


Baseline Assessments for Coral Reef Community Structure and Demographics on West Maui

Data Report

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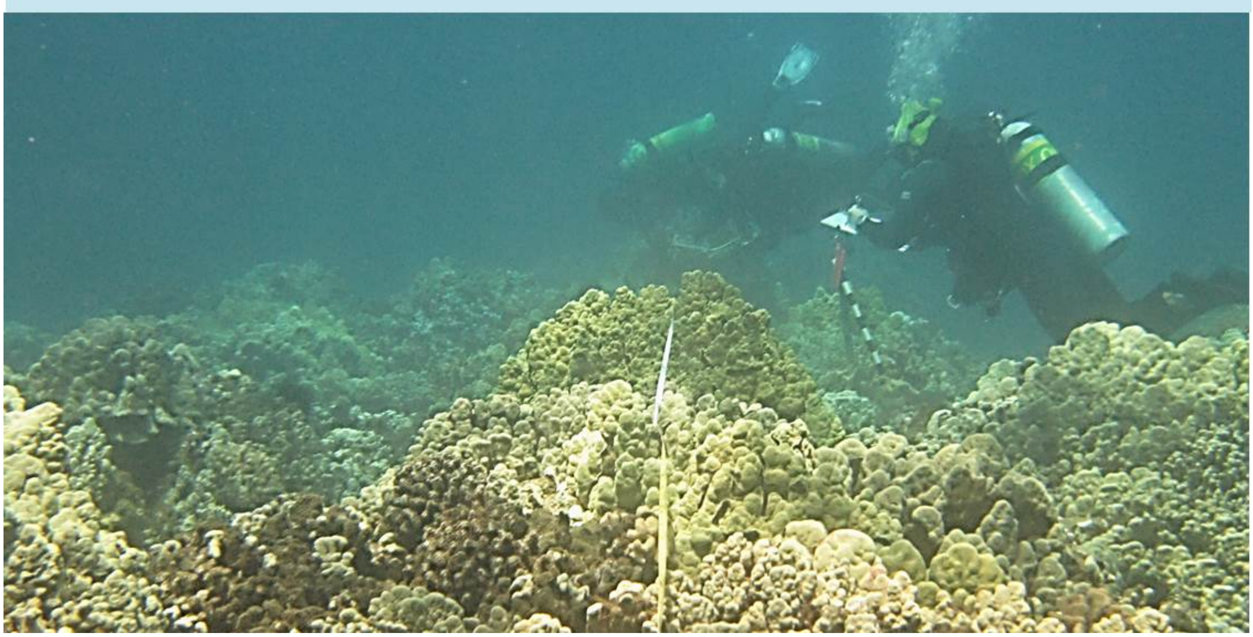

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Executive Summary

The coastal and upslope terrains of West Maui have had a long history of impacts owing to more than a century of human activities. Resource extraction, agriculture, as well as residential and resort development have caused land-based pollution that impairs water quality and adversely impact the adjacent marine ecosystem. Today, West Maui's coral reefs are chronically impacted by the effects of land-based pollution, mainly sedimentation and nutrients, with documented losses of 30 – 75% in coral cover over the last 20 years. Nonetheless, despite their current status and levels of environmental impact, these coral reef communities represent a key local resource and a counterpoint to the overall low coral reef development levels both island- and state-wide. This is of high relevance because the occurrence of coral-rich assemblages and accreted reef complexes statewide is sparse. Only limited segments along the coastlines of Maui, Hawaiʻi, Lanaʻi, Molokaʻi, and Kahoʻolawe, harbor mature, fringing coral reefs; and unfortunately, many of them are seriously threatened by terrestrial runoff.

This report describes the results of baseline assessment surveys of coral reef benthic structure, coral community demographics, and coral condition. These surveys are intended to provide benchmarks for continued monitoring efforts and provide a gauge for comparing and evaluating the effectiveness of management actions to reduce land-based sources of pollution in priority watersheds on West Maui. Within this context, 12 permanent, long-term monitoring sites were strategically established adjacent to the 7 primary stream drainages (Wahikuli, Honokōwai, Mahinahina, Kahana/Kaʻopala, Honokeana, Honokahua, and Honolua) within the five priority watersheds (Wahikuli, Honokōwai, Kahana, Honokahua, and Honolua). Herein, benthic cover and composition, coral demographics, and coral condition of the monitoring sites are described and contrasted in the "Benthic Characterization" and "Synthesis and Discussion" sections of this report.

The baseline assessments revealed that although some areas harbor prominent coral reef structures with high live coral cover and multispecies assemblages, others are characterized by sediment-impacted corals in impoverished and species-poor communities. Mean coral cover varied widely, from 49% at Wahikuli-shallow to 4.6% at Mahinahina-shallow. Similarly, coralline algal cover averaged 12.7% at Kaʻopala and Honokeana-north, but was altogether absent at the Mahinahina sites. Macroalgae was a minor component of the benthos across all study sites, representing only up to 2.3% at Mahinahina-south, while turf algae varied considerably, from 41% at Honokeana-north to 84% at the Honokahua site. Consequently, the Benthic Substrate Ratio (BSR) also varied considerably region wide, with the highest values (≥ 1), suggesting a healthier reef condition reported for the Wahikuli, Honokeana, and Honokōwai sites; and the lowest (≤ 0.5), suggesting impairment in structure and function, recorded at the Honolua and Honokahua sites. Adult colony densities were the highest at the Wahikuli (27 col/m^2) but lowest at the Kaʻopala (7 col/m^2) site. And, colony partial mortality peaked at the Kaʻopala (33%) and was the lowest at the Honokeana Bay (12%). Moreover, in-situ and derived estimates of water turbidity and sediment loading revealed that the Kaʻopala and Wahikuli stream sites ranked the highest for turbidity, whereas the Honokōwai and Kaʻopala sites ranked highest for sediment loading.

Chronic and episodic terrestrial sediment stress has resulted in coral reef community demise, clearly illustrated at the Honolua, Honokahua, and Kaʻopala sites, where coral benthic cover and colony abundances ranked the lowest and levels of turf algae ranked among the highest. Left unattended, land-based pollution impacts will continue to negatively affect the coral reef communities of West Maui. And, under the current turbidity and sediment loading conditions, the coral-rich habitats in the Wahikuli and Honōkowai Watersheds are probably at greatest risk, given they harbor the most prominent and well-developed reefs in the region, characterized by the highest coral cover, colony densities, and structural complexity.

1. Introduction

Elevated levels of turbidity and sedimentation are two of the principal drivers of coral reef degradation worldwide (Rodgers 1990, Erftemeijer et al. 2012). The primary effect of turbidity is decreased light for zooxanthellae photosynthesis and sustenance (Anthony and Fabricius 2000; Phillip and Fabricius 2003; Piniak and Storlazzi, 2008; Storlazzi et al., 2015). Sedimentation effects occur mainly through the direct deposition of particles on the coral surface resulting in re-direction of energy expenditures for clearing excess sediments at the expense of other vital functions, such as calcification, reproduction, growth, and immune response (Riegl and Branch 1995; Anthony and Lacombe 2001). This energetic allocation reduces the fitness of individual corals, leading to increased susceptibility to disease and partial death, reductions in coral cover, abundance, recruitment, and diversity; and ultimately alterations in community structure, composition, and function (Brown et al. 2002; Vargas-Ángel et al. 2006, 2007; Jokiel et al., 2014). In addition, the secondary and indirect impacts of siltation stress to reef corals and associated communities include nutrient loading (nitrogen and phosphorus), lowered levels of dissolved oxygen, and elevated bacterial counts from urbanization and inadequate waste management.

West Maui, once the hideaway of whalers, missionaries, and Hawaiian royalty, is today one of Hawaii's most appealing and vibrant destinations; home to massive resorts, luxury condos, championship golf courses, and spectacular white-sand beaches, together with some of the best snorkeling and surfing conditions State wide. While tourism is today's primary economic driver of the region (Group 70 2016), Currently, the coral reefs off West Maui are chronically affected by land-based sources of pollution (LBSP) owing to more than a century of human impacts originating from agriculture, urban development, and overfishing. Long-term monitoring has documented dramatic changes in coral community composition, with localized losses of 30–75% in coral cover and associated increases in macroalgal and turf algal cover (Jokiel et al. 2004; Chaston and Oberding 2007; Sustainable Resources Group 2012; Group 70 2016). In addition, the limited knowledge of the status of many reefs in the area precludes an assessment of the recovery potential of these reefs.

The first anthropogenic impacts to West Maui likely resulted from the Polynesian settlers who diverted a portion of the water out of the streams into taro gardens and fish ponds (Heart & Partners 2006; Group 70 2016). In addition, resource extraction also occurred from the upland forests to the coastal areas and ocean (Heart & Partners 2006; Group 70 2016). However, the greatest impacts to the natural drainage patterns and the regional ecohydrological balance resulted from the European colonization in the 1800s, which brought livestock, in addition to resource extraction techniques, that significantly altered and transformed the landscape. As such, by the early 1900s, large tracts of land within the larger West Maui region were actively used for sugarcane and pineapple production. And, by the second half of the 20th century, an accelerated urban buildup along the shoreline and associated uplands took place to support the growing local residential population, commercial needs, and tourism interests. Although most of the agricultural activities along West Maui (sugar cane and pineapple farming) were terminated by 2008, the now-fallow agricultural lands continue to be a source of legacy chemicals and fertilizers (Group 70 2016). The main non-point source pollutants identified in these watersheds include sediment and nutrients from agricultural runoff, in addition to other compounds including chemicals, heavy metals, pesticides, as well as bacteria. These are transported off the watersheds in both surface water and as groundwater and delivered to the ocean at various rates and total loads (Swarzenski et al., 2012, 2016; Group 70 2016).

With the intent of best directing funding efforts, in 2010, the State of Hawaii Coral Program prioritized two sites in the main Hawaiian Islands with the greatest chance of success as focal points for management initiatives. The Kahekili Herbivore Fisheries Management Area and adjacent waters was chosen on West Maui. Later in 2011, the U.S. Coral Reef Task Force (USCRTF) (http://www.coralreef.gov/) added a priority watershed partnership designation to this area, and the West Maui Ridge-to-Reef Initiative (WMR2R) (http://www.westmauir2r.com/) was created in 2012 formalizing layers of commitment to interagency and community partner collaboration in this area, including the development of a Watershed Management Plan. Funded by NOAA and the US Army Corps of Engineers, the Watershed Management Plans (WMP) (http://www.westmauir2r.com/watershed-management-plans.html) provide a framework to reduce, capture, and remediate the impacts of non-point source pollutants through the implementation of management practices in priority areas. The WMPs also include recommendations for strategic, long-term trend monitoring of the health of the coral reef ecosystem, which provides information that can be correlated to the implementation of solutions to reduce land-based non-point source pollutants.

1.1 Objectives and metrics

By documenting coral reef benthic community structure and demographic parameters in a spatially comprehensive manner, this work provides benchmarks for continued monitoring efforts, against which to evaluate the effectiveness of management actions to reduce LBSP in priority watersheds on West Maui. Within this context, permanent, long-term monitoring sites were strategically established adjacent to 7 main stream mouths (Wahikuli, Honokōwai, Mahinahina, Kaʻopala, Honokeana, Honokahua, and Honolua) within the 5 priority watersheds (Wahikuli, Honokōwai, Kahana, Honokahua, and Honolua). This information is also of use as the basis to track and improve water quality, enhance ecosystem resilience, and update coral reef protection measures.

This work was completed by staff of NOAA's Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Program (CREP), the State of Hawaii's Department of Land and Natural Resource's Division of Aquatic Resources (Hawaii-DAR), and the U.S. Geological Survey's (USGS) Coastal and Marine Geology Program from July 2014 to May 2016. The work described was funded by the NOAA Coral Reef Conservation Program (CRCP) through two internal projects—*Determining the Efficacy of Watershed Management Activities to Reduce Land-Based Pollution in the Wahikuli and Honokowai Watersheds*, awarded to Bernardo Vargas-Ángel (NOAA-CREP) and *Quantifying Condition of Coral Reef Communities in the Kahana and Honokahua Priority Watersheds, West Maui*, awarded to Paulo Maurin (NOAA-NOS).

2. Methods

2.1 Biological surveys

Permanent, long-term monitoring sites were strategically established at 7 locations adjacent to the main gulch drainages within each of the 5 priority watersheds. In the Honokōwai, and Wahikuli Watersheds six permanent, long-term monitoring sites were established; 1 shallow (4.5–6.0 m) and 1 deep (7.0–10.0 m) at each of the 3 gulch drainages (i.e., Wahikuli, Honokōwai, and Mahinahina). A total of 3 replicate, 25-m transects were deployed at each of the 6 monitoring sites; stainless pins were affixed to the substrate to demarcate the beginning and end of each replicate transect. Correspondingly, in the Kahana–Honolua area, 6 additional long-term, permanent monitoring sites were established; 2 each at Honolua Bay (shallow: 2.0–2.5 m; deep: 7.0–8.0 m) and Honokeana Bay (3.0–4.0 m), and 1 each at Honokahua Bay (4.0 m) and Kaʻopala (3.5 m) (Fig. 1, Table 1). Four replicate 25-m transects were deployed at each of the 2 sites in Honolua Bay and 3 replicate 25-m transects at each of the other four monitoring sites; stainless pins were also affixed to the substrate to demarcate the beginning and 4 of each replicate transect.

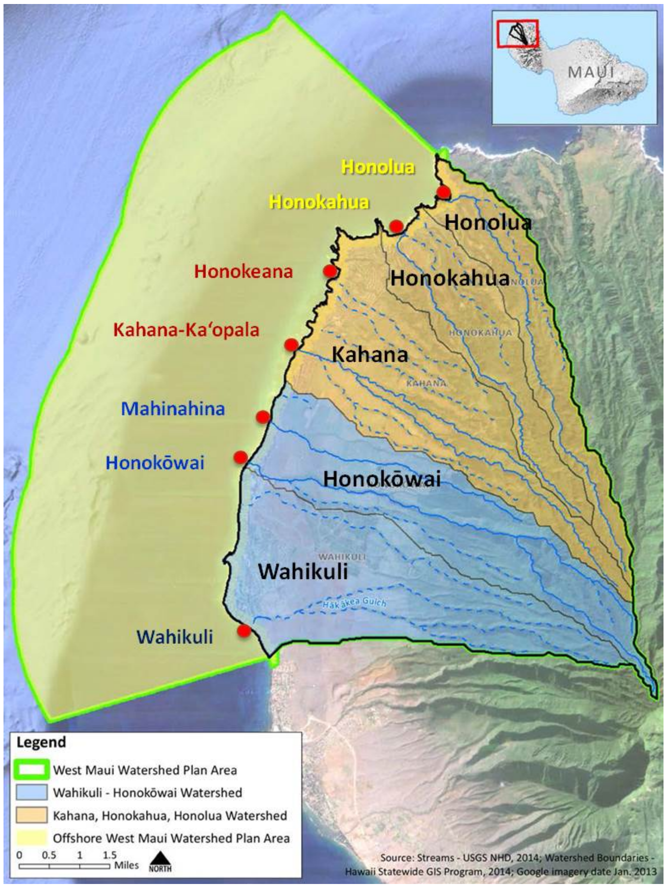

Figure 1- General location of the major study sites on west Maui. Modified from: http://www.westmauir2r.com/

On each transect, the Line-Point-Intercept (LPI) method (Hill and Wilkinson 2004) at 25-cm intervals was implemented to extract information on percent benthic cover. In addition, belt-transect surveys following NOAA (2016) were used to quantitatively assess coral generic richness, colony density, size structure, and condition. Along the same transect line, adult coral colonies were surveyed within 4 (1.0 × 2.5 m) segments in the following manner: 0.0–2.5 m (segment 1); 5.0–7.5m (segment 3); 10.0–12.5 m (segment 5); and 15.0 – 17.5 m (segment 7). All adult coral colonies (> 5 cm maximum 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 only if possible In addition the condition of each colony, including disease and bleaching (see NOAA 2017), was also noted along with the extent (percent of colony affected) and level of severity (range from moderate to acute). In addition, juvenile coral colonies (< 5 cm max diameter) were surveyed within 3 (1.0 × 1.0 m) segments (0.0–1.0 m; 5.0–6.0 m; and 10.0–11.0 m) along the same transects above. Juvenile colonies were distinguished in the field by a distinct tissue and skeletal boundary (not a fragment of larger colony). Each juvenile colony was identified to lowest taxonomic level (genus or species) and measured for size by recording both the maximum and perpendicular diameter to the nearest 2 mm. Finally, still photographs, one every 1 m from the 1-m to the 15-m mark along each transect, were collected along each transect to provide a durable record of the benthic community composition at each study site.

2.2 Sedimentation

Sediment loading was assessed based on the installation of in situ optical backscatter sensors adjacent to strategic point sources (stream mouths), in addition to the deployment of sediment traps and sediment pods. An array of instruments was deployed at each of the shallow monitoring sites at the Mahinahina, Honokōwai, and Wahikuli sites (Table 1). Instrument description and specifics can be found in Storlazzi et al. (2009, 2011) and Field et al. (2012).

The optical backscatter sensors provide high-resolution (10-min) data on turbidity in the water column that provide insight into sediment loads in the nearshore waters. Sediment trap and pod deployments were used to gain spatial and temporal information on sediment accumulation rates, as well as sediment composition (carbonate vs terrigenous) in mass per volume for the sand-, silt-, and clay-sized fractions. Traps and pods were serviced quarterly.

Sediment composition analyses were conducted on dried, weighed samples that were acid treated and subsequently rinsed, dried, and reweighed. Hawaii-DAR Maui conducted the quarterly maintenance of instruments and other deployments; University of Hawaiʻi Maui campus provided assistance with sample pre-processing; the oceanographic instrument data processing and sediment sample analyses were conducted in partnership with the U.S. Geological Survey.

Table 1- Site locations, depth, and number of replicate transects, and instruments deployed at each permanent monitoring site.

Site Name	Site ID	Date	Depth (m)	Latitude	Longitude	No. Transects	Turbidity sensors	Sediment pods	Sediment traps
Wahikuli-shallow	MAI-932	Jul 02/14	4.8	20.9095	-156.6919	3	1	1	1
Wahikuli-deep	MAI-933	Oct 30/14	7.5	20.9092	-156.6925	3	-	-	-
Honokōwai-shallow	MAI-930	Jun 3014	4.8	20.9518	-156.6918	3	1	1	1
Honokōwai-deep	MAI-931	Jul 03/14	7.2	20.9522	-156.6923	3	-	-	-
Mahinahina-shallow	MAI-928	Jun 29/14	6.0	20.9601	-156.6877	3	1	1	1
Mahinahina-deep	MAI-929	Jun 29/14	9.9	20.9593	-156.6887	3	-	-	-
Kaʻopala	MAI-939	Jul 30/15	3.5	20.9820	-156.6768	3	-	-	-
Honokeana-south	MAI-937	Jul 29/15	3.2	20.9918	-156.6693	3	-	-	-
Honokeana-north	MAI-938	Jul 28/15	3.7	20.9922	-156.6690	3	-	-	-
Honokahua	MAI-939	Jul 27/15	4.0	21.0069	-156.6497	3	-	-	-
Honolua-shallow	MAI-935	Jul 22/15	2.2	21.0157	-156.6395	4	-	-	-
Honolua-deep	MAI-934	Jul 20/15	7.8	21.0152	-156.6400	4	-	-	-

2.3 Data analysis

Transect-level data were pooled and averaged to produce site-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 (Somerfield et al., 2008; Osborne et al. 2011)). Additionally, non-parametric Spearman Rank Correlation and Mann Whitney Rank tests were conducted to gauge the association between coral cover and adult colony densities, and differences in partial mortality among coral size classes.

