

Final Baseline Condition Assessment: 2016 West Hawai'i Reef Resilience Marine Surveys

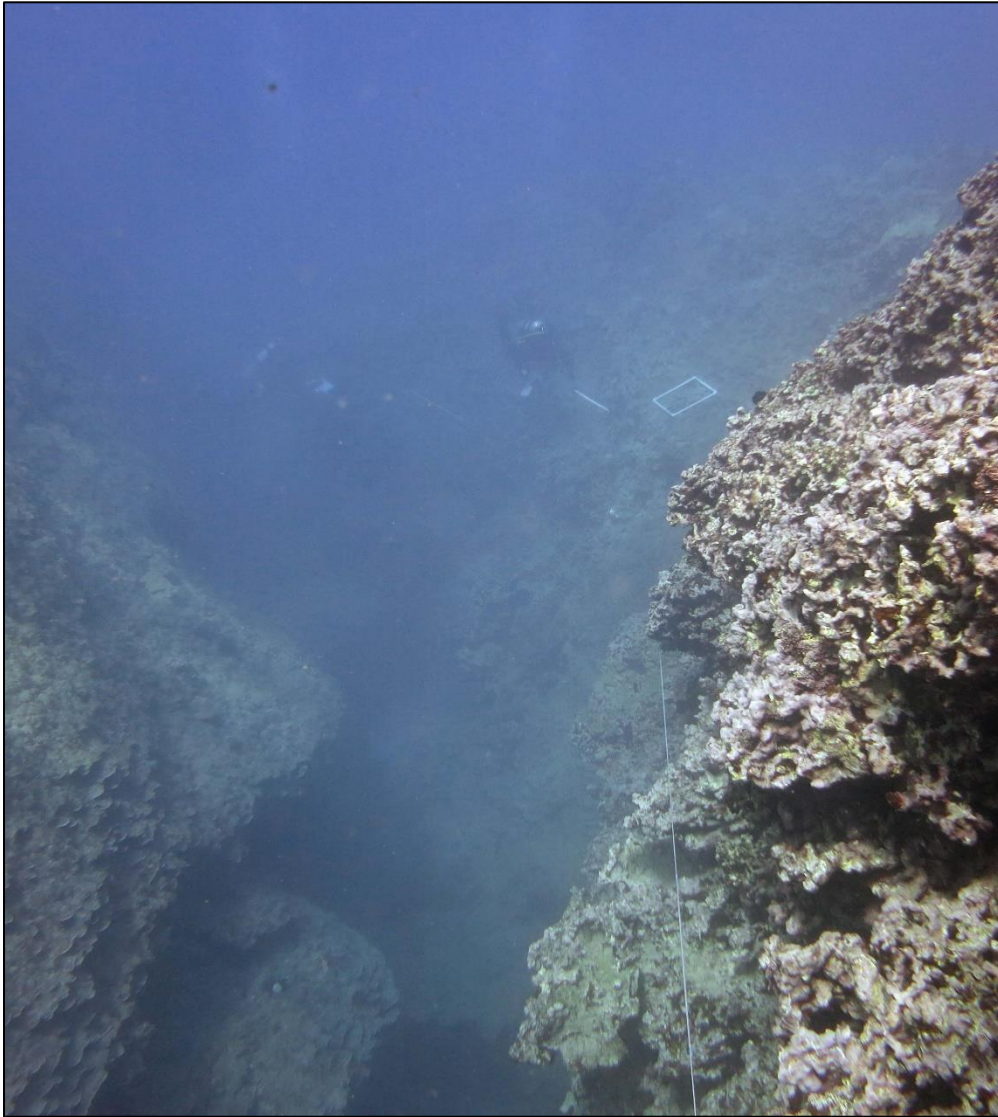


Photo by TNC 2016

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Final Baseline Condition Assessment:
2016 West Hawai‘i Reef Resilience Marine Surveys

by

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Cover Photo: Divers collect data on coral health and disease and coral juveniles at ‘Ōhai‘ula

1.0 Executive Summary

Coral reef resilience is the capacity of a reef to resist or recover from degradation and maintain provisions of ecosystem functions and services. This is especially important within the context of climate change, under which global stressors including rising ocean water temperature and acidification are exerting increasing stress on coral reef ecosystems worldwide and contributing to reef degradation and loss.

Resilience-based management involves the application of resilience theory and tools to deliver ecosystem-based management outcomes into the future, and can include assessing spatial variation in resilience potential and then using these results to target and tailor actions to preserve or restore the resilience of reefs. Such assessments have been recommended by coral reef scientists, managers, and leading conservation organizations, and generally involve measuring or assessing resilience indicators (*e.g.*, coral disease, coral recruitment, herbivorous fish biomass, etc.) across several sites and producing an aggregate score that expresses resilience potential for each site relative to the site with the highest assessed resilience potential. These rankings are intended to assist managers in making targeted decisions.

In October 2015, The Nature Conservancy (TNC) with partners assessed the relative resilience potential of twenty reef locations along priority areas of South Kohala and North Kona, Hawai‘i Island. During these surveys, the research team documented severe, widespread bleaching. In 2016, TNC and its partners returned to the same reef locations and repeated the reef resilience and bleaching surveys conducted in the prior year to assess the post-bleaching condition of these reef areas.

The 2016 study had five objectives: 1) assess the condition of the reef areas surveyed in 2015 one year after the mass bleaching event, and re-rank sites for resilience based on their current status; 2) establish a post-bleaching event baseline for these reef areas against which the long-term consequences of the bleaching event could be compared; 3) determine how well the 2015 reef resilience assessment of West Hawai‘i predicted the resistance to bleaching of the reefs surveyed; 4) use the results of the 2016 surveys to refine the reef resilience survey methods, improving their utility for further surveys in Hawai‘i, and potentially in other coral reef jurisdictions around the world; and 5) share the survey results with community, state, and federal partners to help ensure ongoing management actions are informed by the best possible information on where to engage and with what reef management strategies to maximize the resilience potential of West Hawai‘i reefs.

Twenty-five coral species were identified, and *Porites lobata* (lobe coral) and *P. compressa* (finger coral) were the most abundant, accounting for over 93% of all coral observations. Coral cover at our twenty West Hawai‘i reef locations significantly decreased between 2015 and 2016, dropping from a mean of $25.5 \pm 1.6\%$ to $18.2 \pm 1.3\%$. Mean cover declined at every location except Keawaiki and Kiholo.

Declines in coral cover contributed to a change in the structure of the benthic assemblage between survey years. Coral losses were offset primarily by increases in crustose coralline algae (CCA) and to a lesser extent turf algae. The increase of CCA over turf algae is a positive sign

for recovery on West Hawai‘i’s reefs because CCA is an important settlement substratum for coral larvae, whereas turf generally inhibits coral recruitment and juvenile survival.

Average coral disease prevalence across the survey area was low ($4.4 \pm 0.6\%$), with generally higher disease prevalence at the southern end of the survey area. Five coral diseases were identified (most to least prevalent): *Porites* Growth Anomalies (PorGA), *Montipora* Growth Anomalies (MonGA), *Porites* Tissue Loss Syndrome (PorTLS), *Pocillopora* Tissue Loss Syndrome (PocTLS) and *Porites* Trematodiasis. In addition to the five diseases, two other conditions affected colonies: algal overgrowth (ALOG) and bleaching. ALOG was the most prevalent disease/condition affecting corals on West Hawai‘i. While overall disease prevalence dropped slightly in 2016 compared to 2015, the difference was not statistically significant.

We observed 122 species of reef fish in 26 families across the survey area in 2016. Total fish biomass was $71.1 \pm 9.8 \text{ g/m}^2$. The families Acanthuridae (surgeonfishes) and Scaridae (parrotfishes) contributed the most to total fish biomass, and herbivores accounted for over half of all the total fish biomass. Apex predators were rarely observed. Total fish biomass was significantly lower in 2016 than 2015, but the decline was likely associated with fish biomass elevated in 2015 due to a large fish recruitment in 2014 gradually returning to pre-2014 levels.

Reef Resilience scores for each location were recalculated using the 2016 survey data. At the shallow sites, resilience rankings changed only modestly between 2015 and 2016. In contrast with shallow sites, deep sites showed considerable change in their resilience rankings between years. Deep sites with increased coral recruitment and decreased macroalgal cover and rugosity from 2015 to 2016 tended to show improved resilience rankings at the expense of sites with decreased densities of coral juveniles, and increased macroalgal cover and rugosity. These findings suggest that management actions that improve biological processes (*e.g.*, recruitment) may contribute more to improving a site’s long-term resilience than actions that focus on maintaining a static condition state (*e.g.*, high coral cover).

The influence of environmental data such as temperature variation, nutrients, and fishing on the resilience of all locations was explored using principal component analysis. Sites clustered primarily into three groups aligned along a gradient of stress, and the relative resilience of the locations within each cluster declined with increasing number and intensity of stressors. While consensus is quickly forming that local management alone will be insufficient to offset the effects of global climate change, evidence is emerging that both local and global management are necessary to ensure the survival of many coral reef ecosystems. This study suggests that reducing local stressors can have beneficial effects on the resilience of reefs to climate change. In addition, reducing local stressors that adversely affect ecological processes may produce the most significant long-term benefits.

Given resilience encompasses not only resistance to the effects of a stress event (*e.g.*, the 2015 mass coral bleaching) but also recovery from any resulting impacts, insufficient time has passed to fully assess the rankings for either shallow or deep sites in West Hawai‘i. Permanent transects were established during the 2016 surveys to facilitate revisiting these sites in the future to better evaluate how well the resilience rankings captured both the resistivity of these West Hawai‘i reefs to stress and their recovery ability.

2.0 Introduction

The west coast of Hawai‘i Island contains one of the longest contiguous coral reef systems in the main Hawaiian Islands. These biodiverse reefs are home to culturally- and economically-significant species¹, mitigate wave and storm impacts, and provide recreational and other economic benefits to the residents of the state. Due to their interconnectedness, island communities will acutely feel any degradation of the nearshore coral reefs, and supporting the resilience of these marine ecosystems is a goal within many management plans for West Hawai‘i, and is regularly mentioned by stakeholders.

Coral reef resilience is the capacity of a reef to resist or recover from degradation and maintain provisions of ecosystem functions and services (Mumby *et al.* 2007). This is especially important within the context of climate change, under which global stressors including rising ocean water temperature and acidification are exerting increasing stress on coral reef ecosystems worldwide and contributing to reef degradation and loss.

Resilience-based management involves the application of resilience theory and tools to deliver ecosystem-based management outcomes into the future (Chapin *et al.* 2009), and can include assessing spatial variation in resilience potential and then using the results to target and tailor actions to preserve or restore the resilience of reefs. Such assessments have been recommended by coral reef scientists, managers, and leading conservation organizations (Maynard *et al.* 2015, Anthony *et al.* 2015, McClanahan *et al.* 2012, Graham *et al.* 2013). The assessments generally involve measuring or assessing resilience indicators (*e.g.*, coral disease, coral recruitment, herbivorous fish biomass, etc.) across several sites and producing an aggregate score that expresses resilience potential for each site relative to the site with the highest assessed resilience potential. These rankings are intended to assist managers in making targeted decisions (Maynard *et al.* 2015, Weeks and Jupiter 2013), which would be valuable in Hawai‘i as the frequency of adverse “warm water events” and associated coral bleaching is increasing. Warm water conditions sufficient to trigger coral bleaching events are expected to occur annually in Hawai‘i by the middle of the century (van Hooidink *et al.* 2014).

In October 2015, The Nature Conservancy (TNC) with partners at the Hawai‘i Division of Aquatic Resources (DAR), NOAA’s Coral Reef Ecosystems Division (NOAA CRED), and community organizations in West Hawai‘i assessed the relative resilience potential of reef sites at two depths along priority areas of South Kohala and North Kona along the west coast of Hawai‘i Island. Serendipitously, at the time these surveys were conducted, a prolonged stretch of warm, calm weather led to elevated sea water temperatures and the onset of widespread coral bleaching on West Hawai‘i reefs (Kramer *et al.* 2016, Maynard *et al.* 2016), lasting from September through December 2015 and peaking between October 22-25, 2015 (NOAA CRW 2016). Sea temperatures were been above the bleaching threshold (Degree Heating Weeks = 4 °C-weeks) for two months (NOAA CRW 2016), a level of thermal stress unprecedented in Hawai‘i. The research team documented severe, widespread bleaching in nearly all coral species and down to depths of at least 20 m. Bleaching susceptibility varied widely across taxa, with

¹ Nearly a quarter of the coral and fish species in Hawai‘i are endemic (*i.e.*, can only be found in the Hawaiian Islands).

lobate species such as *Porites lobata* showing less bleaching than branching forms such as *Pocillopora meandrina* (Maynard *et al.* 2016). Due to its severity and duration, the bleaching caused significant coral mortality (Kramer *et al.* 2016, TNC unpubl. data), the long-term consequences of which remain unclear but are the subject of ongoing research.

