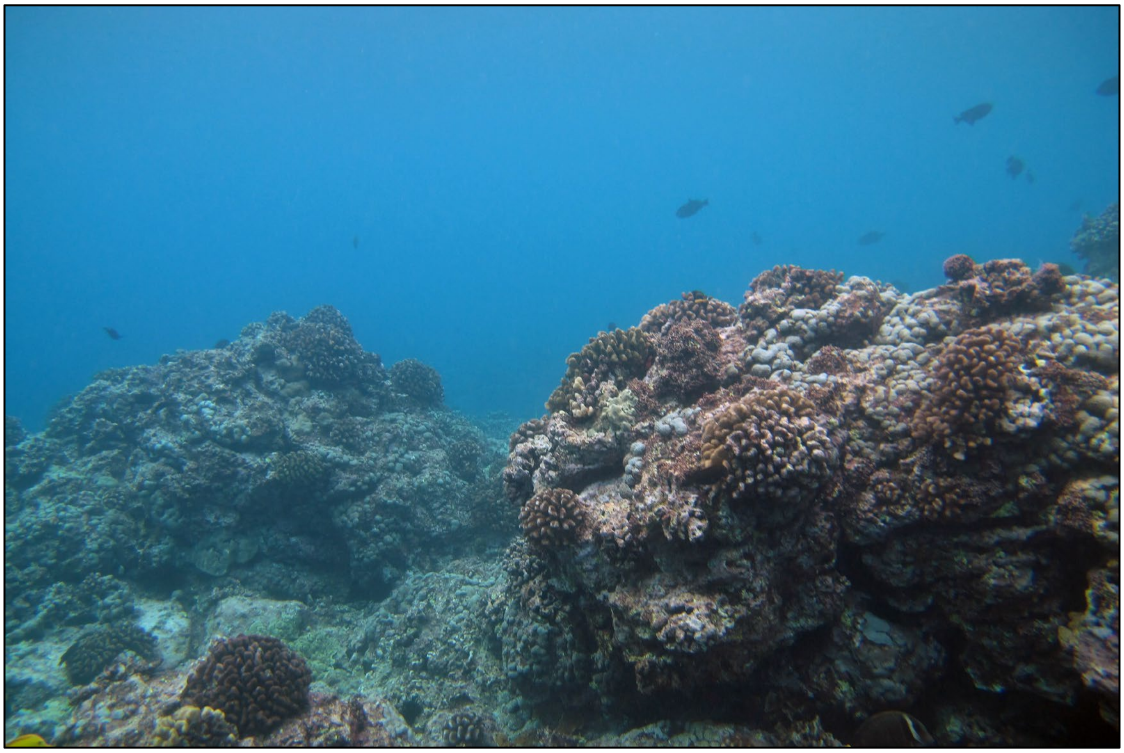
Baseline Biological Surveys of the Coral Reefs of ʻĀhihi-Kīnaʻu Natural Area Reserve, Maui, Hawaii



A reef area within the ʻĀhihi Kīnaʻu Natural Area Reserve. Photo © TNC.

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Baseline Biological Surveys of the Coral Reefs of ‘Āhihi-Kīna‘u Natural Area Reserve, Maui, Hawai‘i

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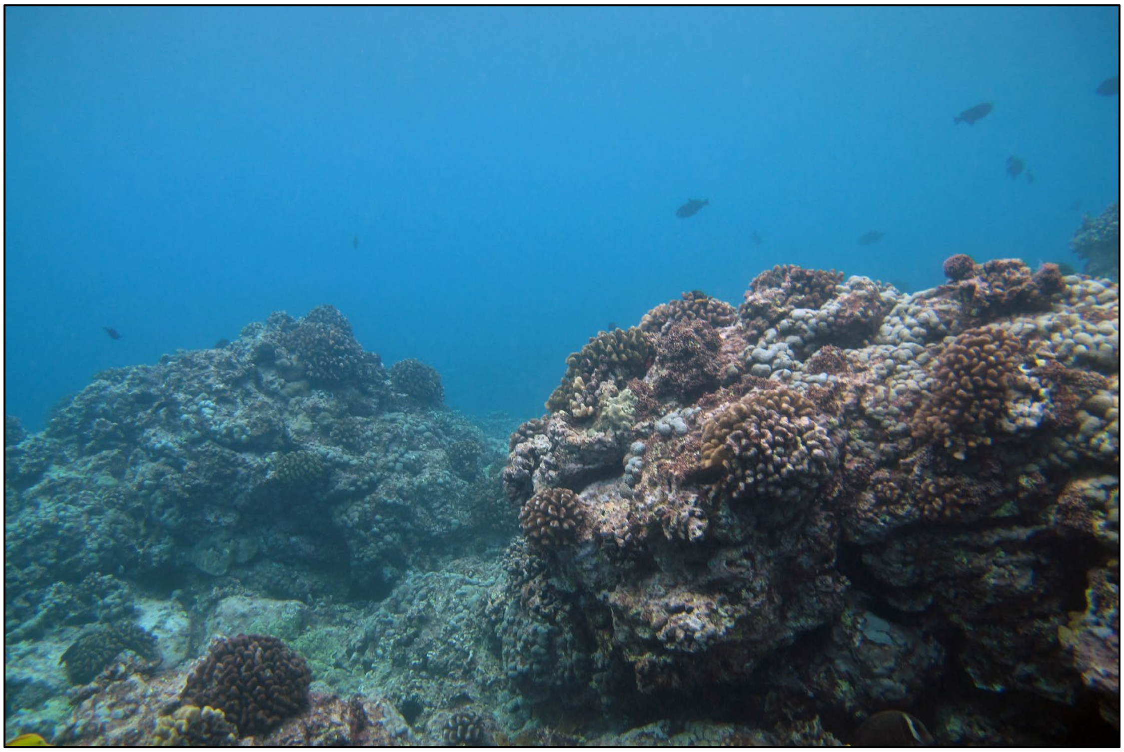

April 20, 2016

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Cover Image: A reef area within the ‘Āhihi Kīna‘u Natural Area Reserve (Site: 2014-AHI17).

1.0 Summary

The ʻĀhihi-Kīnaʻu Natural Area Reserve (hereafter, the Reserve) is the only reserve in Hawaiʻi 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 Hawaiʻi. 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 ʻĀhihi-Kīnaʻu'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

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[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).

