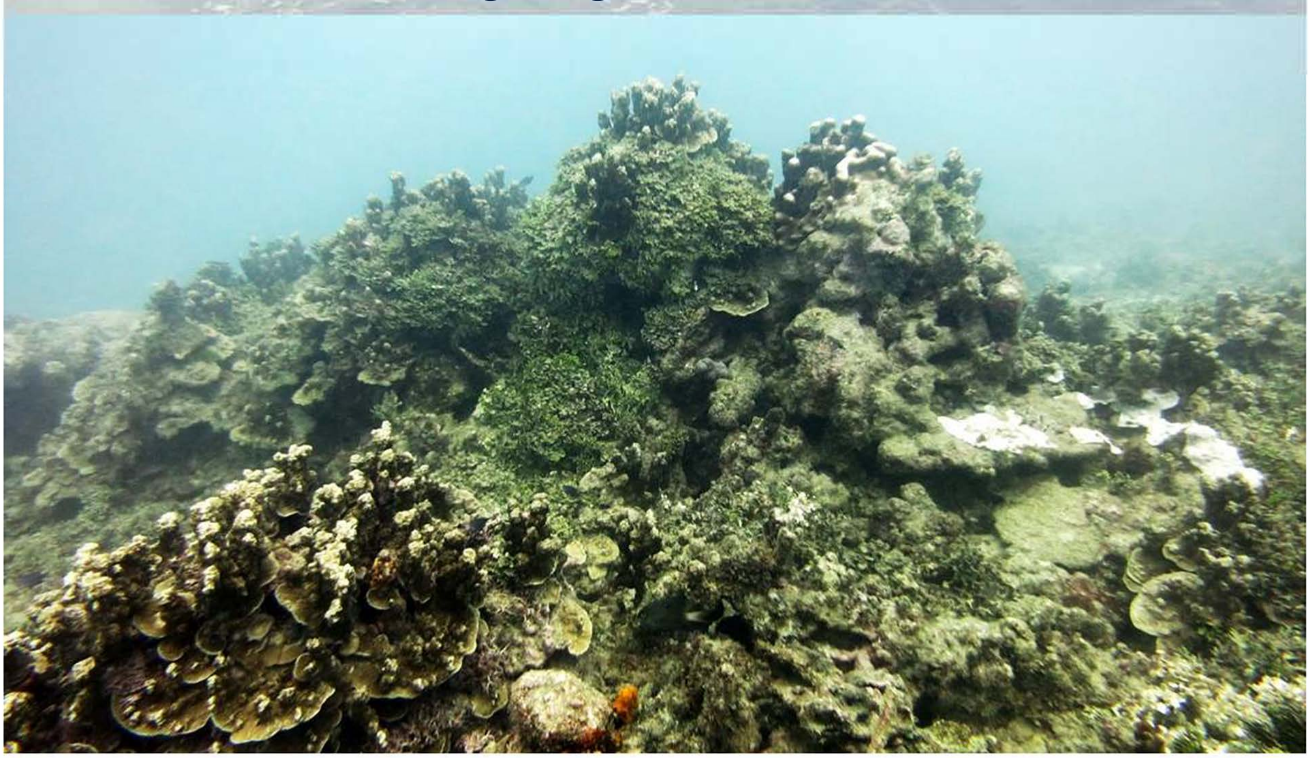
Baseline Surveys for Coral Reef Community Structure and Demographics in Vatia Bay and Faga‘alu Bay, American Samoa

Data Report

Bernardo Vargas-Ángel and Brett D. Schumacher



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Bernardo Vargas-Angel
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1. Objective and purpose

This report describes the results of baseline assessment surveys for coral reef benthic structure, coral community demographics, and health condition conducted in Vatia Bay and Faga‘alu Bay, American Samoa, by the Coral Reef Ecosystem Program (CREP) of NOAA's Pacific Islands Fisheries Science Center (PIFSC), from 23 October to 15 November 2015. The work described was funded by the NOAA Coral Reef Conservation Program (CRCP) through two internal projects entitled: "*Comprehensive Baseline Assessment and Pilot test of Outcome Performance Measures in Faga'alu Bay, American Samoa",* awarded to Suzie Holst (NOAA National Ocean Service) and *"Eutrophication Impacts on Coral Ecosystem Health in Vatia, American Samoa",* awarded to David Whitall (NOAA National Center for Coastal and Ocean Science).

These projects were conceptualized and developed by the respective principal investigators and the authors of this report in consultation with the local marine resource management agencies; including the American Samoa Department of Marine and Wildlife Resources (DMWR) and the American Samoa Coral Reef Advisory Group (CRAG), to fulfill critical information gaps while complementing ongoing local monitoring and management programs and meeting CRCP Jurisdictional and National Objectives. One of the specific goals of both projects was the establishment of a comprehensive baseline for benthic composition and coral demographics to determine the efficacy of management actions aimed at reducing anthropogenic impacts to the adjacent coral reef communities in each of the two management priority areas in American Samoa; i.e., Faga‘alu Bay, a U.S. Coral Reef Task Force (USCRTF) watershed priority site; and Vatia Bay, a Territorial and CRCP priority watershed.

Finally, to quantify the effectiveness of future management interventions, additional long-term monitoring of coral community structure and demographics will be needed for comparison with the baselines presented here. The overall effort required to evaluate the effectiveness of the interventions is significant and requires close coordination between local and federal efforts.

1.1. Background

Land-based sources of pollution (LBSP) represent one of the most persistent and detrimental human-induced threats to coral reef ecosystems in American Samoa and worldwide (Rodgers 1990; Fabricius 2005, Erftemeijer et al. 2012). Impacts from LBSP include sedimentation, turbidity, nutrients, toxicants, and pathogens from a variety of land-based activities that are transported in surface waters, runoff, groundwater seepage, or wind to the adjacent coral reefs. The synergistic effects of these pollutants can cause disease and partial mortality; inhibit coral growth, reproduction, and recruitment processes; and result in alterations to trophic dynamics and shifts in community structure and function (Vargas-Ángel et al. 2006; Moeller et al. 2016). The combination of sedimentation and turbidity are often acknowledged as one of the primary causes of coral reef degradation worldwide (Rodgers 1990) by directly reducing light quality and quantity or directly accumulating over the live corals and smothering tissues (Anthony and Fabricius 2000; Brown et al. 2002; Philip and Fabricius 2003). In addition, excessive influx of dissolved inorganic nutrients (e.g. nitrogen and/or phosphorus) from natural sources or sewage, waste water, and fertilizers promotes increased biomass of fleshy macroalgae. Macroalgae can have deleterious effects on corals by competing with juvenile and adult corals for space on the benthos (Chadwick and Morrow 2011; Fong and Paul 2011). In American Samoa and other U.S. Pacific Islands, many of these concerns are exacerbated by poor land use practices and inadequate waste water management, in addition to local meteorological conditions including elevated rainfall, highly erodible soils, and storm events such as tropical cyclones (EPA 2014).

1.1.1. Vatia Bay

In a process conducted between 2010 and 2012 and led by NOAA CRCP, Vatia watershed was identified as one of two priority watersheds in American Samoa based on biological value, degree of risk and threat, and management effectiveness. Jurisdictional managers have expressed concerns that LBSP from the village of Vatia are having an adverse effect on the coral reef ecosystem in the bay. Land-based contributions of nutrients come from a variety of sources. In Vatia, the most predictable sources are piggeries and septic systems. These contaminants enter the Bay via surface flow in streams or via ground water seepage. However, in addition to nutrient impacts, it is evident that sedimentation stress is also having an adverse effect on the coral reef at Vatia Bay.

1.1.2. Faga‘alu Bay

Parts of Faga’alu Bay have been historically affected by severe siltation stress due to excessive terrigenous runoff, resulting from prolonged and deficient land use practices. The Samoa Maritime rock quarry was found to be a major contributor to the episodic flux of sediments onto the adjacent reef. Local and Federal agencies (The National Fish and Wildlife Foundation, The American Samoa CRAG, the American Samoa Environmental Protection Agency, and NOAA CRCP) engaged in discussions to implement corrective actions at the quarry and reduce LBSP inputs to the coral reefs in Faga‘alu Bay. In Sept–Dec 2014, mitigation actions were implemented at the Samoa Maritime quarry, including the installation of drainage systems, alternative ground cover, and retention ponds (for a complete narrative see Holst et al. 2016). To assess the status and condition of the Faga‘alu reef, pre-intervention baseline data, including benthic cover and demographics, were collected in 2012–2013. These results are presented in Holst et al. (2016). To evaluate the status of the reef immediately after corrective actions were implemented but still too early to expect any meaningful change, a post-intervention baseline data for benthic community structure and demographics were collected in 2015. Herein we present the post-intervention baseline.

2. Methods

2.1 Sampling survey design

A two-stage stratified random sampling design was employed to survey the domain, which encompassed hard bottom reef habitat from 0 to 18 meters within Vatia Bay and Faga’alu Bay. The stratification scheme incorporated two depth categories: shallow (0–6 m) and mid-depth (>6–18 m), and two reef zones: forereef (Vatia and Fag‘alu) and backreef (Faga‘alu only) (Table 1).

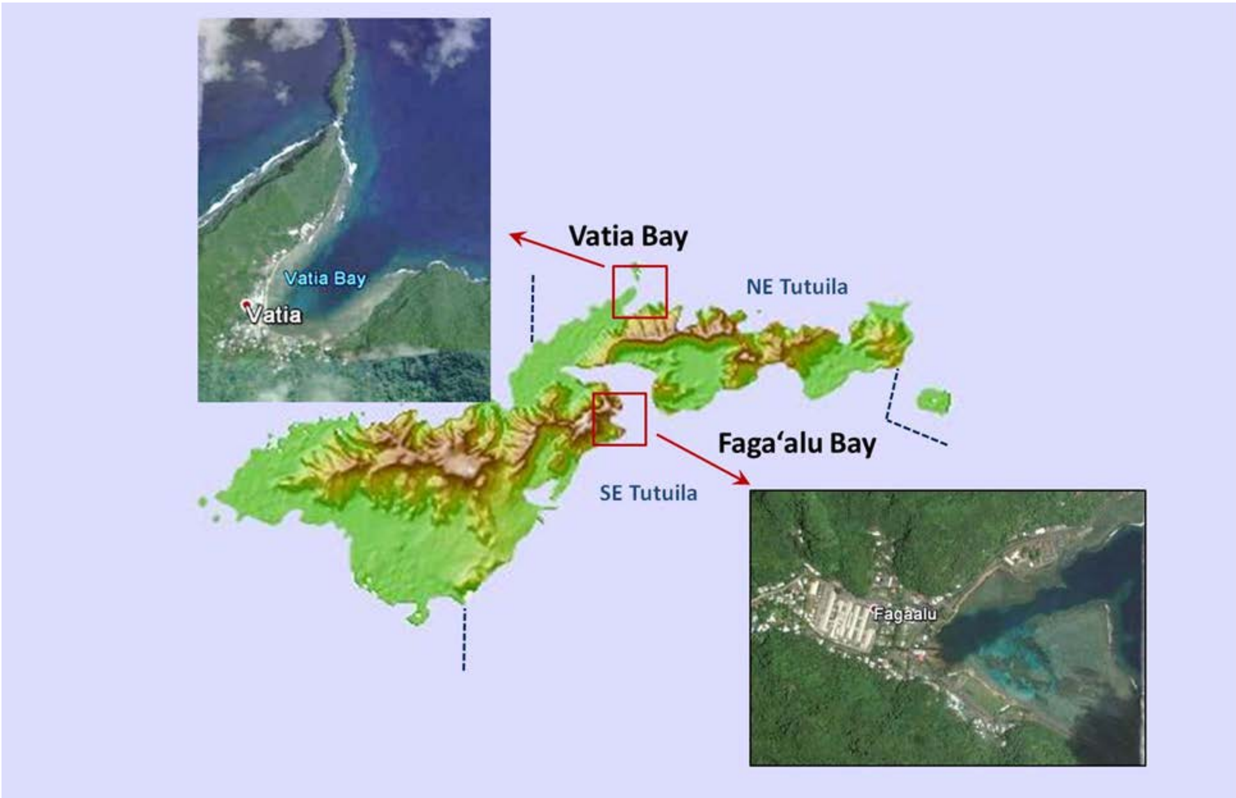

Figure 1. Map displaying the two sampling areas: Vatia Bay and Faga‘alu Bay, Tutuila, American Samoa. Dashed lines illustrate the boundaries between the north-east and south-east subregions, for which benthic cover and demographic data (derived from the 2015 Pacific Reef Assessment and Monitoring Program cruise in American Samoa) are provided for reference (see results section).