2.4 West Maui regional benthic cover maps

Benthic cover maps for West Maui were assembled using all data sources available. To that end, a data sharing request was made to the main groups working and collecting benthic structure information in the region, including: Hawaiʻi-DAR, the Fisheries Ecology Research Laboratory; the University of Hawaiʻi Coral Reef Assessment and Monitoring Program (CRAMP); and NOAA-CREP. All benthic cover data, irrespective of collection method (visual, line-point-intercept, and photo image analysis), were pooled to compile geo-referenced maps illustrating the salient patterns of benthic cover for each: hard corals, coralline algae, macroalgae, turf algae, and the benthic substrate ratio. These maps are intended to provide context to the biological baseline. Maps were assembled such that individual geo-referenced data points were plotted onto an overlaid 50 × 50 m grid, and all data points falling within each grid cell were pooled to compute a grid cell average.

3. Benthic Characterization

Herein, the monitoring sites within each of the 5 watersheds are described in terms of benthic cover and composition, coral demographics, and condition. Only relevant structural and demographic parameter ranges and means are presented to characterize and highlight the particularities of each study site; Appendices 1 – 6 provide the all the raw transect-level data.

3.1 Wahikuli

Wahikuli Watershed is ~ 2,600 Ha, roughly half of which is in fallow agriculture with pockets of coffee farming, and a quarter each in urban and conservation land use. The coastal area next to the stream is bordered by a beach park and resort sections, with low density luxury homes above the highway north of the stream. This drainage has no sediment retention basin. This is the driest of the five watersheds. Two monitoring sites were established adjacent to the stream discharge: inshore Wahikuli-shallow hereafter WAH-S (4 m–5 m) and offshore Wahikuli-deep, hereafter WAH-D (7–8 m). The aggregate reef in this sector contains extensive coral-rich buildups, intermingled with sand patches (Fig 2).

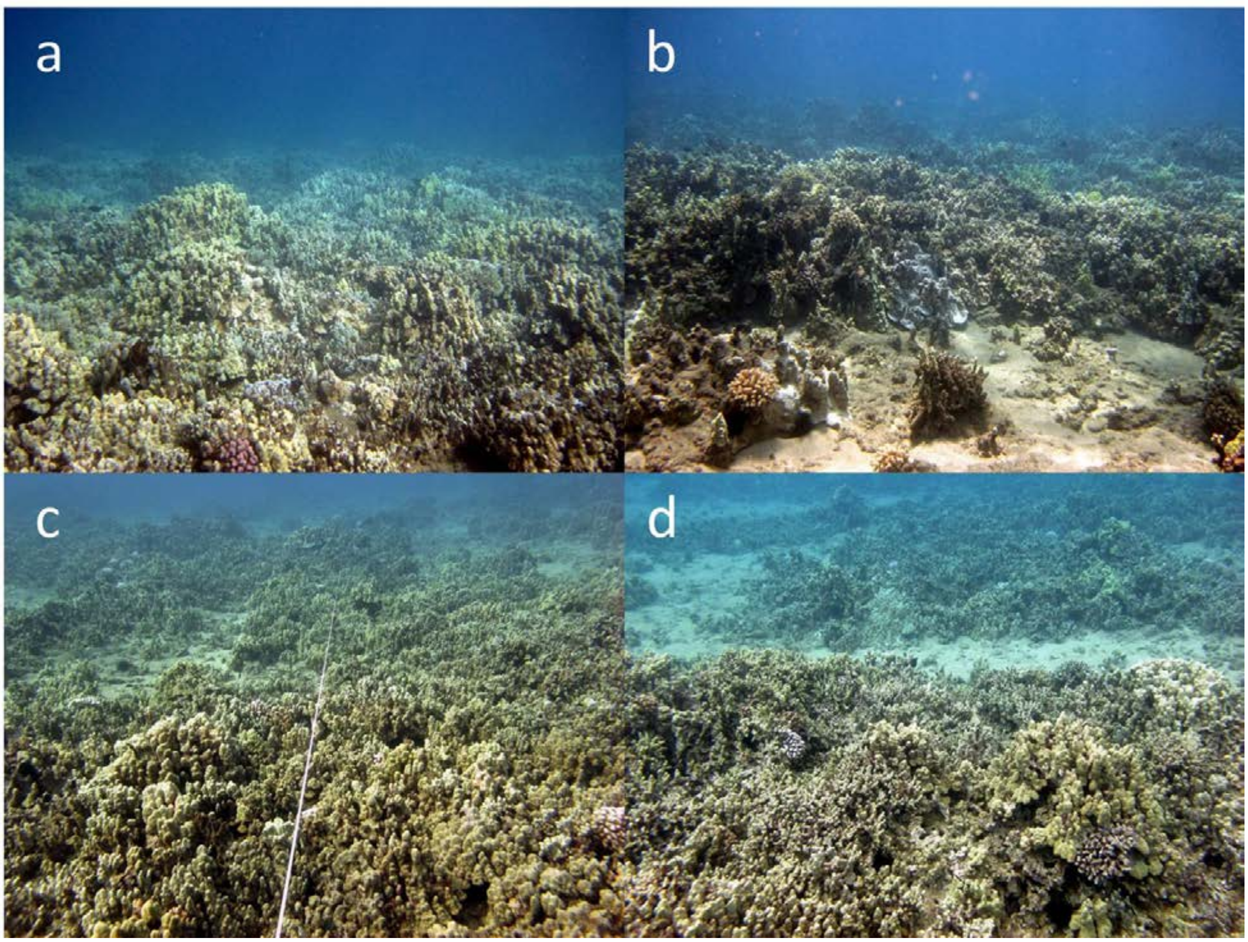

Figure 2- Visual appraisal of the coral communities at Wahikuli. Top panels (a–b): shallow site (WAH-S); lower panels (c–d): deep site (WAH-D). Photo credits: Darla White, DAR Maui.

Overall, live coral cover was high at both sites, ranging between 41–58% at the shallow site and 34–55% at the deep site. Correspondingly, levels of CCA and fleshy macroalgae were low, averaging 0.7% (0.3 SE) and 0%, respectively for the shallow site, and 2% (1.5 SE) and 0.33% (0.3 SE), respectively for the deep site. Turf algal cover was moderately high, representing, on average less than half of the live benthos for both sites (45.0%, 5.5 SE and 47.7%, 5.8 SE, respectively). The BSR at Wahikuli amounted to 1.1 for the shallow site and 1 for the deep site, suggesting an overall good condition. However, despite the relatively high coral cover and BSR values, both sites exhibited advanced levels of urchin bioerosion, which has resulted in remarkably fragile reef structures that are prone to easy breakage and crumbling. This is of concern because live coral colonies that become structurally unstable are easily dislodged or knocked-off, accelerating the mortality process. As such, these relatively healthy reefs are at risk of severe damage from physical impacts such as storm swell, boats groundings, and even divers as they inadvertently come in contact the reef structure with their gear.

A total of 5 scleractinian genera were tallied at Wahikuli, namely, in decreasing order of numerical abundance: *Porites*, *Montipora*, *Pocillopora*, *Pavona*, and *Psammocora*; with *Psammocora* only present at the shallow site. Mean colony densities were the highest recorded in this study: 22 col/m^2 (SE 0.2) for the shallow site and 33 col/m^2 (SE 0.7) for the deep site; with colony densities being consistently higher on the deep transects compared to the shallow. In addition, together the genera *Montipora* and *Porites* represented 40–50% each of all colonies tallied at either site, with *Montipora* being only slightly more abundant at the shallow site. Mean juvenile colony densities exhibited substantial differences between the shallow and deep sites, 5.1 col/m^2 (SE 1.4) and 12 col/m^2 (SE 1.8), respectively, with the deeper site showing the highest abundance of juvenile colonies in the West Maui region. At both Wahikuli sites, the genus *Montipora* contributed more than 70% to the juvenile coral population. Mean adult colony partial mortality was moderately high at both sites; 23.7% (1.7 SE) for the shallow site and 24.4% (SE 2.3) at the deep site, with corals of the genus *Porites* exhibiting the highest levels of partial mortality, averaging 39.0% (2.9 SE) and 41.4% (1.4 SE) at WAH-S and WAH-D, respectively. Finally, prevalence of coral disease and other sub-lethal lesions averaged 1.9% (SE 0.7) at the shallow site and 1.7% (1.2 SE) at the deep site; mean prevalence of bleaching was higher (WAH-S = 5.7%, SE 1.3; WAH-D = 5.3%, 1.3 SE; respectively). Although still low, these were the highest levels of bleaching recorded in this study, which may be due to the timing of the surveys in late October 2014, when moderate, widespread bleaching was reported at several different locales around Maui.

3.2 Honokōwai

Honokōwai Watershed is slightly smaller than Wahikuli at ~ 2,280 Ha with more than half of the area in fallow agriculture and 41% in conservation land. A mere 4% of the watershed is used for high density housing, commercial activity, and ocean front vacation properties. Although there is a dam in the stream above the urban-land use, only a small amount of fine sediment settles out due to the open waffle design of the structure, before the channel is hardened, delivering turbid water to the coast when it rains.

The aggregate reef in this sector is characterized by a series of irregular spur-like coral buildups extending offshore. Two monitoring sites were established adjacent to the stream discharge: inshore Honokōwai-shallow (HON-S: 4.5–5.5 m depth) and offshore Honokōwai-deep (HON-D: 6–8 m depth). Despite the elevated underwater turbidity in this sector, the highest observed during surveys, the Honokōwai sector also harbored extensive coral-rich assemblages (Fig. 3). Coral cover was second highest in the West Maui region, with HON-S averaging 42% (7.4 SE) and HON-D 38.3% (2.3 SE). Levels of CCA were higher than at Wahikuli for the shallow and deep sites, averaging 4.7% (1.5 SE) and 2% (1.5 SE), respectively; interestingly, no macroalgae was recorded on any of the surveyed transects at either depths. Contrastingly, turf algal cover was moderately high, only slightly higher than at Wahikuli, representing 53% (6.2 SE) for the shallow site and 57.3% (3.8 SE) for the deep site. In addition, for Honokōwai, the Benthic Substrate Ratio amounted to 0.9 for the shallow site and 0.7 for the deep site, suggesting some loss of structure and function, particularly for the deep site.

Five coral genera were tallied at the Honokōwai sites, namely, in decreasing order of numerical abundance: *Porites*, *Montipora*, *Pavona*, *Pocillopora*, and *Cyphastrea*; with *Cyphastrea* only present at the shallow site. Mean adult colony densities were relatively high, with no substantial differences between depths; 19.1 col/m^2 (3.2 SE) for the shallow site and 20.9 col/m^2 (0.2 SE) for the deeper site. And, like at Wahikuli, together the genera *Montipora* and *Porites* represented 40%–50% each of all colonies tallied at each site, with *Montipora* being only slightly more abundant at the shallow site.

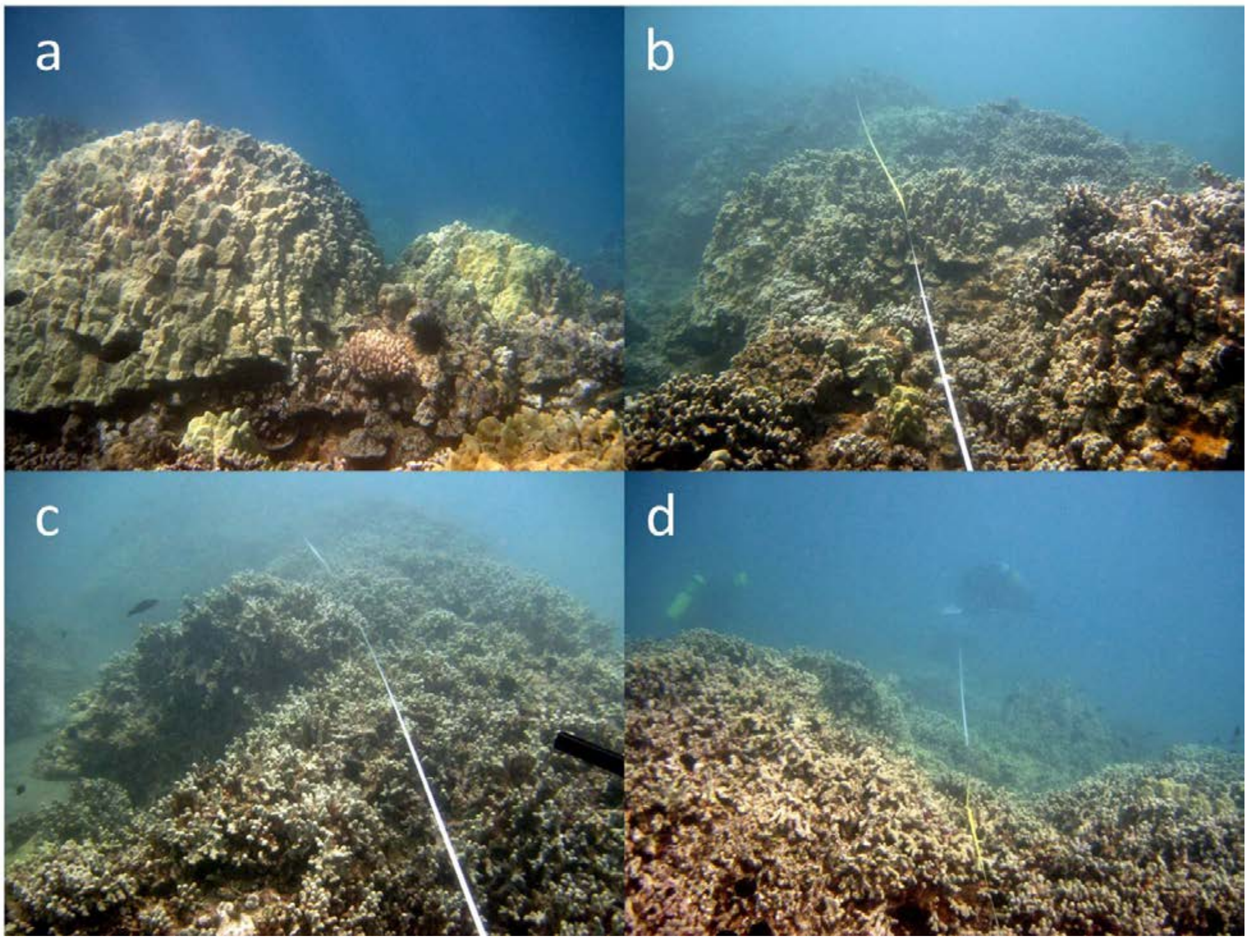

Figure 3- Visual appraisal of the coral communities at Honokōwai. Top panels (a–b): shallow site (HON-S); lower panels (c–d): deep site (HON-D). Photo credits: Hatsue Bailey, NOAA-PIFSC

Comparatively, mean juvenile colony densities were low, 4.4 col/m^2 (1.1 SE) at the shallow site and 4.0 col/m^2 (1.4 SE) at the deep; lower juvenile densities may be related to the elevated levels of turbidity affecting the coral communities adjacent to the stream discharge (Irizazrri-Soto and Weil 2009). However, according to Padilla-Gamiño et al. (2014), sexual reproduction is a resilient process in *Montipora*, with no differences in gamete development or fecundity across different sedimentation regimes. Like at Wahikuli, the genus *Montipora* was the greatest contributor to the juvenile colony population representing 60% and 64% of all juvenile colonies tallied at the shallow and deep sites, respectively. Comparable to Wahikuli, mean adult colony partial mortality was moderately high: 23.6% (2.6 SE) for the shallow and 23.8% (2.6 SE) at the deep, with colonies of *Porites* exhibiting the highest levels of partial mortality among all coral genera, averaging 33% and 36% for HON-S and HON-D, respectively. Finally, although mean prevalence of coral diseases and other lesions was low (HON-S =

3.5%, 1.4 SE; HON-D = 2.4%, 0.9 SE) it was the highest among the survey sites in the two southern watersheds. Mean prevalence of coral bleaching was also low (HON-S = 2.6%, 0.8 SE; HON-D = 2.1%, 0.7 SE) indicating only background levels.

3.3 Mahinahina

Mahinahina stream is in the Honokōwai Watershed. This stream does not reach as high into Puʻu Kukui Watershed Preserve as many of the others, ending just above the conservation boundary. The stream mouth is flanked by condominium vacation properties. Two monitoring sites were established adjacent to the stream discharge: inshore Mahinahina-shallow hereafter MAH-S (5.5–7.0 m depth) and offshore Mahinahina-deep hereafter MAH-D (10-m depth).

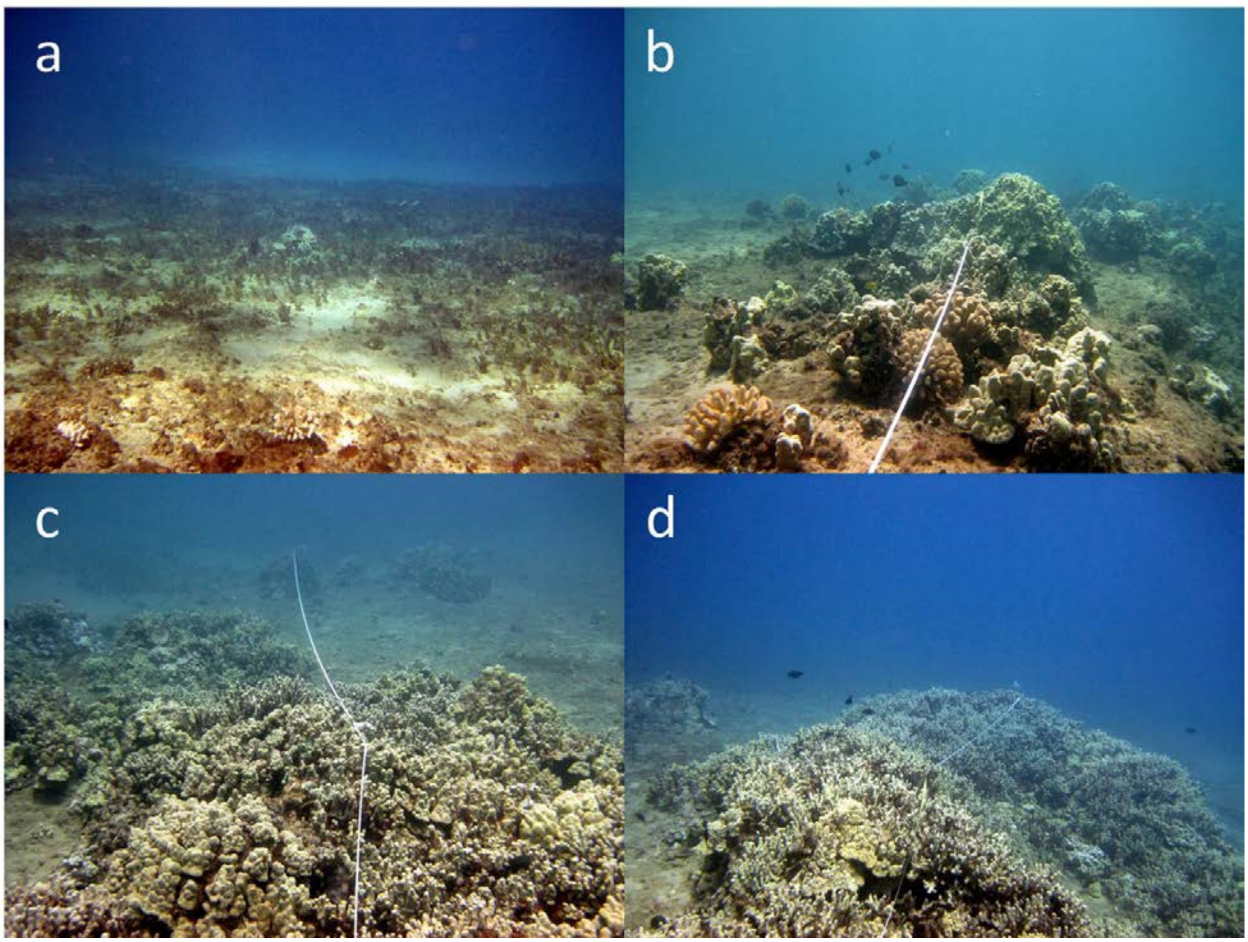

Figure 4- Underwater views of the coral communities at Mahinahina. Top panels (a–b): shallow site (MAH-S); lower panels (c–d): deep site (MAH-D). Photo credits: Hatsue Bailey, NOAA-PIFSC

Of all the monitoring sites assessed in this study, the reef in this sector exhibited the greatest variability in benthic structure and composition: the habitat at MAH-S was characterized by patchy, coral-poor pavement flats dominated by a combination of turf algae and *Halimeda* with sparingly distributed coral colonies. Contrastingly, much like the Honokōwai sites, the aggregate reef at MAH-D was characterized by a series of spur-like, coral-rich build-ups extending offshore at 10– 11 m depth (Fig. 4). Live coral cover at MAH-S was low, ranging between 0.0% and 14% (mean = 4.7, 4.7 SE); only one of the three transects harbored corals, a sparse amalgam of mounding *Porites* and *Pocillopora*. Disparately, MAH-D revealed relatively high live coral cover ranging between 39% and 45% (mean = 42.7%, 1.9 SE); a dense assemblage of *Porites lobata* (40%), *P. compressa* (38%), and *Montipora capitata* (20%).