In 2016, TNC and its partners returned to the same reef locations and repeated the reef resilience and bleaching surveys conducted in the prior year to assess the post-bleaching condition of these reef locations. These new data allow for deeper exploration of the effectiveness of the resilience rankings developed in 2015 to predict the resilience of reef areas to bleaching and bleaching-related mortality, and to shed insight on their recovery potential. Sites ranked with high potential resilience should: a) experience fewer adverse effects of the elevated temperature (*e.g.*, less bleaching, less coral disease, less coral mortality, etc.), and/or 2) display higher potential for recovery than sites with lower rankings. These findings would provide insight into the effectiveness of the resilience ranking method as a potential tool to guide effective management.

3.0 Study Objectives

This study had five objectives:

- Assess the condition of the reef areas surveyed in 2015 one year after the mass bleaching event, and re-rank sites for resilience based on their current status;
- Establish a post-bleaching event baseline for these reef areas against which the long-term consequences of the bleaching event could be compared;
- Determine how well the 2015 reef resilience assessment of West Hawai‘i (Maynard *et al.* 2016) predicted the resistance to bleaching of the reefs surveyed;
- Use the results of the 2016 surveys to refine the reef resilience survey methods, improving their utility for further surveys in Hawai‘i, and potentially in other coral reef jurisdictions around the world, and;
- Share the survey results with community, state, and federal partners to help ensure ongoing management actions are informed by the best possible information on where to engage and with what reef management strategies to maximize the resilience potential of West Hawai‘i reefs.

4.0 Methods

Numerous reef resilience indicators have been proposed in the scientific literature. These were examined by McClanahan *et al.* (2012) and ranked based on their perceived importance, scientific evidence supporting their linkage to resilience, and their feasibility of measurement. In 2015, eleven indicators were selected from this comprehensive list (Table 1) by a suite of Hawai‘i coral reef scientists and managers for investigation at West Hawai‘i (Maynard *et al.* 2016). Seven biological indicators, including six identified by McClanahan *et al.* (2012) (coral cover, coral diversity, coral recruitment, bleaching resistance, macroalgae cover, and herbivorous fish biomass) and rugosity², were used to create an aggregate resilience score and ranking.

² Benthic rugosity is often correlated with abundance and diversity of associated species, especially fish (Friedlander and Parrish 1998).

Table 1. The top 11 of 61 total reef resilience indicators reviewed in McClanahan *et al.* (2012). The rankings were based on perceived importance, scientific evidence, and feasibility of measurement on the resistance and recovery potential of a coral reef. The six biological indicators used at West Hawai‘i by Maynard *et al.* (2016) appear in italics.

	Perceived importance (0 to 10)		Scientific evidence (-5 to +5)		Feasibility (0 to 10)
	Resistance	Recovery	Resistance	Recovery	
(1) <i>Resistant coral species</i>	8.70	6.87	4.07	3.07	8.04
(2) Temperature variability	8.14	5.82	3.64	2.50	7.71
(3) Nutrients (pollution)	6.04	7.21	2.44	3.15	5.63
(4) Sedimentation	5.59	7.04	2.20	2.58	6.73
(5) <i>Coral diversity</i>	6.04	6.39	2.04	2.07	7.07
(6) <i>Herbivore biomass</i>	4.29	7.46	1.64	3.32	7.44
(7) Physical human impacts	4.89	6.78	1.96	2.85	6.38
(8) <i>Coral disease</i>	6.06	5.54	2.31	1.50	6.43
(9) <i>Macroalgae</i>	3.89	7.57	1.33	3.37	8.48
(10) <i>Recruitment</i>	3.46	7.96	1.04	3.86	6.67
(11) Fishing pressure	4.32	7.07	1.46	2.96	7.04

4.1 Locations and Sites

The NOAA Coral Reef Conservation Program, NOAA Habitat Blueprint, and Sentinel Site Program have an overlapping Focus Area on the west side of Hawai‘i Island (hereafter West Hawai‘i). These programs have consolidated their efforts to gather information and provide support for effective management of this area. This Focus Area also overlaps with and is supported by the NOAA Hawaiian Islands Humpback Whale National Marine Sanctuary, and is a focus of the NOAA National Marine Fisheries West Hawai‘i Integrated Ecosystems Assessment Project.

In 2015, reef resilience was assessed at twenty locations selected in consultation with DAR, extending from North Kona to South Kohala Districts of West Hawai‘i (Figure 1). Eighteen locations were spaced approximately ~2.5 kilometers apart within the Focus Area using ArcGIS, and should be representative of the full range of the area’s ecological and physical conditions. At the request of the DAR, two additional locations south of the Focus Area, Honokohau and Keahou, were also surveyed. In addition, seven of the selected locations overlapped with existing DAR West Hawai‘i monitoring sites (Figure 1). At each location, a shallow (5-7 m) and deep (12-15 m) site were surveyed. Location metadata are provided in Appendix A.

In 2016, we returned to these locations to repeat the reef resilience surveys. All locations were surveyed between October 17-29, 2016 except for Honokohau, which was re-surveyed on May 3, 2017. Surveys of Honokohau were delayed to due to the need to obtain additional permits to conduct work within Koloko-Honokohau National Historical Park. As part of the 2016 surveys,

we also installed permanent marker pins, comprised of stainless steel eyebolts, at all locations except Honokohau. Transects at locations that overlapped with an existing DAR-West Hawai‘i monitoring site were offset approximately 100 m from the original 2015 location to avoid interference with DAR’s long-term monitoring effort. At other locations, site photos, field notes, and compass bearings collected in 2015 were used to realign transect for re-surveying and pin installation in 2016. While transects were seldom perfectly realigned, transects at non-DAR

West Hawai‘i Monitoring sites are likely within ~10 m of the 2015 transects. All future surveys will be conducted along these permanently marked transects, allowing us to accurately track the recovery of these sites from the 2015 bleaching event.

4.2 Field Assessments

At all locations, we conducted comprehensive assessments to document spatial patterns of species abundance, biomass and condition. Surveys were conducted along all or part of three replicate 25-m transect lines laid out consecutively within the defined depth ranges at shallow and deep sites. An intervening space of ~10 m was left between the end of one transect and the start of the next. Assessments were conducted by a three- or four-person team, comprised of surveyors who were trained and calibrated to reduce observer variability and produce relevant and credible data. The method for each survey types is summarized in Table 2, with a more-detailed description in Appendix B.

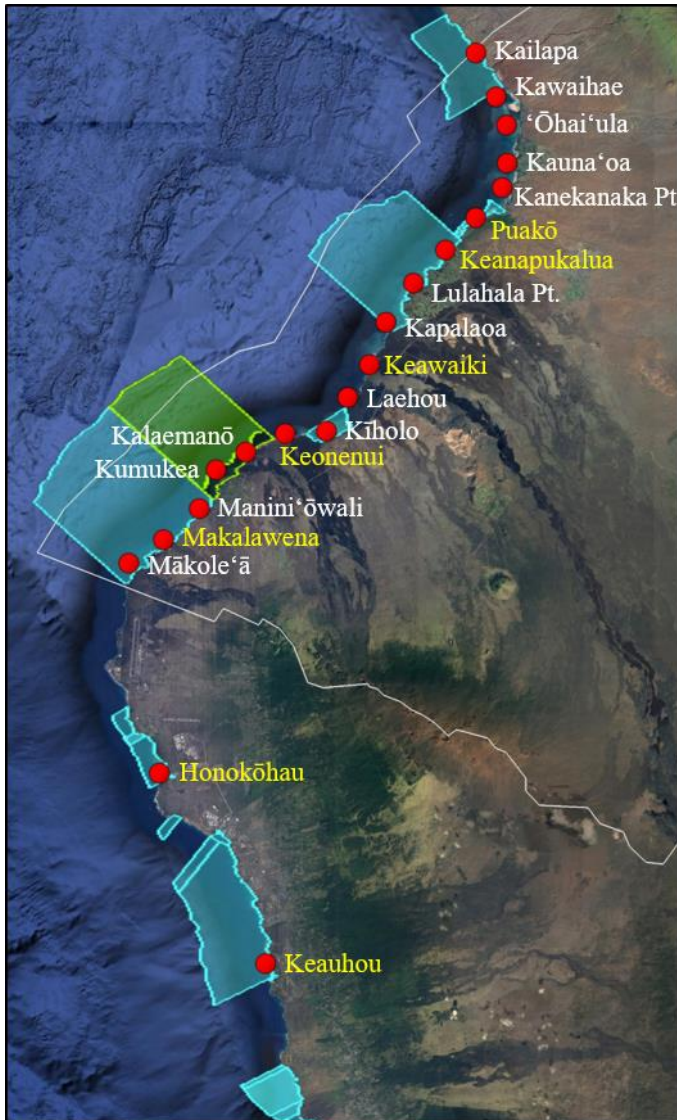


Figure 1. Map of survey locations, at which a shallow and deep site was surveyed. The white line is the boundary of the NOAA’s West Hawai‘i Focus Area. Blue polygons are State of Hawai‘i Fishery Management Areas (FMAs) and Fishery Replenishment Areas (FRA). Both FMAs and FRAs have additional fishing restrictions compared to “open” areas. The green polygon is the Ka‘ūpūlehu Marine Reserve. Two survey location (Kumukea and Kalaemanō) are within the nearshore section of the Marine Reserve, which was closed to all fishing on July 29, 2016. Prior to closure, the Ka‘ūpūlehu Marine Reserve was an FRA. Locations highlighted in yellow overlap with DAR West Hawai‘i Monitoring sites. See text for additional discussion.

4.3 Resilience Rankings

For each biological indicator, data were averaged across the three transects at each site and normalized to a unidirectional scale of 0-1 by dividing by the maximum value for the variable among all 20 sites within the depth strata. To ensure that high scores always inferred higher relative resilience potential, normalized scores were inverted for macroalgae cover and coral disease³. All indicators were equally weighted. Resilience scores were calculated by averaging the normalized indicator scores for each site after which these aggregated scores were also normalized. Sites were then ordered by score and ranked from 1 (highest resilience score) to 20 (lowest resilience score). These rankings express the resilience of all sites as relative to the site with the highest score, *i.e.*, the final resilience scores range from 0-1 and represent decimal percentages of the site with the highest score (1.00). Separate resilience scores were calculated for shallow and deep sites. “Qualitative” classifications for resilience scores were as follows:

High	—————>	Final Score $\geq \bar{x} + 1$ standard deviation (sd)
Medium-high	———>	$\bar{x} + 1$ sd > Final Score $\geq \bar{x}$
Medium-low	———>	\bar{x} > Final Score $\geq \bar{x} - 1$ sd
Low	—————>	$\bar{x} - 1$ sd > Final Score

In 2016, NOAA compiled existing information for a suite of environmental variables from the Ocean Tipping Points project (<http://www.pacioos.hawaii.edu/projects/oceantippingpoints/>) and elsewhere that could be used to quantify the following marine stressors (hereafter environmental indicators) identified by McClanahan *et al.* (2012): temperature variability, nutrients, sedimentation, physical human impacts, and fishing. A total of seventeen variables were initially identified for inclusion in the analysis, but some variables were either comprised predominately of zero values or were significantly correlated with other variables, so the data set was reduced to eleven variables (Table 3). At least one variable was retained for each environmental indicator.

To examine the potential role of marine stressors on reef resilience at the reef location, we conducted a principal component analysis using standardized values for the eleven environmental indicator variables. Loadings for each principal component (PC) were examined to assess the importance of each variable to the PC score (higher loadings implying greater importance). Scores for PC1 and PC2 at each location were plotted and visually examined in relationship to the four resilience classifications (low, med-low, med-high, and high) at each location. To calculate a location ranking, the 2016 resilience classification data from the shallow and deep site at each location were averaged together prior to calculating a normalized ranking as described above. Location rankings were used because the environmental data did not have sufficient spatial resolution to differentiate among shallow and deep sites within a location.

To determine if any of the seven biological indicators could be removed to streamline future assessments, we investigated the effects of removing one or more indicators on the ranking relative to the ranking obtained when all seven indicators were included. For this analysis, we assumed that the ranking derived from all seven indicators was the most complete and accurate

³ In contrast to other biological indicators, lower amounts of coral disease and macroalgal cover are considered to be representative of “better” reef condition.

Table 2. Summary of field survey methods. All surveys were conducted along all or part of each 25-m transect line (three 25-m lines per site). See Appendix B for a more-detailed description of each method.