A geographic information system (GIS) and digital spatial databases of benthic habitats (NOAA National Centers for Coastal Ocean Science, reef zones, and bathymetry were used to facilitate spatial delineation of the sampling survey domain, strata, and sample units. Map resolution was such that the survey domain could be overlain by a grid using a GIS layer with 50 m by 50 m (2,500 m^2 in area) cells. A two-stage sampling scheme following Cochran (1977) was employed to control for spatial variation in population parameters at scales smaller than the 2,500 m^2 grid cell minimum mapping unit. Grid cells containing hard-bottom reef habitats were designated as primary sample units (referred to as sites), while the second-stage sample unit was defined as a diver visual belt transect of fixed area (10 m^2 or less).

The details of two-stage stratified random sampling design implementation for coral reefs are described specifically by Smith et al. (2011). Allocation of sampling effort was proportional to total strata area. Site locations (geographic coordinates) were randomly selected within each stratum. Estimates for strata are generated from site means and are weighted by strata area (Table 1; see Appendix 1 for a complete site metadata). Bay-wide estimates (means and totals) are calculated using weighted strata means.

This document reports domain-wide, strata-level, and site-level estimates of benthic percent cover, adult (≥ 5 cm max diameter) and juvenile (<5 cm max diameter) coral colony density (no. colonies m^{-2}) and abundance (total), partial mortality (mean percent old dead and mean percent recent dead), and the prevalence of diseases and bleaching (all severity types included; pale to white).

Table 1. Summary of benthic community structure and demographic surveys conducted at Vatia Bay and Faga'alu Bay, American Samoa.

Sampling Unit	Area (m^2)	Proportion	# of Surveys
VATIA BAY	389,360	1.00	18
Forereef shallow west	118,544	0.30	4
Forereef shallow east	75,916	0.20	5
Forereef mid-depth west	78,113	0.20	5
Forereef mid-depth east	116,785	0.30	4
FAGA'ALU BAY	229,659	1.00	18
Backreef north	33,519	0.15	3
Backreef south	54,628	0.24	4
Forereef shallow north	19,002	0.08	2
Forereef shallow south	49,614	0.22	3
Forereef mid-depth north	33,159	0.05	2
Forereef mid-depth south	54,628	0.27	4

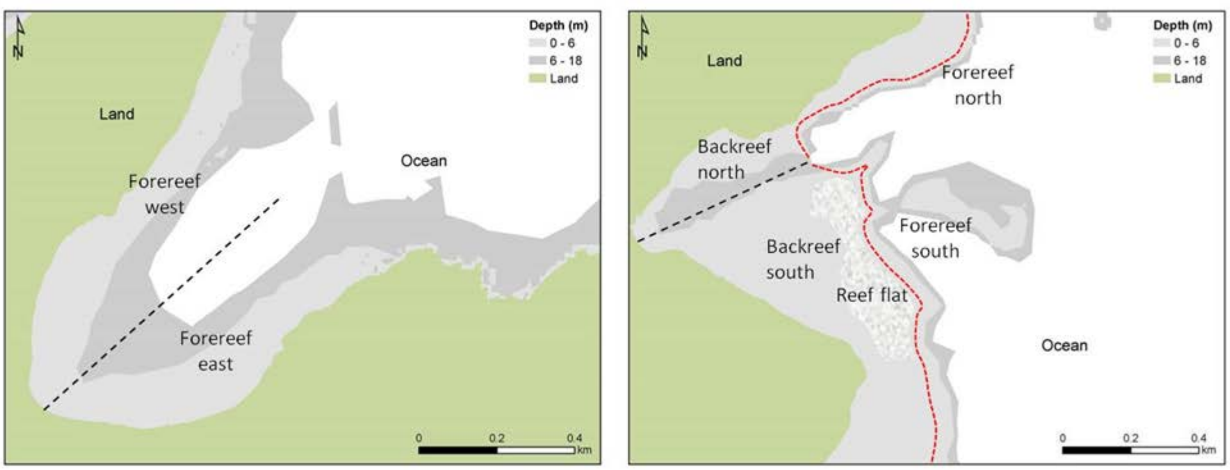

Figure 2. Maps illustrating the distribution and spatial coverage of the sample depth strata at each study area: Vatia Bay (left panel) and Faga'alu Bay (right panel). The strata are 0-6 m deep, 6-18 m deep, ocean, and land. The black dashed lines mark the sand channels that separate the east/west and north/south portions of the bays; the red dotted lines represent the boundary between the forereef and shallow backreef at Faga'alu Bay, and the hatched area illustrates the general location of the reef flat on Faga'alu reef.

2.2 Field protocols

At each site, two haphazardly laid, 18-m transects were the focal point of the surveys. Adult coral colonies were surveyed within four (1.0 × 2.5 m) segments in the following manner: 0–2.5 m (segment 1); 5.0–7.5m (segment 3); 10–12.5 m (segment 5); and 15–17.5 m (segment 7). All adult coral colonies (≥ 5 cm max diameter) whose center fell within 0.5 m on either side of each transect line were identified to the lowest taxonomic level possible (species or genus) and measured for size (maximum diameter to nearest cm). Morphology was also noted. Partial mortality was estimated as percent of the colony in terms of old dead and recent dead, and the cause of recent mortality was identified if possible. The condition of each colony, including disease and bleaching, was also noted along with the extent (percent of colony affected) and level of severity (range from moderate to acute). Finally, juvenile coral colonies (< 5 cm max diameter) were surveyed within three (1.0 × 1.0 m) segments (0–1.0 m; 5.0–6.0 m; and 10.0–11.0 m) along the same transects described above. Juvenile colonies were distinguished in the field from remnant fragments of adult colonies by the presence of a distinct tissue and skeletal boundary. Each juvenile colony was identified to lowest taxonomic level (species or genus) and measured for size by recording both the maximum and perpendicular diameter to the nearest 2 mm. Still photographs were collected to record the benthic community composition at predetermined points along the same 2 transect lines with a high-resolution digital camera mounted on a pole. Photographs were taken every 1 m from the 1 m to the 15 m mark. This work generates 30 photographs per site, which were later analyzed by CREP staff using the web-based software CoralNet. This analysis is the basis for estimating benthic cover and composition at each site.

2.3 Image analysis

Benthic habitat digital images were quantitatively analyzed using CoralNet (Beijbom et al. 2015), whereby 10 stratified random points were projected on each image and benthic elements directly underneath each point were identified to two levels of resolution, (i.e., functional group – 'Tier 2' or genera/functional group – 'Tier 3b') depending on image brightness, contrast, sharpness, and coloration levels. Tier 2 includes classifications such as hard coral differentiated into massive, branching, foliose, encrusting, etc.; macroalgae into upright macroalgae, encrusting macroalgae, bluegreen macroalgae, and *Halimeda*; etc.; sediment into sand and fine sediments Tier 3b includes more detailed classifications such as hard coral differentiated into *Acropora* branching, *Montipora* foliose, *Favia*, *Porites* massive, etc.; macroalgae into *Padina*, *Peysonnelia*, *Lobophora*, etc.; see Appendix 2 for classification category details). All images collected were analyzed unless any exhibited more than 5 combined points classified as Shadow or Unclassified, or more than 1 point was classified as Tape or Wand (including points in the water column), even after points were generated and overlaid three times. If this situation occurred, the image was discarded. Additionally, image analysis quality control was enforced by means of point-to-point, inter-observer calibration exercises that were conducted before image analysis was undertaken. Individual images were randomly assigned to analysts rather than randomizing analyst by site in order to prevent potential individual tendencies from influencing site-level estimates. Finally, to ensure consistency, methodological details pertaining to these standard operating procedures, classification tiers and categories, and definitions are continually maintained with revision histories on the NOAA wiki (https://www.st.nmfs.noaa.gov/confluence/display/CRED/Standard+Operating+Procedures; these can be provided upon request).

2.4 Data analysis

Site-level data were pooled and averaged to produce stratum- and domain-level means and standard errors. The Benthic Substrate Ratio (BSR) (Houk et al. 2010), which is the proportion of calcifying to non-calcifying organisms, was calculated based on values of mean benthic cover as follows: BSR = (hard coral cover + crustose coralline cover)/(macroalgal cover + turf algae cover). The BSR can be used as an indicator of the calcifying capacity of the benthic community. Values of 1 or greater indicate that the cover of calcifying corals + coralline algae (CCA) together is equal or greater than the cover of non-calcifying macroalgae + turf, suggesting a greater resilience potential and temporal persistence of the reef community compared to macroalgae and turf-dominated communities. As such, while the BSR can be used as a rough measure of "reef condition" (Houk et al. 2014), effective community resilience and temporal persistence depend on the frequency, magnitude, and severity of environmental disturbances and insults (Mumby et al. 2005).

One quick measure of reef condition that combines the percent cover of these benthic components is the benthic substrate ratio (BSR): the proportion of carbonate accreting organisms (corals + CCA) to non-carbonate accreting (macroalgae and turf algae). BSR values < 1 indicate dominance of non-calcifying organisms (i.e. more macroalgae + turf algae).

A non-metric multidimensional scaling (nMDS) ordination plot was assembled to visualize the multivariate similarity (or lack thereof) between survey sites based on site-level benthic cover of ecologically important benthic components; including coral (*Acropora* spp., *Astreopora* spp., *Montipora* spp., *Pocillopora* spp., and *Porites* spp.), crustose coralline algae (CCA), macroalgae, turf algae, and sediment (Table 2 and Table 4). A Bray-Curtis similarity matrix was assembled based on the fourth-root transformed data and subsequently an nMDS (1000 restarts) was computed. A separate hierarchal cluster analysis (complete linkage) was computed on the Bray-Curtis similarity matrix and overlaid on the nMDS plot to visualize groups of sites objectively defined by the cluster analysis based on their similarities. Finally, a multivariate, two-way crossed Analysis of Similarities (ANOSIM) was also computed on the Bray-Curtis similarity matrix for comparing the variation in the site-level species abundance and composition among sites grouped by depth (shallow vs mid-depth) and location (inner bay vs. outer bay) for Vatia Bay; and grouped by reef zone (forereef vs. backreef) and cardinal position (north vs south) for Fagaʻalu Bay. Both the nMDS ordination and ANOSIM analyses were conducted implementing PRIMER-E v.6. (Clarke and Gorley 2006).

Schematic representations are provided to illustrate the appraised overall condition of the coral reef communities based on the level of impact to land-based sources of pollution. While these are simplified interpretations of results, they are intended to serve a general tool to potentially guide management decisions.

3. Baseline values

3.1 Vatia Bay

There was considerable variation in the benthic composition across the forereef habitats in Vatia Bay, with overall higher levels of coral cover along the eastern shallow and mid-depth forereef (34.6% and 21.9%, respectively) compared to the west (22.7% and 16.3%) (Table 2, Figure 3). Comparatively, levels of CCA, fleshy macroalgae, and turf algae were not meaningfully different between the eastern and western sectors of the reef.). Although a few survey sites on the eastern side of Vatia bay had BSR > 1 (Figure 3d), none of the mean BSR values were ≥ 1 at the strata level. This condition is not unexpected on coral reefs impacted by LBSP, namely excessive terrigenous sedimentation, turbidity, and excess nutrients, which directly impair reef corals and favor the proliferation of non-calcifiers. The notion that nutrients are negatively affecting the reef at Vatia is illustrated by the high levels of macroalgal cover (>22%) along the mid-depth strata. Conversely, despite the expected elevated concentration of nutrients in Vatia, the higher light levels along the shallow strata are likely promoting the proliferation of corals and CCA compared to the mid-depth strata.