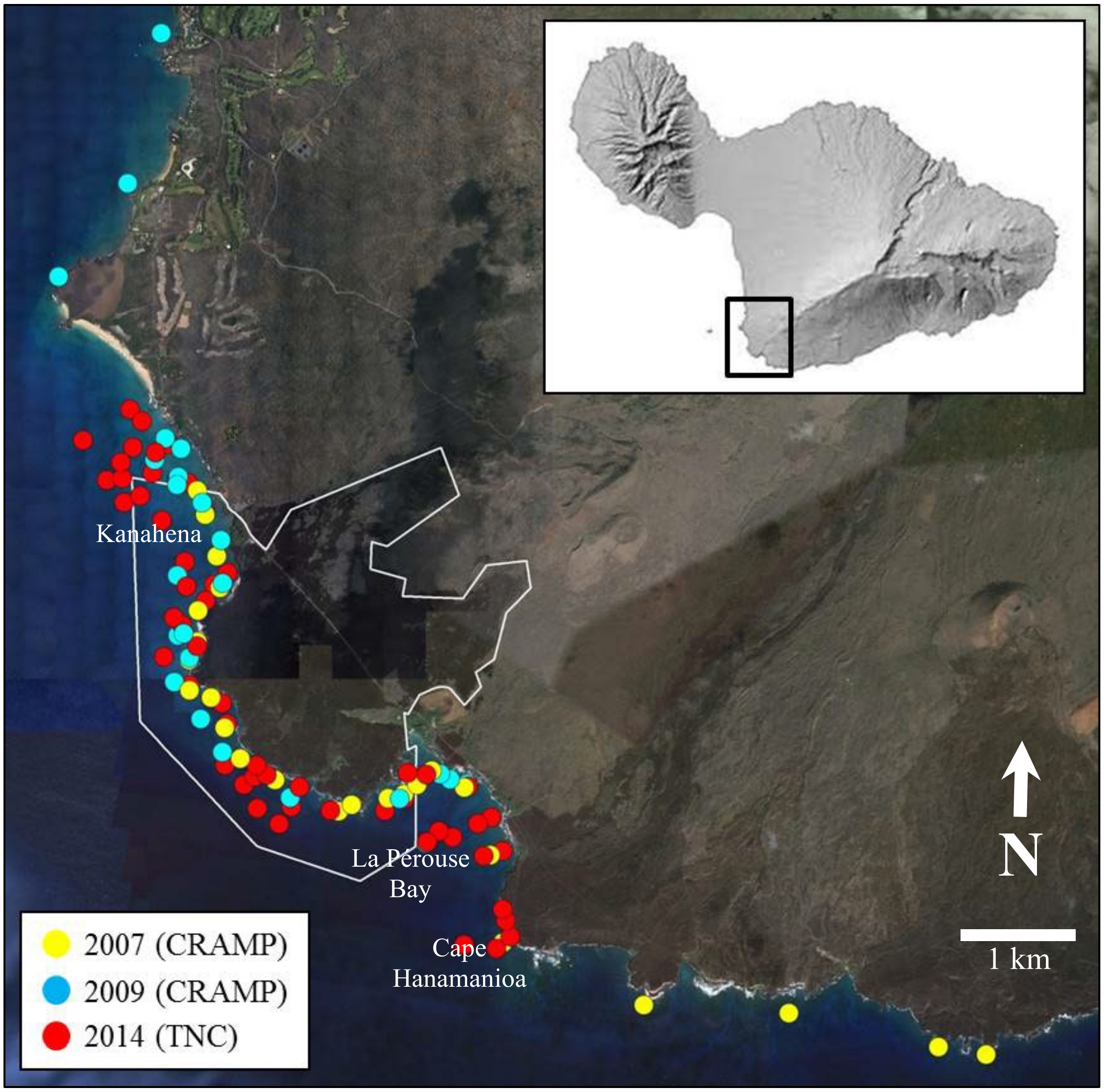

Figure 1. Locations of coral reef survey sites from 2007-2014. The 2007 and 2009 surveys were conducted by the University of Hawaiʻi's Coral Reef Assessment and Monitoring Program (CRAMP). The 2014 surveys were conducted by The Nature Conservancy (TNC) and the Division of Aquatic Resources (DAR). The 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 Hawaiʻi 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.

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[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

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[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.

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[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 Hawai'i, particularly on the island of O'ahu. 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.

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[6] The Reserve's marine boundaries were designated to encompass the entirety of the lava flow at Cape Kīna'u, 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.