Data Type	Location	Method
Coral Health and Disease	0-10 m (1 m-wide belt)	All coral colonies were counted and identified to species. Each colony was inspected for signs of bleaching, known diseases, and algal overgrowth. The prevalence of each condition was calculated separately for each site and by species, as appropriate.
Coral Juveniles	0-10 m (1 m-wide belt)	All coral colonies ≤ 5 cm in diameter (longest dimension) whose geometric center lay within a 0.5 x 0.5 m quadrat were counted and identified to the lowest taxonomic level. Four quadrats were haphazardly spaced ~ 2 m apart within the coral health belt transect.
Rugosity	0-10 m	A rugosity index was calculated by dividing the length of brass chain required to contour the bottom by the 10 m transect length. For this index, a value of one represents a flat surface with no relief, and increasing values represent more topographically complex substratum.
Benthic Cover	0-25 m	Photographs of the bottom were taken at every meter using a Canon G12 or S110 camera mounted on a 0.8 m long PVC monopod, generating 25 images/transect. Twenty randomly-selected photographs from each transect were analyzed using the online tool Coralnet to estimate benthic cover. The benthic component under each of thirty randomly distributed points was identified to the lowest possible taxonomic level. Due to lower taxonomic resolution in the 2015 survey data, when inter-annual comparisons were made, data were aggregated into four major benthic categories: corals, macroalgae, coralline algae, and other substratum.
Fish abundance and Size	0-25 m	All fish within or passing through a 5-m wide belt were identified to species and sized into 5-cm bins (<i>i.e.</i> , 0-5 cm, >5-10 cm, >10-15 cm, etc.). The weight of each fish in grams was calculated using standard weight-length relationships and using coefficients sourced from Fishbase, the USGS Hawai‘i Cooperative Fishery Research Unit and NOAA’s Coral Reef Ecosystem Program.

resilience ranking possible, and therefore, deviation from that ranking represented a loss in accuracy. We measured deviance between the two rankings using absolute cumulative change in position (hereafter, change score), which was calculated as the summation of the absolute differences between the “revised” rankings containing fewer biological indicators and the rankings calculated from all seven. A low change score indicated the revised rankings were

similar to the rankings calculated from all seven. The minimum change score possible was 0 (all rankings stayed the same) and the maximum possible change score was 181. If the revised rankings were re-assigned at random (*e.g.*, using no data from the indicators), the change score follows a normal distribution with a mean and standard deviation of 131 ± 18 .

5.0 Results and Discussion

5.1 Post-bleaching Reef Condition

Turf algae was the most common benthic cover type among the twenty West Hawai‘i locations, averaging $60.2 \pm 1.7\%$ cover (Table 4). Mean coral cover across the survey area was $18.2 \pm 1.3\%$, and was significantly greater at shallow ($20.2 \pm 2.0\%$) compared to deep ($16.4 \pm 1.6\%$) sites (two-way ANOVA, $F_{1,76} = 5.55$, $p = 0.021$). Twenty-five coral species were identified, and *Porites lobata* (lobe coral) and *P. compressa* (finger coral) were the most abundant, accounting

Table 3. Variables for each environmental indicator. Indicators correspond to those in Table 1.

Temperature Variability	
Climate Change - UV	Ultra violet radiation anomaly increase
Climate Change - Ocean Warming	Thermal stress - Maximum Degree Heating Weeks for years 2014 and 2015
Nutrients	
Nutrients - Agriculture/golf	Proxy index for runoff from agricultural land and golf courses
Nutrients - Impervious surfaces	Proxy for runoff from urban / impervious Surface
Nutrients - OSDS/UIW - Nitrogen flux	Nitrogen flux from onsite sewage disposal systems and underground injection wells
Sedimentation	
Sedimentation	Modeled annual sediment load
Physical Human Impacts	
PHI - Marine debris	Marine debris density from 2015 DAR high resolution aerial imagery
PHI - Ship-based shipping	Ship track density
PHI - Tourism/recreation	Invest Recreation Model based on Flickr photo user postings from 2005 - 2014
Fishing	
Fishing - Aquarium fishing	Aquarium fishing average annual catch for years 2013 - 2016
Fishing - Reef fish fishing	Total catch of reef fish for consumption

Table 4. Average percent cover of major benthic groups/species. An * indicates the species was observed during the coral health surveys but not during the benthic cover surveys.

	West Hawai'i	SHALLOW	DEEP
Coral	18.2 ± 1.3	20.2 ± 2.0	16.4 ± 1.6
<i>Porites lobata</i>	13.8 ± 1.4	18.2 ± 1.9	9.5 ± 1.6
<i>Porites compressa</i>	3.1 ± 0.7	1.0 ± 0.5	5.4 ± 1.1
<i>Montipora capitata</i>	0.3 ± 0.1	0.2 ± 0.1	0.5 ± 0.1
<i>Porites monticulosa</i>	0.3 ± 0.2	0.2 ± 0.2	0.5 ± 0.4
<i>Pavona varians</i>	0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.1
<i>Montipora patula</i>	0.1 ± 0.1	0.2 ± 0.1	0.1 ± 0.1
<i>Porites lutea</i>	0.1 ± 0.1	0.1 ± 0.1	<0.1
<i>Pocillopora meandrina</i>	0.1 ± 0.1	0.1 ± 0.1	<0.1
<i>Pavona duerdeni</i>	<0.1	0.1 ± 0.1	<0.1
<i>Leptastrea purpurea</i>	<0.1	<0.1	<0.1
<i>Porites rus</i>	<0.1	<0.1	<0.1
Coral spp.	<0.1	<0.1	<0.1
<i>Montipora flabellata</i>	<0.1	<0.1	*
<i>Pavona maldivensis</i>	<0.1	<0.1	*
<i>Psammocora nierstraszi</i>	<0.1	<0.1	*
<i>Porites bernardi</i>	<0.1	*	<0.1
<i>Cyphastrea ocellina</i>	*	*	*
<i>Fungia scutaria</i>	*	*	*
<i>Leptastrea bewickensis</i>	*	*	*
<i>Leptastrea incrusta</i>	*	*	*
<i>Montipora incrassata</i>	*	*	*
<i>Pocillopora damicornis</i>	*	*	*
<i>Porites annae</i>	*	*	0
<i>Porites brighami</i>	*	0	*
<i>Psammocora haimeana</i>	*	0	*
<i>Psammocora stellata</i>	*	*	*
Turf	60.2 ± 1.7	64.1 ± 2.4	55.7 ± 2.0
CCA	11.9 ± 1.6	9.1 ± 1.5	14.9 ± 2.8
Cyanobacteria	1.6 ± 0.4	1.3 ± 0.5	2.0 ± 0.6
Macroalgae	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Other	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Abiotic	8.0 ± 1.0	5.3 ± 0.7	10.7 ± 1.8
Sand	6.3 ± 0.8	4.8 ± 0.7	7.9 ± 1.4
Rubble	1.5 ± 0.5	0.3 ± 0.1	2.7 ± 0.9
Pavement	<0.1	0.1 ± 0.1	<0.1
Recently Dead Coral	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1

for over 93% of all coral observations. *Montipora capitata* and *P. monticulosa* were next most abundant, but each accounted for only 1.8% of all coral observations. Other coral species were rarely encountered.

Average coral disease prevalence across the survey area was low overall ($4.4 \pm 0.6\%$), with generally higher disease prevalence at the southern end of the survey area (Table 5). The highest disease prevalence was observed at Kalaemanō (13%) and Honokōhau (11%). Overall disease prevalence was significantly higher at shallow ($5.7 \pm 0.9\%$) than deep ($3.1 \pm 0.8\%$) sites (two-way ANOVA, $F_{1,76}=5.02$, $p=0.028$).

Five coral diseases were identified (most to least prevalent): *Porites* Growth Anomalies (PorGA), *Montipora* Growth Anomalies (MonGA), *Porites* Tissue Loss Syndrome (PorTLS), *Pocillopora* Tissue Loss Syndrome (PocTLS) and *Porites* Trematodiasis (Table 5). PorGA occurred at 76% of sites with *Porites* colonies and affected $5.0 \pm 0.5\%$ of *Porites* colonies.

In addition to the five diseases, two other conditions were noted: algal overgrowth (ALOG) and bleaching. ALOG was the most prevalent disease/condition affecting corals on West Hawai‘i with $15.5 \pm 1.4\%$ of all colonies displaying the condition. Bleaching prevalence in 2016 was $5.1 \pm 0.9\%$, which was far less than that observed during the mass bleaching event that affected West Hawai‘i reefs in 2015 ($64.2 \pm 2.7\%$).

TNC completed its 2015 reef resilience surveys near the height of the bleaching event (October 22-25, 2015), and while some coral mortality had certainly occurred by the time the surveys were conducted, the majority of bleaching-related mortality likely occurred in the following months. Coral cover estimates obtained from the 2015 surveys are consistent with pre-bleaching cover estimates from other West Hawai‘i reef areas (Minton *et al.* 2011, 2012, 2014, 2015), and are likely representative of pre-bleaching coral cover.

The 2015 resilience rankings were significantly correlated with bleaching prevalence (Figure 2) at shallow ($r = 0.69$, $p < 0.001$), but not deep ($r=0.35$, $p=0.133$) sites. However, both shallow and deep sites showed a trend toward sites with higher resilience rankings experiencing less bleaching in 2015. Rankings at shallow sites did particularly well at the “ends” of the ranking distribution (*e.g.*, rankings 1-8 and 14-20), but displayed poorer results in the middle (*e.g.*, rankings 9-13). At shallow sites, rankings appear to be a good predictor of a site’s resistivity to the warm water event.

Coral cover at our twenty West Hawai‘i reef locations significantly decreased between 2015 and 2016, dropping from a mean of $25.5 \pm 1.6\%$ to $18.2 \pm 1.3\%$ cover (two-way ANOVA, $F_{1,76}=12.79$, $p < 0.001$). This represents an average relative decline⁴ of $24.9 \pm 4.7\%$. Mean cover declined at every location except Keawaiki and Kīholo (Figure 3).

⁴ Confusion often results when discussing a decline in percent cover. *Absolute change* would be the change in percent cover from year to the next, *i.e.*, $\%cover_{(2016)} - \%cover_{(2015)}$, whereas *relative change* would be scaled relative to the initial year of the survey, *i.e.*, $(\%cover_{(2015)} - \%cover_{(2016)}) / \%cover_{(2015)}$. Relative change allows changes in cover at sites with different coverage of coral to be more easily compared.

Table 5. Prevalence of disease and other conditions by location and depth, with locations arranged from the most northerly (top) to the most southerly (bottom). Values are average percentage of the three transects surveyed at each depth (all values are %). Disease is total prevalence of all diseases and conditions except bleaching (% of colonies). The other five diseases are prevalence for the described genera (% of *Porites*/*Montipora*/*Pocillopora* colonies). Bleaching is the percent of colonies fully- or partially-bleached. Severe bleaching is the percent of colonies with >50% loss of pigmentation. See text for definitions of the disease abbreviations.

Site	Shallow									Deep								
	Disease	PorGA	MonGA	PorTLS	PocTLS	Por Trem	ALOG	Bleach	Sev. Bleach	Disease	PorGA	MonGA	PorTLS	PocTLS	Por Trem	ALOG	Bleach	Sev. Bleach
Kailapa	2.8	3.2	0	0	0	0	19.1	1.8	0.4	1.4	1.9	0	0	0	0	21.3	7.2	2.4
Kawaihae	1	0	0	1.9	0	0	7.2	17.4	0	0	0	0	0	0	18.4	8.5	4.8	
‘Ōhai‘ula	1.8	0.8	0	0	0	0	26.3	8.6	0	0	0	0	0	0	15.2	3.5	0	
Kauna‘oa	3.5	3.2	0	0.6	0	0	15.9	6	1.1	0.8	1	0	0	0	49	6.5	0	
Kanekanaka Pt.	2	2.3	0	0	0	0	15.6	2	1	1.1	1.4	0	0	0	35.6	7.5	1.1	
Puakō	9	11.5	0	0	0	0.4	19.6	0.3	0.3	1.6	2.2	0	0	0	10.4	2.4	0	
Keanapukalua	5.3	7.4	0	0	0	0	21.4	6.7	2	0	0	0	0	0.8	24.4	13.2	1.1	
Lulahala Pt.	6.4	6.5	0	0.6	0	1.1	16.9	2.1	0	1.5	1.7	0	0	0	10.9	11	5.3	
Kapalaoa	4.9	7.5	0	0	0	0.9	27.2	7.2	1.7	1.3	1.5	0	0	0	2.5	20.3	6.9	3.4
Keawaiki	3.1	1.5	0	2.6	8.3	0	20.2	7.2	0.8	0.7	0.9	0	0	0	8.9	14.1	15	3.1
Laehou	0.5	0.7	0	0	0	0	8.6	11.1	4.1	0	0	0	0	0	18.4	10.9	3.8	
Kīholo	10.7	11.5	0	1.8	0	0	9.6	0.4	0.4	6.6	10.1	0.6	0.3	0	0	12.5	1.7	1.3
Kalaemanō	15.2	17	0	1.1	0	0	8.7	0.5	0.5	10	10.5	0	0	0	0.1	11.6	0.7	0.4
Keonenui	2.9	3.8	0.9	0.2	0	0	4.2	4.1	2.4	1.1	1.3	0	0	0	0	9.8	1.6	0.8
Kumukea	4.5	4.2	0	0.6	0	0.2	6.5	2.4	1.9	5.2	5.9	0	0	0	0.2	6.7	3.6	3.2
Manini‘ōwali	10.4	10.3	0	0.5	0	0.2	8.7	0.9	0.5	4.7	5.8	0	0	0	0	10	2.2	2.2
Makalawena	10	11.9	0	1.2	0	1.8	6.7	0.9	0.2	5.9	6.5	0	0.6	0	0.5	9.1	1.3	0.2
Mākole‘ā	7.4	8.4	0	0.2	0	0.2	10.4	2.3	1.6	3.1	3.6	0	0.3	0	0.9	7.9	10.9	7
Honokōhau	8.1	8.3	0	0	0	0.7	12.1	0.7	0	13.2	13.1	0	0	0	0	7.3	0.6	0.3
Keauhou	5	5.2	0	0.5	0	0	10.3	0.5	0	4.9	5.5	0	0	0	1.1	31.4	5.2	3

