OFU AND OLOSEGA ISLANDS

Chapter 4 Ofu and Olosega Islands

4.1 Geopolitical Context

Ofu and Olosega Islands are twin volcanic islands separated by the Asaga Strait, a shallow, narrow break in the reef flat between the islands that is ~ 75 m wide at its narrowest point. The two islands are located in the westernmost part of the Manu`a Islands group, approximately 100 km northeast of Tutuila Island. Ta`u Island, the third island of the Manu`a group, is located approximately 10 km to the southeast. Ofu, with a land area of 7.2 km^2, lies to the west and Olosega, with a land area of 5.4 km^2, lies to the east (Fig. 4.1a). The islands are formed by two eroded, coalescing basaltic shield volcanoes whose slopes dip to the east and west. Steep cliffs, up to 600 m in height, are located on both the northern and southern sides of the two islands.

While volcanic activity has not been recorded for either island in recent history, a submarine eruption took place in 1866 at a distance of 3 km to the southeast of Olosega and along the ridge that connects Olosega with Ta`u (http://www.volcano.si.edu/world/volcano). More recent submarine eruptions during the 2001–2005 period have been observed at Vailulu`u Seamount, located approximately 50 km east of Ta`u, which indicates that the entire region remains geologically active. Ofu and Olosega are connected by a bridge and road built across the shallow reef flat of Asaga Strait. As discussed in Section 4.3, Benthic Habitat Mapping

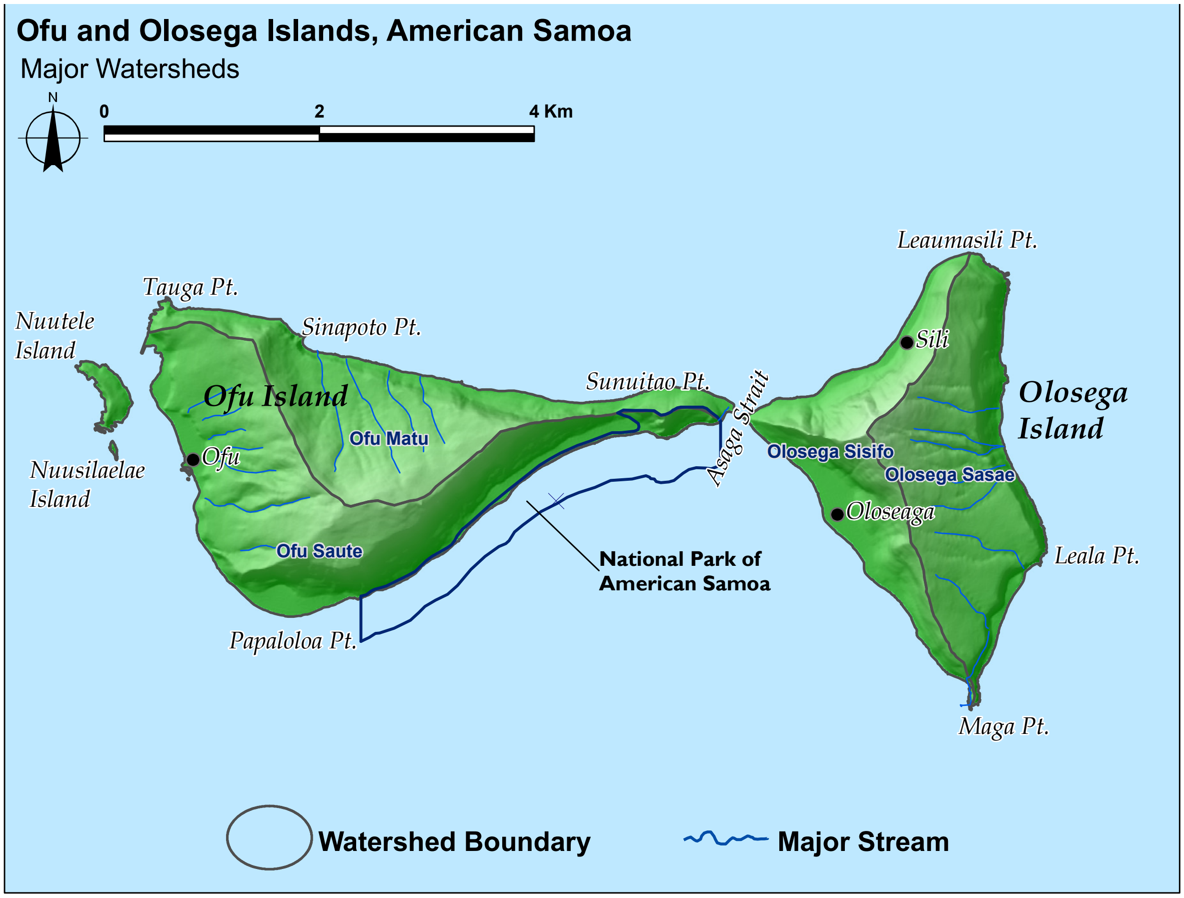

Figure 4.1a. Watersheds boundaries, streams, and counties for Ofu and Olosega. Also shown is the boundary of the National Park of American Samoa.

and Characterization, shallow multibeam mapping was conducted in 2004 and revealed ~ 60 km^2 of previously uncharted bank top (< 300 m) that extends 0.2 to 2 km from shore and then drops abruptly to abyssal depths.

The population of the Manu`a Islands has been steadily decreasing since the 1950s from approximately 3000 residents in 1950 to a little more than 1700 residents in 1980. An additional 600 people left the Manu`a Islands and relocated to Tutuila after the 1987 Hurricane Tusi stripped most of the islands' vegetation and left the majority of the population homeless. According to the 2000 U.S. Census, 1378 residents populated the Manu`a Islands, with 289 located on Ofu and 216 on Olosega (U.S. Census Bureau, 2000). The main population centers are located in Ofu Village (northwestern coast of Ofu), which is the location of the small airport and protected harbor, Olosega Village (southwestern coast of Olosega), and Sili Village (northwestern coast of Olosega; Fig. 4.1a).

Land use trends on the Manu`a Islands continue to follow practices associated with Fa`asamoa society with respect to agriculture and subsistence harvesting. An estimated two-thirds of Ofu and Olosega remain undeveloped.

4.2 Survey Effort

A large amount of physical and biological data has been collected around Ofu and Olosega

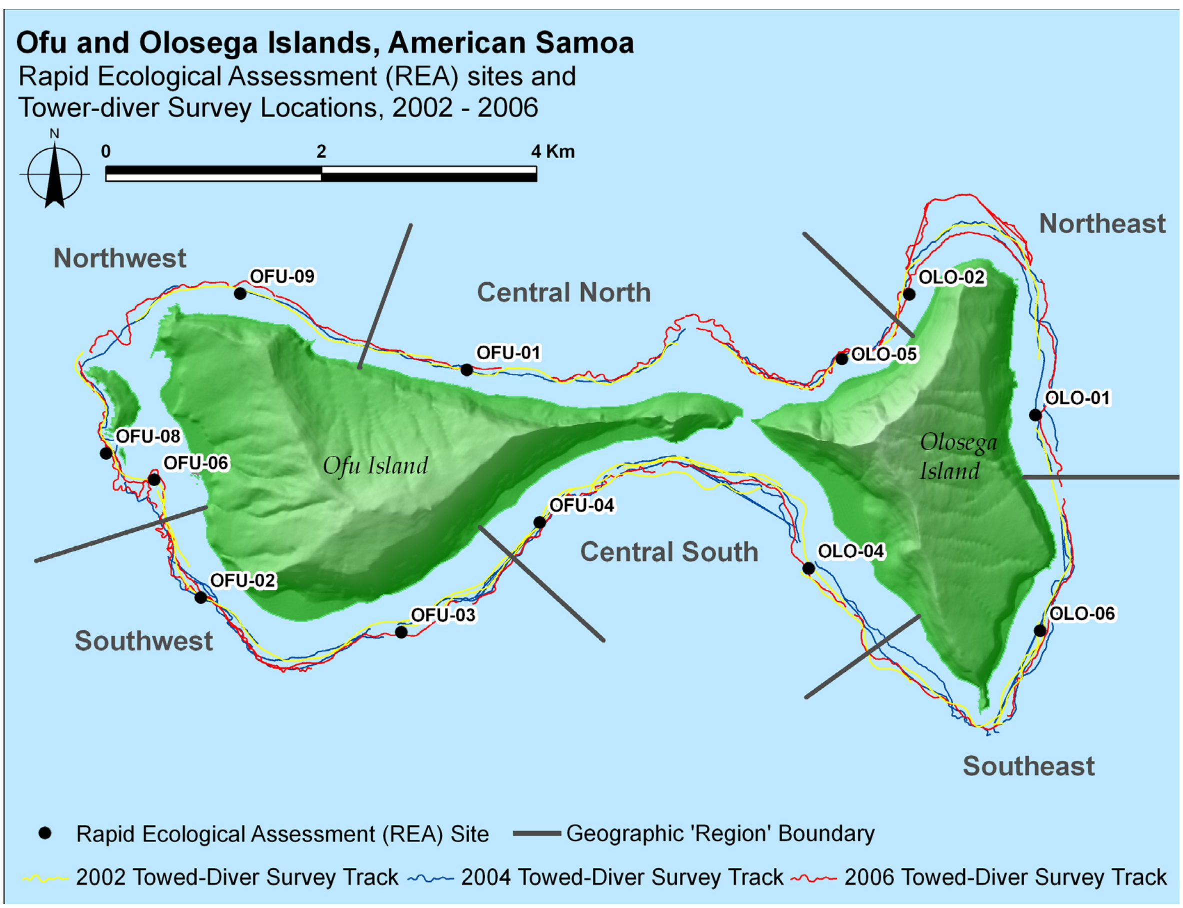

Figure 4.2a. Locations of REA and towed-diver surveys around Ofu and Olosega during ASRAMP 2002, 2004, and 2006. Arbitrary geographic regions have been delineated to aid in discussion of spatial patterns.

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 around these paired islands throughout this chapter, six geographic regions are delineated in Figure 4.2a. Figure 4.2a also shows the locations of Rapid Ecological Assessment (REA) and towed-diver survey efforts during ASRAMP 2002, 2004, and 2006.

Benthic habitat mapping data were collected around Ofu and Olosega using a combination of acoustic and optical survey methods, the extent of which are summarized in Table 4.2a. These are further examined in Section 4.3, Benthic Habitat Mapping and Characterization. The number, mean depth, and area of these survey efforts are presented by year in Table 4.2b.

Table 4.2a. Total area of benthic habitat surveyed from acoustic multibeam sonar and Toad Optical Assessment Device (TOAD) surveys around Ofu and Olosega during ASRAMP 2002, 2004 and 2006.

Survey Type	2002	2004	2006
Acoustic Multibeam Sonar	0	82.3* km^2	gap filling only
TOAD	3 tows	13 tows	10 tows

** Total multibeam surveying conducted across the Manu`a Islands.*

Table 4.2b. Number, area, and depth of REA and towed-diver surveys around Ofu and Olosega during ASRAMP 2002, 2004, and 2006.

Year	REA Surveys		Towed-diver Surveys		
	Number of Surveys	Mean Depth (m)	Number of Surveys	Survey Area (ha)	Mean Depth (m)
2002	6*	13.7 (SD 0.0)	14	46.4	9.8 (SD 4.5)
2004	8*	15.6 (SD 1.1)	17	45.5	11.9 (SD 5.3)
2006	12	14.0 (SD 1.2)	17	46.0	12.6 (SD 4.8)

** No coral disease surveys were conducted in 2002 and 2004.*

The ranges of survey depths from towed-diver surveys are presented for each year in Section 4.5, Corals and Coral Disease: Figure 4.5.1a (2002), Figure 4.5.1d (2004), and Figure 4.5.1j (2006). Although the towed-diver survey methodology is 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.

Spatial and temporal observations of key oceanographic and water quality parameters influencing reef conditions around Ofu and Olosega 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 (see Chapter 2, Section 2.3: Oceanography and Water Quality). A summary of deployed instruments and collection activities is provided in Table 4.2c, and they are further examined in Section 4.4, Oceanography and Water Quality.

Table 4.2c. Numbers of subsurface temperature recorders (STR) deployments and shallow and deep CTD casts around Ofu and Olosega during ASRAMP 2002, 2004, and 2006. 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	2006
STR	0	5	7
Shallow-water CTD casts	39	50	33
Deep-water CTD casts	15*	7*	17*

** Total deep-water CTD casts conducted across the Manu`a Islands.*

4.3 Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization of the nearshore waters around Ofu and Olosega were conducted using acoustic multibeam sonar, underwater video and still imagery, and towed-diver survey observations between the depths of ~ 1 m and ~ 300 m. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products over the depth range between ~ 20 m and ~ 250 m. Optical validation and benthic characterization via underwater video, still imagery, and diver observations were performed using both shipboard towed cameras (i.e., TOAD) in depths between ~ 20 m and ~ 80 m and towed-diver surveys in depths between ~ 1 m and 30 m.

4.3.1 Acoustic Mapping and Optical Validation

Ofu and Olosega are extremely steep, eroding volcanic islands with limited low slope terrestrial habitats. A narrow band of shallow reef flat and lagoon habitats are found immediately seaward of the land around significant portions of both islands. These narrow reef flats and lagoons are most prevalent in areas protected from prevailing southeast trade winds and/or large northwest swells, particularly the south central, southwest, and north central regions of the islands. Immediately offshore in the southeast, northwest, and northeast regions, there

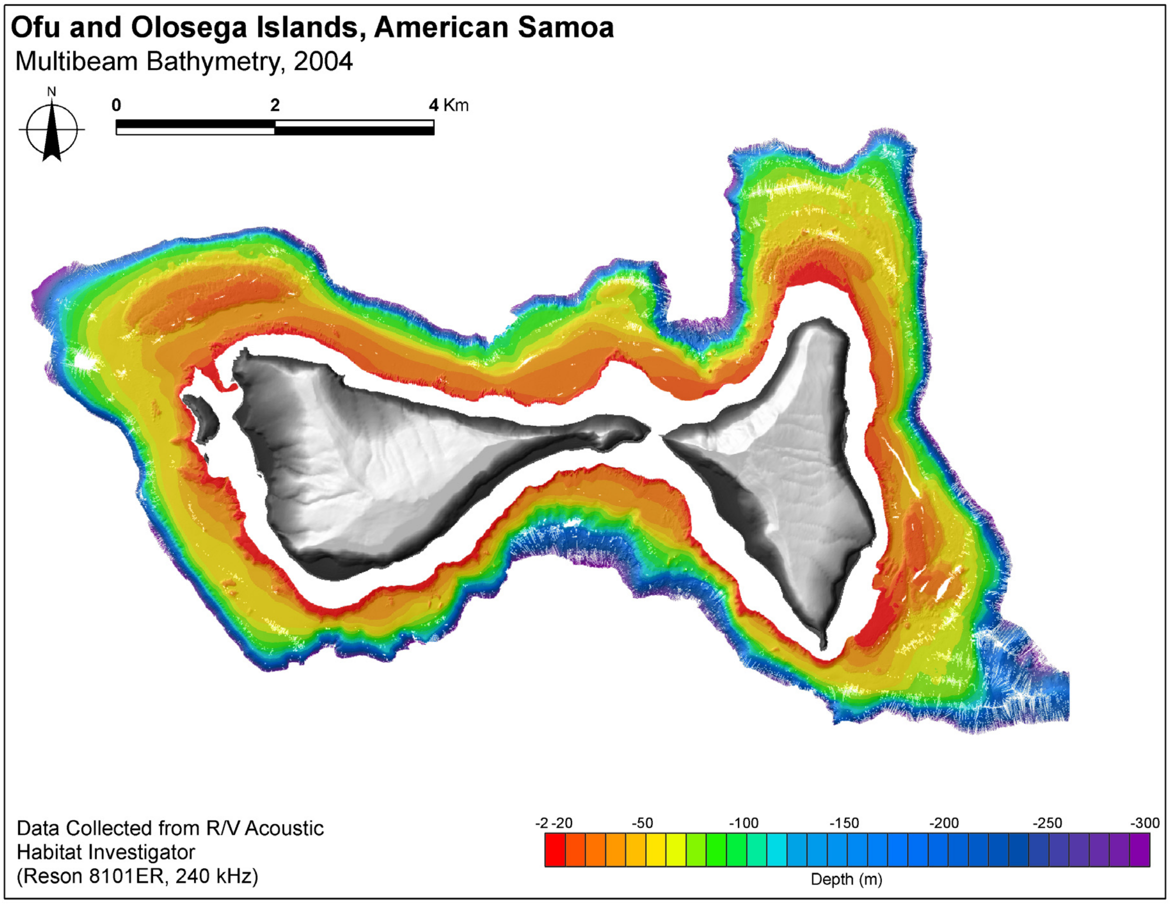

Figure 4.3.1a. Multibeam bathymetry acquisition around Ofu and Olosega in depths between ~ 20 m and ~ 300 m was completed in March 2004 from the R/V *Acoustic Habitat Investigator* (*AHI*). Submerged banks extend southeast and north of Olosega and northwest of Ofu. Elsewhere around the islands, steep slopes are observed.

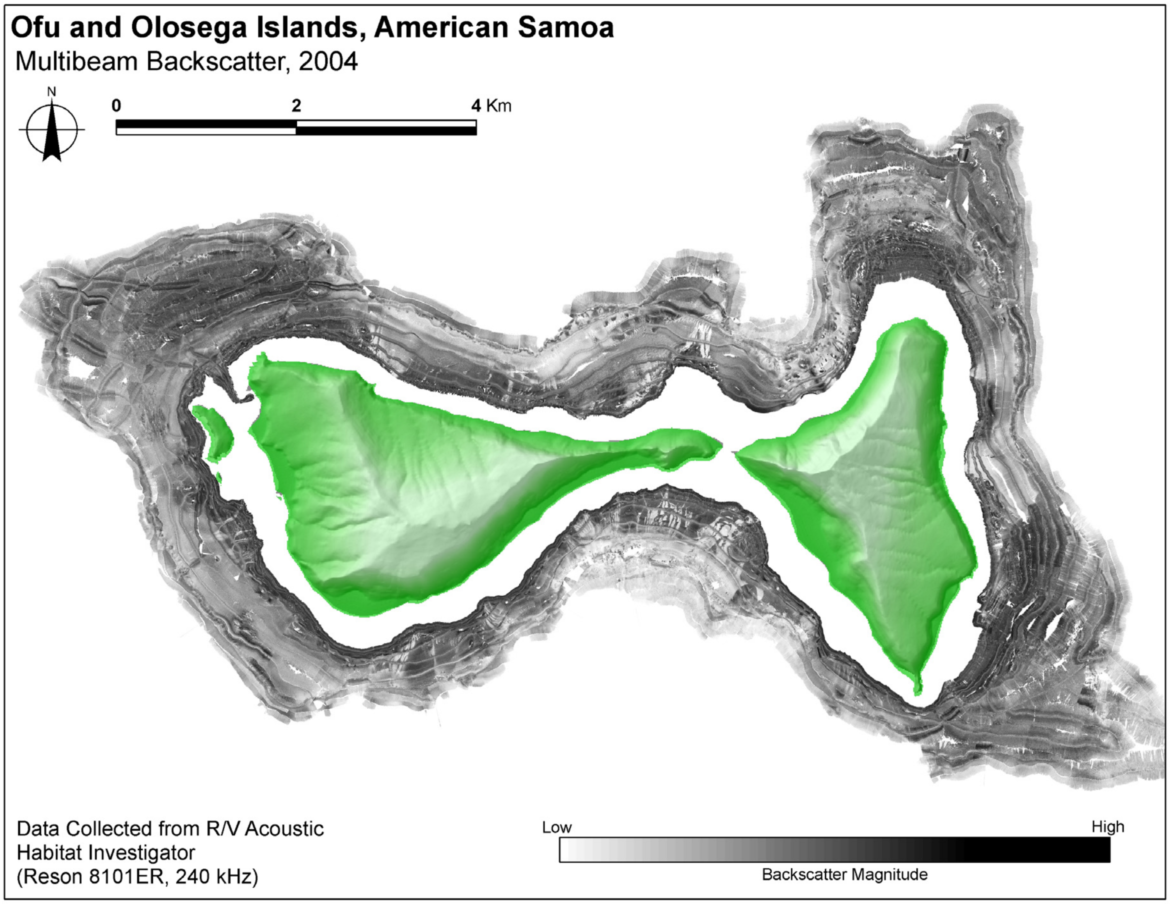

Figure 4.3.1b. Backscatter imagery was acquired in March 2004 during multibeam surveys around Ofu and Olosega from the R/V *AHI*. Lighter shades represent low intensity backscatter and likely indicate substrates that are acoustically absorbent and typically indicate unconsolidated sediment. Darker shades represent high-intensity backscatter and likely indicate consolidated hard-bottom and coral substrates.

are submerged banks extending ~ 2 km offshore over the depth range between ~ 10 m and ~ 100 m (an area encompassing approximately 25 km^2; Figs. 4.3.1a and 4.3.1b). Outside of this bank the slopes drop steeply to depths of 500 m and greater.

One area of major management interest is the southernmost tip of Ofu, in the southwest region (Fig. 4.1a), where the airport is located. This airport lies immediately adjacent to the underwater National Park of American Samoa. The American Samoa Government has been evaluating the feasibility of extending the airport runway westward by filling in portions of the reef to allow larger aircraft to visit Ofu. In 2005, at the request of local and federal management agencies, Coral Reef Ecosystem Division (CRED) scientists integrated all multibeam and optical data in the area into an ArcGIS project, thereby allowing photographic and video data to be quickly and easily displayed in a geographic framework.

During ASRAMP 2002, three TOAD optical surveys were conducted around Ofu and Olosega from the NOAA Ship *Townsend Cromwell*, yielding two video transects and 100 still photos. Thirteen optical data videos were collected around Ofu and Olosega during ASRAMP 2004 from the NOAA Ship *Oscar Elton Sette*. The locations of these optical data tracks are shown in Figure 4.3.1c. Ten optical data videos were collected around Ofu and Olosega from R/V *AHI* during ASRAMP 2006, but these data are still being processed and are not included in

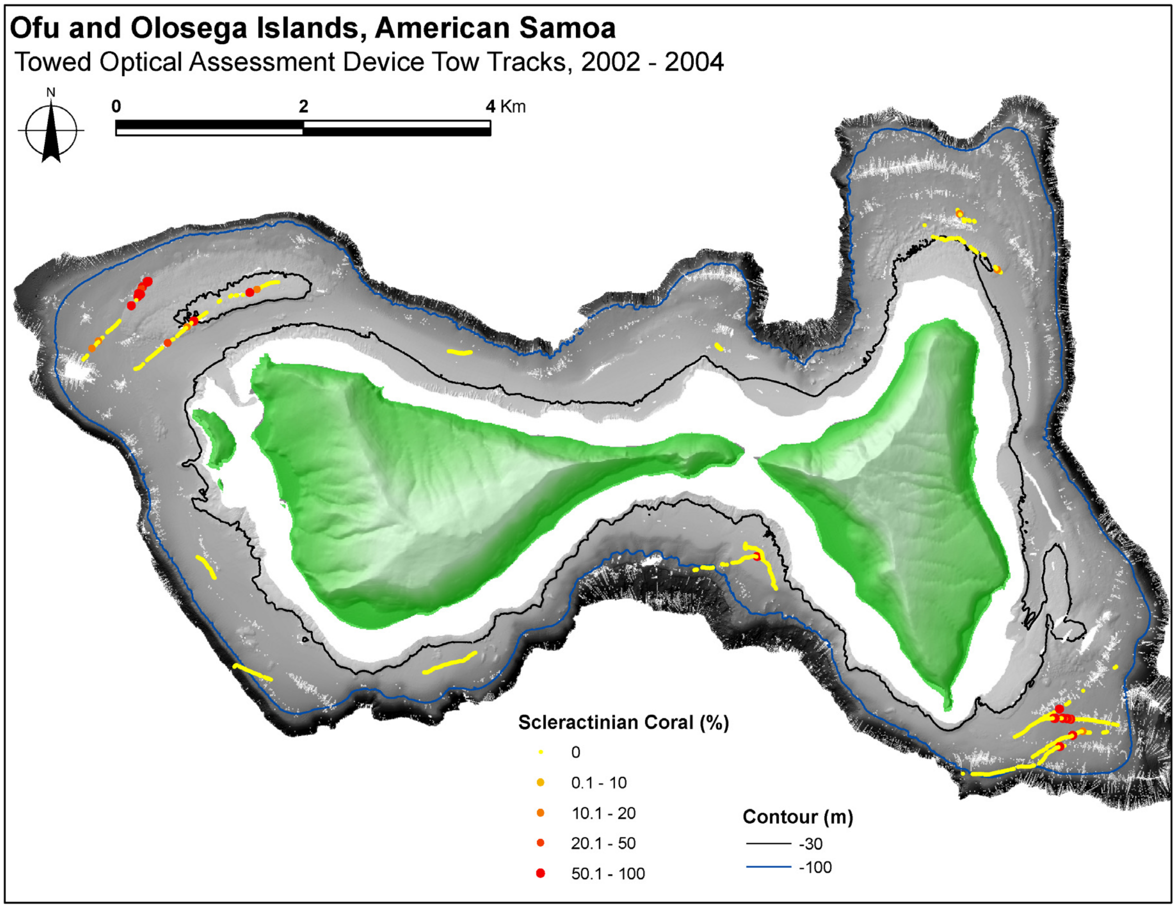

Figure 4.3.1c. TOAD camera sled tracks around Ofu and Olosega during ASRAMP 2002 and 2004. The video imagery are post processed to identify substrate type (sand, rock, etc.), living cover (coral, macroalgae, etc.), and other characteristics. The TOAD survey tracks display percentage of live scleractinian 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.

the figure. Most of the offshore and relatively deep surveys indicated that few corals were found in those areas. However, coral communities have been discovered on each of the three relatively shallow banks extending off the northwest, northeast, and southeast corners of the islands, some at depths in excess of 50 m.

The backscatter imagery from the 2004 surveys was successfully used as a predictive guide for determining sites for the optical surveys in 2006. For example, the backscatter analyses suggested large sand channels and hard-bottom substrates on the northwest bank of Ofu and the northeast bank of Olosega, each of which were confirmed during TOAD surveys in 2006. The hard-bottom substrates on the northwest and northeast banks were observed to support coral-rich environments in some areas.

4.3.2 Habitat Characterization

Towed-diver benthic survey observations around Ofu and Olosega 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. 4.3.2a), percent cover of sand (Fig. 4.3.2b), hard substrate/pavement (Fig.

4.3.2c), rubble (Fig. 4.3.2d), and live coral (Fig. 4.3.2e). Since these habitat characterization maps represent different and complementary components of the same habitats, it is useful to analyze them in relation to each other, the local watersheds, and exposure to prevailing oceanographic conditions.

Habitat complexity was observed to vary significantly around Ofu and Olosega, with observations ranging from low to very high (Fig. 4.3.2a). Habitat complexity appeared consistently high to very high along significant portions of both the north coast of Ofu in the central north region and the shallower portions of the central south region. Scattered areas of increased complexity were observed in the northeast region along the windward coast of Olosega and off Ofu Village in the northwest region.

Generally, most of the forereef slope areas surveyed around Ofu and Olosega were observed to have low-to-moderate sand cover (Fig. 4.3.2b), with several notable exceptions. Areas with the highest consistent levels of sand cover were observed in a section of the windward side of Olosega in the northeast region, a small section in the northwest region north of Nu`utele Island off the Ofu Harbor entrance, and the deep area at the base of the forereef slope in the region south of Asaga Strait in the central south region. As one would expect, the high sand cover area on the windward side of Olosega corresponds well with observed low habitat complexity (Fig. 4.3.2a).

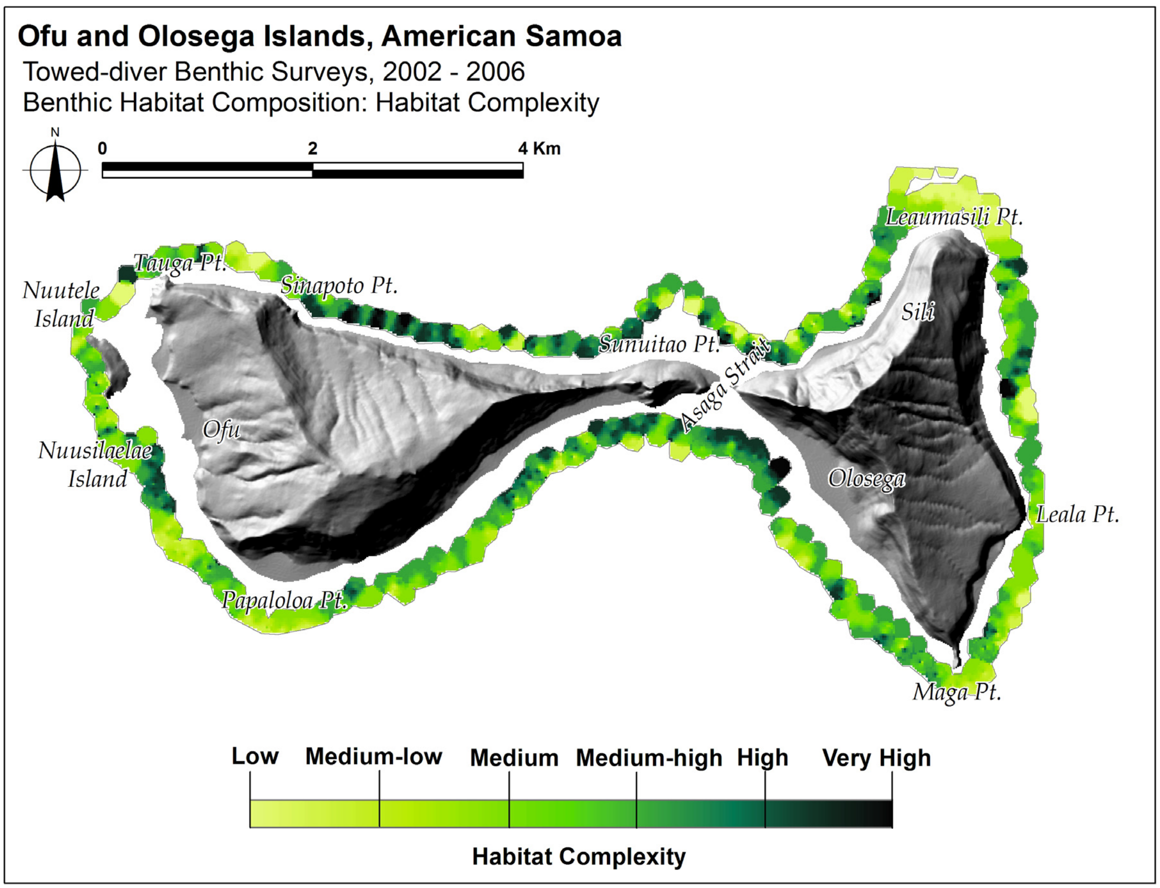

Figure 4.3.2a. Mean benthic habitat complexity concatenated from towed-diver survey observations around Ofu and Olosega during ASRAMP 2002, 2004, and 2006. Habitat complexity was subjectively rated by diver-observers over 5-min ensembles (~ 200 x 10 m) on a 6-point scale representing low (1), medium-low (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.

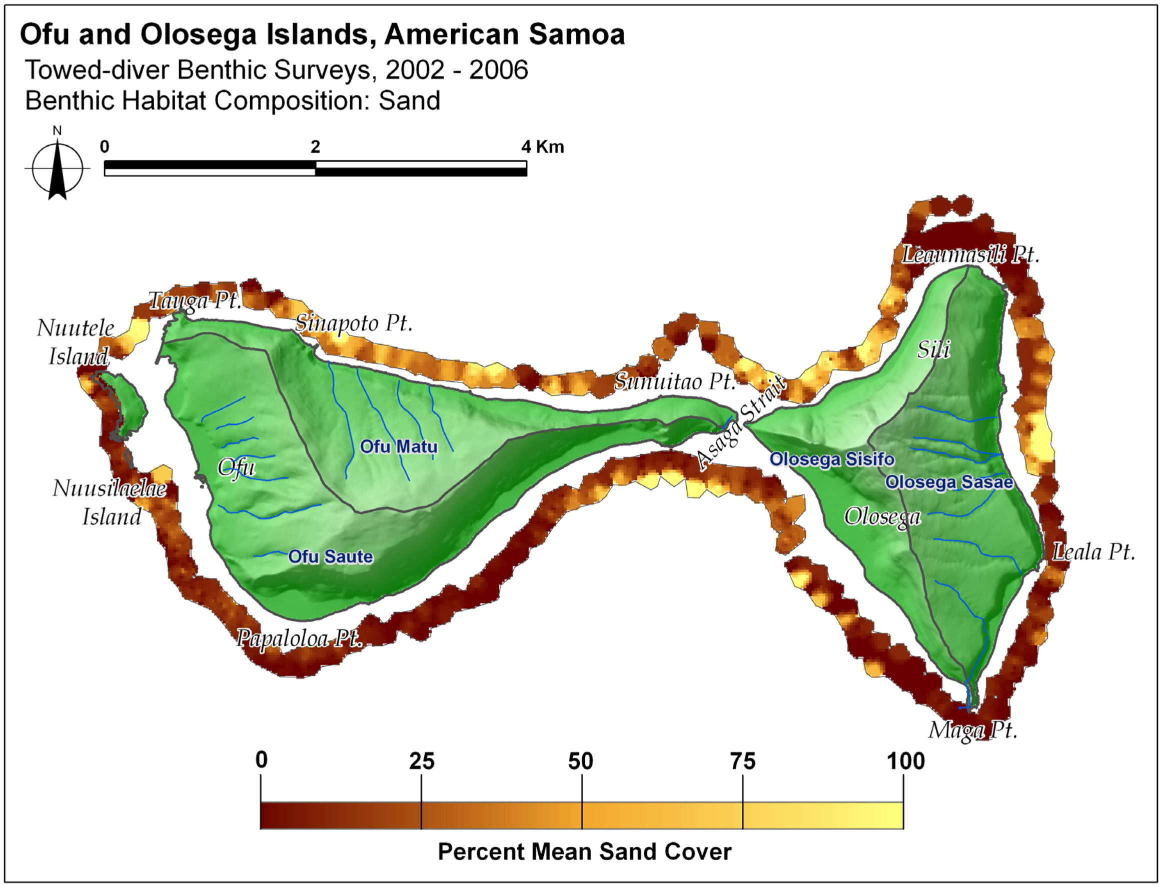

Figure 4.3.2b. Mean percent cover of sand concatenated from towed-diver habitat survey observations around Ofu and Olosega during ASRAMP 2002, 2004, and 2006. Major streams (blue lines) overlay the topographic map of the islands, indicating the location of inputs of freshwater runoff into the marine ecosystem. Selected watershed (Fig. 3.1a) are highlighted in blue. Sand composition was subjectively rated by diver-observers over 5-min ensembles (~ 200 x 10 m) on a 1–100% scale. Light shades indicate high percent cover of sand, and dark shades indicate low percent cover of sand.

Both the complexity and sand cover reversed patterns immediately on either side of this low relief sand channel. The area near Ofu Harbor was likewise observed to vary from high complexity and low sand cover to low complexity and high sand cover. Observations of the central north region, which has generally high complexity as described above (Fig. 4.3.2a), revealed that most of the area has moderate levels of sand cover. This combination of high complexity and moderate sand cover suggests that much of the north coast is dominated by broad spur-and-groove habitat, where grooves are dominated by sand channels between high-relief reef spurs.