It was also noted that there were higher levels of fine sediment cover on the western forereef compared to the east (Table 2). A comparison with community structure in Vatia with reference values for NE Tutuila in general corroborate that macroalgal proliferation and increased sedimentation, in particular, are issues of concern for Vatia Bay (Table 2).

Table 2. Bay-wide and stratum-specific summary statistics (mean and std error) for five functional groups, five scleractinian genera, and two macroalgal taxa at Vatia Bay, derived from the analysis of benthic images acquired during surveys conducted in October–November 2015. Mean benthic cover estimates for north-east Tutuila, derived from the 2015 Pacific Reef Assessment and Monitoring Program cruise in American Samoa, are provided for reference.

	Vatia Bay (all strata)			Forereef shallow east		Forereef shallow west		Forereef mid-depth east		Forereef mid-depth west		NE Tutuila	
	MEAN	SE	%CV	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
BENTHIC COVER													
Hard coral	24.85	5.32	0.21	34.60	7.46	22.67	5.46	21.92	4.55	16.27	2.59	29.64	2.98
Coralline algae	7.20	3.40	0.47	6.93	1.77	11.83	5.68	2.17	1.85	5.53	3.92	9.92	1.47
Macroalgae	17.78	3.21	0.18	10.33	3.18	17.50	2.35	24.83	4.98	22.40	2.79	8.62	0.96
Turf algae	40.14	4.38	0.11	39.87	3.47	39.75	7.21	40.50	1.73	40.80	4.08	44.73	3.22
Sediment	6.51	3.71	0.57	3.20	1.90	5.58	4.84	8.17	4.91	11.33	3.52	2.25	0.58
Benthic substrate ratio	0.66	0.21	0.32	0.94	0.23	0.76	0.33	0.40	0.12	0.35	0.09	0.74	
CORAL GENERA													
Acropora spp.	1.65	0.74	0.45	2.93	1.38	2.08	0.77	0.08	0.08	0.60	0.37	-	-
***Astreopora* spp.**	0.01	0.01	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07	-	-
Monitpora spp.	8.89	4.07	0.46	14.33	4.59	9.58	5.06	6.42	4.47	2.00	1.32	-	-
Pocillopora spp.	0.35	0.19	0.56	0.60	0.19	0.25	0.25	0.25	0.16	0.20	0.13	-	-
Porites spp.	7.63	3.11	0.41	7.60	3.32	4.25	2.27	10.50	3.67	10.00	3.52	-	-
MACROALGAE													
Halimeda spp.	4.82	1.35	0.28	2.60	0.84	3.17	1.70	4.50	1.62	11.13	1.30	-	-
Encrusting macroalgae	4.25	1.30	0.31	1.93	0.63	6.00	1.16	3.67	1.99	5.67	1.86	-	-

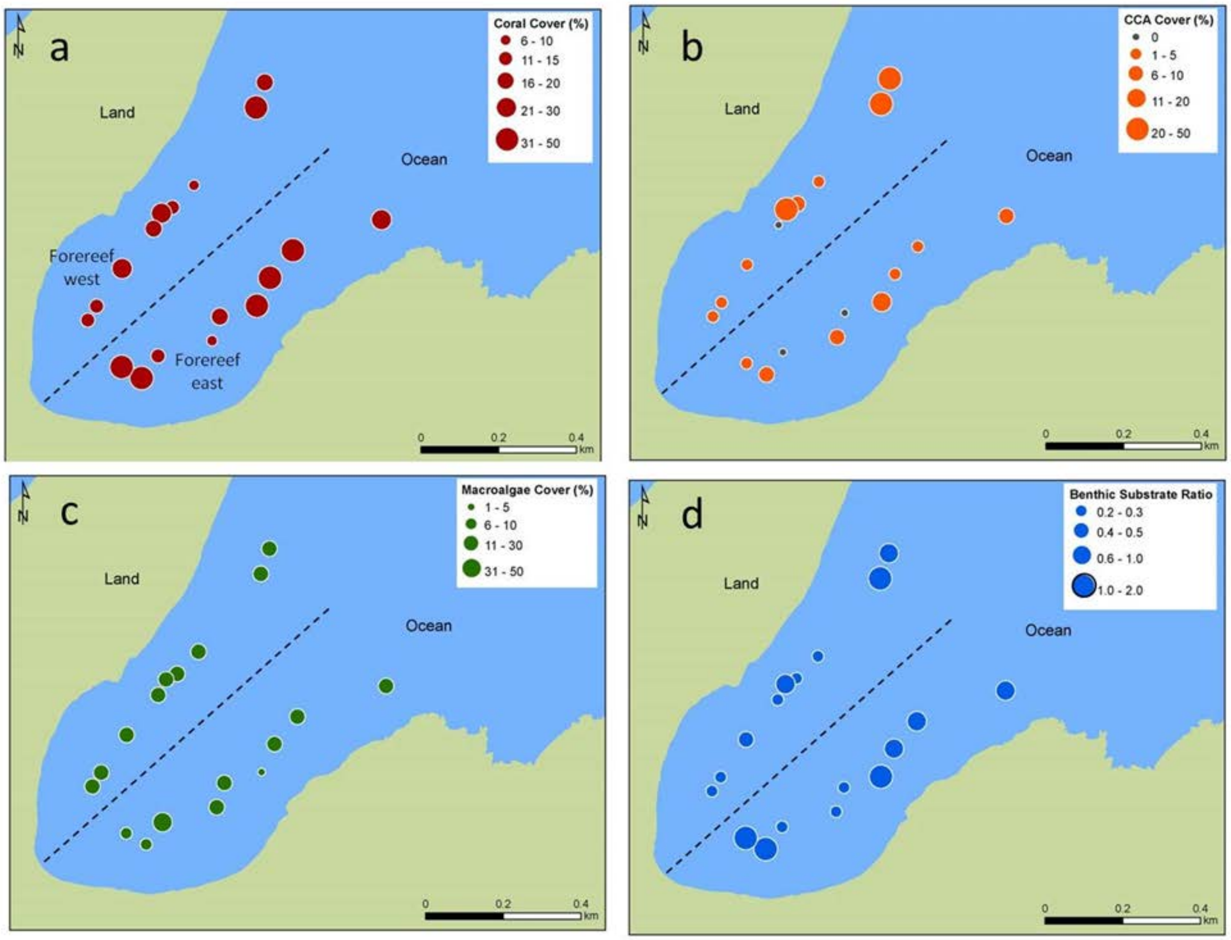

Figure 3. Spatial comparison of mean cover (%) values for (a) live hard coral, (b) crustose coralline algae (CCA), (c) macroalgae, and (d) the benthic substrate ratio (mean cover of calcifying organisms (i.e., corals + crustose coralline algae) divided by mean cover of non-accreting organisms (i.e., macroalgae + turf); the lower the ratio the higher the abundance of algae) at Vatia Bay, derived from the analysis of benthic images acquired during surveys conducted in Oct-Nov 2015. The black dashed line separates the east and west bay sectors.

In addition to the perspective of the east versus west sides of the bay, it is also useful to compare the inner versus outer regions of the bay, since the innermost regions may be more influenced by LBSP due to their proximity to the sources. Illustrated in Figure 4, the nMDS plot shows relative multivariate similarity among sites, with an overlay of groups objectively defined by their similarity in a separate cluster analysis (see methods for details). Figure 4 indicates that the overall benthic composition of the inner bay, mid-depth sites (Group 1) was distinct from the composition in other habitats. Inner bay, mid-depth sites were characterized by higher cover of macroalgae and turf algae. Group 2 was more heterogeneous with respect to habitat, including 2 of the 4 mid-depth, outer bay sites; and 4 of the 7 shallow, inner bay sites. Four out of 5 sites in Group 3 were shallow sites. Interestingly, sites TUT-2140, TUT-2155, and TUT-2156 (see Appendix 1), which are mid-depth sites located in the outer bay, were projected in the nMDS among the shallow sites (Fig 4), likely because these three mid-depth sites exhibited higher coral and CCA cover compared to the Group 1 sites.

Despite some overlap in the visual representation of the data presented by the nMDS, a two-way crossed Analysis of Similarities (ANOSIM) found significant segregation between groups based on habitat. The analysis therefore provides statistical evidence of measurable ecological differences between the shallow and mid-depth sites, as well as between the inner and outer benthic communities ($R = 0.55$, $P<0.001$; $R = 0.66$, $P<0.001$, respectively). These ecological differences are not unexpected and suggest that the inner bay, mid-depth sites appear to be more severely affected by LBSP than shallow or outer bay sites. As such, inner bay and deeper strata coral communities at Vatia Bay are exposed to lower light levels (high turbidity) and higher levels of terrigenous sedimentation compared to shallow-dwelling and outer bay corals.

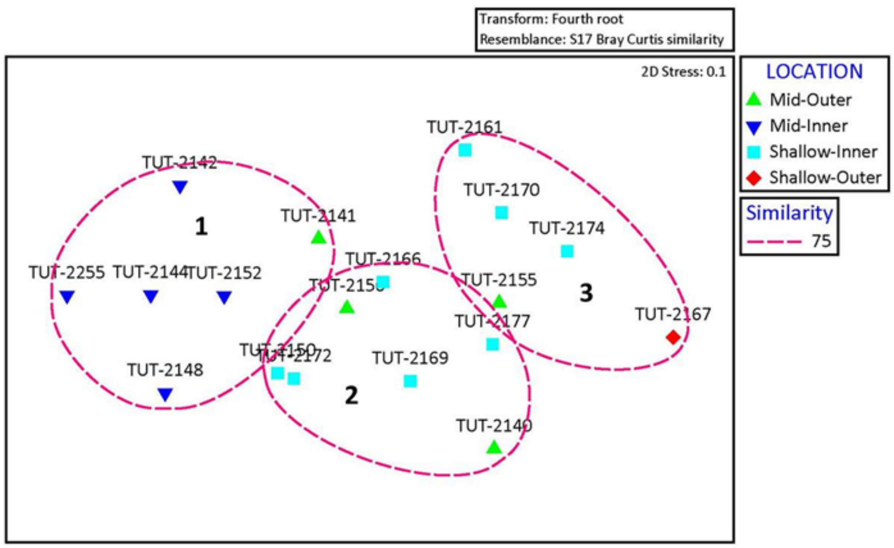

Figure 4. Multi-dimensional scaling plot illustrating the ecological difference between study groups based on benthic cover features: coral, CCA, macroalgae, and turf algae cover, in Vatia Bay, American Samoa.

If sediments are impacting corals at Vatia Bay, we would expect a number of outcomes from coral demographic surveys. Areas with more sediment may have (1) lower adult density, (2) lower juvenile coral density, (3) greater percent old mortality, and (4) greater percent recent mortality (Figure 5). As shown in Table 2, sediment cover was greater on deeper than shallower strata, and on the west versus east side of the bay within depth strata. For comparisons of shallow versus mid-depth habitats, results are consistent with expectations associated with higher sedimentation (lower coral density and higher old mortality in mid-depth strata, Table 3), though other factors may contribute to this pattern as well. Recent colony mortality, which included acute and sub-acute tissue loss and predation, was greater on the mid-depth strata compared to the shallow as well.