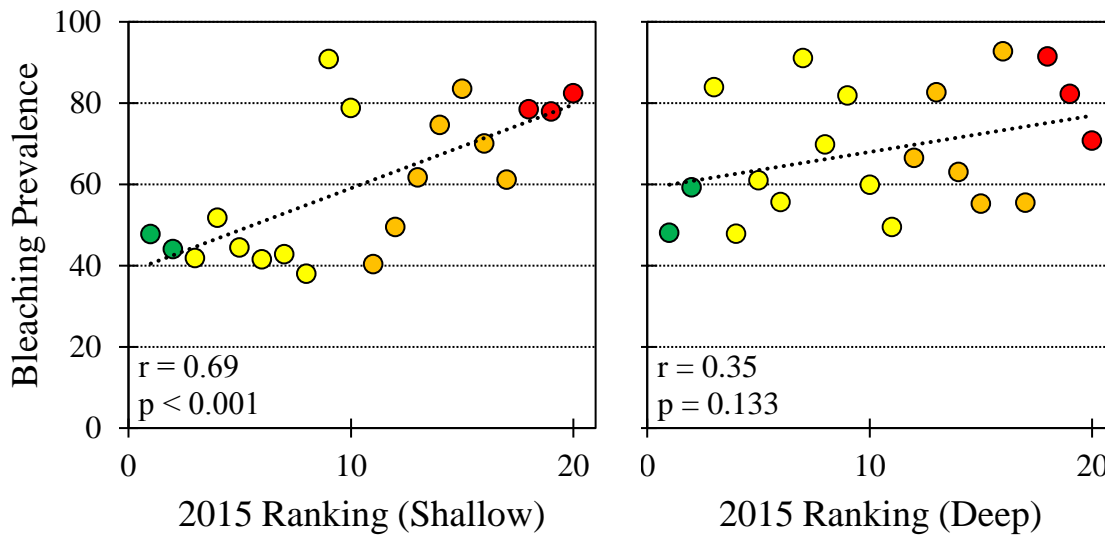


Figure 2. Bleaching prevalence in 2015 versus the 2015 resilience ranking at shallow and deep sites. Colors correspond to resilience classification: high (green), medium-high (yellow), medium-low (orange), and low (red). Trendline was added as a visual aid.

While coral cover significantly declined between 2015 and 2016, there was not a similar decline in coral colony density across the survey area, with many locations actually seeing increases in colony density (Figure 3). Unlike coral cover, however, declines in coral colony density were correlated with bleaching prevalence ($r = -0.43$, $p = 0.030$); sites that experienced higher rates of bleaching tended to lose the most coral colonies. Change in the density of coral colonies showed a spatial pattern, not surprising given bleaching prevalence to the north of the survey area tended to be greater than to the south (Maynard *et al.* 2016, Kramer *et al.* 2016).

It is important to note that surveys in 2016 were not conducted on the exact same areas of the reef as in 2015 because no permanent markers were installed during the earlier survey effort. As such, it is possible the spatial shift in the location of the transect, even though small at most sites, could account for observed changes in coral cover or coral colony density. However, this is not likely the case. If it is assumed no change in coral cover or colony density occurred as a result of the 2015 mass bleaching event, a spatial shift in our transect location should result in no change in the average coral abundance across the survey area because the placement of the new transect at a site in 2016 would have an equal likelihood of sampling an area of the reef with more or less coral abundance than that sampled in 2015. Yet, only 2 of 20 locations experienced an increase in cover, which is exceptionally unlikely ($P(Y \leq 2 \mid n = 20, p = .5) = 0.02\%$), suggesting that average coral cover declined at West Hawai'i. Likewise, coral colony density estimates displayed a strong spatial pattern from north to south, a pattern that is also extremely unlikely under standard probability theory. There is only a 2.7% chance of drawing a run of 8 consecutive increases or decreases at our 20 locations, again suggesting this spatial pattern is not random and, therefore, unrelated to the shift in the transect location within the site.

The apparent disconnect between bleaching and coral cover (no significant correlation) and bleaching and coral colony density (significant negative correlation) likely arises from the way in which bleaching effects manifest themselves at the colony level. Bleaching does not always kill the entire colony, and under less severe bleaching conditions, higher rates of partial mortality compared to total colony mortality would be expected. As bleaching increases, the amount of partial and total colony mortality should also increase. This scenario could result in coral cover

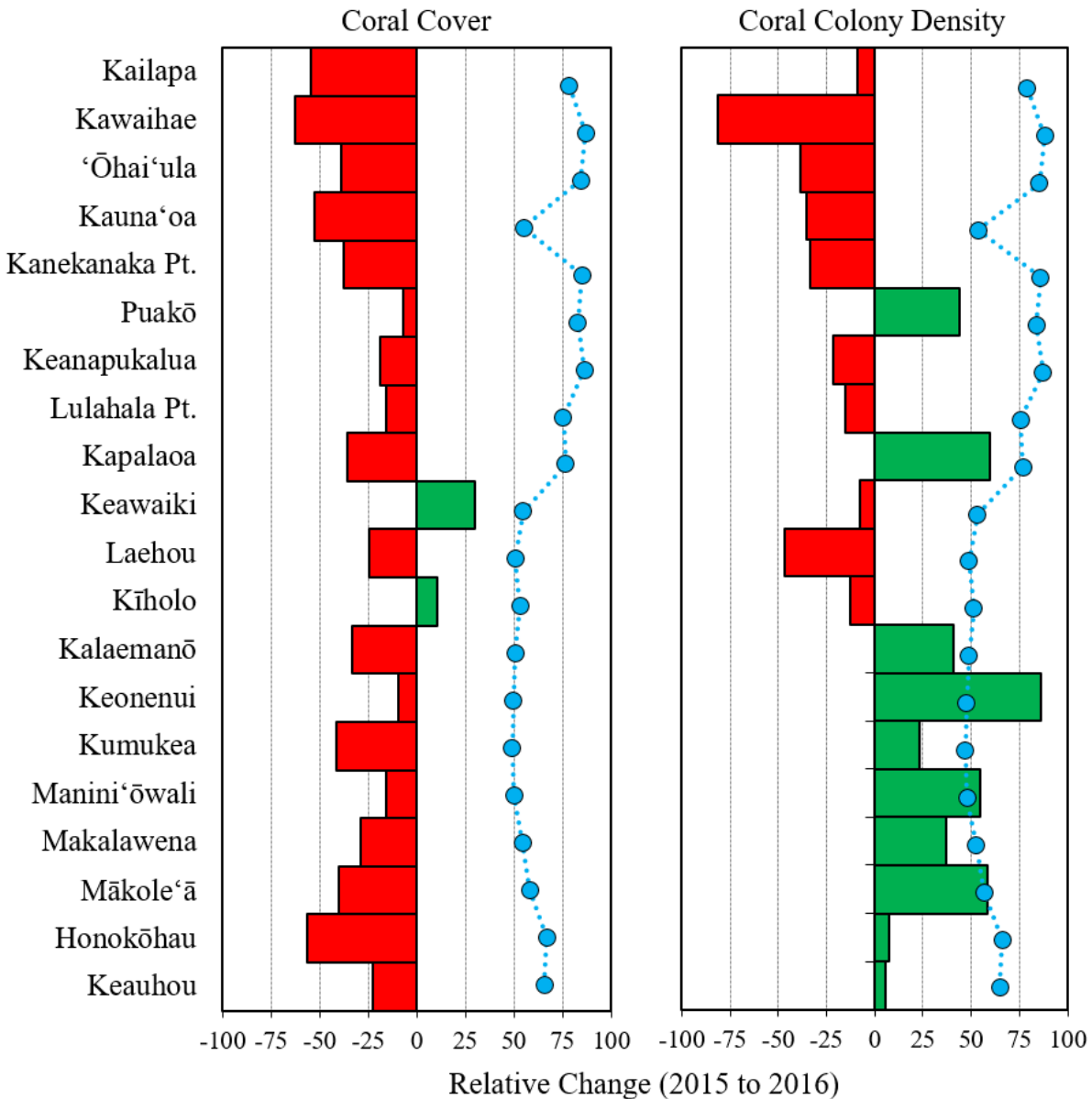


Figure 3. Relative change in coral cover or coral colony density (red/green bars) and bleaching prevalence (blue dots) at twenty West Hawai‘i reef locations. Relative change in coral cover and coral colony density is for the years 2015 to 2016, and bleaching prevalence was that measured during the 2015 mass bleaching event. Sites are arranged from most northerly (top) to most southerly (bottom).

declines without a significant reduction in the density of coral colonies at sites with relatively low bleaching severity/prevalence, but an increasing loss of coral colonies as the bleaching severity/prevalence increases. An increase in partial colony mortality was observed along West Hawai'i during the 2015 event (Kramer *et al.* 2016, Maynard *et al.* 2016) and in 2016 relative to 2013 (NOAA ESD, unpub. data).

Bleached corals that survive often display an increased susceptibility to disease (Brandt and McManus 2007, Harvell *et al.* 2007), with disease prevalence increasing 3-6 months following a bleaching event (Miller *et al.* 2009). Surveys to confirm an increase in disease prevalence 6 months post-bleaching (*e.g.*, April to May 2016) were not conducted, but if an increase did occur, it did not persist a year later. While overall disease prevalence dropped slightly in 2016 compared to 2015, the difference was not statistically significant (t-test, $t_{24}=1.62$, $p=0.118$). Regardless of the ultimate cause, coral mortality that occurred between the 2015 and 2016 surveys were likely associated with the 2015 bleaching event, be it direct mortality from the bleaching or indirect mortality due to bleaching-weakened corals succumbing to subsequent disease or other ecological stressors.

Declines in coral cover contributed to a significant change in the structure of the benthic community between survey years (PERMANOVA; $F_{1,236}=13.23$; $p=0.001$). Coral losses were

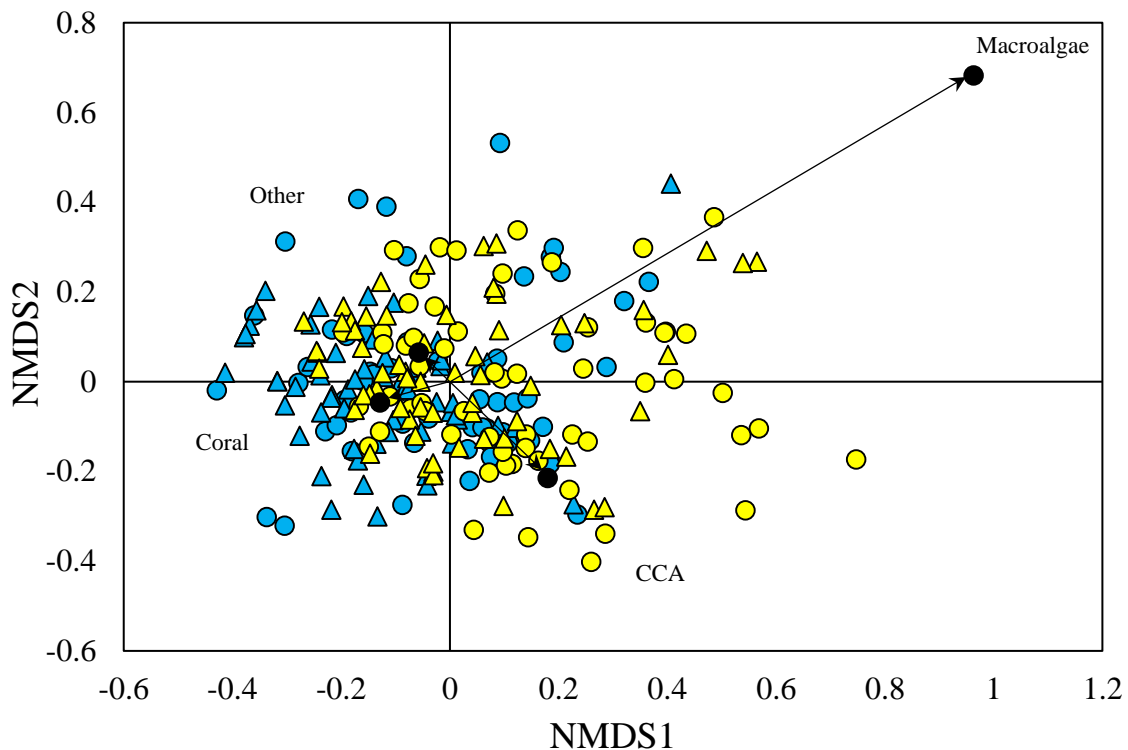


Figure 4. NMDS plot for 20 shallow (triangles) and deep (circles) sites along West Hawai'i in 2015 (blue) and 2016 (yellow). A significant shift in benthic structure occurred between years, shifting the community from coral (black circle in lower left quadrant) and towards other benthic categories. For clarity, group labels for Coral, CCA, and Other have been placed in their corresponding quadrant, and are not directly adjacent their corresponding black circles.

offset primarily by increases in crustose coralline algae (CCA) and to a lesser extent, turf algae (Figure 4). Macroalgal cover increased slightly in 2016 compared to 2015, but still only accounted for <1% cover of the bottom. This shift in benthic composition is consistent with changes frequently observed on reefs following bleaching-related coral mortality events (Graham *et al.* 2015). That the increase in CCA was the largest observed change is a promising sign for potential recovery on West Hawai‘i’s reefs because CCA is an important settlement substratum for coral larvae (Fabricius 2005, Price 2010), whereas turf generally inhibits coral recruitment and juvenile survival (Birrell *et al.* 2005, Ritson-Williams *et al.* 2009).