Notably, no CCA was recorded along any of the survey transects at either the shallow or deep sites; and macroalgae was only documented at MAH-S averaging 2.3% (1.2 SE), mainly *Halimeda*. In contrast, turf algal cover was moderately high, comparable to the Honokōwai sites; 60% (1.0 SE) for MAH-S and 56.7% (3.8 SE) for MAH-D. For the Mahinahina sector, the BSR was equal to 0.1 for the MAH-S and 0.8 for MAH-D; the low value at the shallow site results from almost complete absence of calcifying organisms, a coral and CCA poor site. For MAH-D, the BSR was 0.8 indicating, like HON-D, some loss of calcifying capacity and compromised ecological function.

Similar to Honokōwai, 5 coral genera were recorded in the Mahinhina sector, in decreasing order of numerical abundance: *Porites*, *Montipora*, *Pocillopora*, *Pavona*, and *Leptastrea*; with *Leptastrea* only present at the shallow site. As expected, mean adult coral colony densities on the shallow pavement habitat were the lowest recorded in this study, 2.5 col/m^2 (0.5 SE, range = 1.6–3.1 col/m^2), while mean juvenile colony densities were among the highest, 11.7 col/m^2 (3.7 SE0, range = 6–18.7 col/m^2), predominantly *Montipora capitata* (87%). Contrastingly, on the deeper transects, mean adult colony densities were moderately high, averaging 17.4 col/m^2 (2.1 SE; range = 15–21.5 col/m^2), whereas mean juvenile colony densities were lower 6.7 col/m^2 (0.7 SE), comparable to those at Honokōwai. And, like at MAH-S, the juvenile coral population at MAH-D was dominated by *Montipora* (75%).

Mean colony partial mortality differed between the shallow and deep monitoring sites; it was moderate at MAH-S but second highest at the deep site, 15.7% (4.0 SE) and 28.6% (1.5 SE), respectively. Finally, mean prevalence of coral diseases and other lesions was low, particularly at the deep site, MAH-S = 3.2% (1.8 SE); MAH-D = 1.2% (0.84 SE), respectively. The overall mean prevalence of bleaching in this sector was low, altogether absent at the shallow site and almost negligible at the deep, 0.3% (0.2 SE).

3.4 Kaʻopala

Kaʻopala Gulch is in the Kahana watershed, which occupies ~ 2,373 Ha. Kaʻopala Gulch has a sediment retention basin in the agricultural area, but it is undersized relative to the drainage area, meaning that the trapping efficiency for sediment is likely less than ideal. This gulch reaches the ocean after a small channelized section passing through a residential area and connects to the ocean via a small diameter pipe. Historically and presently, this area is known for high sediment loading and turbidity.

Like most coral reef communities in the three northern watersheds, the reef adjacent to the Kaʻopala gulch does not extend to deep water, so only one monitoring site was established in this sector; inshore Kaʻopala-shallow, hereafter KAO-S. The aggregate reef at KAO-S was also characterized by a series of asymmertic, spur-like coral build-ups running offshore at 3–5 m deep (Fig. 5). Like Honokōwai, the Kaʻopala sector also exhibited considerably high levels of turbidity during surveys.

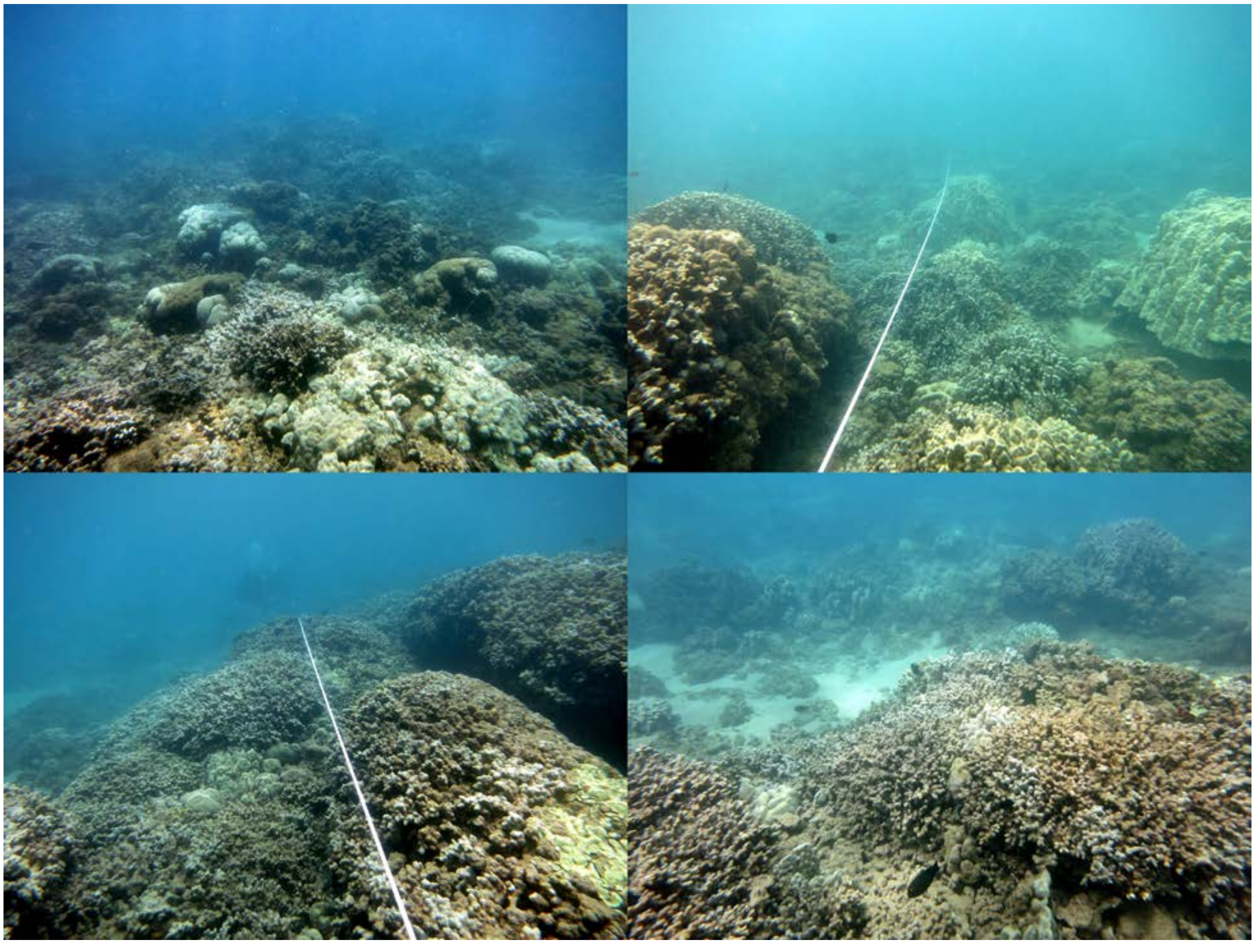
Figure 5- Underwater views of the coral community at Kaʻopala. Photo credits: Darla White, DAR Maui.

Live coral cover varied considerably between transects ranging between 15% and 29% with a mean value of 23.7% (4.4 SE). Of the three coral genera tallied, *Porites* represented 85% of the scleractinian fauna, with similar proportions of *P. lobata* and *P. compressa*. And, together, species of *Montipora* and *Pocillopora* amounted to 15% of the scleractinian fauna (Fig 5). Comparatively, coralline algal cover was high, 12.7% (3.2 SE), the highest level recorded in these baseline assessments. Although higher levels of CCA are not uncommon on shallow reef habitats, these results are somewhat unexpected given the elevated levels of turbidity observed at this site. Altogether, these findings are encouraging as well, because coralline algae are known to facilitate the recruitment of coral larvae, in contrast to macroalgae and turf algae which inhibit it. For the Kaʻopala sector, the Benthic Substrate Ratio was equal to 0.6 suggesting, that structure, composition, and function are compromised by stressors from human activities; this site is expected to exhibit lowered resilience.

Four coral genera were recorded at KAO-S; *Porites*, *Montipora*, *Pocillopora*, and *Pavona* of which *Porites* (an amalgam of *P. compressa* and *P. lobata*) represented 68% and *Montipora* 26% of the coral fauna. KAO-S adult colony densities were the second lowest recorded in this study (mean = 7.3 col/m^2, 1.3 SE; range = 6–9.9 col/m^2); likewise, juvenile colony densities were low as well, averaging 3.6 col/m^2 (1.2 SE; range = 1.3–5.3 col/m^2), comparable to those at HON-D. Colony partial mortality was variable between transects ranging between 28.1% and 37.5%, with a mean of 33.1% (2.7 SE), the highest recorded on these baseline surveys. Finally, mean prevalence of coral diseases and lesions was moderately low at 2.5% (0.7 SE) and mean prevalence of bleaching was just higher than background levels (4.5%, 0.6 SE). In short, in addition to the high levels of turbidity encountered during the surveys, the Ka'opala sector likely revealed some of the most severe, ongoing levels of LBSP impacts, manifested in four features: 1) low proportion of calcifying (coral+ CCA) to non-calcifying (macroalgae + turf algae) organisms; 2) exceedingly high levels of colony partial mortality 3) low adult colony densities; and 4) low juvenile colony densities.

3.5 Honokeana

Honokeana Gulch is located in the Kahana Watershed and ends at a small bay bordered by two vacation rental properties. Past issues with a sewage lift station in the bay resulted in water quality concerns. The gulch originates in former pineapple fields, and is flanked by high density residential and vacation properties towards the coast.

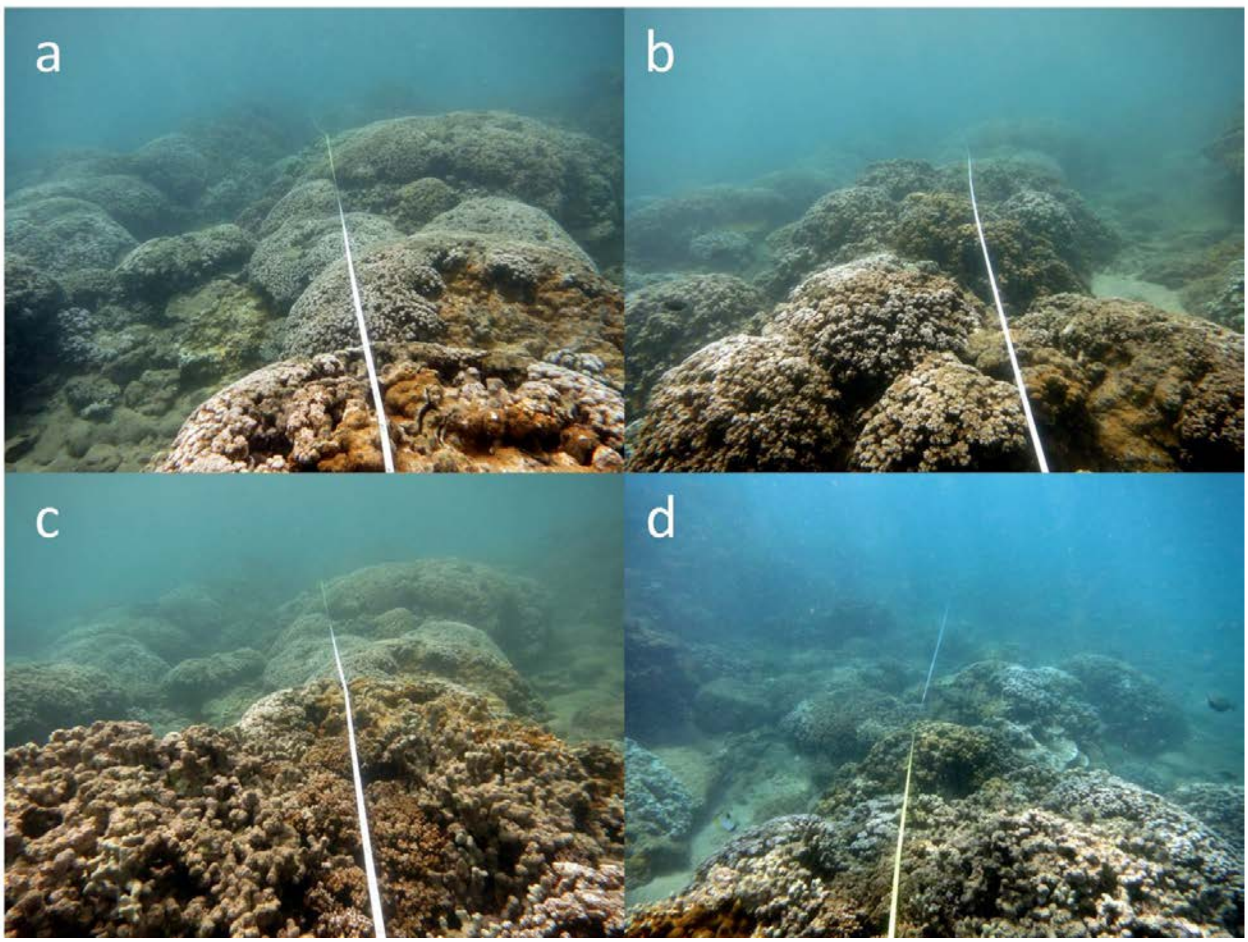

Figure 6- Underwater views of the coral-rich community at Honokeana Bay. Top panels (a–b): north site (HOE-n); lower panels (c–d): south site (HOE-s). Photo credits: Darla White, DAR Maui.

At Honokeana Gulch, coral communities carpet the north and south perimeters of this small, shallow bay (Fig 6). Two monitoring sites were established adjacent to the drainage: Honokeana-north, hereafter HOE-N (1.5–4.3 m depth) and Honokeana-south, hereafter HOE-S (1.8–3.4 m depth). Together with Wahikuli and Honokōwai, this sites exhibited the highest levels of coral cover recorded in this study, ranging between 28% and 48% at HOE-S (mean = 39.3% 8.9 SE) and 31%–55% at HOE-N (mean = 40.3%, 6.1 SE). HOE-S was closer to the drainage outfall, so it might be expected to exhibit poorer reef conditions than HOE-N. However, measures did not show this pattern consistently. Although coral cover did not differ between sites, some structural differences among other components of benthic cover were apparent, namely mean CCA was lower at HOE-S, 7.7 % (1.2 SE) than HOE-N, 12.7% (3.4 SE) and mean turf algae cover was higher, 50.7% (8.9 SE) and 41.3% (6.1 SE), respectively. Similar to most of the study sites, mean macroalgal cover was remarkably low at HOE-N, 0.33% (0.33 SE), and altogether absent at HOE-S. For Honokeana the BSR values were 0.9 for HOE-S and 1.3 for HOE-D; similar to Wahikuli, the higher proportion of calcifying (coral + CCA) to non-calcifying (macroalgae + turf algae) organisms indicate a healthier, less impaired, and resilient reef condition, contrasted to sites with lower proportion of reef calcifiers, like Ka'opala.

At Honokeana, 65–85% of the coral fauna consisted of an amalgam of *Montipora capitata* and *M. patula*, with the higher levels of *Montipora* recorded at the south site. *Porites compressa* and *P. lobata* amounted to 13–31% of all tallied coral colonies. Coral colony densities at HOE-N and HOE-S averaged 12.3 col/m^2 and 11.5 col/m^2, respectively for adults, and 1.9 col/m^2 and 3 col/m^2, respectively for juveniles; these were also predominantly *Montipora* (59% and 64%, respectively). Average colony partial mortality was lower on the north site, 9.3% (1.2 SE) compared to the south site, 14.4% (2.6 SE), potentially underpinning the differential proximity to the stream outfall. Finally, mean prevalence of diseases and bleaching were 6.3% (1.9 SE) and 3.9% (1.2 SE) for HOE-N, and 4.4% (0.7 SE) and 5.5% (1.7 SE), for the south site; the highest levels recorded in this study. The shallow nature of these sites (warmer water and higher UV irradiance) may contribute to the greater incidence of lesions and bleaching (Weil and Croquer 2009).

3.6 Honokahua

Located in the Honokahua Watershed, Honokahua Stream and Mokupea'a Gulch meet just before the coast and come into Honokahua Bay at D.T. Flemmings Beach Park. There are no diversions or basins in this drainage, and neighboring land use is dominated by fallow agriculture. This bay was impacted by highly turbid waters during the 2014–2015 construction of a luxury neighborhood up slope (citation?). The Plantation Golf Course also drains partially into this area.

The reef adjacent to the Honokahua drainage does not extend to deep water, so only one monitoring site was established, inshore Honokahua-shallow, hereafter HOK-S (2.4–4.3 m depth). The aggregate reef in this sector appears to have undergone severe LBSP impacts, resulting in a series of coral-poor, heavily bioeroded carbonate buildups (Fig. 7). Together with the MAH-S site, HOK-S exhibited the lowest levels of live coral cover (8–14%) with a mean value of 11.3% (1.7 SE). Correspondingly, mean cover of coralline algae and macroalgae were also low, 3.3% (1.9 SE, range = 1–7%) and 0.3% (0.3 SE, range = 0.0–1.0%), respectively, whereas turf algae covered on averaged 84% (1.4 SE) of the benthos. At HOK-S, the proportion of calcifying (coral +CCA) to non-calcifying (macroalgae + turf algae) organisms amounted to 0.2. This was the lowest recorded in this study, suggesting an impaired reef condition where the structure, composition, and function appear to be seriously compromised. This value also indicates that the reef community at Honokahua has low resilience potential.

Porites lobata and *P. compressa* represented 79% of the coral fauna, followed by *Montipora (M. capitata*, *M. flabellata*, and *M. patula*) and *Pocillopora meandrina* which amounted to 12% and 9%, respectively. Not unexpectedly, mean adult colony densites were relatively low (10.5 col/m^2, 0.5 SE), while juveniles were relatively high (8.9 col/m^2, 0.9 SE). For individual genera, 63% of the adult colonies were *Porites* and 56% of the juvenile colonies were *Montipora*. Partial mortality was moderate, ranging between 15% and 19% (mean = 17.5% 1.2 SE) and mean prevalence of disease and bleaching were also low (1.3% and 3.8%, respectively); both in the background level range.