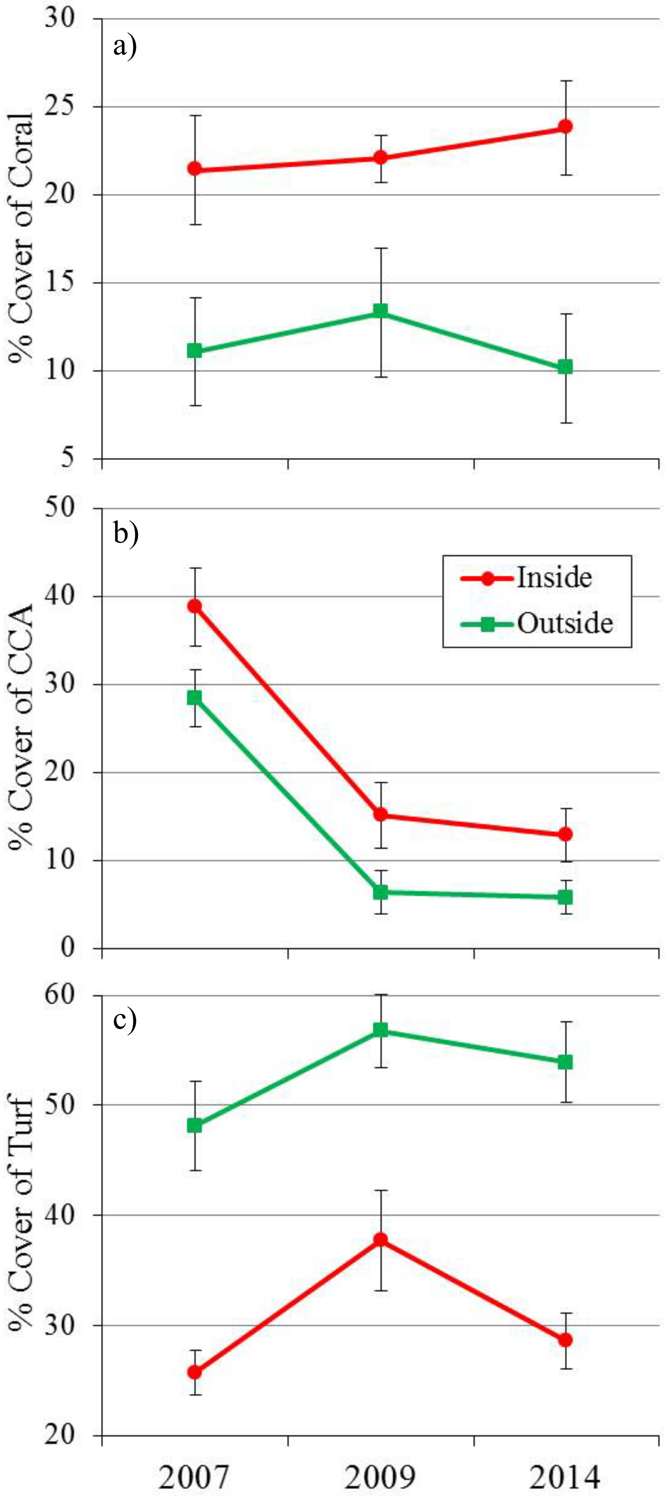

Figure 2. Percent cover of (a) coral, (b) crustose coralline algae (CCA), and (c) turf algae at sites inside and outside the Reserve. Data for 2007 and 2009 are from CRAMP.

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 taʻape), 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).

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[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.

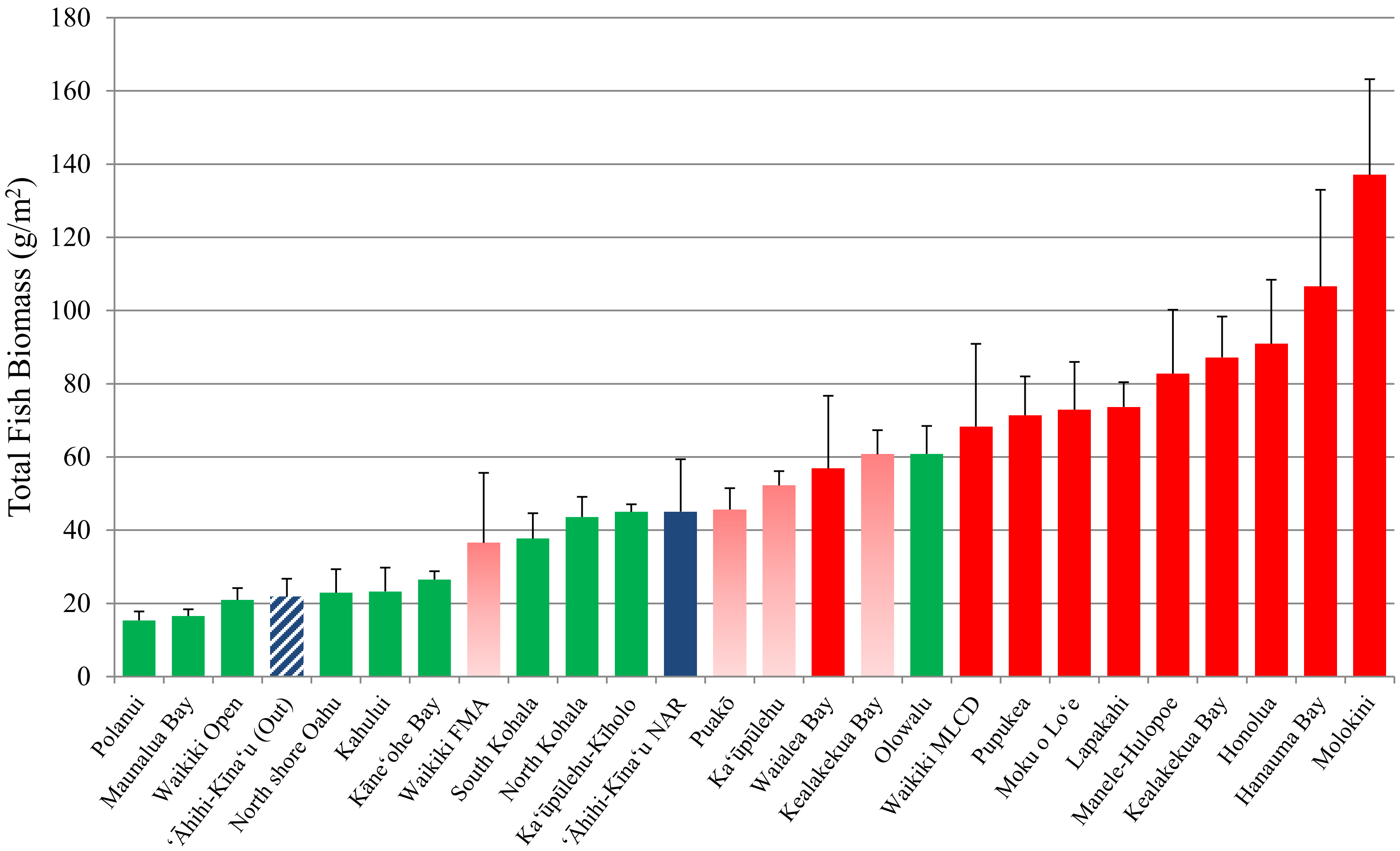

Figure 3. Total fish biomass on the reefs inside the Reserve (solid blue bar) and on reefs outside of, but adjacent to the Reserve boundary (hatched blue bar) compared to 24 other sites in the state of Hawai‘i. Color of bars represents level of fisheries management occurring at the site: green=no additional 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.

