002–2006). Mean coral cover for 2004 (37.7% [SE 3.9]) and 2006 (24.1% [SE 3.6]) REA surveys are graphed in Figure 3.5.3a. Direct comparison of REA percent coral cover values between years is not appropriate because the methods used to estimate percent coral cover were different in 2004 and 2006 (visual estimate and line intercept, respectively). Evaluating percent coral cover on a per-site basis would likely lead to misguided conclusions, because visual estimates can vary widely from estimates derived from more rigorous quantitative methods such as the line point intercept technique. However, a general trend of areas with high and low coral cover was observed. During ASRAMP 2004 and 2006, the highest coral cover was found at TUT-16 (64–73%) off Aunu`u and off the south coast of Tutuila at TUT-09 (60–70%). Relatively low coral cover values recorded at site TUT-08 in the northwest region, at site TUT-13 in the north region, and inside Pago Pago Harbor at site TUT-20 also remained similar between years.

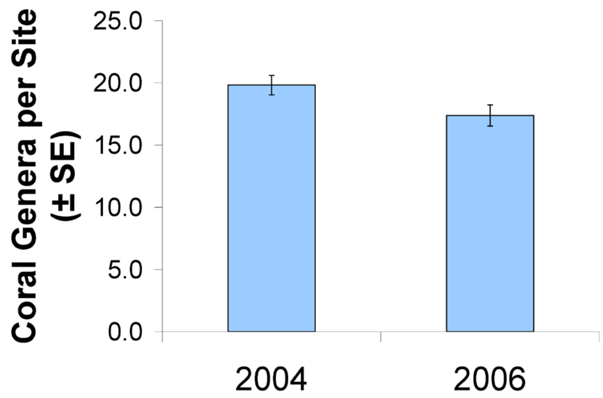

Figure 3.5.3b. Temporal comparison of mean coral genera per site from REA surveys around Tutuila and Aunu`u during ASRAMP 2004 and 2006.

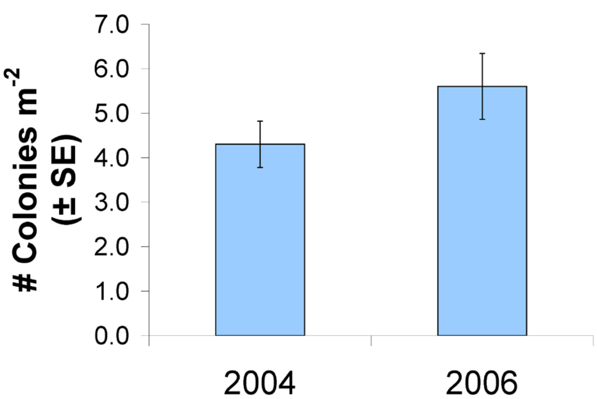

Figure 3.5.3c. Temporal comparison of mean coral colony density from REA surveys around Tutuila and Aunu`u during ASRAMP 2004 and 2006.

Island-wide coral community composition was quite stable between 2004 and 2006, with 37 genera reported in 2004 and 35 genera reported in 2006. During both years, the same suite of coral genera (*Montipora*, *Pavona*, *Porites*, octocorals) each contributed more than 10% of the total numerical abundance of coral colonies. Mean generic richness of corals per site was slightly higher in 2004 (19.8 coral genera per site [SE 0.8]) compared to 2006 (17.4 genera per site [SE 0.8]; Fig. 3.5.3b). The greatest difference in coral richness was seen at site TUT-20 inside Pago Pago Harbor. In 2004, 22 coral genera were reported at TUT-20, while in 2006 only 10 genera were reported. A probable explanation for this difference in estimated coral diversity is that the placement of belt transects varied between years. Sites are located with the use of global positioning system coordinates marked from a dive boat, and currently no permanent transects have been installed in American Samoa. Of the 20 genera reported at TUT-20 in 2004, 14 were rare, with only one or two colonies present. Consequently, a slight change in the placement of the transect lines in 2006 would have easily put many of these genera outside the survey area, thus leading to the large discrepancy in estimated generic richness between survey years.

Coral density increased from a mean of 4.3 coral colonies m^{-2} (SE 0.5) in 2004 to 5.6 colonies m^{-2} (SE 0.7) in 2006 (Fig. 3.5.3c). In both 2004 and 2006, spatial trends in coral density were similar to those in REA coral cover with the highest densities recorded at TUT-09 and TUT-

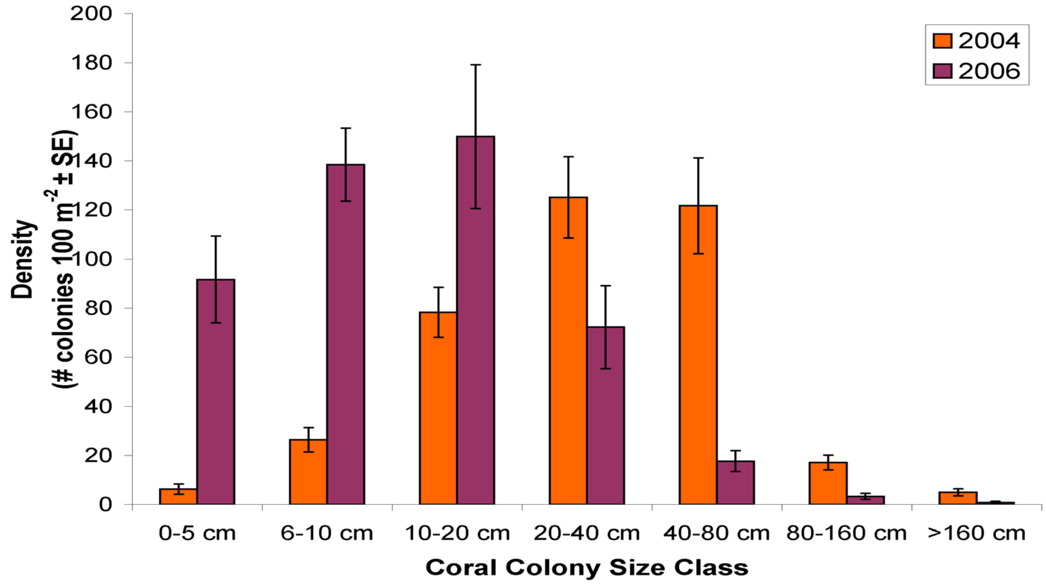

Figure 3.5.3d. Coral colony size-class mean density around Tutuila and Aunu`u for ASRAMP 2004 and 2006. Differences between 2004 and 2006 are thought to be the result of interobserver variability.

16, and lower densities reported at north-facing sites and TUT-20, inside Pago Pago Harbor. Based on REA surveys around Tutuila and Aunu`u during ASRAMP 2004 and 2006 (Fig. 3.5.3d), scleractinian coral size-class distributions appear to have shifted from one in which the majority of corals had diameters greater than 20 cm in 2004 to one in which the majority of corals had diameters less than 20 cm in 2006. Although extreme natural events such as tropical cyclones and other storm activities can have great impacts on coral reef communities, analyses suggest that this difference in estimated size-class distributions between 2004 and 2006 is most likely a result of interobserver variability. There are a number of considerations pertinent to observer variability, including the use of different observers both within and between years and inherent variation in coral morphologies.

In 2004, two coral biologists collected coral population data concurrently (each surveyed one 25-m transect at each site) and their results were combined to produce the coral population parameters presented in this report. An investigation of site-specific data collected in 2004 by the two coral biologists revealed a general trend throughout all American Samoa sites for one of the coral biologists to classify corals into larger size classes than the other coral biologist. Figure 3.5.3e shows that the majority of corals recorded by observer #1 had maximum estimated diameters between 10 cm and 40 cm, while the majority of corals recorded by observer #2 had maximum diameters between 40 cm and 80 cm. In 2006, of the 16 sites where size class data were recorded, 3 were surveyed by observer #1 and the remaining 13 sites were surveyed by 2 additional coral biologists. This observer bias partially explains the temporal differences within the large coral size-classes and leads us to regard interobserver variability as the chief source of the discrepancy of Tutuila and Aunu`u size class distributions between 2004 and 2006.

One potential source for interobserver error derives from the clonal nature of corals which sometimes complicates the estimation of individual coral colony boundaries. While the boundaries of colonies of some genera (e.g., *Pocillopora*) are discrete and therefore their sizes simple to determine, many other taxa (e.g., *Acropora*, *Montipora*, *Porites*, *Favia*, and

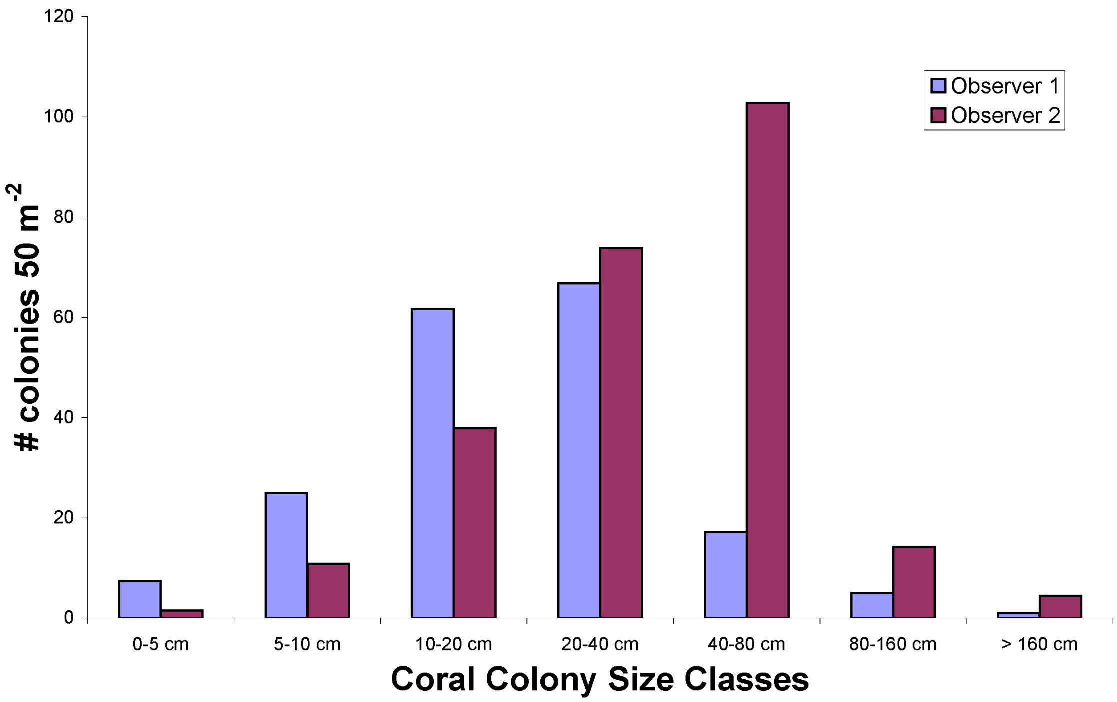

Figure 3.5.3e. Interobserver variability of coral colony size-class mean density around Tutuila and Aunu`u for ASRAMP 2004. Data were collected concurrently by two coral biologists and combined to create Figure 3.5.1j.

Goniastrea) undergo substantial fragmentation and/or fission as part of their life history. This tendency introduces uncertainty in determining the boundaries of individual colonies and hence implicitly introduces interobserver error into the data. Although written criteria were established for making field judgments concerning the number of colonies represented by a spatially fragmented mass of con-specific coral tissue, different judgments will inevitably be made by different field observers. CRED is presently initiating efforts to investigate alternative methods that may reduce the degree to which interobserver error confounds interpretations of apparent temporal variation.

3.6 Algae

3.6.1 Algal Surveys

It is important to note when considering these results that turf algae, crustose coralline red algae, branched non-geniculate coralline red algae, and cyanophytes (blue-green algae) all need to be analyzed microscopically for proper taxonomic identification and, therefore, must be lumped into functional group categories in the field. Of these functional groups, turf algae are the most diverse with the possibility of up to 100 species occurring in a 10 cm^2 area. Also, macroalgae are large, fleshy, sometimes calcified entities that may be identifiable to genus or species in the field, but often require microscopic analysis to confirm taxonomic identities.

2002 Spatial Surveys

A total of 16 towed-diver benthic surveys were conducted around Tutuila during ASRAMP

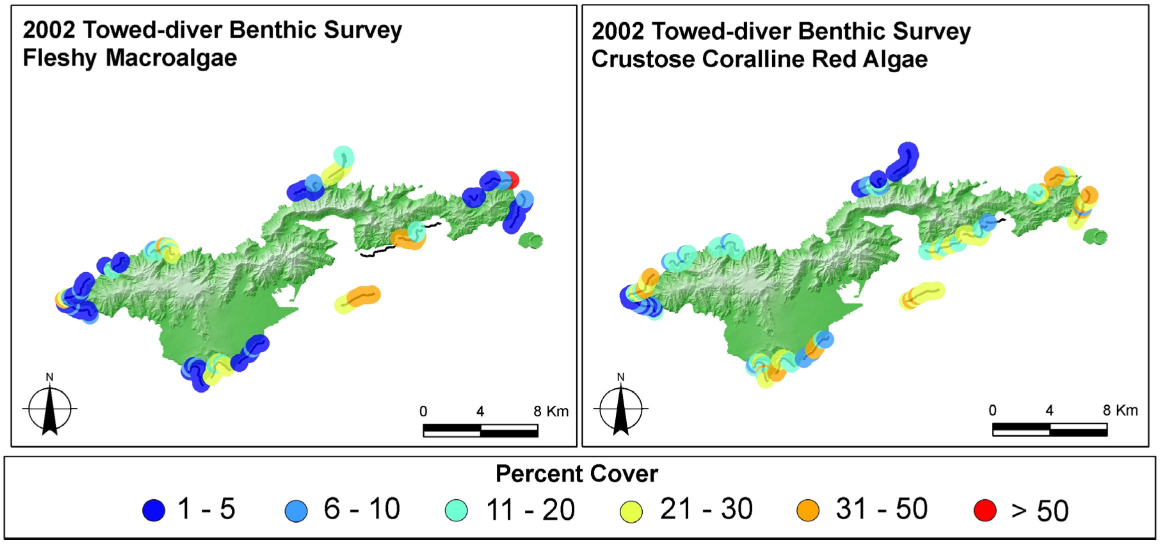

Figure 3.6.1a. Percent cover of fleshy macroalgae (including turf algae) and crustose coralline algae from towed-diver benthic surveys around Tutuila and Aunu`u during ASRAMP 2002. Each colored point represents an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2).

2002, with fleshy macroalgae and crustose coralline red algae covering, on average, 34% of the benthic substrate. Mean fleshy macroalgal cover was 14.8% (SE 1.2) and mean crustose coralline algal cover was 20% (SE 1.1) of the benthic substrate (Fig. 3.6.1a). The greatest percent covers of fleshy macroalgae were observed consistently over Taema Bank, offshore of Pago Pago Harbor, near Alega Bay in the south region, and during a single 5-min segment near Cape Matatula in the northeast region. The greatest percent covers of crustose coralline algae were observed near the westernmost, easternmost, and southernmost points of the island, and offshore of Pago Pago Harbor, all areas of moderately high wave energy and current flow.

Qualitative REA algal surveys were also conducted around Tutuila during ASRAMP 2002, and 14 bags of algal voucher specimens were collected around Tutuila. These surveys provided baseline data used to design and scale the future methodology of algal REA surveys.

2004 Spatial Surveys

A total of 43 towed-diver surveys were conducted around Tutuila and Aunu`u during ASRAMP 2004. The island-wide mean combined algal cover, including macroalgae, turf, and crustose coralline algae, was 63%. Mean fleshy macroalgal cover (including turf) was 33.6% (SE 0.7), and mean crustose coralline algal cover was 29% (SE 0.7) (Fig. 3.6.1b). Generally, greater cover of macroalgae was observed off the north and northwest regions, while greater crustose coralline algal cover was observed along the south point, south, and southeast regions. Macroalgae were not abundant off Cape Matatula, Cape Taputapu, or off the airport runway extension on the south region. Crustose coralline algae were not abundant off the National Park of American Samoa in the north region, Amanave Bay in the southwest region, and in Fagaitua Bay in the southeast region.

In 2004, algal REA surveys were conducted at 22 sites around Tutuila and Aunu`u (Fig.

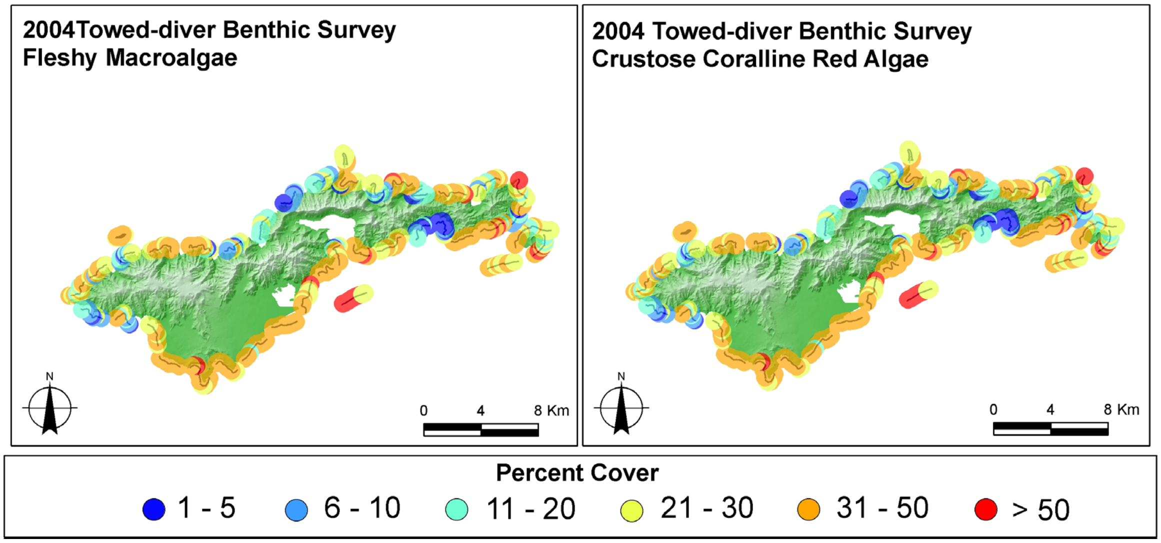

Figure 3.6.1b. Percent cover of fleshy macroalgae (including turf algae) and crustose coralline algae from towed-diver benthic surveys around Tutuila and Aunu`u during ASRAMP 2004. Each colored point represents an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2).