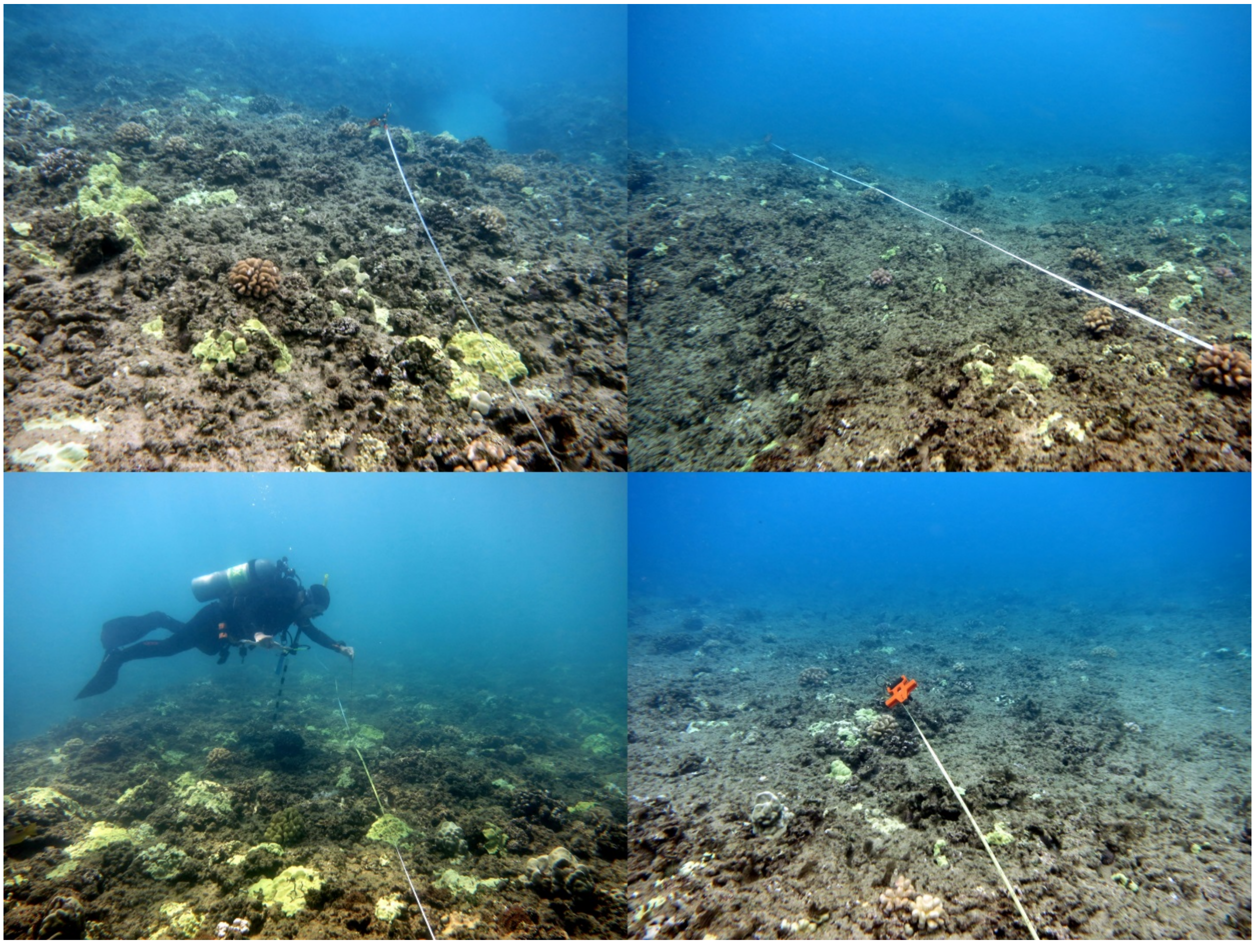
Figure 7- Underwater views of the coral-poor community at Honokahua. Photo credits: Darla White, DAR Maui.

3.7 Honolua

Honolua Watershed is ~ 1,225 Ha and is unique in that 75% of the land use is in conservation, the balance of which is in fallow agriculture. Honolua Stream is the only one in the five watersheds that flows more-or-less regularly, an estimated 80% of the time. There are no desilting basins in this drainage and high sediment loading and turbidity have long been a concern in this area. Since 1990, the reef at Honolua Bay has experienced a dramatic (~ 75%) decline in live coral cover, which appears to have been a gradual, step-wise process, rather than the effect of a single runoff event (Dollar and Grigg 2004, Chaston and Oberdig 2007); since 2007, benthic composition has remained relatively stable.

Two monitoring sites were established within the Bay: Honolua-shallow, hereafter HOA-S (1.5–2.7 m depth) and Honolua-deep, hereafter HOA-D (6.7–9.0 m depth); the HOA-S survey transects were purposely laid to coincide with the CRAMP long-term monitoring sites (Fig 8). Coral cover varied considerably between sites, ranging from 17–38% at HOA-D (mean = 29%, 4.6 SE) to 10–15% on HOA-S (mean = 13.3%, 1.6 SE). Comparatively, mean CCA and turf algal cover were greater on HOA-S 7.8 % (2.1 SE) and 75.3% (2.3 SE, respectively, compared to HOA-D, 1% (0.4 SE) and 58.8% (5.9 SE), respectively; and overall levels of macroalgae were low (0.0–2.0%). The proportion of calcifying (coral +CCA) to non-calcifying (macroalgae + turf algae) organisms amounted to 0.3 on the shallow site and 0.5 on the deep site, corroborating that the dramatic coral and CCA cover losses have resulted in an impaired reef condition, where the structure, composition, and function appear to be compromised by stressors from human activities; as such is expected for these sites to have low resilience potential.

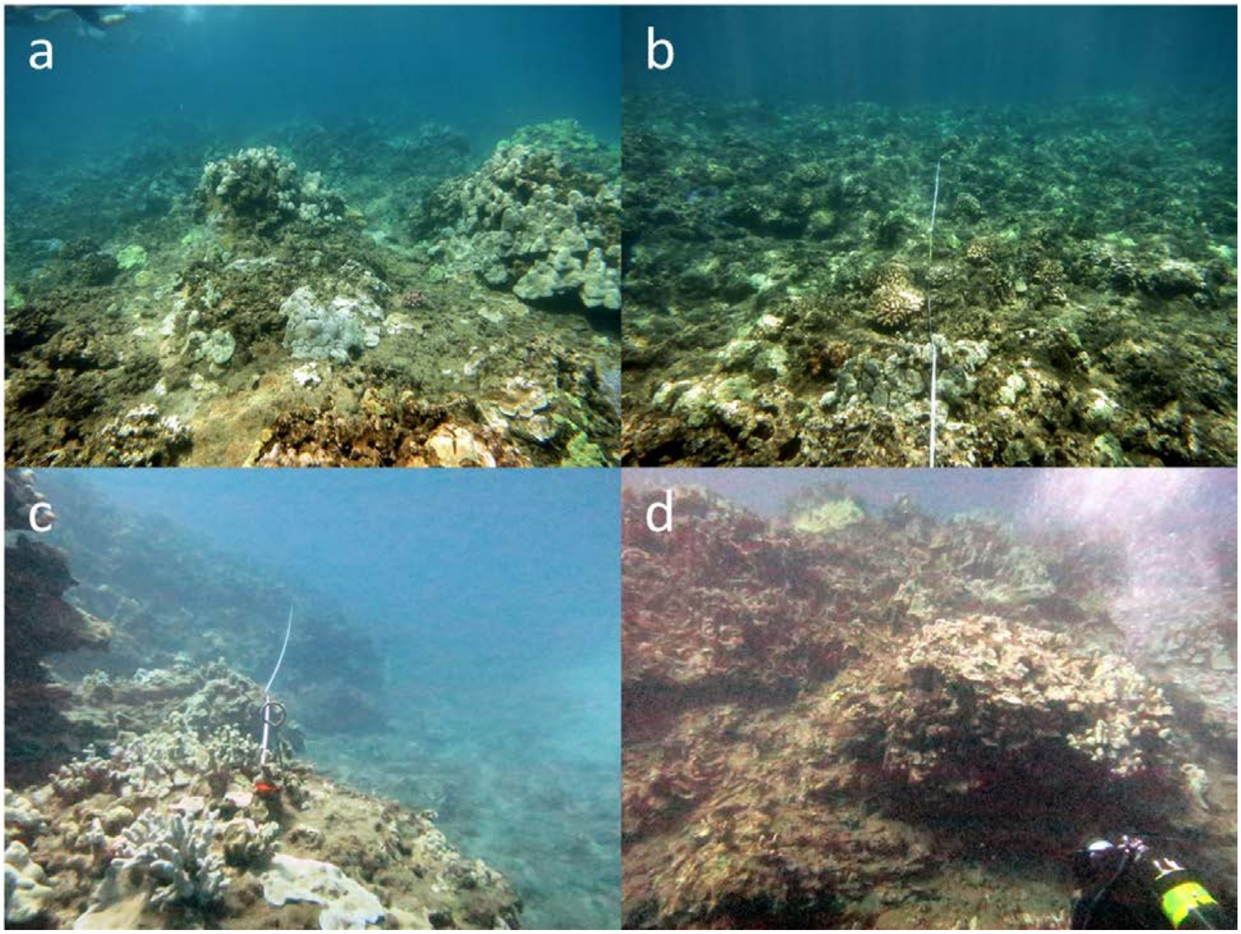

Figure 8- Underwater views of the coral community at Honolua Bay Top panels (a-b): shallow site (HOA-S); lower panels (c-d): deep site (HOA-D). Photo credits: Darla White, DAR Maui.

Of the 7 scleractinian genera tallied, the highest for any of the study sites, more than 90% of the coral colonies were *Porites*, *Montipora*, and *Pavona* (in order of decreasing relative abundance). Mean colony densities were comparable to the sites adjacent to the Honokeana and Honokahua streams: 9.6 col/m^2 (1.3 SE) on HOA-S and 13.9 col/m^2 (1.8 SE) on HOA-D. While 45% and 37% of the colonies tallied on HOA-D were *Porites* and *Montipora* respectively, *Montipora*, *Pavona*, and *Porites* each contributed close to 30% of the colonies on HOA-S. Mean colony partial mortality was moderate at both the shallow and deep sites, 18.8%, and 16.4%, respectively; comparable to the levels reported for Honokahua. Interestingly, colonies of *Pavona* exhibited the highest mean partial mortality, 23.1% (2.7 SE) on HOA-D and *Porites* on HOA-S, 29.3% (3.6 SE). Finally, the mean prevalence of disease and bleaching were low, indicating background levels: 0.6% (0.4 SE) and 1.2% (0.5 SE) at HOA-S, and 2.3% (1.3 SE) and 1.4% (0.5 SE) at HOA-D.

4. Environmental Context
Sediment plumes off West Maui are largely sourced from bank erosion of historic fill terraces (Stock et al., *in prep*). Their presence is a clear indication that the upstream sediment-retention basins are not working properly at stopping the sediment load from all small storms, as expected (Storlazzi et al., 2015).

4.1 Terrestrial sediment baseline
Summary statistics of the terrestrial sediment dynamics and turbidity data derived from the deployment of optical backscatter sensors (OBS), sediment traps, and sediment pods at select study sites, for the September 2014–October 2016 period are presented in Tables 2 and 3. Problems with biofouling of optical backscatter sensors prevented a temporally explicit dataset; notwithstanding a subset of successful deployments and retrievals indicated that the Honokōwai site (HON-S) exhibited the highest levels of underwater turbidity year round, with winter values being almost 4-fold greater than for the summer; likely associated with greater levels of rainfall during those months.[1] Comparatively, water turbidity was much less at Mahinahina and Wahikuli, with no differences between sites for the summer months, but more than 6-fold difference between MAH-S and WAH-S during the winter months.

Table 2. Mean underwater turbidity (NTU) derived from the deployment of optical back-scatter turbidity sensors (OBS) at the Mahinahina (MAH-S), Honokōwai (HON-S), and Wahikuli (WAH-S) siteS.

Season	Statistic	MAH-S	HON-S	WAH-S
Summer	Mean	0.30	0.91	0.30
	Std. deviation	0.16	0.33	0.10
	Minimum	0.17	0.39	0.19
	Maximum	0.92	2.01	0.68
Winter	Mean	1.57	3.53	0.23
	Std. deviation	3.89	5.68	0.18
	Minimum	0.14	0.11	0.03
	Maximum	29.93	53.07	1.22

Logistical challenges with the quarterly retrieval of sediment pods and traps, in addition to some traps and pods being disturbed, also limited the acquisition of a continuous temporal coverage of sediment monitoring data (Table 3). Although the limitations of the data preclude a sound temporal trends evaluation, some general spatial patterns are discernible; an overall gradient in the composition of sediment, with a notable greater percentage of terrigenous sediment at Wahikuli compared to Honokōwai and Mahiahina for all size fractions. Comparatively, the relative terrigenous vs. carbonate content for the different size fractions was similar for the Honokōwai and Mahiahina sites.

4.2 Terrestrial sediment loading and turbidity
Due to number of challenges experienced with the collection of turbidity and sediment composition data at the three instrumented water quality monitoring sites, and to better understand the potential linkages between the status of the reef communities at the study sites and their prevailing environmental regime, spatial annual means for sediment loading and turbidity were accessed from (Falinski et al., *in press*) and the Hawaii Department of Health water quality monitoring program.[2]

[1] https://hi.water.usgs.gov/recent/hawaii/puukukui.html
[2] (http://emdweb.doh.hawaii.gov/CleanWaterBranch/WaterQualityData/default.aspx

Table 3. Sediment composition terrigenous (TERR) vs carbonate ($CaCO_3$) and size fraction analysis of samples collected on sediment traps and sediment pods deployed at the Mahinahina, Honokōwai, and Wahikuli sites. Sample ID prefix denotes sample site locations as follows: MAH-S: Mahinahina shallow; HON-S: Honokōwai shallow, and WAH-S: Wahikuli shallow.

SAMPLE ID-DATE	BULK %TERR	BULK %$CaCO_3$	SAND %TERR	SAND %$CaCO_3$	SILT %TERR	SILT %$CaCO_3$	CLAY %TERR	CLAY %$CaCO_3$
MAH-S-091714_trap	28.12	71.88	20.61	79.39	42.12	57.88	51.63	48.37
HON-S-091714_trap	34.22	65.78	20.67	79.33	36.11	63.89	47.52	52.48
WAH-S-091714_trap	44.73	55.27	36.06	63.94	58.69	41.31	64.02	35.98
MAH-S-031615_pod	31.58	68.42	21.19	78.81	46.60	53.40	61.13	38.87
HON-S-031615_pod	30.54	69.46	24.62	75.38	35.90	64.10	48.79	51.21
WAH-S-031615_pod	52.49	47.51	51.19	48.81	68.75	31.25	73.94	26.06
MAH-S-031615_trap	31.64	68.36	20.52	79.48	37.85	62.15	50.08	49.92
HON-S-031615_trap	60.49	39.51	22.98	77.02	38.39	61.61	49.01	50.99
WAH-S-031615_trap	44.15	55.85	39.78	60.22	66.60	33.40	70.28	29.72
MAH-S-031416_pod	23.27	76.73	21.94	78.06	55.97	44.03	61.62	38.38
HON-S-031416_pod	26.08	73.92	25.53	74.47	54.74	45.26	66.37	33.63
WAH-S-031416_pod	43.24	56.76	39.72	60.28	62.27	37.73	64.06	35.94
MAH-S-031416_trap	26.03	73.97	19.75	80.25	42.53	57.47	51.90	48.10
HON-S-031416_trap	28.12	71.88	17.94	82.06	40.78	59.22	53.95	46.05
WAH-S-031416_trap	44.30	55.70	44.01	55.99	62.04	37.96	70.34	29.66
MAH-S-091216_pod	23.14	76.86	21.29	78.71	48.90	51.10	54.60	45.40
HON-S-091216_pod	32.79	67.21	25.12	74.88	42.29	57.71	52.84	47.16
WAH-S-091216_pod	52.82	47.18	46.74	53.26	58.52	41.48	61.15	38.85
MAH-S-091216_trap	22.30	77.70	17.71	82.29	47.24	52.76	55.32	44.68
WAH-S-091216_trap	41.86	58.14	39.04	60.96	60.86	39.14	67.71	32.29

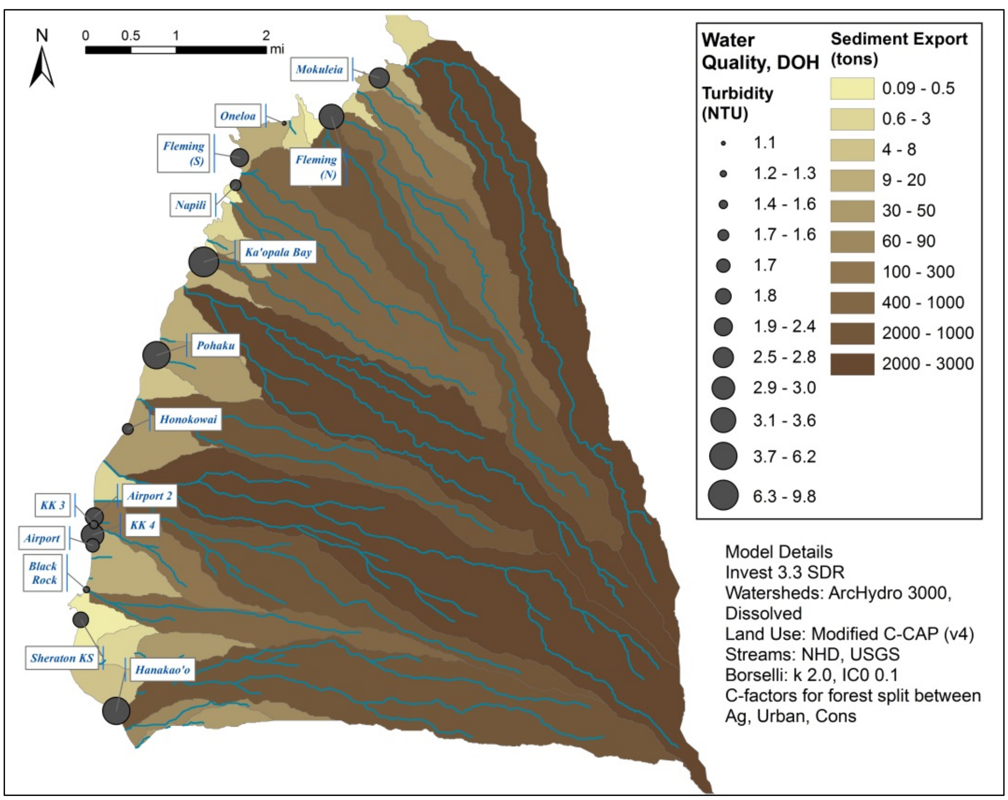

Figure 9- Geo-referenced map illustrating the estimated regional sediment export patterns on West Maui, derived from Invest 3.3 SDR model (Falinski et al., in press).

Figure 9 and Table 4 illustrate and itemize the patterns of modeled terrestrial sediment loading and water turbidity for West Maui. Upon close examination, these data indicate that the Honokōwai, Kaʻopala, and Honolua streams are projected to contribute the highest levels of terrestrial sediment loading to West Maui's coastal waters, whereas the Honokeana and Wahikuli streams the lowest. Kaʻopala is modeled to have the highest levels of water turbidity, followed by Wahikuli and Honokahua. These model data, particularly the high levels of turbidity at Wahikuli, contrast with the baseline values obtained from the optical backscatter sensors deployed in this study. The lower values in this study were likely due to the lack of continuous temporal coverage, which probably excluded a number of terrestrial sediment-discharge events that occurred during the rainy season.