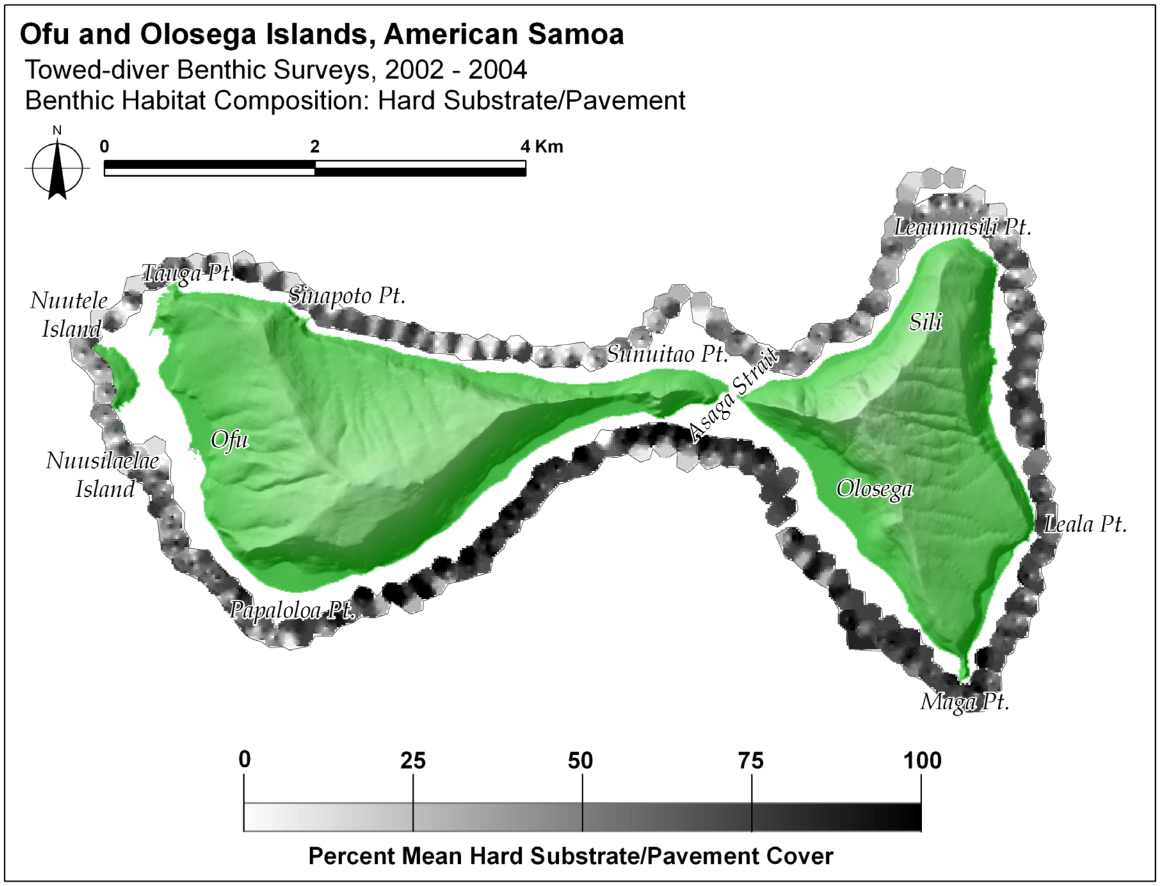

Figure 4.3.2c. Mean percent cover of hard substrate/pavement, concatenated from towed-diver survey observations around Ofu and Olosega during ASRAMP 2002 and 2004. Hard substrate/pavement composition was subjectively rated by diver-observers over 5-min ensembles (~ 200 x 10 m) on a 1–100% scale. Dark shades indicate high percent cover of hard substrate, and light shades indicate low percent cover of hard substrate.

Generally, the percent cover of hard substrate/pavement was variable around Ofu and Olosega with higher values in the central south and southeast regions and relatively lower values in the central north and northwest regions (Fig. 4.3.2c). As one would expect, the percent cover of hard substrate/pavement had an inverse pattern relative to the percent cover of sand. Consistent with observations of complexity and sand cover, variable observations of hard substrate/pavement along the north sides of Ofu and Olosega also suggests a predominance of spur-and-groove habitats.

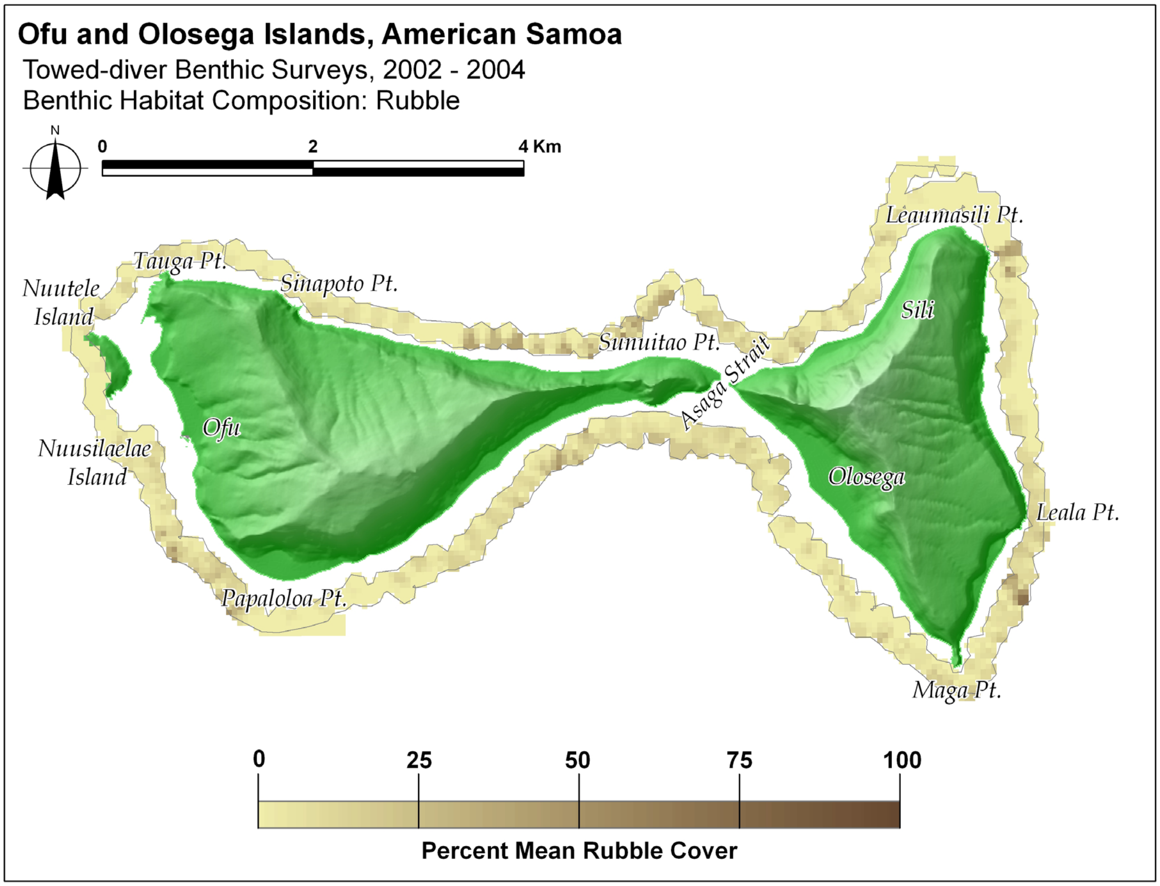

Figure 4.3.2d. Mean percent cover of rubble, concatenated from towed-diver survey observations around Ofu and Olosega during ASRAMP 2002 and 2004. Rubble composition was subjectively rated by diver-observers over 5-min ensembles (~ 200 x 10 m) on a 1–100% scale. Light shades indicate low percent cover of coral rubble, and dark shades indicate high percent cover of coral rubble.

Generally, benthic composition around Ofu and Olosega was observed to have relatively low percent cover of coral rubble, with values at most of the forereef habitats around both islands being less than 10% (Fig. 4.3.2d). Percent cover of rubble was elevated to values of ~ 25% in small patches, most notably along the southeast and northeast windward sides of Olosega in the southeast and northeast regions, in the central north region to the west of Asaga Strait, and in the southwest region near the proposed airport extension of Ofu. The area in the central north region was also observed to have moderate habitat complexity, low sand cover, and moderate hard substrate/pavement cover, possibly indicating pockets of rubble collecting in the grooves instead of sand.

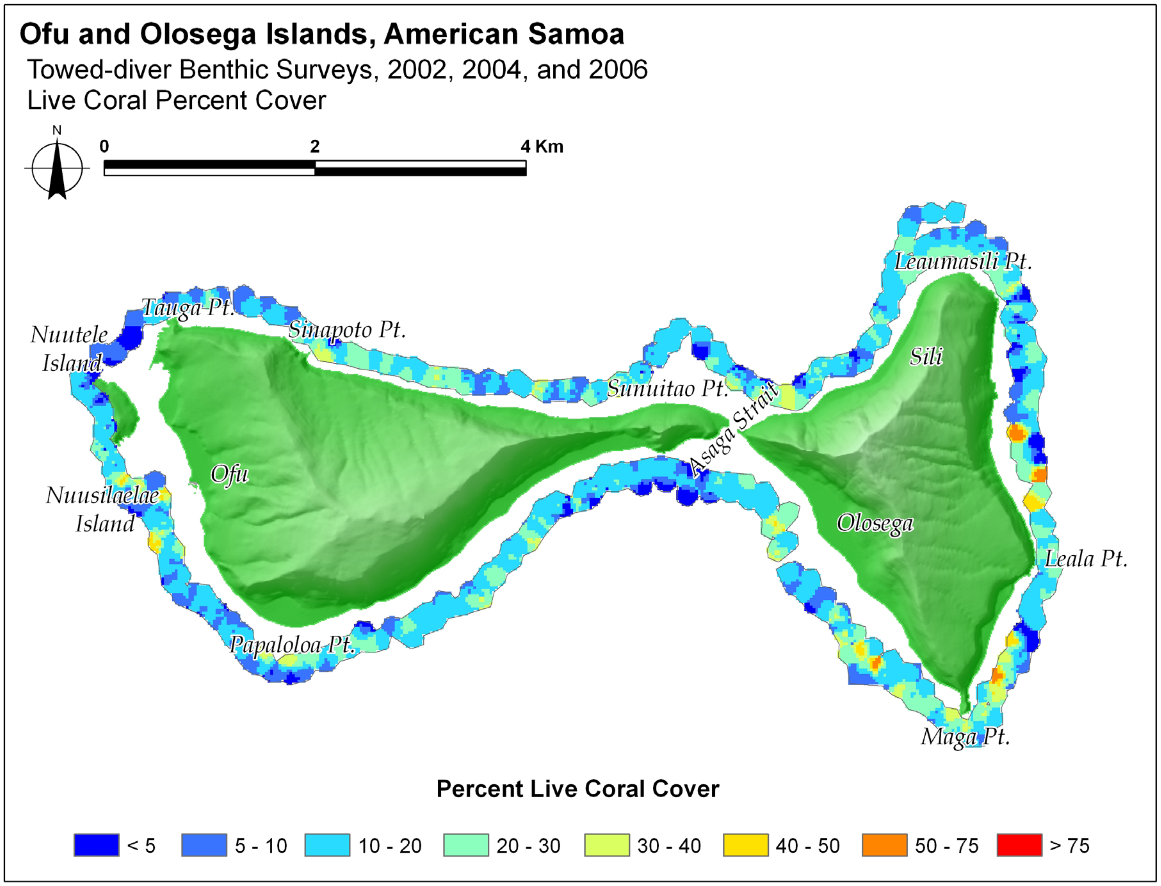

Figure 4.3.2e. Mean percent cover of live scleractinian (stony) coral, concatenated from towed-diver survey observations around Ofu and Olosega during ASRAMP 2002, 2004, and 2006. Live coral cover composition was subjectively rated by diver-observers over 5-min ensembles (~ 200 × 10 m) on a 1–100% scale. Blue colors indicate low percent cover of coral, and reddish colors indicate high percent cover of coral.

Generally, live scleractinian coral cover around Ofu and Olosega was relatively low and variable, with values in most areas in the range between 0% and 30%. The highest percentages of live coral cover, with isolated, localized values of ~ 50%, were found in the northeast and southeast regions on the windward side of Olosega (Fig. 4.3.2e). It appears that the elevated coral cover in the northeast was found in areas of medium-to-high habitat complexity on different sides of a large sand channel (Figs. 4.3.2a and 4.3.2b), while the elevated coral cover in the southeast was located in an area immediately south of a localized area of relatively high rubble composition (Fig. 4.3.2d). Additional localized areas of elevated live coral cover, with values of ~ 40%–50% include the region immediately west of Maga Point in the southeast region, and several localized areas off Ofu Village near REA site OFU-06 and the boundary between the northwest and southwest regions (Fig. 4.2a).

4.4 Oceanography and Water Quality

Oceanographic and water quality observations were collected in the waters surrounding Ofu and Olosega over the period between 2002 and 2006. Instrumentation and equipment descriptions, deployment and retrieval dates and locations, and a subset of results are detailed below. Specific details of deployments and additional data are presented in Appendix II, Table II. ii.

4.4.1 Hydrographic Data

2002 Spatial Surveys

During ASRAMP 2002, 39 shallow-water CTD casts were conducted in nearshore waters around Ofu and Olosega over the February 13–15 period (Fig. 4.4.1a). Data from these vertical profiles showed a stratified water column along northern exposures (A–D) in the northwest and central north regions and around the south sides of the islands (G–J) in the southeast, central south, and southwest regions.

The nearshore water column was relatively well mixed on the eastern side of Olosega (E–F) in the northeast region and to a lesser extent off the southern point of Ofu (J–K) (Fig. 4.4.1b). The area (E–F) is exposed to easterly trade winds and associated seas, which likely caused

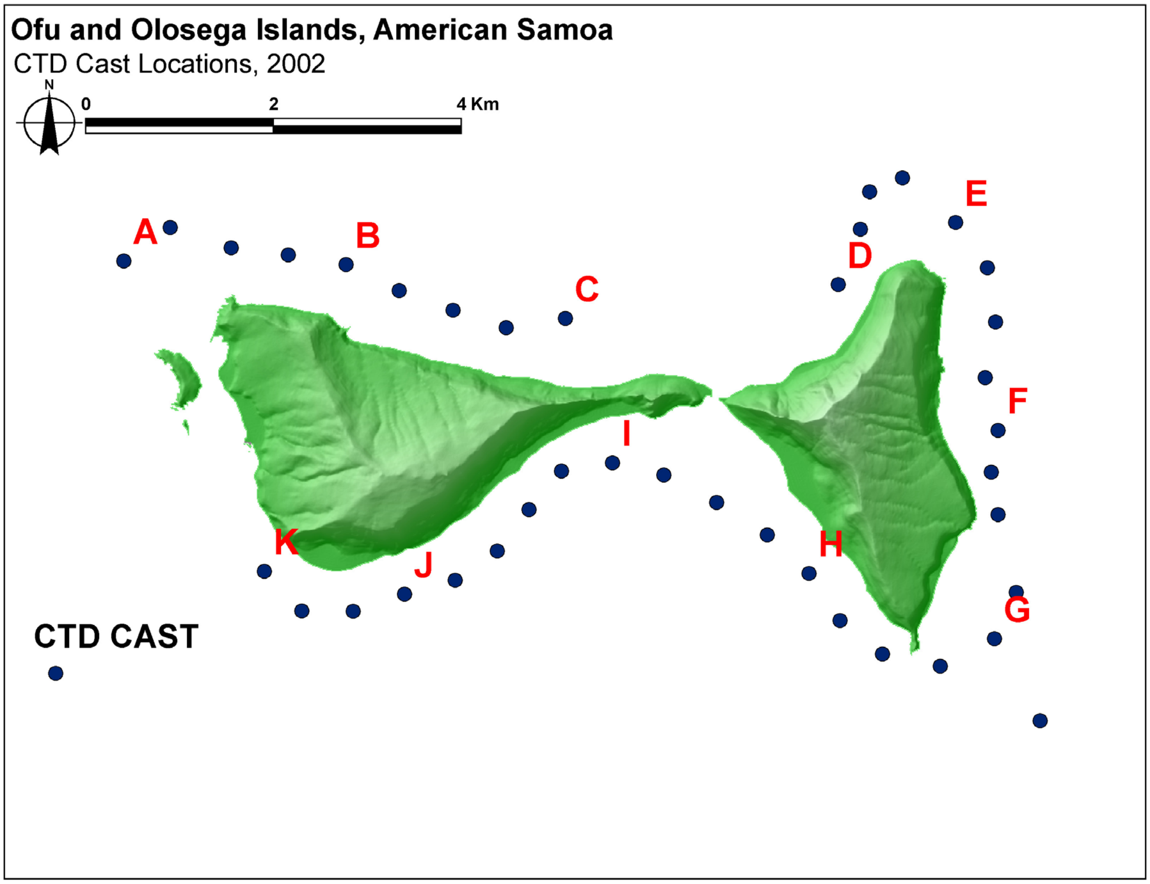

Figure 4.4.1a. Shallow-water CTD cast locations, shown as blue dots, expressed sequentially in a clockwise direction around Ofu and Olosega (A–K) during ASRAMP 2002, February 13–15.

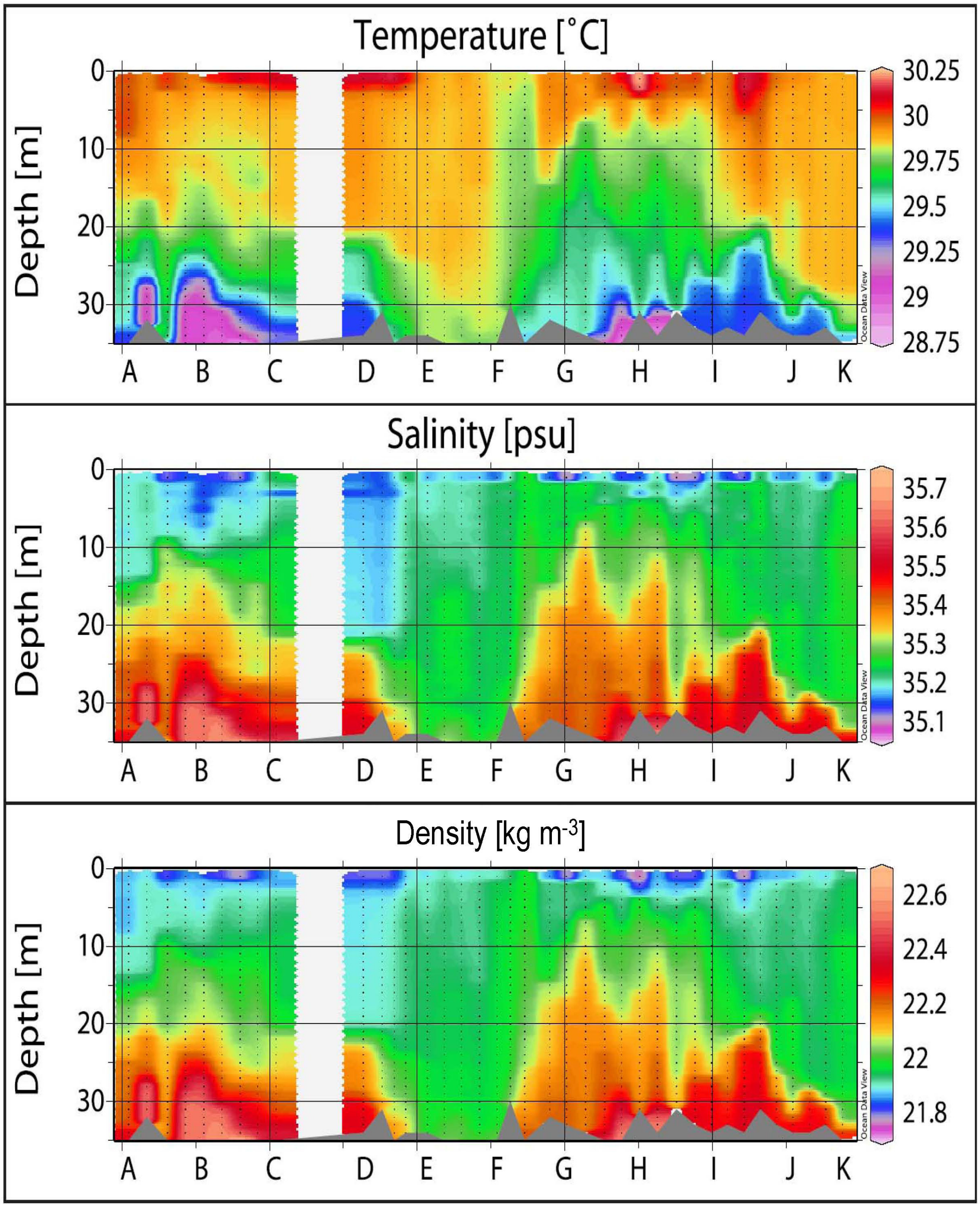

Figure 4.4.1b. Shallow-water CTD cast profiles to a 30-m depth around Ofu and Olosega during ASRAMP 2002, February 13–15, including temperature (°C), salinity (psu), and density (kg m^{-3}). Profiles are shown sequentially in a clockwise direction around the island (A–J), as shown in Figure 4.4.1a.

mechanical mixing of the water column. Other than this small area of mixing, temperature, salinity, and density were consistently stratified around the two islands. Temperature salinity and density were typically related: high temperature (> 30°C) corresponding to low salinity (< 35.2 psu) and low density (< 22 kg m^{-3}). Salinity values were relatively low (< 35.2 psu) in the upper 10 m of the water column in the central north region (B–D). Since bottom-water salinity in the area was elevated, it suggests the source of this low salinity water may have been precipitation or runoff.

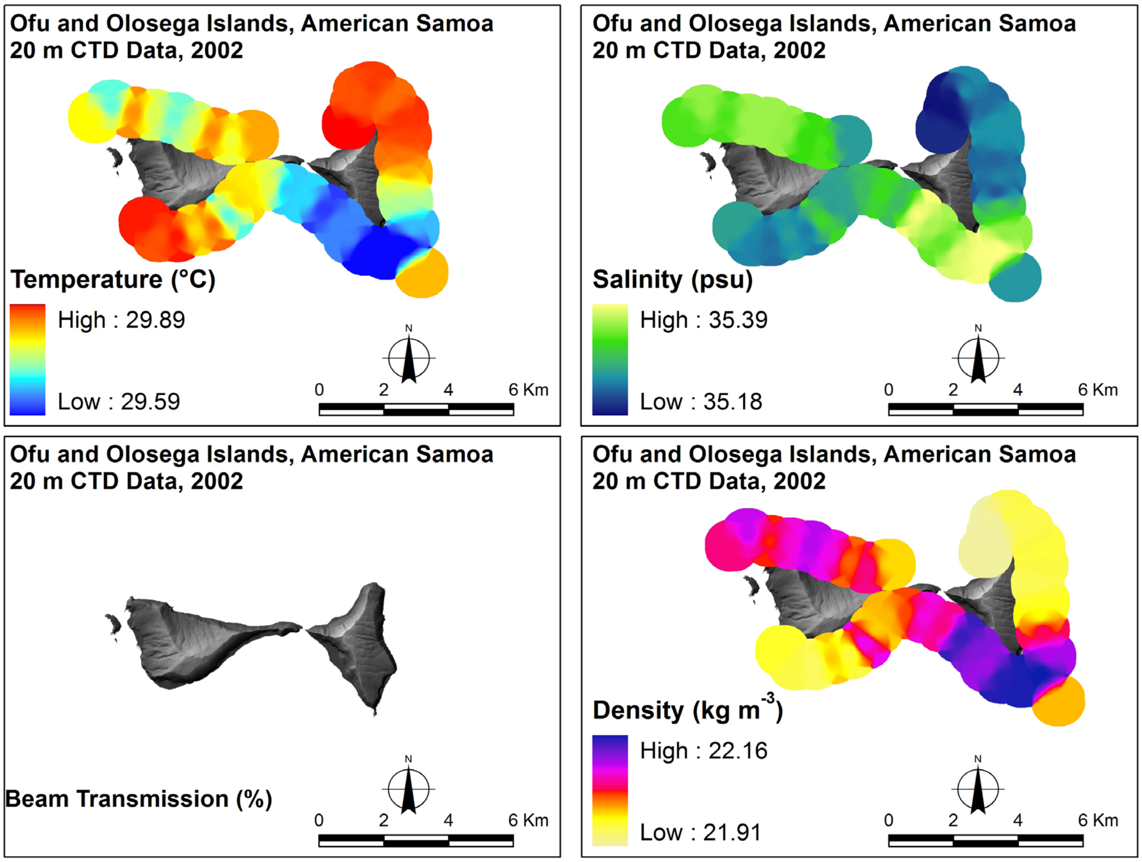

Figure 4.4.1c. Interpolated water temperature (top left), salinity (top right), and density (bottom right) at a 20-m depth derived from shallow-water CTD casts around Ofu and Olosega during ASRAMP 2002, February 13–15. Beam transmission data (bottom left) were not collected.

Spatial analyses of these basic water properties at a 20-m depth from the ASRAMP 2002 surveys indicate clear spatial structure, though ranges in temperature (29.59–29.88°C), salinity (35.18–35.39 psu), and density (21.91–22.16 kg m^{-3}) were relatively small. Spatial patterns in each of the three properties were similar: the northeast and southwest regions were characterized by warmer, fresher, and less dense waters; the southeast region was characterized by cold, salty, and dense waters; and the northwest region was characterized by intermediate values for each of these parameters.

2004 Spatial Surveys

During ASRAMP 2004, 50 shallow-water CTD casts were conducted in nearshore waters around Ofu and Olosega over the periods February 6–8 and 13 (Fig. 4.4.1d). Data from these vertical profiles showed spatial patterns that are notably different from the 2002 surveys, with relatively well-mixed water columns around both islands (Fig. 4.4.1e). The ranges of temperature and salinity variations around the islands over the depth profiles (0–30 m) were < 0.8°C and 35–35.5 psu, respectively. Salinity and density were lowest and beam transmission was highest (low turbidity) on the eastern side of Olosega (F–G). Since the water in the area was much fresher in the upper part of the water column (0–10 m) than near the bottom (20–30 m), the likely cause of this signal may have been runoff from the east side of Olosega. The low density, low salinity surface lens that this created appeared to subsequently get mechanically mixed vertically deeper into the water column by trade winds and wave action. The west side of Ofu in the northwest and southwest regions (K–B) was characterized by warm, fresh, turbid, and less dense surface waters (0–10 m) and cooler, more saline, and more dense bottom waters (20–30 m). Finally, an area of relatively well-mixed cool water (~ 29.2°C) extending from the surface to the bottom was observed in the south central region (I–J), just west of Asaga Strait, the shallow channel between the two islands.

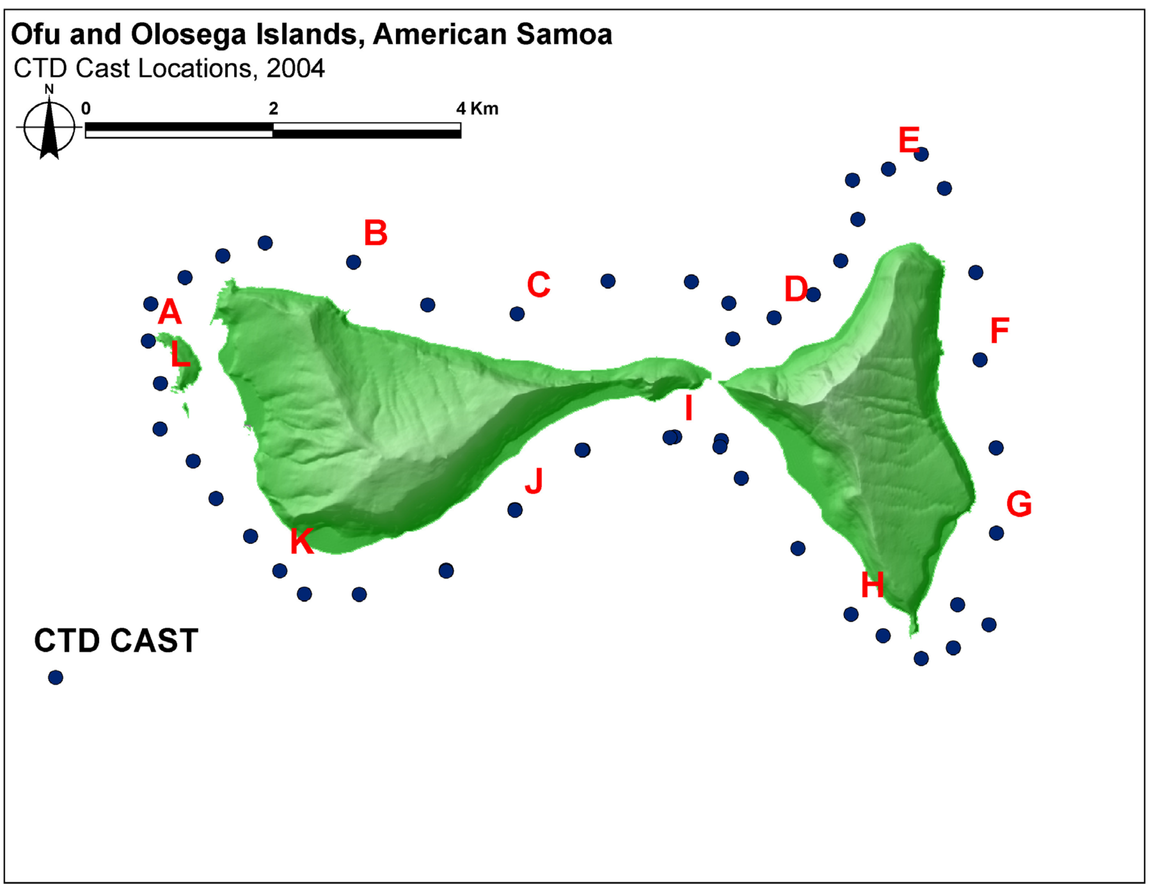

Figure 4.4.1d. Shallow-water CTD cast locations, shown as blue dots, expressed sequentially in a clockwise direction around Ofu and Olosega (A–L) during ASRAMP 2004, February 6–8.

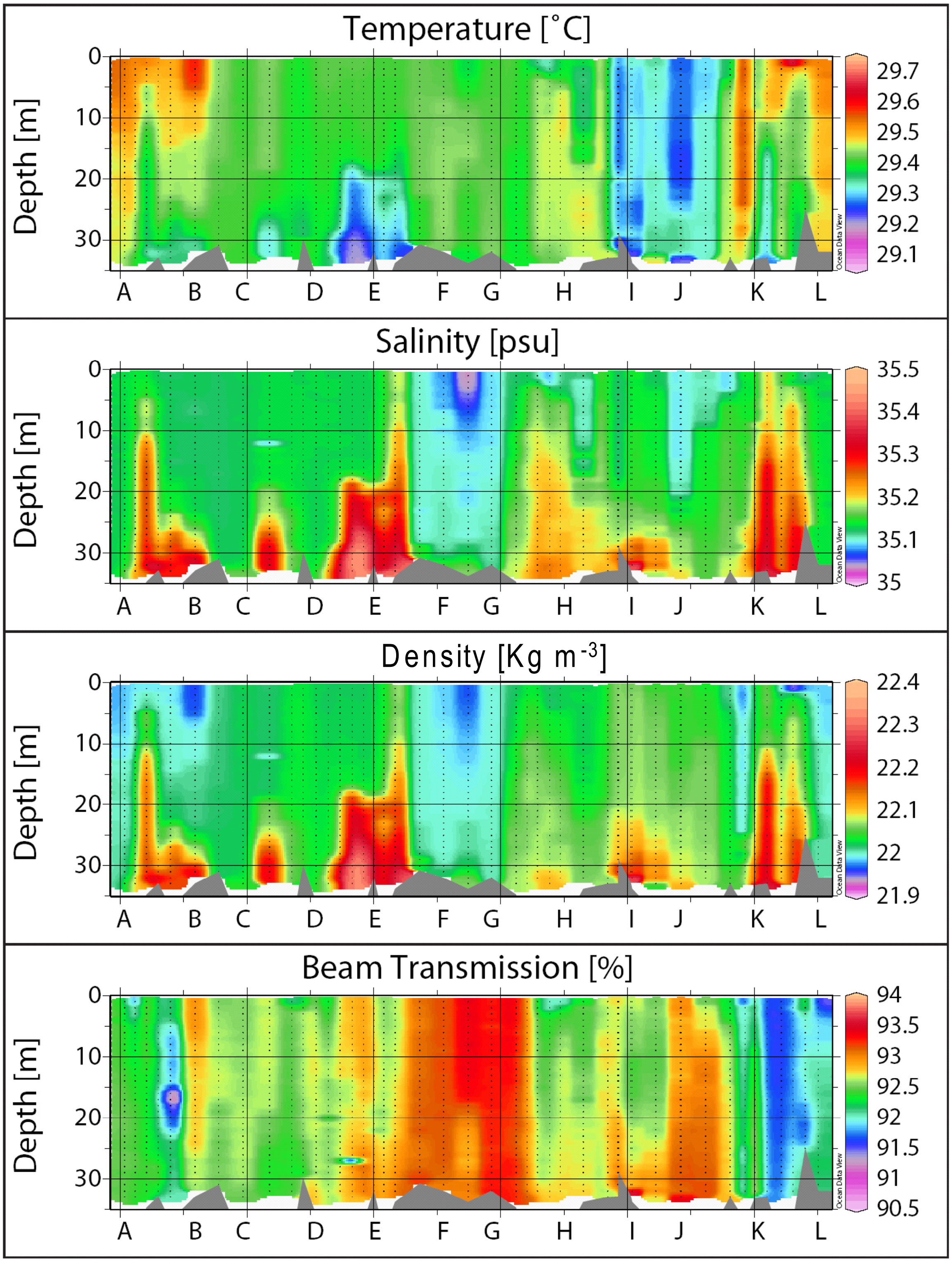

Figure 4.4.1e. Shallow-water CTD casts to a 30-m depth around Ofu and Olosega during ASRAMP 2004, February 6–8, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles are shown sequentially clockwise around the island (A–L), as shown in Figure 4.4.1d.

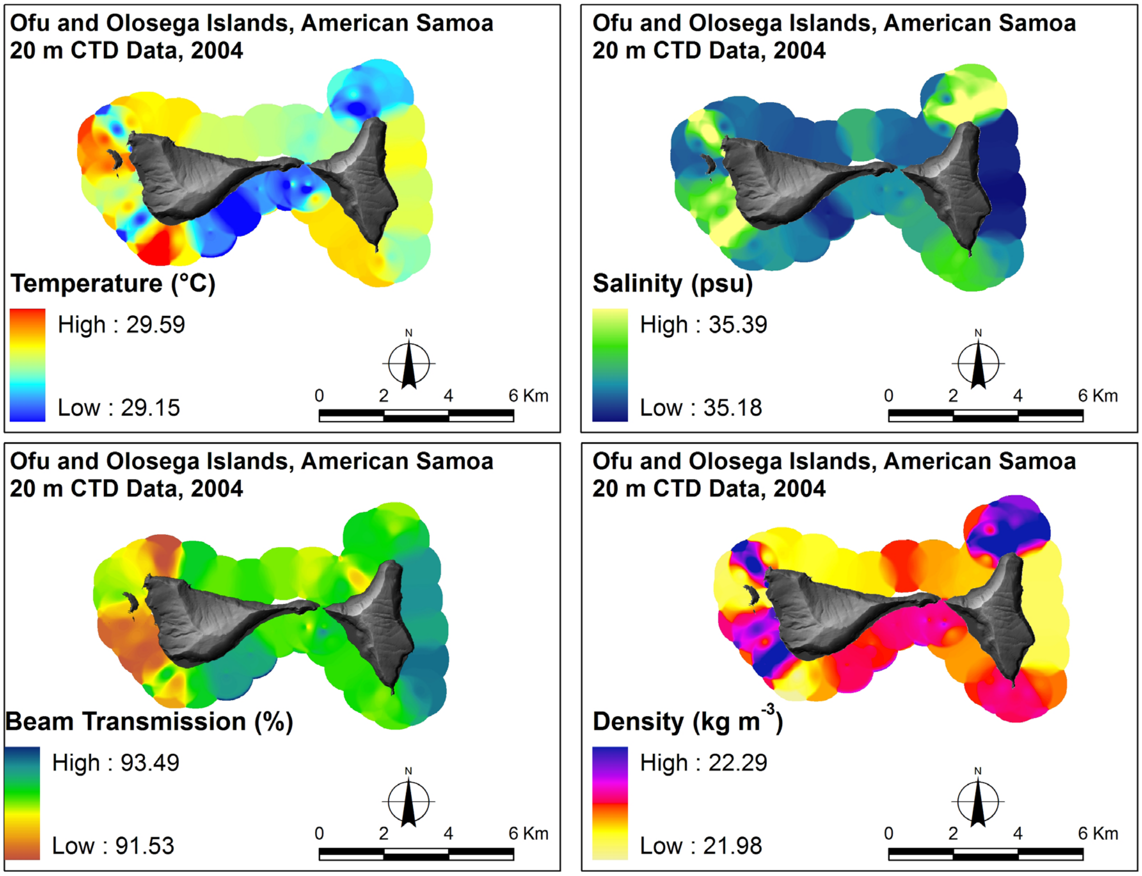

Figure 4.4.1f. Interpolated water temperature (top left), salinity (top right), beam transmission (bottom left) and density (bottom right) at a 20-m depth derived from shallow-water CTD casts around Ofu and Olosega during ASRAMP 2004, February 6–8 and 13.