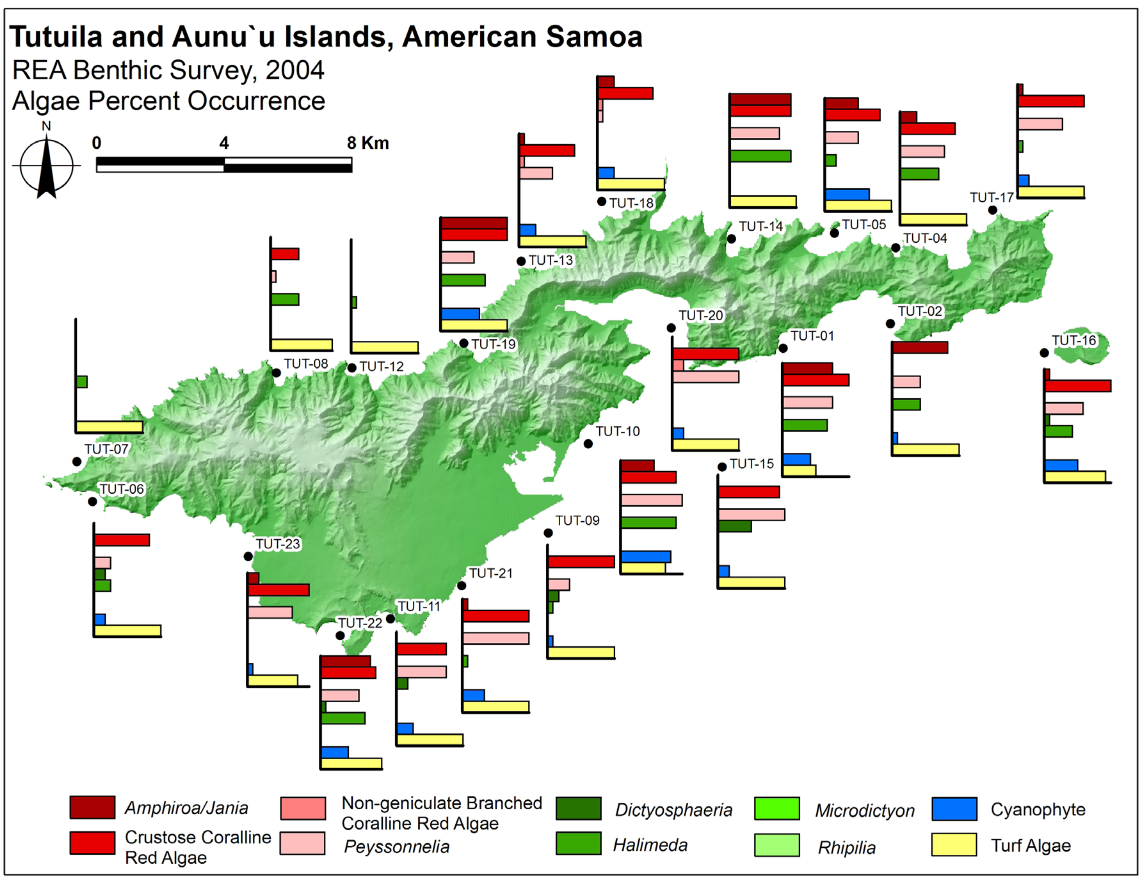

Figure 3.6.1c. Percent occurrence of select macroalgal genera and algal functional groups from REA surveys around Tutuila and Aunu`u during ASRAMP 2004. Percent occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. Length of *x*-axis denotes 100% occurrence.

3.6.1c). Twenty-nine macroalgal genera (9 green, 18 red, and 2 brown) and 4 additional algal functional groups (turf algae, crustose coralline red algae, branched non-geniculate coralline red algae, and cyanophytes) were observed in the field. Once it is complete, laboratory-based taxonomic identification of all algal species (including turf algae, epiphytes, and crustose coralline red algae) will greatly increase the known algal diversity. Sites TUT-19 (National Park of American Samoa) and TUT-22 (Fagatele Bay National Marine Sanctuary) had the highest recorded macroalgal generic diversity with 11 and 9 genera recorded, respectively. Lowest macroalgal diversity was found at sites TUT-20 (Pago Pago Harbor) and TUT-15 (Taema Bank) where only 1 and 2 macroalgal genera were found, respectively.

Around Tutuila and Aunu`u, turf and crustose coralline red algae were the dominant marine flora, observed in over 75% of sampled quadrats (Fig. 3.6.1c). Absence or low abundance of crustose coralline red algae was observed in the northwest region and at TUT-02 in the southeast region of Tutuila. The distribution of cyanophytes around the island was patchy, with the majority of northeast, southeast, and south region sites containing low to moderate abundances of this functional group. Photoquadrats from the three sites in the northwest region of Tutuila contained no cyanophytes.

In 2004, several significant patterns were observed among the relative abundance of macroalgal genera around Tutuila and Aunu`u. This likely stems from Tutuila's large size allowing for many habitats to exist, with each habitat supporting different types of algal communities. Of note, however, the calcified red algal genus, *Peyssonnelia*, was particularly abundant on the south side of the island, occurring in 75% of sampled photoquadrats at sites TUT-11, TUT-21, TUT-10, TUT-20, and TUT-01 (Figs. 3.6.1c and 3.6.1d). In contrast, *Peyssonnelia* occurred in only 50% to 65% of photoquadrats in the southeast and northeast regions of Tutuila, and was lacking in the northwest. Species of the sand-producing, tropical green alga *Halimeda* were locally abundant and found in low to moderate relative abundance at numerous sites around the island with more than 90% of the photoquadrats in Masefau Bay (TUT-14) containing species of the genus. The green alga, *Dictyosphaeria*, was generally absent from photoquadrats at most sites along the north coast while the calcified red algal genera, *Amphiroa*/*Jania*, were generally more abundant in photoquadrats on the eastern half of the island. Although not shown in Figure 3.6.1c, the brown algal genus *Lobophora* was extremely common offshore at Taema Bank (TUT-15), occurring in 100% of sampled photoquadrats. *Lobophora* was completely lacking at all sites on the southern and western parts of Tutuila close to shore, and although found in northeast and 'Aunu`u' regions, it was documented in less than 50% of sampled photoquadrats.

Figure 3.6.1d. A species of the calcified red alga, *Peyssonnelia*, from the island of Tutuila, American Samoa. This alga was particularly abundant on southern shores during ASRAMP 2004. (*Photograph provided by NOAA PIFSC CRED; P. Vroom, JIMAR*)

2006 Spatial Surveys

A total of 44 towed-diver surveys were conducted around Tutuila and Aunu`u during ASRAMP 2006. Mean combined fleshy macroalgae (excluding turf) and crustose coralline algae cover was 27% of the benthic substrate. Mean fleshy macroalgal cover was 10.3% (SE 0.4) and mean crustose coralline algal cover was 16.9% (SE 0.8). The percent cover of fleshy macroalgae was moderately high (3–50%) in only a few scattered areas around Tutuila, including: an area near at the entrance to Pago Pago Harbor near Breaker's Point, an area in Fagaitua Bay in the southeast region, an area in Masefau Bay in the northeast region, and a single segment at Taema Bank (Fig. 3.6.1e). Aside from these few localized areas of moderately high cover, fleshy macroalgae were not observed to vary substantially around the island. The percent cover of crustose coralline algae was generally high (31–50%) across much of the southern regions, including south point, south, southeast, Aunu`u, and Taema Bank, as well as few scattered portions in the northwest and north regions. Very high crustose coralline algal cover (> 50%) was observed at three small, localized areas (single 5-min segments) over the western spur off Aunu`u, off Cape Fogausa, and a submerged offshore reef in the northwest region.

In 2006, algal REA surveys were conducted at the same 22 sites that were sampled in 2004 (Fig. 3.6.1f). Thirty-four macroalgal genera (8 green, 23 red, and 3 brown) and 4 additional algal functional groups (turf algae, crustose coralline red algae, branched non-geniculate coralline red algae, and cyanophytes) were observed in the field. Macroalgal generic diversity at each site ranged from 5 to 16; although once laboratory-based taxonomic identification of algal species is complete, algal diversity for each site will be much higher. Two south shore sites, TUT-22 (Fagatele Bay National Marine Sanctuary) and TUT-21, had the highest recorded macroalgal generic diversity around the island with 16 and 15 genera recorded, respectively. Lowest macroalgal diversity was found off the Tafuna Plain near the airport runway extension (TUT-05) and just north of Cape Taputapu (TUT-07), where only 5 and 6 macroalgal genera were found, respectively.

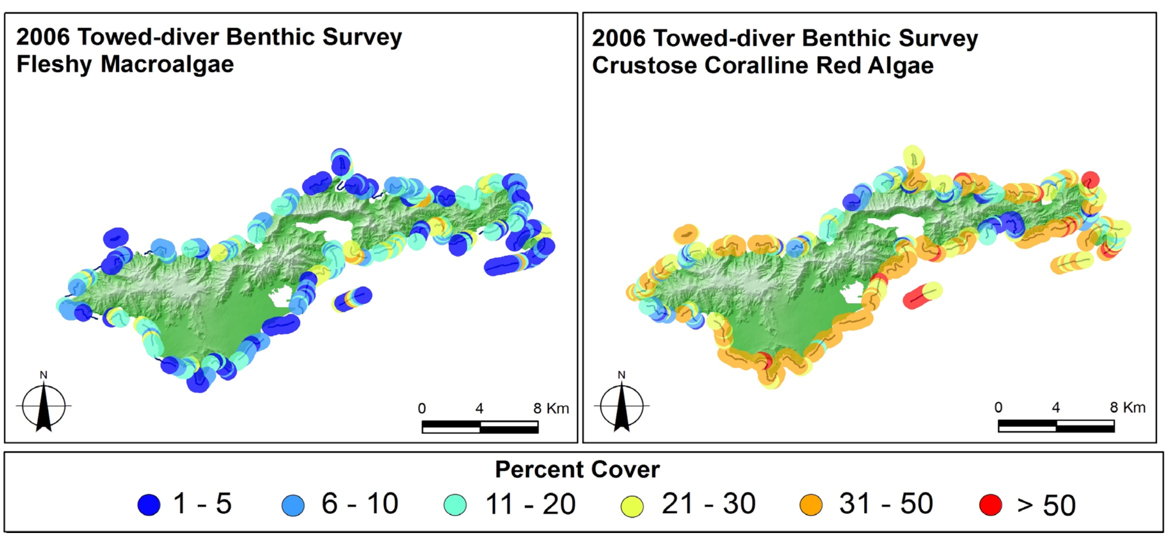

Figure 3.6.1e. Percent cover of fleshy macroalgae (excluding turf algae) and crustose coralline algae from towed-diver benthic surveys around Tutuila and Aunu`u during ASRAMP 2006. Each colored point represents an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2).

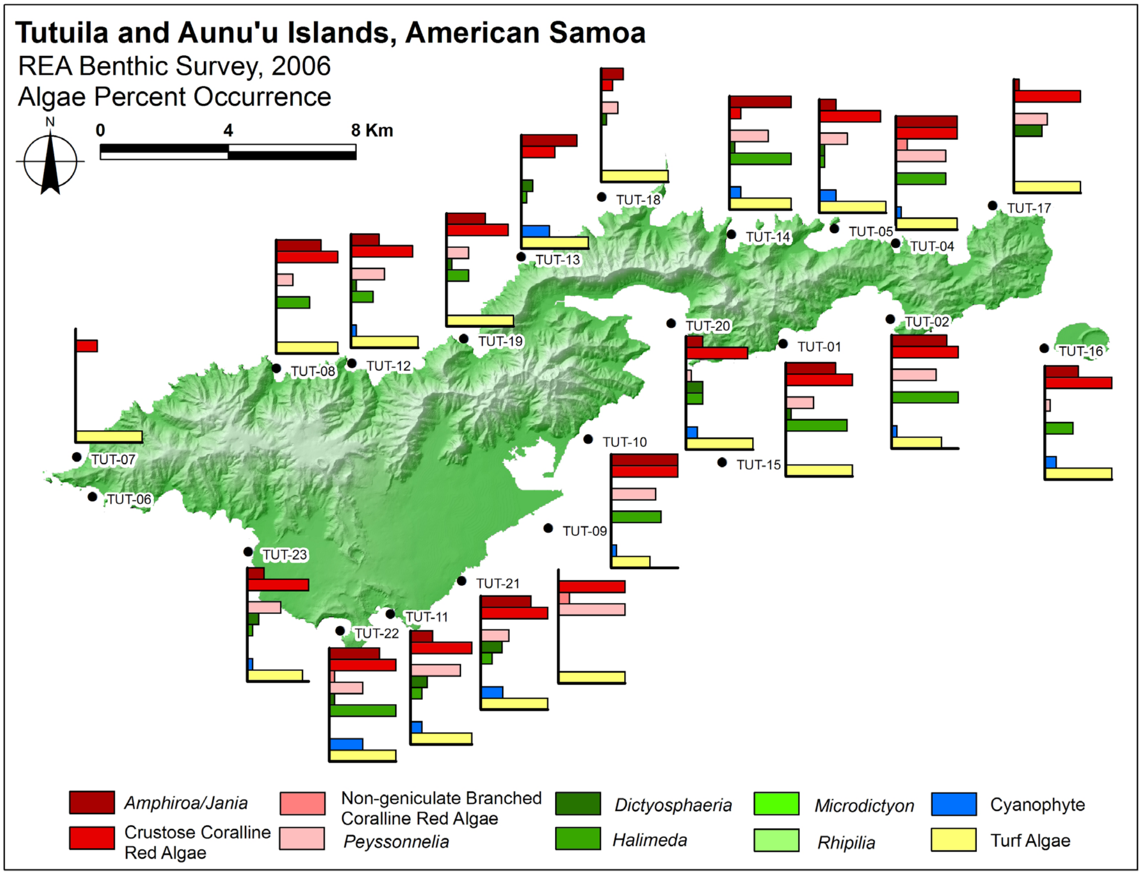

Figure 3.6.1f. Percent occurrence of select macroalgal genera and algal functional groups from REA surveys around Tutuila and Aunu`u during ASRAMP 2006. Percent occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. Only qualitative information was collected at sites TUT-06 and TUT-15 because of weather conditions; therefore, no results are shown. Length of *x*-axis denotes 100% occurrence.

Around Tutuila and Aunu`u, turf algae were the dominant marine flora found, being observed in over 75% of sampled quadrats except for TUT-10, where turf algae was found in only a little above 50% of sampled photoquadrats (Fig. 3.6.1f). Crustose coralline red algae were also prevalent at most sites around the islands (> 75% of sampled photoquadrats per site), but were of lowest abundance near Cape Taputapu at the westernmost point of Tutuila and at TUT-18 in the National Park of American Samoa in the north region. The distribution of cyanophytes around the islands was patchy, with the majority of northeast and southern (south point, south, southeast, and Aunu`u regions) sites containing low to moderate abundances of this functional group. Photoquadrats in the northwest region of Tutuila contained few to no cyanophytes.

In 2006, the south and northeast regions exhibited the highest relative abundance of fleshy and calcified macroalgal genera, although few other obvious distributional trends could be discerned. The calcified, sand-producing green algal genus *Halimeda* occurred in over 90% of sampled photoquadrats at 20% of sites around the island, but the location of these sites appears random (Fig. 3.6.1f). Similarly, the calcified red algal genus, *Peyssonnelia*, occurred in more than 75% of sampled photoquadrats at two south region sites, TUT-11 and TUT-20, and also at one site in the northwest region, TUT-04. The geniculate, calcified, red algal genera *Amphiroa* and *Cheilosporum*, and the brown algal genus, *Dictyota*, were locally abundant, occurring in more than 75% of photoquadrats.

3.6.2 Coralline Algal Disease Surveys

2006 Spatial Surveys

Afflictions to coralline algae were noted while 22 REA surveys were conducted during ASRAMP 2006 (Fig. 3.6.2a). A total of 195 cases were enumerated, almost three times more numerous than coral lesions and disease. Of the 22 sites visited, 9 (41%) contained coralline algal disease. An opposite spatial distribution pattern to that of coral diseases applied to coralline algal disease; the south-facing shores exhibited the majority of the cases (98%). Coralline lethal orange disease (CLOD) was particularly abundant at site TUT-22 in Fagatele Bay National Marine Sanctuary (mean 0.13 cases/m^2), at site TUT-21 south of the airport in the south region (mean 0.06 cases m^{-2}), and at site TUT-15 at Taema Bank (mean 0.09 cases/m^2). The black coralline fungal disease was the second most abundant affliction to coralline algae. Twenty-one cases were enumerated for the whole island, 19 of which occurred at site TUT-10, southwest of Pago Pago Harbor. Additionally, six cases of unidentified coralline algal discoloration were noted at site TUT-11.