We observed 122 species of reef fish in 26 families across the survey area in 2016. Total fish biomass was $71.1 \pm 9.8 \text{ g/m}^2$ and varied from a low of $43.2 \pm 6.5 \text{ g/m}^2$ (Kawaihae) to a high of $165.9 \pm 39.5 \text{ g/m}^2$ (Puako). As on many reefs in the main Hawaiian Islands, the families Acanthuridae (surgeonfishes) and Scaridae (parrotfishes) contributed the most to total fish biomass, 30.4% and 24.6% of the total, respectively (Table 6). Herbivores accounted for over half ($54.5 \pm 2.1\%$) of all the total fish biomass on West Hawai‘i (Figure 5). Apex predators were rarely observed, appearing on less than 8% of the transects and accounting for only $2.0 \pm 0.9\%$ of the total fish biomass.

Total fish biomass did not significantly differ between depths (two-way ANOVA, $F_{1,76} = 2.21$, $p = 0.141$), but variability among the sites was high, potentially obscuring spatial differences. Deep sites showed a trend toward lower fish biomass than shallow ones. This trend was primarily associated with lower biomass of the families Acanthuridae, Scaridae, Ballistidae (triggerfishes), and Kuhliidae (chubs) at deep compared to shallow sites (Table 6).

Total fish biomass was significantly lower in 2016 than 2015 (two-way ANOVA, $F_{1,76} = 4.90$, $p = 0.030$), $71.1 \pm 9.8 \text{ g/m}^2$ compared to $79.6 \pm 4.6 \text{ g/m}^2$. While long-term declines in reef fish populations have been documented for some West Hawai‘i reefs (Minton *et al.* 2012, 2018,

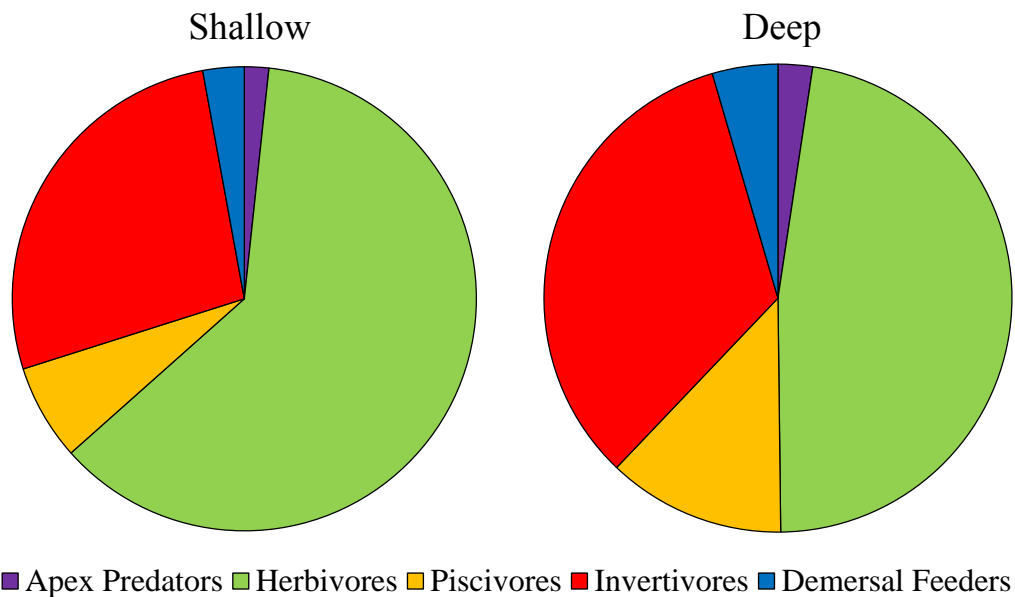


Figure 5. Trophic structure at shallow and deep sites along West Hawai‘i in 2016.

Table 6. Fish biomass by family (g/m²) averaged over all West Hawai‘i survey locations and by depth. Biomass was not estimated for Muraenidae (eels) due to challenges associated with accurately sizing these fish.

Family	West Hawai‘i	Shallow	Deep
Acanthuridae	21.6 ± 2.9	27.3 ± 4.4	16.0 ± 3.5
Scaridae	17.5 ± 2.8	21.8 ± 4.7	13.1 ± 2.9
Balistidae	8.4 ± 3.4	11.8 ± 6.4	4.9 ± 1.9
Labridae	4.3 ± 0.4	4.2 ± 0.5	4.4 ± 0.7
Kuhliidae	3.7 ± 3.7	7.3 ± 7.3	<0.1
Serranidae	3.1 ± 0.8	2.2 ± 0.8	4.0 ± 1.4
Sphyraenidae	2.0 ± 2.0	<0.1	4.0 ± 4.0
Chaetodontidae	1.9 ± 0.2	2.1 ± 0.3	1.7 ± 0.3
Mullidae	1.7 ± 0.6	2.0 ± 1.1	1.5 ± 0.4
Lethrinidae	1.2 ± 0.4	1.0 ± 0.5	1.4 ± 0.7
Pomacentridae	1.1 ± 0.5	0.8 ± 0.2	1.5 ± 1.0
Lutjanidae	0.9 ± 0.6	0.3 ± 0.1	1.5 ± 1.3
Kyphosidae	0.9 ± 0.6	0.7 ± 0.5	1.0 ± 1.0
Holocentridae	0.8 ± 0.4	0.3 ± 0.3	1.4 ± 0.7
Carangidae	0.7 ± 0.4	1.2 ± 0.7	0.3 ± 0.2
Cirrhitidae	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1
Zanclidae	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.1
Aulostomidae	0.2 ± 0.1	0.4 ± 0.2	0.1 ± 0.1
Scorpaenidae	0.2 ± 0.2	<0.1	0.3 ± 0.3
Monacanthidae	0.1 ± 0.1	0.2 ± 0.2	<0.1
Tetraodontidae	0.1 ± 0.1	0.2 ± 0.1	<0.1
Pomacanthidae	0.1 ± 0.1	<0.1	0.1 ± 0.1
Mugilidae	0.1 ± 0.1	0.1 ± 0.1	<0.1
Synodontidae	<0.1	<0.1	0.1 ± 0.1
Ostraciidae	<0.1	<0.1	<0.1
Blenniidae	<0.1	<0.1	<0.1
Muraenidae	present	present	present
Grand Total	71.1 ± 9.8	84.4 ± 16.2	57.8 ± 10.6

Walsh *et al.* 2013), the decline observed from 2015 to 2016 is likely associated with a large fish recruitment in 2014 (Talbot 2014, Minton *et al.* 2017, 2018). TNC and its partners have collected a robust baseline of fish populations at Ka‘ūpūlehu, Hawai‘i (see Minton *et al.* 2018). The Ka‘ūpūlehu survey area overlaps several reef resilience locations, and a sufficient number of surveys sites exist within 150 m of Keonenui reef resilience location crossing multiple years to allow for a reasonable baseline condition to be assembled for this location (Figure 6). This nearly 10-year baseline shows a “spike” in total fish biomass in 2015, corresponding with the

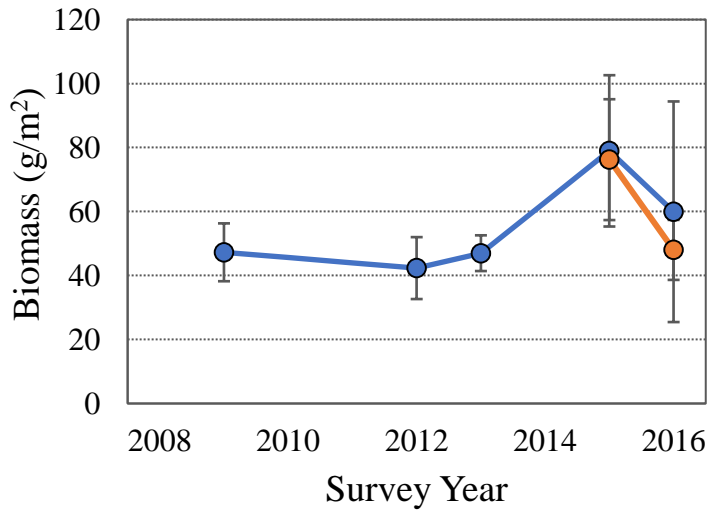


Figure 6. Change in total fish biomass (g/m^2) at Keonenui, Hawai'i from 2009 to 2016. Blue circles are data from Minton *et al.* (2014, 2015, 2018) and include all survey sites within 150 m radius of the Keonenui location. Orange circles are from reef resilience surveys conducted at Keonenui, with values from 2015 from Maynard *et al.* (2016) and for 2016 from this report.

as having high relative resilience, eight with medium-high resilience, seven with medium-low resilience, and three with low resilience. Sites with high and medium-high resilience were characterized primarily by greater density of coral juveniles compared to sites with medium-low and low resilience. Other indicators were less important in discriminating the resilience categories. For example, variability in herbivore biomass, while high among the sites, appeared to provide little toward discriminating resilience categories.

At the shallow sites, resilience rankings changed modestly between years as indicated by a change score of 62. While sites may have changed in rankings, sites designated as having high or medium-high resilience seldom worsened to low or medium-low (Figure 7). For example, Laehou and Kumukea were scored as the most resilient shallow sites in both 2015 and 2016. The largest drop in ranking was 9 positions (Ohae 'ula), from eleven in 2015 to twenty in 2016, while the greatest rise was 8 (Keauhou), from twenty in 2015 to twelve in 2016 (Figure 5). Neither of these jumps moved a site between the low or medium-low categories and the high or medium-high categories.

Normalized resilience scores for deep sites ranged from 0.63 to 1.00 (Table 8). Three sites were classified as having high relative resilience, seven with medium-high resilience, six with medium-low resilience, and four with low resilience. Deep sites with high and medium-high resilience were characterized by greater density of coral juveniles and higher coral cover compared to sites with medium-low and low resilience, whereas other indicators were less important in discriminating resilience categories.

atypically large coral reef fish recruitment event in 2014. As with other fish populations in West Hawai'i, Keonenui now appears to be gradually returning to pre-2014 levels. At this point, we believe it likely that the declines in fish biomass found across all survey locations is due to this same phenomenon, and not a decline associated with coral loss from the 2015 bleaching event. Future survey efforts will be needed to address this definitively.

5.2 2016 Reef Resilience Rankings

Reef Resilience scores for each location were recalculated using the 2016 survey data. Normalized resilience scores for shallow sites ranged from 0.57 to 1.00 (Table 7). As in 2015, two sites were classified

Table 7. Resilience assessment results for shallow (5-7 m) reef areas along the West Hawai‘i coastline. Colors correspond to the resilience category: high (green), medium-high (yellow), medium-low (orange), low (red). Rankings and ranking categories for 2015 are from Maynard *et al.* (2016).