Table 4. Projected sediment export (tons) and turbidity (NTU) values for t select watershed locales on West Maui. Sediment export values were derived from the Invest 3.3 SDR model (Falinski et al., in press); turbidity data herein was obtained from the Hawaii Department of Health water quality database and the annual average values obtain from the deployed optical backscatter sensors.

Watershed/site name	Latitude	Longitude	Loading (Tons)	Turbidity (NTU)
Wahikuli	20.91002	-156.68917	1366	6.04
Honokōwai	20.94127	-156.69244	3362	2.17
Mahinahina	20.95528	-156.68647	1246	1.63
Kahana/Kaʻopala	20.98197	-156.67308	2678	9.84
Napili/Honokeana	20.99422	-156.66742	562	1.61
Honokahua	21.00500	-156.65084	1396	3.61
Mokuleia/Honolua	21.01111	-156.64256	2208	2.84

It should be noted that not all drainages have coastal turbidity data, i.e., Kahana stream consistently shows the highest modeled sediment export, but there is no coastal monitoring to verify turbidity values. While co-authors agree that the modeled data is a fair approximation to the visually assessed extent and severity of the observed turbidity plumes, some of our conclusions may be limited to those areas for which field validation data exist, and may not provide the complete portrayal of the sediment impacts to corals on West Maui.

5. Regional Benthic Characterization

The georeferenced maps presented herein were assembled using all available data irrespective of collection method, in order to best contextualize the results of the site-specific biological baseline.

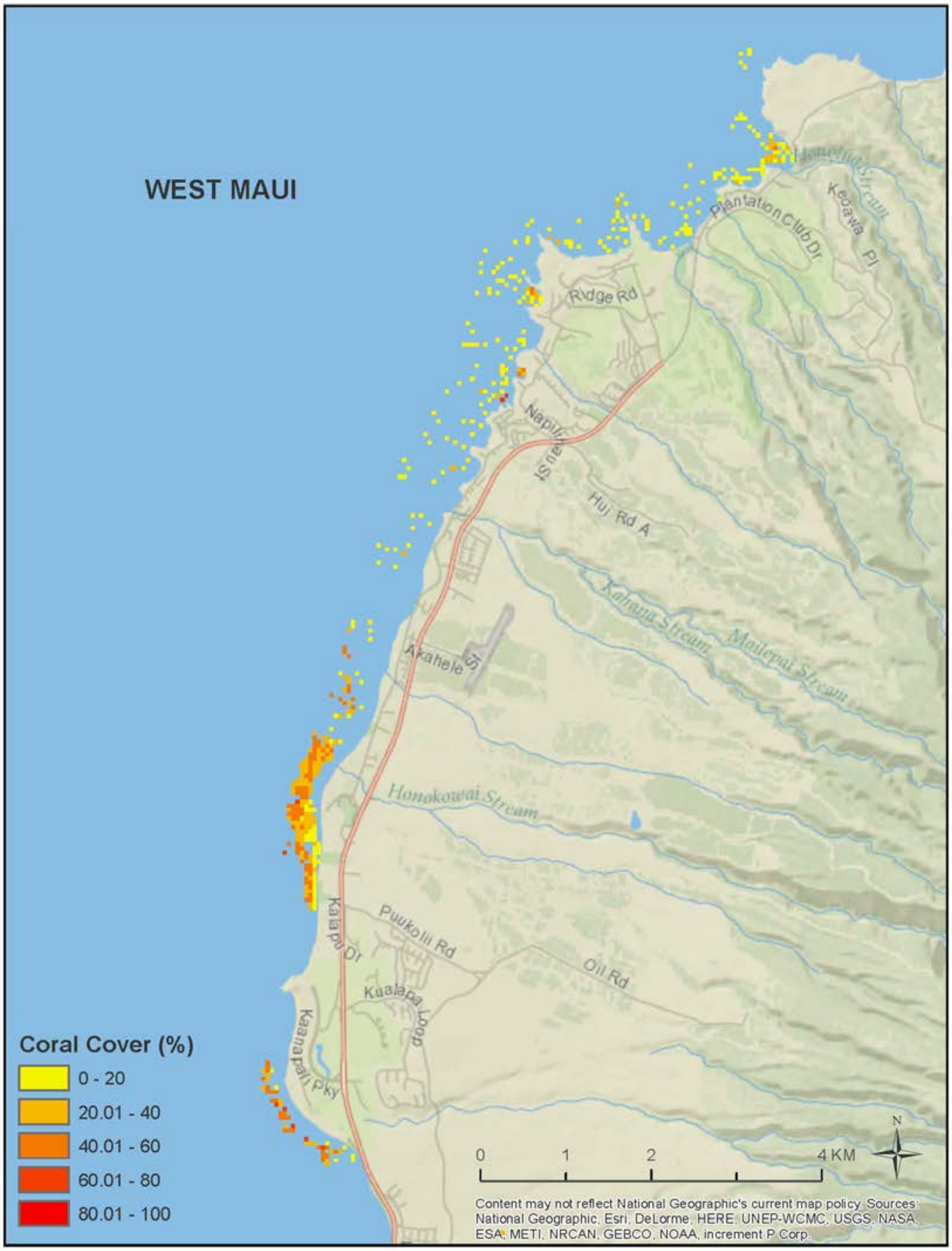

Figure 10- Geo-referenced map illustrating the regional patterns of hard coral cover on the larger West Maui region, in relation to each of the 5 priority watersheds.

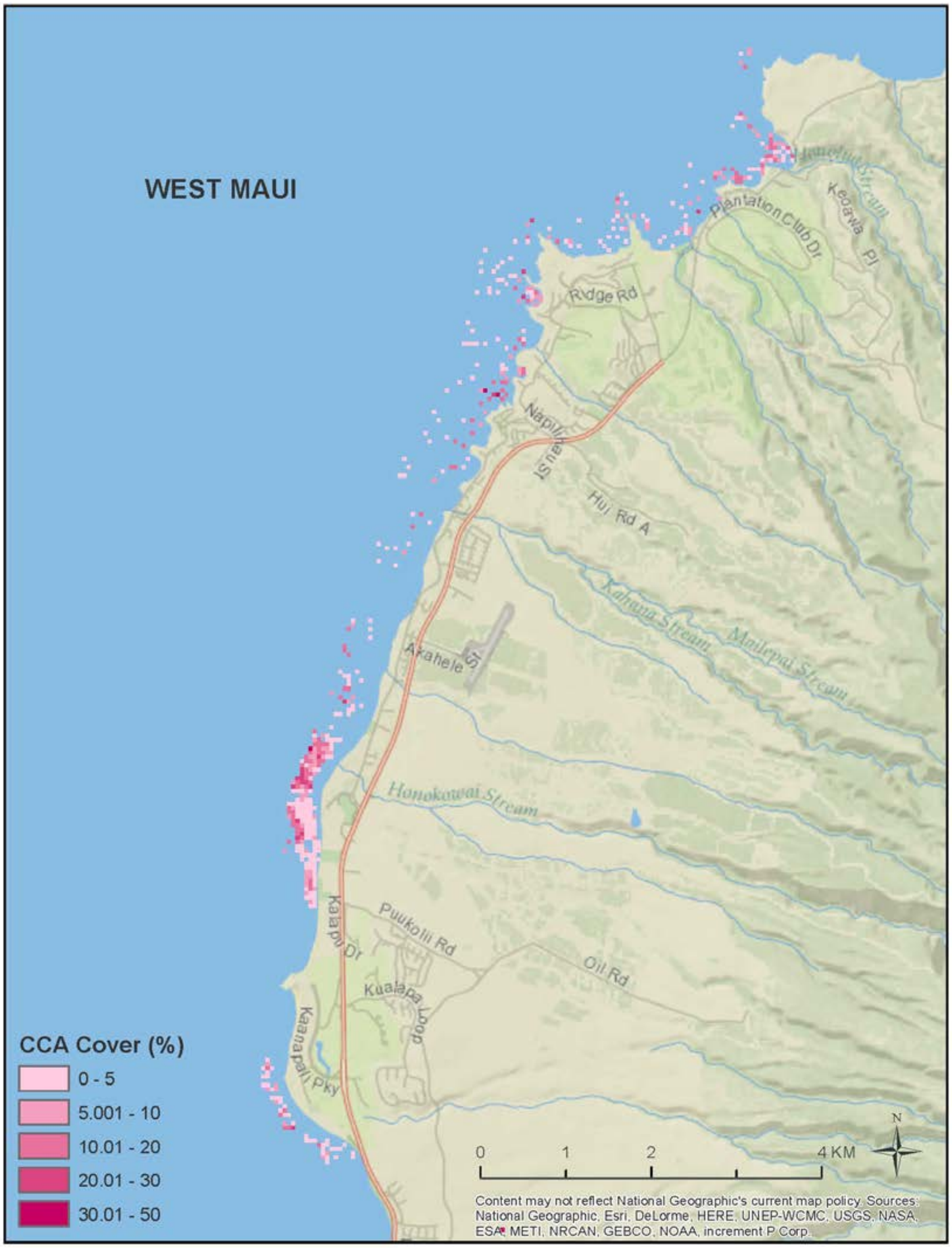

Figure 11- Geo-referenced map illustrating the regional patterns of coralline algal cover on the larger West Maui region, in relation to each of the 5 priority watersheds.

Figure 12- Geo-referenced map illustrating the regional patterns of macroalgae cover on the larger West Maui region, in relation to each of the 5 priority watersheds.

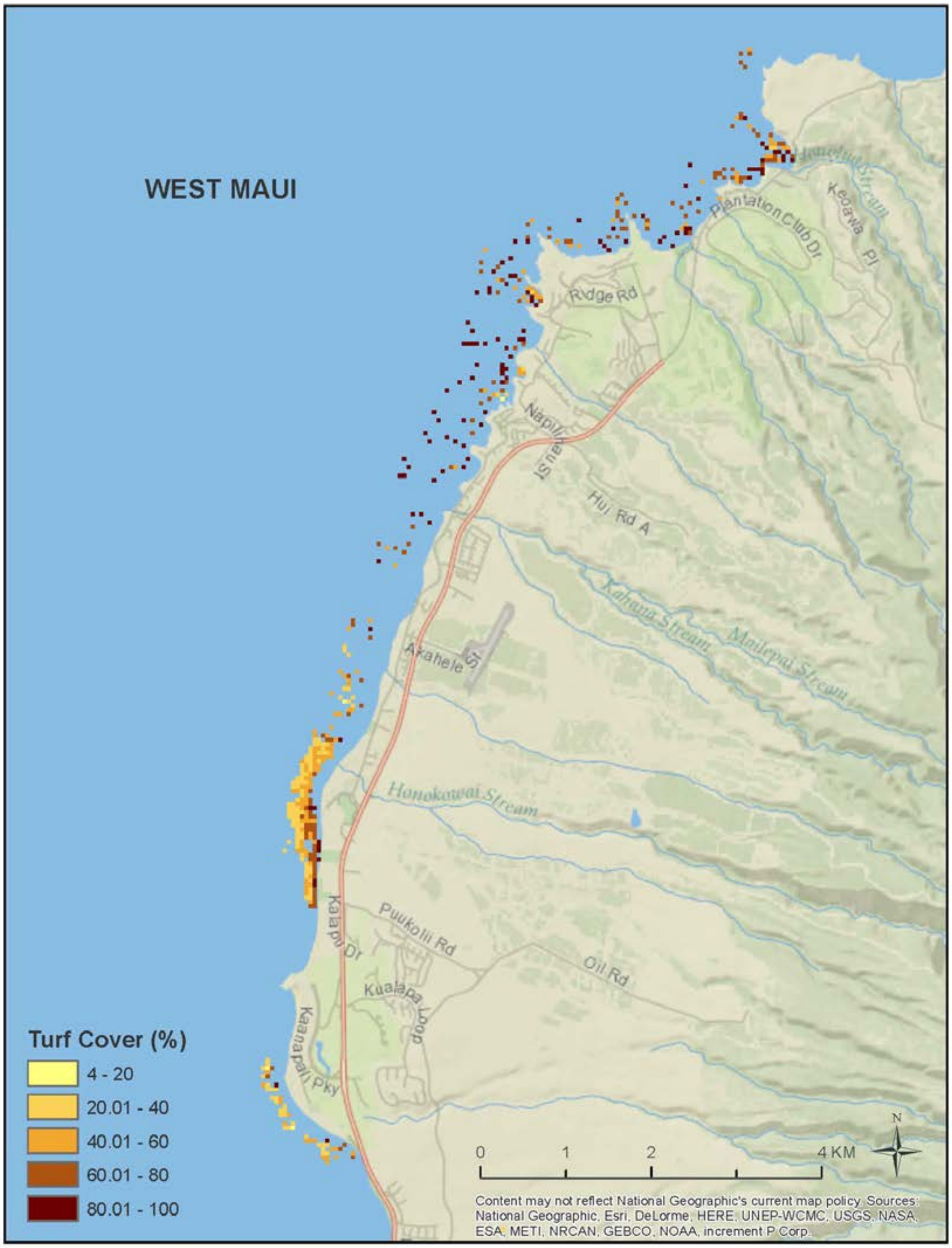

Figure 13- Geo-referenced map illustrating the regional patterns of turf algal cover on the larger West Maui region, in relation to each of the 5 priority watersheds.

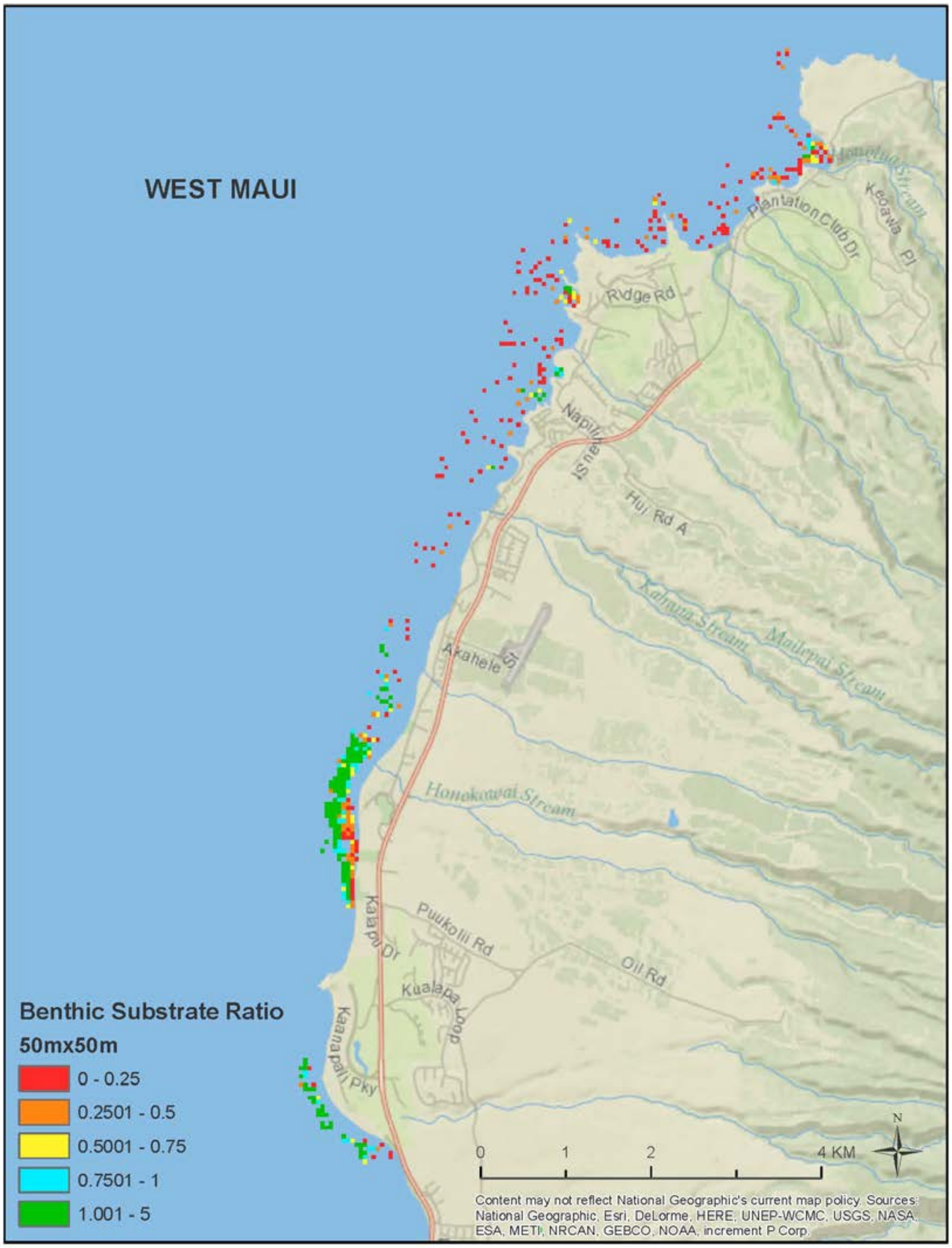

Figure 14- Geo-referenced map illustrating the regional patterns of the benthic substrate ratio [BSR = (coral + crustose coralline algae) ÷ (macroalgae + turf algae)] on the larger West Maui region, in relation to each of the 5 priority watersheds.

West Maui regional patterns of benthic cover illustrated in Figs 10–14 indicate that the highest levels of hard coral cover along West Maui were located in the larger Kaʻanapali area adjacent to the Wahikuli and Honokōwai stream drainages, particularly the Canoe Beach and Kahekili Beach Park areas. This is remarkable, given the elevated levels of chronic anthropogenic impacts prevalent along this area. Patchily distributed coral-rich assemblages were also found to occur in the Kahana Watershed, particularly Kapalua and Honokeana Bays and the area between Honokeana Cove and ʻAlaeloa Point (Fig 10). It has been proposed that the historic differences in land use between the northern and southern West Maui watersheds (i.e., pineapple farming vs. sugarcane farming, respectively) are profoundly implicated in the present levels of coral development on West Maui (Group 70 2016). Currently, coral cover is overall lower and LBSP impacts greater and more widespread throughout the northern watersheds were pineapple was historically cultivated, compared to the southern watersheds where sugarcane was grown. While both pineapple and sugarcane cultivation are heavily dependent on regular and intense use of toxic agrochemicals, pineapple growth requires special soil drainage and aeriation conditions that greatly increase terrain instability and erodibility (Bartholomew et al. 2002).

Consistently, many of the areas containing coral-rich assemblages also harbored relatively high CCA cover, with additional pockets of high CCA cover at Hawea Point and Honolua Bay (Fig 11). Macroalgae cover was relatively low in the Wahikuli and Honokōwai watersheds compared to the northern three watersheds, particularly at Hawea Point, Honokahua Bay, and Honolua Bay (Fig 12). Similarly, levels of turf algal cover were predominantly higher throughout the Kahana, Honokahua, and Honolua Watersheds compared to the south, except for the coral-rich pockets at Kapalua and Honokeana Bays (Fig. 13). Finally, the benthic substrate ratio corroborates that the areas that harbored the best coral reef communities with higher resilience and recovery potential area were clearly located off Canoe Beach and Kahekili Beach Park in the Wahikuli and Honokōwai Watersheds, respectively (Fig 14). Contrastingly, except for the few coral-rich pockets located in Kapalua and Honokeana Bays, and between Honokeana Cove and Alaeloa Point, the Kahana, Honokahua, and Honolua Watersheds harbor coral communities that exhibit signs of LBSP impacts and coral community decline ranging from moderate to severe.