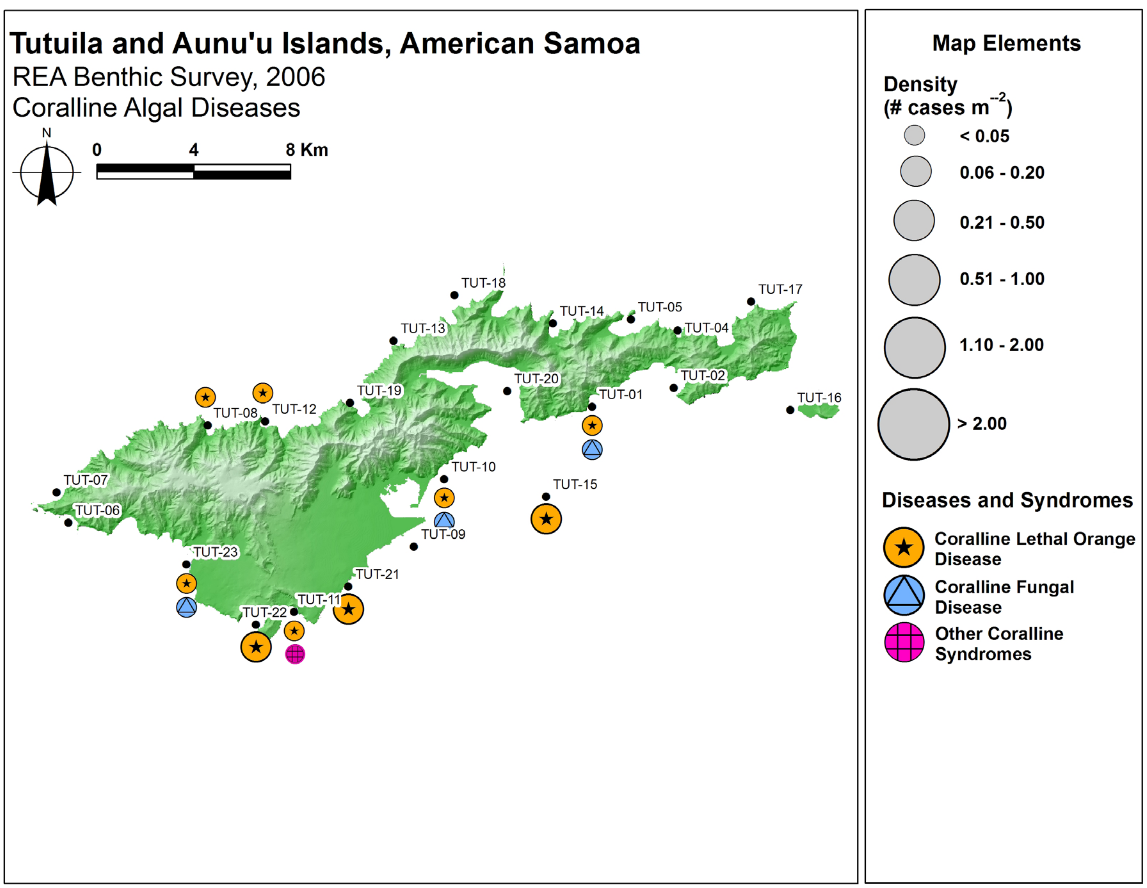

Figure 3.6.2a. Relative abundance of coralline algal diseases around Tutuila and Aunu`u during ASRAMP 2006. Disease density is indicated by the size of the respective disease symbols.

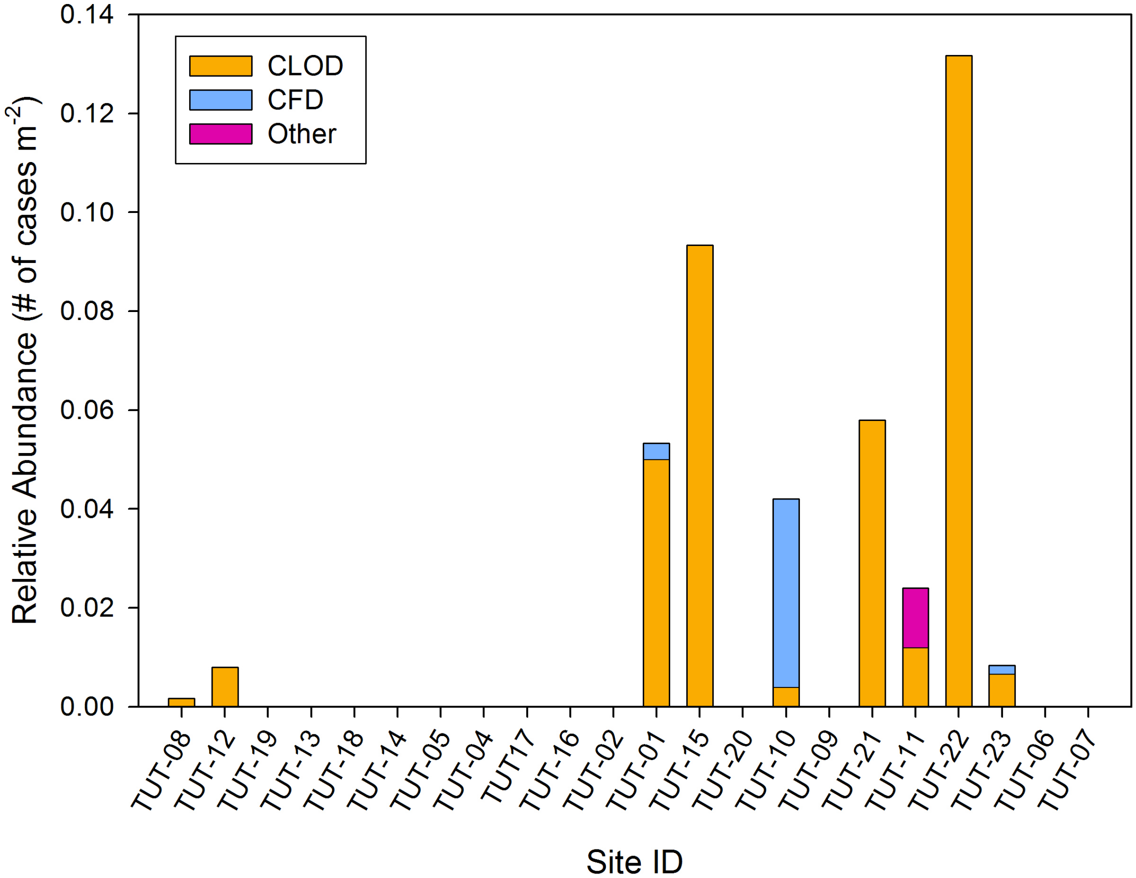

Figure 3.6.2b. Relative abundance of coralline algal disease around Tutuila and Aunu`u during ASRAMP 2006. CLOD: coralline lethal orange disease; CFD: coralline fungal disease; and Other: undetermined coralline discolorations.

3.6.3 Temporal Comparison—Algae

The number of macroalgal genera observed around Tutuila and Aunu`u increased from 29 in 2004 to 34 in 2006, and the relative abundance of fleshy and calcified macroalgal genera also appeared to increase between sampling years (Figs. 3.6.1c and 3.6.1f). The apparent lower algal diversity and abundance in 2004 was likely caused by the passing of Hurricane Heta close to Tutuila in January of 2004 immediately prior to surveys. However, a manuscript being written by Tribollet, Dailer, and Vroom (Tribollet et al., in prep) includes a multivariate statistical temporal analysis of the relative abundance of macroalgae around Tutuila. Preliminary results indicate that despite apparent temporal trends, the mix and relative abundance of algal genera recorded around Tutuila and Aunu`u in 2004 and 2006 did not vary significantly between sampling years.

Anecdotally, many algal population characteristics between the survey years appear similar, and generalized trends pertain to both 2004 and 2006 (Fig. 3.6.3a). Low algal relative abundance along the northwest shore of Tutuila suggests that environmental factors, such as wave energy, may limit algal populations in this area. Fagatele Bay consistently contained among the highest macroalgal diversity seen on the island, suggesting that the increased management protection this area receives may be positively impacting algal community

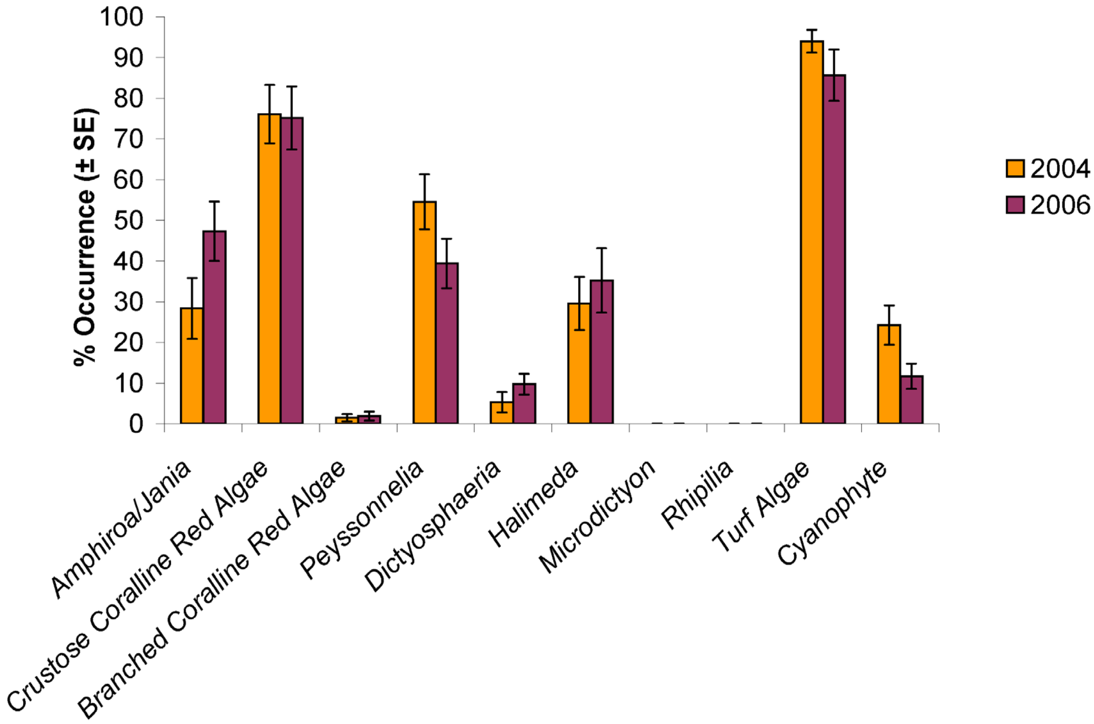

Figure 3.6.3a. Temporal comparison of REA algal genera and functional group percent occurrence around Tutuila and Aunu`u between ASRAMP 2004 and 2006.

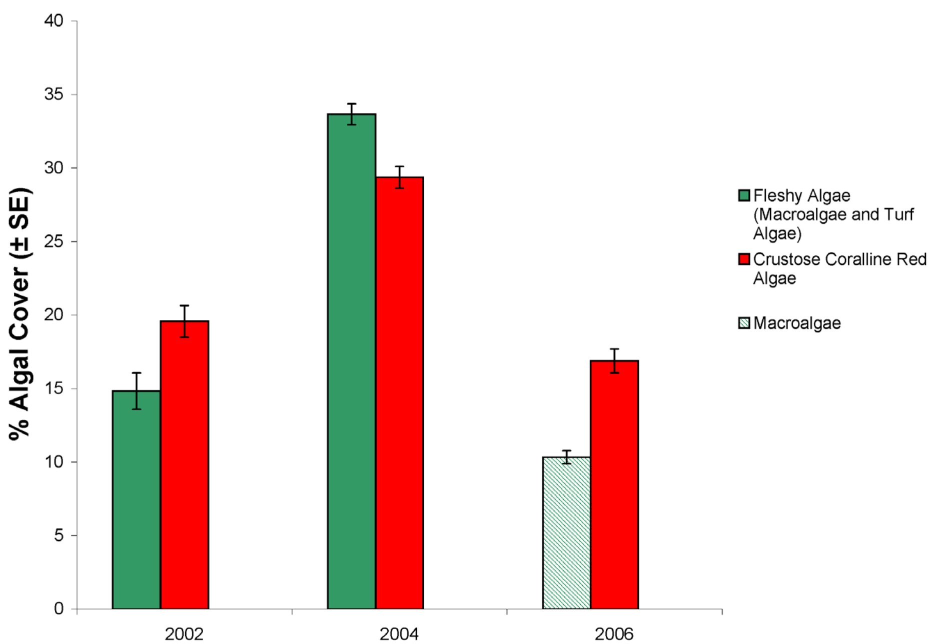

Figure 3.6.3b. Temporal comparison of REA algal genera and functional group percent occurrence around Tutuila and Aunu`u between ASRAMP 2004 and 2006. See Chapter 2, Section 2.4: Reef Benthic (Coral, Algae, Macroinvetebrate) and Fish Surveys for considerations when comparing the results off these methodologies between years.

diversity and structure. No large cyanobacterial outbreaks or monotypic stands of invasive algae were discovered in 2004 or 2006.

A major difference between 2004 and 2006 is the increased abundance of *Amphiroa*/*Jania* at western sites, and the higher percent occurrence of the sand-producing green alga *Halimeda* at multiple sites around the island in 2006 (Fig. 3.6.3a). These population increases may be linked to the absence of heavy storm activity prior to the 2006 surveys. *Jania*, *Amphiroa*, and *Halimeda* are all geniculate calcified genera and may fragment during periods of heavy wave energy, thereby producing asexual reproductive units that can travel in storm-generated currents and resettle when calmer conditions prevail.

As a result of methodological changes, variance in observer's assessment of percent cover of algae, particularly turf algae, and differing tow tracks between years, it is difficult to characterize temporal change in abundance of algae from the existing towed-diver survey observations (Fig. 3.6.3b). Observations of percent cover of crustose coralline algae varied from ~ 20% during ASRAMP 2002 (38 ha) to ~ 30% during ASRAMP 2004 (82 ha) to ~ 17% during ASRAMP 2006 (87.5 ha). Since these observations have not yet been calibrated to determine observer errors or biases, estimates of temporal change should be interpreted with caution. CRED staff members are presently developing methodological revisions to allow more rigorous temporal comparisons during future surveys.

3.7 Benthic Macroinvertebrates

3.7.1 Benthic Macroinvertebrate Surveys

2002 Spatial Surveys

Towed-diver benthic macroinvertebrate surveys around Tutuila during ASRAMP 2002 found variable distributions of giant clams, sea cucumbers, and sea urchins (Fig. 3.7.1a). Giant clams were observed in greatest density in the northwest region with a mean density of 1.4 organisms ha^{-1}. Sea urchins were observed in greatest densities in the south, north and south point regions (3155, 1473, and 1324 organisms ha^{-1}, respectively). Urchins were almost completely absent in the northeast and southeast regions. No crown-of-thorns seastar (COTS) were observed around Tutuila in 2002. As mentioned in the introduction (Section 1.6: Limitations of Pacific RAMP), ASRAMP 2002 surveys were limited by shipboard logistics and development of ongoing methods which may have contributed to the paucity of macroinvertebrates observed in 2002.