Site Name	Normalized			
	Raw Score	Score	2016 Ranking	2015 Ranking
Laehou	0.806	1.000	1	1
Kumukea	0.736	0.913	2	2
Keawaiki	0.687	0.852	3	6
Keonenui	0.666	0.827	4	8
Makalawena	0.663	0.822	5	7
Mākole‘ā	0.662	0.821	6	4
Manini‘ōwali	0.646	0.802	7	5
Keanapukalua	0.644	0.799	8	9
Kapalaoa	0.622	0.771	9	16
Kauna‘oa	0.612	0.760	10	12
Kīholo	0.606	0.751	11	3
Puakō	0.597	0.741	12	20
Keauhou	0.576	0.715	13	13
Kailapa	0.556	0.690	14	14
Honokōhau	0.542	0.672	15	17
Lulahala Pt.	0.532	0.660	16	10
Kanekanaka Pt.	0.529	0.656	17	19
Kawaihae	0.523	0.648	18	15
‘Ōhai‘ula	0.520	0.645	19	18
Kalaemanō	0.455	0.565	20	11

In contrast with shallow sites, deep sites showed considerable change in their resilience rankings between years (change score = 102). Many sites showed large changes in rankings (Figure 7), with the site ranked at 17 in 2015 (Keonenui) jumping to the top ranking in 2016. Among shallow sites, only 30% had a >3 position change between 2015 to 2016 compared to 60% of the deep sites showing a >3 position change over the same time period.

A PCA was conducted on the change in the indicator values between 2015 and 2016 at deep sites. The first three principle components (PC) explained >96% of the variation (Table 9). PC1 was influenced most by changes in fish herbivore biomass (Table 9). The number of coral juveniles had the highest loadings in PC2, countered by moderate loadings for macroalgal cover and rugosity. Coral cover had the highest loading for PC3. The change in ranking for deep sites from 2015 to 2016 was not significantly correlated with either PC1 or PC3, but was negatively correlated with PC2 ($r=0.593$; $p=0.006$). Sites with increased coral recruitment and decreased

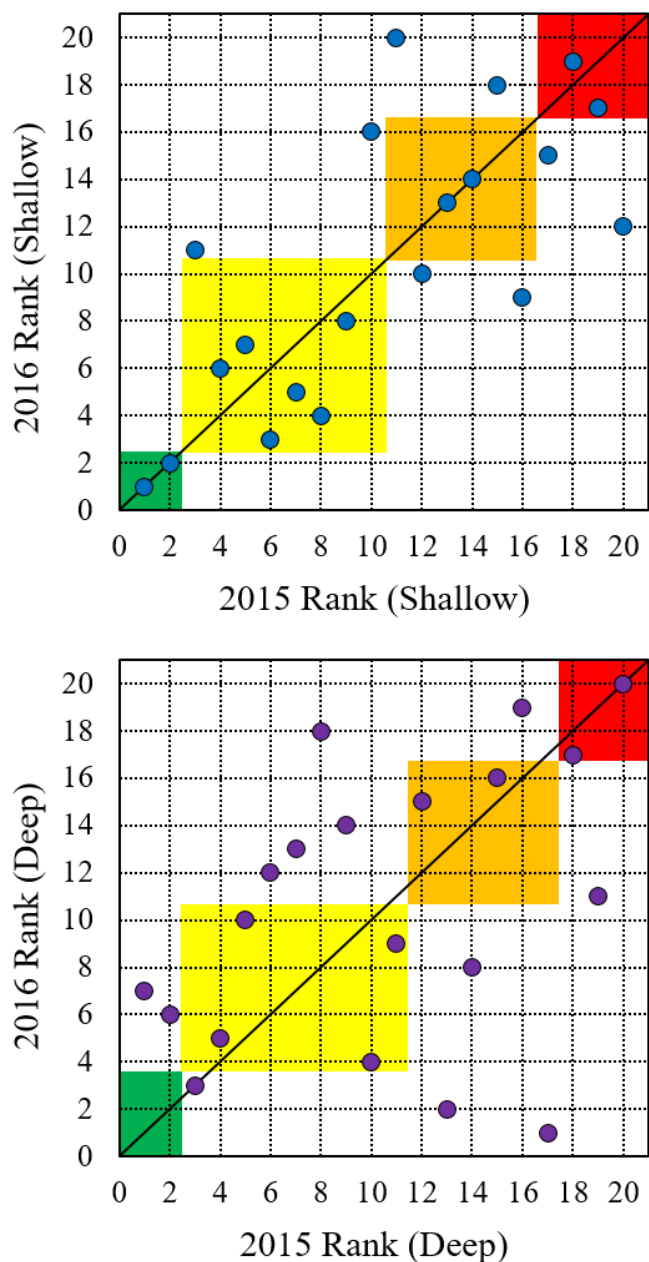


Figure 7. Relationship between 2015 and 2016 rankings for shallow (top) and deep (bottom) reef sites along the West Hawai‘i coastline. Points falling the on the diagonal line represent no change in resilience ranking. For points lying within the colored squares, change in resilience ranking did not shift it outside of its 2015 resilience category: high (green), medium-high (yellow, medium-low (orange), low (red).

macroalgal cover and rugosity from 2015 to 2016 tended to show greater improvement in resilience rankings, while sites with decreased densities of coral juveniles, and increased macroalgal cover and rugosity fell the farthest in the rankings. While positive effects on resilience associated with increased coral recruitment and lower macroalgal cover are intuitive, conventional thought would associate decreased rugosity with decreased resilience. Rugosity, which is considered a measure of small-scale topographic structure, is often positively correlated with fish abundance and biomass, and also with benthic diversity. It is not clear why this study has different findings, but it is possible that potential “benefits” gained from higher rugosity do not confer additional resilience to the community; for example, if higher rugosity resulted in a greater abundance of species that confer less resilience to the assemblage than the species lost as a result of the 2015 bleaching even, the resilience ranking at a site could decline between years. Unfortunately, the 2015 survey data are insufficient to investigating this potential phenomenon due to their low taxonomic resolution, but additional survey data collected in later years may provide better insight.

These findings suggest biological processes (*e.g.*, recruitment) that contribute to recovery are important, and that management actions that improve these processes may contribute more to improving a site’s long-term resilience than actions that focus on maintaining a static condition state (*e.g.*, high coral cover).

Table 8. Resilience assessment results for deep (10-12 m) reef areas along the West Hawai‘i coastline. Colors correspond to the resilience category: high (green), medium-high (yellow), medium-low (orange), low (red). Rankings and ranking categories for 2015 are from Maynard *et al.* (2016).

Site Name	Normalized			
	Raw Score	Score	2016 Ranking	2015 Ranking
Keonenui	0.803	1.000	1	17
Keanapukalua	0.712	0.888	2	13
Puakō	0.701	0.873	3	3
Mākole‘ā	0.688	0.857	4	10
Kumukea	0.683	0.851	5	4
Kīholo	0.668	0.833	6	2
Laehou	0.662	0.824	7	1
Keawaiki	0.652	0.813	8	14
Manini‘ōwali	0.649	0.809	9	11
Makalawena	0.627	0.781	10	5
Kapalaoa	0.589	0.734	11	19
Kauna‘oa	0.582	0.725	12	6
‘Ōhai‘ula	0.573	0.714	13	7
Kailapa	0.565	0.704	14	9
Keauhou	0.560	0.697	15	12
Kalaemanō	0.544	0.678	16	15
Kawaihae	0.534	0.665	17	18
Honokōhau	0.531	0.661	18	8
Kanekanaka Pt.	0.521	0.649	19	16
Lulahala Pt.	0.503	0.627	20	20

Table 9. Loadings for first three principal components. Italics denote large/moderately large loadings for each component.

	PC1	PC2	PC3
Coral disease	1.68	1.58	-0.03
Coral cover	1.76	0.25	<i>-5.07</i>
Macroalgal cover	1.39	<i>2.45</i>	1.80
Coral juveniles	2.74	<i>-6.13</i>	1.30
Herbivore biomass	<i>-9.32</i>	-0.63	0.06
Rugosity	1.75	<i>2.50</i>	1.95
Proportion Explained	52.7	26.4	17.2
Cumulative Proportion	52.7	79.1	96.3

Environmental data for all locations was explored using principal component analysis. The first three principal components explained 86.3% of the sample variability (Table 10). PC1 had four environmental variables with moderate to large loadings. Aquarium fishing, reef fish fishing and nutrients from agricultural/golf courses had the largest loadings while nutrients from impervious surfaces had a moderate loading. PC2 had large loadings associated with fishing. When PC1 and PC2 were plotted, sites clustered primarily into three groups (Figure 8), all of which were heavily influenced by fishing pressure.

Sites within Cluster A (Table 11) were characterized by positive scores for PC2 (Figure 8) resulting primarily from low levels of all fishing at a site, and to a lesser extent low runoff from agricultural land and golf courses (Figure 9). These locations also tended to have moderate to high tourism impacts, and high sediment inputs relative to other locations. This cluster included the two locations near commercial boat harbors (Kawaihae and Honokōhau) and a location offshore from Pelekane Bay (‘Ōhai‘ula), which is heavily impacted by sediment runoff (Minton *et al.* 2011).

Sites within Cluster B (Table 11) were characterized by negative scores associated with both PC1 and PC2 (Figure 8). Locations in this cluster had high take of aquarium fish, but otherwise tended to have the lowest levels for the other environmental variables (Figure 9). These locations are notable for their difficult access, often via unimproved roads, by foot, or by boat. None of these locations are offshore of significant coastal developments.

Table 10. Loadings for first three principal components. See Table 3 for a description of each environmental indicator variable. Italics denote large/moderately large loadings for each component.

	PC1	PC2	PC3
Climate Change - UV	-0.002	0.070	-0.111
Climate Change - Ocean Warming	0.139	0.003	0.060
Nutrients - Agriculture/golf	<i>0.558</i>	-0.145	<i>0.403</i>
Nutrient - Impervious surfaces	<i>0.259</i>	-0.042	-0.138
Nutrients - OSDS/UIW - Nitrogen flux	0.049	-0.003	-0.074
Sedimentation	0.006	0.052	-0.039
PHI - Ship-based shipping	-0.035	0.011	-0.004
PHI - Tourism/recreation	-0.005	0.019	-0.018
PHI - Marine debris	0.192	0.022	0.175
Fishing - Aquarium fishing	<i>-0.766</i>	<i>-0.485</i>	0.127
Fishing - Reef fish fishing	<i>0.555</i>	<i>-0.511</i>	<i>-0.236</i>
Proportion Explained	53.0%	21.0%	12.2%
Cumulative Proportion	53.0%	74.1%	86.3%

Sites within Cluster C (Table 11) were characterized by positive scores for PC1 and negative scores for PC2 (Figure 8). These locations were characterized by high take of reef fish, high nutrient runoff from agricultural lands/golf course and impervious surfaces, as well as high tourism impacts relative to the other West Hawai‘i locations (Figure 9). All five locations in this cluster were offshore of significant developments, either golf courses/resorts (Kauna‘oa, Lulahala Pt., and Keauhou) or residential neighborhoods (Puakō and Keonenui).

Kalaemanō was an unusual location that did not easily fit into any cluster. With the exception of fishing, Kalaemanō had low values for all the environmental variables. For fishing, Kalaemanō was among the highest for both aquarium and reef fishing, which accounts for its near zero score along PC1 and its large negative score along PC2. Interestingly, Kalaemanō had the lowest overall resilience rank.

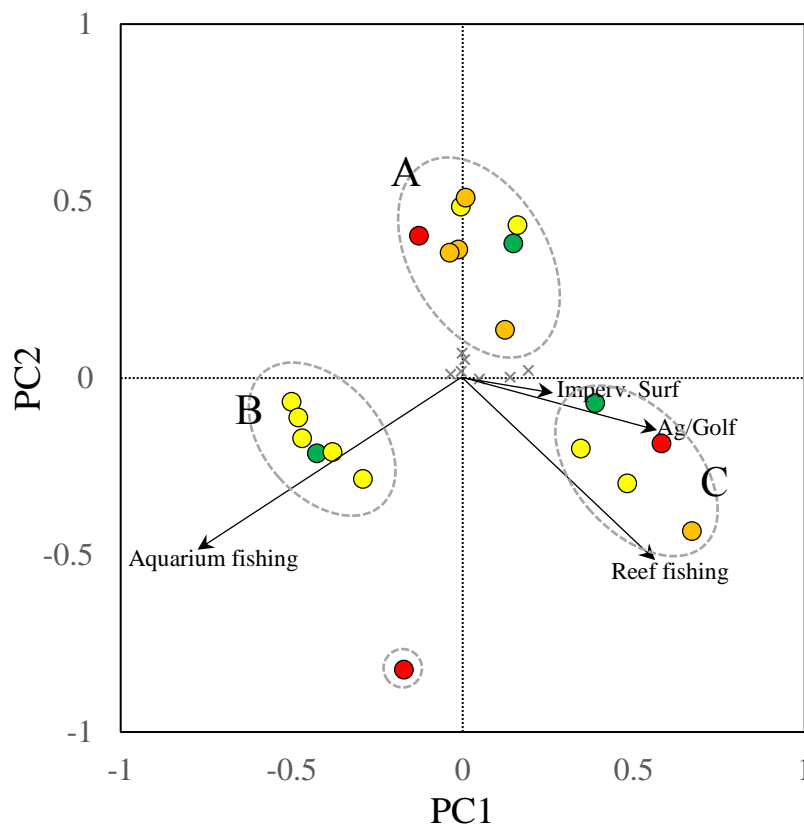


Figure 8. Locations plotted by their PC1 and PC2 scores. Color dots correspond to resilience classification for the location: high (green), medium-high (yellow), medium-low (orange), and low (red). X's are environmental variables that have been left unlabeled to increase figure readability. Three clusters are apparent (A, B, and C) and one site that was not easily classified (Kalaemanō). See text for descriptions of each cluster.