6. Synthesis and Discussion

The coral reef communities of West Maui exhibit a wide range of variability regarding their structure, composition, and condition, which reflects the complex pattern of biological, environmental, and disturbance regimes prevalent across the region. This baseline assessment revealed that mean coral cover varied widely from a high of 49% at Wahikuli-shallow to a low 4.6% at Mahinahina-shallow. Similarly, coralline algal cover averaged 12.7% at Ka'opala and Honokeana-north but was altogether absent at the Mahinahina sites. Interestingly, macroalgae was a minor component of the benthos across all study sites, representing only up to 2.3% at Mahinahina-south, while turf algae varied considerably from a low of 41% at Honokeana-north to a high of 84% at the Honokahua site (Fig 15). Consequently, the benthic substrate ratio also varied considerably across West Maui, with the highest values (≥ 1) that suggest healthier reef conditions reported for the Wahikuli and Honokeana sites and the lowest values (≤ 0.5) that suggest impairment in structure and function reported at the Honolua and Honokahua sites. Nonetheless, despite the relatively high benthic substrate ratios at Wahikuli, both study sites in this watershed exhibited advanced levels of urchin bioerosion, resulting in extremely fragile reef structures prone to easy breakage. This is worrisome because structurally unstable corals are easily dislodged or knocked-off, accelerating the mortality process. As such, these relatively healthy reefs are at high risk of severe damage from physical impacts, such as storm waves, vessel anchoring and groundings, and even divers as they inadvertently contact the reef structure with their gear. The low benthic substrate ratio for the Mahinahina-shallow site (0.1) was largely due to the absence of calcifying organisms (corals + CCA); this site is characterized by a distinctly different benthic assemblage.

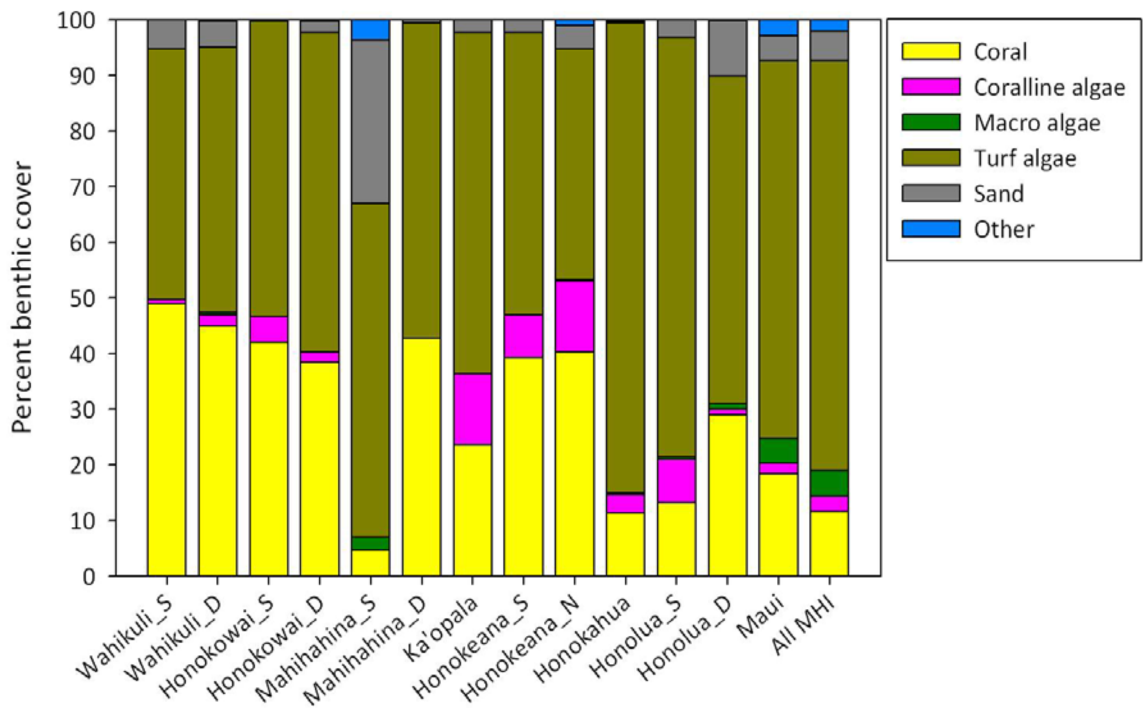

Figure 15- Comparison of mean benthic cover by functional group for the different survey sites off West Maui. Sites are arranged in geographical order from south to north (left to right). Mean benthic cover values for Maui Island and all the main Hawaiian Islands combined (All MHI) added for reference.

Despite their differences in benthic composition and structure, West Maui reef communities represent a key local resource and a counterpoint to the overall low coral reef development levels both island- and state-wide. This is of high relevance because the occurrence of coral-rich assemblages and expansive reef complexes statewide is sparse. Only limited segments along the coastlines of Maui, Hawaiʻi, Lanaʻi, Molokaʻi, and Kahoʻolawe harbor mature, fringing coral reefs; unfortunately, many of these are also seriously threatened by terrestrial runoff (Dollar and Grigg 2004; Jokiel et al. 2004, Jokiel 2006). Approximately 75% of the study reefs exhibited coral cover values exceeding the average island- and state-wide estimates (Fig 15). Relatedly, the mean cover of macroalgae was lower on West Maui; except for the reefs at Mahinahina, Wahikuli-shallow, and Honolua-deep; CCA cover was also greater on West Maui, which contrasted to the island- and state-wide benchmarks. For West Maui, like many reefs worldwide, corals and CCA represent the main source of reef limestone. Although CCA are fundamental to the buildup, maintenance, and temporal persistence of coral reef structures (Littler and Littler 1984; Klumpp and McKinnon 1992), there is also evidence that settlement and metamorphosis of key reef benthic taxa, including scleractinian corals, are induced by external biochemical cues produced by live CCA (Lasker and Kim 1996; Harrington et al. 2004). Because coral recovery is among the top goals of both the U.S. Coral Reef Task Force and the West Maui Watershed Management Plan, restoration efforts moving forward need to incorporate activities that control and reduce the influx of terrestrial sediment and nutrients (resulting in more light for corals and less fertilizers for marcoalgae and turfalgae) to the adjacent marine environment. Promoting the proliferation of CCA is a critical step to increasing the resilience and recovery potential of high-priority reefs; to this end, effective herbivore fisheries management appears to be a key aspect step in that direction (Williams et al., 2016).

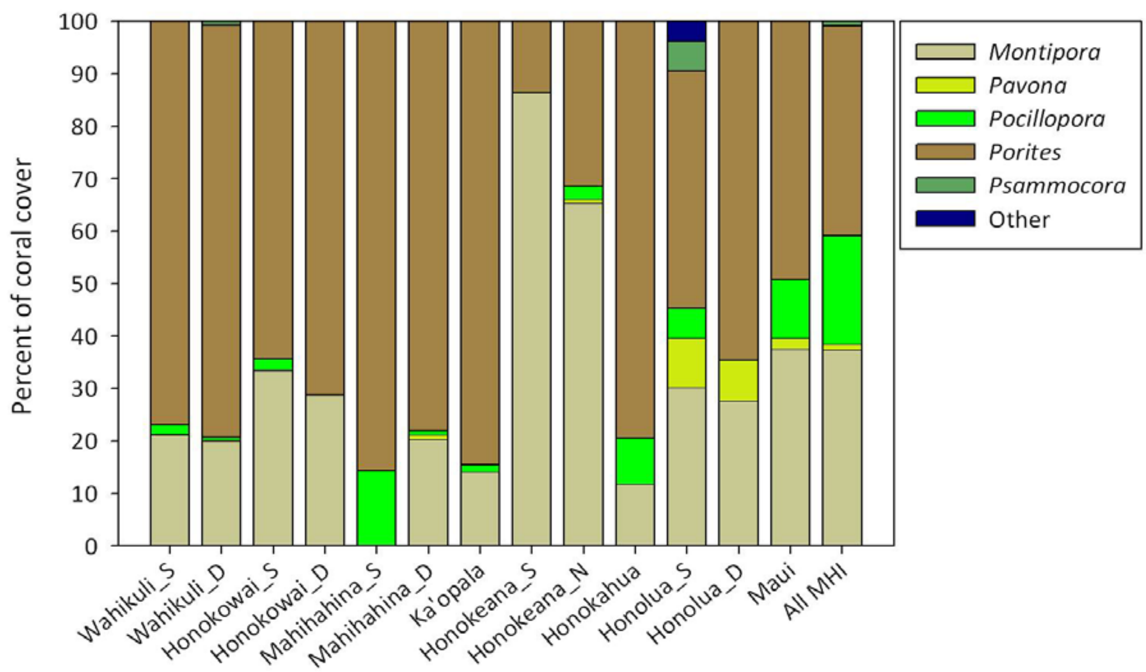

Figure 16- Comparison of mean coral cover by genus for the different survey sites off West Maui. Sites are arranged in geographical order from south to north (left to right). Mean percent of coral cover values for Maui Island and all the main Hawaiian Islands combined (All MHI) added for reference.

With regards to the coral composition, the genera *Porites*, *Montipora*, and *Pocillopora* combined accounted for over 90% of the live coral cover at all survey sites; except for Honolua-shallow, where the genus *Pavona* was more abundant than *Pocillopora*. The genus *Porites*, mainly *P. lobata* and *P.*

compressa, were ubiquitous and together represented over 60% of the live coral cover at all study sites, except for the Honokeana Bay which was dominated by an amalgam of *Montipora capitata* and *M. patula*, and the shallow site at Honolua Bay, where of the 13.3% mean coral cover, the genus *Porites* accounted for 45% (Fig. 16). A synthesis of extensive literature data (Erftemeijer et al., 2012) indicates that corals can be roughly categorized according to their relative sensitivity to turbidity and sedimentation based on their growth and morphology; with massive, encrusting, and branching corals being quite tolerant to high rates of sedimentation (≥ 200 $mg/cm^2/day$), and columnar, encrusting, and massive species being the most tolerant to high levels of suspended sediments (≥ 100 mg/L). As such, it is no coincidence that in this study all survey sites were dominated by sediment- and turbidity-tolerant coral species: massive (*Porites lobata*), encrusting (*Montipora* spp.), and branching (*Porites compressa*, *Montipora capitata*, and *Pocillopora* spp.).

Table 5. Scleractinian coral richness at the different survey sites off West Maui. Sites are listed in geographical order from south to north. WAH: Wahikuli; HON: Honokōwai; MAH: Mahinahina; KAO: Ka'opala; HOE: Honokeana; HOK: Honokahua; HOA: Honolua. S: shallow; D: deep; n: north; s: south.

CORAL SPECIES	WAH-S	WAH-D	HON-S	HON-D	MAH-S	MAH-D	KAO-S	HOE-s	HOE-n	HOK-S	HOA-D	HOA-S
Cyphastrea ocellina			X									
Leptastrea bewickensis					X							
Leptastrea purpurea												X
Leptoseris incrustans											X	
Leptoseris mycetoseroides											X	
Montipora capitata	X	X	X	X	X	X	X	X	X	X	X	X
Montipora flabellata							X		X	X		X
Montipora incrassata			X									X
Montipora patula	X	X	X	X	X	X	X	X	X	X	X	X
Pavona chiriquiensis										X		
Pavona duerdeni	X	X								X	X	X
Pavona maldivensis	X		X			X						
Pavona varians	X	X	X	X		X	X	X	X	X	X	X
Pocillopora damicornis			X				X	X	X			
Pocillopora eydouxi	X	X	X		X		X	X		X		X
Pocillopora meandrina	X	X	X	X	X	X	X	X	X	X	X	X
Pocillopora woodjonesi												X
Porites bernardi											X	
Porites brighami		X									X	
Porites compressa	X	X	X	X		X	X	X	X	X	X	X
Porites duerdeni	X						X	X	X	X	X	X
Porites evermanni	X	X								X		
Porites lichen	X	X										
Porites lobata	X	X	X	X	X	X	X	X	X	X	X	X
Porites monticulosa							X			X	X	
Porites solida		X				X					X	
Psammocora nierstraszi												X
Psammocora stellata	X									X		
TOTAL	13	12	11	6	6	8	11	9	9	14	14	14

Of the 28 scleractinian species tallied in this study, the sites at Honolua-shallow and Honokahua showed the highest coral species richness, with a total of 14 species each. Contrastingly, only 6 species were tallied at the Honokōwai-deep and Mahinahina-shallow sites (Table 5). Because increased turbidity and terrestrial sediment have negative impacts on diversity, these latter findings are not unexpected given that Honokōwai exhibited the highest levels of sediment loading, based on the sediment export values modeled by Falinski et al. (in press) (Table 4). In addition, as indicated above, the Mahinahina-shallow site was characterized by a distinct non reef-building benthic assemblage, dominated by turf and macroalgae growing on a carbonate pavement.

On the other hand, the greater species richness at Honolua-shallow and Honokahua was surprising given that these areas have observed significant historic impacts from increased turbidity and terrestrial sediment in recent decades. This is particularly so for Honolua Bay where sediment from an agricultural field deposited in the bay during the dramatic 2002 runoff event, persisting from over 6 months and resulting in loss of coral cover by 33% between 1992 and 2002 (Dollar and Grigg 2004). Alternatively, by virtue of being shallow (2–4 m) and relatively protected from large waves and high winds, the Honolua and Honokahua sites provide adequate light and habitat conditions that may support greater scleractinian coral species richness. In addition, Wahikuli-shallow (another well-lit and moderately sheltered site) ranked second highest in richness with a total tally of 13 scleractinian species.

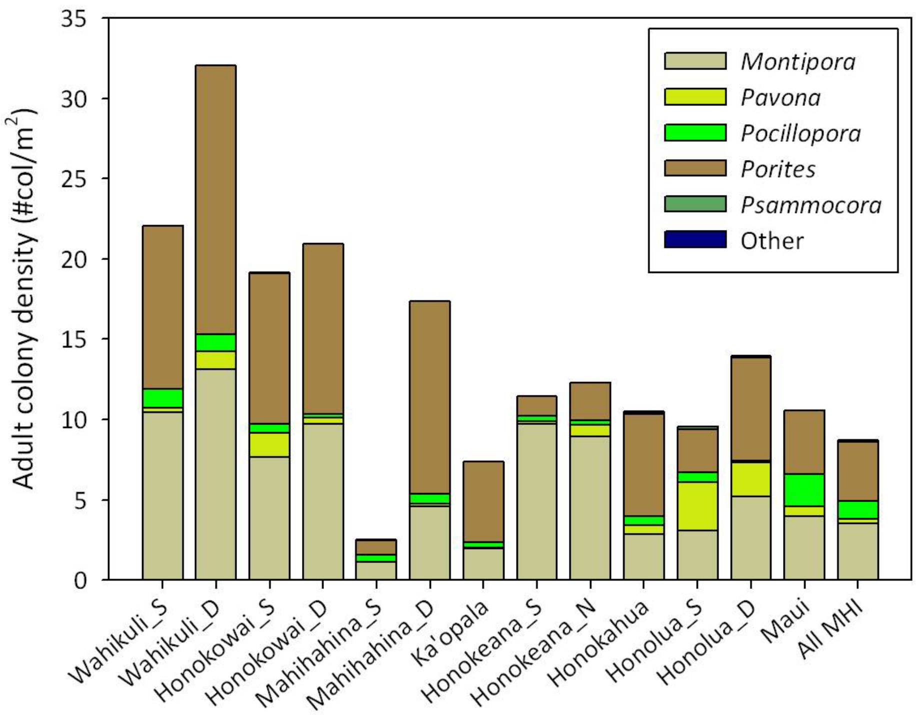

Figure 17- Adult colony densities at the surveys sites off West Maui. Sites are arranged in geographical order from south to north (left to right). Mean adult colony density values for Maui Island and all the main Hawaiian Islands combined (All MHI) added for reference.

In this study, there was a close association between coral cover and adult coral colony densities (r = 0.85; $p < 0.001$; Spearman Rank Correlation). Sites exhibiting the highest levels of coral cover also harbored the greatest colony densities (*Porites*, *Montipora*, or both) (Figs. 15 and 17). That high coral cover was associated with high coral colony densities is to be expected (Roff et al. 2011). It is also expected to find low coral cover and colony densities at sites such as Ka'opala, Honokahua, and Honolua that have been chronically impacted by turbidity and terrestrial sediment from the adjacent agricultural runoff (Dollar and Grigg 2004). However, it is unexpected to find the highest coral cover and colony densities on reefs visibly impacted by elevated levels of turbidity and terrestrial sediments, such as the Wahikuli, Honokōwai, and Mahinahina-deep sites. These elevated and persistent LBSP impacts are of concern, because left unattended the coral-rich reefs at Wahikuli, Honokōwai, and Mahinahina-deep could gradually become impoverished, such as the reef communities at Ka'opala, Honokahua, and Honolua. Again, the low adult colony densities observed at the Mahinahina-shallow site (2.5 col/m^2) are characteristic of the benthic pavement/macroalgae assemblage.

Vermeij and Sandin (2008) found that adult coral colony density exhibited independent effects on coral settlement and early post-settlement survivorship. In their study, coral larval settlement rates increased across low levels of adult cover and saturated at a maximum around 10% cover; and post-settlement survivorship decreased with adult coral cover, revealing structure density dependence in coral settlers. This inverse relationship between adult and juvenile colony densities was observed at Mahinahina-shallow and Honokahua (i.e., low adult density and high juvenile density), as well as the Wahikuli-shallow, Honokōwai, and Honokeana sites (i.e., high adult density and low juvenile density) (Figs. 17 and 18). Conversely, no clear spatial pattern was discernible between coral juvenile densities and patterns of turbidity and sedimentation. Likewise, the high density of juveniles at Wahikuli-deep (i.e., high coral cover and adult densities) is unexpected. Finally, except for the sites at Honokeana, *Porites* exhibited the greatest densities among adult colonies, and *Montipora* (primarily *M. capitata*) the greatest densities among juvenile colonies (Figs 17 and 18). The capacity of *M. capitata* to successfully reproduce and settle in areas of high terrestrial sediment exposure is remarkable (Padilla-Gamiño et al. 2014), highlighting the potential of this species for acclimatization, adaptation, or both.

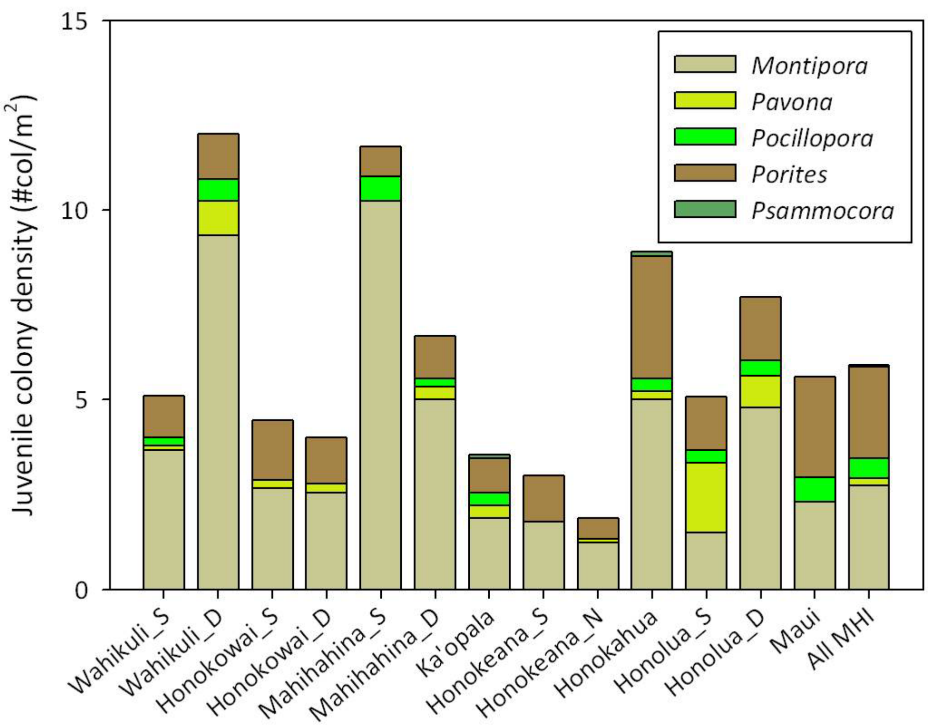

Figure 18- Juvenile colony densities at the surveys sites off West Maui. Sites are arranged in geographical order from south to north (left to right). Mean juveniles colony density values for Maui Island and all the main Hawaiian Islands combined (All MHI) added for reference.