A total of 14 qualitative REA invertebrate surveys, which focused on general macroinvertebrate biodiversity, were conducted around Tutuila during ASRAMP 2002. These surveys provided

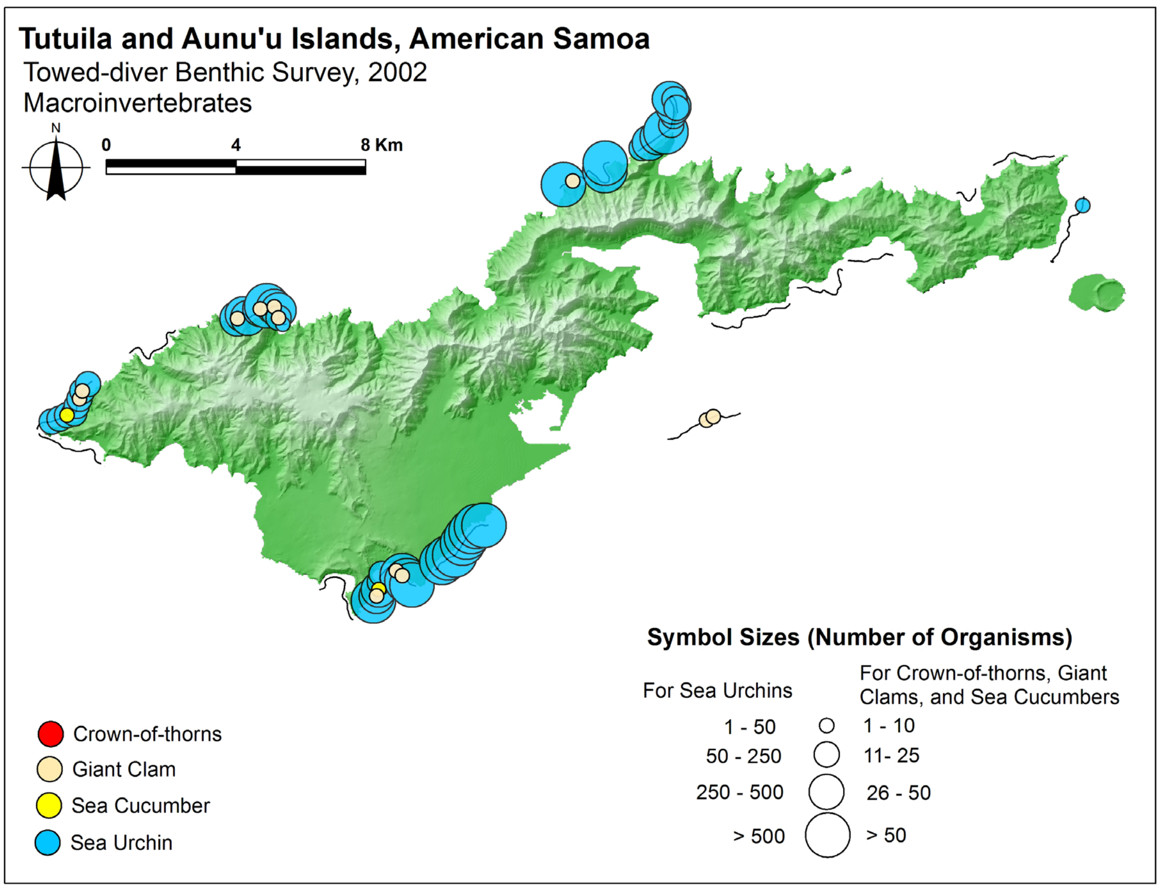

Figure 3.7.1a. Distribution of estimated population densities of COTS, giant clams, sea cucumbers, and sea urchins around Tutuila and Aunu`u from towed-diver benthic surveys during ASRAMP 2002. Circle locations represent an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2). The sizes of the circles indicate the number of organisms counted or estimated in each ~ 2000 m^2 segment with one scale for COTS, giant clams, and sea cucumbers (1–10, 11–25, 26–50, and > 50) and another scale for sea urchins (1–50, 51–250, 250–500, and > 500).

baseline data used to design and scale the future methodology of macroinvertebrate REA surveys. No data are presented.

2004 Spatial Surveys

Towed-diver benthic macroinvertebrate surveys around Tutuila and Aunu`u during ASRAMP 2004 found variable distributions of giant clams, sea cucumbers, and sea urchins (Fig. 3.7.1b). Giant clams were widely distributed around Tutuila and Aunu`u with generally low mean densities (~ 5–10 organisms ha^{-1}). One noteworthy exception was a localized area in the south region with a high density of giant clams (21.7 organisms ha^{-1}). Sea cucumber mean densities were greatest in the north (1.1 organisms ha^{-1}) and northeast regions (0.7 organisms ha^{-1}). Sea urchin mean densities were greatest on Taema Bank (1869 organisms ha^{-1}), off Aunu`u (1623 organisms ha^{-1}), and in the south and south point regions (1515 and 1712 organisms ha^{-1}, respectively). Perhaps more surprising, however, was the near absence of urchins along long stretches of towed-diver survey tracks in the southeast and southwest regions. Only two COTS were observed around Tutuila and Aunu`u in 2004, both in Masefau Bay in the north region.

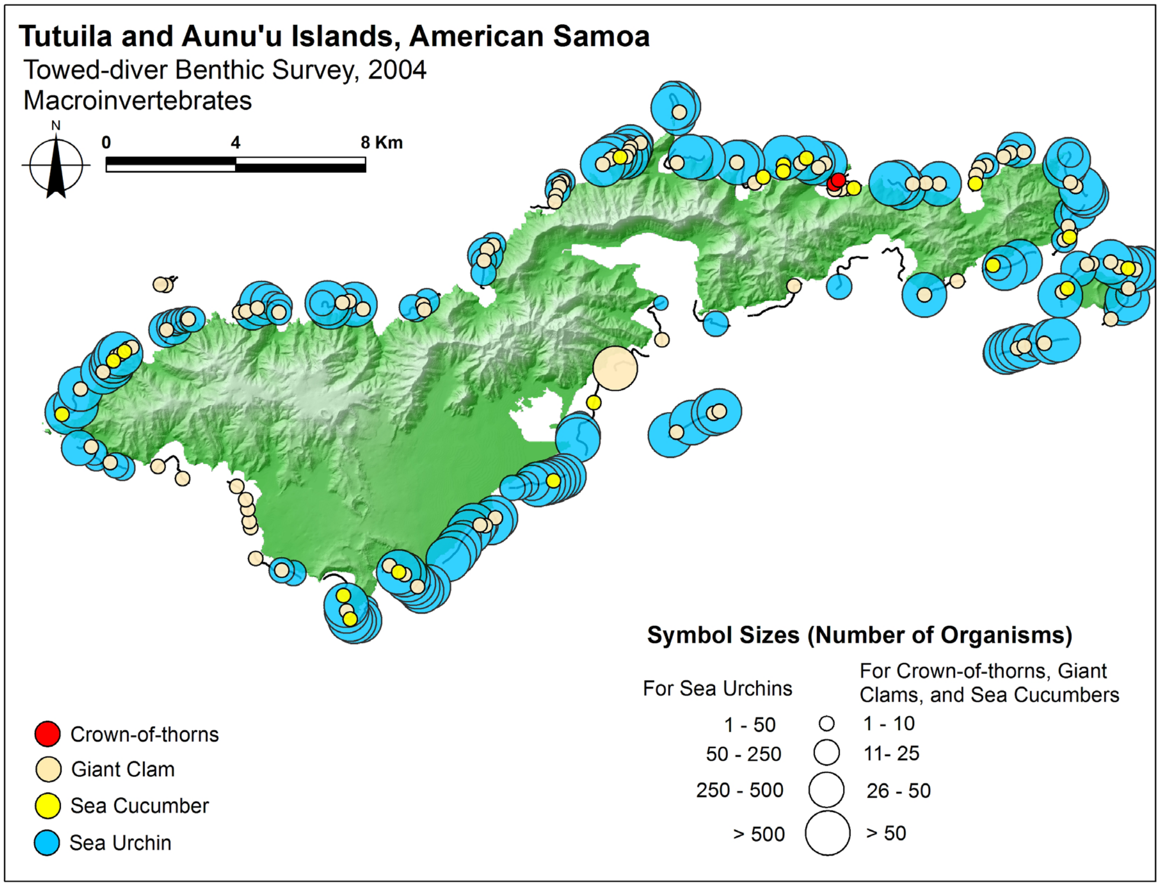

Figure 3.7.1b. Distribution of estimated population densities of COTS, giant clams, sea cucumbers, and sea urchins around Tutuila and Aunu`u from towed-diver benthic surveys during ASRAMP 2004. Circle locations represent an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2). The sizes of the circles indicate the number of organisms counted or estimated in each ~ 2000 m^2 segment with one scale for COTS, giant clams, and sea cucumbers (1–10, 11–25, 26–50, and > 50) and another scale for sea urchins (1–50, 51–250, 250–500, and > 500).

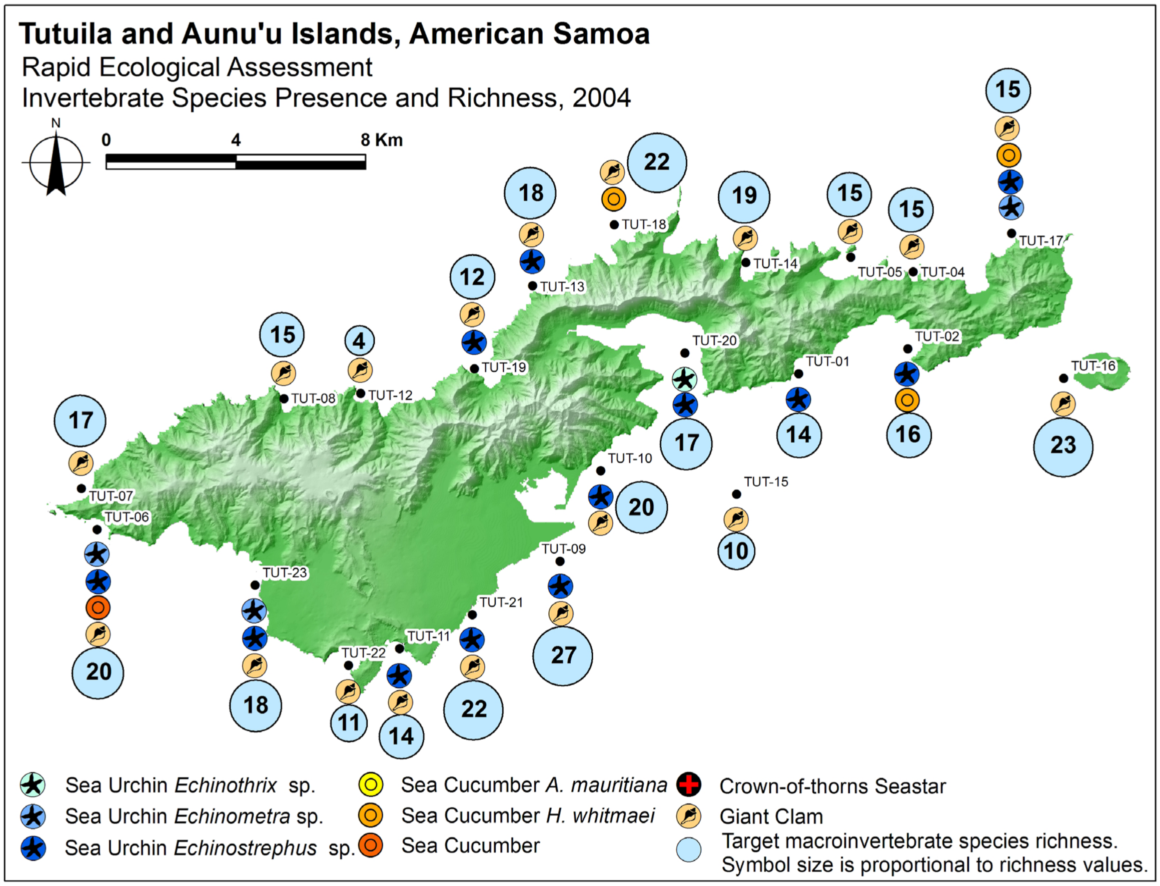

Figure 3.7.1c. Macroinvertebrate species richness, and target macroinvertebrate distribution around Tutuila and Aunu`u from REA surveys during ASRAMP 2004. Size of light blue circles and values in circles indicate target species richness values for each REA site. Other symbols indicate the presence of specific target species.

During ASRAMP 2004, invertebrate species richness at REA sites around Tutuila and Aunu`u was variable, ranging from a total of 4 species found at site TUT-12 in the northwest region, to a high of 27 species recorded at site TUT-09 in the southwest region (Fig. 3.7.1c). Generally, higher species richness was observed on the southern coast of Tutuila. Target invertebrate species were common, with giant clams present at all sites, except the three sites in the southeast region. Sea urchins were found at over half of the REA sites around Tutuila, but were not observed within the northwest region and parts of the northeast region. The most common urchin was *Echinostrephus* sp., which was found mostly off the southern coast. Sea cucumbers were observed at only four widely scattered sites around Tutuila. No COTS were recorded at any of the 22 REA sites.

2006 Spatial Surveys

Towed-diver benthic macroinvertebrate surveys around Tutuila and Aunu`u during ASRAMP 2006 found variable distributions of giant clams, sea cucumbers, and sea urchins (Fig. 3.7.1d). Giant clam mean densities were greatest in the northern region and around the south point region of Tutuila (1.8 and 1.6 organisms ha^{-1}, respectively). Sea cucumber mean densities were greatest in the southeast region (1.5 organisms ha^{-1}) while no sea cucumbers were observed along most of the northern, northeastern, south point, Taema Bank, and southwestern regions. Sea urchin mean densities were greatest around Aunu`u (936 organisms ha^{-1}), in the southern region (747 organisms ha^{-1}), and in the south point region (608 organisms ha^{-1}). Sea urchins were observed in very low densities in the Taema Bank and northwest regions. Only one COTS was observed around Tutuila in 2006, in the south point region within Larsen's Bay.

Macroinvertebrates were common at REA sites around Tutuila and Aunu`u during ASRAMP 2006. Sea urchins were abundant, being present at all but three REA sites, two of which were located in the southwest region of Tutuila (TUT-06, -23). The most common sea urchin was *Echinostrephus aciculatus*, being found at 17 of 22 sites. *Echinometra matheii* was also

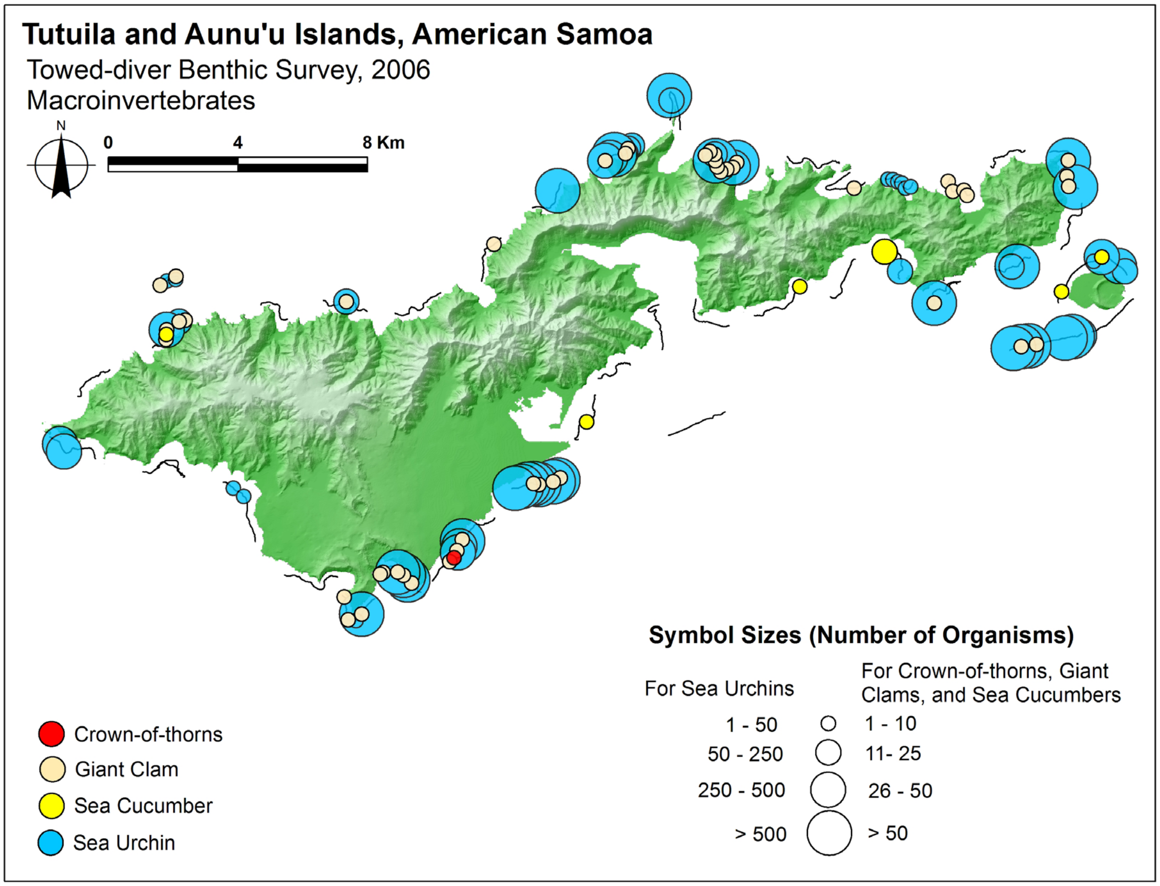

Figure 3.7.1d. Distribution of estimated population densities of COTS, giant clams, sea cucumbers, and sea urchins around Tutuila and Aunu`u from towed-diver benthic surveys during ASRAMP 2006. Circle locations represent an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2). The sizes of the circles indicate the number of organisms counted or estimated in each ~ 2000 m^2 segment with one scale for COTS, giant clams, and sea cucumbers (1–10, 11–25, 26–50, and > 50) and another scale for sea urchins (1–50, 51–250, 250–500, and > 500).

