# Baseline Surveys of the Marine Resources of Kaʻūpūlehu, Hawaiʻi
# 2009-2011

By

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

| **Common Name** | **Hawaiian Name** | **Scientific Name** |
|---|---|---|
| Bewick coral | - | *Leptastrea bewickensis* |
| Crust coral | Koʻa | *Leptastrea purpurea* |
| Rice coral | ʻĀkoʻakoʻa | *Montipora capitata* (=*verrucosa*) |
| Blue rice coral | - | *Montipora flabellata* |
| Sandpaper rice coral | Koʻa | *Montipora patula* |
| Porkchop coral | - | *Pavona duerdeni* |
| Corrugated coral | ʻĀkoʻakoʻa | *Pavona varians* |
| Antler coral | ʻĀkoʻakoʻa | *Pocillopora eydouxi* |
| Cauliflower coral | Koʻa | *Pocillopora meandrina* |
| Finger coral | Pōhaku puna | *Porites compressa* |
| Lobe coral | Pōhaku puna | *Porites lobata* |
| Hump coral | - | *Porites lutea* |
| Plate and pillar coral | - | *Porites rus* |

| **Common Name** | **Hawaiian Name** | **Scientific Name** |
|---|---|---|
| Achilles tang | Pākuʻikuʻi | *Acanthurus achilles* |
| Ringtail surgeonfish | Pualu | *Acanthurus blochii* |
| Eyestripe surgeonfish | Palani | *Acanthurus dussumieri* |
| Whitebar surgeonfish | Māikoiko | *Acanthurus leucopareius* |
| Whitespot surgeonfish | ʻApi | *Acanthurus guttatus* |
| Goldrim surgeonfish | - | *Acanthurus nigricans* |
| Brown surgeonfish | Māʻiʻiʻi | *Acanthurus nigrofuscus* |
| Bluelined surgeonfish | Maiko | *Acanthurus nigroris* |
| Orangeband surgeonfish | Naʻenaʻe | *Acanthurus olivaceus* |
| Thompson’s surgeonfish | - | *Acanthurus thompsoni* |
| Convict tang | Manini | *Acanthurus triostegus* |
| Stareye parrotfish | pōnuhunuhu | *Calotomus carolinus* |
| Spectacled parrotfish | Uhu ʻahuʻula | *Chlorurus perspicillatus* |
| Bullethead parrotfish | Uhu | *Chlorurus spilurus* |
| Hawaiian bristletooth | - | *Ctenochaetus hawaiinsis* |
| Goldring surgeonfish | Kole | *Ctenochaetus strigosus* |
| Bigeye emperor | Mū | *Monotaxis grandoculis* |

| Common Name | Hawaiian Name | Scientific Name |
|---|---|---|
| Paletail unicornfish | Kala lōlō | *Naso brevirostris* |
| Sleek unicornfish | Kala lōlō | *Naso hexacanthus* |
| Orangespine unicornfish | Umaumalei | *Naso literatus* |
| Bluespine unicornfish | Kala | *Naso unicronis* |
| Palenose parrotfish | Uhu | *Scarus psittacus* |
| Ember parrotfish | Uhu ʻeleʻele | *Scarus rubroviolaceus* |
| Yellow tang | Lauʻipala | *Zebrasoma falvescens* |
| Sailfin tang | Māneʻoneʻo | *Zebrasoma veliferum* |

**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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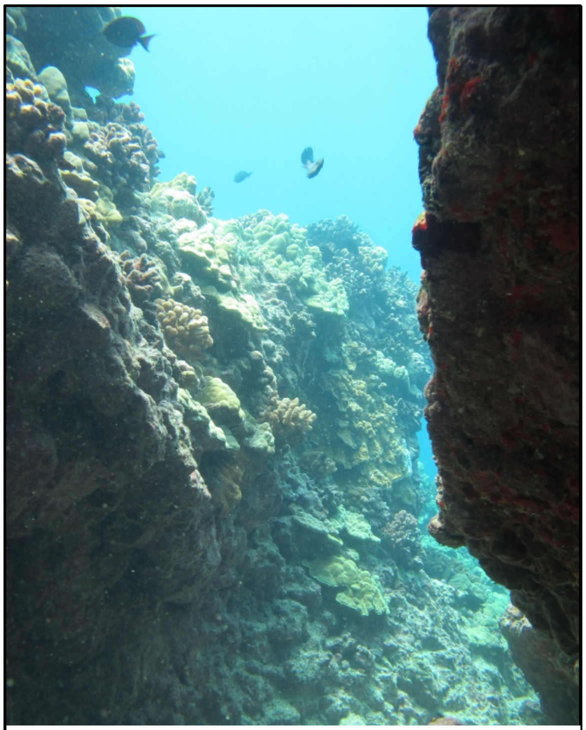
**Cover photo:** A TNC survey diver hovers above a large colony of coral (*Porites* sp.). This colony is approximately 3.5 m in size and, based on growth rates for massive *Porites* species, likely 350-400 years old.

## Summary of Findings

The coastal fishing grounds of Kaʻūpūlehu, north Kona, Hawaiʻi, once renowned for their abundance of fish, lobster, octopus, and limpets, now appear to be in decline. Data collected over the past decade, along with experiential information from the community over the course of many decades, suggest overharvest may be a significant contributor to this decline. To reverse this trend, the Kaʻūpūlehu community asked the state of Hawaiʻi to strengthen the management within the current Kaʻūpūlehu Fish Replenishment Area (FRA) from a limited-take area to a full no-take area for ten years while they develop a sustainable marine resource management plan.

The Nature Conservancy (TNC) has supported this community-led initiative by supplying scientifically credible information on the current status and trend of Kaʻūpūlehu's nearshore reefs, including their corals and fisheries. This report describes the findings from three-years of biological monitoring conducted by the TNC marine monitoring team.



Coral reef at Kaʻūpūlehu, north Kona

Between 2009-2011, the TNC marine monitoring team surveyed a total of 148 sites along Kaʻūpūlehu's 5.8 km (3.6 mi) coastline. Five survey rounds were conducted: Fall 2009, and both Spring and Fall of 2010 and 2011. At each survey site, all fish were identified, counted, and sized along a 25 m transect line. In 2011, information on coral cover and coral colony size was collected at most survey sites.

Based on coral and fish data, Kaʻūpūlehu had two distinct habitat zones: (1) a shallow reef bench that extended over 700 m (750 yd) offshore at its widest point and (2) a narrow fringing reef that dropped quickly into deep water. The bottom community on the bench had significantly lower coral cover than the narrow fringing reef, 30% versus 42.4% cover. The bench also had lower topographical complexity, which partially explained the differences in the species composition and the lower abundance and biomass (weight) of fish on the bench compared to the fringing reef.

The fish assemblage at Kaʻūpūlehu, comprising 134 species, was numerically dominated by surgeonfish, damselfish, and wrasses, which accounted for 81% of all individuals observed. When considering fish weight, surgeonfish, parrotfish and triggerfish accounted for 74% of the total fish biomass. The biomass of all fish at Kaʻūpūlehu is similar to the average of other areas in west Hawaiʻi that are open to fishing, but below that of areas that have additional fishery regulations (*e.g.*, limited take) or are closed to fishing (*e.g.*, no take). Target fish species, which include those fish species most prized by fishers, show a similar trend. However, non-target species show no difference in biomass among open, limited take, and no take areas, suggesting

fishing is the primary stressor reducing fish biomass at Kaʻūpūlehu. While other stressors may also be affecting fish populations, only fishing would selectively reduce the abundance of target species while not affecting non-target species. No significant trend in fish abundance or biomass was detected over the three years of surveys, and Kaʻūpūlehu's fish population appears to be stable, albeit at a level significantly below what it may be capable of supporting under enhanced management.

Yellow tangs and goldring surgeonfish school on Kaʻūpūlehu's reef.

The Kaʻūpūlehu community has requested information on several fish species, including parrotfish or *uhu*, convict tangs or *manini*, bluespine unicornfish or *kala*, ringtail surgeon fish or *pualu*, eyestripe surgeonfish or *palani*, and bigeye emperor or *mū*. These species all show signs of fishery impacts in their abundance, biomass, and size distribution. For many species, the average fish size is below both the legally-harvestable size and the size at maturity for the species. Larger individuals appear to be removed from the population by fishers prior to reaching maturity and, therefore, likely prior to having an opportunity to contribute to future generations of fish.

Rational fisheries management, including full and/or partial closures, and accompanying limits on gear and take, supported by the community and adequately enforced, are likely necessary to alleviate further declines of culturally- and economically-important species. To this end, the Kaʻūpūlehu community has initiated the formal process to establish additional fishing restrictions with the expected result of increased fish abundance and biomass, and improved coral reef health.

## Introduction

The coastal fishing grounds of Kaʻūpūlehu, north Kona, Hawaiʻi, once renowned for their abundance of fish, lobster, octopus, and limpets, now appear to be in decline. Data collected over the past decade, along with experiential information from the community over the course of many decades, suggest overharvest may be a significant contributor to this observed decline. In hopes of reversing this trend, the Kaʻūpūlehu community, through the Kaʻūpūlehu Marine Life Advisory Committee (KMLAC) and with the support of the West Hawaiʻi Fisheries Council, has prepared a rule amendment proposal asking the state of Hawaiʻi to strengthen the management within the current Kaʻūpūlehu Fish Replenishment Area (FRA) from a limited-take area to a full no-take area for ten years while they develop a sustainable marine resource management plan.

The Nature Conservancy's (TNC) role at Kaʻūpūlehu is to support community-led initiatives to increase the health and abundance of coral reef and associated marine communities and evaluate their efficacy. This includes helping the community obtain information on the current status and trends of the biological assemblages, both benthic and fish, on the Kaʻūpūlehu reef. Where applicable, it also includes comparing the status of Kaʻūpūlehu's marine resources with other comparable reef areas in Hawaiʻi.

This report describes the findings from surveys of the Kaʻūpūlehu reef conducted between 2009-2011 by the TNC marine monitoring team. These findings support the experience of community members, and may be used to inform community-led conservation efforts by providing scientifically defensible information that is of interest to the community, region, and state of Hawaiʻi.

## Site Description

Kaʻūpūlehu lies on the west coast of Hawaiʻi Island, approximately 20 km (12.4 mi) north of Kailua-Kona (Figure 1). The survey area extends from the high water mark to the 20-m (~60-ft) depth cline and from Kikaua Point (N19. 813740˚, W156.006339˚) to Kalaemanō (N19.853180˚, W155.956902˚). The area encompasses approximately 240 ha (600 ac) of fringing coral reefs along a 5.8 km (3.6 mi) coastline comprised primarily of basalt.

This coastline hosts 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. 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 are home to a 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 the arid lands of this Kekaha region, but groundwater seeps are common along the coast and are known to occur in 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.

Along the lava shoreline of Kalaemanō, the fringing reef is narrow and drops quickly into deep water. However, a broad shallow reef bench, (hereafter "bench") extends offshore from Kumukehu point to Kahuwai Bay (Figure 1). This bench is a shallow-water carbonate shelf that 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[1]. Along the edges of this area, grooves, caves, and walls drop from 5-10 m, clearly demarcating the bench from the sloping deeper reef in this area, which extends below our survey depth limit. 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.

## Survey Methods

TNC's marine monitoring team surveyed 148 randomly-selected[2] sites over three years on the Kaʻūpūlehu reef (Figure 1). The initial survey was in the fall of 2009. In both 2010 and 2011, two surveys were conducted, one in the spring and one in the fall (Table 1). For a complete listing of all survey sites, see Appendix A.

A detailed description of the survey methods is included in Appendix B. Briefly, survey sites were randomly selected using ArcGIS software. At each survey site, divers identified, sized, and counted all individuals of all species of fish within two replicate 25x5 m belt transects. Using fish length and published size to weight conversions, fish biomass (weight) was calculated for each size class of fish for each species and summed to obtain total fish biomass.

**Table 1.** Dates and number of surveys conducted by TNC's marine monitoring team at Kaʻūpūlehu, Hawaiʻi. Starting in 2011, benthic data were collected at some survey sites.

| Survey Date | Total Survey Sites | Benthic Data |
|---|---|---|
| **2009** | | |
| Fall (Sept 14-17) | 29 | |
| **2010** | | |
| Spring (Mar 9-12) | 21 | |
| Fall (Sept 13-16) | 30 | |
| **2011** | | |
| Spring (May 23-27) | 37 | 8 |
| Fall (Oct 17-20 | 31 | 31 |

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[1] Accounts from those familiar with the area maintain that in the early 1990's this shallow reef bench was populated by large numbers of coral reef fish species, notably surgeon fish.

[2] Random sites are selected in order to get an unbiased measure of the community across the Kaʻūpūlehu 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 Kaʻūpūlehu's coral reef community.