The spatial patterns of observed physical water properties around Ofu and Olosega at a 20-m depth during ASRAMP 2004 were characterized by relatively small, but noteworthy, ranges in temperature (29.15–29.59°C), salinity (35.18–35.39 psu), beam transmission (91.53–93.49%), and computed density (21.98–22.29 kg m^{-3}) (Fig. 4.4.1f). The eastern side of Olosega was observed to have low salinity and density value, and moderately high beam transmission (low turbidity) and temperature, possibly suggesting a vertically mixed freshwater lens formed by precipitation or runoff during the sampling period. The submerged bank in the northeast region and the western part of the central south region off Ofu were characterized by cool, saline, dense waters with moderate beam transmission. Interestingly, very strong and distinct spatial gradients between the east and northeast sides of Olosega were observed. Significant spatial variability was observed along the western side of Ofu in the southwest and northwest regions, where alternate areas of warm and cool, fresh and saline, and low and high beam transmission were observed in close proximity. Beam transmission was generally lowest (high turbidity) in this area, particularly off Ofu Village and an area off the northern point of the island.

2006 Spatial Surveys

During ASRAMP 2006, 33 CTD casts were conducted in nearshore waters around Ofu and Olosega over the period February 26–28 (Fig. 4.4.1g). In addition, water samples were collected for nutrient analyses at depths of 1, 10, 20, and 30 m, where possible, at 18 of the CTD sites. At these locations, 35 Dissolved Inorganic Carbon (DIC) samples and 61 water samples were collected for analyses of nutrient concentration.

Vertical profiles of water properties from the shallow-water CTD surveys around Ofu and Olosega during ASRAMP 2006 found noteworthy spatial patterns of all observed properties (Fig. 4.4.1h). Areas with both well-mixed and stratified water columns were observed around the two islands. The nearshore waters were vertically well mixed along the north sides of the two islands from the northwest point of Ofu in the northwest region through the central north region, to the north point of Olosega in the northeast region (A–C). The nearshore waters were generally well stratified along the windward side of Olosega in the northeast and southeast regions and along most of the south coasts of both islands in the southeast, central south, and southwest regions (C–G), being most pronounced along the southwest (lee) sides of both Ofu and Olosega, possibly as a result of decreased mechanical mixing by wind and wave energy. Two regions of warm, low-saline, low-density waters were observed off the north side of Olosega (B–C) and off the western side of Ofu (F–A). Additionally, a region of relatively cool, high-salinity, high-density, bottom water (> 20 m) occurred around the

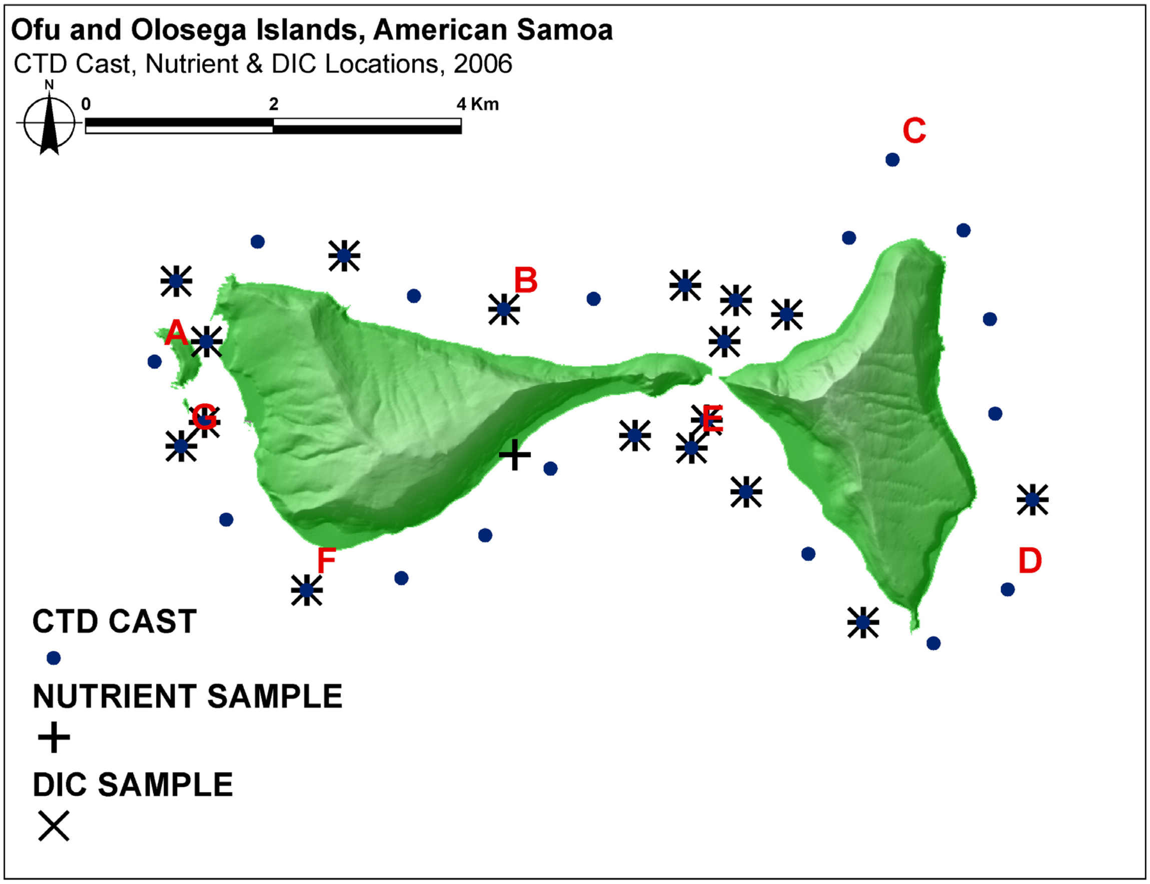

Figure 4.4.1g. Shallow-water CTD cast, nutrient and dissolved inorganic carbon (DIC) water sample locations around Ofu and Olosega (A–G) during ASRAMP 2006, February 26–28.

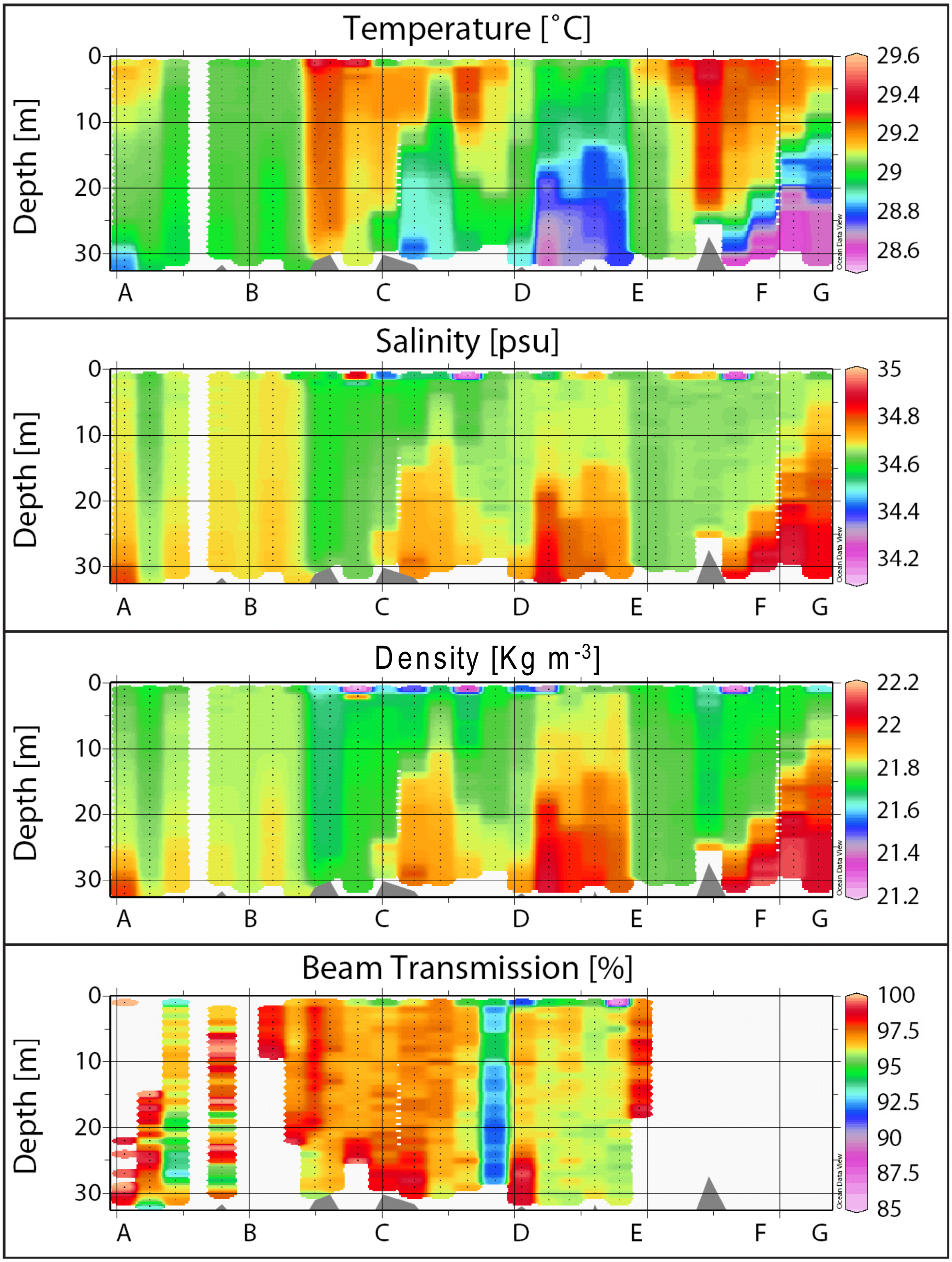

Figure 4.4.1h. Shallow-water CTD cast profiles to a 30-m depth around Ofu and Olosega during ASRAMP 2006, February 26–28, including, temperature (°C); salinity (psu); density (kg m^{-3}); and beam transmission (%). Profiles are shown sequentially in a clockwise direction around the island (A–G), as shown in Figure 4.4.1g.

southern point of Olosega (D–E). Within this region beam transmission observations were high, suggesting upwelling of deeper water into this region. Beam transmission during this time was intermittent based on a faulty instrument.

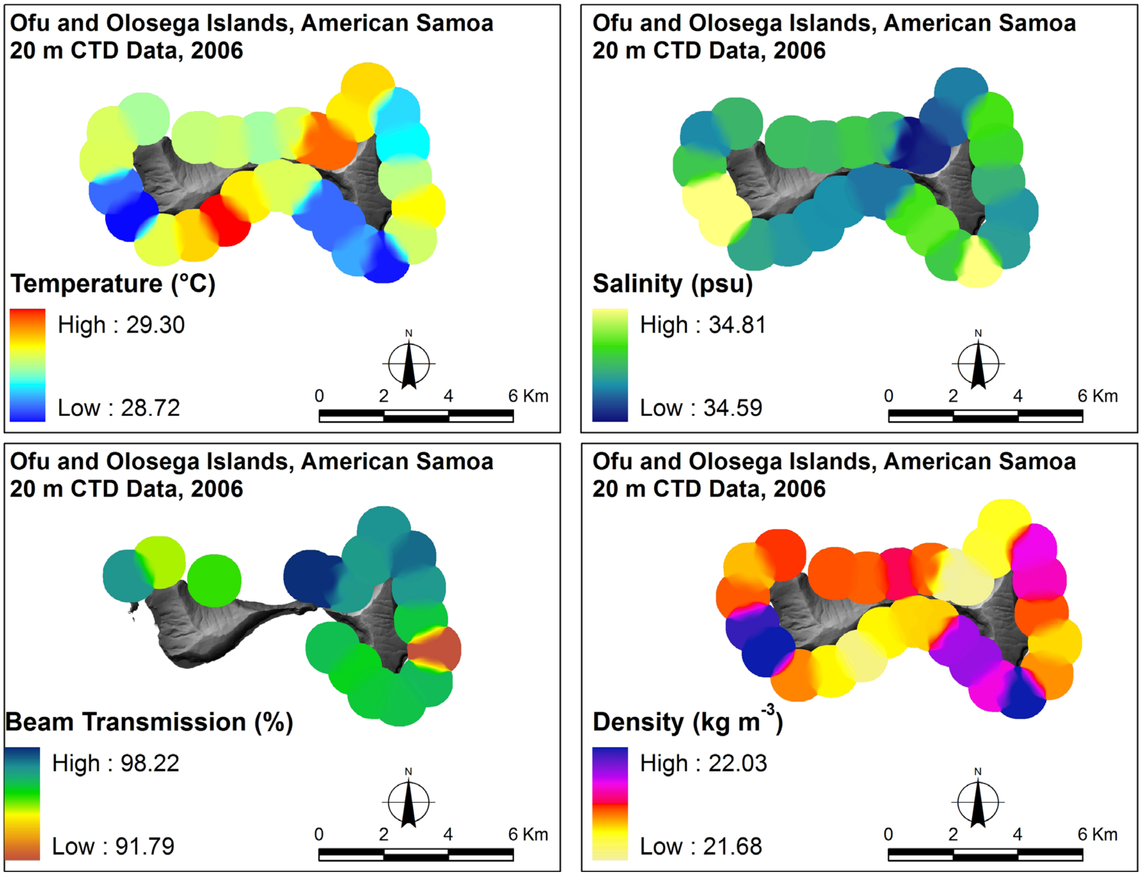

Figure 4.4.1i. Interpolated water temperature (top left), salinity (top right), beam transmission (bottom left) and density (bottom right) at a 20-m depth, derived from shallow-water CTD casts around Ofu and Olosega during ASRAMP 2006, February 26–28.

The spatial patterns of observed physical water properties around Ofu and Olosega at a 20-m depth during ASRAMP 2006 were characterized by moderate ranges in temperature (28.72–29.30°C), salinity (34.59–34.81 psu), density (21.68–22.03 kg m^{-3}), and beam transmission (91.79–98.22%; Fig. 4.4.1i). A distinct oceanographic feature along the northern coastline where the two islands meet was characterized by relatively warm water temperatures, low salinity and density, and very high beam transmission (low turbidity). These characteristics suggest a freshwater feature at that location during the sampling period. Similar characteristics were also seen along the western portion of the southern coastline off the southeast coast of Ofu. The eastern side of Olosega showed local variability in these physical oceanographic parameters, including a region with low beam transmission (high turbidity). The western side of Ofu was observed with relatively cold, saline, and dense water, suggesting a possible upwelling feature in that region.

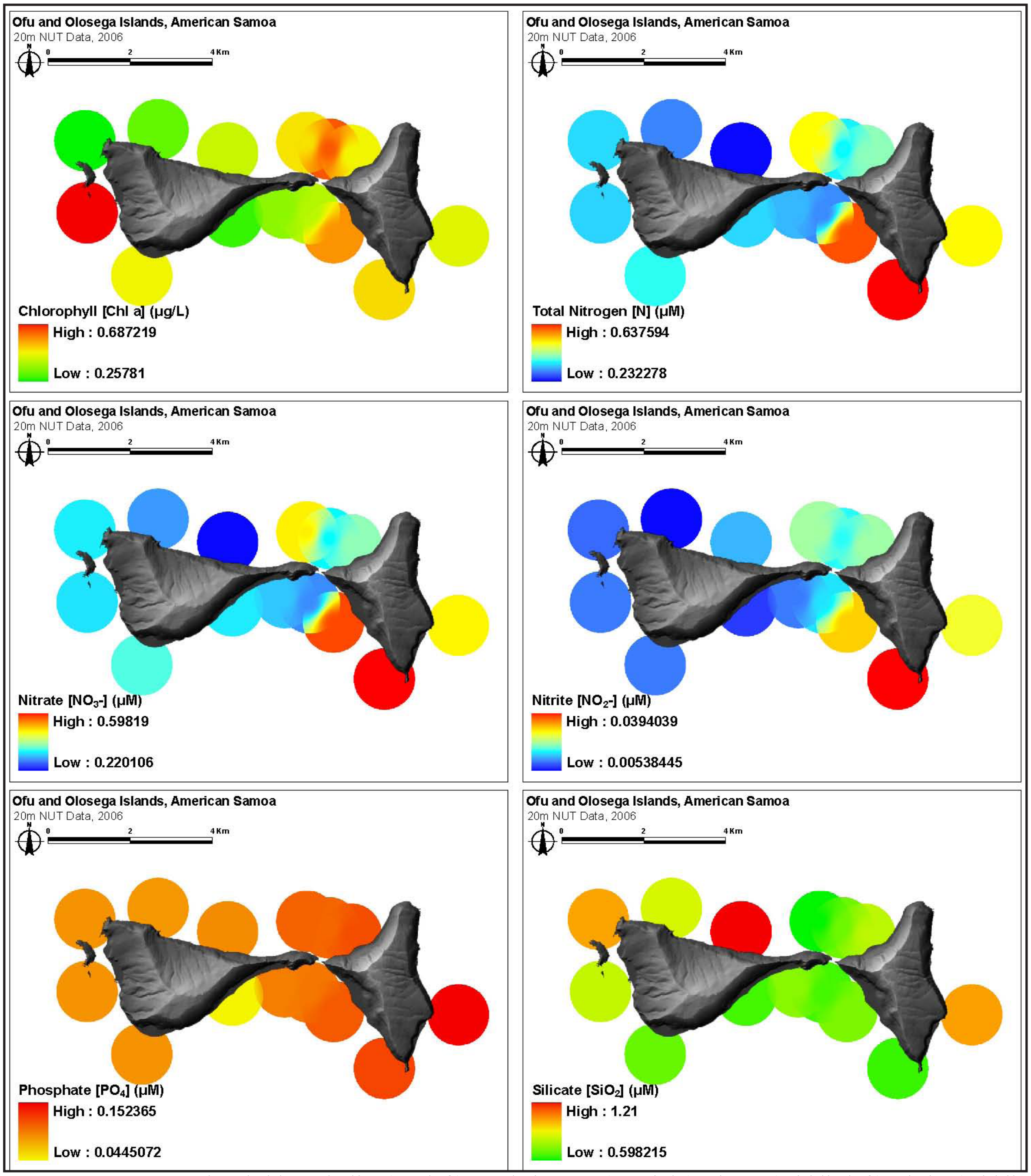

Figure 4.4.1j. Interpolated chlorophyll-a (top left), total nitrogen (top right), nitrate (middle left), nitrite (middle right), phosphate (bottom left) and silicate (bottom right) concentrations, at a 20-m depth derived from water samples collected in concert with shallow-water CTD casts around Ofu and Olosega during ASRAMP 2006, February 26–28.

Water quality, as deduced by laboratory analyses of key nutrients from the in situ water samples collected at a of 20-m depth around Ofu and Olosega during ASRAMP 2006, showed interesting spatial patterns (Fig. 4.4.1j). The following ranges in water quality parameters were observed around the two islands: chlorophyll-a, 0.26–0.69 µg L^{-1}; phosphate (PO_4) 0.04–0.15 µM; silicate (SiO_2), 0.60–1.21 µM; and total nitrogen ($N_{tot} = NO_3 + NO_{2-}$), 0.23–0.64 µM. Sites near inhabited locations, northwest of Ofu and southwest of Olosega, had higher chlorophyll-a and total nitrogen values, respectively. The highest values of nitrates, nitrites, and total nitrogen were observed in the southeast region, possibly indicating upwelling or current-derived nutrients. It is possible that this may also be associated with the submerged volcanic ridgeline that extends to the eastern coastline of Olosega from nearby Ta`u. Values of the nitrates, nitrites, and total nitrogen were generally low around all sides of Ofu. Chlorophyll-a was substantially highest off Ofu Village, with significantly lower values around the remainder of Ofu.

4.4.2 Temporal Comparison—Hydrographic Data

During each of the ASRAMP survey periods in 2002, 2004 and 2006, the nearshore CTD and water quality data exhibited noteworthy spatial heterogeneity, though actual ranges of most properties were relatively small. Temperature variations were small between sample periods. Salinity showed minimal variability between sample periods; however, salinity values were considerably lower during 2006. Density observations tended to parallel salinity more so than temperature, which is typically the dominant constituent when computing density. Turbidity measurements, when comparing 2004 and 2006, were extremely low at select locations in the latter survey period; the reason is unknown without additional observations.

4.4.3 Time Series Observations

A suite of moored instruments were deployed around Ofu and Olosega over the period between 2002 and 2006 to collect time series observations of key oceanographic properties influencing reef conditions (Fig. 4.4.3a). Deployment and retrieval dates are detailed in

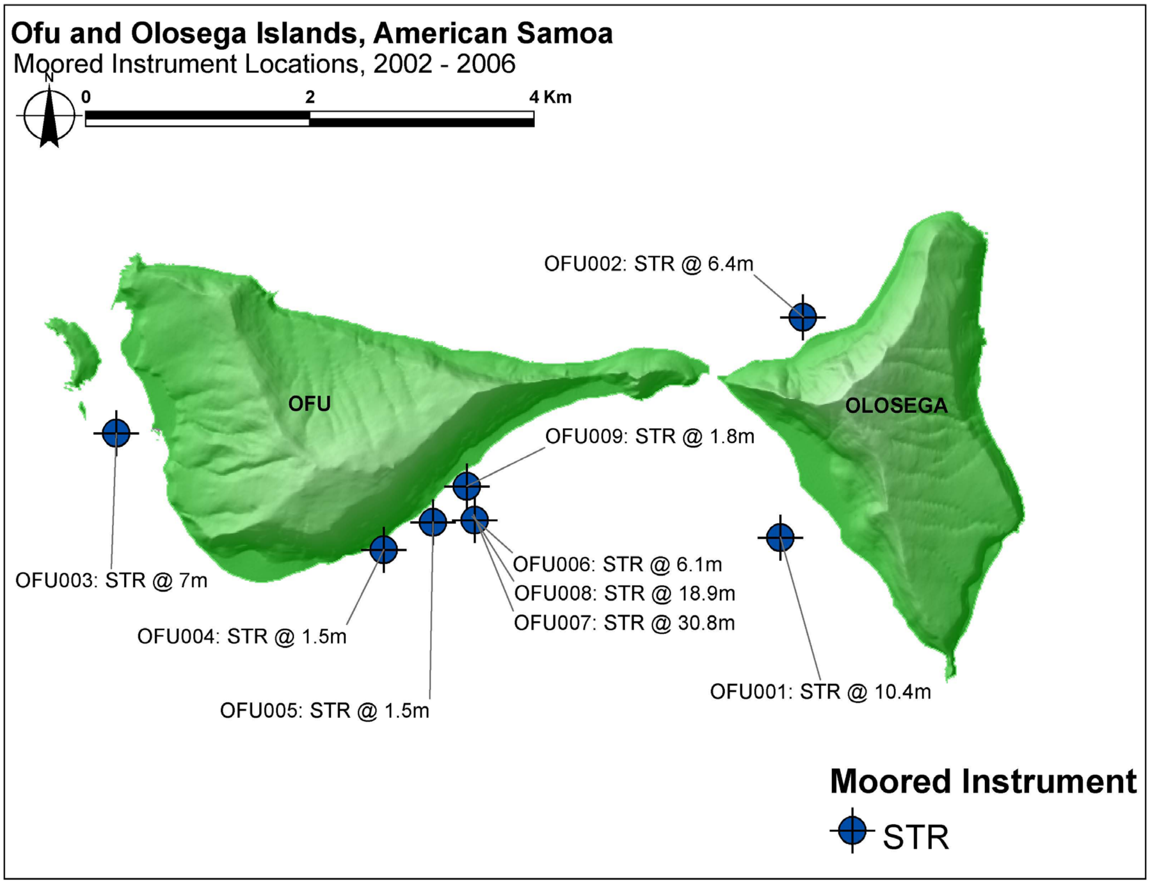

Figure 4.4.3a. Locations and depths of STR deployments around Ofu and Olosega between 2002 and 2006.

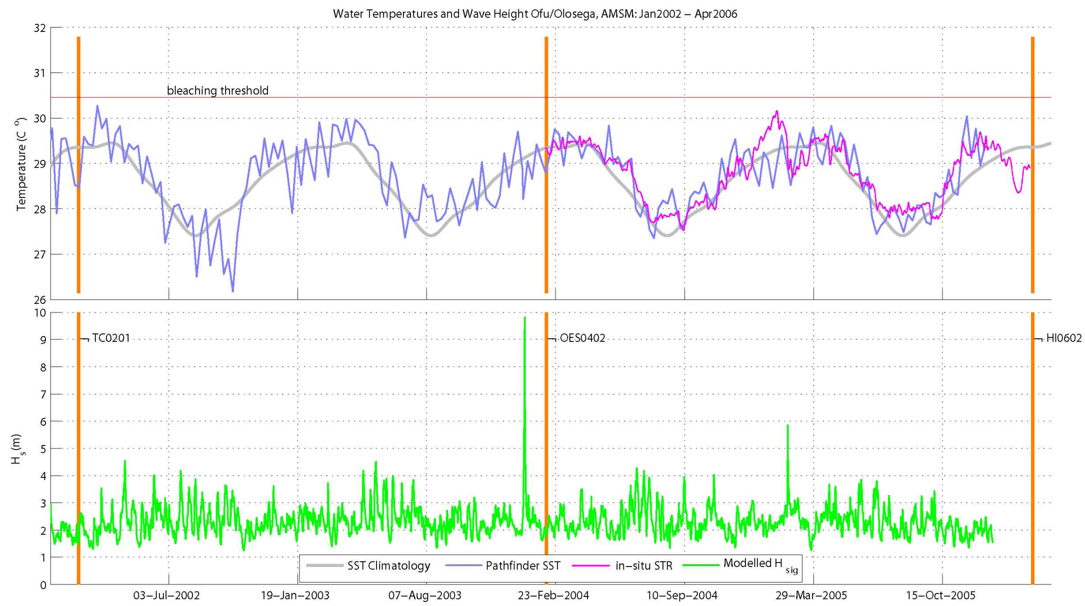

Figure 4.4.3b. SST and wave height time series records at Ofu and Olosega between January 2002 and April 2006. Remotely sensed data (SST climatology and weekly Pathfinder-derived SST) and modeled significant wave height derived from Wave Watch III are overlaid with CRED in situ temperature observations from an STR deployed at a 1.5-m depth at OFU005, in Ofu Lagoon. The horizontal red and vertical orange bars represent the bleaching threshold and the ASRAMP research cruise dates, respectively.

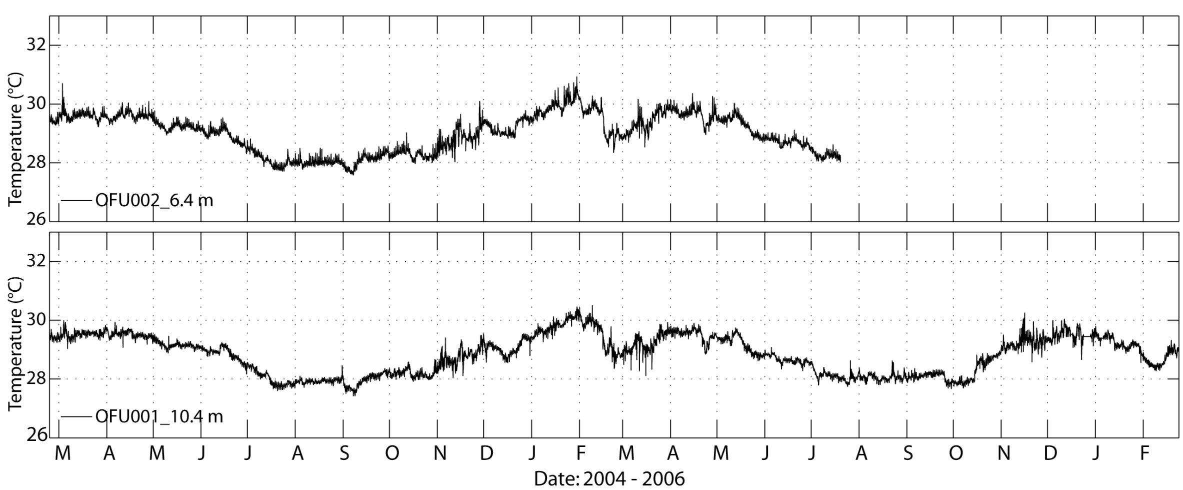

Figure 4.4.3c. Time series observations of sea temperature, over the period March 2004 to February 2006 from an STR deployed at OFU002 in a water depth of 6.4 m north of Olosega Island (top panel) and at OFU001 in a water depth of 10.4 m west of Olosega Island (bottom panel). See Figure 4.4.3a for mooring locations.

Appendix II, Table II. ii. Figure 4.4.3b shows a time series of in situ and remotely sensed sea surface temperature (SST) and modeled wave properties from January 2002 to April 2006.

Pathfinder SST and in situ temperature observations around Ofu and Olosega show strong seasonal variation, with warmest temperatures (~ 30°C) during January–March and coolest temperatures (~ 27.5°C) in June–August (Fig. 4.4.3b; top panel). A particularly cool episode, with temperatures falling 2°C below the SST climatology, was observed in austral winter in 2002, before sharply rising 3°C to return to climatological temperatures later that year. In situ temperature observations tended to track satellite-derived temperature observations closely, with one exception in early 2005, when in situ values were nearly 1.5°C above Pathfinder-derived SST.

Temperature time series from two subsurface temperature recorders (STRs) from 2004 to 2006 show 2–3°C temperature fluctuations as a result of seasonal variability (Fig. 4.4.3c). In each of these time series records, minimal (< 1°C) diurnal temperature fluctuations were observed.

Modeled significant wave height data for Ofu and Olosega reveal weak seasonal variability superposed with episodic, cyclone-induced extreme wave events. Larger wave heights (~ 3–4 m) typically occurred during winter months compared to smaller wave heights (~ 2 m) during the summer months. Two extreme swell events were observed during the time series record: the first, in January 2004, was produced by cyclone Heta and the second, in February 2005, was produced by Cyclones Olaf and Percy (Fig. 4.4.3b; bottom panel).

4.5 Coral and Coral Disease

4.5.1 Coral Surveys

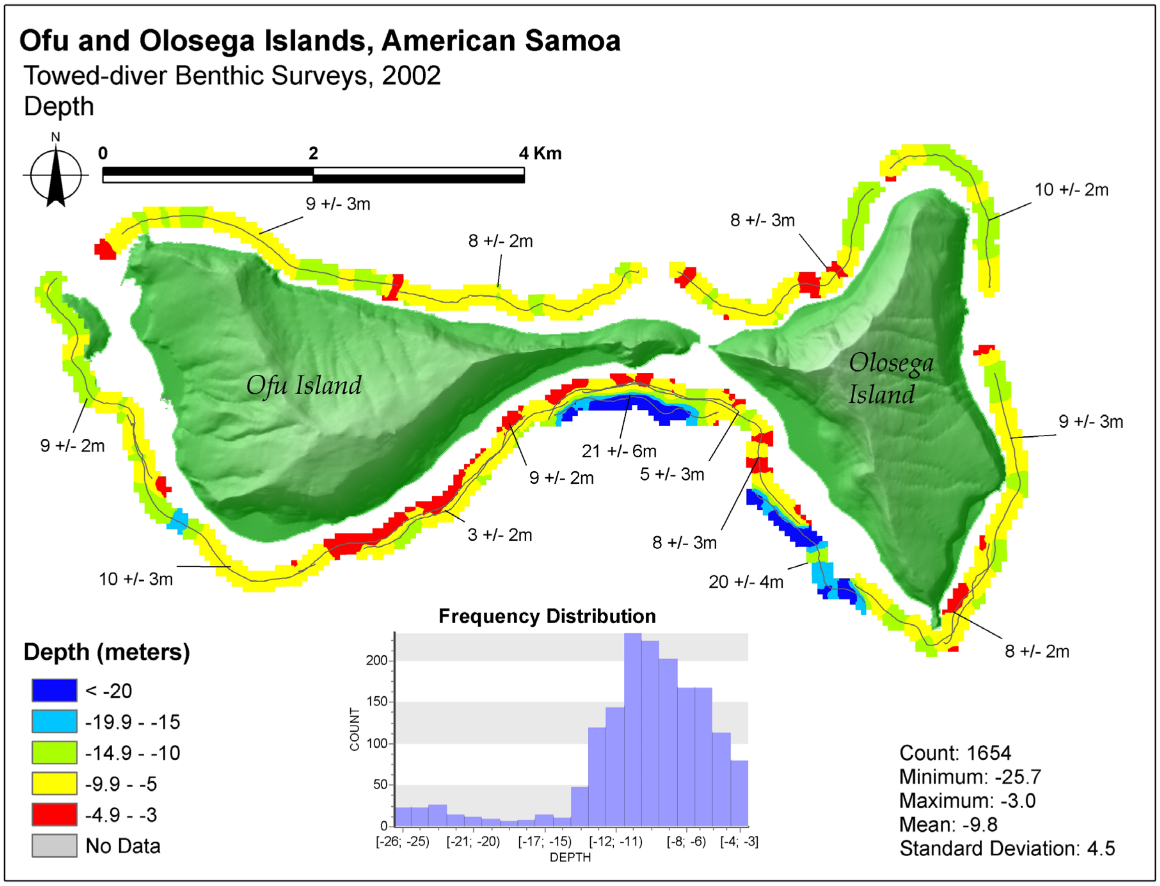

Figure 4.5.1a. Towed-diver survey tracks around Ofu and Olosega during ASRAMP 2004. Towed-diver survey tracks are color coded with mean depths for each 5-min segment. Mean depths and standard deviations for each towed-diver survey are shown in black text. Depth histogram and statistics (counts, minimum depth, maximum depth, mean, and standard deviation) from 30-sec depth recordings during towed-diver surveys are included.

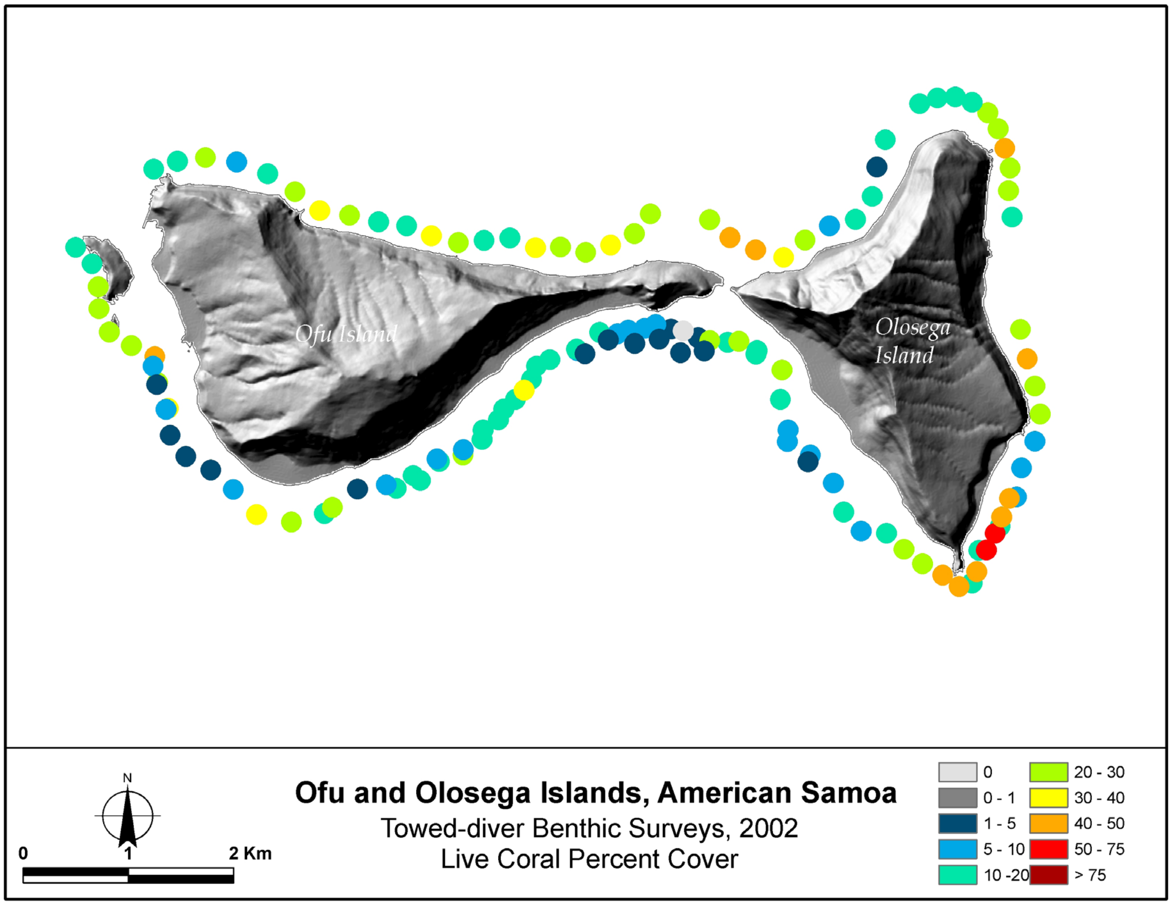

Figure 4.5.1b. Towed-diver benthic survey observations of live scleractinian (stony) coral cover around Ofu and Olosega during ASRAMP 2002. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 × 10 m (~ 2000 m²). Symbol size represents 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.