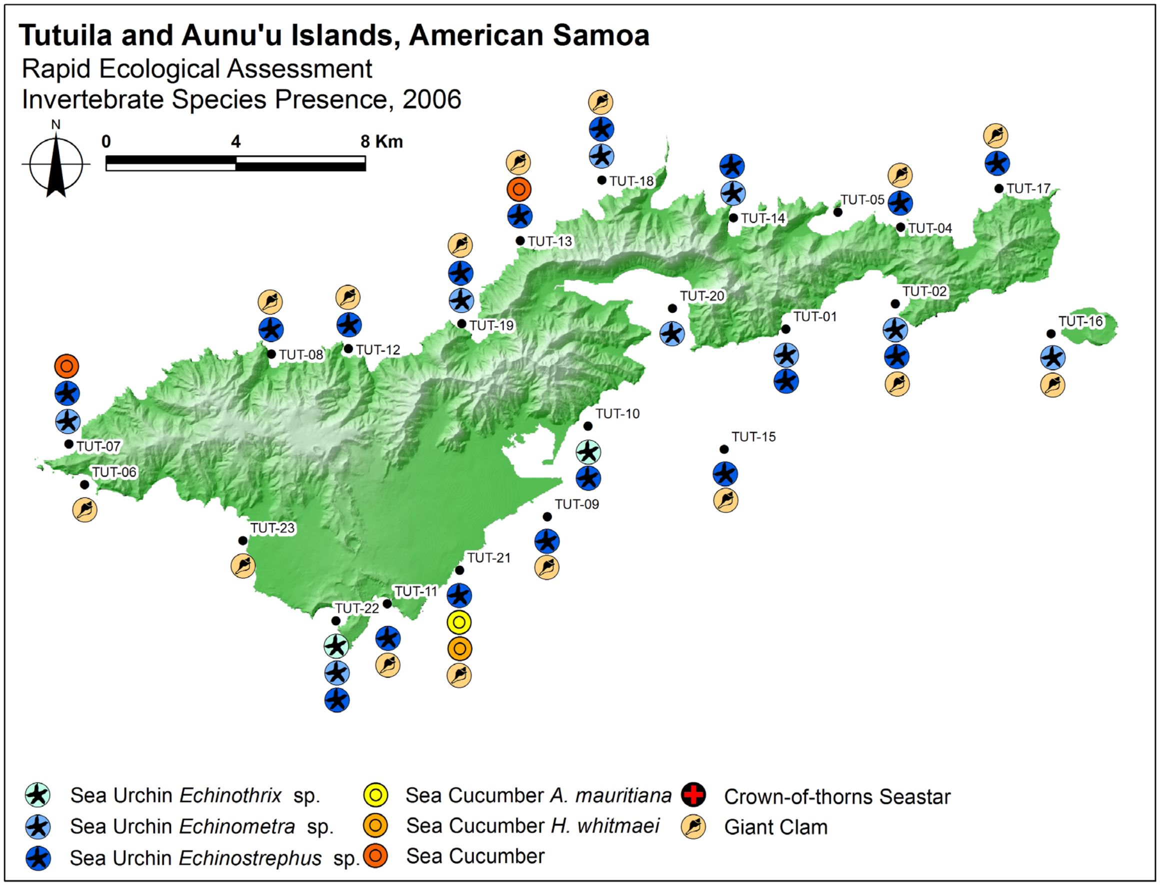

Figure 3.7.1e. Target macroinvertebrate distribution around Tutuila and Aunu`u from REA surveys during ASRAMP 2006. surveys during ASRAMP 2006.

commonly found at sites in the south and southeast regions of Tutuila and at Aunu`u (TUT-20, -01, -02, -16). Giant clams were widely distributed, being present at 15 of the 22 REA sites around Tutuila. As observed during towed-diver macroinvertebrate surveys, giant clams were absent at sites TUT-20, TUT-01, and TUT-10 in the south region. Sea cucumbers were relatively uncommon and no COTS were recorded at REA sites in 2006.

Macroinvertebrate species richness was not quantified in 2006 at REA sites.

3.7.2 Temporal Comparison—Benthic Macroinvertebrates

Temporal patterns of island-wide mean benthic macroinvertebrate density (organisms ha^{-1}) around Tutuila and Aunu`u from towed-diver benthic surveys during ASRAMP 2002, 2004, and 2006 cruises are shown in Figure 3.7.2a (COTS), Figure 3.7.2b (giant clams), Figure 3.7.2c (sea cucumbers), and Figure 3.7.2d (sea urchins). Towed-diver survey results show trends in density within each surveyed organism and between each sampling year.

Benthic macroinvertebrate distribution and abundance around Tutuila and Aunu`u in 2002, 2004 and 2006 were temporally and spatially variable; however patterns emerge around specific coastlines. In general, higher densities of sea urchins were observed along the southern coast, with the exception of Pago Pago Harbor and the southeast region, where overall macroinvertebrate densities were low (Figs. 3.7.1b and 3.7.1d). In addition, while

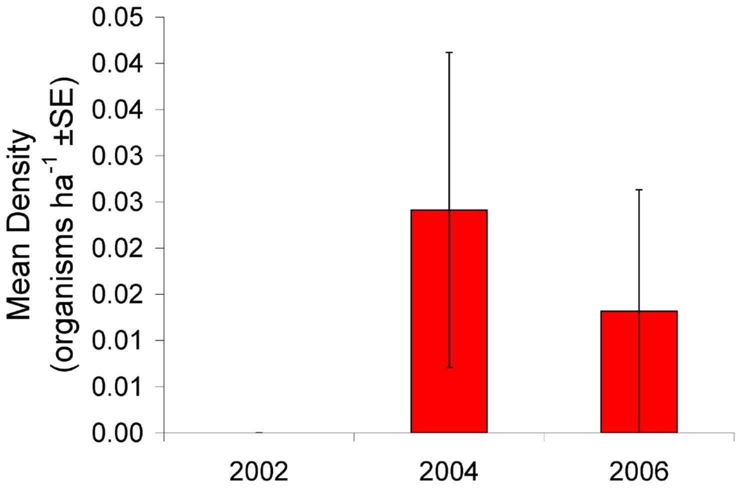

Figure 3.7.2a. Mean density of COTS around Tutuila and Aunu`u from towed-diver surveys during ASRAMP 2002, 2004 and 2006.

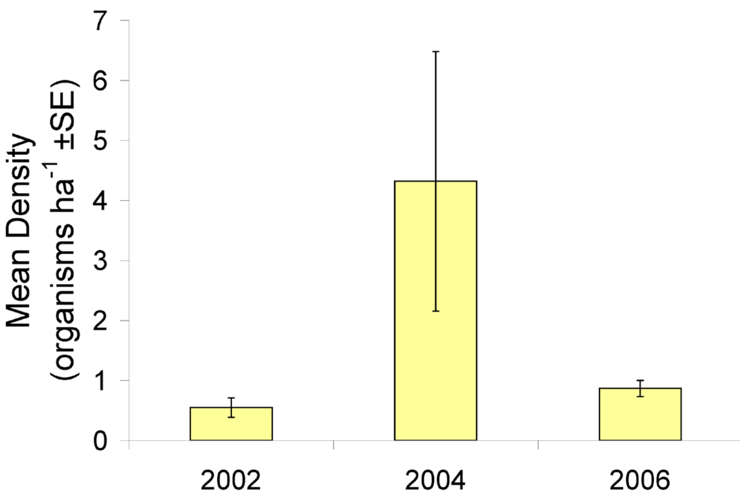

Figure 3.7.2b. Mean density of giant clams around Tutuila and Aunu`u from towed-diver surveys during ASRAMP 2002, 2004, and 2006.

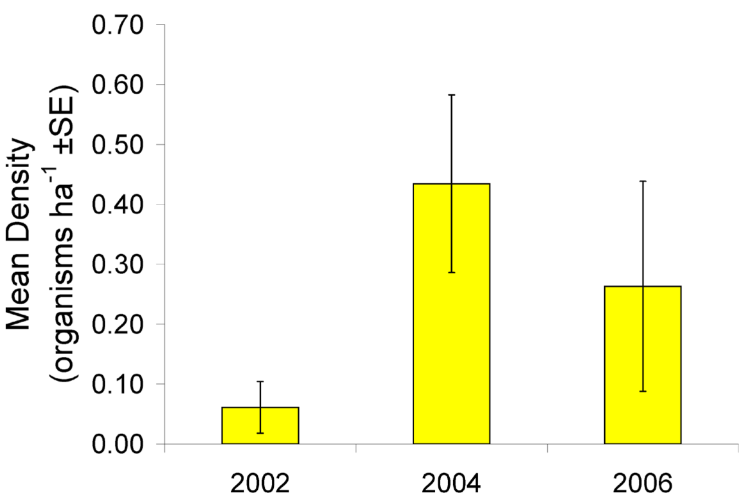

Figure 3.7.2c. Mean density of sea cucumbers (holothuroids) around Tutuila and Aunu`u from towed-diver surveys during ASRAMP 2002, 2004 and 2006.

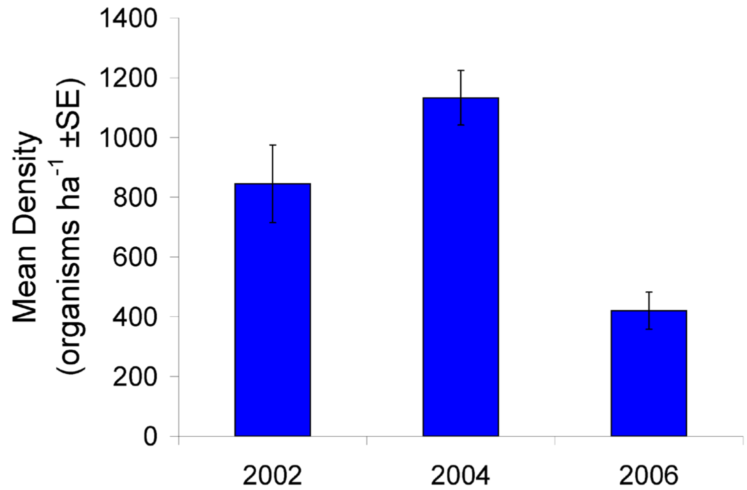

Figure 3.7.2d. Mean density of sea urchins (echinoids) around Tutuila and Aunu`u from towed-diver surveys during ASRAMP 2002, 2004 and 2006.

surveys indicated an overall broad distribution of giant clams around the island, very few were reported in the southeast region during either towed-diver or REA surveys in all years (Figs. 3.7.1a, 3.7.1 b, 3.7.1c, 3.7.1d, and 3.7.1e). COTS observations were rare in all years.

It is important to note that quantifying benthic macroinvertebrate communities presents multiple challenges. Benthic macroinvertebrates are specialized and can be mobile in the marine environment. Both REA and towed-diver surveys sampling methodologies can vary in location and depth, thereby varying the specific reef system that is surveyed and affecting the benthic macroinvertebrate survey results. Changes that have occurred in the towed-diver methodology over these survey years and observer errors impact the comparability of data across years. Because of these known discrepancies in macroinvertebrate data, results must be analyzed with caution.

3.8 Reef Fish

3.8.1 Reef Fish Surveys

2002 Spatial Surveys

The majority of the biomass of large fish (total length > 50 cm) around Tutuila during ASRAMP 2002 towed-diver surveys were composed of wrasses, sharks, and jacks (Fig. 3.8.1a). Barracudas were encountered in discrete schools on the western end of the island, south of Cape Taputapu, in the northwest region. Parrotfish were observed to be more evenly distributed, but seemed to be most consistent across reefs along in portions of the southeast, south, and Taema Bank regions of the island. In general, the northern side of Tutuila had the highest biomass of large fish. The mean large fish biomass for the island was 0.048 tons ha^{-1} (SE 0.040).

Shark species were uncommon during the ASRAMP 2002 surveys, with a small number of whitetip reef sharks (*Triaenodon obesus*) scattered along the southern shores of the

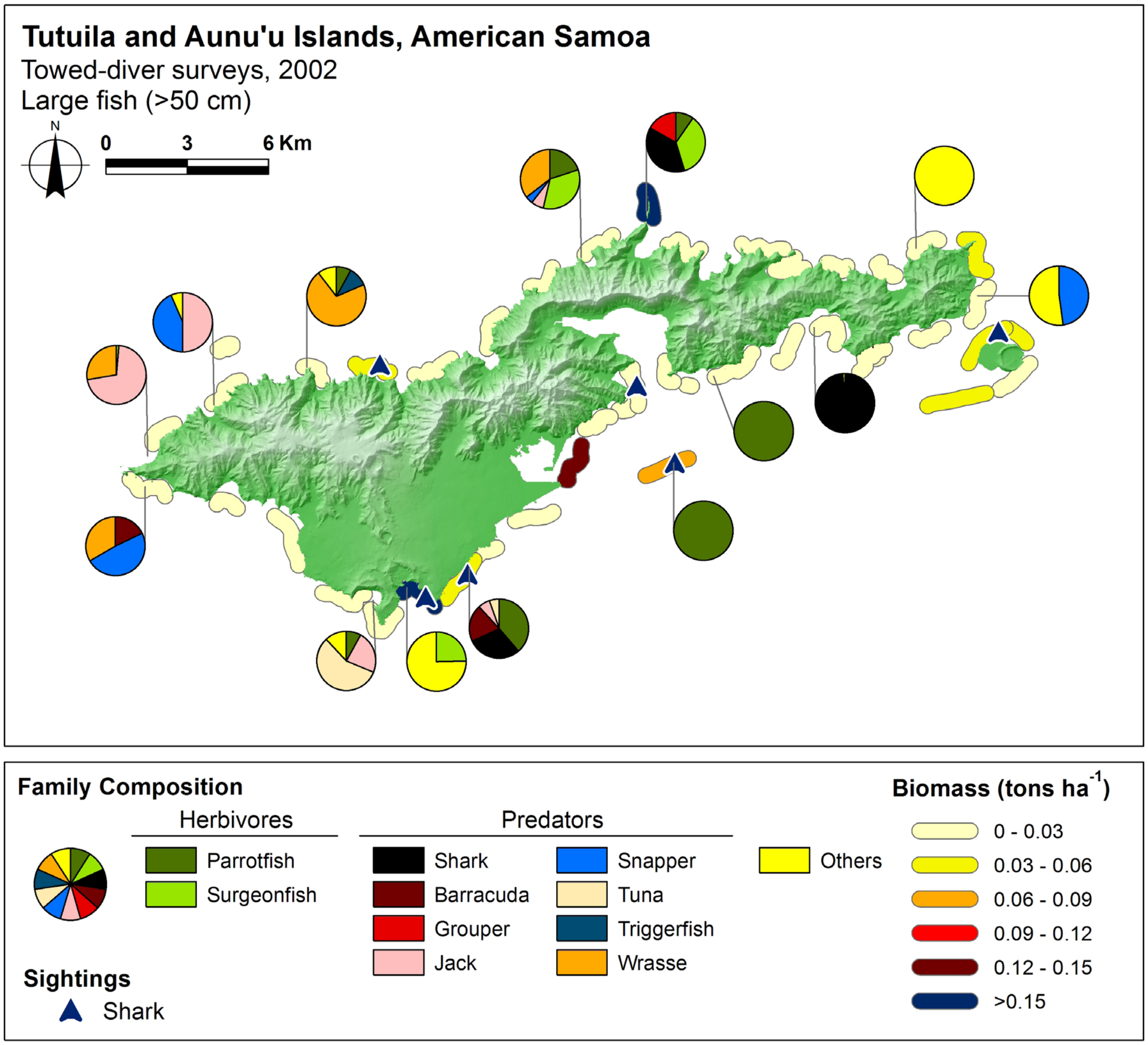

Figure 3.8.1a. Large fish biomass, family composition, and individual shark sightings around Tutuila recorded during ASRAMP 2002 towed-diver surveys. Large fish (length > 50 cm) biomass on each individual towed-diver survey is represented by the color of the survey track (tons ha^{-1}). Composition by trophic group is indicated by the family colors (green—mostly herbivores; other colors—mostly predators or mixed). Individual shark sightings, observed inside or outside the survey area, are represented by blue triangles.

island (Fig. 3.8.1a). Very few gray reef sharks (*Carcharhinus amblyrhynchos*) were observed. An adult leopard shark (*Stegostoma varium*) was recorded just north of the channel between Tutuila and Aunu`u, and a juvenile of the same species was seen (not during quantitative survey) in the same area. Jacks were also uncommon during the 2002 surveys, aside from the sighting of a school of about 60 bigeye trevallies (*Caranx sexfasciatus*). While jack density was low, diversity was as expected with five species present: bigeye trevally (*Caranx sexfasciatus*), giant trevally (*C. ignobilis*), bluefin trevally

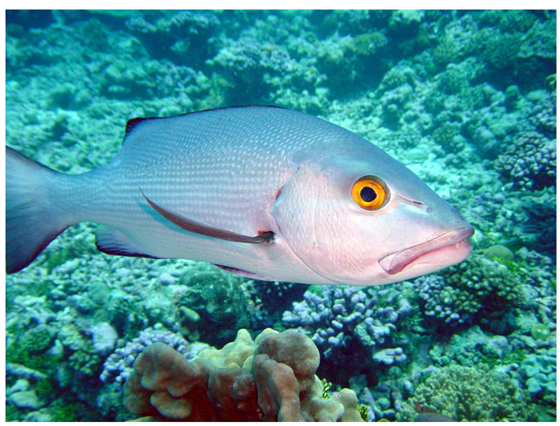

Figure 3.8.1b. Twinspot snapper (*Lutjanus bohar*) on reef, American Samoa. (*Photograph provided by NOAA PIFSC CRED; R. Schroeder, JIMAR*)