Patterns are less consistent in the west than the east side of the bay. Juvenile colony density on the western mid-depth fore-reef was threefold greater compared to the eastern mid-depth fore-reef (3.1 col/m2 and 0.9 col/m2, respectively), which is contrary to expectations. Differences between juvenile colony density in the western and eastern shallow forereef strata appeared to be relatively minor (4.0 col/m2 and 3.5 col/m2, respectively). Similarly, no meaningful differences in old partial mortality were apparent between west and east shallow forereef strata (6.3% and 6.2%, respectively) despite the difference in sediment cover (5.6% and 3.2%, respectively). Conversely, old partial mortality was over two-fold greater on the western mid-depth fore-reef compared to the eastern mid-depth forereef

(14.0% and 6.8%, respectively), which is consistent with expectations of sedimentation effects. Recent mortality was slightly greater within the mid-depth stratum on the west compared to the east. Sediment cover at mid-depth sites was 11.3% on the west and 8.2% on the east. It is likely that wind-driven surface water motion has an effect on the distribution and settlement of terrigenous sediments in the bay, which in turn may affect some demographic patterns. While formal studies of water circulation patterns have not been conducter in Vatia, the western shallows likely benefit from greater water motion from swells generated by prevailing winds. This water motion may frequently resuspend sediments in shallower waters, thereby preventing deleterious effects from sediment depostion and smothering. Deeper, more quiescent waters would have less water motion, which may explain the higher mortality in these zones.

Coral bleaching and other lesions had relatively low occurrence, with mainly background levels (<3%) across all strata. Interestingly, except for recent mortality, coral demographic measures (e.g., colony densities (adults and juveniles) and partial mortality) did not differ widely between Vatia Bay as a whole and NE Tutuila (Table 3). No meaningful site ordination was obtained when an nMDS plot was computed using demographic data (i.e., colony densities, partial mortality, disease, and bleaching).

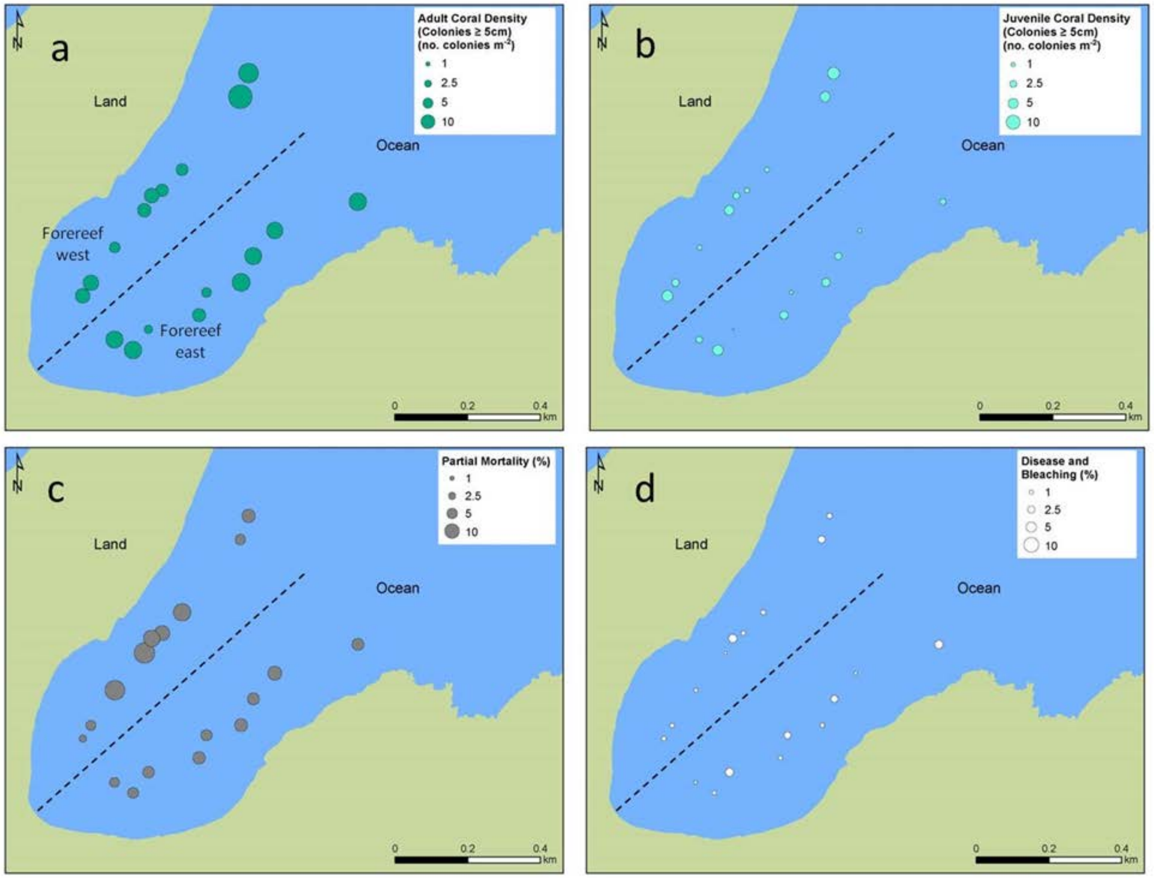

Figure 5. Spatial comparison of site-specific values for (a) adult colony densities, (b) juvenile colony densities, (c) old partial mortality, and (d) coral disease at Vatia Bay, derived from belt-transect surveys conducted in October–November 2015.

Table 3. Bay-wide and stratum-specific summary statistics (mean and ± std error) for adult and juvenile coral colony density, colony partial mortality (old and recent), and condition (disease and bleaching) for total scleractinians at Vatia Bay, derived from baseline assessments conducted in Oct-Nov 2015. Mean demographic estimates for north-east Tutuila, derived from the 2015 Pacific Reef Assessment and Monitoring Program cruise in American Samoa, are provided for reference.

	Vatia Bay (all strata)			Forereef Shallow East		Forereef Shallow west		Forereef Mid-depth east		Forereef Mid-depth west		NE Tutuila (all strata)	
	MEAN	SE	%CV	MEAN	se	MEAN	SE	MEAN	se	MEAN	SE	MEAN	SE
DEMOGRAPHICS													
Density - Adults	12.66	2.72	0.21	14.06	1.30	15.23	4.07	9.89	2.46	9.89	2.46	11.29	1.74
Density - Juveniles	3.04	0.75	0.25	3.47	0.57	4.00	0.88	0.92	0.39	3.06	1.19	2.65	1.74
Old mortality	7.91	1.43	0.18	6.34	0.63	6.23	2.22	6.84	0.75	14.04	2.12	7.85	0.60
Recent mortality	1.64	0.61	0.37	0.72	0.19	0.34	0.07	2.69	1.28	3.98	1.42	0.26	0.19
Disease & Lesions	0.40	0.17	0.42	0.29	0.22	0.41	0.14	0.87	0.24	0.07	0.07	0.82	0.25
Bleaching	1.67	0.61	0.36	1.18	0.56	2.10	0.85	2.22	0.69	1.21	0.20		

3.1.1 Vatia Bay Survey Outlook:

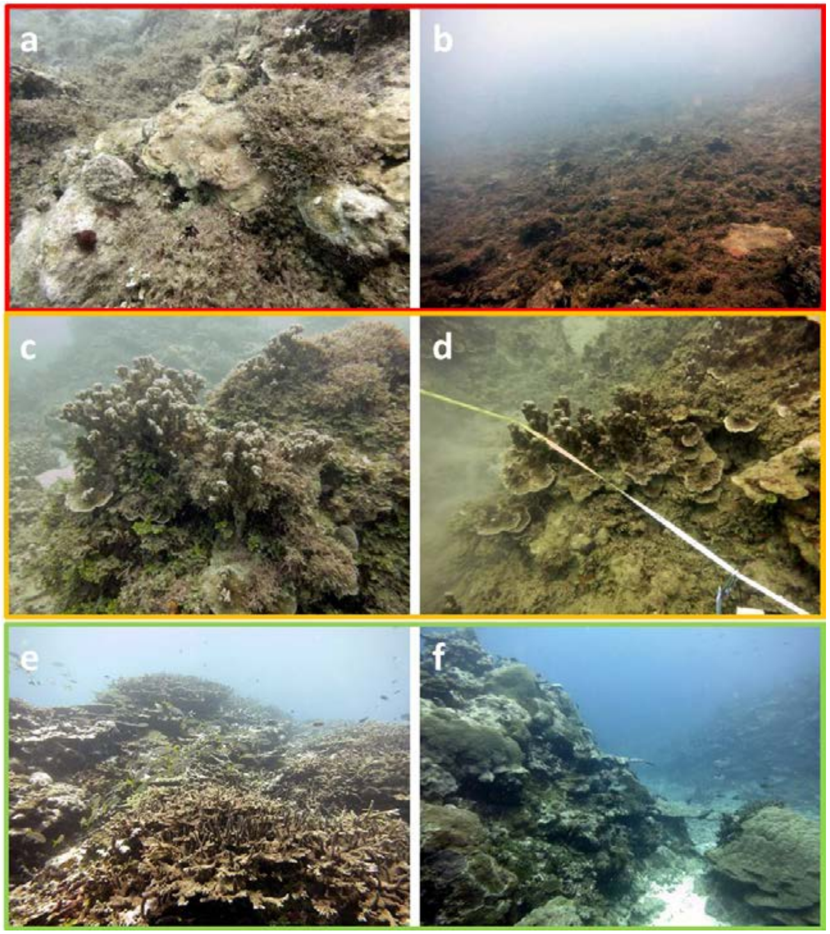

Figure 6. Visual comparison of the overall coral community condition across the gradient of land-based sources of pollution impacts, on the mid-depth strata. NOAA photo credit: Brett Schumacher and Bernardo Vargas-Ángel.

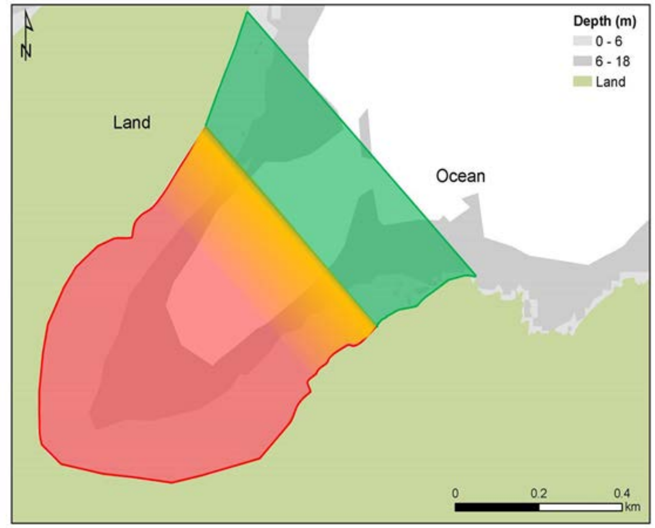

Figure 7. Schematic representation illustrating the overall appraised condition of the mid-depth coral reef community at Vatia Bay, based on the level of impact from land-based sources of pollution

- **Alert:** Inner Bay (4–6 m). Very poor reef condition with severe damage. Reef community dominated by fleshy macroalgae; very low coral cover.
- **Concern:** Middle Bay (~5–10 m). Poor to fair condition; considerable to moderate damage. Reef community dominated by plating/branching corals (*Porites rus*) intermingled with patches of sediment and calcifying macroalgae
- **Low concern:** Outer Bay (10–15 m): Fair to good condition; minor damage. Robust coral reef development; community characterized by diverse assemblage of corals with low levels of macroalgae

3.1.2 Vatia Bay Survey Overview:

1. Excess influx of organic nutrients resulting from inadequate waste water management, piggeries, and septic systems are believed to be the main sources of LBSP to corals in Vatia Bay.
2. Baseline surveys indicate that increased water turbidity and terrigenous sedimentation (likely from runoff due to poor land use practices) are also important sources of impact to corals at Vatia Bay.
3. Vatia Bay is a relatively small and enclosed body of water; it is likely that the wind-driven surface water motion has an effect on the distribution, residence time, and settlement of terrigenous sediments in the bay.
4. The most evident signs of LBSP impacts to the coral reef community are observable along both the eastern and western inner bay portions of the forereef, at depths ranging between 5 and 10 m.
5. There are measurable ecological differences in the benthic community composition and structure that relate to LBSP impacts:
   - Shallow vs. mid-depth: Overall, higher coral and CCA cover and lower macroalgal turf, and sediment cover on shallow compared to mid-depth strata. Also, higher partial mortality on mid-depth stratum compared to the shallow, particularly on the west side of the bay.
   - Inner bay vs outer bay: Gradient of increasing coral and CCA cover and decreasing macroalgae and turf algae cover from inner outer bay ; most evident in the mid-depth stratum.
6. While coral colony densities (adults and juveniles) and partial mortality did not differ substantially between Vatia Bay and NE Tutuila, relatively healthy reef in the outer bay may mask the more impacted inner bay when it is viewed as a whole. Benthic cover metrics corroborate that macroalgal proliferation and increased sedimentation are issues of concern for Vatia Bay.
7. Higher levels of sediment cover measured on the western mid-depth forereef could be a factor in the increased partial mortality measured on that stratum.