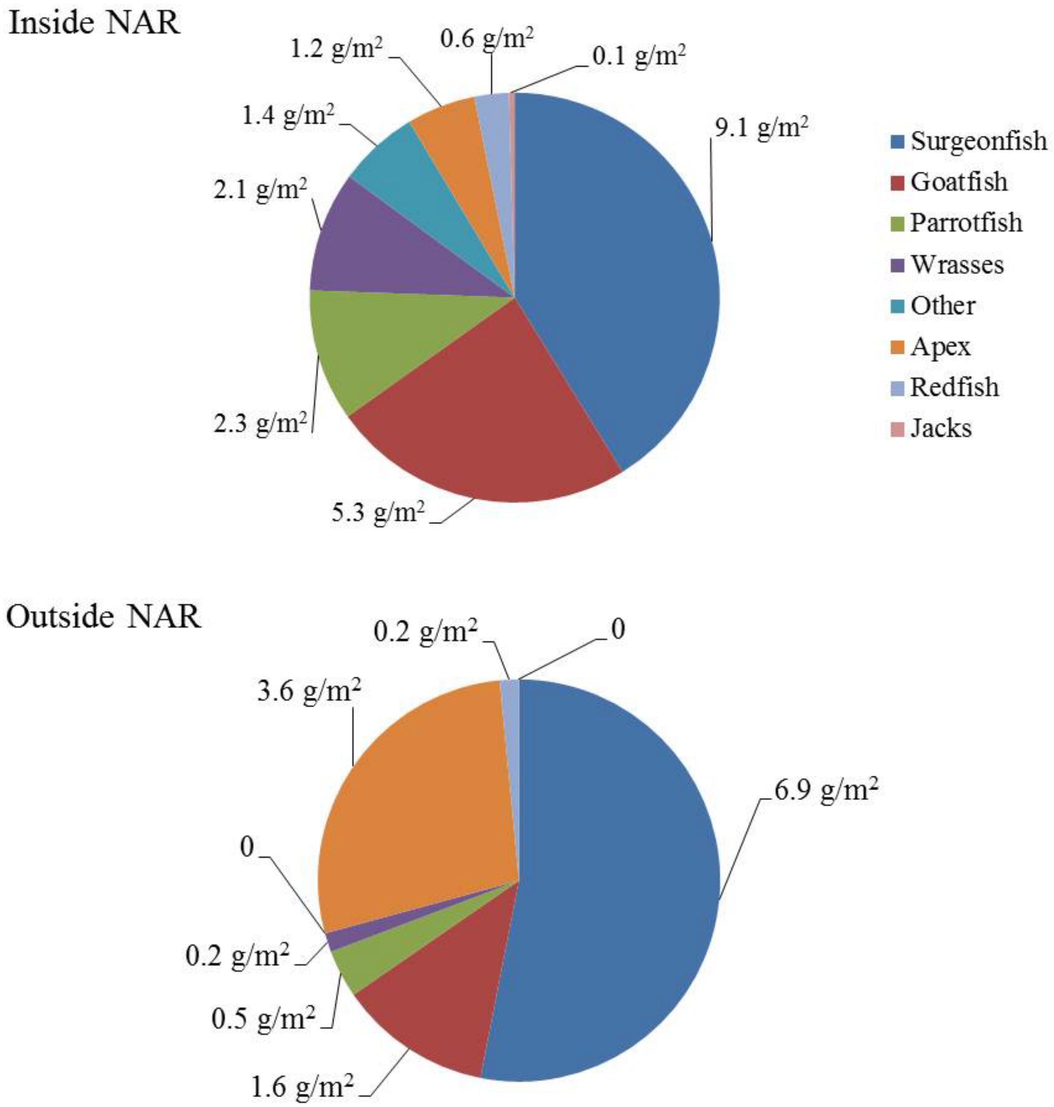

Figure 4. Composition of target fish inside (top) and outside (bottom) the Reserve. Values are biomass (g/m^2) of all fish within that target fish group.

As with total fish biomass, when comparisons were made with other Maui and statewide reefs, target fish biomass at ‘Āhihi-Kīna‘u 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.

