

# Establishing the Baseline Condition of Marine Resources: Results of 2012 and 2013 Ka‘ūpūlehu, Hawai‘i Marine Surveys

by

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Photo by Peter French

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

Common Name	Hawaiian Name	Scientific Name
Rice coral	‘Āko‘ako‘a	<i>Montipora capitata</i> (=verrucosa)
Sandpaper rice coral	Ko‘a	<i>Montipora patula</i>
Cauliflower coral	Ko‘a	<i>Pocillopora meandrina</i>
Finger coral	Pōhaku puna	<i>Porites compressa</i>
Lobe coral	Pōhaku puna	<i>Porites lobata</i>

Common Name	Hawaiian Name	Scientific Name
Ringtail surgeonfish	Pualu	<i>Acanthurus blochii</i>
Eyestripe surgeonfish	Palani	<i>Acanthurus dussumieri</i>
Brown surgeonfish	Mā‘i‘i‘i	<i>Acanthurus nigrofuscus</i>
Orangeband surgeonfish	Na‘ena‘e	<i>Acanthurus olivaceus</i>
Convict tang	Manini	<i>Acanthurus triostegus</i>
Green jobfish	Uku	<i>Aprion virescens</i>
Peacock groupers	Roi	<i>Cephalopholis argus</i>
Bullethead parrotfish	Uhu	<i>Chlorurus spilurus</i>
Goldring bristletooth	Kole	<i>Ctenochaetus strigosus</i>
Black durgon	Humuhumu ‘ele‘ele	<i>Melichthys niger</i>
Striped mullet	‘Ama‘ama	<i>Mugil cephalus</i>
Bigscale soldierfish	‘Ū‘ū	<i>Myripristis berndti</i>
Orangespine unicornfish	Umaumalei	<i>Naso literatus</i>
Sixfeeler threadfin	Moi	<i>Polydactylus sexfilis</i>
Bigeye scad	Akule	<i>Selar cumenophthalmus</i>
Saddle wrasse	Hinālea lau-wili	<i>Thalassoma duperrey</i>
Yellow tang	Lau‘ipala	<i>Zebrasoma falvescens</i>

**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 because a single Hawaiian name can apply to multiple species. Hawaiian names were obtained primarily from three sources: Randall (2007) for fish, and Hoover (1998) and Bernice P. Bishop Museum's (<http://www.bishopmuseum.org/research/natsci/invert/hawaiiannames.html>) for invertebrates.

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**Cover photo:** Kaupulehu ahupua‘a extends from the fringing reef to the summit of Hualalai mountain in North Kona, Hawai‘i Island (photo by Peter French).

## 1.0 Summary of Findings

The coastal fishing grounds of Ka‘ūpūlehu, north Kona, Hawai‘i were once renowned for their abundance of fish, lobster, octopus, and limpets, but monitoring efforts since the early 1990s show coral cover and fish abundance at Ka‘ūpūlehu have significantly declined, reinforcing the observations of longtime community members.

To reverse this trend, the Ka‘ūpūlehu community asked the State of Hawai‘i to institute a 10-year moratorium—a resting period—on fish harvest, within the current Ka‘ūpūlehu Fish Replenishment Area (FRA) to allow resident fish populations an opportunity to recover and to improve the overall health of their nearshore coral reef ecosystem.

The Nature Conservancy (TNC) supported this community-led initiative by supplying scientifically credible information on the current status and trends of Ka‘ūpūlehu’s nearshore reefs, including their corals and fisheries. Our survey design and sampling protocols were specifically chosen to provide compatibility with other monitoring efforts in Hawai‘i. The valuable baseline assessment of fish and benthic assemblages, collected within the Ka‘ūpūlehu FRA from 2009-2013 and in adjacent areas (control sites) from 2012-2013, represents one of the strongest pre-management datasets in existence and will be critical to assessing the effectiveness of the proposed 10-year resting period.

In 2012 and 2013, TNC and partners at the University of Hawai‘i’s Fisheries Ecology Research Lab surveyed 416 sites both inside and outside the Ka‘ūpūlehu FRA. The marine resources across the survey area showed signs of impact, especially from overharvest. Species targeted by fishers had lower biomass at Ka‘ūpūlehu-Kīholo compared to areas closed to fishing, whereas no difference in biomass was found for non-target species. While other stressors may be affecting the fish assemblage at Ka‘ūpūlehu, only fishing would selectively reduce the abundance of target fish species while not affecting non-target species, suggesting that the community-supported 10-year resting period can have a measureable benefit to the areas fisheries. .

Few differences were found between the benthic and reef fish assemblages inside and outside the FRA, which is not surprising considering the contiguous nature of the reef structure and that the current protections within the FRA are primarily limited to species collected for the aquarium market. Some aquarium species showed positive effects from the FRA protection in terms of higher biomass of large individuals, fish that contribute disproportionately more to the total breeding potential due to their greater sperm and egg production and the higher survivorship of their larvae.

We hope this scientifically credible information will strengthen community-led management efforts and help the Ka‘ūpūlehu community share their story and explain their decisions as they work to return abundance to their reefs.

## 2.0 Introduction

One commonality shared by many communities in Hawai‘i is an awareness of decline in the size, abundance, and variety of coral reef fishes. This observation is consistent with fisheries data that shows a drastic reduction in catch of coral reef species (Kittinger *et al.* 2011), and is bolstered by fisheries-independent<sup>1</sup> data showing vast disparities in fish and coral communities, both between the Main and Northwestern Hawaiian Islands (Friedlander and DeMartini 2002), and across the geographic range of the Main Hawaiian Islands (Williams *et al.* 2008, Friedlander *et al.* 2013).

The coral reefs of Ka‘ūpūlehu, north Kona, Hawai‘i were once renowned for their abundant nearshore fish species such as striped mullet or ‘ama‘ama (*Mugil cephalus*), bigscale soldierfish or ‘ū‘ū (*Myripristis berndti*), sixfeeler threadfin or moi (*Polydactylus sexfilis*), ringtail surgeonfish or pualu (*Acanthurus blochii*), bigeye scad or akule (*Selar cumenophthalmus*) and convict tang or manini (*Acanthurus triostegus*), and invertebrates species such as lobster, octopus, and limpets. While many of these species are still present, the Ka‘ūpūlehu community has observed a decline in abundance over the past decades. Stender (1999) documented a 41% decline in fish abundance and 26% decline in fish diversity over a six-year period from 1992 to 1998. Extending this data set, TNC has documented a nearly 75% decline in the abundance of target species between 1992 and 2011, compared to a ~25% decline in non-target species, concluding that impacts to the fish assemblage were consistent with overharvest (Minton *et al.* 2014).

Additionally, between 1992 and 1998, coral cover at Ka‘ūpūlehu declined by 31% (Stender 1999). A further 25% decline in coral cover was documented between 2003 and 2007 (Walsh *et al.* 2010). These findings were consistent with declines observed on other west Hawai‘i reefs (Minton *et al.* 2012).

To reverse these trends, the Ka‘ūpūlehu community, through the Ka‘ūpūlehu Marine Life Advisory Committee (KMLAC) and with the support of the West Hawai‘i Fisheries Council, has prepared a rule amendment proposal asking the State of Hawai‘i to strengthen management within the current Ka‘ūpūlehu FRA from a limited-take area to a full no-take area for ten years. If successful, this resting period will increase the abundance and size of economically- and culturally-important fishery species, such as parrotfish (uhu), surgeonfish (including pualu, palani, manini), and emperors (mū), and should improve the overall condition of the coral reef.

Currently, the Ka‘ūpūlehu FRA is open to the harvest of all non-aquarium fishery species, and is a popular site for both the local community and non-community members to fish. The proposed rules have received strong support from the Ka‘ūpūlehu community, but community leaders have also expressed concerns that fishers may be displaced from Ka‘ūpūlehu into adjacent areas, increasing harvest impacts on adjacent nearshore fishery resources, a result they wish to avoid. Individuals and groups from outside the community have opposed the resting period, raising concerns about their right to fish, adjacent impacts due to fisher displacement, and the

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<sup>1</sup> Data used to assess fisheries is classified as *fishery-independent* or *fishery-dependent*. Fishery-dependent data is collected from the fishery itself (*e.g.*, catch data, creel data, etc.). Fishery-independent data is obtained in the absence of any fishing activity (*e.g.*, transect surveys).

effectiveness of closures. While marine protected areas have been shown to provide positive benefits to fisheries in other areas (Malloy *et al.* 2009, Babcock *et al.* 2010), some vocal opponents on Hawai‘i Island and elsewhere in the state oppose them on the grounds that the success of protected areas elsewhere does not mean they will be successful in Hawai‘i, although several studies in Hawai‘i have already demonstrated positive benefits (Friedlander *et al.* 2006, Stamoulis and Friedlander 2013). Furthermore, the Hawaiian tradition of managing fisheries at the local scale reflects long held knowledge that rules and limits are vital to sustainable fishing.

Closures of areas to fishing have been shown to increase biomass of fishery species within the protected area and in adjacent areas through spillover in Hawai‘i (Stamoulis and Friedlander 2013) and through larval export (Harrison *et al.* 2012). These benefits accrue over time and may require from a few years to several decades to be realized depending on the life history of the fish species and other environmental factors (Babcock *et al.* 2010, McClannahan and Humphries 2012). Based on available data from other protected areas, the 10-year resting period proposed by the Ka‘ūpūlehu community should be of sufficient length to provide tangible benefits to many economically and culturally important fish species as well as cascading positive benefits to the entire reef community.

The establishment of a community-initiated 10-year resting period in Ka‘ūpūlehu provides an opportunity to collect and disseminate conclusive evidence of the benefits (or not) of marine protected areas to the coral reef ecosystem, local communities, and fishermen of Hawai‘i. Demonstrating the effect of the new community-initiated rules on the fisheries and coral reefs of Ka‘ūpūlehu and its adjacent areas, will be important to establishing the long-term effectiveness of community-driven fisheries management in the state of Hawai‘i.

This report describes the findings from surveys of the Ka‘ūpūlehu reef and adjacent reefs conducted between 2012-2013 by the TNC marine monitoring team and partners at the University of Hawai‘i’s Fisheries Ecology Research Laboratory<sup>2</sup>. These surveys were specifically designed and conducted to establish a rigorous baseline condition of fish and benthic resources both inside the proposed community management area and in adjacent areas. Combined with data previously collected by TNC, five years of baseline information is now available inside the Ka‘ūpūlehu FRA, and represents one of the strongest pre-management datasets in existence. These baseline data will be critical to assessing the effectiveness of the proposed 10-year resting period, and we hope it will be used to strengthen community-led management efforts by providing scientifically credible information that is of interest to the community, region, and state of Hawai‘i.

### **3.0 Site Description**

The survey area, collectively referred to in this report as Ka‘ūpūlehu-Kīholo, lies on the west coast of Hawai‘i Island, approximately 20 km (12.4 mi) north of Kailua-Kona (Figure 1), and

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<sup>2</sup> Creel surveys have been conducted to assess fishing effort within the study area. Those results are discussed elsewhere (Koike *et al.* 2015)

extends from the high water mark to the 20-m (~60-ft) depth cline and from approximately 1 km west of Kikaua Point to the north end of Kīholo Bay (Figure 1). The area encompasses coral reefs along approximately 12 km (7.5 mi) of coastline comprised primarily of basalt. It includes the entirety of shallow water reef within the Ka‘ūpūlehu FRA and approximately 6 km of shallow water reef adjacent to the FRA.

