Reef Monitoring Summary Report for Āhihi-Kīnaʻu Natural Area Reserve, Polanui, and Wailuku, Maui & Kahoʻolawe, Hawaiʻi

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This report was supported by The Nature Conservancy under cooperative agreement award #NA13NOS4820145 from the National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Conservation Program, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of NOAA, the NOAA Coral Reef Conservation Program, or the U.S. Department of Commerce.

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NOAA CORAL REEF CONSERVATION PROGRAM

Baseline Biological Surveys of the Coral Reefs of ʻĀhihi-Kīnaʻu Natural Area Reserve, Maui, Hawaiʻi

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April 20, 2016

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Cover Image: A reef area within the ʻĀhihi Kīnaʻu Natural Area Reserve (Site: 2014-AHI17).

1.0 Summary

The ‘Āhihi-Kīna‘u Natural Area Reserve (hereafter, the Reserve) is the only reserve in Hawai‘i that includes a marine ecosystem within its management jurisdiction. It includes 327 ha (807 ac) of submerged land, from which harvesting of marine plants and animals (i.e., fishing) and operating and anchoring of vessels are prohibited, making it the largest single marine area closed to harvest in Hawai‘i. In recent years, the Reserve has faced increasing pressure on its unique resources and biological communities, prompting the Department of Land and Natural Resources to develop a management plan which was finalized and adopted in 2012.

At the invitation of the Reserve, The Nature Conservancy's (TNC) marine monitoring team conducted surveys of ‘Āhihi-Kīna‘u's marine resources. The surveys were intended to update and extend the existing body of coral reef information available to the Reserve, and provide a current baseline condition from which the effectiveness of management actions implemented in accordance with the Reserve’s Management Plan could be assessed.

From December 2-5, 2014, TNC's marine monitoring team surveyed fish and benthic assemblages at a total of 55 randomly-selected sites both inside and outside the Reserve. Coral cover was significantly higher inside than outside the Reserve, and dominated by the lobe coral *Porites lobata*. Reefs inside the Reserve also had higher cover of crustose coralline algae and lower cover of turf algae than reefs outside, suggesting reef habitat inside the Reserve was in relatively good condition and of "higher quality" than adjacent reefs. The benthic community appears to have changed little from 2007 to 2014, but the surveys reported here were conducted prior to a significant bleaching event in 2015 whose effects are unknown.

The reef fish assemblage showed benefits from these management measures. Reefs inside the Reserve had significantly higher total fish and target fish biomass than reefs outside the boundary. The average number of fish species per survey site was also higher inside the Reserve. While differences in habitat quality inside and outside the Reserve could explain some of these differences, it is clear that fishing pressure has a much greater impact outside the Reserve’s boundary. Impacts from fishing within the Reserve were found, however, on parrotfish and, to a lesser extent, wrasses. Patterns of parrotfish abundance inside the Reserve were indicative of illegal poaching. Even with the benefits associated with the Reserve’s management, the fish biomass in the Reserve was lower than would be expected for an area closed to fishing, suggesting there is considerable room for improvement in both compliance with the Reserve’s rules and the condition of the Reserve’s coral reef resources.

The Reserve staff face significant challenges to addressing the primary threats identified (e.g., climate change and adjacent development) because the sources of these threats lie outside their management authority. Meaningfully addressing these threats will require the Reserve to engage in management actions at a county or state scale. Specific strategies to implement and promote these actions still need to be developed.

2.0 Introduction

The Natural Area Reserves System was established in 1970 to protect the best examples of Hawaiʻi's unique natural ecosystems. ʻĀhihi-Kīnaʻu Natural Area Reserve (hereafter, the Reserve), established in 1973, was the first Natural Area Reserve designated in the state and the only one to encompasses a marine ecosystem. While the land encompassed within the Reserve is of average size compared to other Natural Area Reserves, its marine portion is nearly three times as large as the largest Marine Life Conservation District (MLCD) in the state, making ʻĀhihi-Kīnaʻu important to Hawaiʻi's coral reef conservation efforts.

The Reserve is situated on the southern shoreline of Maui Island, in the *moku* of Honuaʻula on the southwest flank of Haleakalā (Figure 1). From north to south, the Reserve spans four *ahupuaʻa* (Onau, Kanahena, Kualapa, and Kalihi), and its geographic boundaries encompass the entirety of the lava flow at Cape Kīnaʻu, as well as portions of other older lava flows and the adjacent waters. In total 828 ha (2,045 ac), consisting of 327 ha (807 ac) of submerged lands along 4.8 km (3 mi) of the coastline, fall under the Reserve's management (Natural Area Reserves System 2012). Harvesting of marine plants and animals (i.e., fishing), operating and anchoring of vessels, and otherwise damaging the reef are prohibited within the Reserve's boundary[1].

Due to its close proximity to the town of Kīhei and the resort areas of Wailea and Mākena, ʻĀhihi-Kīnaʻu is the most heavily used of the state's nineteen Natural Area Reserves. Rapid population growth[2] and development adjacent to ʻĀhihi-Kīnaʻu has increased pressure on the Reserve's unique resources and biological communities. The Reserve staff has observed damage to cultural sites and anchialine pools, illegal harvest of fish and other marine organisms, and harassment of endangered animals (Natural Area Reserves System 2012). These damages, as well as crowding and safety issues, led the Department of Land and Natural Resources (DLNR), the state agency that oversees the Natural Area Reserve System, to restrict access to areas of the Reserve, and highlighted the need for a management plan.

In 2008, the DLNR and the ʻĀhihi-Kīnaʻu Natural Area Reserve/Keoneʻōʻio Advisory Group began a planning process with the assistance of The Nature Conservancy (TNC) that resulted in the development and adoption of the ʻĀhihi-Kīnaʻu Natural Area Reserve Management Plan in 2012. This plan provides recommendations to balance the needs of human use with natural and cultural resource protection within the Reserve, and provides

[1] In 1997, the Lu'uwai family of Makena requested access to the Reserve for the purposes of teaching subsistence fishing to their children in their ancestral grounds. In 1999, A Special Use Permit for traditional and cultural activities within the Reserve was granted to the family allowing them to fish from shore.

[2] The communities within 10 miles of the Reserve have tripled in population since 1980. Concurrently, improved access via a paved road to La Pérouse Bay/Keoneʻōʻio in the 1990s, made the Reserve an increasingly popular recreation destination. As early as 2001, visitor counts by "Friends of Keoneʻōʻio" recorded over 800 people and as many as 339 vehicles per day within the Reserve. In recent years the Reserve has averaged approximately 250,000 visitors per year (Natural Area Reserves System 2012).

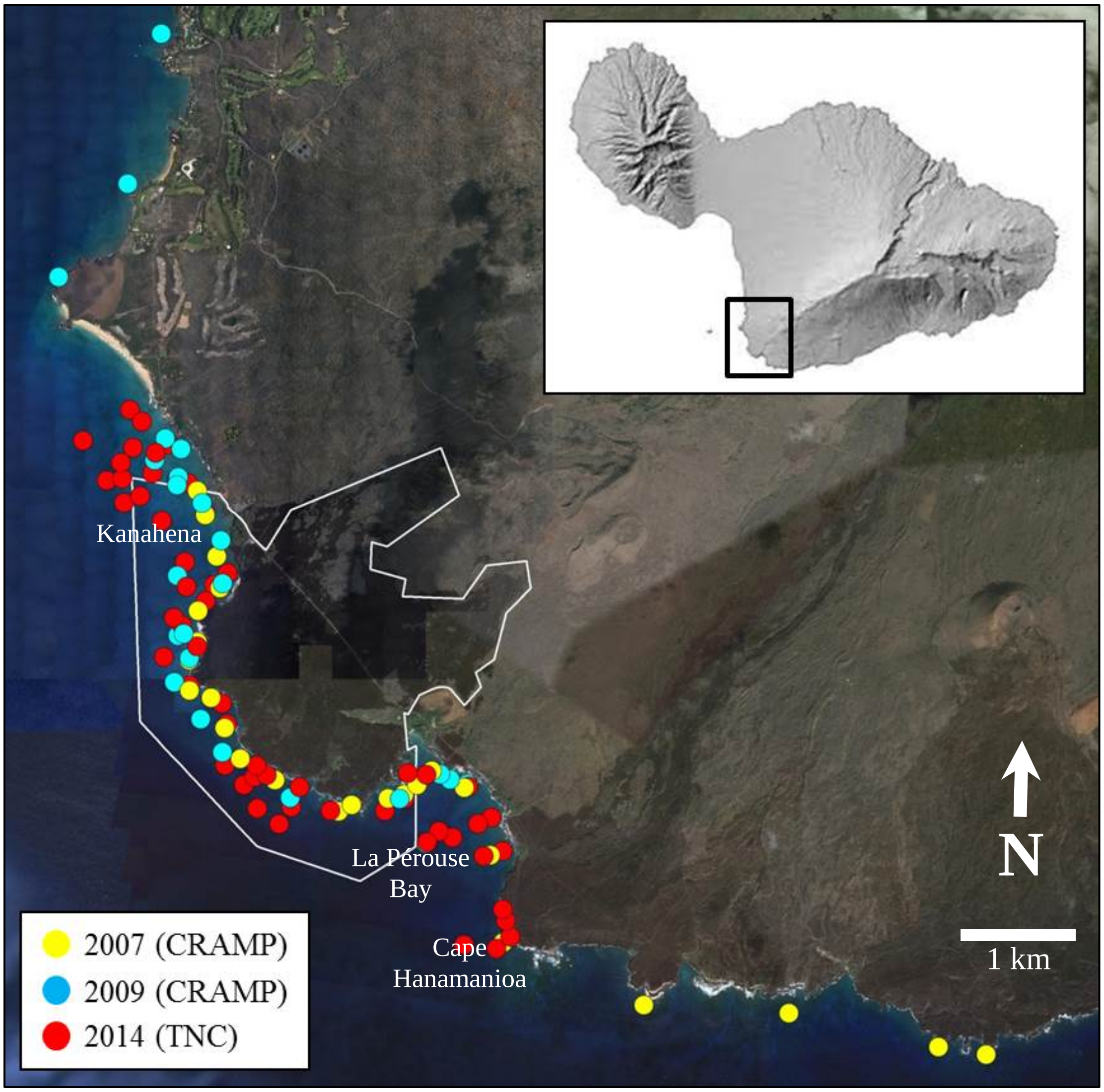

Figure 1. Locations of coral reef survey sites from 2007-2014. The 2007 and 2009 surveys were conducted by the University of Hawai‘i’s Coral Reef Assessment and Monitoring Program (CRAMP). The 2014 surveys were conducted by The Nature Conservancy (TNC) and the Division of Aquatic Resources (DAR). The white line is the boundary of the Reserve.

recommendations to reduce threats associated with development, alien invasive species, and climate change.

In 2013, TNC's marine monitoring team was invited by the Reserve staff to conduct surveys of the Reserve's marine resources to provide information on their status and condition. Previous marine surveys conducted in 2007 and 2009 by the Coral Reef Assessment and Monitoring Program (CRAMP) at the University of Hawai‘i found the Reserve's shallow-water coral reefs to be diverse and in good condition (Rodgers *et al.* 2009). Thirty-three species of coral were found within the Reserve, including several rare species. Herbivorous fish were common, accounting for almost 75% of the total fish biomass, with goldring surgeonfish, *Ctenochaetus strigosus* (known locally as kole), being the most commonly observed species (Rodgers *et al.* 2009; discussed in more detail below).

The surveys described in this report used comparable methods and are intended to update the existing body of coral reef information available for the Reserve, document any changes in resource condition over the past several years, and establish a current baseline condition from which the effectiveness of management actions implemented in accordance with the Reserve's Management Plan can be assessed.

3.0 Survey Methods

3.1 Survey Sites

The survey area lies on the southwest coast of Maui Island and extends from the high water mark to the 20 m (~60 ft) depth cline and from approximately Kanahena (near the Reserve entrance) in the northwest to Cape Hanamanioa, which forms the eastern side of La Pérouse Bay (Figure 1). The area encompasses coral reefs along approximately 9 km (5.6 mi) of coastline comprised primarily of young basalt lava flows interspersed with sandy beaches. It includes the entirety of shallow water reef within the Reserve and the adjacent shallow water reef approximately 1.25 km (0.8 mi) to either side of the Reserve's boundary (Figure 1).

From December 2-5, 2014, TNC's marine monitoring team and biologists from DLNR's Division of Aquatic Resources (DAR) surveyed 55 randomly-selected[3] sites, of which twenty-seven were outside and twenty-eight sites were inside the Reserve's boundary (Figure 1). Appendix A contains the positional information and associated site metadata (e.g., depth, rugosity, date surveyed, etc.) for all 55 survey sites.

3.2 Survey Methods

Sites were surveyed by divers deployed from small boats. The survey teams navigated to each predetermined site using a Garmin GPS unit. Once on site, the survey team descended directly to the bottom, where divers established two transect start-points approximately 10 m apart. From each start-point, divers deployed a separate 25 m transect line along a predetermined compass heading, with the two transect lines running parallel to the other. If the pre-determined compass bearing would result in a large change in depth, the direction of the transect was altered slightly to stay near the original depth contour. Specific survey methods are briefly discussed below. For a full description of the fish and benthic survey methods used, see Appendix B.

[3] Random sites were selected in order to get an unbiased measure of the community across the survey area. Using a non-random site selection method, such as selecting sites known to have high fish abundance, would provide a skewed or biased assessment of the coral reef community inside and outside the Reserve.

Benthic Cover

Photographs of the bottom were taken every meter along one 25 m transect line at each survey site using a Canon G12 or S110 camera mounted on a 0.8 m long 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 later analyzed to estimate the percent cover of coral, algae, and other benthic organisms present.

Each selected photograph was imported into Adobe Photoshop CS5 where its color, contrast, and tone were auto-balanced to improve photo quality prior to analysis. Photos were analyzed using the Coral Point Count program with Excel extension (CPCe) developed by the National Coral Reef Institute (Kohler and Gill 2006). Using CPCe, 30 random points[4] were overlaid on each digital photograph, and the benthic component under each point was identified to the lowest possible taxonomic level. Additionally, if a random point fell on a coral showing obvious paling or bleaching, the condition was noted. Bleached corals can be difficult to identify in photographs, so the estimate of bleaching from this analysis represents a conservative estimate of the actual level of coral bleaching that was occurring during surveys. All photographs were processed by the same person 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.

Within-site variability in hard bottom habitat was estimated by calculating the coefficient of variation (CV) of the percent cover of unconsolidated bottom (i.e., percent cover of sand and rubble) in all photos at a site. A high CV would correspond to a site with high patchiness in the presence of hard bottom.

Rugosity

To estimate the topographic complexity of the bottom at each site, an index of rugosity was calculated along the first 10 meters of one 25 m 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 relief, and increasing values represent more topographically complex substratum. Rugosity was collected at nearly all survey sites (Appendix A).

Fish

All fish surveys were conducted by trained and calibrated divers. Divers slowly deployed the parallel 25 m transect lines while identifying to species and sizing 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

[4] The number of points analyzed on each photograph (30 points) and the number of photographs at each site (20 photographs) were selected after determining that these values represented the optimal effort to achieve the greatest power to detect statistical differences.

along each of the two 25 m transects. Divers took between 10 and 15 minutes to complete each belt survey. Using fish length and published size-to-weight conversions, fish biomass (i.e., weight of fish) was calculated for each size class of fish for each species and summed to obtain total fish biomass.

This method closely corresponds with that used by Friedlander and colleagues for the "Fish Habitat Utilization Study" (FHUS) as well as other work in Hawaiʻi, and therefore provides comparable data. Details of Friedlander and colleagues' method are available in a number of publications (Friedlander *et al.* 2006, 2007a, 2007b). The FHUS was conducted in the early 2000s and represents a comprehensive look at sites across a range of management areas in Hawaiʻi. In addition to the FHUS data, additional comparisons can be made with other sites at which TNC's marine monitoring team has collected fish information. Data from these additional TNC sites were collected between 2009 and 2014, and often include multiple annual survey events at a location. Together, these data comprise a formidable spatial and temporal comparative data set for fish assemblages.

Following the completion of the transect surveys, a 5-minute timed swim was conducted at a subset of survey sites (26 sites) during which the two fish surveyors swam approximately 5 m apart, identifying to species and sizing into 5 cm bins all target[5] fish larger than 15 cm within or passing through a 5 m wide belt (centered on the surveyor) that extended from the ocean bottom to the surface. During the timed swim, surveyors communicated with each other to ensure that each fish was recorded by only one surveyor (i.e., fishes were not double counted), effectively creating a single 10 m wide belt transect.

Timed swims were initiated along the same compass heading as the 25 m transects and shifted as necessary to maintain a constant water depth. If short stretches of increased water depth or non-hard bottom habitat were encountered, surveyors quickly traversed them and continued to survey. If longer stretches of non-hard bottom or a significant change in depth were encountered, divers altered course to maintain a relatively constant depth and to avoid swimming into extensive areas of non-hard bottom habitat.

3.3 Previous ʻĀhihi-Kīnaʻu Coral Reef Surveys

In 2007 and 2009, CRAMP conducted surveys in the same general area as TNC's 2014 assessments (Figure 1). The CRAMP surveys employed a similar suite of survey methods to collect information on benthic cover and richness, and fish biomass and abundance at sites both inside and outside the Reserve (Table 1). For a detailed description of the CRAMP survey methods, see Rodgers *et al.* (2009). The CRAMP data were used to examine temporal trends both inside and directly adjacent to the reserve.

[5] For a list of species that comprise "target fish" for this report, see table B.1 in Appendix B.

Table 1. Number of sites surveyed by TNC in 2014 and CRAMP in 2007 and 2009, both inside and outside the Reserve.

Site Location	2014	2009	2007
Inside the Reserve	28	16	13
Outside the Reserve	27	8	11
TOTAL	**55**	**24**	**24**

3.4 Data Analysis

All data from the 2014 surveys were entered into a custom Access database and checked for errors. In this report, all means are presented as the average ± the standard error of the mean (SEM). Standard parametric and non-parametric statistical approaches, as appropriate, were used to test for differences between years and location (inside versus outside the Reserve). In most cases, a multifactor analysis of variance (ANOVA) including sample year and location (inside/outside the Reserve) was used to examine summary-level variables (e.g., total fish biomass, total fish abundance). As necessary, fish biomass and abundance were log-transformed to correct skewness and variance prior to analysis. Tukey multiple comparisons were used to identify differences within significant factors. Multivariate analysis on the benthic and fish assemblages was conducted using the suite of non-parametric multivariate procedures included in the PRIMER statistical software package (Plymouth Routines in Multivariate Ecological Research). For a full description of the statistical methods, see Appendix B.

Comparisons with the 2007 and 2009 CRAMP benthic surveys required data "reconciliation" to ensure comparability. This was especially necessary for the benthic data because some benthic categories were differentially defined by the CRAMP and TNC survey teams (pers. comm. Y. Stender). While lower taxonomic categories (e.g., species, genera) for benthic organisms were often not directly comparable, higher taxonomic groupings were. Therefore, temporal comparisons were made across three broad taxonomic groupings for benthic organisms: coral, turf algae, and crustose coralline algae (CCA), which in Hawai‘i usually comprise the vast majority of benthic organisms. The exception was coral, where species identifications were consistent across survey efforts, so temporal comparisons of the coral assemblage were also possible at the species-level. As it was not possible to reconcile other benthic organisms/groups (e.g., macroalgae, sponges, zoanthids, abiotic substratum, etc.) among survey years, these were not analyzed for temporal trends. No data reconciliation was needed for the CRAMP fish data. We determined all of the fish data were useable because surveyors in all years were calibrated with TNC divers either directly or through shared partners.

4.0 Results and Discussion

4.1 Benthic Assemblage

2014 Survey

Seventeen species of coral were observed within the survey area, with the lobe coral *Porites lobata* comprising more than half of all coral cover (Table 2). The benthic assemblage structure was significantly different inside compared to outside the Reserve boundary (ANOSIM; R=0.29; p=0.001). These differences were primarily associated with higher coral cover (especially *P. lobata*) inside compared to outside the Reserve. Coral cover was significantly higher inside the Reserve than on adjacent reefs (ANOVA; $F_{1,51}$=11.41; p=0.001), covering 23.8 ± 3.1% and 10.1 ± 2.6% of the bottom, respectively. Additionally, cover of CCA was higher inside than outside the Reserve (Table 2), while the reverse was true for turf algae, suggesting the coral reef habitat inside the Reserve may be "higher quality" than that directly adjacent to it. Reasons for this difference are not entirely clear, and could be a result of enhanced protection afforded by the Reserve's management or possibly an artifact of the initial selection criteria used when establishing the Reserve's boundaries[6].

Cover of unconsolidated bottom (and its inverse, hard bottom) was identical inside and outside the Reserve (Table 2), but rubble was significantly more common inside the Reserve compared to sand outside. More rubble inside the Reserve could be related to the higher cover of coral (the likely source of the rubble), but more likely it indicates that the reefs inside the Reserve experience greater impacts from high wave energy events than reef areas surveyed outside the Reserve. This would be consistent with increased wave exposure expected on a peninsula, and is further supported by the presence of a popular surfing site located inside the Reserve (referred to as "Dumps" or Kanahena).

In June 2014, a prolonged stretch of warm, calm weather led to elevated sea temperatures and the onset of widespread coral bleaching in Hawaiʻi, particularly on the island of Oʻahu. While reports of bleaching on Maui were scarce, the DAR documented bleaching at Molokini, and noted bleaching affected about 10% or less of Maui's coral colonies. The event lasted late into the calendar year.

The 2014 surveys were completed in December, toward the end of the bleaching event. By the time these surveys were conducted, bleaching rates were low within the survey area, and did not significantly differ inside (1.3 ± 0.8% of coral tissue) and outside (<0.1%) the Reserve, suggesting the event likely had negligible impact on coral reefs within and adjacent to the Reserve.

[6] The Reserve's marine boundaries were designated to encompass the entirety of the lava flow at Cape Kīnaʻu, so this non-random placement of the boundary to encompass hard bottom has likely affected the composition of the benthic assemblage.

Table 2. Mean (± SEM) cover of benthic groups/organisms inside and outside the Reserve.

	Inside	**Outside**
Coral	23.7 ± 3.1	10.1 ± 2.6
Porites lobata	14.6 ± 2.2	6.5 ± 1.7
Porites compressa	5.1 ± 1.4	0.7 ± 0.4
Montipora patula	1.6 ± 0.5	0.6 ± 0.4
Pavona varians	1.3 ± 0.5	0.5 ± 0.4
Pavona duedeni	1.1 ± 0.3	0.3 ± 0.1
Pocillopora meandrina	0.4 ± 0.1	1.2 ± 0.3
Montipora capitata	0.3 ± 0.1	<0.1
Porites lutea	0.1 ± 0.1	0
Porites c.f. *bernardi*	<0.1	<0.1
Cyphastrea ocellina	<0.1	<0.1
Leptastrea purpurea	<0.1	0
Unidentified Coral	<0.1	0
Montipora flabellata	<0.1	0
Psammocoa stellata	<0.1	0
Leptastrea transversa	<0.1	0
Porites rus	<0.1	0
Pocillopora damicornis	0	<0.1
Turf	29.6 ± 2.4	52 ± 4.0
CCA	12.9 ± 3.0	5.8 ± 1.9
Macroalgae	0.2 ± 0.1	1.5 ± 1.0
Halimeda sp.	0.1 ± 0.1	0.8 ± 0.5
Other Algae	0.1 ± 0.1	0.1 ± 0.1
Dictyota spp.	0	0.6 ± 0.5
Zoanthids	0.1 ± 0.1	<0.1
Cyanobacteria	<0.1	0
Other	1.6 ± 0.3	0.6 ± 0.2
Abiotic	30.5 ± 0.8	30.5 ± 0.9
Sand	15.9 ± 2.8	24.4 ± 4.1
Rubble	14.3 ± 3.0	6.1 ± 3.3
Recently Dead Coral	0.2 ± 0.1	<0.1
Pavement	<0.1	<0.1
Depth (ft.)	30.0 ± 2.4	28.4 ± 2.5
Rugosity	13.5 ± 0.4	12.0 ± 0.4

Hawaiʻi experienced a second bleaching event in the latter half of 2015 that affected Maui more severely than the 2014 event. DAR estimated that over 50% of the corals at many sites around Maui bleached during this event, including Makena, which is on the northern edge of the survey area. It is reasonable to believe that bleaching within the Reserve was significantly higher in 2015 than what we observed in December 2014, and it's possible that more than half of the coral experienced bleaching. Follow-up surveys to assess the potential impact of the 2015 bleaching event should be conducted to determine the current status of the coral assemblage.

Temporal Trends

Due to differences in photo-interpretation to quantify benthic cover, we determined that direct comparisons between the TNC and CRAMP surveys could only be made for coral cover (total and by species), CCA, and turf algae. After data reconciliation, we determined that photo-analysts used slightly different criteria for distinguishing other groups, so their direct comparability was uncertain.

There was no signifant change in total coral cover (cover of all coral species) between 2007 and 2014 either inside or outside the Reserve (ANOVA; $F_{2,95}$=0.07; p=0.932). As in 2014, coral cover was significantly higher inside the Reserve in both 2007 and 2009 (Figure 2a). In contrast, cover of CCA was significantly higher in 2007 than in either 2009 or 2014 (ANOVA; $F_{2,95}$=27.24; p<0.001), and was higher inside the Reserve than outside for each year (ANOVA; $F_{1,95}$=9.17; p=0.003). Reasons for the observed decrease in CCA between 2007 and 2009 are unknown, but CCA cover appears to have been stable since 2009 (Figure 2b). Cover of turf algae also significantly varied with time (ANOVA; $F_{2,95}$=2.96; p=0.057), but no consistent temporal trend was found. Turf algae cover was significantly higher in 2009 than in 2007 (Figure 2c), but cover in other survey years did not differ. In all years, turf algae cover outside the Reserve was significantly higher than inside (ANOVA; $F_{1,95}$=50.16; p<0.001).

Coral assemblage, described as the relative cover of coral species, showed no change over time (ANOSIM; R=0.012; p=0.570). While the coral assemblage inside the Reserve was significantly different from that outside the Reserve (ANOSIM; R=0.146, p=0.001), the low R-value suggests the difference is not likely ecologically significant (Clarke and Warwick 2001), which is expected considering the contiguous nature of the reef. As in 2014, the coral assemblage in CRAMP surveys (both 2007 and 2009) was dominated by *P. lobata* and *P. compressa* and to a lesser extent *Pocillopora meandrina* and *Pavona varians* (Table 3).

Overall, the reefs of ʻĀhihi-Kīnaʻu appear to have been stable between 2007 and 2014, with little change in the assemblage structure.

a)

b)

c)

Figure 2. Percent cover of (a) coral, (b) crustose coralline algae (CCA), and (c) turf algae at sites inside and outside the Reserve. Data for 2007 and 2009 are from CRAMP.

4.2 Fish Assemblage

2014 Survey

A total of 105 species representing 23 families of fishes were observed during the 2014 surveys (Table 4). More fish species were observed inside than outside the Reserve's boundary, 95 compared to 89 species, and the average number of species per survey site inside the reserve (26.9 ± 1.1 species/site) was significantly greater than outside (18.5 ± 1.7 species/site) (t-test; T=4.07; df=43; $p<0.001$). Total fish biomass was significantly higher inside the Reserve (44.4 ± 14.3 g/m^2) than outside (22.0 ± 4.8 g/m^2) (ANOVA; $F_{1,98}=14.1$; $p<0.001$), but was also considerably more variable. Fish biomass at survey sites inside the Reserve ranged from 9.9 g/m^2 to 419.4 g/m^2, compared to 1.1 g/m^2 to 111.3 g/m^2 outside the Reserve.

Surgeonfishes (Acanthuridae) and snappers (Lutjanidae) accounted for the majority of the fish biomass both inside (51% of total biomass) and outside (60%) the Reserve. While surgeonfishes tend to be among the most abundant fish on nearshore Hawaiian reefs, snappers tend to be relatively rare. Parrotfishes (Scaridae) and wrasses (Labridae) also tend to be among the common fish families on Hawaiian reefs, however both were relatively uncommon in and near the Reserve. Parrotfishes, an economically and culturally important fish family, accounted

Table 3. Percent cover of coral by species inside and outside the Reserve in 2007, 2009, and 2014. Data for 2007 and 2009 surveys were provided by CRAMP.

	2007		**2009**		**2014**	
	Inside	**Outside**	**Inside**	**Outside**	**Inside**	**Outside**
Coral	21.4 ± 3.1	11.1 ± 1.4	22.0 ± 3.6	13.3 ± 2.7	23.7 ± 3.1	10.1 ± 2.6
Porites lobata	10.9 ± 2.7	6.3 ± 1.3	12.3 ± 3.5	10.2 ± 2.2	14.6 ± 2.2	6.5 ± 1.7
Porites compressa	4.8 ± 2.2	1.6 ± 1.4	2.9 ± 1.5	0.3 ± 0.2	5.1 ± 1.4	0.7 ± 0.4
Montipora patula	1.2 ± 0.9	0.7 ± 0.6	0.8 ± 0.6	0.4 ± 0.3	1.6 ± 0.5	0.6 ± 0.4
Pavona varians	2.3 ± 0.8	0.2 ± 0.1	0.4 ± 0.1	0.1 ± 0.1	1.3 ± 0.5	0.5 ± 0.4
Pavona duedeni	0.8 ± 0.3	0.2 ± 0.1	1.1 ± 0.5	0.2 ± 0.2	1.1 ± 0.3	0.3 ± 0.1
Pocillopora meandrina	0.3 ± 0.3	1.8 ± 1.1	2.8 ± 1.4	1.3 ± 0.7	0.4 ± 0.1	1.2 ± 0.3
Montipora capitata	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.4 ± 0.2	0.3 ± 0.1	<0.1
Porites lutea	0	0	0	0	0.1 ± 0.1	0
Porites c.f. *bernardi*	0	0	0	0	<0.1	<0.1
Cyphastrea ocellina	0.1 ± 0.1	<0.1	0.1 ± 0.1	<0.1	<0.1	<0.1
Leptastrea purpurea	0	0	0	0	<0.1	0
Unidentified Coral	0.1 ± 0.1	0	0.1 ± 0.1	0	<0.1	0
Montipora flabellata	0.1 ± 0.1	0.1 ± 0.1	0	0.4 ± 0.4	<0.1	0
Psammocoa stellata	0.7 ± 0.5	0	0	0	<0.1	0
Leptastrea transversa	0	0	0.1 ± 0.1	0	<0.1	0
Porites rus/Porites monticulosa	0	0	1.2 ± 1.2	0	<0.1	0
Pocillopora damicornis	<0.1	<0.1	0	0	0	<0.1
Fungia scutaria	0.1 ± 0.1	0	<0.1	0	0	0
Pocillopora edouxyi	0	<0.1	0.1 ± 0.1	0	0	0
Porites brighami	0	0	0	<0.1	0	0

Table 4. Biomass (g/m^2) and abundance (individuals/125 m^2) of fish by family inside and outside the Reserve. Families are ordered by decreasing biomass inside the Reserve.

	Biomass		**Abundance**	
	Inside	**Outside**	**Inside**	**Outside**
Acanthuridae	12.5 ± 1.8	9.3 ± 1.7	63.6 ± 5.9	35.4 ± 6.2
Lutjanidae	10.1 ± 9.2	3.9 ± 2.8	0.3 ± 0.1	0.3 ± 0.1
Mullidae	5.3 ± 4.2	1.6 ± 1.0	3.2 ± 0.7	7.9 ± 6.4
Labridae	3.5 ± 0.6	1.1 ± 0.2	11.6 ± 1	7.6 ± 1.2
Balistidae	2.9 ± 0.7	2.4 ± 0.4	3.1 ± 0.8	3.1 ± 0.4
Serranidae	2.5 ± 0.6	0.1 ± 0.1	0.5 ± 0.1	0.1 ± 0.1
Scaridae	2.3 ± 0.7	0.5 ± 0.2	2.6 ± 0.9	0.8 ± 0.3
Chaetodontidae	1.5 ± 0.2	1.2 ± 0.5	8.2 ± 1.8	5.1 ± 1.4
Lethrinidae	1.4 ± 0.9	0	0.5 ± 0.3	0
Pomacentridae	0.8 ± 0.2	1.0 ± 0.8	13.2 ± 2.7	18.6 ± 6
Holocentridae	0.6 ± 0.4	0.2 ± 0.2	0.7 ± 0.5	0.6 ± 0.6
Tetraodontidae	0.3 ± 0.1	0.2 ± 0	2.7 ± 0.3	2.1 ± 0.3
Cirrhitidae	0.2 ± 0.1	0.1 ± 0	1.4 ± 0.2	1.9 ± 0.4
Monacanthidae	0.2 ± 0.1	0.1 ± 0	0.2 ± 0.1	0.3 ± 0.1
Pomacanthidae	0.1 ± 0.1	<0.1	0.9 ± 0.3	0.1 ± 0.1
Zanclidae	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.3 ± 0.2
Carangidae	0.1 ± 0.1	0	<0.1	0
Aulostomidae	<0.1	<0.1	<0.1	0.1 ± 0.1
Ostraciidae	<0.1	<0.1	0.1 ± 0	0.1 ± 0.1
Blenniidae	<0.1	0	<0.1	0
Fistulariidae	0	0.2 ± 0.1	0	0.2 ± 0.1
Apogonidae	0	<0.1	0	<0.1
Microdesmidae	0	<0.1	0	0.5 ± 0.5
Total Biomass	**44.4 ± 14.3**	**22.0 ± 4.8**	**113.1 ± 7.0**	**85.1 ± 17.8**

for 5% of total fish biomass inside the Reserve, and only 2% outside. In contrast, biomass of parrotfishes at Polanui, Maui (Minton *et al.* 2014) accounted for 11% of the total fish biomass and at several sites in east Maui, exceeded 13% of the total fish biomass (TNC unpublished data). Elsewhere on Maui, biomass of wrasses tends to comprise 9-11% of the total fish biomass, but comprised only 8% and 5% inside and outside the Reserve, respectively.

Snappers tend to comprise a relatively small percentage of the total fish biomass on other Hawaiian reefs, so their relative abundance in the survey area suggests a shift in the fish assemblage structure in and near the Reserve. Higher snapper biomass was associated with introduced blue-lined snapper *Lutjanus kasmira* (bluestriped snapper or ta‘ape), which accounted for nearly 65% of the snapper biomass, and native green jobfish *Aprion virescens* (uku), accounting for nearly 31% of the biomass. However, most of the biomass of the blue-lined snapper was associated with a single survey site inside the Reserve (2014-AHI06) where over 1,600 individuals were observed. This site accounted for all but one blue-lined snapper observed throughout the course of the 2014 surveys. While this large school may represent a statistical outlier and blue-lined snapper may not be widespread or common across most of the Reserve, its presence within the Reserve's boundary cannot be ignored.

Compared to other reefs on Maui and around the state, total fish biomass at the Reserve is not as high as would be expected for an area closed to fishing (i.e., MLCDs)[7]. Total fish biomass in the Reserve is the lowest among all of the areas closed to fishing for which data are available. Total fish biomass inside the reserve was also lower than many open areas on Maui where fishing pressure is believed to be relatively low, including Olowalu (Figure 3) and several other sites on Maui with less accessibility (TNC unpublished data). However, benefits associated with the protection provided by the Reserve are nevertheless apparent: total reef fish biomass inside the Reserve was double that on reefs directly adjacent to but outside the Reserve.

Target Fishes

Target fishes[8] refer to fish desirable for food, commercial activity, and/or cultural practices that reside in the habitats and depth ranges surveyed by the TNC marine monitoring team. Like total fish biomass, target fish biomass was significantly higher inside the Reserve (22.1 ± 5.3 g/m^2) than outside (12.9 ± 3.2 g/m^2) (ANOVA; $F_{1,98}=21.31$; $p<0.001$). This was in direct contrast to non-target fish, which showed no difference inside and outside the Reserve (ANOVA; $F_{1,98}=0.77$; $p=0.381$), 5.0 ± 0.3 g/m^2 compared to 4.2 ± 0.8 g/m^2, respectively. Taken together, these findings suggest fishing has contributed to the decrease in target fish outside of the Reserve.

Surgeonfishes and goatfishes accounted for the greatest percentage of total target fish biomass across the project area (Figure 4), comprising about 64% both inside and outside the Reserve. Apex predator biomass was higher outside the Reserve than inside, but this was primarily associated with a high biomass of *Aprion virescens* (uku), especially at one site (2014-AHI50) where its biomass was 7.5-times higher than the next highest site. Notably, the contribution of parrotfish and wrasses to total target fish biomass was lower outside the Reserve than inside, and no jacks or "other" target fish (i.e., *Chanos chanos*, *Cirrhitus pinnulatus*, *Monotaxis grandoculis*) were observed outside the Reserve. On other Hawaiian reefs, surgeonfish, parrotfish, and wrasses tend to be the most common target fish groups, with goatfish locally common when favorable habitat is present (i.e., sand, which is important foraging habitat for goatfish).

[7] Several MLCDs allow some fishing, but it is generally heavily restricted, e.g., limited gear, fishing time period, or species that can be harvested. For this report "closed" means very little to no fishing occurs at the site.

[8] See Appendix B for a list of species that comprise the target fish for this report.

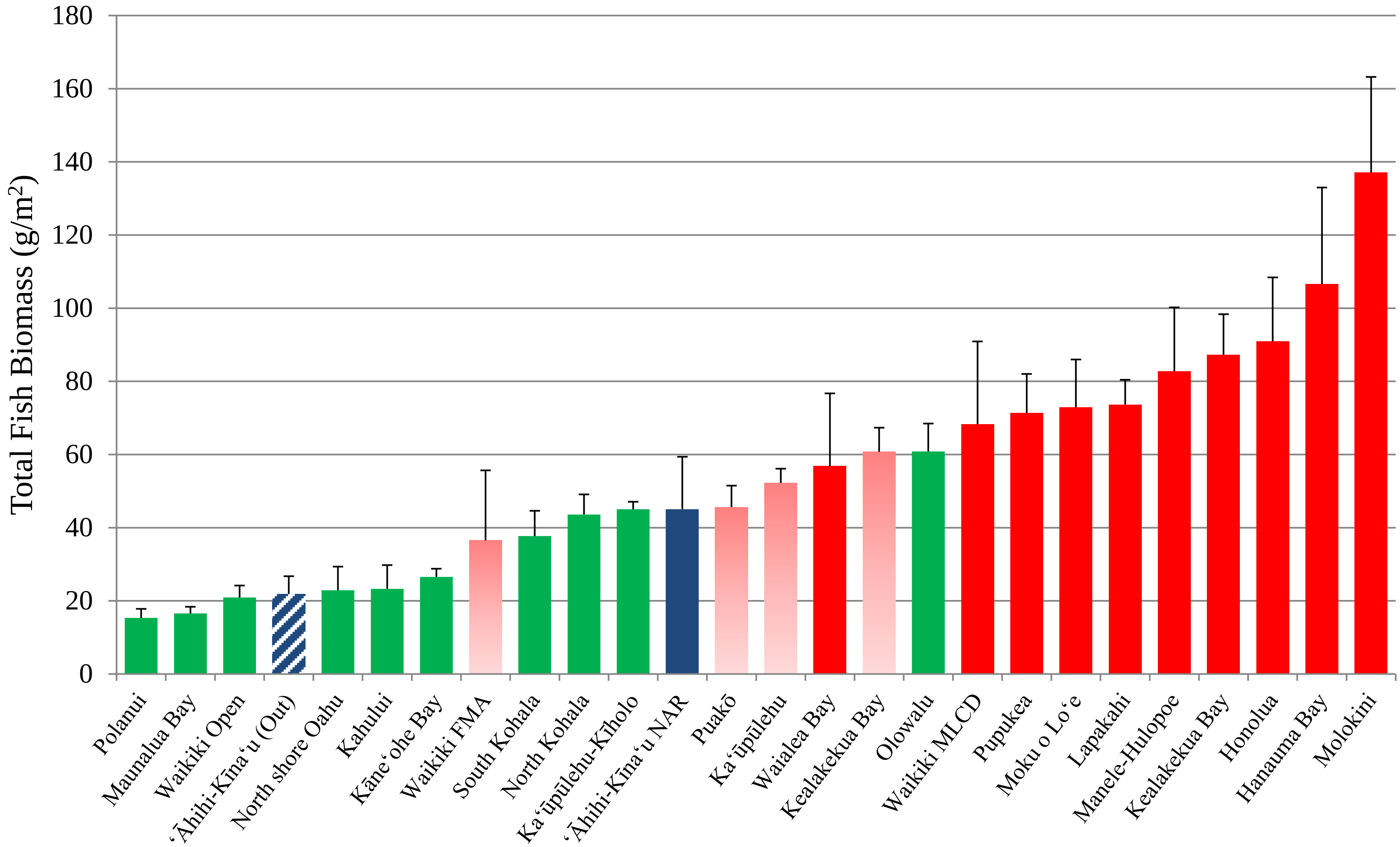

Figure 3. Total fish biomass on the reefs inside the Reserve (solid blue bar) and on reefs outside of, but adjacent to the Reserve boundary (hatched blue bar) compared to 24 other sites in the state of Hawaiʻi. Color of bars represents level of fisheries management occurring at the site: green=no additional fishing regulations; red=no take allowed; gradated red=limited take allowed. The Reserve is a no-take area, while adjacent reefs are open to harvest and have no additional fishing regulations. Data for other sites are from Friedlander (UH) and TNC.