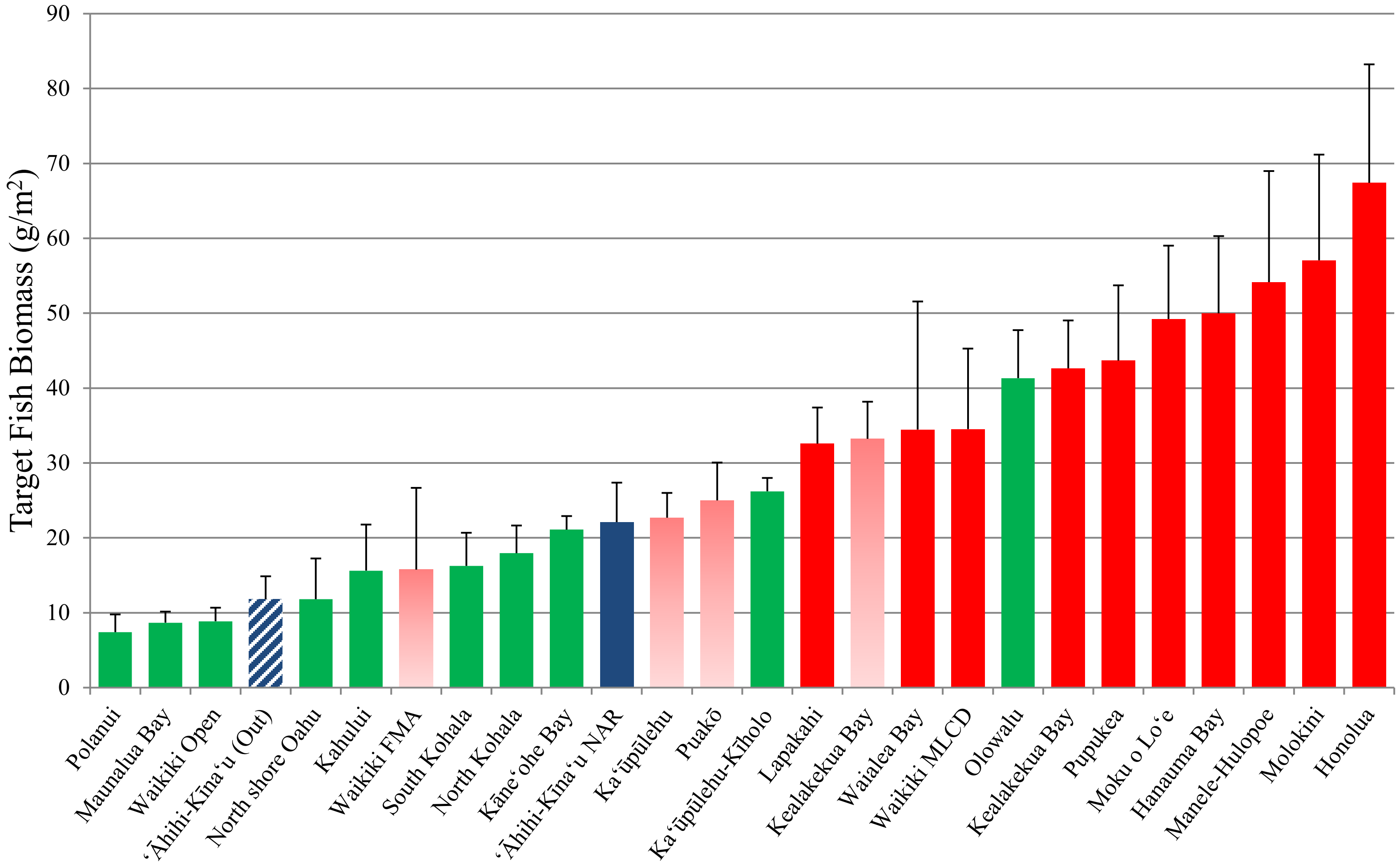

Figure 5. Target fish biomass on the reefs inside the Reserve (solid blue bar) and on reef outside of, but adjacent to the Reserve boundary (hatched blue bar) compared to 24 other sites in the state of Hawaiʻi. Color of bars represents level of fisheries management occurring at the site: green=no additional 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 Loʻe on Oʻahu being lower.

Invasive Fishes

Recently, many communities across Hawaiʻi 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 toʻau) (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

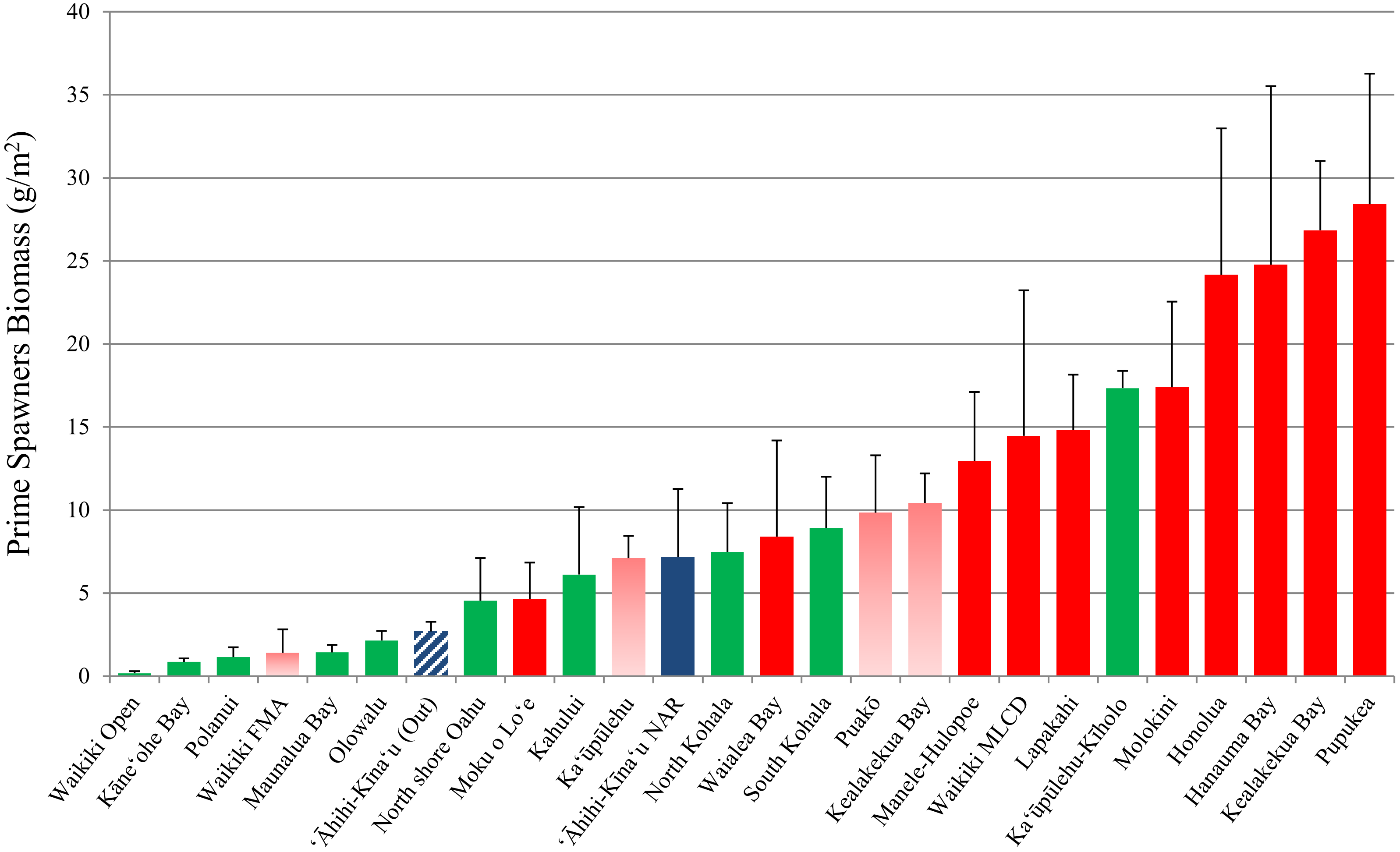

Figure 6. Prime spawner biomass on the reefs inside the Reserve (solid blue bar) and on reef outside of, but adjacent to the Reserve boundary (hatched blue bar) compared to 24 other sites in the state of Hawaiʻi. Color of bars represents level of fisheries management occurring at the site: green=no additional 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.

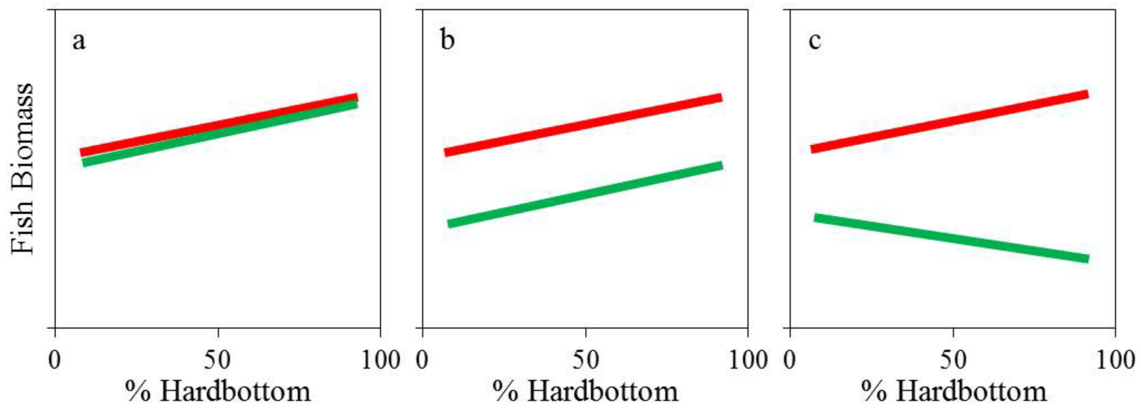

Figure 7. Conceptual figures for examining the potential effect of habitat differences on the fish assemblage inside (red lines) and outside (green lines) the ʻĀhihi-Kīnaʻu Reserve. Percent hard bottom is a quantitative measure of the amount of reef habitat available to the reef fish assemblage. Assuming 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