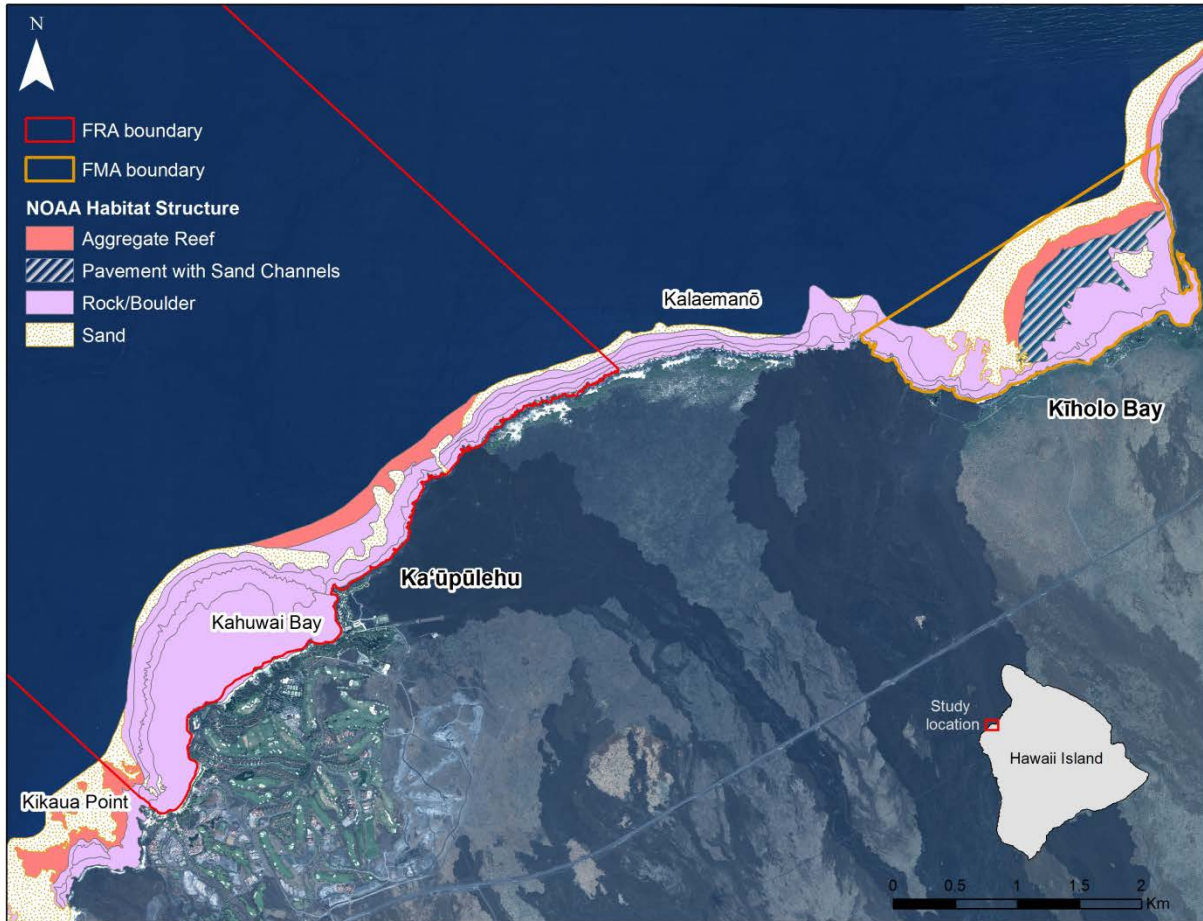
Coastal development along the proposed rest area at Ka‘ūpūlehu includes two resorts (one of which closed in 2011 due to damage from the Pacific-wide tsunami), a golf course, three public beach access areas, and several private residences. In contrast, Kīholo, the community to the north of Ka‘ūpūlehu and outside the boundary of the proposed rest area is relatively undeveloped, with a small resident population. Kīholo also has a culturally significant Hawaiian fishpond that is currently undergoing restoration by the Kīholo community through local non-profit Hui Aloha Kiholo, in collaboration with TNC and other partners.

Coastal habitats include dozens of anchialine pools, sheltered sandy bays, rocky lava benches, steep black sand beaches, salt works, and exposed sea cliffs formed by recent volcanic activity. The uplands of Ka‘ūpūlehu have dryland forest that extends to the summit of Hualalai mountain and provides habitat for many rare and endangered plant species. There are no streams or other permanent surface waters in this arid region, but groundwater seeps are common along the coast and are known to occur within the project area, perhaps best exemplified in the sacred spring Waiokāne, where sufficient freshwater flowed into the sea to provide fresh drinking water for the former resident population, and at Kīholo where freshwater inputs are extensive and well documented (Economy and Colbert 2013, Most *et al.* 2014)

Along much of the coastline, the fringing reef is narrow and drops quickly into deep water (Figure 1). However, a broad, shallow carbonate bench extends offshore between Kumukehu point and Kahuwai Bay. This bench extends over 700 m (~750 yd) offshore at its widest point. The shallow portions of this habitat are scoured by winter swells and remain relatively barren throughout the year. Along the edges of this area, grooves, caves, and walls drop from 5-10 m, clearly demarcating the bench from the sloping deeper reef which extended below the survey depth limit. The coral reef community on the bench has been shown to be significantly different from that on the predominantly narrow fringing reef to the north and south (Minton *et al.* 2014). Farther south lies the sandy beach of Uluweuweu, where the reef slopes more gradually with patch reefs and pavement channels slowly transitioning into coral dominated habitat.

Two areas with enhanced fishery management occur within the survey area (Figure 1). The Kīholo Fishery Management Area (FMA) encompasses the interior of Kīholo Bay, while the Ka‘ūpūlehu FRA extends from Kikaua Point to the northern boundary of the Ka‘ūpūlehu ahupua‘a. Both areas prohibit the use of lay gill and fine mesh nets and fish feeding and are located within the West Hawai‘i Regional Fishery Management Area (WHRFMA). The WHRFMA limits take of aquarium species, reef predators, and species of special concern, prohibits SCUBA spearfishing, and requires additional catch reporting and labelling of gear by





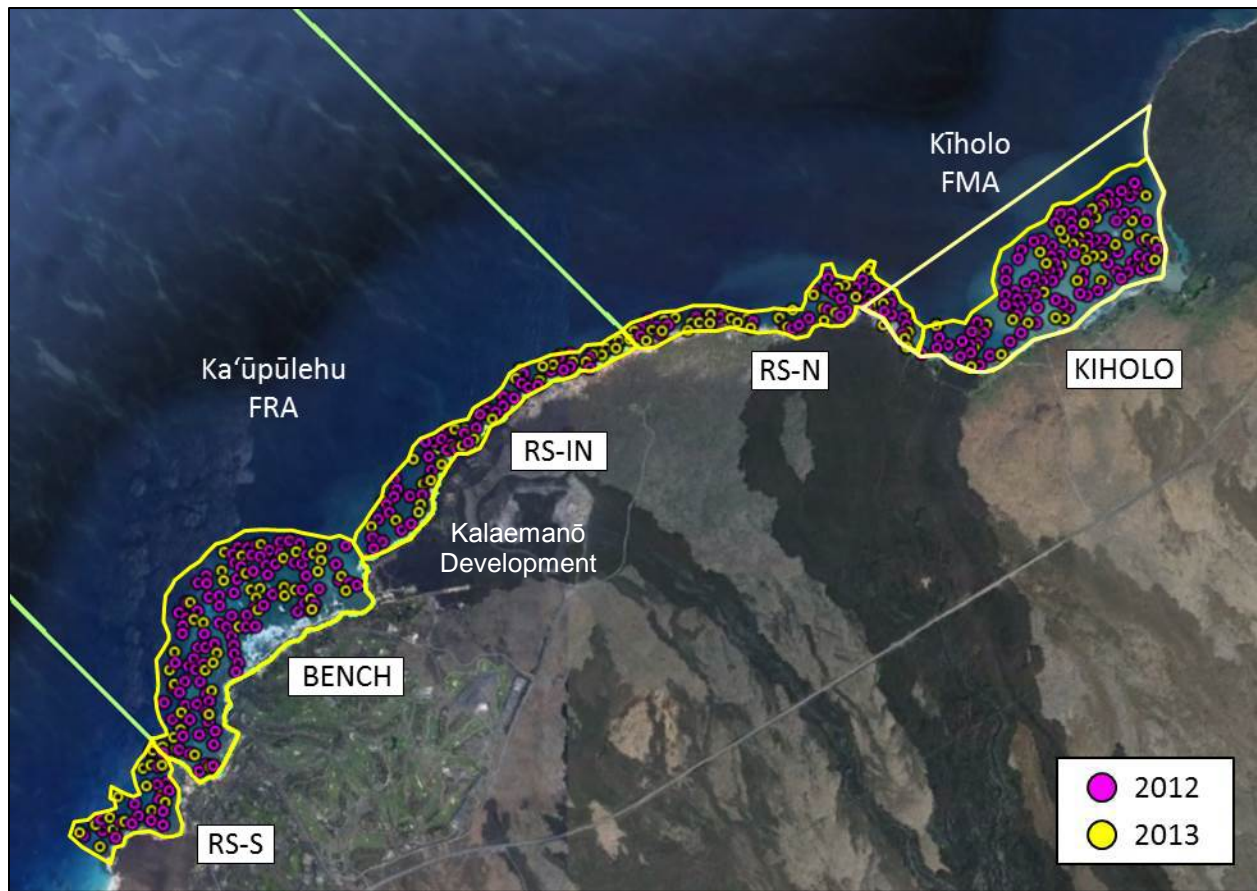
**Figure 1.** Ka'upulehu-Kiholo area of west Hawai'i. The Ka'upulehu Fish Replenishment Area (FRA), one of nine FRAs within the West Hawai'i Regional Fisheries Management Area, was established with community support in 2000. The Kiholo Fishery Management Area was established in 1997 and restricts the use of lay gill nets, but otherwise allows fishing with some additional reporting requirements. The Ka'upulehu community has proposed to enact a 10-year resting period within the Ka'upulehu FRA that would make it a full no-take reserve.

permitted reef fishers. The new community-proposed rules, if enacted, will establish a 10-year resting period within the Ka'upulehu FRA without changing the management of Kiholo FMA or adjacent areas.

#### 4.0 Survey Methods

Over the course of two years, the monitoring teams surveyed 416 randomly-selected<sup>3</sup> sites, including 290 in 2012, and 126 sites in 2013 (Figure 2). Sites were stratified across two factors: management status and reef area. Management status included two levels, inside and outside the Ka'upulehu FRA. Reef areas included: 1) an area of aggregate reef south of the Ka'upulehu

<sup>3</sup> Random sites were selected in order to get an unbiased measure of the community across the Ka'upulehu reef. 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 Ka'upulehu's reef community.



**Figure 2.** Survey sites at Ka'upulehu, Hawai'i, 2012-2013 stratified across five reef areas: RS-S, BENCH, RS-IN, RS-N, and KĪHOLO. See text for a description of each area.

FRA (hereafter, RS-S for “Reef Slope – South”), 2) the shallow bench within the Ka'upulehu FRA (BENCH), 3) the narrow fringing reef inside the Ka'upulehu FRA extending from Kumukehu point to the northern FRA boundary (RS-IN), 4) the narrow fringing reef extending from the northern boundary of the FRA to Kīholo Bay (RS-N), and 5) the shallow, relatively flat area within the Kīholo Bay (KĪHOLO) (Figure 2).

Prior to conducting surveys in 2013, we used the data collected in 2012 to determine the optimal number of sites to survey in 2013 (Appendix A). This resulted in a significant reduction in sampling effort while maintaining a high level of statistical rigor, and should provide guidance for future survey efforts along the Ka'upulehu-Kīholo reef area.

A detailed description of the survey methods used is included in Appendix B. Briefly, survey sites were randomly selected within the project area using ArcGIS software (Figure 2). In 2012, surveys sites were assigned across the survey area without regard to management status or reef area (*i.e.*, a simple random survey design). In 2013, they were assigned based on the results of the optimal sample size analysis, taking into account both management status and reef area in order to maximize sampling efficiency (Appendix A). Factors were assigned *post-hoc* to the 2012 survey sites prior to analysis (Table 1). At each survey site, divers identified, sized, and counted all individuals of all species of fish within two replicate 25x5 m belt transects. Using

**Table 1.** Survey sites at Ka‘ūpūlehu 2009-2013. Data from 2009-2011 are from fall survey events only (see Minton *et al.* 2014).

	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2102</b>	<b>2013</b>
Inside FRA	29	30	22	140	60
BENCH				96	34
RS-IN				44	26
Outside FRA			9	150	66
RS-S			4	18	9
RS-N			5	38	26
KĪHOLO				94	31
<b>TOTAL</b>	<b>29</b>	<b>30</b>	<b>31</b>	<b>290</b>	<b>126</b>

fish length and published size-to-weight conversions, fish biomass (weight of fish) was calculated for each size class of fish for each species and summed to obtain total fish biomass. Following the collection of fish data, photographs were taken along one 25-m transect line and rugosity (bottom topography) was estimated using a standardized chain method along the first 10 m of the line. Photographs of the bottom were taken every meter, and these "photo-quadrats" were later analyzed to estimate the percent cover of the coral (by three broad morphological types), algae (macroalgae, turf, and crustose coralline), and other benthic organisms present.