3.2 Faga‘alu Bay

As indicated in the prior baseline survey (Holst et al. 2016), Faga‘alu Bay exhibits an observable gradient of LBSP coral community deterioration from the inner bay to the outer bay, as well as from the north to the south. Coral cover is conspicuously low on the northern backreef, and to a lesser extent on the northern forereef (Fig 7, Table 4); the areas directly impacted by terrigenous runoff. Contrastingly, small pockets of moderately high coral cover occur along the southern backreef and the shallow southern forereef. These areas are visibly less impacted by turbidity and sedimentation stress as they are routinely flushed with clear, clean waters coming from the south during the incoming tides. The southern mid-depth forereef also exhibits relatively low coral development. This latter stratum is unquestionably impacted by pollution originating from Pago Harbor (EPA 2014); therefore, structural and demographic spatial patterns within may be in part driven by the influence of Pago Harbor water quality.

Low coral cover, high levels of turf algae and sediment cover, and the resulting low proportion of reef-building organisms (coral + CCA) to non-reef building (macroalgae + turf algae) exemplify the main structural differences between the northern, sediment-impacted areas and the less-impacted south. A comparison with community structural reference values for SE Tutuila indicate that while hard coral and CCA cover are comparable with Faga‘alu Bay, there is a greater proportion of macroalgae to turf cover in Faga‘alu Bay compared to SE Tutuila, particularly along the forereef strata (Figure 8, Table 4).

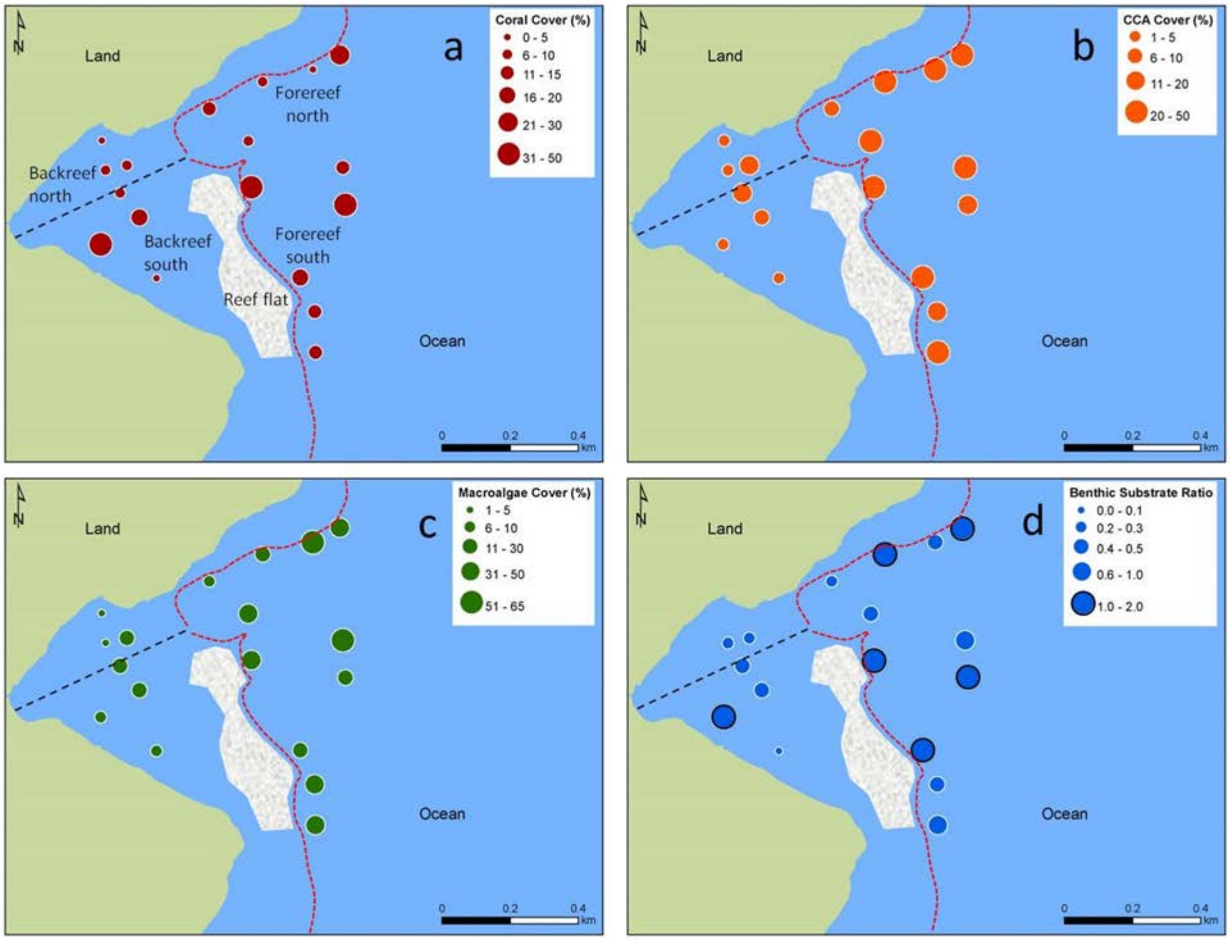

Figure 8. Spatial comparison of mean cover (%) values for (a) live hard corals, (b) crustose coralline algae (CCA), (c) macroalgae, and (d) the benthic substrate ratio (mean cover of calcifying organisms, i.e., corals + crustose coralline algae divided by mean cover of non-accreting organisms, i.e., macroalgae + turf) at Faga'alu Bay, derived from the analysis of benthic images acquired during surveys conducted in Oct-Nov 2015. The black dashed line separates the north and south sectors of the bay; the red dotted line represents the boundary between the forereef and the shallow backreef. The shallow reef flat, emergent during low tide (hatched area) is illustrated for reference.

Table 4. Bay-wide and stratum-specific estimates of benthic cover for five functional groups, five scleractinian genera, and two macroalgal taxa at Faga'alu Bay, derived from the analysis of benthic images acquired during surveys conducted in October–November 2015. Mean benthic cover estimates for south-east Tutuila derived from the 2015 Pacific Reef Assessment and Monitoring Program cruise in American Samoa are provided for reference.

	Faga'alu Bay (all strata)			Forereef shallow north		Forereef shallow south		Forereef mid-depth north		Forereef mid-depth south		Backreef north		Backreef south		SE Tutuila* (all strata)	
	MEAN	**SE**	**%CV**	**MEAN**	**SE**	**MEAN**	**SE**	**MEAN**	**SE**	**MEAN**	**SE**	**MEAN**	**SE**	**MEAN**	**SE**	**MEAN**	**SE**
BENTNIC COVER																	
Hard coral	15.93	7.08	0.44	16.83	11.17	23.67	8.62	7.50	3.17	15.92	6.09	4.67	2.17	17.33	9.21	17.13	1.57
Coralline algae	17.54	4.10	0.22	40.67	8.67	25.89	6.70	14.67	7.67	21.25	1.76	5.11	2.95	6.00	2.71	17.34	1.45
Macroalgae	27.31	7.04	0.26	24.00	6.33	29.89	10.39	34.83	26.17	47.33	5.37	6.33	3.75	15.00	3.97	16.82	1.60
Turf algae	32.26	7.55	0.23	13.33	8.33	14.44	5.14	29.00	21.67	12.42	3.53	73.11	7.80	52.83	10.75	41.71	2.93
Sediment	1.92	0.99	0.52	0.00	0.00	0.00	0.00	5.17	5.17	0.00	0.00	5.89	2.89	3.33	1.28	0.71	0.19
Benthic Substrate Ratio	0.71	0.19	0.27	1.55	0.15	1.20	0.28	0.34	0.05	0.69	0.22	0.13	0.06	0.43	0.21	0.60	
CORAL GENERA																	
Acropora spp.	1.59	0.90	0.56	2.67	2.67	2.67	0.69	0.00	0.00	0.75	0.28	0.00	0.00	2.50	1.89		
Astreopora spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Monitpora spp.	1.69	0.70	0.41	3.17	2.17	3.56	1.93	0.33	0.33	2.33	0.24	0.00	0.00	0.08	0.08		
Pocillopora spp.	0.98	0.45	0.46	2.83	2.50	2.78	0.78	0.00	0.00	0.33	0.14	0.22	0.11	0.08	0.08		
Porites spp.	3.29	1.94	0.59	1.67	0.00	1.56	0.78	0.17	0.17	0.00	0.00	2.56	1.37	10.25	6.57		
MACROALGAE																	
Halimeda spp.	0.06	0.06	1.00	0.00	0.00	0.00	0.00	0.17	0.17	0.08	0.08	0.22	0.22	0.00	0.00		
Encrusting macroalgae	23.29	5.990	0.25	23.83	6.17	29.78	10.30	34.67	26.33	44.67	4.97	2.00	0.88	3.92	1.49		

Illustrated in Fig. 9 are the results of the nMDS ordination plot using the benthic cover data for Faga‘alu Bay, showing the relative multivariate similarity among sites, with an overlay of groups objectively defined by their similarity in a separate cluster analysis. As such, the nMDS plot indicates that overall the benthic composition was distinct between reef zones (forereef vs. backreef) and, to a lesser degree, cardinal position (north vs. south), with sites clustering in four main groups based on their measured similarities. Groups 1 and 2 contain forereef sites only, which are characterized by high cover of coralline algae and encrusting macroalgae (*Peyssonnelia*). While group 1 is fairly uniform in its composition (mainly forereef south sites), group 2 is split between forereef north and forereef south sites. Correspondingly, Groups 3 and 4 include mostly backreef sites and are characterized by higher cover of turf algae, sediments, and overall greater cover of the coral *Porites* (particularly the southern backreef). In this case, group 3 is fairly uniform in its composition (mainly backreef south sites), and group 4 is split between forereef and backreef sites, as well as north and south sites. This suggests that although the sediment-impacted north reef is relatively distinct from the less impacted south, the distinction between backreef north and forereef north is not that clear. All north reef sites in group 4 were characterized by high levels of turf algal (range: 50.6–84.0%) and sediment cover (range: 5.7–11.0%); the high levels of turf algal cover (84.0%) grouped backreef south site TUT-2243 with the north reef sites. Additionally, the two-way crossed Analysis of Similarities (ANOSIM) supported the above-mentioned segregation, providing formal statistical evidence of measurable strong ecological differences between the forereef vs. backreef sites and, to a lesser extent, between the northern and southern bay communities ($R = 0.90$; $P<0.001$; $R = 0.34$, $P<0.01$; respectively). The ordination plot also illustrates how the similarity between Groups 1 and 2 (forereef sites) is greater than between Groups 3 and 4 (backreef sites), which underpins the overall differences between the sediment-impacted north backreef and the less-impacted south. These findings also corroborate the trends reported during baseline pre-construction baseline assessment conducted in 2012 and 2013 (Holst et al. 2016).