2002 Spatial Surveys

Fourteen towed-diver surveys, with a mean depth of 9.8 m, were conducted around Ofu and Olosega during ASRAMP 2002. Individual towed-diver survey track depths ranged from 3 m (SD 2) to 21 m (SD 6; Fig. 4.5.1a). An island-wide mean of 20.3% (SE 3.5) live scleractinian (stony) coral cover was observed (Fig. 4.5.1b). The island-wide mean dead coral percent cover was 3.3% (SE 0.6), which was assessed as an independent component of the benthic community (Fig. 4.5.1c).

The area of highest observed live coral cover was recorded in the southeast region around Maga Point (9 tow segments, mean: 43.3%) in relatively shallow water. In addition, other areas of high live coral cover were found in the northwest region (5 tow segments south of Nu`utele Island, mean: 31.0%), in the central north region (10 tow segments north of Sunuitao Point, mean: 31.0%), and in the northeast region (5 tow segments east of Leaumasili Point, mean: 29%). Low coral cover in the central south region was found to align with deeper towed-diver survey depths, suggesting that coral communities around Ofu and Olosega were stratified by depth. Two areas of elevated dead coral were observed: in the southwest region

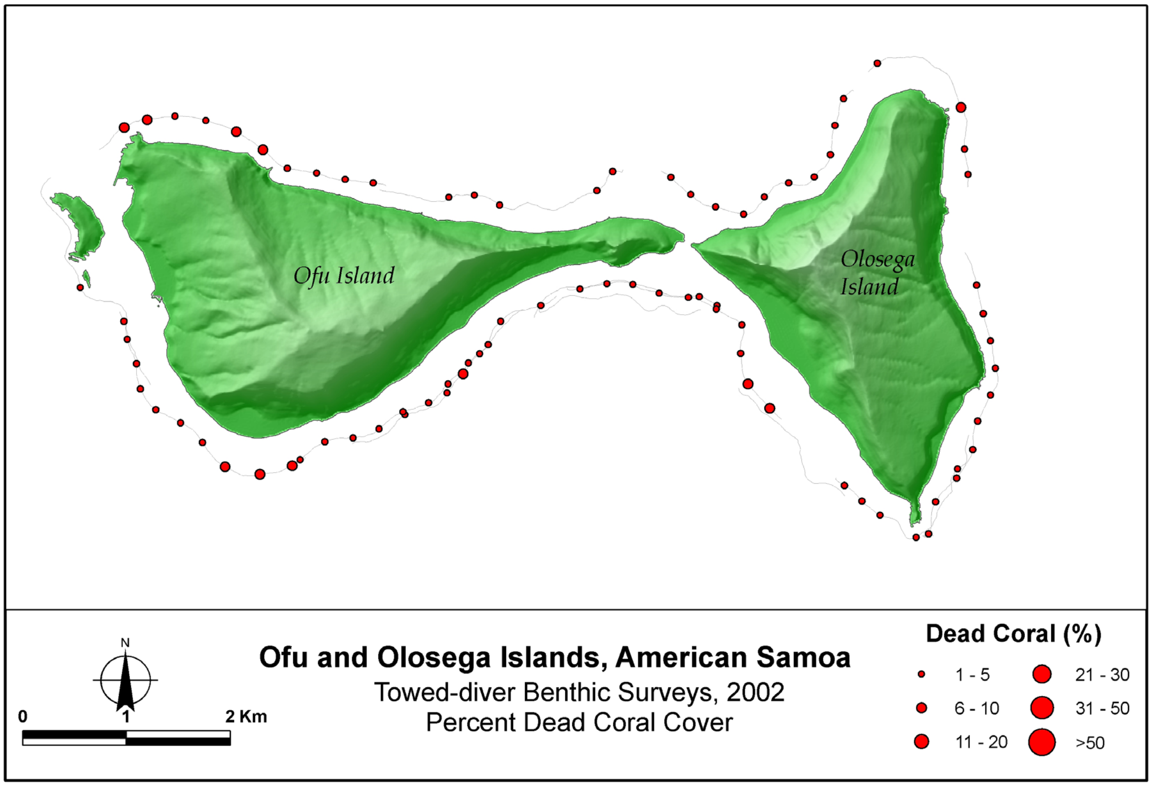

Figure 4.5.1c. Towed-diver benthic survey observations of dead coral cover around Ofu and Olosega during ASRAMP 2002. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 × 10 m (~ 2000 m^2). Symbol size represents the percent dead coral cover on the benthic habitat.

(3 tow segments adjacent to Papaloloa Point, mean: 8.6%) and in the northwest region (6 tow segments off of Ta`uga Point, mean: 8.3%).

REA coral surveys during ASRAMP 2002 were the first surveys conducted in American Samoa by CRED. Though seven sites were surveyed around Ofu and Olosega by a CRED coral biologist, much of the focus of those surveys was to explore different coral monitoring methodologies. Since the surveys were exploratory and qualitative in nature, no data are presented in this more quantitative report.

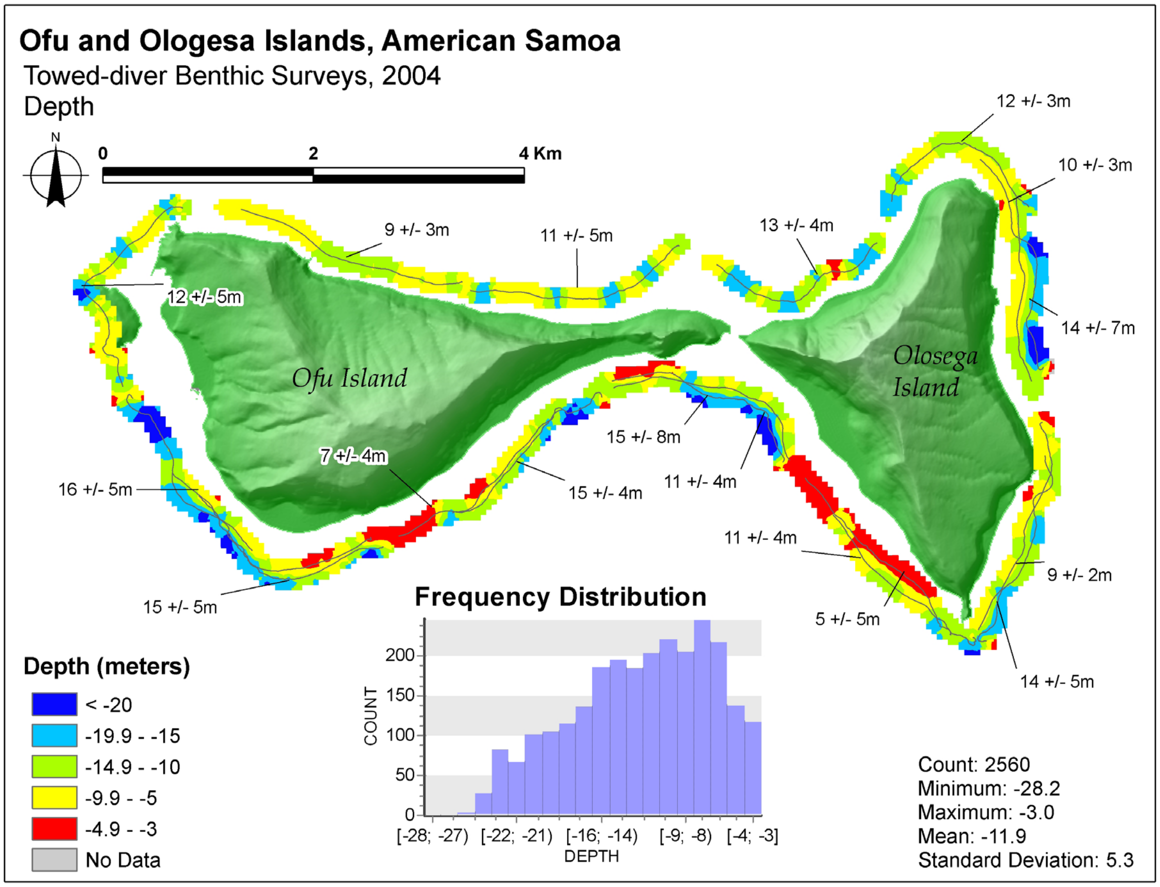

Figure 4.5.1d. Towed-diver survey tracks around Ofu and Olosega during ASRAMP 2004. Towed-diver survey tracks are color coded with mean depths for each 5-min segment. Mean depths and standard deviations for each towed-diver survey are shown in black text. Depth histogram and statistics (counts, minimum depth, maximum depth, mean, and standard deviation) from 30-sec depth recordings during towed-diver surveys are included.

2004 Spatial Surveys

A total of 18 benthic towed-diver surveys were conducted around Ofu and Olosega during ASRAMP 2004, with a mean tow depth of 11.9 m. Individual towed-diver survey depths ranged from 5 m (SD 5) to 15 m (SD 8; Fig. 4.5.1d). The southwest, central south, and southeast regions had the greatest range of variability in towed-diver survey depths, while the northwest, central north, and northeast regions had consistent mid-range depths. An island-wide mean percent cover of live scleractinian coral was recorded at 14.5% (SE 1.2; Fig. 4.5.1e). An island-wide mean estimate of the percent of stressed coral from the towed-diver benthic surveys was 2.4% (SE 0.8; Fig. 4.5.1f).

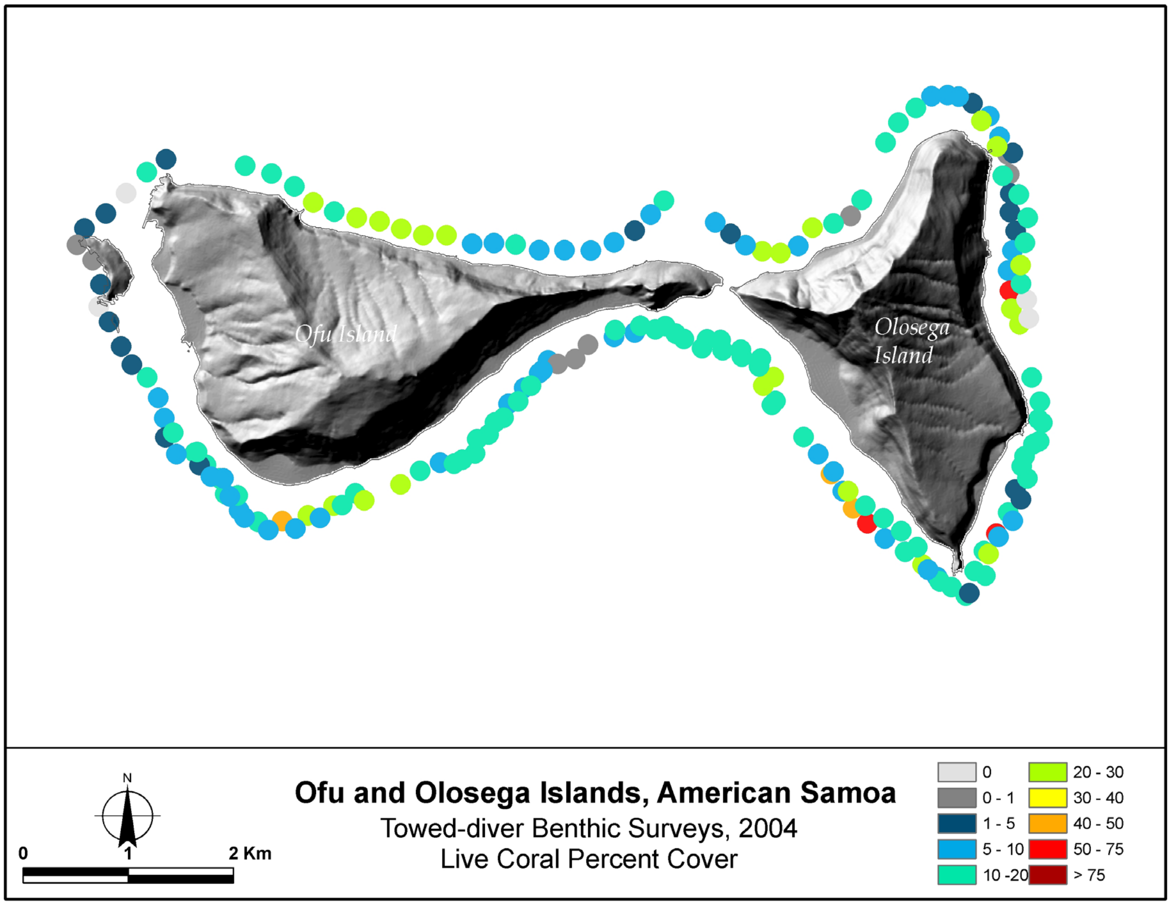

Figure 4.5.1e. Towed-diver benthic survey observations of live scleractinian (stony) coral cover around Ofu and Olosega during ASRAMP 2004. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 × 10 m (~ 2000 m^2). Symbol size represents the percent live coral cover on the benthic habitat.

Percent cover of live scleractinian coral from towed-diver benthic surveys around Ofu and Olosega showed significant spatial variation (Fig. 4.5.1e). The two specific locations with the highest observed live percent coral cover were in the northeast region (50%) and in the southeast region (52%). High live coral cover was also recorded in the southeast region (west of Maga Point, 3 tow segments, mean: 43.6%), in the northwest and central north regions (east of Sinapoto Point, 7 tow segments, mean: 25.9%), and in the southwest region (adjacent to Papaloloa Point, 9 tow segments, mean: 22.6%).

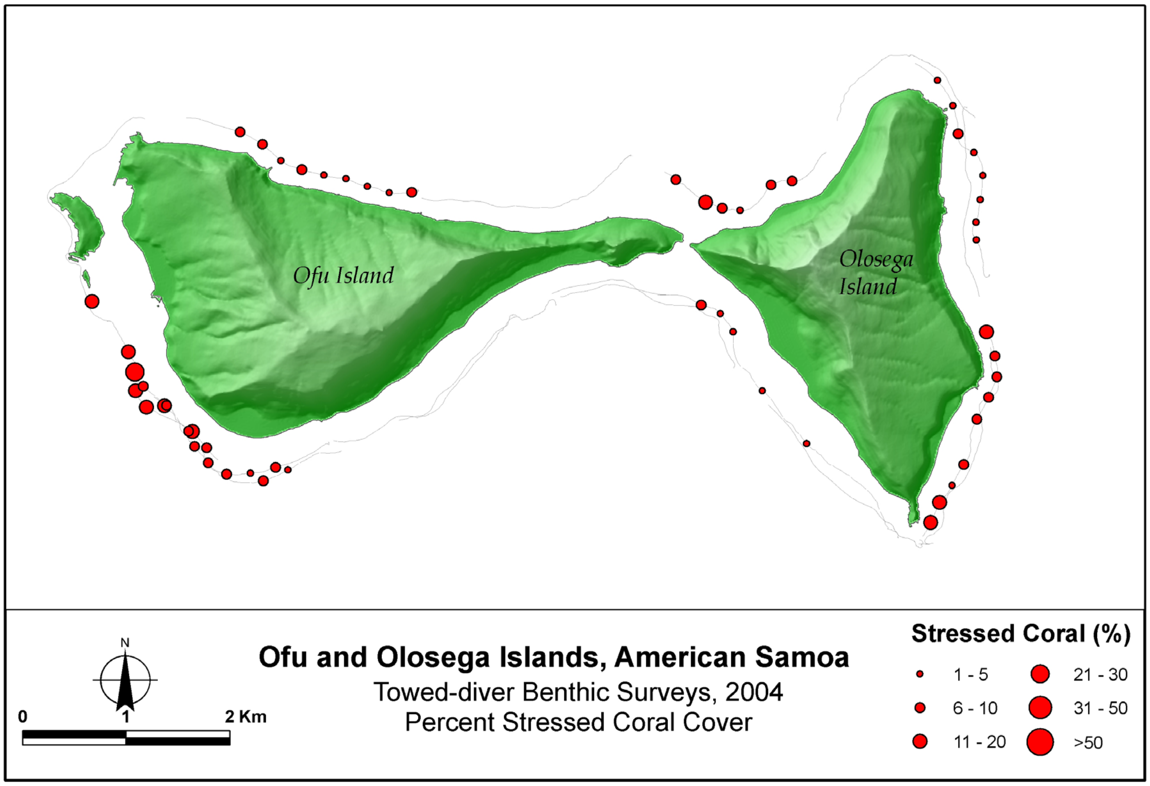

Figure 4.5.1f. Towed-diver benthic survey observations of stressed coral cover around Ofu and Olosega during ASRAMP 2004. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 × 10 m (~ 2000 m^2). Symbol size represents the percent of stressed coral cover of the total coral benthic coverage. Note that stressed coral cover was measured as a percentage of overall coral cover in 2004.

The percent cover of stressed corals was generally low-to-moderate around Ofu and Olosega, though three separate regions had elevated values (Fig. 4.5.1f). The highest estimate of stressed coral was recorded in the southwest and the most southern tip of the northwest region (9 tow segments, mean: 15.1%). High coral stress was also recorded in the southeast region (9 tow segments, mean: 8.9%) and in the central north region (6 tow segments, mean: 7.2%). The alternating spatial pattern of stressed coral observations between towed-diver surveys suggests the possibility of observer bias.

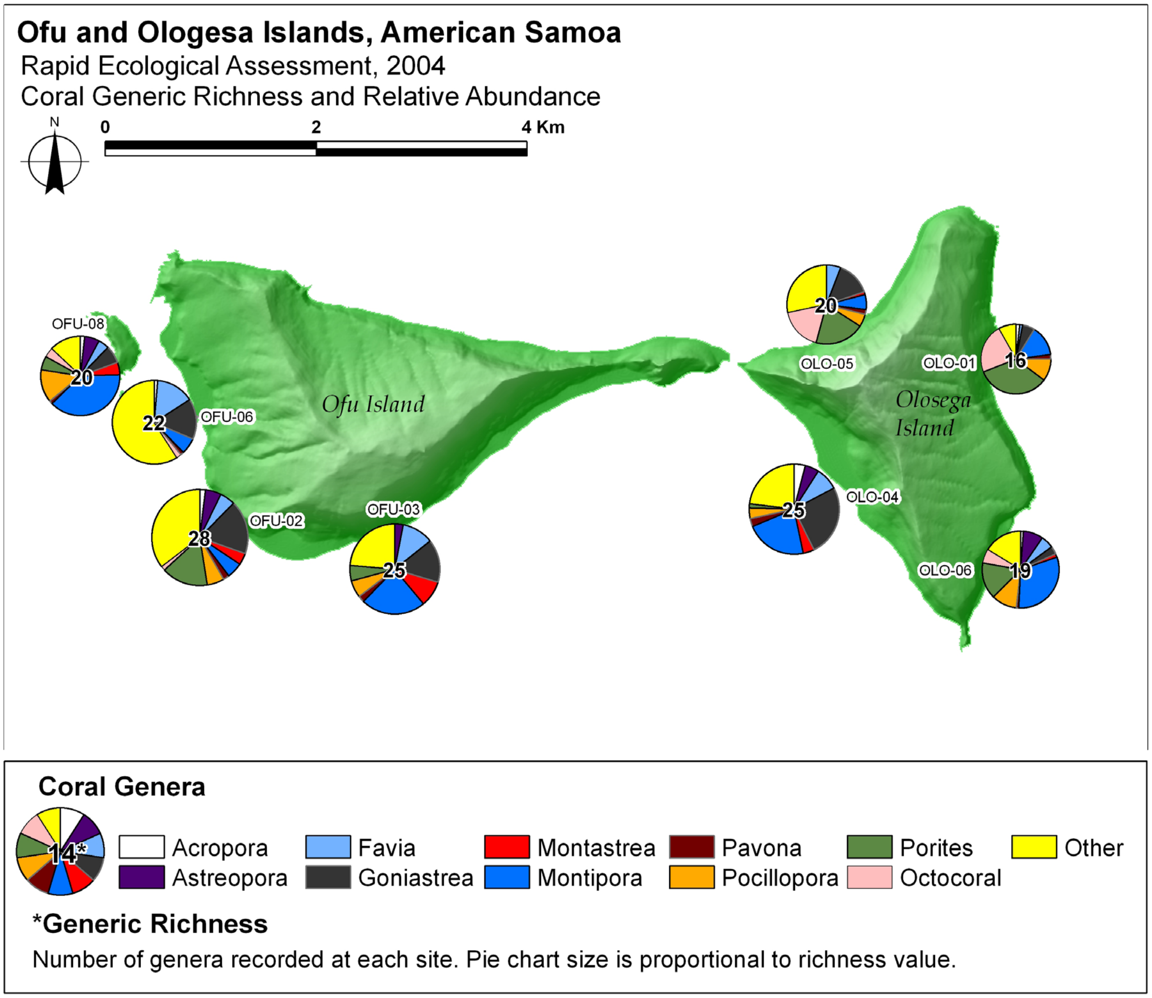

Figure 4.5.1g. Relative abundance of coral genera and generic richness from REA surveys around Ofu and Olosega during ASRAMP 2004. Percent relative abundance of key coral genera are indicated by color-coded portions of the pie charts. Size of the pie charts and black numbers in the center of the pie charts indicate the number of coral genera observed at each REA site.

Eight coral REA surveys were conducted around Ofu and Olosega during ASRAMP 2004. Colonies belonging to at least 34 anthozoan/hydrozoan genera were reported around the two islands (Fig. 4.5.1g). The coral communities varied greatly among sites with no single genus of corals dominating all sites. Members of the genera *Montipora*, *Goniastrea*, and *Porites* were the most common corals, with each genus contributing more than 10% of the total number of colonies at Ofu and Olosega.

Generic richness was relatively high at Ofu and Olosega, with an average of 21.9 (SE 1.3) coral genera recorded per site (Fig. 4.5.1g). Higher diversity was recorded at sites off the south coast of the islands in the southwest and central south regions, with the highest coral genera count (28) recorded at OFU-02. Site-specific data regarding the relative abundance of coral genera, by colony counts within belt transects, are shown in Appendix III, Table III.iii.

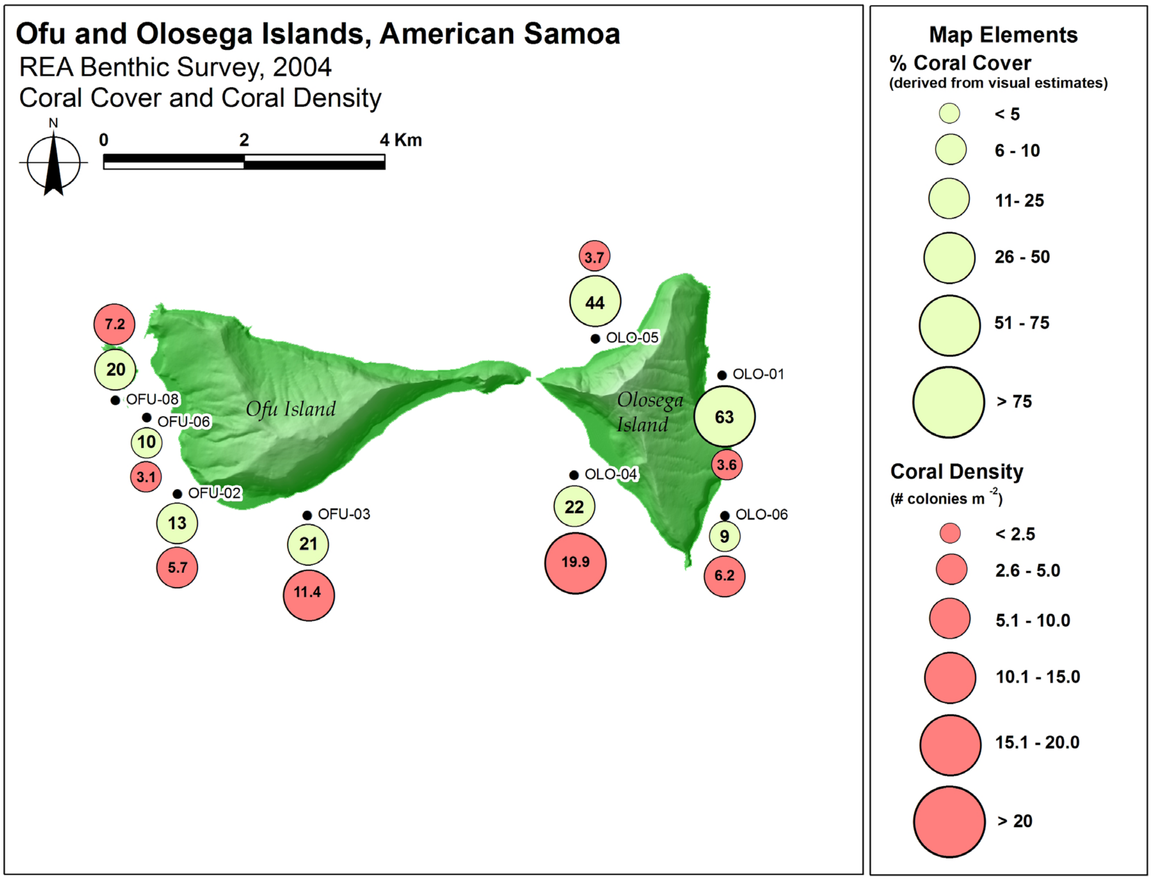

Figure 4.5.1h. Live scleractinian (stony) coral cover and coral colony density from REA surveys around Ofu and Olosega during ASRAMP 2004. The size of the symbol is proportional to the value of each parameter. It is important to note that coral percent cover was determined by qualitative visual estimates.

The mean percent live scleractinian (stony) coral cover (derived through visual estimates) observed during REA surveys around Ofu and Olosega was 25.3% (SE 6.3; Fig. 4.5.1h). High coral covers (44% and 63%) were observed at OLO-05 in the central north region and OLO-01 off east coast of Olosega in the northeast region, respectively. Relatively low coral cover (9%) was recorded at OLO-06 along the southeast region of Olosega.

During ASRAMP 2004 surveys around Ofu and Olosega, a total of 4041 coral colonies were counted within a survey area of 678 m^2. Mean coral density per site was 7.6 colonies m^{-2} (SE 1.9; Fig. 4.5.1h). Coral density was low (≤ 3.6 colonies m^{-2}) at site OLO-05 in the central north region off Olosega, site OLO-01 in the northeast region on the windward side of Olosega, and at site OFU-06 in the northwest region off Ofu Village. Two relatively high coral densities were recorded along the central south and southwest regions of the islands, with densities of 19.9 colonies m^{-2} and 11.4 colonies m^{-2} at OLO-04 and OFU-03, respectively.

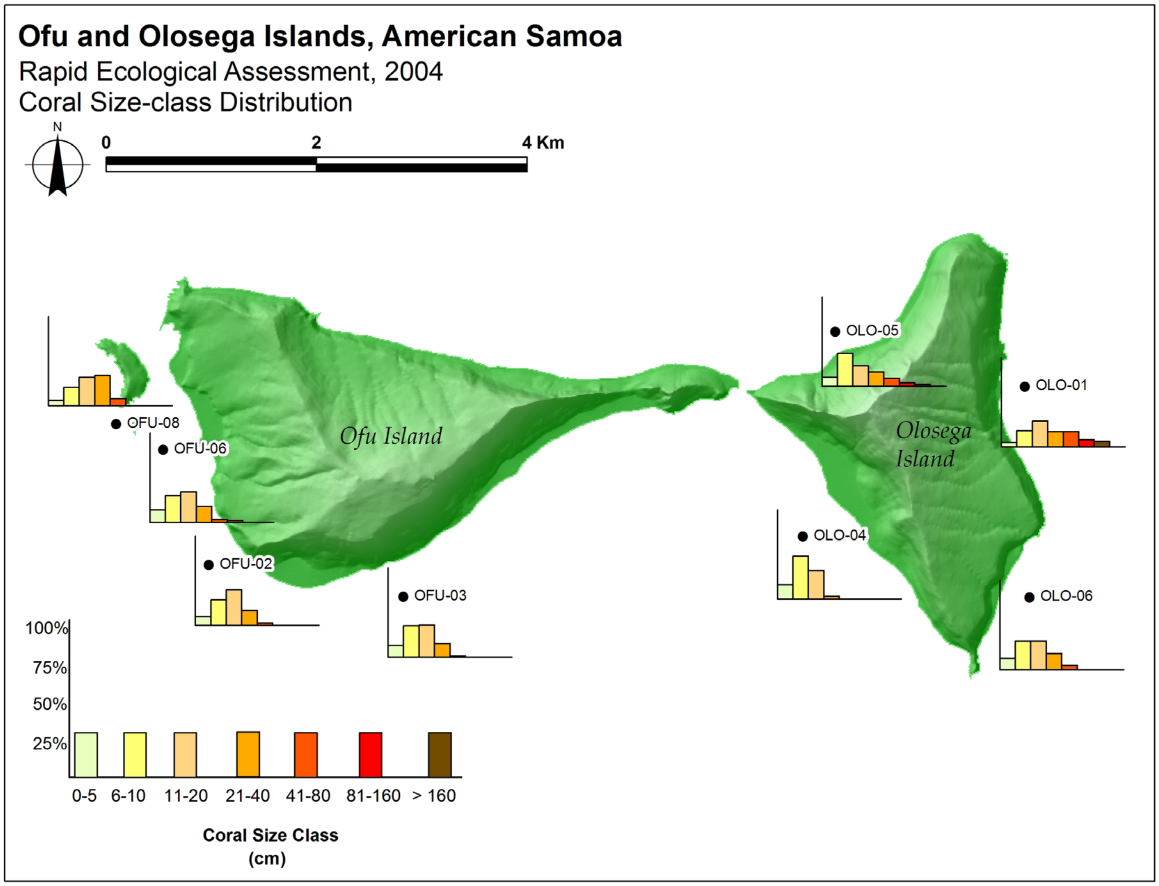

Figure 4.5.1i. Scleractinian coral size-class distribution around Ofu and Olosega from REA surveys during ASRAMP 2004. The height of the *y*-axis in each size class chart represents 100%. The seven observed size classes (0–5, 6–10, 11–20, 21–40, 41–80, 81–160, and > 160 cm), are color coded in size frequency diagrams at each REA site.

Size class distributions show the majority of corals (75.1%) had maximum diameters less than 20 cm (Fig. 4.5.1i) during the ASRAMP 2004 surveys. Corals with maximum diameters less than 5 cm were common; six of eight sites had more than 10% of corals within this size class. Only two sites, OLO-05 and OLO-01, in the central north and northeast regions off the north and east coasts of Olosega, respectively, had abundant large corals with more than 10% of corals measuring greater than 40 cm in diameter.

2006 Spatial Surveys

A total of 17 towed-diver benthic surveys were conducted around Ofu and Olosega during ASRAMP 2006, with a mean towed-diver survey depth of 12.6 m. Individual towed-diver surveys ranged in depth from 7 m (SD 3) to 17 m (SD 4; Fig. 4.5.1j). These surveys characterized live scleractinian (stony) coral cover, and found an island-wide mean of 17.9% (SE 1.5; Fig. 4.4.1k). Stressed coral was also characterized by these surveys and was gathered as a subset percentage of live coral percent cover. An island-wide mean of 3.3% (SE 0.4) stressed coral was found (Fig. 4.5.11l).

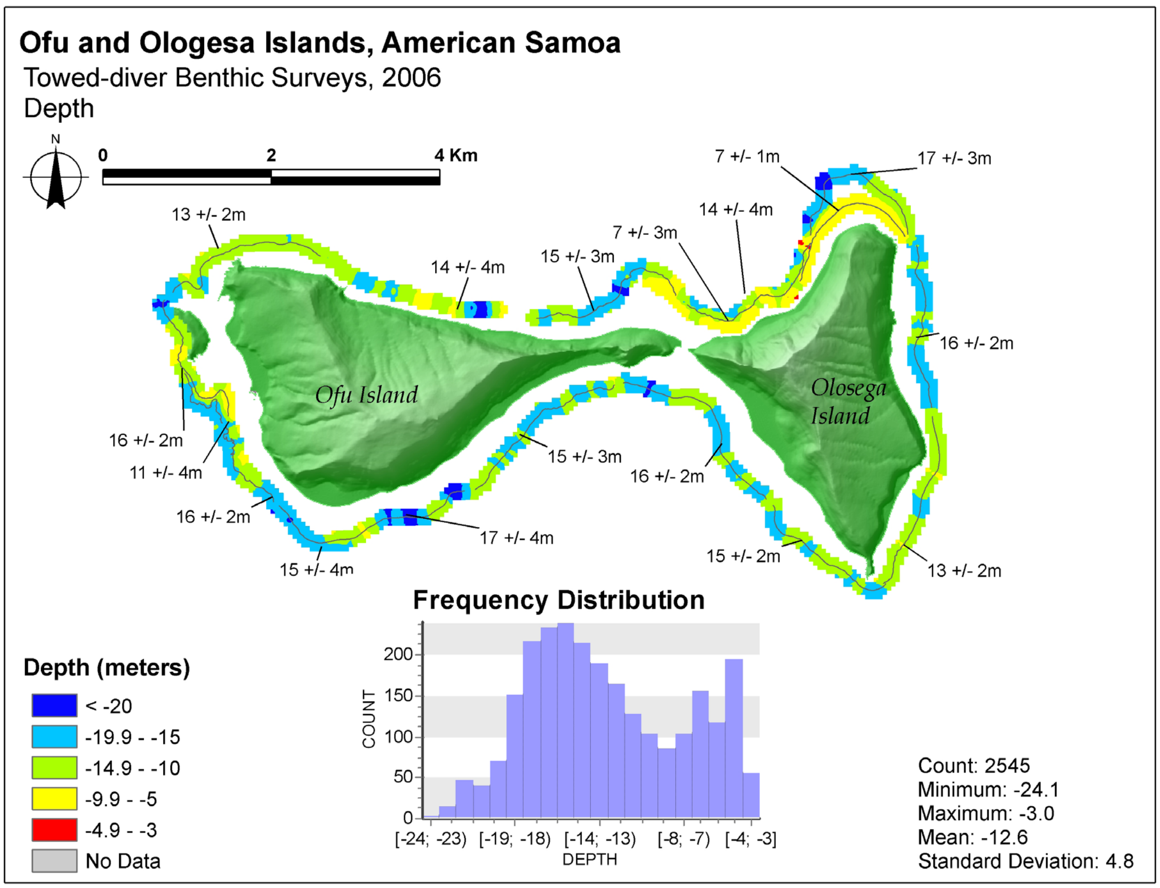

Figure 4.5.1j. Towed-diver survey tracks around Ofu and Olosega during ASRAMP 2006. Towed-diver survey tracks are color coded with mean depths for each 5-min segment. Mean depths and standard deviations for each towed-diver survey are shown in black text. Depth histogram and statistics (counts, minimum depth, maximum depth, mean, and standard deviation) from 30-sec depth recordings during towed-diver surveys are included.