All data were entered into a custom Access database and checked for errors. Between 2009 and 2011, TNC conducted fish and benthic surveys within the Ka‘ūpūlehu FRA using identical methods (though with substantially lower sample sizes); data from those surveys are directly comparable with those collected in 2012 and 2013. Surveys in 2010 and 2011 were conducted in the fall and spring (Minton *et al.* 2014). For comparison here, only data from the fall sampling events were used to reduce possible seasonal variation. Thus, for sites within the Ka‘ūpūlehu FRA, we were able to examine a time series covering 2009-2013 using directly comparable data (*i.e.*, same survey area, season, sampling design, and survey methods).

All means are presented as the average  $\pm$  the standard error of the mean (SEM). Standard parametric and non-parametric statistical approaches, as appropriate, were used to test for differences between management status, among reef areas, and between years. In most cases, a multifactor ANOVA including sample year, management status, and reef area was used to examine summary-level variables (*e.g.*, total fish biomass, total fish abundance). Tukey multiple comparisons were used to identify differences within significant factors. As necessary, fish biomass and abundance were log-transformed to correct skewness prior to analysis. Multivariate analysis on the fish assemblage 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.

## 5.0 Results and Discussion

### 5.1 Benthic Assemblage

Coral cover at Ka‘ūpūlehu-Kīhōlo (Table 2) was consistent with that on other north Kona, Hawai‘i reefs, including Puakō (Minton *et al.* 2012) and the outer reef areas of Pelekane Bay (Minton *et al.* 2011).

As previous surveys have adequately described coral species richness in Ka‘ūpūlehu-Kīhōlo (Brock 2012, Minton *et al.* 2014), the 2012-2013 surveys identified coral to three morphological categories rather than individual species: massive (primarily *Porites lobata*), branching (primarily *P. compressa* and *Pocillopora meandrina*), and encrusting (primarily *Montipora* spp.). Massive corals dominated the Ka‘ūpūlehu-Kīhōlo reef, accounting for over 79% of all observed coral.

#### 5.1.1 Management status

Coral cover at Ka‘ūpūlehu-Kīhōlo varied by management status (ANOVA;  $F=38.75$ ;  $df=1,342$ ;  $p<0.001$ ), with the reef inside the Ka‘ūpūlehu FRA having significantly lower coral cover than outside. Lower cover of massive coral inside the FRA explained most of the observed difference between reefs inside and outside the FRA, but in general, the structure and relative composition of the coral assemblage was similar inside and outside the FRA. The decrease in coral cover was offset by a roughly similar increase in the cover of turf algae inside the FRA (Table 2). Otherwise, no other differences were found in the benthic assemblage between reef inside and outside the FRA.

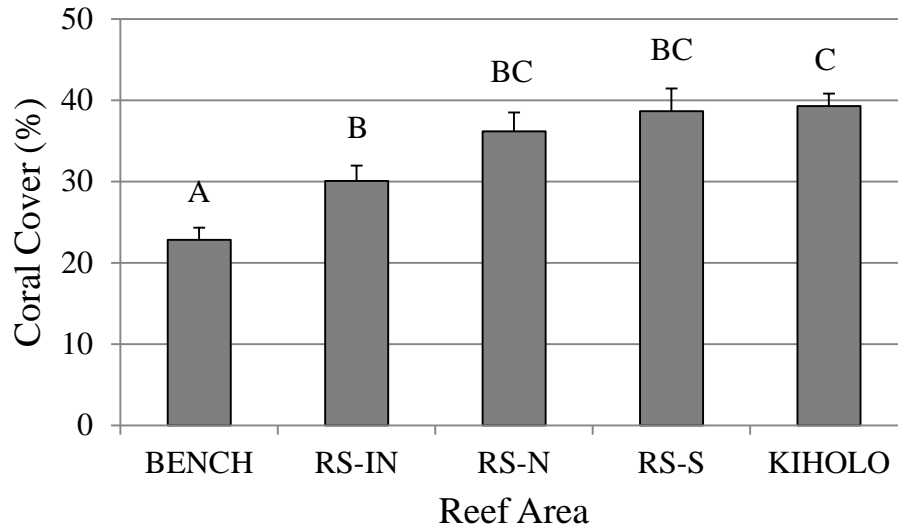
#### 5.1.2 Reef area

Coral cover's relationship with reef area was complex (Figure 3). Minton *et al.* (2014) identified a broad shallow reef bench that extends offshore from Kumukehu point to Kahuwai Bay (=BENCH) characterized by lower coral cover than the non-BENCH area inside the FRA (=RS-IN), likely due to more variable environmental conditions associated with a combination of higher wave action and groundwater inputs on the bench compared to other areas (Minton *et al.* 2014). Coral cover in RS-IN was significantly lower than in KIHŌLO, but was not different from other reef slope areas (RS-N and RS-S). The benthic community on the three reef slope areas was similar, regardless of their geographic location or management status. The difference in coral cover found between the benthic assemblages inside and outside the FRA are likely associated with differences in the physical structure of the reef, particularly the BENCH area which comprises about half of the reef area within the FRA. No other differences among areas were found.

#### 5.1.3 Time

While coral cover at Ka‘ūpūlehu-Kīhōlo did not significantly differ between sampling years (ANOVA;  $F=0.91$ ;  $df=1,342$ ;  $p=0.341$ ), determining how the 2012-2013 data compare with historical data would provide for the insight as to whether the benthic assemblage is stable or has





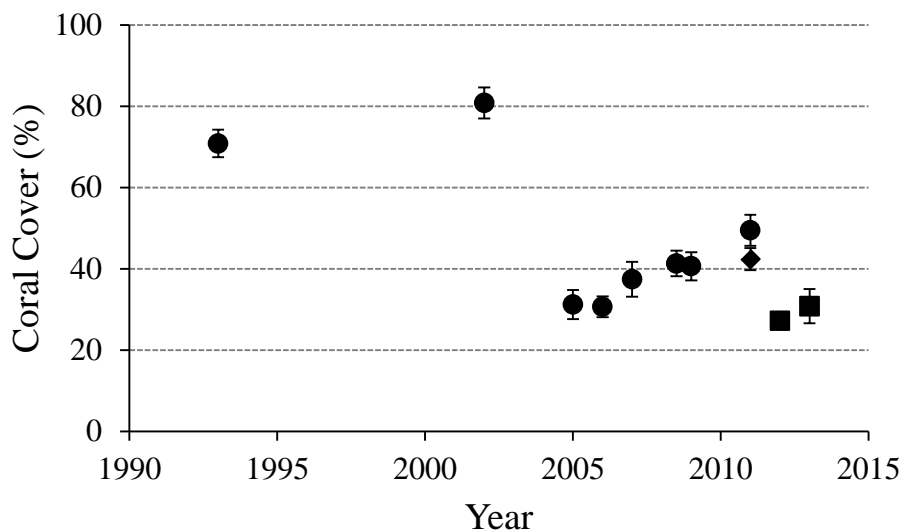
**Figure 3.** Coral cover by reef area. Bars with the same letter are not significantly different.

undergone change. Such comparisons with historical data sets are often complicated by the different methods and areas surveyed, but may still be illustrative.

In 2011, TNC conducted similar benthic surveys primarily within the boundary of the Ka‘ūpūlehu FRA, and found higher coral cover when compared to either 2012 or 2013 (Table 2). Reasons for this difference are not clear, and while a "real" decline in coral cover cannot be discounted, they seem unlikely over such a short time period (1 year) considering Hawai‘i experienced no significant wide-spread coral impacts in 2011. However, a localized event that impacted corals in the Ka‘ūpūlehu vicinity cannot be dismissed, or it is also possible the difference is the result of differential sampling effort. The decline may also be the continuation of a longer term trend; Walsh *et al.* (2012) noted a significant decline in coral cover at their Ka‘ūpūlehu monitoring site between 2003 and 2011.

Since the early 1990s, several benthic surveys have been conducted offshore of the Kalaemanō development (Figure 2). Using slightly different methods than our surveys, Brock (2012) found coral cover had declined since 1993, but had been gradually increasing since 2005 (Figure 4), from  $31.2 \pm 3.6\%$  to  $49.5 \pm 3.8\%$  cover. Brock’s 2011 cover estimate were slightly higher, but still consistent with Minton *et al.*'s (2014) cover estimate for survey sites in the same general area as Brock's transects. Both estimates were higher than those of Walsh *et al.* (2012), but the exact location of their monitoring site relative to the Brock's transects isn't clear. Coral cover in the same general area as Brock's surveys was lower in 2012 and 2013 (Figure 4), and appears to continue the downward trend from 1993.

Reasons for the drop in coral cover observed by Brock (2012) in 2005 are unclear, but prior to 2005, surveys were conducted by others (Marine Research Consultants), and it's not clear if the methods or sites surveyed are directly comparable. Survey methods were the same from 2011 to 2013 except for the level of taxonomic resolution, which should not affect total coral cover estimates. Reasons for the drop in coral cover between 2011 and 2012 are unclear, but relatively



**Figure 4.** Change in average coral cover near Kalaemanō from 1993-2011. Data for 1993 and 2002 (circles) are from Marine Research Consultants (in Brock 2012). For 2005-2011 (circles), data are from Brock (2012) and include only coral cover data from the author's *P. lobata* and *P. compressa* biotopes. Data for 2011 (diamond) are from Minton *et al.* (2014). Data for 2012 and 2013 (squares) are from the subsample of 30 sites in 2012 and 25 sites in 2013 for the current study that were near Brock's fixed transects. Error bars are SEM.

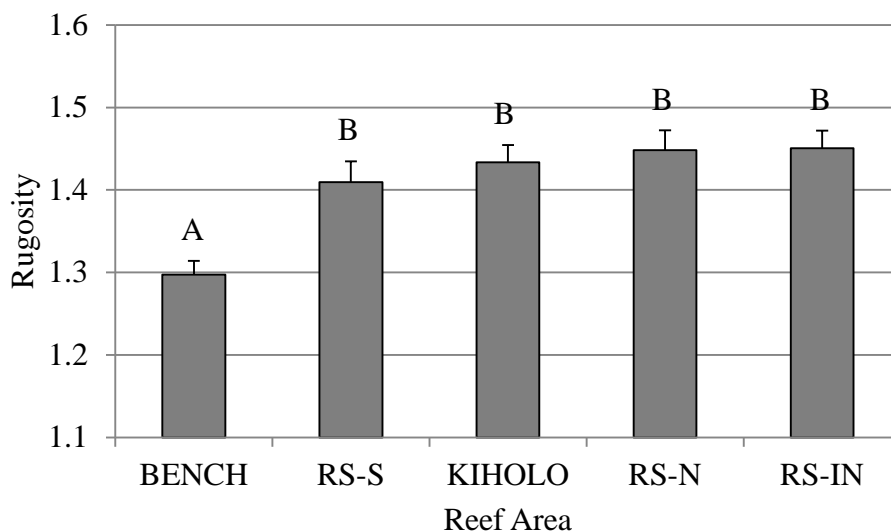
few sites were surveyed in 2011 in the vicinity of Brock's transects, so natural variability in the benthic assemblage is one possible explanation.

Hawai'i's Coral Reef Assessment and Monitoring Program (CRAMP) has documented declines in coral cover across the state of Hawai'i since the early 1990s, but has not observed a precipitous drop between 2002-2005, as observed by Brock (2012) at Ka'ūpūlehu (CRAMP 2008). At Puakō, several kilometers north of Ka'ūpūlehu, coral cover has declined to approximately half of what it was in the 1970s to  $32.6 \pm 4.2\%$  cover by 2010 (Minton *et al.* 2012), albeit with a more gradual decline in recent years. Assuming the coral decline is "real" at Ka'ūpūlehu, it would be consistent with that observed at Puakō.

#### 5.1.4 Rugosity

Rugosity, or three-dimensional structure of the habitat, has been shown to be an important predictor of fish assemblages in Hawai'i, with higher rugosity (*i.e.*, greater three-dimensional structure) being associated with higher abundance and diversity of fish (Friedlander and Parrish 1998). Corals are the primary structure producing organisms on reefs, and their colony morphology (*e.g.*, branching, encrusting, massive) is directly correlated with bottom rugosity.