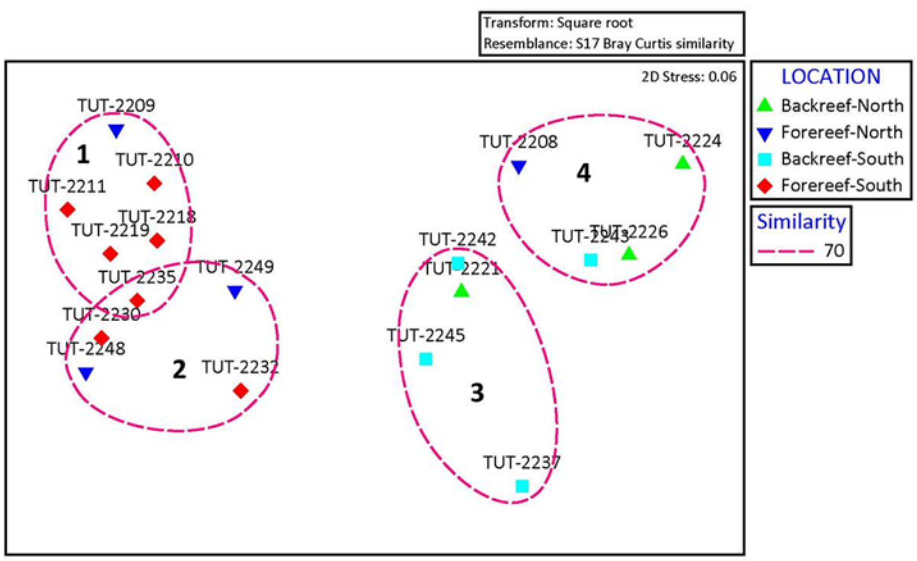

Figure 9. Non-metric multi-dimensional scaling plot illustrating the ecological difference between survey sites based on benthic cover features; namely, coral, CCA, macroalgae, and turfalgae cover, in Faga‘alu Bay, American Samoa.

Coral demographic metrics at Faga'alu Bay also showed considerable variation between the sediment-impacted north sectors and the less-impacted south, as well as between the backreef and the forereef (Fig 8, Table 5). Essentially, adult colony densities were lower on the northern forereef strata compared to the southern counterpart (8.38 col/m2 and 14.34 col/m2, respectively). Colony partial mortality, both recent and old, were greater on the northern forereef compared to the south (15.4% and 8.78%, respectively). These findings are in line with the observed gradient of LBSP impacts on the reef, which is corroborated by the benthic cover trends reported herein, as well as the benthic structure and population patterns reported for the pre-construction baseline assessment (Holst et al. 2016; NOAA unpublished data).

Contrastingly, colony densities (adult and juvenile) and partial mortality did not differ substantially between the northern and southern sectors of the backreef (Figure 10, Table 6). While these findings are somewhat unexpected considering the differing levels of sedimentation stress each of the two areas is subject to, they are consistent with the results obtained during the pre-construction baseline assessment (Holst et al. 2016). Only recent colony mortality differed between the two stata, with the northern backreef being more than two-fold greater, compared to the south.

Comparing reefs of Faga'alu Bay as a whole to coral demographic reference values for SE Tutuila indicates that adult and juvenile colony density is similar. Notwithstanding this result, higher values were recorded for colony partial mortality (old and recent), as well as disease, in Faga'alu Bay compared to SE Tutuila; levels of disease and recent mortality were over two-fold greater in Faga'alu Bay (Table 5). These findings suggest that even if the density of coral in Faga'alu Bay is similar to that found in other reefs in the region, these corals are generally less healthy.

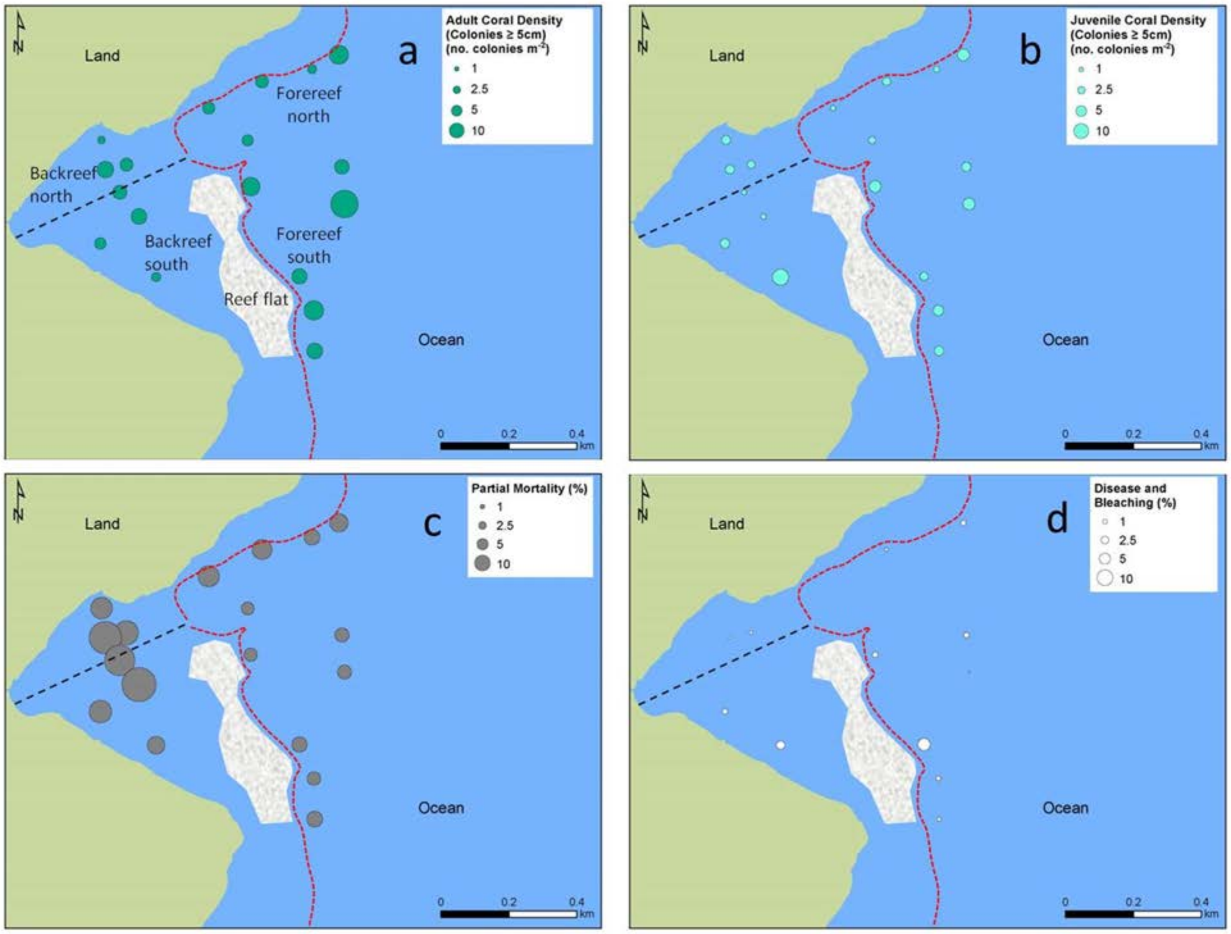

Figure 10. Spatial comparison of site specific values for: (a) adult colony densities, (b) juvenile colony densities, (c) partial mortality, and (d) coral disease at Faga'alu Bay, derived from belt-transect surveys conducted in October–November 2015. The black dashed line separates the north and south sectors of the bay; the red dotted line represents the boundary between the forereef and the shallow backreef. The shallow reef flat, emergent during low tide (hatched area) is illustrated for reference.

Table 5. Bay wide and stratum-specific estimates of juvenile and adult coral density and colony partial mortality (old and recent) for total scleractinians at Fagaʻalu Bay, from baseline assessments conducted in October–November 2015. Mean demographic estimates for southeast Tutuila derived from the 2015 Pacific Reef Assessment and Monitoring Program cruise in American Samoa are provided for reference.

	Fagaʻalu Bay(all strata)			Forereef Shallow north		Forereef Shallow south		Forereef Mid-depth north		Forereef Mid-depth south		Backreef north		Backreef south		SE Tutuila*	
	MEAN	**SE**	**%CV**	**MEAN**	**SE**	**MEAN**	**SE**	**MEAN**	**SE**	**MEAN**	**SE**	**MEAN**	**SE**	**MEAN**	**SE**	**MEAN**	**SE**
DEMOGRAPHY																	
Density - Adults	11.02	3.47	0.32	11.58	4.18	17.99	7.41	5.18	1.63	11.61	2.59	7.31	2.59	7.38	1.59	10.17	2.74
Density - Juveniles	4.04	1.16	0.29	4.67	1.67	4.27	0.93	1.50	0.17	4.25	0.73	3.26	0.30	4.43	2.40	3.53	0.75
Old mortality	17.01	3.40	0.20	14.69	1.19	9.17	0.49	14.17	4.33	7.41	0.34	28.14	7.00	29.43	7.84	12.86	3.63
Recent mortality	1.71	0.63	0.37	0.66	0.23	0.43	0.19	1.27	0.26	0.76	0.23	5.10	2.16	2.31	0.79	0.79	0.36
Disease	1.02	0.78	0.76	0.50	0.18	2.74	2.18	0.00	0.00	0.28	0.16	0.23	0.23	1.19	0.93	0.50	0.39
Bleaching	0.42	0.29	0.70	0.63	0.63	0.36	0.36	0.00	0.00	0.80	0.33	0.16	0.16	0.21	0.21		

3.2.1 Faga‘alu Bay Survey Outlook

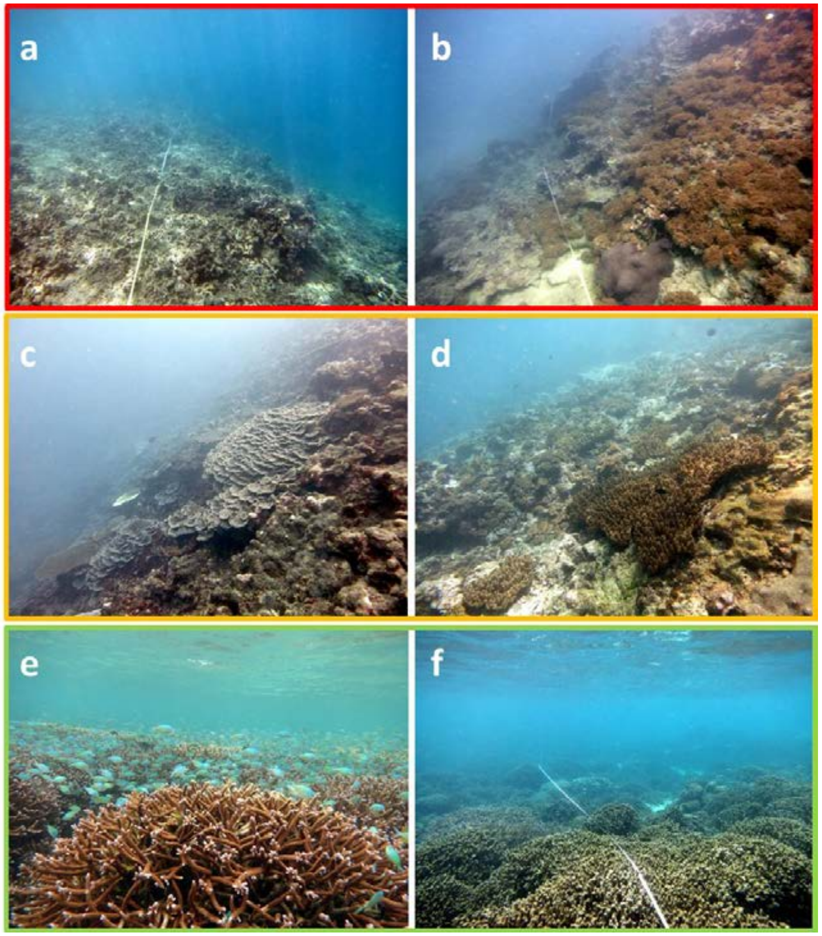

Figure 11. Visual comparison of the overall coral community condition across the gradient of land-based sources of pollution impacts, on the forereef (a-d) and backreef (e-f). NOAA photo credit: Brett Schumacher and Bernardo Vargas-Ángel.