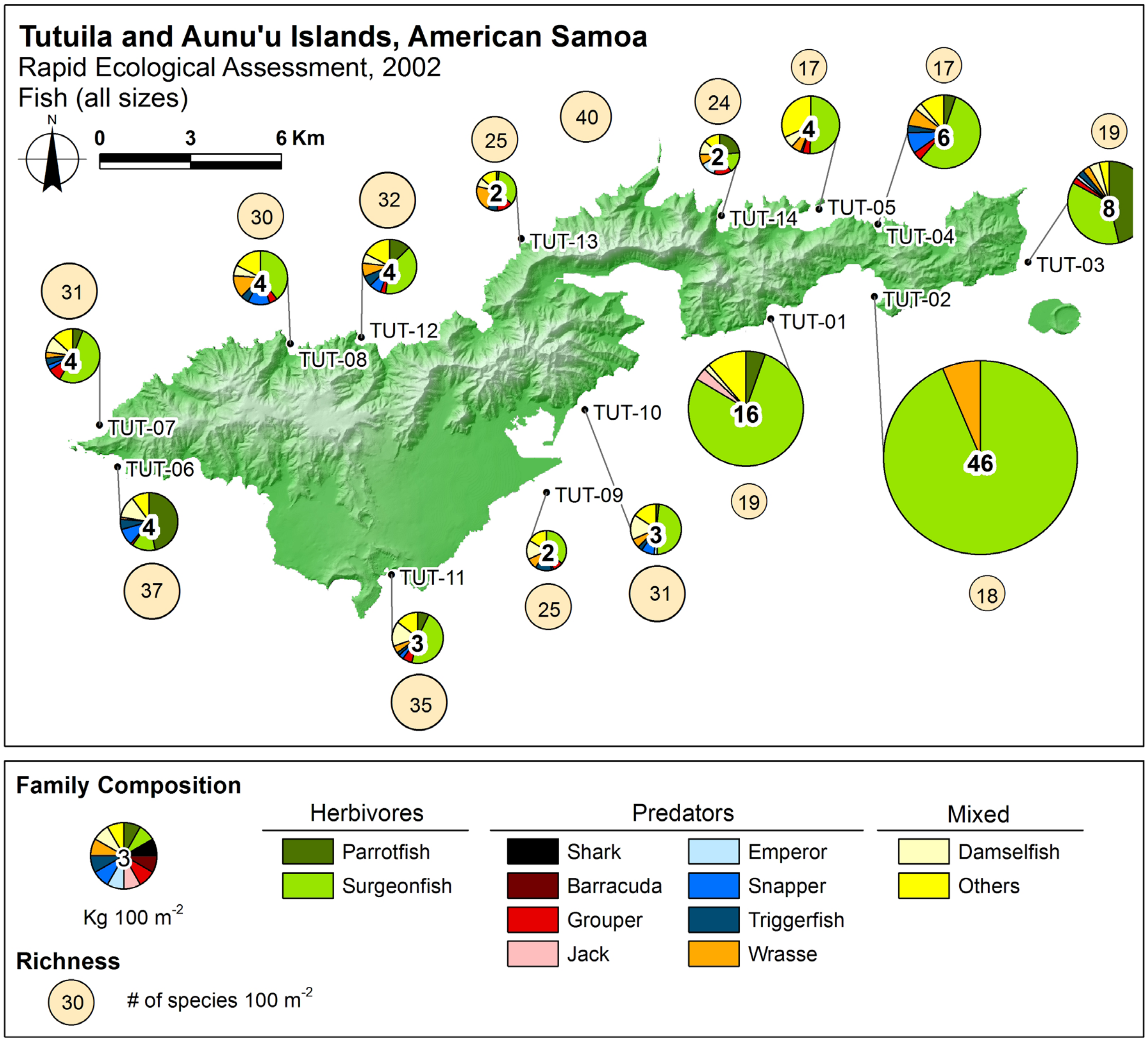

Figure 3.8.1c. Total fish biomass, family composition, and species richness of fishes around Tutuila and Aunu`u recorded during ASRAMP 2002 REA belt-transect surveys. Total fish biomass (all species and size classes) is represented at each site by the size of the pie chart with the actual biomass value in the center (kg 100 m^{-2}). Composition by trophic group is indicated by the family colors (green—mostly herbivores; other colors—mostly predators or mixed). Species richness at each REA site is indicated by numbers (species 100 m^{-2}) and the size of the beige circles.

(*C. melampygus*), yellow-spotted trevally (*Carangoides orthogrammus*), and rainbow runner (*Elagatis bipinnulata*). About 15 species of groupers were noted, the most common being the small flagtail (*Cephalopholis urodeta*) and peacock groupers (*Cephalopholis argus*). Nine species of snappers (Lutjanidae) were observed, with the twinspot snapper (*Lutjanus bohar*; Fig. 3.8.1b) being the most common in 2002. A relatively high number of humphead wrasses (*Cheilinus undulatus*) were seen at the western point of Tutuila near Cape Taputapu (Fig. 3.8.1a.).

In 2002, total fish biomass was generally similar around Tutuila, 7.6 kg 100 m^{-2} (SE 4.6), except for two particular sites in the southeast region (TUT-01 and TUT-02), where a massive recruitment event of the surgeonfish *Ctenochaetus striatus* was observed (Fig. 3.8.1c). At these sites, juvenile *Ctenochaetus striatus* (5-10 cm in length) were found in high densities of around 250 individuals 100 m^{-2}. Few predators were recorded around the island on belt-transect surveys during ASRAMP 2002 surveys.

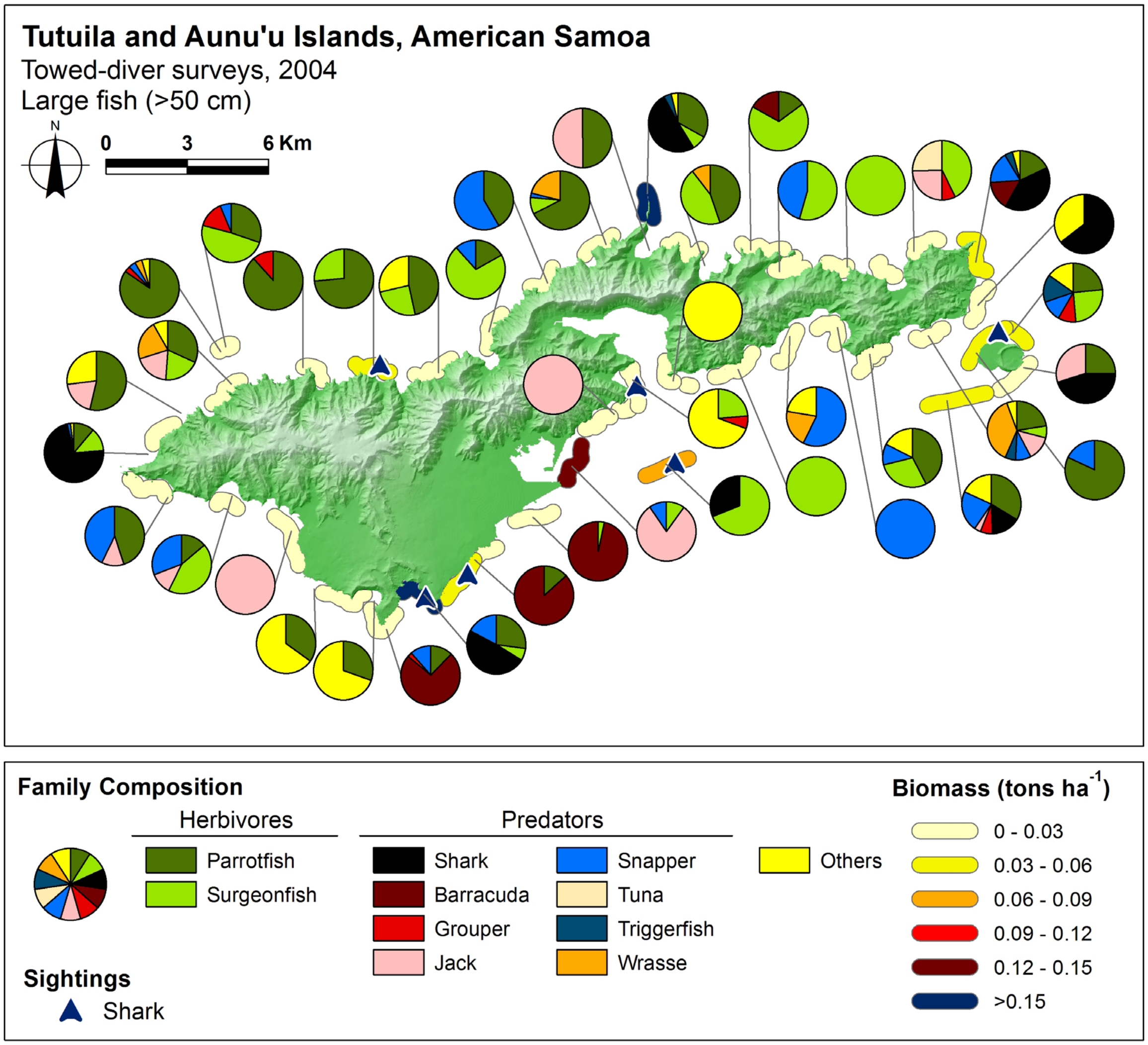

Figure 3.8.1d. Large fish biomass, family composition, and individual shark sightings around Tutuila and Aunu`u recorded during ASRAMP 2004 towed-diver surveys. Large fish (length > 50 cm) biomass on each individual towed-diver survey is represented by the color of the survey track (tons ha^{-1}). Composition by trophic group is indicated by the family colors (green—mostly herbivores; other colors—mostly predators or mixed). Individual shark sightings, observed inside or outside the survey area, are represented by blue triangles.

Based on ASRAMP 2002 REA surveys, fish species richness was greatest (~ 30–40 species 100 m^{-2}) along the western half of Tutuila in the south point, southwest, and northwest regions compared to the lower richness found along the eastern half of the island (~ 20 species100 m^{-2}; Fig. 3.7b).

2004 Spatial Surveys

During the ASRAMP 2004 surveys, conditions at about half of the sites along the north side of Tutuila were hampered by large swells that resuspended sediment in the water column and reduced visibility (i.e., 1–4 m). For this reason, some of the quantitative fish data at these sites need to be interpreted with caution.

During 2004 towed-diver surveys around Tutuila and Aunu`u, both barracudas and parrotfish were the large fishes with the highest biomass, with barracudas present in large schools (Fig. 3.8.1d). The large fish biomass was 0.041 tons ha$^{-1}$ (SE 0.016) for Tutuila and Aunu`u. Sharks were observed all around the island, particularly at the eastern end, south of Cape Matatula. A total of nine humphead wrasses were sighted at numerous spatially distributed sites around the island.

During 2004, total fish biomass from REA surveys was generally equally distributed around Tutuila, as in 2002 (Fig. 3.8.1e). The mean total fish biomass in 2004 was 9.4 kg 100 m^{-2} (SE 5.5). Two particular sites, TUT-17 near Cape Matatula in the northeast region and TUT-21 off the Tafuna Plain (Vaitogi) in the south region had exceptionally elevated fish biomass estimates caused by shark sightings, while TUT-11 in Larsen's Bay in the south point region had elevated biomass primarily because of a high surgeonfish abundance (Fig. 3.8.1e). Herbivores were the dominant trophic group, surgeonfish being abundant in all regions on the south side of the island and parrotfish most abundant in the north region.

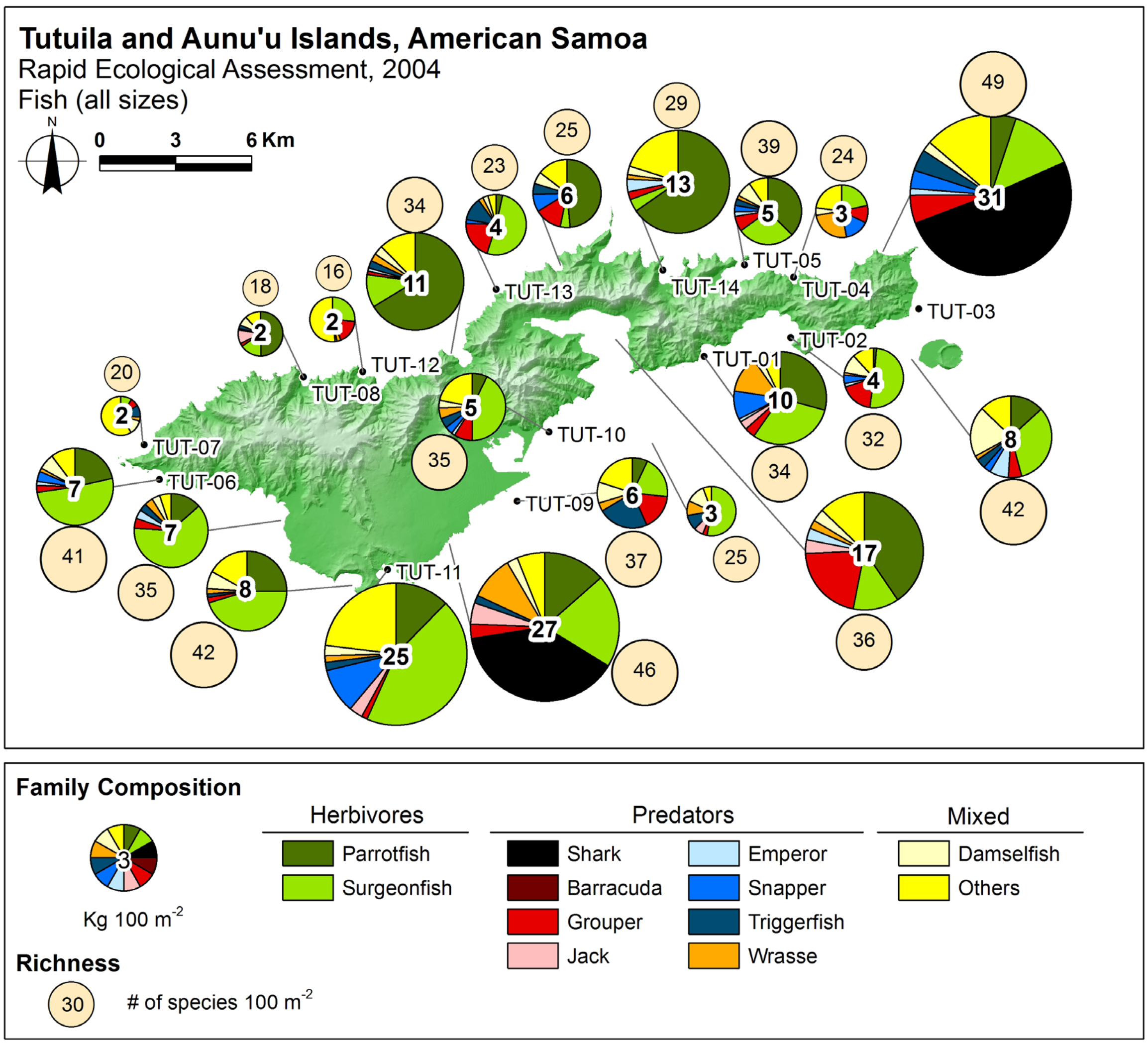

Figure 3.8.1e. Total fish biomass, family composition, and species richness of fishes around Tutuila and Aunu`u recorded during ASRAMP 2004 REA belt-transect surveys. Total fish biomass (all species and size classes) is represented at each site by the size of the pie chart with the actual biomass value in the center (kg 100 m^{-2}). Composition by trophic group is indicated by the family colors (green—mostly herbivores; other colors—mostly predators or mixed). Species richness at each REA site is indicated by numbers (species100 m^{-2}) and the size of the beige circles.

Stationary point counts were initiated in 2004 to more effectively measure abundance of medium to large fish (> 25 cm total length). Based on biomass estimates from the stationary point count surveys, parrotfish were the dominant taxon for medium-to-large fish around Tutuila. Other relatively common families included snappers, groupers, surgeonfish, emperors, and wrasses.

During the ASRAMP 2004 surveys, fish species richness was highest in the south point region (~ 42–54 species 100 m^{-2}; Fig. 3.8.1e). Species richness was also moderately high in the southwest, south, and southeast regions (~ 25–42 species 100 m^{-2}). In addition, a previously unsurveyed site, TUT-17, near Cape Matatula in the northeast region also demonstrated high diversity (~ 45 species 100 m^{-2}). Most of the north shore sites were observed to have fewer species, with less than 30 per 100 m^{-2}. The lowest species richness was observed in the northwest region with ~ 16–34 species 100 m^{-2}.