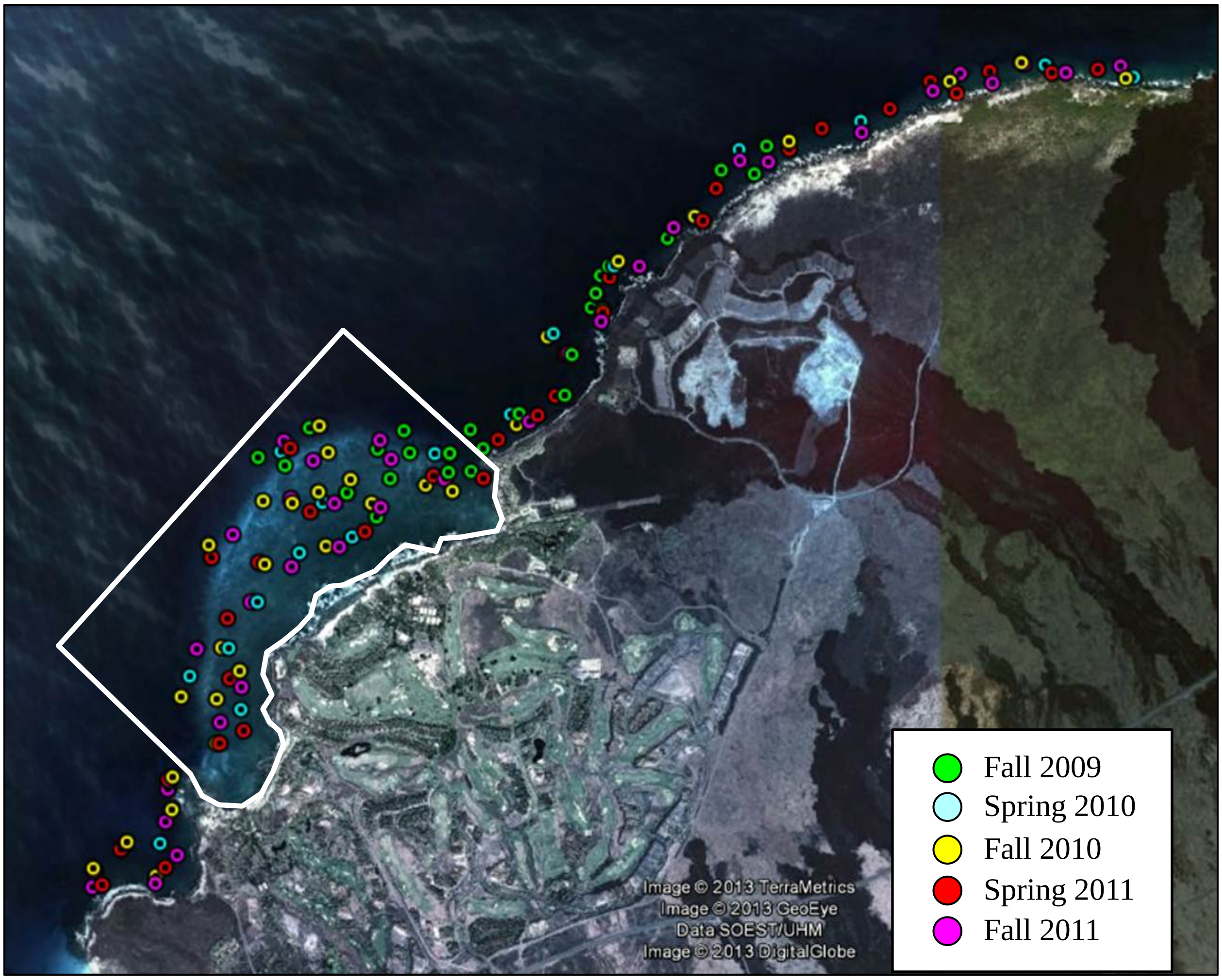

**Figure 1.** Monitoring sites at Ka‘ūpūlehu, Hawai‘i, 2009-2011. White box encompasses the bench described in the text.

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, algae, and other benthic organisms present. Data on coral colony size and density were collected *in situ* by a single diver. All coral colonies whose center lay within a 0.25 meter-square quadrat were identified to the lowest taxonomic level, measured along their longest dimension, and binned into the following size categories: <1cm, >1-2 cm, >2-5 cm, >5-10 cm, >10-20 cm, >20-40 cm, >40-80 cm, >80-160 cm, >160 cm. As many 0.25 meter-square quadrats as possible were haphazardly surveyed along one of the 25-m transect lines in the time available (~20-25 minutes). Where appropriate, coral fragments and partial colony mortality were also noted. For a full description of benthic methods, including details on coral colony delineation and sizing, see Appendix B.

A member of TNC's marine monitoring team collects rugosity data at Ka'ūpūlehu.

All means are presented as the average ± the standard error of the mean (SEM). Standard parametric and non-parametric statistical approaches were used to test for differences. Multivariate analyses on benthic and fish assemblages were 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.

## Results and Discussion

### Benthic Assemblage

Thirty-two benthic taxa were observed at Ka'ūpūlehu, including fourteen species of coral. Coral covered an average of 37.2 ± 2.8% of the bottom (Table 2), which is above the state average (21.7 ± 1.6%; CRAMP), but in line with cover on other West Hawai'i reefs, such as Puakō (Minton *et al.* 2012) and Pelekane (Minton *et al.* 2011). Turf algae was the dominant taxonomic group, covering 46.2 ± 2.9% of the bottom.

While some species varied with depth[3], no relationships between higher benthic taxa (*e.g.*, coral, macro algae, turf algae, etc.) and depth or location were found. When the assemblage as a whole was examined, however, the benthic assemblage on the bench was significantly different from that on non-bench areas of the reef. This difference was not manifested in distinct shifts in species composition, but resulted primarily from small changes in the percent cover of lobe coral, turf, and sand (Figure 2). The bench had greater percent cover of turf and sand and lower cover of coral than the non-bench habitat (Table 3). The bench's benthic community was also more variable than the non-bench benthic community. This is likely associated with more variable environmental conditions due to factors such as wave action and groundwater inputs on the bench compared to non-bench areas, although this study did not specifically investigate these conditions.

Not surprisingly, differences in benthic composition directly affected bottom rugosity. Rugosity on the bench was significantly lower than that in non-bench areas (ANOVA; F=28.1; df=1, 93; p<0.001). This is primarily the result of lower coral cover at bench sites, especially for the larger, structure-building species such as lobe corals (Table 3).

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[3] For example, cover of finger and rice corals were positively correlated with depth, and thus were more common at deep than at shallow sites.

**Table 2.** Mean (±SEM) percent cover of the bottom by major biological taxa and abiotic groups on the Kaʻūpūlehu reef, Hawaiʻi.

| Taxa/Group | Percent Cover |
|---|---|
| Coral Total | 37.2 ± 2.7 |
| Lobe coral | 28 ± 2.4 |
| Cauliflower coral | 4.2 ± 0.6 |
| Finger coral | 1.6 ± 0.5 |
| Sandpaper rice coral | 1.4 ± 0.2 |
| Rice coral | 0.9 ± 0.2 |
| Hump coral | 0.5 ± 0.1 |
| Porkchop coral | 0.2 ± 0.1 |
| Corrugated coral | 0.2 ± 0.1 |
| Antler coral | 0.1 ± 0.1 |
| Unidentified coral | 0.1 ± 0.0 |
| Bewick Coral | <0.1 |
| Crust coral | <0.1 |
| Blue rice coral | <0.1 |
| Plate and pillar coral | <0.1 |
| Macro Algae | <0.1 |
| Turf Algae | 46.2 ± 2.9 |
| Crustose Coralline Algae | 4.7 ± 0.6 |
| Other | 1.7 ± 0.2 |
| Abiotic Total | 8.3 ± 1.4 |
| Sand | 8.2 ± 1.4 |
| Pavement | 0.1 ± 0.1 |
| Rubble | <0.1 |

Since the early 1990s, numerous benthic surveys have been conducted offshore of the Kalaemanō development (see 2011 and references therein). Using slightly different methods than TNC's surveys, Brock (2012) found coral cover had declined since 1993, but had been gradually increasing since 2005 (Figure 3), from 31.2 ± 3.6% to 49.5 ± 3.8% cover. Brock's 2011 cover estimate is slightly higher than TNC's, but consistent with our findings. Reasons for the sudden 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 is unclear if the methods or sites surveyed are comparable.

Hawaiʻi's Coral Reef Assessment and Monitoring Program (CRAMP) has documented declines in coral cover across the state of Hawaiʻi since the early 1990s, but did not observed a precipitous drop between 2002-2005 as was observed by Brock (2012) at Kaʻūpūlehu (CRAMP

**Table 3.** Mean (±SEM) percent cover of the bottom by major biological taxa and abiotic groups, depth (m), and rugosity for the bench and non-bench benthic assemblages identified at Kaʻūpūlehu.

| | **Bench** | **Non-Bench** |
|---|---|---|
| Coral Total | 29.9 ± 5.0 | 42.4 ± 2.7 |
| Lobe coral | 21.9 ± 4.2 | 32.3 ± 2.6 |
| Cauliflower coral | 4.2 ± 1.1 | 4.3 ± 0.7 |
| Finger coral | 1.6 ± 0.9 | 1.6 ± 0.6 |
| Sandpaper rice coral | 0.7 ± 0.3 | 1.9 ± 0.3 |
| Rice coral | 0.4 ± 0.2 | 1.2 ± 0.2 |
| Hump coral | 0.5 ± 0.2 | 0.5 ± 0.2 |
| Porkchop coral | <0.1 | 0.2 ± 0.1 |
| Corrugated coral | 0.2 ± 0.1 | 0.3 ± 0.1 |
| Antler coral | 0.2 ± 0.1 | 0 |
| Unidentified coral | 0.1 ± 0.1 | <0.1 |
| Bewick coral | 0 | <0.1 |
| Crust coral | <0.1 | <0.1 |
| Blue rice coral | 0 | <0.1 |
| Plate and pillar coral | 0 | <0.1 |
| Macroalgae | <0.1 | <0.1 |
| Turf Algae | 51.7 ± 5.8 | 42.3 ± 2.8 |
| Crustose Coralline Algae | 3.6 ± 0.6 | 5.5 ± 0.9 |
| Other | 0.9 ± 0.2 | 0.6 ± 0.1 |
| Abiotic | 11.6 ± 2.7 | 6.0 ± 1.2 |
| Sand | 11.4 ± 2.8 | 6.0 ± 1.2 |
| Pavement | 0.3 ± 0.2 | 0 |
| Rubble | <0.1 | <0.1 |
| Depth (ft) | 21.4 ± 1.4 | 27.7 ± 1.1 |
| Rugosity | 1.29 ± 0.03 | 1.52 ± 0.03 |

2008). At Puakō, several kilometers north of Kaʻūpūlehu, coral cover has declined to approximately half of what it was in the 1970s to 32.6 ± 4.2% cover by 2010 (Minton *et al.* 2012).

### Coral Colony Size

The size of individual coral colonies yields demographic information that can provide insight into the "health" and future potential for coral assemblages. While coral size is not necessarily directly correlated with colony age, in many cases smaller colonies do indeed represent younger corals, and the smallest colonies are representative of new recruits into the population. The constant arrival of new coral recruits is vital to the long-term persistence of a coral population,

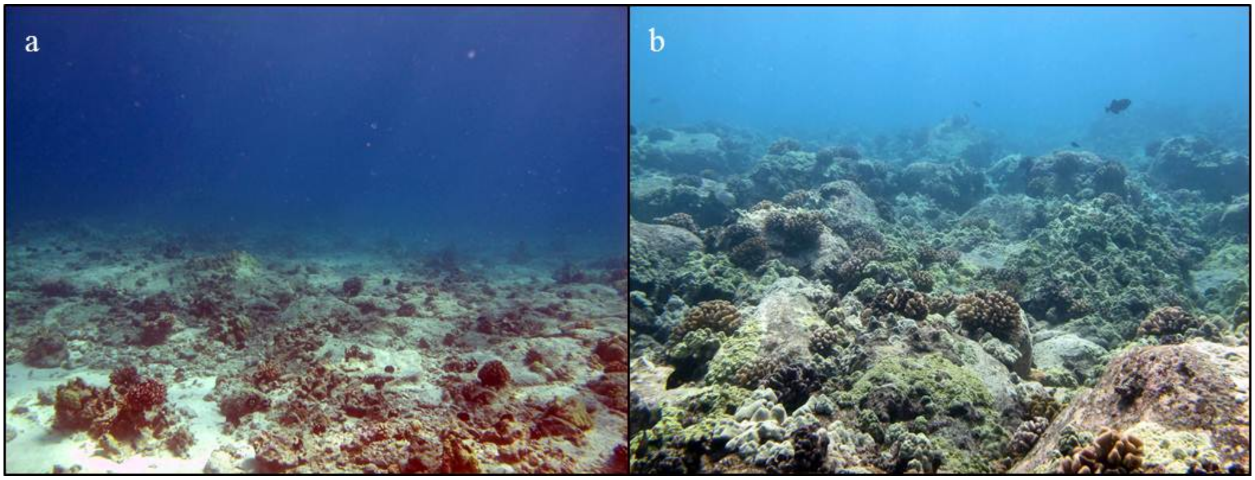


**Figure 2.** Representative photographs of a survey site on the bench (a) and in the non-bench area (b). Note the greater topographic structure and higher cover of live coral at the non-bench site.