The 2016 resilience rankings for each location were uncorrelated with both PC1 and PC2. Clusters A and C comprised sites across the range of rankings (Figure 6), but tended to have sites in the lower half. The average rank for Clusters A and C were 12.6 and 10.2, respectively, but given these clusters have different numbers of locations within them, their average ranking needs to be adjusted; this can be done by dividing the average ranking by the highest possible average ranking for the cluster given its size (4.5 for Cluster A and 3 for Cluster C). This gives adjusted average rankings of 2.8 and 3.4 for Clusters A and C, respectively (note: the average resilience ranking for Cluster C is lower than that for Cluster A once adjusted). In contrast, locations in Cluster B had rankings in the top half, including the top ranked location (Laehou), and no location ranked below 10. The six locations in

Cluster B had an average resilience ranking of 6.3 and an adjusted ranking of 1.8, indicating Cluster B had the highest average resilience ranking of the three clusters.

While it is difficult to separate the effect of specific stressors on reef resilience, one generalization may be possible. Increasing the number of stressors appears to lower resilience for a reef area. In this study, the three clusters of locations lie along a gradient of stress with Cluster B having the fewest stressors (primarily aquarium fishing), followed by Cluster A (primarily non-fishing), followed by Cluster C (both non-fishing and fishing). Likewise, relative resilience declines from Cluster B to Cluster A to Cluster C.

While consensus is quickly forming that local management alone will be insufficient to offset the effects of global climate change (Anthony *et al.* 2014, Bruno and Valdivia 2016, Weijerman *et al.* 2018), evidence is emerging that both local and global management are necessary to ensure the survival of many coral reef systems (Anthony *et al.* 2014, Wolff *et al.* 2017). This study indicates that reef resilience is negatively correlated with the number and intensity of stressors, and implies that reducing local stressors can have beneficial effects on the resilience of reefs to climate change. In addition, reducing local stressors that adversely affect ecological processes, such as coral recruitment, may produce the most significant long-term benefits.

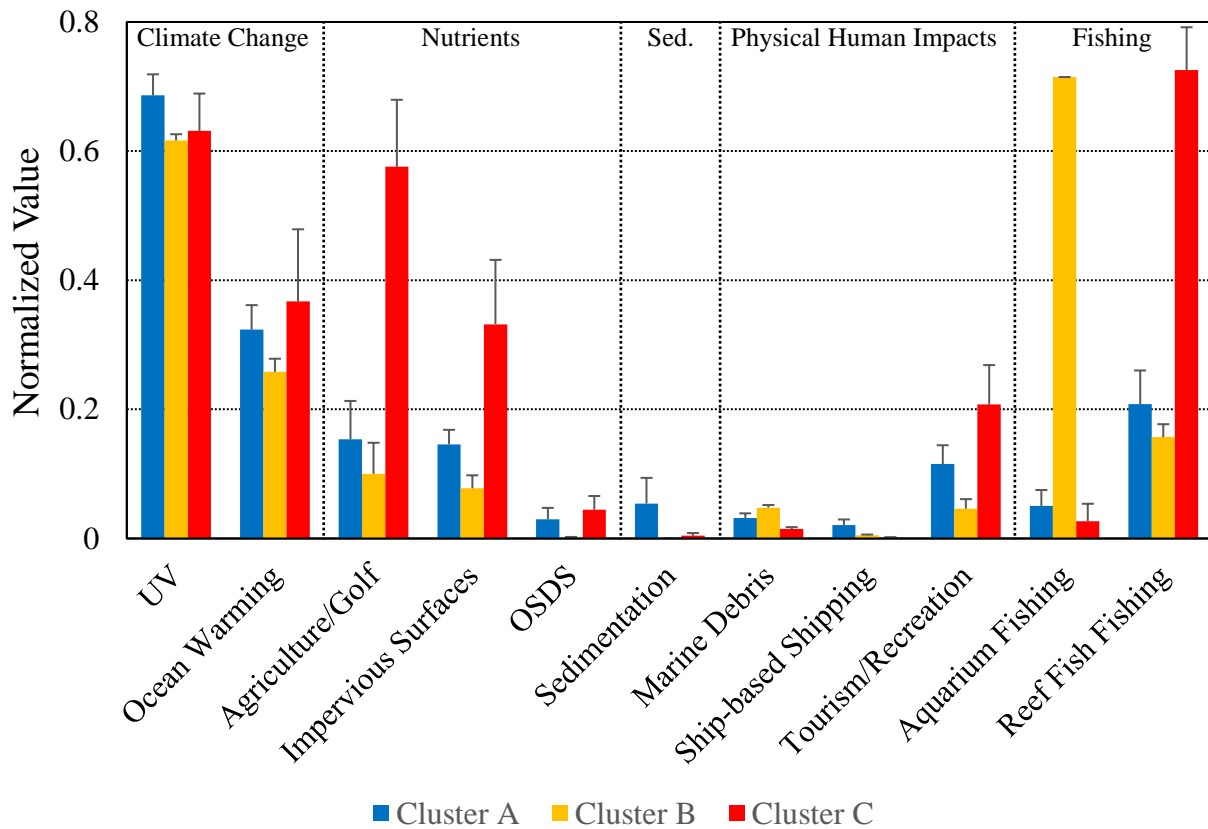


Figure 9. Mean (SEM) of all environmental variables among the three clusters identified in the principal component analysis. Values have been normalized relative to the entire West Hawaii coast.

Table 11. Sites listed by clusters identified in PCA. Number in parentheses are the overall resilience rank of the location from the 2016 surveys.

Cluster A	Cluster B	Cluster C	No Cluster
Kailapa (14)	Keawaiki (4)	Kauna‘oa (12)	Kalaemanō (20)
Kawaihae (18)	Laehou (1)	Puakō (5)	
‘Ōhai‘ula (15)	Kīholo (10)	Lulahala Pt. (19)	
Kanekanaka Pt. (16)	Manini‘ōwali (8)	Keonenui (2)	
Keanapukalua (7)	Makalawena (9)	Keauhou (13)	
Kapalaoa (11)	Mākole‘ā(6)		
Kumukea (3)			
Honokōhau (17)			

5.3 Refining Resilience Rankings

Resilience rankings were derived from seven biological indicators, six of which were considered among the most important by McClanahan *et al.* (2012). Given the time and resources needed to collect the data on the seven indicators, there is merit in determining if all of the data collection is necessary, *i.e.*, could one or more indicator be removed without affecting the rankings as compared to those generated using all seven? As an index value, differentiation among sites is achieved by differences in the indicator scores among sites. Scores for an indicator with low variability among the sites have less potential to differentiate sites than scores for an indicator with high variability.

At shallow sites, macroalgae cover (CV=0.05) and rugosity (0.09) had the lowest variability of the seven indicators (Table 12), and herbivore biomass had the greatest variability (1.13). All other indicators had similar variability ranging from 0.34 to 0.50. At deep sites, rugosity had the lowest variability (0.13), less than half that of the next closest indicator. Herbivore biomass again showed the highest variability (0.93), and all other indicators had a CV between 0.28 and 0.45.

At shallow sites, the change score for removing either macroalgal cover or rugosity was 14 and 16, respectively, which was approximately half the change score when any other single indicator was removed (range: 28-68). While the low change score indicates that rankings changed little overall with the removal of either macroalgal cover or rugosity, removing macroalgal cover resulted in at least one site having a large change in ranking position (e.g. >7 positions). In contrast, removing rugosity resulted in no ranking increase or decrease >2 positions. Likewise, when removing two indicators, if macroalgal cover or rugosity was one of the two indicators removed, the change score averaged 49 ± 6 (range: 30-92), compared to 60 ± 7 (range: 34-96) if neither of these indicators were among the two removed. Removing both macroalgae and rugosity resulted in a change score of 30. In all cases, removing two indicators (regardless of

Table 12. Mean, standard deviation, and coefficient of variation (CV) of the normalized values for each of the seven indicators incorporated into the resilience ranking score. CD=coral disease, CC=coral cover, MC=macroalgal cover, BR=bleaching resistance, CR=coral recruitment, HB=herbivore biomass, RU=rugosity

	CD	CC	MC	BR	CR	HB	RU
Shallow							
Mean	0.62	0.57	0.93	0.61	0.48	0.19	0.87
St. dev	0.21	0.25	0.04	0.29	0.24	0.21	0.08
CV	0.34	0.45	0.05	0.48	0.50	1.13	0.09
Deep							
Mean	0.76	0.49	0.77	0.65	0.60	0.24	0.82
St. dev	0.21	0.22	0.26	0.28	0.23	0.23	0.11
CV	0.28	0.45	0.33	0.44	0.39	0.93	0.13

their identity) resulted in at least one large change in position in the rankings, an undesirable outcome. For deep water sites, removing only rugosity resulted in a change shore of 66, with multiple changes in the rankings >5 positions. Removing other indicators produced similar or worse results. Considering the changes to the rankings that would occur with removal of any single factor and the performance of the rankings across years, we recommend that all indicators continue to be used when calculating the resilience rankings.

Shallow water rankings were robust between years, suggesting this approach may have performed well in capturing the site’s resistivity to change in the short term when tested by an extreme bleaching event. The approach appeared to perform less well at deeper sites, as indicated by large changes in the rankings from 2015 to 2016, and the poor relationship between the rankings and bleaching prevalence. Reasons for this disparity by depth are not entirely clear, but this change in ranking at deep sites between years may be reflective of different resistivity (and greater variability in resistivity) to thermal stress at deep compared to shallow sites, which has been observed elsewhere (Penin *et al.* 2007), and could be associated with different thermal stress histories (Jokiel and Coles 1990, Marshall and Baird 2000, Silverstein *et al.* 2015). Alternatively, factors controlling resistivity may change with depth, and our choice of biological indicators may fail to adequately capture them.

Given resilience encompasses both resistance and recovery, insufficient time has passed to fully assess the rankings for either shallow or deep sites. Our findings suggest that dynamic processes such coral recruitment are important to maintaining resilience, suggesting recovery will play a key role in the future condition of the West Hawai‘i sites. How well the resilience rankings captured both the resistivity of these West Hawai‘i reefs to stress and the recovery ability of these sites will require additional surveys in the future. The installation of permanent transect markers at these sites should allow the collection of data capable of answering these and other questions.

5.4 Sharing Study Results

To aid scientists, managers, and communities in incorporating the results of the resilience assessment and management recommendations developed into their discussions and actions, we shared our findings with interested stakeholders through presentations and an outreach document.

In January 2017, we gave a 30 minute presentation with preliminary results from our October 2016 surveys to the members of the West Hawai'i Fishery Council, whose members were interested in the changes observed from 2015 and 2016 and the ability to use reef resilience assessments to develop management recommendations. In March 2017, we shared our results with the Kona staff of DAR as part of a half-day meeting to discuss the results of the resilience surveys and how to use them to influence management along West Hawai'i, and received valuable feedback on how to incorporate the data on the environmental indicators into the analysis presented here. In September of 2017, we presented to another West Hawai'i stakeholder group, the South Kohala Coastal Partnership, where participants were particularly interested in the rankings of the sites that they were most connected to, and information on the stressors that were most effecting those sites.

A presentation to NOAA's O'ahu-based staff was given as part of the NOAA IRC Seminar Series in December 2018. The results were also presented to general science, management, and community members in large meetings, with 150 attendees of the Symposium on West Hawaii's Marine Ecosystem: Bridging the Gap Between Science and Management in Kona in December 2017, and with 100 attendees of the Hawai'i Conservation Conference in Honolulu in July 2017.

In order to easily share the key findings on the condition of West Hawai'i's reefs with interested stakeholders, we developed a 2-page handout to distribute at community meetings, presentations, and other conservation-oriented venues. The handout can be found in Appendix C.

6.0 Future Work

TNC repeated the reef resilience surveys in 2017, and plans to return to these locations periodically over the next decade to monitor the recovery of these reef sites from the 2015 mass bleaching event. These data will be essential to examining the role of recovery in the resilience of West Hawai'i reefs.