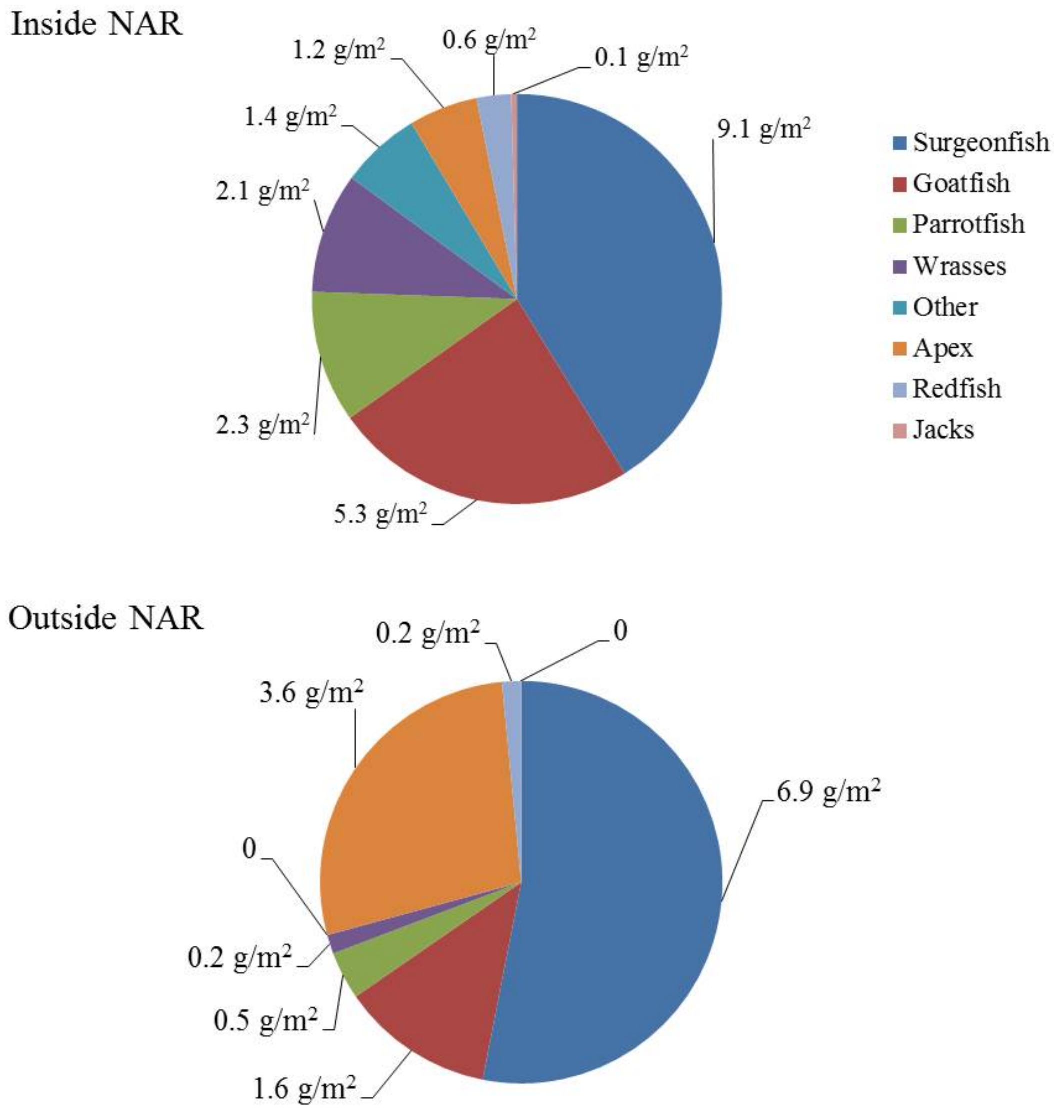

Figure 4. Composition of target fish inside (top) and outside (bottom) the Reserve. Values are biomass (g/m^2) of all fish within that target fish group.

As with total fish biomass, when comparisons were made with other Maui and statewide reefs, target fish biomass at ʻĀhihi-Kīnaʻu was not as high as would be expected for an area closed to fishing (Figure 5). Target fish biomass was the lowest among all of the areas closed to fishing, and was also lower than many areas open to fishing on Maui. As was the case with total fish biomass, the Reserve still appears to be providing positive benefits to target fish species, especially goatfish, parrotfish, and wrasses, which have three to ten times more biomass inside the Reserve than on adjacent reefs.

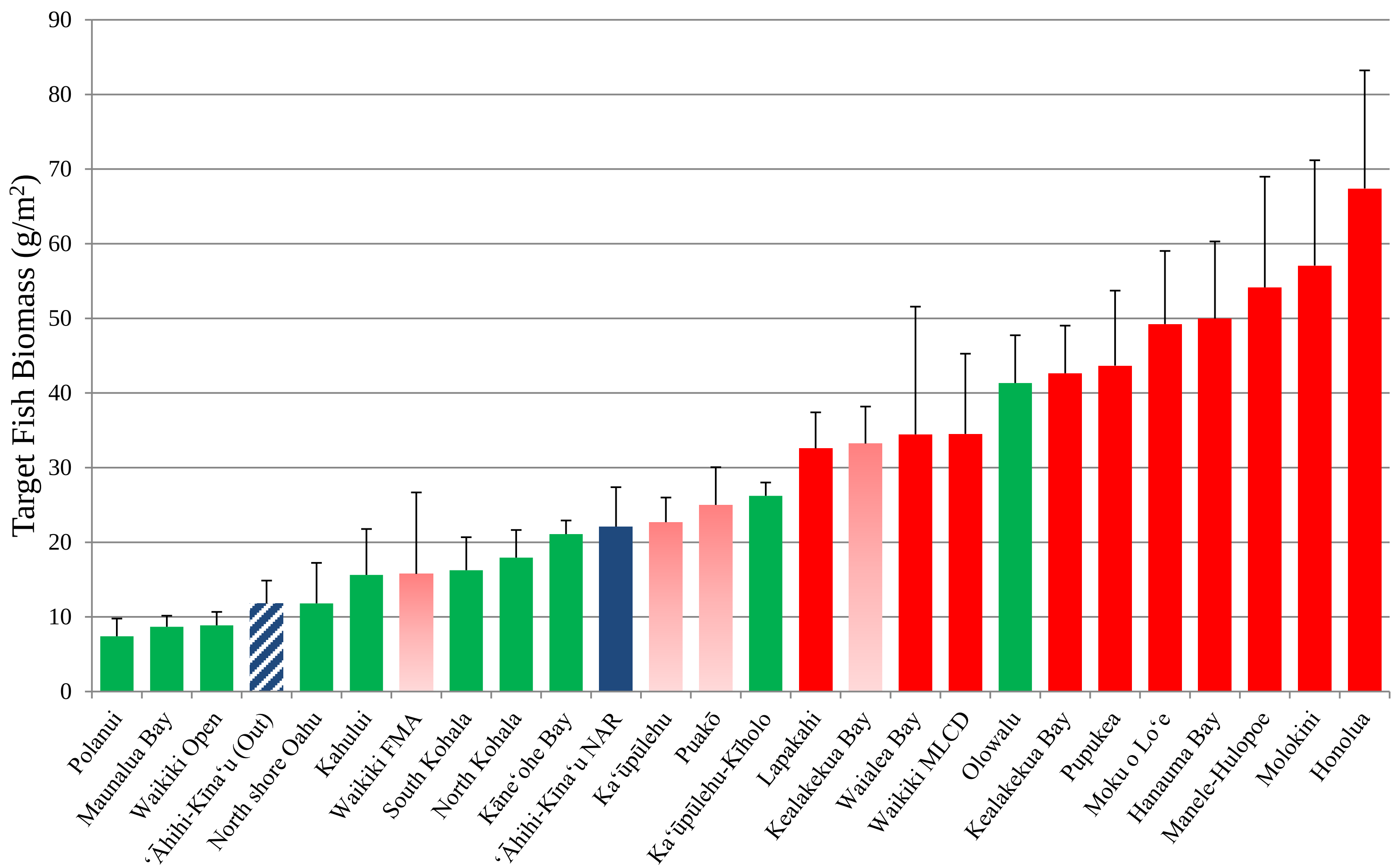

Figure 5. Target fish biomass on the reefs inside the Reserve (solid blue bar) and on reef outside of, but adjacent to the Reserve boundary (hatched blue bar) compared to 24 other sites in the state of Hawaiʻi. Color of bars represents level of fisheries management occurring at the site: green=no additional fishing regulations; red=no take allowed; gradated red=limited take allowed. The Reserve is a no-take area, while adjacent reefs are open to harvest and have no additional fishing regulations. Data for other sites are from Friedlander (UH) and TNC.

Prime Spawners

Prime spawners are large target fishes (>70% their maximum size) which are generally prized by fishers and tend to contribute disproportionately more to the total reproductive potential of the population than smaller individuals due to their greater egg and sperm production (i.e., higher fecundity) and the higher survivorship of their larvae (Williams *et al.* 2008). Therefore, prime spawner biomass is a good indicator of fishing impacts (e.g., as fishing pressure increases, the biomass of prime spawners is likely the first thing to decrease), and represents an important component of ecological function (i.e., population breeding potential).

While average prime spawner biomass was nearly three times higher inside the Reserve (7.18 ± 4.10 g/m^2) compared to outside (2.6 ± 0.6 g/m^2), it was not significantly different (t-test; T=0.68; df=48; p=0.500) due primarily to the high variability of prime spawners inside the Reserve. Unlike sites outside the Reserve, eight sites inside had biomass >4 g/m^2, with two sites having >20 g/m^2, including a site with biomass as high as 115.5 g/m^2. Outside the Reserve, five sites had prime spawner biomass >4 gm/m^2, with no sites >20 g/m^2. While many sites inside the Reserve had comparable prime spawner biomass to the sites outside, more sites with high prime spawner biomass were encountered inside the Reserve, suggesting the reserve infers some positive effect on large target fish.

Despite the Reserve appearing to afford some protection to large target fish, prime spawner biomass inside the Reserve was lower than would be expected for an area closed to fishing (Figure 6). The Reserve had the second lowest prime spawner biomass of any closed area, with only Moku O Lo‘e on O‘ahu being lower.

Invasive Fishes

Recently, many communities across Hawai‘i have raised concerns about the abundance of invasive fish on Hawaiian reefs, particularly the peacock grouper, *Cephalopholis argus* (roi). While growing scientific evidence suggests invasive fish species have minimal impacts on native Hawaiian reef fish populations (Schumacher and Parrish 2005, Dierking *et al.* 2009, TNC unpublished data), there is the perception among some stakeholders that invasive fishes are significantly impacting native species through direct competition and/or predation.

Three species of invasive fishes were observed in the survey area: *Cephalopholis argus*, *Lutjanus kasmira*, and *L. fulvus* (blacktail snapper or to‘au) (Table 5). In general, invasive fish were rare on the survey transects. Only four *L. fulvus* and 36 *C. argus* were observed at the 55 sites surveyed in 2014. *L. kasmira* numbers were inflated by a single large school at one survey site (2014-AHI06). This single school accounted for all but one individual seen during the 2014 surveys. Including the large school of bluestriped snapper, invasive fish comprised 12.8% of all fish individuals and 17.7% of all fish biomass observed in 2014, making them a common component of the average reef fish assemblage in the project area. However, for the majority of the project area, invasive fish were rare. At sites other than the 2014-AHI06, invasive fish accounted for 0.3% of

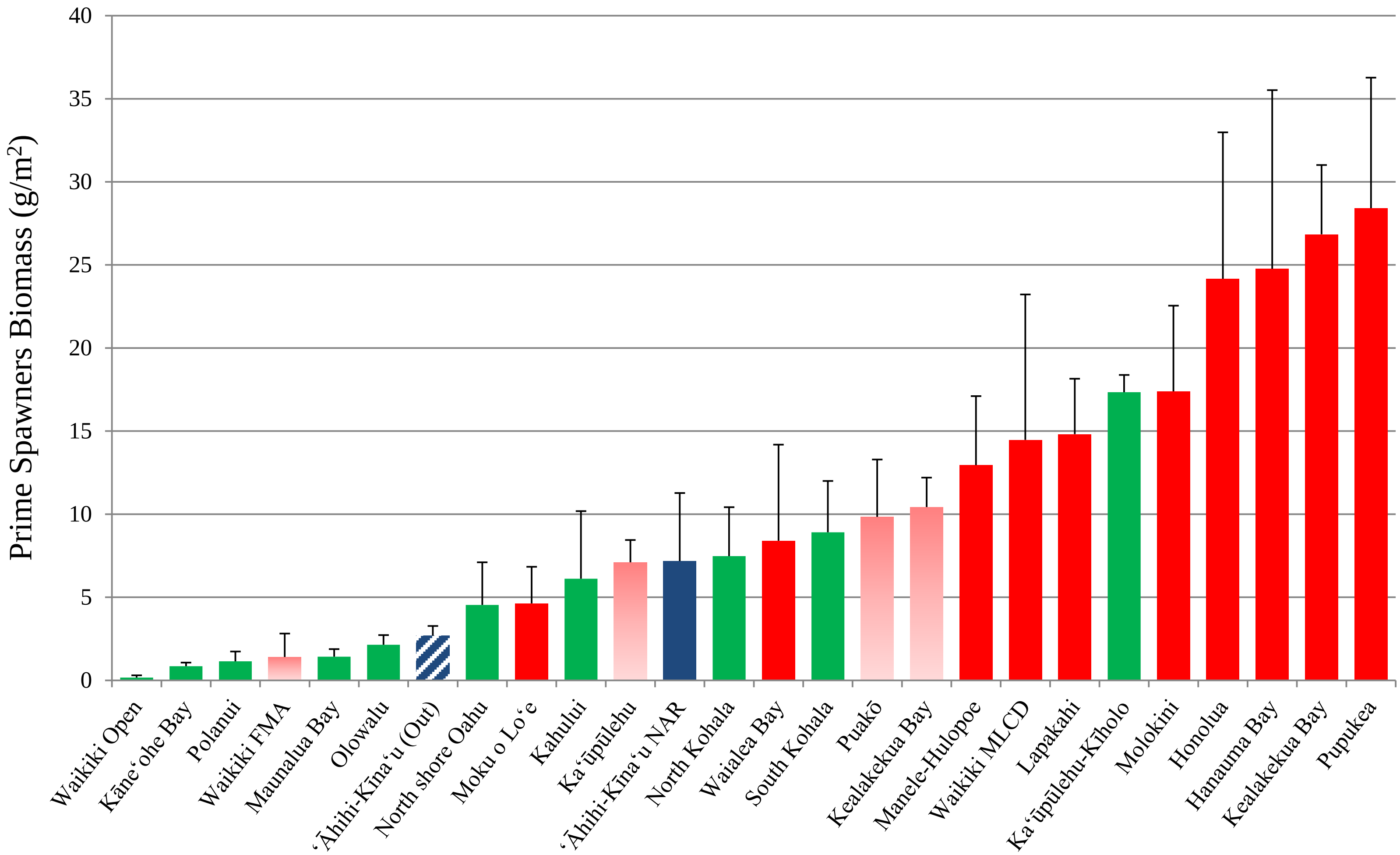

Figure 6. Prime spawner biomass on the reefs inside the Reserve (solid blue bar) and on reef outside of, but adjacent to the Reserve boundary (hatched blue bar) compared to 24 other sites in the state of Hawaiʻi. Color of bars represents level of fisheries management occurring at the site: green=no additional fishing regulations; red=no take allowed; gradated red=limited take allowed. The Reserve is a no-take area, while adjacent reefs are open to harvest and have no additional fishing regulations. Data for other sites are from Friedlander (UH) and TNC.

Table 5. Mean (± SEM) biomass (g/m^2) of three invasive fish species inside and outside the Reserve.

	Inside	**Outside**
Peacock grouper (roi)	2.5 ± 0.6	0.1 ± 0.1
Bluestriped snapper (ta‘ape)	9.0 ± 9.0	0
Blacktail snapper (to‘au)	0.1 ± 0.1	<0.1
Total	11.6 ± 9.2	0.1 ± 0.1

all individuals and 4.6% of the total fish biomass, suggesting these species are not a significant issue in general, but may be locally abundant.

Invasive fish biomass was significantly higher inside (11.6 ± 9.2 g/m^2) than outside (0.1 ± 0.1 g/m^2) the Reserve (t-test; T=4.19; df=27; $p<0.001$), with the majority of that biomass represented by the single large school of *L. kasmira*. *C. argus* are a significant concern among many Maui ocean stakeholders, and while their levels inside ‘Āhihi-Kīna‘u are higher than many reef areas in the state, they are among the lowest for areas closed to fishing.

Habitat Relationship

Differences between the fish assemblage inside and outside the Reserve could be related to differences in habitat quality. Benthic analysis suggests that the Reserve may contain higher quality fish habitat than adjacent reefs. Quantifying "habitat quality" is extremely challenging, but to examine possible stressors affecting the Reserve, such potential habitat differences must be addressed.

To assess habitat quality and determine its effect on the fish assemblage in the survey area, we compared the relationship of fish biomass to the percent of hard bottom for fish inside and outside the Reserve. If we assume habitat quality is the sole (or overwhelmingly most important) factor affecting fish biomass, we would expect the relationship (e.g., a regression/trend line) between fish biomass and amount of available habitat (e.g., percent cover of hard bottom) to be identical if habitat quality were the same inside and outside the Reserve (Figure 7a). If habitat quality was higher inside the Reserve, we would expect the same relationship, but instead of overlapping, the two lines would be offset, with the line for the higher quality habitat parallel to and above the line for the lower quality habitat (Figure 7b). Deviations from these outcomes (e.g., Figure 7c) imply that the fish assemblages are experiencing either: (1) differential habitat effects or (2) factors in addition to variable habitat quality. Furthermore, examination of the biomass to habitat relationship among different species groups may also provide valuable insight into any non-habitat stressors acting on the fish assemblage inside and outside the Reserve.

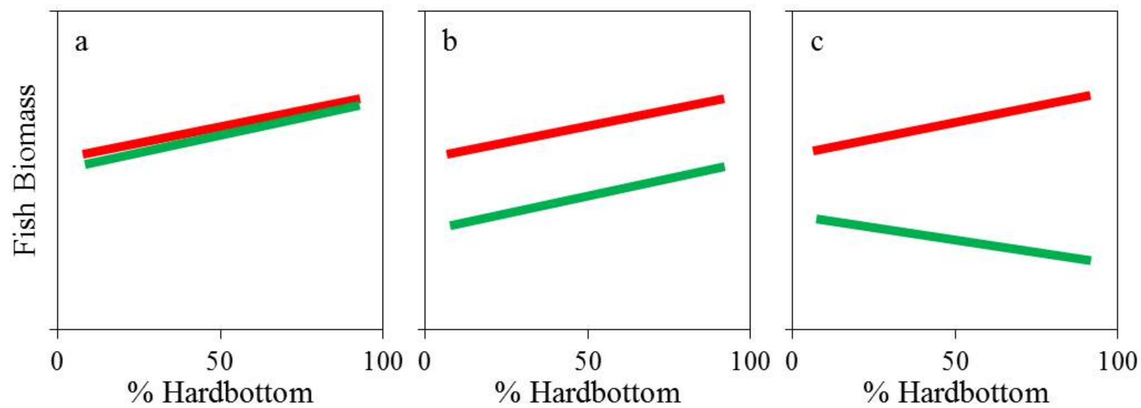

Figure 7. Conceptual figures for examining the potential effect of habitat differences on the fish assemblage inside (red lines) and outside (green lines) the ʻĀhihi-Kīnaʻu Reserve. Percent hard bottom is a quantitative measure of the amount of reef habitat available to the reef fish assemblage. Assuming habitat quality is the primary factor affecting the biomass of fish on reefs inside and outside the Reserve, lines would be overlapping if all habitat is of equal quality (a), but parallel and offset if the quality is different inside than outside the Reserve (b). If factors unrelated to the amount of available habitat are affecting the fish assemblage, the lines would no longer be parallel (c).

Examining the relationship of total fish biomass with percent of hard bottom does not produce two parallel lines, suggesting a simple "habitat quality" explanation is inadequate to explain differences in total fish biomass inside and outside the Reserve. Sites with a high percentage of hard bottom (>80%) have similar total fish biomass regardless of their location (Figure 8), but as the amount of hard bottom decreases, reefs outside the Reserve experience declines in total fish biomass, whereas those inside the Reserve do not.

Total fish biomass decreases outside the Reserve as the habitat becomes more heterogeneous (30-70% hard bottom), but does not decline at similar sites inside the Reserve, suggesting that differences in total fish biomass inside and outside the Reserve are being driven primarily by sites with less hard bottom. This pattern is consistent for most groups of fish examined (figures not shown).

A possible explanation for this pattern is that the more heterogeneous habitat inside the Reserve is of "higher quality" than that outside the Reserve, perhaps a result of enhanced protection afforded by the Reserve’s management or possibly an artifact of the initial selection criteria used when establishing the Reserve’s boundaries. Fish respond to the physical structure of their habitat, and features such as bottom topography (e.g., rugosity) and small-scale heterogeneity of hard bottom (e.g., patchiness) can have significant effects on the amount of fish biomass present. Bottom topography, measured by rugosity, was significantly higher inside than outside the Reserve for sites with 30-70% hard bottom, but were not different for sites with >80% hard bottom (Table 6). Likewise, 30-70% hard bottom sites outside the Reserve had less small-scale heterogeneity than those inside, suggesting a uniformity of habitat outside the Reserve compared to more variable habitat inside the Reserve. This trend disappeared for sites with >80% hard

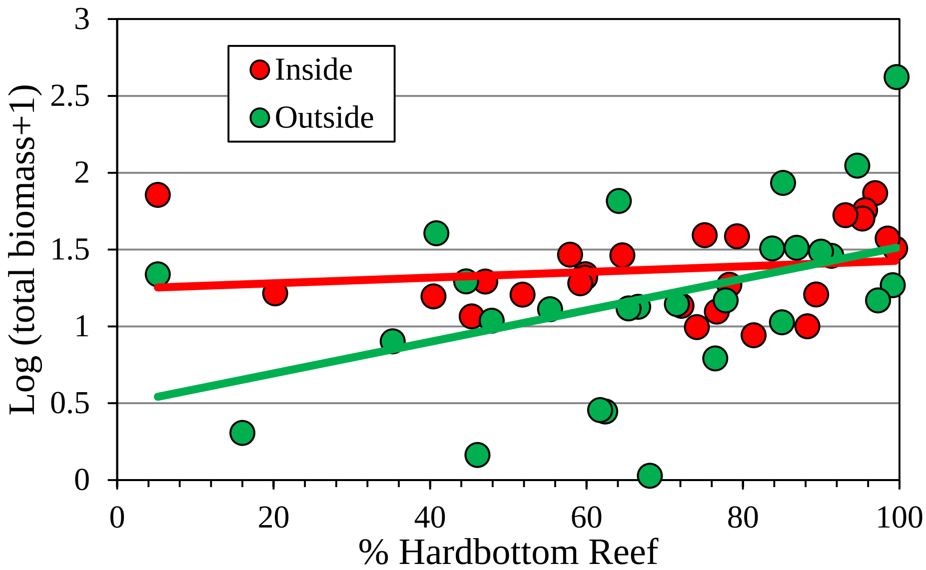

Figure 8. Log-transformed total fish biomass (g/m^2) versus percent cover of hard bottom at sites inside (red circles/line) and outside (green circles/line) the Reserve. Lines are linear trend lines and intended as a visual aid to illustrate the biomass-hard bottom relationship.

bottom, indicating a greater similarity in the physical habitat among >80% hard bottom sites inside and outside the Reserve. Therefore, differing reef quality inside compared to outside the Reserve for areas of 30-70% hard bottom appears to be a significant driver of the lower total fish biomass on the reefs outside the Reserve's boundary.

A few groups, however, did not adhere to this relationship; notably, several target fish groups, including parrotfish and targeted wrasses species (Figure 9a,b) showed lower biomass levels on >80% hard bottom areas outside the Reserve than in comparable hard

Table 6. Mean (± SEM) topographic complexity and small-scale variability of coral reef habitat inside and outside the Reserve for sites with 30-70% cover of hard bottom and >80% cover of hard bottom. Topographic complexity was estimated using a rugosity index, and small-scale variability was measured as the coefficient of variation (CV) of percent cover of sand within a site.

	Inside	**Outside**	**p**
30-70% Hard bottom			
Topographic complexity	1.33 ± 0.5	1.12 ± 0.5	T=2.83; p=0.011
Small-scale variability	76.3 ± 6.1	53.9 ± 5.6	T=2.69; p=0.015
>80% Hard bottom			
Topographic complexity	1.36 ± 0.8	1.33 ± 0.6	T=0.56; p=0.581
Small-scale variability	215.0 ± 126.0	181.0 ± 128.0	T=0.37; p=0.714

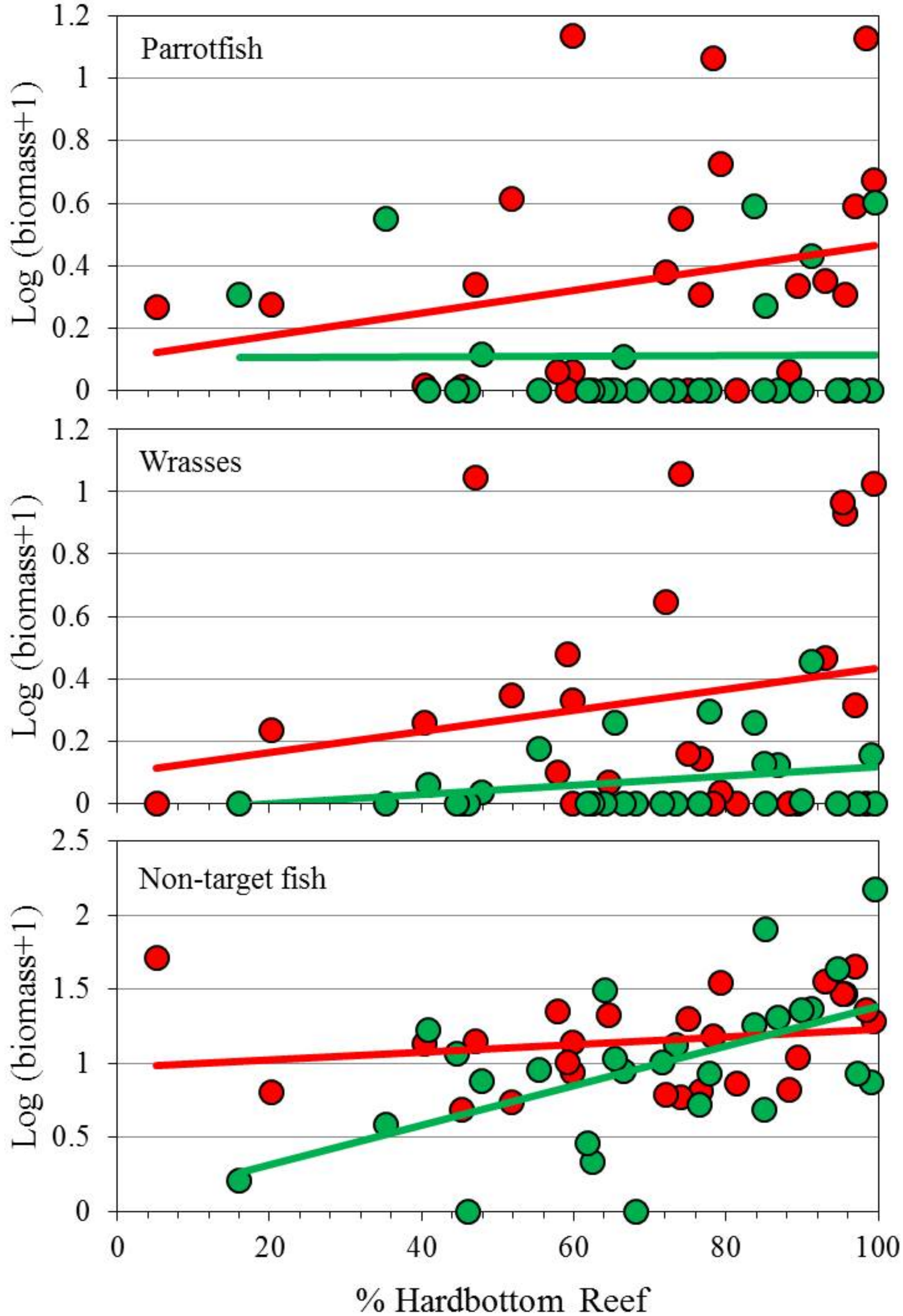

Figure 9. Parrotfish, wrasse, and non-target fish biomass (g/m^2) versus percent cover of hard bottom at sites inside (red circles/lines) and outside (green circles/lines) of the Reserve. Lines are linear trend lines and intended as a visual aid to illustrate the biomass-hard bottom relationship.

bottom areas inside the Reserve, suggesting factors other than "habitat quality" are affecting these groups. For comparison, non-target fish showed a pattern similar to total fish biomass (Figure 9c). The only factor that differentially affects these target fish groups compared to non-target fish groups is fishing pressure, suggesting fishing likely accounts for the lower parrotfish and wrasse biomass outside the Reserve.

This conclusion is further supported when fish biomass is plotted against distance from the Reserve boundary. Total fish biomass outside the Reserve shows a decline near the boundary, which potentially could be explained by a disproportionate number of "low quality" 30-70% hard bottom sites near the boundary. However, this is not the case. No relationship was found between the amount of hard bottom at a site or the site's rugosity, and its distance inside or outside the Reserve's boundary, suggesting this pattern is not an artifact of the spatial distribution of the hard bottom. Looking more closely at the species responsible for the observed boundary effect, the decline is driven primarily by sharp drops in some target fish groups, especially wrasses and parrotfish, both of which are nearly absent at sites close to, but still outside the Reserve boundary (Figure 10), suggesting a significant boundary fishing effect is occurring, where fishing pressure is highest along the Reserve's boundary and decreases with distance from the boundary. Additionally, the biomass of parrotfish appears to increase inside the Reserve with increasing distance from the boundary, further supporting a boundary/fishing effect on this target fish group. These data also suggest that illegal poaching of parrotfish may be occurring inside the Reserve. While it is possible that the decreasing trend in parrotfish biomass inside the Reserve could be explained by fish swimming over the Reserve's boundary where they are then legally caught, studies of parrotfish movement and behavior in Hawai‘i suggest this explanation is inadequate. The linear distance inside the Reserve over which the decline has been detected (>1 km) exceeds the relatively modest movement distance (rarely >350 m) for parrotfishes studied in the state (Meyer *et al.* 2010, Howard *et al.* 2013). Coral reef fish generally show high site fidelity, and the size of the Reserve is likely sufficient that fish >500 m from the boundary rarely leave.

Temporal Trends

Total fish biomass did not change between 2007 and 2014 (Figure 11) either inside or outside the Reserve (ANOVA; $F_{2,98}$=2.50; p=0.087), but biomass inside the Reserve was significantly greater than outside for all years (ANOVA; $F_{1,98}$=14.1; p<0.001). While no statistically significant difference was found among years, the low p-value (p=0.087) suggests that meaningful ecological differences may be present: total fish biomass both inside and outside the Reserve may have declined since 2007, but we do not have enough surveys conducted across those years to offer a definitive conclusion. In all years, surgeonfish were the most common family, accounting for approximately 30% of the total fish biomass both inside and outside the Reserve (Table 7). Two families in particular appear to have changed their relative biomass over time: triggerfish had higher biomass in both 2007 and 2009 compared to 2014, and goatfish were more common in 2014 than in either 2007 or 2009. High snapper biomass inside the Reserve in 2014 was linked to a large school of *L. kasmira* at a single site (2014-AHI06), while a single site outside the Reserve had unusually high *A. virescens* (uku) biomass (2014-AHI50). In general, snapper biomass was consistent across the survey area between 2007 and 2014.

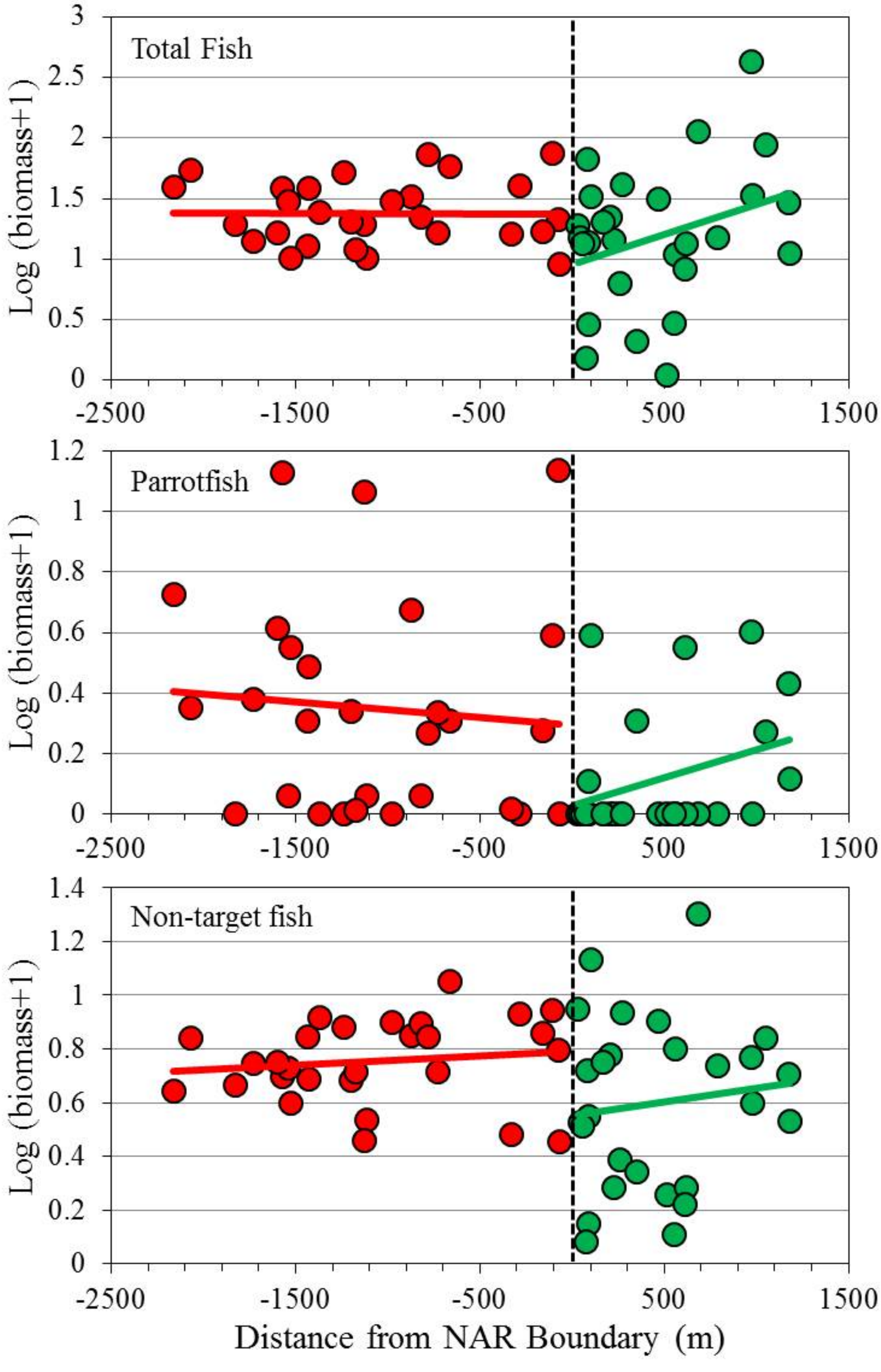

Figure 10. Total fish, parrotfish and non-target fish biomass (g/m^2) versus distance from the Reserve boundary. Negative numbers indicate increasing distance from the boundary into the Reserve, whereas positive numbers indicate increasing distance away from the Reserve boundary into open areas. Fishing is prohibited at sites inside the Reserve (red circles/lines), but poaching is considered a problem. Sites outside the Reserve (green circles/lines) are open to fishing.

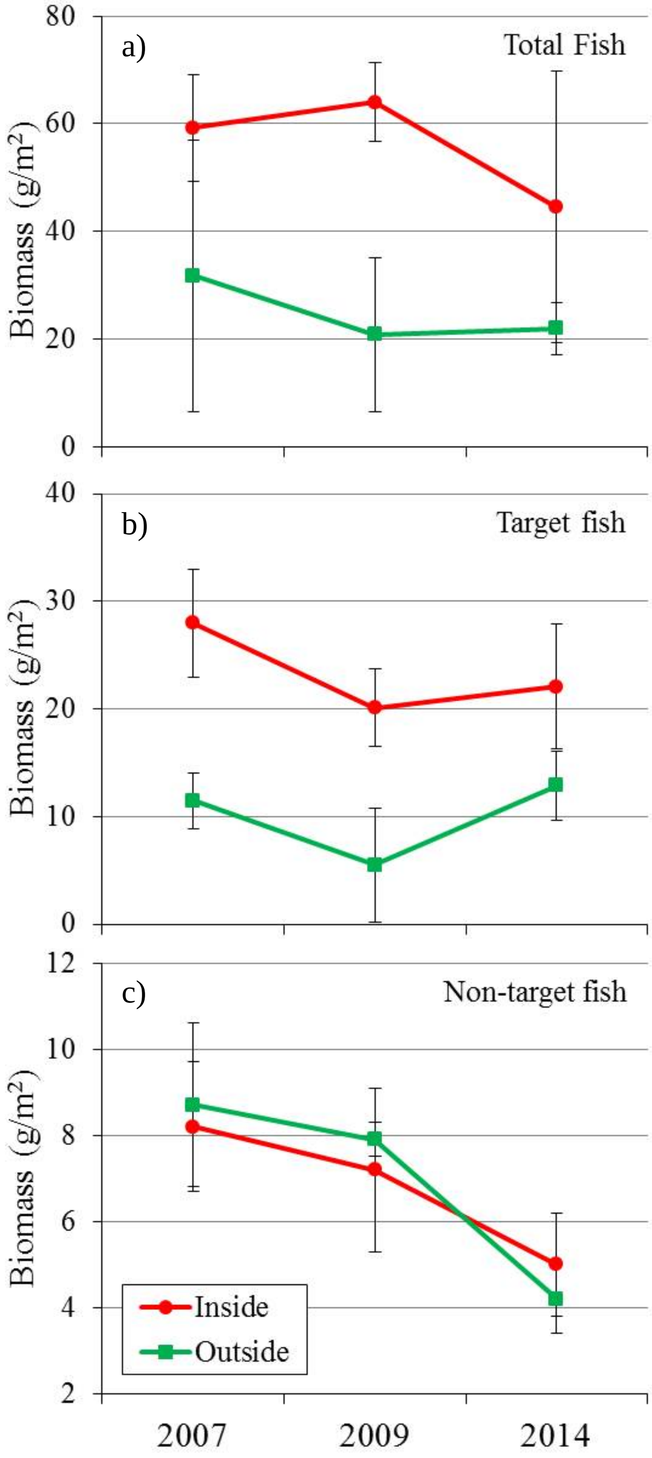

Figure 11. Total fish (a), target fish (b), and non-target fish (c) biomass (g/m^2) inside and outside the Reserve. Data for 2007 and 2009 are from CRAMP.