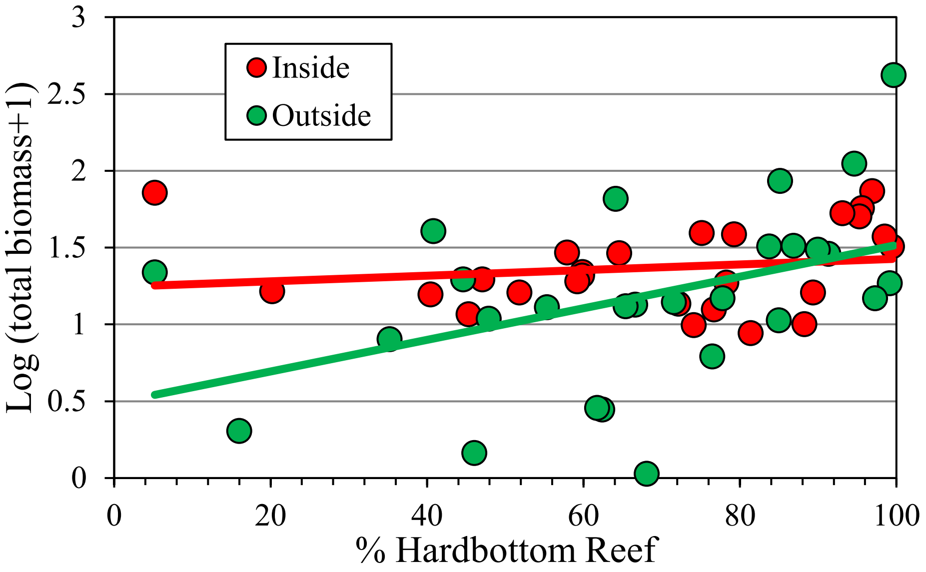

Figure 8. Log-transformed total fish biomass (g/m^2) versus percent cover of hard bottom at sites inside (red circles/line) and outside (green circles/line) the Reserve. Lines are linear trend lines and intended as a visual aid to illustrate the biomass-hard bottom relationship.

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

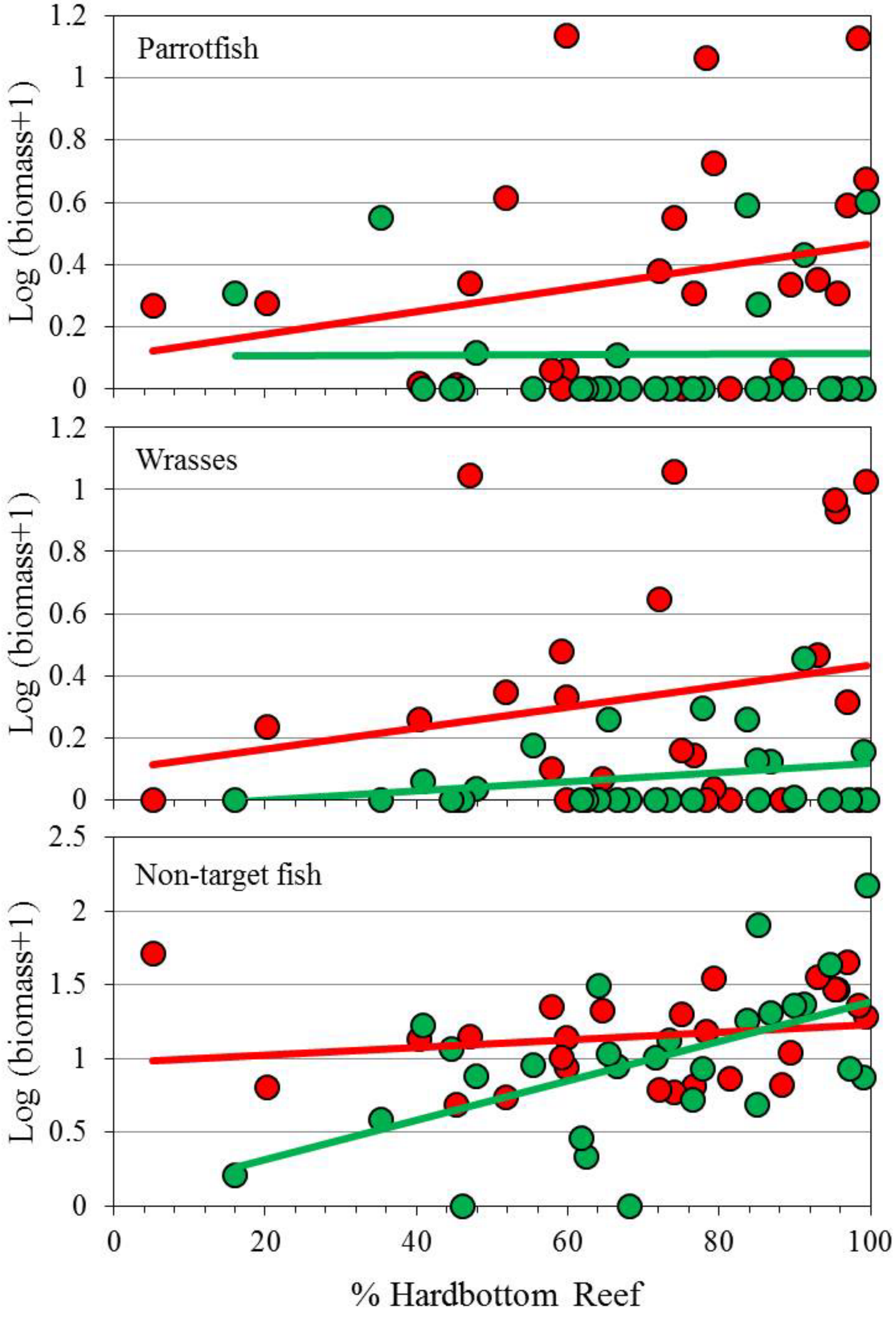

Figure 9. Parrotfish, wrasse, and non-target fish biomass (g/m^2) versus percent cover of hard bottom at sites inside (red circles/lines) and outside (green circles/lines) of the Reserve. Lines are linear trend lines and intended as a visual aid to illustrate the biomass-hard bottom relationship.