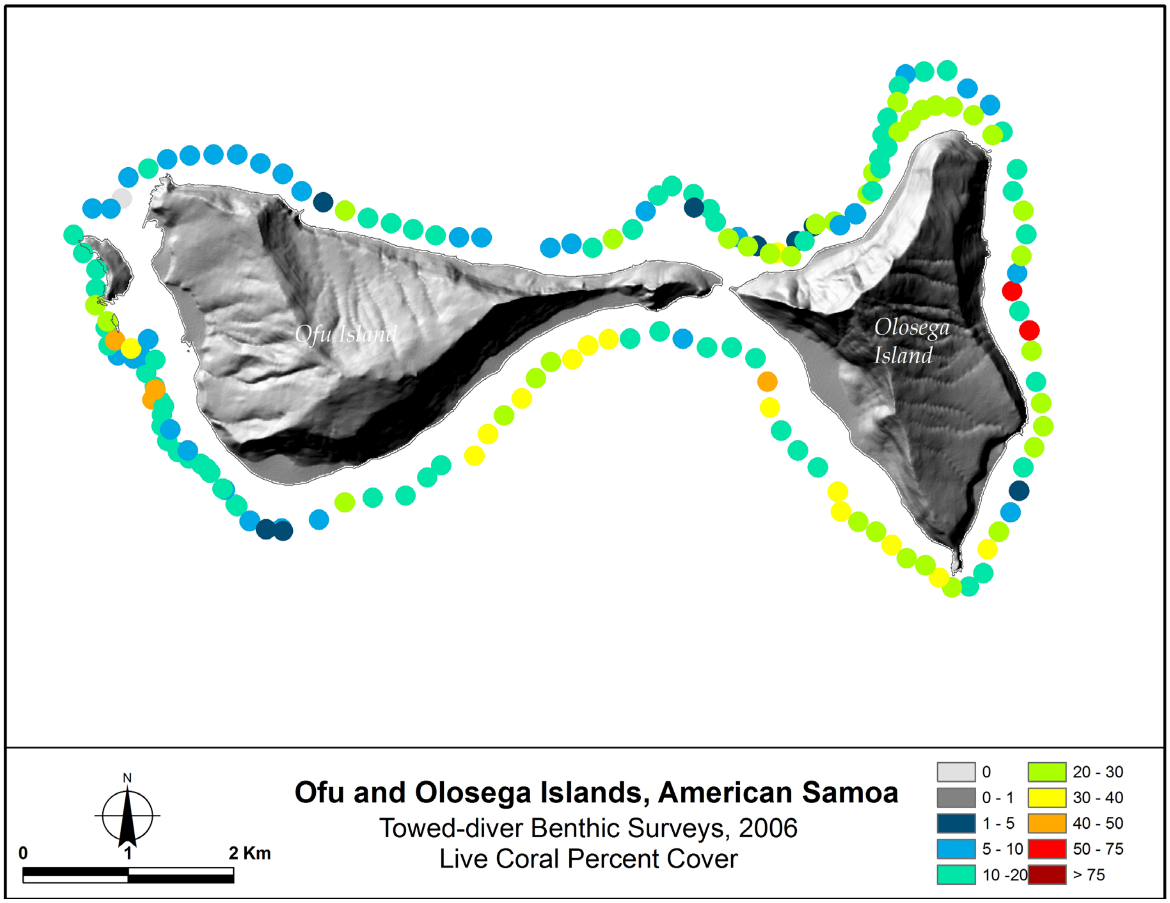

Figure 4.5.1k. Towed-diver benthic survey observations of live scleractinian (stony) coral cover around Ofu and Olosega during ASRAMP 2006. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 × 10 m (~ 2000 m^2). Symbol size represents 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.

On the east coast of Olosega, in the northeast region, a small area of high live coral was observed (3 tow segments, mean: 42.3%). High live coral cover was also recorded in the central south region (west of Sunuitao Point, 9 tow segments, mean: 31.7%), in the northwest region (south of Nu`usilaelae Island, 8 tow segments, mean: 27.8%) and in the southeast and central south regions (west of Maga Point, 8 tow segments, mean: 28.8%).

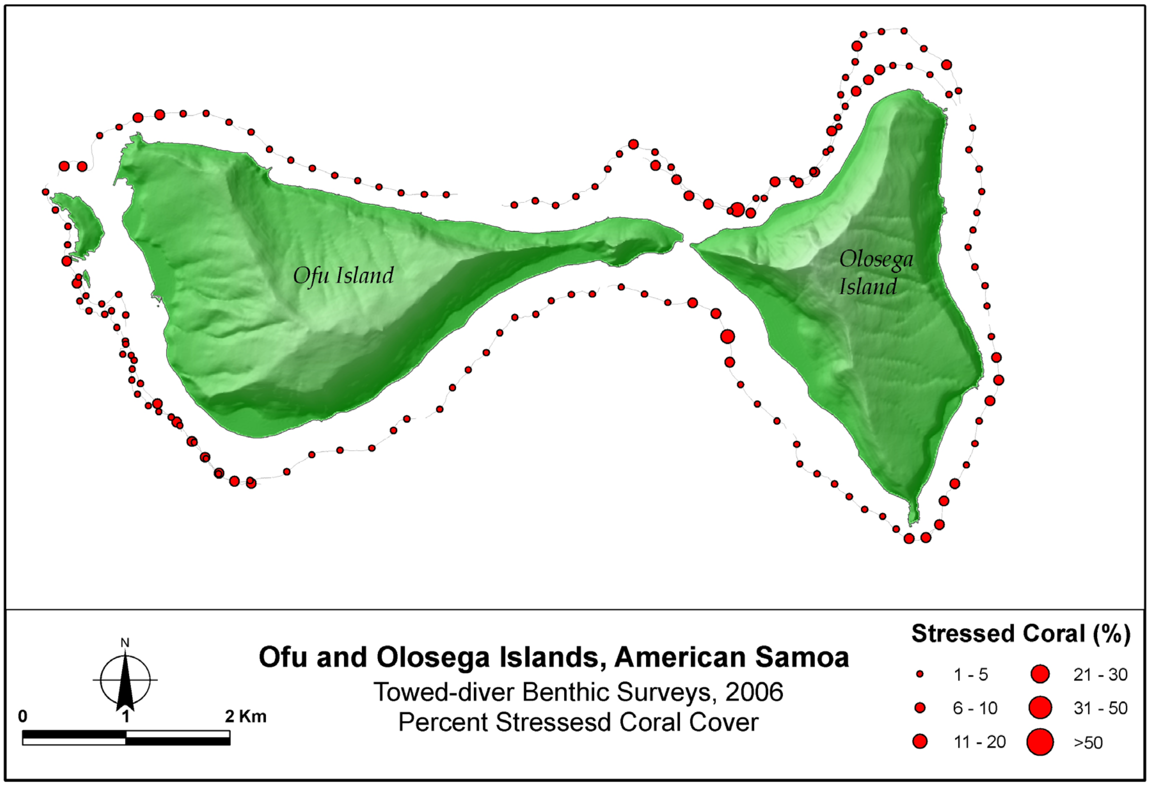

Figure 4.5.1l. Towed-diver benthic survey observations of stressed coral cover around Ofu and Olosega during ASRAMP 2006. Each colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 × 10 m (~ 2000 m^2). Symbol size represents the percent of stressed 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.

Hotspots of stressed coral were observed in the central north (8 tow segments, mean: 11.1%) and in the central south (4 tow segments, mean 9.4%) regions. In addition, regions of elevated stressed coral included the southeast (Maga Point, 5 tow segments, mean: 7.5%; Leala Point, 3 tow segments, mean: 7.5%) and the southwest (8 tow segments, mean: 6.9%; Fig. 4.5.1l).

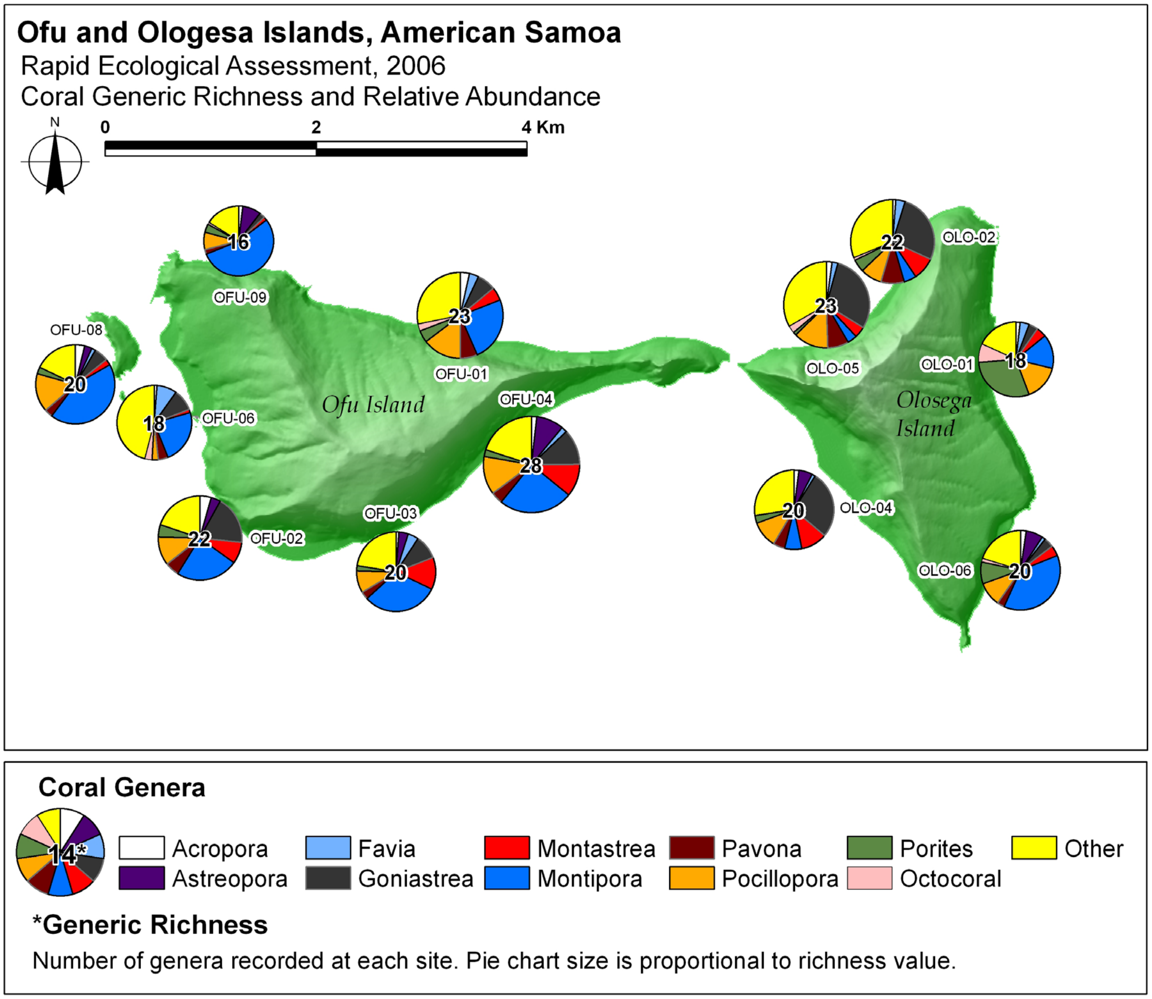

Figure 4.5.1m. Relative abundance of coral genera and generic richness from REA surveys around Ofu and Olosega during ASRAMP 2006. Percent relative abundances of key coral genera are indicated by color-coded portions of the pie charts. Size of pie charts and black numbers in center of pie charts indicate the number of coral genera observed at each REA site.

Twelve coral REA surveys were conducted around Ofu and Olosega during ASRAMP 2006. Colonies belonging to 34 anthozoan/hydrozoan genera were reported, with members of the genera *Montipora*, *Goniastrea*, and *Pocillopora* each contributing more than 10% of the total number of colonies (Fig. 4.5.1m). *Montipora* was the most common coral at most sites, with the exception of sites OLO-02, -04, -05, making up on average 24% of the coral community. Coral communities off the southwest coast of Olosega were dominated by *Goniastrea*, where it constituted, on average, 28% of the coral community, in comparison to constituting 8.1% of the coral community at the remaining sites around Ofu and Olosega.

Generic richness was relatively high around Ofu and Olosega, with an average of 20.8 (SE 1.0) coral genera recorded per site (Fig. 4.5.1m). The highest coral diversity was observed at OFU-04 in the central south region, where 28 coral genera were recorded. Interestingly, this high generic diversity (28) was found at a site showing among the lowest live coral cover (16.7%; Fig. 4.5.1n). Site-specific data regarding the relative abundance of coral genera, by colony counts within belt transects, are shown in Appendix III, Table III. iv.

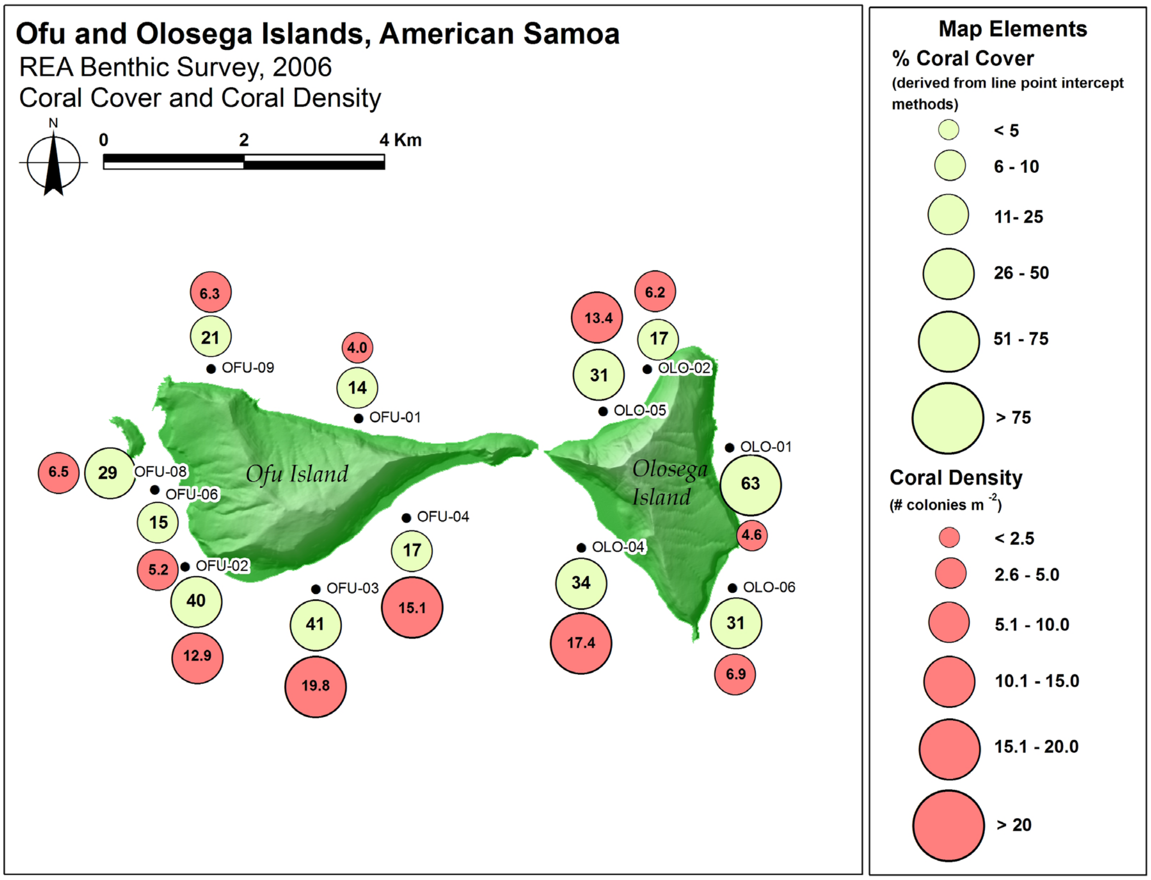

Figure 4.5.1n. Live coral cover and coral colony density from REA surveys around Ofu and Olosega during ASRAMP 2006. The size of the symbol is proportional to the value of each parameter.

Island-wide mean percent scleractinian (stony) coral cover around Ofu and Olosega, derived from the line-intercept method, was 29.7% (SE 4.8). Live coral cover was highest (62.7%) in the northeast region on the east side of Olosega (OLO-01) (Fig. 4.5.1n). Relatively high coral cover (~ 40%) was also recorded in the central south and southwest regions (OFU-02, -03). Relatively low coral cover (< 20%) was observed at the following four sites: OLO-02, OFU-01, OFU-06, and OFU-04.

During ASRAMP 2006 surveys around Ofu and Olosega, a total of 4185 coral colonies were counted within a total survey area of 495 m^2. Mean coral density per site was 9.9 colonies m^{-2} (SE 1.8; Fig. 4.5.1n). In general, coral density was relatively high around Ofu and Olosega, especially at sites in the central south and southwest regions of the islands (OFU-02, -04 and OLO-04), with the highest density (19.8 colonies m^{-2}) recorded at OFU-03. The lowest coral density (4.0 colonies m^{-2}) was recorded in the central north region at OFU-01.

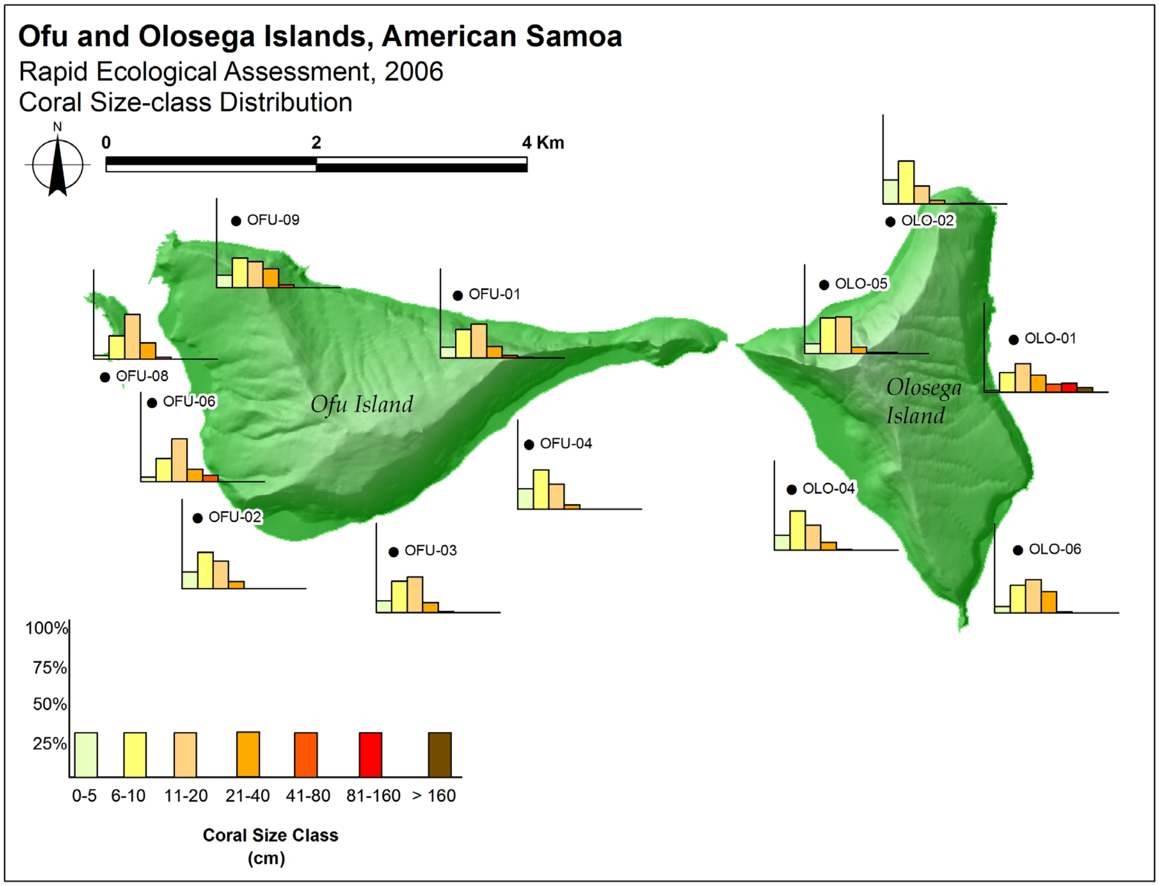

Figure 4.5.1o. Scleractinian coral size-class distribution around Ofu and Olosega from REA surveys during ASRAMP 2006. The height of the *y*-axis in each size class chart represents 100%. The seven observed size classes (0–5, 6–10, 11–20, 21–40, 41–80, 81–160, and > 160 cm), are color coded in size frequency diagrams at each REA site.

During ASRAMP 2006, coral size class distributions showed the majority of corals (85.2%) had maximum diameters less than 20 cm (Fig. 4.5.1o), with the greatest number of colonies occurring in the 5–10 cm size class. Small corals were common, especially off the north and south coasts, where all eight sites had more than 10% of corals with maximum diameters less than 5 cm. Only one site, OLO-01 off the east coast of Olosega, had abundant large corals, with 24% of corals having maximum diameters greater than 40 cm.

4.5.2 Coral Disease Surveys

2006 Spatial Surveys

Coral health and disease REA surveys covered a total survey area of 4800 m^2 around Ofu and Olosega during ASRAMP 2006. A total of 22 cases of coral disease and predation were detected, translating to an estimated overall mean prevalence of 0.05% (SE 0.03; Figs. 4.5.2a and 4.5.2b). Around Ofu and Olosega, bleaching and growth anomalies were the only two afflictions observed to affect corals within the 10–15 m depth contours. Of the 12 sites surveyed, coral diseases were observed at 50%; the northeast, northwest, southeast, and southwest regions exhibited the majority of cases. Overall, the most common affliction encountered was bleaching, which affected corals in the genera *Platygyra*, *Leptoria*, *Montipora*, and *Porites*. Prevalence of bleaching did not exceed 0.16%, and bleaching was generally mild and focal within colonies. Prevalence of skeletal growth anomalies amounted to 0.16% at site OLO-01, on the east coast of Olosega, where all cases were detected. Interestingly, all cases of growth anomalies occurred only on *Acropora abrotanoides*. Finally, signs of *Acanthaster* and *Drupella* predation were observed at sites OLO-04 and OLO-06, where prevalence values amounted to 0.01 and 0.14%, respectively.

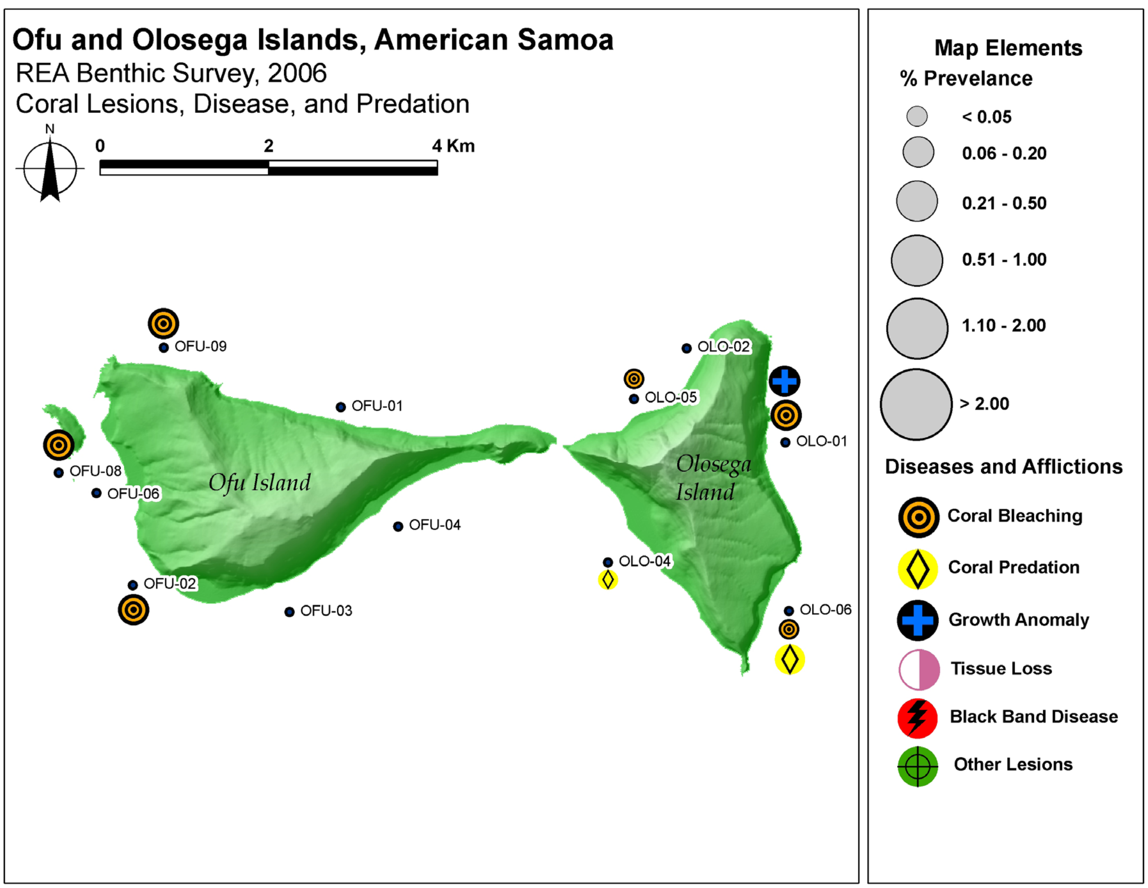

Figure 4.5.2a. Prevalence of predation, bleaching, growth anomalies, tissue loss, black band disease, and other lesions at Ofu and Olosega during ASRAMP 2006. Prevalence was calculated relative to the average colony density estimates and is indicated by the size of the respective symbols.

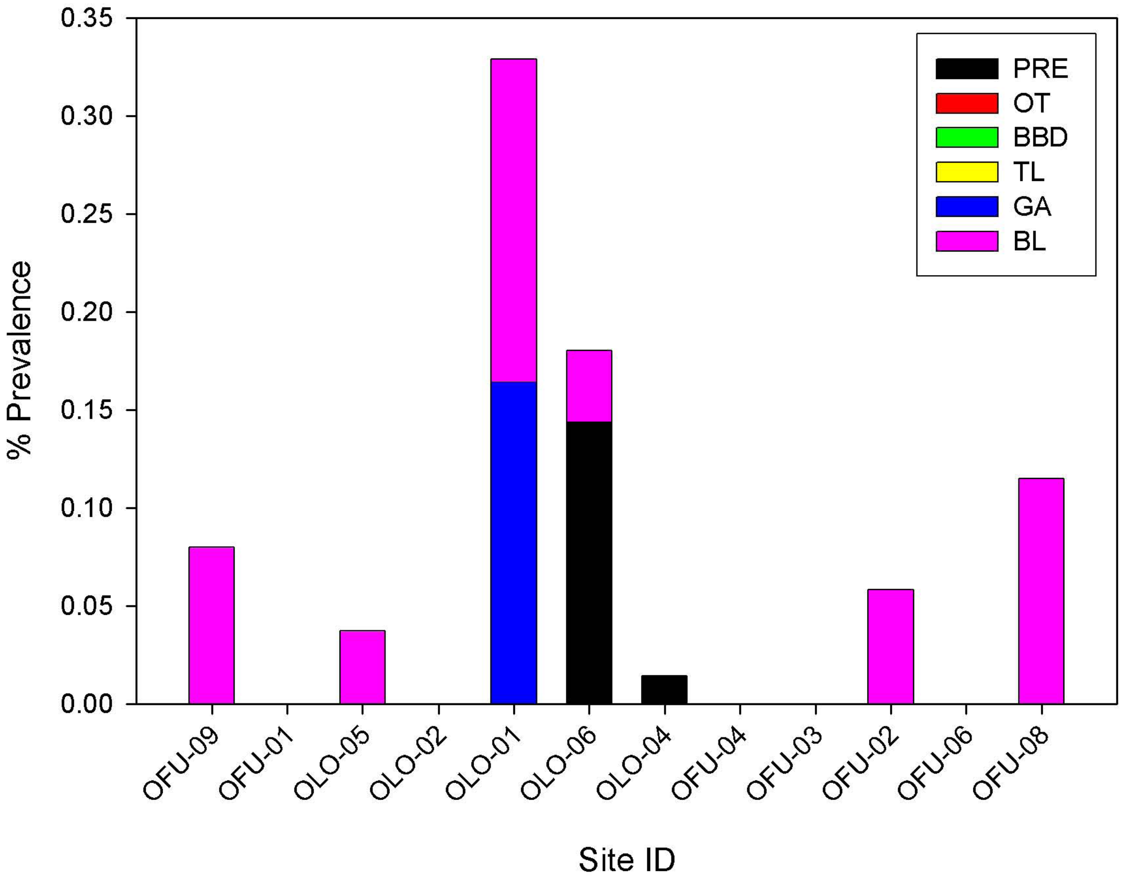

Figure 4.5.2b. Prevalence of predation, bleaching, growth anomalies, tissue loss, black band disease, and other lesions around Ofu and Olosega during ASRAMP 2006. Prevalence was calculated relative to the average colony density estimates. PRE—*Acanthaster* and/or *Drupella* predation; OT—other lesions, including hyperpigmented irritations; BBD—black band disease; TL— tissue loss; GA—skeletal growth anomalies; and BL—bleaching.

4.5.3 Temporal Comparison—Coral and Coral Disease

The distribution of high scleractinian coral cover observed during towed-diver benthic surveys around Ofu and Olosega over the three ASRAMP cruises was sporadic, which is likely a result of natural variation and differing towed-diver depths between survey years. The overall means of towed-diver coral cover around Ofu and Olosega were between 14% and 20% (Fig. 4.5.3a). However, locations around the two islands show elevated coral cover levels across the three survey years. The northeast and southeast regions of Olosega showed consistent high coral cover, especially around the east and west sides of Maga Point, with mean values of 43.3%, 43.6%, and 42.3% in 2002, 2004, and 2006, respectively. High coral cover was also recorded along the southern coast of Nu`utele Island and along Nu`usilaelae Island in 2002 and 2006 (mean: 31% and 27%, respectively). Shallower towed-diver tracks roughly corresponded with areas of elevated coral cover over all years.

Mean island-wide live scleractinian coral percent cover around Ofu and Olosega during ASRAMP 2004 and 2006 REA surveys were 25.3% (SE 6.3) and 29.0% (SE 4.8), respectively (Fig. 4.5.3a). Although these values are similar, it is important to note the methods to estimate coral percent cover were different in 2004 (visual estimates) and 2006 (line point intercept technique). For both years, site OLO-01 off the east side of Olosega in the northeast region

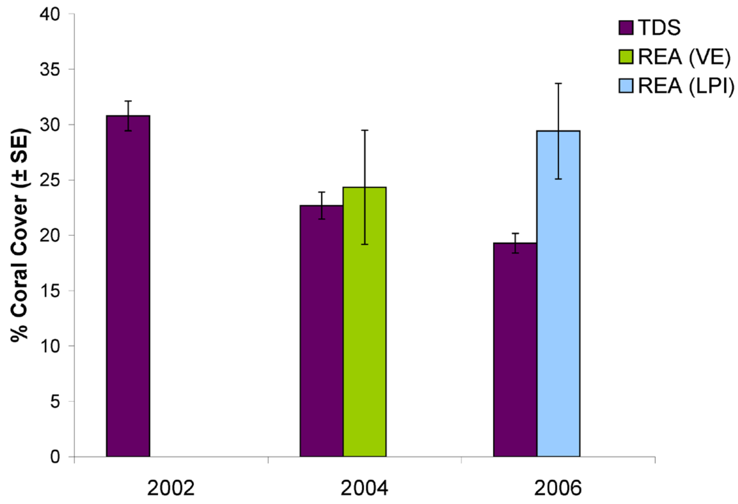

Figure 4.5.3a. Temporal comparison of mean percent live coral cover from REA surveys and towed-diver surveys around Ofu and Olosega during ASRAMP 2002, 2004, and 2006. The purple bars represent observations collected during towed-diver habitat surveys. The green bar represents REA data collected by visual 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.

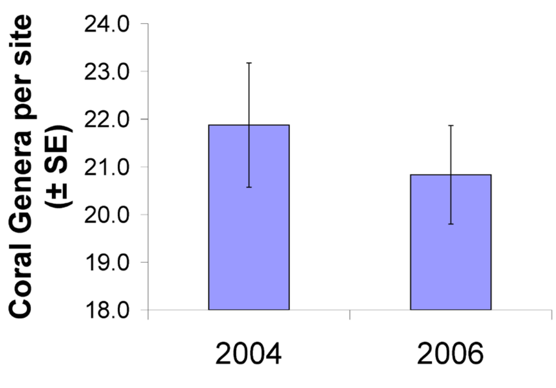

Figure 4.5.3b. Temporal comparison of mean coral genera per site around Ofu and Olosega during ASRAMP 2004 and 2006 REA surveys.

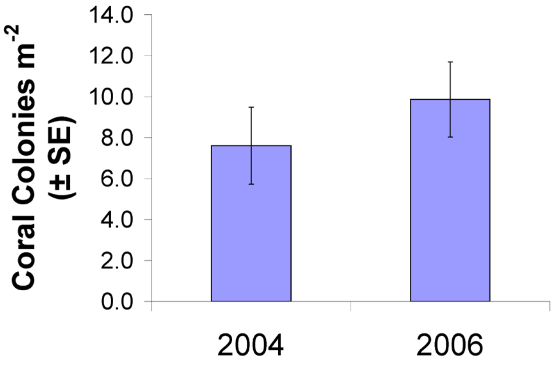

Figure 4.5.3c. Temporal comparison of mean coral colony density around Ofu and Olosega during ASRAMP 2004 and 2006 REA surveys.

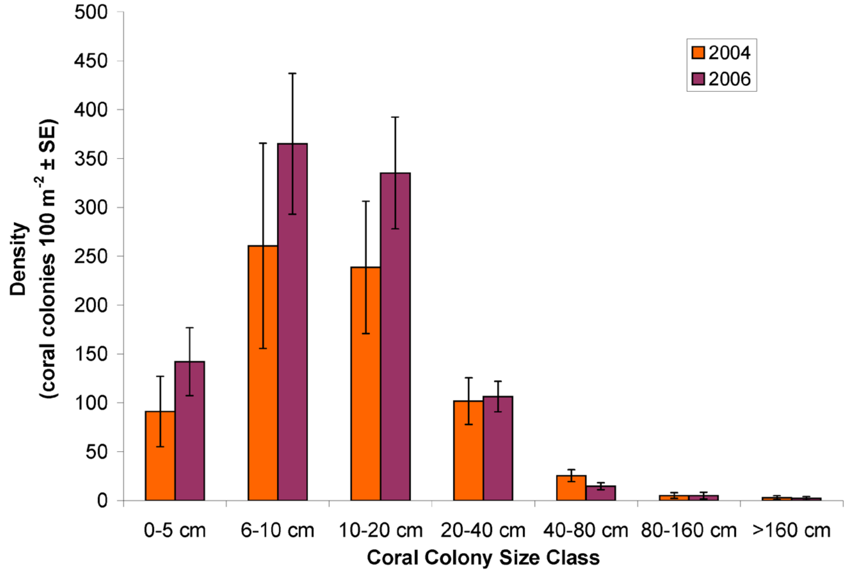

Figure 4.5.3d. Coral colony size class mean density from REA surveys around Ofu and Olosega during ASRAMP 2004 and 2006.

had the highest live coral percent cover around the islands (63% for both years), which corresponded geographically to the high values recorded by towed divers. REA data from 2006 also showed elevated coral cover values along the southern shore of Olosega and Ofu (OFU-03, 41%; OFU-02, 40%; OLO-04, 34%). In addition, site OLO-05 had elevated coral percent cover during both years (2004, 44%; 2006, 31%).

Island-wide, 34 coral genera were observed around Ofu and Olosega during both 2004 and 2006. Generic richness between survey years was relatively uniform, with a mean of 21.9 genera per site (SE 1.3) during ASRAMP 2004 and a mean of 20.8 (SE 1.0) during ASRAMP 2006 (Fig. 4.5.3b), even with the additional sampling effort in 2006. *Montipora* and *Goniastrea* were the dominant genera in both years. In 2004, *Porites* was a numerically dominant genus, and in 2006 *Pocillopora* was a dominant genus. This change could be accounted for by a recruitment event or variability in transect locations.

Coral colony density was relatively consistent between 2004 and 2006 REA surveys. In 2004 the mean density was 7.6 colonies m^{-2} (SE 1.9) and in 2006 it was 9.9 colonies m^{-2} (SE 1.8; Fig. 4.5.3c). For both years, colony density was low in the northwest and southwest regions and high in the central south and southeast regions. Interestingly, site OLO-01, which has consistent high coral cover, had consistently low colony density.

Coral colony mean size class density was relatively comparable between 2004 and 2006, with no discernable shifts in community size structure (Fig. 4.5.3d). For both years the largest coral colonies were observed at site OLO-01 on the east side of Olosega, which is also consistently the site of the highest coral cover.

4.6 Algae

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. As well, 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.

