A Collaboration of Scientists and Citizen Scientists to Collect Data on Shallow Coral Reefs Communities to Further Community-Based Conservation in Hawai‘i

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NOAA CORAL REEF CONSERVATION PROGRAM

A Collaboration of Scientists and Citizen Scientists to Collect Data on Shallow Coral Reefs Communities to Further Community-Based Conservation in Hawai‘i

by

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Cover Image: (top) Surveys teams head to the Nihoa's reefs. (bottom right) Snorkeler photographs the reef at Nihoa. (bottom left) A large jack, common at Nihoa, cruises the shallow water reef

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

1.0 Summary

Many communities in Hawai‘i have witnessed a decline in the condition of their coral reef resources, including the size, abundance, and variety of coral reef fish. These conditions in the inhabited Main Hawai‘i Islands (MHI) stand in contrast to those in the Northwestern Hawaiian Islands (NWHI), where reefs are dominated by large, apex predators and high coral reef fish biomass. This discrepancy has been linked to human population density, and especially fishing access and activity. In response to these trends of decline, community-driven efforts are underway to increase fishery recovery and sustainability by better managing nearshore resources through harvest reductions and/or closures (voluntary or regulated).

The Nature Conservancy (TNC) assists many communities with the collection of shallow water fisheries data through surveys conducted by researchers from our staff and by partners, and by engaging "citizen scientists" in data collection. These efforts are intended to address two significant challenges to communities seeking to enact local management: 1) a lack of recent scientific information on shallow water fish assemblages from which to establish baseline conditions, and 2) few data from relatively pristine sites against which communities can compare their reefs and understand the range and/or degree of potential degradation. The goal of this project was to work with citizen scientists to collect comprehensive, scientifically-rigorous data on fish populations in the shallow water reefs of Nihoa Island, and to directly compare it with data from sites in the MHI, including those of the citizen scientists who helped collect the information.

Due to unexpectedly calm weather that delayed their arrival to Nihoa, a survey team of four TNC staff and two citizen scientists (from Polanui, Maui and Ka‘ūpūlehu, Hawai‘i) was unable to conduct the surveys on Nihoa planned for 2015. Thus, a second team of surveyors, including two TNC staff and one citizen scientist (from Wailuku, Maui), returned to Nihoa in the summer of 2016 and successfully surveyed 36 sites around the island, using 5-minute timed swim surveys (TSS) to collect information on fish assemblage composition, abundance and biomass. The team was also able to collect data from 22 sites using citizen science fish surveys methods, as well as samples for an ongoing NOAA ciguatera study.

A total of 45 species representing 14 families of fishes were observed at Nihoa in 2016. Fishes were not evenly distributed around Nihoa: reefs along the north side of the island had lower abundance and biomass of fishes than those along the south and west. Total fish biomass at Nihoa was over twice that of 12 locations in the MHI, and the fish assemblage was dominated by apex predators, especially barracudas, jacks, and sharks. The biomass of resource fish (*i.e.*, species especially prized by fishers) was nearly twice as great around Nihoa compared to the MHI. While higher species abundance contributed to the greater biomass at Nihoa, fish were also larger, especially apex predators and parrotfishes.

2.0 Introduction

One commonality that many communities in Hawaiʻi share is a perception of decline in the condition of their coral reef resources, including the size, abundance, and variety of coral reef fishes. These perceptions are supported at many sites by scientific surveys. For example, at Puakō (Hawaiʻi Island) coral cover has decreased by nearly 50% over the past fifty years, and the maximum size of fish caught has declined (Minton *et al.* 2012). Similarly, fish abundance and coral cover have significantly decreased at Kaʻūpūlehu (Hawaiʻi Island) since the early 1990s (Minton *et al.* 2014). The perception by community members and findings by scientist are consistent with commercial fisheries data dating back to 1900 that indicate a drastic reduction in landings of coral reef species (Shomura, 1987) and with recent stock assessments that demonstrate overfished stocks for 11 of 27 species investigated (Nadon 2017). These fishery dependent findings are bolstered by fishery independent data showing vast disparities in fish and coral assemblages between the Main Hawaiian Islands (MHI) and the Northwestern Hawaiian Islands (NWHI) (Friedlander and DeMartini 2002), across the geographic range of the MHI (Williams *et al.* 2008), and between areas open to fishing and within no-take zones (Friedlander *et al.* 2006, Minton *et al.* 2014).

These declines are correlated with human population density and access to fishing (Williams *et al.* 2008, Williams *et al.* 2011, Friedlander *et al.* 2013). The coral reef data, along with observational information from communities around the state, suggest land-based activities and overharvest are significant contributors to this trend. In hopes of achieving sustainability, many communities have undertaken efforts to enact community-developed fishery rules, including voluntary or regulated closures and/or harvest reductions. Many communities are in the early stages of developing strategic conservation plans, and are actively engaging government agencies and conservation organizations for guidance and assistance, both in the planning process and with the collection of scientifically-rigorous data to inform and support this process. The Nature Conservancy (TNC) has worked closely with many communities around the state, assisting with the collection of shallow water fisheries data, and helping to develop effective survey protocols for their "citizen scientists." These efforts involve significant outreach, including engaging citizen scientists in data collection, handling, and management, which allow stakeholders to experience firsthand the state of their coral reef resources and/or to monitor changes in those resources through time as management actions are implemented. Currently, two significant challenges communities face to their management efforts are: 1) a lack of recent scientific information on shallow water reef fish assemblages from which to establish baseline conditions, and 2) few data from relatively pristine sites against which communities can compare their reefs and understand the range and/or degree of potential degradation.

This project was designed in collaboration with NOAA and the Office of Hawaiian Affairs (OHA) staff to provide communities with information on relatively pristine reefs to which they can compare the condition of the reefs they are seeking to manage. In addition, data collected by the surveys would further augment the Monument's knowledge of Nihoa's shallow water marine resources, where most information comes from SCUBA surveys of deeper reefs. Our goal was to collect comprehensive data on shallow water fish populations on the reefs of Nihoa Island within the Papahānaumokuākea Marine National Monument, and to compare those with data from the MHI, including the reefs adjacent to each citizen scientist's community. Citizen scientists directly assisted in data collection as a means to engage and educate these key stakeholders in the practice of applied, community-driven science, and in the value of marine managed areas. These individuals could then share their experiences in the Monument with their communities, and champion the benefits of both preserving places like the Monument and of working towards improving management on their local reefs.

3.0 Survey Methods

Nihoa Island is located at the southern end of the NWHI chain and is the tallest of ten islands and atolls in the Papahānaumokuākea Marine National Monument (Figure 1). At approximately 240 km northwest of Kaua'i, it is the closest of the NWHI to the eight MHI.