Average rugosity was significantly lower inside the FRA than outside (ANOVA,  $F=9.37$ ,  $df=1$ ,  $320$ ,  $p=0.002$ ). While the difference was relatively small ( $1.35 \pm 0.01$  compared to  $1.43 \pm 0.01$ ), it's likely ecologically significant (see below). The lower rugosity inside the FRA was due to the BENCH area, which had significantly lower rugosity than all other reef areas (Figure 5).



**Figure 5.** Rugosity by reef area. Bars with the same letter are not significantly different.

The lower rugosity on the BENCH is the result of its lower coral cover, especially massive corals, compared to other areas.

## 5.2 Fish Assemblage

A total of 163 taxa representing 39 families of fish were observed at Ka‘ūpūlehu-Kīholo in 2012-2013. Species richness in 2012 (159 species) was higher than in 2013 (129 species), but this is the result of greater sampling effort in 2012; jackknife estimates<sup>4</sup> of the species richness were nearly identical when accounting for different samples sizes. Combining the sampling years, a jackknife analysis estimates approximately 180 fish species at Ka‘ūpūlehu-Kīholo.

Surgeonfish (Acanthuridae), wrasses (Labridae), damselfish (Pomacentridae), and parrotfish (Scaridae) were numerically the most abundant, accounting for approximately 82% of all observed individuals in both 2012 and 2013 (Table 3). Surgeonfish, parrotfish, and triggerfish (Balistidae) contributed the most to the total fish biomass, accounting for 63.3% and 72.2% of the total fish biomass in 2012 and 2013, respectively. These fish families were also the most common in previous surveys (Minton *et al.* 2014).

### 5.2.1 Time

No differences were found between survey years for total fish abundance (ANOVA:  $F=2.86$ ;  $df=1,408$ ;  $p=0.092$ ), total fish biomass (ANOVA:  $F=1.81$ ;  $df=1,408$ ;  $p=0.179$ ), or species richness per survey site (ANOVA:  $F=0.01$ ;  $df=1,408$ ;  $p=0.985$ ). Extending the analysis back to

<sup>4</sup> Jackknifing is a statistical method used to estimate the "true" species richness for an area from a random sample. Deriving species richness directly from random samples will almost always result in an under-estimation of the "true" richness for the entire area, and will depend on the amount of area sampled, *i.e.*, number of survey sites in this case.



**Table 3.** Average abundance (number of individuals/transect) and average biomass (g/m<sup>2</sup>) of fish by family at Ka'ūpūlehu-Kīholo in 2012-2013. Species are arranged by decreasing 2012 biomass.

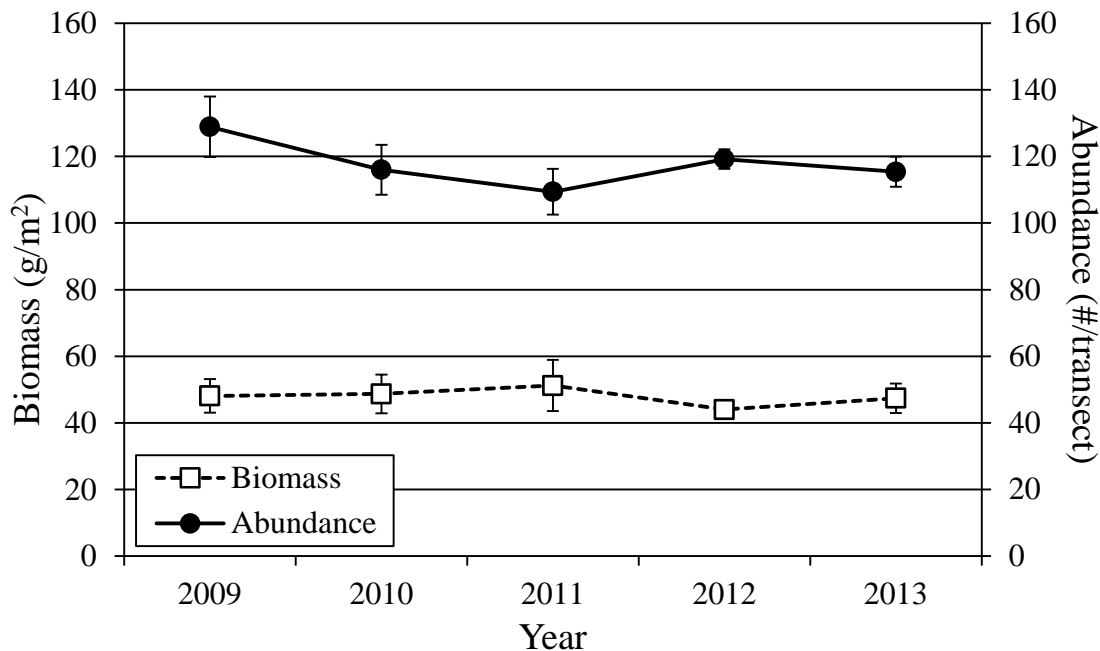
Fish Family	Abundance		Biomass	
	2012	2013	2012	2013
Surgeonfish (Acanthuridae)	48.7 ± 1.8	52.0 ± 2.9	16.1 ± 1.2	22.0 ± 3.8
Parrotfish (Scaridae)	5.9 ± 0.4	7.8 ± 0.9	8.3 ± 0.6	8.0 ± 0.9
Wrasses (Labridae)	19.4 ± 0.5	19.1 ± 1	4.9 ± 0.2	4.4 ± 0.4
Triggerfish (Balistidae)	2.2 ± 0.1	3.0 ± 0.4	3.5 ± 0.2	4.3 ± 0.6
Groupers (Serranidae)	0.3 ± 0	0.3 ± 0	3.0 ± 0.4	1.2 ± 0.2
Goatfish (Mullidae)	2.7 ± 0.3	2.7 ± 0.5	1.4 ± 0.2	1.3 ± 0.3
Butterflyfish (Chaetodontidae)	4.5 ± 0.2	5.8 ± 0.4	1.4 ± 0.1	1.9 ± 0.2
Damselfish (Pomacentridae)	24.7 ± 1.7	16.4 ± 1.4	1.2 ± 0.1	0.9 ± 0.1
Snappers (Lutjanidae)	0.4 ± 0.2	0.4 ± 0.2	1.1 ± 0.2	0.8 ± 0.2
Squirrelfish (Holocentridae)	0.9 ± 0.3	0.7 ± 0.4	1.0 ± 0.3	1.0 ± 0.7
Hawkfish (Cirrhitidae)	3.8 ± 0.2	3.9 ± 0.3	0.5 ± 0	0.4 ± 0
Emperors (Lethrinidae)	0.1 ± 0	0.1 ± 0	0.4 ± 0.3	0.2 ± 0.2
Porcupinefish (Diodontidae)	<0.1	0 ± 0	0.3 ± 0.1	0.1 ± 0.1
Pufferfish (Tetraodontidae)	2.3 ± 0.1	1.1 ± 0.1	0.3 ± 0	0.1 ± 0
Filefish (Monacanthidae)	0.2 ± 0	0.1 ± 0	0.1 ± 0	0.2 ± 0.1
Trumpetfish (Aulostomidae)	0.2 ± 0	0.1 ± 0	0.1 ± 0	0.1 ± 0
Moorish Idol (Zanclidae)	0.1 ± 0	0.2 ± 0	0.1 ± 0	0.2 ± 0.1
Jacks (Carangidae)	1 ± 0.4	0.6 ± 0.3	0.1 ± 0	<0.1
Angelfish (Pomacanthidae)	0.5 ± 0.1	0.3 ± 0.1	0.1 ± 0	<0.1
Chubs (Kyphosidae)	<0.1	0.2 ± 0.2	0.1 ± 0	0.3 ± 0.3
Lizardfish (Synodontidae)	<0.1	<0.1	<0.1	<0.1
Blennies (Blenniidae)	0.7 ± 0.1	0.6 ± 0.2	<0.1	<0.1
Cornetfish (Fistulariidae)	<0.1	<0.1	<0.1	<0.1
Boxfish (Ostraciidae)	0.2 ± 0	0.1 ± 0	<0.1	<0.1
Flounders (Bothidae)	<0.1	0	<0.1	0
Needlefishes (Belonidae)	0.1 ± 0.1	<0.1	<0.1	<0.1
Scorpionfish (Scorpaenidae)	<0.1	0	<0.1	0
Remoras (Echeneidae)	<0.1	0	<0.1	0
Bigeyes (Priacanthidae)	<0.1	<0.1	<0.1	<0.1
Cardinalfishes (Apogonidae)	<0.1	0	<0.1	0
Sandperches (Pinguipedidae)	<0.1	0	<0.1	0
Gobies (Gobiidae)	<0.1	0	<0.1	0
Wormfishes (Microdesmidae)	<0.1	0	<0.1	0
Coral Crouchers (Caracanthidae)	<0.1	0	<0.1	0
Mantas (Mobulidae)	<0.1	0	<0.1	0
Eels (Muraenidae)	0.1 ± 0	<0.1	<0.1	<0.1

Table 3 (continued).

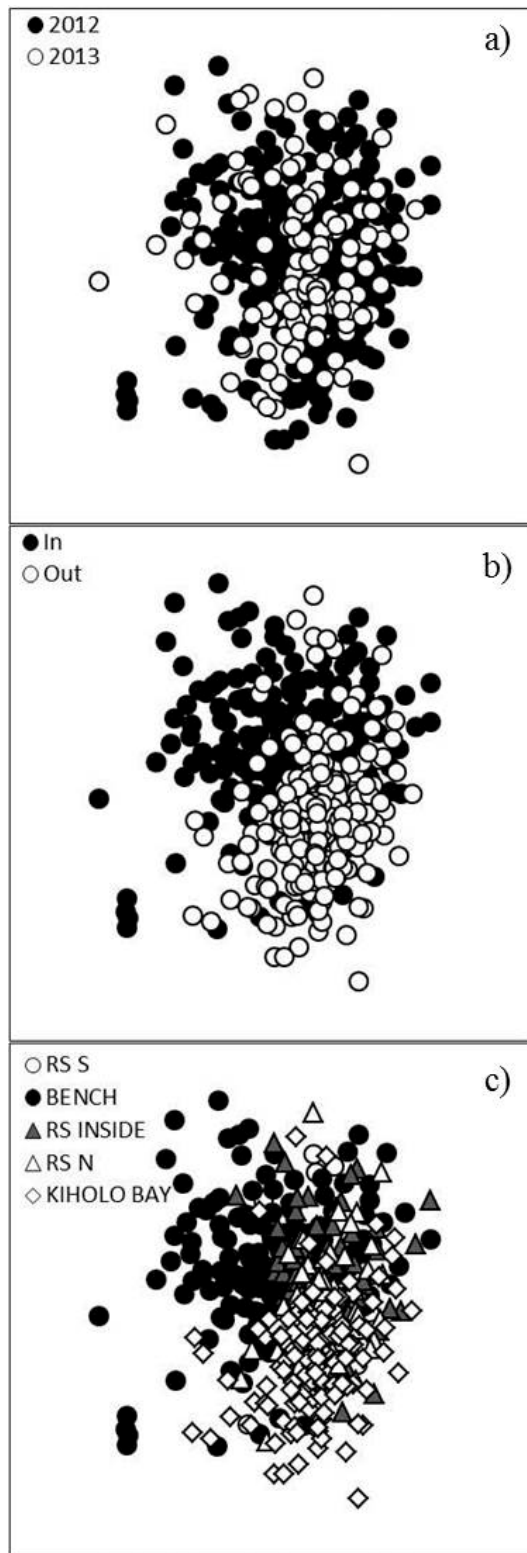
Fish Family	Abundance		Biomass	
	2012	2013	2012	2013
Unidentified	<0.1	<0.1	<0.1	<0.1
Milkfish (Chanidae)	0	<0.1	0	<0.1
Eagle Rays (Myliobatidae)	0	<0.1	0	<0.1
<b>TOTAL</b>	<b>119.2 ± 2.9</b>	<b>115.4 ± 4.5</b>	<b>44.0 ± 1.9</b>	<b>47.4 ± 4.4</b>

2009, no trend in total fish abundance or total fish biomass is apparent (Figure 6), suggesting the fish assemblage has been stable over the past five years.