4.6.1 Algal Surveys

2002 Spatial Surveys

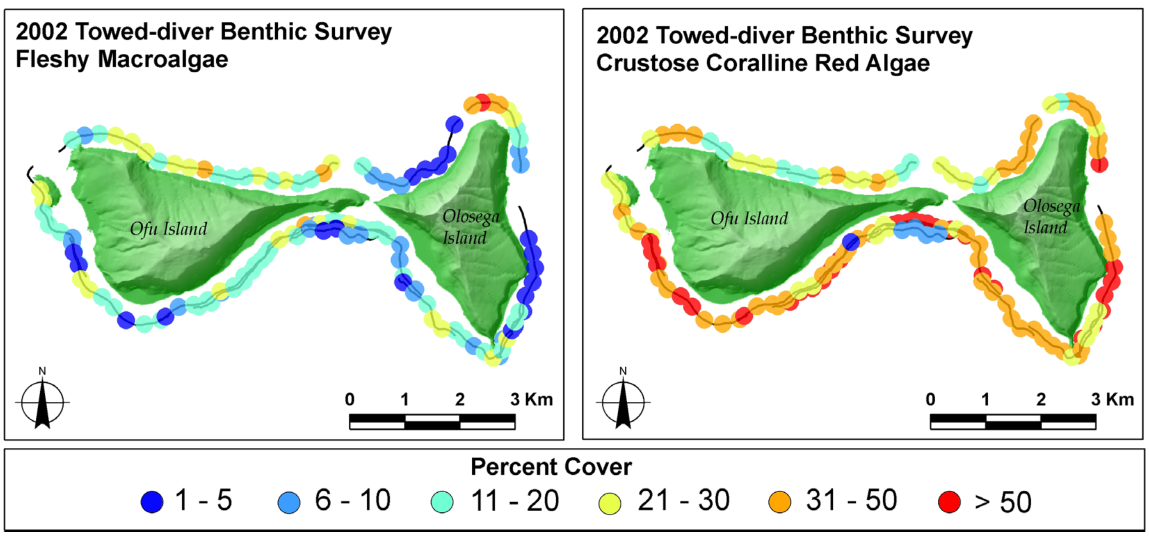

Figure 4.6.1a. Percent cover of fleshy macroalgae (including turf algae) and crustose coralline algae from towed-diver benthic surveys around Ofu and Olosega during ASRAMP 2002. Each colored point represents an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 × 10 m (~ 2000 m^2).

A total of 14 towed-diver benthic surveys were conducted around Ofu and Olosega during ASRAMP 2002, with fleshy macroalgae and crustose coralline red algae constituting, on average, 57.5% of the benthic substrate. Mean fleshy macroalgal cover was 17.2% (SE 1.0) while crustose coralline red algae covered 40.3% (SE 1.3) of the benthic substrate (Fig. 4.6.1a). The highest percent cover of fleshy macroalgae was observed off the northern point of Olosega in the northeast region, although the northern side of Ofu also has a higher percent cover of fleshy macroalgae than most other areas. The highest percent covers of crustose coralline red algae were observed in the southwest, central south, and southeast regions of the islands.

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

2004 Spatial Surveys

A total of 17 towed-diver benthic surveys around Ofu and Olosega during ASRAMP 2004 found a mean combined fleshy macroalgal and crustose coralline red algal cover of 68%. The percent cover of crustose coralline red algae was higher than fleshy macroalgae around the islands, with each functional group covering 42.5% (SE 1.2) and 25.6% (SE 0.9) of the benthic substrate, respectively (Fig. 4.6.1b). Crustose coralline red algae exhibited the highest percent cover in the southwest and southeast regions of the islands. Fleshy macroalgae were most abundant in a localized area on the western coast of Ofu just south of Nu`u tele Island in the northwest region but were also fairly prevalent in the central south and southeast regions.

During ASRAMP 2004, quantitative algal surveys were conducted at seven sites around Ofu and Olosega (Fig. 4.6.1c). A total of 12 macroalgal genera (4 green, 7 red, and 1 brown) and 3 additional algal functional groups (turf algae, crustose coralline red algae, and cyanophytes) were observed in the field. Diversity of large, easily observed macroalgal genera (some of which contain multiple species) at each site ranged from 3 to 7, although once laboratory-based taxonomic identification of all algal species (including turf algae, epiphytes, and crustose coralline red algae) from each site is completed, algal diversity for each site will be much higher. OFU-02, located in the southwest region off the southern end of Ofu and close to the proposed runway extension, exhibited the greatest algal diversity. OFU-06, offshore from the village of Ofu, and OLO-01 off the east side of Olosega in the northeast region, had the lowest macroalgal diversity.

Around Ofu and Olosega, turf algae were the dominant marine flora found, being observed in more than 75% of sampled quadrats (Fig. 4.6.1c). Similarly, crustose coralline red algae were extremely prevalent at all sites around the islands (> 75% of sampled photoquadrats per

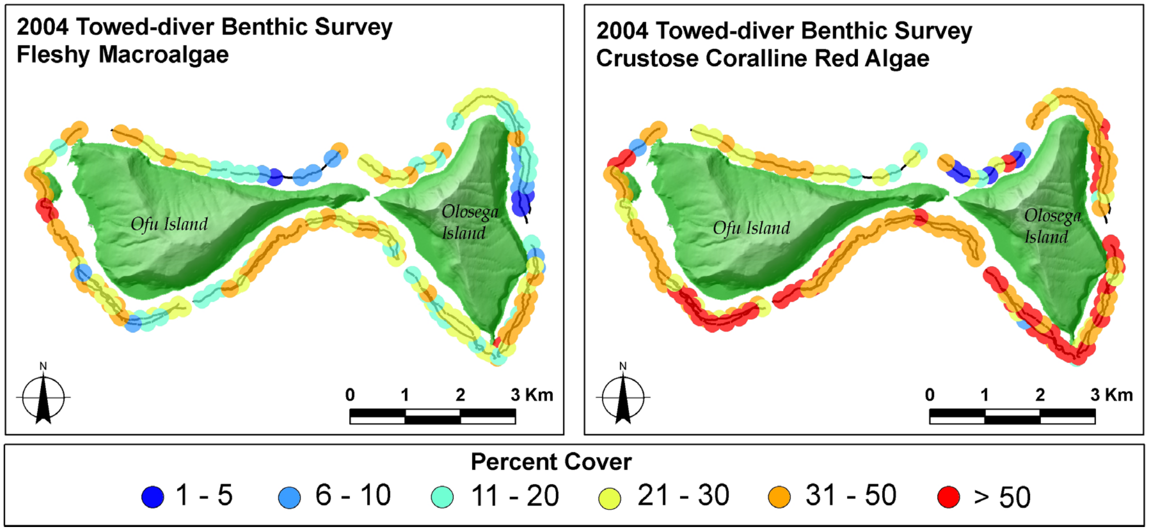

Figure 4.6.1b. Percent cover of fleshy macroalgae (including turf algae) and crustose coralline algae from towed-diver benthic surveys around Ofu and Olosega during ASRAMP 2004. Each colored point represents an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 × 10 m (~ 2000 m^2).

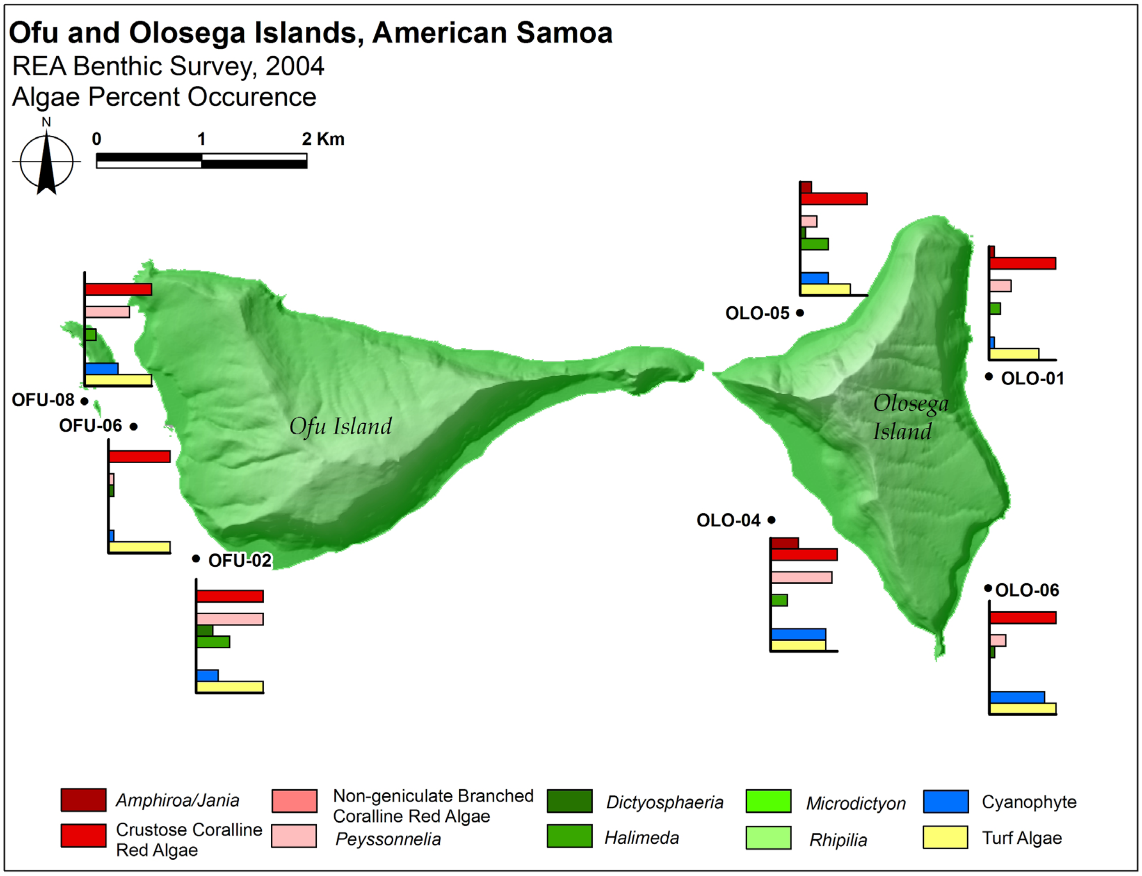

Figure 4.6.1c. Percent occurrence of select macroalgal genera and algal functional groups from REA surveys around Ofu and Olosega during ASRAMP 2004. Percent occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. Length of *x*-axis denotes 100% occurrence.

site). Cyanophytes were found at all sites sampled around the islands, although no definite distributional trends were obvious.

During ASRAMP 2004, the most ubiquitous macroalgae observed was the calcified, sand-producing genus *Halimeda*, although except for OFU-02, it was of fairly low abundance at most sites and occurred in < 50% of sampled photoquadrats. The red alga, *Peyssonnelia*, was also common and, at times, locally abundant, occurring in more than 75% of photoquadrats at some western and southern sites. Overall, few obvious distributional trends were observed among macroalgal populations around Ofu and Olosega. The calcified red algal genera, *Amphiroa*/*Jania*, were only found in photoquadrats from sites around Olosega, although poor sampling coverage on north and south shores of Ofu may not have allowed for adequate habitat assessments around this island. *Laurencia*, a red algal genus in the order Ceramiales, had a disjunct distribution, being found in photoquadrats in the northwest region of Ofu, and in very high abundance in the southeast region off Olosega.

2006 Spatial Surveys

A total of 17 towed-diver benthic surveys were conducted around Ofu and Olosega during ASRAMP 2006, with fleshy macroalgae and crustose coralline red algae constituting, on

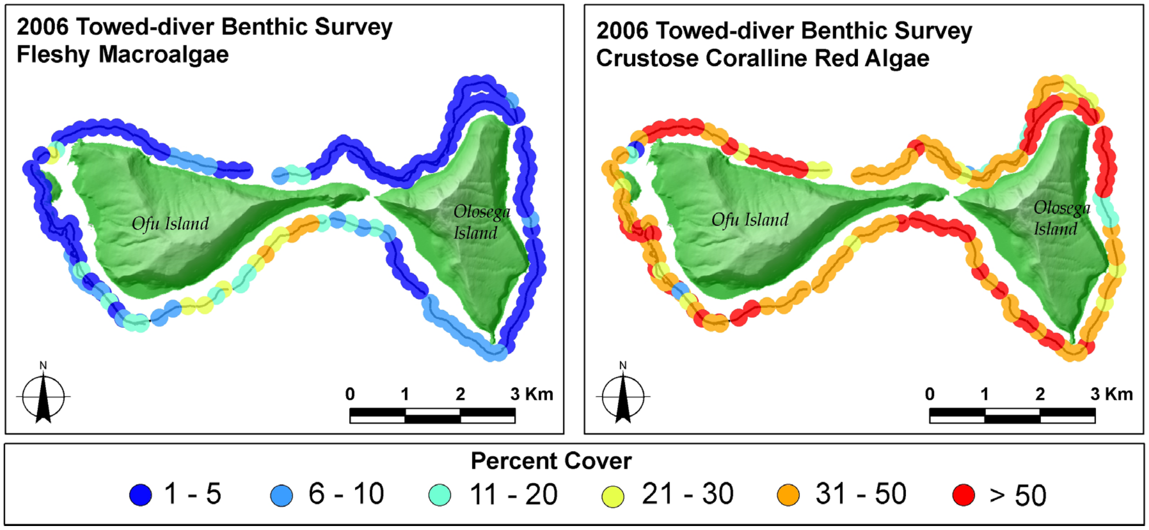

Figure 4.6.1d. Percent cover of fleshy macroalgae (including turf algae) and crustose coralline algae from towed-diver benthic surveys around Ofu and Olosega during ASRAMP 2006. Each colored point represents an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 m × 10 m (~ 2000 m^2).

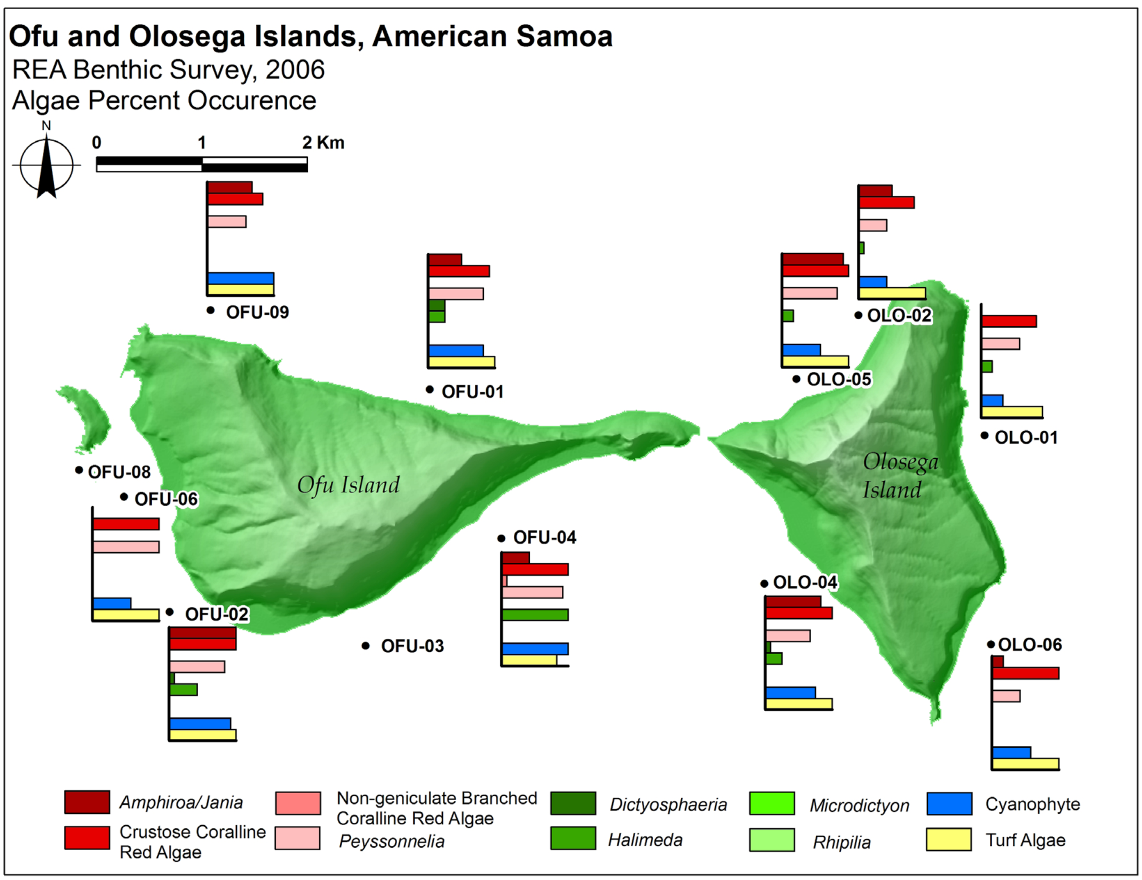

Figure 4.6.1e. Percent occurrence of select macroalgal genera and algal functional groups from REA algal surveys around Ofu and Olosega during ASRAMP 2006. Percent occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. OFU-03 and OFU-08 were not surveyed in 2006. Length of *x*-axis denotes 100% occurrence.

average, 48.3% of the benthic substrate (Fig. 4.6.1d). Mean fleshy macroalgal cover was 5.3% (SE 0.6) while crustose coralline red algae covered 43.0% (SE 1.3) of the benthic substrate. The percent cover of fleshy macroalgae was relatively low around both islands, with the densest populations occurring in the central south region off the southeast coast of Ofu. In contrast, crustose coralline red algae were very abundant around both islands, with observations in many areas exceeding 50% cover. The lowest percent covers of crustose coralline red algae were observed in a few segments off the eastern side of Olosega and a couple of segments in the northwest region, both localized areas with high sand cover (Fig. 4.3.2b).

During ASRAMP 2006, quantitative algal surveys were conducted at 10 sites around Ofu and Olosega, including six of the seven sites surveyed in 2004. A total of 22 macroalgal genera (7 green, 13 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. Diversity of large, easily observed macroalgal genera (some of which contain multiple species) at each site ranged from 4 to 12, although once laboratory-based taxonomic identification of all algal species (including turf algae, epiphytes, and crustose coralline red algae) from each site is completed, algal diversity for each site will be much higher. OFU-01, OLO-02, and OLO-05, all north shore sites in the central north and northeast regions, exhibited the highest algal diversity. Surprisingly, the two lowest diversity sites, OFU-09 and OLO-01 bordered each side of the highest diversity area. The same number of macroalgal genera (although not the same genera taxonomically) were found at all south shore sites.

Around Ofu and Olosega, turf algae were the dominant marine flora being observed in more than 75% of sampled quadrats at every site (Fig. 4.6.1e). Similarly, crustose coralline red algae were found in at least 75% of photoquadrats at each site. Cyanophytes were found at all sites sampled around the islands, and although no definite distributional trends were obvious, they anecdotally appear more abundant around Ofu than Olosega. The calcified red algal genus, *Peyssonnelia*, was among the most prevalent species found, occurring in more than 75% of photoquadrats at 50% of sites surveyed. Similarly, an unidentified member of the red algal order Gelidiales and the geniculate, calcified, red alga, *Jania*, were recorded in more than 75% of photoquadrats at 40% of sites visited. The green alga, *Halimeda*, was a common although not abundant member of the algal flora at most sites sampled, and was particularly prevalent at OFU-04 in the central south region.

4.6.2 Coralline Algal Disease Surveys

2006 Spatial Surveys

Coralline algal diseases were abundant at Ofu and Olosega with a total of 278 cases enumerated (Figs. 4.6.2a and 4.6.2b). Coralline algal disease was detected at all sites, except for OFU-03, on the south-facing shore. More than 75% of all cases detected were found at sites OFU-01, -04, and -08 in the central north, central south, and northwest regions. Two types of coralline afflictions were detected: coralline lethal orange disease (CLOD) and an unidentified coralline discoloration. CLOD was common and abundant, accounting for greater than 96% of all coralline algal disease cases.

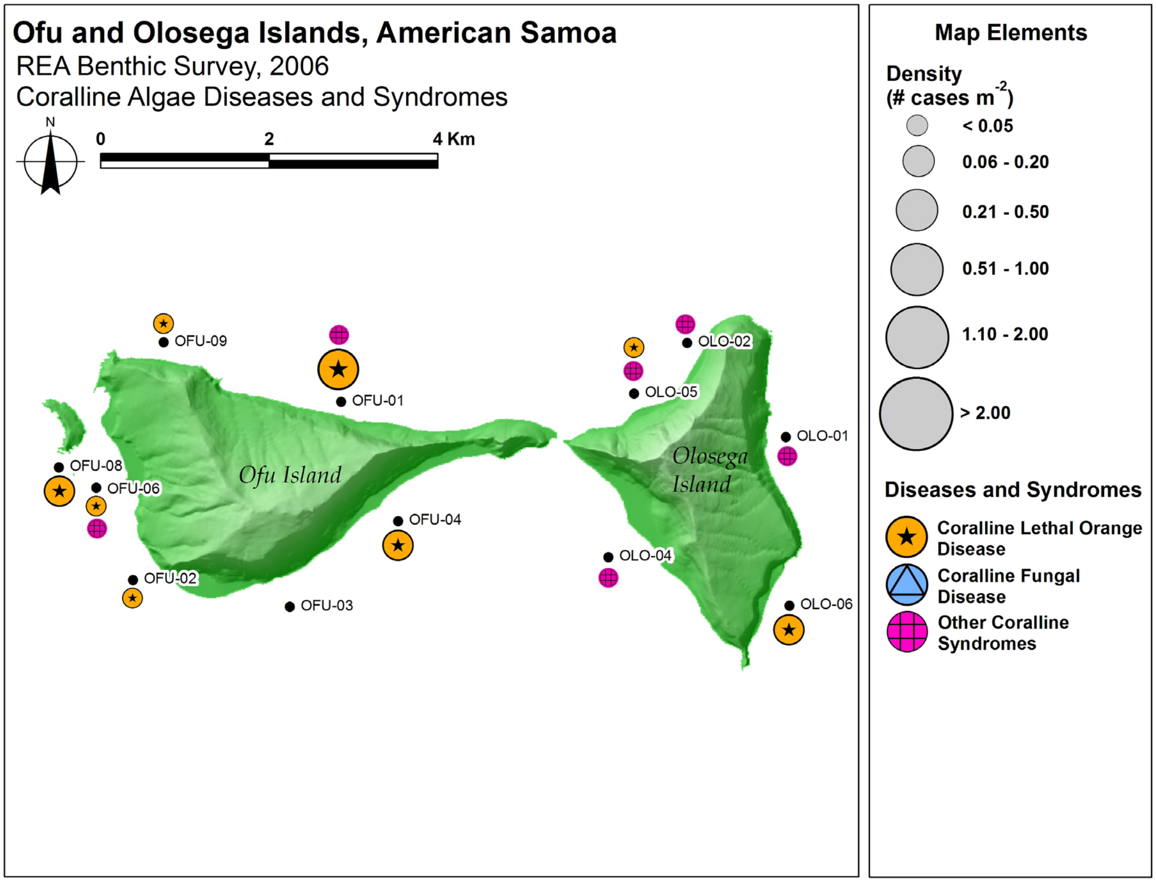

Figure 4.6.2a. Relative abundance of coralline algal diseases around Ofu and Olosega during ASRAMP 2006. Disease density is indicated by the size of the respective symbols.

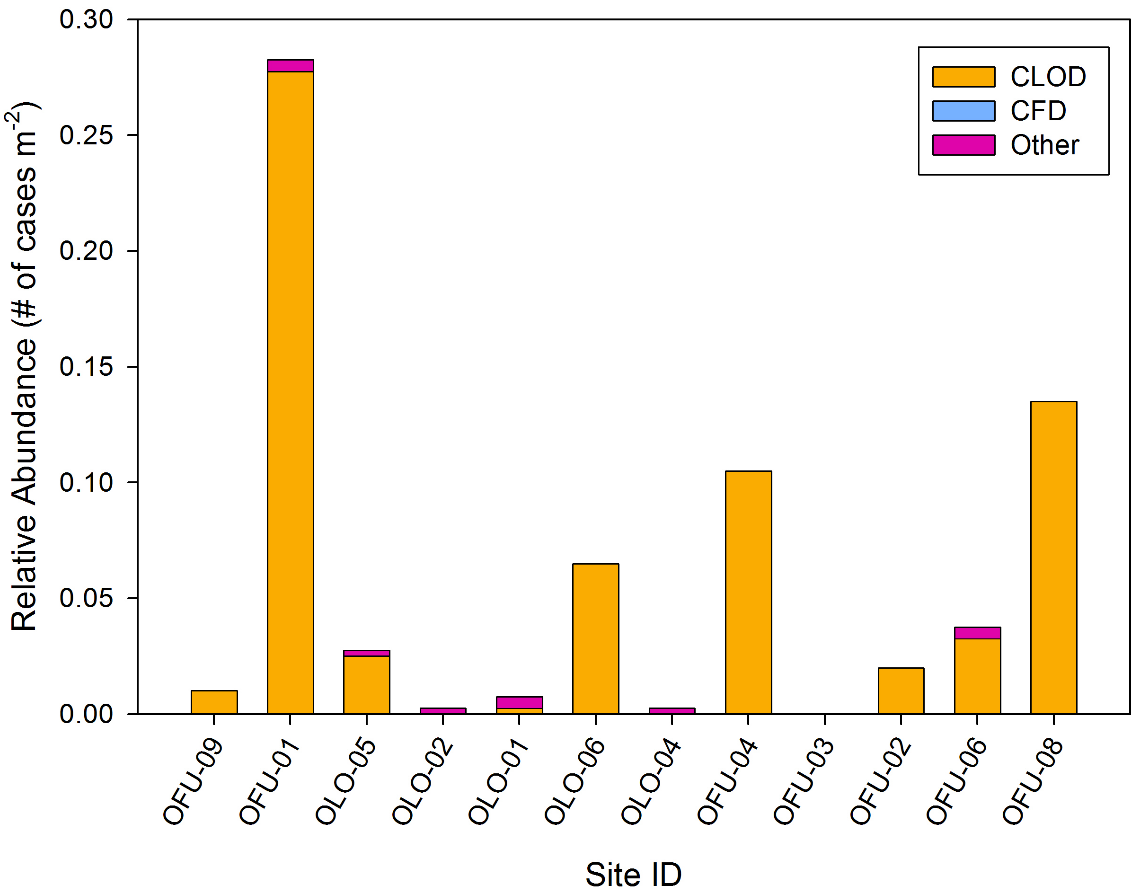

Figure 4.6.2b. Relative abundance of coralline algal disease around Ofu and Olosega during ASRAMP 2006. CLOD: coralline lethal orange disease; CFD: coralline fungal disease; Other: undetermined coralline discolorations.

4.6.3 Temporal Comparison—Algae

Temporal comparisons of both REA algal data and towed-diver survey data are shown in Figures 4.6.3a and 4.6.3b, respectively. A greater sampling density around Ofu and Olosega during ASRAMP 2006 allowed for a more complete picture of algal populations. Populations of the calcified, geniculate red algal genera *Amphiroa/Jania* were more evenly distributed and of greater abundance around the two islands than was indicated during the ASRAMP 2004 sampling period. Cyanophytes also exhibited a much higher and more evenly distributed pattern around the islands than was previously discerned. Distributional patterns of the calcified, sand-producing green alga, *Halimeda*, remained similar between survey periods. As in 2004, lowest algal diversity and abundance occurred off the populated coast of Ofu Village.

As also noted for Ta`u (Section 5.6), a dramatic difference between the number of algal genera and their abundance was reported around Ofu and Olosega between the 2004 and 2006 sampling periods. In 2004, Ofu and Olosega did not exhibit much diversity of macroalgal genera, but by 2006 they contained macroalgal populations almost twice as diverse as seen in 2004. Although Tropical Cyclone Heta did not pass directly over the Manu`a Islands, it is hypothesized that severe wave energy generated from the storm scoured benthic communities shortly before 2004 surveys were conducted, shredding algal communities and making the islands appear to have low algal diversity. By 2006, observations of the algal communities suggest they may have fully recovered.

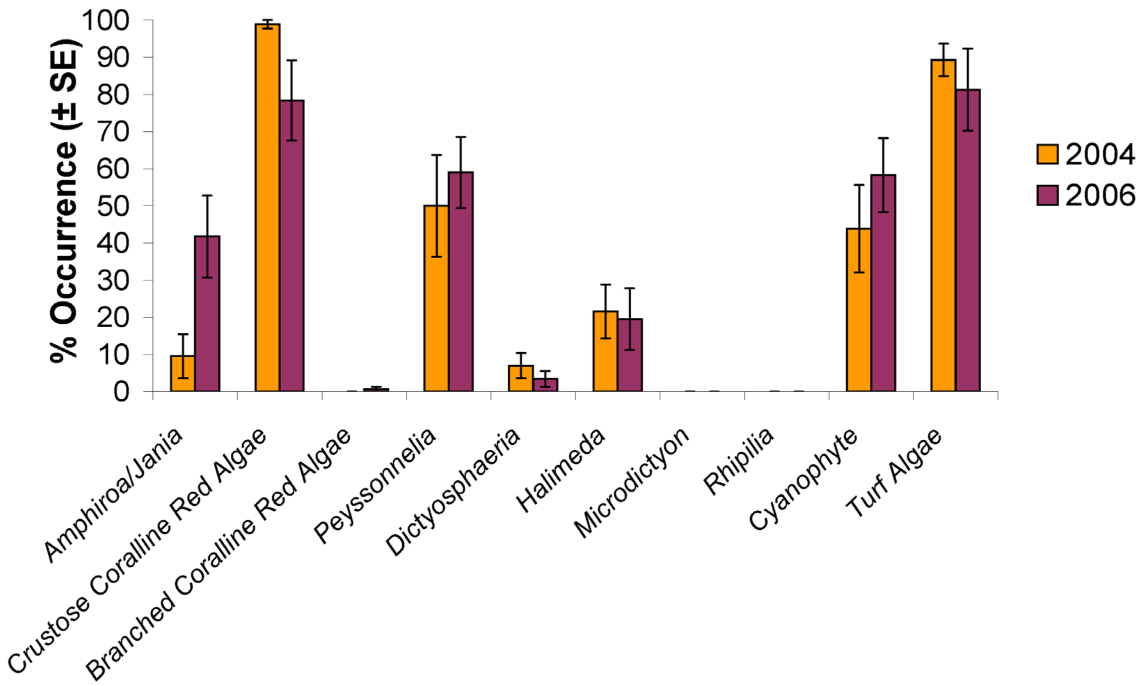

Figure 4.6.3a. Temporal comparison of REA algal genera and functional group percent occurrence around Ofu and Olosega between ASRAMP 2004 and 2006.

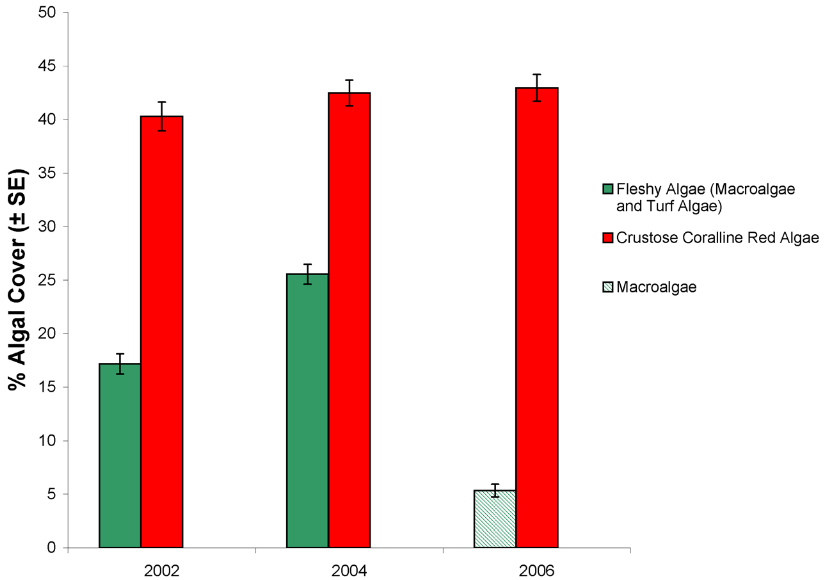

Figure 4.6.3b. Temporal comparison of towed-diver benthic survey algal percent cover results for fleshy, crustose coralline and macroalgae for 2002, 2004, and 2006 ASRAMP surveys around Ofu and Olosega. See Chapter 2, Section 2.4: Reef Benthic (Coral, Algae, Macroinvetebrate) and Fish Surveys for considerations when comparing the results off these methodologies between years.

4.7 Benthic Macroinvertebrates

4.7.1 Benthic Macroinvertebrate Surveys

2002 Spatial Surveys

Towed-diver benthic macroinvertebrate surveys around Ofu and Olosega during the ASRAMP 2002 cruise found relatively low densities of giant clams, sea cucumbers and sea urchins (Fig. 4.7.1a). Crown-of-thorns seastars (COTS) were observed within the northwest and central north regions (1.1 and 0.2 mean organisms ha^{-1}, respectively). As mentioned in the introduction (Chapter 1, Section 1.6: Limitations of Pacific RAMP), 2002 surveys were limited by shipboard logistics and methods development which may have contributed to the paucity of macroinvertebrates observed in 2002. A total of six qualitative REA invertebrate surveys, focusing on general macroinvertebrate biodiversity, were conducted around Ofu and Olosega during ASRAMP 2002. These surveys provided baseline data used to design and scale the future methodology of macroinvertebrate REA surveys. No data are presented.

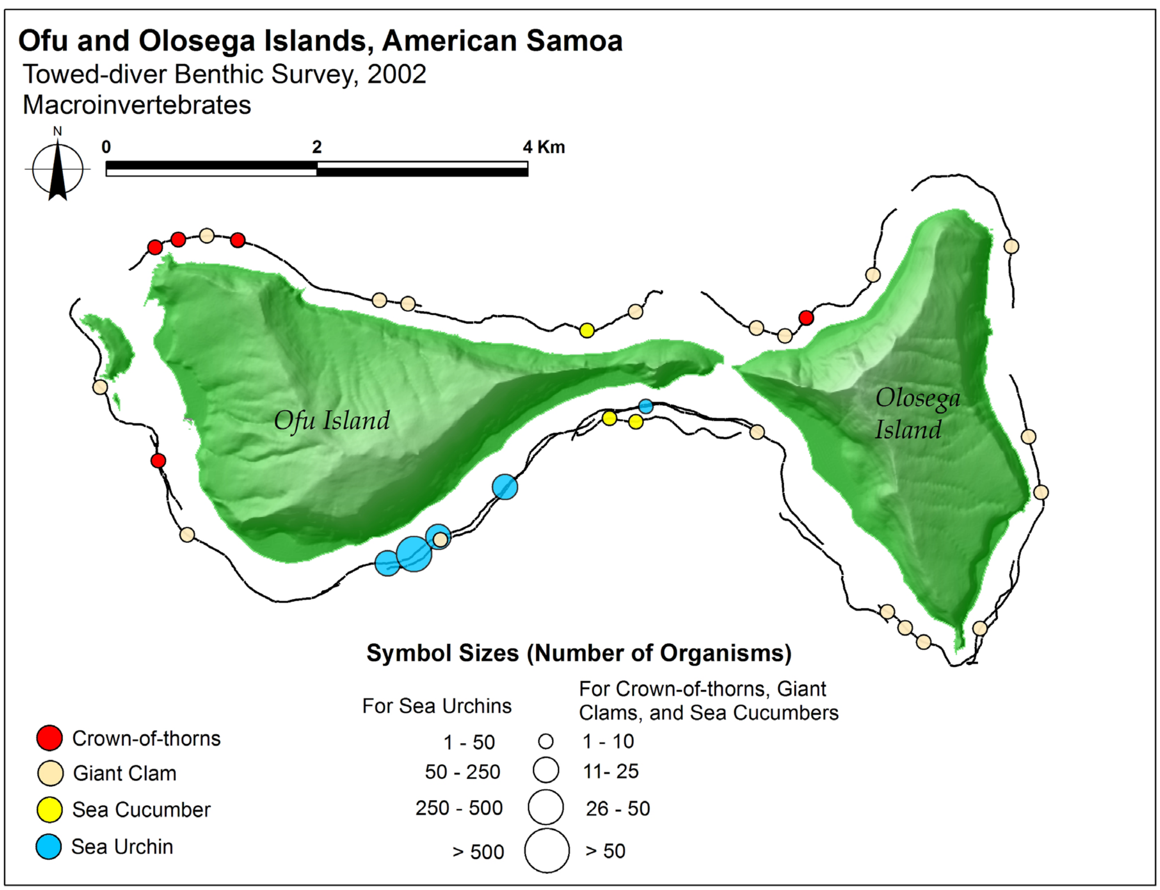

Figure 4.7.1a. Distribution of estimated population densities of COTS, giant clams, sea cucumbers, and sea urchins around Ofu and Olosega from towed-diver benthic surveys during ASRAMP 2002. Circle locations represent an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 × 10 m (~ 2000 m^2). The sizes of the circles indicate the number of organisms counted or estimated in each ~ 2000 m2 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).