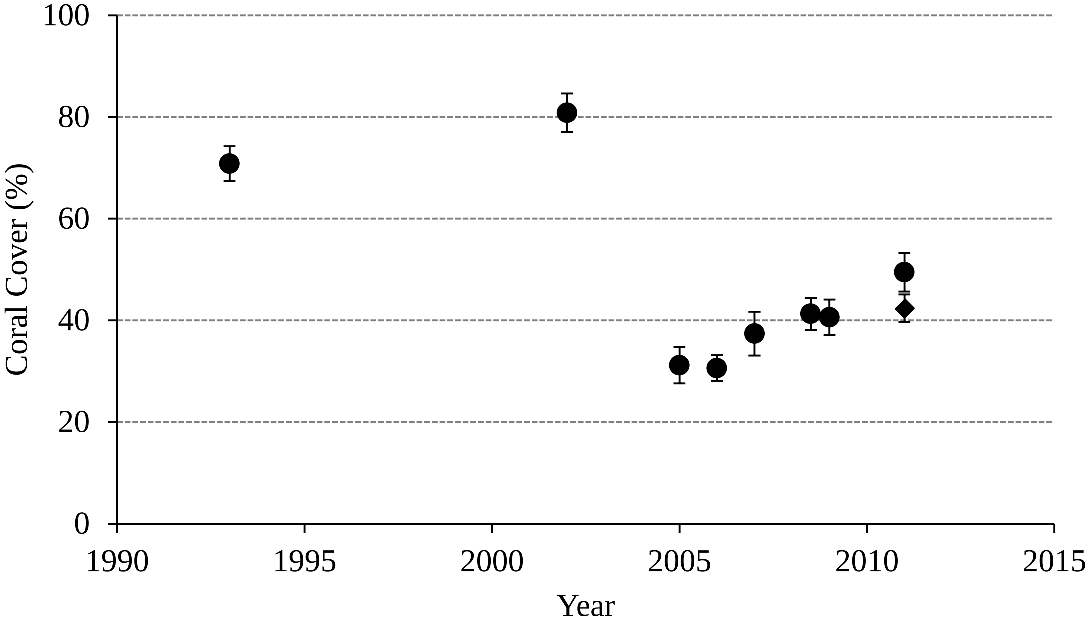


**Figure 3.** Change in average coral cover on the non-bench area of Ka‘ūpūlehu from 1993-2011. Data for 1993 and 2002 (circles) are from Marine Research Consultants (in Brock 2012). For 2005-2011 (circles), data are from Brock (2012) and include only coral cover data from the author’s *P. lobata* and *P. compressa* biotopes. Data for 2011 (diamond) are from this report. Error bars are SEM.

and the number of new recruits directly contributes to the ability of a coral population to recover from an impact. Additionally, large corals provide three-dimensional structure to the reef, which promotes increased abundance and biodiversity of associated groups such as fish, snails, and crustaceans. As the primary organisms providing structure to reefs, corals are critical members of the coral reef ecosystem, and their persistence and health is necessary to support healthy coral reef function and fisheries.

During the 2011 fall surveys, TNC assessed the size of coral colonies at 20 survey sites at Kaʻūpūlehu. Lobe corals accounted for the majority of colony observations (1040 out of 1623 coral colonies) and dominated the average colony size and size-frequencies calculations. Kaʻūpūlehu reefs had coral colonies of all sizes, ranging from new recruits (<2 cm) to corals in excess of 1.6 m (Figure 4). A handful of large colonies (>3 m) were also observed, suggesting conditions favorable to coral growth have existed at the site for an extended period of time, probably on the order of centuries. Nearly 24% of coral colonies were <2 cm, suggesting coral recruitment at Kaʻūpūlehu is strong, and that the reef has a high recovery potential if damaged.

For some coral species, fragmentation of larger individuals is an important form of reproduction. In these species, fragments are able to reattach to the bottom and grow. Even though these fragmented colonies are genetically indistinguishable from the parent colony, they provide the same ecological services (*e.g.,* consolidation of the reef, three-dimensional structure, etc.) as a new genetically distinct recruit. Given the dominance of lobe coral and encrusting species at Kaʻūpūlehu, it is not surprising that fragmentation was uncommon (<0.05% of observed colonies were fragments).

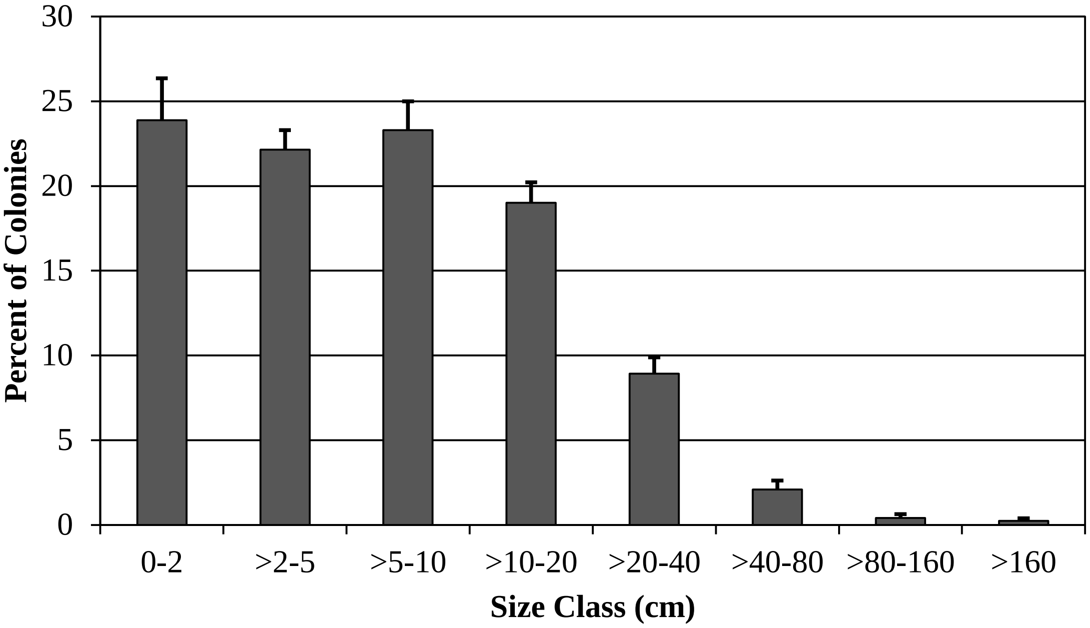
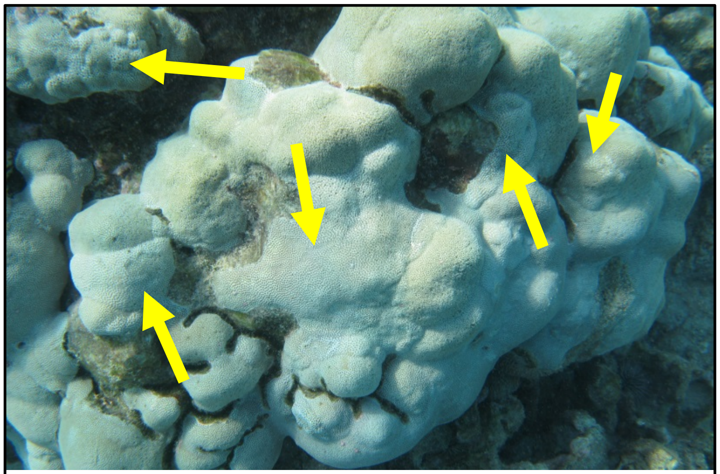


**Figure 4.** Coral colony size-frequency (cm) at Kaʻūpūlehu. Data are averaged across all coral species at 20 survey sites. Error bars are SEM.

Partial mortality occurs when part of a coral colony dies, usually as result of some environmental stressor that differentially impacts the colony. For example, corals inundated by sediment often experience partial mortality on the top, when sediment collects and smothers the coral tissue, but not along the sides where sediment cannot settle. As a result, patterns of mortality can sometimes provide clues to the source of tissue death. Generally, areas with high partial mortality in corals are under some degree of environmental stress. Some species, such as lobe coral, often show signs of partial mortality[4]. At Ka'ūpūlehu, partial mortality was rare (pers. obs.).

These surveys did not focus on coral disease[5], but recent evidence has emerged that coral disease, especially growth anomalies on lobe corals, may be common at Ka'ūpūlehu (Couch *et al.* in review). The spatial distribution, pathology, and causes of coral disease in Hawai'i are poorly understood. Disease is often associated with environmental factors such as elevated nutrients, toxicants, and climate associated stresses (*e.g.*, elevated temperature), but the cause of the observed coral disease at Ka'ūpūlehu is currently unknown and warrants further investigation.



Growth anomalies (arrows), a form of coral disease on a lobe coral colony at Ka'ūpūlehu. The incidence of coral disease on Ka'ūpūlehu's reefs may be among the highest in west Hawai'i.

Fish Assemblage

Over the course of three years, a total of 134 species representing 28 families of fish were observed at Ka'ūpūlehu (Table 4). Surgeonfish (Acanthuridae), damselfish (Pomacentridae), wrasses (Labridae), and parrotfish (Scaridae) were the most abundant numerically, accounting for 81.1% of all observed individuals. Surgeonfish, parrotfish, and triggerfish contributed the most to fish biomass, accounting for 73.6% of the total fish biomass at Ka'ūpūlehu.

While species diversity, total individual abundance and total biomass were significantly lower in Spring 2011[6] compared to Fall 2010 (Table 5), no other differences were found among the seasons or years. No significant correlation was found between time and any of the three summary variables. The data suggest a downward trend in all three variables, but the time series is too short to determine if this is a real decline or an artifact of high annual variation found in most fish populations.

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[4] Cauliflower corals (*Pocillopora meandrina*) appear to undergo senescence, so partial mortality in this species should be interpreted with caution.

[5] Coral surveyors did note the presence of coral disease at Ka'ūpūlehu, but did not quantify it in the 2011surveys.

[6] A tsunami that hit Ka'ūpūlehu on March 11, 2011, is a possible explanation for the 2011 data.

**Table 4.** Species diversity, average abundance (number of individuals/transect) and average biomass (g/m$^2$) of fish by family. Species are arranged by decreasing biomass.

| Fish Family | Species | Abundance | Biomass |
|---|---|---|---|
| Surgeonfish (Acanthuridae) | 19 | 34.4 ± 2.5 | 19.8 ± 1.6 |
| Parrotfish (Scaridae) | 5 | 7.0 ± 0.8 | 9.9 ± 0.9 |
| Triggerfish (Balistidae) | 6 | 3.6 ± 0.5 | 6.6 ± 0.8 |
| Wrasses (Labridae) | 21 | 17.9 ± 0.8 | 3.1 ± 0.2 |
| Groupers (Serranidae) | 1 | 0.4 ± 0 | 2.1 ± 0.3 |
| Emperors (Lethrinidae) | 1 | 0.1 ± 0.1 | 1.4 ± 1.0 |
| Butterflyfish (Chaetodontidae) | 14 | 3.6 ± 0.3 | 1.3 ± 0.1 |
| Damselfish (Pomacentridae) | 12 | 20.1 ± 1.5 | 1.1 ± 0.1 |
| Goatfish (Mullidae) | 7 | 1.4 ± 0.1 | 1.0 ± 0.1 |
| Hawkfish (Cirrhitidae) | 4 | 5.0 ± 0.3 | 0.6 ± 0.0 |
| Squirrelfish (Holocentridae) | 7 | 0.5 ± 0.1 | 0.5 ± 0.1 |
| Jacks (Carangidae) | 2 | 0.8 ± 0.4 | 0.4 ± 0.2 |
| Snappers (Lutjanidae) | 4 | 0.3 ± 0.1 | 0.4 ± 0.1 |
| Pufferfish (Tetraodontidae) | 5 | 1.7 ± 0.2 | 0.2 ± 0.0 |
| Chubs (Kyphosidae) | 1 | 0.1 ± 0.0 | 0.2 ± 0.1 |
| Moorish Idol (Zanclidae) | 1 | 0.1 ± 0 | 0.2 ± 0.0 |
| Filefish (Monacanthidae) | 4 | 0.1 ± 0 | 0.1 ± 0.0 |
| Eels (Muraenidae) | 4 | <0.1 | 0.1 ± 0.1 |
| Blennies (Blenniidae) | 4 | 0.5 ± 0.1 | <0.1 |
| Angelfish (Pomacanthidae) | 1 | 0.2 ± 0 | <0.1 |
| Boxfish (Ostraciidae) | 1 | 0.1 ± 0 | <0.1 |
| Lizardfish (Synodontidae) | 2 | <0.1 | <0.1 |
| Trumpetfish (Aulostomidae) | 1 | <0.1 | <0.1 |
| Flounders (Bothidae) | 1 | <0.1 | <0.1 |
| Milkfish (Chanidae) | 1 | <0.1 | <0.1 |
| Porcupinefish (Diodontidae) | 1 | <0.1 | <0.1 |
| Cornetfish (Fistulariidae) | 1 | <0.1 | <0.1 |
| Scorpionfish (Scorpaenidae) | 1 | <0.1 | <0.1 |
| Total | 134 | 97.9 | 49.3 |

Average total fish biomass at Kaʻūpūlehu was 49.3 g/m$^2$ (440 lbs/acre), which is consistent with open sites (*i.e.*, subject to no additional regulations beyond statewide fishing rules) in west Hawaiʻi (Figure 5), but below areas with additional fishing regulation (*e.g.*, South Kona Fishery Management Area (FMA), Kona FMA, Puako FMA) and areas closed to fishing (*e.g.*, Kealekekua Bay and Lapakahi Marine Life Conservation Districts (MLCDs)).