Based on data collected during the 2013 and 2016 NOAA Main Hawaiian Islands Reef Assessment and Monitoring Program research expeditions, average site-level partial coral mortality for the island of Maui was 9.9% and 19.4%, respectively (CREP unpublished data). With regards to water temperatures, 2013 was a normal year while 2014 and 2015 were an anomalously warm years that resulted in extensive, state-wide coral bleaching and mortality. In this study, mean old partial mortality (colony areas heavily covered with turf algae or other, where skeletal features are no longer visible) for all sites and coral taxa combined was 20.9% (range = 9.5–33.1%) (Fig. 19a); this is over two-fold greater than the island average for a normal year and slightly greater than the island-wide average after a major bleaching event year. Because partial mortality is a cumulative process, the elevated and widespread levels of partial mortality across West Maui are troublesome and clearly an indication of past and present impacts, environmental stress, and community deterioration.

With the greatest estimated levels of sediment loading (Table 4), the high levels (23–33%) of old partial mortality at Kaʻopala and Honokōwai are anticipated (Fig. 19a). At Wahikuli, however, in addition to the direct effects of high turbidity (Table 4), high levels of mean old partial mortality (~ 24%) may also reflect the impact of the sea urchin grazing and the alarming levels of bioerosion taking place in those communities. Although sea urchins are key reef herbivores, known to regulate levels of turf algae, uncontrolled populations of echinoid grazers can have a destructive effect on disturbed reefs. Because of their ability to excavate and erode the calcium carbonate coral framework, bioerosion rates caused by sea urchins grazing on reef surfaces can exceed those of net reef carbonate production (Glynn 1988, Glynn 1990). This imbalance, which can transform flourishing reefs into piles of coral rubble in matter of years, has been reported for other Pacific reefs, and is generally associated with the compound effects of environmental disturbances, namely: 1) removal of sea urchin natural predators (e.g., triggerfish) due to overfishing; and 2) increased influx of inorganic nutrients, terrigenous sediment, and chemicals and toxicants from LBSP (Pari et al. 2002, Glynn 1997).

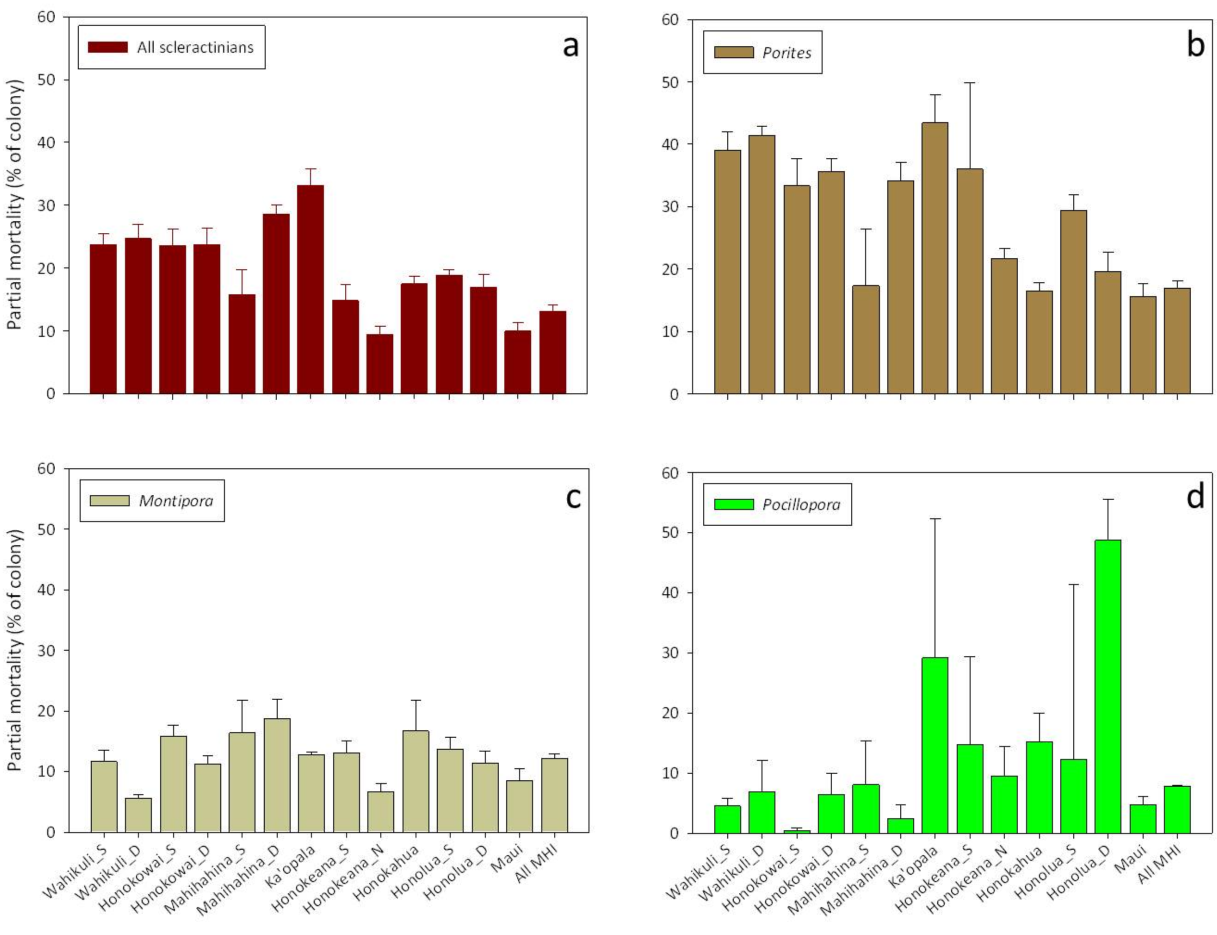

Figure 19- Mean adult old partial mortality (±SE) at the survey sites off West Maui. All sites combined (a), Montipora (b), Porites (c), and Pocilopora (d). Sites are arranged in geographical order from south to north (left to right). Mean adult partial mortality values (±SE) for Maui Island and all the main Hawaiian Islands combined (All MHI) added for reference.

Within this context, colonies of the genus *Porites* revealed exceedingly high levels of mean old partial mortality (Fig. 19b), specifically *P. lobata* and *P. compressa* at the Wahikuli, Honokōwai, and Kaʻopala reefs, where it exhibited partial mortality levels ranging between 33.3% and 43.4%. Contrastingly, site-level old partial mortality for the genus *Montipora* ranged between 5.5% and 18.6%; this is considerably lower than the *Porites*, underpinning the resilient and sediment-tolerant nature of the Hawaii *Montipora* (Fig. 19c). As such, the higher colony densities of *Montipora* relative to *Porites* recorded at Honkeana Bay are likely implicated in the lower levels of overall partial mortality measured in the bay (~ 9.5–14.8%). Interestingly, the *Pocillopora* revealed relatively lower levels of partial mortality (0.4–8%) throughout the two southern watersheds compared to the northern three (9.5–48.7%), particularly at Kaʻopala and Honolua (Fig. 19d). The drivers of such notable spatial differences are unclear, particularly for Honokeana Bay, which is characterized by relatively low levels of turbidity and sediment loading (Table 4). Comparatively, neither *Montipora* nor *Porites* exhibited such notable spatial variability in old partial mortality patterns.

When old partial mortality was examined relative to mean colony size, it was clear that larger colonies exhibited substantially higher levels of partial mortality. For example, the *Montipora* and *Porites* colonies smaller than 30 cm in maximum diameter exhibited overall mean old partial mortality values of 10.8% and 25.1%, respectively, compared to conspecifics 30 cm or larger which averaged: 32.0% and 47.3%, respectively, and those differences were statistically significant ($p < 0.001$; $T_{Montipora} = 195.0$; $T_{Porites} = 219.0$; Mann-Whitney Rank Sum). Similarly, the *Pocillopora* colonies smaller than 10 cm in max dimeter exhibited a mean partial mortality of 3.7% compared to 16.1% on larger colonies ($p < 0.01$; $T = 108.0$; Mann Whitney Rank Sum). Because partial mortality is a cumulative process, the positive relationship with colony size corroborates the occurrence of sustained, detrimental environmental conditions over time, in this case, mainly turbidity and sedimentation stress. The fact that larger colonies have proportionally less live tissue than smaller colonies can have significant implications for sexual reproduction and recovery potential.

Recent colony mortality, i.e., recent loss of live tissue caused by predation (crown-of-thorns seastars, fish, and mollusks), rapid tissue wasting, terrestrial sediment stress, overgrowth, and physical damage (excludes other lesions) was low across West Maui (0.4%). Although it varied widely between individual colonies (0.0–10.0%), site means were low overall, ranging between 0.05% at Wahikuli-shallow and 1.2% at Kaʻopala. We anticipated documenting higher levels of recent mortality associated to terrestrial sediment stress, particularly at Kaʻopala and Honokōwai that are exposed to heavy sediment loading; however, only two cases were observed and recorded. This may reflect the fact that this is a chronic disturbance, where sediments are continuously resuspended resulting in elevated water turbidity, and therefore partial mortality is a slow, ongoing process rather than an acute, catastrophic event that would bury and kill many corals (or parts of corals) in a relatively short time period.

Likewise, the occurrence of other coral lesions, i.e., bleaching and disease, was also spatially variable, yet site means were low (0.0–5.7%), background levels for most sites (Fig. 20). The highest mean prevalence of coral bleaching (5.3%–5.7%) were reported at the sites exhibiting the higher levels of live coral cover, i.e., Wahikuli and Honokeana-north, with the Kaʻopala site subsequently after (4.5%). Although 2014 and 2015 were anomalously warm years, we determined that the baseline data collected in this study, particularly live coral cover and colony partial mortality (old and recent), were not significantly affected by the occurrence of the mass coral bleaching events documented in the main Hawaiian Islands during those 2 years. First and foremost, the majority of baseline surveys were conducted between June and August of 2014 and 2015; this is prior to the onset of bleaching conditions, which occurred in months of September and October for both years. Secondly, even though the Wahikuli-deep site surveys occurred in October of 2014, low levels of coral bleaching (< 10%) and minor associated mortality were observed throughout West Maui that year (Darla White, pers. observ.).

Contrastingly, in 2015 widespread coral bleaching conditions and associated mortality were reported around Maui and state-wide, starting in September and peaking in October, with reported coral cover losses of up to 60% on the West Maui area (DAR 2017); by this time then baseline surveys were concluded. Notwithstanding, it is clear that multiple, overlapping disturbances can have compound, damaging effects; and that climate change and coral bleaching considerations need to be an integral part of the West Maui Watershed Management Plan.

Twelve different types of coral diseases were documented in this study (Table 6), all causing chronic and slow progressing lesions, commonly found (except *Porites* trematodiasis) along a gradient of increasing human pressure (Vargas-Ángel 2009; Aeby et al. 2011). *Porites* trematodiasis, pigmentation responses, tubeworm infestations, and algal infections were the most ubiquitous and prevalent diseases [details regarding Pacific coral disease nomenclature and etiology can be found in Raymundo et al. (2008) and NOAA (2017)]. However, overall occurrence of diseases was low; mean prevalence ranged between 0.6% at Honolua-shallow and 6.3% at Honokeana-south (Fig. 20). The relatively low levels of disease and high levels of old partial mortality documented herein indicate that the impeding turbidity and terrestrial sediment impacts may be overriding the impacts from disease and that disease lesions could be resulting in old partial mortality before they become chronic. On a related note, except for Honolua Bay, for those areas where 2 sites were deployed (shallow and deep; i.e., Wahikuli, Honokōwai, and Mahinahina) disease prevalence was consistently greater on the shallow site compared to the deep. While patterns of host distribution and susceptibility can determine patterns of disease prevalence (Calnan et al. 2008, Weil and Cróquer 2009), shallow sites are also consistently exposed to a greater range of temperature and light conditions (particularly the upper range) compared to deeper sites; which can also lead to stress and the development of disease (Hobbs et al. 2015).

Table 6- Presence/absence of coral diseases at the different survey sites on West Maui. Sites are listed in geographical order from south to north. WAH: Wahikuli; HON: Honokōwai; MAH: Mahinahina; KAO: Ka'opala; HOE: Honokeana; HOK: Honokahua; HOA: Honolua. S: shallow; D: deep; n: north; s: south.

Diseases & lesions	**WAH-S**	**WAH-D**	**HON-S**	**HON-D**	**MAH-S**	**MAH-D**	**KAO-S**	**HOE-s**	**HOE-n**	**HOK**	**HOA-D**	**HOA-S**
Algal infections	x		x	x	x	x						
Barnacle infestation								x	x		x	
Cyanphyte infection							x	x	x			
Discolorations			x	x		x						
Fungal infection					x							
Porites discolored swelling	x						x			x		
Porites pigmentation response	x	x	x	x		x	x		x		x	
Porites trematiodiasis	x	x		x		x	x	x	x	x	x	
Skeletal growth anomalies	x	x	x	x					x		x	
Tubeworm infestations								x	x	x	x	x
Subacute tissue loss			x									
Other			x									

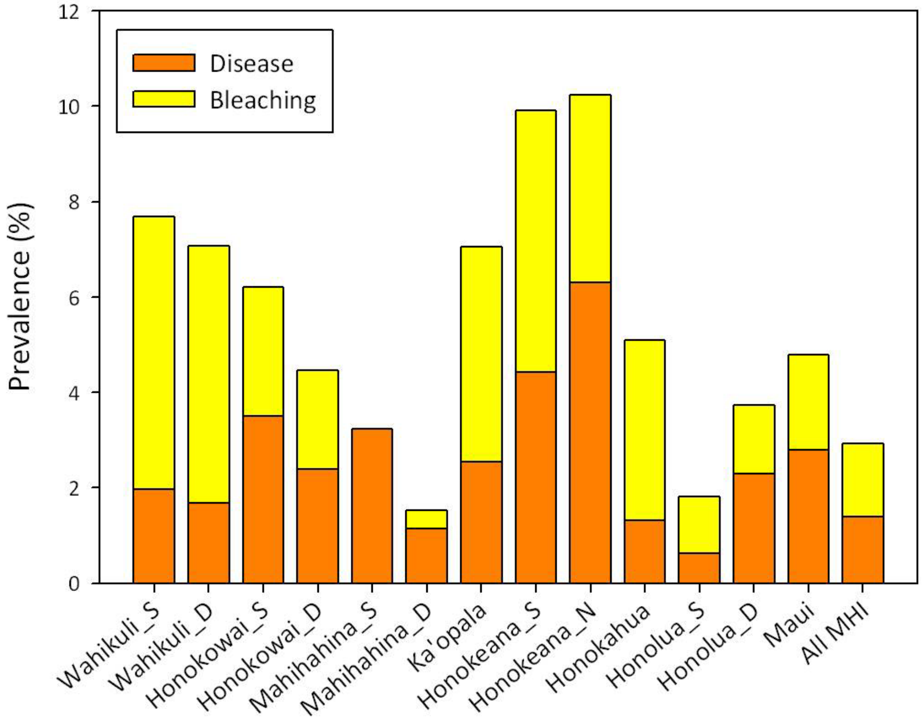

Figure 20- Mean prevalence of coral bleaching and disease at the survey sites on West Maui. Sites are arranged in geographical order from south to north (left to right). Mean prevalence of bleaching and disease for Maui Island and all the main Hawaiian Islands combined (All MHI) added for reference.

The biological surveys summarized herein provide a quantitative assessment of coral reef community condition and status on West Maui. The benthic structure and coral demographic data show that despite the relatively high levels of turbidity and terrestrial sediment loading, live coral cover and adult colony densities were the highest off the Wahikuli and Honokōwai watersheds compared to the northern three Watersheds. Reefs off the southern watersheds, together with those at Honokeana Bay, also exhibited the highest benthic substrate ratios; features that have fundamental implications for reef calcifying capacity, coral larval recruitment, and overall community resilience potential. Although species richness generally decreases along gradients of increasing terrestrial sediment stress, West Maui reefs exhibited a mixed pattern, with highly-impacted sites such Ka‘opala, Honokahua, and Honolua showing levels of coral richness comparable to less-impacted reefs at Wahikuli and Honokōwai. Similarly, spatial patters of recent mortality and disease did not show strong relationships with patterns of terrestrial sediment stress and impact; notwithstanding, a relationship between disease prevalence and depth was documented. However, it is plausible that the impacts from turbidity and terrestrial sediment may be superseding those of disease, and disease lesions could be resulting in old partial mortality before they become chronic. Like the other biological metrics, old partial colony mortality was spatially variable, with exceedingly high levels associated to the areas with the highest turbidity and terrestrial sediment loading; i.e., Ka‘opala, Honokōwai, and Wahikuli. This is of concern because reefs harboring the highest coral cover and adult colony densities (Honokōwi and Wahikuli) were observed to have the highest levels of partial colony mortality, likely an indication of environmental stress and impending reef community deterioration, with potentially significant consequences to sexual reproduction and resilience potential.

7. Conclusions

- Nearshore coral reef habitats off West Maui exhibited a wide range of variability regarding the structure, composition, and condition, which reflects the complex pattern of biological, environmental, and disturbance regimes prevalent across West Maui. Despite their differences in benthic composition and structure, these reef communities represent a key local resource and contrast to the overall low coral reef development levels both island and state-wide.

- With mean coral cover ranging between 30% and 58%, the Wahikuli and Honokōwai Watersheds contain the greatest extent and concentration of coral-rich habitat in West Maui, with relatively well developed, spur-and-groove coral reef complexes off Canoe Beach, Kahekili Beach Park, and Honokōwai Point. Patchy coral-rich habitats were also found in the Kahana Watershed, particularly off Kapalua and in Honokeana Bay, as well as the area between Honokeana Cove and ʻAlaeloa Point.

- The genera *Porites*, *Montipora*, and *Pocillopora* combined accounted for more than 90% of the live coral cover at all survey sites.

- Of the 28 scleractinian species tallied in this study, sites at Honolua-shallow and Honokahua showed the highest richness with a total of 14 species each; these sites were observed to have relatively richer than expected coral diversity, given that these areas have experienced significant historic impacts from increased turbidity and terrestrial sediment.

- Sites exhibiting the highest levels of coral cover also harbored the greatest colony densities. These reefs also exhibited elevated levels of colony partial mortality and bioerosion, as well as severe levels of sediment loading and water turbidity. Echinoid bioerosion was a factor damaging reefs in West Maui, possibly as an indirect result from overfishing and increased nutrient influx.

- Although partial mortality was examined relative to mean colony size, it was clear that larger colonies exhibited substantially higher levels of partial mortality and proportionally less live tissue than smaller colonies, which could have significant implications for sexual reproduction and recovery potential.

- The reefs off the Honolua and Honokahua Watersheds, and adjacent to the Kaʻopala gulch, exhibited advanced stages of deterioration, reflecting severe and recurrent impacts of LBSP, typified by the lower levels of coral cover and colony densities, in addition to intermediate and high levels of turbidity and terrestrial sediment loading. Historic, dramatic, coral-impacting terrestrial sediment runoff events have been documented for some of these locales.

- Left unattended, LBSP will continue to negatively affect the coral reef communities of West Maui. And, under the current turbidity and terrestrial sediment loading conditions, it appears that the Wahikuli and Honokowai Watersheds are probably at greatest risk because they harbor the most prominent and well-developed reefs in West Maui, containing the highest coral cover, colony densities, and structural complexity.