2004 Spatial Surveys

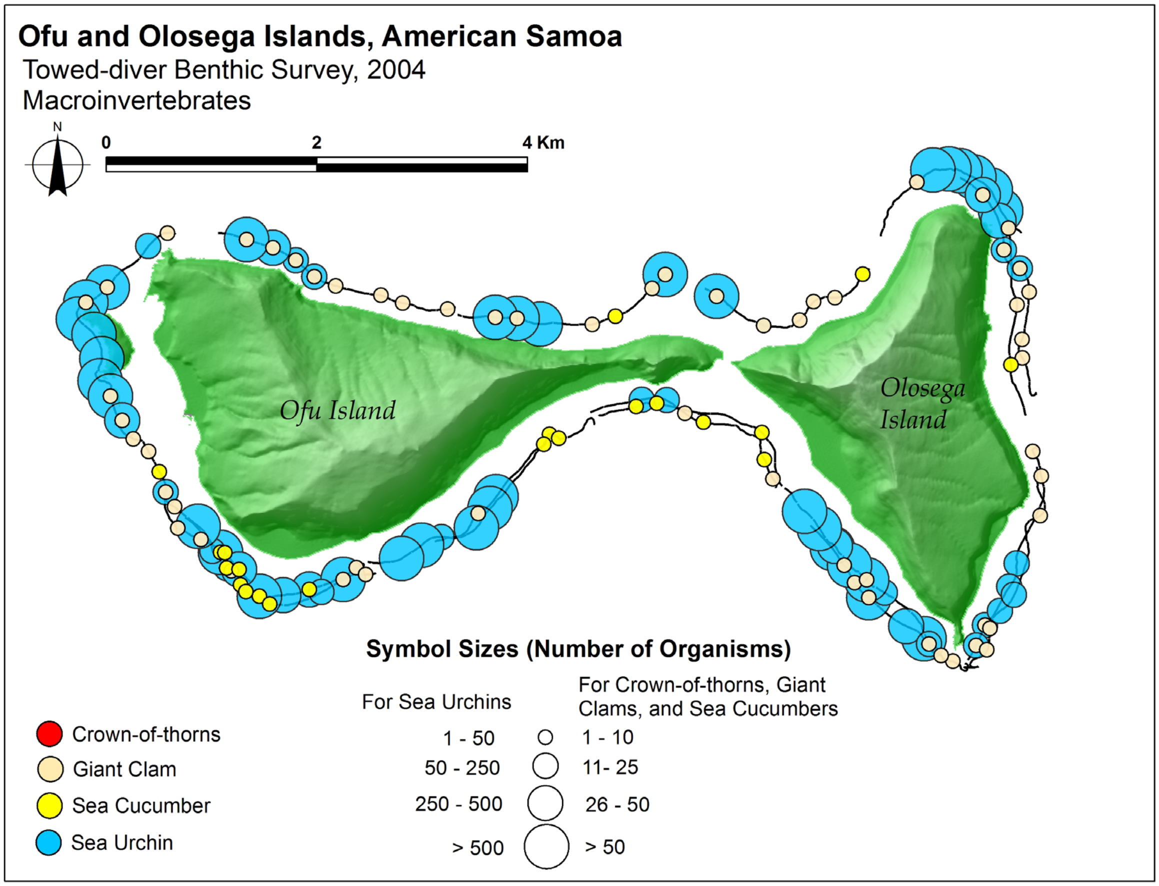

Figure 4.7.1b. Distribution of estimated population densities of COTS, giant clams, sea cucumbers, and sea urchins around Ofu and Olosega from towed-diver benthic surveys during ASRAMP 2004. Circle locations represent an integrated estimate over 5-min observation segments covering a survey swath of ~ 200 × 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).

Towed-diver benthic macroinvertebrate surveys around Ofu and Olosega during the ASRAMP 2004 cruise found variable distributions of sea cucumbers and sea urchins (Fig. 4.7.1b). Giant clams were evenly distributed around Ofu and Olosega (3.3 mean organisms ha^{-1}). Sea urchin density was patchy, with the highest values found along Nu`utele Island in the northwest region (2453 mean organisms ha^{-1}) and the southwest region (1339 mean organisms ha^{-1}). High sea urchin densities were observed near the corners of the southwest, southeast, and northeast regions of the islands; lowest densities were observed in the central north and central south regions. Sea cucumbers were most common in the central south, central north, and southwest regions (1.9, 0.6, and 1.9 mean organisms ha^{-1}, respectively). No COTS were observed.

During ASRAMP 2004, invertebrate species richness was variable among the seven REA sites surveyed around Ofu and Olosega (Fig. 4.7.1c). Target species richness values ranged from a low of 10 invertebrate species in the northeast region off Olosega (OLO-01) to a

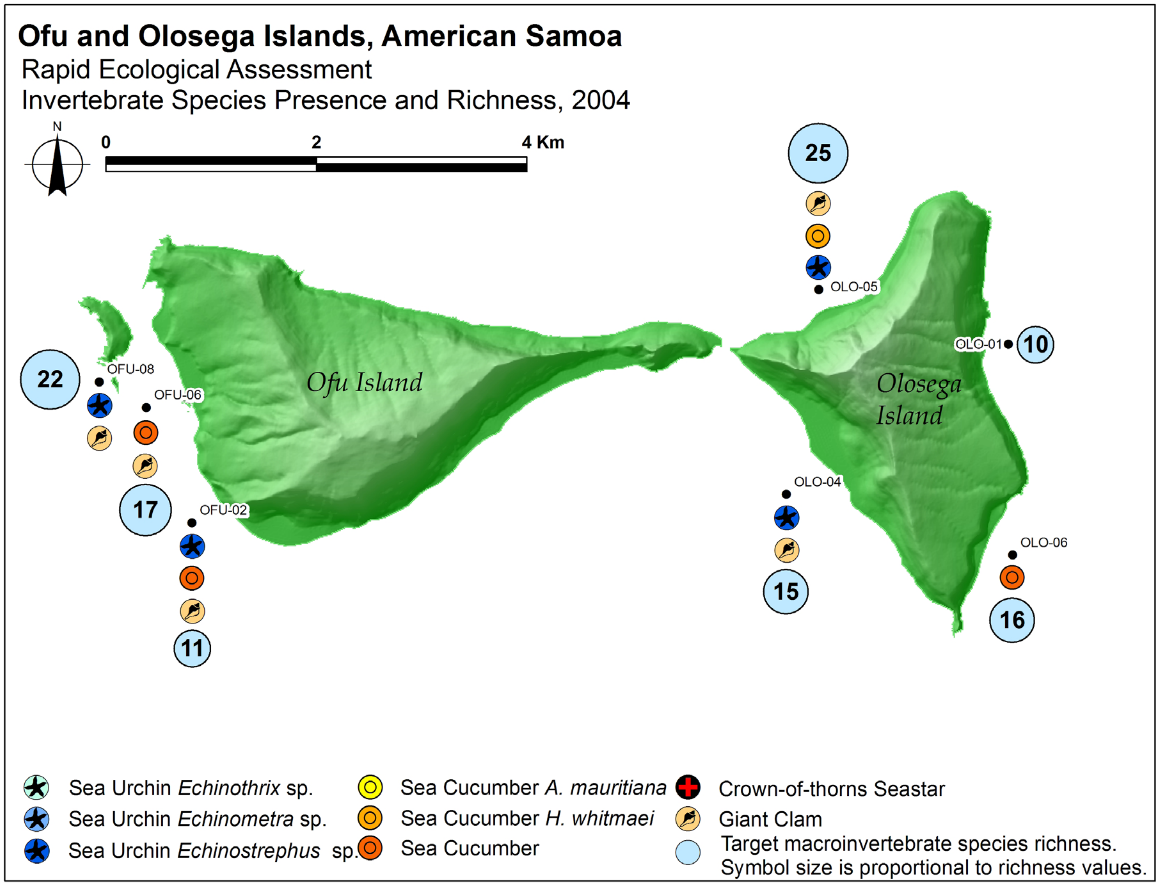

Figure 4.7.1c. Macroinvertebrate species richness, and target macroinvertebrate distribution around Ofu and Olosega from REA surveys during ASRAMP 2004. Size of light blue circles and values in circles indicate target species richness values for each REA site. Other symbols indicate the presence of specific target species.

high of 25 species found off the north coast of Olosega (OLO-05). Giant clams were found at most REA sites except off the east coast of Olosega (OLO-01). The only species of sea urchin found was *Echinostrephus aciculatus*, which was found at most sites, excluding OLO-01 and OLO-06 off the east coast of Olosega. Sea cucumbers were present at three of seven sites, two of which were located off the west coast of Ofu. Four different species of sea cucumbers were recorded at these sites, including *Stichopus chloronotus*, *Bohadschia argus*, and *Holothuria hilla*. No COTS were observed during REA surveys.

2006 Spatial Surveys

Towed-diver benthic macroinvertebrate surveys around Ofu and Olosega during ASRAMP 2006 found patchy distributions of sea urchins and sea cucumbers, while giant clams were evenly distributed (Fig. 4.7.1d). Sea urchins were concentrated within the northwest region along the west coast of Nu`utele Islands (693 mean organisms ha^{-1}) and off the north tip of Olosega (1006 mean organisms ha^{-1}) in the northeast region. Giant clams were evenly distributed around Ofu and Olosega (3.3 mean organisms ha^{-1}). No COTS were observed.

During ASRAMP 2006, invertebrate species richness was variable among the 12 REA sites surveyed around Ofu and Olosega (Fig. 4.7.1e). Giant clams were present at 10 of the 12 REA sites. The only species of sea urchin found during REA surveys was *Echinostrephus aciculatus*, being found at 7 of 12 sites. Sea cucumbers were present at 4 of 12 REA sites. Two species of sea cucumbers were present, *Holothuria whitmaeii* and an unidentified holothuroid, both being present at two sites. No COTS were observed during REA surveys.

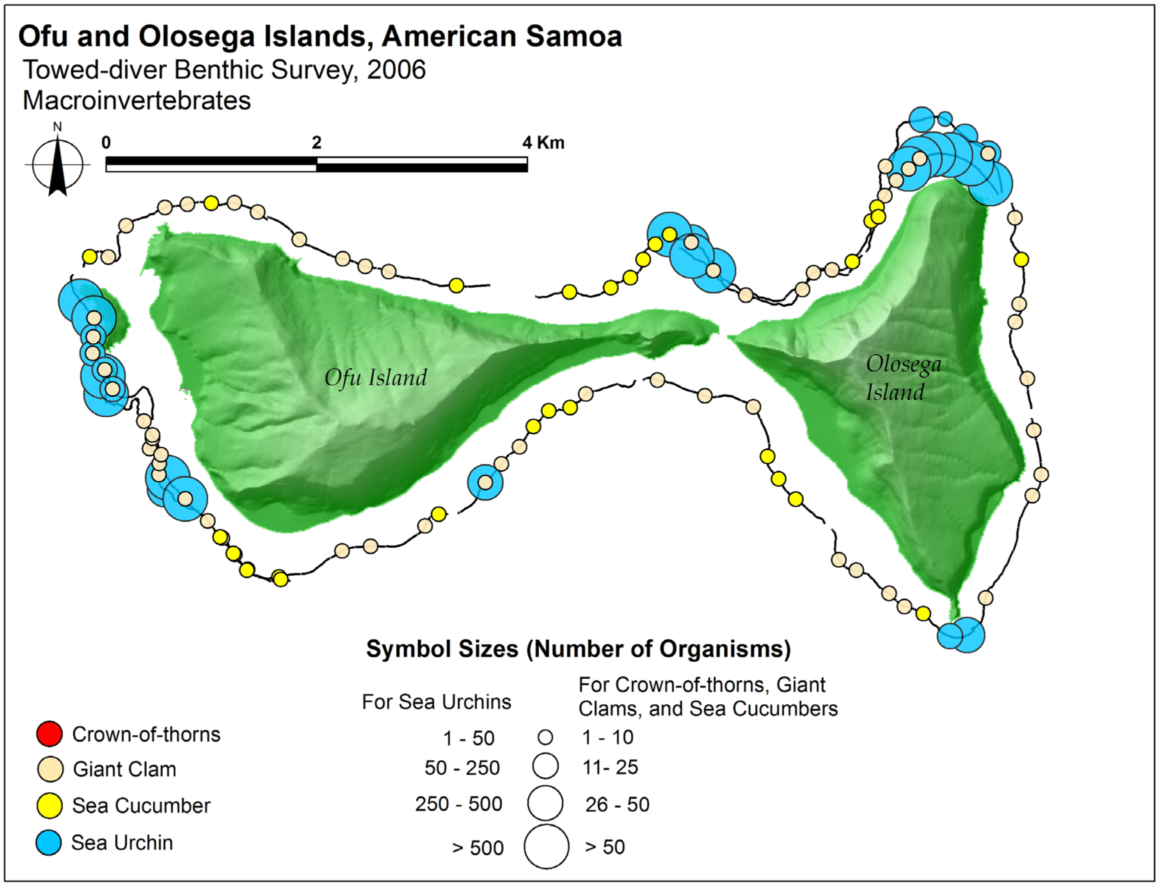

Figure 4.7.1d. Distribution of estimated population densities of COTS, giant clams, sea cucumbers, and sea urchins around Ofu and Olosega from towed-diver benthic surveys during ASRAMP 2006. Circle locations represent an integrated estimate over 5-min observation segments covering a survey swath of ~ 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).

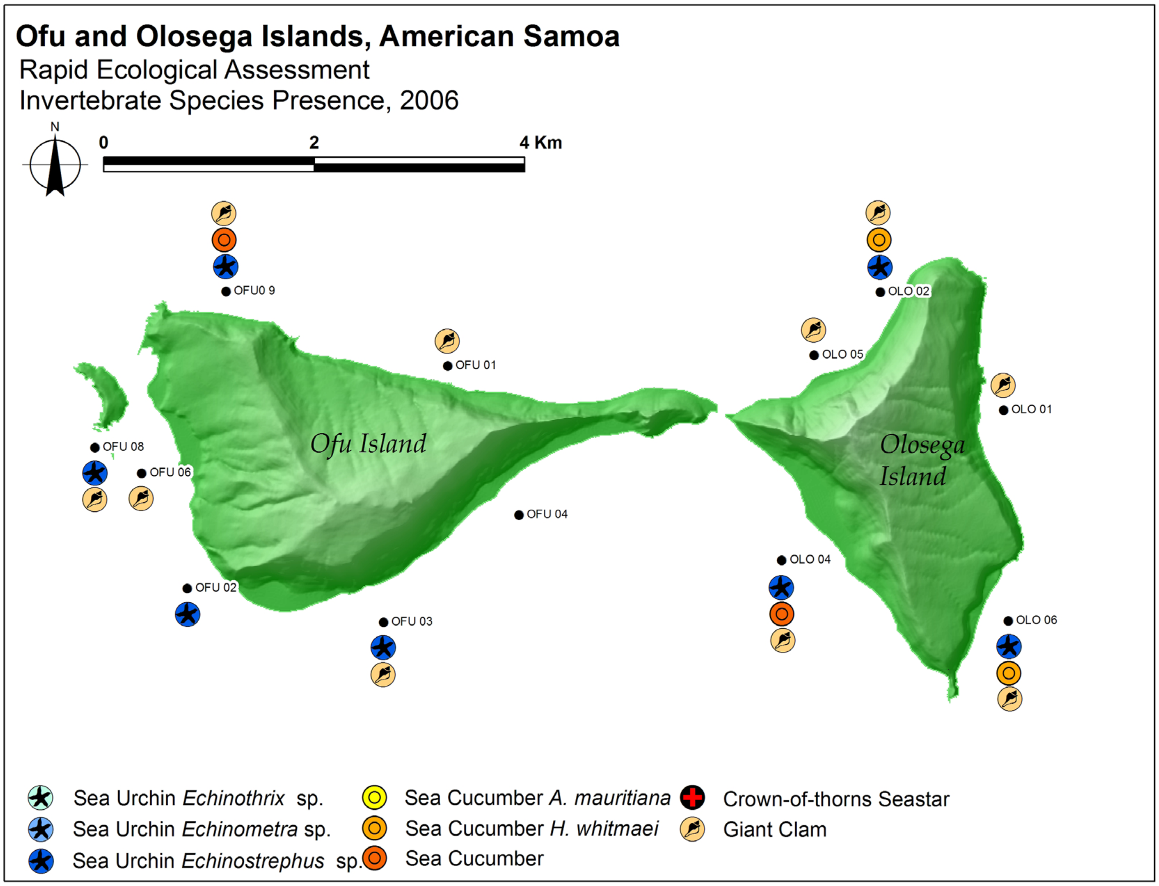

Figure 4.7.1e. Target macroinvertebrate distribution around Ofu and Olosega from REA surveys during ASRAMP 2006.

4.7.2 Temporal Comparison—Benthic Macroinvertebrates

Temporal patterns of island-wide mean benthic macroinvertebrate density (organisms ha^{-1}) around Ofu and Olosega from towed-diver benthic surveys during ASRAMP 2002, 2004

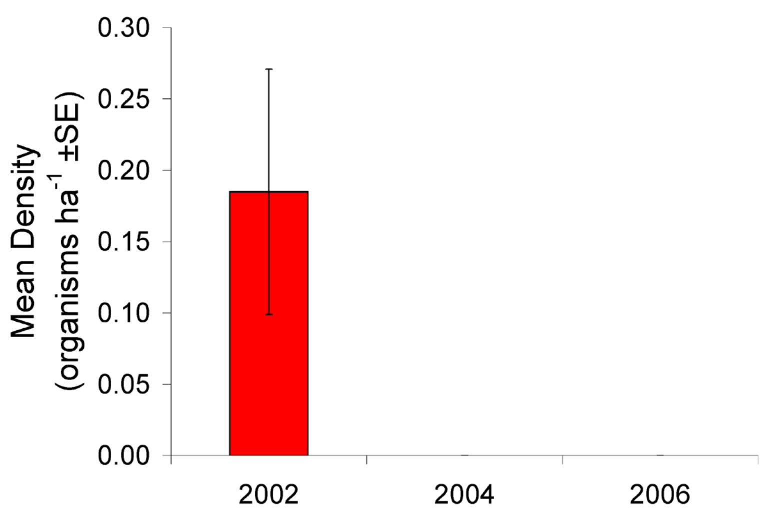

Figure 4.7.2a. Mean density of COTS around Ofu and Olosega from towed-diver surveys during ASRAMP 2002, 2004 and 2006.

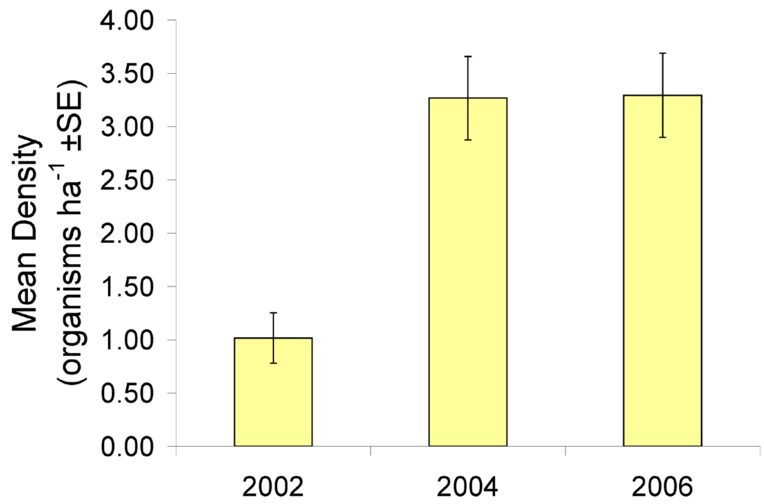

Figure 4.7.2b. Mean density of giant clams around Ofu and Olosega from towed-diver surveys during ASRAMP 2002, 2004, and 2006.

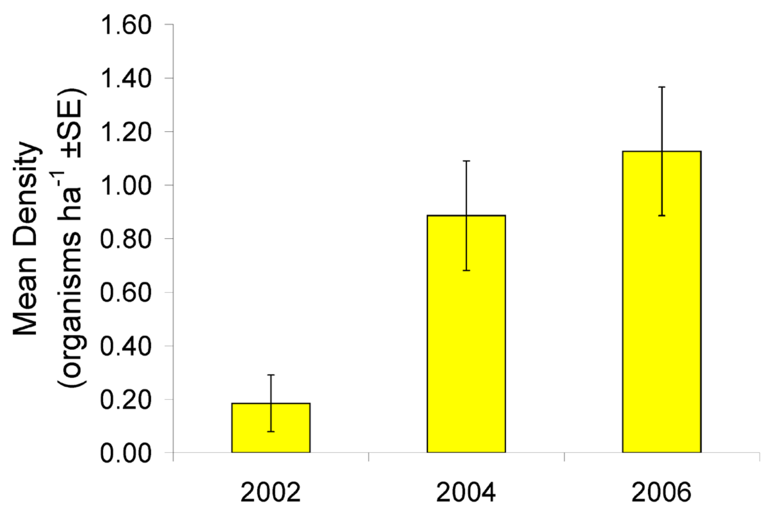

Figure 4.7.2c. Mean density of sea cucumber (holothuroids) around Ofu and Olosega from towed-diver surveys during ASRAMP 2002, 2004 and 2006.

and 2006 are shown in Figures 4.7.2a (COTS), 4.7.2b (giant clams), 4.7.2c (sea cucumbers), and 4.7.2d (sea urchins). Towed-diver survey results show trends in density among each surveyed organism and between each sampling year.

Only five COTS were observed around Ofu and Olosega during the 2002 towed-diver benthic surveys, and none was observed during 2004 or 2006 surveys. Densities of giant clams, sea cucumbers, and sea urchins were relatively similar along the forereefs of Ofu and Olosega during 2004 and 2006 towed-diver surveys. Neither giant clam nor sea cucumber mean densities were substantially different between the 2004 and 2006 surveys. As discussed in the introduction and methods chapters, numerous logistical and operational challenges were encountered during the 2002 surveys which render those macroinvertebrate counts suspect. Although spatially and temporally patchy, sea urchins were the most common benthic macroinvertebrate observed during both years. Observations indicate substantially fewer sea urchins were recorded during 2006 compared to 2004.

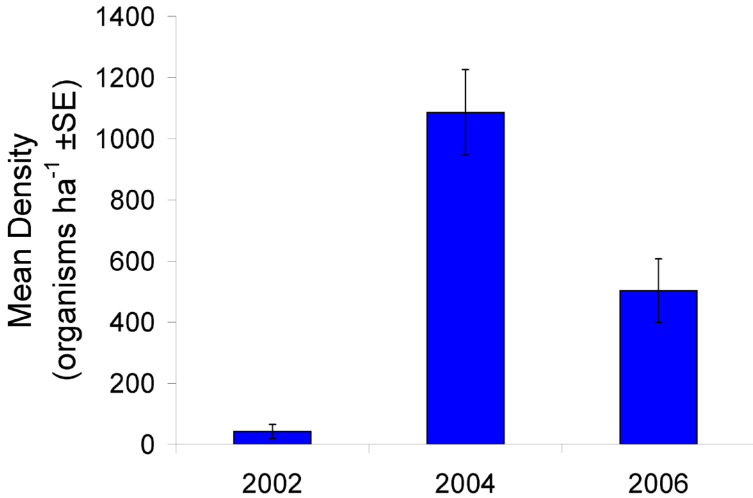

Figure 4.7.2d. Mean density of sea urchins (echinoids) around Ofu and Olosega from towed-diver surveys during ASRAMP 2002, 2004 and 2006.

4.8 Reef Fish

4.8.1 Reef Fish Surveys

2002 Spatial Surveys

Large fish (total length > 50 cm) biomass measured by towed divers was evenly distributed around Ofu and Olosega during ASRAMP 2002; ~ 0.028 tons ha^{-1} (SE 0.017; Fig. 4.8.1a). One towed-diver survey in the central north region of the islands had particularly elevated biomass due mainly to shark and humphead wrasse sightings. Generally, most of the biomass was parrotfish and snappers.

Sharks were widely observed around both islands; none was recorded in the southeast region off Olosega (Fig. 4.8.1a). Blacktip reef sharks (*Carcharhinus melanopterus*) accounted for the majority of shark sightings. A few humphead wrasses were sighted but only around Ofu.

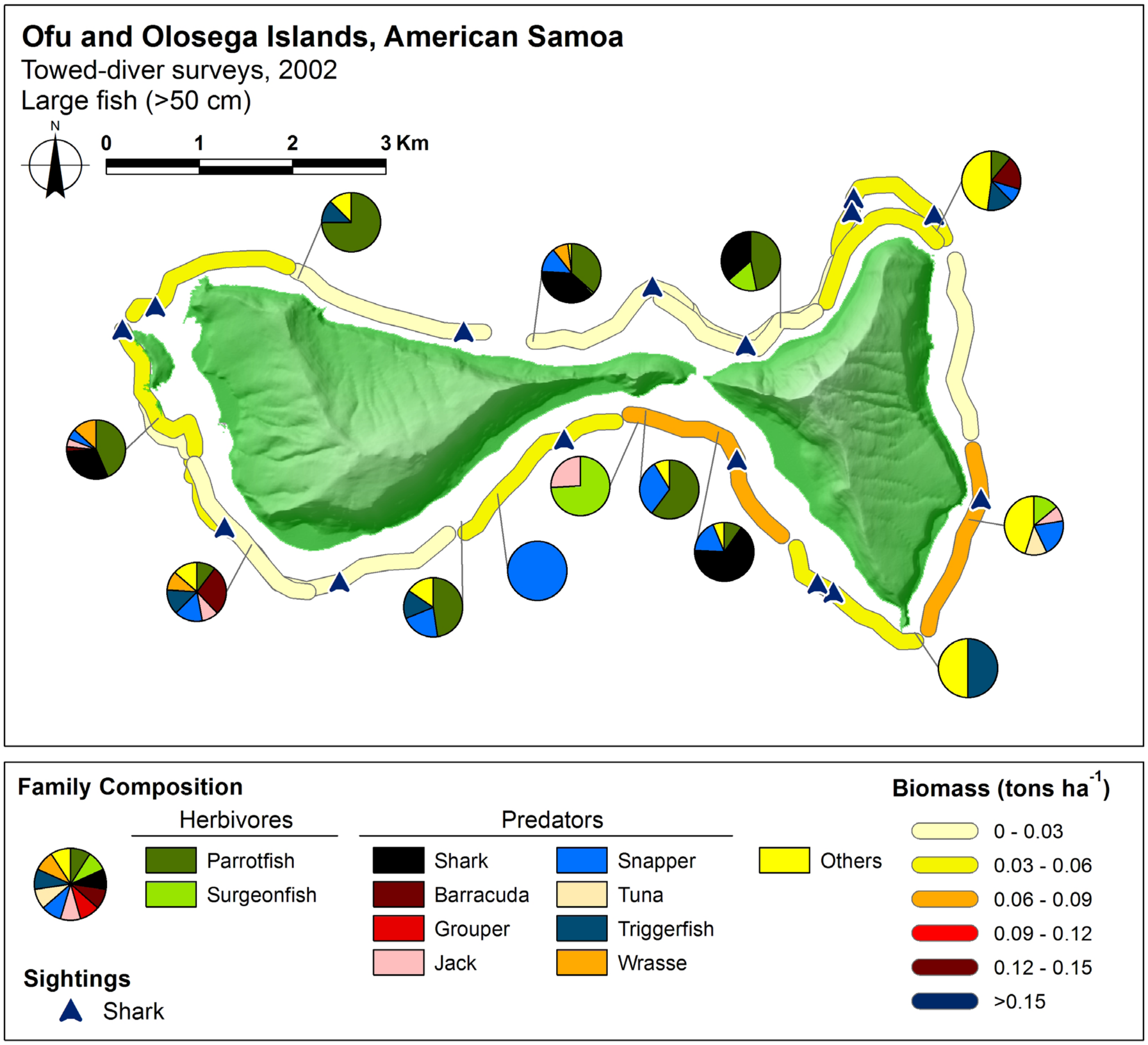

Figure 4.8.1a. Large fish biomass, family composition, and individual shark sightings around Ofu and Olosega recorded during ASRAMP 2002 towed-diver surveys. Large fish (length > 50 cm) biomass on each individual towed-diver survey is represented by the color of the survey track (tons ha^{-1}). Composition 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.

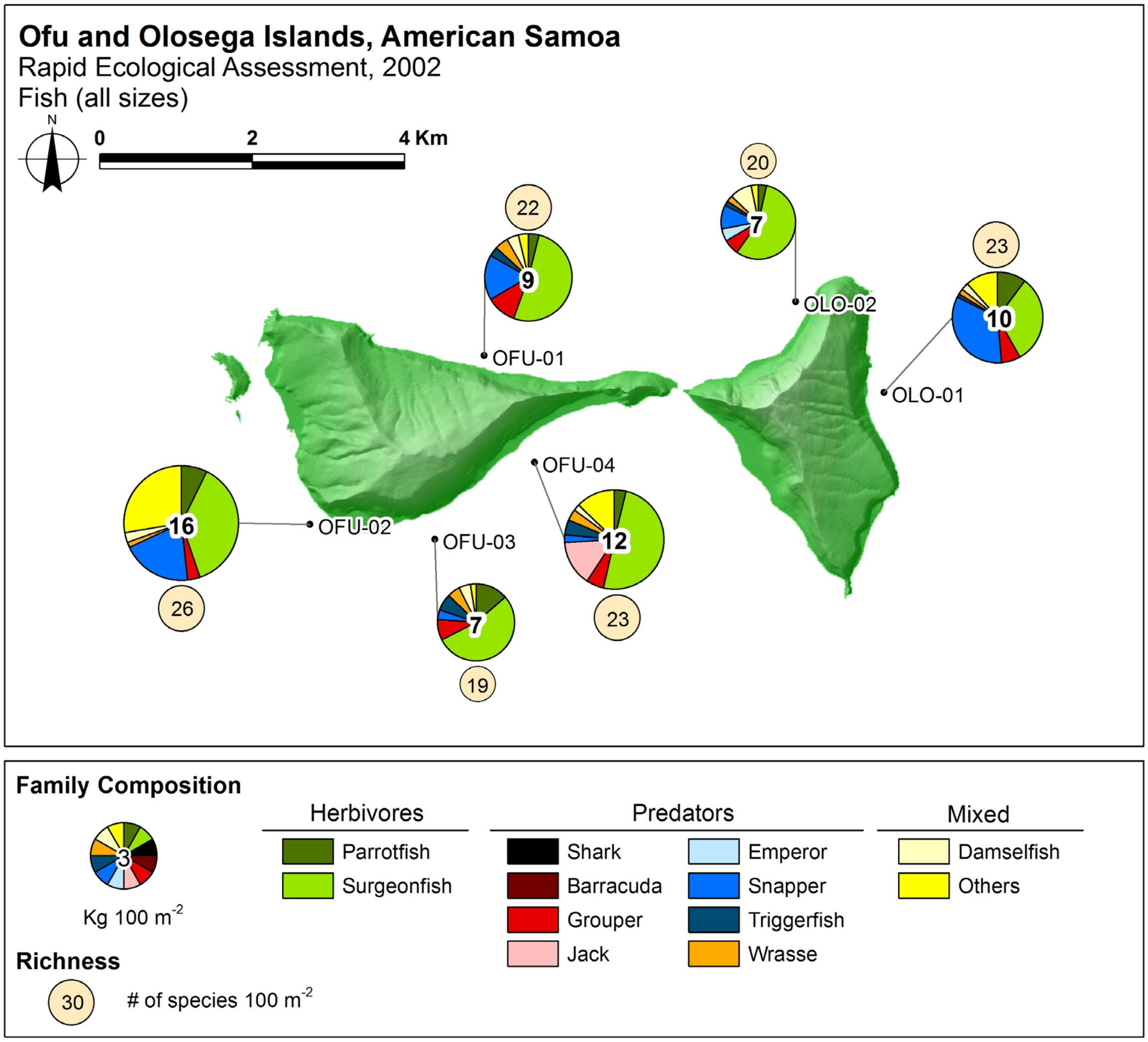

Figure 4.8.1b. Total fish biomass, family composition, and species richness of fishes around Ofu and Olosega recorded during ASRAMP 2002 REA belt-transect surveys. Total fish biomass (all species and size classes) is represented at each site by the size of the pie chart, with the actual biomass value 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 a number (# species 100 m^{-2}) and the size of beige circles.

Total fish biomass was similar around the two islands, with biomasses ranging from 7 to 16 kg 100 m^{-2} of reef habitat (Fig. 4.8.1b). Herbivores, mainly surgeonfish, were the most dominant group at all sites. Top predators were present in moderate abundance at most sites and were mostly represented by snappers and groupers. Mean total fish biomass for these islands in 2002 was 10.2 kg 100 m^{-2} (SE 2.0).

Species richness was relatively low at most sites around Ofu and Olosega (~ 20–25 species 100 m^{-2} at most sites; Fig. 4.8.1b). No clear geographic pattern emerged from the 2002 data.

2004 Spatial Surveys

Results from towed-diver surveys during ASRAMP 2004 showed that parrotfish made up the

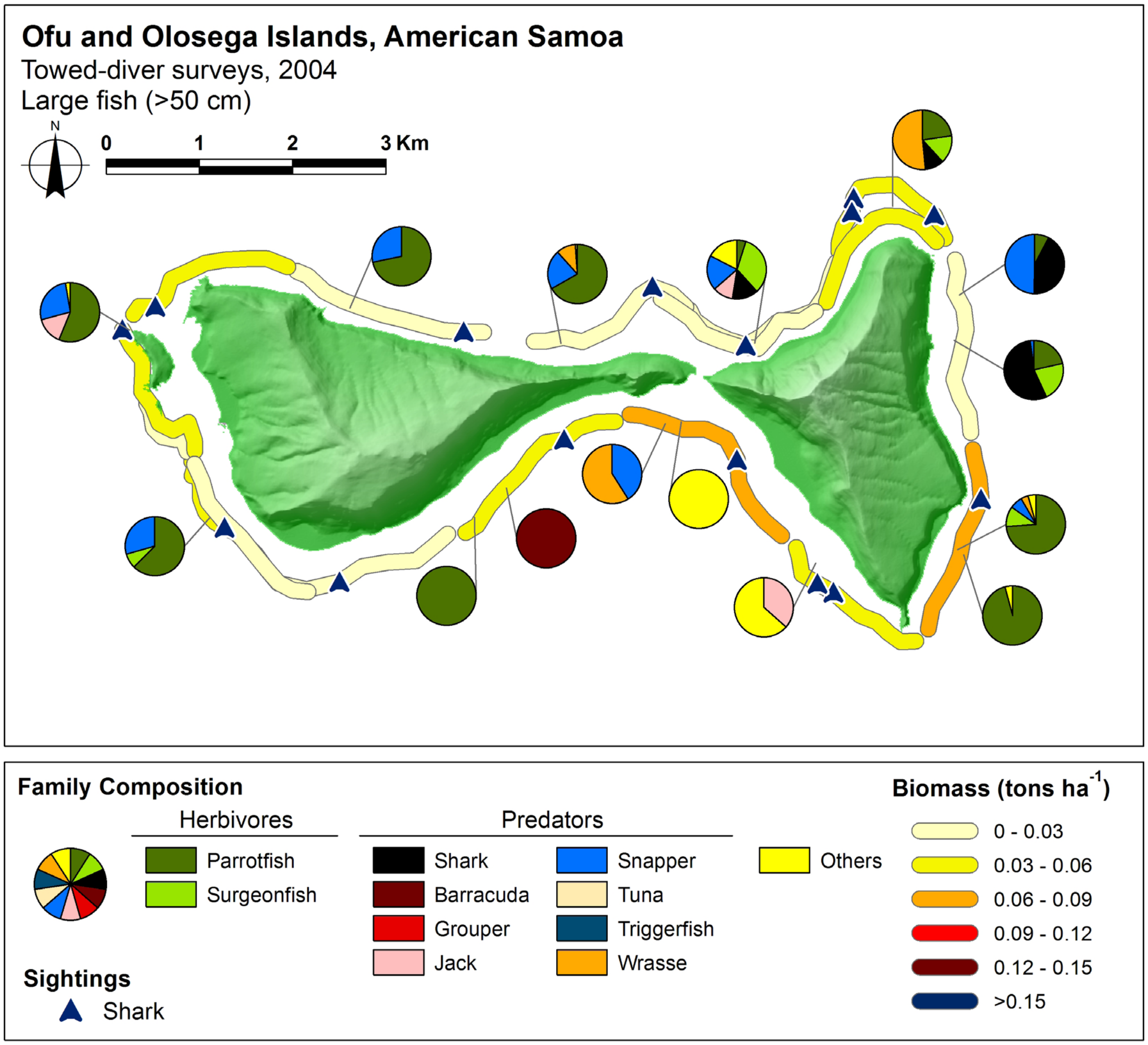

Figure 4.8.1c. Large fish biomass, family composition, and individual shark sightings around Ofu and Olosega recorded during ASRAMP 2002 towed-diver surveys. Large fish (length > 50 cm) biomass on each individual towed-diver survey is represented by the color of the survey track (tons ha^{-1}). Composition 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.

majority of large fish biomass around Ofu and Olosega, followed by sharks, surgeonfish, and snappers (Fig. 4.8.1c). Jack diversity was low, with bluefin trevallies (*Caranx melampygus*) accounting for most observations. A large school of barracudas was observed in the central south region off the southeast coast of Ofu. Overall, large fish biomass was 0.039 tons ha^{-1} (SE 0.025) and appeared to be slightly greater in the central north, central south, and northeast regions of the islands.