Nihoa is characterized by steep slopes and sheer sea cliffs. Its submerged coral reef habitat grows on the remnants of a former volcanic cone, which along the north shore of the island is a steep cliff made up of successive layers of lava. Due to the steepness,

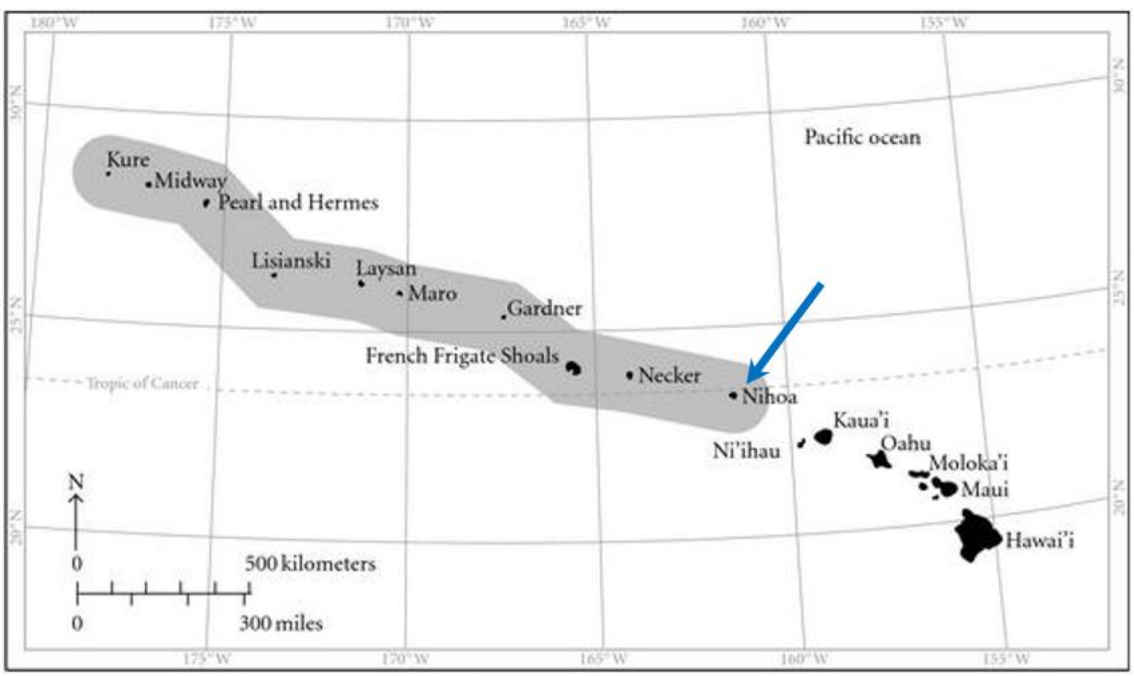

Figure 1. The Hawaiian Archipelago. The blue arrow identifies Nihoa. The shaded area is the Papahānaumokuākea Marine National Monument, which encompasses all the NWHI and has no permanent human residents. Islands outside the shaded area comprise the inhabited MHI.

heavy wave action during at least some portion of the year. Thus, coral cover tends be Nihoa has relatively little shallow water benthic substratum, most of which is exposed to low, <25% cover, and is most prevalent at depths >10 m (PNMN 2017). Submerged sea cliffs, caves, lava tubes, and basalt pinnacles, boulders, cobbles, and benches are common.

3.1 2015 Surveys

From June 28 to July 7, 2015, our team sailed to the islands of Lehua and Nihoa with the voyaging canoe *Hikianalia*, her crew from the Polynesian Voyaging Society (PVS), and staff from OHA. The team consisted of four TNC staff and two community members, Ekolu Lindsey from Polanui, Maui and Kaikea Nakachi from Kaʻūpūlehu, Hawaiʻi. The intention was to conduct approximately 40 surveys on the shallow reefs around Nihoa, however, due to unexpectedly calm winds, travel time was twice what was expected, and the team only had one afternoon in which they could survey only two sites on the north side of the island. Thus, TNC requested and received an extension so they could continue the partnership with OHA and NOAA and return to Nihoa the next summer to complete the proposed work.

3.2 2016 Survey Sites

Between August 20 and 22, 2016, our team and partners from OHA returned to Nihoa with the three-masted staysail schooner, *Makani Olu,* and her crew from the Marimed Foundation. The survey team was comprised of two members of the TNC marine monitoring team and community member Marcus Murray from Wailuku, Maui. With three days at the island, the team conducted surveys at 36 sites around the perimeter of Nihoa (Figure 2). At each site, a single 5-minute timed swim survey (TSS) was conducted, following the methods described in section 3.3. At the first site of the day or following any break in which surveyors returned to the boat, the team re-entered the water at a point that had been selected randomly using ArcGIS prior to entering the field. If the surveyors did not return to the boat upon completion of the TSS, they swam approximately 25 meters (*e.g.*, 25 kick cycles) along the shore and established a new site from which they started a new TSS. The latitude and longitude[1] of each TSS start and endpoint point were determined using a handheld Garmin GPS unit, and water depth was measured with a Hawkeye depth sounder at both the starting and ending points of each TSS. This site selection method allowed for a relatively uniformly distribution of sites around the perimeter of Nihoa while maximizing efficiency so that as many surveys as possible could be completed in the limited time available for the work. The TSS starting points, compass bearing, and average depth for each site are in Appendix A.

[1] Due to the island's isolation and poor satellite coverage, the latitude and longitude at some sites could not be accurately determined. Some sites, especially along the north shore, appear to be the offset by as much as 80 m.

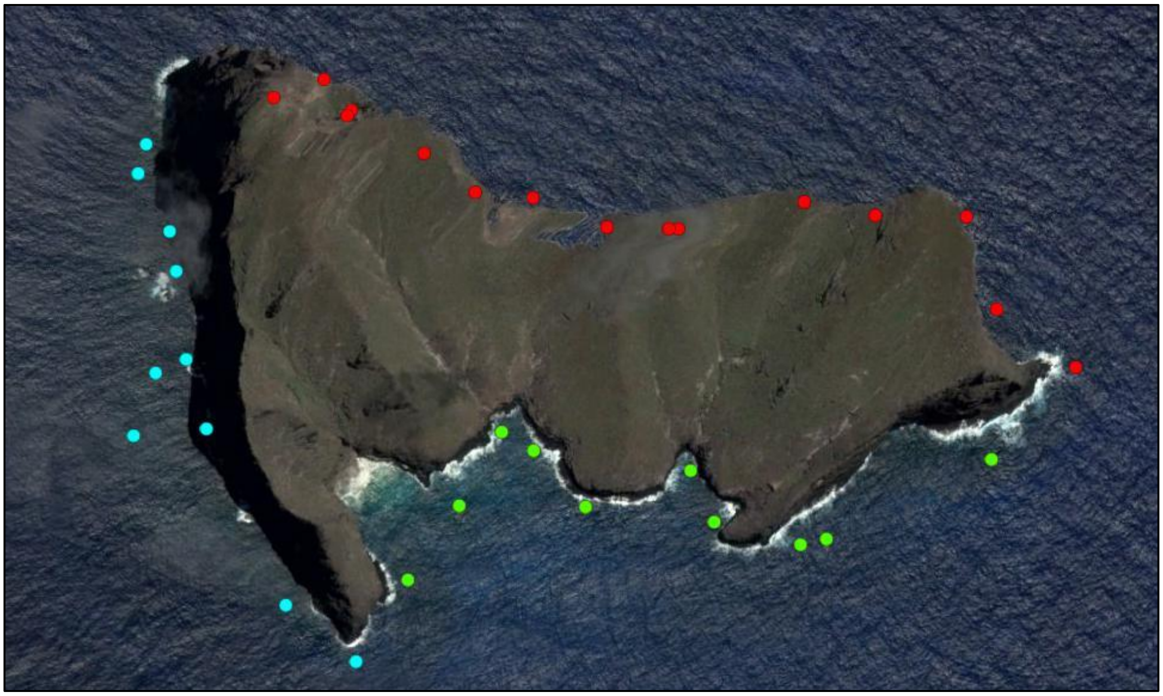

Figure 2. Sites surveyed along north (red), south (green) and west (blue) shores of Nihoa in 2016. Due to the island's isolation, the latitude and longitude at some sites, especially along the north shore, could not be accurately determined.