No difference in the structure of the fish assemblage was found between sampling years (ANOSIM;  $R < 0.01$ ,  $p = 0.4$ ), and the nMDS plots shows considerable overlap of the clusters (Figure 7a). This suggests that sampling in both years adequately captured the range of the composition of the fish assemblage at Ka‘ūpūlehu-Kīholo, and that decreasing the sampling effort in 2013 did not impact its characterization; future sampling at approximately the 2013 level should be adequate for assessing potential changes in the fish assemblage as a result of the proposed management action within the Ka‘ūpūlehu FRA.



**Figure 6.** Total fish biomass (g/m<sup>2</sup>) and total fish abundance (individuals/transect) within the Ka‘ūpūlehu FRA from 2009 to 2013. Data from 2012 and 2013 includes only sites within the Ka‘ūpūlehu FRA. Data for 2009-2011 are from Minton *et al.* (2014).



**Figure 7.** nMDS plots for (a) year, (b) management status, and (c) reef area. In these plots, points that are closer together have more similar fish assemblage structure – *i.e.*, similar numbers of similar species. Plots were generated from fish biomass data from 2012 and 2013. Stress for all figures is 0.24, which is considered high (Clarke 1993), and indicates that the 2-d plots may not accurately visually represent the relationship of the points to each other.

### 5.2.2 Management Status

Total fish abundance (ANOVA;  $F=0.29$ ;  $df=1,408$ ;  $p=0.591$ ), total fish biomass (ANOVA;  $F=2.60$ ;  $df=1,408$ ;  $p=0.107$ ), and number of species per survey site (ANOVA;  $F=0.76$ ;  $df=1,408$ ;  $p=0.384$ ) did not vary with management status (Table 4). While total species richness was slightly higher outside the FRA (155 to 145 species), this is likely the result of greater sampling effort outside the FRA ( $n=216$ ) compared to inside ( $n=200$ ).

Differences were found in the structure of the fish assemblage inside and outside the FRA (ANOSIM;  $R=0.158$ ;  $p=0.001$ ), however. The differences were best explained by higher biomass of triggerfish (*e.g.*, *Melichthys niger*) and surgeonfish (*e.g.*, *Acanthurus olivaceus*) inside the FRA compared to reefs outside. Peacock groupers, or roi, (*Cephalopholis argus*) and bullethead parrotfish (*Chlorurus spilurus*) had slightly (but not significantly) higher biomass outside the FRA.

It is important to note that the difference between the fish assemblages inside and outside the FRA is relatively small, as suggested by the small R-value in the ANOSIM analysis and the considerable overlap of survey points in the nMDS plot (Figure 7b). Given the contiguous nature of the Ka‘ūpūlehu-Kīholo reef, this is not surprising. The difference between the assemblages inside and outside the FRA may not be ecologically significant, but instead, may be the result of higher spatial variability in the fish assemblage

inside the FRA boundary than outside (note the greater dispersion of points for inside compared to outside the FRA in Figure 9b) and not a clear, consistent difference in assemblage structure.

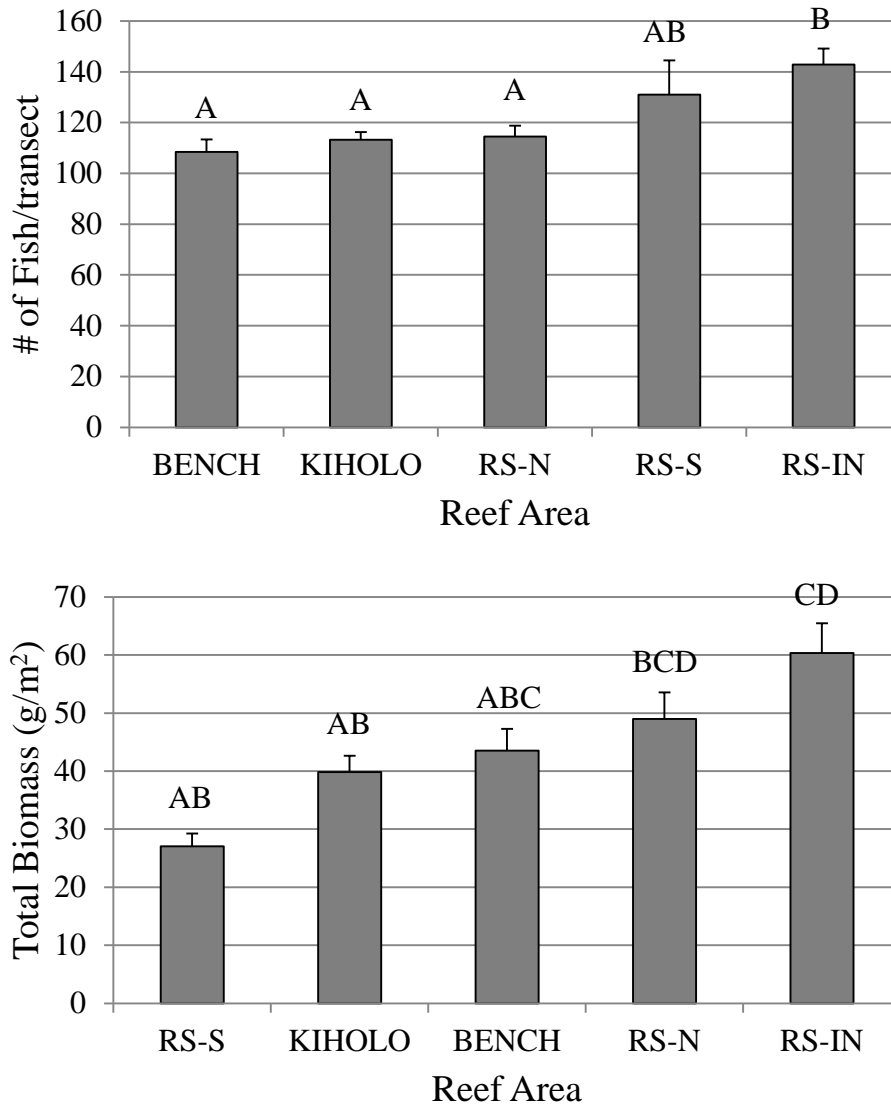
**Table 4.** Fish Abundance (individuals/transect), biomass (g/m<sup>2</sup>), total species richness, and number of species per survey site for fish assemblages inside and outside the Ka‘ūpūlehu FRA and across the entirety of the Ka‘ūpūlehu-Kīholo survey area.

	2012 (n=290)	2013 (n=126)
<b>Inside FRA</b>		
Abundance	124.7 ± 4.9	110.3 ± 7.5
Biomass	48.6 ± 3.4	51.2 ± 6.7
Total Richness	143 taxa	103 taxa
Richness per site	20.9 ± 0.5	19.9 ± 0.7
<b>Outside FRA</b>		
Abundance	114.1 ± 3.3	120.0 ± 5.1
Biomass	39.7 ± 1.8	44.0 ± 5.8
Total Richness	149 taxa	120 taxa
Richness per site	19.4 ± 0.3	20.8 ± 0.5
<b>Ka‘ūpūlehu-Kīholo Area</b>		
Abundance	119.2 ± 2.9	115.4 ± 4.5
Biomass	44.0 ± 1.9	47.4 ± 4.4
Total Richness	159 taxa	129 taxa
Richness per site	20.1 ± 0.3	20.3 ± 0.4

Communities across west Hawai‘i have raised concerns about the abundance of roi, an invasive grouper that has the potential to consume large quantities of juvenile fish, especially native fish (Dierking 2007), but recent research has found the effect of roi on fish assemblages to be insignificant four years after targeted roi removal from three acres of coral reef at Puakō (TNC and FERL, unpublished data). Roi biomass at Ka‘ūpūlehu-Kīholo ( $2.4 \pm 0.3$  g/m<sup>2</sup>) was relatively low compared to other areas on west Hawai‘i Island, and was not significantly different inside compared to outside the FRA.

### 5.2.3 Reef Area

While total fish abundance, total fish biomass, and species richness per survey site did not vary between survey years or management status, significant differences were found among the five reef areas for total abundance (ANOVA:  $F=16.27$ ;  $df=1,408$ ;  $p<0.001$ ) and biomass (ANOVA:  $F=7.53$ ;  $df=1,408$ ;  $p=0.006$ ), but not for species richness per survey site (ANOVA:  $F=5.27$ ;  $df=1,408$ ;  $p=0.368$ ) (Table 5). Closer inspection finds no consistent pattern of site relationships for total fish abundance and biomass (Figure 8). For instance, reef slope areas generally had higher fish abundance, but included areas with both the highest and lowest biomass, making interpretation of the results difficult. However, there appears to be a weak relationship with



**Figure 8.** Total fish abundance (a) and total fish biomass (b) by reef area. Bars with the same letter are not significantly different.

rugosity (Figure 5), where sites with higher rugosity have higher abundance (Correlation,  $r=0.294$ ,  $df=414$ ,  $p<0.001$ ) and biomass (Correlation,  $r=0.221$ ,  $df=414$ ,  $p<0.001$ ).

While reef area explained a significant amount of the variability in fish assemblage structure, the small R value suggests the differences among the areas are more a product of the large sample size than meaningful ecological differences. Examination of the nMDS plots (Figure 7c) shows considerable overlap of the five reef areas. Considering all available information, we conclude there is little ecologically meaningful difference among the fish assemblages in the five reef areas.

**Table 5.** Fish Abundance (individuals/transect), biomass (g/m<sup>2</sup>), total species richness, and average number of species observed per site for five reef areas in Ka‘ūpulehu-Kiholo.

	2012 (n=290)	2013 (n=126)
<b>RS-S</b>		
Abundance	131.8 ± 18.6	129.5 ± 17.4
Biomass	27.7 ± 3.1	25.7 ± 2.9
Total Richness	94 taxa	65 taxa
Richness per site	21.3 ± 1.0	21.6 ± 1.7
<b>BENCH</b>		
Abundance	112.7 ± 5.5	96.4 ± 11
Biomass	42.3 ± 3.7	47.1 ± 10
Total Richness	129 taxa	90 taxa
Richness per site	20.3 ± 0.7	18.8 ± 1.0
<b>RS-IN</b>		
Abundance	151.3 ± 8.6	128.5 ± 8.6
Biomass	62.6 ± 6.5	56.5 ± 8.5
Total Richness	118 taxa	86 taxa
Richness per site	22.1 ± 0.5	21.2 ± 0.8
<b>RS-N</b>		
Abundance	109.6 ± 4.6	121.8 ± 8
Biomass	44.6 ± 3.5	55.4 ± 10
Total Richness	118 taxa	102
Richness per site	19.7 ± 0.5	21.2 ± 0.8
<b>KIHOLO</b>		
Abundance	112.5 ± 3.4	115.7 ± 6.9
Biomass	39.9 ± 2.4	39.7 ± 8.8
Total Richness	127 taxa	96 taxa
Richness per site	19 ± 0.4	20.2 ± 0.6

#### 5.2.4 Target Fish

Target fish<sup>5</sup> include fish desirable for food, commercial activity, or cultural practice that reside within the survey area. Total target fish biomass did not significantly differ between years (ANOVA: F=1.80; df=1,408; p=0.179) or with management status (ANOVA: F=2.60; df=1,408; p=0.107); on average, total target fish biomass was the same inside and outside the FRA, which is not surprising considering the FRA currently does not provide additional protection for most target species, as described in this report. Current FRA rules protect only the 40 species on the State of Hawai‘i’s white list and only from commercial aquarium collection, and few of these white list species are represented in our target fish category.

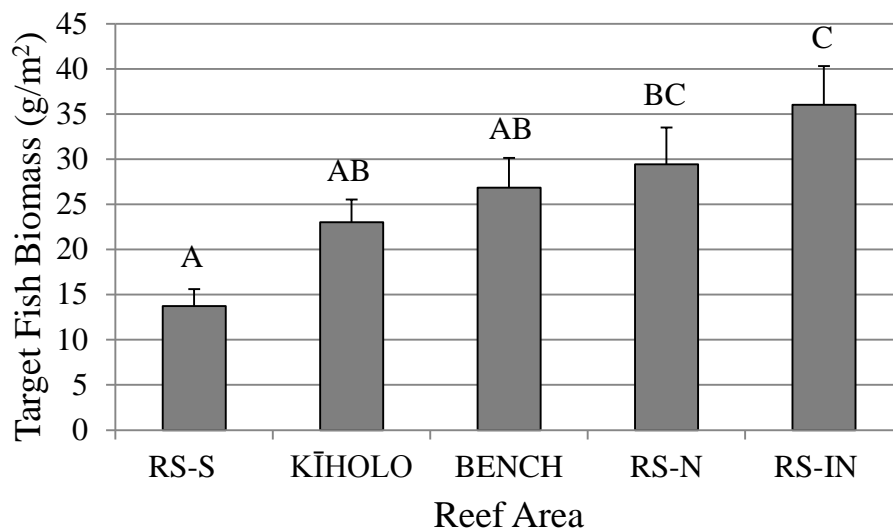
<sup>5</sup> Those fish most prized by fishers. See Appendix B for a list of species that comprise the target fish for this report.