Sharks were sighted frequently in the northeast region on the east side of Olosega. A few humphead wrasses were observed at scattered locations around both islands (Fig. 4.8.1c).

During ASRAMP 2004, overall total fish biomass was similar between sites, 14.3 kg100 m^{-2} (SE 5.1), with the highest recordings around the western and eastern sides of the islands (~ 30 kg of fish 100 m^{-2}; Fig. 4.8.1d). Surgeonfish and, to a lesser extent, parrotfish dominated the biomass at most sites. Predator biomass was only moderately abundant at most sites, except

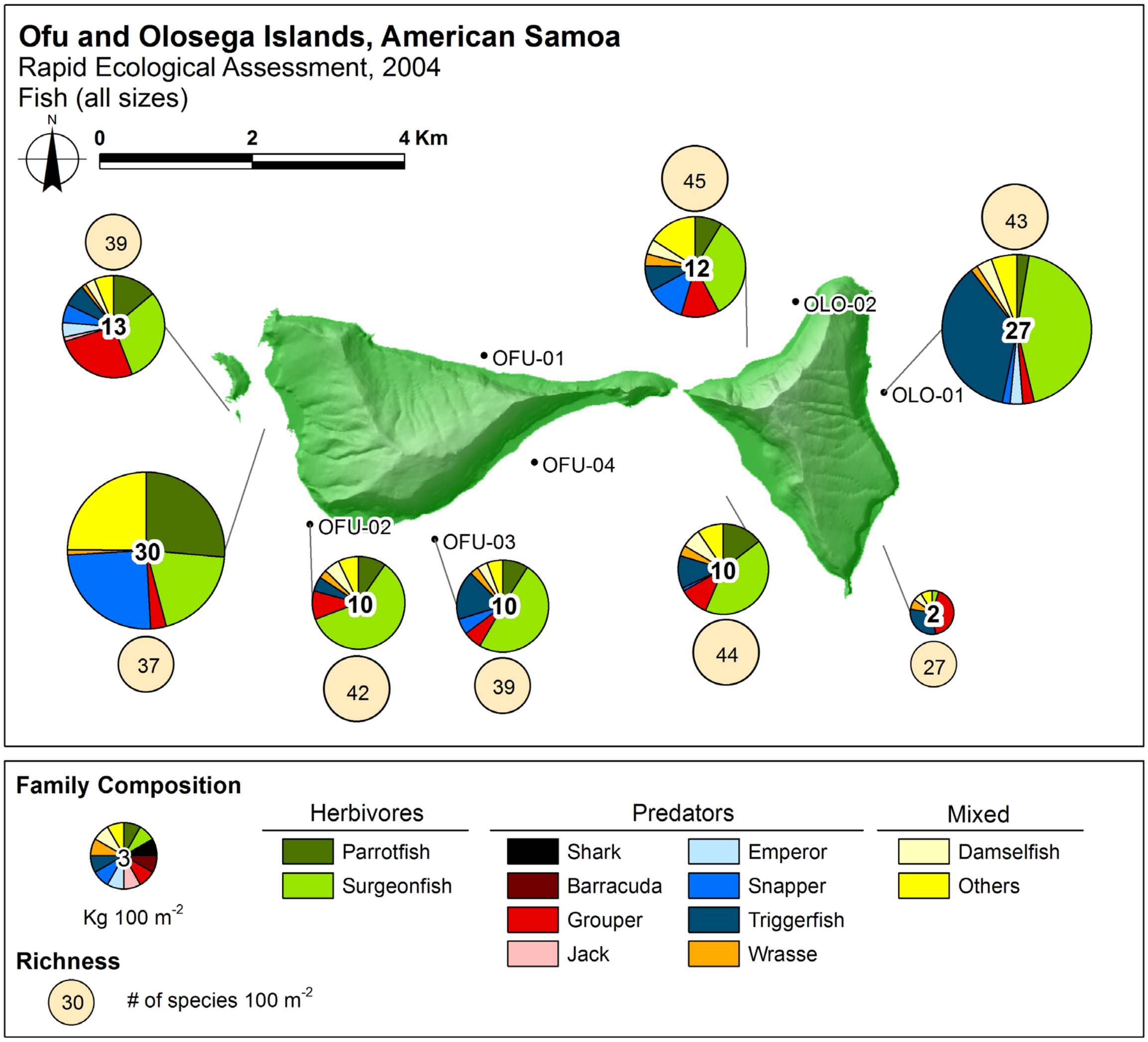

Figure 4.8.1d. Total fish biomass, family composition, and species richness of fishes around Ofu and Olosega recorded during ASRAMP 2004 REA belt-transect surveys. Total fish biomass (all species and size classes) is represented at each site by the size of the pie chart with the actual biomass value 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 (# species 100 m^{-2}) and the size of the beige circles.

for two sites, where large quantities of snappers (OFU-06) and triggerfish (OLO-01) were recorded. Groupers, mainly *Cephalopholis argus*, were recorded in noticeable abundance at nearly all sites.

Parrotfish and groupers were the majority of the biomass for medium-large fish surveyed on stationary point counts. Snappers, surgeonfish, and wrasses had slightly lower biomass. The most common large fish was the peacock grouper (*Cephalopholis argus*). The most common snappers were the smalltooth jobfish (*Aphareus furca*), twinspot snapper (*Lutjanus bohar*), and blue-lined snapper (*L. kasmira*).

Similar to 2002, fish species richness was relatively constant around the two islands (Fig. 4.8.1d). However, richness was much higher in 2004 than in 2002 (~ 40 species 100 m^{-2}), likely a reflection of the fact that the 2002 surveys were more exploratory in nature.

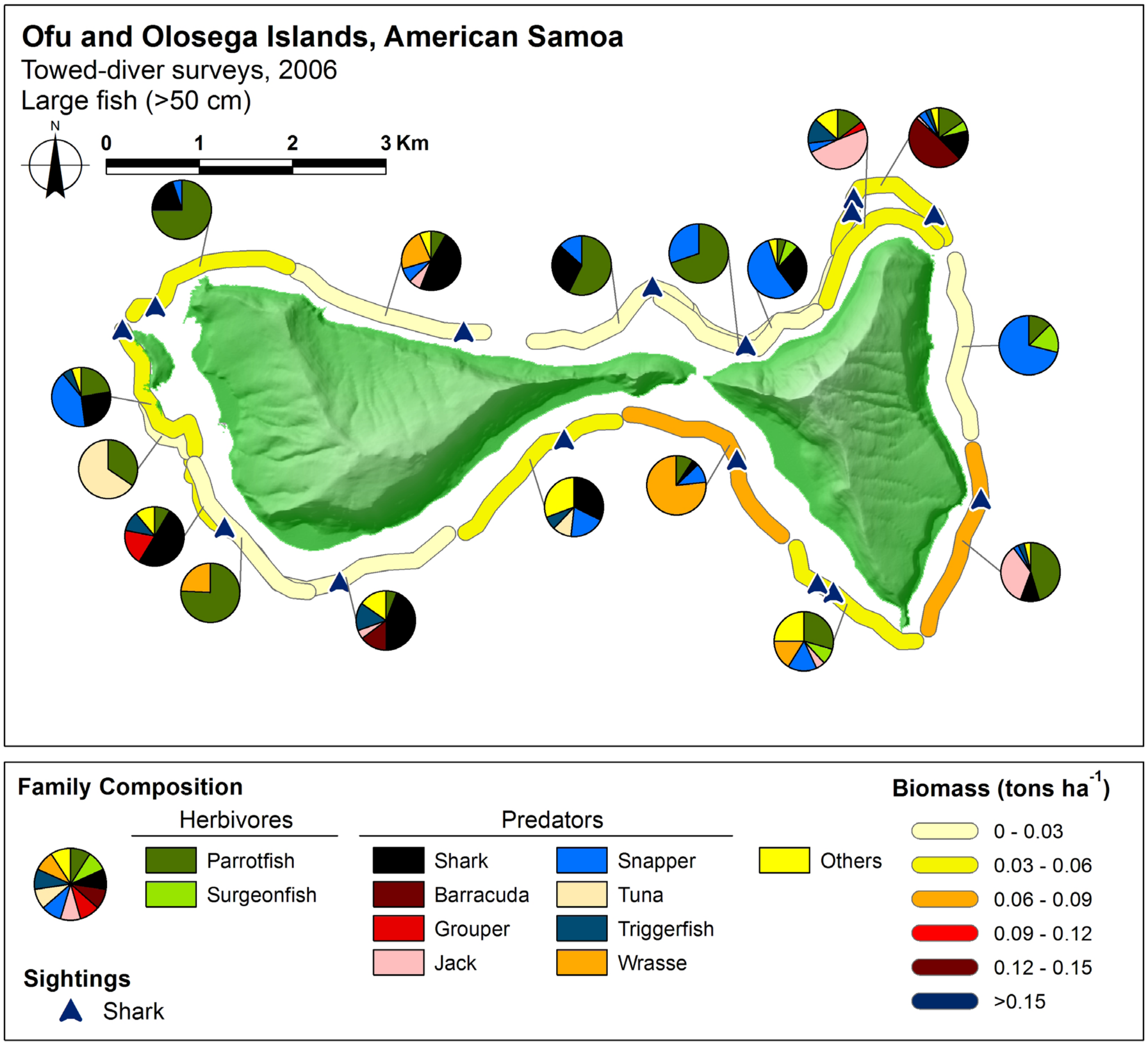

Figure 4.8.1e. Large fish biomass, family composition, and individual shark sightings around Ofu and Olosega recorded during ASRAMP 2006 towed-diver surveys. Large fish (length > 50 cm) biomass on each individual towed-diver survey is represented by the color of the survey track (tons ha^{-1}). Composition 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.

2006 Spatial Surveys

On towed-diver surveys during ASRAMP 2006, overall large fish biomass (all families pooled) was similar to 2004, 0.033 tons ha^{-1} (SE 0.014), and evenly distributed around the islands. Large parrotfish, snappers, and sharks were the majority of the large fish biomass. Sharks and humphead wrasses were observed regularly around both islands. Sharks were sighted particularly frequently in 2006 (Fig. 4.8.1e).

Similar to previous years, the total reef fish biomass during ASRAMP 2006, 5.4 kg 100 m^{-2} (SE 1.2), was distributed evenly at sites around the two islands. Surgeonfish and parrotfish were the majority of reef fish biomass (Fig. 4.8.1f); for example, the Steephead parrotfish (*Chlorurus microrhinos*) was commonly seen around Ofu and Olosega (Fig. 4.8.1g). Grouper (i.e., *Cephalopholis argus*) and triggerfish biomass were also relatively important at many sites.

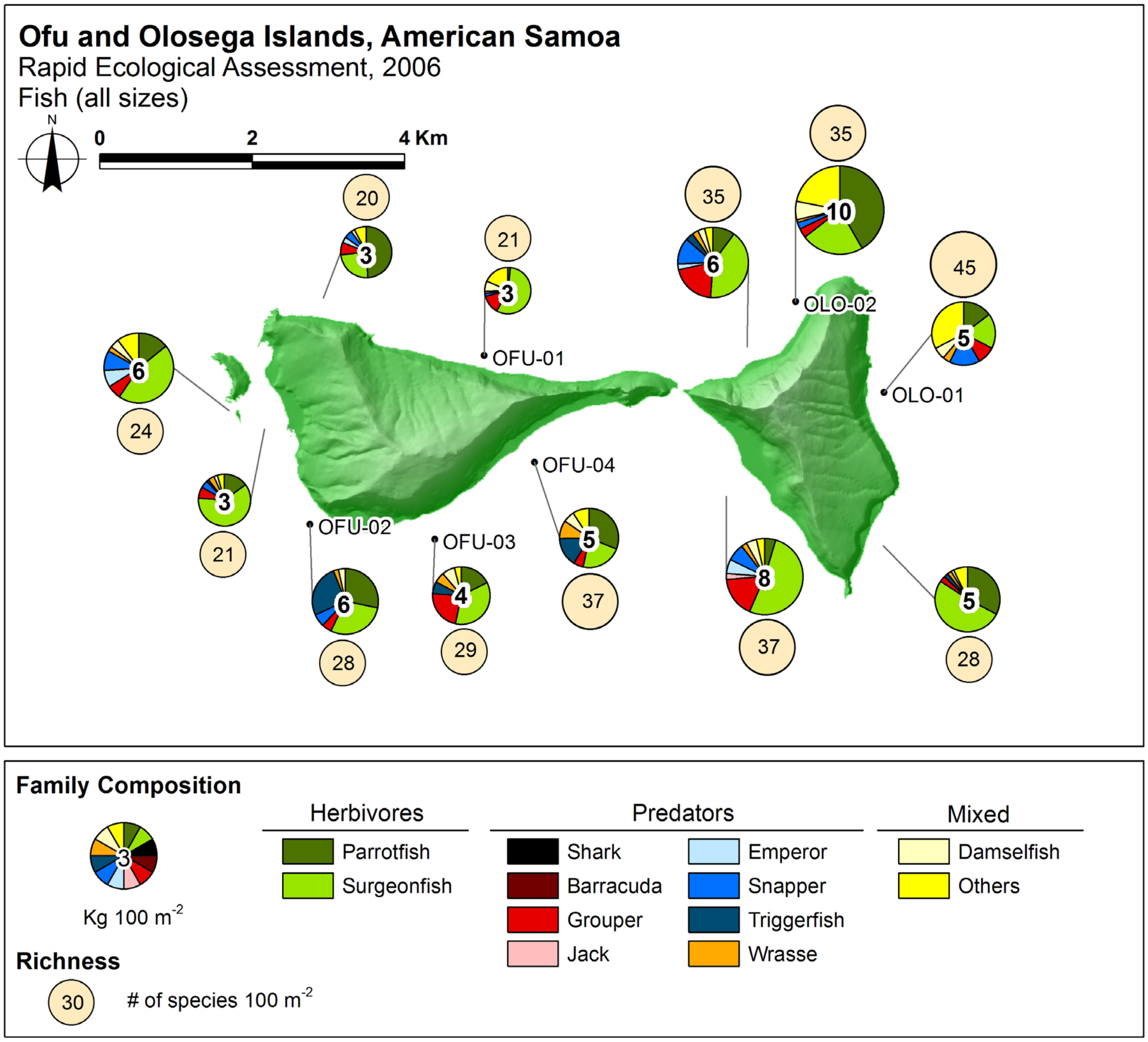

Figure 4.8.1f. Total fish biomass, family composition, and species richness of fishes around Ofu and Olosega recorded during ASRAMP 2006 REA belt-transect surveys. Total fish biomass (all species and size classes) is represented at each site by the size of the pie chart with the actual biomass value 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.

On stationary point counts during ASRAMP 2006, parrotfish and groupers again accounted for the highest biomass of medium-large fish around Ofu and Olosega, followed by snappers, wrasses, and surgeonfish.

Species richness was generally higher around Olosega and in the central south section of Ofu (~ 30–45 species 100 m^{-2}) compared to the west side (~ 20–30 species 100 m^{-2}; Fig. 4.8.1f).

Figure 4.8.1g. Steephead parrotfish (*Chlorurus microrhinos*), a common species on Samoan reefs. (*Photograph provided by NOAA PIFSC CRED; R. Schroeder, JIMAR*)

4.8.2 Temporal Comparison—Reef Fish

The three ASRAMP survey periods in 2002, 2004, and 2006 showed no clear geographic patterns of total fish biomass around Ofu and Olosega. The majority of the biomass was herbivorous surgeonfish and parrotfish. Total fish biomass around these islands was slightly above 1 tons ha^{-1} in 2002 and 2004 but appears to have decreased to 0.54 tons ha^{-1} in 2006 (Fig. 4.8.2a). Overall, total fish biomass is around 1.0 tons ha^{-1} (SE 0.3) for Ofu and Olosega.

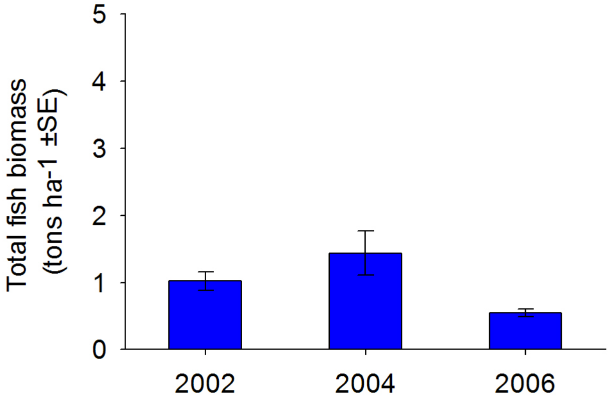

Figure 4.8.2a. Total fish biomass around Ofu and Olosega during ASRAMP 2002 (6 sites), 2004 (8 sites), and 2006 (12 sites) REA surveys.

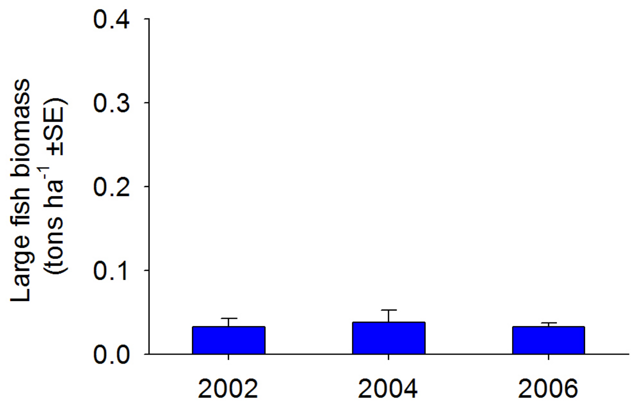

Figure 4.8.2b. Large fish biomass around Ofu and Olosega from towed-diver surveys during ASRAMP 2002 (13 surveys), 2004 (18 surveys), and 2006 (17 surveys).

Large fish biomass is mostly parrotfish, barracudas, and shark species and is distributed evenly around the island in all years surveyed. Large fish biomass remained constant in all years surveyed at around 0.033 tons ha^{-1} (SE 0.019; Fig. 4.8.2b). Sharks and humphead wrasses were frequently sighted around both islands, although with no clear geographic pattern emerging between years. There does not appear to be a population of bumphead parrotfish around these islands.

There is no consistent species richness pattern between years around Ofu and Olosega, with similar species counts occurring around both islands in all years surveyed.

All the biomass per island means referenced in the above section can be found in Appendix IV, Tables IV.i and IV.ii. Fish density per island means can also be found in Appendix IV, Tables IV.iii and IV.iv.

4.9 Island Summary and Integration

Ofu and Olosega are extremely steep, quickly eroding volcanic islands in the Manu`a Island group that are located in an area that remains geologically dynamic and active. Bathymetric and backscatter data from multibeam surveys (Figs. 4.3.1a and 4.3.1b) around the islands revealed the presence of a narrow (~ 1 km) insular shelf, with banks extending off the northwestern, northeastern, and southeastern sides up to 2 km offshore. The shelf and banks were generally composed of mostly hard substrate extending seaward from the reef crest. Sand fields were also located at the base of the forereef slope off the watershed drainage areas on the north sides of both islands visible within the backscatter imagery (Fig. 4.3.1b), which corresponded with shallower towed-diver observations that found high levels of sand cover in the central north and northwest regions (Fig. 4.3.2b). Towed-diver observations in the north also noted elevated sand cover and habitat complexity within/east of the Asaga Strait separating Ofu and Olosega, suggesting sand channel(s) in rugose habitat (Figs. 4.3.2a and 4.3.2b). Two broad sand channels were identified off the east side of Olosega that merged into a sand field at the base of the forereef slope in that location. Along the northeast windward coast of Olosega, towed-diver surveys also identified an area of moderate-high complexity corresponding with low/moderate sand cover that was immediately followed by an area of low complexity with a visible parallel change from low to high sand cover.

In each of the ASRAMP survey periods in 2002, 2004, and 2006, the nearshore CTD and water quality observations exhibited spatial heterogeneity, though in many cases the ranges of the spatial changes were relatively small. Between survey periods, temperature and salinity variations were generally small. Despite the relatively small changes in physical properties, some spatial patterns around Ofu and Olosega were clear.

A particularly cool episode, with temperatures reaching nearly 2°C below the SST climatology, was observed in austral winter 2002 before sharply rising 3°C to climatologically normal temperatures in late 2002. In situ temperature observations generally tracked satellite-derived temperature products rather closely, with one exception in early 2005, when in situ values were nearly 1.5°C above satellite SST. Salinity values island-wide were considerably lower during the 2006 surveys in comparison with previous years and may be attributed to above-average rainfall (Fig. 3.4.3d). Density observations tended to parallel salinity more closely than temperature, which is typically the dominant constituent when computing density. Turbidity levels, when comparing 2004 and 2006, were extremely high at select locations in the latter survey period (Fig. 4.4.1i), most likely a result of the exceptional precipitation preceding the ASRAMP 2006 surveys.

In general, the northern coastline, including the northwest, central north, and northeast regions was characterized by infrequent, long period swells from North Pacific boreal winter storms, while the southern coastline, including the southwest, central south, and southeast regions, was characterized by frequent short period (8–12 sec) waves (~ 2 m) from trade wind swells and less frequent, larger (~ 3 m), longer period (12–18 sec) swells generated by winter storms in the Southern Ocean (Fig. 3.4.3f). Aside from the large-scale east to west currents, no nearshore current data are available to resolve finer scale patterns.

The forereef slope off the north side of Ofu in the central north region and the eastern portion of the northwest region was characterized during towed-diver benthic surveys as having very high habitat complexity, moderate levels of sand, hard substrate/pavement, and rubble, and moderate-to-low live coral cover (Figs. 4.3.2a, 4.3.2b, 4.3.2c, 4.3.2d, and 4.3.2e). Combined, these characteristics describe the high-relief spur-and-groove habitat of the area, reflecting the regions exposure to significant wave energy during austral summer months as long period ocean swells from the northwest sector (Fig. 3.4.3f) impact the biogeography of these northern exposed reefs, despite the fact that these swells are generated by North Pacific winter storms located more than 5000 km away.

Other results from the 2004 and 2006 surveys were likely influenced by the large-swell event generated by Tropical Cyclone Heta in January 2004. In 2004, the eastern side of Olosega displayed low salinity and density values, and high-beam transmission values (low turbidity), suggesting the presence of a freshwater lens during the sampling period in that region (Figs. 4.4.1e and 4.4.1f). The cause of this signal was likely rainfall and subsequent runoff from the many streams which line the east side of Olosega, which may have caused an influx of freshwater to the surface waters that mixed deeper into the water column through trade wind and wave action. In contrast, the western part of the island group showed localized variability, including the lowest measured beam transmission values (high turbidity) of the survey period. While the western side of Ofu also has a number of mapped streams, no evidence of a freshwater influx was observed in the 2004 nearshore CTD survey data.

Conversely, in 2006, the eastern part of the island group showed much more local variability in these physical oceanographic parameters, including a region with some of the lowest measured beam transmission values (Figs. 4.4.1h and 4.4.1i). The area around the northern Asaga Strait was characterized by relatively high water temperature and beam transmission values, along with low salinity and density values. These characteristics suggest a freshwater feature at that location during the sampling period in 2006 because of rainwater runoff and the formation of a freshwater lens near the surface, or through some other mechanism that was undetected. In contrast, the western coastline displayed relatively cold, saline, and dense water, suggesting a possible upwelling feature in that region (Figs. 4.4.1h and 4.4.1i). The leeward sides of both Ofu and Olosega were observed to be more stratified than around most of the rest of the islands, likely indicating surface heating and lack of wave-induced vertical mixing.

The southwestern shoreline of Olosega showed the highest total nitrogen (N_{tot}; Fig. 4.4.1j) in the American Samoa Archipelago, possibly indicating a deep subsurface source. Sites near the northwest village of Ofu and the town of Olosega along the southern coast all showed higher Chlorophyll-a values than most of the other areas of the island group (Fig. 4.4.1j).

Figure 4.3.2e shows estimates of live coral percent cover from towed-diver surveys integrated across the survey years and probably provides the most complete picture of live coral distribution patterns. The highest consistent live coral cover values were recorded along the east-facing, windward coast in the northeast and southeast regions of Olosega, which mirrored localized areas of moderate-to-high habitat complexity that bordered low-complexity sand channels (Figs. 4.3.2a and 4.3.2b). The east and west sides of Maga Point at the southern tip of Olosega in the southeast region also showed especially high live coral cover, with mean values of 43.3%, 43.6%, and 42.3% in 2002, 2004, and 2006, respectively (Figs. 4.5.1b, 4.5.1e, and 4.5.1k). Additional high coral cover areas varied by year, and included areas of the central south and northwest regions (Figs. 4.5.1b, 4.5.1e, and 4.5.1k).

Since towed-diver survey tracks varied between the survey years, Figure 4.3.2e also shows gradients of live coral cover in the inshore-offshore (shallow-deep) direction. In many areas, such as the east and west sides of Maga Point in the southeast region, higher live coral cover values were observed in the shallower inshore areas. In other areas, high live coral cover values were observed at intermediate or deeper depths further offshore. These observed patterns support the hypothesis that coral community structure is both spatially heterogeneous and depth-stratified around Ofu and Olosega. These patterns were likewise observed during TOAD optical surveys, where there were few colonies observed during offshore and relatively deep tows (Fig. 4.3.1c). On each of the three relatively shallow banks extending off corners of the two islands, coral communities were noted, specifically on the submerged banks in the southeast, northeast, and northwest regions. Interestingly, some of these communities occurred at depths greater than ~ 50 m, which indicates that coral stratification does not necessarily preclude the formation of deeper colonies. Though deeper coral communities are generally limited by penetration of sufficient light to support photosynthesis, their depth provides some ecological benefits, such as significantly reduced exposure to damaging wave energy from surface gravity waves.

Similarly, coral growth and depth stratification patterns noted during towed-diver and TOAD surveys were also mirrored in some of the REA surveys between years. For example, site OFU-02, located on the southwestern corner of Ofu in the southwest region, shows mixed results between years. In 2004, low coral cover, low coral density, and high diversity were recorded. In 2006, a survey at the presumed same site revealed a threefold increase in coral cover, a twofold increase in coral density, and a 20% reduction in the number of reported genera. A closer examination of dive metadata revealed that the 2004 survey of OFU-02 was completed in water depths ranging between ~ 5 and ~ 15 m, while the 2006 survey was completed in depths ranging between ~ 14 and 20 m. In this case, the higher coral cover and density were observed in the deeper depth range, possibly a reflection of the increased wave energy in the shallower habitat.

A total of 34 coral genera were found around Ofu and Olosega. *Montipora* and *Goniastrea* were the most dominant genera in 2004 and 2006, with *Porites* and *Pocillopora* also appearing dominant in 2004 and 2006, respectively (Figs. 4.5.1g and 4.5.1m). The change could be a result of recruitment events, variability in transect locations or some other unknown mechanisms.

The REA site with the highest live scleractinian coral cover was consistently OLO-01 (2004/2006, 63%; Figs. 4.5.1h and 4.5.1n) in the northeast region on the east side of Olosega. This site also coincided with the area of highest live coral cover from the towed-diver benthic surveys (Figs. 4.3.2e, 4.5.1e, and 4.5.1k). The towed-diver benthic survey also found this area to have high habitat complexity that bordered a distinct sand channel (Figs. 4.3.2a and 4.3.2c), which ran from the reef crest to the sand field at the base of the slope (Fig. 4.3.1b). REA data from 2006 also showed elevated coral cover values in the central south region of Ofu and Olosega (OFU-03, 41%; OFU-02, 40%; OLO-04, 34%; Fig. 4.5.1m), while site OLO-05 on the eastern end of the central north region had elevated percent live coral cover for both years (2004, 44%; 2006, 31%; Fig. 4.5.1m).

The lowest overall live coral cover was found in the northwest region at OFU-06 (2004, 10%; 2006: 15%; Fig. 4.5.1m), which coincidentally appears to lie in an area of low-medium complexity (Fig. 4.3.2a) and sand cover (Fig. 4.3.2b) bordered to the east and west by areas of higher complexity and coral cover (Fig. 4.3.2e). Other areas of low coral cover included OFU-09 (2006, 21%; Fig. 4.5.1m) in the northwest region and OFU-01 in the central north region (2006: 14%). OLO-06 in the lower southeast region recorded low coral cover in 2004 (9%) vs. much higher cover in 2006 (31%), which may be attributed to shifts in the site selection/depth changes or transect variability.

During 2004 and 2006, colony densities were highest along the southern-facing shores of the central south, and southwest regions of Ofu and Olosega. Specific sites of high coral density included OLO-04 (2004, 19.9; 2006: 17.4 colonies m^{-2}) and OFU-04 in the central south region (2006: 15.1 colonies m^{-2}), along with OFU-03 in the southwest region (2004, 11.4; 2006, 19.8 colonies m^{-2}). Coral densities were consistently lowest in the northwest and southwest regions, although sites in the southeast (OLO-01 and OLO-06) also recorded low coral densities in both 2004 and 2006 (Figs. 4.5.1h and 4.5.1n).

Generic richness around Ofu and Olosega between 2004 (21.9 genera/site [SE 1.3]) and 2006 (20.8 genera/site [SE 1.0]) was relatively uniform, even with the additional sampling effort in 2006 (Fig. 4.5.3b). Interestingly, OLO-01 had the highest recorded live coral cover and largest coral colony sizes around Ofu and Olosega during both 2004 and 2006 (Figs. 4.5.1h, 4.5.1i, 4.5.1n, and 4.5.1o), but also had the one of the lowest coral generic richness values of the island system in comparison with other REA sites in both 2004 and 2006 (Figs. 4.5.1g and 4.5.1m). In contrast, the highest coral diversity was recorded at OFU-04 in the central south region where 28 coral genera were recorded, but live coral cover was among the lowest observed (16.7%).

There are a number of potential hypotheses for some of these observed trends. Larger, more stable coral communities at sites OLO-01 and OLO-05 in the northeast and central north regions may have higher coral cover, larger colonies, diminished species richness, and decreased colony densities as a result of protected cover from large swells generated by southern storms and/or other moderate-to-high levels of environmental disturbance (Fig. 3.4.3f). Though site OLO-01 on the east side of Olosega is exposed to prevailing trade wind swells, it is generally protected from the larger swell wave energy from both the south and northwest, which may help explain why that area has the highest live coral cover and largest coral size class distributions around Ofu and Olosega. Being exposed to persistent trade wind-driven ocean circulation, the reefs in that area are continually flushed and nourished, yet they are not exposed to the extreme and destructive wave events of other areas around these two islands. The vertical profiles of water properties for the shallow-water CTD surveys generally found the east end of Olosega to have a well-mixed water column, suggesting an increased likelihood of localized upwelling of nutrients (Figs. 4.4.1b and 4.4.1e). High coral densities of smaller colonies in portions of the central south and southwest regions might be congruent with higher levels of species richness, also suggesting an oceanographic link to wave energy.

Sea surface temperature observations between February 2002 and February 2004 revealed no evidence of temperatures exceeding the bleaching threshold, and no large-scale bleaching was observed during ASRAMP 2002 or 2004 surveys. Bleaching of colonies was the most common coral disease/affliction observed during 2006 REA field surveys (Figs. 4.5.2a and 4.5.2b). Towed-diver benthic surveys found regions of elevated stressed coral in the southeast region near REA site OLO-06 (Maga Point, 5 tow segments, mean: 7.5%; Leala Point, 3 tow segments, mean: 7.5%), the southwest region near OFU-02 (8 tow segments, mean: 6.9%), and the central north region near OLO-05 (8 tow segments, mean: 11.1%; Figs. 4.5.1f and 4.5.1l), indicating a possible connection. However, towed-diver benthic surveys also found elevated levels of stressed coral in different locations in the central south (4 tow segments, mean 9.4%), which did not visibly correspond to nearby REA sites. Considering the overall mean decrease in salinity observed during 2006 relative to the previous years, it is possible that elevated terrestrial runoff and freshwater input resulted in these localized coral stress areas. Coral stress and diseased areas did not appear to directly correspond with areas of human habitation.

Turf algae and coralline crustose red algae were the dominant benthic organisms around the nearshore areas of Ofu and Olosega and were fairly evenly distributed. However, several interesting observations were noted. The percent cover of fleshy macroalgae was relatively low around both islands in both 2004 and 2006 (Figs. 4.6.1b and 4.6.1d), with the densest populations occurring along the central south region along the southeast coast of Ofu. the greatest macroalgal diversity was observed at REA site OFU-02, located in the southwest region near the southern point of Ofu close to the proposed runway extension. In contrast, site OFU-06, offshore of Ofu village in the northwest region, and site OLO-01, off the east side of Olosega in the northeast region, had the lowest macroalgal diversity (Figs. 4.6.1c and 4.6.1e). In general, coralline crustose red algae cover was highest on the southern versus northern coastline, which may be a result of exposure to higher levels of wave and current energies. In addition, populations of the calcified red algal *Amphiroa*/*Jania* and cyanophytes were more evenly distributed and of greater abundance around the two islands in 2006 than during 2004 surveys, and populations of macroalgae were almost twice as diverse in 2006 versus 2004. These changes in populations are hypothesized to be a result of, in part, wave energy generated by Tropical Cyclone Heta at 1 month prior to the ASRAMP 2004 surveys. The cyclone may have affected the abundance and distribution of algal species as observed during surveys in 2004, but algal communities may have recovered by the time the 2006 surveys were conducted. Of note, coralline algal diseases were also abundant and widespread (all REA sites except for OFU-03) around Ofu and Olosega, with a total of 278 cases (Figs. 4.6.2a and 4.6.2b).

Macroinvertebrate distributions were relatively similar during towed-diver benthic surveys from each year. Only five COTS were observed over 138.1 ha of reef surveyed around Ofu and Olosega by the towed-diver survey teams, all of which were recorded in 2002 (Figs. 4.7.1a, 4.7.1b, and 4.7.1d). No additional COTS were sighted by either towed-diver or REA teams during subsequent years. Although there were no obvious patterns in the distribution of giant clams, *Tridacna* sp. were relatively common, with more than 100 individuals observed during towed-diver surveys in both 2004 and 2006. Giant clams were also common at REA sites (present at 10 of 12 sites; Fig. 4.7.1e). Sea cucumbers were observed to be widely distributed around Ofu and Olosega during towed-diver surveys in both 2004 and 2006, and there were notable patterns of aggregation along the southwest corner of Ofu in the southwest region, along the southeast side of Ofu and southwest side of Olosega in the central south region, and a small area just northwest of Asaga Strait in the central north region (Figs. 4.7.1b and 4.7.1d). Generally, each of these areas tended to be characterized by relatively higher percent cover of coral rubble habitat (Fig. 4.3.2d). While spatially and temporally patchy, sea urchins were the most common invertebrate observed around Ofu and Olosega (Figs. 4.7.1b and 4.7.1d). Generally, sea urchins were observed in high densities off the west coast of Nu`utele Island in the northwest region, off the southern point of Ofu in the southwest region, off the northern bank of Olosega in the northeast region, and north of Asaga Strait in the central north region in both 2004 and 2006. During 2004, significantly more urchins were observed, particularly in the southeast region and along the north coast of Ofu in the northwest region, where few were observed during 2006 surveys.

With respect to fish populations, there was no clear geographical pattern of the total fish biomass around Ofu and Olosega. The majority of the biomass was relatively evenly distributed and composed primarily of herbivorous surgeonfish and parrotfish, with total fish biomass averaging around 1.0 tons ha^{-1}. Large fish biomass was mostly parrotfish, barracudas,