3.3 5-minute Timed Swim Surveys

A pair of trained and calibrated snorkelers from TNC's marine monitoring team conducted a single TSS at each site. For each TSS, 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, effectively creating a single 10 m wide belt transect. Throughout the survey, the two snorkelers 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. A third snorkeler, a citizen scientist, acted as a safety snorkeler, and collected site metadata, including GPS waypoints, depth at the starting and ending points of the TSS, and collected wide-scale habitat photographs along the path of the TSS.

3.4 Additional Data Collection

To provide data directly comparable to the citizen science data collected by communities on Maui, Marcus Murray (Wailuku, Maui) led OHA and TNC staff in conducting Presence/Absence surveys at 22 sites distributed around the island. In these surveys, observers noted the presence or absence of a predetermined suite of species within the survey area, with species included representing species that are common within the area as well as species that used to be abundant but have become rare in recent years. These surveys are used by multiple communities within the Maui Nui Makai Network (of which Wailuku and Polanui are members) to track changes over time in their resources.

NOAA also requested assistance from the team with an ongoing ciguatera testing study. The team was asked to collect samples of fish that are periodically harvested under permit for consumption within the Monument, and in consultation with NOAA, collected 25 uʻu (*Myripristis berndti*) using 3 prong spears. The depth of capture and size for each individual collected was recorded, and whole-fish specimens stored for future processing. These samples have been transferred to NOAA, and will be analyzed for ciguatera by partners from the University of South Alabama & Dauphin Island Sea Lab.

3.5 Comparable Timed Fish Surveys in Main Hawaiian Islands

Between 2009 and 2015, TNC's marine monitoring team completed 691 comparable TSS at 12 locations across four islands in the MHI (Figure 3). Four of the locations – Polanui, Kaʻūpūlehu, and Kāʻehu and Kananhā (both Wailuku area) – correspond with the communities represented by the citizen scientist involved in this work.

It is important to note that all TSS are standardized by time and not distance swam by the survey teams. All fish surveyors are trained to swim at a similar speed, but distance covered is also heavily influenced by the direction and strength of the prevailing current and whether teams encounter unsuitable habitat over which they must quickly swim. While it is possible some TSS cover more distance than others, which could result in higher fish counts because of an increase in the number of "encounters," the time limitation and training provided to the surveyors likely makes these differences relatively small. Thus, any discrepancies that may occur in total fish counts because of differences in area surveyed are likely minor relative to the natural variability of reef fish populations.

3.6 Data Analysis

All TSS data were compiled in a custom Access database and checked for errors. Individual fish biomass (*e.g.*, wet weight of fish) was calculated from estimated fish lengths using size-to-weight conversion parameters from FishBase (Froese and Pauly, 2010) or the Hawaiʻi Cooperative Fisheries Research Unit. For analyses, fish survey data were pooled into several groups, including all fish, by family, and by resource groups, including a select non-resource group for comparison. Resource fish refer to fish desirable for food, commercial activity, and/or cultural practices in Hawaiʻi (see Williams *et al.* 2008) that reside within the survey area, whereas non-resource[2] fish are species not routinely targeted by fishers to any significant degree (Table 1). For this

[2] Nearly all fish species are taken by some fishers at some time in Hawaiʻi, therefore designating a fish species as either 'resource' or 'non-resource' 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.

report, all abundance and biomass values are presented as the mean ± the standard error of the mean (SEM), unless otherwise specified. Standard parametric and non-parametric statistical approaches, as appropriate, were used to test for differences among shores (north, south, and west) around Nihoa and between locations (Nihoa vs. MHI). When necessary, fish biomass and abundance were log-transformed to correct skewness and reduce heteroscedasticity prior to analysis. Multivariate analysis on 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). Prior to analysis in PRIMER, 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). Non-metric multidimensional scaling (nMDS) plots were generated to explore patterns (Clarke and Gorley 2006) in fish assemblage structure. Key taxa representative of the shores around Nihoa or between locations (Nihoa vs. MHI)