However, the analysis of management status was complicated by differences in target fish biomass among the reef areas (ANOVA:  $F=7.53$ ;  $df=1,408$ ;  $p=0.006$ ). Target fish biomass on the BENCH was significantly lower than RS-IN, which had the highest target fish biomass of all five reef areas (Figure 9). Patterns in target fish biomass were similar to those seen for total fish biomass.

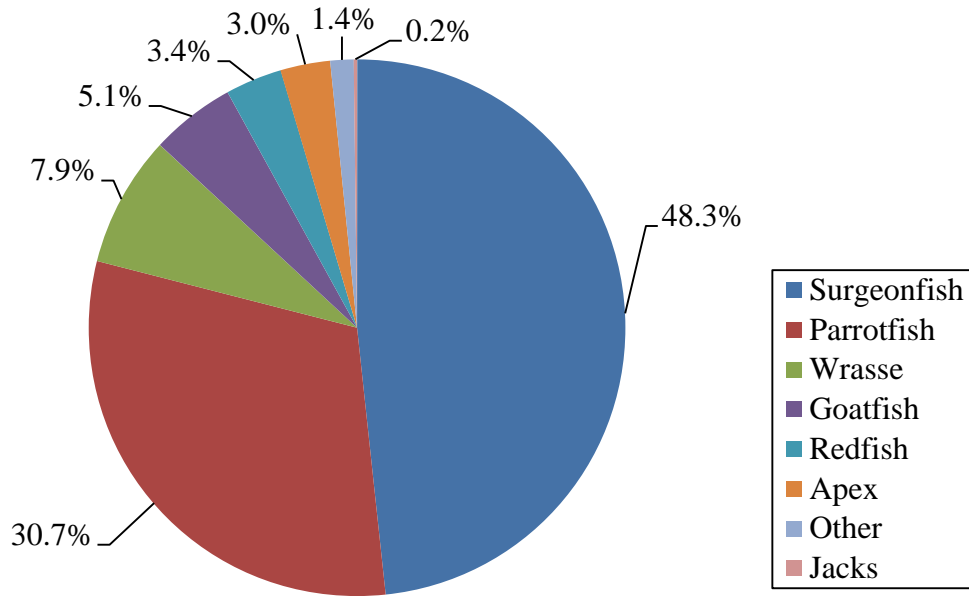
While the total target fish biomass varied among reef areas, the relative biomass of the target fish groups (*e.g.*, surgeonfish, jacks, apex predators, etc.) was similar, with some notable differences. Surgeonfish formed a larger proportion of the target fish assemblage in the two areas inside the FRA (BENCH and RS-IN) compared to the three areas outside the FRA (RS-S, RS-N, and KĪHOLO). Four of the target surgeonfish are listed on the state's white list (DLNR 2013), and they showed a larger per species increase in biomass inside the FRA compared to non-white listed surgeonfish species, suggesting a disproportionately higher benefit of being inside the Ka‘ūpūlehu FRA.

Combining all data for 2012 and 2013, surgeonfish and parrotfish accounted for 48.8% and 30.7%, respectively, of the target fish biomass at Ka‘ūpūlehu-Kīhōlo (Figure 10), which is consistent with previous findings (Minton *et al.* 2014). Apex predators, such as sharks, were nearly absent, comprising 3.0% of the target fish biomass; 77% of the apex predator biomass was comprised of green jobfish or uku (*Aprion virescens*). On coral reefs where human impacts, especially fishing pressure, are low, apex predators are a significant component of coral reef fish assemblage (Friedlander and DeMartini 2002, Sandin *et al.* 2008), and historical accounts of sharks at Kalaemanō (which translates to “The Point of the Shark”), suggest this area once hosted a much larger resident population of apex species.

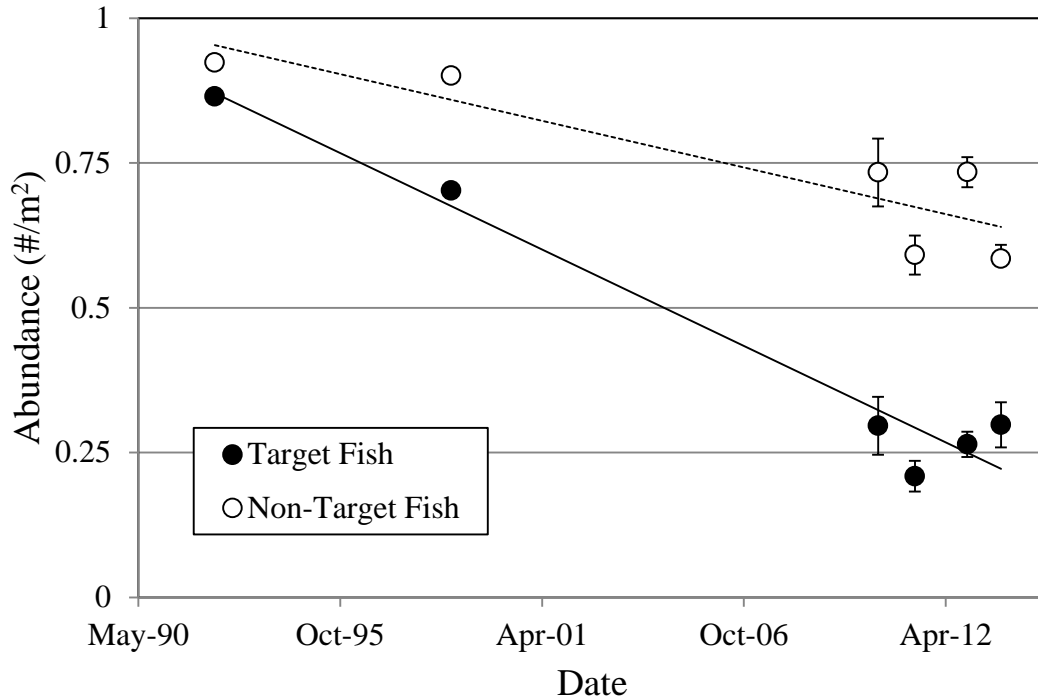
Target fish abundance between 2009 and 2013 has been relatively stable, but appears to have declined since 1992 (Figure 11). Stender (1999) documented a 41% decline in fish abundance and 26% decline in fish diversity over a six-year period from 1992 to 1998. From 1992 to 2013,



**Figure 9.** Total target fish biomass by reef area. Bars with the same letter are not significantly different.



**Figure 10.** Composition (% of total biomass) of target fish assemblage by group

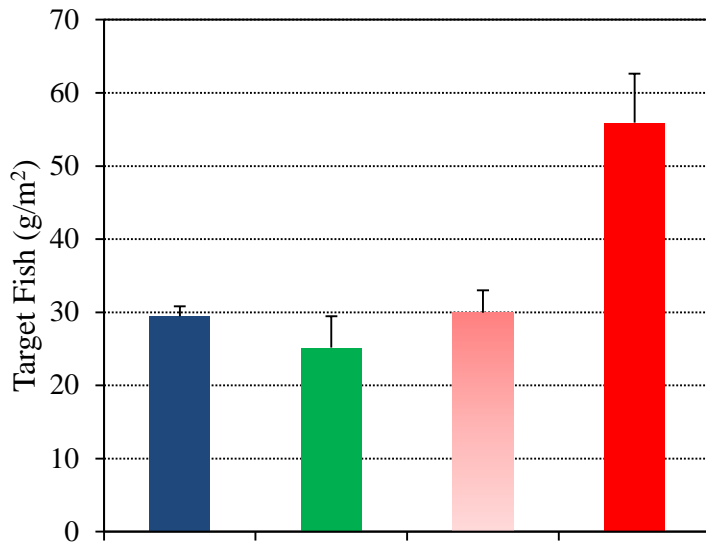


**Figure 11.** Change in target and non-target fish abundance at Ka'ūpūlehu between 1992 and 2012. Target fish are a select group of species prized by fishers and non-target species are species not generally fished in the state (see Williams 2008 for a list of target species). Data for 1992 and 1998 are from Stender (1999), 2010-2011 from Minton *et al.* (2014), and 2012-13 from this report.



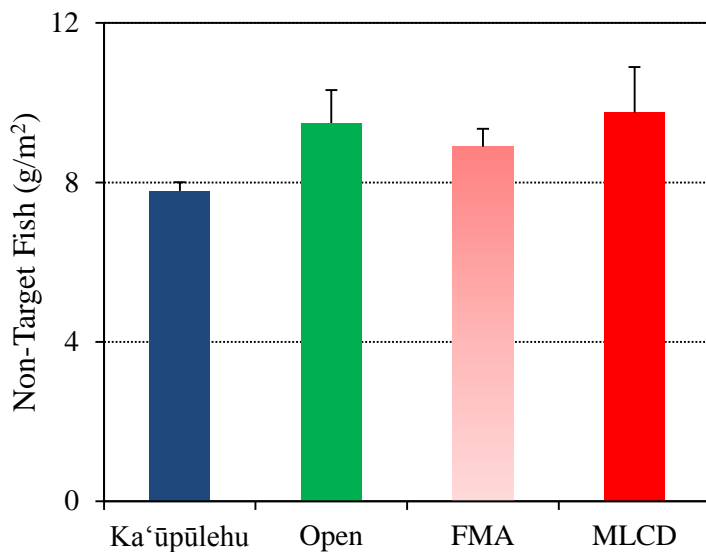
the abundance target species declined nearly 75% compared to about 25% for non-target species, suggesting harvesting has impacted Ka‘ūpūlehu's nearshore fishes.

Target fish biomass in the Ka‘ūpūlehu FRA (BENCH and RS-IN) was similar to other west Hawai‘i areas open to fishing and to other partially-protected areas within the WHRFMA (*e.g.*, South Kona FMA, Kona FMA, Puakō FMA) (Figure 12a). The WHRFMA was established to protect aquarium fish species from overharvest, but until recently<sup>6</sup>, afforded few additional protections to species not collected for the aquarium industry, so similarities are not surprising.



The Ka‘ūpūlehu FRA has less target fish biomass than west Hawai‘i areas closed to fishing (*e.g.*,

Kealekekua Bay and Lapakahi MLCD). In contrast, the biomass of non-target species was similar among the Ka‘ūpūlehu FRA, the WHRFMA, and west Hawai‘i MLCDs (Figure 12b). While other stressors may be affecting the fish assemblage at Ka‘ūpūlehu, only fishing would selectively reduce the abundance of target fish species while not affecting non-target species.



### 5.2.5 Prime Spawners

Prime spawners are large target fishes (>70% their maximum size) generally prized by fishers, and which tend to contribute disproportionately more to the total breeding potential of the population than smaller individuals due to the prime spawner’s 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

**Figure 12.** Biomass (g/m<sup>2</sup>) of target (top) and non-target (bottom) fish at Ka‘ūpūlehu, within areas open to fishing (n=11), within limited fishing FMAs (n=4), and within closed-to-fishing MLCDs (n=10). Note: different scales. (Figure from Minton *et al.* 2014)

<sup>6</sup> In 2014, the state approved a scuba spear fishing ban for all of west Hawai‘i.

represents an important component of ecological function (*i.e.*, population breeding potential).

Prime spawner biomass was highly variable, ranging from 0 to 146 g/m<sup>2</sup> at survey sites, with no prime spawners observed at 15% of the sites. Prime spawner biomass varied between survey years (ANOVA: F=23.59; df=1,408; p<0.001), management status (ANOVA: F=12.00; df=1,408; p=0.001), and among the reef areas (ANOVA: F=4.63; df=1,408; p=0.032).