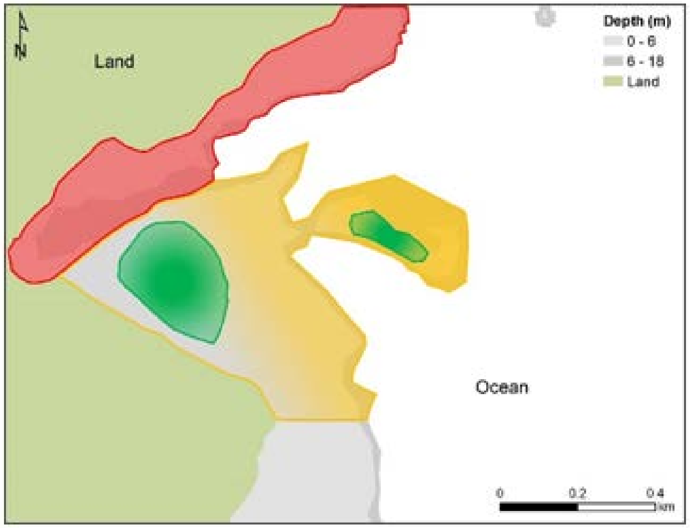

Figure 12. Schematic figure illustrating the appraised overall condition of the coral reef community at Faga‘alu Bay, based on the level of impact to land-based sources of pollution

- **Alert**: North backreef and forereef (2–15 m). Very poor reef condition with severe damage. Very low coral cover; particularly the shallow back reef.
- **Concern:** Widespread; all reef zones (2–15 m). Poor to fair condition; considerable to moderate damage. Modest to low coral cover; forereef communities dominated by coralline algae and encrusting red macroalgae (*Peyssonnelia*). Reef flat mainly covered by coral rubble.
- **Low concern:** Southern shallow forereef and back reef (2–6 m). Fair to good condition; minor damage. Highest levels of coral cover in the bay; backreef dominated by branching *Porites*; shallow forereef dominated by *Acropora* and *Pocillopora.*

3.2.2 Faga‘alu Bay Survey Overview:

1. The reef in Faga’alu Bay has been chronically impacted by excessive turbidity and sedimentation derived from the rock quarry located above the village of Faga‘alu.
2. By the end of 2014, mitigation actions were completed at the rock quarry to reduce the sediment transport away from the quarry grounds and into the stream during heavy rainfall conditions. A pre-construction baseline assessment was completed in 2012–2013. The survey data presented herein represent the first assessment since the mitigation actions were completed.
3. Measurable ecological differences between strata indicate that coral cover is conspicuously low on the northern backreef and shallow forereef and, to a lesser extent, on the mid-depth northern forereef; these areas are directly impacted by LBSP (sedimentation and turbidity). Turf algae proliferation, higher sediment cover, and an overall low proportion of calcifying organisms (coral + CCA) to non calcifiers (macroalgae + turf algae) typify these sediment-impacted strata. These structural differences are corroborated by the benthic substrate ratio.
4. Coral colony densities (adults and juveniles) and partial mortality did not differ substantially between the northern and southern backreef strata. While these findings are unexpected based on the differing levels of sedimentation impact at each sector, they are consistent with the results obtained during the 2012–2013 pre-construction baseline assessment.
5. Recent colony mortality was more than two-fold higher on the northern backreef compared to the south. The higher levels of sediment cover measured on the northern backreef could be implicated in the increased recent partial mortality measured on that stratum.
6. Additional LBSP impacts originating from Pago Harbor are presumed to affect the forereef communities at Faga‘alu, characterized by moderately low coral cover and dominated by crustose coralline algae and encrusting red macroalgae.
7. Structural and demographic differences between Faga‘alu Bay (all strata) and SE Tutuila include: higher macroalgal and sediment cover, lower turf algal cover, and greater levels of partial mortality (old and recent) and disease. These differences provide evidence of the impacts that LBSP are having on the benthic communities in Faga‘alu Bay.

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5. Appendices

Table A1.1 -Vatia survey site metadata.

	Site	Site Latitude	Site Longitude	Date	Min Depth (ft)	Max Depth (ft)	Reef Zone	Cardinal direction	Depth Category
Vatia	TUT-2150	-14.2484	-170.67383	4-Nov-15	13	20	Forereef	East	Shallow
Vatia	TUT-2161	-14.24625	-170.67233	3-Nov-15	13	19	Forereef	East	Shallow
Vatia	TUT-2166	-14.24872	-170.67403	3-Nov-15	13	20	Forereef	East	Shallow
Vatia	TUT-2167	-14.24381	-170.67014	12-Nov-15	15	20	Forereef	East	Shallow
Vatia	TUT-2169	-14.24774	-170.66982	12-Nov-15	15	21	Forereef	West	Shallow
Vatia	TUT-2170	-14.24839	-170.67012	5-Nov-15	3	13	Forereef	West	Shallow
Vatia	TUT-2172	-14.2492	-170.67116	5-Nov-15	10	14	Forereef	West	Shallow
Vatia	TUT-2174	-14.25006	-170.67279	5-Nov-15	3	8	Forereef	West	Shallow
Vatia	TUT-2177	-14.2498	-170.67325	12-Nov-15	7	13	Forereef	West	Shallow
Vatia	TUT-2140	-14.2464	-170.66724	4-Nov-15	35	44	Forereef	West	Mid
Vatia	TUT-2141	-14.24711	-170.66929	2-Nov-15	37	46	Forereef	West	Mid
Vatia	TUT-2142	-14.24955	-170.67241	2-Nov-15	24	33	Forereef	West	Mid
Vatia	TUT-2144	-14.24864	-170.67098	2-Nov-15	33	44	Forereef	West	Mid
Vatia	TUT-2148	-14.24561	-170.67158	3-Nov-15	36	48	Forereef	East	Mid
Vatia	TUT-2152	-14.24753	-170.67324	3-Nov-15	26	36	Forereef	East	Mid
Vatia	TUT-2155	-14.24323	-170.66994	6-Nov-15	36	45	Forereef	East	Mid
Vatia	TUT-2156	-14.24612	-170.67207	4-Nov-15	25	36	Forereef	East	Mid
Vatia	TUT-2255	-14.24661	-170.67251	6-Nov-15	35	42	Forereef	East	Mid

Table A1.2 -Faga‘alu survey site metadata.

Location	Site	Site Latitude	Site Longitude	Date	Min Depth (ft)	Max Depth (ft)	Reef Zone	Cardinal direction	Depth Category
Faga'alu	TUT-2221	-14.28985	-170.6799	10-Nov-15	2	6	Backreef	North	Shallow
Faga'alu	TUT-2224	-14.2892	-170.68056	7-Nov-15	3	3	Backreef	North	Shallow
Faga'alu	TUT-2226	-14.28998	-170.68046	7-Nov-15	3	7	Backreef	North	Shallow
Faga'alu	TUT-2230	-14.2928	-170.67533	29-Oct-15	18	22	Forereef	South	Shallow
Faga'alu	TUT-2232	-14.29089	-170.67414	10-Nov-15	12	19	Forereef	South	Shallow
Faga'alu	TUT-2235	-14.29477	-170.67493	29-Oct-15	16	21	Forereef	South	Shallow
Faga'alu	TUT-2237	-14.29193	-170.68059	31-Oct-15	3	6	Backreef	South	Shallow
Faga'alu	TUT-2242	-14.29058	-170.68008	10-Nov-15	6	11	Backreef	South	Shallow
Faga'alu	TUT-2243	-14.29282	-170.67912	31-Oct-15	3	5	Backreef	South	Shallow
Faga'alu	TUT-2245	-14.29122	-170.67957	11-Nov-15	6	12	Backreef	South	Shallow
Faga'alu	TUT-2248	-14.28695	-170.67429	9-Nov-15	13	21	Forereef	North	Shallow
Faga'alu	TUT-2249	-14.28765	-170.67632	9-Nov-15	12	19	Forereef	North	Shallow
Faga'alu	TUT-2208	-14.28836	-170.67773	9-Nov-15	33	38	Forereef	North	Mid
Faga'alu	TUT-2209	-14.28733	-170.675	9-Nov-15	35	45	Forereef	North	Mid
Faga'alu	TUT-2210	-14.28921	-170.6767	11-Nov-15	37	47	Forereef	South	Mid
Faga'alu	TUT-2211	-14.28991	-170.67421	10-Nov-15	36	44	Forereef	South	Mid
Faga'alu	TUT-2218	-14.2937	-170.67495	29-Oct-15	40	46	Forereef	South	Mid

Faga'alu	TUT-2219	-14.29043	-170.67662	29-Oct-15	38	45	Forereef	South	Mid

Appendix 2 – Benthic image analysis classification tiers (from Lozada-Misa et al. 2017)

TAXON NAME	Genus/species Codes (TIER 3b)	Genus/species Codes (Tier 3)	Morphological Group Codes (TIER 2)	Functional Group Codes (TIER 1)
Branching hard coral	BR	BR	BR	CORAL
Columnar hard coral	COL	COL	COL	CORAL
Encrusting hard coral	ENC	ENC	ENC	CORAL
Foliose hard coral	FOL	FOL	FOL	CORAL
Free hard coral	FREE	FREE	FREE	CORAL
Massive hard coral	MASS	MASS	MASS	CORAL
Tabular hard coral	TA	TA	TA	CORAL
Non-scleractinian hard coral	MISP/HCOE/HYCO	NS	NS	CORAL
Acanthastrea spp	ACAS	ACAS	ENC	CORAL
Acropora abrotanoides	ACBR	ACBR	BR	CORAL
Acropora clathrata	ACTA	ACTA	TA	CORAL
Acropora cytherea	ACTA	ACTA	TA	CORAL
Acropora digitifera	ACBR	ACBR	BR	CORAL
Acropora humilis	ACBR	ACBR	BR	CORAL
Acropora hyacinthus	ACTA	ACTA	TA	CORAL
Acropora monticulosa	ACBR	ACBR	BR	CORAL
Acropora nasuta	ACBR	ACBR	BR	CORAL
Acropora nobilis	ACBR	ACBR	BR	CORAL
Acropora paniculata	ACTA	ACTA	TA	CORAL
Acropora samoensis	ACBR	ACBR	BR	CORAL
Acropora spp_branching	ACBR	ACBR	BR	CORAL
Acropora spp_tabulate	ACTA	ACTA	TA	CORAL
Acropora tenuis	ACBR	ACBR	BR	CORAL
Acropora valida	ACBR	ACBR	BR	CORAL
Alveopora spp.	GOAL	GOAL	ENC	CORAL
Astreopora spp.	ASSP	ASSP	ENC	CORAL
Barabattoia spp.	ENC	NEW	ENC	CORAL
Caulastrea spp.	ENC	NEW	ENC	CORAL
Cladopsammia spp.	ENC	ENC	ENC	CORAL
Coeloseris spp.	MASS	MASS	MASS	CORAL
Coscinaraea spp.	COSP	COSP	ENC	CORAL
Cycloseris spp.	FREE	FREE	FREE	CORAL
Cyphastrea spp.	CYPS	CYSP	ENC	CORAL
Diaseris spp.	FREE	FREE	FREE	CORAL
Diploastrea heliopora	DISP	MASS	MASS	CORAL
Distichopora spp.	HYCO	NS	NS	CORAL
Echinophyllia spp.	ECHL	ECHL	ENC	CORAL
Echinopora spp.	ECHP	ECHP	ENC	CORAL
Euphyllia spp.	EUSP	ENC	BR	CORAL
Favia spp.	FASP	FASP	MASS	CORAL
Favites spp.	FAVS	FAVS	MASS	CORAL
Fungia spp.	FUSP	FREE	FREE	CORAL
Galaxea spp.	GASP	GASP	ENC	CORAL
Gardineroseris spp.	MASS	MASS	MASS	CORAL
Goniastrea spp.	GONS	GONS	MASS	CORAL
Goniopora spp.	GOAL	GOAL	ENC	CORAL
Halomitra spp.	FREE	FREE	FREE	CORAL
Heliopora spp.	HCOE	NS	NS	CORAL
Herpolitha spp.	FREE	FREE	FREE	CORAL