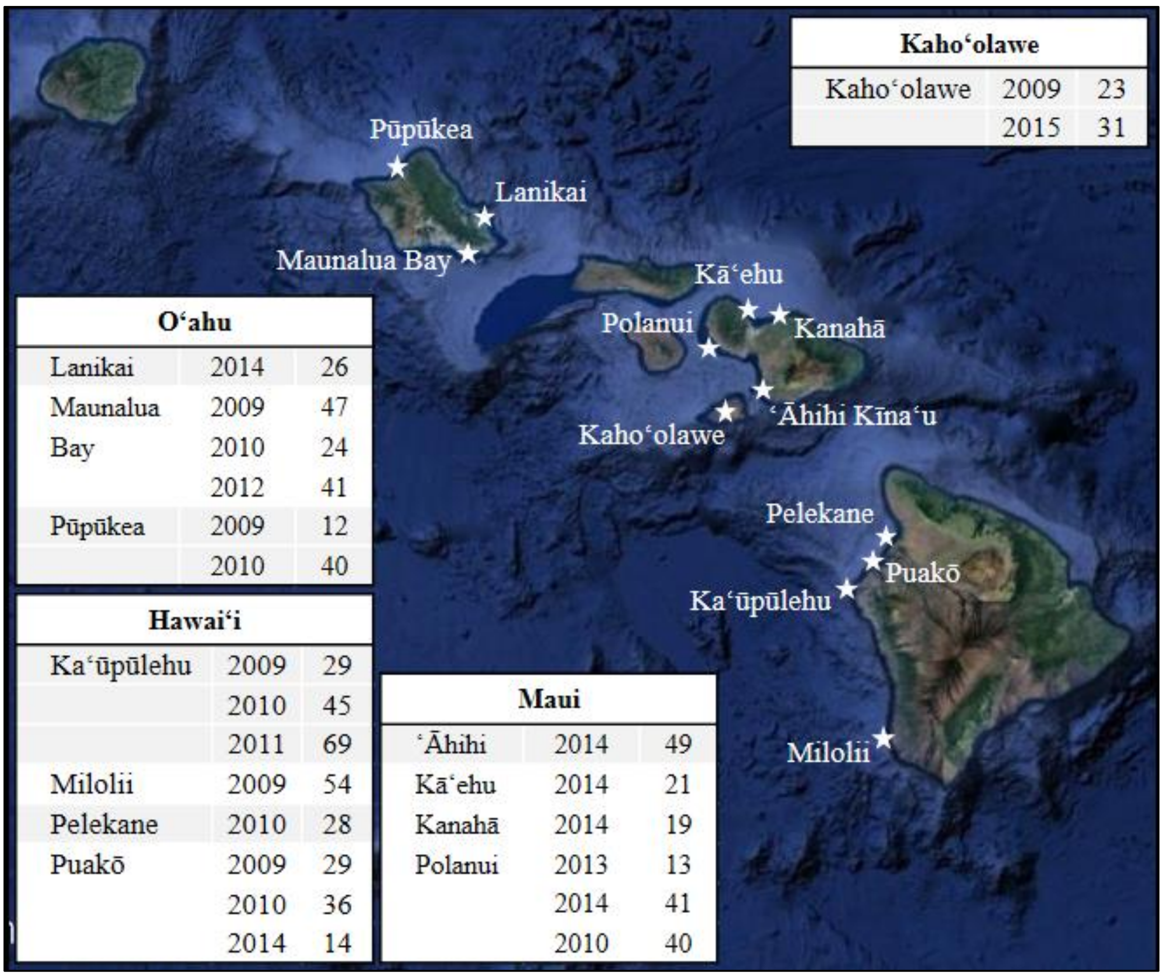

Figure 3. Locations in the MHI where 691 comparable TSS sites were surveyed by TNC' marine monitoring team between 2009 and 2015. Each island table includes location names, year surveyed and number of sites surveyed.

Table 1. Fish species comprising the seven resource species groups and the non-resource group used in this report. Groups are modified from Williams *et al.* (2008).

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

Non-resource	
Acanthurus nigrofuscus	*Chaetodon quadrimaculatus*
Acanthurus nigricans	*Chaetodon unimaculatus*
Chaetodon multicinctus	*Plectroglyphidodon* spp.
Chaetodon ornatissimus	*Stegastes* spp.
All wrasses, except those listed above	
All hawkfishes, except *Cirrhitus pinnulatus*	
All triggerfishes, except planktivorous species	

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

4.0 Results and Discussion

A total of 45 species representing 14 families of fishes were observed at Nihoa in 2016 (Table 2). Total biomass was 48,425 ± 6,650 g/TSS, and variability among the sites was high: biomass ranged from 0 to 189,700 g/TSS. Total fish abundance was 47.7 ± 5.5 fish/TSS, and also ranged widely, from 0 to 124.5 fish/TSS. Surgeonfishes (Acanthuridae) and chubs (Kyphosidae) accounted for 50% of the total fish biomass and 80% of all individuals observed at Nihoa (Table 2). Compared to reefs in the MHI, barracudas (Sphyraenidae), jacks (Carangide) and sharks (Carcharhinidae) comprised a large percentage of the total fish biomass at Nihoa. In the MHI surgeonfishes, parrotfishes (Scaridae) and wrasses (Labridae) generally contribute the most to the total fish biomass on nearshore reefs, often >60% of the total fish biomass.

Fishes were not distributed uniformly around Nihoa. Reefs along the north shore had lower total fish abundance than reefs along both the south and west (Kruskal-Wallis, H_2=14.8, p=0.001), and had lower total fish biomass (Kruskal-Wallis, H_2=8.5, p=0.014) than reefs along the west (Figure 4). The north shore reefs also showed high inter-site variability in biomass: the coefficient of variance (CV) for total fish biomass for the north shore (CV=35%) was over twice that of the south (15%) and west (11%) shores. In contrast, the inter-site variability was similar for abundance for all shores, with the north (20%) shore reefs only a slightly more variable than either the south (17%) or west (14%)

Table 2. Biomass (g/TSS) and abundance (individuals/TSS) of fishes by family at Nihoa in 2016. Families are ordered by decreasing biomass.

	Species	Biomass	Abundance
Acanthuridae	15	12,250 ± 1,375	26.5 ± 3.5
Kyphosidae	1	11,625 ± 2,325	12.0 ± 2.5
Sphyraenidae	2	5,950 ± 4,275	0.5 ± 0.4
Carangide	4	4,325 ± 1,900	0.7 ± 0.3
Scaridae	5	4,000 ± 775	1.2 ± 0.2
Balistidae	2	2,525 ± 900	2.6 ± 0.9
Carcharhinidae	2	2,300 ± 1,850	<0.1
Lutjanidae	3	2,250 ± 1,250	2.0 ± 0.8
Lethrinidae	1	1,100 ± 375	0.4 ± 0.1
Belonidae	1	975 ± 925	0.9 ± 0.8
Oplegnathidae	2	475 ± 150	0.2 ± 0.1
Mullidae	5	325 ± 150	0.5 ± 0.2
Serranidae	1	275 ± 150	0.1 ± 0.1
Labridae	1	75 ± 25	0.1 ± 0.1
Total Biomass	45	48,425 ± 6,650	47.7 ± 5.5

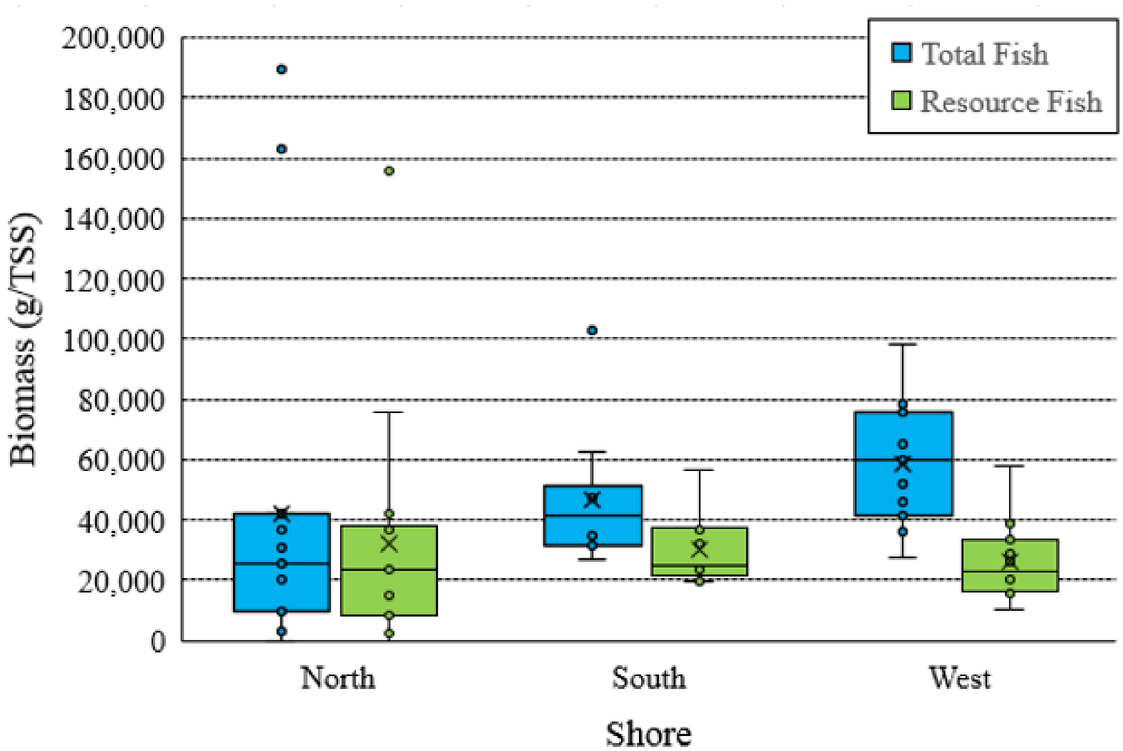

Figure 4. Box and whisker plot of total fish and resource fish biomass (g/TSS) along the north, south and west shores of Nihoa. Small circles above the "whiskers" represent sites with unusually high biomass (*i.e.*, "outliers").

shore reefs. This higher variability in biomass compared to abundance, suggest the presence of spatially heterogeneous, large-bodied fishes on north shore reefs, specifically a few large fish were found at a relatively small number of north shore sites (see the "outliers" in Figure 4), compared to west and south shores, driving up the variability in total fish biomass while have only a small effect of on total fish abundance.