Target fish biomass (Figure 12b) followed a similar pattern as total fish biomass, with no statistically significant difference among years (ANOVA; $F_{2,98}$=2.18; p=0.065), but with higher target fish biomass inside compared to outside the Reserve (ANOVA; $F_{1,98}$=21.3; p<0.001). Annual differences may again be ecologically significant, this time with 2009 likely having lower target fish biomass than either 2007 or 2014, but the low number of surveys across years makes this uncertain.

In contrast, non-target fish (Figure 12c) showed clear, statistically significant differences among survey years (ANOVA; $F_{2,98}$=7.18; p=0.001), but unlike total and target fish biomass did not significantly vary inside compared to outside the Reserve in any year (ANOVA; $F_{1,98}$=0.77; p=0.381). While it is unclear why non-target fish biomass has significantly decreased since 2007, the decline appears unrelated to the Reserve, as both biomass of non-target fishes has decreased similarly both inside and outside the Reserve. The finding that non-target fish populations are consistently similar inside and outside the Reserve further supports the conclusion that fishing pressure adversely affects the target fish assemblage outside the Reserve, and that the fishing restrictions within the Reserve provide a positive effect on the fish assemblage. If, instead of

fishing

Table 7. Biomass of fishes (g/m^2) inside and outside the Reserve in 2007, 2009, and 2014. Data for 2007 and 2009 surveys were provided by CRAMP. Data for 2014 were collected by TNC for this report. Data are ordered by decreasing biomass inside the Reserve in 2014.

	2007		2009		2014	
Fish Family	**Inside**	**Outside**	**Inside**	**Outside**	**Inside**	**Outside**
Acanthuridae	33.0 ± 5.5	16.8 ± 5.5	24.1 ± 5	11.3 ± 2.9	12.5 ± 1.8	9.3 ± 1.7
Lutjanidae	0.1 ± 0.1	0.3 ± 0.3	0.2 ± 0.1	0	10.1 ± 9.2	3.9 ± 2.8
Mullidae	1.4 ± 0.8	0.6 ± 0.3	0.8 ± 0.4	0.3 ± 0.1	5.3 ± 4.2	1.6 ± 1.0
Labridae	2.7 ± 0.5	3.2 ± 0.9	2.6 ± 0.8	1.6 ± 0.3	3.5 ± 0.6	1.1 ± 0.2
Balistidae	8.0 ± 3.7	2.6 ± 1	22.1 ± 20.4	1.9 ± 0.7	2.9 ± 0.7	2.4 ± 0.4
Serranidae	3.9 ± 1.0	0.8 ± 0.8	1.1 ± 0.7	0	2.5 ± 0.6	0.1 ± 0.1
Scaridae	5.3 ± 1.5	2.9 ± 1.5	5.1 ± 4.1	1.1 ± 0.8	2.3 ± 0.7	0.5 ± 0.2
Chaetodontidae	1.2 ± 0.3	1.0 ± 0.4	1.7 ± 0.5	0.7 ± 0.3	1.5 ± 0.2	1.2 ± 0.5
Lethrinidae	0	0	0	0	1.4 ± 0.9	0
Pomacentridae	2.3 ± 1.3	2.3 ± 0.7	4.8 ± 3.8	3 ± 1	0.8 ± 0.2	1.0 ± 0.8
Holocentridae	0.5 ± 0.3	0	0	0	0.6 ± 0.4	0.2 ± 0.2
Tetraodontidae	0.1 ± 0	0.2 ± 0	1 ± 0.9	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0
Cirrhitidae	0.3 ± 0.1	0.6 ± 0.3	0.2 ± 0.1	0.4 ± 0.2	0.2 ± 0.1	0.1 ± 0
Monacanthidae	0.2 ± 0.2	0.1 ± 0.1	0	0.1 ± 0.1	0.2 ± 0.1	0.1 ± 0
Pomacanthidae	<0.1	0	0.1 ± 0.1	0	0.1 ± 0.1	<0.1
Zanclidae	0.1 ± 0.1	0.2 ± 0.2	0	0	0.1 ± 0.1	0.1 ± 0.1
Carangidae	0.1 ± 0.1	0	0	0	0.1 ± 0.1	0
Aulostomidae	<0.1	0.1 ± 0.1	0.2 ± 0.1	0.1 ± 0.1	<0.1	<0.1
Ostraciidae	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Blenniidae	<0.1	0.1 ± 0	0	<0.1	<0.1	0
Fistulariidae	0	0	0	0	0	0.2 ± 0.1
Apogonidae	0	0	0	0	0	<0.1

Microdesmidae	0	0	0	<0.1	0	<0.1
Kyphosidae	0.1 ± 0.1	0	0	0	0	0
Mugilidae	<0.1	0	0	0	0	0
Caracanthidae	0	0	0	<0.1	0	0
Muraenidae	0	0.1 ± 0.1	0	0	0	0
Scorpaenidae	0	0	0	<0.1	0	0
Total Biomass	**59.2 ± 10.0**	**31.7 ± 7.3**	**64.0 ± 25.3**	**20.8 ± 4.6**	**44.4 ± 14.3**	**22.0 ± 4.8**

pressure, factors such as habitat or water quality were driving differences in fish assemblages inside and outside of the Reserve, those factors would affect all fish equally, and we would see the same differences inside and outside of the Reserve for target and non-target fishes.

5.0 Management Recommendations

The ‘Āhihi-Kīna‘u NAR Management Plan identified several threats to coral reef resources, including three that were classified as high threats (Table 8). Evidence of adverse impacts to marine resources attributable to two of the three high threats was found during the course of the 2014 surveys (and can be reasonably assumed to have occurred in 2015):

- Illegal harvest: Overall target fish biomass inside the Reserve is lower than that found in almost all other areas around the state with comparable management, suggesting that something is effecting the populations of these fisheries species. Parrotfish populations show evidence of illegal poaching within the Reserve. Parrotfish were absent at most sites outside but near the Reserve boundary. Inside the reserve, parrotfish biomass was positively correlated with distance from the boundary: the farther in from the boundary, the greater the parrotfish biomass. This relationship is indicative of a "boundary effect" and likely associated with fishers crossing the boundary to poach parrotfish. While poaching appears to be happening, it is unclear how significant a threat this activity is on the overall condition of the Reserve's coral reefs. Addressing poaching, especially in a flagship Natural Area Reserve, should be a high priority for management.

- Climate Change: Climate change is expected to result in elevated sea water temperature which is the primary cause of coral bleaching. High water temperatures in the latter half of 2014 resulted in a significant bleaching event in some parts of the state, but coral in the Reserve did not appear to be severely affected. In 2015, a second bleaching event occurred as a result of high water temperatures, and early data suggest that Maui reefs were particularly hard hit. Over 50% of the corals bleached on reefs adjacent to the survey area (Makena), as well as on many other Maui reefs. It is highly likely that bleaching in the Reserve was more severe in 2015 compared to 2014. Evidence is strong that one of the best strategies to help reefs recover from bleaching events is to ensure healthy populations of herbivores to control algal growth, which lowers competition with recovering corals and allows new corals to settle and grow. The large herbivore population in the Reserve is a benefit, but data suggesting that some of the most important herbivores (i.e., parrotfishes) are being poached within the Reserve is particularly troubling and should be addressed by the Reserve’s staff.

Table 8. Threats to coral reefs identified in the ‘Āhihi-Kīna‘u NAR Management Plan (Natural Area Reserves System 2012)

Threat	
Illegal harvest of marine species	High
Proposed adjacent coastal or upslope development (e.g., land-based pollution and nutrients and resulting alien algae growth, light pollution, altered wilderness qualities and viewplanes, hydrologic regime change)	
Climate change and severe weather impacts to native biodiversity (habitat shifting and alteration, e.g., coral bleaching; severe lack of rain and temperature extremes; runoff from severe storms; ocean pH change)	
Human trampling	Medium
Motorized ocean vessels in the Reserve; anchoring	
Protected species harassment	
Potential of alien species introduction	
Impact of existing introduced species (e.g., roi, ta‘ape, to‘au)	
Impact of problematic native species (e.g., crown-of thorns sea star) fish disease, coral disease	
Existing coastal development (e.g., land-based pollution and nutrients, lights at night, viewplanes)	
Unexploded ordnance	Low
Marine debris	

- Adjacent coastal or upslope development: Impacts to coral reefs from adjacent coastal or upslope development were not observed during these surveys, but these impacts are often difficult to identify, and are likely manifested indirectly through impacts associated with increased human use and degraded water quality. For example, sediment-laden storm water has been observed entering the Reserve at Kanahena, likely the result of nearby development, and La Pérouse Bay, likely from upslope ranch lands. The biological surveys conducted as part of this assessment are likely not sensitive enough to detect these types of impacts.

Few of the actions proposed in the ‘Āhihi-Kīna‘u NAR Management Plan will directly address these high-ranked threats, although "effective enforcement of use regulations" will likely reduce (or eliminate) illegal poaching. The Reserve staff face significant challenges to address climate change and adjacent development because the sources of these threats lie outside their management authority. Climate change is likely the most significant long-term threat facing the Reserve's coral reefs, and the global drivers of climate change cannot be solved at the local level. However, management actions that reduce local stressors on the Reserve's coral reefs would increase the resilience of the reefs within the Reserve, making them better able to resist the impacts of the climate change as well as recover from damages that may occur.

To this end, reducing illegal harvest and damage from human use (e.g., trampling and anchoring) would provide some benefit to reef resilience. To achieve more substantial increases in reef resilience, management actions will need to be taken at a county or state level, including:

- Rational and effective fishery management in waters surrounding the Reserve, which would increase fish abundance and re-establish impacted trophic structure. Currently, fish assemblages in the main Hawaiian Islands are lacking apex predators and important grazers such as parrotfish and surgeonfish. These herbivores control algae which often directly compete with corals. Additionally, appropriate fishery management would increase the number of prime spawners, improving the reproductive capacity of the assemblage.

- Improvements in coastal water quality, which would reduce metabolic stresses (e.g., from sediment that settles onto coral), reduce direct competition from fast growing algae (e.g., nutrient enrichment that fertilizes algal growth), improve coral reproduction through decreased larval mortality (e.g., reducing chemical pollutants that can kill larvae), and improve settlement (e.g., reducing sediment that covers reef settlement sites).

Specific actions to promote these should be developed and implemented.

6.0 Acknowledgements

This project could not have been completed without the assistance of many people. In particular we would like to thank Dr. Scott Fretz, Dave Quisenberry, Peter Landon, Betsy Gagne, Charmian Dang from Hawaiʻi Division of Forestry and Wildlife, the ʻĀhihi-Kīnaʻu Natural Area Reserve/Keoneʻōʻio Advisory Group, and Russell Sparks (DAR). DAR on Maui provided significant logistical support, without which these surveys could not have been completed. B&B Scuba provided tanks and exceptional and flexible service that facilitated our long days in the water. Funding for this project was provided by the National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Conservation Program, the Harold K. L. Castle Foundation, and other private funders.

This report was prepared by The Nature Conservancy under cooperative agreement award #NA13NOS4820145 from the NOAA Coral Reef Conservation Program, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of NOAA, the NOAA Coral Reef Conservation Program, or the U.S. Department of Commerce.

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Appendix A. ‘Āhihi-Kīna‘u NAR Site Data

Site Code	Location	Date	Lat.	Long.	Rugosity	Depth (m)	Distance from Reserve boundary (m)
2014-AHI03	Inside	12/3/2014	20.60930458	-156.4418292	1.26	13.4	-1197
2014-AHI04	Inside	12/3/2014	20.61843457	-156.4397615	1.23	4.9	-162
2014-AHI05	Inside	12/4/2014	20.59789706	-156.4380766	1.59	11.3	-1829
2014-AHI06	Inside	12/3/2014	20.61443003	-156.4415597	1.03	13.4	-661
2014-AHI07	Inside	12/3/2014	20.59726951	-156.42221	1.30	3	-74
2014-AHI09	Inside	12/5/2014	20.61258693	-156.4390086	1.35	6.7	-820
2014-AHI10	Inside	12/5/2014	20.59516481	-156.422501	1.32	10.4	-104
2014-AHI11	Inside	12/3/2014	20.6067046	-156.4433734	1.05	12.5	-1536
2014-AHI12	Inside	12/3/2014	20.61126712	-156.439755	1.23	4.9	-976
2014-AHI13	Inside	12/2/2014	20.60293542	-156.438329	1.60	5.8	-2161
2014-AHI14	Inside	12/5/2014	20.59631171	-156.4364321	1.50	13.7	-1595
2014-AHI16	Inside	12/5/2014	20.6075717	-156.4404978	1.50	6.7	-1370
2014-AHI17	Inside	12/2/2014	20.59786236	-156.4353384	1.25	4.3	-1571
2014-AHI22	Inside	12/4/2014	20.59450189	-156.4323129	1.60	11	-1125
2014-AHI23	Inside	12/2/2014	20.59695016	-156.4355403	1.65	8.8	-1528
2014-AHI24	Inside	12/3/2014	20.6177822	-156.4435473	1.43	13.4	-331
2014-AHI25	Inside	12/5/2014	20.60989517	-156.4425174	1.08	11.9	-1172
2014-AHI26	inside	12/3/2014	20.60125183	-156.4378992	1.45	8.5	-2068
2014-AHI27	Inside	12/5/2014	20.61242374	-156.4414088	1.22	11.3	-875
2014-AHI28	Inside	12/3/2014	20.61352847	-156.4378493	1.72	4.6	-731
2014-AHI29	Inside	12/2/2014	20.59418589	-156.4242013	1.20	9.4	-280
2014-AHI31	Inside	12/5/2014	20.59421824	-156.4289213	1.20	4.6	-779
2014-AHI32	Inside	12/2/2014	20.60439672	-156.441146	1.45	7.3	-1729
2014-AHI36	Inside	12/5/2014	20.59612496	-156.4316005	1.55	7.6	-1114

Site Code	Location	Date	Lat.	Long.	Rugosity	Depth (m)	Distance from Reserve boundary (m)
2014-AHI37	Inside	12/2/2014	20.59710086	-156.4344579	1.47	14	-1430
2014-AHI38	Inside	12/3/2014	20.59439267	-156.4352703	1.05	13.1	-1434
2014-AHI39	Inside	12/5/2014	20.59312373	-156.4333778	1.08	15.2	-1236
2014-AHI41	Out	12/3/2014	20.59252367	-156.4195048	1.40	5.5	209
2014-AHI43	Out	12/2/2014	20.59615849	-156.4169706	1.45	7	472
2014-AHI44	Out	12/3/2014	20.59314251	-156.4161182	1.30	4.9	562
2014-AHI45	Out	12/2/2014	20.58526101	-156.4136911	1.18	3.7	1054
2014-AHI47	Out	12/5/2014	20.58394077	-156.4133065	1.40	9.1	1180
2014-AHI48	Out	12/2/2014	20.58299345	-156.4145067	1.22	13.7	1173
2014-AHI50	Out	12/4/2014	20.58329972	-156.4173262	1.48	14.6	978
2014-AHI51	Out	12/5/2014	20.59202495	-156.4183183	1.20	3.4	33
2014-AHI53	Out	12/4/2014	20.59364911	-156.4149409	1.17	4.9	685
2014-AHI55	Out	12/2/2014	20.59091887	-156.4139681	1.50	4.6	790
2014-AHI57	Out	12/3/2014	20.58616667	-156.4139644	1.30	8.5	971
2014-AHI58	Out	12/4/2014	20.59164215	-156.4205407	1.79	8.8	103
2014-AHI59	Out	12/2/2014	20.59713238	-156.4205954	1.25	7.3	93
2014-AHI60	Out	12/5/2014	20.59051671	-156.4156204	1.10	5.8	622
2014-AHI61	Out	12/4/2014	20.62084126	-156.4412663	1.00	13.4	43
2014-AHI62	Inside	12/4/2014	20.61978933	-156.4454379	1.00	5.8	-69
2014-AHI64	Out	12/3/2014	20.62331803	-156.4441037	1.12	6.1	262
2014-AHI65	Out	12/5/2014	20.62115533	-156.442241	1.12	15.2	60
2014-AHI66	Out	12/4/2014	20.61925725	-156.4468412	1.10	7.6	80
2014-AHI68	Out	12/4/2014	20.62681127	-156.4463131	1.05	4.6	614
2014-AHI70	Out	12/5/2014	20.62585213	-156.4452841	1.00	11.9	515
2014-AHI72	Out	12/5/2014	20.62251253	-156.4471154	1.20	4.6	170
2014-AHI73	Out	12/4/2014	20.62397978	-156.4429997	1.02	8.8	353

Site Code	Location	Date	Lat.	Long.	Rugosity	Depth (m)	Distance from Reserve boundary (m)
2014-AHI74	Out	12/4/2014	20.62164601	-156.4443825	1.00	14	74
2014-AHI76	Out	12/4/2014	20.62430123	-156.4504104	1.00	14.9	557
2014-AHI77	Out	12/3/2014	20.62106573	-156.4483474	1.00	13.7	230
2014-AHI79	Out	12/3/2014	20.62120956	-156.4469992	1.10	9.1	89
2014-AHI80	Out	12/3/2014	20.62372891	-156.4460624	1.26	13.4	273

Appendix B. TNC Survey Methods and Data Analysis

The overarching goal of TNC's marine monitoring program is to detect change in the biological community over time on specific reef areas around the main Hawaiian Islands. In addition to detecting temporal change, the marine monitoring program seeks to provide data that can be used to compare coral reef areas with other reef ecosystems across the state and beyond. Such comparisons can provide a context within which to understand any observed changes. Thus, survey design and sampling protocols were specifically chosen to provide the greatest likelihood of compatibility with other monitoring efforts currently underway in Hawaiʻi.

In 2014, TNC's marine monitoring team (along with a diver from DAR) conducted benthic and fish surveys of the reefs in and adjacent to the ʻĀhihi-Kīnaʻu Natural Area Reserve (the Reserve). Members of the monitoring team have hundreds of hours of experience conducting underwater surveys of coral reefs, and provide regular monitoring for numerous sites around the main Hawaiian Islands. All surveyors are trained and calibrated to reduce differences among observers that can sometimes confound data in large, long-term monitoring programs.

Survey Sites

The survey area in the Reserve and adjacent reefs covered over 5 km of coastline and included coral reef habitat between 3 and 15 m deep. Fifty-five sites were randomly generated in ArcGIS with twenty-seven sites lying outside and twenty-eight sites inside the Reserve boundary.

Sites were surveyed by divers deployed from small boats. The survey teams navigated to each predetermined site using a Garmin GPS unit. Once on site, the survey team descended directly to the bottom, where divers established two transect start points approximately 10 m apart. From each start-point, divers deployed a 25 m transect line along a predetermined compass heading, with the transects running parallel to each other. If the bearing resulted in a large change in depth, divers would follow the depth contour instead, to keep a consistent depth.

Benthic Community Surveys

Benthic surveys were not designed to collect comprehensive biodiversity data. Instead, surveys were designed to collect quantitative data on specific taxa, primarily individual coral species, algae at higher taxonomic resolution (e.g., red, green, brown, turf, crustose coralline, etc.), and abiotic substratum type when the bottom was something other than hard substratum.

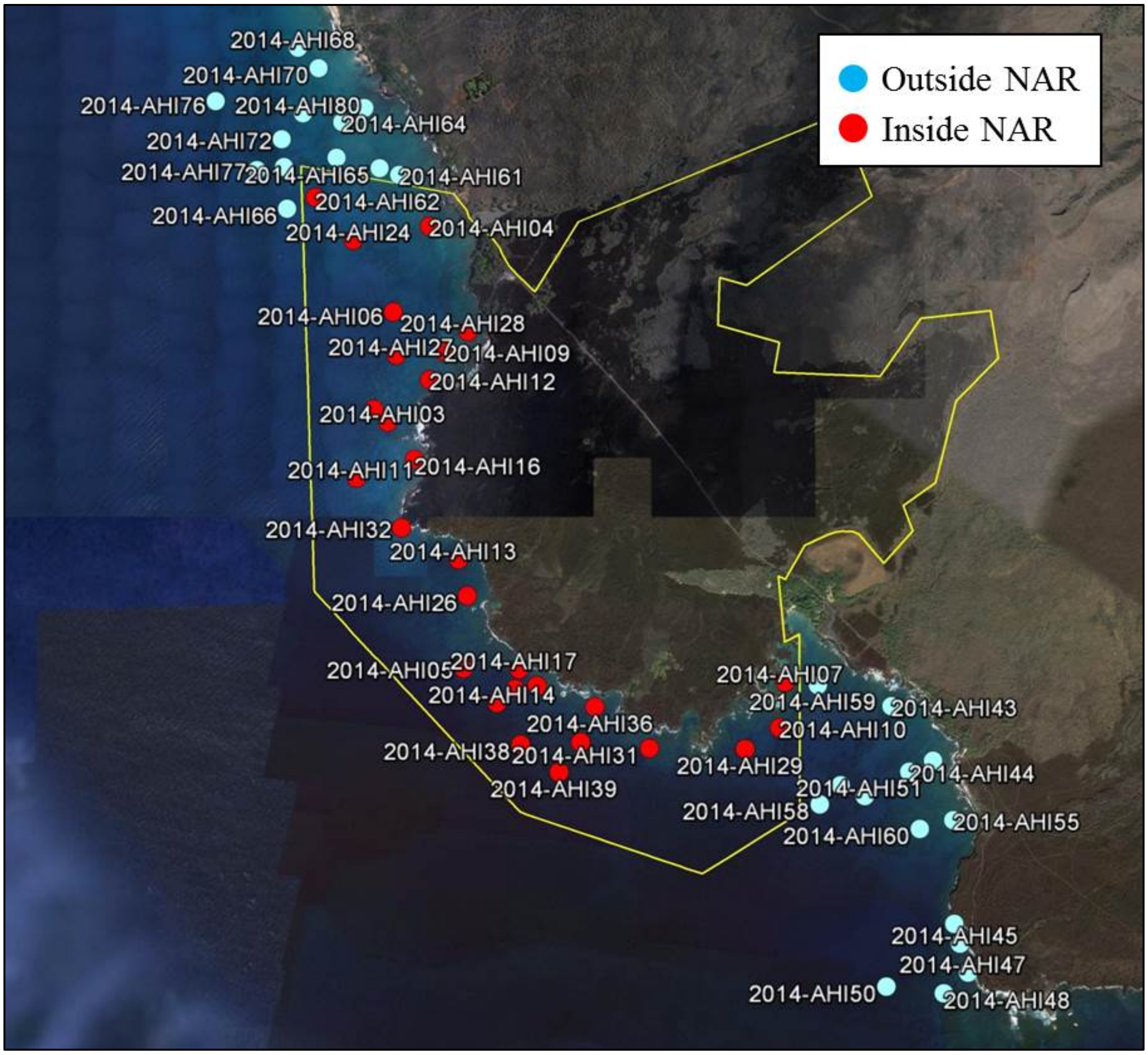

Figure B.1. ‘Āhihi-Kīna‘u NAR with the 55 randomly generated marine monitoring sites surveyed during December 2014.

At all sites, benthic photographs were collected at 1 m intervals along one of the two 25 m transect lines. Photographs were taken with a Canon G12 or S110 camera mounted on a 0.8 m long monopod, resulting in images that covered approximately 0.8 x 0.6 m of the bottom. Prior to photographing each transect, the camera was white balanced to improve photograph quality. A 5 cm scale bar marked in 1 cm increments was included in all photographs.

Each photograph was imported into Adobe Photoshop CS5 where its color, contrast, and tone were auto balanced to improve photo quality prior to analysis using the Coral Point Count program with Excel extension (CPCe) developed by the National Coral Reef Institute (Kohler and Gill 2006). Using CPCe, 30 random points were overlaid on 20 randomly selected digital photographs, and the benthic component under each point was identified to the lowest possible taxonomic level. To reduce observer variability, all photographs were processed by a single individual. The raw point data from all photographs on a transect line were combined to calculate the percent cover of each benthic component for the entire belt transect. The number of photos analyzed and points per photo were derived from a power analysis conducted to determine the optimal sampling effort to maximize the statistical power of annual comparisons.

Fish Community Surveys

All fish within or passing through a 5 m wide belt along each of the two 25 m transects deployed at each survey site were identified to species and sized into 5 cm bins (i.e., 0-5 cm, >5-10 cm, >10-15 cm, etc.) Divers moved slowly along the transects, taking between 10 and 15 minutes to complete each belt survey. This method closely corresponds with that used by Dr. Alan Friedlander and colleagues for the "Fish Habitat Utilization Study" (FHUS), and provides comparable data. Details of their method and results of those surveys are given in a number of recent publications (Friedlander *et al.* 2006, Friedlander *et al.* 2007a, 2007b).

A 5-minute timed swim was conducted after divers completed surveying the 25 m transect lines. For the timed swims, the two fish surveyors swam approximately 5 m apart and visually counted all fish larger than 15 cm within or passing through a 5 m wide column (centered on the surveyor) extending from the ocean bottom to the surface. Divers communicated with each other to ensure that each fish was recorded by only one surveyor (i.e., fish were not double counted). All fish were identified to the lowest possible taxonomic level and sized into 5 cm bins.

Data Analysis

Individual fish biomass (wet weight of fish per m^2 of reef area) was calculated from estimated lengths using size to weight conversion parameters from FishBase (Froese and Pauly, 2010) or the USGS Hawai‘i Cooperative Fisheries Research Unit (HCFRU). For analyses among survey sites, fish survey data were pooled into several broad categories, including: (1) all fishes, excluding manta rays; (2) target fishes[9], which are reef species targeted or regularly harvested by fishers (Table B.1); (3) prime spawners[10], which are target fishes larger than 70% of the maximum size reported for the species; and (4) non-target fishes, which are species not targeted by fishers to any significant degree. Non-target taxa included: non-target wrasses (all wrasse species other than those listed in Table B.1); non-target surgeonfishes (*Acanthurus nigrofuscus* and *A. nigricans*);

[9] Nearly all fish species are taken by some fishers at some time in Hawai‘i, therefore designating a fish species as either ‘targeted' or ‘non-targeted' is oftentimes difficult. These two groupings are intended to represent the high and low ends of the fishing pressure continuum. The majority of fish biomass at most sites is comprised of species that fall somewhere in the middle of this continuum, and these species were not included in either group for these analyses.

[10] Large target fishes are generally heavily targeted by fishers. In addition, fishes at the high end of their size range tend to be a disproportionately important component of total stock breeding potential due to greater fecundity of large individuals, and higher survivorship of larvae produced by large fishes (Williams *et al.* 2008). Therefore ‘prime spawner' biomass is likely to be a good indicator of fishing impacts, and represents an important component of ecological function (i.e., population breeding potential).

hawkfishes (all species except the stocky hawkfish, *Cirrhitus pinnulatus*); triggerfishes excluding planktivores; corallivorous butterflyfishes (*Chaetodon multicinctus, C. ornatissimus*, *C. quadrimaculatus* and *C. unimaculatus*); and benthic damselfishes (all *Plectroglyphidodon* and *Stegastes* species).

Standard parametric and non-parametric statistical approaches, as appropriate, were used to test for differences between years and location (inside and outside the Reserve). As necessary, fish biomass and abundance were log-transformed to correct skewness and heteroscedasticity prior to analysis. All means are presented as the average ± the standard error of the mean (SEM).

Benthic and fish communities were examined using the suite of non-parametric multivariate procedures included in the PRIMER statistical software package (Plymouth Routines in Multivariate Ecological Research) (Clarke and Warwick 2001). These procedures have gained widespread use for analyzing marine ecological community data, and have significant advantages over standard parametric procedures (see Clarke 1993 for additional information).

Prior to analysis, percent cover data for each benthic category were square-root transformed and a Bray-Curtis similarity matrix generated (Clarke and Warrick 2001, Clarke and Gorley 2006). Non-metric multidimensional scaling (nMDS) plots were generated to explore patterns (Clarke and Gorley 2006) in benthic composition.

As with the benthic community data, fish biomass data at all sites were square-root transformed and a Bray-Curtis similarity matrix generated (Clarke and Warrick 2001, Clarke and Gorley 2006) prior to analysis in PRIMER. Non-metric multidimensional scaling (nMDS) plots were generated to explore patterns (Clarke and Gorley 2006) in fish community structure.

Table B.1. The fish species targeted by fishers in Hawaiʻi included as "Target Fish" for this report.

<u>Surgeonfishes (Acanthuridae)</u>	<u>Apex</u>
Acanthurus achilles	*Aphareus furca*
Acanthurus blochii	*Aprion virescens*
Acanthurus dussumieri	All Priacanthidae (big-eyes)
Acanthurus leucopareius	All Sphyraenidae (barracuda)
Acanthurus nigroris	
Acanthurus olivaceus	<u>Goatfishes (Mullidae)</u>
Acanthurus triostegus	All
Acanthurus xanthopterus	
Ctenochaetus spp.	<u>Jacks (Carangidae)</u>
Naso spp.	All
<u>Wrasses (Labridae)</u>	<u>Soldier/Squirrelfishes(Holocentridae)</u>
Bodianus albotaeniatus	*Myripristis* spp.
Cheilio inermis	*Sargocentron spiniferum*

Coris flavovittata
Coris gaimard
Iniistius spp.
Oxycheilinus unifasciatus
Thalassoma ballieui
Thalassoma purpureum

Sargocentron tiere

Others
Chanos chanos
Cirrhitus pinnulatus
Monotaxis grandoculis

Parrotfishes (Scaridae)
All

Key taxa representative of zones were selected using PRIMER's SIMPER analysis. Any taxa with a DISS/SD>1.4 were considered to be representative of the zone. The ratio of the average dissimilarity and standard deviation (DISS/SD) is given as a measure of how consistently the species contributes to the characterization of differences between groups, with larger values (>1.4) indicating greater consistency as a discriminating species (Clarke and Warrick 2001).

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Appendix C. Glossary of Scientific Terms

Abundance: The relative representation of a species in a particular ecosystem. It is usually measured as the number of individuals found per sample.

Assemblage: All of the various species of a particular type or group that exist in a particular habitat (e.g., all fish, all coral). A species assemblage is a subset of all of the species within an ecological community, e.g., the fish assemblage is part of the coral reef community.

Belt Transect: A sampling unit used in biology to investigate the distribution of organisms in relation to a certain area. It records the number of individuals for all the species found between two lines.

Benthic Organism: An animal or plant that resides primarily on the bottom, whether attached (e.g., coral, algae), or unattached (e.g., snail, crabs).

Biomass: The mass of living biological organisms in a given area or ecosystem at a given time. Usually expressed as a mass or weight per unit area, e.g., tons/acres or g/m^2.

Prime spawners: Large target fishes (>70% their maximum size) that are generally prized by fishers and tend to contribute disproportionately more to the total reproductive potential of the population than smaller individuals due to their greater egg and sperm production (i.e., higher fecundity) and the higher survivorship of their larvae. Prime spawner biomass is a good indicator of fishing impacts.

Quadrat (Photo-quadrat): A square used in ecology to isolate a sample, usually about with a relatively small area (e.g., 0.25 m^2 or 1 m^2). A quadrat is suitable for sampling sessile or slow-moving animals. A photo-quadrat is a picture taken of a quadrat.

Rugosity: A measure of small-scale variations in the height of the reef. As a measure of complexity, rugosity is presumed to be an indicator of the amount of habitat available for colonization by benthic organisms (those attached to the seafloor), and shelter and foraging area for mobile organisms.

Target fishes: Fish desirable for food, commercial activity, and/or cultural practices that reside in the habitats and depth ranges surveyed by the TNC marine monitoring team. Nearly all fish species are taken by some fishers at some time in Hawaiʻi, therefore designating a fish species as either ‘targeted’ or ‘non-targeted’ is oftentimes difficult. These two groupings are intended to represent the high and low ends of the fishing pressure continuum. The majority of fish biomass at most sites is comprised of species that fall somewhere in the middle of this continuum.

Summary of Findings
2014 Coral Reef and Fish Surveys: Polanui, Maui

Fed by fresh water streams and shoreline springs along Maui's Lāhaina coastline, Polanui's reef, called Nā Papalimu O Pi'ilani, was known for its abundance of fish and edible limu (algae). But like other reefs adjacent to high population centers, it now shows signs of significant human impact associated with sediment, runoff, overharvest, and recreational overuse. Improved management can help address these stressors, which are contributing to the reef's decline and to the consistently low fish populations observed over multiple years.

The Nature Conservancy conducted surveys measuring the size, distribution, and abundance of coral and reef fish at depths of 10-60 ft in 2012, 2013, and 2014. The data collected during the surveys provides valuable baseline information to inform the management efforts of Polanui Hiu, the local community group working to restore this stretch of reef.

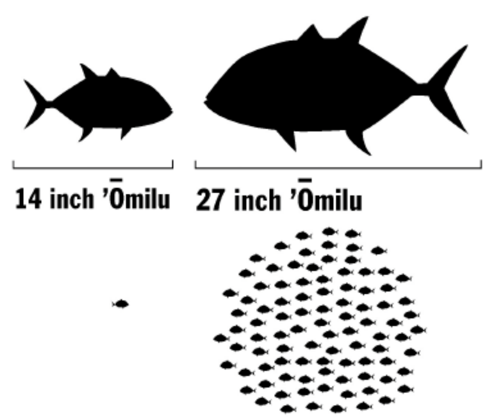
Of more than 40^{+} sites surveyed statewide, Polanui had the lowest stocks of popular food fish like kūmū.

Key Findings: Polanui's Fish

- Total fish biomass (weight of all fish) at Polanui was significantly lower than that found in 2012. It was lower than all other sites surveyed on Maui and among the lowest of 40^{+} sites surveyed across the state.
- The biomass of target fish (those highly prized and harvested) was significantly lower than that found in 2012 and was the lowest of 40^{+} sites surveyed across the state.
- The biomass of prime spawners (fish with the highest reproductive potential) continues to be among the lowest in the state.
- Apex predators were not observed in areas surveyed in 2014.

Bigger Fish Make More Fish

Old, large fish produce more and healthier larvae and are responsible for the vast majority of reproduction. A 27-inch 'ōmilu, for example, makes 86 times the number of eggs produced by an 'ōmilu half its size.



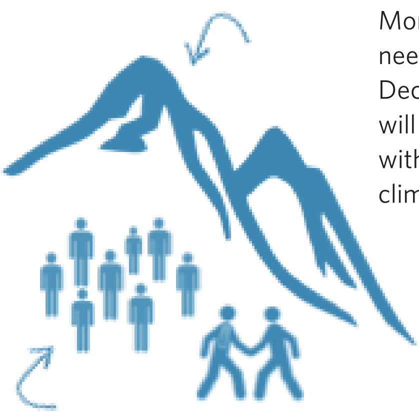
Key Findings: Polanui's Corals

- There were 12 species of coral observed at depths of 10-60 ft and average coral cover was about 20%.
- Turf algae, which can smother or stress reefs, was common, covering 92% of the bottom in shallow water. Sand and silt covered as much as 80% of the bottom at deeper sites.
- Several species of coral showed evidence of paling, bleaching, disease (e.g., growth anomalies), and "pink tissue," which is a characteristic response to stress.



Unlike healthier reefs on Maui's southwest coast (top left), coral at Polanui showed evidence of stress, including pink tissue (top right). Turf algae and sedmient surrounding the corals (left), likely the result of runoff and poor water quality, impedes recovery and the growth of new coral.

Management Recommendations



More effective upland management is needed to improve water quality. Decreasing sedimentation and runoff will increase the ability of the reef to withstand global threats such as climate change.

Additional research is needed to determine the magnitude of each potential stressor, and whether the changes in fish populations observed between 2012 and 2014 are associated with natural variability or represent a continuing downward trend at Polanui.

Regardless, the consistently low total fish biomass at Polanui over multiple years is indicative of the relatively poor condition of its fish resources and coral reef habitat.

Additional fishery management, supported by the community and adequately enforced, is needed to halt further declines in fish populations and promote recovery.

For Additional Information

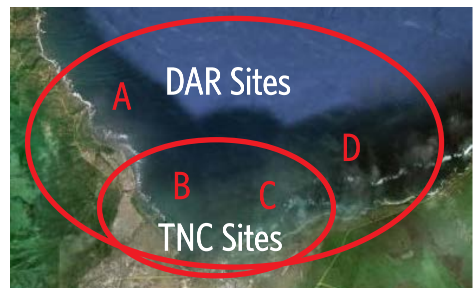
Contact Roxie Sylva , Maui Marine Coordinator, at rsylva@tnc.org or 808-856-7669.

How You Can Help

Polanui Hiu is building an engaged community of volunteer citizen scientists who help monitor reef fish populations. The group meets the first Saturday of the month at the Lindsey ʻOhana residence at 393 Front Street. Stop by or contact Ekolu Lindsey at polanuihiu@hawaii.rr.com, facebook.com/polanuihiucmma, @polanuihiu, or 276.5593 to learn about Polanui Hiu's activities and explore ways to get involved.

Summary of Findings
2015 Coral Reef and Fish Surveys: North Shore, Maui

Maui's north shore is home to one of Hawai'i's largest coral reefs, spanning roughly 3,000 acres. Once prized for an abundance of he'e, ula, and limu (octopus, lobster, and seaweed) and known for big wintery surf, the area attracts surfers, paddlers, divers, and fishermen. But the cumulative effects of land-based pollution and overharvest have led to declines in coral cover and in the number and size of prized fish, like parrotfishes and goatfishes.



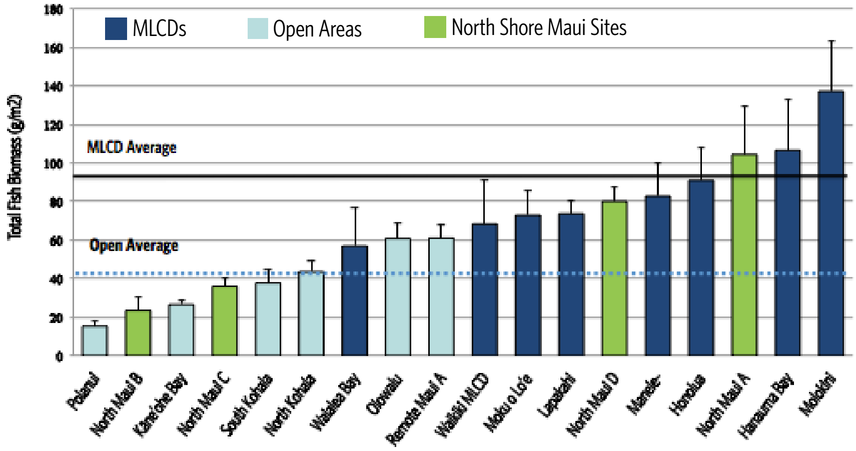
TNC and DAR surveyed four reef areas. Our data confirmed a broad range of abundance, species richness, and the condition of fishes and coral habitat along Maui's north shore.