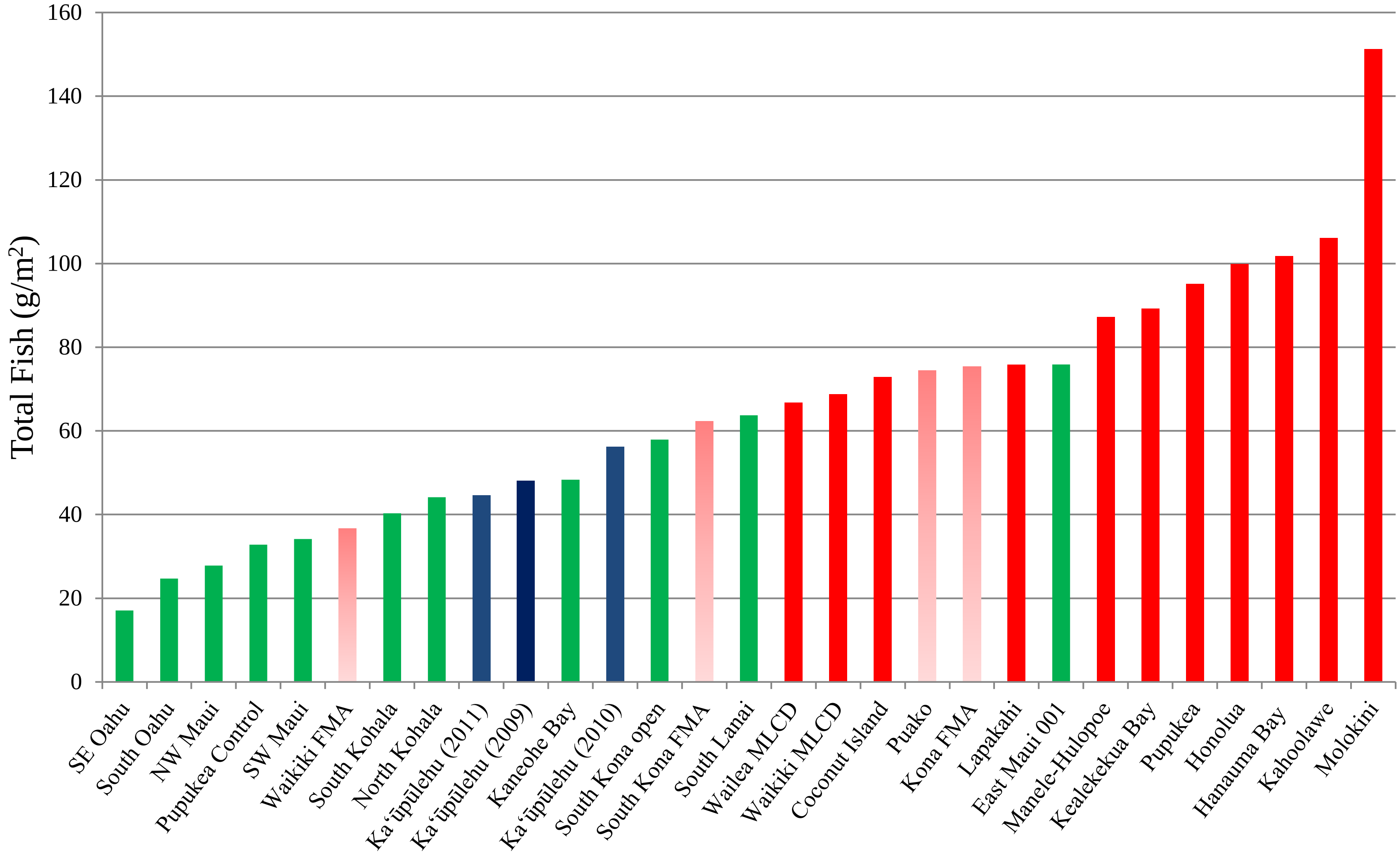

**Figure 5.** Total fish biomass at Ka‘ūpūlehu (blue bars) and 26 other sites in the state of Hawai‘i. Color of bars represents level of fisheries management occurring at the site: green=no additional fishing regulations; red=no take allowed; gradated red=limited take allowed. Data for sites other than Ka‘ūpūlehu are from Dr. Alan Friedlander (USGS) and TNC.

**Table 5.** Species diversity, individual abundance (individuals/transect) and total biomass (g/m$^2$) for each survey round.

| Survey Date | Species | Abundance | Biomass |
|---|---|---|---|
| **2009** | | | |
| Fall (Sept 14-17) | 29.8 ± 1.2 | 128.9 ± 9.1 | 48.1 ± 5.0 |
| **2010** | | | |
| Spring (Mar 9-12) | 29.5 ± 1.8 | 137.5 ± 12.5 | 64.5 ± 10.3 |
| Fall (Sept 13-16) | 28.3 ± 1 | 116.0 ± 7.5 | 48.7 ± 5.8 |
| **2011** | | | |
| Spring (May 23-27) | 26.5 ± 1.3 | 90.7 ± 4.9 | 39.1 ± 5.0 |
| Fall (Oct 17-20 | 28.2 ± 0.9 | 109.4 ± 6.9 | 51.2 ± 7.7 |

Interestingly, surveys conducted by Brock (2012) at Kaʻūpūlehu between 2005 and 2010 estimated average fish biomass over six times higher (328 g/m$^2$) than this survey. While Brock's estimate for 2011 was lower than the average (191.4 g/m$^2$), it was still almost four times our estimate for the same general area. Brock's 2011 value exceeds estimates for all other areas in west Hawaiʻi (both open and closed to fishing), and is greater than published estimates for the main Hawaiian Islands and many of the remote Northwestern Hawaiian Islands (Friedlander and DeMartini 2002), raising concerns that Brock's fish biomass estimates are not comparable to those produced by other survey methods.

Fish assemblages at bench sites that were <30 ft had significantly lower species diversity (t-test, T=7.02, df=76, p<0.001) and total biomass (t-test, T=4.01, df=102, p<0.001) than sites in deeper water and at non-bench sites. Fish communities are known to respond to changes in topography (*i.e.*, rugosity), and the difference in rugosity at bench versus non-bench sites could explain the observed differences in the fish assemblages. Using a statistical technique, the effect of topography can be removed from the analysis; if the biomass difference remains, then factors other than topography are likely driving differences in fish biomass between bench and non-bench sites. However, when the data were adjusted for rugosity, no significant difference in biomass was observed (t-test, T=1.24, df=82, p=0.219), suggesting that topography was the primary reason for biomass differences between bench and non-bench fish assemblages and not other potential stressors (*e.g.*, differential fishing pressure). When species abundance was also adjusted for topography, non-bench sites were still more diverse than bench sites (t-test, T=2.35, df=70, p=0.021), suggesting that factors other than the bottom topography (e.g., the number of different habitat types available) were affecting the composition of the fish assemblage.

In addition to examining total fish biomass and species diversity, it is possible to examine the composition of individual species and sizes of fishes that comprise the fish assemblage. This is desirable because two fish assemblages with the same number of species and total biomass could still be different because these summary values do not account for the identity of the species or size structure in the assemblage. Fish assemblage structure did not significantly vary by year (ANOSIM; R=0.014; p=0.215) or season (ANOSIM; R=0; p=0.469). However, the fish assemblage on the bench was significantly different from that on the rest of the reef. This difference was most pronounced for bench sites <30 ft deep (ANOSIM; R=0.603; p=0.001; Figure 6). Fish assemblages seaward of the bench (deeper than 30 ft) resembled fish assemblages at non-bench areas, suggesting depth (or possibly distance off shore) is ameliorating the factors responsible for the different assemblages.

The fish assemblage at bench sites tended to be more variable than the assemblage at non-bench sites. This is apparent in the wide spread of the bench points in the nMDS plot[7] (Figure 6; open circles). The similarity among fish assemblages at deeper sites and at non-bench sites tended to be higher (average similarity=48%) than that among bench sites <30 ft deep (average similarity=35%). Reasons for the increased variability at bench sites <30 ft deep are not entirely clear. While variability in bottom topography was the same between bench and non-bench sites, bench sites had nearly twice the variability in the percent cover of benthic species compared to non-bench sites (Table 3). This variability in the benthic environment (*e.g.*, patchiness) may contribute to the variability observed in the associated fish assemblage.

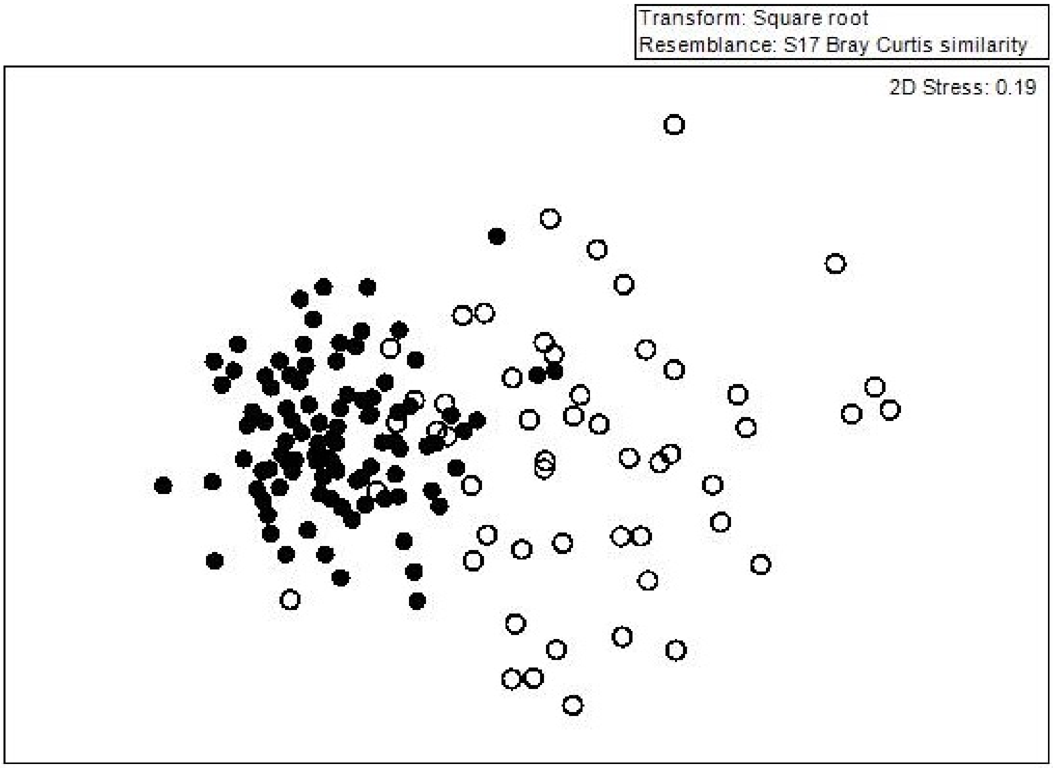

**Figure 6.** nMDS plot of fish assemblages at bench sites <30 ft (open circles) and at deeper and non-bench sites (close circles). Fish taxon biomass data were used in the analysis.

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[7] Non-metric multi-dimensional scaling (nMDS) plots are a graphical way to illustrate similarities between the biological assemblages at each survey site. Each point represents the fish assemblage structure at a given survey site. The distance between any two points is directly correlated to how similar the assemblages at those two sites are to each other. The more similar they are, the closer they will be in the nMDS plot.

Deeper and non-bench sites had higher biomass of every fish family except triggerfish and pufferfish, which were more common at bench sites <30 ft deep. Deeper and non-bench sites had 6.9x higher biomass of groupers (primarily introduced Peacock Grouper or roi), 2.5x higher biomass of parrotfish, and 1.5x higher biomass of surgeon fish than bench sites <30 ft deep. Additionally, deeper and non-bench sites had significantly more species of surgeonfish, butterflyfish, wrasses, and parrotfish than bench sites <30 ft deep. In contrast, bench sites had a greater number of species of triggerfish and blennies, which is likely indicative of the low relief, turf-rich bottom on the bench.

### Target Fish

Target fish[8] include fish desirable for food, commercial activity, or cultural practice that reside in the habitats and depth ranges surveyed by our divers. Surgeonfish and parrotfish accounted for 48.9% and 34.6%, respectively, of the target fish biomass at Kaʻūpūlehu (Figure 7). Apex predators, such as jacks and sharks, were nearly absent (1.1%). On coral reefs where human impacts, especially fishing pressure, are low, apex predators tend to be a significant component of the coral reef fish assemblage (Friedlander and DeMartini 2002), and historic accounts of sharks at Kalaemanō (which translates to "The Point of the Shark"), suggest this area once hosted a resident population of apex predators.