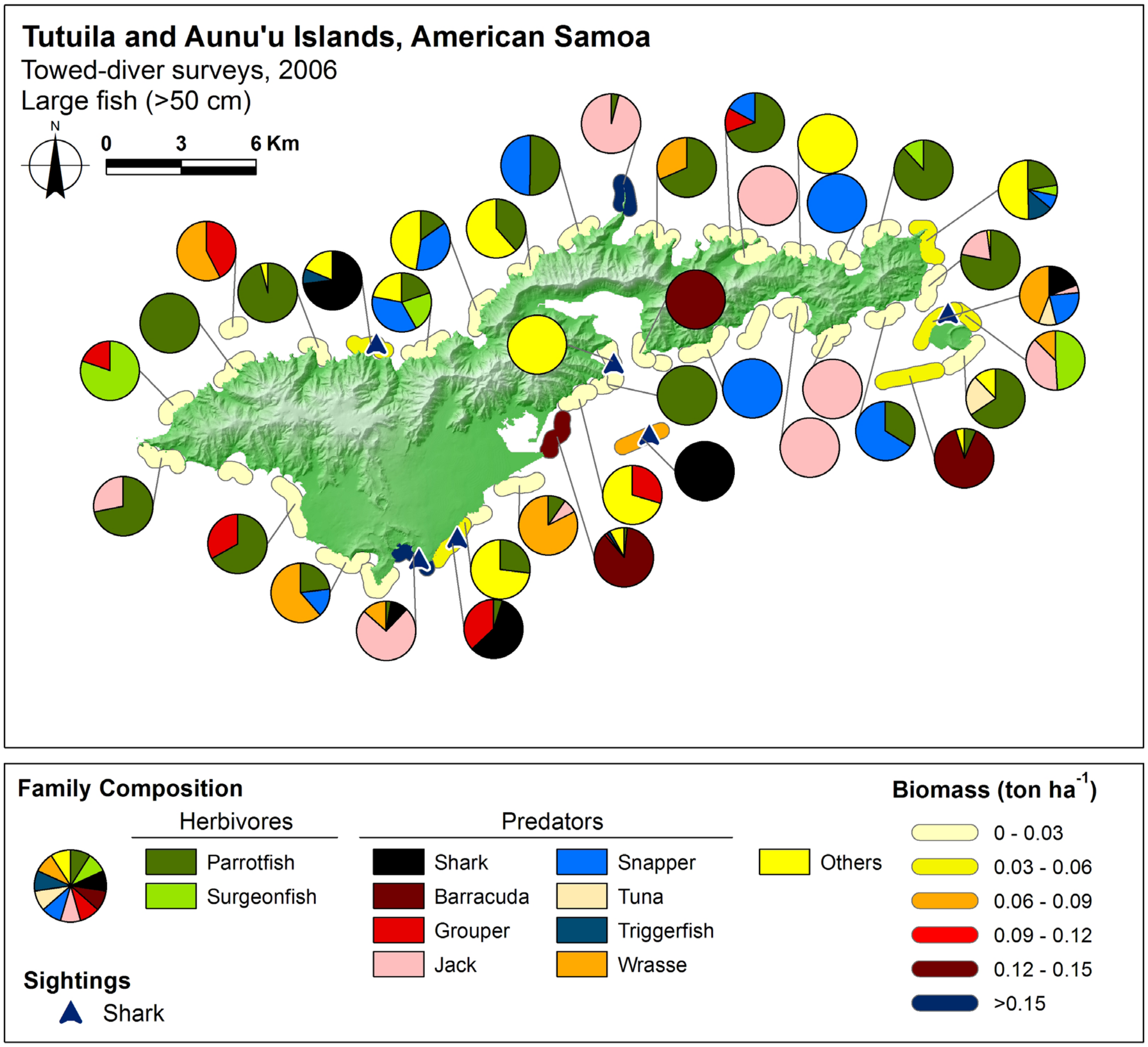

Figure 3.8.1f. Large fish biomass, family composition, and individual shark sightings around Tutuila and Aunu`u recorded during ASRAMP 2006 towed-diver surveys. Large fish (length > 50 cm) biomass on each individual towed-diver survey is represented by the color of the survey track (tons ha^{-1}). Composition by trophic group is indicated by the family colors (green—mostly herbivores; other colors—mostly predators or mixed). Individual shark sightings, observed inside or outside the survey area, are represented by blue triangles.

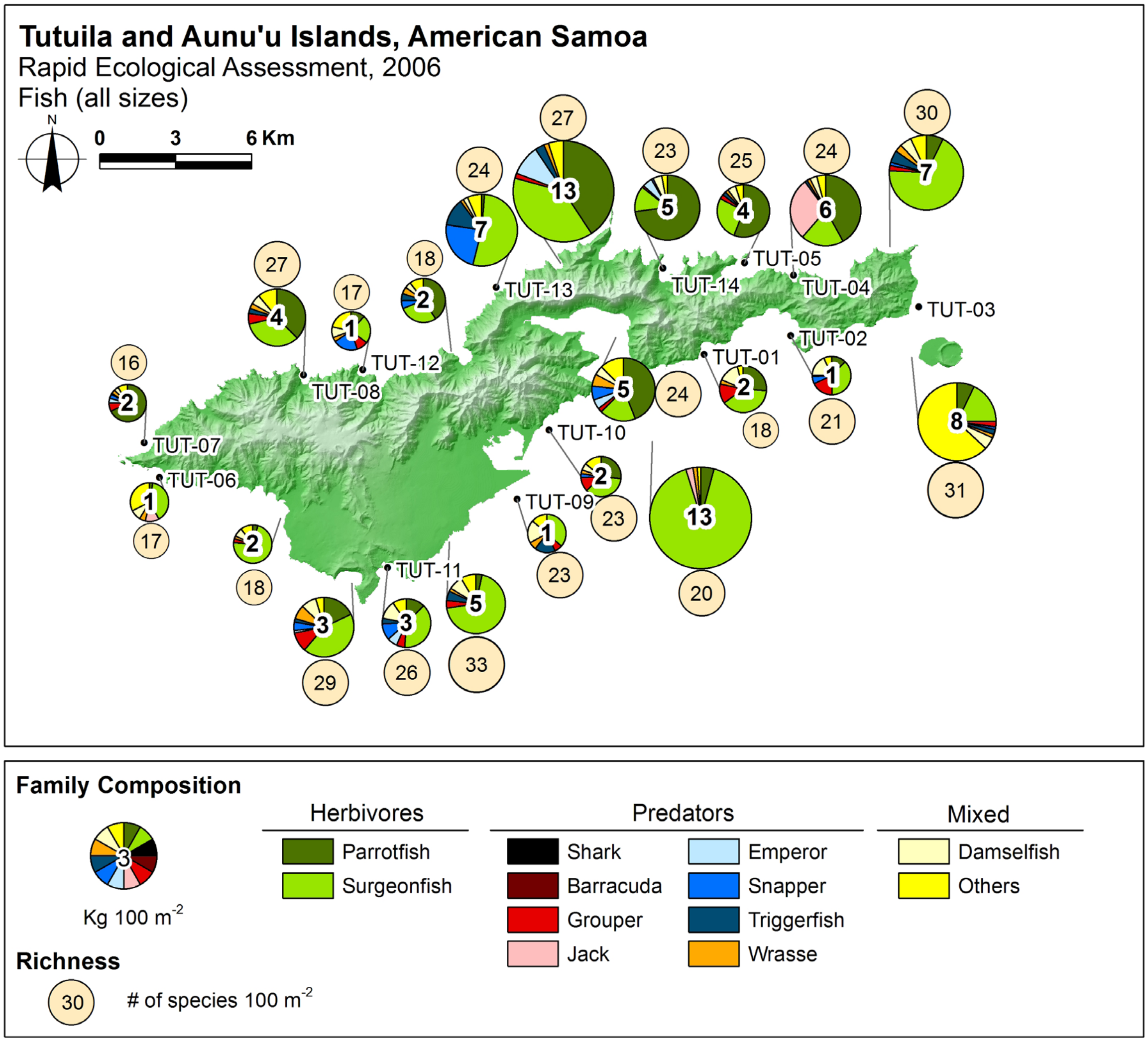

Figure 3.8.1g. Total fish biomass, family composition, and species richness of fishes around Tutuila and Aunu`u recorded during ASRAMP 2006 REA belt-transect surveys. Total fish biomass (all species and size classes) is represented at each site by the size of the pie chart with the actual biomass value in the center (kg 100 m^{-2}). Composition by trophic group is indicated by the family colors (green—mostly herbivores; other colors—mostly predators or mixed). Species richness at each REA site is indicated by numbers (species 100 m^{-2}) and the size of the beige circles.

2006 Spatial Surveys

During the ASRAMP 2006 large fish towed-diver surveys, parrotfish, sharks, and jacks made up the majority of the large fish biomass around Tutuila and Aunu`u (Fig. 3.8.1f). Common large fish included bigeye trevallies (*Caranx sexfasciatus*) and blackfin barracudas (*Sphyraena qenie*). Mean large fish biomass was 0.042 tons ha^{-1} (SE 0.026).

A total of nine humphead wrasses (*Cheilinus undulatus*) were observed widely scattered, though predominantly along the southern regions of Tutuila during the 2006 surveys (Fig. 3.8.1f). Six sharks (from three species) and one bumphead parrotfish (*Bolbometopon muricatum*) were sighted around Tutuila (Fig. 3.8.1f).

During the ASRAMP 2006 REA surveys, the general pattern of total fish biomass was similar to previous years, with the southern sections of Tutuila harboring a mean fish biomass of ~ 3 kg 100 m^{-2} and the northern sections harboring a mean fish biomass of ~ 5 kg 100 m^{-2} (Fig. 3.8.1g). However, reef fish biomass was generally much lower than in 2002 and 2004. Surgeonfish and parrotfish dominated total biomass at most sites island-wide. Piscivores were rarely recorded during fish belt-transect surveys. Total fish biomass in 2006 was around 4.5 kg 100 m^{-2} (SE 1.8).

Estimates of abundance of medium-large fish surveyed using stationary point counts remained relative low around Tutuila during ASRAMP 2006 (Fig. 3.8.1g). Parrotfish (i.e., *Scarus japanensis*) biomass estimates continued to dominate this size class, with fewer surgeonfish, snappers (*Macolor* spp.), wrasses (*Halichoeres* spp.), and groupers (*Cepahlopholis* spp.). Twin-spot snappers (*Lutjanus bohar*) were rare.

In 2006, there were generally fewer species encountered per 100 m^2 (~ 20-30 species at most sites), and there was a less discernable spatial pattern in species richness between sides of the island (Fig. 3.7f). Though less than during ASRAMP 2004 surveys, relatively high species richness was observed in the south point (26–33 species100 m^{-2}) region, Aunu`u (31 species 100 m^{-2}), and near Cape Matatula (30 species 100 m^{-2}). Lowest species richness was observed in the northwest and southwest regions.

3.8.2 Temporal Comparison—Reef Fish

Estimates of total mean fish biomass (tons ha^{-1}) around Tutuila and Aunu`u, with and without recruitment events, from the 2002, 2004, and 2006 REA surveys are shown in Figure 3.8.2a. Total mean fish biomass estimates around Tutuila are relatively consistent between 2002 and 2004, followed by a steep decrease in 2006. Only one significant recruitment event was reported during ASRAMP surveys around Tutuila in the 3 years surveyed, a localized recruitment of *Ctenochaetus striatus* at TUT-02 and TUT-01 in 2002. Considering all years surveyed, it is apparent that total fish biomass is distributed fairly evenly around the island and is predominantly composed of herbivorous fish (e.g., parrotfish and surgeonfish). The all-year average for total fish biomass is 0.72 tons ha^{-1} (SE 0.41).

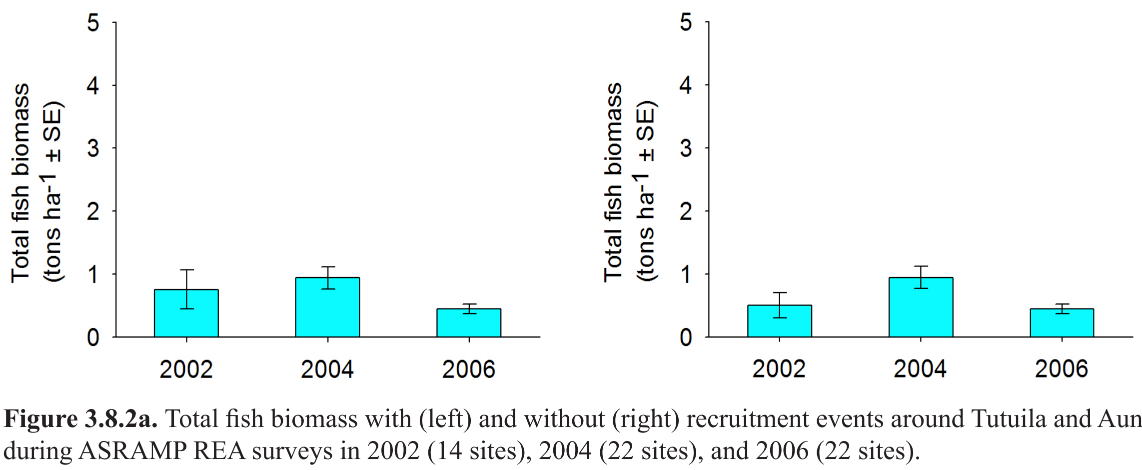

Figure 3.8.2a. Total fish biomass with (left) and without (right) recruitment events around Tutuila and Aunu`u during ASRAMP REA surveys in 2002 (14 sites), 2004 (22 sites), and 2006 (22 sites).

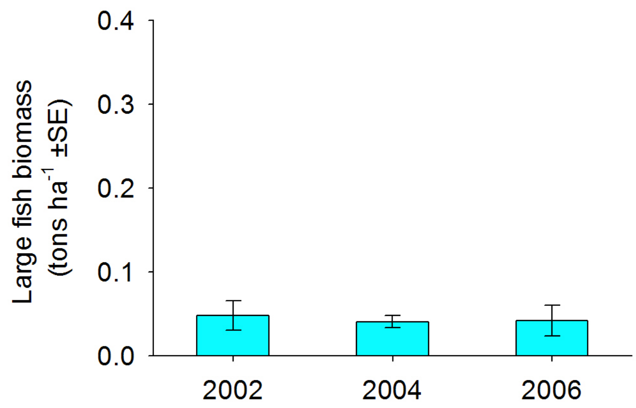

Figure 3.8.2b. Large fish biomass around Tutuila Aunu`u during ASRAMP towed-diver surveys in 2002 (16 tow surveys), 2004 (43 tow surveys), and 2006 (44 tow surveys).

Mean large fish biomass estimates (tons ha^{-1}) for the 2002, 2004, and 2006 towed-diver surveys (Fig. 3.8.2b) are almost an order of magnitude less than the mean total fish biomass (from REA belt-transect surveys) around Tutuila (> 50 cm fish represent ~ 10% of the total fish biomass). Mean large fish biomass estimates show temporal consistency across the sampling years. No particular section of the island has higher large fish biomass, although areas near prominent points and capes (Step's and Cockscomb Points and Capes Matatula and Taputapu) and offshore islands (Aunu`u) and banks (Taema) appeared to have relatively higher large fish biomass than most of the other coastal areas. The all-year average for large fish biomass is 0.044 tons ha^{-1} (SE 0.027). Species of particular interest (sharks and humphead wrasses) are generally sighted around the entire island, with a similar distributional pattern as noted for large fish. During towed-diver and REA surveys over the three ASRAMP cruises, only a single bumphead parrotfish (*Bolbometopon muricatum*) was observed indicating that they are either extremely rare or they do not have a preference for the habitat, depth range or time of day surveyed during ASRAMP.

Relative patterns of species richness around Tutuila in 2006 are somewhat different from previous years surveyed with fewer species encountered at REA sites and a less discernable spatial distribution pattern. Though this pattern was less consistent in 2006, the south point region of Tutuila generally harbored fish communities with the highest species richness.

3.9 Island Summary and Integration

In the preceding sections of this chapter, the spatial structure and temporal variability of the individual components of the coral reef ecosystems around Tutuila and Aunu`u were discussed. These components included the geological, physical, chemical, and biological descriptions which spanned, to varying degrees, portions of the terrestrial, atmospheric, and marine environments of Tutuila and Aunu`u.

While the ecosystem observations of ASRAMP appear to be relatively complete compared with many monitoring datasets, many variables cannot adequately be measured and are only sparsely observed spatially and temporally. Though necessarily incomplete, this synopsis of observed patterns and relationships provides an essential framework that can be used to build an improved understanding of ecosystem dynamics and greater ability to infer cause and effect relationships. In addition, quantitative methodologies using multivariant statistical analyses and ecosystem modeling approaches are currently being developed for incorporation into future reports and to allow for an improved understanding of ecosystem integration.

Although some biological groups, or parameters relevant to them, showed a fairly even distribution around the island, the distribution and abundance of most biological groups or parameters showed spatial variations around the island. Several discernable geographic patterns emerged when combining biological and physical observations and comparing results among disciplines.

Bathymetry, which describes the depth structure of the benthic environment, is one of the many factors by which biological communities are stratified. Multibeam-derived bathymetry completed around Tutuila and Aunu`u has revealed what is hypothesized to be a relict barrier reef with ridge-like structures as shallow as 20 m around the perimeter of the island platform. Inside this barrier, shelves extend from the north coast and offshore banks with depths ranging to 100 m surround the south, east, and west sides (Fig. 3.3.1a). It is hypothesized that these relict barrier reefs and submerged banks may dampen incoming wave energy or episodic wave events, potentially providing a small degree of protection to nearshore environments. Based on acoustic backscatter observations, it appears that most of the offshore bank that extends to the north of Tutuila is hard substrate (Fig. 3.3.1b), except for sediment that appears to have been discharged from several watershed embayments, and collecting in a band parallel to shore at the base of a gentler slope below the forereef slope of the living reef at a depth of ~ 100 m. The base of this slope may represent a paleo shoreline, and possibly the position of sea level during the last glacial maximum that ended ca. 18 000 years ago. It also appears that scattered pockets of sediment have collected in low areas on the offshore shelf (Fig. 3.3.1b). Some living coral colonies were recorded during optical TOAD surveys over the ridge-like structures around the perimeter of the presumed relict barrier (Fig. 3.3.1c). In some cases, high concentrations of corals were observed, suggesting that these structures may support significant coral reef communities.

In the northeast region of Tutuila, backscatter data suggests that the insular shelf is primarily composed of hard substrate. An exception was noted within an oval-shaped sediment field located in a depression (ca. 2 × 3 km footprint) immediately offshore of Masefau Bay, with several patch reefs extending up above the sediment field (Fig. 3.3.1b). TOAD optical validation surveys conducted in this region in depths > 30 m (Fig. 3.3.1c) showed several high concentrations of live coral colonies, with tows from the ridge at the northeastern corner of the Tutuila shelf showing the highest percentages of coral cover of any TOAD surveys on the shelf.

Water samples collected at 11 sites along the length of the northern coast in 2006 indicated that nitrate and nitrite exhibited spatial homogeneity, with more heterogeneous distributions of chlorophyll-a, phosphate, and silicate (Fig. 3.4.1j). Shallow-water CTD casts in all 3 survey years showed the water column along the northern coast was generally warmer, more saline, and more stratified during the period sampled (February/March) compared to waters on the south side of Tutuila (Figs. 3.4.1b, 3.4.1e, and 3.4.1h). During the austral summer, all sections of the northern coast were influenced by infrequent, long period swell (Fig. 3.3.2a) stemming from North Pacific boreal winter storms.