Prime spawner biomass was nearly 60% greater inside the FRA than outside. Interestingly, the increase was driven by 378% higher biomass of orangeband surgeonfish and 169% higher biomass of orangespine unicornfish (*Naso literatus*); both are white list species and thus are protected from aquarium harvest within the Ka‘ūpūlehu FRA. Prime spawners of white list species had 126% (median) greater biomass inside the FRA than outside, compared to no difference for non-aquarium species.

Follow-up multiple comparisons found few significant differences among the five reef areas, due to high prime spawner variability, especially inside the FRA. However, prime spawner biomass on the BENCH and RS-IN showed a trend toward higher biomass compared to reef areas outside the FRA.

#### 5.2.6 Aquarium Fish

Hawai‘i has designated a white list of aquarium species that cannot be harvested within the Ka‘ūpūlehu FRA for commercial take. Thirty-four of the 40 white-listed species were observed during these surveys, but most were rare. The most commonly observed white list species, accounting for 50% of the observed aquarium fish biomass (Table 6), were goldringed bristletooth or kole (*Ctenochaetus strigosus*), yellow tangs (*Zebrasoma flavescens*), roi, and brown surgeonfish (*Acanthurus nigrofuscus*).

While 20 of the 34 species had higher biomass inside compared to outside the FRA, the FRA had no significant effect on the total biomass of aquarium fish species (ANOVA; F=0.65; df=1,408; p=0.421). This comparison, however, is complicated by the allowance of take of white list species for non-aquarium trade purposes (*e.g.*, consumption). Therefore, while the Ka‘ūpūlehu FRA affords protection to white list species, significant take can still occur, especially for species that are prized for other purposes. Given this, species that are heavily fished for the aquarium trade and lightly fished for other reason (*e.g.*, yellow tang) should accrue the most benefit from the Ka‘ūpūlehu FRA. Indeed yellow tang biomass is significantly higher inside the FRA compared to outside, but for goldringed bristletooth, a prized food fish, this not the case. Given that only a few of the species on the white list account for the majority of the aquarium fish take, it is not surprising that most species-specific increases were negligible, and total aquarium fish biomass was ~8% higher inside compared to outside the FRA.

In studies specifically designed to assess its effectiveness, the WHRFMA has been shown to be effective at managing key aquarium species (Tissot *et al.* 2004, Williams *et al.* 2009, DLNR 2014). The current study was not designed to test the effectiveness of the WHRFMA on aquarium species and lacks sufficient historical baseline data to do so. Like all species at

**Table 6.** Biomass (g/m<sup>2</sup>) inside (n=200) and outside (n=216) the FRA for the nine aquarium species that compromised >5% of the total aquarium fish biomass. The remaining 25 species comprised only 13% of the total aquarium fish biomass. Harvest importance for the 40 species on the aquarium white list was obtained from Walsh *et al.* (2013) and is the rank of fish by average total catch from 2010-2012. All differences are significant at p<0.001 except those marked with *ns*.

Species	Harvest Importance	Inside FRA	Outside FRA	Percent Diff
<i>Ctenochaetus strigosus</i>	2	2.2 ± 0.2	4.3 ± 0.2	-95.6
<i>Zebrasoma flavescens</i>	1	3.4 ± 0.4	1.7 ± 0.2	50.4
<i>Cephalopholis argus</i>	40	2.3 ± 0.5	2.5 ± 0.3	-8.3 <sup>ns</sup>
<i>Acanthurus nigrofuscus</i>	10	1.6 ± 0.2	2.8 ± 0.2	-72.8
<i>Thalassoma duperrey</i>	13	1.4 ± 0.1	2.0 ± 0.1	-44.7
<i>Acanthurus olivaceus</i>	11	2.7 ± 0.4	0.6 ± 0.1	78.9
<i>Melichthys niger</i>	31	2.1 ± 0.2	1.1 ± 0.3	46.8
<i>Naso literatus</i>	4	1.9 ± 0.2	0.9 ± 0.1	51.6
<i>Acanthurus dussumieri</i>	33	0.7 ± 0.2	1.6 ± 1.1	-137.1 <sup>ns</sup>

Ka‘ūpūlehu, differences in aquarium fish species biomass were best explained by reef areas (ANOVA; F=11.62; df=1,408; p=0.001). Regardless, positive effects on some aquarium species were observed, especially for larger individuals of some species (see section 4.2.5 Prime Spawners).

### 5.2.7 Assessing Future Change

The Ka‘ūpūlehu community has developed, proposed, and championed enhanced management regulations for the Ka‘ūpūlehu FRA which will be among the first of its kind in the state of Hawai‘i, and may serve as a "test case" for future community-based efforts. Monitoring the effectiveness of the new regulations is essential to inform future efforts. The data collected from 2009-2013 provide a powerful baseline assessment of the condition of the coral reefs and fish populations for the Ka‘ūpūlehu-Kīholo area, including both the area to receive enhanced management (Ka‘ūpūlehu FRA) and areas directly adjacent that will remain unchanged (Kīholo to the north and reefs to the south). Future data collection, if conducted using similar methods and survey design to those used in this current effort, can be compared directly to this baseline information.

The data presented in this report can also be used to inform future monitoring and research at Ka‘ūpūlehu. The ability to detect change is directly related to the variability of the study population. Highly variable populations make it difficult to detect small changes, and thus require larger samples sizes to compensate. Optimal survey designs attempt to decrease variability, often through stratification of sampling. Understanding the contribution of each source to the total variability of the assemblage is key to designing a statistically rigorous survey.

The variability of the data collected in 2012-2013 can be partitioned into three separate sources: spatial (reef area), temporal (year), and methodological (observers), with the remaining variability attributable to other unidentified sources. For five of six summary variables investigated (Table 7), spatial variability contributed most to the total variability. Surprisingly, method "error" introduced relatively little variability, an average just over 1% of the total variability, but this value may be misleading, as "observer" is a coarse measure of method error. About one-quarter of the total variability remained unexplained, and likely could be attributed to factors such as fish behavior (*e.g.*, diurnal and other movement), variability in the environment (*e.g.*, groundwater inputs), depth, etc.

Optimal sampling should maximize replication across the largest source of variability. Therefore, the sampling design employed during this survey was statistically rigorous. Future assessments of Ka‘ūpūlehu should continue to employ a large number of sampling units across the project area in order to capture the high spatial variability of the Ka‘ūpūlehu-Kīholo reef. Given the relatively low temporal variability, especially for five of the six summary values in Table 7, relatively few annual events should be needed to demonstrate a relatively small change in the fish assemblage.

**Table 7.** Contribution of temporal, spatial, and method sources of variability to the total variability of six summary fish assemblage variables.

<b>Source</b>	<b>Temporal</b>	<b>Spatial</b>	<b>Method</b>	<b>Other Sources</b>
Total Biomass	5.2	72.5	2.1	20.2
Total Abundance	12.7	58.8	0.1	28.4
Target Biomass	3.4	78.7	0.8	17.2
Target Abundance	3.6	79.3	2.9	14.3
PS Biomass	57.7	25.2	0.2	16.8
PS Abundance	8.5	46.6	0.3	44.6
Average Contribution	15.2 ± 8.6%	60.2 ± 8.7%	1.1 ± 0.5%	23.6 ± 4.7%

## 6.0 Conclusions

The reef adjacent to Ka‘ūpūlehu-Kiholo shows signs of human impact associated with fishing. Target fish biomass is lower than that found in west Hawai‘i MLCs and similar to areas open to fishing, but no concurrent drop in non-target fish biomass is observed. While other stressors may be affecting the fish assemblage at Ka‘ūpūlehu, only fishing would selectively reduce the abundance of target species while not affecting non-target species. Prime spawner biomass is also less than that found in areas closed to fishing. While total fish abundance at Ka‘ūpūlehu-Kīholo currently appears stable (2009-2013), data suggest the area has experienced a large decline in fish abundance since 1992. Concurrently, the reef has experienced a significant decrease in coral cover since 1990, a trend observed by several researchers at Ka‘ūpūlehu-Kīholo, but also on other west Hawai‘i reefs, suggesting a widespread, regional problem.

In response, the Ka‘ūpūlehu community has initiated a formal process to establish additional fisheries management rules within the Ka‘ūpūlehu FRA, with the expected result of increased

fish abundance and biomass, and increased coral reef health. The proposed 10-year rest area is likely to increase both the size and abundance of resource fish species in Ka'ūpūlehu. Upon conclusion of the rest period, subsequent rational fisheries management supported by the community and adequately enforced, will likely be necessary to maintain sustainable population levels for culturally- and economically-important species.

The surveys conducted in 2012 and 2013 expand the baseline condition assessment within the Ka'ūpūlehu FRA and provide comparative baseline information for the reef directly adjacent to the Ka'ūpūlehu FRA. Few differences were found between the benthic and reef fish assemblages inside and outside the FRA or between years; however, differences among reef areas demonstrate the importance of using a stratified survey design for future assessments. The baseline established here provides an unprecedented opportunity to document the response of coral reef and fish populations to community-sponsored rules in Hawai'i and, potentially, to the efficacy of community management based upon closure (*kapu*) to restore nearshore marine resources in Hawai'i.

## 7.0 Acknowledgements

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## Appendix A. Power Analysis

### A1. Initial Power Analysis and Sample Size Estimate

In 2012, TNC and its partners completed 290 surveys along the Ka‘ūpūlehu-Kīholo coastline, an unprecedented expenditure of effort to thoroughly sample the near shore reefs of the region. These data were used to estimate the optimal survey effort needed for 2013 using a variety of statistical techniques.

Target fish, or those most prized by fishers, are of primary interest to the community and other stakeholders, so we focused on developing an optimal survey design to generate rigorous statistical power to detect at least a 20% change in the target fish biomass between two sampling events.

Target fish in 2012 had a higher variability in biomass than non-target fish or total fish biomass: 87.8% of the mean (=Coefficient of Variation [CV]) compared to 57.2% and 68.5% for non-target and total fish biomass respectively. This makes any estimate of power for non-target fish and total fish biomass conservative; thus any design that maximizes power using target fish data will also be sufficiently powerful to detect the same or small amount of change for non-target or total fish biomass data.

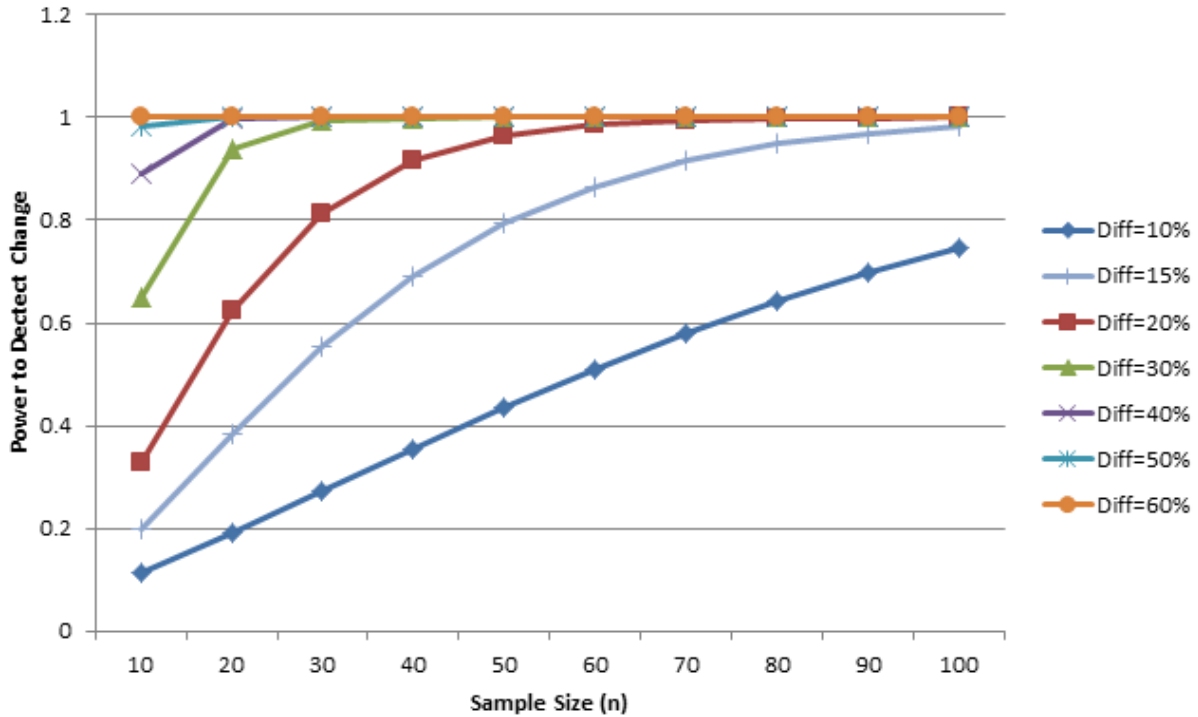
For the power analysis, target fish biomass was  $\log(x+1)$  transformed to correct skew, and the power was estimated for 10 pre-determined sample sizes (10, 20, 30, 40, 50, 60, 70, 80, 90, 100) and five levels of change to detect (10%, 20%, 30%, 40%, 50% change) using a one-factor ANOVA design with three levels (*e.g.*, inside, upstream, downstream) and an assumption that the three zones will diverge over time. The entire data set was used to estimate a "global" standard deviation ( $\sigma$ ) and to calculate the mean initial target fish biomass.