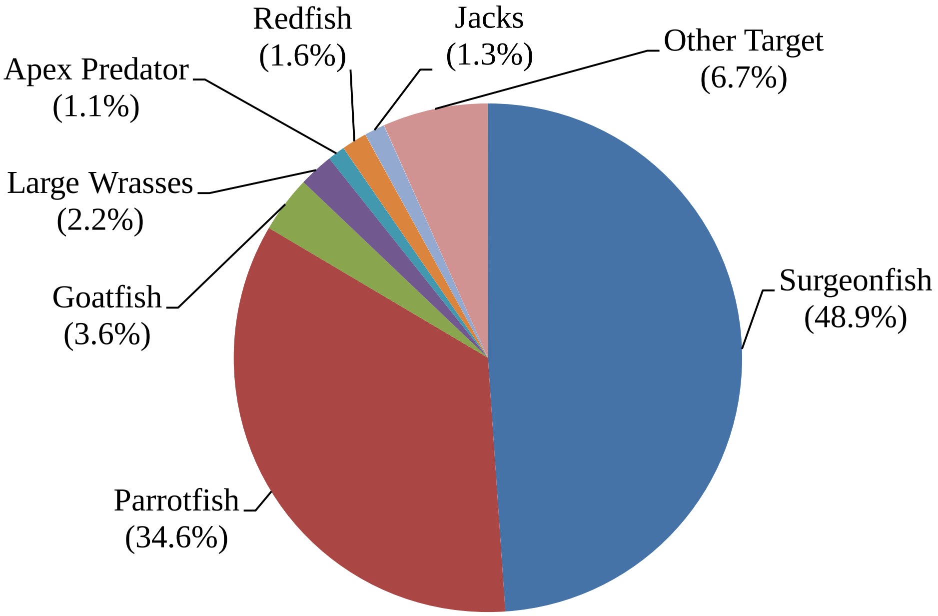

**Figure 7.** Proportion of target fish biomass by category. Numerical values represent the percent of the total target fish biomass.

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[8] Those fish most prized by fishers. See Appendix B for a list of species that comprise the target fish for this report.

Target fish biomass at Kaʻūpūlehu did not vary among years (ANOVA, F=0.42; df=2,147; p=0.658) or between seasons (ANOVA, F=0.02; df=1,148; p=0.889), but did vary spatially. Again, deeper sites and non-bench sites had significantly higher target fish biomass than bench sites <30 ft deep (t-test; t=3.32; df=109; p=0.001), but when biomass was corrected for differences in bottom rugosity, this difference disappeared, suggesting differences in habitat are primarily responsible for the lower target fish biomass on the bench.

Average biomass of target fish across the survey area varied from year-to-year, ranging between 26.1 ± 3.9 g/m$^2$ (in 2009) and 31.6 ± 4.1 g/m$^2$ (in 2010). This range is consistent with locations outside of fishery management areas in west Hawaiʻi (Figure 8 and 9), but below that of marine managed areas (*e.g.*, South Kona FMA, Kona FMA, Puako FMA) and well below areas closed to fishing (*e.g.*, Kealekekua Bay and Lapakahi MLCD). In contrast, biomass of non-target species[9] was similar among Kaʻūpūlehu, west Hawaiʻi managed areas, and west Hawaiʻi areas closed to fishing (ANOVA; F=0.4, df=3,26; p=0.76) (Figure 9). This suggests that while there is no evidence of fishing driving small-scale distributional patterns within Kaʻūpūlehu (*i.e.*, bench versus non-bench areas), it has likely impacted the fish assemblage along the entirety of the Kaʻūpūlehu coastline. While other stressors may also be affecting fish populations, only fishing would selectively reduce the abundance of target species while not affecting non-target species.

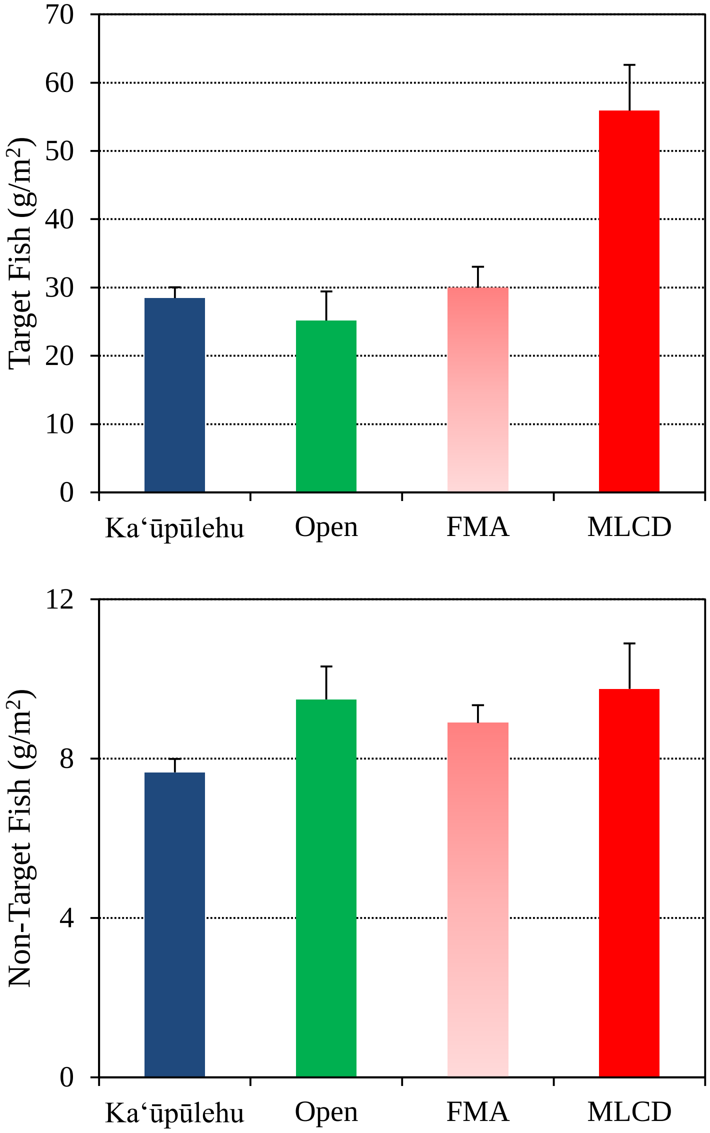

**Figure 8.** Biomass (g/m$^2$) of target (top) and non-target (bottom) fish at Kaʻūpūlehu, within areas open to fishing (n=11), within limited fishing FMAs (n=4), and within closed-to-fishing MLCDs (n=10). Note: different scales.

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[9] Nearly all fish species are targeted to some extent in Hawaiian fisheries. Non-target fish include species that were not significantly targeted in recreational or commercial (including aquarium) fisheries. See Appendix B.

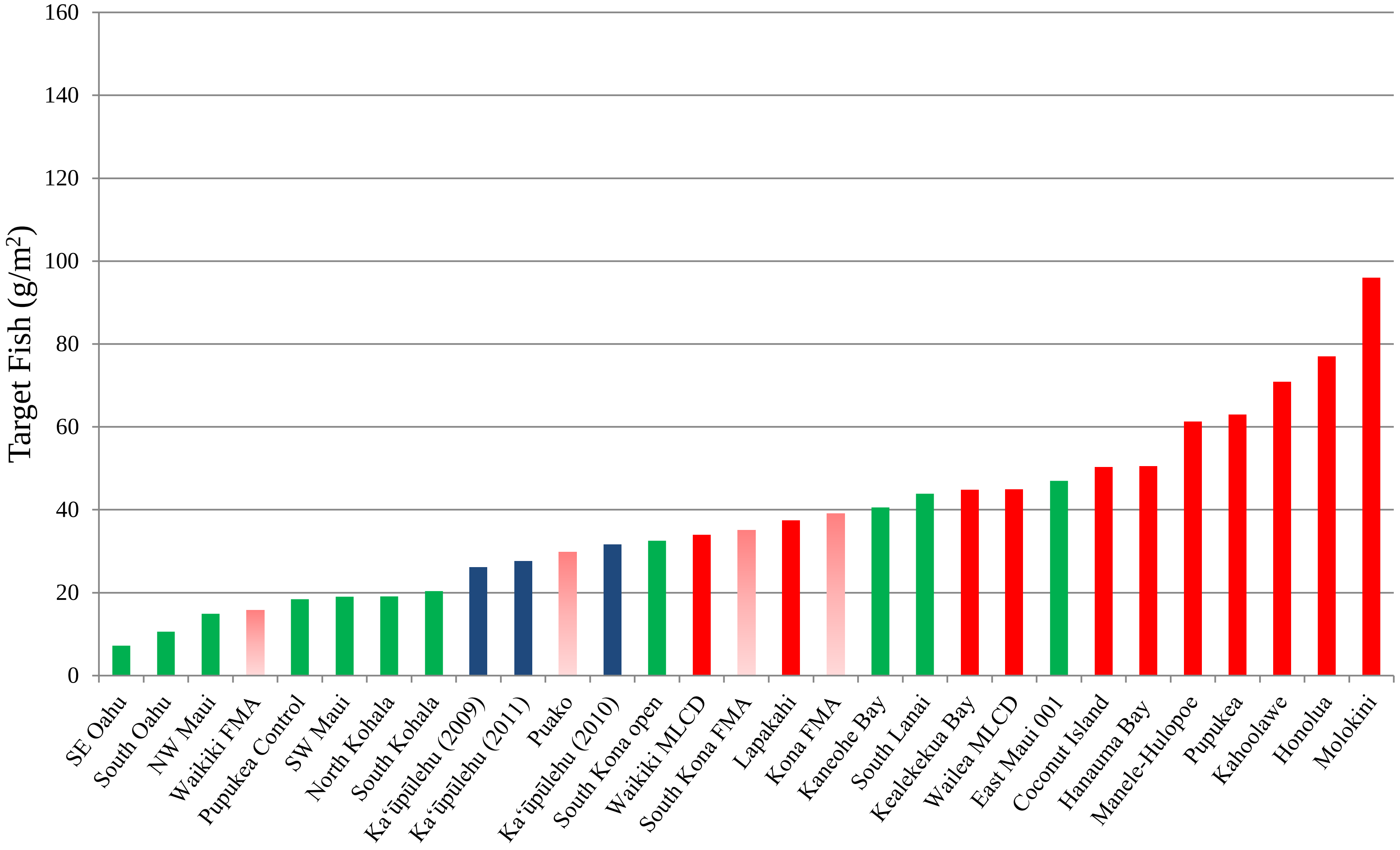

**Figure 9.** Target fish biomass at Kaʻūpūlehu (blue bars) and 26 other sites around the state of Hawaiʻi. Color of bars represents level of fisheries management occurring at the site: green=no additional fishing regulations; red=no take allowed; gradated red=limited take allowed. Data for sites other than Kaʻūpūlehu are from Dr. Alan Friedlander (USGS) and TNC.

## Fish and Benthic Assemblages

While bottom topography can significantly affect the abundance and composition of fish assemblages, the actual structure of the benthic assemblage (*e.g.*, species composition and relative abundance) can also have a significant effect. Some fish species are closely associated with specific benthic species. For example, the abundance of coral-feeding butterflyfish is often directly correlated with the cover of their preferred coral species.

At Kaʻūpūlehu, fish assemblage structure was significantly correlated with benthic assemblage structure, especially the presence of the lobe coral and to a lesser extent, rice coral (RELATE TEST; $\rho=0.388$; $p=0.001$). These two coral species provide significantly different contributions to bottom topography. Lobe corals have a mounding form and are the primary species providing three-dimensional relief. In contrast, rice coral is encrusting and provides little accessible topographic relief. This result supports early findings that fish biomass is likely associated with three-dimensional reef structure and not necessarily with specific species composition of the benthic community.

## Fish Assemblage and Public Access

Due to its ruggedness, access to the Kaʻūpūlehu coastline is limited to three access points. While these access points are focal areas for most human activities, including numerous forms of ocean recreation and fishing, they are relatively close together, and it's likely that all areas of coastline are effectively equally accessible. This complicates any analysis of the potential impact of public access on Kaʻūpūlehu's fish assemblage because any potential impacts would be evenly, or nearly evenly, applied across the survey area.

Overall, data support the finding of a significant fishery impact across the entirety of the Kaʻūpūlehu reef, but with little variation within the Kaʻūpūlehu survey area. This conclusion is supported by direct comparison with other areas under varying levels of fishing intensity along the west Hawaiʻi coast and across the state (Figure 9), the differential impacts observed on target vs. non-target species (Figure 8), and a lack of correlation between the fish assemblage and public access points in Kaʻūpūlehu.

## Key Fish Species

The Kaʻūpūlehu community has requested information about several species of fish, including parrotfish or *uhu* (family Scaridae), convict tangs or *manini* (*Acanthurus triostegus*), bluespine unicornfish or *kala* (*Naso unicornis*), ringtail surgeonfish and yellowfin surgeonfish or *pualu* (*Acanthurus blochii* and *Acanthurus xanthopterus*), eyestripe surgeonfish or *palani* (*Acanthurus dussumieri*), and bigeye emperor or *mū* (*Monotaxis grandoculis*).