In the northwest and north regions (Fig. 3.2a), towed-diver surveys indicate that coral cover was generally low (< 10%), with the exception of occasional spots in which cover increased to 30–40% along narrow spurs extending seaward off points of land (Figs. 3.5.1e and 3.5.1l). Much of the nearshore area in the north region lies within the National Park of American Samoa; REA sites TUT-13 and TUT-18 lie within the National Park boundaries, while sites TUT-19 (Fagasa Bay) and TUT-14 lie immediately adjacent to the west and east borders of the park, respectively (Fig. 3.2a). Similar to towed-diver surveys, REA surveys at many northwest and north locations (TUT-07, 08, 12, 19, 13, 18) also found low coral cover (Figs. 3.5.1h and 3.5.1o). Coral diversity was generally low in these regions as well, with the exception of the two most northerly sites, TUT-18 and TUT-14, both inside shallow embayments and either within, or adjacent to, National Park boundaries (Figs. 3.5.1g and 3.5.1n). Site TUT-13, within the National Park, was distinctive for its high abundance of the coral genus *Astreopora* and for an unusually high proportion of very small (< 5 cm) coral colonies which, together with low colony density, suggests a high level of coral recruitment at this site. Site TUT-19 in Fagasa Bay had among the highest turbidity values in 2004, and time series datasets of in situ SST from moored instruments show that the bay experienced a maximum surface temperature 1.5°C above the SST climatology, or 0.5°C degree above the bleaching threshold, in the austral summers of 2002-2003. Towed-diver surveys in 2006 reported an unusually high level of coral stress (25%) during a single 5-min observation segment near Fagasa Bay (Fig. 3.5.1m). Although no additional information regarding the type or potential cause of the stress was noted, it is possible that heightened SST may have weakened coral communities in this region. Relative to the island-wide average incidence of coral disease of 0.12% (SE 0.03), disease prevalence was moderately high along the north coast (Figs. 3.5.2a and 3.5.2b), with the only observed case of *Porites* black-band disease seen in American Samoa found in the northwest region (Fig. 3.5.2b), and *Acropora* white syndrome seen in the north region.

With regard to algal communities in the northwest and north regions, towed-diver surveys indicated high macroalgal cover but low cover by crustose coralline algae (Figs. 3.6.1a, 3.6.1b, and 3.6.1e); site-specific REA surveys along this coast also reported low cover by crustose coralline algae, with TUT-18, inside the National Park, having the lowest such cover of all sites around Tutuila. Low macroalgal generic diversity also typified the northwest and north regions, with the exception of site TUT-19 in Fagasa Bay, where the highest macroalgal diversity (11 genera) of all sites around Tutuila was recorded in 2006. Crustose coralline algal disease (i.e., CLOD) was present only in low abundance (northwest region) or was lacking (north region; Fig. 3.6.2a). Sea urchins were found in high densities in the northwest and north regions in 2002 and 2004, but appeared to be much less abundant in 2006 (Figs. 3.7.1a, 3.7.1b, and 3.7.1d).

Towed-diver surveys in shallow (< 30 m) water in the northeast region showed generally higher coral cover than in the northwest and north regions; coral cover values ranged from < 5% to 40%, with highest values found on either side of, but not at Cape Matatula (Figs. 3.5.1e and 3.5.1l). Higher than average coral diversity was observed at REA sites TUT-04 and TUT-17 in both survey years (Figs. 3.5.1g and 3.5.1n) and, as in the northwest and north regions, the incidence of coral disease was moderately high relative to the island-wide average (Figs. 3.5.2a and 3.5.2b). In contrast to the low crustose coralline algae cover along the northwest and north regions, towed divers reported localized high cover of this algal functional group in the eastern portion of the northeast region in all survey years (Figs. 3.6.1a, 3.6.1b, and 3.6.1e). No coralline lethal algal disease (i.e., CLOD) was reported from this region in 2006 REA surveys (Fig. 3.6.2g). Sea urchins were encountered in especially low densities by towed divers in 2002 (Fig. 3.7.1a), with increased densities observed in subsequent survey years (Figs. 3.7.1b and 3.7.1d). As in the north region, somewhat reduced abundance and diversity of fish were recorded in the northeast region compared to other regions of Tutuila.

Many of the parameters characterizing the nature of northern coral reef communities, particularly those in the northwest and north regions, vary substantially from those characterizing southern coast communities. The wide (4 km average) insular shelf (< 100-m depth) that extends along the entire north coast continues to extend along the southwest region of the island. However, the shelf is more attenuated in its offshore extent along the south and southeast regions, and drops steeply to abyssal depths off the "south point" region (Fig. 3.3.1a). Moored instruments indicate the predominant wave regime in the austral winter is from the southeast, with occasional higher waves from the southwest caused by winter storms (Fig. 3.4.3a). Thus, the "south point" region, including Fagatele and Larsen's Bays, is more exposed to extreme winter wave events than regions partially protected by the offshore bank. CTD casts around the island in all three survey years indicate that the water column (< 35 m) on the south side is cooler, less saline, and less stratified than along the northern coast (Figs. 3.4.1b, 3.4.1e, and 3.4.1h) during the period sampled (February/March), which likely reflects the broad watersheds and large embayments on the south side compared with those on the north (Fig. 3.1a).

The convergence of several independent metrics suggests that the southern coast, taken as a whole, harbors more robust coral communities than those found in the north. Towed-diver surveys generally show higher coral cover along southern regions (Figs. 3.5.1b, 3.5.1e, and 3.5.1l), with levels of stressed coral lower along the southern coast (Fig. 3.5.1f). Site-specific REA surveys also indicate overall higher coral cover (Figs. 3.5.1h and 3.5.1o), higher coral diversity (Figs. 3.5.1g and 3.5.1n), higher coral densities (Fig. 3.5.1o), and a number of sites where there was an unusually high proportion (> 25% of total) of large (> 40 cm maximum diameter) coral colonies. Compared to the north coast, southern REA sites showed a lower incidence of coral disease (Figs. 3.5.2a and 3.5.2b). Towed-diver surveys found high sea urchin densities along the southern coastline in 2004 and 2006, although surveys in the areas immediately to the east and west of Pago Pago Harbor found a marked drop in numbers (Figs. 3.7.1b and 3.7.1d). Site-specific surveys for macroinvertebrates in 2004 indicated that higher species richness was observed along the southern coast, with the most common sea urchin, *Echinostrephus* sp., being found mostly off the southern coast. In contrast to this general pattern of more robust reef communities along the southern coast, 2006 REA surveys revealed that an opposite spatial distribution to that of coral diseases applied to CLOD, as the south-facing shores exhibited the majority (98%) of the CLOD cases observed (Fig. 3.6.2a).

In general, total fish biomass (predominantly composed of herbivorous fish, e.g., parrotfish and surgeonfish) and large (> 50 cm) fish biomass (Figs. 3.8.1a, 3.8.1d, and 3.8.1f) were fairly evenly distributed around the island, with somewhat reduced abundance and diversity of fish recorded in the north region compared to other regions of Tutuila. Site-specific fish surveys in 2004 indicated more diverse fish communities were found along the southern coast, and in the "south point" region in particular, though this pattern was less discernable in 2006.

As discussed above, each described biological community (corals, algae, macroinvertebrates, and fish) revealed some discernable island-wide distribution patterns and congruencies with oceanographic variables. Certain southern sites showed some particularly interesting multidisciplinary convergences of biological parameters that fell outside average values and therefore, deserve special attention. These sites, moving from west to east along the south shore, are Fagatele Bay (TUT-22), Larsen's Bay (TUT-11), Taema Bank (TUT-15), Pago Pago Harbor (TUT-20), and Aunu`u (TUT-16).

Benthic communities at Fagatele Bay National Marine Sanctuary (TUT-22) stand out in numerous regards. A towed-diver survey in 2002 spanned the width of the bay and estimated high coral cover (> 50%) on four of the six tow segments (Fig. 3.5.1b). A towed-diver survey conducted in 2004 estimated lower, but still high, values of coral cover (maximum 40–50%; Fig. 3.5.1e), with only low incidences of stressed coral reported (Fig. 3.5.1f). Towed-diver surveys in 2006 did not cover the interior of the Bay where high coral cover was observed in 2002 and 2004 (Fig. 3.5.1l). REA surveys were not conducted at Fagatele Bay in 2002 but were included in subsequent years at the special request of the Sanctuary Manager. REA surveys conducted in both 2004 and 2006 reported higher than average coral cover (Figs. 3.5.1h and 3.5.1o), higher than average coral diversity (Figs. 3.5.1g and 3.5.1n), and an unusually high proportion (> 25% of total) of large (> 40 cm maximum diameter) coral colonies (Figs. 3.5.1j and 3.5.1p). In addition, higher than average coral density (Fig. 3.5.1h) was reported in 2004. No evidence of coral disease was found in 2006 (Figs. 3.5.2a and 3.5.2b) and only a low incidence of coral predation was observed (Fig. 3.5.2a). REA surveys for algae conducted in 2004 and 2006 showed that Fagatele Bay contained among the highest macroalgal diversity seen at Tutuila. However, CLOD was particularly abundant at Fagatele during 2006 surveys (Fig. 3.6.2b). Fish communities were also among the most diverse in both 2004 (Fig. 3.8.1e) and 2006 (Fig. 3.8.1g). These combined results indicate a particularly robust biological assemblage at Fagatele Bay, suggesting that the current management protection this area receives may be positively impacting the ecosystem. On the other hand, a current meter off Step's Point (Fig. 3.4.3e) to the east of the Bay showed mostly south-westward flow, which may carry water masses east to west along the south shore of Tutuila; this may be a source of contaminants discharged from Pago Pago Harbor around Step's Point and toward Fagatele Bay.

Adjacent to Fagatele Bay, and roughly comparable in size, is Larsen's Bay (TUT-11). Like Fagatele Bay, there is a steep descent to depths greater than 500 m just beyond the embayment (Fig. 3.3.1a), such that the bays are not as protected from southerly winter wave regimes (Fig. 3.3.2b) as are other nearshore areas fronted by the wider offshore bank. REA surveys in 2004 and 2006 showed higher than average coral cover (Figs. 3.5.1h and 3.5.1o) and coral diversity (Figs. 3.5.1g and 3.5.1n) in Larsen's Bay, with an usually high proportion (> 25% of total) of large (> 40 cm maximum diameter) colonies reported in 2004 (Fig. 3.5.1j). Algal surveys in both years showed the calcified red genus *Peyssonnelia* (Fig. 3.6.1d) was particularly abundant, occurring in 75% of sampled photoquadrats (Figs. 3.6.1c and 3.6.1f).

However, six cases of unidentified algal discoloration were noted at this site in 2006 (Fig. 3.6.2b). Larsen's Bay was noteworthy among fish REA surveys in 2004 as the site of highest fish species richness (54 species, Fig. 3.8.1e) and for its elevated biomass, primarily because of surgeonfish sightings.

Taema Bank (TUT-15) is a shallow (< 15 m, Figs. 3.5.1a, 3.5.1d, and 3.5.1k) bank off the southern coast of Tutuila. Open to south swell (Fig. 3.4.3a), its biological communities reflect its exposed and scoured nature. REA surveys in 2004 and 2006 revealed lower than average coral cover (Figs. 3.5.1h and 3.5.1o), lower than average coral diversity (Figs. 3.5.1g and 3.5.1n), and an unusually high proportion (> 10% of total) of very small (< 5 cm maximum diameter) coral colonies (Fig. 3.5.1j). Towed-diver surveys in 2002 and 2004 recorded the highest estimates of recently dead coral (10.0%, Fig. 3.5.1c) and low live coral cover (1–10%, Fig. 3.5.1e), respectively. Algal REA surveys in 2004 indicated this site had the next-to-lowest macroalgal diversity (two genera), with the encrusting genus *Lobophora* extremely common. In 2006, a towed-diver survey indicated Taema harbored among the highest percent cover of fleshy macroalgae (Fig. 3.6.1a), and an REA survey indicated a particularly high abundance of CLOD (Fig. 3.6.2b). High densities of sea urchins were recorded at Taema (Fig. 3.7.1b) by a towed diver in 2004. Fish surveys in all years conclude that, while no particular section of the island had higher large fish biomass, Taema was among the few sites that appeared to have relatively higher large fish biomass than most of the other coastal areas. This collective physical and biological profile of low coral and algal diversity, high algal cover, high urchin density, and relatively high large fish biomass appear to characterize a habitat responding to higher-energy ocean conditions than those experienced by more nearshore areas bounded by the land mass.

Towed-diver and REA surveys in the outer portion of Pago Pago Harbor (TUT-20) also reveal a number of biological parameters below island-wide average values, and oceanographic data provide water quality metrics indicative of conditions that challenge healthy reef communities. Low coral cover was recorded by towed divers in 2004 (Fig. 3.5.1e) and 2006 (Fig. 3.5.1l), with unusually high coral stress values (10–28% of cover) reported inside the eastern harbor entrance near Breakers Point in both years (Figs. 3.5.1f and 3.5.1m). REA surveys in 2004 and 2006 reported very low coral cover values (Figs. 3.5.1h and 3.5.1o) and were among the lowest coral densities (Figs. 3.5.1h and 3.5.1o). The relatively high coral diversity (22 genera) reported in 2004 (Fig. 3.5.1g) was likely a result of the presence of one or two colonies in the majority (14) of these genera, which were not captured within the slightly varied placement of belt transects in 2006, when only 10 genera were reported (Fig. 3.5.1n). Algal REA surveys in 2004 recorded the lowest macroalgal diversity (one genus) at this site (Fig. 3.6.1c), while towed divers in 2006 reported among the highest percent cover values of fleshy macroalgae (Fig. 3.6.1e). Perhaps surprisingly, no coral diseases or coralline lethal algal disease (i.e., CLOD) were noted at this site in 2006 (Figs. 3.6.2a and 3.6.2b). Overall macroinvertebrate densities were low at sites immediately east and west of the harbor (Figs. 3.7.1b and 3.7.1d). No giant clams were seen during either towed-diver or REA surveys in all years, even though island-wide REA surveys otherwise show a broad distribution of giant clams (Figs. 3.7.1c and 3.7.1e). High turbidity and some of the highest nutrient levels were measured in the Pago Pago Harbor region in 2006 (Fig. 3.4.1j), likely caused by increased terrestrial runoff generated by exceptional rainfall during January–March, 2006 (Fig. 3.4.2d).

In contrast to the ecologically compromised condition of Pago Pago Harbor, Aunu`u (TUT-16) displayed above-average values in a number of biological parameters. The highest coral cover (43.5% average) reported by towed divers in 2004 was observed along the northern side of Aunu`u, with > 75% coral cover estimated for some tow segments (Fig. 3.5.1e). High coral cover (35% average) was also reported by towed divers along the northern side of Aunu`u in 2006 (Fig. 3.5.1l), although a higher than average incidence of stressed coral was reported along the southeast side (Fig. 3.5.1m). The highest coral cover values were reported at this site in REA surveys in 2004 and 2006 (73% and 64%, respectively; Figs. 3.5.1h and 3.5.1o). Higher than average coral diversity (Fig. 3.5.1g), high colony density (Fig. 3.5.1h), and an unusually high proportion (> 25%) of large (> 40 cm maximum diameter) colonies (Fig. 3.5.1j) were recorded at this site in 2004. Neither coral disease, predation, nor coralline lethal algal disease was observed at this site in 2006 (Figs. 3.5.2a, 3.5.2b, and 3.5.2a). High sea urchin densities (Fig. 3.7.1d, e) and relatively high fish species richness (42 species) were observed in 2006 (Fig. 3.8.1e) and, while no particular section of the island had higher large fish biomass, Aunu`u was among the few sites that appeared to have a large fish biomass higher than in most other coastal areas. Collectively, these parameters describe a robust, thriving coral reef community. An apparent upwelling of cooler offshore water, captured by CTD casts just south of Aunu`u in 2004 (Fig. 3.4.1e, Temperature), may be a factor contributing to the richer biological assemblage here. Sea surface temperatures anomalously cooler than climatological values, detected by in situ and satellite methods in June 2005 (~ 1.5°C and ~ 1.0°C), also suggest the presence of oceanographic mechanisms by which extreme thermal events, such as those that can result in coral bleaching, may be moderated at this location.

The topography of the terrestrial environment (including watershed dynamics), bathymetry of the marine environments, and temporally varying oceanographic conditions determine the specific conditions in which biological communities develop. The composition and health of these communities are shaped by the complex interactions of diverse factors including depth, benthic composition, prevailing and episodic oceanographic and water quality parameters, extreme environmental events, such as tropical cyclones and anomalous thermal events, species and trophic interactions, and activities of humans both in the marine environment and adjacent terrestrial habitats. Of all the islands in American Samoa, Tutuila contains the greatest land area, greatest area and diversity of coral reef habitats, and the highest coral, algal, and fish species diversity. Some taxonomic groups, or parameters relevant to them, showed a fairly even spatial distribution around the island. Giant clams and sea cucumbers, assessed through both towed-diver and REA surveys, were widely distributed (albeit at low densities), in comparison with sea urchin populations, which were variable both spatially and temporally between years. There was a general absence of COTS, with only three COTS observed during all three ASRAMP surveys by both survey methods combined. In all survey years, total fish biomass and biomass of large (> 50 cm) fish were relatively consistently distributed around Tutuila.

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