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Appendix A.

Twenty locations (shallow and deep survey sites) originally surveyed in 2015 and repeated in 2016. See text in the methods section for additional discussion of realignment and installation of the 2016 transect.

#	Location	Survey Site Lat./Long.	Cluster	Notes
1	Kailapa	S: (20.05962, -155.84837) D: (20.05939, -155.84876)	A	North Kohala FRA
2	Kawaihae	S: (20.03571, -155.83661) D: (20.03566, -155.83714)	A	Near harbor
3	‘Ōhai‘ula	S: (20.02049, -155.82993) D: (20.0204, -155.8312)	A	Offshore of Pelekane Bay (sediment)
4	Kauna‘oa	S: (20.00066, -155.82893) D: (19.99986, -155.83092)	C	Near golf course
5	Kanekanaka Pt.	S: (19.98635, -155.83212) D: (19.98668, -155.8338)	A	FRA
6	Puakō	S: (19.96976, -155.84755) D: (19.97007, -155.84764)	C	Puakō Bay and Puakō Reef FMA; near residential development; DAR Long-term Monitoring Site
7	Keanapukalua	S: (19.95174, -155.86589) D: (19.95194, -155.86681)	A	Puakō-Anaehoomalu FRA / Netting Restricted Area; near golf course; DAR Long-term Monitoring Site
8	Lulahala Pt.	S: (19.93455, -155.88426) D: (19.93513, -155.88478)	C	Puakō-Anaehoomalu FRA / Netting Restricted Area; near golf course
9	Kapalaoa	S: (19.91363, -155.89874) D: (19.91402, -155.9006)	A	Puakō-Anaehoomalu FRA / Netting Restricted Area
10	Keawaiki	S: (19.89031, -155.90777) D: (19.89013, -155.91025)	B	DAR Long-term Monitoring Site
11	Laehou	S: (19.87313, -155.92201) D: (19.87344, -155.92252)	B	
12	Kīholo	S: (19.85513, -155.93415) D: (19.85527, -155.93479)	B	Kīholo Bay FMA
13	Kalaemanō	S: (19.85339, -155.95826) D: (19.85392, -155.95844)		
14	Keonenui	S: (19.843, -155.98045) D: (19.84298, -155.98122)	C	Ka‘ūpūlehu Marine Reserve; near residential development; DAR Long-term Monitoring Site

#	Location	Survey Site Lat./Long.	Cluster	Notes
15	Kumukea	S: (19.83415, -155.9976) D: (19.83444, -155.99803)	A	Ka'ūpūlehu Marine Reserve; near hotel/resort
16	Manini'ōwali	S: (19.81315, -156.00703) D: (19.81344, -156.00761)	B	Kikaua Pt- Mākole'ā Netting Restricted Area
17	Makalawena	S: (19.79692, -156.0268) D: (19.79738, -156.02708)	B	Kikaua Pt- Mākole'ā Netting Restricted Area; DAR Long-term Monitoring Site
18	Mākole'ā	S: (19.78396, -156.04752) D: (19.78407, -156.048)	B	
19	Honokōhau	S: (19.6722, -156.03036) D: (19.6719, -156.03117)	A	Kaloko-Honokōhau FRA / Netting Restricted Area; near harbor; DAR Long-term Monitoring Site
20	Keauhou	S: (19.5684, -155.96903) D: (19.56838, -155.96933)	C	Kailua-Keauhou FRA; near golf course; DAR Long-term Monitoring Site

Appendix B.

Survey Methods

Coral Health

Coral health and disease surveys were conducted along the first 10 m of each transect. All coral colonies within a 1-m wide belt were identified to species and enumerated. The condition of each colony was assessed, and any signs of diseases (*i.e.*, growth anomalies, trematodiasis, and tissue loss syndrome) and/or compromised health (*i.e.*, algal overgrowth, discoloration, bleaching or paling, physical damage, gastropod predation and crown-of-thorns predation) were noted. Coral health and coral colony size surveys were conducted by trained and calibrated divers to reduce surveyor variability.

Coral health was examined using disease prevalence, calculated as follows:

$$\text{Prev} = \frac{\text{\# of colonies with at least 1 type of DZ or COMP}}{\text{\# of total colonies}}$$

The prevalence of each condition for all coral or for individual species was calculated as follows:

$$\text{Prev}_{(\text{DZ or COMP})} = \frac{\text{\# of colonies with a specific DZ or COMP}}{\text{\# of total colonies or \# of colonies of a species}}$$

Coral Juveniles

All coral colonies ≤ 5 cm in diameter (longest dimension) whose geometric center lay within a 0.5 x 0.5 m quadrat were counted and identified to the lowest taxonomic level. Four quadrats were haphazardly spaced ~ 2 m apart within the first 10 m of each transect, corresponding with coral health belt transect.

Benthic Topography (Rugosity)

The topographic complexity of the bottom at each site was estimated using an index of rugosity calculated along the first 10 meters of each transect by dividing the length of brass chain required to contour the bottom by the 10-m transect length (McCormick 1994). For this index, a value of one represents a flat surface with no topographic relief, and increasing values represent more topographically complex substratum.

Benthic Cover

At each survey site, photographs of the bottom were taken every meter along each 25-m transect line using a Canon Powershot camera or equivalent mounted on a 0.8-m PVC monopod. This generated 25 images for each survey site, with each photo covering approximately 0.8 x 0.6 m of the bottom. A 5-cm scale bar marked in 1-cm increments was included in all photographs.

Twenty randomly-selected photographs from each transect were analyzed to estimate the percent cover of coral, algae, and other benthic organisms present. As needed, selected photographs were imported into Adobe Photoshop CS5 where their color, contrast, and tone were auto-balanced to improve photo quality prior to analysis. Photos were analyzed using Coralnet, an online repository and resource for benthic images analysis maintained by the University of California San Diego (Beijbom *et al.* 2015). Thirty random points were overlaid on each digital photograph, and the benthic component under each point was identified to the lowest possible taxonomic level, primarily individual coral species, algae at higher taxonomic resolution (*e.g.*, red, green, brown, turf, and crustose coralline, but sometimes genera), and abiotic substratum type. All photographs were processed by the same analyst to reduce potential observer variability. Once completed, the raw point data from each photograph was combined to calculate the percent cover of each benthic component for the survey site.

Coral Reef Fish Abundance and Biomass

While slowly deploying the parallel 25-m transect lines, each diver identified to species and sized into 5-cm bins (*i.e.*, 0-5 cm, >5-10 cm, >10-15 cm, etc.) all fish within or passing through a 5-m wide belt along their transect. Divers took between 10 and 15 minutes to complete the survey. Individual fish biomass (=wet weight) was calculated using the mean length of the size bin and size-to-weight conversion parameters from FishBase (Froese and Pauly 2010), the USGS Hawai'i Cooperative Fishery Research Unit (HCFRU), and NOAA's Coral Reef Ecosystems Program. All fish surveys were conducted by trained and calibrated divers to reduce surveyor variability.

Appendix C. Outreach Document



Coral Reefs and Bleaching

Corals form the three-dimensional structure of reefs, providing the foundation for coral reef ecosystems. Coral reefs provide more than \$360 million annually in valuable services to the people of Hawai'i, including protection from storm surge, food for local families, recreational opportunities, and an important tie to our cultural heritage. Coral bleaching critically threatens these important ecosystems and the services they provide to people. Coral bleaching is a stress response caused by the breakdown of the symbiotic relationship between the coral and the algae (zooxanthellae) that live inside its tissues. When the coral expels these algae, the coral skeleton becomes visible, giving it a pale or "bleached" appearance. Mass bleaching events are caused by higher-than-normal ocean temperatures associated with a warming planet and are expected to increase in severity, extent, and frequency. Bleached corals may eventually die if temperatures remain high and the symbiosis is not reestablished. But corals can also recover from bleaching, with zooxanthellae repopulating the coral tissue to normal densities in the months or year following the end of the thermal stress.

Severe bleaching at Keanapukalua in October, 2015.



Coral Bleaching in Hawai'i

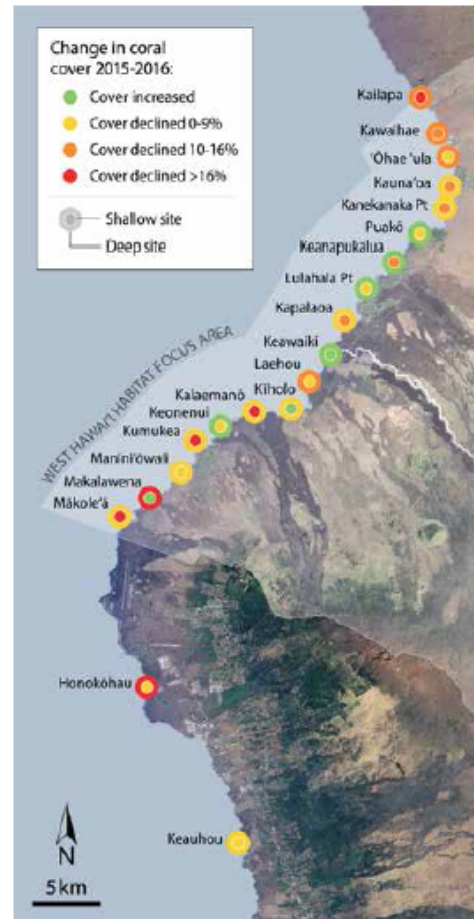
By early October 2015, the west side of Hawai'i Island had experienced severe thermal stress for 18 consecutive weeks; more stress for longer than anywhere else in the Hawaiian archipelago. Scientists from The Nature Conservancy, The National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Ecosystem Program (CREP), and Hawai'i's Division of Aquatic Resources (DAR) conducted field surveys at shallow (5-8 m) and deep (12-15 m) areas of 20 reef sites to assess coral bleaching impacts. The team surveyed more than 14,000 coral colonies across the South Kohala and North Kona regions of West Hawai'i in 2015 assessing the prevalence (proportion of coral colonies that bleached) and severity of bleaching of each colony. The same sites were surveyed in October of 2016 to examine changes in coral reef community condition and composition between 2015 and 2016.

Highlights: Extent and Severity of Bleaching in 2015

- 38-92% of all coral colonies on North Kona and South Kohala reefs were partially or fully bleached.
- An average of $68 \pm 15\%$ of shallow water (18-21') and $60 \pm 18\%$ of deeper water (38-42') corals were partially or fully bleached.
- Average bleaching severity across all colonies was -75%, and similar in shallow and deeper reef zones.
- Survey sites in South Kohala (north end of the survey area) experienced worse bleaching than those in North Kona (south end of the survey area).

Changes to Coral Reef Community Condition: 2015 to 2016

- Coral loss between 2015 and 2016 was greatest where severe bleaching prevalence in 2015 was highest. Overall, survey data suggest that roughly half of the coral that was severely bleached in 2015 died due to bleaching in the months after the 2015 thermal stress event.
- Declines in coral cover (percent of the reef area made up by corals) and coral density (number of coral colonies per unit area) were greater in the northern survey sites and lower in the southern sites.
- In the shallow reef areas, coral cover decreased from 28% in 2015 to 20% in 2016. Average coral cover decline was 8% and the largest decline observed was 21%.
- In the deep reef areas, coral cover decreased from 23% in 2015 to 16% in 2016. Average coral cover decline was 6% and the largest decline observed was 37%.
- Though coral cover decreased on average in both depths, average coral density hardly changed. The most likely explanation for coral density not declining with coral cover is that bleaching mostly caused partial rather than whole colony mortality.
- Macroalgae, which can often increase following coral mortality and then inhibit coral recovery, did not increase as coral cover decreased. Macroalgae cover was <1% in 2015 and was also <1% again in 2016.
- Many coral recruits were observed during 2015 and 2016 surveys meaning reefs are starting to recover.



Coral cover changes between October, 2015 and October, 2016 caused by severe coral bleaching in West Hawaii in 2015.

How We Can Help Improve Reef Resilience

For the first time in history, the Hawaiian Islands experienced back-to-back bleaching events in 2014 and 2015. These events and the likelihood that they will continue into the future require us to improve our understanding of bleaching impacts. We also need to continue to apply reef resilience principles to ensure we're doing everything we can to reduce mortality and support recovery on Hawai'i's reefs. We will continue to monitor coral reefs in West Hawai'i, and are working to identify and prioritize conservation actions that will promote recovery. Such actions involve minimizing local stressors (e.g., land-based pollution, runoff, and overfishing of herbivores) that are within our control and compromise coral health and the reef's ability to resist and recover from future bleaching events.

For Additional Information

Contact Dr. Eric Conklin at econklin@tnc.org or Dr. Dwayne Minton at dminton@tnc.org for additional information on these results and plans for future surveys. Visit reefresilience.org for additional information on coral bleaching and reef resilience principles.

Mahalo Nui Loa

To Moana Ohana LLC for helping to make this work possible.

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