- Although coral recovery is one of the ultimate goals of both the US Coral Reef Task Force and the West Maui Watershed Management Plan, moving forward, restoration efforts need to incorporate activities that control and reduce the influx of terrestrial sediment and nutrients to the adjacent coastal waters. However, additional considerations, including herbivore fisheries management and climate change, are critical linkages to increasing the resilience and recovery potential of high-priority coral reefs.

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10. Appendices

Appendix 1- Benthic cover by functional group for the different survey sites on West Maui. Sites are listed in geographical order from south to north. S: shallow; D: deep; n: north; s: south; BRS: Benthic Substrate Ratio = (coral+CCA)(macro+turf).

Site Name	Site ID	Transect	CCA	CORAL	CYAN	INVT	MACRO	TURF	SAND	BSR
Wahikuli_s	MAI-932	1	0.00	58.00	0.00	0.00	0.00	34.00	8.00	1.71
		2	1.00	48.00	0.00	0.00	0.00	51.00	0.00	0.96
		3	1.00	41.00	0.00	0.00	0.00	50.00	8.00	0.84
Wahikuli_d	MAI-933	1	5.00	55.00	0.00	0.00	0.00	37.00	2.00	1.62
		2	1.00	46.00	0.00	0.00	1.00	49.00	3.00	0.94
		3	0.00	34.00	0.00	0.00	0.00	57.00	9.00	0.60
Honokōwai_s	MAI-930	1	5.00	39.00	0.00	0.00	0.00	56.00	0.00	0.79
		2	2.00	56.00	0.00	0.00	0.00	41.00	1.00	1.41
		3	7.00	31.00	0.00	0.00	0.00	62.00	0.00	0.61
Honokōwai_d	MAI-931	1	5.00	36.00	0.00	0.00	0.00	59.00	0.00	0.69
		2	1.00	43.00	0.00	0.00	0.00	50.00	6.00	0.88
		3	0.00	36.00	1.00	0.00	0.00	63.00	0.00	0.57
Mahinahina_s	MAI-928	1	0.00	0.00	6.00	0.00	4.00	58.00	32.00	0.00
		2	0.00	0.00	1.00	0.00	3.00	61.00	35.00	0.00
		3	0.00	14.00	3.00	1.00	0.00	61.00	21.00	0.23
Mahinahina_d	MAI-929	1	0.00	39.00	0.00	0.00	0.00	60.00	1.00	0.65
		2	0.00	45.00	0.00	0.00	0.00	55.00	0.00	0.82
		3	0.00	44.00	0.00	0.00	0.00	55.00	1.00	0.80
Ka'opala	MAI-939	1	10.00	29.00	0.00	0.00	0.00	59.00	2.00	0.66
		2	9.00	27.00	0.00	0.00	0.00	59.00	5.00	0.61
		3	19.00	15.00	0.00	0.00	0.00	66.00	0.00	0.52
Honokeana_S	MAI-938	1	10.00	31.00	0.00	0.00	0.00	58.00	1.00	0.71
		2	7.00	32.00	0.00	0.00	0.00	61.00	0.00	0.64
		3	6.00	55.00	0.00	0.00	0.00	33.00	6.00	1.85
Honokeana_N	MAI-937	1	6.00	48.00	3.00	0.00	1.00	41.00	1.00	1.29
		2	17.00	45.00	0.00	0.00	0.00	31.00	7.00	2.00
		3	15.00	28.00	0.00	0.00	0.00	52.00	5.00	0.83
Honokahua	MAI-936	1	7.00	8.00	0.00	0.00	0.00	84.00	1.00	0.18
		2	1.00	12.00	0.00	0.00	0.00	87.00	0.00	0.15
		3	2.00	14.00	1.00	0.00	1.00	82.00	0.00	0.19
Honolua_s	MAI-934	1	2.00	34.00	0.00	0.00	2.00	58.00	4.00	0.60
		2	1.00	38.00	0.00	0.00	1.00	43.00	17.00	0.89
		3	0.00	27.00	1.00	0.00	0.00	63.00	9.00	0.43
		4	1.00	17.00	0.00	0.00	1.00	71.00	10.00	0.25
Honolua_d	MAI-935	1	6.00	15.00	0.00	0.00	0.00	72.00	7.00	0.29
		2	5.00	17.00	0.00	0.00	1.00	74.00	3.00	0.29
		3	14.00	11.00	0.00	0.00	1.00	73.00	1.00	0.34
		4	6.00	10.00	0.00	0.00	0.00	82.00	2.00	0.20

Appendix 2- Benthic cover by functional group for the different survey sites on West Maui.. Sites are listed in geographical order from south to north. S: shallow; D: deep; n: north; s: south; MOSP: Montipora; PAVS: Pavona; POCS: Pocillopora; POSP: Porites; PSSP: Psammocora.

Site Name	Site ID	Transect	MOSP	PAVS	POCS	POSP	PSSP
Wahikuli_s	MAI-932	1	14.00	0.00	0.00	44.00	0.00
		2	12.00	0.00	3.00	33.00	0.00
		3	5.00	0.00	0.00	36.00	0.00
Wahikuli_d	MAI-933	1	12.00	0.00	0.00	43.00	0.00
		2	9.00	0.00	1.00	35.00	1.00
		3	6.00	0.00	0.00	28.00	0.00
Honokōwai_s	MAI-930	1	12.00	0.00	0.00	27.00	0.00
		2	23.00	0.00	2.00	31.00	0.00
		3	7.00	0.00	1.00	23.00	0.00
Honokōwai_d	MAI-931	1	10.00	0.00	0.00	26.00	0.00
		2	21.00	0.00	0.00	22.00	0.00
		3	2.00	0.00	0.00	34.00	0.00
Mahinahina_s	MAI-928	1	0.00	0.00	0.00	0.00	0.00
		2	0.00	0.00	0.00	0.00	0.00
		3	0.00	0.00	2.00	12.00	0.00
Mahinahina_d	MAI-929	1	10.00	0.00	0.00	29.00	0.00
		2	4.00	0.00	1.00	40.00	0.00
		3	12.00	1.00	0.00	31.00	0.00
Kahana/Ka'opala	MAI-939	1	6.00	0.00	0.00	23.00	0.00
		2	3.00	0.00	0.00	24.00	0.00
		3	1.00	0.00	1.00	13.00	0.00
Honokeana_S	MAI-938	1	31.00	0.00	0.00	0.00	0.00
		2	19.00	0.00	0.00	13.00	0.00
		3	52.00	0.00	0.00	3.00	0.00
Honokeana_N	MAI-937	1	28.00	0.00	1.00	19.00	0.00
		2	33.00	0.00	0.00	12.00	0.00
		3	18.00	1.00	2.00	7.00	0.00
Honokahua	MAI-936	1	2.00	0.00	0.00	6.00	0.00
		2	0.00	0.00	1.00	11.00	0.00
		3	2.00	0.00	2.00	10.00	0.00
Honolua_s	MAI-934	1	7.00	1.00	0.00	26.00	0.00
		2	7.00	1.00	0.00	30.00	0.00
		3	12.00	2.00	0.00	13.00	0.00
		4	6.00	5.00	0.00	6.00	0.00
Honolua_d	MAI-935	1	5.00	1.00	1.00	7.00	0.00
		2	7.00	1.00	0.00	9.00	0.00
		3	2.00	1.00	2.00	4.00	1.00
		4	2.00	2.00	0.00	4.00	2.00

Appendix 3- Adult colony densities (#col/m^2) for the different survey sites on West Maui. Sites are listed in geographical order from south to north. S: shallow; D: deep; n: north; s: south; MOSP: Montipora; PAVS: Pavona; POCS: Pocillopora; POSP: Porites; PSSP: Psammocora; OTHER: all other scleractinians.

Site Name	Site ID	Transect	MOSP	PAVS	POCS	POSP	PSSP	OTHER	TOTAL
Wahikuli-S	MAI-932	1	9.80	0.20	1.40	11.00	0.00	0.00	22.40
		2	10.60	0.00	0.90	10.20	0.10	0.00	21.80
		3	11.00	0.60	1.20	9.20	0.00	0.00	22.00
Wahikuli-D	MAI-933	1	16.00	1.50	1.40	13.50	0.00	0.00	32.40
		2	11.66	0.69	0.80	17.49	0.00	0.00	30.63
		3	11.77	1.14	0.91	19.20	0.00	0.00	33.03
Honokōwai-S	MAI-930	1	7.20	3.90	0.80	13.60	0.00	0.10	25.60
		2	8.70	0.20	0.90	6.50	0.00	0.00	16.30
		3	7.00	0.40	0.10	8.00	0.00	0.00	15.50
Honokōwai-S	MAI-931	1	8.00	0.30	0.20	12.30	0.00	0.00	20.80
		2	13.20	0.10	0.30	7.70	0.00	0.00	21.30
		3	8.00	0.70	0.20	11.80	0.00	0.00	20.70
Mahinahina-S	MAI-928	1	0.50	0.00	0.40	0.60	0.00	0.10	1.60
		2	2.00	0.00	0.20	0.90	0.00	0.00	3.10
		3	0.80	0.00	0.80	1.20	0.00	0.10	2.90
Mahinahina-D	MAI-929	1	5.40	0.20	0.40	9.50	0.00	0.00	15.50
		2	2.40	0.20	0.70	11.80	0.00	0.00	15.10
		3	6.00	0.00	0.70	14.80	0.00	0.00	21.50
Ka'opala	MAI-939	1	2.50	0.10	0.40	6.90	0.00	0.00	9.90
		2	2.50	0.10	0.10	3.30	0.00	0.00	6.00
		3	0.80	0.10	0.50	4.80	0.00	0.00	6.20
Honokeana-s	MAI-938	1	10.00	0.10	0.70	3.10	0.00	0.00	13.90
		2	13.50	0.40	0.20	0.40	0.00	0.00	14.50
		3	5.60	0.00	0.10	0.30	0.00	0.00	6.00
Honokeana-n	MAI-937	1	12.40	0.10	0.70	1.50	0.00	0.00	14.70
		2	10.00	0.50	0.20	2.40	0.00	0.00	13.10
		3	4.40	1.50	0.10	3.00	0.00	0.10	9.10
Honokahua-S	MAI-936	1	4.60	0.80	0.50	4.90	0.00	0.00	10.80
		2	2.00	0.60	0.60	7.50	0.30	0.10	11.10
		3	1.90	0.40	0.50	6.70	0.10	0.00	9.60
Honolua-S	MAI-934	1	4.30	2.10	0.00	4.40	0.00	0.00	10.80
		2	4.60	2.00	0.10	12.50	0.00	0.00	19.20
		3	5.60	1.60	0.40	5.10	0.00	0.00	12.70
		4	6.20	2.80	0.00	3.60	0.00	0.50	13.10
Honolua-D	MAI-935	1	5.00	4.80	0.20	2.70	0.00	0.00	12.70
		2	3.30	2.70	0.50	4.10	0.10	0.00	10.70
		3	1.80	2.40	1.00	2.50	0.20	0.10	8.00
		4	2.20	2.10	0.90	1.40	0.20	0.00	6.80

Appendix 4- Juvenile colony densities (#col/m²) for the different survey sites on West Maui. Sites are listed in geographical order from south to north. S: shallow; D: deep; n: north; s: south; MOSP: Montipora; PAVS: Pavona; POCS: Pocillopora; POSP: Porites; PSSP: Psammocora.

Site Name	**Site ID**	**Transect**	**MOSP**	**PAVS**	**POCS**	**POSP**	**PSSP**	**TOTAL**
Wahikuli-S	MAI-932	1	1.67	0.33	0.67	2.33	0.00	5.00
		2	2.67	0.00	0.00	0.00	0.00	2.67
		3	6.67	0.00	0.00	1.00	0.00	7.67
Wahikuli-D	MAI-933	1	8.67	0.67	0.33	2.00	0.00	11.67
		2	12.33	1.00	0.67	1.33	0.00	15.33
		3	7.00	1.00	0.75	0.25	0.00	9.00
Honokōwai-S	MAI-930	1	3.33	0.67	0.00	2.67	0.00	6.67
		2	2.33	0.00	0.00	0.67	0.00	3.00
		3	2.33	0.00	0.00	1.33	0.00	3.67
Honokōwai-S	MAI-931	1	1.00	0.00	0.00	0.33	0.00	1.33
		2	4.00	0.67	0.00	0.00	0.00	4.67
		3	2.67	0.00	0.00	3.33	0.00	6.00
Mahinahina-S	MAI-928	1	16.00	0.00	1.67	1.00	0.00	18.67
		2	9.33	0.00	0.00	1.00	0.00	10.33
		3	5.33	0.00	0.33	0.33	0.00	6.00
Mahinahina-D	MAI-929	1	4.67	0.00	0.33	0.33	0.00	5.33
		2	5.33	0.33	0.33	1.67	0.00	7.67
		3	5.00	0.67	0.00	1.33	0.00	7.00
Ka'opala	MAI-939	1	1.00	0.00	0.00	0.33	0.00	1.33
		2	4.00	0.00	0.00	0.00	0.00	4.00
		3	0.67	1.00	1.00	2.33	0.33	5.33
Honokeana-s	MAI-938	1	2.33	0.00	0.00	1.33	0.00	3.67
		2	3.00	0.00	0.00	1.33	0.00	4.33
		3	0.00	0.00	0.00	1.00	0.00	1.00
Honokeana-n	MAI-937	1	1.33	0.00	0.00	0.33	0.00	1.67
		2	0.67	0.00	0.00	0.00	0.00	0.67
		3	1.67	0.33	0.00	1.33	0.00	3.33
Honokahua-S	MAI-936	1	4.67	0.33	0.00	2.33	0.00	7.33
		2	5.00	0.00	0.00	4.00	0.00	9.00
		3	5.33	0.33	1.00	3.33	0.33	10.33
Honolua-S	MAI-934	1	0.33	0.33	0.00	1.00	0.00	1.67
		2	2.50	3.00	0.00	2.50	0.00	8.00
		3	3.33	0.00	0.67	0.67	0.00	4.67
		4	13.00	0.00	1.00	2.50	0.00	16.50
Honolua-D	MAI-935	1	1.33	1.67	0.00	1.00	0.00	4.00
		2	1.67	2.33	0.00	1.00	0.00	5.00
		3	0.33	3.00	1.00	2.00	0.00	6.33
		4	2.67	0.33	0.33	1.67	0.00	5.00

Appendix 5- Adult colony partial mortality (% of total colony surface) for the different survey sites on West Maui. Sites are listed in geographical order from south to north. S: shallow; D: deep; n: north; s: south; MOSP: Montipora; PAVS: Pavona; POCS: Pocillopora; POSP: Porites; PSSP: Psammocora; OTHER: all other scleractinians.

Site Name	Site ID	Transect	MOSP	PAVS	POCS	POSP	PSSP	OTHER	TOTAL
Wahikuli-S	MAI-932	1	12.86	0.00	5.21	33.41	0.00	0.00	22.36
		2	14.13	0.00	2.00	43.07	0.00	0.00	27.11
		3	7.92	11.67	6.25	40.71	0.00	0.00	21.64
Wahikuli-D	MAI-933	1	6.81	4.67	3.57	39.44	0.00	0.00	20.17
		2	5.49	38.33	17.14	40.75	0.00	0.00	26.66
		3	4.27	2.00	0.00	44.10	0.00	0.00	27.22
Honokōwai-S	MAI-930	1	18.51	9.10	1.25	41.11	0.00	0.00	28.47
		2	16.77	10.00	0.00	26.15	0.00	0.00	19.50
		3	12.33	17.50	0.00	32.73	0.00	0.00	22.91
Honokōwai-S	MAI-931	1	13.13	6.67	12.50	39.72	0.00	0.00	28.75
		2	12.17	0.00	6.67	34.48	0.00	0.00	20.10
		3	8.21	17.14	0.00	32.73	0.00	0.00	22.41
Mahinahina-S	MAI-928	1	19.00	0.00	0.00	4.33	0.00	5.00	7.88
		2	24.25	0.00	22.50	12.78	0.00	0.00	20.81
		3	6.00	0.00	1.63	34.83	0.00	60.00	18.59
Mahinahina-D	MAI-929	1	17.78	0.00	0.00	40.11	0.00	0.00	30.77
		2	13.33	0.00	0.00	30.29	0.00	0.00	25.79
		3	24.80	0.00	7.14	31.86	0.00	0.00	29.09
Ka'opala	MAI-939	1	13.68	3.00	12.50	34.65	0.00	0.00	28.14
		2	12.60	5.00	75.00	49.42	0.00	0.00	33.77
		3	12.00	10.00	0.00	46.19	0.00	0.00	37.47
Honokeana-s	MAI-938	1	15.83	60.00	0.14	30.13	0.00	0.00	18.55
		2	9.34	0.00	44.00	15.50	0.00	0.00	9.73
		3	13.98	0.00	0.00	62.33	0.00	0.00	16.17
Honokeana-n	MAI-937	1	4.92	0.00	12.14	23.53	0.00	0.00	7.13
		2	9.07	1.00	16.50	23.00	0.00	0.00	11.43
		3	6.14	4.67	0.00	18.43	0.00	0.00	9.81
Honokahua-S	MAI-936	1	14.57	48.13	7.00	18.61	0.00	0.00	18.54
		2	26.50	32.50	15.17	14.33	50.00	50.00	18.84
		3	8.95	10.00	23.40	16.55	10.00	0.00	15.06
Honolua-S	MAI-934	1	13.95	28.43	0.00	26.59	0.00	0.00	21.92
		2	15.43	25.25	90.00	18.43	0.00	0.00	18.80
		3	7.45	17.88	7.50	19.43	0.00	0.00	13.57
		4	8.84	20.64	0.00	13.86	0.00	28.00	13.47
Honolua-D	MAI-935	1	17.26	16.98	2.50	20.59	0.00	0.00	17.63
		2	13.00	5.00	29.00	29.15	5.00	0.00	17.84
		3	16.11	15.00	17.50	33.20	27.50	0.00	21.38
		4	8.55	27.86	0.11	34.36	0.00	0.00	18.46

Appendix 6- Prevalence (%) of coral bleaching, diseases and lesion at the different survey sites on West Maui. Sites are listed in geographical order from south to north. S: shallow; D: deep; n: north; s: south.

Site Name	Site ID	Transect	Disease & lesions	Bleaching
Wahikuli-S	MAI-932	1	1.79	8.04
		2	2.75	3.67
		3	1.36	5.45
Wahikuli-D	MAI-933	1	0.31	3.11
		2	2.62	7.49
		3	2.10	5.59
Honokōwai-S	MAI-930	1	1.17	1.17
		2	6.13	3.68
		3	3.23	3.23
Honokōwai-S	MAI-931	1	3.38	3.38
		2	3.29	1.88
		3	0.49	0.98
Mahinahina-S	MAI-928	1	6.25	0.00
		2	0.00	0.00
		3	3.45	0.00
Mahinahina-D	MAI-929	1	0.00	0.65
		2	0.66	0.00
		3	2.79	0.47
Ka'opala	MAI-939	1	1.06	5.32
		2	3.33	5.00
		3	3.23	3.23
Honokeana-s	MAI-938	1	5.76	2.16
		2	4.17	7.64
		3	3.33	6.67
Honokeana-n	MAI-937	1	3.42	6.16
		2	10.00	2.31
		3	5.49	3.30
Honokahua-S	MAI-936	1	1.85	3.70
		2	0.00	4.50
		3	2.08	3.13
Honolua-S	MAI-934	1	0.00	1.94
		2	1.10	0.55
		3	5.79	2.48
		4	2.33	0.78
Honolua-D	MAI-935	1	1.57	2.36
		2	0.93	0.93
		3	0.00	0.00
		4	0.00	1.47