### *Parrotfish or uhu (Family Scaridae)*

Five species of parrotfish were observed at Kaʻūpūlehu, with just two species, the bullethead (*Chlorurus spilurus*) and palenose (*Scarus psittacus*) parrotfish, accounting for over 88% of observed individuals (Table 6). In total, parrotfish contributed 9.9 ± 0.9 $g/m^2$ to the total fish biomass. Parrotfish occurred at most sites (131 out 148 sites), but their biomass was heavily skewed, with 61% (90 out of 148 sites) of the sites having less than the average biomass and 13.5% (20 out of 148 sites) having biomass >20 g/m$^2$. The highest recorded parrotfish biomass was 76.6 g/m$^2$, recorded at a site in Fall 2010. This type of distribution is not unexpected due to the schooling nature of many parrotfish species. Parrotfish were observed on 90% of the 5-minute timed swims (129 out of 143).

The bullethead parrotfish had a mean size 16.9 cm at Kaʻūpūlehu (max. size=40 cm), but only 4% of the population was greater than 30.5 cm (12 inches), the legal harvestable size in Hawaiʻi. When considering all parrotfish except the palenose (which has a maximum size of 30 cm and thus is naturally below the legal size limit to harvest), only 9.6% of the parrot fish population is of legal harvestable size.

For most parrotfish species, sexually mature individuals were relatively rare at Kaʻūpūlehu; only for bullethead parrotfish were more than half of the observed individuals of reproductive size. Only 29% of palenose, 12% of ember, and 50% of spectacled (small sample size) parrotfish were sexually mature (Table 6).

**Table 6.** The number of individuals observed (N), average (±SEM) size, maximum size, size at maturity, and percent of the fish observed that were larger than the size at maturity for the five parrotfish species observed at Kaʻūpūlehu. All sizes are in centimeters. Maximum size (cm) is for the species in Hawaiʻi.

| **Parrotfish** | **N** | **Average size** | **Max. Size**[1] | **Size at Maturity**[2] | **Percent Mature** |
|---|---|---|---|---|---|
| Bullethead | 1055 | 16.9 ± 0.2 | 40 | 15 | 61% |
| Palenose | 1024 | 13.4 ± 0.1 | 30 | 15 | 29% |
| Ember | 250 | 22.9 ± 1.4 | 71 | 37.5 | 12% |
| Stareye | 12 | 16.7 ± 2.2 | 50 | 20 | 33% |
| Spectacled | 6 | 25.0 ± 4.1 | 66 | 20 | 50% |

[1] From Randall (2007)
[2] From Fishbase (Froese & Pauly 2011)

### *Surgeonfish*

Surgeonfish are economically- and culturally-important fishery species. In total, surgeonfish were the most abundant fish observed at Kaʻūpūlehu, contributing 19.8 ± 1.6 g/m$^2$ to total fish biomass. Numerically, they accounted for 35% of the fish abundance and 40% of the fish biomass, and are a family that is significant ecologically and as a fishery. We observed 19 species of surgeonfish (Table 7), of which the brown surgeonfish was numerically the most abundant and the yellow tang had the greatest biomass.

**Table 7.** Surgeonfish biomass (g/m$^2$), and relative abundance at Ka‘ūpūlehu. Species are ordered from highest to lowest for both biomass and relative abundance among all surgeonfish.

| **Surgeonfish species** | **Biomass (g/m$^2$)** | **Surgeonfish species** | **Rel. Abund. (%)** |
|---|---|---|---|
| Yellow tang | 4.0 | Brown surgeonfish | 27.9 |
| Orangeband surgeonfish | 3.1 | Goldring surgeonfish | 24.3 |
| Goldring surgeonfish | 3.0 | Yellow tang | 17.3 |
| Orangespine unicornfish | 2.5 | Orangespine unicronfish | 8.5 |
| Brown surgeonfish | 1.8 | Orangeband surgeonfish | 8.4 |
| Sleek unicornfish | 1.3 | Whitebar surgeonfish | 2.6 |
| Bluespine unicornfish | 0.8 | Convict tang | 2.0 |
| Whitebar surgeonfish | 0.7 | Sleek unicornfish | 2.0 |
| Hawaiian bristletooth | 0.6 | Paletail unicornfish | 1.5 |
| Paletail unicronfish | 0.5 | Eyestripe surgeonfish | 1.3 |
| Eyestripe surgeonfish | 0.4 | Bluespine unicornfish | 1.1 |
| Convict tang | 0.4 | Hawaiian bristletooth | 0.9 |
| Bluelined surgeonfish | 0.3 | Bluelined surgeonfish | 0.8 |
| Ringtail surgeonfish | 0.2 | Ringtail surgeonfish | 0.7 |
| Achilles tang | 0.1 | Achilles tang | 0.5 |
| Sailfin tang | <0.1 | Whitespot surgeonfish | <0.1 |
| Whitespot surgeonfish | <0.1 | Sailfin tang | <0.1 |
| Goldrim surgeonfish | <0.1 | Goldrim surgeonfish | <0.1 |
| Thompson’s surgeonfish | <0.1 | Thompson’s surgeonfish | <0.1 |

The community at Ka‘ūpūlehu is interested in numerous species of surgeonfish, including convict tangs or manini (*Acanthurus triostegus*), bluespine unicornfish or kala (*Naso unicornis*), ringtail surgeonfish or pualu (*Acanthurus blochii*[10]), and eyestripe surgeonfish or palani (*Acanthurus dussumieri*). These species are discussed in more detail below.

*Convict tangs or manini (Acanthurus triostegus)*

Convict tangs, or manini, were the seventh most commonly observed surgeonfish at Ka‘ūpūlehu, with an average abundance of 1.0 ± 0.3 individuals/site, but account for only 2% of all surgeonfish (Table 7). Due to their small size, convict tangs contributed only 0.4 ± 0.1 g/m$^2$ to the total fish biomass at Ka‘ūpūlehu, and contributed only 1.8% of the surgeonfish biomass. Convict tang populations were patchily distributed across Ka‘ūpūlehu, which is not surprising given the schooling nature of this species. Most survey sites had no convict tangs; they occurred at only 33 of 148 survey sites (22%), but when present, schools of up to 57 individuals were observed along survey transects. Due to their relatively small size, convict tangs were recorded

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[10] The yellowfin surgeonfish (*Acanthurus xanthopterus*) are also locally called pualu, but this species was not observed at Ka‘ūpūlehu.

infrequently on 5-minute timed swims (3 out of 143), with only individuals >15 cm in length quantified. Convict tangs were found at bench and non-bench sites and occurred across the entirety of the Kaʻūpūlehu reef (Figure 10).

Convict tangs reach reproductive maturity at 9.4 cm[11] for males and 17.3 cm for females (Longenecker *et al.* 2008). Convict tangs were difficult to sex in the water, so it is problematic to determine what percentage of the population is greater than the size of maturity. Longenecker *et al.* (2008) found a male:female sex ratio of 43:57 in their population. Assuming a similar sex ratio, approximately 87% of observed males but <7% of observed females were likely above the size at maturity (Table 8).

A school of convict tangs (manini) swim across the reef at Kaʻūpūlehu.

In Hawaiʻi, the legal size for convict tang harvest is 12.7 cm (5 in), which is significantly smaller than the size of maturity for females (17.3 cm or 6.8 in). The average size of convict tangs at Kaʻūpūlehu was 12.2 ± 0.1 cm (maximum size: 24 cm), but approximately 52% of the population was above legal harvest size. However, most individuals above legal size were between 12.7 and 15 cm; <7% of all observed individuals were greater than 15 cm in size.

**Table 8.** The number of individuals observed (N), average (±SEM) size, maximum size, size at maturity, and percent of the fish observed that were larger than the size at maturity for four surgeonfish species at Kaʻūpūlehu. All sizes are in centimeters. Maximum size is for the species in Hawaiʻi.

| Surgeonfish | N | Average size | Max. Size[1] | Size at Maturity | Percent Mature |
|---|---|---|---|---|---|
| Convict tang | 284 | 12.2 ± 0.1 | 20 | M: 8.4[2] | 87% |
| | | | | F: 17.3 | 7% |
| Bluespine unicorn | 47 | 32.5 ± 0.7 | 62 | M: 30.2[3] | 97% |
| | | | | F: 40.0 | 5% |
| Eyestripe surgeon | 32 | 35.6 ± 1.1 | 54 | M: ? | ? |
| | | | | F: ? | ? |
| Ringtail surgeon | 28 | 26.0 ± 1.3 | 42 | M: ? | ? |
| | | | | F: ? | ? |

[1]From Randall (2007)
[2]From Longenecker *et al.* (2008)
[2]From Eble *et al.* (2009)

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

**Figure 10.** Distribution of convict tang at Ka‘ūpūlehu. White box encompasses the bench area.

*Bluespine Unicornfish or kala (Naso unicornis)*

Bluespine unicornifish, known locally as *kala*, were the eleventh most common surgeonfish species at Ka‘ūpūlehu (Table 7). On average, less than one individual (0.2 ± 0.1 individuals/transect) was observed per survey transect, and they comprised about 1% of all observed surgeonfish. Due to their relatively large size, bluespine unicornfish contributed 0.9 ± 0.4 g/$m^2$ to the total fish biomass. Bluespine unicornfish were absent at most survey sites, occurring along only 16 of 148 transects (11% of sites). Given their relatively large size, however, bluespine unicornfish were sighted more often on the 5-minute timed swims, with an additional 124 individuals observed on 20 of 143 timed swims (14% of timed swims). Bluespine unicornfish were found almost exclusively at bench sites directly offshore of the Four Seasons Resort and Kona Village Resort (21 of the 26 sites; 81%) (Figure 11). This species tends to favor relatively shallow water habitat with leafy algae, which likely makes the bench area better habitat.

Bluespine unicornfish reach a maximum size of 69 cm and become sexually mature at 30.2 cm[12] for males and 40.0 cm for females (Eble *et al.* 2009). Using only the sightings along transects[13],

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[12] Eble *et al.* (2009) give sizes in fork length, but provide a conversion to obtain total length.

[13] Fish observations during timed swims exclude smaller individuals and focus only on fish >15 cm in total length.

**Figure 11.** Distribution of bluespine unicornfish at Ka‘ūpūlehu. White box encompasses the bench area.

the average size of bluespine unicornfish at Ka‘ūpūlehu was 32.5 ± 0.7 cm (Table 8). Determining the sex of bluespine unicornfish in the water is difficult, so individuals were not sexed at Ka‘ūpūlehu, thus determining the percent of the population larger than the size at maturity is a challenge. Eble *at al.* (2009) found a male:female ratio of 55:45. Using this sex ratio, 97% of the observed males, but only 5% of the observed females were larger than the size at maturity.

The legal harvest size for the species is 35.6 cm (14 inches) which, like convict tangs, is below the size at maturity for females (37.8 cm or 14.9). Approximately 36% of observed individuals were large enough to legally harvest.

*Eyestripe surgeonfish or palani* (*Acanthurus dussumieri)*

The eyestripe surgeonfish, or *palani*, were rare at Ka‘ūpūlehu; an average of 0.1 ± 0.04 individuals/transect were observed during three years of surveys. They contributed 0.4 ± 0.2 g/$m^2$ to the area’s total fish biomass (Table 7). As with other relatively rare surgeonfish, they had a patchy distribution, occurring on transects at only 10 of 148 sites (7%) over three years of surveys. Like other large, mobile species, eyestripe surgeonfish were observed more frequently on 5-minute timed swims; divers observed 168 individuals on 36 out of 143 5-minute timed swims (25% of timed swims). Eyestripe surgeonfish were observed across the survey area, occurring as frequently on bench sites as on non-bench sites (Figure 12).