The fish assemblage on the north shore was significantly different from both the south and west shores (ANOSIM, R=0.286[3], p=0.001). On the west shore, the fish assemblage was characterized by high biomass of surgeonfishes, chubs, triggerfishes (Balistidae) and parrotfishes. Likewise, surgeonfishes, chubs, and triggerfishes were also indicative of the south shore reefs. In contrast, only surgeonfish were consistently found among the north shore sites, and the presence of other fish families was highly variable, especially apex predators. For example, barracuda were present at only five north shore survey sites (Table 3), but when present, they could comprise as much as 80% of the total fish biomass at the site. In contrast, no barracuda were observed at any west or south shore survey sites. Sharks and jacks, while present to some extent on all shores, were also tended to be more abundant and have higher biomass on north shore reefs (Table 3).

[3] Given the variability in the fish assemblage at Nihoa, an R=0.286 suggests that shore is an ecologically meaningful predictor of fish assemblage structure.

Table 3. Biomass (g/TSS) and abundance (individuals/TSS) on north, south and west shores for barracuda, jacks and sharks.

	Sites (%)	Abundance	Biomass
Barracuda			
North	6 (40%)	7.8 ± 5.6	85,500 ± 54,750
South	0	0	0
West	0	0	0
Jacks			
North	6 (40%)	2.2 ± 1.1	38,425 ± 18,200
South	5 (50%)	1.5 ± 0.9	10,325 ± 6,200
West	3 (27%)	0.5 ± 0.1	6,375 ± 1,925
Sharks			
North	1 (7%)	1.0	128,275
South	0	0	0
West	1 (9%)	2.0	37,425

Fish biomass at Nihoa was approximately twice as great as any comparable location in the MHI (Figure 5), including areas effectively closed to fishing (*e.g.*, Kahoʻolawe, Pūpūkea) or which have low fishing effort due to their relative isolation and/or community management (*e.g.*, Miloliʻi). This higher biomass was the result of both more and larger fish at Nihoa compared to any area in the MHI. Both resource and non-resource fish groups showed "right-shifted" size-frequency distributions, that is, a greater percentage of individuals were present in large size class bins at Nihoa compared to the MHI (Figure 6). This right shift of the size-frequency distribution also resulted in a larger average size at Nihoa compared to the MHI, a trend also noted by Friedlander and DeMartini (2002). This difference in size was especially evident for apex predators and parrotfish, both of which were nearly twice as large, on average, at Nihoa as than the MHI.

4.1 Resource Fish

Unlike total fish biomass, resource fish biomass did not significantly differ among shores (Kruskal-Wallis, H_2=1.02, p=0.600) (Figure 4), indicating that differences among the shores in total fish biomass were driven primarily by "non-resource" species. Non-resource fish biomass did significantly vary by shore (Kruskal-Wallis, H_2=15.03, p=0.001). While total resource fish biomass did not vary among the shores, resource fish abundance was significantly lower on the north shore compared to the south and west shores (Kruskal-Wallis, H_2=13.21, p=0.001), again suggesting individuals were larger on the north shore reefs. Non-resource fish abundance was also significantly lower on the north shore reefs (Kruskal-Wallis, H_2=16.25, p<0.001). Large apex predators were more

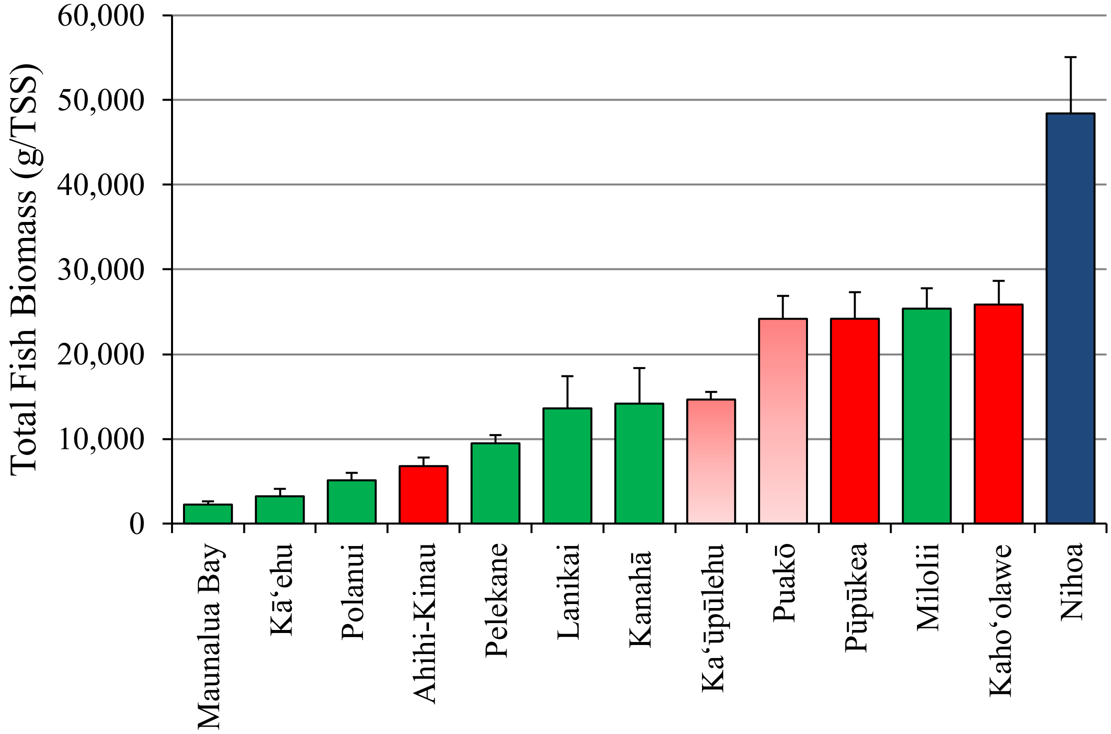

Figure 5. Total fish biomass on the reefs around Nihoa (blue bar) compared to 12 other locations in the Main Hawaiian Islands. Color of bars represents level of fisheries management occurring at the site: green=no additional fishing regulations; red=no take allowed; gradated red=limited take allowed.

common on north shore reefs compared to relatively small-bodied surgeonfish, which tended to dominate west and south shore resource fish assemblages (Figure 7).

Resource fish biomass at Nihoa was significantly greater than any location in the MHI (Figure 8). Apex predators comprised a large percentage of the total resource fish biomass at Nihoa compared to the MHI (Figure 8). This is consistent with other findings for the NHWI islands (Friedlander and DeMartini 2002), as well as for other areas remote from human influence (Sandin *et al.* 2008, Mourier *et al.* 2016). In contrast, parrotfishes contributed less to the total resource fish biomass in Nihoa than in MHI (Figure 9), likely a result of the limited areal extent and cover of reef building corals compared to many of the sites surveyed in the MHI. Even with the reduction in available habitat, however, fish abundance and biomass was much higher at Nihoa, likely a direct result of lower human-associated impacts.

<u>4.2 Invasive Fish</u>

Recently, many communities across Hawaiʻi have raised concerns about the abundance of invasive fish on Hawaiian reefs, particularly the peacock grouper, *Cephalopholis argus*, known locally as roi. While growing scientific evidence suggests invasive fish species have minimal impacts on native Hawaiian reef fish populations (Schumacher and

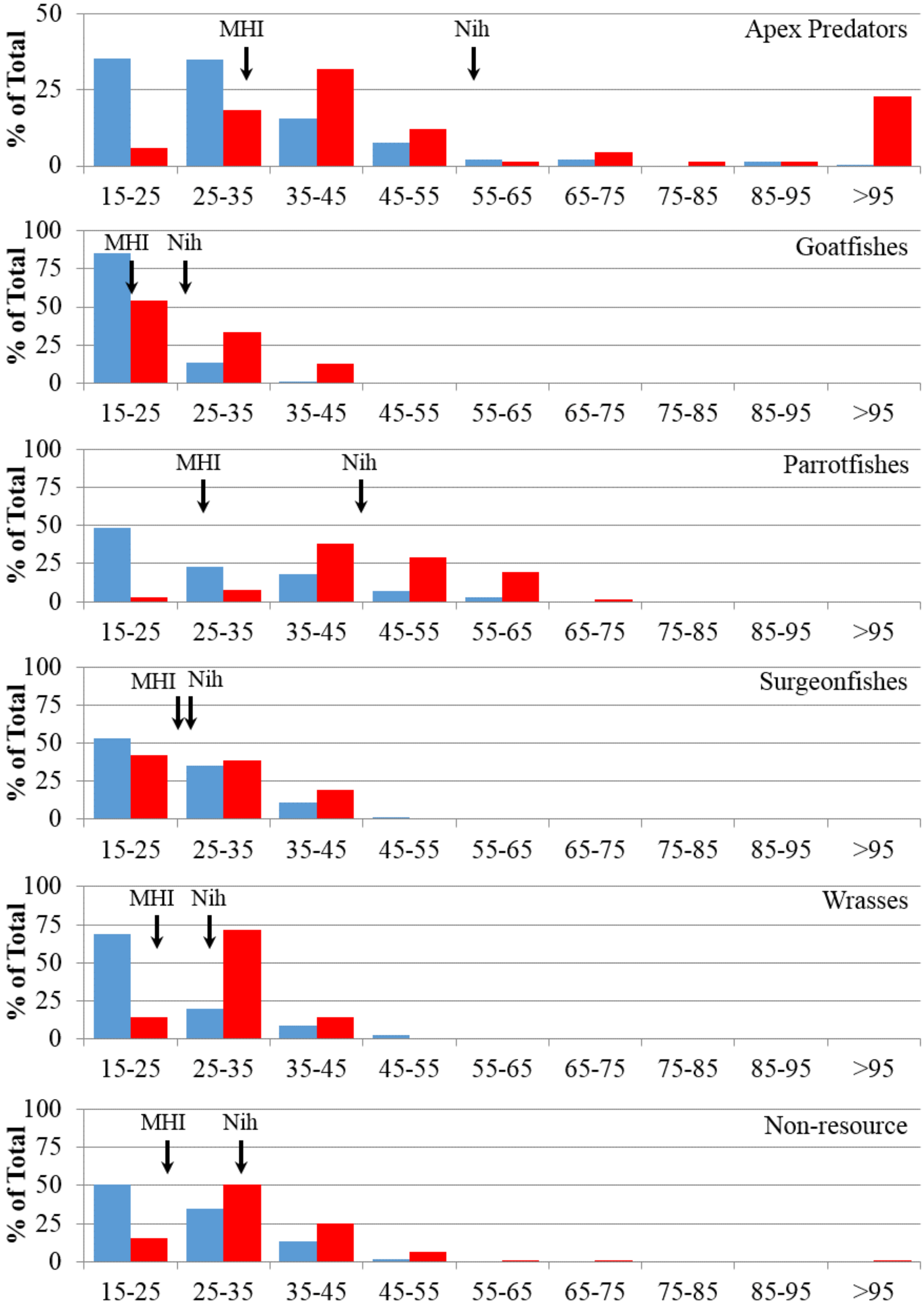

Figure 6. Size-frequency distribution of 5 resource species groups and a non-resource group at Nihoa (red) and in the MHI (blue). Size classes are in centimeters, and arrows mark the mean fish size in the group for Nihoa (=Nih) and the MHI. For species in each group, see Table 1.

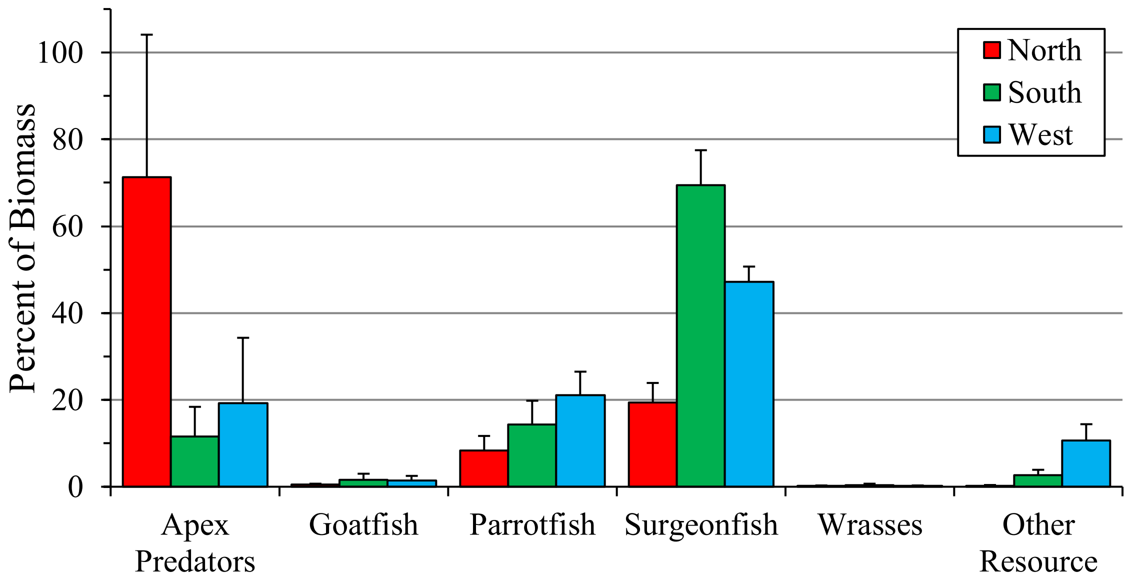

Figure 7. Percent of total resource fish biomass represented by six resource fish species groups in north, south and west zones of Nihoa. For species in each group, see Table 1. Error bars are SEM.

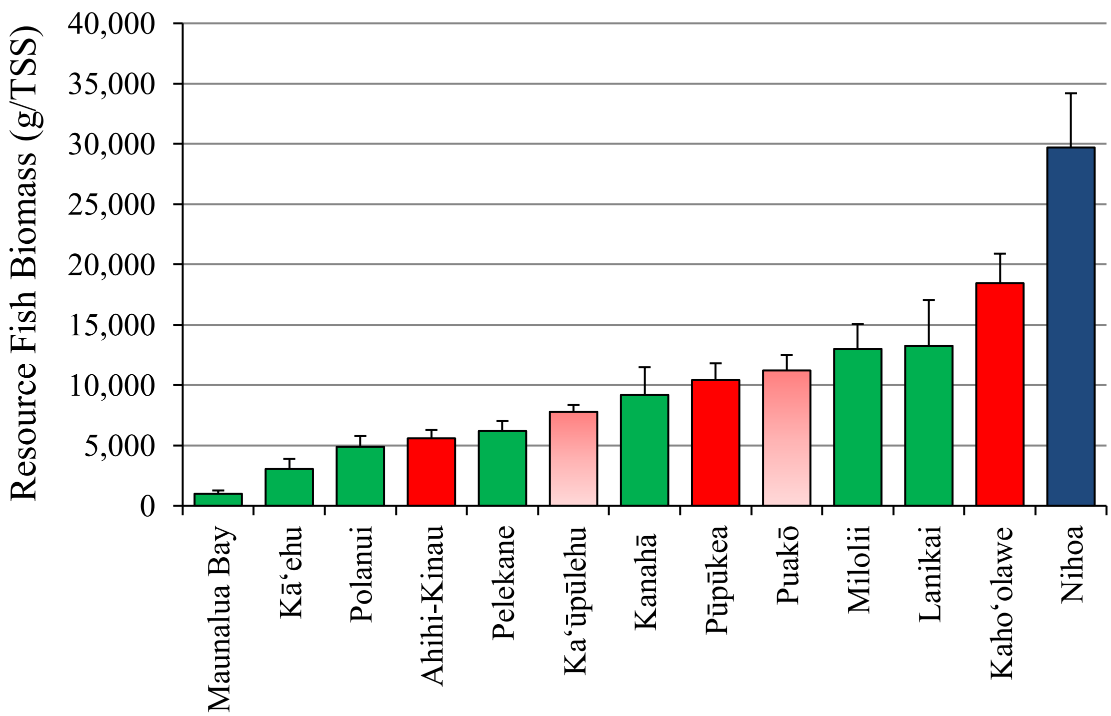

Figure 8. Resource fish biomass on the reefs around Nihoa (blue bar) compared to 12 other locations in the Main Hawaiian Islands. Color of bars represents level of fisheries management occurring at the site: green=no additional fishing regulations; red=no take allowed; gradated red=limited take allowed.

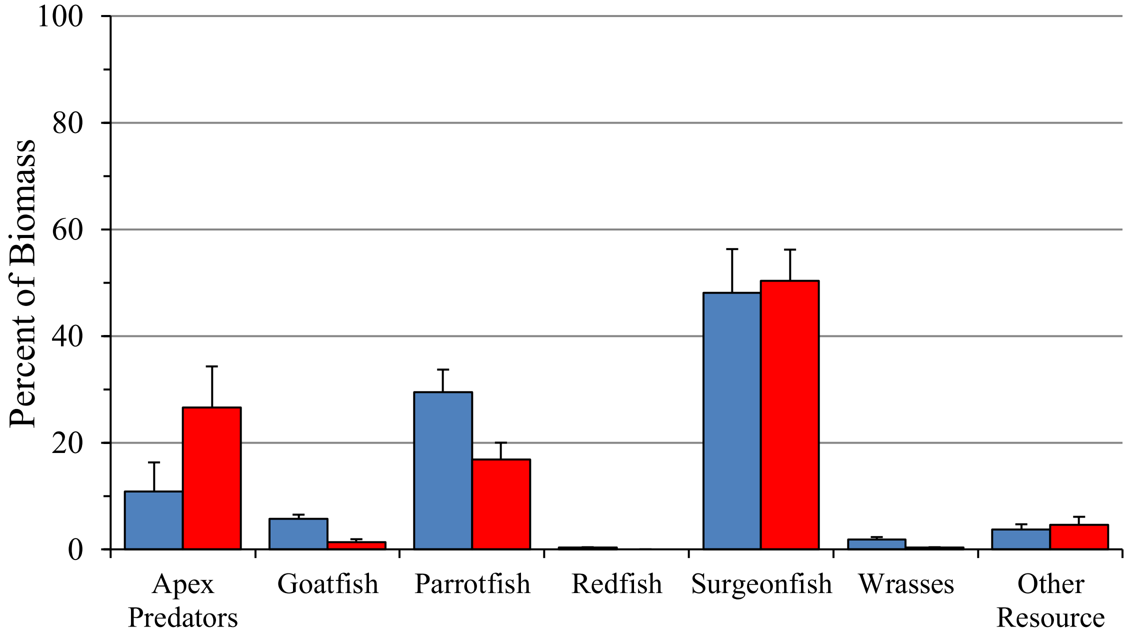

Figure 9. Percent of total resource fish biomass represented by seven resource fish species groups in the MHI (blue) and around Nihoa (red). For species in each group, see Table 1. Error bars are SEM.

Parrish 2005, Dierking *et al.* 2009, Giddens 2017), there is the perception among some stakeholders that invasive fishes are significantly impacting native species through direct competition and/or predation.

Invasive fishes were relatively rare at Nihoa. Only eight roi were observed at Nihoa, all at sites along the south shore. Bluestriped snapper (*Lutjanus kasmira*) were more common (101 total individuals) and found along both and north and south shore reefs of Nihoa, often in schools of 15-20 individuals. Only a single bluestriped snapper was observed along the west shore. A third invasive fish species, the blacktail snapper (*Lutjanus kasmira)*, was not observed on Nihoa.

Both the abundance (Kruskal-Wallis, H_1=6.39, p=0.011) and biomass (Kruskal-Wallis, H_1=4.12, p=0.042) of invasive fish were significantly lower on Nihoa than at comparable sites in the MHI. Three possible explanations for this include: 1) the invasive species have not yet naturally dispersed to Nihoa in large numbers; 2) Nihoa's reefs are not a preferred habitat, and/or 3) the relatively intact native fish assemblage at Nihoa may be able to resist invasion.

The three invasive fish species were introduced to Hawaiʻi between 1955 and 1961 and within 15 years all three had spread throughout the MHI. Currently, the bluestriped snapper is found throughout the Hawaiian Archipelago and the peacock grouper occurs at all islands south of French Frigate Shoals (Gaither *et al.* 2012). Both species have shown adequate dispersal potential, suggesting this has not limited their ability to colonize

Nihoa. The blacktail snapper is currently restricted to the MHI, and its low population growth in Hawaiʻi may be inhibiting its ability to spread.