A series of power curves were generated and plotted (Figure A.1) and it was estimated that ~25 survey sites in each area were sufficient to detect a 20% change in the target fish biomass, and ~40 surveys sites were needed to detect a 15% change.

Initial Recommendation: We believe that 40 sites per area (inside, upstream and downstream) are sufficient to achieve the power and sensitivity required. This equates to a minimum sample size of 120 samples split evenly among the three strata. Power and sensitivity would be better for non-target fish and total fish biomass because they have lower variability. Corals tend to be less variable than fish, so power is expected to be as good or higher for corals.

### A2. Refining the Power Analysis and Sample Size Estimate

After closer examination of the survey area, a second power analysis was run with four different strata: BENCH, RS-IN, RS-N, and KĪHOLO (Table A.1). For each strata, the mean, standard deviation and coefficient of variation were calculated from the 2012 target fish biomass data. Given that the range of variability for each area was relatively small, a pooled variability could be used which would produce results similar to the initial power analysis.



**Figure A.1.** Power curves generated from 2012 target fish biomass data. Each line represents a level of change that can be detected. Sufficient power is considered to be 0.7.

In an attempt to refine the sampling, however, we conducted a bootstrap analysis to examine how the number of survey sites within each strata would affect the standard deviation of the mean for each reef area to determine if less than 40 survey sites could be sampled per area without significantly increasing the variability estimate.

For the BENCH area, reducing the number of survey site to 30 introduced significantly more variability in the range of the estimated standard deviation, so we recommend surveying at least 40 sites in this area (Table A.2). Increasing the number of survey sites to 50 cut the variability of the standard deviation estimates in half, but increasing the sample size resulted in little gain in precision. For RS-IN, 25-30 survey sites were found to be sufficient. For RS-N, 30-40 survey sites were needed. For KĪHOLO, 40-50 survey sites were needed.

**Table A.1.** Mean, standard deviation, and coefficient of variation for target fish biomass in four areas of the Ka‘ūpulehu-Kīholo survey area.

Strata	n	Mean	SD	CV
BENCH	96	1.65	0.48	0.292
RS-IN	44	1.89	0.25	0.132
RS-N	65	1.71	0.33	0.193
KĪHOLO	94	1.61	0.40	0.248
ALL	299	1.71	0.41	0.238

**Table A.2.** Recommended number of survey sites to achieve sufficient power to detect a 15% change in the target fish biomass in four areas of the Ka‘ūpūlehu-Kīholo reef.

<b>Strata</b>	<b>Suggested N</b>	<b>Actual N</b>
BENCH	40-50	34
RS-IN	25-30	26
RS-N	30-40	26
KĪHOLO	40-50	31
<b>TOTAL</b>	<b>135-170</b>	<b>117</b>

In 2013, divers surveyed 117 sites within these strata, with an additional 9 sites surveyed in RS-S, which was not included as a stratum in our original power analysis. Follow-up analysis showed this level of sampling was sufficient to adequately capture the range of variability, and produced estimates that were similar to the 2012 survey event. Ideally, future survey events would include ~20 more survey sites, with more sites surveyed on the BENCH, RS-N, and KĪHOLO.

## 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.

All benthic and fish surveys at Ka'ūpūlehu were conducted by TNC's marine monitoring team and researchers from the University of Hawai'i at Mānoa and Hilo. 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.

### Survey Sites

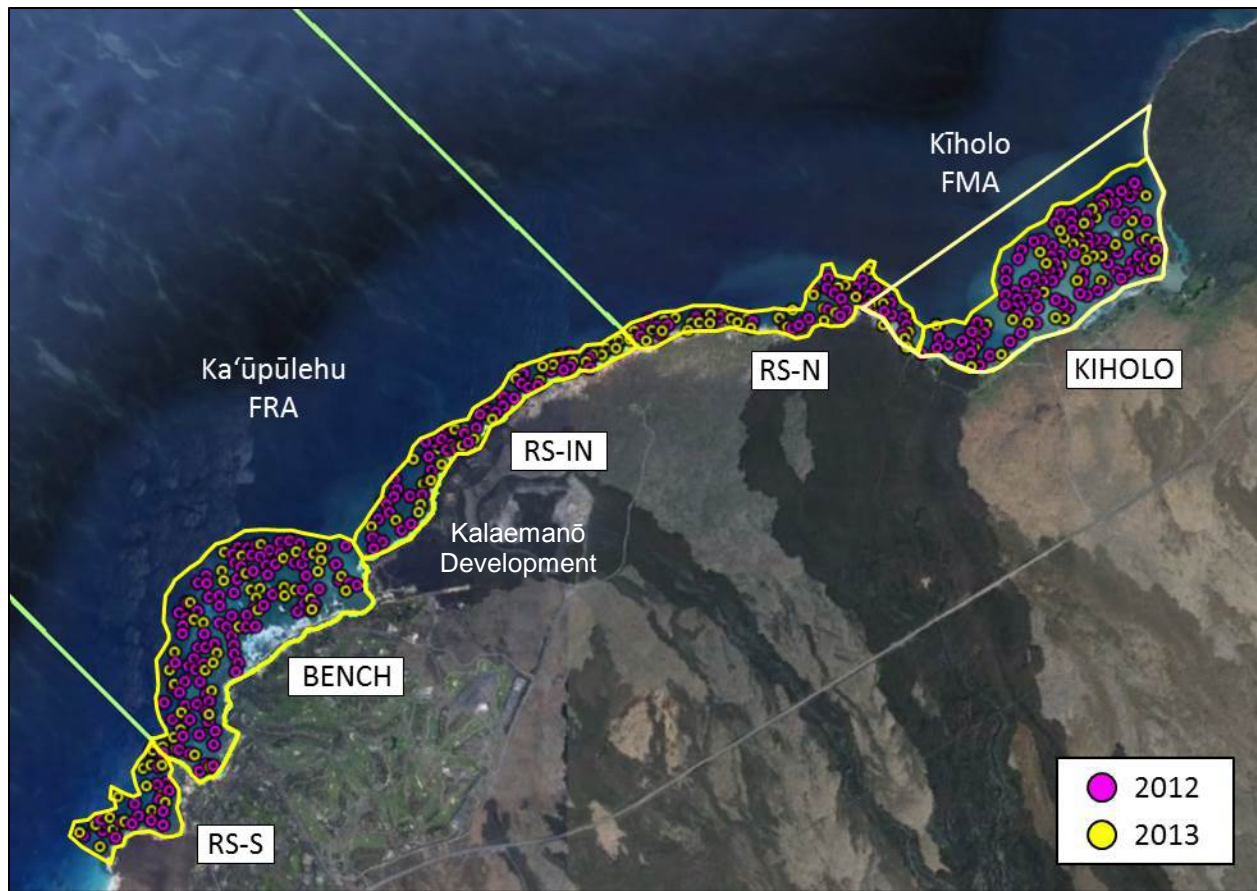
The survey area covered approximately 20 km (12.4 mi) of coastline and included coral reef habitat from high tide to the 20-m (60 ft) depth cline. A total of 416 sites (290 in 2012 and 126 in 2013) were randomly generated using ArcGIS. Sites were stratified across two factors: management status and reef area. Management status included two levels, inside and outside the Ka'ūpūlehu FRA. Reef areas included: 1) an area of aggregate reef south of the Ka'ūpūlehu FRA (hereafter, RS-S for "Reef Slope – South"), 2) the shallow bench within the Ka'ūpūlehu FRA (BENCH), 3) the narrow fringing reef inside the Ka'ūpūlehu FRA extending from Kumukehu point to the northern FRA boundary (RS-IN), 4) the narrow fringing reef extending from the northern boundary of the FRA to Kīholo Bay (RS-N), and 5) the shallow, relatively flat area within Kīholo Bay (KĪHOLO) (Figure B.1).

The survey team 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, parallel to each other.

### 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.

At each survey site, 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 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.



**Figure B.1.** Survey sites at Ka'ūpūlehu, Hawai'i, 2012-2013 stratified across five reef areas: RS-S, BENCH, RS-IN, RS-N, and KĪHOLO. See text for a description of each area.

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, 15 random points were overlaid on each digital photograph, and the benthic component under each point was identified into broad categories: coral by morphological form (branching, encrusting, massive), algae (macroalgae, turf, and crustose coralline), and other benthic organisms present. To reduce observer variability, all photo-processors were trained and calibrated prior to beginning photo analysis. 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.

### 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).

### Data Analysis

Individual fish biomass (wet weight of fish per m<sup>2</sup> of reef area) was calculated from estimated lengths using size to weight conversion parameters from FishBase (Froese and Pauly, 2010) or the Hawai'i Cooperative Fisheries Research Unit (HCFRU) at the University of Hawai'i (UH). For analyses among survey sites, fish survey data were pooled into several broad categories, including: (1) all fishes, excluding manta rays; (2) target fishes<sup>3</sup>, which are reef species targeted or regularly harvested by fishers (Table B.1); (3) prime spawners<sup>4</sup>, 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, *Cirrhites pinnulatus*); triggerfishes excluding planktivores; corallivorous butterflyfishes (*Chaetodon multicinctus*, *C. ornatissimus*, *C. quadrimaculatus* and *C. unimaculatus*); and benthic damselfishes (all *Plectroglyphidodon* and *Stegastes* species). In addition, data were pooled by family for parrotfish and target surgeonfish. Those abundant and conspicuous fishes provide important ecosystem services (*i.e.*, herbivory).

All means are presented as the average  $\pm$  the standard error of the mean (SEM). Standard parametric and non-parametric statistical approaches, as appropriate, were used to test for differences between management status, among reef areas, and between years. In most cases, a multifactor ANOVA including sample year, management status, and reef area was used to examine summary-level variables (*e.g.*, total fish biomass, total fish abundance). Tukey multiple comparisons were used to identify differences within significant factors. As necessary, fish biomass and abundance were log-transformed to correct skewness prior to analysis.

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).

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<sup>3</sup> 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.

<sup>4</sup> 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.

<u>Surgeonfishes (Acanthuridae)</u>	<u>Apex</u>
<i>Acanthurus achilles</i>	<i>Aphareus furca</i>
<i>Acanthurus blochii</i>	<i>Aprion virescens</i>
<i>Acanthurus dussumieri</i>	All Priacanthidae (big-eyes)
<i>Acanthurus leucopareius</i>	All Sphyraenidae (barracuda)
<i>Acanthurus nigroris</i>	
<i>Acanthurus olivaceus</i>	<u>Goatfishes (Mullidae)</u>
<i>Acanthurus triostegus</i>	All
<i>Acanthurus xanthopterus</i>	
<i>Ctenochaetus</i> spp.	<u>Jacks (Carangidae)</u>
<i>Naso</i> spp.	All
<u>Wrasses (Labridae)</u>	<u>Soldier/Squirrelfishes(Holocentridae)</u>
<i>Bodianus albotraeniatus</i>	<i>Myripristis</i> spp.
<i>Cheilio inermis</i>	<i>Sargocentron spiniferum</i>
<i>Coris flavovittata</i>	<i>Sargocentron tiere</i>
<i>Coris gaimard</i>	
<i>Iniistius</i> spp.	<u>Others</u>
<i>Oxycheilinus unifasciatus</i>	<i>Chanos chanos</i>
<i>Thalassoma ballieui</i>	<i>Cirrhitus pinnulatus</i>
<i>Thalassoma purpureum</i>	<i>Monotaxis grandoculis</i>
<u>Parrotfishes (Scaridae)</u>	
All	

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.

#### References for Appendix B

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