TAXON NAME	Genus/species Codes (TIER 3b)	Genus/species Codes (Tier 3)	Morphological Group Codes (TIER 2)	Functional Group Codes (TIER 1)
Hydnophora spp.	HYSP	HYSP	MASS	CORAL
Isopora spp.	ISSP	ISSP	ENC	CORAL
Leptastrea spp.	LEPT	LEPT	ENC	CORAL
Leptoria spp.	LPHY	PLLE	MASS	CORAL
Leptoseris spp.	LESP	LESP	ENC	CORAL
Lobophyllia spp.	LOSY	LOSY	MASS	CORAL
Merulina spp.	MESP	FOL	FOL	CORAL
Millepora spp.	MISP	NS	NS	CORAL
Montastraea spp.	MONS	MASS	MASS	CORAL
Montipora aequituberculata	MOFO	MONE	FOL	CORAL
Montipora caliculata	MOEN	MOEN	ENC	CORAL
Montipora capitata	MOBR	MONE	BR	CORAL
Montipora capitata	MOEN	MONE	ENC	CORAL
Montipora capitata	MOFO	MONE	FOL	CORAL
Montipora flabellata	MOEN	MOEN	ENC	CORAL
Montipora foveolata	MOEN	MOEN	ENC	CORAL
Montipora incrassata	MOBR	MOEN	BR	CORAL
Montipora patula	MOEN	MOEN	ENC	CORAL
Montipora peltiformis	MOEN	MOEN	ENC	CORAL
Montipora spp_branching	MOBR	MONE	BR	CORAL
Montipora spp_encrusting	MOEN	MOEN	ENC	CORAL
Montipora spp_foliose	MOFO	NEW	FOL	CORAL
Montipora tuberculosa	MOEN	MOEN	ENC	CORAL
Montipora turgescens	MOEN	MOEN	ENC	CORAL
Montipora venosa	MOEN	MOEN	ENC	CORAL
Montipora verrilli	MOEN	MOEN	ENC	CORAL
Montipora verrucosa	MOEN	MOEN	ENC	CORAL
Mycedium spp.	ENC	ENC	ENC	CORAL
Oulophyllia spp.	OUSP	MASS	MASS	CORAL
Oxypora spp.	FOL	ENC	FOL	CORAL
Pachyseris spp.	PACS	FOL	FOL	CORAL
Paraclavarina spp.	BR	NEW	BR	CORAL
Pavona bipartita	PAMA	PAVS	MASS	CORAL
Pavona cactus	PAFO	PAVS	FOL	CORAL
Pavona chiriquiensis	PAEN	PAVS	ENC	CORAL
Pavona clavus	PAMA	PAVS	MASS	CORAL
Pavona decussata	PAFO	PAVS	FOL	CORAL
Pavona diffluens	PAEN	PAVS	ENC	CORAL
Pavona duerdeni	PAMA	PAVS	MASS	CORAL
Pavona explanulata	PAEN	PAVS	ENC	CORAL
Pavona explanulata	PAMA	PAVS	MASS	CORAL
Pavona frondifera	PAFO	PAVS	FOL	CORAL
Pavona maldivensis	PAEN	PAVS	ENC	CORAL
Pavona minuta	PAEN	PAVS	ENC	CORAL
Pavona spp_encrusting	PAEN	PAVS	ENC	CORAL
Pavona spp_foliose	PAFO	PAVS	FOL	CORAL
Pavona spp_massive	PAMA	PAVS	MASS	CORAL
Pavona varians	PAEN	PAVS	ENC	CORAL
Pavona venosa	PAMA	PAVS	MASS	CORAL
Pectinia spp.	FOL	NEW	FOL	CORAL
Platygyra spp.	PLSP	PLLE	MASS	CORAL
Plerogyra spp.	PLER	ENC	BR	CORAL

TAXON NAME	Genus/species Codes (TIER 3b)	Genus/species Codes (Tier 3)	Morphological Group Codes (TIER 2)	Functional Group Codes (TIER 1)
Plesiastrea spp.	ENC	MASS	ENC	CORAL
Pocillopora spp.	POCS	POCS	BR	CORAL
Podabacia spp.	FOL	FREE	FOL	CORAL
Porites annae	POBR	PONM	BR	CORAL
Porites arnoudi	POFO	POMA	FOL	CORAL
Porites arnoudi	POMA	POMA	MASS	CORAL
Porites australiensis	POMA	POMA	MASS	CORAL
Porites bernardi	POEN	POMA	ENC	CORAL
Porites brighami	POEN	POMA	ENC	CORAL
Porites compressa	POBR	PONM	BR	CORAL
Porites cylindrica	POBR	PONM	BR	CORAL
Porites densa	POMA	POMA	MASS	CORAL
Porites duerdeni	POBR	POMA	BR	CORAL
Porites evermanni	POMA	POMA	MASS	CORAL
Porites horizontalata	POBR	POMA	BR	CORAL
Porites horizontalata	POEN	POMA	ENC	CORAL
Porites horizontalata	POFO	POMA	FOL	CORAL
Porites lichen	POBR	POMA	BR	CORAL
Porites lichen	POEN	POMA	ENC	CORAL
Porites lobata	POEN	POMA	ENC	CORAL
Porites lobata	POMA	POMA	MASS	CORAL
Porites lutea	POEN	POMA	ENC	CORAL
Porites lutea	POMA	POMA	MASS	CORAL
Porites monticulosa	POBR	POMA	BR	CORAL
Porites monticulosa	POEN	POMA	ENC	CORAL
Porites monticulosa	POFO	POMA	FOL	CORAL
Porites murrayensis	POEN	POMA	ENC	CORAL
Porites murrayensis	POMA	POMA	MASS	CORAL
Porites rus	POBR	PONM	BR	CORAL
Porites rus	POEN	PONM	ENC	CORAL
Porites rus	POFO	PONM	FOL	CORAL
Porites solida	POEN	POMA	ENC	CORAL
Porites solida	POMA	POMA	MASS	CORAL
Porites spp_branching	POBR	PONM	BR	CORAL
Porites spp_encrusting	POEN	PONM	ENC	CORAL
Porites spp_foliose	POFO	NEW	FOL	CORAL
Porites spp_massive	POMA	POMA	MASS	CORAL
Porites vaughani	POEN	POMA	ENC	CORAL
Psammocora spp.	PSSP	PSSP	ENC	CORAL
Sandalolitha spp.	FREE	FREE	FREE	CORAL
Scapophyllia spp.	ENC	ENC	ENC	CORAL
Scolymia spp.	ENC	ENC	ENC	CORAL
Seriatopora spp.	BR	NEW	BR	CORAL
Stylaster spp.	HYCO	NS	NS	CORAL
Stylocoeniella spp.	ENC	ENC	ENC	CORAL
Stylophora spp.	STYS	STYS	BR	CORAL
Symphyllia spp.	SYSP	LOSY	MASS	CORAL
Tubastraea spp.	ENC	ENC	ENC	CORAL
Turbinaria spp.	TURS	TURS	FOL	CORAL
Black coral - Antipatharia	USC	USC	USC	SC
Cladiella spp.	OCTO	OCTO	OCTO	SC
Dendronephthya spp.	OCTO	OCTO	OCTO	SC

TAXON NAME	Genus/species Codes (TIER 3b)	Genus/species Codes (Tier 3)	Morphological Group Codes (TIER 2)	Functional Group Codes (TIER 1)
Lobophytum spp.	OCTO	OCTO	OCTO	SC
Octocoral	OCTO	OCTO	OCTO	SC
Pachyclavularia spp.	OCTO	OCTO	OCTO	SC
Sarcophyton spp.	OCTO	OCTO	OCTO	SC
Sinularia spp.	OCTO	OCTO	OCTO	SC
Soft Coral	OCTO	OCTO	OCTO	SC
Stereonephthya spp	OCTO	OCTO	OCTO	SC
Unclassified soft coral	USC	USC	USC	SC
Wire coral - Antipatharia	USC	USC	USC	SC
Anemone	AMNE	AMNE	AMNE	INV
Bivalve	BI	BI	BI	INV
Bryozoan	BRY	BRY	BRY	INV
Corallimorph	CMOR	CMOR	CMOR	INV
Discosoma spp.	CMOR	CMOR	CMOR	INV
Giant clam	GC	GC	GC	INV
Palythoa spp.	ZO	ZO	ZO	INV
Protopalythoa spp.	ZO	ZO	ZO	INV
Rhodactis spp.	CMOR	OCTO	CMOR	INV
Sponge	SP	SP	SP	INV
Tunicate	TUN	TUN	TUN	INV
Unclassified sessile invertebrate	UI	UI	UI	INV
Zoanthus spp.	ZO	ZO	ZO	INV
Asparagopsis spp.	ASPP	ASPP	UPMA	MA
Avrainvillea spp.	AVSP	AVSP	UPMA	MA
Blue-green macroalga	BGMA	BGMA	UPMA	MA
Brown macroalgae	BRMA	UPMA	UPMA	MA
Caulerpa spp.	CAUL	CAUL	UPMA	MA
Dictyopteris spp.	DICO	DICO	UPMA	MA
Dictyosphaeria spp.	DICT	DICT	UPMA	MA
Dictyota spp.	DICO	DICO	UPMA	MA
Encrusting macroalgae	EMA	EMA	UPMA	MA
Green macroalgae	GRMA	UPMA	UPMA	MA
Halimeda spp.	HALI	HALI	UPMA	MA
Lobophora spp.	LOBO	LOBO	UPMA	MA
Microdictyon spp.	MICR	MICR	UPMA	MA
Neomeris spp.	NEOM	NEOM	UPMA	MA
Padina spp.	PADI	PADI	UPMA	MA
Peyssonnelia spp.	PESP	PESP	UPMA	MA
Red macroalgae	RDMA	UPMA	UPMA	MA
Seagrass	SG	SG	UPMA	MA
Upright macroalgae	UPMA	UPMA	UPMA	MA
CCA growing on hard substrate	CCAH	CCAH	CCAH	CCA
CCA growing on rubble	CCAR	CCAR	CCAR	CCA
Turf growing on hard substrate	TURFH	TURFH	TURFH	TURF
Turf growing on rubble	TURFR	TURFR	TURFR	TURF
Hard substrate	HARD	HARD	HARD	TURF
Rubble substrate	RUB	RUB	RUB	TURF
Fine sediment	FINE	FINE	FINE	SED
Sand	SAND	SAND	SAND	SED
Mobile fauna	MOBF	MOBF	MOBF	MOBF
Shadow	SHAD	SHAD	SHAD	UC
Unclassified benthos	UNK	UC	UNK	UC

TAXON NAME	Genus/species Codes (TIER 3b)	Genus/species Codes (Tier 3)	Morphological Group Codes (TIER 2)	Functional Group Codes (TIER 1)
Tape	TAPE	TAPE	TAPE	TW
Wand	WAND	WAND	WAND	TW