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 Hawaiʻi 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.

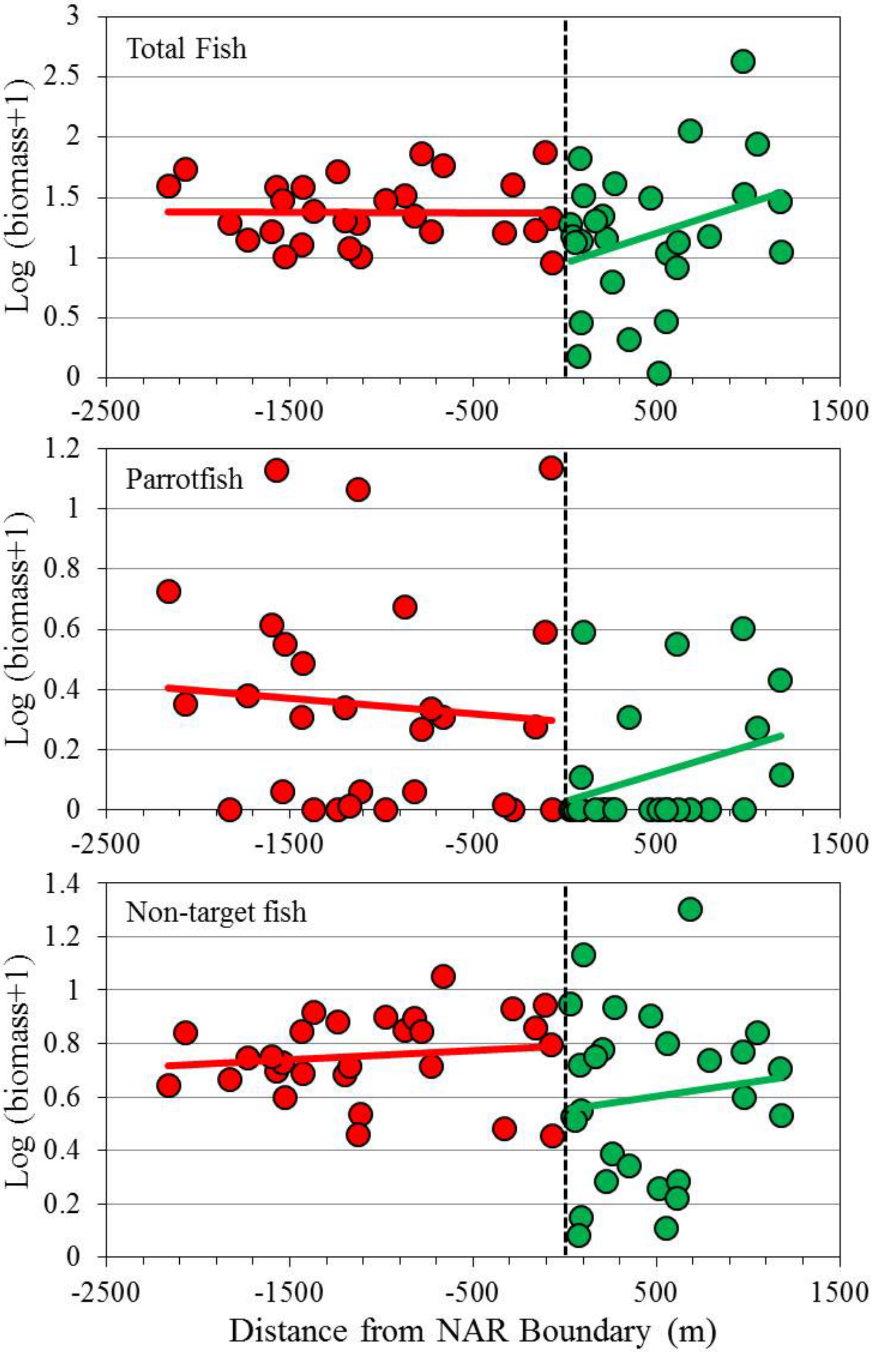

Figure 10. Total fish, parrotfish and non-target fish biomass (g/m^2) versus distance from the Reserve boundary. Negative numbers indicate increasing distance from the boundary into the Reserve, whereas positive numbers indicate increasing distance away from the Reserve boundary into open areas. Fishing 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.