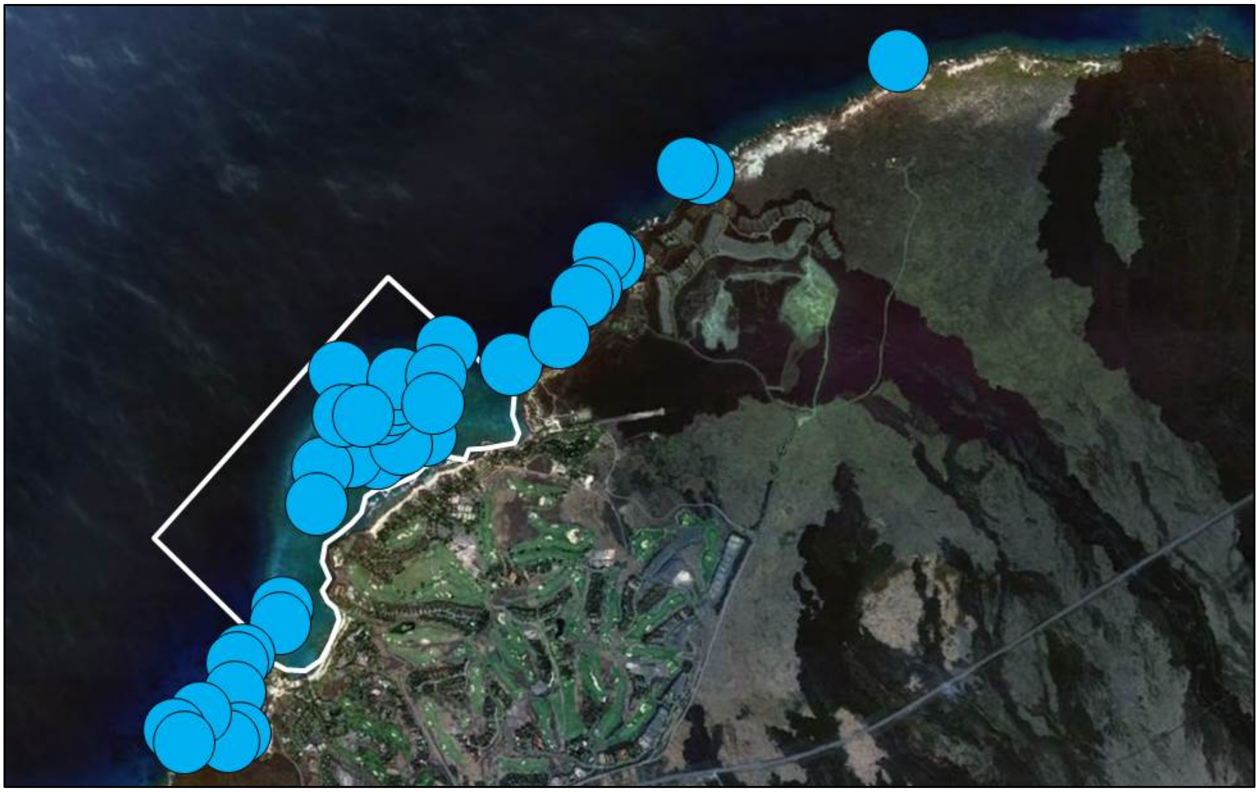

**Figure 12.** Distribution of eyestripe surgeonfish at Kaʻūpūlehu. White box encompasses the bench area.

While maximum size for eyestripe surgeonfish is 54 cm, a size at maturity has not been published. This species is also not regulated in Hawaiʻi, so no minimum harvest size has been established. Using only sightings along transects, eyestripe surgeonfish at Kaʻūpūlehu averaged 35.6 ± 1.1 cm (Table 8).

*Ringtail surgeonfish or pualu*[14]*(Acanthurus blochii)*

Ringtail surgeonfish, or *pualu*, were rare at Kaʻūpūlehu, with 0.1 ± 0.05 individual/transect. They contributed only 0.2 ± 0.1 g/$m^2$ to the total biomass at Kaʻūpūlehu (Table 7). Numerically, they accounted for <1% of all observed surgeonfish individuals and were seen on transects at only 13 of 148 survey sites (9% of sites). Surveyors on the 5-minute timed swims observed 82 individuals on 24 of 143 swims (17% of timed swim). Ringtail surgeonfish occurred at both bench and non-bench sites, but were more commonly observed at non-bench locations and at deeper sites on the bench (Figure 13).

While maximum size for ringtail surgeonfish has been estimated at 42 cm in Hawaiʻi, little has been published on its size at maturity. This species is not regulated in Hawaiʻi, so no minimum

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[14] The yellowfin suregonfish (*Acanthurus xanthopterus*) are also locally called *pualu*, but this species was not observed at Kaʻūpūlehu.

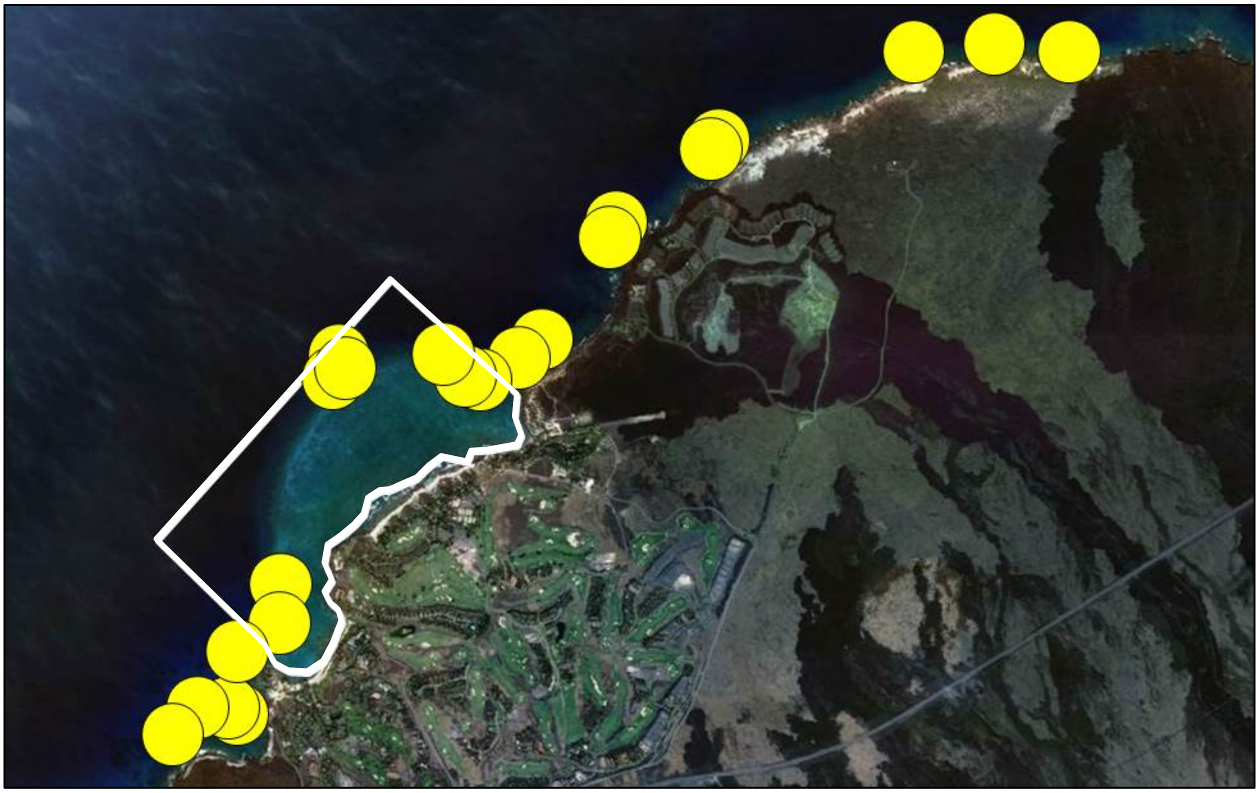

**Figure 13.** Distribution of ringtail surgeonfish at Kaʻūpūlehu. White box encompasses the bench area.

harvest size has been established. Ringtail surgeonfish averaged 26.0 ± 0.1.3 cm in length at Kaʻūpūlehu (Table 8), with just under half of the individuals occurring in the 27.5-32.5 cm size class.

*Bigeye emperor or mū (Monotaxis grandoculis)*

Bigeye emperors are large (max size=60 cm) fish that are prized for food and were once commonly observed in large schools in many areas of Kaʻūpūlehu including the bench area. On West Hawaiʻi reefs today, they are generally found at mid-depth (30-60 ft).

Over the course of three years, 34 bigeye emperors were observed at six different survey sites spread across the Kaʻūpūlehu survey area. Bigeye emperors were observed at bench (5 individuals at two sites) and non-bench (29 individuals at four sites) sites (Figure 14). Not surprising considering their wary behavior, bigeye emperors were sighted more often on the 5-minute timed swims, with an additional 54 individuals observed on 20 of 143 timed swims (14% of timed swims). Overall, bigeye emperor appear to be widely distributed, and while relatively uncommon, are not rare in Kaʻūpūlehu.

**Figure 14.** Distribution of bigeye emperor at Kaʻūpūlehu. White box encompasses the bench area.

Using only the sightings along transects[15], the average size of emperors observed at Kaʻūpūlehu was 37.3 ± 0.9 cm, which is below the published size of reproductive maturity for the species, 43.0 cm (Cakacaka et al. 2010). Fish ranged in size from about 17-50 cm, with approximately 37% of individuals above the size of reproductive maturity. Smaller size classes were not observed at Kaʻūpūlehu, but due to the species' cryptic nature and wary behavior, it is possible, although unlikely, they eluded observation by survey teams. The juveniles are known to occur within the depth range and habitat type of the Kaʻūpūlehu surveys.

## Management Recommendations

The reef adjacent to Kaʻūpūlehu shows signs of human impact associated with heavy fishing. Fish biomass is lower at Kaʻūpūlehu than at other locations in west Hawaiʻi that have implemented additional fishery regulations. In response to this difference, the Kaʻūpūlehu community has initiated the formal process to establish additional fisheries management rules 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 size and abundance of resource fish species in Ka'ūpūlehu. Subsequent rational fisheries management actions supported by the

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[15] Fish observations during timed swims exclude smaller individuals and focus only on fish >15 cm in total length.

community and adequately enforced, are likely necessary to ensure sustainable fishing effort continues to alleviate further declines of culturally- and economically-important species.

While this survey did not document many impacts to the benthic community, evidence is emerging from other sources that coral disease at Kaʻūpūlehu is among the highest in west Hawaiʻi. Causes of coral disease are not well-documented and determining causal relationships in the ocean is extremely difficult. The high prevalence of coral disease at the site, however, is suggestive that additional human impacts may be occurring, and may be associated with terrestrial pollutants or nutrients entering the marine environment through surface runoff or submarine groundwater inputs. Examining these potential sources of stress was beyond the scope of this survey project, but further investigation of coral disease and water quality in the area is warranted.

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All photographs were taken by the TNC marine monitoring team.

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## Appendix A.  Kaʻūpūlehu Site Data

| Site | Date Surveyed | Lat. | Long. |
|---|---|---|---|
| KAU09-01 | 9/14/2009 | 19.84583247 | -155.9775444 |
| KAU09-02 | 9/14/2009 | 19.84528656 | -155.9778004 |
| KAU09-03 | 9/14/2009 | 19.833369 | -155.993754 |
| KAU09-04 | 9/14/2009 | 19.83432999 | -155.9886999 |
| KAU09-05 | 9/14/2009 | 19.83437416 | -155.9875752 |
| KAU09-06 | 9/14/2009 | 19.83521805 | -155.9886324 |
| KAU09-07 | 9/15/2009 | 19.84961959 | -155.9728567 |
| KAU09-08 | 9/15/2009 | 19.84848367 | -155.9751216 |
| KAU09-09 | 9/15/2009 | 19.84399625 | -155.9807161 |
| KAU09-10 | 9/15/2009 | 19.84204997 | -155.98159 |
| KAU09-11 | 9/15/2009 | 19.83707179 | -155.9851805 |
| KAU09-12 | 9/15/2009 | 19.835439 | -155.986975 |
| KAU09-13 | 9/15/2009 | 19.84272212 | -155.9813665 |
| KAU09-14 | 9/15/2009 | 19.83794594 | -155.9829091 |
| KAU09-15 | 9/16/2009 | 19.8435453 | -155.9811233 |
| KAU09-16 | 9/16/2009 | 19.83628004 | -155.99092 |
| KAU09-17 | 9/16/2009 | 19.835023 | -155.998186 |
| KAU09-18 | 9/16/2009 | 19.83640743 | -155.9956248 |
| KAU09-19 | 9/16/2009 | 19.83524504 | -155.990627 |
| KAU09-20 | 9/16/2009 | 19.83515804 | -155.988671 |
| KAU09-21 | 9/16/2009 | 19.83223602 | -155.992286 |
| KAU09-22 | 9/16/2009 | 19.833369 | -155.993754 |
| KAU09-23 | 9/17/2009 | 19.83632002 | -155.98761 |
| KAU09-24 | 9/17/2009 | 19.84831511 | -155.9734684 |
| KAU09-25 | 9/17/2009 | 19.83983992 | -155.98255 |
| KAU09-26 | 9/17/2009 | 19.84193992 | -155.9810199 |
| KAU09-27 | 9/17/2009 | 19.83464196 | -155.996848 |
| KAU09-28 | 9/17/2009 | 19.83541 | -155.99223 |
| KAU09-29 | 9/17/2009 | 19.83402992 | -155.9916 |
| KAU-2010S-02 | 3/11/2010 | 19.85263598 | -155.963699 |
| KAU-2010S-12 | 3/12/2010 | 19.83530397 | -155.997039 |
| KAU-2010S-13 | 3/11/2010 | 19.83291596 | -155.994979 |
| KAU-2010S-16 | 3/10/2010 | 19.81559702 | -156.006301 |
| KAU-2010S-23 | 3/11/2010 | 19.83129599 | -155.993499 |
| KAU-2010S-32 | 3/9/2010 | 19.84637604 | -155.976532 |
| KAU-2010S-34 | 3/11/2010 | 19.83520498 | -155.989379 |
| KAU-2010S-36 | 3/10/2010 | 19.82320896 | -155.999038 |
| KAU-2010S-38 | 3/11/2010 | 19.85077998 | -155.96817 |
| KAU-2010S-40 | 3/11/2010 | 19.84083099 | -155.983474 |
| KAU-2010S-45 | 3/11/2010 | 19.85284603 | -155.954589 |