Fishermen, non-profit organizations, and state agencies have taken action to combat these impacts and restore the reefs and fisheries. Since 2009, their collaborative efforts have resulted in 1) new rules for the Kahului Harbor Fisheries Management Area, 2) the state's first Community Fisheries Enforcement Unit tasked with increasing public awareness of pono fishing practices and curbing illegal fishing activities, and 3) the state's first island-specific fishing rules—Maui's bag and size limits for parrotfishes and goatfishes.

To assess current conditions and provide baseline data to measure the impacts of these actions, The Nature Conservancy (TNC) conducted surveys measuring the size and distribution of coral and reef fish at sites near Kahului, and Hawai'i's Division of Aquatic Resources (DAR) conducted similar surveys further east and west of the commercial center (*see map*). Results were compared with findings from 40^{+} other sites surveyed in the Main Hawaiian Islands.

Key Findings

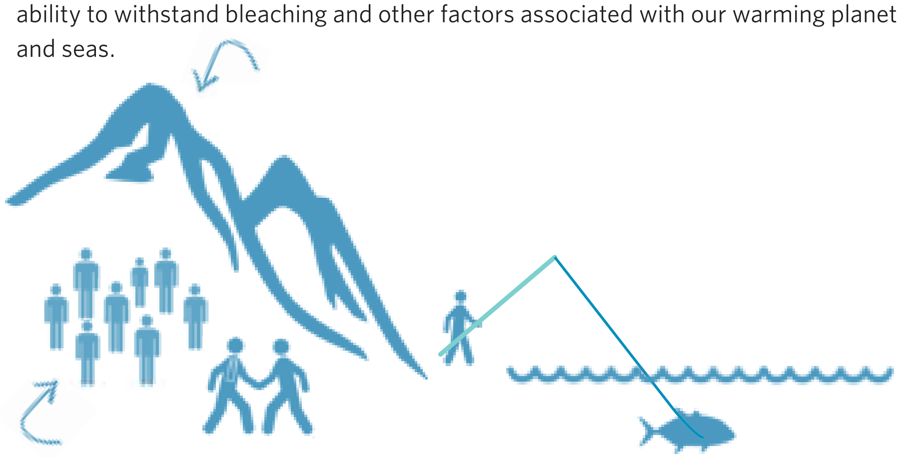
- Shallow reefs at all sites, likely pounded by large winter waves, were flat and dominated by encrusting corals (*top*). Deeper reefs were more complex, with spurs-and-grooves, overhangs, ledges, mounding and branching corals (*bottom*).
- Site A, the survey area furthest west, had the highest fish biomass (total weight of all fish) and the most prime spawners (fish with highest reproductive potential).
- Site B, just to the west of Kahului, had poor water clarity (due to sediment), few prime spawners, and the lowest fish biomass of the four sites, comparable to many sites on O'ahu.
- Site C, to the east of Kahului, had poor water clarity, low fish biomass, and few prime spawners.
- Site D, the survey area farthest east and the greatest distance from Kahului, had high fish and prime spawner biomass, only slightly lower than Site A.



Surveys at four North Maui sites revealed fish populations that varied widely depending on habitat and proximity to Kahului. Fish stocks at sites furthest from Kahului were comparable to stocks in Marine Life Conservation Districts, while those near Kahului were similar to other open areas.

Management Recommendations

Sedimentation and runoff compromise water quality and reef health. More effective upland management will reduce these pressures, increasing coral health and its ability to withstand bleaching and other factors associated with our warming planet and seas.



Continued effective fishery management and enforcement is needed to halt further declines in fish populations and promote recovery.

Increasing prime spawner biomass is crucial to restoring fisheries. Ongoing engagement with the Community Fisheries Enforcement Unit is needed to increase understanding and compliance with Maui's bag and size limits.

Additional research is needed to determine whether the variability in fish populations can be definitively attributed to natural variations or to human pressures. Ongoing monitoring can identify the corals that are able to resist or recover from bleaching so management efforts can be focused on those corals most likely to survive and thrive into the future.

For Additional Information on the Surveys

Contact Russell Sparks, Aquatic Biologist, Division of Aquatic Resources, Maui Office at Russell.T.Sparks@hawaii.gov or Dr. Eric Conklin, Marine Science Director, The Nature Conservancy, at econklin@tnc.org.

How You Can Help

Practice Pono Fishing

The new Maui bag and size limits for parrotfishes and goatfishes were adopted to help prevent the over harvest of these highly targeted species. Learn and follow these regulations, which can be found at (http://dlnr.hawaii.gov/dar), and encourage fellow fishers to do the same.

Report Illegal Fishing

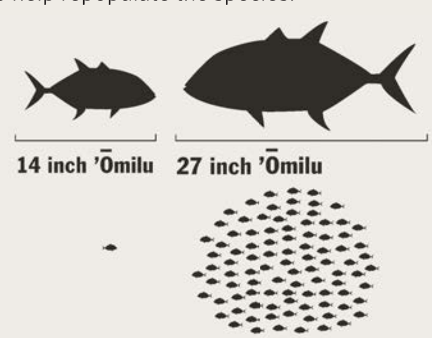
Regulations won't help replenish fisheries if rules aren't followed. Call DOCARE's North Maui Community Fisheries Enforcement Unit at 643-DLNR (3567) to report illegal fishing.

Support Wailuku CMMA

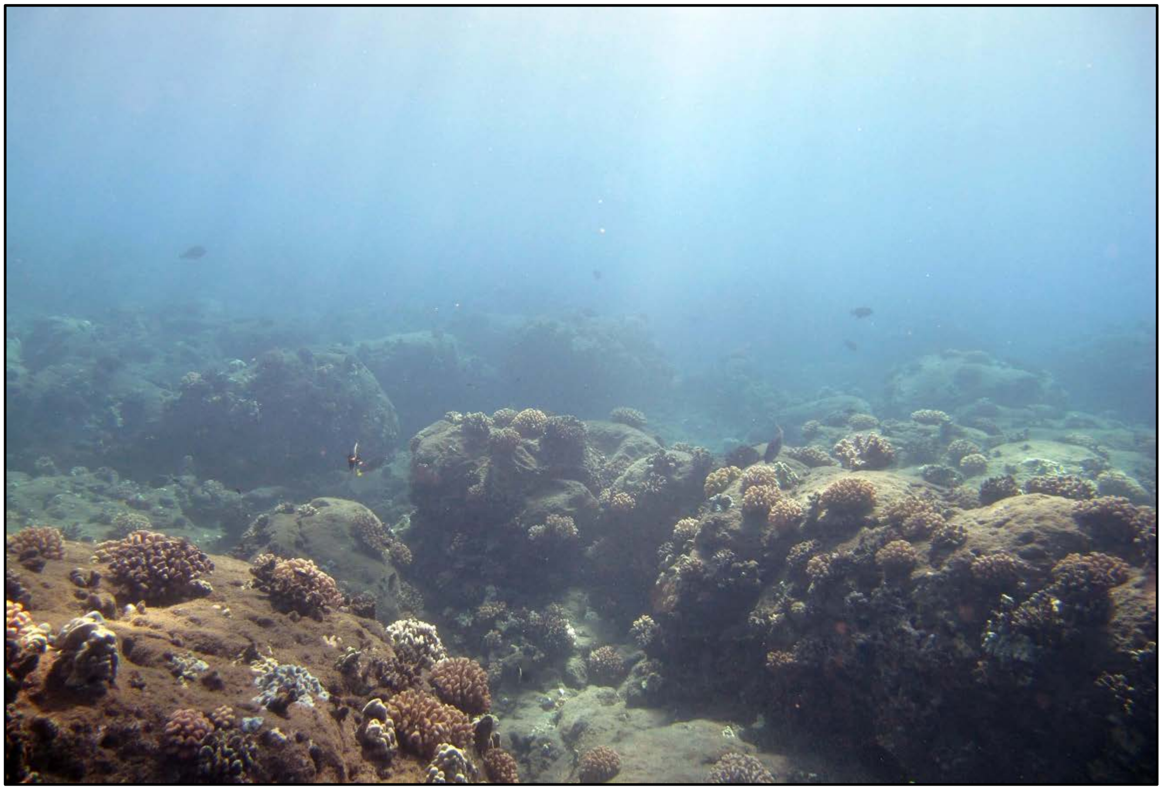
Established in 2010, the Wailuku Community Managed Makai Area (CMMA) is working to restore health and abundance to the *moku* of Wailuku. The community group meets every third Sunday of the month at Kahului Harbor. Contact the group at wailukucmma @gmail.com or visit facebook.com /WailukuCmma to learn about the group's activities and explore ways to get involved.

Bigger Fish Make More Fish

Old, large fish (prime spawners) produce more and healthier larvae and are responsible for the vast majority of reproduction. A 27-inch ʻōmilu, for example, makes 86 times the number of eggs produced by an ʻōmilu half its size. Leave old, large fish in the ocean so they can continue to help repopulate the species.



Baseline Biological Surveys of the Coral Reefs of Kahoʻolawe, Hawaiʻi 1981-2015



Coral reef at Kahoʻolawe. Photo © TNC.

This report was prepared by The Nature Conservancy under cooperative agreement award #NA13NOS4820145 from the NOAA Coral Reef Conservation Program, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of NOAA, the NOAA Coral Reef Conservation Program, or the U.S. Department of Commerce.

Baseline Biological Surveys of the Coral Reefs of Kahoʻolawe, Hawai'i 1981-2015

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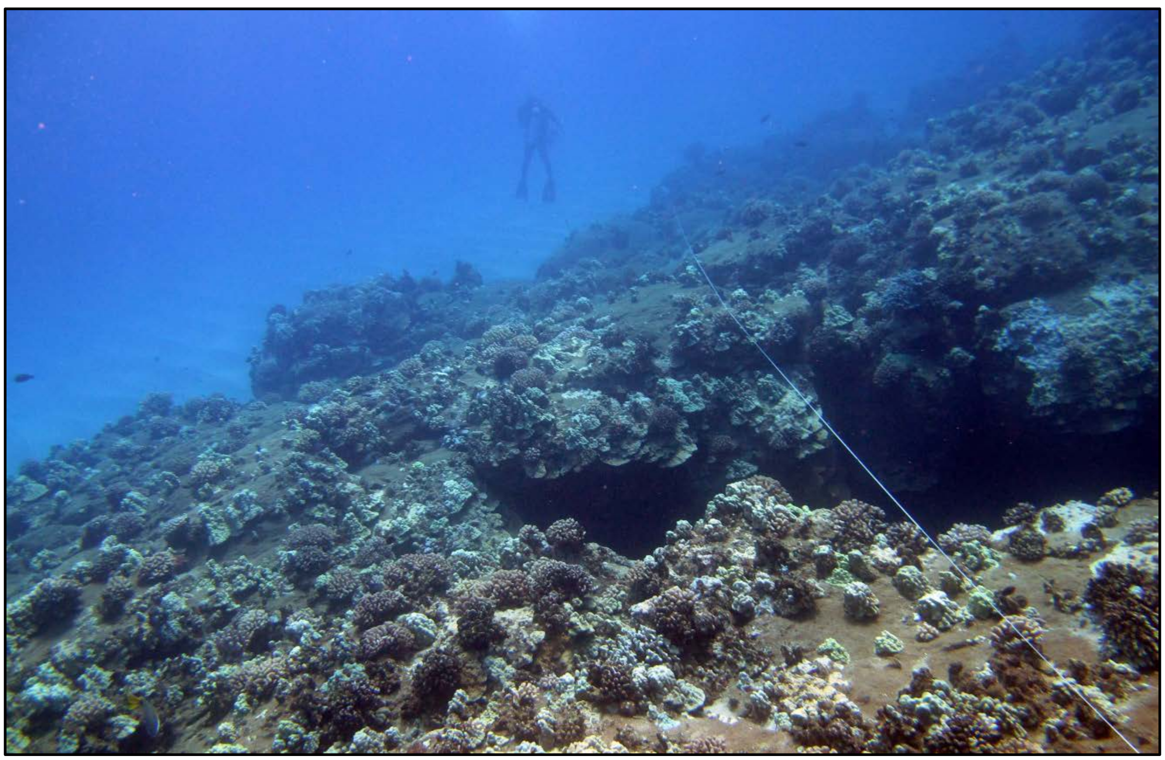

April 22, 2016

List of Acronyms

CAP	Conservation Action Plan
CCA	Crustose Coralline Algae
CPCe	Coral Point Count with Excel Extension
CRAMP	Coral Reef Assessment and Monitoring Program
FERL	University of Hawai‘i’s Fisheries Ecology Research Lab
FHUS	Fish Habitat Utilization Study
FMA	Fisheries Management Area
HIMB	Hawai‘i Institute of Marine Biology
KIRC	Kaho‘olawe Island Reserve Commission
MLCD	Marine Life Conservation District
MOP	University of Hawai‘i’s Marine Option Program
TNC	The Nature Conservancy

List of English Common, Hawaiian, and Scientific Names of Species Included in this Report

Common Name	Hawaiian Name	Scientific Name
Ocellated coral	-	*Cyphastrea ocellina*
Oval mushroom coral	ʻĀkoʻakoʻa	*Fungia scutaria*
Bewick coral	-	*Leptastrea bewickensis*
Crust coral	Koʻa	*Leptastrea purpurea*
Transverse coral	-	*Leptastrea transversa*
Rice coral	ʻĀkoʻakoʻa	*Montipora capitata* (=*verrucosa*)
Blue rice coral		*Montipora flabellata*
Branching rice coral		*Montipora incrassata*
Sandpaper rice coral	Koʻa	*Montipora patula*
Porkchop coral	-	*Pavona duedeni*
Maldive coral	-	*Pavona maldivensis*
Corrugated coral	ʻĀkoʻakoʻa	*Pavona varians*
Antler coral	-	*Pocillopora eydouxi*
Cauliflower coral	Koʻa	*Pocillopora meandrina*
False lichen coral	-	*Porites c.f. bernardi*
Finger coral	Pōhaku puna	*Porites compressa*
Lobe coral	Pōhaku puna	*Porites lobata*
Hump coral	-	*Porites lutea*
Plate-and-pillar coral	-	*Porites rus*

Common Name	Hawaiian Name	Scientific Name
Hawaiian sergeant	Mamo	*Abudefduf abdominalis*
Achilles tang	Pākuʻikuʻi	*Acanthurus achilles*
Ringtail surgeonfish	Pualu	*Acanthurus blochii*
Eyestripe surgeonfish	Palani	*Acanthurus dussumieri*
Whitebar surgeonfish	Māikoiko	*Acanthurus leucopareius*
Brown Surgeonfish	Māʻiʻiʻi	*Acanthurus nigrofuscus*
Bluelined surgeonfish	Maiko	*Acanthurus nigroris*
Orangeband surgeonfish	Naʻenaʻe	*Acanthurus olivaceus*
Thompson’s surgeonfish	-	*Acanthurus thompsoni*
Convict tang	Manini	*Acanthurus triostegus*
Smalltoothed jobfish	Wahani	*Aphareus furca*
Green jobfish	Uku	*Aprion virescens*

Common Name	**Hawaiian Name**	**Scientific Name**
Stareye parrotfish	Pōnuhunuhu	*Calotomus carolinus*
Hawaiian whitespotted toby	-	*Canthigaster jactator*
Barred jack	Ulua	*Carangoides ferdau*
Island jack	Ulua	*Carangoides orthogrammus*
Giant trevally	Ulua aukea	*Caranx ignobili*
Bluefin trevally	Ōmilu	*Caranx melampygus*
Potter's angelfish	-	*Centropyge potteri*
Peacock grouper	Roi	*Cephalopholis argus*
Multiband butterflyfish	-	*Chaetodon multicinctus*
Hawaiian morwong	Kīkākapu	*Cheilodactylus vittatus*
Spectacled parrotfish	Uhu ʻahuʻula	*Chlorurus perspicillatus*
Bullethead parrotfish	Uhu	*Chlorurus spilurus*
Agile chromis	-	*Chromis agili*
Chocolate-dip chromis	-	*Chromis hanui*
Oval chromis	-	*Chromis ovalis*
Blackfin chromis	-	*Chromis vanderbilti*
Threespot chromis	-	*Chromis verater*
Goldring bristletooth	Kole	*Ctenochaetus strigosus*
Mackerel scad	ʻōpelu	*Decapterus macarellus*
Bird wrasse	Hinālea iʻiwi	*Gomphosus varius*
Ornate wrasse	Lāʻō	*Halichoeres ornatissimus*
Blacktail snapper	Toʻau	*Lutjanus fulvus*
Bluestriped snapper	Taʻape	*Lutjanus kasmira*
Black durgon	Humuhumu ʻeleʻele	*Melichthys niger*
Bigeye emperor	Mū	*Monotaxis grandoculis*
Yellowstripe goatfish	*Wekeʻā*	*Mulloidichthys flavolineatus*
Yellowfin goatfish	Weke ʻula	*Mulloidichthys vanicolensis*
Paletail unicornfish	Kala lōlō	*Naso brevirostris*
Sleek unicornfish	Kala lōlō	*Naso hexacanthus*
Orangespine unicornfish	Umaumalei	*Naso literatus*
Arc-eye hawkfish	Pilikoʻa	*Paracirrhites arcatus*
Goldsaddle goatfish	Moāno ukali	*Parupeneus cyclostomus*
Island goatfish	Munu	*Parupeneus insularis*
Manybar goatfish	Moāno	*Parupeneus multifasciatus*
Sidespot goatfish	Malu	*Parupeneus pleurostigma*
Whitesaddle goatfish	Kūmū	*Parupeneus porphyreus*
Bright-eye damselfish	-	*Plectroglyphidodon imparipennis*
Blue-eye damselfish	-	*Plectroglyphidodon johnstonianus*
Regal parrotfish	Lauia	*Scarus dubius*

Common Name	Hawaiian Name	Scientific Name
Palenose parrotfish	Uhu	*Scarus psittacus*
Ember parrotfish	Uhu ʻeleʻele	*Scarus rubroviolaceus*
Pacific gregory	-	*Stegastes fasciolatus*
Hawaiian gregory	-	*Stegastes marginatus*
Old woman wrasse	Hinālea luahine	*Thalassoma ballieui*
Saddleback wrasse	Hinālea	*Thalassoma duperrey*
Yellow tang	Lauʻipala	*Zebrasoma falvescens*

Note on names:
This report uses English common names to allow for easier reading for those not familiar with scientific names. English common names were selected for use over Hawaiian names to avoid confusion since a single Hawaiian name can often apply to multiple species. Hawaiian names were obtained primarily from three sources: Randall (2007) for fish, and Hoover (1998) and Bernice P. Bishop Museum for invertebrates.

Table of Contents

Cover Image: A survey diver hangs in the water above a reef inside the Kahoʻolawe Island Reserve.

1.0 Summary

The Island of Kahoʻolawe has a complex history that has resulted in a century of sparse human occupation and light exploitation of its coral reef resources. For much of its modern history, the island has been off-limits to most fishing, making it a *de facto* marine reserve, and therefore less impacted by overharvest than other more populated areas of Hawaiʻi. In 1990, the Kahoʻolawe Island Reserve (hereafter, the Reserve) was established for the preservation of Kahoʻolawe's archaeological, historical and environmental resources, rehabilitation, re-vegetation, habitat restoration and education.

At the invitation of the Kahoʻolawe Island Reserve Commission (KIRC), The Nature Conservancy's marine monitoring team joined its partners at UH's Fisheries Ecology Research Lab and the KIRC to conduct surveys of Kahoʻolawe's marine resources in 2015. These surveys were intended to update and extend the existing body of coral reef information and provide a current baseline condition from which the effectiveness of management actions could be assessed. Data on benthic and fish assemblages were collected at 50 randomly-selected sites around Kahoʻolawe and compiled with historical data dating back to 1981.

The benthic assemblage significantly varied with wave exposure. Exposed reefs were dominated by robust and encrusting corals whereas sheltered reef areas had higher coral species diversity and higher diversity of colony morphology. Sheltered reefs tended to be more heavily affected by terrestrial-derived sediment, although the impact of sediment on the assemblage structure was complex. Over the past three decades, coral cover appears to have increased on sheltered reefs, while remaining relatively stable on exposed reefs.

The fish assemblage was dominated by surgeonfishes, snappers, parrotfishes and groupers. Invasive fishes were abundant, and while the effect of these invasive fish on native species inside the Reserve is currently unknown, growing scientific evidence suggests the negative impacts of these species in Hawaiʻi are likely small. The fish assemblage showed a strong spatial pattern: biomass was highest on the west side of the Reserve (farthest from Maui) and decreased to the east (nearest to Maui). The drop in biomass was associated primarily with a disproportionally large decrease in the biomass of target fishes, or those species most prized by fishers. Spatial variability in habitat and water quality, preferential selection of the Reserve's western reefs by large fish, depressed regional fish stocks, and legal fishing along the Reserve boundary were investigated and found to be inadequate explanations, while fishing within the Reserve, and most likely illegal poaching, was determined to be the most likely cause of the observed spatial pattern.

Climate change is likely the most significant long-term threat facing Kahoʻolawe's nearshore reefs. Reducing local stressors such sediment erosion and potential damage from human use, as well as ensuring fishery harvests are sustainably managed both within the Reserve and at the county or state scale, would likely increase the resilience of the Reserve's reefs to the effects of climate change.

2.0 Introduction

Hawaiian reefs provide culture, food, commerce, and recreation to residents and visitors alike, yet despite their importance, Hawaiʻi's nearshore marine environment suffers from pollution, overfishing, invasive species, and over-development, particularly around the more populated areas of the state (Friedlander *et al.* 2008, Williams *et al.* 2008, Friedlander *et al.* 2013).

The island of Kahoʻolawe has a complex history that has resulted in a century of sparse human occupation and light exploitation of its coral reef resources. Archeological evidence suggests that Hawaiians came to Kahoʻolawe as early as 400 A.D., settling in small fishing villages along the island's coast (King 1993). Following western contact, the island was briefly used as a penal colony and, for nearly a century, for sheep and cattle grazing (1858-1941). In 1942, the island was used as a bombing range by the U.S. Navy, an activity that continued until 1990 (KIRC 2014). Overgrazing and aerial bombing destroyed vegetation, promoting erosion which continues to be a threat to Kahoʻolawe's nearshore marine ecosystems. During the military bombing era and until it was turned over to the Kahoʻolawe Island Reserve Commission (KIRC), the island was off-limits to fishing, making it a *de facto* marine reserve (Dames & Moore 1997)[1].

In 1993, the Kahoʻolawe Island Reserve (hereafter, the Reserve) was placed under the administration of the KIRC, which was established for the preservation of Kahoʻolawe's archaeological, historical and environmental resources, rehabilitation, re-vegetation, habitat restoration, and education (Dames & Moore 1997). Currently only limited take of marine life is permitted for cultural, spiritual, and subsistence purposes and all other fishing (including bottom fishing), ocean recreation, commercial and/or any other activities are strictly prohibited (or highly regulated[1]) within the Reserve. Access to the Reserve is highly restricted because of the continued presence of unexploded ordnance, as well as for the protection of marine resources. As a result of this history of intensive restrictions on fishing, the fisheries resources around Kahoʻolawe are less impacted by overharvest than those of other more populated areas of the state.

This is not to say that the reefs are in pristine condition, however. In many areas, sediment from the eroded landscape is a significant threat to the Reserve's nearshore reefs. Other potential threats include existing and potential introductions of marine invasive species, runoff of pollutants, and illegal harvest (poaching). In locations where human access and use is permitted, there are also concerns regarding the effect of authorized resource extraction.

A number of previous marine resource surveys conducted around Kahoʻolawe have documented a diverse coral reef ecosystem (Kawamoto *et al.* 1981, Cox *et al.* 1995, Stanton 2005, 2006, 2007, 2008, Friedlander *et al.* 2010), including a higher standing stock of reef fishes compared to other locations in Hawaiʻi.

[1] Limited trolling (2 days a month) was permitted starting in 1968 (Dames & Moore 1997), and limited fishing activity is still permitted by the KIRC with appropriate approvals and permits.

In 2009 and again in 2015, The Nature Conservancy's (TNC) marine monitoring team and its partner at UH's Fisheries Ecology Research Lab (FERL, Dr. Alan Friedlander) were invited to conduct surveys of Kahoʻolawe's marine resources to provide information on their status and condition. Results from the 2009 surveys have been published elsewhere (Friedlander *et al.* 2010).

This report focuses on the findings of the 2015 surveys, and is intended to update and extend the existing body of coral reef information available for the island of Kahoʻolawe. This information will also provide a current baseline condition from which the effectiveness of management actions implemented in accordance with the Reserve's Ocean Management Plan can be assessed.

2.1 Description of Kahoʻolawe

Kahoʻolawe is a heavily eroded basalt island located approximately 11 km (7 mi) southwest of Maui across the ʻAlalākeiki Channel. At 116.5 km^2 (45 mi^2), it's the smallest of the eight main Hawaiian Islands. The Reserve is protected from northern swells by Molokaʻi and Maui Islands, but is exposed to southern swells.

The southern coast of Kahoʻolawe consists of steep cliffs with two large bays, Kamohio and Waikahalulu (Figure 1). Although this coastline receives the impact of strong waves, some protected habitats with high coral cover are found within these two large bays (Friedlander *et al.* 2010). Due to the often hazardous sea conditions, the Reserve's south-facing reefs are poorly studied. The surveys conducted by TNC and partners in 2009 (Figure 1, red circles) are currently the most comprehensive assessments available.

The western end of the island has two large beaches, Honokanaiʻa (Smuggler's Cove) and Keana a ke Keiki (Twin Sands). A wide, relatively shallow shelf with the remnants of Black Rock and Kuia Shoal extends offshore. This portion of the island experiences strong southern swell, and previous surveys have found low coral cover (Kawamoto *et al.* 1981, Cox *et al.* 1995, Stanton 2005, 2006, 2007, 2008, Friedlander *et al.* 2010).

The northern coast is characterized by low rocky cliffs, interspersed with numerous, small, silty pocket beaches. Numerous gulches incised along the coast funnel eroded soil onto a relatively shallow shelf that extends offshore. Turbidity is often high after periods of rain and when wave events disturb the sediment on the bottom. Normal trade winds can mobilize inshore sediment deposits moving them out of the bays and along the coast. Previous surveys have found diverse reefs with high coral cover (Kawamoto *et al.* 1981, Cox *et al.* 1995, Stanton 2005, 2006, 2007, 2008, Friedlander *et al.* 2010).

The eastern end of Kahoʻolawe includes a large bay, Kanapou Bay, that is often exposed to waves through the ʻAlenuihāhā Channel, which separates Maui from Hawaiʻi Island. Although wave disturbance can be high, coral communities in deeper water have been found to be relatively diverse with moderate coral cover (Cox *et al.* 1995, Stanton 2005, 2006, 2007, 2008, Friedlander *et al.* 2010).

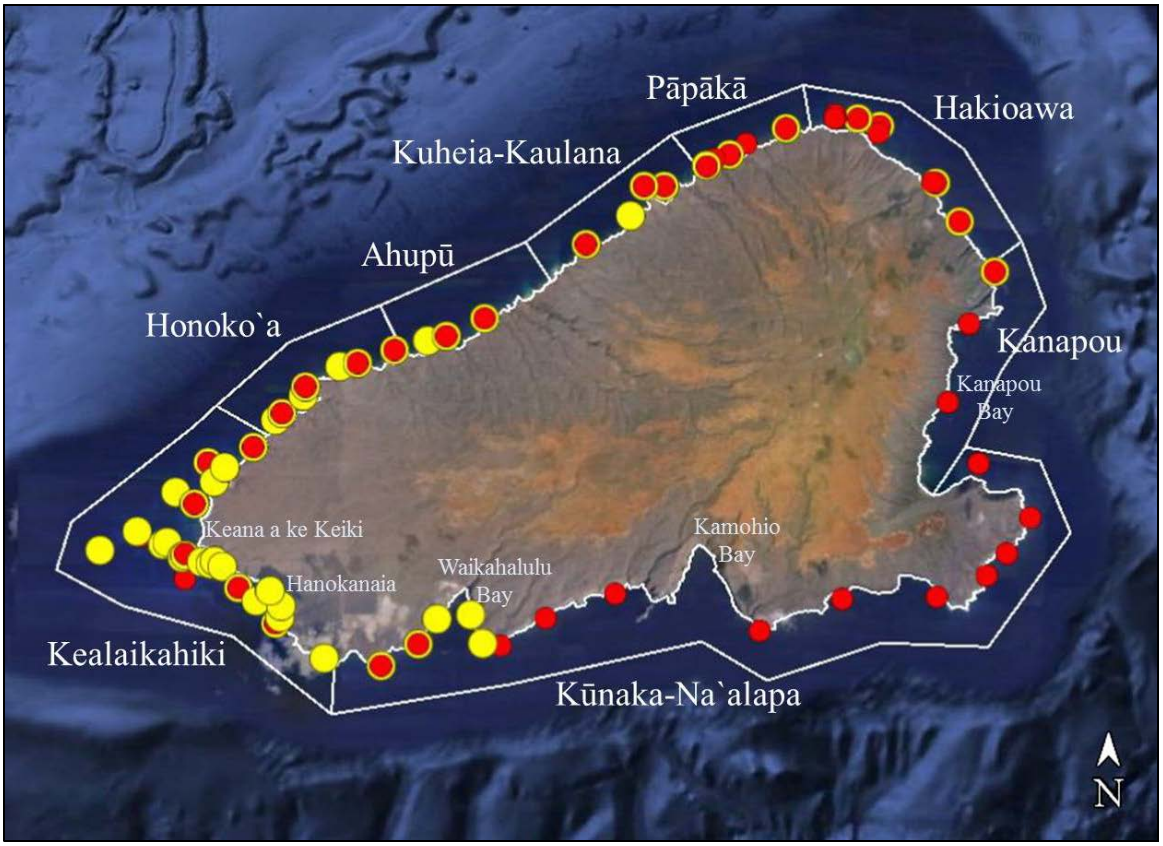

Figure 1. Locations of coral reef survey sites on Kahoʻolawe for 2009 (red) and 2015 (yellow). The white lines and names represent Kahoʻolawe's *ʻili* (subdivision of an ahupuaʻa).

3.0 Survey Methods

3.1 Survey Sites

The survey area encompassed the entire shallow water reefs around the island of Kahoʻolawe, extending from approximately 3 m to 20 m (~10-60-ft) deep and fringing approximately 47 km (27.2 mi) of coastline.

From June 15-19, 2015 TNC's marine monitoring team and FERL partners surveyed 50 randomly-selected[2] sites within the survey area (Figure 1). Due to hazardous sea conditions during the time of the surveys, surveys along the south and southeast coastline (within the *ʻili* of Kunaka/Naʻalapa and Kanapou) were limited in number and restricted primarily to the western end of the Kunaka/Naʻalapa *ʻili* (Figure 1). Twenty of the 2015 surveys sites were conducted at the same GPS coordinates as sites surveyed by teams in 2009, and while no permanent transect markers were installed in 2009, for the purposes

[2] Random sites were selected in order to get an unbiased measure of the community across the survey area. Using a non-random site selection method, such as selecting sites known to have high fish abundance, would provide a skewed or biased assessment of the Reserve's coral reef community.

of this report, it was assumed these were the same sites as those previously surveyed. Due to the restricted spatial extent of the 2015 surveys compared to the 2009 surveys, the re-surveyed sites were used to examine potential changes in the reef community between 2009 and 2015. The distribution of sites by *‘ili*, is provided in Table 1. Appendix A contains the positional information and available site metadata (e.g., depth, rugosity, date surveyed etc.) for all 50 survey sites in both 2009 and 2015.

Several sites of specific interest were identified by KIRC natural resource staff, including two sites where human access is permitted (Honokanai‘a and Hakioawa) and three sites with similar reef structure where access is not permitted (Honokoa, Kuikui and Pāpākāiki). Additionally, Stanton (2005, 2006, 2007, 2008) identified five "access" (Hakioawa, Kuheia, Maka‘alae, Honokoa, and Honokanai‘a) and five closely paired "control" sites (Lae ‘O Kuikui, Pāpākāiki, ‘Oawapalua Laepaki and Honukanaenae) where access was not permitted. These ten sites were re-visited as part of the 2009 and 2015 survey efforts, and were used to assess the potential effects of human access on the reef community using a paired design (Table 2).

3.2 Data Collection Methods

Sites were surveyed by divers deployed from small boats. The survey teams navigated to each predetermined site using a Garmin GPS unit. Once on site, the survey team descended directly to the bottom, where divers established two transect start-points approximately 10 m apart. From each start-point, divers deployed a separate 25 m transect line along a predetermined compass bearing, with the two transect lines running parallel to the other. If the bearing resulted in a large change in depth, the transects were altered to follow the depth contour. Specific survey methods are briefly discussed below. For a full description of the fish and benthic survey methods used, see Appendix B.

Table 1. Number of survey sites in 2009 and 2015 by *‘ili*. The designation of sheltered/exposed *‘ili* were determined based Hawai‘i’s dominant swell regime and supported by analysis of the 2015 benthic cover data (see section 4.1)

	2009	**2015**
Sheltered	26	22
Ahupū	2	3
Hakioawa	9	4
Honoko‘a	4	7
Kanapou	3	1
Kuheia-Kaulana	3	4
Pāpākā	5	3
Exposed	20	28
Kealaikahiki	8	23
Kūnaka-Na‘alapa	12	5
Total Surveys	**46**	**50**

Table 2. Ten paired sites used to examine potential effects of human access on the Reserve's coral reefs. These sites were originally surveyed by Stanton (2005).

Access	Control
Honokanaiʻa	Honukanaenae
Honokoa	Laepaki
Makaʻalae	ʻOawapalua
Kuheia	Pāpākāiki
Hakioawa	Lae ʻO Kuikui

Benthic Cover

Photographs of the bottom were taken every meter along one 25 m transect line at each survey site using a Canon G12 or S110 camera mounted on a 0.8 m long 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 later analyzed to estimate the percent cover of coral, algae, and other benthic organisms present.

Each selected photograph was imported into Adobe Photoshop CS5 where its color, contrast, and tone were auto-balanced to improve photo quality prior to analysis. Photos were analyzed using the Coral Point Count program with Excel extension (CPCe) developed by the National Coral Reef Institute (Kohler and Gill 2006). Using CPCe, 30 random points[3] were overlaid on each digital photograph, and the benthic component under each point was identified to the lowest possible taxonomic level. Additionally, if a random point fell on a coral showing obvious paling or bleaching, the condition was noted. Bleached corals can be difficult to identify in photographs, so the estimate of bleaching from this analysis represents a conservative estimate of the actual level of coral bleaching that was occurring during the surveys. All photographs were processed by the same person 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.

Rugosity

To estimate the topographic complexity of the bottom at each site, an index of rugosity was calculated along the first 10 meters of one 25 m 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 relief, and

[3] The number of points analyzed on each photograph (30 points) and the number of photographs at each site (20 photographs) were selected after determining that these values represented the optimal effort to achieve the greatest power to detect statistical differences.

increasing values represent more topographically complex substratum. Rugosity was collected at nearly all survey sites in 2015 (Appendix A).

Fish

All fish surveys were conducted by trained and calibrated divers. Divers slowly deployed the parallel 25 m transect lines while identifying to species and sizing 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 each of the two 25 m transects. Divers took between 10 and 15 minutes to complete each fish survey. Using fish length and published size-to-weight conversions, fish biomass (i.e., weight of fish) was calculated for each size class of fish for each species and summed to obtain total fish biomass.

This method closely corresponds with that used by Friedlander and colleagues for the "Fish Habitat Utilization Study" (FHUS) as well as other work in Hawai‘i, and therefore provides comparable data. Details of Friedlander and colleagues' method are available in a number of publications (Friedlander *et al.* 2006, 2007a, 2007b). The FHUS was conducted in the early 2000s and represents a comprehensive view of sites across a range of management areas in Hawai‘i. In addition to the FHUS data, additional comparisons can be made with other sites at which TNC's marine monitoring team has collected fish information. Data from these additional TNC sites were collected between 2009 and 2015, and often include multiple annual survey events at a location. Together, these data comprise a formidable spatial and temporal comparative data set for fish assemblages.

Following the completion of the transect surveys, a 5-minute timed swim was conducted at a subset of survey sites (30 sites) during which the two fish surveyors swam approximately 5 m apart, identifying to species and sizing into 5 cm bins all target[4] fish larger than 15 cm within or passing through a 5 m wide belt (centered on the surveyor) that extended from the ocean bottom to the surface. During the timed swim, surveyors communicated with each other to ensure that each fish was recorded by only one surveyor (*i.e.*, fishes were not double counted), effectively creating a single 10 m wide belt transect.

Timed swims were initiated along the same compass bearing as the 25 m transects and shifted as necessary to maintain a constant water depth. If short stretches of increased water depth or soft bottom habitat were encountered, surveyors quickly traversed them and continued to survey. If longer stretches of soft bottom or a significant change in depth were encountered, divers altered course to maintain a relatively constant depth and to avoid swimming into extensive areas of soft bottom habitat.

<u>3.3 Previous Kaho‘olawe Coral Reef Surveys</u>

In 2009, TNC, the Hawai‘i Cooperative Fishery Research Unit, and KIRC, conducted resource surveys at 46 sites around the island of Kaho‘olawe (Table 3). The results of these surveys have been published elsewhere (Friedlander *et al.* 2010), but the data have

[4] For a list of species that comprise "target fish" for this report, see table B.1 in Appendix B.

been incorporated into this report to examine temporal trends and improve the spatial resolution of the analysis. Many of the surveyors involved in the 2015 surveys were also involved in 2009, and all divers involved in both surveys were calibrated amongst themselves to reduce observer variability, making the 2009 and 2015 datasets directly and easily comparable.

Between 2004 and 2008, the University of Hawai‘i's Marine Option Program (MOP) conducted twice-annual surveys (generally March and August) at 10 sites in the Reserve (Stanton 2005, 2006, 2007, 2008). In both 2009 and 2015, these locations were resurveyed, but due to differences in the survey methods used, the fish datasets were not easily comparable. However, the MOP benthic data were comparable after some data reconciliation (see below).

Between 1998 and 2003 (exact date unknown), the Coral Reef Assessment and Monitoring Program (CRAMP) established and surveyed a monitoring site at Hakioawa (Friedlander *et al.* 2003). With some data reconciliation (see below), the CRAMP surveys produced both fish and benthic data that are comparable with TNC and partner's 2009 and 2015 surveys.

In 1993, researchers form the Hawai‘i Institute of Marine (HIMB) and the National Marine Fisheries Service conducted fish and benthic surveys at 10 sites primarily along the leeward coast of the island (Cox *et al.* 1995). The methods used in the 1993 surveys did not collect comparable fish data, but with some data reconciliation, the benthic data collected during those surveys was comparable with the 2009 and 2015 surveys.

In 1981, 27 transects spread over six sites were surveyed as part of a project to examine the effects of sedimentation (Kawamoto *et al.* 1981). Again, due to differences in methods, fish data were not directly comparable with TNC and partner's 2009 and 2015 datasets, but coral cover data were comparable.

Table 3. The number of sites surveyed (sheltered/exposed *‘ili*) by TNC and partners (2009 and 2015) and others (1981-2008) around Kaho‘olawe from 1981 to 2015.

Site Location	**1981[a]**	**1993[b]**	**2003[c]**	**2005-2008[d]**	**2009[e]**	**2015[f]**
Benthic	6 (5/1)	18 (10/8)	1 (1/0)	10 (8/2)	28 (14/14)	50 (22/28)
Fish	6 (5/1)	18 (10/8)	1 (1/0)	10 (8/2)	46 (26/20)	50 (22/28)
TOTAL	**6**	**18**	**1**	**10**	**46**	**50**

[a]Kawamoto *et al.* 1981
[b]Cox *et al.* 1995
[c]Friedlander *et al.* 2003
[d]Stanton 2005, 2006, 2007, 2008
[e]Friedlander *et al.* 2010
[f]This report

3.4 Data Analysis

All data from the 2015 surveys were entered into a custom Access database and checked for errors. In this report, all means are presented as the average ± the standard error of the mean (SEM). Standard parametric and non-parametric statistical approaches, as appropriate, were used to test for differences between years and location (exposed versus sheltered *‘ili*). In most cases, a multifactor ANOVA including sample year (2009 and 2015) and location (leeward/windward) was used to examine summary-level variables (*e.g.*, total fish biomass, total fish abundance, etc.). As necessary, fish biomass and abundance were log-transformed to correct skewness and heteroscedasticity. Tukey multiple comparisons were used to identify differences within significant factors. Multivariate analysis on the benthic and fish assemblages was conducted using the suite of non-parametric multivariate procedures included in the PRIMER statistical software package (Plymouth Routines In Multivariate Ecological Research). For a full description of the statistical methods, see Appendix B.

Data Reconciliation

During the 2009 surveys, fish data were collected using the same methods and in many cases the same dive teams, so no reconciliation was necessary prior to making comparisons with the 2015 survey data. However, the 2009 benthic data needed to be reconciled because some benthic categories were defined differently by the photo-analysts. While lower taxonomic categories (*e.g.*, species, genera) for benthic organisms were often not directly comparable, higher taxonomic groups (e.g., coral, turf algae, crustose coralline algae [CCA], etc.) were. Therefore, temporal comparisons were restricted to broad taxonomic groups for benthic organisms. One notable exception was corals, for which comparable species-level data were available.

In most cases, fish data from the pre-2009 surveys could not be reconciled sufficiently for quantitative analysis, but qualitative comparisons were possible. While benthic methods varied between the pre-2009 and 2009-2015 surveys, the resulting data were sufficiently comparable at higher taxonomic levels. Qualitative species level comparisons were also possible within some benthic groups, notably corals. To improve the analysis, sites were grouped by sheltered and exposed *‘ili* (Table 1). For exposed *‘ili*, only sites within the *‘ili* of Kealaikahiki were used in the analysis because pre-2009 surveys did not have sites in the Kūnaka-Na‘alapa *‘ili*.

4.0 Results and Discussion

4.1 Benthic Assemblage

2015 Survey

Nineteen species of coral were observed within the survey area with the lobe coral (*Porites lobata*) and sandpaper rice coral (*Montipora patula*) comprising more than half of all coral cover (Table 4). Together, coral, turf algae (turf), and CCA accounted for >80% of Kaho‘olawe’s benthic cover.

The benthic assemblage significantly differed among the *‘ili* (ANOSIM; R=0.526; p=0.001). Two groups were identified, with the south and west facing *‘ili* of Kunaka/Na‘alapa and Kealaikahiki having a benthic assemblage typical of wave-exposed reefs and the remaining *‘ili* having benthic assemblage typical of less-exposed or sheltered reefs (Figure 2), which is consistent with expectations givens Hawai‘i’s dominant swell regimes and the shelter provided to Kahoolawe from northern swells by other islands (Figure 3).

Reef structure in Hawai‘i is strongly influenced by wave exposure (Storlazzi *et al.* 2005, Jokiel 2006). For most of the Hawaiian Islands, the largest and most frequent wave energy comes out of the north (Vitousek and Fletcher 2008), but due to shelter provided by Maui, Moloka‘i and Lāna‘i, wave exposure on Kaho‘olawe is primarily from the south (Figure 3), with secondary exposure from the east through the ‘Alenuihāhā Channel.

Wave-exposed reefs tend to be dominated by coral species with robust or low relief growth forms, such as lobe corals and various encrusting species, while more delicate growth forms are found with higher frequency on wave-sheltered reefs (Jokiel 2006). On

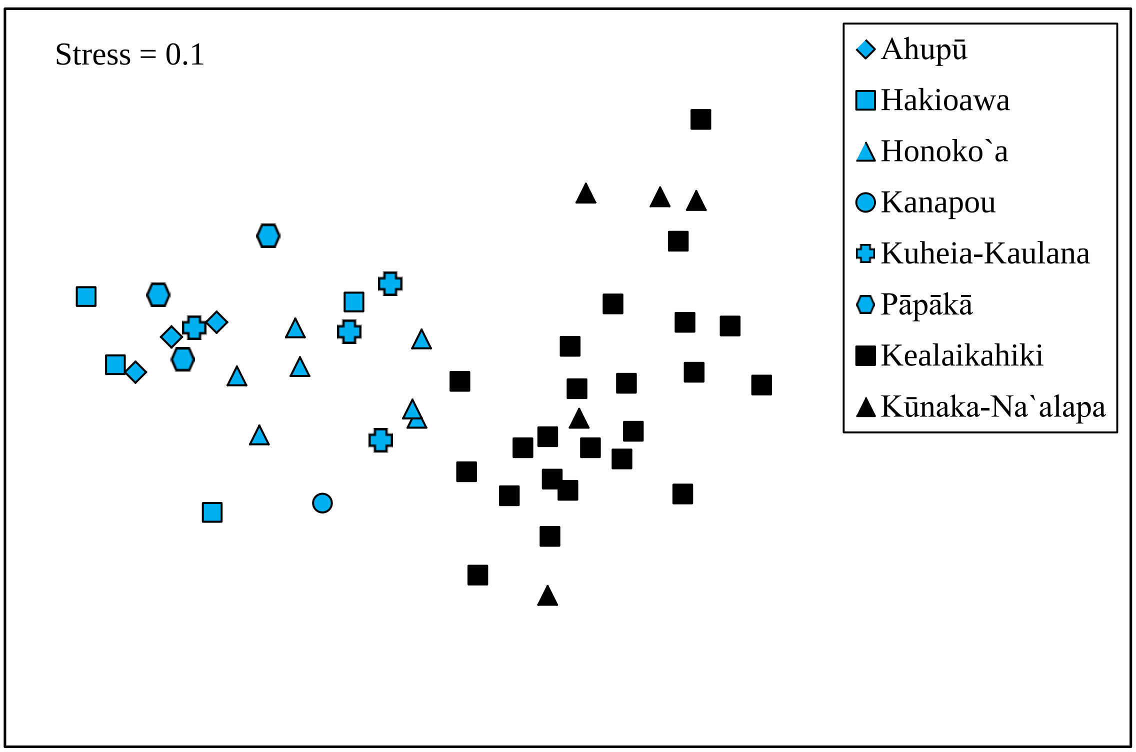

Figure 2. nMDS plot of 2015 survey sites by *‘ili*. Blue symbols represent sites in *‘ili* designated as sheltered, and black symbols represent sites in *‘ili* considered exposed, based on the composition of the benthic assemblage (see text). Plots were generated using benthic cover data for all organisms.

Table 4. Mean (± SEM) cover of benthic organisms at sheltered and exposed sites on Kaho‘olawe in 2015. Scientific names appear at the front of this report.

	Kaho‘olawe	**Exposed**	**Sheltered**
Coral	28.4 ± 3.5	10.2 ± 1.4	51.7 ± 3.7
Sandpaper rice coral	9.0 ± 1.1	5.6 ± 0.8	13.3 ± 1.9
Lobe coral	6.2 ± 1.4	0.3 ± 0.2	13.9 ± 2.4
Rice coral	4.3 ± 1.0	0.1 ± 0.1	9.7 ± 1.8
Finger coral	4.1 ± 1.0	0.1 ± 0.1	9.2 ± 1.7
Cauliflower coral	3.2 ± 0.4	3.8 ± 0.7	2.4 ± 0.4
Corrugated coral	0.6 ± 0.2	0	1.3 ± 0.4
Plate-and-pillar coral	0.4 ± 0.4	0	1.0 ± 1.0
Hump coral	0.2 ± 0.1	0	0.4 ± 0.3
Porkchop coral	0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.1
False lichen coral	0.1 ± 0.1	0.1 ± 0.1	<0.1
Maldive coral	0.1 ± 0.1	0	0.1 ± 0.1
Antler coral	<0.1	<0.1	0
Ocellated coral	<0.1	<0.1	<0.1
Blue rice coral	<0.1	0	<0.1
Bewick coral	<0.1	<0.1	<0.1
Crust coral	<0.1	<0.1	0
Oval mushroom coral	<0.1	0	<0.1
Transverse coral	<0.1	0	<0.1
Branching rice coral	<0.1	0	<0.1
Turf	51.8 ± 3.2	66.6 ± 3.0	33.0 ± 3.3
Macroalgae	0.3 ± 0.1	0.4 ± 0.2	0.2 ± 0.1
Dictyota spp.	0.1 ± 0.1	0.2 ± 0.2	0
Halimeda sp.	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Red Macroalgae	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Other Macroalgae	<0.1	<0.1	0
CCA	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Other	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Bluegreen algae	<0.1	<0.1	<0.1
Abiotic	15.4 ± 2.2	20.1 ± 3.3	9.5 ± 2.2
Sand	11.9 ± 2.0	14.6 ± 3.1	8.5 ± 2.1
Rubble	3.4 ± 1.1	5.3 ± 1.7	1.0 ± 0.3
Recently Dead Coral	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Pavement	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Depth (ft.)	30.3 ± 1.4	32.9 ± 1.9	27.1 ± 2.0
Rugosity	13.9 ± 1.0	12.3 ± 0.7	15.8 ± 1.9

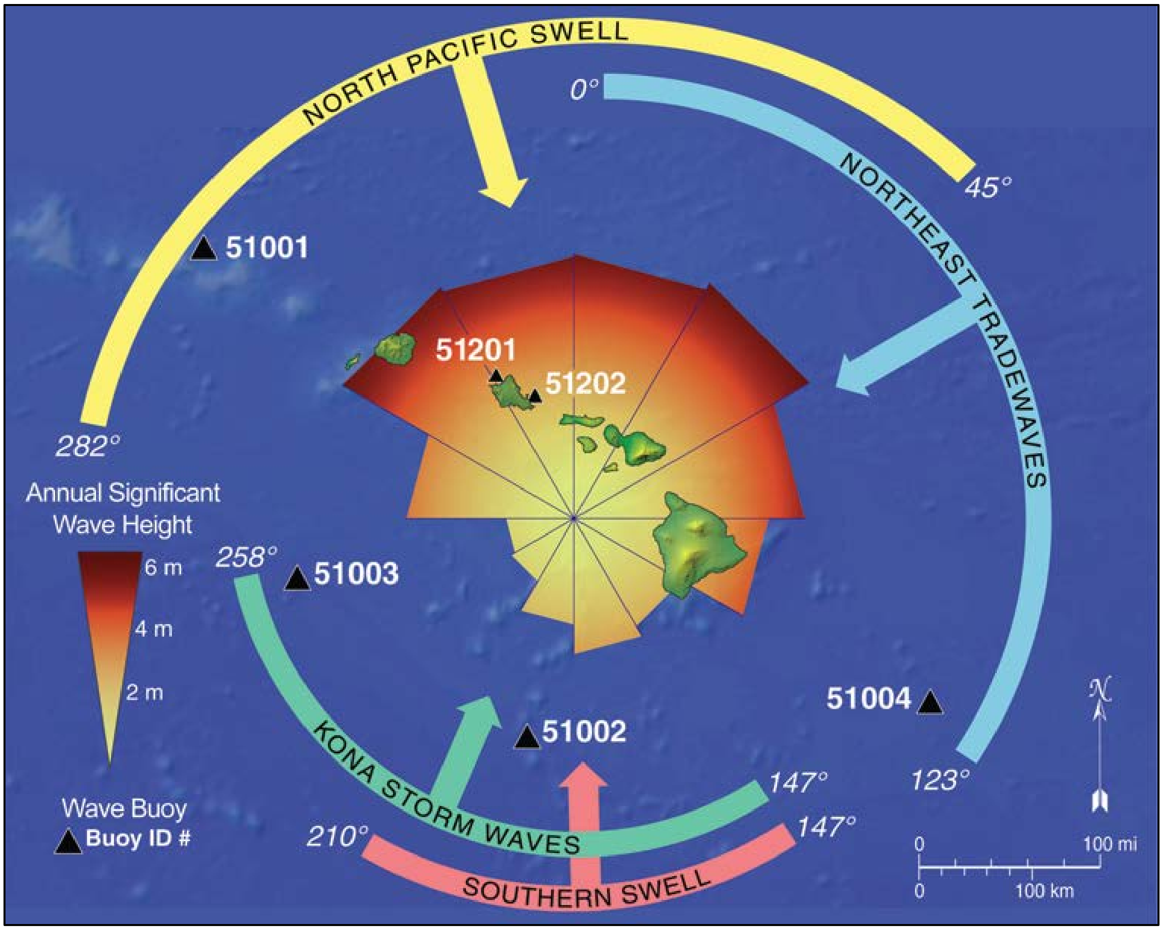

Figure 3. Hawai‘i’s dominant swell regimes (figure from Vitousek & Fletcher [2008]).

Kaho‘olawe, differences in the cover of four species of coral—sandpaper rice coral, finger coral (*Porites compressa*), rice coral (*Montipora capitata*), and lobe coral—explained nearly 60% of the difference observed between exposed and sheltered benthic assemblages (via SIMPER analysis). Sandpaper rice coral, lobe coral, and rice coral were more common and finger coral less common on exposed compared to sheltered reefs (Table 4), which is consistent with differences in wave exposure.

Coral cover on sheltered reefs (51.7 ± 3.7%) was five-times higher than on exposed reefs (10.2 ± 1.4%), and species diversity was 1.5 times greater at sheltered (17 species) compared to exposed (11 species) sites. Two wave resistant species, sandpaper rice coral and cauliflower corals (*Pocillopora meandrina*), were the dominant species on exposed reefs, while lobe coral and other encrusting species were present but not necessarily abundant. Rice coral has two wave-dependent growth forms in Hawai‘i; only the robust, encrusting form was found at exposed sites, whereas both the encrusting and more delicate branching forms were found on sheltered reefs (Plate 1). Exposed reefs also had higher cover of turf and abiotic substratum, especially rubble (Table 4).

The *'ili* identified here as sheltered and exposed (Table 1) differ somewhat from previous researchers (Friedlander *et al.* 2010) in that reefs in Kanapou *'ili* are consistent with a wave-sheltered reef. It should also be noted that in 2015, only one site was surveyed in the Kanapou *'ili*, but examination of the 2009 sites surveyed in Kanapou support its designation as a sheltered *'ili*. However, KIRC staff have noted that Hakioawa and Pāpākā *'ili* experience significant wave action as a result of "wrap around" swell coming through the ʻAlenuihāhā Channel. While these reefs undoubtedly receive periodic high wave events, benthic assemblage structure suggests these wave events are either not frequent and/or severe enough to result in a shift in species composition to one more consistent with a wave-exposed reef.

No significant difference in coral cover was found between the "access" and "control" sites (Paired t-test, t=1.07, p=0.363). While the paired sites had a wide range of coral cover, ranging from ~1% to ~75%, the difference between the pairs was not significant. Assemblage structure also did not differ (ANOSIM; R=-0.229; p=0.971), suggesting little effect of human access on the benthic assemblage. It should be noted, however, that potential effects of human access may be obscured by larger "regional" impacts (e.g., island-wide sedimentation), and access areas should continue to be closely monitored, especially as restoration actions continue to reduce other significant stressors.

Terrestrial-derived sedimentation was not directly monitored as part of this project, but it could be detected in benthic photos via its red-to-dark brown color (Plate 1). Of the fifty sites surveyed in 2015, twenty sites (40%) showed evidence (presence/absence) of terrestrial-derived sediment on the reef (Figure 4). These sites were more common on the wave-sheltered (north and east) sides of the island, which is not surprising considering waves are capable of suspending sediment off the bottom and facilitating transport off the reef. Additionally, vegetation on the east side of the island is less intact than on the west side, likely promoting more erosion along this sheltered coastline.

The potential effect of terrestrial sediment on coral has been well documented in the scientific literature (see Rogers 1990 and Fabricious 2005 for reviews), but findings on Kahoʻolawe appear to run counter to general expectations. On the exposed side of Kahoʻolawe, no difference in coral cover was found between sites with and without photographic evidence of terrestrial-derived sediment (Figure 5). In contrast, sites on sheltered reefs with terrestrial-derived sediment had higher coral cover on average than sites without (ANOVA; $F_{3,46}$=60.86; p<0.001).

Coral cover alone does not tell the entire story, however. Examining the entire benthic assemblage using a multivariate analysis finds significant differences between sites with and without terrestrial-derived sediment only for exposed reef (ANOSIM; R=0.701; p=0.001) and not for sheltered ones (ANOSIM; R=0.136; p=0.117). This seeming paradox arises from:

1) On exposed reefs, a shift occurs in the coral species composition from lobe and cauliflower corals to finger coral (almost perfectly offsetting each other) along with a large, concurrent increase in abiotic substratum, especially sand, at sites

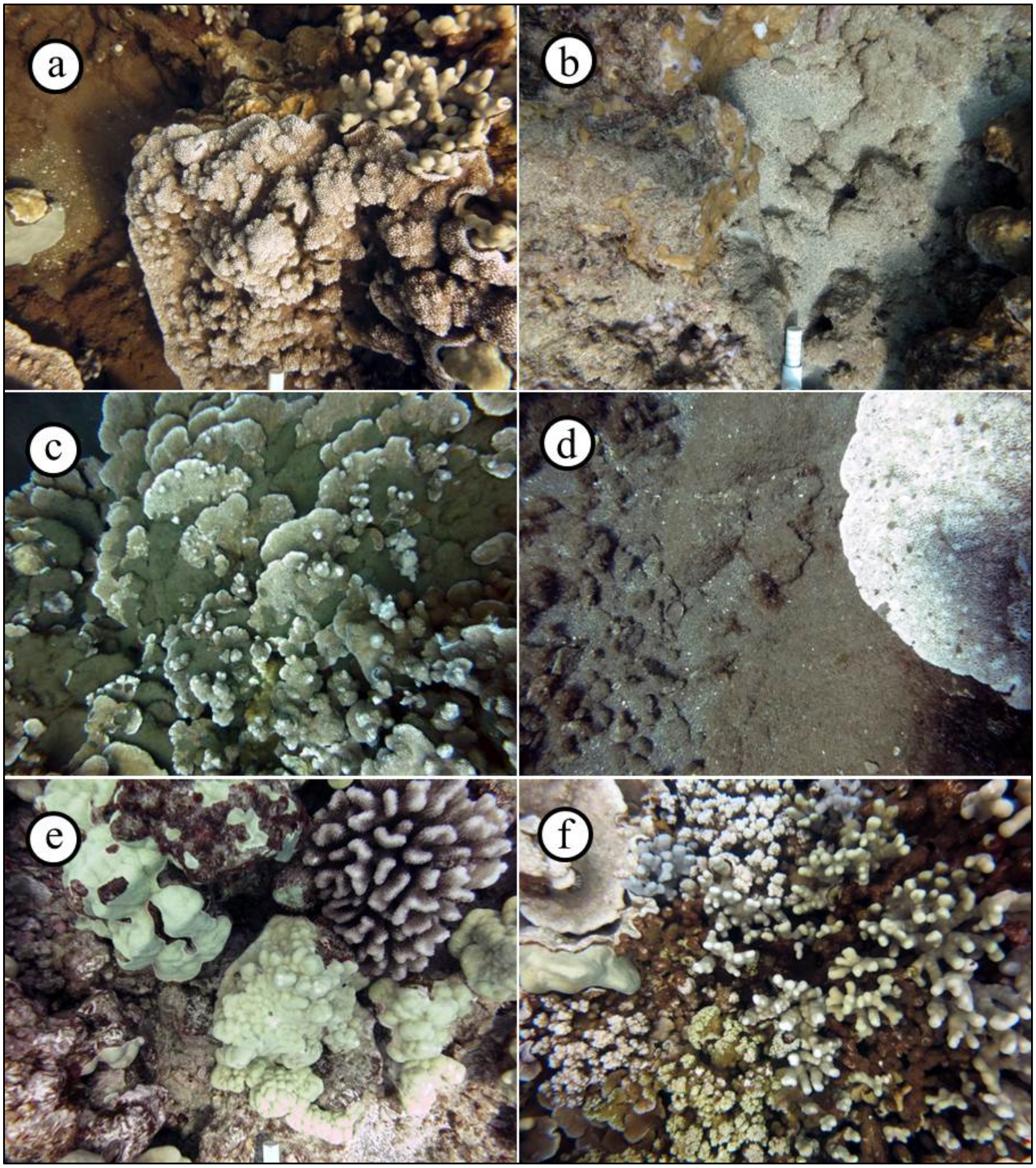

Plate 1. a) Brown-colored terrestrial-derived sediment on and around a rice coral colony (survey site: 2015-KIRC119). b) Marine sand near a sandpaper rice coral colony (2015-KIRC054). c) Terrestrial-derived sediment atop a rice coral colony (2015-KIRCHakioawa) d) A bleached rice coral colony surrounded by terrestrial derived sediment (2015-KIRC116a). e) Coral species typical on an exposed reef include low growing lobe corals and robust branching cauliflower corals (2015-KIRC068). f) Corals such as finger coral and the branching morphology of rice coral typically found on wave-sheltered reefs (2015-KIRC121).

with terrestrial-derived sediment. This results in no significant change in total coral cover (Figure 5), but a shift in both species composition and the amount of abiotic substratum.

2) At sheltered sites, small changes occur in the cover of numerous coral species, but there were notable increases in finger coral, the branching form of rice coral, and other rarer coral species. These small increases are not offset by concurrent decreases in lobe coral and cauliflower corals at sites with terrestrial-derived sediment (as was seen in the exposed sites with terrestrial sediments). Additionally, there is no significant change in non-coral taxa. This results in an increase in total coral cover (Figure 5) without significantly changing the species composition or the amount of abiotic substratum.

Examining these findings as a whole, it appears that sediment is not the primary stressor shaping the benthic assemblage structure on the Reserve's reefs. Sheltered sites without terrestrial-derived sediment were found primarily on the eastern and western edges of the island, abutting the dividing line between sheltered and exposed *'ili* (Figure 4). These reef areas likely represent transition zones from sheltered to exposed reefs, and they likely receive periodic high wave events that may be sufficient to partially reduce coral

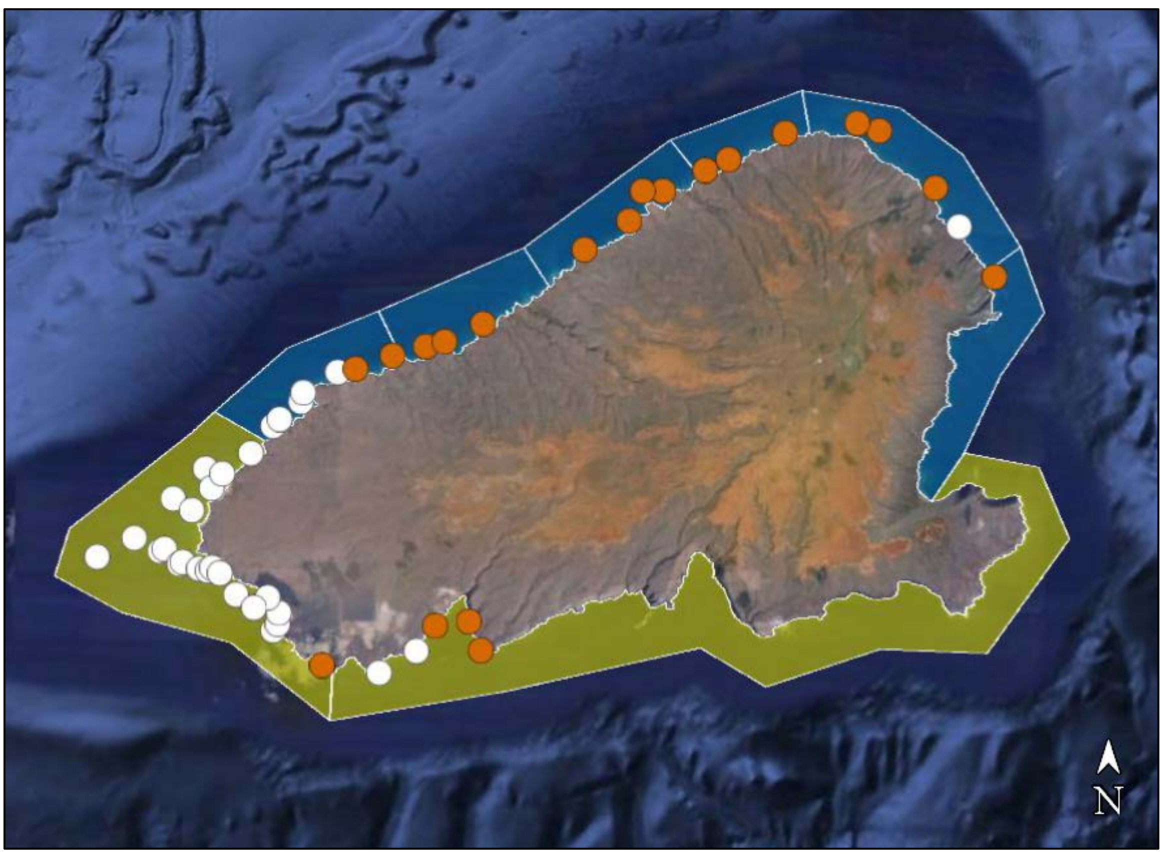

Figure 4. The presence (brown circles) or absence (white circles) of terrestrial-derived sediment at the 2015 Kaho'olawe survey sites. Exposed *'ili* are shaded green; sheltered *'ili* are shaded blue.

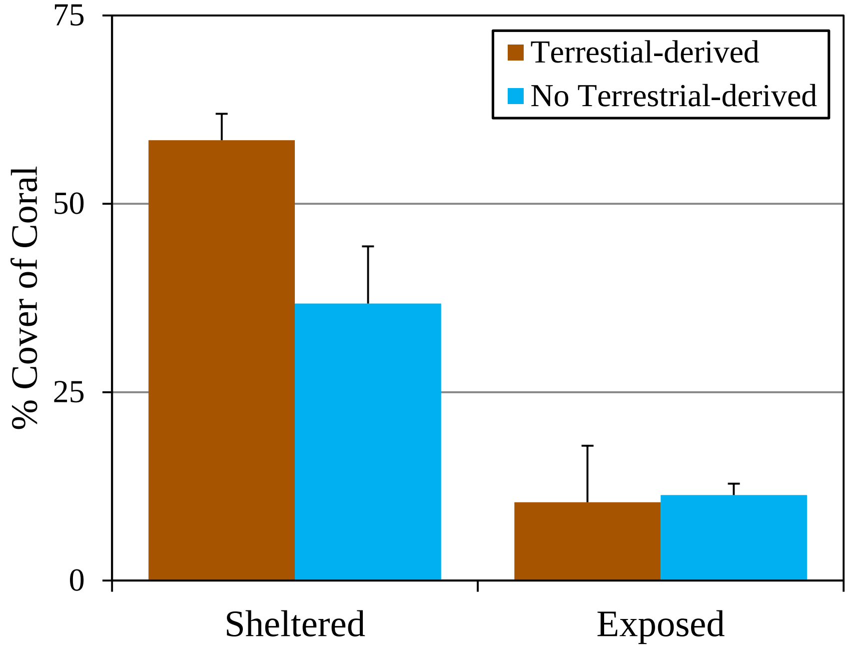

Figure 5. Coral cover on sheltered and exposed reefs with and without evidence of terrestrial-derived sediment.

cover. This explanation is supported by the site at the eastern edge of the sheltered "zone" which doesn't have terrestrial-derived sediment and clusters near the exposed sites in the nMDS plot, suggesting it has a high similarity with sites characterized by the exposed reef assemblage. Coral species expected on wave-sheltered reefs were more common at sites with terrestrial-derived sediment compared to those without. While terrestrial sediment could appear to be a "benefit" to the Reserve's reefs, this is likely not the case, and the higher coral cover and species diversity is more likely the result of a reduction in wave exposure than the presence of terrestrial-derived sediment. Wave action appears to be a primary structuring agent on the Reserve's reefs, which would be consistent with other findings in Hawaiʻi (Dollar 1982, Storlazzi *et al.* 2002, Jokiel *et al.* 2004).

Even so, these findings do not indicate that sediment is having *no* impact on Kahoʻolawe's reefs. Sediment effects on coral and other benthic organisms are well documented and cannot be dismissed within the Reserve, and it may indeed be the case that coral cover and diversity could be higher at these sheltered sites if they were not affected by sediments. While sediment effects appear smaller than wave action effects on the Reserve's benthic assemblage, this survey was not designed to directly examine these relationships and lacks the sensitivity to effectively do so. Additional, targeted research would be needed to separate wave action and sediment effects on Kahoʻolawe's benthic assemblage.

In 2014 and 2015, Hawaiʻi experienced two significant bleaching events. The 2014 event, which lasted from approximately July-December 2014, did not significantly effect

Table 5. Percent of coral tissue bleached (±SEM) by species for Kahoʻolawe and exposed/ sheltered reefs. For plate-and-pillar coral (*Porites rus*) and oval mushroom coral (*Fungia scutaria*), an insufficient number of observations did not allow an estimate of the tissue bleaching rate to be made, but bleached colonies were observed in photographs.

	Kahoʻolawe	**Exposed**	**Sheltered**
Rice coral	33.0 ± 6.4	51.5 ± 14.6	23.7 ± 5.5
Cauliflower coral	28.6 ± 5	20.7 ± 6.4	38 ± 7.6
Sandpaper rice coral	9.9 ± 4.6	28.9 ± 14.5	2.2 ± 0.8
Corrugated coral	6.3 ± 6.3	-	6.3 ± 6.3
Finger coral	3.1 ± 2.1	-	3.8 ± 2.5
Lobe coral	2.1 ± 0.6	1.7 ± 0.7	2.5 ± 1.1
Plate-and-pillar coral	Yes	-	-
Oval mushroom coral	Yes	-	-
% Coral Bleached	**8.3 ± 1.9**	**9.4 ± 3.1**	**6.8 ± 1.5**

corals on Maui (and presumably Kahoʻolawe). The second bleaching event occurred in the latter half of 2015 (approximately August-December 2015), and affected Maui more severely than the 2014 event. The State Department of Land and Natural Resources, Division of Aquatic Resources, estimated that over 50% of the corals at many sites around Maui bleached during the 2015 event, including at Makena, a location across the ʻAlalākeiki Channel from Kahoʻolawe.

Bleaching was observed in seven coral species during the 2015 surveys of Kahoʻolawe (Table 5). These survey were conducted in June 2015, between the peaks of the 2014 and 2015 bleaching events, when bleaching rates were presumably at their lowest. The overall bleaching rate oberved was low, and did not significantly vary with exposure (ANOVA; $F_{1,49}$=0.06; p=0.808) or sediment (ANOVA; $F_{1,49}$=0.07; p=0.792). Bleaching also did not significantly vary with human access (Paired t-test, t_4=0.79, p=0.472), but the sample size is small and given the high variability in the data, the power to detect a difference is low. Species-specific bleaching rates varied, with bleaching tolerant species (Marshall and Schuttenberg 2006), such as lobe coral, showing low rates of tissue bleaching, and more susceptible species, such as rice coral exhibiting up to 50% bleaching (Table 5). It is reasonable to believe that bleaching rates were significantly higher on Kahoʻolawe in the months following these surveys, however, which is supported by observations from the KIRC natural resources staff. Follow-up surveys to assess the potential impact of the 2015 bleaching event should be conducted to determine the current status of the coral assemblage.

Bleaching information was not collected as part of the 2009 surveys, but Stanton (2006, 2007, 2008) documented high incidence of bleaching from 2005-2007, especially for rice coral and cauliflower coral. Comparison of bleaching rates through time, however, is not possible because Stanton collected information on percent of colonies bleached (incidence), whereas the present surveys collected information on the percent of coral tissue bleached from benthic photos; these two data types are not comparable. However, qualitative comparisons find a similar pattern of bleaching with rice and cauliflower coral displaying the greatest amount of bleaching.

Temporal Trends (1981-2015)

Due to differences in photo-interpretation between the 2009 and 2015 surveys, we determined that direct comparisons could only reliably be made for higher taxonomic groups (*e.g.*, coral, macroalgae, turf, etc.) and for individual coral species. The 2009 survey effort used slightly different criteria for distinguishing other non-coral species, so their direct comparability with the 2015 dataset was uncertain. For surveys prior to 2009, we determined that only coral cover could be confidently compared with the 2009 and 2015 surveys.

At the 20 sites surveyed in 2009 and re-surveyed in 2015, there was no significant change in coral cover between survey years for sites on sheltered (t-test, t=1.23, p=0.245) or exposed (t-test, t=0.75, p=0.48) reefs within the Reserve (Figure 6).

Looking at the coral assemblage, no difference was found for exposed sites (ANOSIM; R=0.076; p=0.154), but a significant difference was found for sheltered ones (ANOSIM;

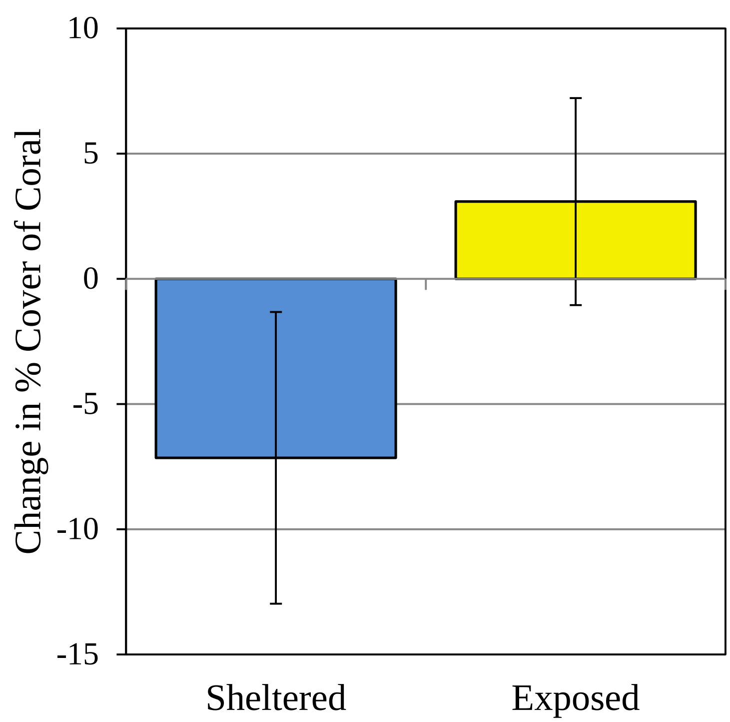

Figure 6. Average change in coral cover at 20 sites surveyed in 2009 and 2015. Change is not significantly different from zero for either sheltered or exposed reefs.

R=0.214.; p=0.006). However, the difference among the sheltered reef sites was driven primarily by a single site (Figure 7)[5], and the associated R-statistic is fairly low, suggesting the difference between the 2009 and 2015 communities are likely small and not ecologically meaningful. This conclusion is further supported when examining the contribution of the various benthic groups to the observed difference. No single species drives the change between years; instead, small changes across many coral species contribute equally to the observed shift in assemblage structure.

Looking back to 1981, the coral cover in exposed *'ili* showed no discernable trend (Pearson Correlation, r=0.239, p=0.569), but coral cover in sheltered *'ili* showed a significant increase (Pearson Correlation, r=0.851, p=0.004) over the same time period (Figure 8). The reason(s) for increased coral cover on sheltered reefs is not known, but possible explanations include:

(1) Improved water quality conditions, especially regarding sediment, have improved the habitat leading to better coral recruitment and growth. This explanation is

Figure 7. nMDS plot of the 20 sites surveyed in both 2009 (circles) and 2015 (triangles). Assemblage structure did not signfifcantly differ for exposed reef sites (black symbols), and a single site (circled in red) created a significant result for the sheltered sites (blue symbols). Deeper investigation showed no meaningful ecological difference between the 2009 and 2015 survey sites.

[5] Unlike other survey sites, this "unusual" site (2009-KIRC048) was primarily "silt" (82%) with coral heads interspersed. Removing it from the analysis results in R=0.194, p=0.029

consistent with the observed increase in coral cover on sheltered reefs, where the majority of sites with terrestrial-derived sediment occur.

(2) A series of "good" coral recruitment years. This explanation would potentially improve conditions island-wide, but the cover on the sheltered reefs appears to consistently increase, which is likely inconsistent with periodic “good” recruitment years. However, data on coral recruitment is not available at Kahoʻolawe so it is not possible to adequately assess coral recruitment over this time period.

(3) Potential methodological "errors" in the survey work. All survey approaches have "method-associated" error that can increase the variability of the data. While this type of "error" can result in what appears to be an increasing trend in the data—especially data conducted by different researchers at different times with different methods—given the length of the time series and the consistent trend, it is unlikely that this type of "error" adequately explains the increasing trend.

(4) Different surveyors and methods may have produced different results. This explanation is not consistent with the data because the same surveyors conducted the surveys from 2005-2008, during which the increasing trend continued.

While coral cover has increased on the north (sheltered) side of the Reserve, the lack of historical data for the south (exposed) side of the Reserve makes it difficult to draw a solid conclusion about these reefs. It appears that coral cover on the Reserve’s exposed reefs has not significantly changed over the past 35 years, which is itself a significant finding given that data from elsewhere in Hawaiʻi has documented large, significant declines in coral cover at many sites, including Puakō (Minton *et al.* 2012), Kaʻūpūlehu, (Minton *et al.* 2015) and several other west Hawaiʻi Island sites (Walsh *et al.* 2013), as well as numerous sites on Maui and Oʻahu (Rodgers *et al*. 2014). Overall, the reefs of Kahoʻolawe appear to have been stable or improving between 1993 and 2015.

4.2 Fish Assemblage

2015 Surveys

A total of 135 species representing 30 families of fishes were observed during the 2015 Kahoʻolawe surveys (Tables 6 and 7). More fish species were observed on exposed than sheltered reefs, 122 compared to 101 species, but the average number of species per survey site did not vary by exposure (t-test; T=0.49; df=38; p=0.625): 24.5 ± 0.7 and 25.5 ± 1.8 species/site for sheltered and exposed, respectively.

Five fish families contributed over 60% of the total fish biomass, with surgeonfish contributing the most on both exposed and sheltered reefs (Table 6). Surgeonfishes (Acanthuridae), parrotfishes (Scaridae) and wrasses (Labridae), three of the top five

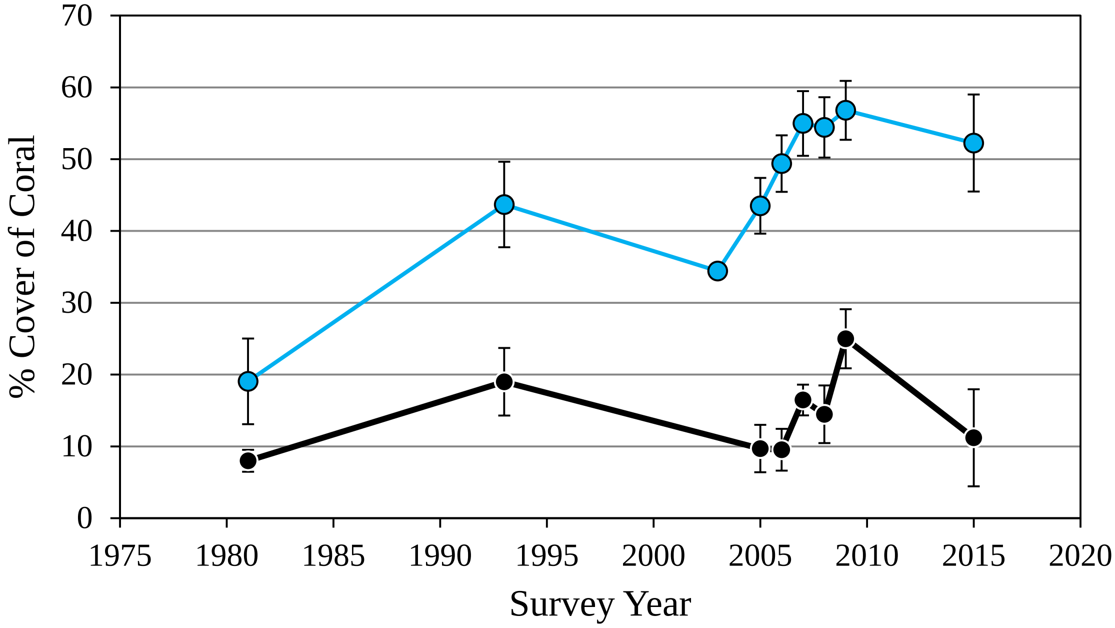

Figure 8. Change in coral cover at Kaho‘olawe from 1981-2015 for sheltered (blue) and exposed (black) *‘ili*. For reefs in sheltered *‘ili*, the increase was significant (Pearson Correlation, r=0.851, p=0.004), but no trend was found for exposed *‘ili* (Pearson Correlation, r=0.239, p=0.569). Data are from Kawamoto *et al.* (1981), Jokiel *et al.* (1995), Friedlander *et al.* (2003), Stanton (2005, 2006, 2007, 2008), Friedlander *et al.* (2010).

species by biomass, tend to be among the most common fish families on Hawaiian reefs. In contrast, the other two families, snappers (Lutjanidae) and groupers (Serranidae), tend to comprise a relatively small percentage of the total fish biomass on other Hawaiian reefs. High snapper biomass on Kaho‘olawe was associated with the smalltoothed jobfish (*Aphareus furca*), which accounted for 55% of all snapper biomass. Grouper biomass was comprised exclusively of the invasive peacock grouper or roi (*Cephalopholis argus*).

Families generally comprised of small bodied fish were most abundant on Kaho‘olawe’s reefs, with damselfish (Pomacentridae), surgeonfish, and wrasses (Labridae) being numerically dominant (Table 7). These three families dominated sheltered reefs, accounting for nearly 95% of all fish individuals observed, whereas they accounted for approximately 75% of the observed fish on exposed reefs.

Total fish biomass was significantly higher on Kaho‘olawe’s exposed (170.9 ± 30.3 g/m^2) compared to sheltered (100.6 ± 17.5 g/m^2) reefs (ANOVA; $F_{1,95}$=9.71; p=0.002). Fish abundance, however, did not significantly vary with exposure (ANOVA; $F_{1,95}$=2.95; p=0.089). Fish assemblage structure also significantly varied with exposure (ANOSIM; R=0.244; p=0.001), but the relatively small R-statistic suggests only a small, and likely not ecologically meaningful difference. A follow up SIMPER analysis identified no key

Table 6. Biomass (g/m^2) of fish by family on the sheltered and exposed coasts of Kahoʻolawe. Families are ordered by decreasing biomass for the entire island.

	Kahoʻolawe	**Sheltered**	**Exposed**
Surgeonfishes (Acanthuridae)	43.7 ± 7.3	35.5 ± 11.3	50.2 ± 9.6
Snappers (Lutjanidae)	23.8 ± 7.3	9.0 ± 3.7	35.5 ± 12.3
Parrotfishes (Scaridae)	12.5 ± 2.0	9.7 ± 2.5	14.7 ± 3.0
Groupers (Serranidae)	10.9 ± 1.7	13.7 ± 2.4	8.7 ± 2.2
Triggerfishes (Balistidae)	9.7 ± 2.0	5.5 ± 1.9	13 ± 3.1
Wrasses (Labridae)	7.0 ± 1.1	5.2 ± 1.5	8.4 ± 1.6
Emperors (Lethrinidae)	6.6 ± 1.8	4.8 ± 2.6	7.9 ± 2.4
Jacks (Carangidae)	4.6 ± 2.1	1.6 ± 0.8	6.8 ± 3.6
Squirrel/Soldierfishes (Holocentridae)	4.3 ± 1.4	1.4 ± 0.4	6.6 ± 2.3
Goatfishes (Mullidae)	3.8 ± 1.6	0.8 ± 0.3	6.1 ± 2.7
Butterflyfishes (Chaetodontidae)	3.2 ± 0.4	3.4 ± 0.4	3.2 ± 0.7
Damselfishes (Pomacentridae)	2.7 ± 0.8	2.2 ± 0.5	3.2 ± 1.3
Filefishes (Monacanthidae)	2.4 ± 0.8	3.4 ± 1.5	1.6 ± 0.7
Chubs (Kyphosidae)	2.0 ± 1.3	3.6 ± 2.9	0.7 ± 0.4
Requiem sharks (Carcharhinidae)	1.6 ± 1.6	0	2.9 ± 2.9
Hawkfishes (Cirrhitidae)	0.6 ± 0.1	0.4 ± 0.1	0.7 ± 0.1
Moorish Idol (Zanclidae)	0.3 ± 0.1	0.2 ± 0.1	0.4 ± 0.1
Trumpetfishes (Aulostomidae)	0.1 ± 0.1	0.2 ± 0.2	0.1 ± 0.1
Barracudas (Sphyraenidae)	0.1 ± 0.1	0	0.2 ± 0.2
Angelfishes (Pomacanthidae)	0.1 ± 0.1	<0.1	0.1 ± 0.1
Puffers (Tetraodontidae)	0.1 ± 0.1	0.1 ± 0	0.1 ± 0.1
Morwongs (Cheilodactylidae)	<0.1	0	0.1 ± 0.1
Porcupinefishes (Diodontidae)	<0.1	0	0.1 ± 0.1
Blennies (Blenniidae)	<0.1	<0.1	<0.1
Cardinalfishes (Apogonidae)	<0.1	<0.1	0
Boxfishes (Ostraciidae)	<0.1	0	<0.1
Coral crouchers (Caracanthidae)	<0.1	0	<0.1
Moray eels (Muraenidae)	<0.1	<0.1	<0.1
Eagle rays (Myliobatidae)	<0.1	0	<0.1
Milkfish (Chanidae)	<0.1	<0.1	0
Total Biomass	140.0 ± 19.1	100.6 ± 17.5	170.9 ± 30.3

Table 7. Abundance (individuals/125 m^2) of fish by family on the leeward and windward coasts of Kahoʻolawe. Families are ordered by decreasing biomass for the entire island

	Kahoʻolawe	**Sheltered**	**Exposed**
Damselfishes (Pomacentridae)	115.1 ± 10.9	117.6 ± 13.7	113.1 ± 16.5
Surgeonfishes (Acanthuridae)	60.3 ± 5.6	61.6 ± 8.4	59.4 ± 7.6
Wrasses (Labridae)	14.0 ± 0.9	10.8 ± 0.8	16.5 ± 1.4
Butterflyfishes (Chaetodontidae)	9.1 ± 1.1	9.3 ± 0.7	8.8 ± 2.0
Triggerfishes (Balistidae)	8.0 ± 1.5	4.1 ± 1.1	11 ± 2.3
Snappers (Lutjanidae)	7.3 ± 3.9	1.9 ± 0.5	11.5 ± 7
Parrotfishes (Scaridae)	6.5 ± 1.8	5.9 ± 1.2	6.9 ± 3.0
Morwongs (Cheilodactylidae)	4.4 ± 3.2	0	7.9 ± 5.7
Hawkfishes (Cirrhitidae)	3.7 ± 0.4	2.3 ± 0.3	4.8 ± 0.5
Goatfishes (Mullidae)	3.7 ± 1.5	1.1 ± 0.4	5.7 ± 2.6
Groupers (Serranidae)	2.4 ± 0.5	2.8 ± 0.4	2.1 ± 0.9
Squirrel/Soldierfishes (Holocentridae)	1.7 ± 0.5	1.0 ± 0.6	2.3 ± 0.7
Emperors (Lethrinidae)	1.6 ± 0.4	1.5 ± 0.4	1.6 ± 0.6
Jacks (Carangidae)	1.4 ± 0.8	0.3 ± 0.1	2.2 ± 1.4
Puffers (Tetraodontidae)	0.9 ± 0.1	1.1 ± 0.2	0.7 ± 0.1
Chubs (Kyphosidae)	0.6 ± 0.3	1.0 ± 0.7	0.2 ± 0.1
Filefishes (Monacanthidae)	0.5 ± 0.2	0.4 ± 0.2	0.6 ± 0.2
Moorish Idol (Zanclidae)	0.4 ± 0.1	0.2 ± 0.1	0.6 ± 0.2
Angelfishes (Pomacanthidae)	0.3 ± 0.1	0.2 ± 0.1	0.4 ± 0.2
Trumpetfishes (Aulostomidae)	0.2 ± 0.1	0.3 ± 0.2	0.1 ± 0.1
Blennies (Blenniidae)	0.1 ± 0.1	<0.1	0.1 ± 0.1
Moray eels (Muraenidae)	<0.1	<0.1	0.1 ± 0.1
Cardinalfishes (Apogonidae)	<0.1	<0.1	0
Coral crouchers (Caracanthidae)	<0.1	0	<0.1
Requiem sharks (Carcharhinidae)	<0.1	0	<0.1
Milkfish (Chanidae)	<0.1	<0.1	0
Porcupinefishes (Diodontidae)	<0.1	0	<0.1
Eagle rays (Myliobatidae)	<0.1	0	<0.1
Boxfishes (Ostraciidae)	<0.1	0	<0.1
Barracudas (Sphyraenidae)	<0.1	0	<0.1
Total Abundance	222.4 ± 12.5	197.8 ± 14.8	254.5 ± 19.5

species responsible for the observed difference between exposed and sheltered fish assemblages; instead, the difference was the result of small shifts in the relative biomass of many species (50+ species). This suggests that the observed difference in total fish biomass between exposed and sheltered reefs may be primarily the result of larger average size for individuals within a species rather than a shift in the assemblage structure from small- to large-bodied species. Comparing the average size of individuals for the nine species with highest biomass (for the tenth species, giant trevally or *ulua aukea* [*Caranx ignobili*], too few individuals were observed to make meaningful comparisons), individuals on exposed reefs were an average of 5% larger than those on sheltered reefs (Table 8). The only exceptions were green jobfish or *uku* (*Aprion virescens*) and blacktailed snapper or *to'au* (*Lutjanus fulvus*), which tended to have a smaller average size on exposed reefs.

Total fish biomass also did not differ between sites with and without terrestrial sediment for either exposed or sheltered reefs (ANOVA; $F_{3,46}=1.29$; $p=0.287$). No effect of "access" was found (Paired t-test, t=1.65, p=0.198), suggesting potential impacts from the allowed human access were not detectable, but given the small sample size and the variability of fish populations, this analysis likely had low power to detect differences. Access areas should continue to be closely monitored to detect any emerging effects.

Target fishes[6] refer to fish desirable for food, commercial activity, and/or cultural practices that reside in the habitats and depth ranges surveyed by TNC's marine monitoring team and its partners. Target fish biomass was highly variable (92.0 ± 13.7 g/m^2) and did not significantly vary with wave exposure (ANOVA; $F_{1,95}=0.03$; $p=0.854$). Surgeonfish were the most common target fish group (Figure 9), accounting for 41% of

Table 8. Average fish size (cm) for the ten species with greatest biomass on sheltered and exposed reefs.

	Sheltered		Exposed			
	n	**Size**	**n**	**Size**	**Δ (cm)**	**Δ (%)**
Green jobfish	12	60.4	31	47.7	-12.7	-21
Peacock grouper	148	29.5	74	32.2	2.7	9.2
Eyestripe surgeonfish	15	28	51	30.3	2.3	8.2
Ember parrotfish	78	29.3	104	36	6.7	22.9
Ringtail surgeonfish	45	25.1	54	25.6	0.5	2
Sleek unicornfish	9	22.2	23	25.7	3.5	15.8
Bigeye emperor	50	25.8	65	30.2	4.4	17.1
Bullethead parrotfish	78	22.5	40	23	0.5	2.2
Blacktail snapper	48	26.8	37	23.5	-3.3	-12.3
Giant trevally	2	35	5	102	67	191.4

[6] See Appendix B for a list of species that comprise the target fish for this report.

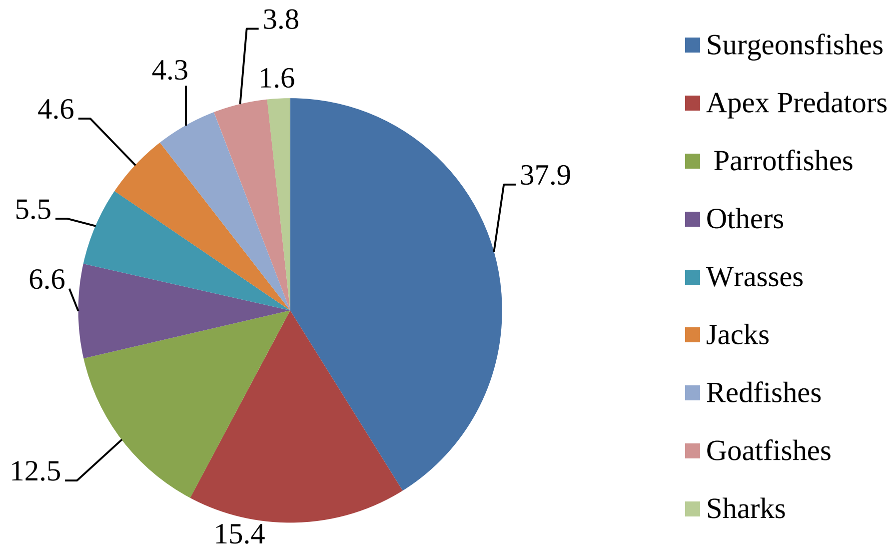

Figure 9. Target fish biomass (g/m^2) by target group for Kaho'olawe in 2015. See Appendix B for a complete list of species in each target fish group.

the total target fish biomass. Apex predators, rare on most Hawaiian reefs, contributed the next most to total target fish biomass (17%), and together with jacks and sharks, accounted for 23% of the target fish biomass. The absence of these three groups on many of Hawai'i's reefs has been attributed to high fishing pressure.

As with total fish biomass, target fish biomass showed no effect from terrestrial-derived sediment on both exposed and sheltered reefs (ANOVA; $F_{3,46}$=1.68; p=0.185) or those with human access (Paired t-test, t=2.21, p=0.114).

Prime spawners are large target fishes (>70% their maximum size) which are generally prized by fishers and tend to contribute disproportionately more to the total reproductive potential of the population than smaller individuals due to their greater egg and sperm production (*i.e.*, higher fecundity) and the higher survivorship of their larvae (Williams *et al*. 2008). Therefore, prime spawner biomass is a good indicator of fishing impacts (*e.g.*, as fishing pressure increases, the biomass of prime spawners is likely the first thing to decrease), and represents an important component of ecological function (*i.e.*, population breeding potential).

Prime spawner biomass in the Reserve was 37.7 ± 7.7 g/m^2, with a diverse assemblage contributing: 467 individual prime spawners were observed along survey transects, encompassing 37 species in nine fish families. Prime spawner biomass on exposed reefs was significantly higher than on sheltered ones (ANOVA; $F_{1,95}$=9.87; p=0.002), which is consistent with the finding that fish individuals were, on average, larger on the exposed compared to sheltered reefs (Table 8).

Prime spawner biomass showed no relationship with terrestrial-derived sediment (ANOVA; $F_{3,46}$=2.09; p=0.115), but did show a significant effect of human "access"

(Paired t-test, t=3.91, p=0.030). The effect, however, was not consistent with human access causing a negative impact; prime spawner biomass was significantly higher at "access" compared to "control" sites, a result that is difficult to interpret and should be viewed with caution given the small sample size.

Spatial Patterns within the Reserve

Total fish biomass, target fish biomass and prime spawner biomass were all highest on the west end of Kahoʻolawe, but also more variable (Figure 10), a finding consistent with that observed in 2009 (Friedlander *et al.* 2010). In 2015, <20% of the sites along the north and east coast of the Reserve had above average total fish (>140.0 g/m^2), resource fish (>92.0 ± 13.7 g/m^2), and prime spawner (>37.7 ± 7.7 g/m^2) biomass, compared to 50% of the sites in the westernmost *ʻili*. This pattern did not hold for non-target fish, where roughly half of all sites in all areas of the Reserve had above average non-target fish biomass, as would be expected.

While interesting, these patterns alone are not sufficient to understand the factors that may be responsible for them. Plotting the average ratio of target fish to total fish biomass and prime spawner to total fish biomass can be more informative (Figure 11). These ratios adjust for differences in total fish biomass, and represent the proportion of the total fish biomass comprised of target fish and prime spawners. All stressors and reef

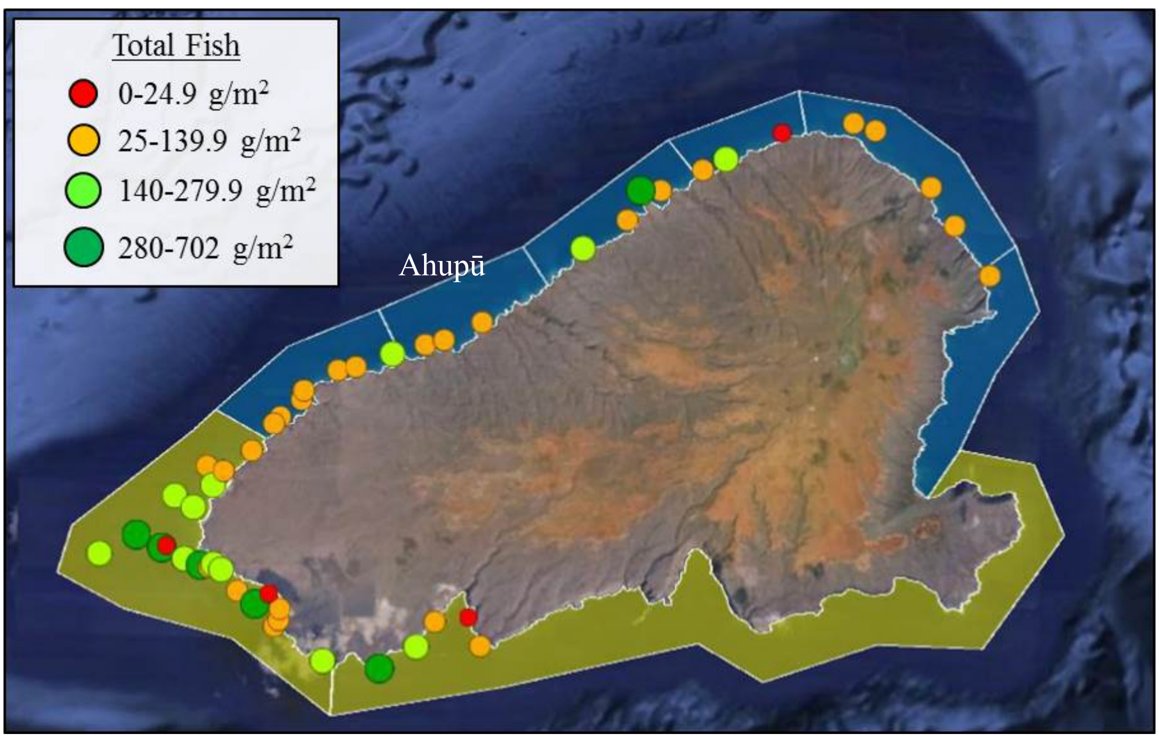

Figure 10. Total fish, target fish and prime spawner (both next page) biomass at survey sites in 2015. Red and orange circles are below the average biomass for each group, whereas light and dark green circles are sites with above average biomass. Exposed *ʻili* are shaded green; sheltered *ʻili* are shaded blue.

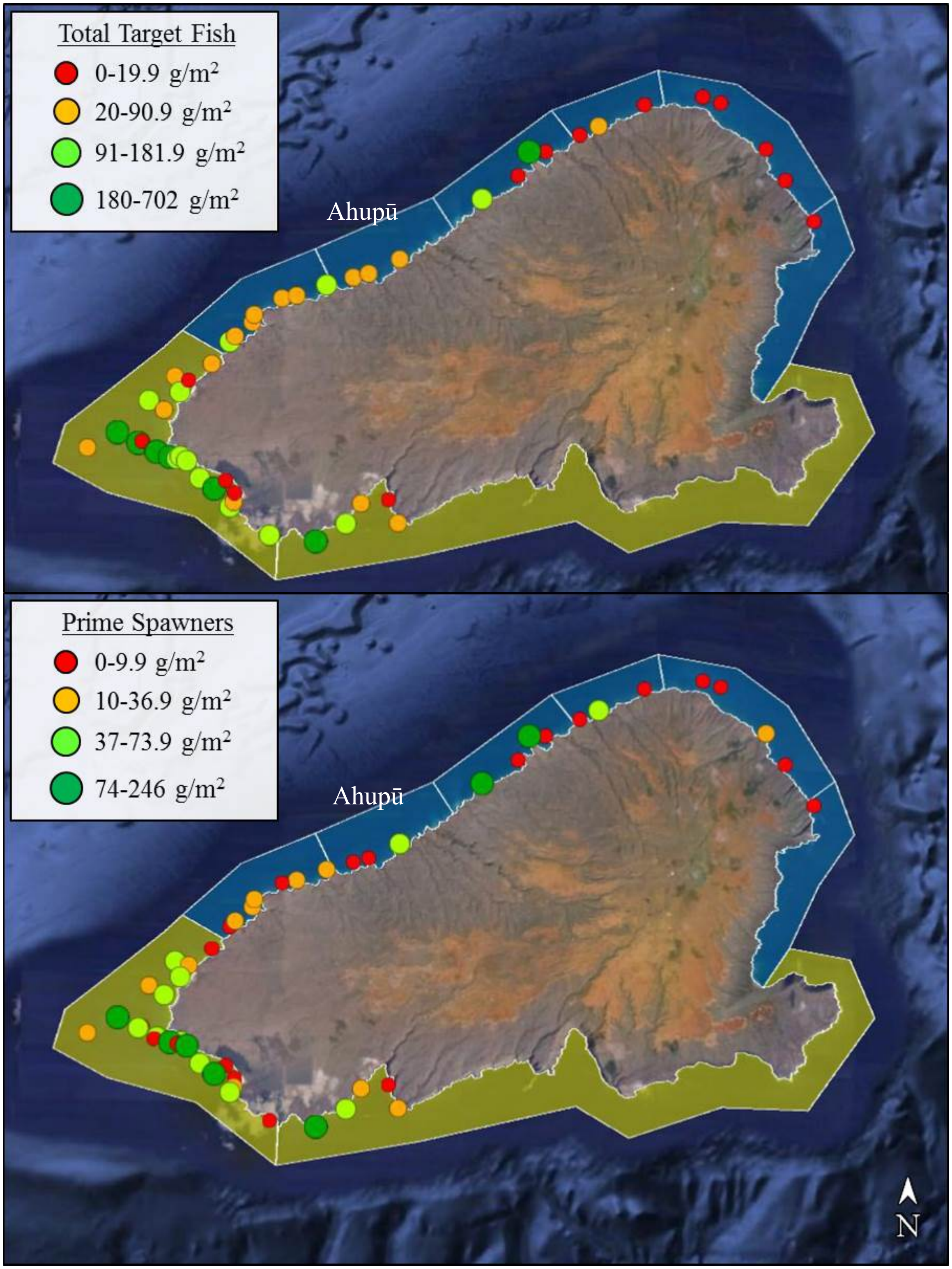

Figure 10 (continued). Total fish (previous page), target fish and prime spawner biomass at survey sites in 2015. Red and orange circles are below the average biomass for each group, whereas light and dark green circles are sites with above average biomass. Exposed *'ili* are shaded green; sheltered *'ili* are shaded blue.

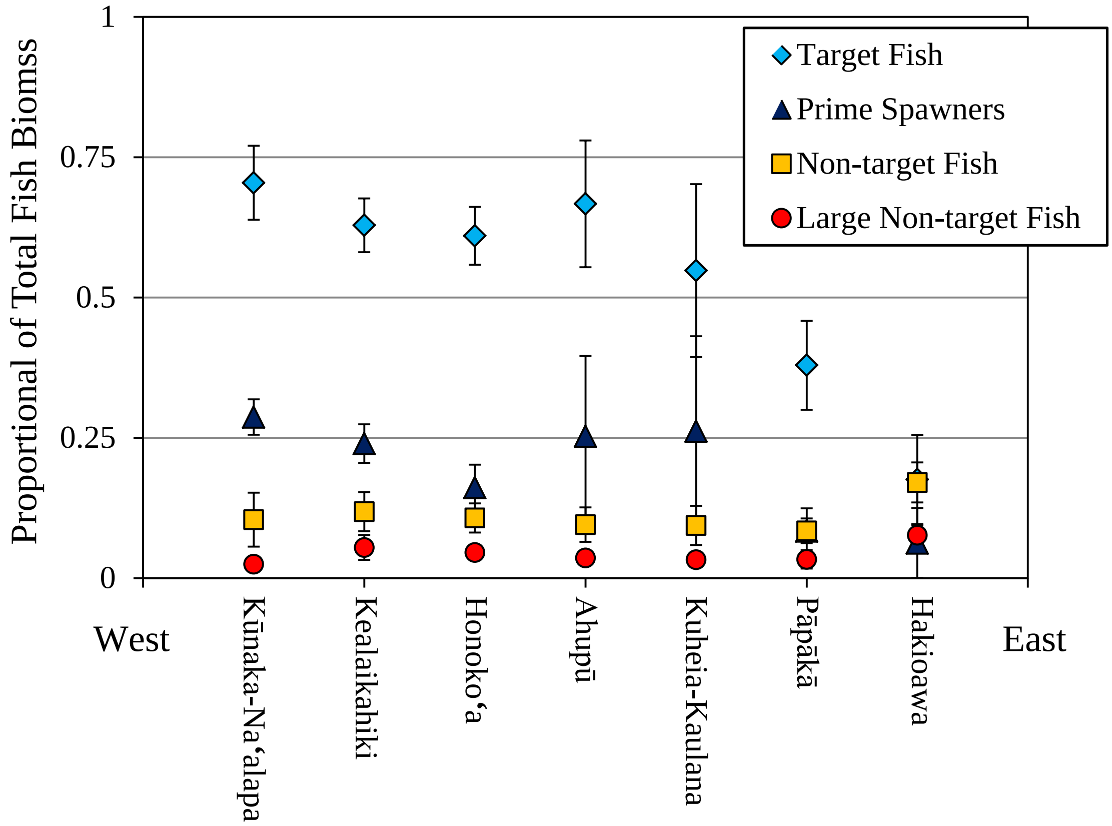

Figure 11. The proportion of the total fish biomass comprised of target fish, prime spawners, non-target fish, and large non-target fish by *'ili*. *'Ili* are arranged by their approximate position on Kahoʻolawe, from west (farthest from Maui) to east (closest to Maui).

conditions being equal, we would expect these proportions to be roughly the same across the Reserve. However, eastern *'ili* have proportionally fewer target fish (Pearson Correlation, r=-0.877, p=0.009) and prime spawners (Pearson Correlation, r=-0.753, p=0.050) than western *'ili*, indicating these groups are being disproportionately (*i.e.*, more strongly) acted upon by whatever factors are causing the reduction in total fish biomass in the eastern *'ili*. In contrast, non-target fish (Pearson Correlation, r=0.317, p=0.489) and non-target fish >70% their maximum size[7] (Pearson Correlation, r=0.440, p=0.323) showed no change in the relative contribution, suggesting they are not differentially affected by these same factors. Therefore, the drop in total fish biomass moving east across the Reserve is primarily associated with a disproportionate decrease in target fish, including prime spawners.

[7] Non-target fish >70% of the species maximum size are analogous to prime spawners, which are target fish >70% of the species' maximum size.

There exist several possible explanations for this observed spatial pattern:

1) *Differences in benthic habitat quality*. Fish respond to the physical structure of their habitat, and features such as bottom topography (*e.g.*, rugosity) and small-scale heterogeneity of hardbottom (*e.g.*, local patchiness) can have significant effects on the amount of fish biomass present (Friedlander and Parrish 1998, Minton *et al.* 2011). On most coral reefs, a positive correlation in general exists between fish biomass and three-dimensional relief. However, reefs on exposed shores, including the westernmost *ʻili*, had lower rugosity (and lower coral cover and species diversity) than those in sheltered areas, but more fish. Additionally, all fish species, regardless of their fishery status, should be affected by the physical structure of benthic habitat, yet the ratio of non-target species was not spatially correlated. The available data suggests little difference in benthic quality across the Reserve; therefore this explanation does not adequately explain the observed spatial distribution of fish.

2) *Difference in water quality*. Locations with terrestrial-derived sediment inputs are likely areas with high runoff, the primary transport mechanism for land-based pollutants such as chemicals from unexploded ordinance (few other pollution sources likely exist on the island). No relationship was found between the fish assemblage and the presence or absence of terrestrial-derived sediment, suggesting differences in water quality within the Reserve do not adequately explain the observed spatial pattern.

3) *Western point of the Reserve is preferred by large fish*. Projections of reef into deep water and off points of land often seem to attract or to be preferred by large fish. The western end of Kahoʻolawe forms a shelf that extends out toward open ocean, and could be attractive habitat to large fish. If this were the case, it could explain the observed spatial pattern. However, the relative distribution of prime spawners and large non-target fish species (Figure 11) do not support this explanation: while the proportion of prime spawners decreases in the eastern *ʻili*, the proportion of larger non-target fish shows little spatial relationship. Large fish in general do appear to favor the western side of the Reserve.

4) *Depressed regional fishery stocks.* Oceanographic data suggest that at least some of the Reserve's larval supply originates from Maui (Storlazzi *et al.* 2006), and low fishery stocks on Maui could adversely impact fish populations within the Reserve. Without additional information, it is difficult to examine this hypothesis, but the distribution of fish from Kahoʻolawe appears to run counter to what would be expected: locations closer to the potential source (*i.e.*, Maui) should receive more larvae and thus have more fish. More likely, however, the relatively small size of Kahoʻolawe would promote fairly uniform larval import. While regionally depressed fishery stocks may be adversely affecting the Reserve's target species populations; it likely does not adequately explain the observed spatial patterns within the Reserve.

5) *Fishing outside the Reserve boundary*. External fishing pressure, directly along the boundary of the Reserve which is 3.2 km (2 mi) offshore of Kahoʻolawe, could account for the observed spatial patterns. The eastern most *ʻili* are closest to Maui, the primary source of most fishing pressure in the Maui Nui region and legal fishing conducted along the Reserve's boundary could be lowering target fish and prime spawner biomass in the *ʻili* closest to Maui. This would require target fish to be highly mobile because they would need to leave shallow water reefs near Kahoʻolawe in order to be legally harvested. While this is a possibility with some species, notably jacks, apex predators, and some other highly mobile species, the relative contribution of these mobile species shows what might be a slightly decreasing trend (Pearson Correlation, r=-0.551, p=0.2), but one that is not strong enough to adequately explain the lower fish biomass in the eastern *ʻili* (Figure 12). The proportion of non-mobile, more reef-associated target species (e.g., parrotfishes, target surgeonfishes, etc.) shows a stronger decreasing trend (Pearson Correlation, r= -0.676, p=0.095) than that of mobile target fish, suggesting the observed spatial pattern is being driven primarily by these reef-associated target fish species which would not be caught in deeper water. Therefore, direct effects from fishing outside the boundary do not adequately explain the observed spatial pattern within the Reserve.

6) *Proximity to Maui, fishing inside the Reserve, and poaching*. The eastern side of the Reserve is closest to Maui and could therefore be subject to greater impacts from Maui-based activities such as fishing or pollution from land runoff. Target fish, including prime spawners, are affected by this proximity while non-target fish are not, suggesting fishing, and likely poaching as the primary cause of the observed spatial pattern for fish in the Reserve. While it is difficult to cleanly separate permitted from illegal fishing inside the Reserve, no effect on the fish assemblage was found associated with permitted access points in the Reserve, suggesting a broader effect, such as illegal fishing, is occurring. Data suggest that poaching, if it is occurring, is most prevalent east of Ahupū *ʻili*.

Comparisons with other Hawaiian Reefs

Compared to other reefs on Maui and around the state (Figure 13), Kahoʻolawe had the highest total fish biomass of all areas in 2015 (and fourth highest in 2009), regardless of management status (*e.g.*, Marine Life Conservation District [MLCD], Fisheries Management Areas [FMA], etc.). In 2015, Kahoʻolawe's total fish biomass was over three times greater than the average total fish biomass on Maui reefs open to fishing (n=9), and 1.5 times greater than Maui's MLCDs (n=3).

The Reserve's highly diverse target fish assemblage, with 51 species in 12 families and no target fish group accounting for more than 42% of the total target fish biomass (Figure 9), stands in contrast to other reefs around the state. For example, at Polanui, Maui, surgeonfish account for approximately 70% of the target fish biomass while jacks, apex predators, redfish, and other target fishes were nearly absent (Minton *et al.* 2014).

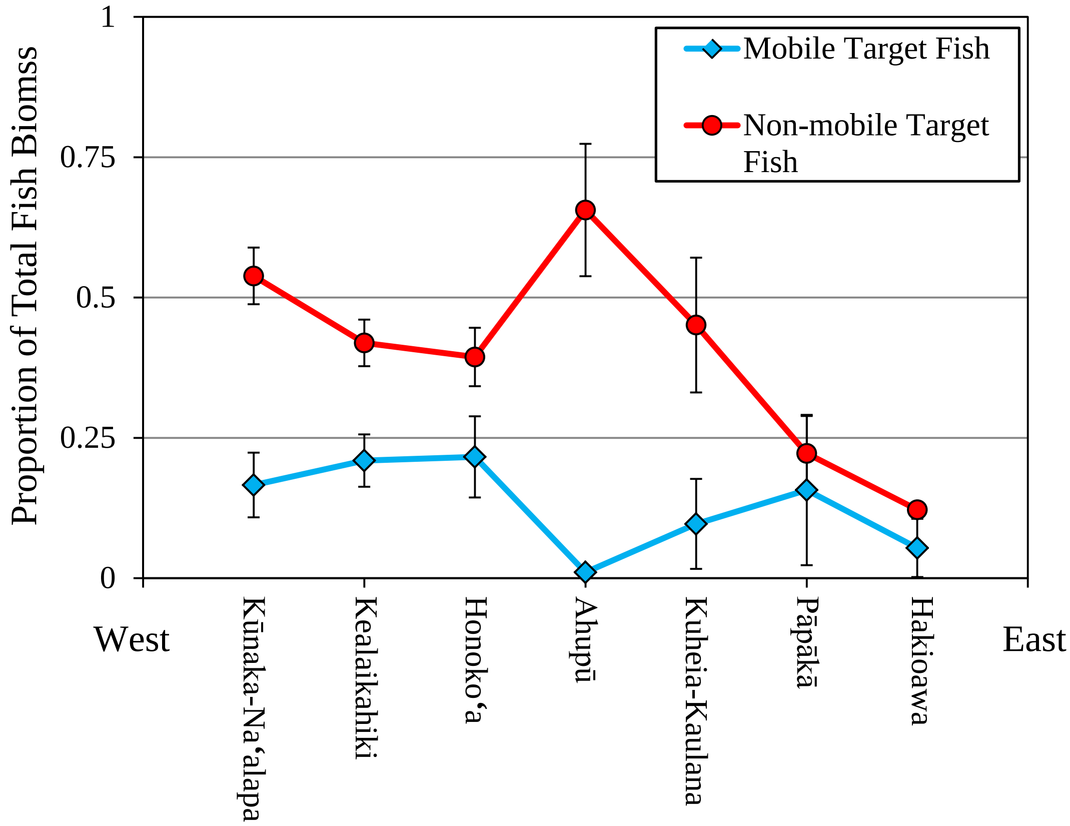

Figure 12. The proportion of the total fish biomass comprised of "mobile" and "non-mobile" target fish by *'ili*. *'Ili* are arranged by their approximate position on Kaho'olawe, from west (farthest from Maui) to east (closest to Maui). See text for a description of mobile vs. non-mobile target fish (page 29).

Similar patterns have been documented at Wailuku, Maui, where surgeonfish and small parrotfish comprised over 75% of the target fish biomass while jacks, redfish, apex predators, and other target fish were nearly absent (TNC, unpublished data).

As with total fish biomass, when compared to other reefs on Maui and across the state, Kaho'olawe had the highest target fish biomass of any area surveyed, regardless of management status (Figure 14). Compared to other reefs in the state, fishing pressure does not appear to be severely affecting Kaho'olawe's fish assemblage. This is further supported when comparing Kaho'olawe's target and non-target fish biomass to state averages by management category (Figure 15). On heavily fished reefs, target fish biomass is significantly lower than in areas protected from fishing (*i.e.*, MLCDs), whereas non-target fish biomass is similar regardless of management status. In the Reserve, target fish biomass is twice that of areas closed to fishing making its nearshore fishing stocks among the best in the state.

In 2015, the Reserve also had among the highest prime spawner (37.7 ± 7.7 g/m^2) biomass of any area surveyed in the main Hawaiian Islands regardless of management

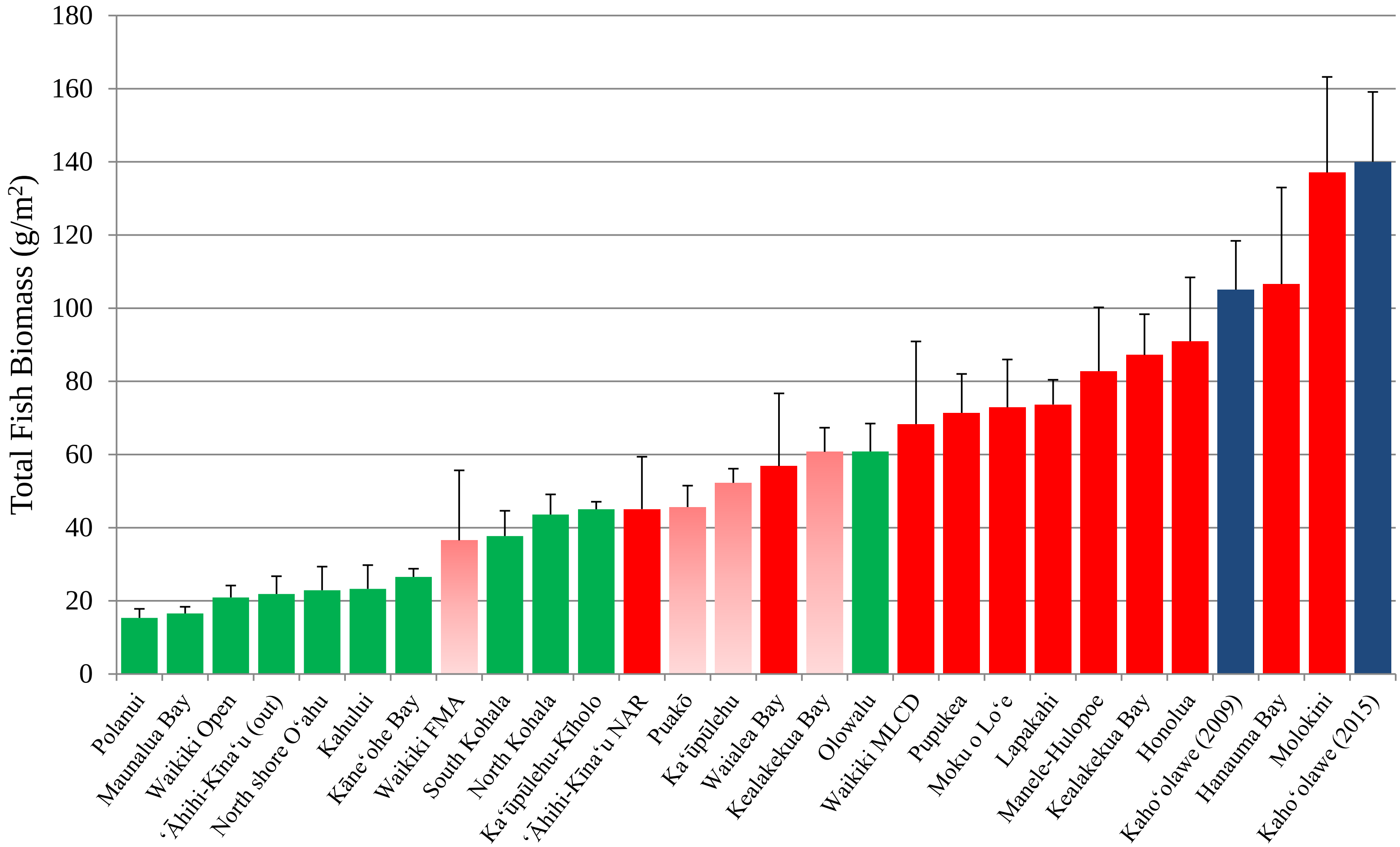

Figure 13. Total fish biomass on the reefs surrounding Kahoʻolawe (solid blue bar). Color of bars represents level of fisheries management occurring at the site: green=no additional fishing regulations; red=no take allowed; gradated red=limited take allowed. Data for other sites are from Friedlander (UH) and TNC.

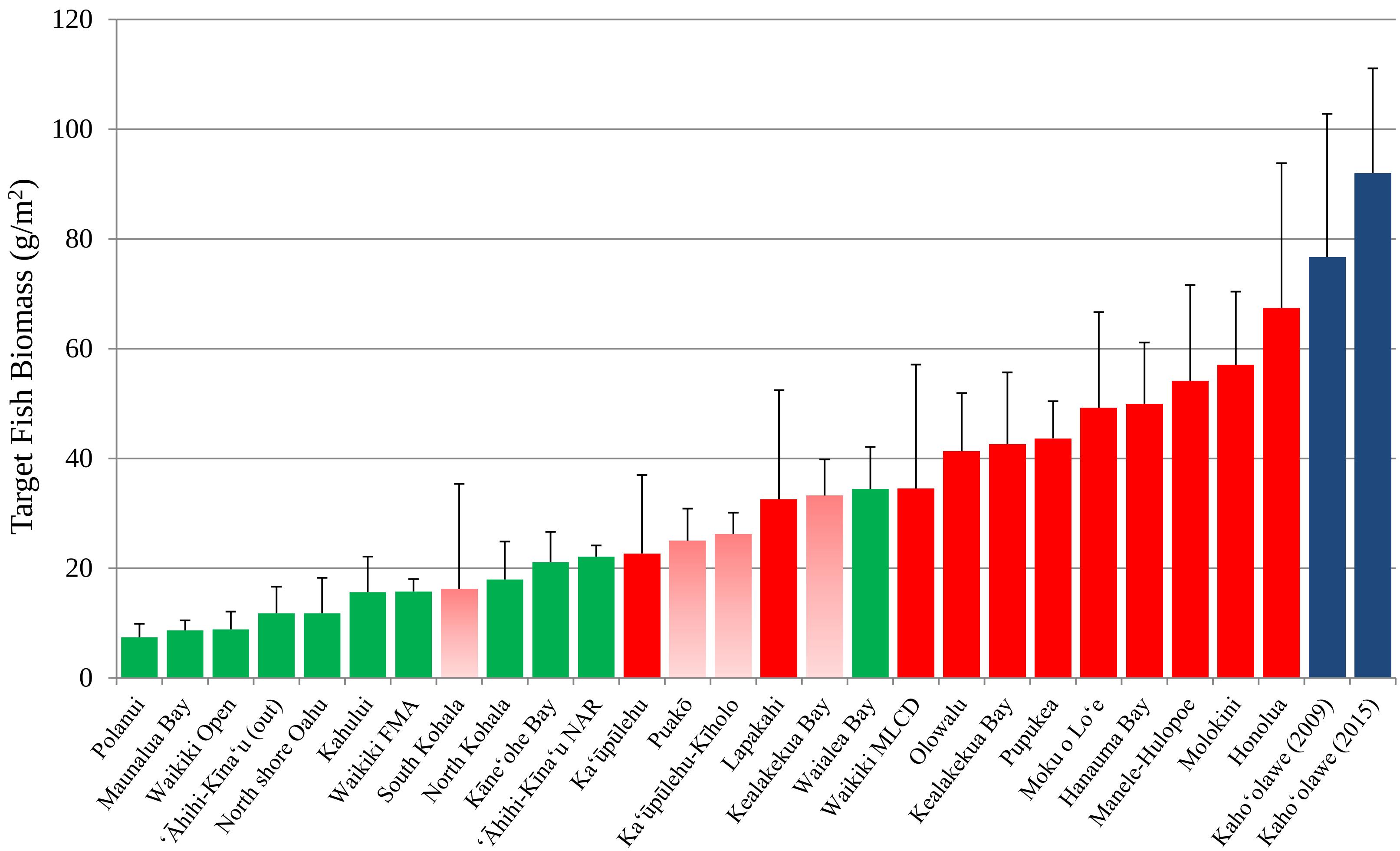

Figure 14. Target fish biomass on the reefs around Kahoʻolawe (solid blue bar). Color of bars represents level of fisheries management occurring at the site: green=no additional fishing regulations; red=no take allowed; gradated red=limited take allowed. Data for other sites are from Friedlander (UH) and TNC.

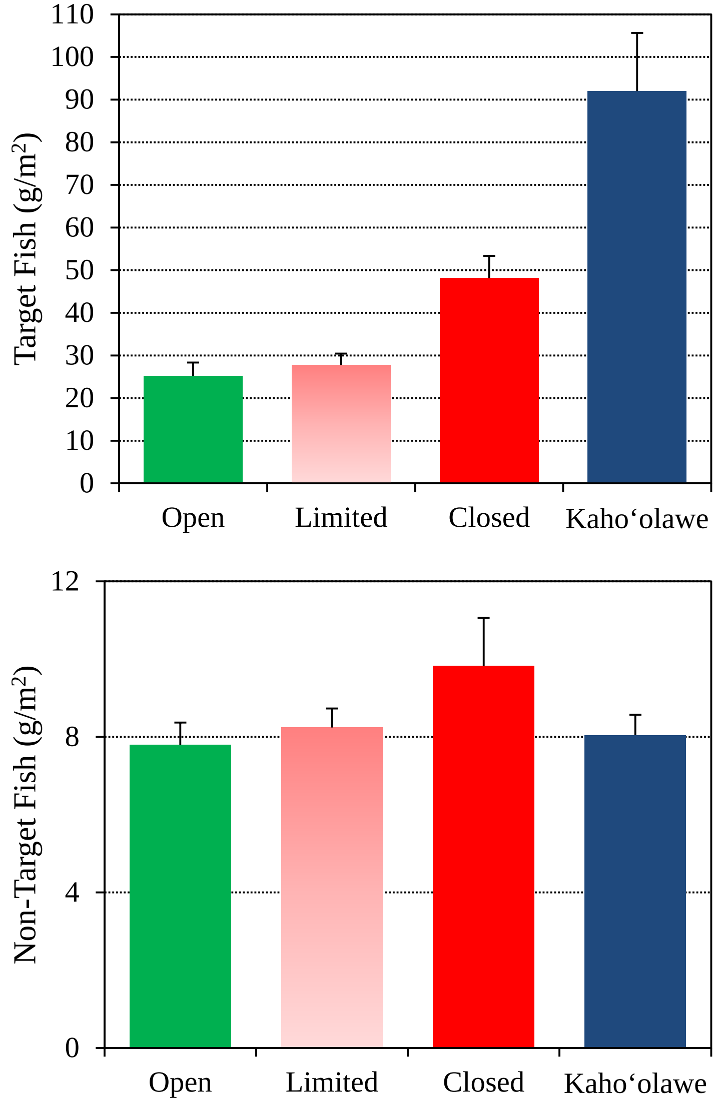

Figure 15. Comparison of Kaho'olawe target and non-target fish biomass in areas open to fishing, with limited fishing regulations (e.g., inside an FMA) or closed to all or most fishing (e.g., MLCDs). Values represent statewide averages.

status (Figure 16). While prime spawner biomass was lower in 2009 (17.6 ± 5.4 g/m^2), it was still similar to the statewide average for MLCDs (19.1 ± 3.3 g/m^2), further supporting relatively healthy fish stocks within the Reserve compared to the rest of the main Hawaiian Islands.

Temporal Trends

Total fish biomass did not significantly change between the 2009 and 2015 surveys on both exposed (t-test, t_7=0.88, p=0.411) and sheltered (t-test, t_{17}=1.88, p=0.079) reefs. Additionally, there was no change in target fish or prime spawner biomass. While fish

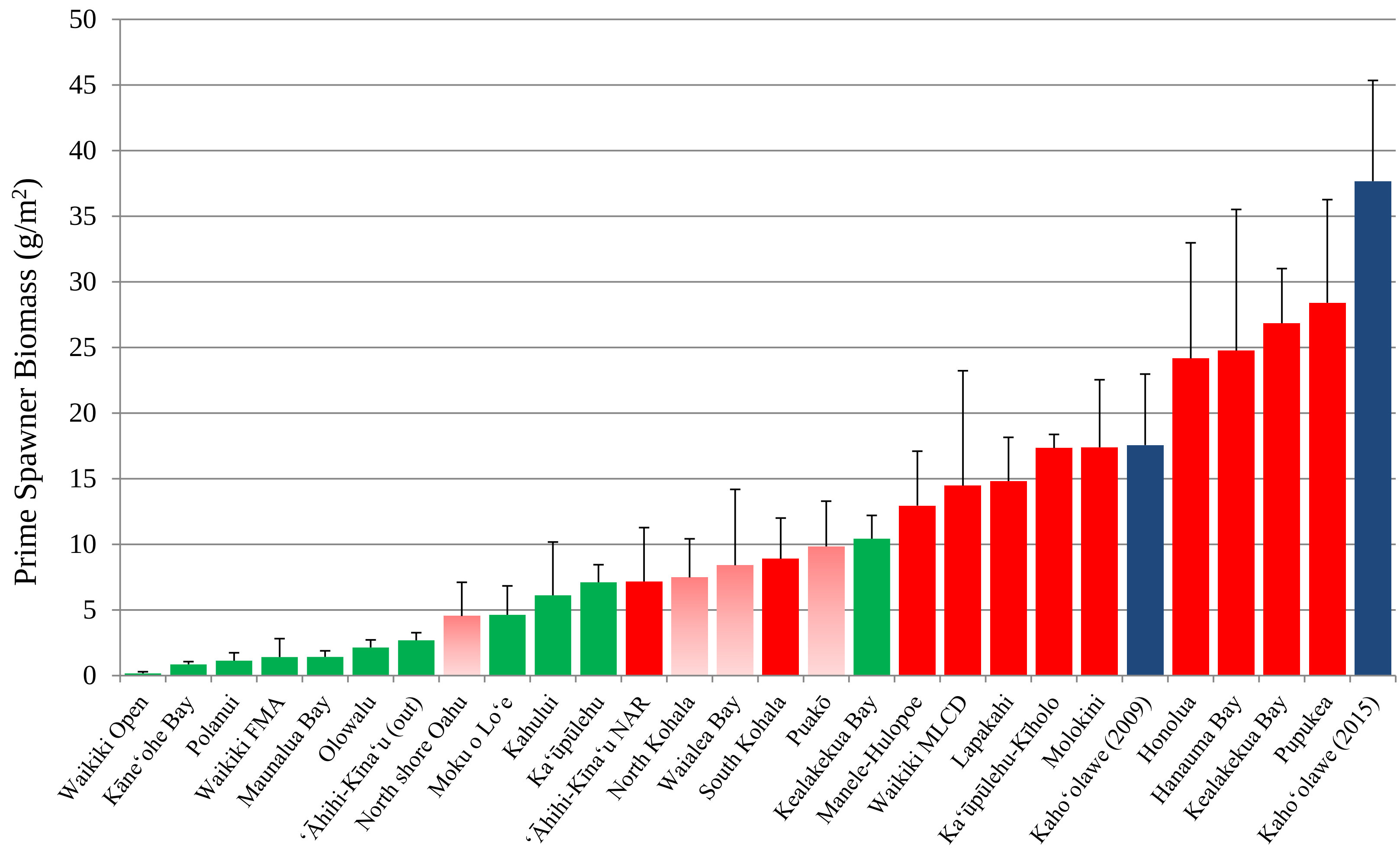

Figure 16. Prime spawner biomass on the reefs around Kaho'olawe (solid blue bar). Color of bars represents level of fisheries management occurring at the site: green=no additional fishing regulations; red=no take allowed; gradated red=limited take allowed. Data for other sites are from Friedlander (UH) and TNC.

assemblages on exposed reefs did not change over time (ANOSIM; R=0.072; p=0.208), a significant difference was found for fish assemblages on sheltered reefs (ANOSIM; R=0.16; p=0.004), but given the low R-statistic, this difference is likely not ecologically meaningful, which was supported by a follow-up SIMPER analysis that identified no key species that explained a large amount of the difference. Examining all available information, it appears the fish assemblage has remained stable between 2009 and 2015.

Comparing the surveys conducted in 2009 and 2015 to older surveys is problematic. Differences in data collection methods and the lack of biomass information create significant challenges for direct comparisons. Qualitative comparisons, however, are possible. The top twenty species by abundance can be ranked and compared to examine potential shifts in assemblage structure over time. Compiled species rankings (Table 9) suggest there has been little change in the structure of Kahoʻolawe's fish assemblage over the past three decades. Little change has occurred in the five most abundant species. It appears that yellow tangs (*Zebrosoma flavescens*) may have increased in abundance since 1981. Unranked in 1981, yellow tangs became mid-ranked in the early 2000s and highly ranked in 2009 and 2015, suggesting an increase in their numbers over time.

4.3 Invasive Fishes

Recently, many communities across Hawaiʻi have raised concerns about the abundance of invasive fish on Hawaiian reefs, particularly the peacock grouper or *roi* (*Cephalopholis argus*). While growing scientific evidence suggests invasive fish species have minimal impacts on native Hawaiian reef fish populations (Schumacher and Parrish 2005, Dierking *et al.* 2009, TNC unpub. data), there is the perception among some stakeholders that invasive fishes are significantly impacting native species through direct competition and/or predation.

Three species of invasive fishes were observed in the Reserve in 2015: peacock groupers, bluestriped snapper (*Lutjanus kasmira*), and blacktail snapper (*L. fulvus*) (Table 10). Invasive fish biomass was among the highest recorded in the state and nearly seven-times higher than the statewide average for MLCDs (3.2 ± 1.0 g/m^2).

The total biomass of invasive fish did not differ by exposure (ANOVA; $F_{1,95}$=2.92; p=0.091), although invasive fish biomass on exposed reefs was highly variable with many exposed reef sites having no invasive fish. However, peacock grouper biomass on sheltered reefs (13.4 ± 2.4 g/m^2) was almost twice that found on exposed reefs (8.7 ± 2.2 g/m^2), whereas bluestriped snapper were significantly more common on exposed (6.4 ± 4.1 g/m^2) compared to sheltered (<0.1 g/m^2) reefs. These distributions are likely habitat related. Peacock groupers are a dominant fore reef and lagoon predator in their native home range (Randall and Brock 1960), and can be significant components of the shallow water reef and lagoon ecosystems where they are introduced (Shpigel and Fishelson 1985), including some areas of Hawaiʻi. While sometimes found in high energy locations (Shpigel and Fishelson 1985), peacock groupers seem to prefer less exposed areas. In contrast, blueline snappers can be abundant in high energy environments in Hawaiʻi (Friedlander *et al.* 2002) and elsewhere (Newman and Williams 1996).

Table 9. Top 20 fish species by abundance. Ranks go from 1 (most abundant) to 20 as identified in surveys from 1981 to 2015.

Species	1981	2005	2006	2007	2009	2015
Blackfin chromis	1	1	1	1	1	1
Agile chromis	5	3	4	2	4	2
Brown Surgeonfish	3	2	2	3	2	3
Goldring bristletooth	4	6	5	6	5	4
Saddleback wrasse	2	4	3	4	6	5
Yellow tang		16	10	10	3	6
Black durgon		9	14	7	11	7
Sleek unicornfish					7	8
Hawaiian morwong						9
Whitebar surgeonfish	10	5	6	5		10
Arc-eye hawkfish	20	12	8	11	12	11
Bluestriped snapper	16	8			13	12
Blacktail snapper						13
Orangespine unicornfish		15	18	16		14
Multiband butterflyfish	8	14	16	20		15
Bullethead parrotfish		11	15	12	18	16
Thompson’s surgeonfish					19	17
Peacock grouper		10		19	16	18
Hawaiian sergeant						19
Orangeband surgeonfish		18				20
Achilles tang	19					
Bluelined surgeonfish	13					
Convict tang		13				
Hawaiian whitespotted toby	17	20	11	13	17	
Potter’s angelfish	18					
Chocolate-dip chromis	9	19		18	14	
Oval chromis	6				15	
Threespot chromis	15					
Bird wrasse		7	7	8		
Ornate wrasse			13			
Yellowfin goatfish					8	
Paletail unicornfish				15	9	
Manybar goatfish	12	17	19	14	10	
Bright-eye damselfish	14		12			
Blue-eye damselfish	11		9	9	20	
Palenose parrotfish			17			
Hawaiian gregory			20			
Pacific gregory	7					

Table 10. Mean (± SEM) biomass (g/m^2) of three invasive fish on exposed and sheltered reefs on Kahoʻolawe and the statewide average for MLCD. Data for Kahoʻolawe are from 2015 surveys. MLCD data are from Friedlander (UH) and TNC.

	Kahoʻolawe	**Exposed**	**Sheltered**	**MLCD**
Peacock grouper	10.9 ± 1.7	8.7 ± 2.2	13.4 ± 2.4	1.8 ± 1.7
Blacktail snapper	4.9 ± 3.2	6.8 ± 5.8	2.4 ± 0.8	0.2 ± 0.1
Bluestriped snapper	3.7 ± 2.3	6.4 ± 4.1	<0.1	1.3 ± 0.9
Total	19.5 ± 5.7	22.1 ± 10.0	16.2 ± 2.9	3.2 ± 1.0

4.4 Fish Species of Interest

KIRC has requested information on specific species of interest, including convict tangs or *manini* (*Acanthurus triostegus*), goldring bristletooth or *kole* (*Ctenochaetus strigosus*), goatfishes, parrotfishes or *uhu*, and jacks.

Convict tangs

In 2015, convict tangs or *manini* were relatively rare at Kahoʻolawe (Figure 17), appearing at only 9 of 50 survey sites and comprising 0.2 ± 0.1 g/m^2 of the total fish biomass at Kahoʻolawe. A total of 58 convict tangs were observed, with an average length of 11.0 ± 0.7 cm.

Convict tangs reach reproductive maturity at 9.4 cm[8] for males and 17.3 cm for females (Longenecker *et al.* 2008). It is not possible to determine the sex of convict tangs observed during visual surveys, so it is problematic to calculate the percentage of the population greater than the size at maturity. Longenecker *et al.* (2008) found a male:female sex ratio of 43:57 in their population (collected on Oʻahu and Hawaiʻi Island). Assuming a similar sex ratio in the Reserve, 75% of observed males but only 7% of females were likely above the minimum size at maturity.

In Hawaiʻi, the legal harvest size for convict tangs is 12.7 cm (5 in), which is significantly smaller than the size at maturity for females. The average size of convict tangs at Kahoʻolawe was under the legal harvest size; only 42% of the observed individuals on transects were greater than 12.7 cm.

Goldring bristletooth

Goldring bristletooth or *kole* are often the most abundant and conspicuous surgeonfish on Hawaiian reefs, and were the fourth most abundant fish observed in 2015 (Table 9). They comprised 2.2 ± 0.4 g/m^2 of the total fish biomass and had a density of 21.3 ± 3.1

[8] Longenecker *et al.* (2008) give sizes in fork length, but provides a conversion to obtain total length. Total lengths are used in this report.

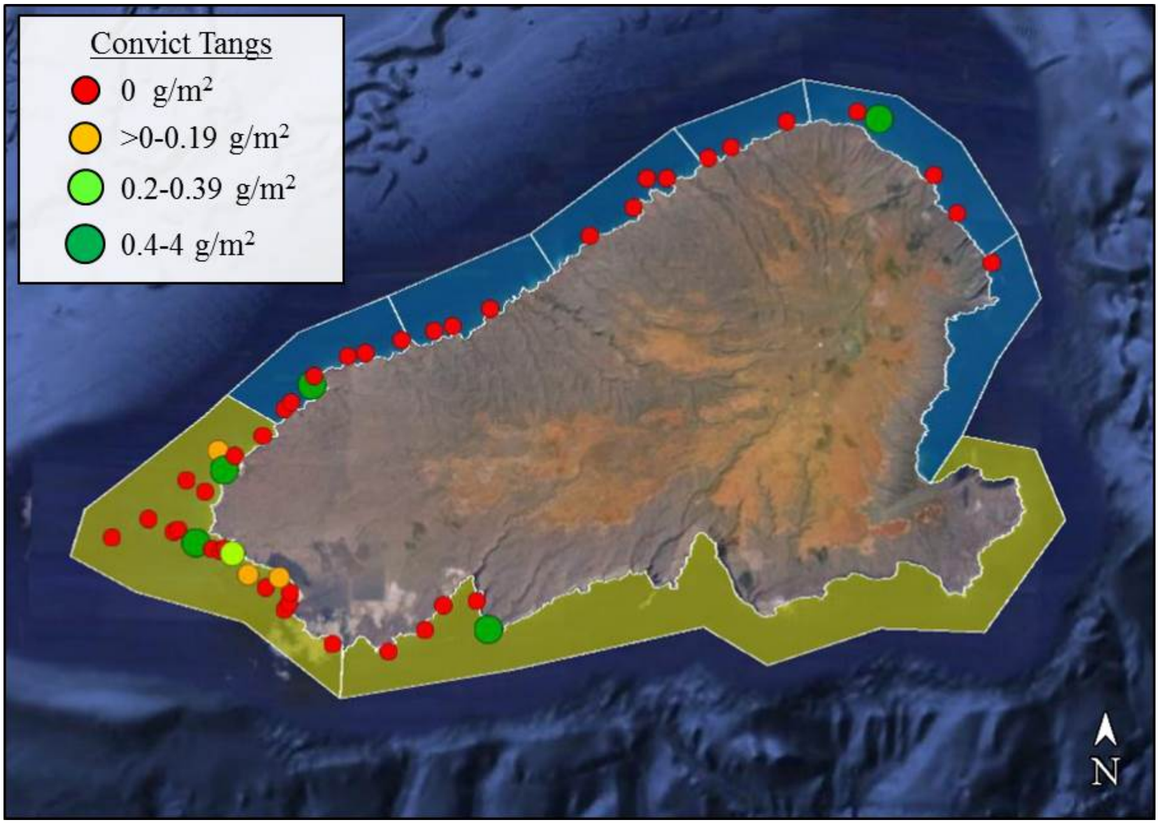

Figure 17. Biomass of convict tangs at survey sites in 2015. Red and orange circles are below the average species biomass, whereas light and dark green circles are sites with above average biomass. Exposed *'ili* are shaded green; sheltered *'ili* are shaded blue.

fish/125m^2 (Figure 18). Goldring bristletooth were more common on Kaho'olawe than on many other Maui reefs (range of four Maui sites: 0.3-6.6 fish/125m^2).

The average size of goldring bristletooth in the Reserve in 2015 was 9.5 ± 0.1 cm. Goldring bristletooth reach reproductive maturity at 11.0 cm[9] for males and 9.1 cm for females (Langston *et al.* 2009). While it is not possible to determine the sex of individual fish during visual surveys, approximately 30% of the population was larger than 11 cm, the size at sexual maturity for females.

Goatfishes (family Mullidae)

Seven species of goatfish were observed at Kaho'olawe in 2015, with two species, the manybar goatfish or *moāno* (*Parupeneus multifasciatus*) and the yellowstripe goatfish or *weke'ā* (*Mulloidichthys flavolineatus*), being the most common on transects (Table 11). Of the remaining species, the sidespot goatfish or *malu* (*Parupeneus pleurostigma*) and the whitesaddle goatfish or *kūmū* (*Parupeneus porphyreus*), were relatively rare in the survey area.

[9] Langston *et al.* (2009) give sizes in fork length, but provides a conversion to obtain total length. Total lengths are used in this report.

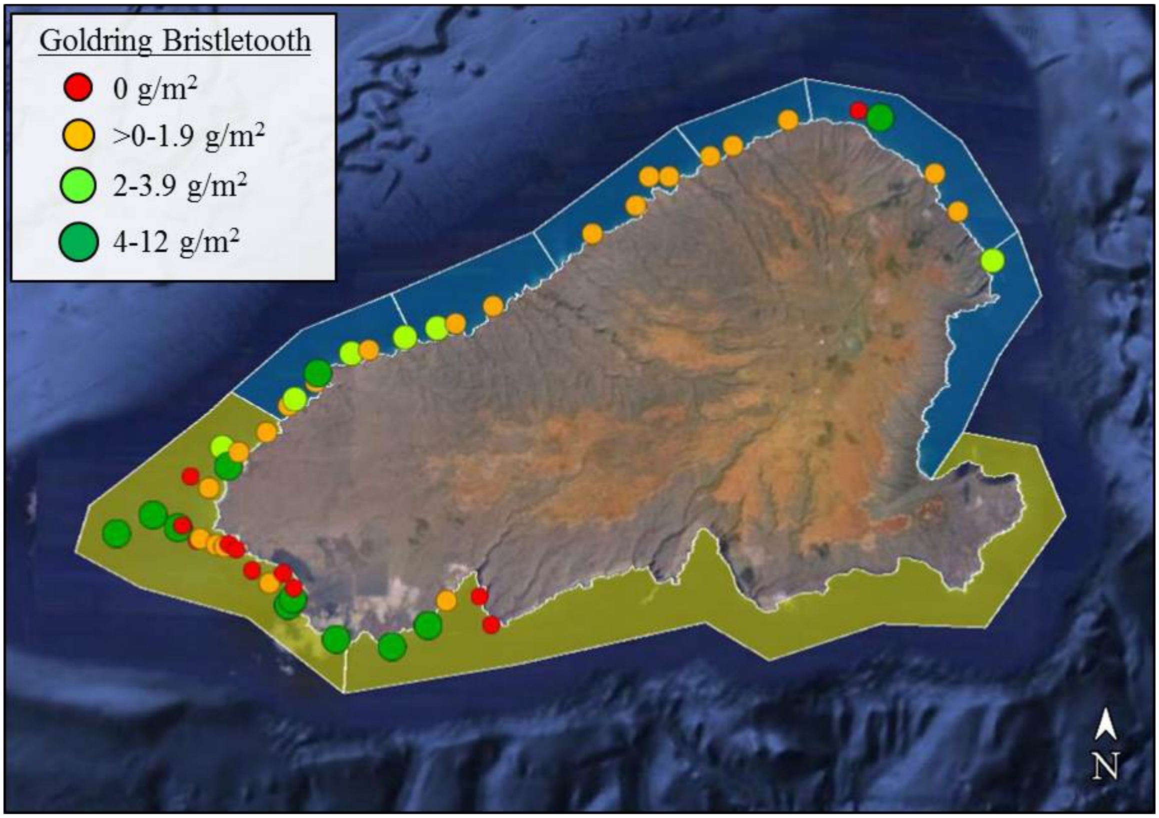

Figure 18. Biomass of goldring bristletooth at survey sites in 2015. Red and orange circles are below the average species biomass, whereas light and dark green circles are sites with above average biomass. Exposed *'ili* are shaded green; sheltered *'ili* are shaded blue.

Total goatfish biomass did not change between the 2009 and 2015 surveys (ANOVA; $F_{1,92}=2.25$; $p<0.137$), but was significantly lower on the sheltered (0.8 ± 0.3 g/m^2) compared to exposed (6.1 ± 2.7 g/m^2) reefs (ANOVA; $F_{1,95}=20.42$; $p<0.001$) (Figure 19). Further analysis suggests the near absence of goatfish from sheltered reefs was associated with presence of terrestrial-derived sediment on the reef, which is not surprising considering sand flats are important foraging grounds for many of these fishes. When the presence of terrestrial-derived sediment was included in the analysis, reef exposure became non-significant, and the presence of terrestrial-derived sediment was important ($p=0.063$). Sites with terrestrial-derived sediment had lower goatfish biomass (0.6 ± 0.3 g/m^2) than sites without (5.9 ± 2.5 g/m^2), suggesting goatfish favor "clean" sediment for foraging and may benefit from activities that reduce terrestrial erosion onto Kaho'olawe's nearshore reefs.

Average fish size was larger at Kaho'olawe than other Maui reefs. For example, at Polanui, Maui, manybar goatfish averaged only 11.8 ± 1.8 cm (Minton *et al*. 2014) compared to 15. 9 $\pm$ 0.6 cm on Kaho'olawe, suggesting fishing pressure on the species may be lower in the Reserve than elsewhere. Under new fishing rules enacted (DAR

Table 11. The number of goatfish individuals observed (N) on transects (5-minute timed swims), average biomass (g/m^2), average size, maximum size, size at maturity, and percent of the fish observed larger than the size at maturity for the six goatfish species observed at Kahoʻolawe in 2015. All sizes are in centimeters. Maximum size is for the species in Hawai'i.

Goatfish	N	Average Biomass	Average size[1]	Max. Size[2]	Size at Maturity[3]	Percent Mature
Yellowstripe	183 (2)	1.7 ± 1.3	22.3 ± 0.2	36.5	F:20.2[4] M: ?	>90%
Manybar	97 (40)	0.6 ± 0.2	15.9 ± 0.6	30	F: 15.2[5] M: 14.5	~40%
Island	38 (20)	0.7 ± 0.2	21.3 ± 1.6	40.6	?	-
Yellowfin	30 (6)	0.3 ± 0.3	21.3 ± 0.8	38	F:19.8[4] M: ?	~50%
Goldsaddle	13 (11)	0.3 ± 0.2	24.3 ± 3.3	50	?	-
Sidespot	3 (3)	<0.1	-	33	?	-
Whitesaddle	2 (0)	0.1 ± 0.1	-	51	26	-

[1]Average size calculated from individuals on transects only
[2]From Randall (2007)
[3]From Fishbase (Froese & Pauly 2011), unless otherwise noted
[4]From Cole (2009), converted from standard length using coefficients from Fishbase.com
[5]From Longenecker and Langston (2008)

2015), the legal harvest size is 12.7 cm for "small" goatfish species (manybar, sidespot, yellowfin, yellowstripe, and island) and 30.5 cm for large species (whitesaddle and goldsaddle). The average size for all small goatfish species exceeds the new minimum harvest size by at least 2 cm (Table 11), providing further support that fishing pressure on these species is likely low in the Reserve.

Parrotfish

Six species of parrotfish were observed at Kahoʻolawe in 2015, with the bullethead parrotfish (*Chlorurus spilurus*) being the most common on both transects and along timed swims (Table 12). Parrotfish contributed 12.5 ± 2.1 g/m^2 to the total fish biomass at Kahoʻolawe (Figure 20).

A sufficient number of individuals for four species were observed during the 2015 surveys to calculate species-specific average length (Table 12). The average size for each species was below the current legal harvest size for Maui County (DAR 2015): 25.4 cm (10 in) for small parrotfish species (stareye [*Calotomus carolinus*], bullethead, regal

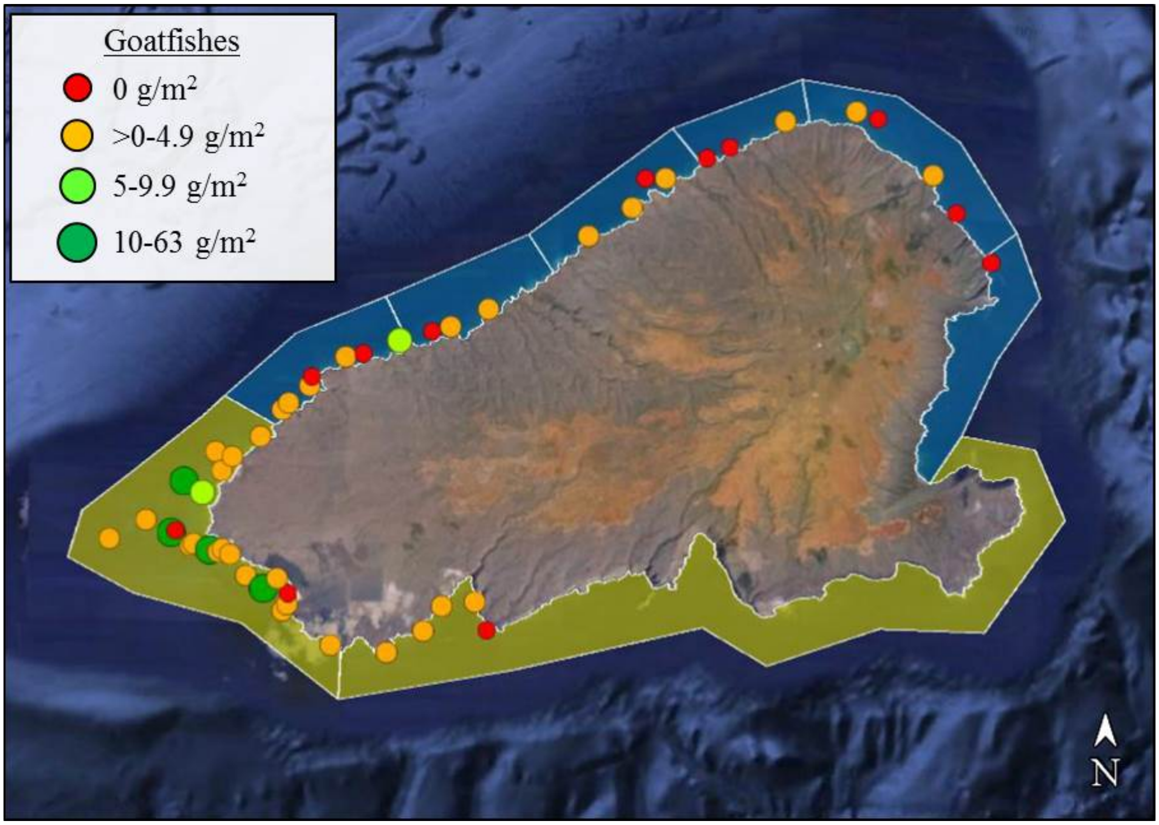

Figure 19. Biomass of all goatfishes at survey sites in 2015. Red and orange circles are below the average goatfish biomass, whereas light and dark green circles are sites with above average biomass. Exposed *'ili* are shaded green; sheltered *'ili* are shaded blue.

[*Scarus dubius*], and palenose [*S. psittacus*]) and 35.6 cm (14 in) for large species (spectacled [*Chlorurus perspicillatus*] and ember [*S. rubroviolaceus*]). While average size may have been under the legal take limit, individuals greater than legal harvest size were observed for all species.

Sexual maturity in parrotfish is complicated by their reproductive mode as protogynous sequential hermaphrodites (female-first, sex-changers). Most "small" sexually mature individuals are female and undergo sex change to male at a larger body size. For the four species for which an average size could be calculated, the proportion of the population above the size at maturity for females ranged from 17-56% and for males from 6-11% (Table 12).

On other reefs around the state parrotfish individuals tend to be smaller in size, with populations that have a lower percentage of individuals at or above the size at maturity. For example, at Polanui, no parrotfish were observed above the legal harvest size (30.5 cm at the time of the survey) and only 8% of palenose parrotfish exceeded the size at maturity for females (Minton *et al.* 2014).

Table 5. The number of parrotfish individuals observed (N) on transects (5-minute timed swims), average biomass (g/m^2), average size, maximum size, size at maturity, and percent of the fish observed larger than the size at maturity for the four parrotfish species observed at Kaho‘olawe in 2015. Biomass is in g/m^2 and all sizes are in centimeters. Maximum size is for the species in Hawai‘i. No average size was calculated for species with <5 individuals.

Parrotfish	N	Average Biomass	Average size	Max. Size[1]	Size at Maturity[2]	Percent Mature[3]
Bullethead	253 (214)	3.2 ± 1.3	14.7 ± 0.5	40	F: 17 M: 27	38/6%
Ember	196 (141)	6.4 ± 1.1	22.3 ± 0.9	71	F: 35 M: 47	17/6%
Palenose	166 (46)	1.5 ± 0.3	15.9 ± 0.5	30	F: 14 M: 23	56/11%
Stareye	16 (3)	0.4 ± 0.1	23.8 ± 2.2	50	F: 24 M: 37	38/6%
Regal	2 (8)	0.1 ± 0.1	-		?	-
Spectacled	2 (6)	0.9 ± 0.6	-		F: 34 M: 46	-

[1]From Randall (2007)
[2]From DeMartini and Howard (2016)
[3]First number equals the percent of fish exceeding size at maturity for female and second number is percent above size at maturity for males.

Jacks

Five species of jacks were observed at Kaho‘olawe in 2015, but three were relatively rare (Table 13). Only single individuals of both barred (*Carangoides ferdau*) and island (*Carangoides orthogrammus*) jacks, both known locally as *ulua*, and seven giant trevally were observed in the project area. Mackerel scad or *‘ōpelu* (*Decapterus macarellus*) are schooling fish occasionally found over deeper reef areas. While they were the most abundant in terms of individuals (~150 fish), they occurred primarily in two large schools of greater than 50 individuals.

In total, jacks contributed 4.6 ± 2.1 g/m^2 to the total fish biomass (Figure 21). The bluefin trevally or *‘ōmilu* (*Caranx melampygus*), for which enough fish were observed to estimate average size, had an average length of 34.9 ± 1.7 cm in the Reserve, including four individuals greater than 50 cm in length (the max. size in Hawai‘i is 83 cm). Approximately half of the bluefin trevally were larger than the size at maturity (Table 13).

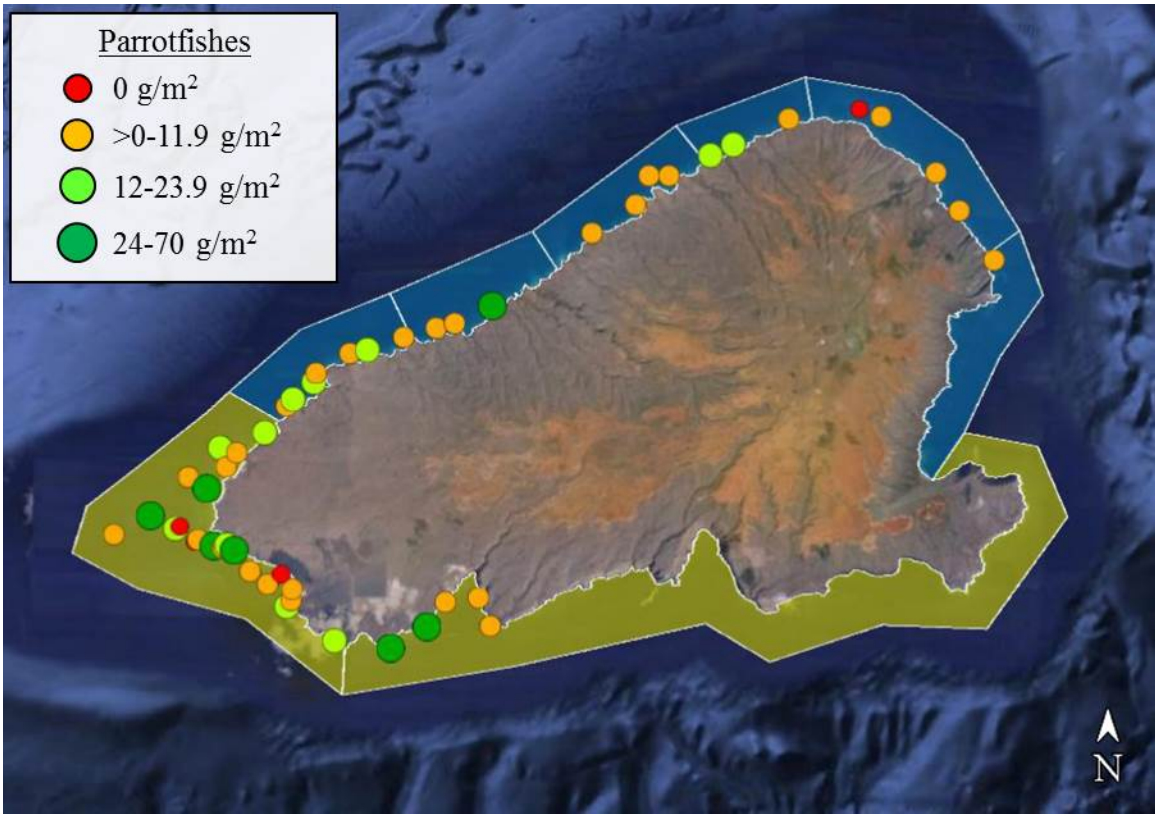

Figure 20. Biomass of all parrotfishes at survey sites in 2015. Red and orange circles are below the average parrotfish biomass, whereas light and dark green circles are sites with above average biomass. Exposed *'ili* are shaded green; sheltered *'ili* are shaded blue.

Minimum legal harvest size for jacks in Hawai'i is 25.4 cm (10 in). Eighty-one percent of the bluefin trevally were above the minimum legal harvest size in the Reserve, suggesting fishing pressure is low. Bluefin trevally are capable of traveling large distances (>3 km) over open water, but these long distance forays are relatively rare, with individuals showing high site fidelity, especially at night, and with active daytime foraging along reefs within one kilometer (Holland *et al.* 1996). Given the distance of open water between Kaho'olawe and Maui (~11 km), the rate of movement of the bluefin trevally between the two islands is likely low.

5.0 Management Recommendations

The Kaho'olawe Island Reserve: 'Ili O Kealaikahiki Conservation Action Plan (CAP) (KIRC 2014) and the Kaho'olawe Ocean Management Plan (Dames & Moore 1997) identify several threats to Kaho'olawe's coral reef resources, including three classified as high threats (Table 14). The effects of several of these threats on the Reserve's marine resources can be further examined in relation to the findings in this report:

Table 13. The number of jackss (N) observed on transects (5-minute timed swims), average biomass, average size, maximum size, size at maturity, and percent of the fish observed larger than the size at maturity for the jack species observed at Kahoʻolawe in 2015. Biomass is in g/m^2 and all sizes are in centimeters. Maximum size is for the species in Hawaiʻi. No average size was calculated for species with <5 individuals.

Jacks	N	Average Biomass	Average size	Max. Size[1]	Size at Maturity[2]	Percent Mature
Mackerel scad	95 (50)	NA[3]	school[3]	32	24.5	-
Bluefin trevally	37 (13)	2.1 ± 0.7	34.9 ± 1.7	83	35	50%
Giant trevally	2 (5)	4.2 ± 1.9	-	165	60	-
Barred jack	1 (0)	0.1 ± 0.1	-	55	?	-
Island jack	1 (0)	0.1 ± 0.1	-	79	?	-

[1]From Randall (2007)
[2]From Honebrink (2001)
[3]This species usually occurs in large schools, making sizing individuals and estimating biomass difficult.

- Erosion and sedimentation (High Threat): At many of the 2015 survey sites, evidence of terrestrial-derived sediment was observed on the reef, sometimes completely smothering coral. Terrestrial-derived sediment was more common in sheltered *ʻili* than exposed ones. However, there was no relationship with the presence of sediment and decreased coral cover or diversity. Coral diversity and cover was correlated with exposure, suggesting the effects of sediment on the benthic assemblage are secondary to exposure, a finding consistent with other research in Hawaiʻi. Sediment effects were detected for goatfish, which appeared to favor sites with marine sediment over those with evidence of terrestrial-derived sediment. Sediment has been an issue on Kahoʻolawe's reefs for over a century, and it is likely that the coral reef community has become generally acclimatized to it. There is evidence, however, that coral cover has increased since the 1980s, following the implementation of erosion control measures, so benefits from continued erosion control may be realized.

- Lack of knowledge about resources (Medium Threat): Over the past three decades, numerous marine surveys have been conducted at Kahoʻolawe, documenting benthic and fish diversity and abundance. These efforts, taken as a whole, have likely documented a large percentage of the fish and coral diversity within the Reserve. Prior to 2009, surveys were conducted at a limited number of sites, providing poor spatial resolution on species distributions. Data collected in 2009 and 2015, however, had high spatial coverage and provide a significantly improved view of species distributions. Additional surveys are unlikely to

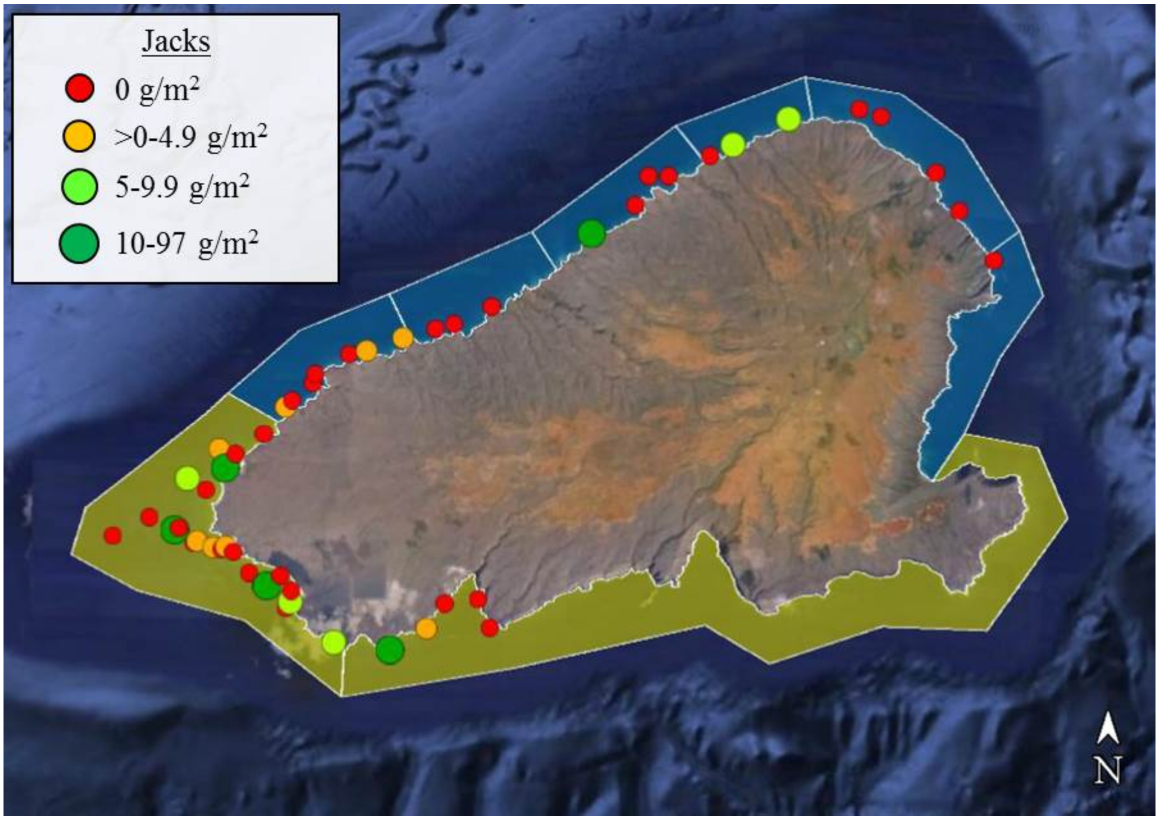

Figure 21. Biomass of all jacks at survey sites in 2015. Red and orange circles are below the average jack biomass, whereas light and dark green circles are sites with above average biomass. Exposed *'ili* are shaded green; sheltered *'ili* are shaded blue.

identify a large number of new records for fish or coral. However, mobile invertebrates, the very shallow-water reef community (<3 m), and the intertidal zone, appear to be inadequately surveyed at this time.

- Human access and impacts (Medium Threat): No differences were found between benthic or fish assemblages at "access" and "control" sites, but the sample sizes were small and the power to detect differences was likely low. Given the low level of human access, impacts are likely very small to insignificant, but a targeted investigation could be warranted.

- Harvest/Overharvest (Medium Threat): For the Reserve as a whole, little evidence of adverse impacts resulting from the current harvest of marine resources (legal and/or illegal) was found. The biomass of resource fish and prime spawners (two measures that are good indicators of overharvest) in the Reserve were the highest found in the main Hawaiian Islands, suggesting relatively healthy fish stocks. Mean fish size for species often exceeded the legal harvest size, and a large proportion of the fish populations examined were above the species' size at maturity. The composition of the fish assemblage appears to have been stable for several decades. However, within the Reserve, the likely effects of fishing/poaching were detected from the spatial distribution of fish biomass; eastern *'ili*—those closest to Maui—had lower biomass of target fish than western *'ili*, in contrast to equivalent non-target fish biomas.

- Introduced fish species (Low Threat): Three introduced fish species were commonly observed on Kahoʻolawe's reefs, raising concerns about their potential impact on the native community. Current scientific research conducted in Hawaiʻi has found few negative impacts from these invasive fish on native populations (Schumacher and Parrish 2005, Dierking *et al.* 2009, TNC unpub. data). But the invasive fish biomass on Kahoʻolawe exceeds that found on most reefs in Hawaiʻi, increasing the potential for adverse impacts, and thus may warrant further investigation to determine their effect, if any, on the Reserve's coral reefs (e.g., a fish removal experiment might be useful). In all likelihood, the removal of these invasive fish would have little impact on the Reserve's native fish assemblage; however, there may be reasons other than direct ecological benefits to justify their removal from the Reserve.

Climate change was not identified as a threat in the Reserve's management plans, but is likely the most significant long-term threat facing Kahoʻolawe's nearshore reefs. Climate change is expected to result in elevated sea water temperature, which is a primary cause of coral bleaching. Bleaching was observed in the 2015 surveys, but has also been observed frequently in past surveys, suggesting it may also be a response, in part or in whole, to other stressors (*e.g.*, sedimentation). In 2015, however, bleaching was independent of exposure and terrestrial-derived sediment, suggesting a regional stressor. High water temperatures in the latter half of 2014 resulted in a significant bleaching event, which only lightly affected Maui reefs. In 2015, a second bleaching event occurred as a result of high water temperatures, and early data compiled by KIRC natural

Table 14. Threats to nearshore coral reefs identified in the Kahoʻolawe Island Reserve: ʻIli O Kealaikahiki CAP (KIRC 2014) and the Kahoʻolawe Ocean Management Plan (Dames & Moore 1997).

Threat	
Potential alien species introduction via vessel	High
Erosion and sedimentation	
Fuel spill and vessel grounding	
Human trampling	Medium
Lack of knowledge of or presence of resources	
Increased human access	
Overharvesting	
Inappropriate vegetation	Low
Aquatic diseases and pathogens	
Introduced fish species	

resource staff suggest the Reserve's reefs were affected. Given recent events, climate change represents a significant, long-term threat to Kaho'olawe's reefs.

The KIRC staff faces significant challenges to address climate change because the source of this threat lies outside their management authority. Climate change cannot be solved at the local Kaho'olawe or Maui Nui level. Instead, management actions that reduce local stressors on Kaho'olawe's coral reefs need to be implemented in order to increase reef resilience. High reef resilience will reduce the susceptibility of the Reserve's reefs to the effects of climate change, and increase the ability of the reef to recover following damage. To this end, reducing sediment erosion and potential damage from human use, and ensuring fishery harvests are sustainably managed within the Reserve would increase reef resilience. Unfortunately, these "Reserve-derived benefits" are likely to be modest because these stressors appear to be having relatively small effects on the Reserve's marine resources.

Prevailing currents from west Maui have been shown to move primarily southwest (Storlazzi *et al.* 2006), suggesting, many of the marine species on Kaho'olawe may be at least partially dependent on the influx of larvae from Maui. Marine resources from Maui, especially those from the south shores, nearest to Kaho'olawe, show signs of significant impact from people, including decreased fish stocks and degraded benthic assemblages. Enhancing reef resilience includes actions such as increasing reproductive output and larval supply, protecting important trophic relationships, and improving the health of benthic assemblages, and will likely require management actions at a county or state scale, including:

- Rational and effective fishery management at a regional/state-wide scale, which would increase fish abundance across Maui Nui and re-establish degraded trophic structures (*i.e.*, apex predators, sharks, and jacks). Currently, fish assemblages in the main Hawaiian Islands are lacking apex predators and abundant populations of important grazers such as parrotfish and surgeonfish. These herbivores control algae which often directly compete with corals. Additionally, appropriate fishery management would increase the number of prime spawners, improving the reproductive capacity of the assemblage.

- Improvements in coastal water quality, which would reduce metabolic stresses (*e.g.*, through sediment reduction), reduce direct competition from fast growing algae (*e.g.*, through nutrient enrichment reduction), and improve coral reproduction through decreased larval mortality (*e.g.*, through chemical pollutants reduction) and improved settlement (*e.g.*, through sediment reduction).

Specific actions to promote these should be developed and implemented by the KIRC.

6.0 Acknowledgements

We thank Mike Naho'opi'i (KIRC Executive Director), Jen Vander Veur, Grant Thompson, Paul Higashino, Hoʻoleia Kaʻeo, and Kupaʻa Luat-Hueu all with the KIRC, without whom this project could not have been completed. Hawaiian Islands Humpback Whale National Marine Sanctuary provided boat support and captain Carmen DeFazio. Finally, we thank Roxie Sylva and Emily Fielding (TNC's Maui Marine Program) for their hospitality, logistical support, and most importantly, their tireless coordination with local partners.

This report was prepared by The Nature Conservancy under cooperative agreement award #NA13NOS4820145 from the NOAA Coral Reef Conservation Program, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of NOAA, the NOAA Coral Reef Conservation Program, or the U.S. Department of Commerce.

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Appendix A. Kaho'olawe Survey Site Data (2009 & 2015)

Site Code	Wave Exposure	Date	Lat.	Long.	Rugosity	Depth (m)
2009-KIRC010	Exposed	08-Oct-09	20.51596	-156.69258	*No data*	32
2009-KIRC011	Exposed	07-Oct-09	20.52249	-156.70346	*No data*	36
2009-KIRC022	Exposed	08-Oct-09	20.53197	-156.70152	*No data*	31
2009-KIRC025	Exposed	08-Oct-09	20.53986	-156.69878	*No data*	58
2009-KIRC028	Exposed	07-Oct-09	20.52573	-156.71257	*No data*	40
2009-KIRC048	Sheltered	08-Oct-09	20.55879	-156.66833	*No data*	48
2009-KIRC054	Sheltered	08-Oct-09	20.54923	-156.68372	*No data*	38
2009-KIRC064	Exposed	06-Oct-09	20.50494	-156.63925	*No data*	35
2009-KIRC065	Exposed	06-Oct-09	20.5293	-156.53157	*No data*	34
2009-KIRC066	Exposed	06-Oct-09	20.52249	-156.53633	*No data*	53
2009-KIRC068	Exposed	06-Oct-09	20.50526	-156.65602	*No data*	43
2009-KIRC069	Exposed	06-Oct-09	20.51018	-156.63013	*No data*	50
2009-KIRC070	Exposed	06-Oct-09	20.51825	-156.54045	*No data*	36
2009-KIRC072	Exposed	06-Oct-09	20.50776	-156.58661	*No data*	30
2009-KIRC073	Exposed	06-Oct-09	20.51484	-156.61598	*No data*	41
2009-KIRC074	Exposed	06-Oct-09	20.51422	-156.55057	*No data*	33
2009-KIRC076	Exposed	06-Oct-09	20.51383	-156.56986	*No data*	39
2009-KIRC079	Exposed	06-Oct-09	20.50113	-156.66356	*No data*	35
2009-KIRC080	Sheltered	06-Oct-09	20.55131	-156.5483	*No data*	38
2009-KIRC083	Exposed	06-Oct-09	20.53962	-156.54207	*No data*	45
2009-KIRC090	Sheltered	06-Oct-09	20.56625	-156.54396	*No data*	47
2009-KIRC101A	Sheltered	09-Oct-09	20.5925	-156.61012	*No data*	51
2009-KIRC116A	Sheltered	08-Oct-09	20.58141	-156.62192	*No data*	25
2009-KIRC119	Sheltered	08-Oct-09	20.56731	-156.64253	*No data*	25
2009-KIRC121	Sheltered	05-Oct-09	20.5985	-156.5927	*No data*	18

Site Code	Wave Exposure	Date	Lat.	Long.	Rugosity	Depth (m)
2009-KIRC125	Sheltered	05-Oct-09	20.60349	-156.58122	*No data*	24
2009-KIRC128a	Sheltered	05-Oct-09	20.6054	-156.57132	*No data*	28
2009-KIRC134A	Sheltered	09-Oct-09	20.59762	-156.59579	*No data*	25
2009-KIRC135	Sheltered	05-Oct-09	20.59623	-156.59732	*No data*	29
2009-KIRC137	Sheltered	09-Oct-09	20.60607	-156.57117	*No data*	40
2009-KIRC140a	Sheltered	05-Oct-09	20.60537	-156.57114	*No data*	27
2009-KIRC143a	Sheltered	05-Oct-09	20.60394	-156.56212	*No data*	43
2009-KIRC145A	Sheltered	05-Oct-09	20.59325	-156.55138	*No data*	29
2009-KIRC152a	Sheltered	05-Oct-09	20.60535	-156.56657	*No data*	37
2009-KIRC158	Sheltered	09-Oct-09	20.57617	-156.53877	*No data*	36
2009-KIRC159	Sheltered	09-Oct-09	20.58571	-156.54594	*No data*	30
2009-KIRCHokioawa	Sheltered	05-Oct-09	20.59308	-156.55075	*No data*	
2009-KIRCHonokanaia	Exposed	07-Oct-09	20.50918	-156.68504	*No data*	36
2009-KIRCHonukanaenae	Exposed	07-Oct-09	20.51764	-156.70346	*No data*	31
2009-KIRCK3	Sheltered	09-Oct-09	20.5925	-156.606	*No data*	36
2009-KIRCK4	Sheltered	09-Oct-09	20.60059	-156.58932	*No data*	32
2009-KIRCK5	Sheltered	08-Oct-09	20.56128	-156.66084	*No data*	39
2009-KIRCK6	Sheltered	08-Oct-09	20.56394	-156.6503	*No data*	37
2009-KIRCK7	Sheltered	08-Oct-09	20.5543	-156.67894	*No data*	40
2009-KIRCK8	Exposed	08-Oct-09	20.54278	-156.68956	*No data*	33
2009-KIRCKuikui	Sheltered	05-Oct-09	20.6026	-156.56245	*No data*	31
2015-KIRC010	Exposed	6/15/2015	20.51596	-156.69258	*No data*	27.00
2015-KIRC022	Exposed	6/16/2015	20.53197	-156.70152	16.25	25.50
2015-KIRC025	Exposed	6/17/2015	20.53986	-156.69878	14.70	35.50
2015-KIRC048	Sheltered	6/17/2015	20.55879	-156.66833	14.20	16.00
2015-KIRC054	Sheltered	6/17/2015	20.54923	-156.68372	12.50	17.00
2015-KIRC068	Exposed	6/16/2015	20.50526	-156.65602	17.25	40.50

Site Code	Wave Exposure	Date	Lat.	Long.	Rugosity	Depth (m)
2015-KIRC079	Exposed	6/16/2015	20.50113	-156.66356	11.20	56.00
2015-KIRC101a	Sheltered	6/19/2015	20.59249995	-156.61012	14.50	49.50
2015-KIRC116a	Sheltered	6/18/2015	20.58140994	-156.62192	13.90	29.50
2015-KIRC119	Sheltered	6/19/2015	20.56731	-156.64253	32.50	25.50
2015-KIRC121	Sheltered	6/19/2015	20.5985	-156.5927	14.50	15.50
2015-KIRC125	Sheltered	6/18/2015	20.60349	-156.58122	13.75	25.00
2015-KIRC135	Sheltered	6/18/2015	20.59642403	-156.5974246	16.50	19.00
2015-KIRC152a	Sheltered	6/15/2015	20.60535	-156.56657	*No data*	45.00
2015-KIRC158	Sheltered	6/15/2015	20.57617	-156.53877	4.40	25.00
2015-KIRC159	Sheltered	6/15/2015	20.58571	-156.54594	19.50	37.00
2015-KIRC207	Exposed	6/16/2015	20.51085415	-156.6453653	11.50	32.50
2015-KIRC208a	Exposed	6/16/2015	20.50255367	-156.6751222	*No data*	36.00
2015-KIRC209	Exposed	6/16/2015	20.51540258	-156.6861351	*No data*	20.50
2015-KIRC210	Exposed	6/18/2015	20.52310358	-156.7207337	13.50	49.50
2015-KIRC211	Sheltered	6/18/2015	20.55814113	-156.6719609	31.00	35.00
2015-KIRC212	Sheltered	6/18/2015	20.56304611	-156.6541414	15.20	25.00
2015-KIRC215	Sheltered	6/19/2015	20.58685558	-156.6128775	12.30	19.50
2015-KIRC227	Exposed	6/16/2015	20.50538422	-156.6429328	7.80	30.00
2015-KIRC228	Exposed	6/16/2015	20.5134678	-156.688955	13.50	
2015-KIRC229	Exposed	6/16/2015	20.5242243	-156.7079933	14.50	39.00
2015-KIRC229a	Exposed	6/16/2015	20.52462749	-156.7070729	3.50	45.50
2015-KIRC233a	Exposed	6/18/2015	20.52173733	-156.7040387	12.00	47.50
2015-KIRC234a	Exposed	6/16/2015	20.53417993	-156.7053299	5.00	23.50
2015-KIRC241	Exposed	6/16/2015	20.51003352	-156.652209	*No data*	26.50
2015-KIRC242a	Exposed	6/18/2015	20.52670335	-156.7131799	*No data*	49.00
2015-KIRC246	Sheltered	6/18/2015	20.55255625	-156.679416	1.53	21.50
2015-KIRC247	Sheltered	6/18/2015	20.54793178	-156.685053	*No data*	25.00

Site Code	Wave Exposure	Date	Lat.	Long.	Rugosity	Depth (m)
2015-KIRCHakioawa	Sheltered	6/29/2015	20.59308	-156.55075	15.10	36.50
2015-KIRCHonokanaia	Exposed	6/15/2015	20.50918	-156.68504	11.80	26.00
2015-KIRCHonukanaenae	Exposed	6/17/2015	20.52053151	-156.6982995	*No data*	34.00
2015-KIRCK3	Sheltered	6/19/2015	20.5925	-156.606	*No data*	26.00
2015-KIRCK5	Sheltered	6/17/2015	20.56128	-156.66084	29.50	30.00
2015-KIRCK6	Sheltered	6/17/2015	20.56394	-156.6503	7.80	34.00
2015-KIRCK7	Sheltered	6/17/2015	20.5543	-156.67894	*No data*	26.00
2015-KIRCK8	Exposed	6/17/2015	20.54278	-156.68956	*No data*	26.00
2015-KIRCKA1	Exposed	6/17/2015	20.52088497	-156.7000636	12.80	36.00
2015-KIRCKA2	Exposed	6/17/2015	20.52211225	-156.7033849	14.00	37.00
2015-KIRCKAU1	Exposed	6/17/2015	20.53890263	-156.6953624	11.50	30.00
2015-KIRCKAU2	Exposed	6/17/2015	20.53616392	-156.6975182	14.50	20.00
2015-KIRCKuikui	Sheltered	6/15/2015	20.60393999	-156.5621199	15.70	13.00
2015-KIRCMUA	Exposed	6/17/2015	20.51039267	-156.6841291	12.50	27.00
2015-KIRCPUU1	Exposed	6/17/2015	20.52001988	-156.6958506	12.20	20.00
2015-KIRCPUU2	Exposed	6/17/2015	20.52105689	-156.6974351	13.75	27.50
2015-KIRCWeightRoom	Exposed	6/17/2015	20.51251145	-156.6838962	13.50	21.5

Appendix B. TNC Survey Methods and Data Analysis

The overarching goal of TNC's marine monitoring program is to detect change in the biological community over time on specific reef areas around the main Hawaiian Islands. In addition to detecting temporal change, the marine monitoring program seeks to provide data that can be used to compare coral reef areas with other reef ecosystems across the state and beyond. Such comparisons can provide a context within which to understand any observed changes. Thus, survey design and sampling protocols were specifically chosen to provide the greatest likelihood of compatibility with other monitoring efforts currently underway in Hawai'i.

TNC's marine monitoring team, along with partners at the University of Hawai'i's Fisheries Ecology Research Lab, conducted all benthic and fish surveys. Members of the monitoring teams have hundreds of hours of experience conducting underwater surveys of coral reefs, and provide regular monitoring for numerous sites around the main Hawaiian Islands. All surveyors are trained and calibrated to reduce differences among observers that can sometimes confound data in large, long-term monitoring programs.

<u>Survey Sites</u>

The survey area on Kaho'olawe and adjacent reef covered approximately 47 km of coastline and included coral reef habitat between 3 and 20 m deep. Fifty sites were randomly generated in ArcGIS within this area.

Sites were surveyed by divers deployed from a small boat or, for some sites close to shore, divers swam out from the beach. The survey teams navigated to each predetermined site using a Garmin GPS unit. Once on site, the survey team descended directly to the bottom, where divers established two transect start points approximately 10 m apart. From each start-point, divers deployed a 25 m transect line along a predetermined compass heading, with the transects running parallel to each other. If the bearing resulted in a large change in depth, the transect was "bent" to follow the depth contour.

<u>Benthic Community Surveys</u>

Benthic surveys were not designed to collect comprehensive biodiversity data. Instead, surveys were designed to collect quantitative data on specific taxa, primarily individual coral species, algae at higher taxonomic resolution (*e.g.*, red, green, brown, turf, crustose coralline, etc.), and abiotic substratum type when the bottom was something other than hard substratum.

At sites where benthic data were collect, benthic photographs were collected at 1 m intervals along one of the two 25 m transect lines. Photographs were taken with a Canon G11 camera (or equivalent) mounted on a 0.8 m long monopod, resulting in images that covered approximately 0.8 x 0.6 m of the bottom. Prior to photographing each transect,

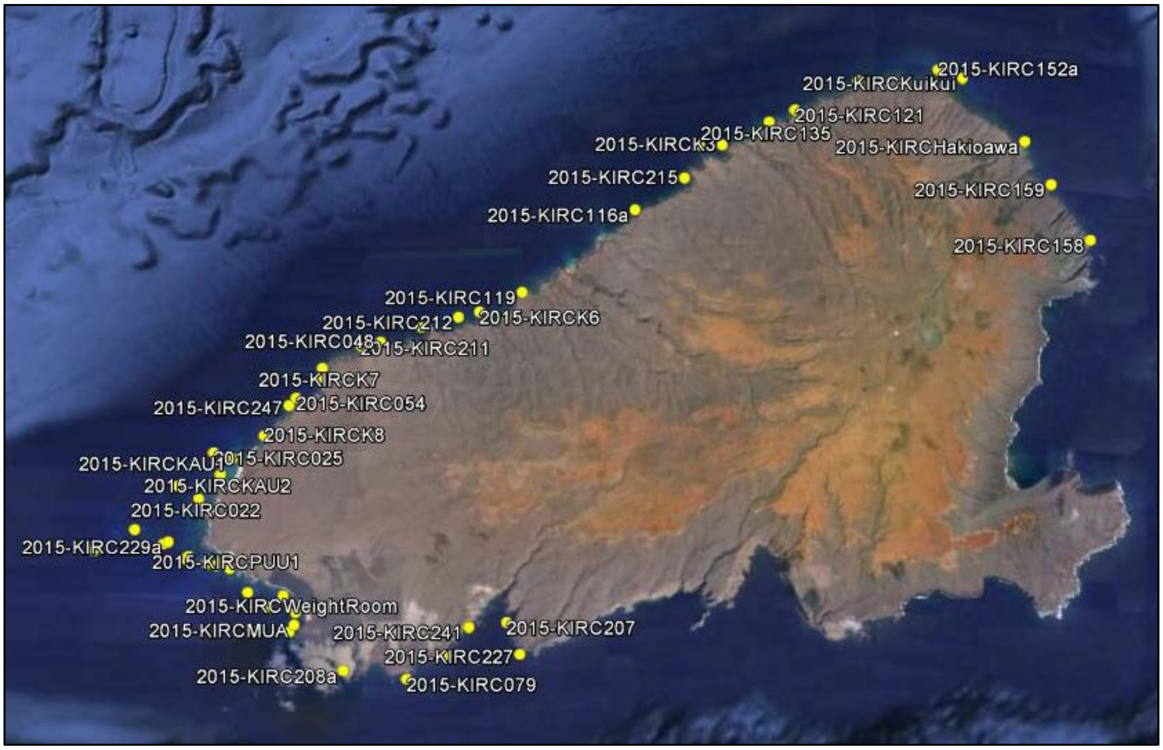

Figure B.1. Kahoolawe with the 50 randomly-generated marine monitoring sites surveyed during June 2015.

the camera was white balanced to improve photograph quality. A 5-cm scale bar marked in 1-cm increments was included in all photographs.

Each photograph was imported into Adobe Photoshop CS5 where its color, contrast, and tone were autobalanced to improve photo quality prior to analysis using the Coral Point Count program with Excel extension (CPCe) developed by the National Coral Reef Institute (Kohler and Gill 2006). Using CPCe, 30 random points were overlaid on 20 randomly selected digital photographs, and the benthic component under each point was identified to the lowest possible taxonomic level. To reduce observer variability, all photographs were processed by a single individual. The raw point data from all photographs on a transect line were combined to calculate the percent cover of each benthic component for the entire belt transect. The number of photos analyzed and points per photo were derived from a power analysis conducted to determine the optimal sampling effort to maximize the statistical power of annual comparisons.

Fish Community Surveys

All fish within or passing through a 5 m wide belt along each of the two 25 m transects deployed at each survey site were identified to species and sized into 5 cm bins (*i.e.*, 0-5 cm, >5-10 cm, >10-15 cm, etc.) Divers moved slowly along the transects, taking between 10 and 15 minutes to complete each belt survey. This method closely corresponds with that used by Dr. Alan Friedlander and colleagues for the “Fish Habitat

Utilization Study" (FHUS), and provides comparable data. Details of their method and results of those surveys are given in a number of recent publications (Friedlander *et al.* 2006, Friedlander *et al.* 2007a, 2007b).

At some sites, a 5-minute timed swim was conducted after divers completed surveying the 25 m transect lines. For the timed swims, the two fish surveyors swam approximately 5 m apart and visually censused all fish larger than 15 cm within or passing through a 5 m wide column (centered on the surveyor) extending from the ocean bottom to the surface. Divers communicated with each other to ensure that each fish was censused by only one surveyor (*i.e.*, fish were not double counted). All fish were identified to the lowest possible taxonomic level and sized into 5 cm bins.

<u>Data Analysis</u>

Individual fish biomass (wet weight of fish per m^2 of reef area) was calculated from estimated lengths using size to weight conversion parameters from FishBase (Froese and Pauly, 2010) or the USGS Hawai‘i Cooperative Fisheries Research Unit (HCFRU). For analyses among survey sites, fish survey data were pooled into several broad categories, including: (1) all fishes, excluding manta rays; (2) target fishes[10], which are reef species targeted or regularly harvested by fishers (Table B.1); (3) prime spawners[11], which are target fishes larger than 70% of the maximum size reported for the species; and (4) non-target fishes, which are species not targeted by fishers to any significant degree. Non-target taxa included: non-target wrasses (all wrasse species other than those listed in Table B.1); non-target surgeonfishes (*Acanthurus nigrofuscus* and *A. nigricans*); hawkfishes (all species except the stocky hawkfish, *Cirrhitus pinnulatus*); triggerfishes excluding planktivores; corallivorous butterflyfishes (*Chaetodon multicinctus, C. ornatissimus, C. quadrimaculatus* and *C. unimaculatus*); and benthic damselfishes (all *Plectroglyphidodon* and *Stegastes* species).

Standard parametric and non-parametric statistical approaches, as appropriate, were used to test for differences between years. As necessary, fish biomass and abundance were log-transformed to correct skewness and heteroscedasticity prior to analysis. All means are presented as the average ± the standard error of the mean (SEM).

Benthic and fish communities were examined using the suite of non-parametric multivariate procedures included in the PRIMER statistical software package (Plymouth

[10] Nearly all fish species are taken by some fishers at some time in Hawai‘i, therefore designating a fish species as either ‘targeted’ or ‘non-targeted’ is oftentimes difficult. These two groupings are intended to represent the high and low ends of the fishing pressure continuum. The majority of fish biomass at most sites is comprised of species that fall somewhere in the middle of this continuum, and these species were not included in either group for this analysis.

[11] Large target fishes are generally heavily targeted by fishers. In addition, fishes at the high end of their size range tend to be a disproportionately important component of total stock breeding potential due to greater fecundity of large individuals, and higher survivorship of larvae produced by large fishes (Williams *et al.* 2008). Therefore ‘prime spawner’ biomass is likely to be a good indicator of fishing impacts, and represents an important component of ecological function (*i.e.*, population breeding potential).

Table B.1. The fish species targeted by fishers in Hawai'i included as "Target Fish" for this report.

Surgeonfishes (Acanthuridae)
- *Acanthurus achilles*
- *Acanthurus blochii*
- *Acanthurus dussumieri*
- *Acanthurus leucopareius*
- *Acanthurus nigroris*
- *Acanthurus olivaceus*
- *Acanthurus triostegus*
- *Acanthurus xanthopterus*
- *Ctenochaetus* spp.
- *Naso* spp.

Wrasses (Labridae)
- *Bodianus albotaeniatus*
- *Cheilio inermis*
- *Coris flavovittata*
- *Coris gaimard*
- *Iniistius* spp.
- *Oxycheilinus unifasciatus*
- *Thalassoma ballieui*
- *Thalassoma purpureum*

Parrotfishes (Scaridae)
- All

Apex
- *Aphareus furca*
- *Aprion virescens*
- All Priacanthidae (big-eyes)
- All Sphyraenidae (barracuda)

Goatfishes (Mullidae)
- All

Jacks (Carangidae)
- All

Soldier/Squirrelfishes(Holocentridae)
- *Myripristis* spp.
- *Sargocentron spiniferum*
- *Sargocentron tiere*

Others
- *Chanos chanos*
- *Cirrhitus pinnulatus*
- *Monotaxis grandoculis*

Non Target
- *Acanthurus nigricans*
- *Acanthurus nigrofuscus*
- *Anampses chrysocephalus*
- *Anampses cuvier*
- *Chaetodon lunulatus*
- *Chaetodon multicinctus*
- *Chaetodon ornatissimus*
- *Chaetodon quadrimaculatus*
- *Chaetodon reticulatus*
- *Chaetodon unimaculatus*
- *Chromis agilis*
- *Chromis hanui*
- *Chromis leucura*
- *Cirrhitops fasciatus*
- *Coris venusta*
- *Gomphosus varius*
- *Halichoeres ornatissimus*
- *Labroides phthirophagus*
- *Labridae sp.*
- *Macropharyngodon geoffroy*

Non Target (continued)
- *Novaculichthys taeniourus*
- *Oxycheilinus bimaculatus*
- *Paracirrhites arcatus*
- *Paracirrhites forsteri*
- *Plectroglyphidodon imparipennis*
- *Plectroglyphidodon johnstonianus*
- *Pseudocheilinus evanidus*
- *Pseudocheilinus octotaenia*
- *Pseudocheilinus tetrataenia*
- *Pseudocheilinus cerasinua*
- *Rhinecanthus aceleatus*
- *Rhinecanthus rectangulus*
- *Stegastes marginatus*
- *Stethojulis balteata*
- *Sufflamen bursa*
- *Sufflamen fraenatus*
- *Thalassoma duperrey*
- *Thalassoma lutescens*
- *Thalassoma quinquevittatum*
- *Thalassoma trilobatum*

Routines in Multivariate Ecological Research) (Clarke and Warwick 2001). These procedures have gained widespread use for analyzing marine ecological community data, and have significant advantages over standard parametric procedures (see Clarke 1993 for additional information).

Prior to analysis, percent cover data for each benthic category were square-root transformed and a Bray-Curtis similarity matrix generated (Clarke and Warrick 2001, Clarke and Gorley 2006). Non-metric multidimensional scaling (nMDS) plots were generated to explore patterns (Clarke and Gorley 2006) in benthic composition.

As with the benthic community data, fish biomass data at all sites were square-root transformed and a Bray-Curtis similarity matrix generated (Clarke and Warrick 2001, Clarke and Gorley 2006) prior to analysis in PRIMER. Non-metric multidimensional scaling (nMDS) plots were generated to explore patterns (Clarke and Gorley 2006) in fish community structure.

Key taxa representative of zones were selected using PRIMER's SIMPER analysis. Any taxa with a DISS/SD>1.4 were considered to be representative of the zone. The ratio of the average dissimilarity and standard deviation (DISS/SD) is given as a measure of how consistently the species contributes to the characterization of differences between groups, with larger values (>1.4) indicating greater consistency as a discriminating species (Clarke and Warrick 2001).

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Appendix C. Glossary of Scientific Terms

Abundance: The relative representation of a species in a particular ecosystem. It is usually measured as the number of individuals found per sample.

Assemblage: All of the various species of a particular type or group that exist in a particular habitat (e.g., all fish, all coral). A species assemblage is a subset of all of the species within an ecological community, e.g., the fish assemblage is part of the coral reef community.

Belt Transect: A sampling unit used in biology to investigate the distribution of organisms in relation to a certain area. It records the number of individuals for all the species found between two lines.

Benthic Organism: An animal or plant that resides primarily on the bottom, whether attached (e.g., coral, algae), or unattached (e.g., snail, crabs).

Biomass: The mass of living biological organisms in a given area or ecosystem at a given time. Usually expressed as a mass or weight per unit area, e.g., tons/acres or g/m^2.

Prime spawners: Large target fishes (>70% their maximum size) that are generally prized by fishers and tend to contribute disproportionately more to the total reproductive potential of the population than smaller individuals due to their greater egg and sperm production (i.e., higher fecundity) and the higher survivorship of their larvae. Prime spawner biomass is a good indicator of fishing impacts.

Quadrat (Photo-quadrat): A square used in ecology to isolate a sample, usually about with a relatively small area (e.g., 0.25 m^2 or 1 m^2). A quadrat is suitable for sampling sessile or slow-moving animals. A photo-quadrat is a picture taken of a quadrat.

Rugosity: A measure of small-scale variations in the height of the reef. As a measure of complexity, rugosity is presumed to be an indicator of the amount of habitat available for colonization by benthic organisms (those attached to the seafloor), and shelter and foraging area for mobile organisms.

Target fishes: Fish desirable for food, commercial activity, and/or cultural practices that reside in the habitats and depth ranges surveyed by the TNC marine monitoring team. Nearly all fish species are taken by some fishers at some time in Hawaiʻi, therefore designating a fish species as either ‘targeted’ or ‘non-targeted’ is oftentimes difficult. These two groupings are intended to represent the high and low ends of the fishing pressure continuum. The majority of fish biomass at most sites is comprised of species that fall somewhere in the middle of this continuum.