Peacock groupers are a dominant fore reef and lagoon predator in their native home range (Randall and Brock 1960), and can be significant components of the shallow water reef and lagoon ecosystems where they are introduced (Shpigel and Fishelson 1985). While sometimes found in high energy locations (Shpigel and Fishelson 1985), peacock groupers prefer less exposed areas, which might account for their scarcity at Nihoa and their restricted distribution to the south side of the island. In contrast, bluestriped snappers can be abundant in high energy environments in Hawaiʻi (Friedlander *et al.* 2002) and elsewhere (Newman and Williams 1996), but may be limited to some extent by the amount of contiguous habitat available at Nihoa.

Intact native communities have been shown have greater potential to resist invasion (Stachowicz *et al.* 1999), a concept often referred to as biotic resistance. Biotic resistance can be reduced by adverse effects from landbased stressors and overfishing (Anton *et al.* 2014); thus, the relatively "pristine" conditions at Nihoa, especially the intact trophic structure dominated by apex predators (Mourier *et al.* 2016), may contribute to keeping invasive fish from becoming a dominant component of the coral reef fish assemblage at Nihoa.

4.3 Community Engagement

Visiting the Monument was a valuable learning experience for all three of the community members that were able to join the survey teams, as well as an excellent opportunity for media coverage for the Monument. Some of the coverage obtained for the *Hikianalia* voyage can be found at:

- ʻŌiwi TV Video, "Voyage to Nihoa - Science at Sea" https://www.youtube.com/watch?v=zvdm76qJb8w
- KHON-2 News, **"**Hikianalia sets sail on northwest voyage to Niihau, Nihoa" http://khon2.com/2015/06/28/hikianalia-sets-sail-on-northwest-voyage-to-niihau-nihoa
- Hōkūleʻa Crew Blog, "The romance of sailing is gone" http://www.hokulea.com/crew-blog-chad-wiggins-the-romance-of-sailing-is-gone
- Hōkūleʻa Website, "Hikianalia Update | Voyaging to Papahānaumokuākea" http://www.hokulea.com/hikianalia-update-voyaging-to-nihoa

Ekolu Lindsey (Polanui, Maui) spoke about his experiences to more than 100 people at a *Mālama Honua* event and a National Civic Club Convention. He also spoke about the voyage on *Hikianalia* and his time on Nihoa with the community organization Polanui Hiu, and with the West Maui Senior Center.

Kaikea Nakachi took a series of photographs throughout the voyage to record the methods used, and was able to share what he learned with the Kaʻūpūlehu community, which at the time had proposed a 10-year rest area along their coastline. In July 2016, that proposal was signed by Governor Ige, instituting the first-ever community rest area in Hawaiʻi, which prohibits fishing to allow depleted stocks to recover. After returning to his home in west Hawaiʻi, Kaikea enrolled in the Masters program at the University of Hawaiʻi at Hilo where he is working with state and federal scientists and managers to incorporate culturally appropriate standards into Hawaiʻi shark research. Using skills he acquired during the voyage, Kaikea mobilized students to conduct habitat surveys at sites where octopus abundance surveys were completed in 2014, improving the utility of data collected by community members at Kaʻūpūlehu.

Marcus Murray shared his experience in Nihoa with Maui Nui Makai Network at the September 23-25, 2016. The Network is a Maui-based community group focused on improving fisheries on the Northshore of Maui. As an avid diver, fisher, and waterman, the lasting impression that snorkeling the waters of Nihoa made on Marcus will be a touchstone for his future conversations and advocacy for marine management in Hawaiʻi.

4.4 Conclusions

The surveys conducted provide new information on the shallow water fish assemblage around Nihoa, filling a gap in knowledge for this critical resource. These surveys show similar results to the deeper, SCUBA surveys conducted previously, with more, larger fish found in the protected waters of the Monument than can be found in the waters of the MHI. Bringing members of community groups that are working on improving marine management within their areas to the Monument afforded them a transformative opportunity to see what reefs in Hawaiʻi can look like. The experience inspired them to share their stories with their communities and to work towards community-based management in their areas.

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We thank Papahānaumokuākea Marine National Monument, including NOAA, the U.S. Fish and Wildlife Service, Hawaiʻi Department of Land and Natural Resources, and the Office of Hawaiian Affairs for supporting this project. We especially thank the Polynesian Voyaging Society and the crew of the voyaging canoe *Hikanalia*, as well as the Marimed Foundation and crew of the *Makani Olu*, for making this research possible.

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Appendix A. Nihoa Site Data

Site Code	Shore	Date	Lat.	Long.	Bearing	Depth (m)
NIH01	West	8/20/2016	23.06372	-161.92917	160	16
NIH02	West	8/20/2016	23.06229	-161.92872	160	33
NIH03	West	8/20/2016	23.06021	-161.92838	160	8
NIH04	West	8/20/2016	23.05909	-161.928	150	33
NIH05	West	8/20/2016	23.06324	-161.9293	no data	24
NIH06	West	8/20/2016	23.06323	-161.9293	170	60
NIH07	West	8/20/2016	23.06164	-161.92859	150	28
NIH08	West	8/20/2016	23.05999	-161.92891	150	20
NIH09	West	8/20/2016	23.05898	-161.92927	330	45
NIH10	North	8/21/2016	23.06255	-161.91628	90	67
NIH11	North	8/21/2016	23.06277	-161.91753	270	60
NIH12	North	8/21/2016	23.06233	-161.91975	270	37
NIH13	North	8/21/2016	23.06233	-161.91992	270	35
NIH14	North	8/21/2016	23.06236	-161.92101	290	70
NIH15	North	8/21/2016	23.06284	-161.92232	290	40
NIH16	North	8/21/2016	23.06293	-161.92334	300	67
NIH17	North	8/21/2016	23.06357	-161.92425	300	60
NIH18	North	8/21/2016	23.06428	-161.92555	290	77
NIH19	North	8/21/2016	23.06479	-161.92604	300	85
NIH20	South	8/21/2016	23.0576	-161.91913	30	47
NIH21	South	8/21/2016	23.05842	-161.91954	210	40
NIH22	South	8/21/2016	23.05784	-161.92137	300	30
NIH23	South	8/21/2016	23.05874	-161.92228	300	23
NIH24	South	8/21/2016	23.05904	-161.92284	200	19
NIH25	South	8/21/2016	23.05786	-161.92357	230	19
NIH26	South	8/21/2016	23.05668	-161.92445	190	35
NIH27	West	8/21/2016	23.05539	-161.92533	320	60
NIH28	West	8/21/2016	23.05628	-161.92656	340	45
NIH29	North	8/22/2016	23.06253	-161.91467	120	67
NIH30	North	8/22/2016	23.06102	-161.91416	90	45
NIH31	North	8/22/2016	23.06008	-161.91279	210	75
NIH32	South	8/22/2016	23.0586	-161.91429	240	42
NIH33	South	8/22/2016	23.05733	-161.91718	220	36
NIH34	South	8/22/2016	23.05724	-161.91763	240	42
NIH35	North	8/22/2016	23.06419	-161.92562	290	63
NIH36	North	8/22/2016	23.06449	-161.92693	300	77