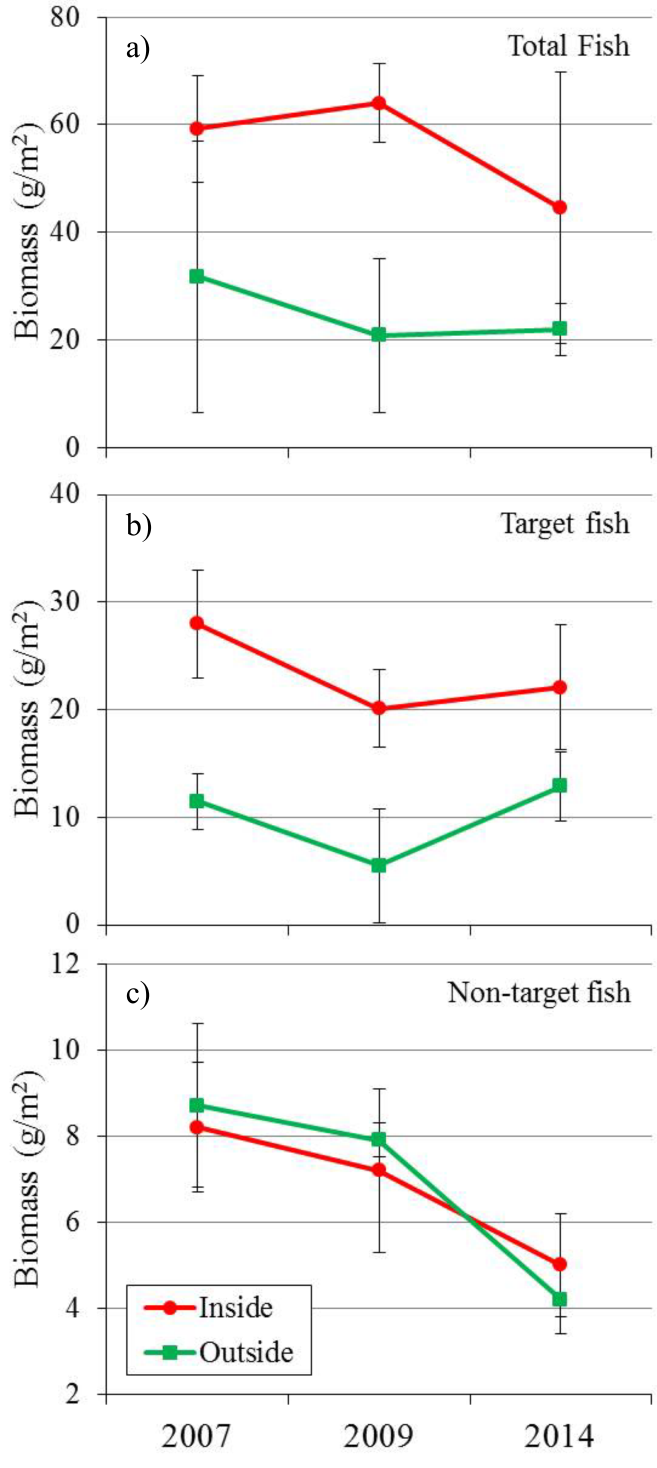

Figure 11. Total fish (a), target fish (b), and non-target fish (c) biomass (g/m^2) inside and outside the Reserve. Data for 2007 and 2009 are from CRAMP.

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 ʻĀhihi-Kīnaʻu 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 ʻĀhihi-Kīnaʻu 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, taʻape, toʻau)	
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 ʻĀhihi-Kīnaʻu 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.

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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 Hawai‘i.

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 ‘Āhihi-Kīna‘u 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.

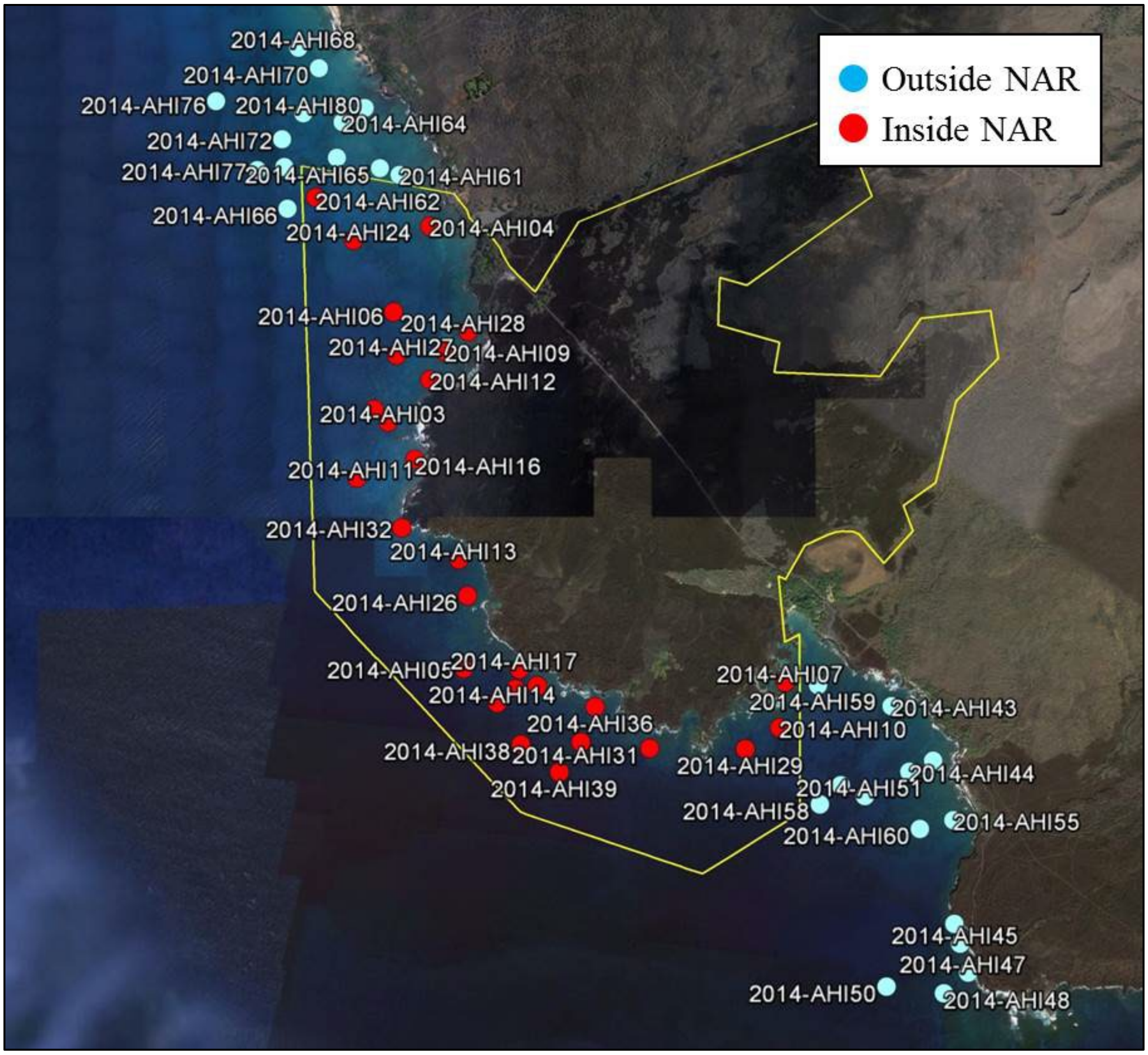

Figure B.1. ‘Āhihi-Kīna‘u NAR with the 55 randomly generated marine monitoring sites surveyed during December 2014.

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*);

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[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.

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*

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*

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

Parrotfishes (Scaridae)
All

Sargocentron tiere

Others
Chanos chanos
Cirrhitus pinnulatus
Monotaxis grandoculis

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 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.