| Site | Date Surveyed | Lat. | Long. |
|---|---|---|---|
| KAU-2010S-46 | 3/10/2010 | 19.81693603 | -156.003067 |
| KAU-2010S-47 | 3/10/2010 | 19.81985201 | -156.002593 |
| KAU-2010S-54 | 3/12/2010 | 19.82477303 | -156.001586 |
| KAU-2010S-57 | 3/9/2010 | 19.84945304 | -155.974227 |
| KAU-2010S-59 | 3/10/2010 | 19.83055796 | -155.996124 |
| KAU-2010S-64 | 3/11/2010 | 19.85342002 | -155.958984 |
| KAU-2010S-67 | 3/10/2010 | 19.82608404 | -155.999649 |
| KAU-2010S-68 | 3/9/2010 | 19.84400103 | -155.980453 |
| KAU-2010S-69 | 3/10/2010 | 19.828249 | -155.998214 |
| KAU-2010S-70 | 3/9/2010 | 19.83704103 | -155.98561 |
| KAU-2010F-02 | 9/15/2010 | 19.85264344 | -155.9637325 |
| KAU-2010F-03 | 9/15/2010 | 19.83650451 | -155.9951284 |
| KAU-2010F-07 | 9/15/2010 | 19.81700141 | -156.0047109 |
| KAU-2010F-09 | 9/16/2010 | 19.82370048 | -156.000244 |
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| KAU-2010F-22 | 9/16/2010 | 19.83526155 | -155.9946918 |
| KAU-2010F-23 | 9/14/2010 | 19.83398683 | -155.993578 |
| KAU-2010F-24 | 9/15/2010 | 19.83656201 | -155.9853107 |
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| KAU-2010F-31 | 9/13/2010 | 19.84984112 | -155.9717377 |
| KAU-2010F-32 | 9/16/2010 | 19.82501862 | -155.9990984 |
| KAU-2010F-33 | 9/15/2010 | 19.85278434 | -155.9549661 |
| KAU-2010F-35 | 9/14/2010 | 19.83002094 | -155.9978527 |
| KAU-2010F-36 | 9/14/2010 | 19.81851317 | -156.0024766 |
| KAU-2010F-37 | 9/13/2010 | 19.8442255 | -155.9802413 |
| KAU-2010F-45 | 9/15/2010 | 19.83091872 | -156.0006376 |
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| KAU-2010F-59 | 9/16/2010 | 19.8337244 | -155.9898442 |
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| KAU-2010F-65 | 9/14/2010 | 19.81576785 | -156.0063941 |
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| KAU11 02 | 5/24/2011 | 19.81638777 | -156.0022189 |

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| KAU11 07 | 5/25/2011 | 19.81488682 | -156.0064339 |
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| KAU11 10 | 5/24/2011 | 19.84262849 | -155.9813084 |
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| KAU11 13 | 5/24/2011 | 19.84139669 | -155.9810919 |
| KAU11 14 | 5/26/2011 | 19.85256901 | -155.9616118 |
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| KAU11 16 | 5/24/2011 | 19.83268102 | -155.9920767 |
| KAU11 17 | 5/23/2011 | 19.82261033 | -156.0000688 |
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| KAU11 24 | 5/24/2011 | 19.84893059 | -155.9741841 |
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| KAU11 27 | 5/25/2011 | 19.83309391 | -155.9965413 |
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| KAU11 36 | 5/25/2011 | 19.82425938 | -155.9990041 |
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| KAU11 39 | 5/24/2011 | 19.8314094 | -155.9994408 |
| KAU11 40 | 5/23/2011 | 19.83670249 | -155.9846657 |
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| KAU11 43 | 10/18/2011 | 19.82465266 | -155.9995875 |
| KAU11 44 | 10/17/2011 | 19.82747887 | -155.9997102 |
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| KAU11 47 | 10/18/2011 | 19.83404266 | -155.9869623 |
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| KAU11 49 | 10/18/2011 | 19.85044093 | -155.970107 |

| Site | Date Surveyed | Lat. | Long. |
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| KAU11 54 | 10/20/2011 | 19.85135715 | -155.9667128 |
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| KAU11 72 | 10/19/2011 | 19.81580724 | -156.0028037 |
| KAU11 73 | 10/17/2011 | 19.81499227 | -156.0059414 |
| KAU11 74 | 10/20/2011 | 19.85304435 | -155.9586493 |
| KAU11 75 | 10/17/2011 | 19.83790588 | -155.9833741 |
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| KAU11 77 | 10/20/2011 | 19.85263632 | -155.9647004 |
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| KAU11 80 | 10/19/2011 | 19.83033358 | -156.0005002 |

## Appendix B. TNC Survey Methods and Data Analysis

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

TNC’s marine monitoring team and researchers from the University of Hawaiʻi at Mānoa conducted all benthic and fish surveys at Kaʻūpūlehu. 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 at Kaʻūpūlehu was delineated in ArcGIS (Figure B.1). The survey area covered approximately 1.2 km of coastline and included coral reef habitat between 3 and 15 m deep. Twenty-seven randomly generated sites were surveyed by divers deployed from a small boat. 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.

Each photograph was imported into Adobe Photoshop CS5 where its color, contrast, and tone were autobalanced to improve photo quality prior to analysis using the Coral Point Count program with Excel extension (CPCe) developed by the National Coral Reef Institute (Kohler and Gill 2006). Using CPCe, 30 random points were overlaid on each digital photograph, and

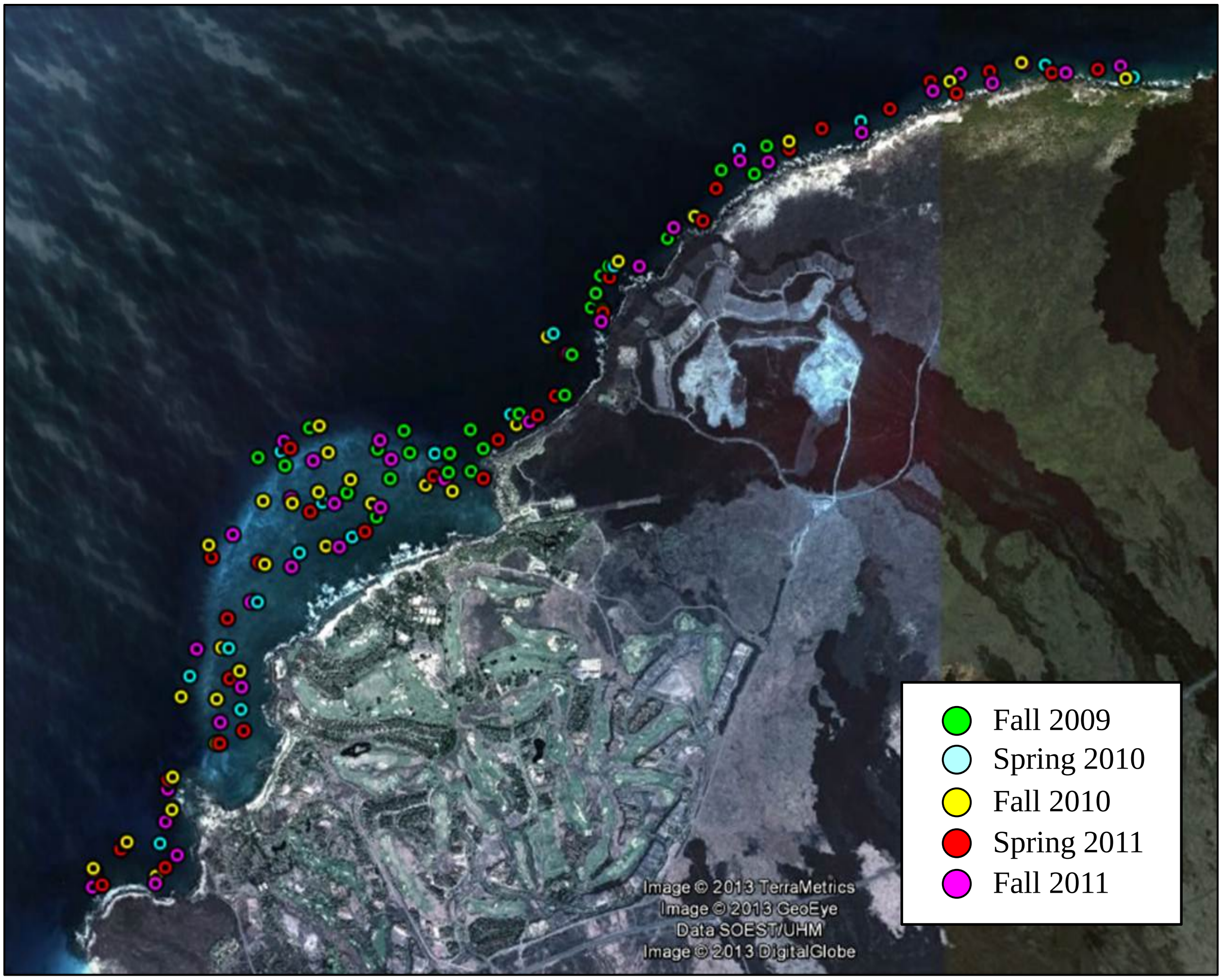

**Figure B.1.** Ka‘ūpūlehu reef with the 148 randomly generated marine monitoring sites surveyed during Fall 2009, Spring and Fall 2010, and Spring and Fall 2011.

the benthic component under each point was identified to the lowest possible taxonomic level. To reduce observer variability, all photographs were processed by a single individual. The raw point data from all photographs on a transect line were combined to calculate the percent cover of each benthic component for the entire belt transect.

Data on coral colony size and density were collected *in situ* by a single diver. All coral colonies whose center lay within a 0.25 meter-square quadrat were identified to the lowest taxonomic level and their longest dimension measured using a plastic ruler. To improve efficiency in water, colonies were binned into the following size categories: <1cm, >1-2 cm, >2-5 cm, >5-10 cm, >10-20 cm, >20-40 cm, >40-80 cm, >80-160 cm, >160 cm. Colonies were individually distinguished by a variety of factors including color and morphology, but most importantly tissue and or skeletal boundary separation. Most colonies were distinguishable based on these parameters. However, at some sites, *Porites compressa* was extensive and grew in large amalgamated beds, which did not allow for reliable colony delineation in the time available. At these sites, the presence of *P. compressa* was noted, but colonies were not delineated or sized.

Other species present in the quadrats were delineated and sized as described above. As many 0.25 meter-square quadrats as possible were haphazardly surveyed along one of the 25-m transect lines in the time available (~20-25 minutes). This resulted in from 4-20 quadrats surveyed at each survey site, depending upon the density of corals at the site.

Fish Community Surveys

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

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

Timed swims where aligned on depth contours. Short stretches of increased water depth or non-hard bottom habitat were quickly traversed by divers. If longer stretches of non-hard bottom or a significant change in depth was encountered, divers altered course to maintain a relatively constant depth and to avoid swimming into extensive areas of non-hard bottom habitat.

Data Analysis

Individual fish biomass (wet weight of fish per $m^2$ of reef area) was calculated from estimated lengths using size to weight conversion parameters from FishBase (Froese and Pauly, 2010) or the 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[16], which are reef species targeted or regularly harvested by fishers (Table B.1); (3) prime spawners[17], which are target fishes larger than 70% of the maximum size reported for the species; and (4) non-target fishes, which are

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[16] 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.

[17] 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 resource fish targeted by fishers in Hawai‘i included as “Target Fish” for this report.

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

species not targeted by fishers to any significant degree. Non-target taxa included: non-target wrasses (all wrasse species other than those listed in Table B.1); non-target surgeonfishes (*Acanthurus nigrofuscus* and *A. nigricans*); hawkfishes (all species except the stocky hawkfish, *Cirrhitus pinnulatus*); triggerfishes excluding planktivores; corallivorous butterflyfishes (*Chaetodon multicinctus, C. ornatissimus, C. quadrimaculatus* and *C. unimaculatus*); and benthic damselfishes (all *Plectroglyphidodon* and *Stegastes* species). In addition, data were pooled by family for parrotfish and target surgeonfish. Those abundant and conspicuous fishes provide important ecosystem services (*i.e.*, herbivory).

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

Prior to analysis, percent cover data for each benthic category were square-root transformed and a Bray-Curtis similarity matrix generated (Clarke and Warrick 2001, Clarke and Gorley 2006).

Non-metric multidimensional scaling (nMDS) plots were generated to explore patterns (Clarke and Gorley 2006) in benthic composition.

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

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## Appendix C. Glossary of Scientific Terms

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

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

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

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

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

**Diversity Index:** A quantitative measure that reflects how many different of species are in a dataset, and simultaneously takes into account how evenly the individuals are distributed among those species. Also see Evenness.

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

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

**Turbidity:** A measure of the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye.