Long-Term Monitoring of Coral Reefs of the Main Hawaiian Islands

Final Report

2009 NOAA Coral Reef Conservation Program

State of Hawai'i Monitoring Report
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SUMMARY OF FINDINGS

O’ahu:

- Lay Net Restricted sites appear to have the highest fish biomass on average, and both these and MLCD sites have higher biomass than fully open areas. The MMA site had intermediate biomass, and was not clearly different from MLCD or open sites.

- Lay Net Restricted areas compared favorably with MLCD and Open sites in species composition and biomass. A longer time series will be needed to determine if these areas are inherently healthy coral reef areas or are responding to the recent restrictions on the use of lay gill nets

- The surgeonfish family is by far the dominant fish family on O’ahu reefs by biomass, followed by triggerfish, goatfish, wrasse, and parrotfish families.

Maui

Benthic

- Nine of the 20 currently monitored coral reefs have experienced significant changes (paired t-tests of first survey year vs. most recent survey year, $p<0.05$), with coral cover declining at 7 sites and increasing at 2 sites.

- Coral cover declines at three sites (Honolua Bay, Mā’alaea Bay, and Papaula Point) were so severe that these individual reefs may have already experienced a total coral reef ecosystem collapse.

- Sites experiencing significant coral reef declines appear to be affected by anthropogenic impacts such as land based pollution, sedimentation and overfishing.

- Monitoring sites with stable high coral cover (Kanahena Bay, Olowalu, and Molokini) appear to be away from urban areas, are fairly remote or are located offshore.

Fish

- Comparisons between fully protected reserves versus areas open to fishing show that marine reserves have consistently higher resource fish biomass levels, larger sized fish, greater numbers of apex predators, and the greater abundances of schooling grazers.

Shallow Water Habitat and Fish Surveys (lay-net regulation assessment surveys)

- Fish biomass levels were higher in areas where past lay-net fishing effort was lower.

- Qualitative habitat assessments show the areas that experienced the highest past lay-net fishing effort had the most degraded reef habitats with algal cover at 20% or higher at most of these survey locations.

Kahekili Herbivore Baseline

- Benthic community structure and fish biomass varied significantly by habitat, and therefore may have markedly different responses to the management implementation.

Volunteer Herbivore Grazing Assessments

- General grazing trends for both acanthurids and scarids were similar. A significant negative correlation for grazing rate versus fish size was observed, which is intuitive because smaller fishes require continuous energy for growth. Conversely, bite sizes increased with fish size.

- The area of algae scraped by scarids over a year has a significant positive linear relationship to size (i.e. larger fish have a greater impact on algal removal).

- Both scarids and acanthurids are critical grazers for controlling algae on the reefs. Not enough data was gathered on kyphosids due to infrequent presence of this family in the study sites.

Roi Control Assessments

- When data on both CPUE and the number of roi escaped are combined, a significant decline in roi abundance can be seen.

- While roi have been substantially reduced, they are still present in moderate densities despite months of removal effort.

- Ciguatera analysis of fish weighing over one pound indicates that 69% of the population contains ciguatoxin.

Coral Disease Assessments

- HIMB researchers’ data showed a 47% decrease in coral cover over a period of one year at a site known as Montipora Pond, wherein a nearly monotypic stand of Montipora capitata has a chronic outbreak of Montipora white syndrome. DAR Maui took over monthly monitoring efforts to learn more about this outbreak. The outbreak shows patterns of waxing and waning, with an increase in coral mortality.

Hawaiʻi

Benthic

Coral and Habitat Surveys

- Total Coral cover declined significantly at 6 northern sites in West Hawai'i between 2003 and 2007. A strong winter storm in 2004 was likely responsible for the declines but a major sediment event in 2006 may also have affected sites at Kamilo Gulch and Waiaka'ilio Bay on the North Kohala coast.

- No invasive alien algal or coral species were detected at any site. Macroalgal cover was very low at all sites.

- The distribution of the octocoral *Sarcothelia edmonsoni* around developed areas near Kona and its virtual absence around undeveloped shoreline areas suggests possible anthropogenic (pollution) influence. Since other studies have cited octocoral as a pollution indicator and shoreline development in West Hawai'i is expected to continue to increase, further studies should be undertaken to determine the relationship between octocoral presence and land based pollution.

Coral Disease Surveys

- The following coral diseases were recorded at West Hawaiʻi monitoring sites in 2010: *Porites* growth anomaly, *Porites* tissue loss syndrome, *Porites* multifocal tissue loss, *Porites* trematodiasis, *Montipora* growth anomaly, *Pavona varians* hypermycosis, *Pocillopora* tissue loss.

- *Porites spp.* were the most susceptible to disease (mean prevalence of 3.76 ± 3.58%), with the most widespread diseases including growth anomalies, trematodiasis, and tissue loss syndrome of *Porites spp*.

- Though thought to be a common condition, the possible senescence reaction of *Pocillopora meandrina* (i.e. progressive age-related colony death) was observed at only two sites likely attributed to the low number of Pocilloporids present at monitoring sites.

- Overall disease prevalence and prevalence of *Porites* growth anomalies were positively correlated with total estimated size and total number of submarine groundwater (SGD) “plumes”.

- West Hawaiʻi sites show a significant negative relationship between disease prevalence and distance from harbors/boat ramps (overall disease prevalence: r = -0.402, p = 0.028), particularly for *Porites* growth anomalies (r = -0.658, p = 0.000) and *Porites* tissue loss syndrome (r = -0.701, p = 0.000).

- No significant changes in disease densities were found between survey years 2007 and 2010 for ten DAR monitoring sites (p = 0.18). However, cases of *Porites* growth anomalies and *Porites* tissue loss syndrome slightly increased at four sites located in close proximity to harbors/boat ramps.

- No statistically significant relationships were found between prevalence of coral diseases and abundances of corallivorous butterflyfishes and parrotfishes for West Hawaii's reefs.

Fish

- The abundance of both aquarium and food fishes increased significantly in West Hawai'i over the last 11 years. The overall number of fishes not substantially harvested for either food or for the aquarium trade, did not change significantly although individual species within this group may have.

- Examination of the temporal trends of some of the most common reef fish families indicates that acanthurids have been increasing over the past eleven years while labrids have decreased. Overall, chaetodontids and pomacentrids have been relatively stable although some species within the family have either increased or declined.

Introduced Species/Fish Die-Off

- Transect data reflects overall low abundance of ta'ape in the reef areas of the study sites and they are rarely found in the shallower water where resource fish surveys are conducted. Ta'ape are numerous in some locales usually along drop-offs and deeper reef areas but their distribution is highly patchy and they are not at all abundant in many reef areas in West Hawai'i. Ta'ape numbers also appear to have declined from earlier periods.

- There has been a marked decrease in roi abundance both on West Hawai'i transect (56% decrease) and free swim surveys (55% decrease). This decline may be related in part to an unusual fish die-off in West Hawai'i which first became apparent in May 2006.

- Early in 2010 a die-off of large puffers, with external symptoms quite similar to the previous mortalities, began to occur on Maui and Hawai'i Island. Over the ensuing months low numbers of dead and dying puffers were progressively reported up the island chain as far as Kaua'i (Oct. 2010).

- West Hawai'i monitoring data indicates a substantial decline has occurred in the abundance of the Hawaiian spotted toby (*Canthigaster jactator*) and the spotted puffer (*Arothron meleagris*) with a precipitous drop of the latter species in 2009/2010.

- As of November 2010 a total of 106 puffers have undergone both gross and microscopic examination. All assays for viruses (including electron microscopy) have so far come up negative and all attempts to incriminate any infectious agent as a cause have come to naught.

- An examination of roi and two of the most abundant species in roi's prime habitat the yellow tang (*Zebrasoma flavescens*) and kole (*Ctenochaetus strigosus*) fails to indicate direct negative impact on either species.

- Examination of the relationship between roi abundance and the abundance of various species and functional groups shows no significant negative relationships. In other words having more roi in an area does not result in having less total fish, small prey fish, other piscivores, yellow tang Young-of-Year (YOY), kole YOY or all YOY.

- The estimated roi population in West Hawai'i in the 30'-60' depth range (hard bottom only) is 58,839 individuals.

Aquarium Species

- Ten years after closure of the FRAs, the top 20 aquarium species showed a small overall increase in abundance relative to the period before the FRAs were operational. Most of the increase was attributed to the top two species yellow tang and goldring surgeonfish (kole) which comprise 91% of the West Hawai′i aquarium catch.

- Seven of the top 10 most collected species (representing <6% of all collected fish) decreased in overall density. Three of these decreases were significant (Achilles tang, multiband butterflyfish and black surgeonfish).

- The FRAs were 'effective' (increases in FRAs relative to long-term MPAs) for eight of the top 10 collected species with three being statistically significant. With only a single exception the FRAs were highly effective in increasing the abundance of yellow tang along the West Hawai′i coastline.

- A decrease of yellow tang in open areas to below baseline levels is largely attributable to an increase in the number of aquarium collectors and collected animals relative to the period when the FRAs were established. Kole are more abundant and much less collected than the yellow tang with populations in open areas remaining relatively stable. Achilles tang show a declining trend.

- Concerns over continued expansion of the aquarium fishery and harvesting effects in the open areas has prompted DAR and the West Hawai′i Fisheries Council (WHFC) to develop a 'white list' of 40 species which can be taken by aquarium fishers. All other species are off limits.

- Based on an analysis of the differences in density between open and protected areas there was clear evidence of an aquarium collecting impact for only 5 of the 33 white list species analyzed. Four of the 5 are among the 10 most heavily collected species. For the others, it appears that inclusion on the white list poses little or no threat to their populations.

- Based on a comparison of catch and estimated population abundance in the 30'-60' depth range aquarium collecting is having a major impact on Achilles and yellow tang with aquarium fishing mortalities of 80% and 60% respectively. Achilles tang has had low levels of recruitment over the past decade and substantial numbers of larger fish (i.e. 'breeders') are taken for human consumption. Yellow tang have generally recruited reliably but the numbers of collectors and aquarium take has risen substantially over the past decade.

- For most of the species on the white list collecting impact, in terms of the % of the population being removed annually, is relatively low with 10 species having single digit % catch and 18 species having % catch values <1%.

- Eight *no lay gill netting* areas were established in West Hawai'i in 2005, comprising 25% of the coastline (including already protected areas). Nearshore monitoring results did not find major differences in food fish abundance in/out of the *no lay gill netting* areas. The lack of a marked effect of protection may be due to several factors including the relatively low number of lay gill nets that are presently being used (i.e. registered) in West Hawai'i.

Invertebrates

- Crown-of-thorns starfish have a low absolute abundance on West Hawai'i reefs and there has been an overall decreasing trend in abundance over the last four years.

- Three species of monitored urchins have been increasing on West Hawai'i reefs with the collector urchin, *T. gratilla* exhibiting the greatest increase. This increase is not related to an increase in benthic algae as a food supply.

East Hawai'i

- Abundance of fishes is significantly greater at both Waiopae MLCD and Waiopae open sites than at Richardson's Ocean Center (ROC). Species richness is higher in the MLCD as compared to ROC. The MLCD and ROC sites have the highest similarity in fish communities, and the OPEN and ROC communities have the lowest similarity.

- Over the 12 years of surveying of fishes at Waiopae and ROC, there appears to have been a slight increase in fishes observed between 1999 and 2006, followed by a three-year decline. No net increase in fish abundance has been observed at Waiopae MLCD since its establishment in 2003.

CONTRIBUTORS

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OBJECTIVES

Proposed work under this grant is directed to continuing and enhancing the coral reef monitoring program within the Hawai'i Division of Aquatic Resources (DAR) of the Department of Land and Natural Resources, State of Hawai'i. DAR is the agency responsible for management of nearshore and coral reef areas within state waters. All objectives under this grant have been completed. Many specific objectives identified in the original proposal were expanded through the ability of staff to increase the number of sites monitored. Grant objectives and accomplishments include:

- Conduct resource fish surveys at 40 Maui sites three times per year
- Conduct fish and mobile invertebrate surveys three times a year, and benthic surveys at a minimum of once every two years at 5 fully integrated monitoring stations on Maui
- Continue to conduct annual surveys of the 20 established Maui CRAMP sites biannually
- Conduct shallow water fish and habitat surveys three times a year at 56 transect sites that were in heavily lay gill-net fished areas prior to lay net fishing ban in Maui waters
- Establish survey sites and conduct quarterly resource fish and invertebrate surveys of 15 O′ahu monitoring sites, including sites on all shores
- Establish permanent transects and conduct benthic surveys of O′ahu monitoring sites a minimum of once every three years
- Conduct quarterly fish and invertebrate surveys of 12 West Hawai`i fully integrated sites and an additional 16 small-scale integrated sites (i.e. all existing WHAP sites) and 3 East Hawai'i sites.
- Conduct quarterly resource fish monitoring surveys at 12 West Hawai'i sites
- Conduct 6 replicate Adult yellow tang surveys using Jet Boots at 16 West Hawai′i sites
- Conduct Shallow Water Resource Fish Surveys at 144 West Hawai′i sites
- Conduct 4 Random Fish Surveys at 3 West Hawai′i sites
- Conduct visual coral disease surveys at all MHI fully-integrated stations (12 on Hawai'i, 15 on O`ahu, 5 on Maui) at a minimum of once every three years. To the extent that it is possible, support baseline surveys of coral disease at all sites where that has not yet been done.
- Assist CRAMP in monitoring of 4 established West Hawai′i sites
- Field trial deployment of in-situ water quality sampling devices (temperature, salinity), and continue to deploy temperature loggers.
- Provide DAR personnel with monitoring tools to accomplish data collecting, analysis and dissemination
- Use Maui and Hawai`i sites to train DAR biologists and technicians in field monitoring protocols
- Train DAR personnel to assist in data analysis, interpretation and database usage
- Continue development and integration of DAR monitoring data processing and analysis capability
- Disseminate the results of this work and make recommendations on the role of managed areas and the impacts of fishing to DAR, coral reef ecosystem managers, the scientific community, the West Hawai′i Fisheries Council and the public.

O'ahu Surveys

Methods

In 2007, O'ahu DAR staff designed and began to implement a long term monitoring program designed to track the trends in coral reef resource health around the island. The central component of this monitoring program is a series of "integrated" sites, where fish community and benthic cover data are collected along a series of permanently marked transects sites (Figure 1).

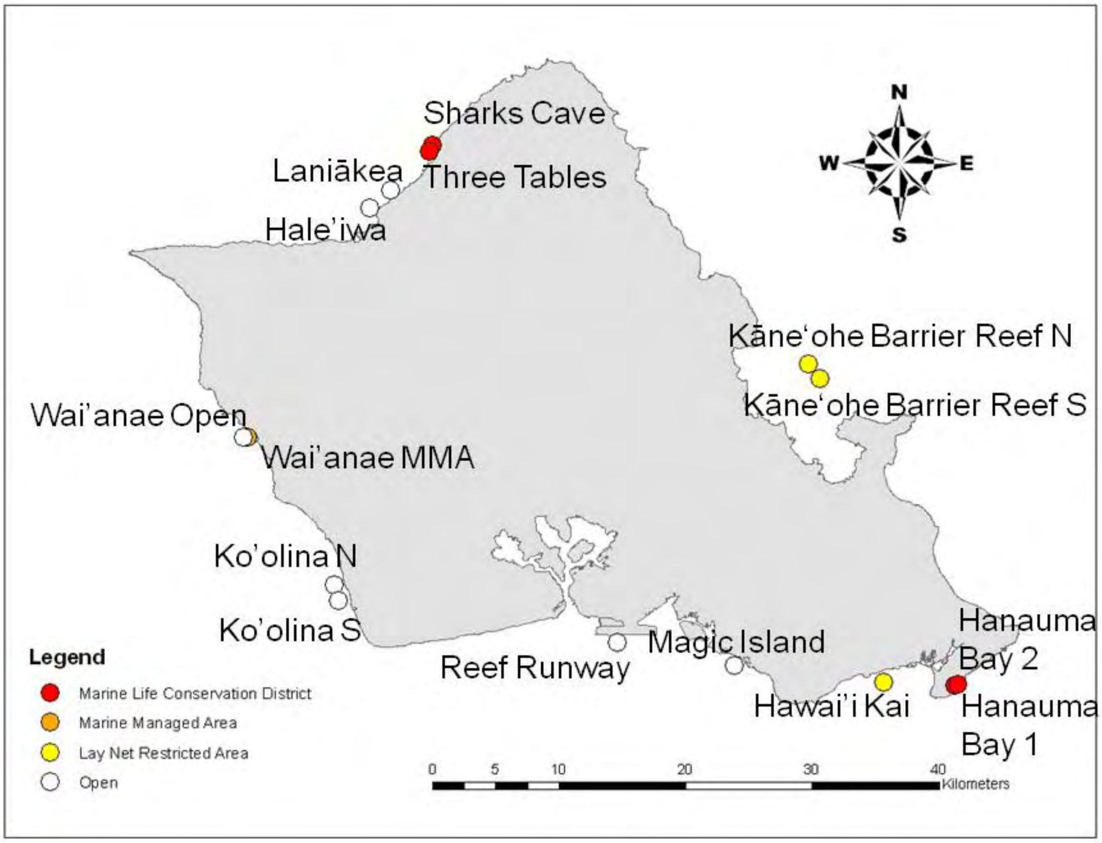


Figure 1. O'ahu integrated (co-located fish and benthic) survey sites

These sites are distributed around the island, and across a range of protection status. Marine Life Conservation Districts (MLCDs) on O'ahu are areas where no take of marine life is permitted. The Marine Managed Area (MMA) in Wai'anae only allows pole-and-line fishing, as well as limited netting of crabs and baitfish. Lay Net Restricted (LN Rest) areas prohibit the use of lay gill nets, but are otherwise open to fishing. And open areas have no take restrictions beyond state-wide limits on certain species and regulations concerning specific gear types.

The goal is to visit each of these sites three times per year, weather and staff time permitting, and collect data using the suite of methods described below.

Table 1. O’ahu integrated benthic monitoring sites with their corresponding district, location, depth, and management or protection status.

Site	District	Latitude	Longitude	Mean Depth (m)	Status
Hanauma Bay 1	East O’ahu	21.26757	-157.69363	12.3	MLCD
Hanauma Bay 2	East O’ahu	21.26887	-157.69157	10.7	MLCD
Kāne’ohe Barrier Reef S	East O’ahu	21.48529	-157.79003	12.3	Lay Net Restricted
Kāne’ohe Barrier Reef N	East O’ahu	21.49580	-157.79785	11.3	Lay Net Restricted
Hale’iwa	North O’ahu	21.60617	-158.10928	6.9	Open
Laniākea	North O’ahu	21.61900	-158.09483	7.8	Open
Sharks Cove	North O’ahu	21.65086	-158.06475	8.7	MLCD
Three Tables	North O’ahu	21.64603	-158.06706	11.1	MLCD
Hawai’i Kai	South O’ahu	21.26997	-157.74410	9.4	Lay Net Restricted
Magic Island	South O’ahu	21.28175	-157.85071	7.3	Open
Reef Runway	South O’ahu	21.29817	-157.93342	10.3	Open
Ko Olina N	West O’ahu	21.33910	-158.13505	8.3	Open
Ko Olina S	West O’ahu	21.32793	-158.13139	7.7	Open
Wai’anae MMA	West O’ahu	21.44361	-158.19628	7.0	MMA
Wai’anae Open	West O’ahu	21.44394	-158.19933	9.2	Open

Benthic Survey Methods

Fixed Photo-Transects

To obtain high-resolution data on the benthic cover of specific sites over time (i.e., to detect small to moderate percent change in key benthic components such as coral cover), a series of short (25-m-long) fixed transects were permanently installed in 2007. At each site, stainless steel eyebolts are drilled and epoxied into the reef at the start and end of 4 permanent transects. The transects are arrayed in an ‘H’ pattern: 2 parallel rows of 2 transects (one deep row and one shallow row), with 10 m between transects in each row and between rows. This methodology was initially developed on Hawai’i Island and forms the basis for both benthic and fish/invertebrate monitoring on both these islands.

Along each of these transects, a high quality digital still camera is used to take photographs at 1 m intervals along the length of the transect. Photographs are taken perpendicularly to the reef, and a camera stand is used to ensure that the camera is at a standard height of 0.75 m above benthos.

The data are subsequently analyzed using Photogrid computer software, with the composition of the benthic community under a series of 25 randomly generated points determined to the lowest possible taxonomic level possible (e.g., species of corals, genera of algae).

Due to the slow pace of change in benthic communities, these surveys are scheduled to be repeated every three years.

Benthic Assessments

As a complement to the high-resolution data collected by the fixed photo-transects described above, a series of benthic assessments are conducted over a broader area around each site. This method is not intended to detect fine-scale changes in benthic cover, but instead to detect ecosystem-level changes in dominant components of the benthic community. While this method is more subjective than photo-quadrat, it is a method of benthic habitat assessment that is currently also used in Florida for a cooperative monitoring program implemented by NOAA Fisheries, the National Park Service, the University of Miami, and the Florida Fish and Wildlife Research Institute. It has been evaluated over the course of these studies to be a viable means of assessing benthic cover—particularly when time constraints and oceanographic conditions preclude the use of other methods.

These assessments are conducted on the return leg of a 5-minute timed swim (targeting larger, more mobile fish) that typically covers 120-150m. At the “far end” of this swim, the diver buddy pair stops and does a benthic assessment, and then stops at one-minute intervals along the 5-minute return to conduct additional assessments, resulting in a total of six benthic assessments per diver per transect.

For each benthic assessment, each surveyor estimates the relative percent of benthos (reef bottom) in each of several general categories in a circle with a radius of 5 m. The surveyor first estimates the percent of substrate within this circle that is sand. Of the remaining hard bottom, the surveyor then estimates the percent cover of live coral, crustose coralline algae (CCA), macroalgae, other benthic cover (e.g. sponge or zoanthids), and bare substrate. For example, if 50% of benthos is sand, but ¾ of non-sand area is coral, that is recorded as 75% coral.

Unlike the fixed photo-transects, the benthic assessments are conducted every time the sites are surveyed, with a target of three survey periods per year.

Fish Survey Methods

To obtain high-resolution data on the fish community at specific sites over time, a series of short (25-m-long) fixed transects were permanently installed in 2007 (as above in the Benthic Monitoring section). At each site, stainless steel eyebolts are drilled and epoxied into the reef at the start and end of 4 permanent transects. The transects are arrayed in an ‘H’ pattern: 2 parallel rows of 2 transects (one deep row and one shallow row), with 10 m between transects in each row and between rows. Six stainless steel eyebolts (the circles in Figure 2) permanently mark the end points of the four 25m transect lines.

Each transect is surveyed by a pair of divers swimming in parallel on either side of the transect line, each diver recording all fishes within a 2 m-wide belt on their side of the line. Divers first swim rapidly down the transect recording larger mobile fishes transiting the line, mid-water species and any conspicuous rare or uncommon species. They then turn around and return back down the same transect slowly and carefully recording all other fishes in and around the benthos within the same 2m-wide belt.

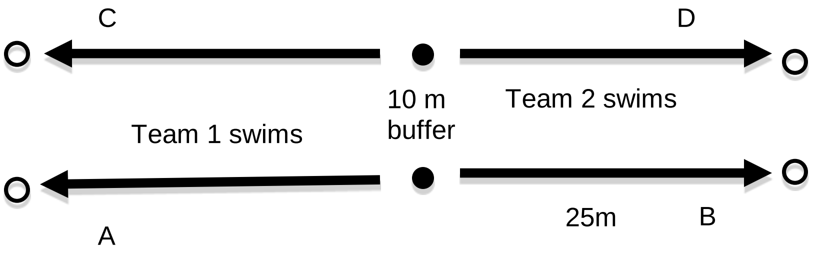


Figure 2. Diagram of 'integrated' fish survey transect configuration.

All species of fishes are recorded and sized, with particular attention to small site-attached or semi-cryptic species, fish recruits, and total fish community richness. Data from the two observers on a transect are then pooled into one 4 m x 25 m transect, with a total of four replicate 4 m x 25 m transects distributed across the 'H' sampling design.

The sizes of all fishes are visually estimated to the nearest 5 cm and recorded in 5cm bins (i.e. 1-5cm="A", 6-10cm="B", 11-15cm="C", etc.). Measured hash marks on the top of diver-held data slates serve as visual size references. Fishes whose sizes indicate they have recently recruited are noted as "R".

The size estimates of the fish are then converted to biomass using known length-weight relationships (www.fishbase.org) and unpublished data from the Hawai'i Cooperative Fishery Research Unit), with fish biomass per unit area being the most frequent unit of analysis. This methodology was initially developed on Hawai'i Island and is presently utilized both on O'ahu and Maui.

Results:

A total of fifteen permanent fish and benthic monitoring sites were established in 2007, and baseline data collected. Due to inclement weather and unsafe sea conditions, common at some of the survey sites, the desired frequency of three surveys per site per year was rarely achieved over the past three years (Table 2). The short time series available at present and low levels of temporal replication prohibited statistical analyses of these data (i.e., low statistical power to detect the modest changes likely within the limited time frame). However, data from both the fish and benthic monitoring is graphically summarized below.

Table 2. Summary of integrated survey sites and sampling frequency achieved over the first three years of this long term monitoring program.

Survey Summaries			
Site Name	**2007**	**2008**	**2009**
Hale'iwa	1	2	1
Hanauma Bay 1	1	1	2
Hanauma Bay 2		1	2
Hawai'i Kai	1	2	2
Kāne'ohe Bay Barrier Reef N	1	3	1
Kāne'ohe Bay Barrier Reef S	1	3	1
Ko'olina N	1	2	2
Ko'olina S	1	2	2
Laniākea	1	2	1
Magic Island	1	3	2
Reef Runway	1	3	1
Sharks Cove	1	2	1
Three Tables	1	2	1
Wai'anae MMA	1	3	1
Wai'anae Open	1	3	1

Benthic Surveys

Fixed Photo-Transects

An initial round off photographs was taken from all transects at each of the fifteen established permanent transects in 2007. These photos have not yet been analyzed. However DAR O'ahu recently hired a monitoring coordinator with expertise in benthic studies, and analysis of these photos (as well as the second round of photos collected in 2010) is currently underway.

Benthic Assessments

While the primary interest in the benthic assessments is to quantify the status and trends in hard-bottom communities, accurately describing the overall habitat and habitat quality requires estimation of the amount of sand present at the survey sites. Sand cover within the protection regimes varied from over 35% at the single MMA site surveyed, to < 10% for the LN Restricted sites (Figure 3).

Looking only at the hard-bottom habitat, similar trends are seen in the biological cover of the sites across the different protection regimes (Figure 4). Combined coral and reef-building crustose coralline algae (CCA) cover is approximately 40% at all sites, with the exception of the Waianae MMA. The dominant category in all protection regimes is

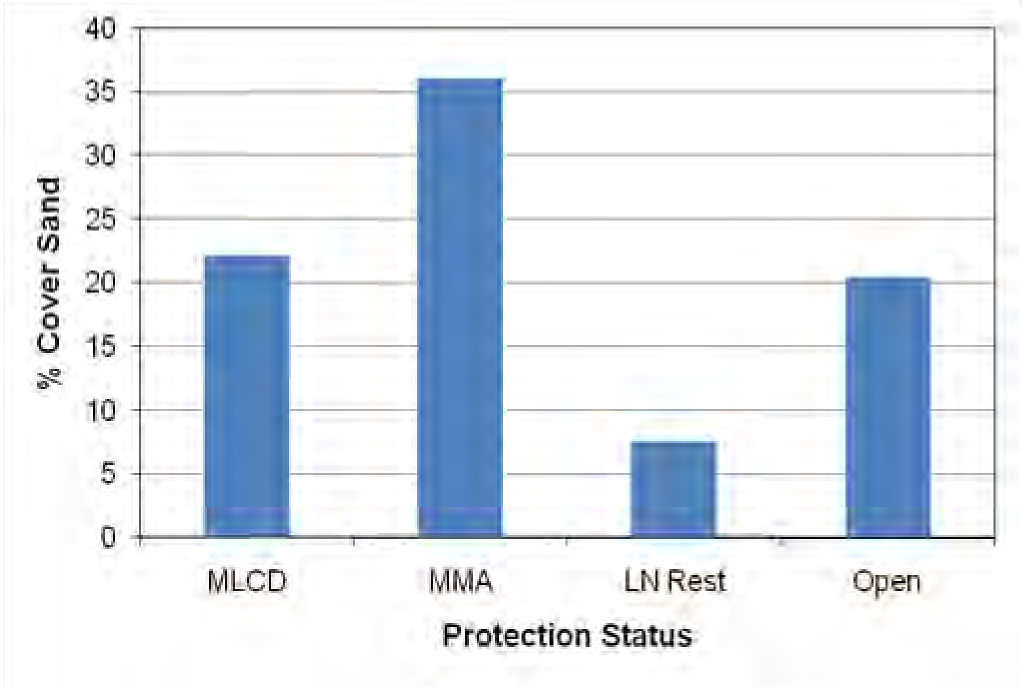


Figure 3. Mean percent cover of sand by protection status at all integrated monitoring sites around O'ahu. Data are averaged across all survey periods.

"substrate", which typically consists of fine turf algae growing on calcium carbonate reef. Macroalgae had low percent cover across all protection levels.

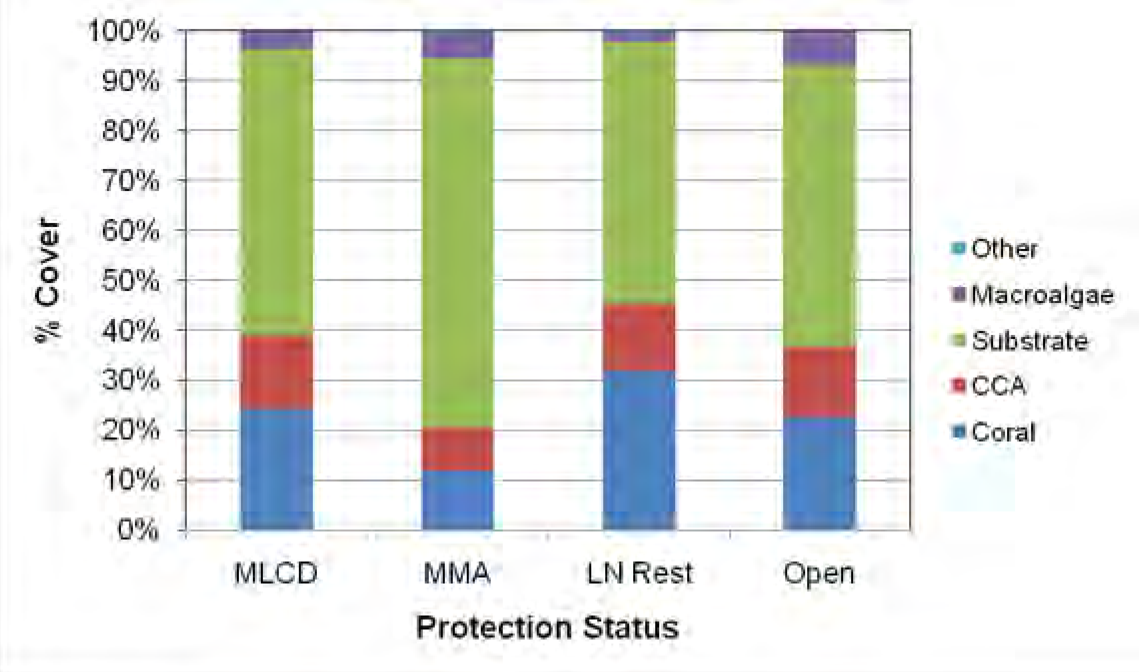


Figure 4. Mean percent cover of non-sand substrata by protection status at all integrated monitoring sites around O'ahu. Data are averaged across all survey time periods.

When the data are examined by site, it can be seen that there is a considerable amount of variability within a given management level for benthic cover by sand (Figure 5). MLCD sites, for instance, range from under 10% sand to over 40%.

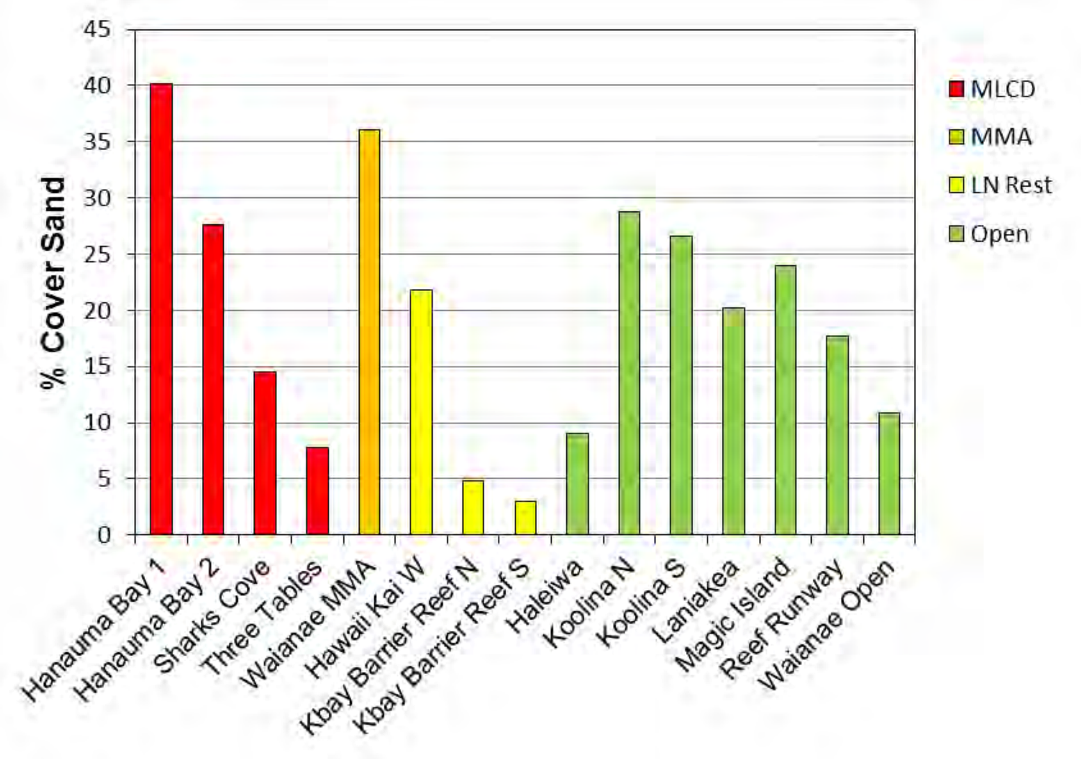


Figure 5. Mean percent cover of sand at individual integrated monitoring sites around O’ahu. Data are averaged across all survey time periods.

Similarly, biological cover varies substantially between sites (Figure 6). The relatively sheltered Hanauma Bay MLCD has 60% cover of coral and reef-building CCA, while the wave-exposed North Shore Three Tables and Shark’s Cove MLCD sites have less than 20%. Protection status does not appear to be driving relationships in benthic coverage amongst these sites, as several LN Restricted and Open sites approach or exceed 50% cover of calcifiers (corals and CCA). Macroalgae are found in abundance at some sites, with the Open areas of Laniākea and Haleiwa both exceeding 10% cover, and greater than 20% cover in the case of Laniākea. Both of these sites are on the North Shore, and it is interesting to note that while these sites have similar coverage of reef calcifiers as the North Shore MLCD sites, the two Open sites have substantially more macroalgae.

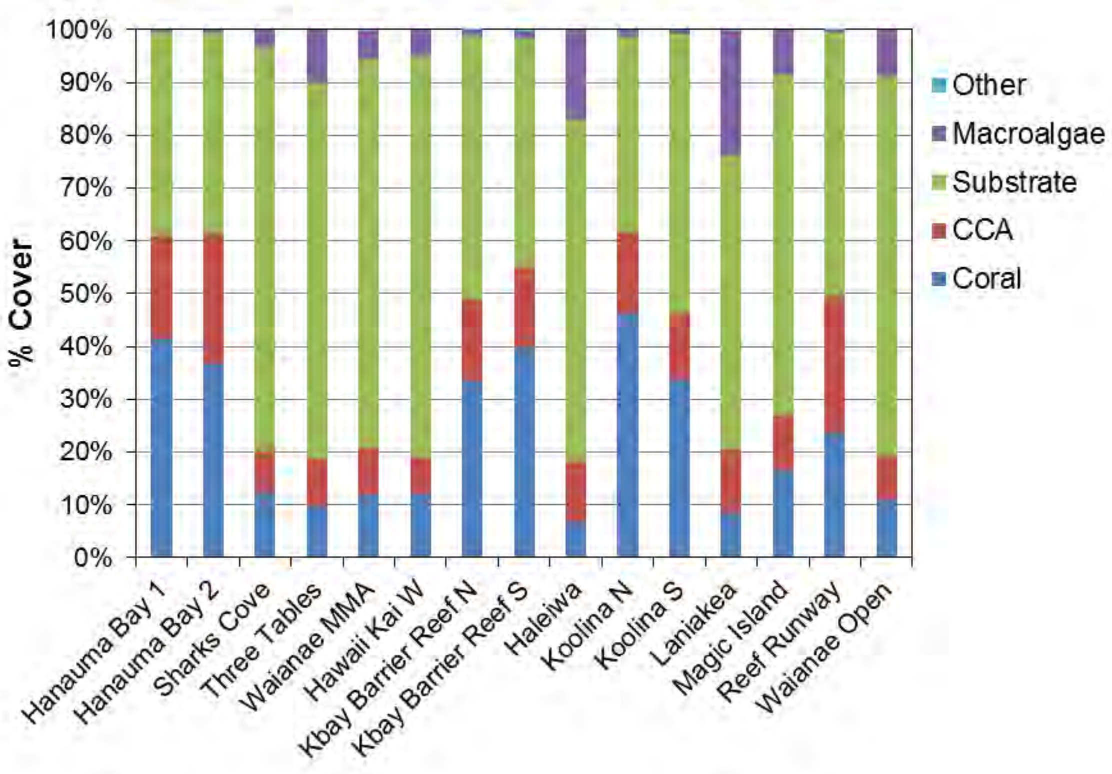


Figure 6. Mean percent cover of non-sand substrata at individual integrated monitoring sites around O'ahu. Data are averaged across all survey time periods.

While three years is a short time period over which to expect to see substantial changes in benthic community structure, there are suggestions of downward trends in calcifier cover in the sites at all protection levels except for the MMA site, which has the lowest coverage of corals and corallines of any protection status (Figure 7). It must be stressed, however these are preliminary data, and the trends rely heavily on unreplicated surveys from the inaugural monitoring year of 2007. These trends will be followed closely in future benthic assessment data, as well as in the fixed photo-transect surveys.

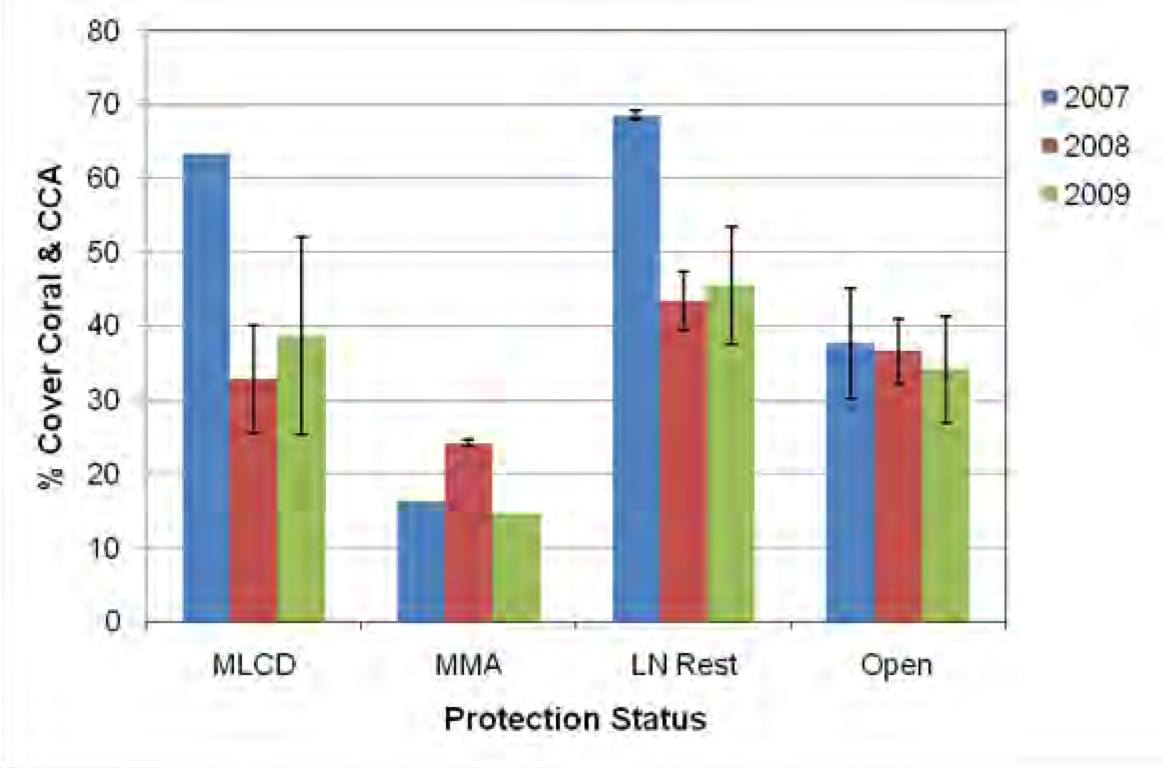


Figure 7. Mean percent cover (±SE) of coral and crustose coralline algae (CCA) at all integrated monitoring sites on O'ahu over time.

While coral and CCA cover are potentially declining, there is a suggestion that macroalgal cover is increasing across multiple protection regimes (Figure 8). The data on macroalgal cover is highly variable, and the trend is again largely based on the poorly replicated 2007 surveys. As with the coverage of the calcifiers, these trends will be followed over future survey years. Potential increases in macroalgal cover at the expense of coral and CCA coverage would be a significant management concern for long term trends in the health of coral reef communities.

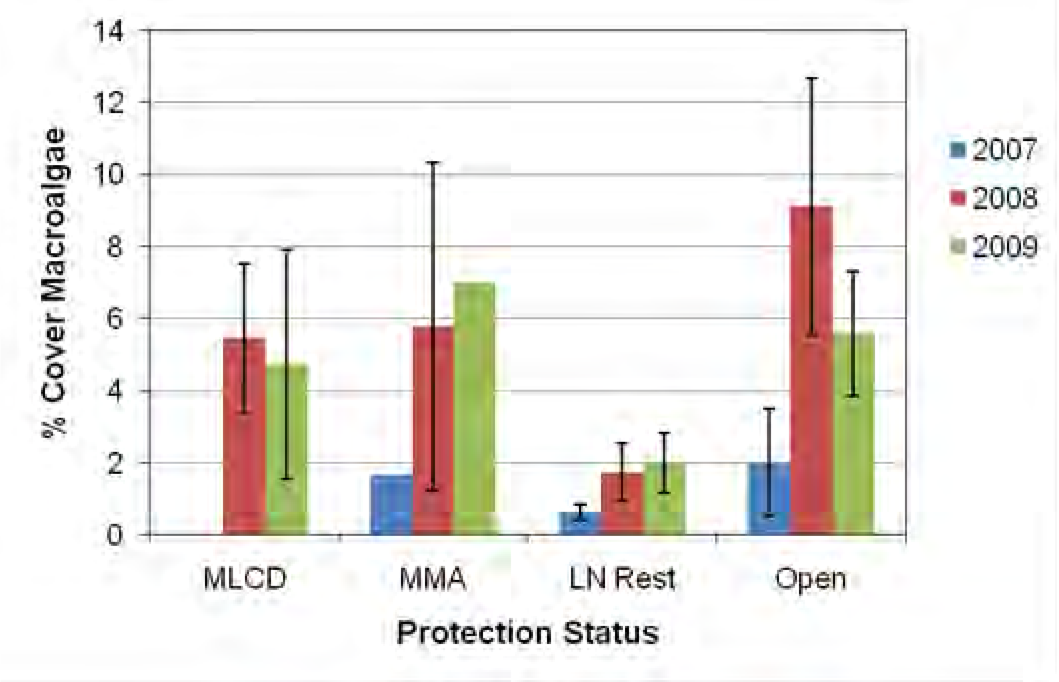


Figure 8. Mean percent cover (±SE) of macroalgae at all integrated monitoring sites on O'ahu over time. Lack of error bars indicates lack of replication in that protection status that year.

Fish Surveys:

The ability of marine protected areas to enhance the fish stocks in Hawai'i has been demonstrated in a number of rigorous studies to enable fish stocks (Friedlander et al 2003, 2007a, 2007b, Williams et al 2009). However, with the fifteen sites surveyed around O'ahu, the O'ahu MLCDs have lower total fish biomass than the largely-open Lay Net Restricted areas (Figure 9), and the mean value of approximately 25 g/m^2 is substantially less than other data from the Pūpūkea MLCD (Sharks Cove and Three Tables) and Hanauma Bay MLCD (each ca. 100 g/m^2 from Friedlander *unpublished data*, The Nature Conservancy *unpublished data*).

When examined at the level of the individual site, it can be seen that the Kāneʻohe Bay Barrier Reef sites are driving the difference between the Lay Net Restricted Sites and the MLCD sites (Figure 10), with the non-Kāneʻohe Lay Net Restricted sites having substantially lower biomass. Both MLCD and Lay Net Restricted sites appear to have higher biomass on average than the fully open areas.

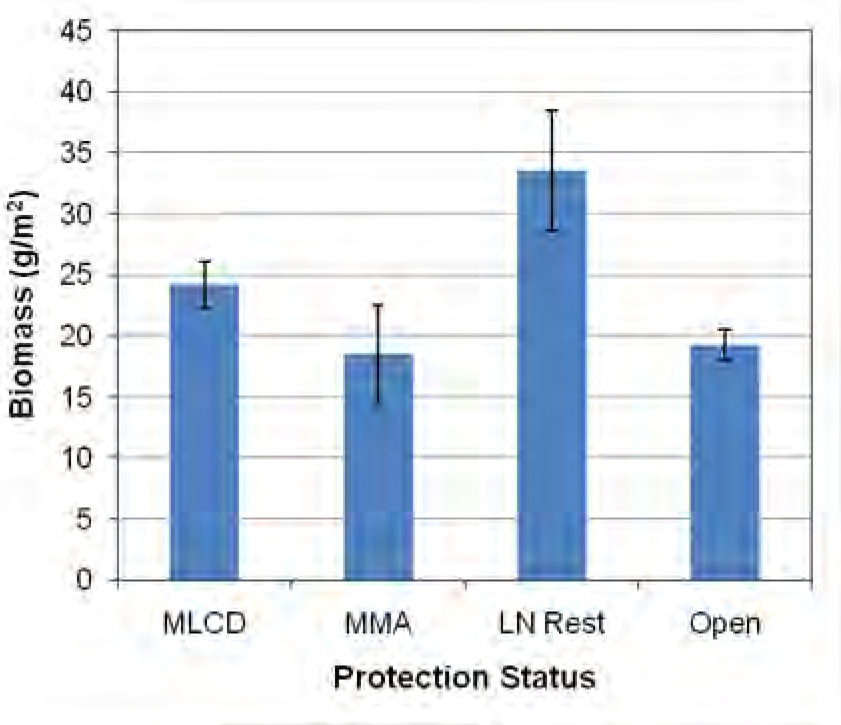


Figure 9. Mean total fish biomass (± SE) of all integrated survey sites on O'ahu. Data are averaged across all survey time periods.

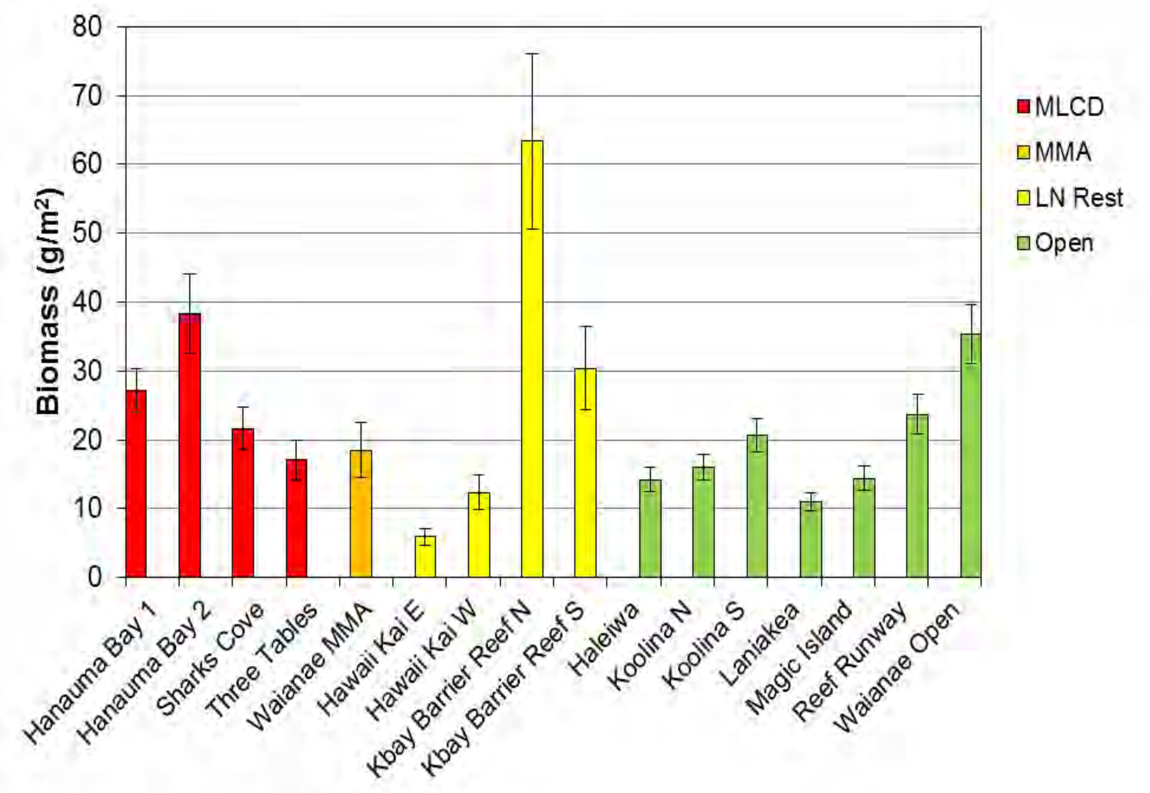


Figure 10. Mean total fish biomass (± SE) of all integrated survey sites on O'ahu by site and protection status. Data are averaged across all survey time periods.

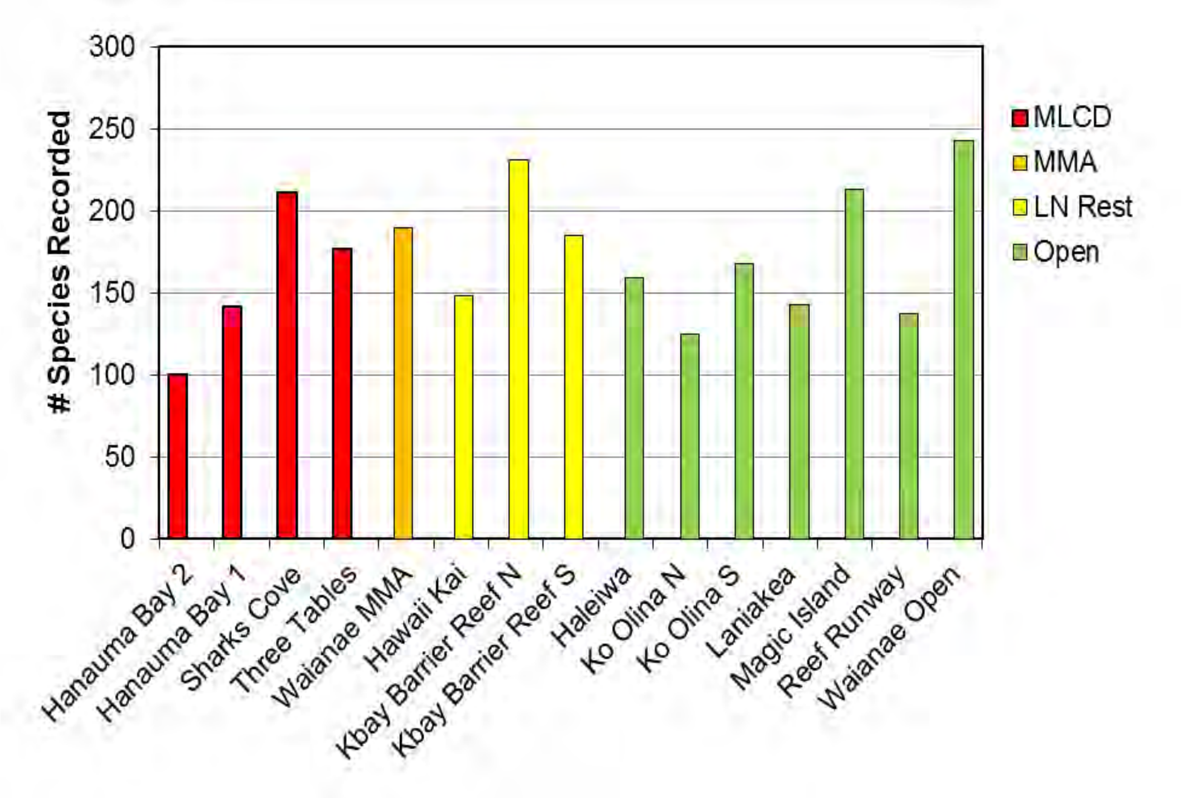


Figure 11. Cumulative number of species recorded from integrated survey sites on O'ahu by protection status.

Species richness does not appear to vary among protection status, though there is considerable variability between sites (Figure 11).

Surgeonfishes have the highest biomass of all families across sites of all protection levels, with triggerfishes, parrotfishes, wrasse, and goatfishes being the families with the next highest biomass (Figure 12). The only piscivorous family in the top eight most abundant fish families was the sea bass family, the only representative of which is the introduced grouper, *Cephalopholis argus.* No native piscivores were seen at any site in abundance, with herbivores (surgeonfish, parrotfish, damselfish) and invertivores (butterflyfish, wrasse, goatfish – though representatives of the latter can be piscivorous) predominating.

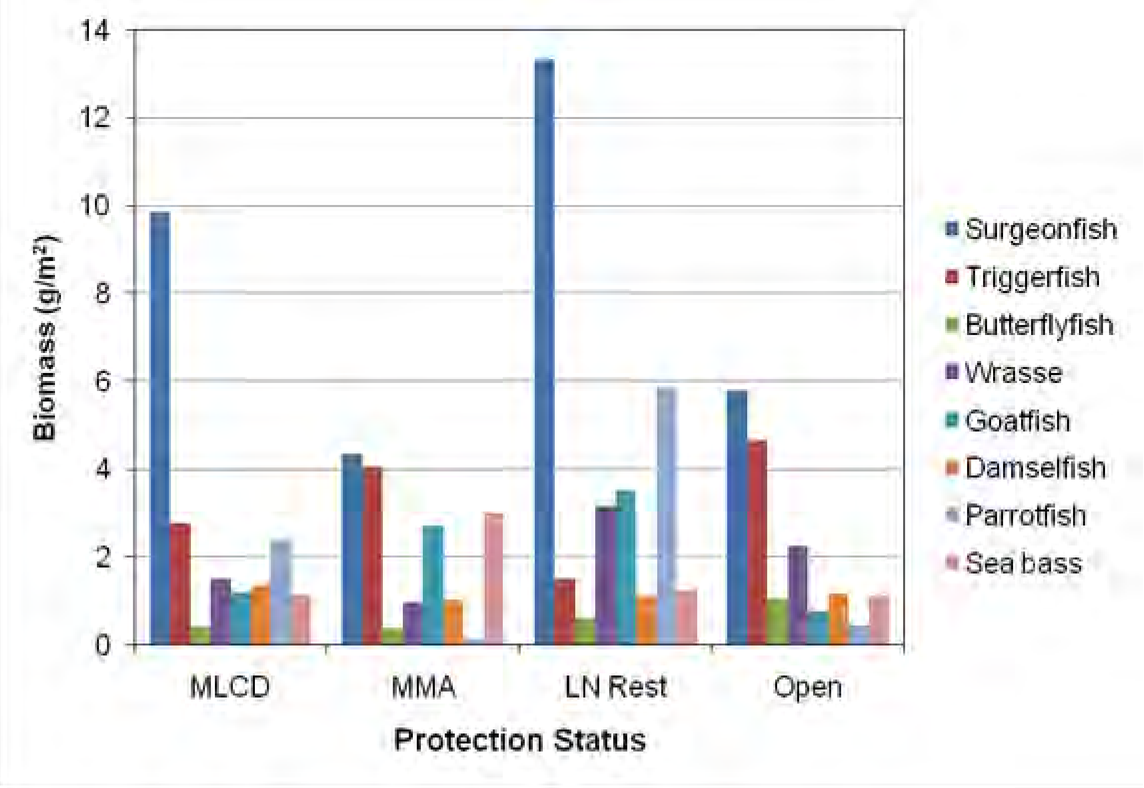


Figure 12. Mean biomass on O’ahu of the eight fish families most abundant by biomass against protection status of the survey sites.

With only three years of survey data, temporal trends in biomass are not apparent by family or protection status (Figure 13). There are suggestions of a few trends, however. The biomass of triggerfish and sea bass may be increasing in MLCD’s, for instance. Lay Gill Net restricted areas show a possible trend in increasing surgeonfish biomass. Trends such as these, however, are reliant on a very small number of observations and will need to be borne out over future surveys.

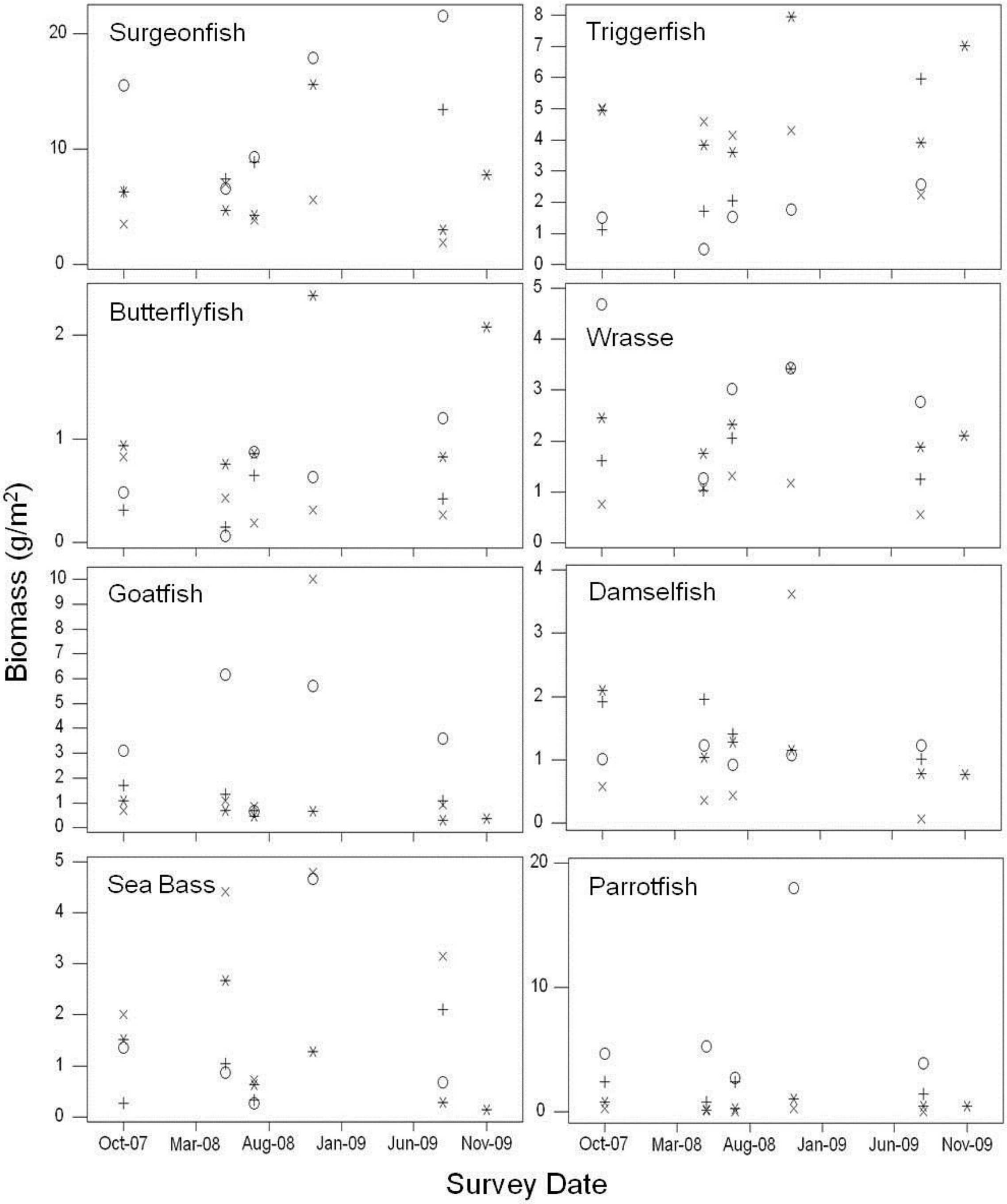


Figure 13. Mean biomass on O'ahu of the eight most abundant fish families by biomass over time. Symbols represent protection status: MLCD (+), MMA (X), LN Rest (O), and Open (*).

Maui Surveys

Benthic Survey Methods

Maui staff continue to work collaboratively with CRAMP (Coral Reef Assessment and Monitoring Program) to gather and analyze coral data and integrate it into the overall DAR and UH-CRAMP databases. CRAMP monitoring sites (Figure 14, Table 3) were selected on the basis of existing historical data, degree of perceived environmental degradation and/or recovery, level of management protection, and extent of wave exposure. A total of 10 sites are surveyed, with two reef area stations, a shallow (1-4m) and a deep (6-13m) station at each site (Table 3).

Each station consists of ten randomly chosen 10m permanent transects marked by small stainless steel stakes at both endpoints. Digital stills were taken every half meter perpendicular to the substrate at a height of 0.5m along the transect line. Approximately 24 overlapping still photos are acquired and approximately 11 non-overlapping images analyzed with Photo grid 1.0 software, for each 10 m long transect line. The analysis uses 25 randomly generated points per image with the analysis results calculated for percent benthic coverage.

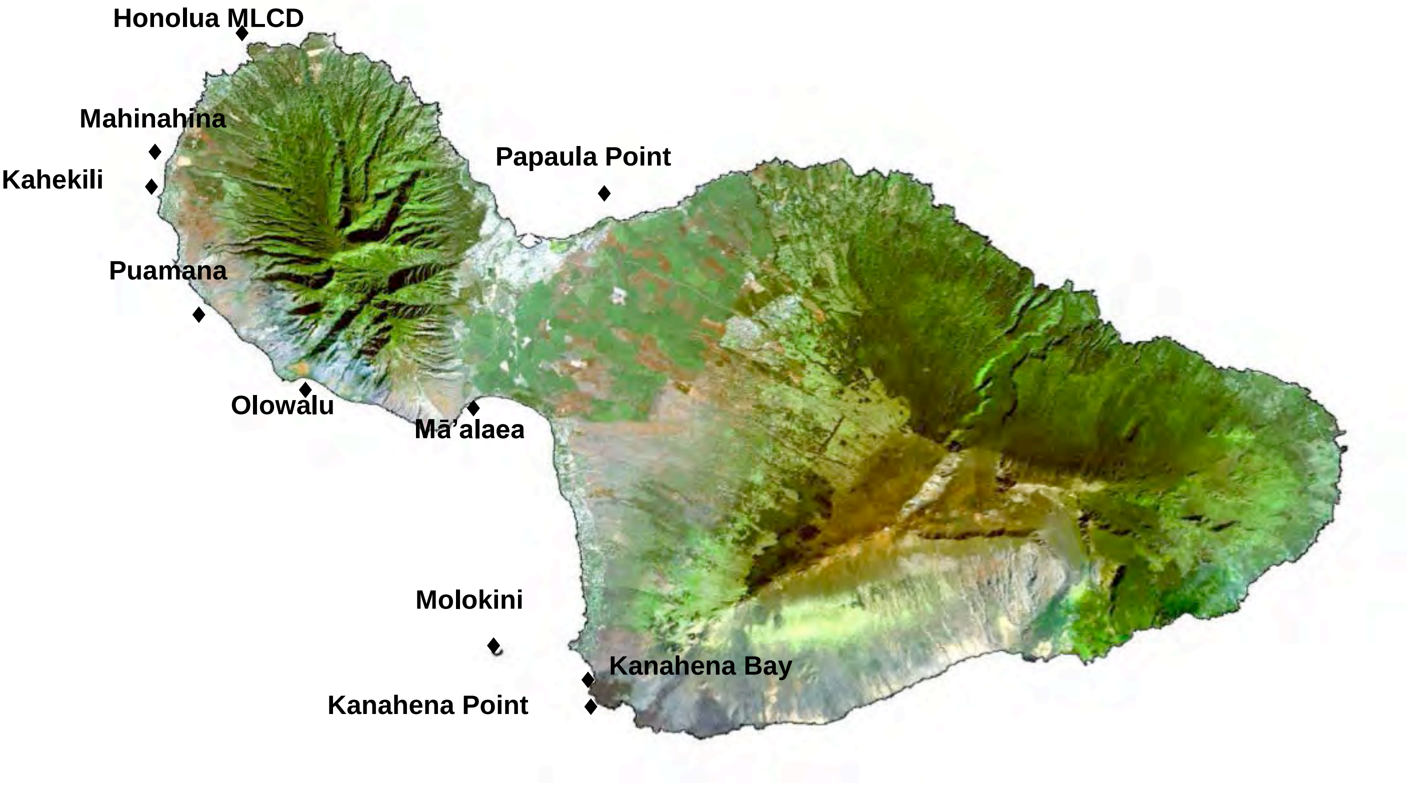


Figure 14. Maui Coral Reef Assessment Monitoring Sites.

Table 3. Maui Coral Reef Assessment Monitoring Sites listed with their corresponding depth, location, and management status.
***Sites with temperature loggers deployed.**

Island	Site Name	Depth (m)	Latitude	Longitude	Status
Maui	Honolua North	3	21.00.923	-156.38.343	MLCD
Maui	Honolua South	3	21.00.831	-156.38.380	MLCD
Maui	Kahekili	3	20.56.257	-156.41.595	OPEN
Maui	Kahekili	7	20.56.274	-156.41.623	OPEN
Maui	Kanahena Bay	1	20.37.049	-156.26.241	NARS
Maui	Kanahena Bay	3	20.37.015	-156.26.301	NARS
Maui	Kanahena Point	3	20.36.089	-156.26.214	NARS
Maui	Kanahena Point*	10	20.36.070	-156.26.280	NARS
Maui	Mā’alaea	3	20.47.378	-156.30.607	OPEN
Maui	Mā’alaea	6	20.47.332	-156.30.596	OPEN
Maui	Mahinahina	3	20.57.436	-156.41.252	OPEN
Maui	Mahinahina	10	20.57.461	-156.41.336	OPEN
Maui	Molokini	8	20.37.889	-156.29.795	MLCD
Maui	Molokini	13	20.37.940	-156.29.783	MLCD
Maui	Olowalu	3	20.48.505	-156.36.693	OPEN
Maui	Olowalu	7	20.48.363	-156.36.733	OPEN
Maui	Papaula Point	4	20.55.307	-156.25.571	OPEN
Maui	Papaula Point*	10	20.55.462	-156.25.571	OPEN
Maui	Puamana	3	20.51.369	-156.40.033	OPEN
Maui	Puamana*	13	20.51.322	-156.40.111	OPEN

Benthic Survey Results

In 1999 and 2000, the years Maui benthic surveys started, coral cover averaged 30.7% ± 5.4 SE for the 18 stations (9 sites) around Maui County. At the same 18 stations with the latest available data (2009 for most sites), coral cover was 25.8% ± 4.0 SE. This slight decline in living coral cover does not appear to be ecologically significant when viewed as a whole, but this approach tends to masks substantial changes that are occurring at the individual site level. Figure 2 shows the temporal changes at the 20 currently monitored reef sites. Nine of these 20 currently monitored reefs have experienced significant changes (paired t-tests of first survey year vs. most recent survey year, $p<0.05$). Coral cover has declined at 7 sites and increased at 2 of these sites. Of particular concern are the coral cover declines at Honolua Bay, Mā’alaea Bay, and Papaula Point where the documented coral declines have been so severe that these individual reefs may have already experienced a total coral reef ecosystem collapse. All three of these locations appear to be effected by anthropogenic impacts (land based pollution, overfishing, etc.). Conversely, sites which have sustained high coral cover tend to be away from urban areas, are fairly remote or are located offshore (Kanahena Bay, Olowalu, and Molokini). The only sites showing significant increases are within Kanahena Bay. The increased coral cover documented in Kanahena Bay is likely the result of natural recovery from past physical disturbances in the mid 1990's. In addition, Kanahena Bay is within the ʻĀhihi Kīnaʻu Natural Area Reserve (NAR), and this area has recently undergone extensive on site management to prevent any extractive practices and to better control the potential impacts from recreational non-consumptive users.

The negative impacts of terrigenous sediments on coral reefs are considered a major contributing factor to reef degradation all over the world (Wilkinson 2004). The coral cover within the reef flats of Honolua Bay have been rapidly declining for several years. This decline appears, at least in part, to be the result of large, periodic, heavy sedimentation events. The most recent evidence occurred in January 2005 when heavy rainfall produced a large sediment plume within the bay. That same year a decline of nearly 50% of the coral cover on the Bay's south reef was documented (Figure 15 &16). The fact that this heavy sedimentation event coincided with relatively calm ocean conditions make it highly likely that the sedimentation was what caused the observed coral decline. Further evidence to this effect was that nearly all of the impacted coral were a shallow water species (Purple Rice Coral, *Montipora flabellata*) that is adapted to live in high wave energy environments and is not known to be very tolerant to sedimentation stress (Figure 16).

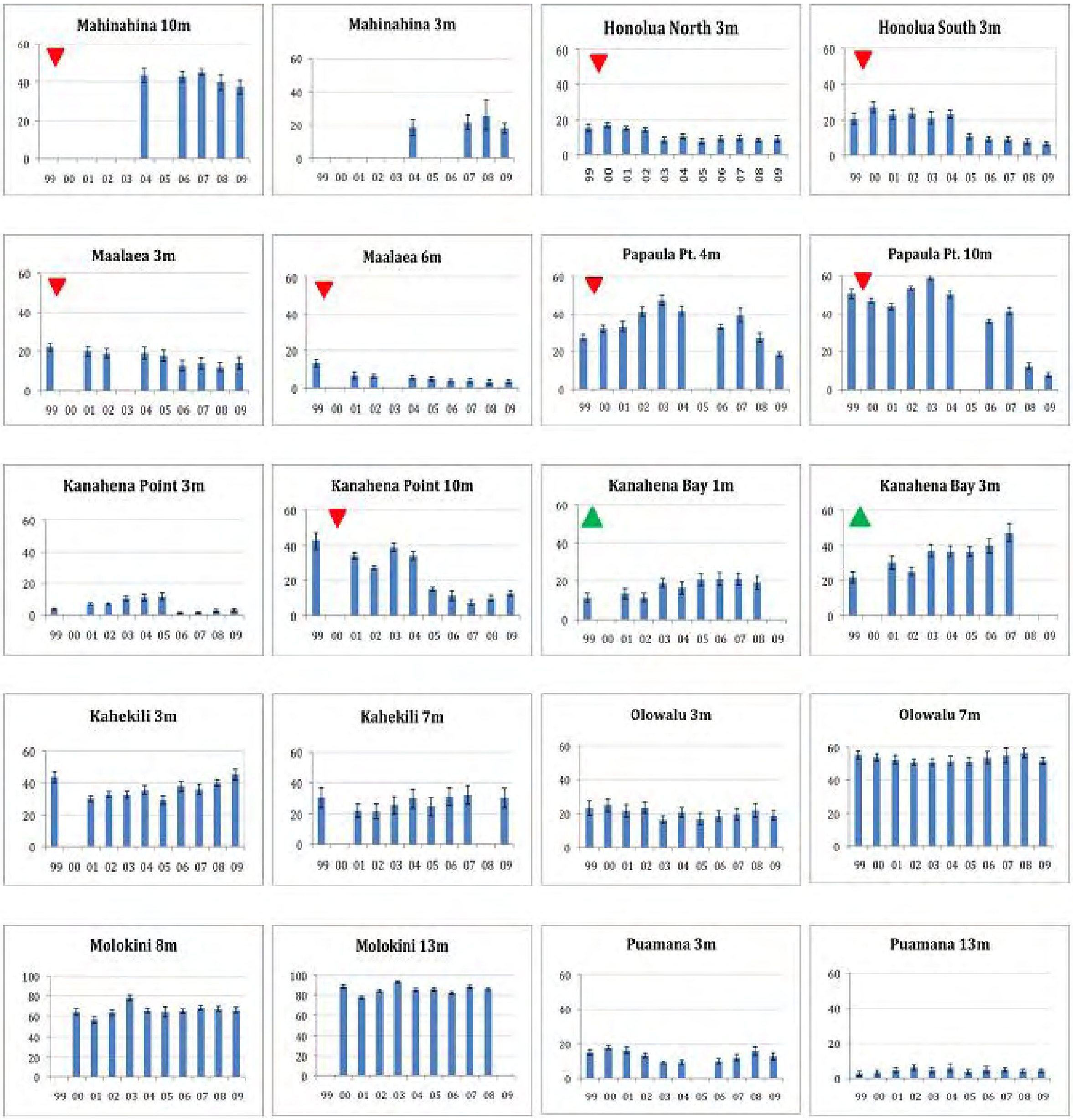


Figure 15. Temporal changes in percent coral cover at the 20 Maui monitoring stations. Significance tests (paired t-tests) compared the first and the last year's coverage. Solid red triangle represents significant decrease (p-value <0.05). Green triangle represents significant increase in coral cover.

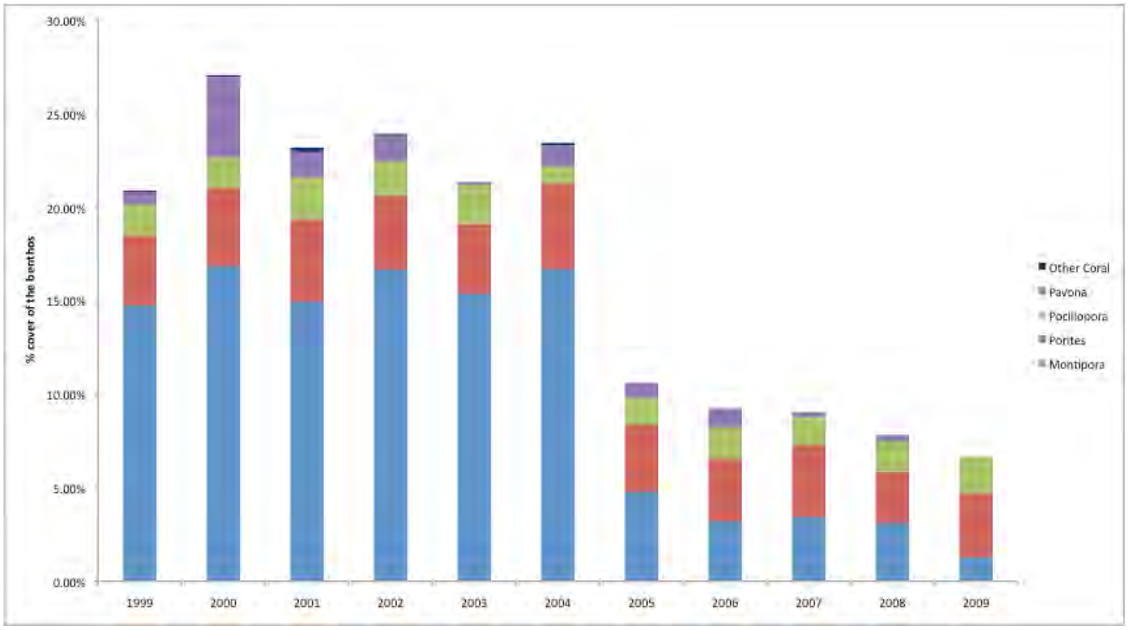


Figure 16. Honolua Bay South Reef percent coral cover plotted by coral genera.

Several of the monitored Maui reefs may be experiencing negative impacts from land-based nutrient pollution. This is of particular concern for reefs with declining coral cover accompanied by increases in macroalgae cover. Ma‘alae‘a Bay and Papa‘ula Point have experienced the most severe declines (Figures 15 & 17).

In 1972, the coral reefs within Ma‘alae‘a Bay were described as being “striking in their diversity and in the presence of rare corals species” (Kinzie, 1972). Similarly, a U.S. Fish and Wildlife environmental assessment in 1993 estimated coral cover in the vicinity of DAR’s survey sites to be between 50% and 75% (FWS 1994). These scientific assessments describe a once healthy and diverse reef ecosystem. The Mā’alaea reef is now extremely degraded and heavily overgrown by algae.

At Papaula Pt., coral cover on the 10m site has declined from around 60% in 2002 to less than 8% in 2009. Much of this decline has occurred in the last two years. Over this same time period a dramatic increases in macroalgae, particularly *Acanthophora spicifera* has occurred (Figure 17).

As a result of these rapid reef ecosystem collapses, fish stocks are suffering the double whammy of overfishing and lack of suitable habitat and are in very poor condition. These sites are now being dominated by small wrasses, triggerfish and puffers, with very few herbivorous species available to help control the explosive algal growth. Some combination of elevated nutrient levels and low herbivory are likely driving the observed increases in macroalgal cover, elevated nutrients have been implicated at other areas around Maui for *Hypnea* and *Ulva* blooms (Smith and Smith, 2006). However, in the case of *Acanthophora spicifera*, which is a highly preferred food for grazing fishes (Hunter, 1999), low grazing pressure might be a more fundamental causal factor. There appears to be a relationship between highly-depleted herbivore stocks (e.g. Mā’alaea) and abundant *Acanthophora*, and conversely, no or very limited *Acanthophora* growth at sites where grazing fishes are abundant (e.g. Honolua Bay). This evidence has led to the recent management action at North Kāʹanapali (see Kahekili Herbivore FMA Baseline Assessment).

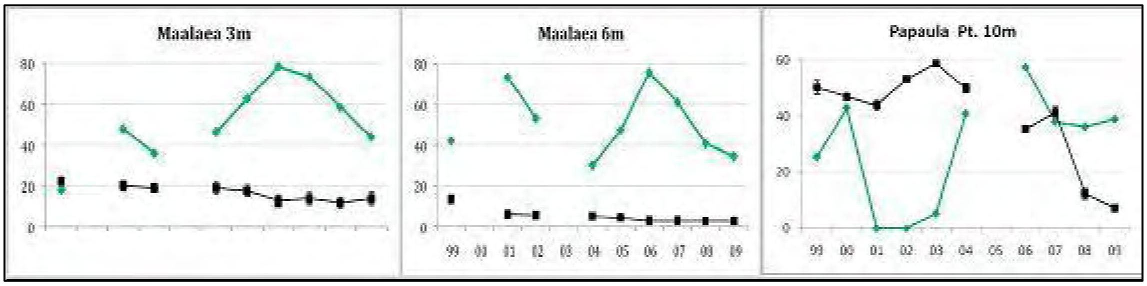


Figure 17. Long-term temporal changes in percent coral (black line) and macroalgae (green line) at both of the Ma‘alae‘a sites and at the offshore Papa‘ula Point site.

Finally, the dramatic decrease in live coral cover at one site (Kanahena Pt. 10m in 2005, and Kanahena Pt. 3m in 2006, Figure 15 &18) was attributable to a localized bloom of the crown of thorns starfish (COTS). Increased COTS densities were initially observed in areas just southeast of Kanahena Point in 2004, and at the time of one of our surveys in 2005, COTS density was roughly one starfish per 10 m^2 of reef at Kanahena Pt. Before the COTS outbreak, coral cover on the deep site was at 34% in 2004 and 12% on the shallow site in 2005. After the outbreak, the coral cover dropped to as low as 7% at the deep site in 2007 and 2% at the shallow site in 2006. The most affected coral genera was *Montipora*, whereas other genera, particularly *Porites*, appeared to be much less affected (Figure 18). Fortunately these reefs appear to be recovering. A comparison of the coral cover on the deep site from 2007 to 2009 showed a significant increase (paired t-test p<0.01). On the shallow site, comparisons between 2006 and 2009 show a similar recovery (paired t-test P<0.06). Although the COTS outbreak resulted in a rapid decline in coral cover the long-term effects of this event on the coral community and potential recovery will be monitored.

It is too early to determine if this localized coral predation event will result in changes in coral diversity, but it appears a trend from Montiporid towards more Poritid corals may have resulted. Overall increase in coral diversity within a reef system could help make the reef more resistant to future stressors and improve overall resilience (Carpenter 1997; Birkeland and Lucas 1990).

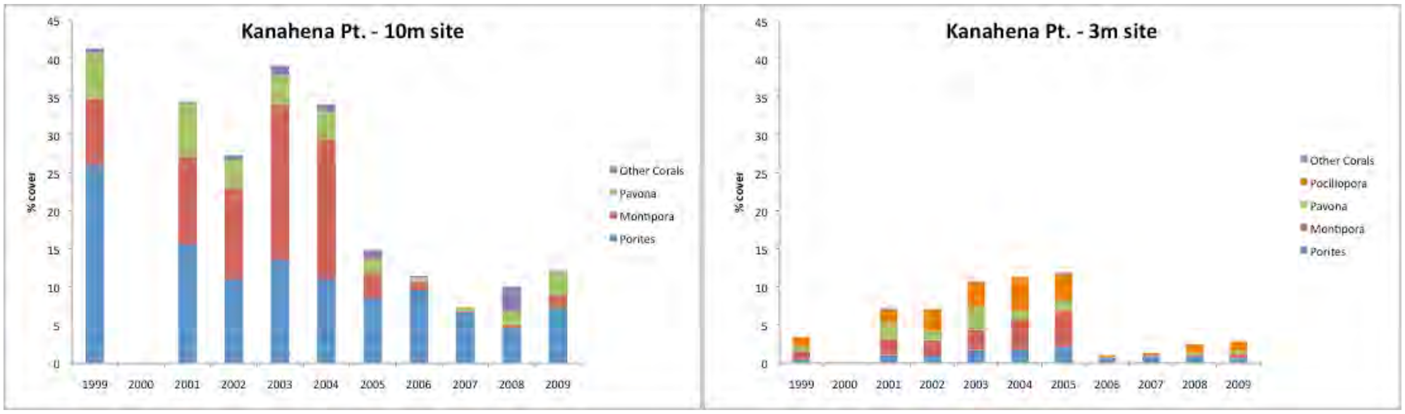


Figure 18. Coral percent cover for Kanahena Point 10 & 3m monitoring sites. Different color bars represent different coral genera.

Fish Survey Methods

Three types of fish surveys are conducted on Maui: (1) resource fish surveys, (2) “integrated” fish population and urchin surveys, and (3) nearshore habitat and fish assessments (HAFA).

Resource Fish Surveys

The resource fish surveys are conducted three times per year at eight sites (Figure 19). Four sites are within a reserve, where fishing is prohibited or severely restricted and four are within a ‘control’ area where fishing is permitted. Sites were selected to be in relative close proximity with relatively similar reef structure. The area pairs are:

Three marine reserves on Maui:

- ‘Āhihi Kīna‘u Natural Area Reserve (NAR), control at La Perouse Bay
- Molokini MLCD, controls at Makena and Keawakapu
- Honolua-Mokule`ia MLCD and control sites between Kapalua Bay and Lipoa Point

One marine reserve on Lāna’i

Manele-Hulopo’e MLCD and control area Lighthouse on southwest coast of Lāna’i.

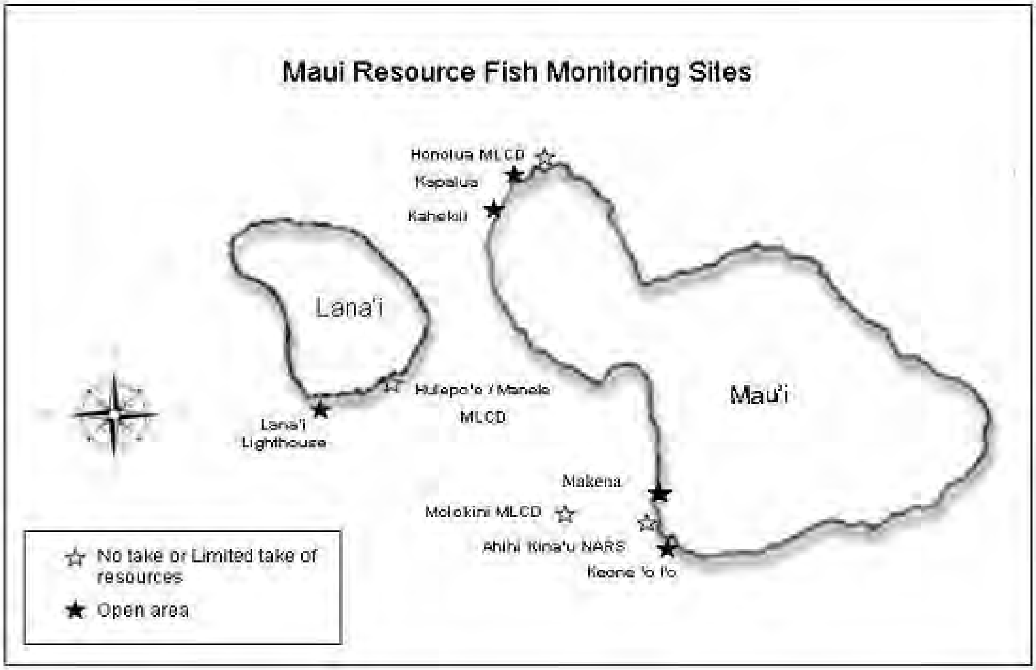


Figure 19. Maui resource fish survey areas.

All of the Maui closed areas are fully protected no-take reserves. Manele-Hulopo'e MLCD on Lāna'i permits pole and line fishing from shore. The Maui County survey areas were selected to allow pairwise comparisons between protected areas and controls, but it should be noted that differences in habitat and exposure exist between reserve and control areas, particularly between the Molokini MLCD and its control area. Therefore, although we attempt to draw conclusions about performance of individual reserves, we also look for broad patterns across all areas within each management strata (i.e. protected vs. open).

Five sub sites are surveyed per survey location (3 at 3-5m depth and 2 at 10m depth) using the 'resource fish' survey method. For this method, 2 pairs of divers start at a fixed center point and head in opposite directions. Each pair of divers swim parallel to each other, 10m apart, and follow a depth contour, for a five minute period. Each diver records all main fishery target species that ≥ 15cm and within a 5m wide belt. Dives are conducted using SCUBA. Abundance and biomass are then standardized for the area covered on each timed swim.

Starting points for each survey are based on the site coordinates for the center point. End points are determined by taking a GPS point from a Garmin handheld GPS that is attached to the dive float.

<u>'Integrated' Fish Surveys</u>

An 'integrated' fish survey, wherein all fish species and select invertebrates are assessed, was also conducted at each of the eight locations. Integrated survey sites used the same H transect design (Figure 2) as utilized on Hawai'i Island and O'ahu. This design is generally consistent with the fish survey methods in West Hawai'i and

O’ahu with several small differences. On Maui when the transects are being deployed fish >15cm TL are counted as the lines are rolled out. Additionally after completion of the fixed transect surveys, the dive pair swims back towards the end pin recording the number of large sea urchins within a 1 m swath on their side of the line. Each diver pair conducts surveys along two 25m lines that start at their central eyebolt. When finished with both lines, each diver then conducts a 5-minute present/absent survey of all fish species that were not seen on transect, but were in the general area of the survey site.

HAFA Surveys

The nearshore habitat and fish assessment or HAFA surveys are designed to record both the abundance and size of targeted fish species to establish the status and trends of specific reef fishes that were commonly taken by lay-gillnets prior to the lay-gillnet ban that went into effect in March of 2007 (HAR 13-75-12.4). Since several of the fish species potentially affected by gillnet fishing are herbivores, the surveys also assess relative sea urchin abundance, and benthic cover [e.g., coral, crustose coralline algae, macroalgae, sand, and substrate (rock, rubble, turf algae, etc.)].

HAFA Surveys are conducted three times per year at seven shallow water reef areas where lay-gillnets were previously used (Figure 20). Each survey location has eight sub-sites.

A HAFA survey is comprised of two parts: (1) an outward swim while counting fish followed by (2) an inward swim designed to qualitatively assess urchins and the benthic composition. Swimmers start their swim at a fixed GPS point. A five minute rapid assessment swim on a designated bearing is utilized with one pair of observers (snorkeling) at a depth contour of 2-4m. Within a 5m wide belt, each observer records all herbivorous fishes ≥ 10cm as well as, all other resource fish (wrasse, goatfishes, snappers, etc.) ≥ 15cm. The benthic assessments are conducted at each one-minute swim interval while returning to the starting location, and the end of the fish survey. The benthic assessment is conducted by looking at an estimated 5m-radius circle of benthos centered at the surveyor. When the five-minute fish survey is complete, the GPS location is marked and the surveyors begin the urchin and benthic composition assessments. This results in a total of six benthic assessments per transect. Upon completion of the return swim, the surveyors rank the urchin and general algae abundance using a DACOR scale (Dominant, Abundant, Common, Occasional, or Rare). In addition, the dominant algal species are identified and recorded.

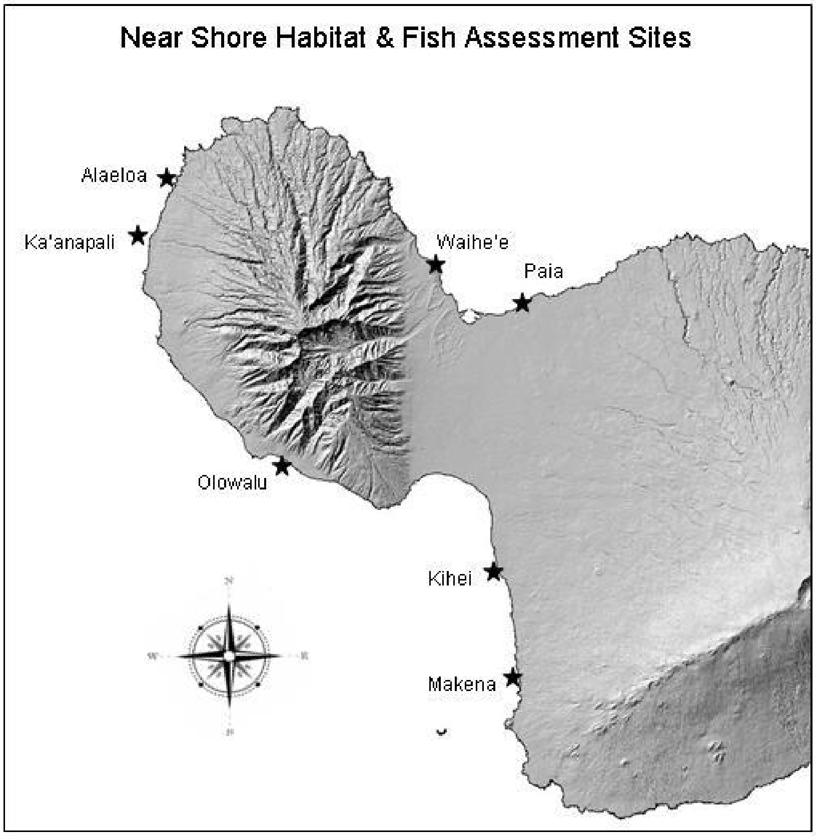


Figure 20. Maui HAFA survey sites.

Data Analysis

For all fish surveys the total length (TL) was estimated to the nearest centimeter. Length estimates of fishes from visual censuses were converted to weight using the following length-weight conversion: W = aSLb. The parameters a and b are constants for the allometric growth equation where SL is standard length in mm and W is weight in grams. Total length was converted to standard length (SL) by multiplying standard length to total length-fitting parameters obtained from FishBase (http://www.fishbase.org) and unpublished data on 150 species commonly observed on visual fish transects in Hawaiʻi (Hawaiʻi Cooperative Fishery Research Unit). In the cases where length-weight information did not exist for a given species, the parameters from similar bodied congeners were used. All biomass estimates were converted to grams per square meter (g m^{-2}) to facilitate comparisons with other studies in Hawai`i.

Fish Survey Results

<u>Resource Fish and Integrated Surveys</u>

Fish survey results indicate a positive effect of closure to fishing. Compared to their controls, the three fully closed reserves (Honolua-Mokule`ia MLCD, ʻĀhihi Kīnaʻu NAR, and Molokini MLCD) had:

- Higher total food fish biomass (all ‘food fishes’ combined) (Figure 9). However, differences were only significant in two cases: between Molokini MLCD and its Makena control, and between Honolua Bay MLCD and its Kapalua control ($p<0.05$ paired t-tests of total biomass per survey round);
- A greater prevalence of apex predators (carangids and lethrinids) (Figure 21);
- Greater abundance and larger size target fishes (Figures 21 & 22); and
- Large schools of manini (the surgeonfish *Acanthurus triostegus*). Large manini schools were also observed at sites where fishing pressure was presumed to be low due to relative inaccessibility and low human population density (i.e. Lānaʼi Lighthouse, Figure 24).

As previously noted, important differences in habitat and exposure exist between reserve and control areas, particularly between Molokini MLCD and its control. It is also noteworthy that the highest fish biomass at any surveyed area was at the Lānaʼi Lighthouse control (a fished, but fairly remote location). It would therefore be overly simplistic to ascribe all differences among areas simply to management status (open or closed).

These observed size distribution trends were further investigated by independently looking at four relatively commonly-encountered and heavily-targeted fish species [*Caranx melampygus* (Bluefin Trevally), *Naso unicornis* (Bluespine Unicornfish), *Monotaxis grandoculis* (Bigeye Emperor), and *Scarus rubroviolaceus* (Redlip Parrotfish)]. For all four species, reserves contained more and larger fishes than open areas (Figure 22). The biological implication of these results is important because large individuals are an important component of most targeted species' breeding stock. They produce disproportionally more gametes than smaller fish, and those gametes tend to be more able to survive to become recruits (Birkeland & Dayton, 2005). Marine reserves make up less than 2% of nearshore waters in Maui County; therefore, their potential for substantially increasing spawning stocks is limited. Our results nevertheless indicate that these few marine reserves likely contribute disproportionately to total population spawning potential in Maui County.

The high fish biomass at the Lānaʼi sites and the lack of a clear distinction between the partially closed (Manele-Hulopo`e MLCD) and the open area (Lighthouse) deserve further comment. Lānaʼi has a small resident population, and as a result, sites are likely to have lower fishing pressure compared to most reefs on Maui. The Manele-Hulopoʼe MLCD is the only Maui county reserve area that is not a complete no-take reserve. Fishing with pole and line from shore is permitted.

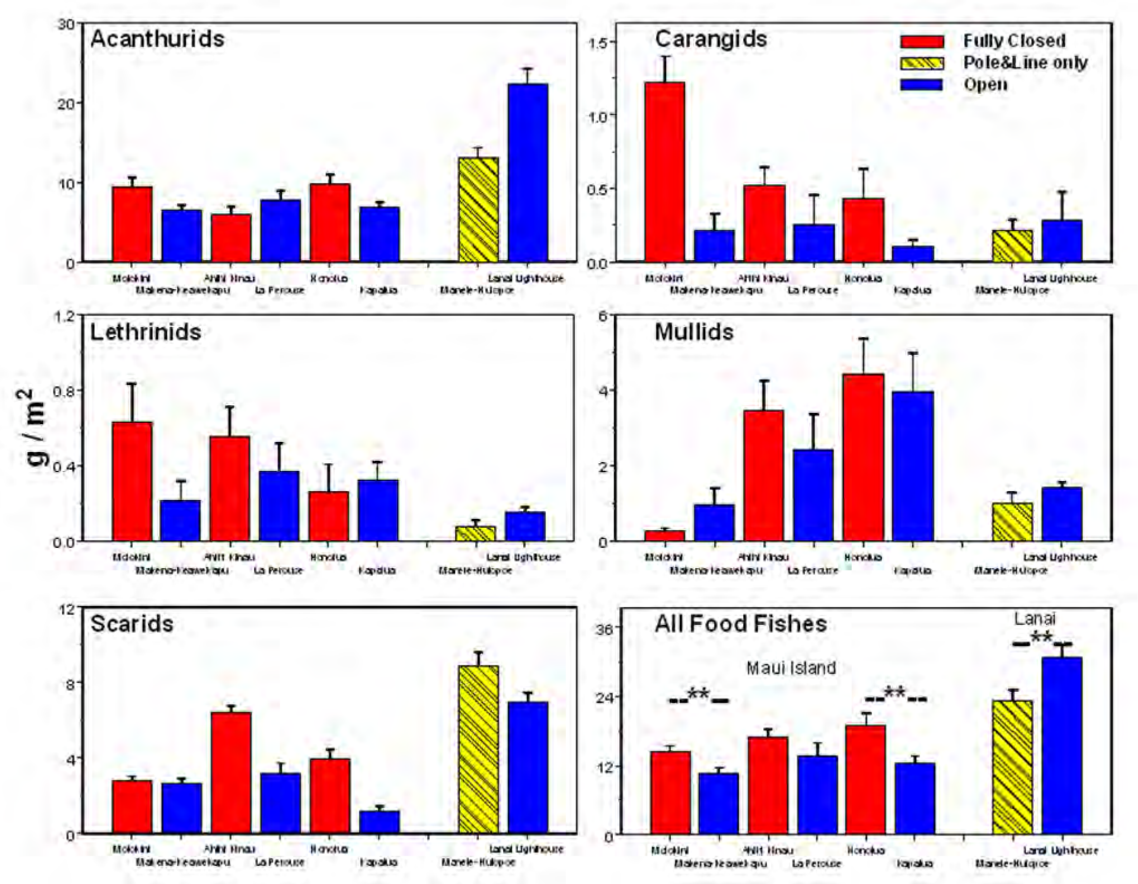


Figure 21. Mean and SE of biomass of 'resource fishes' at Maui County sites. Data are averages of all surveys in 2005-2009. Significant pair-wise differences indicated by ** ($p<0.05$).

The MLCD also has the most accessible section of coastline on the island, with a paved road leading down to the ocean and a public park with showers and bathroom facilities. Due to this easy access, it is likely that even though there is no spear fishing, netting, or vessel-based fishing allowed within the reserve, it still gets the majority of near-shore fishing activity in that vicinity. In contrast, the Lighthouse control area is located along the southwest coast of Lāna'i, where the shoreline is only accessible via a rough off-road jeep trail. Fish behavior and shore-based structures indicate that the Lighthouse area does get fished, but it seems likely that fishing pressure is relatively low. It is therefore reasonable to assume there is no clear distinction in absolute fishing pressure between the Lāna'i reserve and open area.

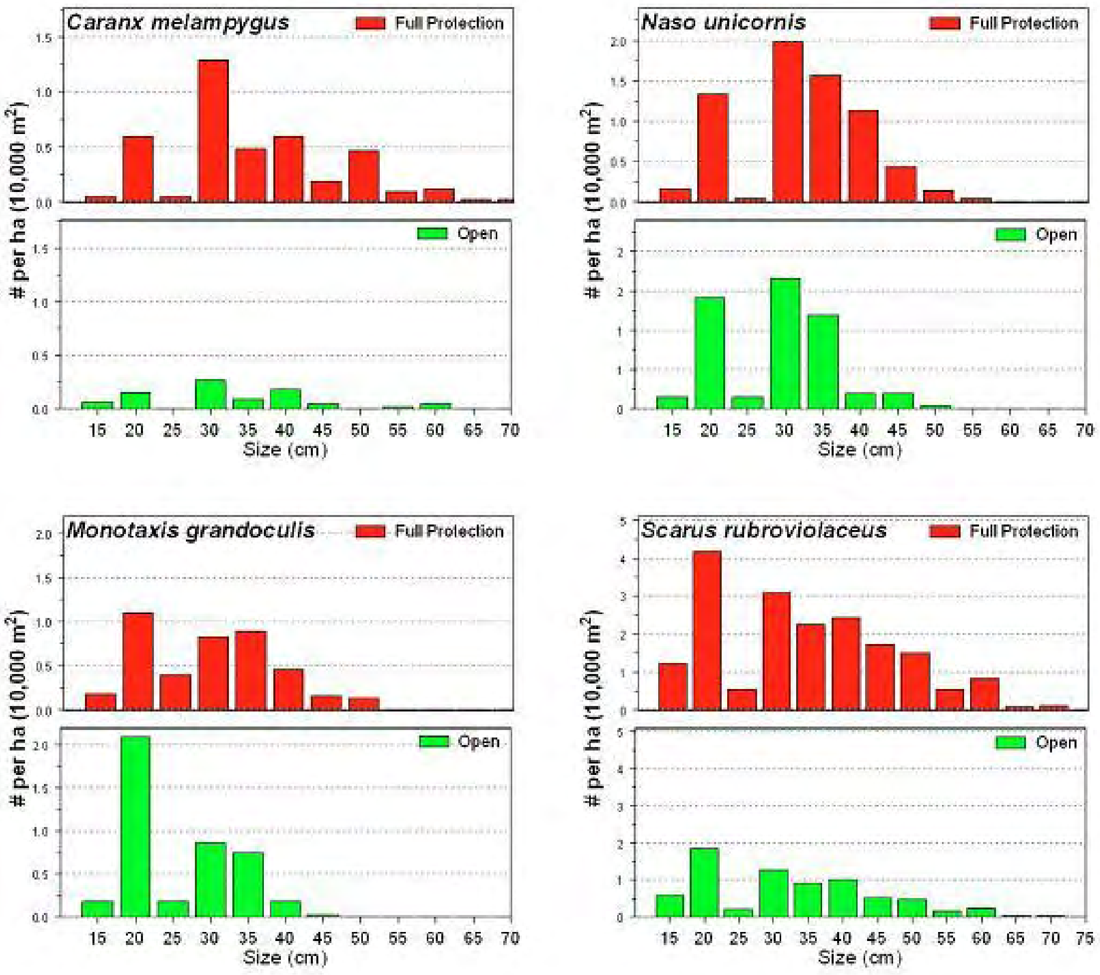


Figure 22. Number and sizes of key target fishes in protected and open areas on Maui. Data pooled into all protected monitoring stations (red) and all open sites (green).

Maui County fish surveys indicate that herbivore fish stocks are likely depleted at several of the survey locations. Several areas (Figure 21) had low acanthurid and scarid biomass. Large schools of manini (*Acanthurus triostegus*), a key shallow-water grazer, occurred only in reserves or in the relatively remote areas on Lāna'i (Figure 23). Both Lāna'i areas had large populations of manini, but the only survey sites on Maui Island with abundances greater than 125 manini/ha., were within the Honolua MLCD. In contrast, all of the Maui open access sites had manini densities < 5/ha. This observed distribution of large manini schools strongly suggests that fishing pressure is having an impact on this species.

Our growing concern about the spread of invasive algae on Maui, and the evidence that herbivore stocks are generally depleted on several Maui reefs suggest that additional management actions to protect or restore herbivore populations may be productive. Significantly, even a partially protected reserve such as Manele-Hulopo`e MLCD can maintain large populations of herbivorous fishes (Figure 23), which suggests that partially-protected reserves, where only herbivores are protected, may have some utility while being more acceptable to fishers than fully protected areas.

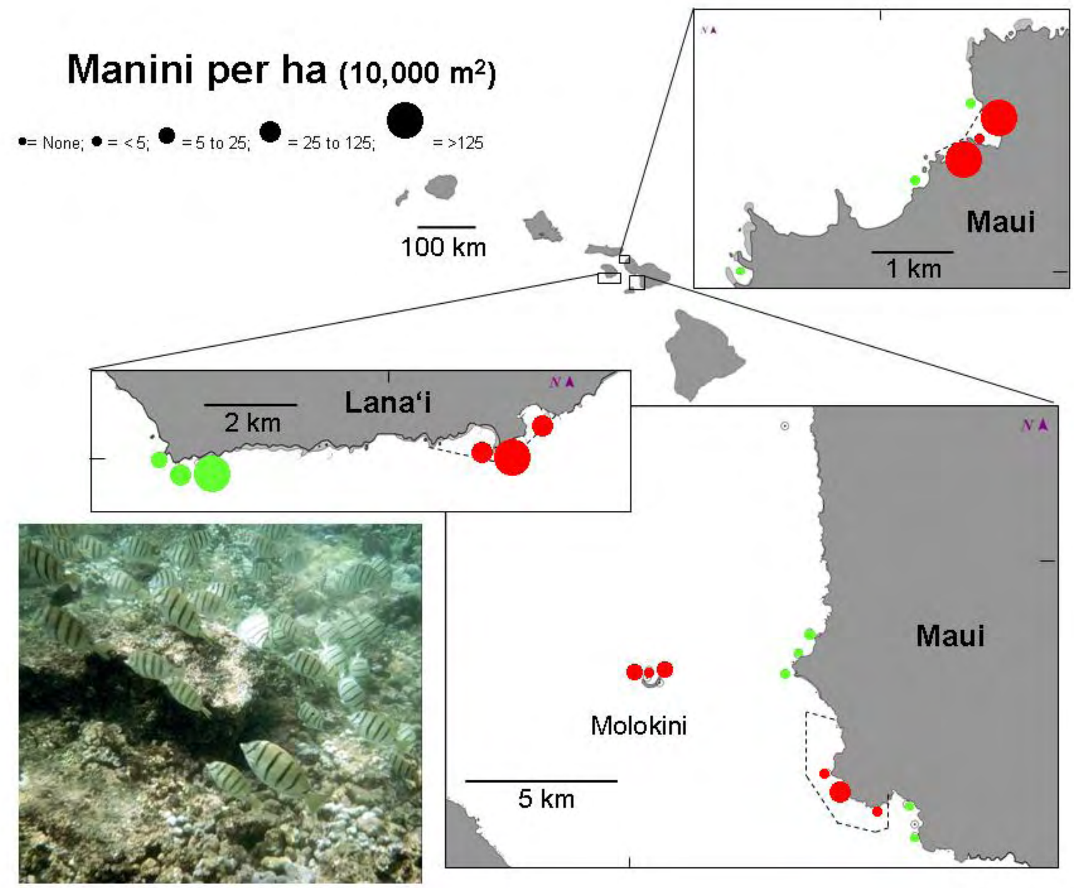


Figure 23. Manini abundance at Maui DAR monitoring stations. Density represented by size of circles. Red circles are areas where net fishing is prohibited, green circles are from open sites (no restrictions on net fishing).

HAFA Surveys

In March of 2007, new lay gill-net regulations went into effect (HAR 13-75-12.4). These new rules banned the use of lay gillnets in Maui waters. Previous to this law, there was concern that laynet fishing was indiscriminately catching and killing large numbers of nearshore reef fish. Many of these fish were herbivores, which provide important ecosystem services for maintaining healthy coral reefs. The new HAFA surveys were implemented in early 2007 in an effort to develop baseline information on shallow water reefs that tended to be heavily fished by laynets. These surveys looked at fish biomass levels, as well as, basic qualitative habitat characteristics. The seven sites on Maui were all rated by the intensity of past laynet fishing based on the observations by Maui resource managers. These ratings resulted in the following list of sites in order from highest laynet fishing intensity to lowest; Waiheʻe, Pāʼia, Aealoa, Kihei, Makena, Kāʼanapali, and Olowalu. Although not enough time has passed to look at trends in fish biomass, we can characterize the baseline fish and habitat on the surveyed sites in relation to the intensity of past laynet fishing. These results are displayed in Figures 24 and 25 below.

In general, there appears to be a trend towards higher fish biomass with lower past laynet fishing intensity (Figure 25). The Makena, Kāʼanapali and Olowalu sites all had the highest overall fish biomass with primary and secondary consumer levels higher than the other sites. It appears, that both the Pāʼia and Aealoa sites had high herbivore densities, but much of these fish tended to be brown surgeonfish (*Acanthurus nigrofuscus*). Brown surgeonfish, although important herbivores are not very desirable as food fish and therefore are often avoided by fishers. It was also clear that the four highest laynet fished sites had very low levels of secondary consumers, much of which are targeted by net fishers (i.e. goatfish). Going hand in hand with the fish biomass levels is the overall health of the coral reef habitats at these survey sites. The Makena, Kāʼanapali and Olowalu sites all had low levels of macroalgae and fairly healthy coral reefs (>30% coral cover). The four highest laynet fished sites, however, displayed macroalgae cover near 20% or higher (Figure 25). These results suggest that if the new laynet regulations are effective, we should be able to measure increasing reef fish biomass levels along with increases in overall coral reef ecosystem health.

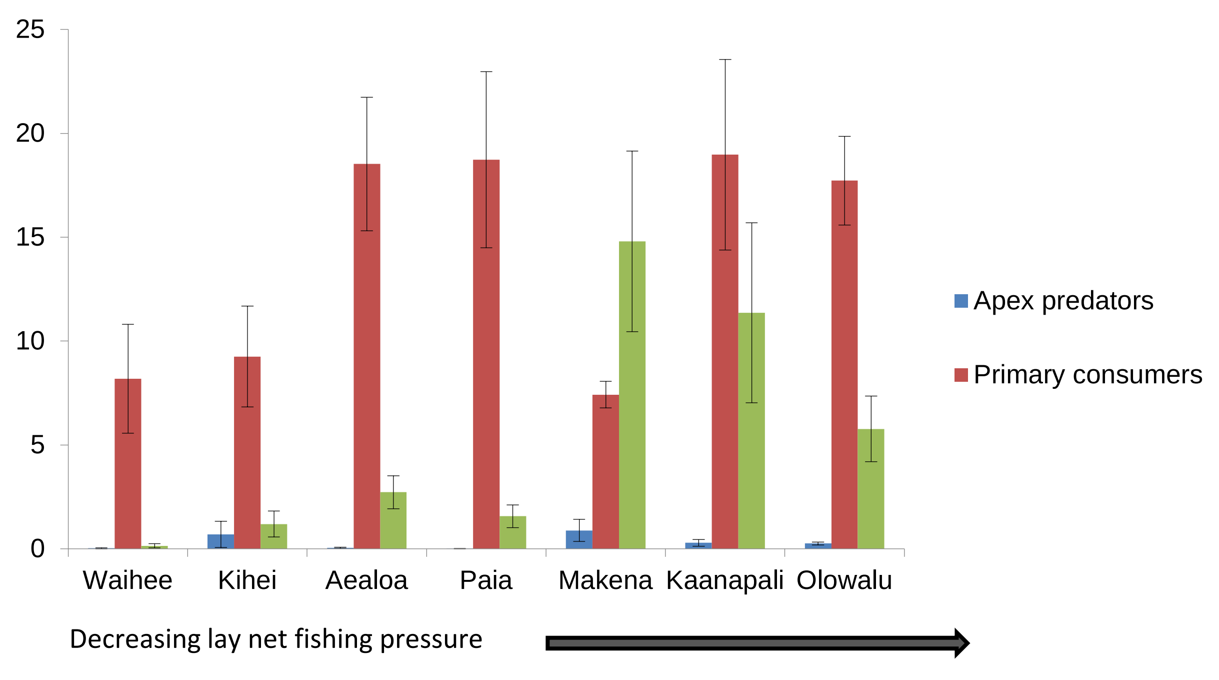


Figure 24. Fish Biomass plotted by trophic guild for 7 shallow water HAFA survey sites. Graphs organized by site in terms of decreasing lay gill-net fishing pressure.

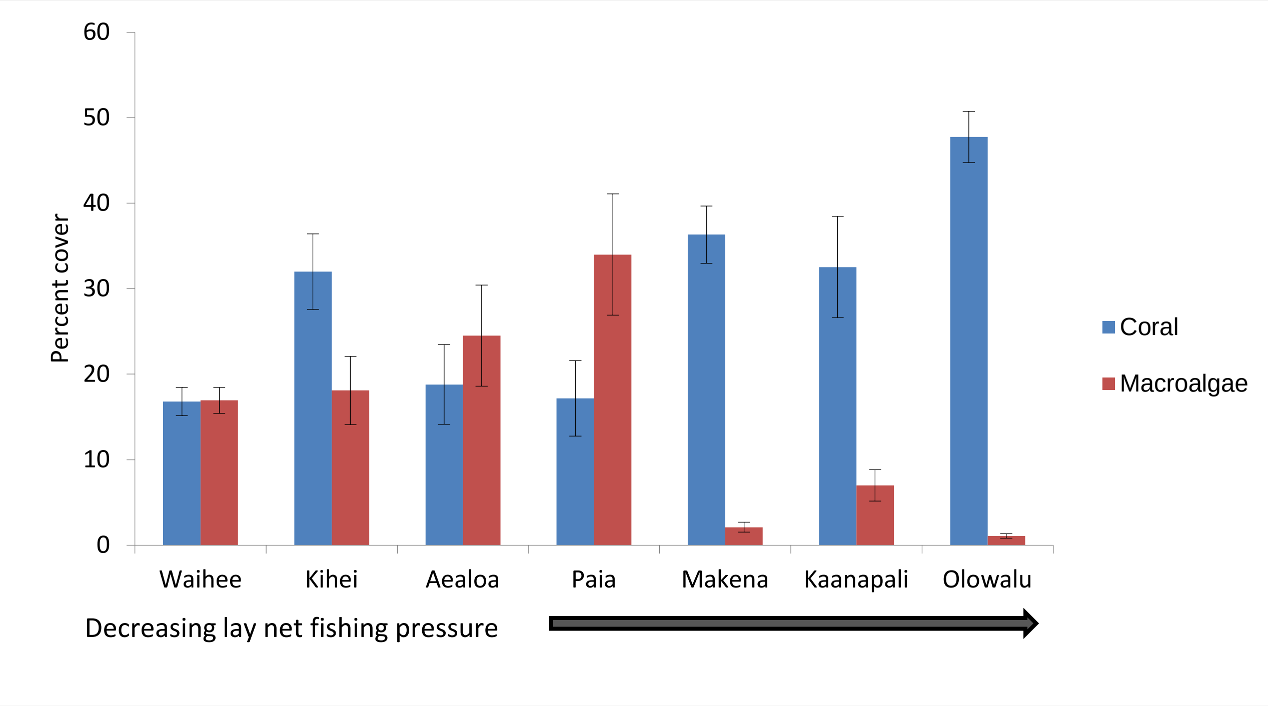


Figure 25. Habitat characteristics plotted by percent cover of coral and macroalgae for the 7 shallow water HAFA survey sites. Graphs organized by site in terms of decreasing lay gill-net fishing pressure.

Kahekili Herbivore FMA Baseline Assessment

In July 2009, the Hawaiʻi Division of Aquatic Resource (DAR) established the Kahekili Herbivore Fisheries Management Area (KHFMA). This new marine managed area encompassing coral reefs offshore of the Kahekili Beach Park in West Maui. The KHFMA was implemented in November 2009, with the installation of State rule signage at beach access points within the region. This reef tract was previously known for high coral cover, but recent degradation has led to significant increases in algal cover at the expense of corals. The goal of the HFMA is to increase the reef's capacity to resist this phase shift from coral to macroalgal domination by prohibiting the take of herbivorous fish and sea-urchins.

The aims of this assessment project were to: (1) design and implement a statistically and scientifically valid baseline of pre-KHFMA establishment conditions on the Kahekili reef; and (2) utilize new and existing data generated by DAR and partners, from survey programs in Maui and elsewhere, to draw broader conclusions about the relationships between local herbivore stocks and benthic algal communities (particularly in terms of reefs' vulnerability to macroalgal overgrowth).

DAR staff along with staff from the UH Botany Department, designed and implemented baseline surveys in 2008 and 2009. Fish and benthic communities were surveyed at a total of 242 sites within the HFMA in January and August of 2008 and September 2009. Starting in 2009, surveys were also conducted at Canoe Beach, a control site to the south of the KHFMA with no changes to fisheries management.

Survey sites were grouped into six broad habitat categories, with baseline benthic and fish community data analyzed for those different habitats.

Purpose

The reef in the KHFMA, while still in relatively good condition, has been intermittently stressed by the seasonal blooms of the invasive alga *Acanthophora spicifera*. The specific goal of the KHFMA is to restrict take of herbivorous fishes and sea-urchins to thereby restore the reef's capacity to prevent invasive algal blooms from occurring. The new management regulations were implemented on the KHFMA in November 2009, with public presentations and signage used to inform ocean users of the changes to management at Kahekili. The baseline assessment effort was designed to generate meaningful data against which eventual effectiveness of the HFMA can be assessed.

While the main spatial focus of this work was on the KHFMA, the problem of coral to algal phase shifts is a concern for many Hawaiʻi reef areas, particularly around heavily populated parts of the state. Therefore, this project was also designed to support wider-scale collaborative projects in the state related to herbivory and macroalgal domination of local reefs.

Methods and Results

Survey methods were established with previous work as reported by Ivor Williams, HCRI FY07, Project Title: KAHEKILI ECOSYSTEM RECOVERY AREA -Science Planning and Support; Grant Number: NA07NOS4000193; Date: May 23, 2008.

Surveys sites were haphazardly located on hard bottom areas within the KHFMA boundaries with the aim of broadly covering the full extent of the area and with adequate replication within different habitat categories (Figure 26).

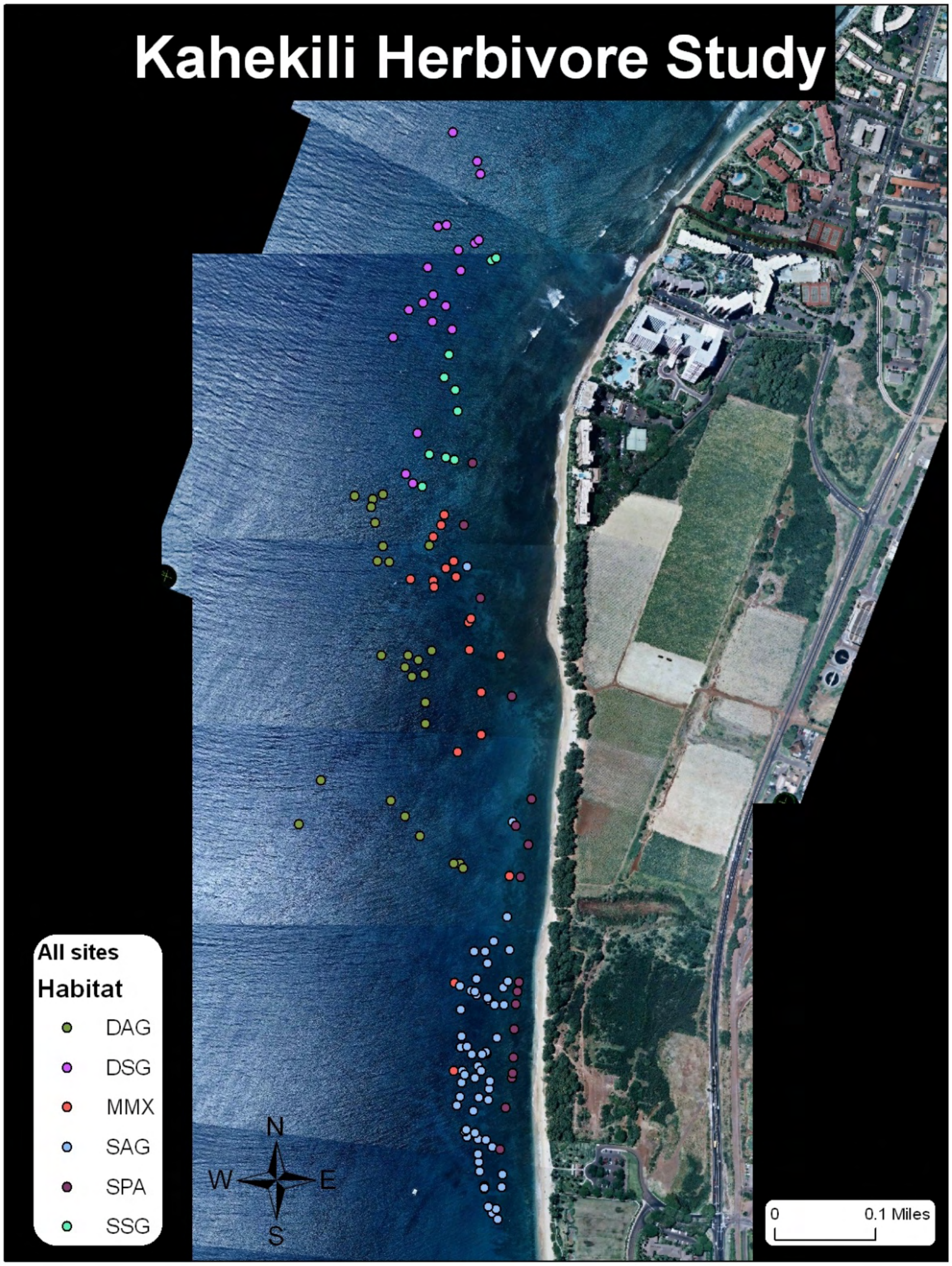


Figure 26. Location of 2008 Kahekili Baseline Surveys. January and August 2008 surveys combined. See Table 2 for a description of the six habitat types.

Reef habitats vary considerably within the KHFMA, and hence survey habitats were grouped into 6 broad classifications (Table 4) corresponding with distinct ecological zones within the KHFMA. These habitats vary considerably in their fish and benthic communities, and therefore may have markedly different responses to the implementation of the KHFMA.

Table 4. Habitat classifications within the Kahekili HMFA.

Habitat	Depth Range (ft.)	Characteristics
Deep Aggregate Reef (DAG)	23 - 50	Some patches and sand, but substrate largely dominated by corals. Consequently, reef has moderate or high complexity.
Shallow Aggregate Reef (SAG)	5 - 23	As above (but shallower-largely corresponding with depth range of fringing reef in front of Kahekili Beach Park)
Mid-Deep Spur and Groove (DSG)	17 – 40	Spur and groove habitat – by around 15ft, physical structure is well established and by deeper portions of this habitat, spurs are up to about 15ft off the bottom
Shallow Spur and Groove (SSG)	10 – 13	Spur and groove (confined to northern edge of proposed HFMA). Shallow spur and groove begin to develop at around 10 ft deep, but do not develop substantial physical relief until 15ft deep or lower. Shallow spur-and-groove areas were also clearly more sedimented than deeper spur-and-groove
Mixed Mid-Depth (MMX)	10 – 25	Mixed medium depth and deeper habitat. Coral cover low and coral distribution patchy, abundant loose sediment and sand patches are common
Shallow Pavement (SPA)	4 – 8	Largely flat, low relief and low coral cover areas dominated by limestone pavement and loose sediment

Surveys were conducted from a small boat with survey teams of two divers. The divers entered the water over hard bottom habitat and swam straight down to the nearest suitable habitat (hard bottom large enough to lay a 25m survey transect in). One diver tied the starting point of the survey transect and the other recorded the transect start location using a GPS in a waterproof bag attached to a surface float. Compass bearings were taken for each transects, and whenever possible were run parallel to the shoreline running approximately northwards. In total, 242 surveys were conducted throughout the KHFMA prior to its implementation in November 2009 (Figure 26).

Survey transects were of 25m length, with one diver conducting fish surveys using methods closely based on those used by NOAA-CRED throughout the state of Hawai'i: species, number and size (in 5cm slots) was recorded for all fishes larger 15 cm total length (TL) within a 4-m wide belt centered on the diver as they laid out the 25 m transect tape. The diver would then return along the transect, recording species, number and size of all fishes smaller than 15 cm TL in a 2m wide belt centered on the transect line.

The other diver followed the fish surveyor, and conducted a photo quadrat survey of the benthos under the transect line, and then recorded all sea-urchins within a 1m-wide belt, during the return swim along the transect line.

As expected, significant differences were found in the composition of the benthic communities in the different habitat types (Figure 27; two-factor ANOVA with survey date and habitat type as factors, Tukey's multiple comparisons for post hoc comparisons of means). Coral cover was significantly different across the habitats ($F_{5,\,137} = 35.38$, $p < .001$), with cover in MMX and SPA significantly lower than the other habitats. Turf algae coverage also varied significantly with habitat type ($F_{5,\,137} = 29.68$, $p < .001$), with SPA having significantly more turf algae than any other site, and MMX having significantly more turf than any of the remaining sites with the exception of DSG.

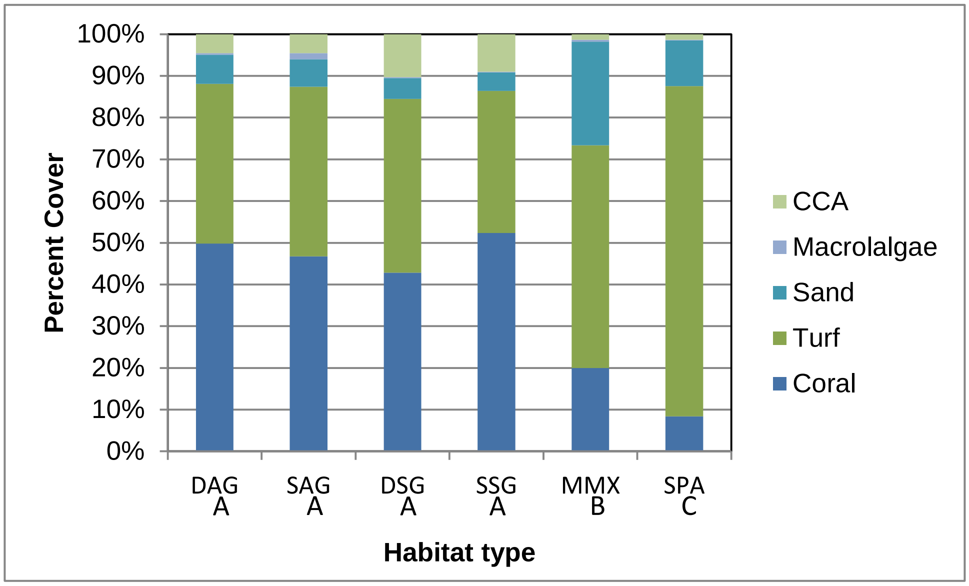


Figure 27. Benthic community composition (percent cover) by habitat type within the HFMA. Habitats with different letter designations have significant differences in coral cover.

Fish communities also showed marked variation in size and composition. (Figure 28) Total fish biomass was significantly different across the habitats ($F_{5,\,240} = 3.97$, $p = .002$), with biomass in SAG and SPA significantly higher than in MMX (though SSG had the highest biomass, there was large variability in surveys from that habitat).. Total herbivore biomass also varied significantly with habitat type ($F_{5,\,240} = 7.24$, $p < .001$), with SSG, SAG, SPA and DSG having the highest herbivore biomass numbers, and MMX significantly lower biomass (Figure 17).

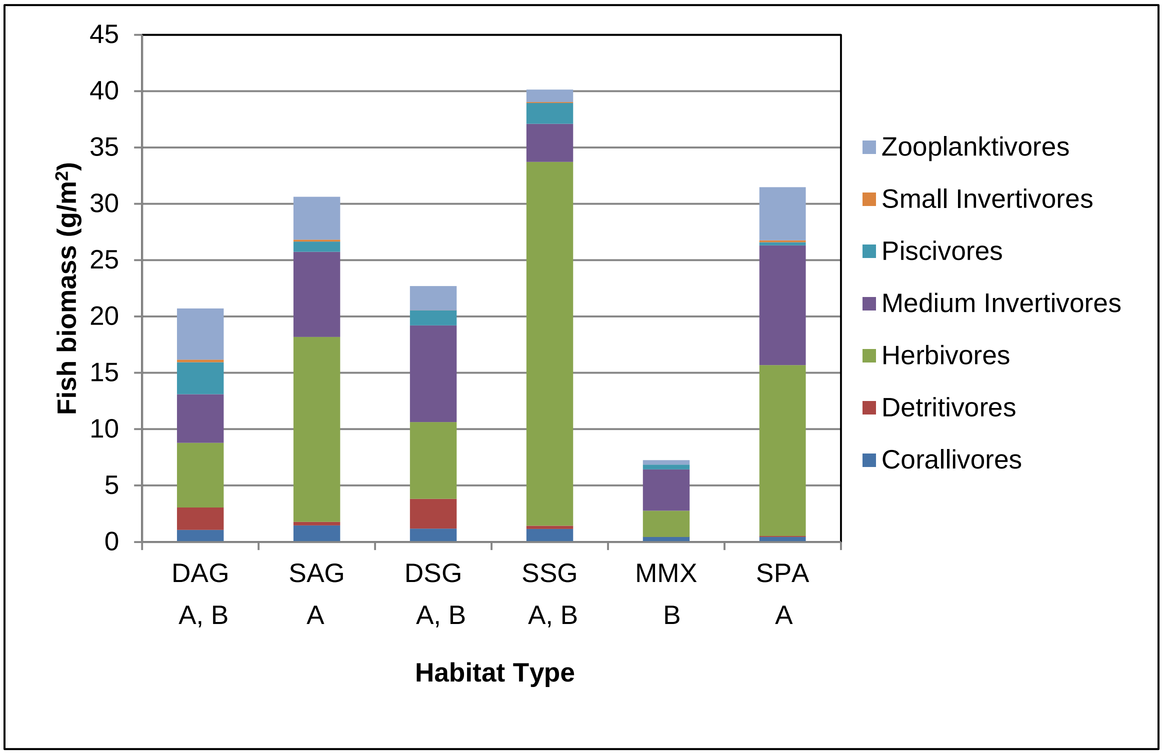


Figure 28. Fish biomass in grams per m^2 by habitat type and trophic group.

With 242 sites surveyed over three different dates, a firm baseline has been established to assess the effectiveness of the KHMFA both at protecting herbivores, and at affecting change to the structure of the benthic communities. Subsequent survey rounds (the next is planned for September 2010) will evaluate the success of this novel management strategy.

Citizen Science - Kahekili Herbivore Enhancement Area (HEA) Surveys

Citizen scientist surveys are an integral part of the overall assessment of the new KHFMA, and, just as importantly, have engaged the community stakeholders to learn, participate, and share their knowledge with others in the community. The community volunteers take part in data collection surveys, education, outreach, and frequently participate in helping develop public policy (e.g. public testimonies to EPA, County Council, and the Mayor's Wastewater Community Working Group, Makai Watch, etc.). Four different reef fish survey protocols were developed to enhance our knowledge base of the critical grazing fishes, and multiple community training workshops have been held that included a background of the science behind the establishment of the KHFMA, as well as protocols and goals of the surveys.

Over the course of 2008, eight training workshops for the KHFMA herbivore fish snorkel surveys were held, three public talks on the importance of herbivores on the reef were given, and 57 field survey days were coordinated. In 2009, there were four training workshops, four public talks, four educational institution talks, eight field trainings, and 54 field survey days. More than 100 community members have participated, contributing over 2,400 hours of volunteer effort. Volunteer training workshops were advertised in local papers, facilitated by the local non-profit Project S.E.A.- Link, and held at the Lahaina Civic Center, the NOAA Humpback Whale Sanctuary in Kihei, the Jean-Michel Cousteau Ambassadors of the Environment Center, and Maui Community College.

Herbivore grazing pressure surveys were the first protocol implemented. These surveys were conducted to assess the contributions of individual species of grazers to overall levels of herbivory within the KHMFA and track how these levels change over time in response to the implementation of the KHMFA. The herbivore grazing pressure surveys were conducted by volunteers from the local community, as well as DAR staff.

Three additional survey protocols were introduced in March of 2009 to compliment the herbivore grazing pressure data and to attract new volunteers who may have found the herbivore grazing survey too challenging. The first was the behavior survey, where volunteers record the first behavior observed for each individual fish of a given species in a specific habitat. This survey was well received by volunteers and has become the most ‘popular’ of the four reef fish survey protocols.

A second timed grazing survey was designed as a quantitative measure of the total time an individual fish spent grazing. For this survey the same fish was followed for 5-10 minutes and the amount of time the fish engaged in actual grazing activity was recorded. This survey provided a higher resolution of grazing activity by species and size class. Lastly, a protocol was developed specifically to better characterize the composition and sizes of fishes in larger schools (> 50 individuals). The effects of these schools on the reef were not well-captured with the existing protocols, and this method should allow DAR to assess changes over time for these important grazers. Both of these surveys have proven too challenging for the majority of volunteers and will be taken over by DAR staff.

Volunteer Herbivore Grazing Survey and Results

In these surveys, individual fish of the various species of acanthurids (surgeonfish), scarids (parrotfish), and kyphosids (rudderfish) were observed, with the grazing rate (number of bites during a one minute observation period) by species, size class, behavior, and habitat recorded. All surveys from February 2008 through February 2009 were conducted from 9am until 11am, mainly for simplicity of scheduling volunteer observers. In order to explore grazing rates and behavior at different times of day, surveys from March through July 2009 were scheduled from noon until 2pm, and August data was collected between 2pm and 5pm. Thereafter, surveys were divided into three time slots, morning, mid-day, and afternoon, and selected randomly. Observations were made from within the HFMA and also from a number of appropriate control sites around the island. These areas included: Honolua Bay, Kapalua Bay, Olowalu, ‘Āhihi Kīna‘u Natural Area Reserve (NAR), and Maluaka. Data were only collected on individual fishes that exhibited natural (i.e. undisturbed) behavior and only in optimal water visibility conditions.

Data were collected from 14 species of acanthurids (n = 3127 observations) and seven species of scarids (n = 1083 observations). *Chlorurus perspicillatus* and *Calotomus zonarchus* are uncommon and the sample sizes were small, so these data were excluded from the analysis. Similarly, only three kyphosids were observed during the observation time periods so data from those individuals was also removed from the analysis. Most fishes were observed while grazing, though all behaviors were recorded. It was common for the fish to have multiple behaviors over the observation time period leading to the development of new protocols to focus on the percent of time fishes spend grazing (see herbivore behavior survey results).

General grazing trends for both acanthurids and scarids were similar. A significant negative correlation (Pearson's, -0.276; p-value < 0.001) for grazing rate (bites per minute) versus fish size (total length) was observed, which is intuitive because smaller fishes require continuous energy for growth. Conversely, bite sizes increased with fish size.

Calculations based on bite size and grazing behavior of *Chlorurus* and *Scarus* species from Ong (2008) indicate the area of algae scraped by scarids over a year has a significant positive linear relationship to size (Pearson's, 0.925; p-value < 0.001), as illustrated in Figure 29. While *Scarus psittacus* was the smallest of the three species, they also had a significantly greater bite rate than the other parrotfish species (Figure 29 & Table 5).

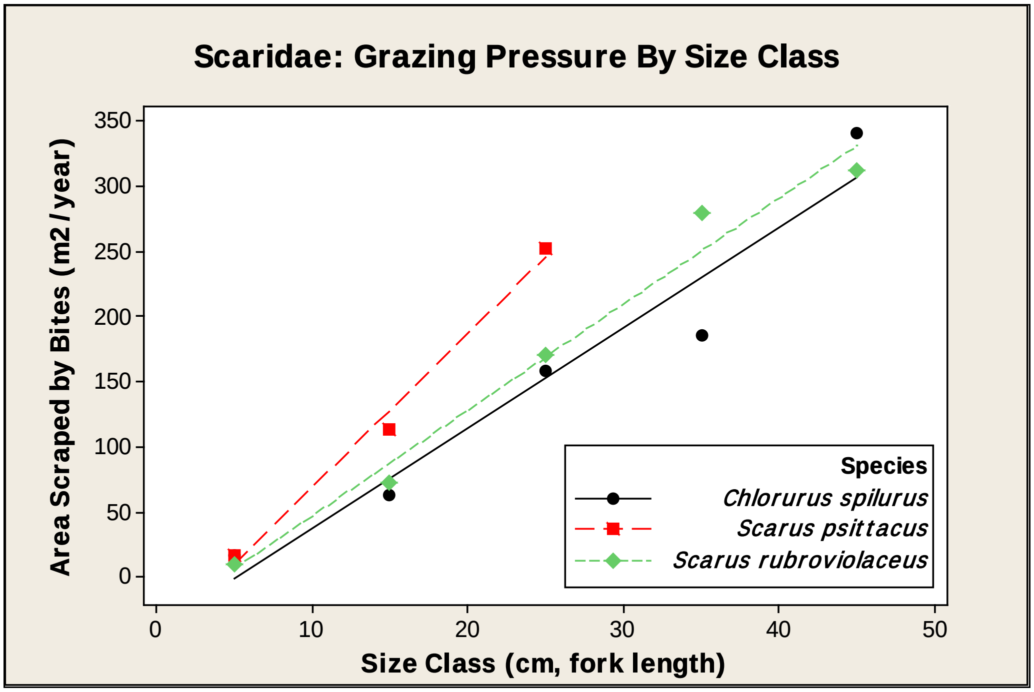


Figure 29. Parrotfish grazing pressure by size class calculated for area (m^2) scraped annually, based on bite data for *Chlorurus* and *Scarus* spp. by Ong (2008). Pearson's correlation for positive linear relationship is significant (0.925, p-value = 0.000).

Acanthurids overall had significantly greater grazing rates than scarids (ANOVA, n = 4210; p-value < 0.001). Acanthurids have greater overall species richness and population sizes, though not significantly so. Although no bite size data was available for analysis, surgeonfishes in healthy abundances assuredly rival the grazing potential of parrotfishes. Both are critical grazers for controlling algae on the reefs.

Table 5 a-d. Parrotfish grazing pressure by size class calculated for area (m^2) scraped annually, based on bite data for *Chlorurus* and *Scarus* spp. by Ong (2008).

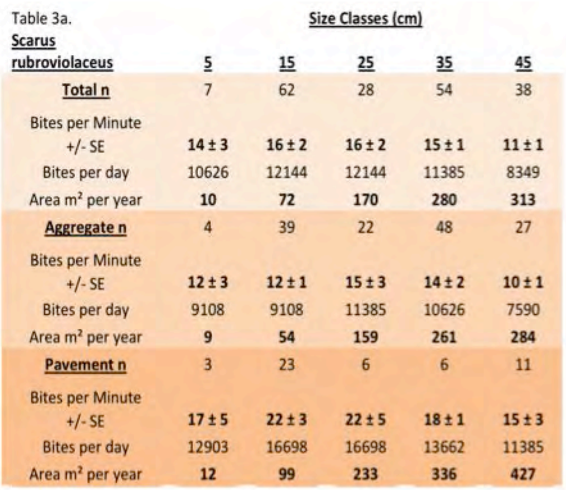


Table 3a.			Size Classes (cm)		
Scarus rubroviolaceus	5	15	25	35	45
Total n	7	62	28	54	38
Bites per Minute +/- SE	**14 ± 3**	**16 ± 2**	**16 ± 2**	**15 ± 1**	**11 ± 1**
Bites per day	10626	12144	12144	11385	8349
Area m² per year	**10**	**72**	**170**	**280**	**313**
Aggregate n	4	39	22	48	27
Bites per Minute +/- SE	**12 ± 3**	**12 ± 1**	**15 ± 3**	**14 ± 2**	**10 ± 1**
Bites per day	9108	9108	11385	10626	7590
Area m² per year	**9**	**54**	**159**	**261**	**284**
Pavement n	3	23	6	6	11
Bites per Minute +/- SE	**17 ± 5**	**22 ± 3**	**22 ± 5**	**18 ± 1**	**15 ± 3**
Bites per day	12903	16698	16698	13662	11385
Area m² per year	**12**	**99**	**233**	**336**	**427**

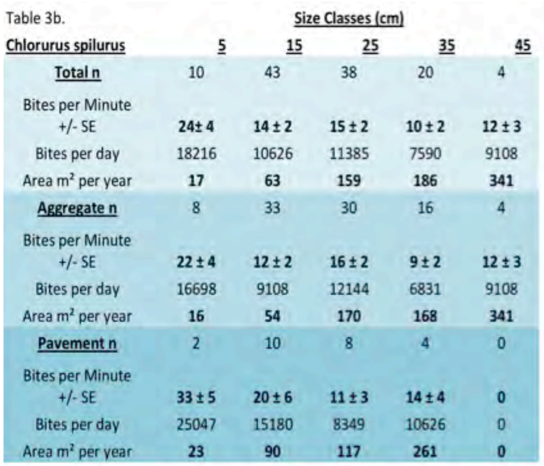


Table 3b.			Size Classes (cm)		
Chlorurus spilurus	5	15	25	35	45
Total n	10	43	38	20	4
Bites per Minute +/- SE	**24± 4**	**14 ± 2**	**15 ± 2**	**10 ± 2**	**12 ± 3**
Bites per day	18216	10626	11385	7590	9108
Area m² per year	**17**	**63**	**159**	**186**	**341**
Aggregate n	8	33	30	16	4
Bites per Minute +/- SE	**22 ± 4**	**12 ± 2**	**16 ± 2**	**9 ± 2**	**12 ± 3**
Bites per day	16698	9108	12144	6831	9108
Area m² per year	**16**	**54**	**170**	**168**	**341**
Pavement n	2	10	8	4	0
Bites per Minute +/- SE	**33 ± 5**	**20 ± 6**	**11 ± 3**	**14 ± 4**	**0**
Bites per day	25047	15180	8349	10626	0
Area m² per year	**23**	**90**	**117**	**261**	**0**

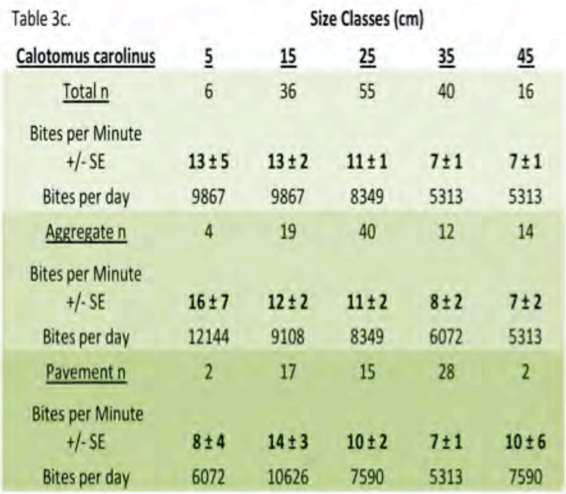


Table 3c.			Size Classes (cm)		
Calotomus carolinus	5	15	25	35	45
Total n	6	36	55	40	16
Bites per Minute +/- SE	**13 ± 5**	**13 ± 2**	**11 ± 1**	**7 ± 1**	**7 ± 1**
Bites per day	9867	9867	8349	5313	5313
Aggregate n	4	19	40	12	14
Bites per Minute +/- SE	**16 ± 7**	**12 ± 2**	**11 ± 2**	**8 ± 2**	**7 ± 2**
Bites per day	12144	9108	8349	6072	5313
Pavement n	2	17	15	28	2
Bites per Minute +/- SE	**8 ± 4**	**14 ± 3**	**10 ± 2**	**7 ± 1**	**10 ± 6**
Bites per day	6072	10626	7590	5313	7590

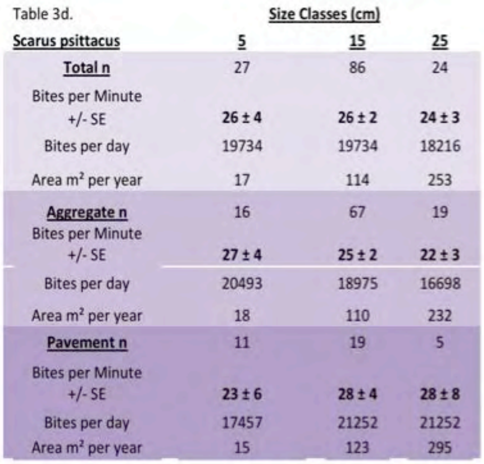


Table 3d.		Size Classes (cm)	
Scarus psittacus	5	15	25
Total n	27	86	24
Bites per Minute +/- SE	**26 ± 4**	**26 ± 2**	**24 ± 3**
Bites per day	19734	19734	18216
Area m² per year	17	114	253
Aggregate n	16	67	19
Bites per Minute +/- SE	**27 ± 4**	**25 ± 2**	**22 ± 3**
Bites per day	20493	18975	16698
Area m² per year	18	110	232
Pavement n	11	19	5
Bites per Minute +/- SE	**23 ± 6**	**28 ± 4**	**28 ± 8**
Bites per day	17457	21252	21252
Area m² per year	15	123	295

Herbivore Behavior Survey and Results

The herbivore behavior survey provides an estimate of how fish allocate their time between grazing and other behaviors throughout the day. Snorkelers swam in a set direction within a specific habitat type and noted the behavior of an individual of the target species at first sight, pausing only a few seconds to confirm the behavior. Fish species are chosen by the observer *in situ* and choices were usually based on their experience level. The behavior categories are grazing (including foraging), swimming (travelling), "hanging out" (semi-stationary), and interaction (with another organism).

A total of 7327 individuals from 18 species of acanthurids and scarids have been observed at six different sites and in several different habitats (Table 6). Observations were made between the hours of 9:00 am and 5:00 pm, with the bulk of the survey effort allocated between 9:00 am and 2:00 pm.

Table 6. Behavior Survey. Data collected on fish behavior along a roaming swim. The behavior recorded is the first behavior observed for a given individual.

Species	Total n	% Grazing	% Swimming	% Interaction	% HangingOut	% Other
Acanthuridae						
Acanthurus blochii	**86**	76	21	2	1	0
A. dussumieri	**36**	81	8	6	6	0
A. leucopareius	**153**	50	36	3	8	3
A. nigrofuscus	**1580**	76	22	2	1	0
A. olivaceus	**701**	78	18	3	2	0
A. triostegus	**1920**	73	21	1	3	1
Ctenochaetus strigosus	**52**	69	29	0	2	0
Naso brevirostris	**546**	40	55	1	3	1
N. lituratus	**273**	59	34	4	2	0
N. unicornis	**292**	57	40	1	2	0
Zebrasoma flavissimus	**1123**	77	20	1	3	0
Z. veliferum	**27**	52	37	0	11	0
Scaridae						
Calotomus carolinus	**56**	61	30	7	2	0
Chlorurus spilurus	**49**	73	24	2	0	0
Scarus psittacus	**282**	72	26	1	1	0
S. rubroviolaceus	**201**	59	37	1	1	1

Overall, both acanthurids and scarids spent the majority of their time grazing (70% and 66% respectively), followed by swimming, with little time devoted to other activities (Figure 30). Both families show relatively constant grazing activity, regardless of time of day (Figure 31), but there is a suggestion of higher feeing rates in the afternoon, which has been hypothesized to be an optimal time for concentrated grazing activity due to the accumulation of photosynthate over the course of the day. However, the small sample sizes for these time periods makes it difficult to draw any concrete conclusions.

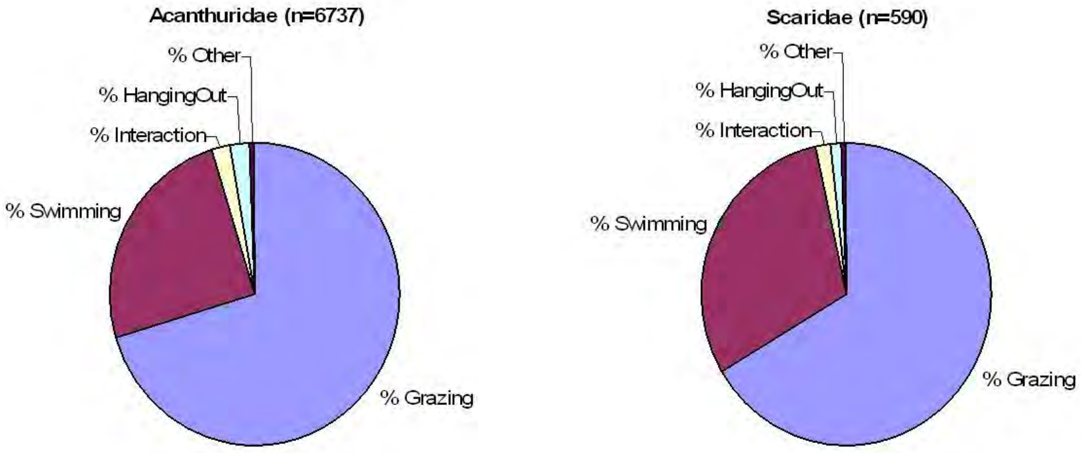


Figure 30. Percentage of time spent in the six behavior categories for acanthurids (surgeonfishes) and scarids (parrotfishes).

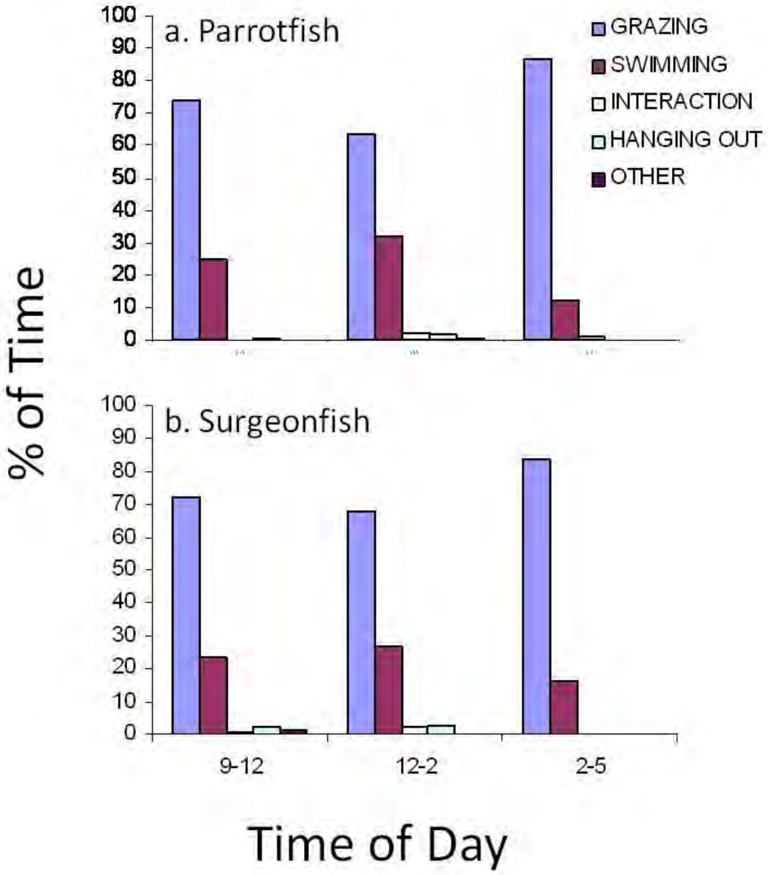


Figure 31. Diel patterns in observed behavior for acanthurids and scarids.

These observations (herbivore grazing and behavior surveys) were collected by trained volunteer citizen scientists who contributed their time and skills to help DAR develop a better understanding of the importance of herbivore fishes in the coral reef ecosystem. More than 100 community members participated in the 532 surveys (through February 2010) for greater than 2400 volunteer hours. Through their involvement in these surveys, volunteers have become more informed about the status of Maui's reefs, and they have helped to begin to fill in some knowledge gaps in the state's overall understanding of how to best manage Maui's coral reef ecosystems.

Introduced Species

Roi were intentionally introduced as food fish to Hawai'i in the 1950s in response to declines in commercial catches of native food fish. Assessments of the composition of Hawai'i's fish communities at the time determined that "many of the important shallow water game and food fishes such as the snappers and groupers abounding in the central and western Pacific are conspicuously missing in the Hawaiian Fauna." It was thought that introducing several mid-size predatory fish into Hawaiian waters that fit this "empty niche" would enhance fish catches (Division of Fish and Game, 1956). Species were selected for introduction based on their ecological characteristics and popularity as food fishes in their native ranges. Almost 16,000 fishes of 12 species were introduced in the late 1950s and 1960s with only Roi (peacock grouper, *Cephalopholis argus*), ta'ape (*Lutjanus kasmira*) and to'au (*Lutjanus fulvus*) becoming established.

However, due to the prevalence of ciguatera fish poisoning in roi, they are infrequently targeted and eaten by fishers. In the absence of sustained fishing pressure, roi populations have increased on some reefs around the state in recent years, leading to concerns amongst fishers and managers that roi may be a detriment to Hawai'i's reefs rather than a boon to fishers. The results of research to date have been mixed, with roi having been demonstrated to consume large numbers of native reef fishes especially in the smaller size ranges, but without documented impact on the size and composition of those fish communities (Dierking 2007, 2008; DAR unpublished data, also see pg. 87 of this report).

Although there is little scientific evidence to suggest that roi are having an overall deleterious impact on Hawai'i's reef fish communities there is strong sentiment amongst some members of the fishing community that roi is decimating Hawai'i's native reef fish populations. Multiple roi removal initiatives have been organized at the grass-roots level since 2008 as a proactive step by fishers to combat the perceived threat (Wood, 2010). "Roi Roundup" fishing tournaments are touted to be an environmental conservation movement with the aim of restoring Hawai'i's native reef fish populations (D. Tanaka, pers. comm.). These tournaments were founded on the island of Maui, and are now being held on the islands of Maui, O'ahu, Moloka'i, and Hawai'i.

Community assisted roi removal efforts were first conducted in West Hawai'i in 1999 by DAR in an effort to obtain information on roi feeding habits and ciguatoxicity. Such removals were undertaken in the same locale (Kūki'o, North Kona) for four years (1999, 2002, 2003 and 20046). Some of the key findings from this work were: 1) the degree of ciguatoxicity of the roi population at Kūki'o could vary dramatically between years 2) there was no significant relationship between the size of a roi and ciguatoxicity and 3) a substantial portion (67%) of the roi captured had empty stomachs even though efforts were made to reduce the loss of prey items by regurgitation during capture. A similar high number of empty guts have been found in other studies around the world.

DAR's original attempt to partner with and learn from these Roi Roundup events on Maui involved the establishment of a new integrated fish monitoring site at Canoe Beach (in front of the Hyatt at the southern end of Honokao'o Beach, Lahaina). This site serves as a control site for Kahekili, and the hope was to collect data from an area where roi are heavily targeted (Canoe Beach) and from the adjacent area at Kahekili, where DAR asked that fisherman not target roi so as not to confound the results of the KHMFA regulations. However, many fishermen did continue to target roi in the KHFMA, and as a result it is unlikely DAR will be able to measure any roi eradication impacts with in-water visual census assessment methods.

Figure 32. 'Kill Roi Day' event on April 18th at Olowalu, Maui. Mayor Charmaine Tavares and local fishers support community management of roi populations.

Subsequently, DAR has shifted research emphasis on Maui to opportunistically collecting data on the impact of this grassroots roi control efforts on roi populations. Data on the number and size of invasive fishes seen and caught at three Roi Roundup tournaments and, more recently, monthly 'Kill Roi Days' (KRD) were collected on-site. Tournaments can be either open to fishing from all sites on Maui or a discreet stretch of coastline, but the monthly KRD efforts have been focused primarily on one site, Olowalu. Fishers have removed well over 1000 introduced fishes including roi (*Cephalopholis* *argus*), ta'ape (*Lutjanus kasmira*), and to'au (*Lutjanus fulvus*) from Olowalu alone (Figure 32). Fish weighing greater than one pound were sent to Dr. Paul Bienfang's lab at UH Mānoa for ciguatera analysis. Fish weighing less than one pound were sold to a public aquarium for fish food or donated to organic farmers for composting.

At Olowalu, we have the best time series of data on roi removal, with data for roi removals conducted in July, August and November of 2009 and January and February of 2010. The following analyses use only the data from experienced fisherman present at these events (defined as fisherman who's catch per unit effort exceeded 0.5 roi caught/hour), as their efforts yielded the most consistent data on roi abundance and catch.

Over this seven month time period the catch per unit effort (CPUE) for roi is trending downward (Figure 33), as are the total number of roi per hour that escape fishermen (Figure 34). The CPUE may be showing signs of leveling out at 0.5 roi per hour, though the trend is not significant. The number of roi seen that escape capture by fisherman has declined significantly from the initial Roi Roundup events. Taken together, these data suggest that overall abundance of roi has been reduced at these sites.

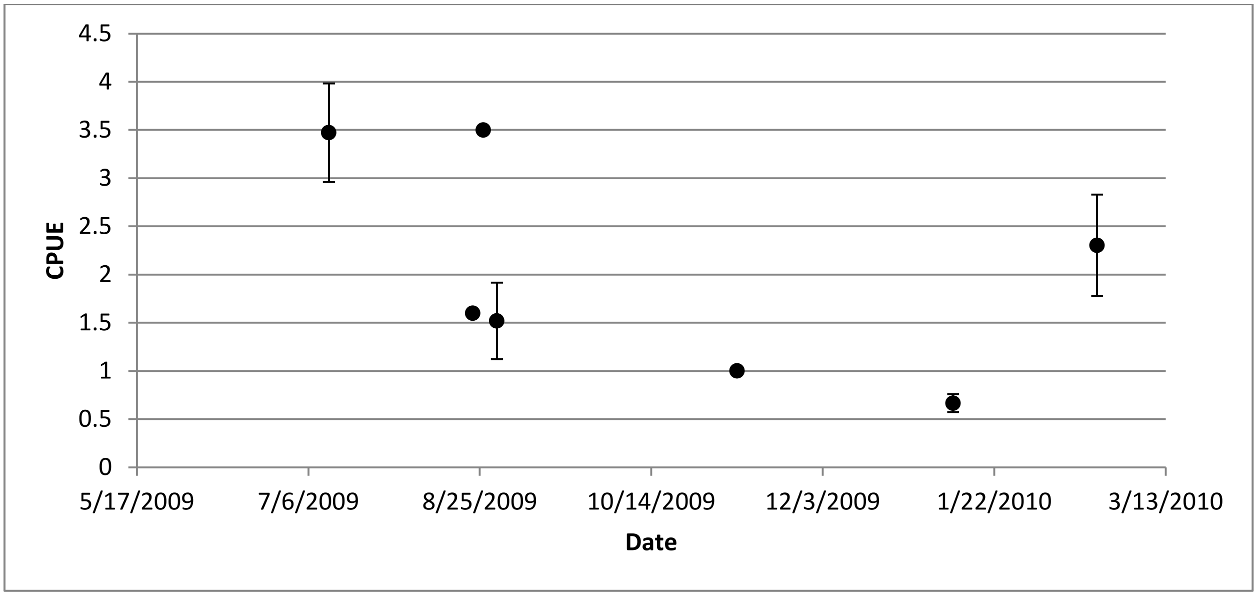


Figure 33. Average number of roi caught per hour by experienced fisherman (CPUE) at Olowalu, Maui. The CPUE trends downward but is not significant due to the rise in the CPUE in 2/21/2010. Error bars are standard error of the mean.

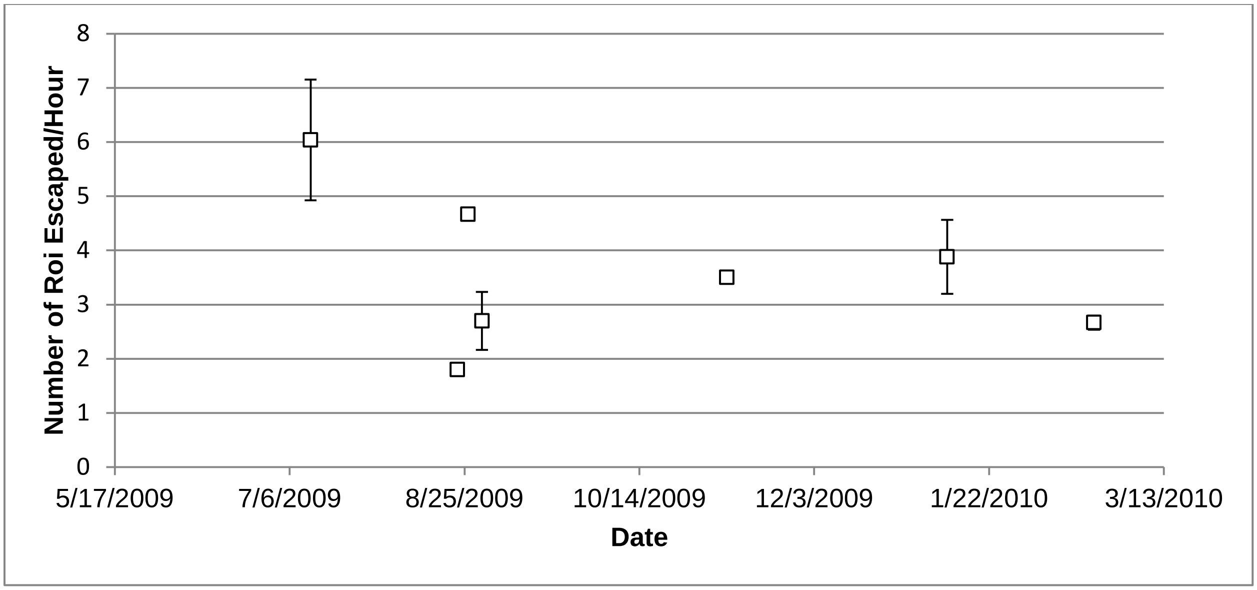


Figure 34. Average number of roi per hour that escaped catch by experienced fisherman at Olowalu, Maui. The downward trend is marginally significant (p=0.052). Error bars are standard error of the mean.

When data on both CPUE and the number of roi escaped are combined, a significant decline in roi abundance can be seen (Figure 35), with the average number of roi seen per hour declining by almost a factor of four. This indicates that these events are significantly decreasing the abundance of roi at Olowalu. However, it also suggests that, while roi have been substantially reduced, they are still present in moderate densities despite months of removal effort.

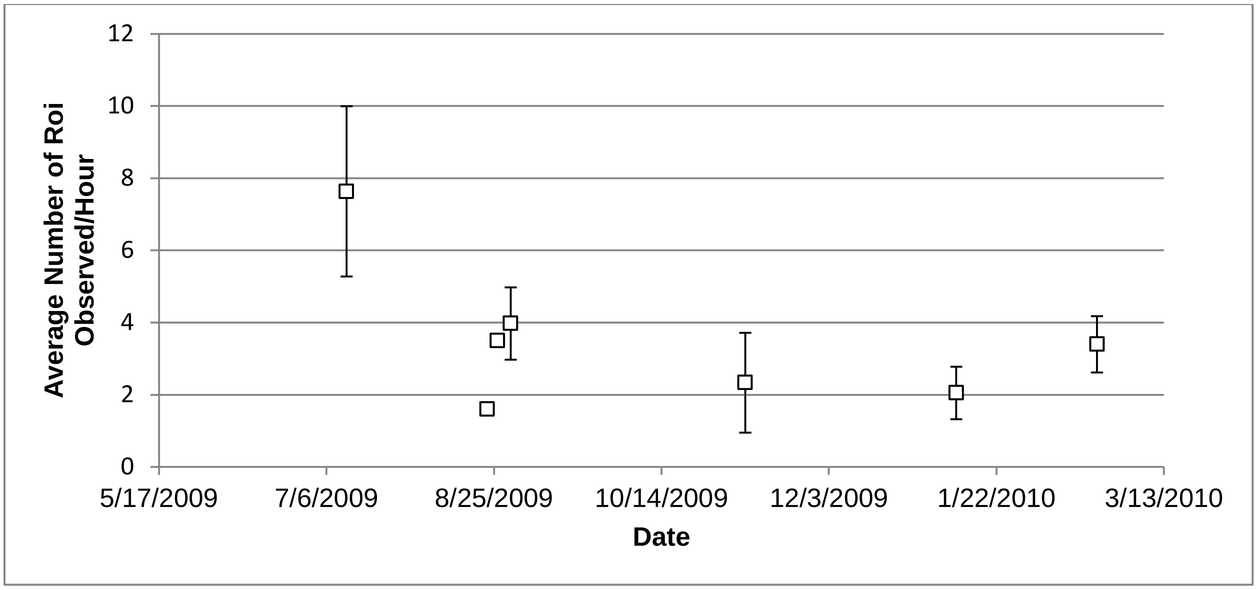


Figure 35. Average number of roi observed per hour (total of “roi caught” and “roi left”) at Olowalu, Maui has significantly decreased since July 2009 (p=0.001). Error bars are standard error of the mean.

Based on the results from Dr. Paul Bienfang’s lab, there were a total of 551 roi from Maui caught between July 20, 2008 and November 8, 2009, with the majority of fish coming from the leeward side of island. 414 of these roi have been tested for ciguatera (137 remain untested). Of these, 287 roi tested positive (69%) and 127 tested negative (31%). The relative toxicity rank assigned to the positive Maui fish ranged from 2.19 to 170.89. This is in contrast to positive Oahu fish, whose rank ranged from 35.26 to 60.85. Maui roi body weights versus relative toxicity rank shows no correlation of weight with ciguatoxicity and thus larger fish are not necessarily more toxic. The average body weight of roi received from Maui is 990.04g. The average weight of the negative fish from Maui is 946.35g, and the positive fish average weight is 1052.2g.

Coral Disease

‘Āhihi Outbreak

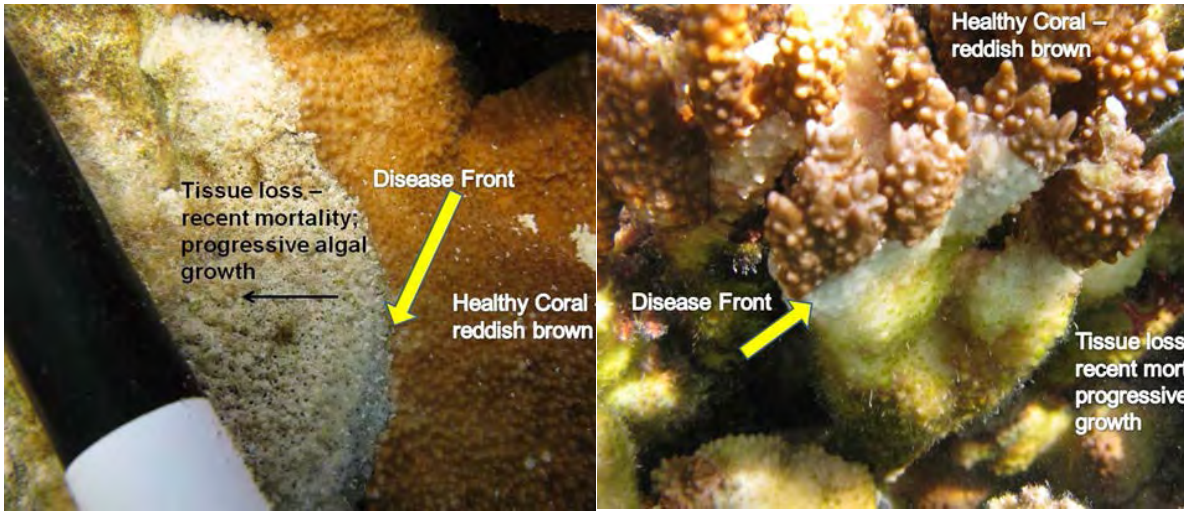


Figure 36. White Syndrome (tissue loss) outbreak at ‘Ahīhī Kīna‘u Natural Area Reserve, in a semi-enclosed ‘pond’ adjacent La Perouse Bay. Monitoring is ongoing.

In January, 2010, researchers from the University of Hawai‘i at Mānoa (UHM) and Hawai‘i Institute of Marine Biology (HIMB) were performing their research within the ‘Āhihi Kina’u NAR, when they reported a coral disease (white syndrome) outbreak (Figure 36). This outbreak had been ongoing for approximately one year when DAR learned of it. Percent cover data from Yuko Stender’s research indicated a 47% decline in coral cover over that time frame. Dr. Greta Aeby visited the site with the Maui DAR team to coordinate monitoring and sampling of the outbreak. Monthly or bi-monthly surveys of ten marked colonies using photographs and semi quantitative estimates of live, diseased, and old dead are ongoing. Samples for histology and micro work have been collected and sent out for analysis to Dr Thierry Work and Dr Sean Callahan, respectively, as is consistent with the Rapid Response Contingency Plan. Additionally, an inventory of the area (diseases and associated species) is planned for later this fall, utilizing the extra manpower of visiting coral disease biologists and Eyes of the Reef volunteers.

NOAA DZ Surveys

The NOAA Coral Reef Watch and NOAA/NMFS Coral Reef Ecosystems Division (CRED) have partnered with DAR on each island to collect coral disease (DZ) data to feed into a computer model for the development of a satellite prediction tool. This tool utilizes sea surface temperature (SST) data as an indicator of potential disease outbreaks, and has been thus far successful on the Great Barrier Reef. Hawai‘i poses new challenges to this tool, given that the reefs are very close to the shoreline, increasing the need for finer resolution imagery.

Surveys are performed three times a year (April, July, and late September), and the four priority sites for this project include established fish survey and CRAMP sites at Molokini, Keawakapu, Kahekili, and Honolua Bay. Additionally, all of the CRAMP sites will be surveyed in July. Dr. Bernardo Vargas-Angel is the project PI, and Dr. Greta Aeby is the survey advisor. Megan Ross from UHM/HIMB is a participant in the Maui surveys, and CRED is also sending biologists to assist with the field work. All data are sent back to CRED for analysis, and a copy will be housed at DAR Maui as well.

Internships and Community Education Programs

The Kahekili volunteer surveys and projects relating to the research and management of the KHFMA have become a focus for community groups and student learning. The Kahekili project and associated research has been incorporated into the Ka Ipu Kukui Fellowship Program (www.kaipukukui.org) which trains future leaders of the community. The fellows of 2008 and 2009 participated in presentations relating to the importance of herbivores and the history of the issues surrounding the project, field survey training, and engaged in discussion about the challenges of managing stressors to the reef.

The Marine Option Program at Maui Community College, led by Donna Brown, has provided students with multiple opportunities to give presentations and trainings to classes and encouraged them to participate in volunteer surveys. In addition, Derek Masaki of USGS, an instructor in Geographic Information Systems (GIS) at MCC, brought his students to Kahekili to learn about collecting field data and created a GIS by focusing on the stressors to the reef.

In 2009, two students from Kamehameha School’s KA`IMI internship program (http://maui.ksbe.edu//faculty/prmikell/Ka%60imiHome.html) gained valuable skills while aiding the project by mapping freshwater seeps (point sources of freshwater intrusion) and ‘dead zones’ (obvious death of *Porites compressa* beds) out on the reef. The ‘dead zone’ map led to a NOAA Hawai‘i Coral Program funded grant to investigate these anomalies beginning late 2010.

Additionally, Carrie DeMott, an herbivore survey volunteer, is a science teacher at Maui Preparatory Academy. She has taken the initiative to integrate the herbivore surveys and related science into her class curriculum. Students are graded on their knowledge and skills relating to the Kahekili herbivore surveys.

Partnerships

The Division of Aquatic Resources (DAR) has been working collaboratively with the Coral Reef Alliance’s (CORAL; www.coral.org) Hawai‘i Manager, Liz Foote, to help create a web platform for the data collected from community-based volunteer surveys (http://monitoring.coral.org). This will enable DAR managers to broaden the scope and efficiencies of monitoring and data collection by enabling broader volunteer involvement. Other organizations that have contributed toward this partnership effort in the online Web Portal include the NOAA Humpback Whale Marine National Monument and Robin Knox, junior researcher in Celia Smith's lab at the University of Hawai'i Botany Department. Both of these groups focus on water quality monitoring for part of their activities.

The data web portal was developed to allow volunteer citizen scientist to independently collect and enter data (http://monitoring.coral.org). Additionally, basic information collection regarding special resource issues has also been incorporated to allow recreational users to enter data any time they go snorkeling or spearfishing. The type of information collected on this web portal includes catch data and the total observed number of the alien fish roi (*Cephalopholis argus*), the number of large parrotfish observed (>45cm), and the number of large grazing fish schools observed (large schools are defined as having > 300 individuals). With contributions from the NOAA Humpback Whale National Sanctuary office, other community-based data will also be available at this site for managers including water quality data. Managers will have access to these data, and volunteers can see reports and access information that is important to them. Currently the portal is active but is still under construction.

In addition to the web portal project, CORAL has been an integral partner by helping educating the community stakeholders to raise awareness regarding the new KHFMA, sustainable tourism, the 'Take a Bite out Of Fish Feeding' Campaign, responsible stewardship, and coral reef etiquette.

Project S.E.A.-Link (Science, Education, Awareness), a local non-profit directed by Liz Foote, has also been an invaluable partner through initiating press releases, assisting in securing facilities for public talks and trainings, and list serve communications to the greater Maui community. Project S.E.A. Link specializes in providing links between agencies, organizations, and the community with an emphasis on assisting community based efforts that benefit managers.

The NOAA Hawaiian Islands Humpback Whale National Marine Sanctuary and the Jean-Michel Cousteau Ambassadors of the Environment Center have both been gracious hosts on numerous occasions providing free facilities for public volunteer training workshops. These groups have been true partners in our efforts to educate and engage the local community in the research and management efforts on Maui's coral reef habitats.

Hawai'i Island Surveys

Benthic Monitoring

Methods

Benthic surveys were initially conducted in West Hawai'i in 1999 and then again in 2003. More recently, surveys were conducted at 26 monitoring sites in 2007 (Figure 47). Three additional sites were surveyed in either 2005 or 2009. The images used for analysis in 1999 were captured by digital video. The resolution of the video images was very poor however compared to the subsequent surveys which used much higher resolution digital still images (Olympus 5060 in 2003 and Olympus 7070 in 2007). Specifically, octocoral was not detectable in the 1999 video capture images, nor was it possible to distinguish live finger coral from dead finger coral. It was therefore determined that it was not valid to compare data taken with these two different techniques.

To obtain images of consistent size and quality, a 75cm clear Plexiglas® spacer rod is attached to the underwater housing and used as a guide to steady the camera at a fixed height (0.75m) above the benthos. A white balance feature was used to compensate for loss of red light at depth, giving the images a more natural appearance without artificial lighting. Four transects 25m in length were photographed at each site. Images were taken at 1m intervals from a standard height of 0.75cm starting at the 0 point and ending at the 25m mark, producing 26 images per transect.

Images were analyzed using the Coral Point Count with Excel extensions software program (CPCe Kohler and Gill 2006). Data was pooled by transect. The resulting configuration was 4 transects per site, 26 frames per transect, 20 stratified random points per image (4 rows, 5 columns), 520 individual data points per transect, and 2080 points per site. Proportion of each benthic category was determined for each image and percent cover was calculated for each transect, Total percent cover was obtained by calculating the mean percent cover of the 4 transects.

Results

Complete benthic data for the 2003 and 2007 surveys, presented as percent coverage, are contained in Appendices B-E. Comparisons of total coral cover (paired two-sample T tests) were performed on the percent total coral cover mean values for individual transects (1-4) (Table 7).

Between Lapakahi, the northernmost site, and Keahole Point, a distance of approximately 37 coastal miles, there are 9 survey sites. One site, Unualoha, was added in 2007 and therefore no comparative data is available. Of the 8 "northern" sites (north of Keāhole Point) that were compared, 6 showed statistically significant declines in total coral cover between 2003 and 2007. Lapakahi, Kamilo Gulch and Waiaka'ilio Bay (the three northernmost sites), Keawaiki, 'Anaeho'omalu and Ka'upulehu all declined significantly. Only Puakō and Makalawena showed no significant change (Figure 37).

A severe storm with large swells caused extensive coral damage along the West Hawai'i coast north of Keāhole Point in January 2004. This damage was noted during surveys soon after the storms occurred. The declines at Kamilo Gulch and Waiaka'ilio Bay may also have been influenced by a major sediment runoff event caused by heavy rainfall in October 2006. A reconnaissance was conducted offshore of several intermittent streams near these sites soon after the event. Thick layers of sediment covering large amounts of coral were observed and sediment was recorded at water depths of 90 feet. Numerous dead coral were observed during subsequent reconnaissance.

South of Keāhole Point 15 sites were compared. Three sites, Wawaloli Beach, Papawai Bay and South Oneo Bay showed statistically significant increases in total coral cover between 2003 and 2007. All other sites showed no change.

Table 7. 2003 and 2007 coral cover at West Hawai'i sites.

Site (N to S)	2003	2007	Δ	p=	
Lapakahi	19.50%	11.40%	-8.10%	0.004	Decline
Kamilo	49.50%	38.20%	-11.30%	0.020	Decline
Waiaka'ilio Bay	54.40%	42.50%	-11.90%	0.047	Decline
Puakō	49.90%	47.80%	-2.10%	0.604	No Change
‘Anaeho'omalu	41.20%	31.50%	-9.70%	0.038	Decline
Keawaiki	29.90%	16.70%	-13.20%	0.006	Decline
Ka'upulehu	40.90%	31.20%	-9.70%	0.033	Decline
Makalawena	45.20%	47.60%	2.40%	0.553	No Change
Wawaloli Beach	33.32%	42.25%	8.93%	0.015	Increase
Wawaloli	37.21%	37.51%	0.31%	0.859	No Change
Honokōhau	48.29%	48.74%	0.45%	0.894	No Change
Papawai	32.21%	38.31%	6.10%	0.044	Increase
S. Oneo Bay	56.09%	61.86%	5.77%	0.025	Increase
N. Keauhou	31.92%	31.10%	-0.81%	0.356	No Change
Kualani	52.81%	59.78%	6.97%	0.124	No Change
Red Hill	30.68%	33.22%	2.54%	0.511	No Change
Keopuka	15.98%	15.59%	-0.39%	0.602	No Change
Kealakekua Bay	27.10%	28.64%	1.54%	0.595	No Change
Ke'ei	31.20%	28.67%	-2.54%	0.424	No Change
Ho'okena (Kalahiki)	36.53%	39.62%	3.09%	0.263	No Change
Ho'okena (Auau)	28.18%	28.44%	0.26%	0.925	No Change
Miloli'i (Omaka'a)	29.76%	27.08%	-2.68%	0.491	No Change
Miloli'i (Manukā)	30.35%	33.17%	2.82%	0.488	No Change
Lapakahi	19.50%	11.40%	-8.10%	0.004	Decline
Kamilo	49.50%	38.20%	-11.30%	0.020	Decline

Octocoral Distribution

Benthic surveys revealed a most interesting distribution of one or more species of octocorals centered on the urbanized areas of Kailua-Kona (Figure 39). The Bishop Museum checklist (http://www2.bishopmuseum.org/HBS/invert/results.asp) lists 11 species of shallow water octocorals occurring in Hawai‘i. At least one of the species in question appears to be the blue octocoral *Sarcothelia (Anthelia) edmondsoni (*Figure 38).

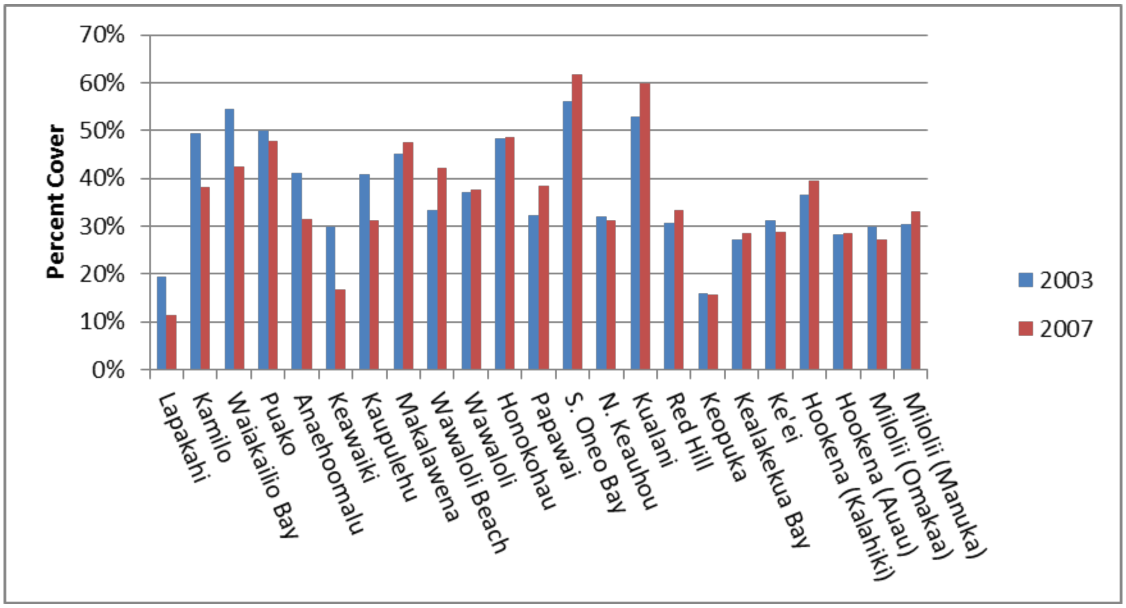


Figure 37. Comparison between survey years of percent coral cover across West Hawai‘i monitoring sites.

although the taxonomy of the group is somewhat confused*.* The original taxonomic description for S. *edmondsoni* is actually a brown morph common in calm lagoons on the windward side. The blue morph is more abundant in fore reef areas with heavy wave surge and is most likely a separate species. Both varieties have long histories in Hawai'i and are presumably native and/or endemic (Sam Kahng, pers. comm.)

The apparent concentration of *Sarcothelia edmondsoni* in the vicinity of Honokōhau Harbor and the areas directly north and south (Figure 39) may suggest anthropogenic influence on the distribution of octocoral in West Hawai'i. Published studies have suggested that octocorals may be indicators of pollution (Baker and Webster 2010, Hernandez-Munoz et al. 2008). With the planned increase in development in these areas and the possible associated rise in point source pollution further investigation into octocoral distribution and its potential as a pollution indicator is suggested.

An analysis of octocoral percent cover changes between 2003 and 2007 showed no statistically significant change in all but one of the West Hawai'i sites where octocoral has been recorded. Papawai Bay declined from 18.2% to 10.9% (p=.018).
The next benthic surveys to be conducted in early 2011 will permit octocoral percent cover comparisons of the 6 sites that were added after 2003.

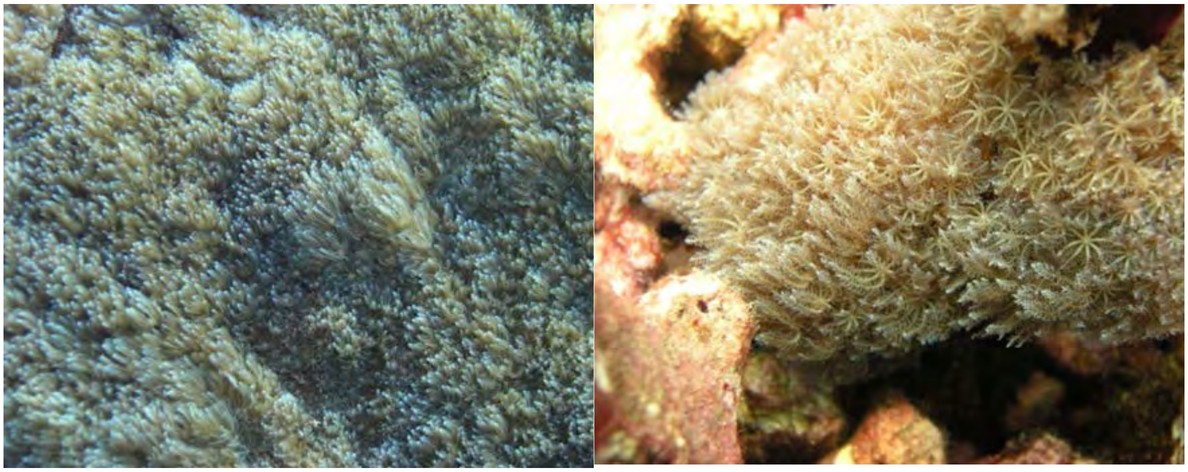


Figure 38. *Sarcothelia edmonsoni* (left) and another unidentified octocoral found on West Hawai’i reefs.

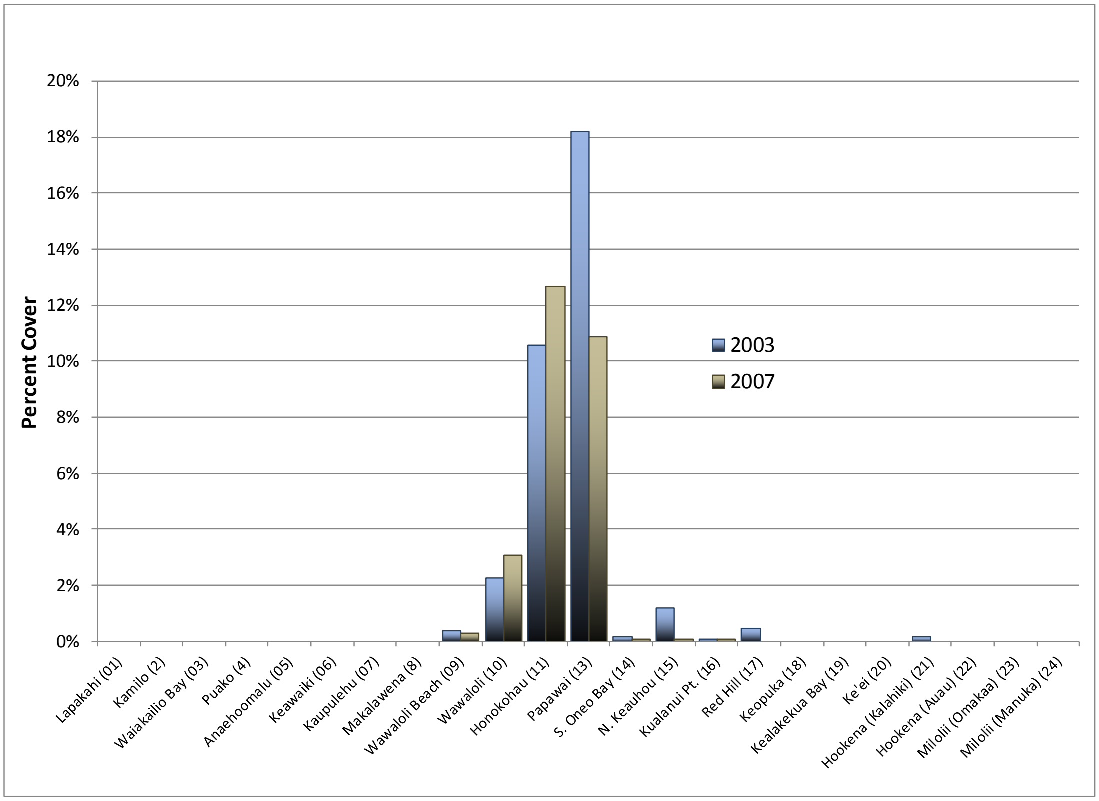


Figure 39. Comparison between survey years of percent cover of octocoral across West Hawai‘i monitoring sites.

Coral Disease

Methodology

Coral disease surveys were conducted at 28 West Hawaiʻi sites, and at Okoe and Hōnaunau Bays. Surveys were conducted from March to July 2010 by four survey divers: Courtney Couch (Cornell University), Camille Barnett (DAR), Kara Osada-D'Avella (DAR), and Linda B. Preskitt (DAR). Two permanent transects were surveyed at each site.

Field surveys

An area of 1 x 25 meters was surveyed for coral disease along each transect. Larger areas were surveyed at sites with low occurrences of disease, while (due to time constraints) the full 25 m^2 was not surveyed at several sites with high disease frequency. Disease assessment included all corals within the survey area inspected for signs of trematodiasis, growth anomalies, tissue loss syndrome, multifocal tissue loss, hypermycosis, and other progressive conditions. When disease was present, colony size and species were recorded along with the number, size, shape and color of the lesion(s) observed. All diseased colonies were photographed and described, excluding colonies with only *Porites* trematodiasis. In addition, 1-2cm fragments from diseased coral colonies were sampled for histological analyses, helping to further differentiate between tissue loss and biological interactions (e.g. predation).

Colony assessment

Colony counts were conducted in conjunction with coral disease surveys. For each transect line, a 1 x 10 meter area was surveyed with the aid of a 1m square quadrat. Each coral colony within the survey area was recorded to species level and assigned to one of seven size classes; 0-5cm, 5.1-10cm, 10.1-20cm, 21.1-40cm, 41.1-80cm, 80.1-160cm and >160cm.

Calculations and Analyses

We calculated mean colony density (colonies/m^2) for each site by averaging the number of colonies of each genus on both transects and dividing by the average area surveyed for each site. Mean colony density was then multiplied by the area surveyed for disease to obtain estimated number of colonies. At each site we calculated total estimated disease prevalence for each disease as follows: (total no. cases of a specific disease for the genus) ÷ (estimated number of colonies for the genus). Total disease prevalence for each site was calculated using the method described above using total number of colonies and total number of diseased cases for each site (all genera combined).

In 2007, Dr. Greta Aeby and Steve Cotton (DAR) conducted initial coral disease surveys at 10 WHAP sites (Table 8) (DAR 2007). This dataset was compared with data collected in 2010 to assess changes in coral disease frequencies. Prevalence (% of diseased colonies per site) data between the two surveys were not comparable due to substantial differences in colony counts between 2007 and 2010, with significantly more small colonies (colonies <10cm) counted in 2010 than 2007. This difference was believed to be due to observer changes rather than biological changes. Therefore, data were compared using disease abundance per m^2 rather than disease prevalence.

Coral disease prevalence data were non-parametric; therefore Spearman rank correlation analyses were employed. Paired t-tests were used for comparisons of disease per m^2 between 2007 and 2010 surveys at ten WHAP sites (JMP® v8.0.2.2, ©2009 SAS Institute Inc.)

Results

Coral disease by size class

Coral diseases were observed across all colony size classes, with the greatest percentages of disease cases occurring in the larger size categories (Figure 40). Coral colonies less < 5cm accounted for 18% of total colonies (18.3% of *Porites* spp.) recorded in count surveys, yet accounted for only 1% of the total cases of diseased colonies (1.1 % of *Porites* spp.). These findings imply West Hawaii's small corals (<5 cm) are less susceptible to disease than the larger and subsequently older colonies. Linear growth rates of coral colonies are both species and size specific, and are affected by a suite of environmental factors such as depth, temperature, light irradiation and latitude.

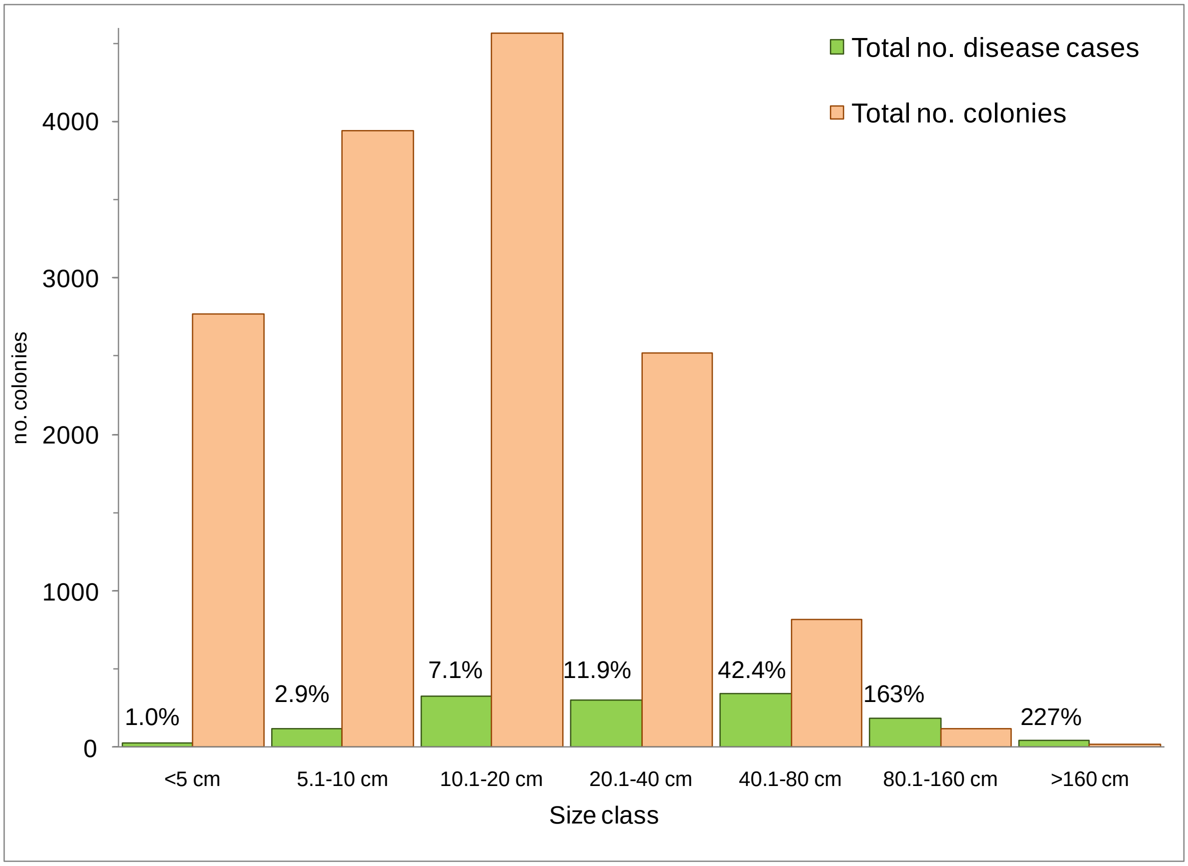


Figure 40. Size structure of coral colonies recorded in West Hawai'i during surveys conducted in 2010. Percentages reflect % of diseased colonies recorded within each size class.

Therefore it is difficult to age colonies based on size. Given an overall slow growth rate (ranging from 7.4 – 16.7 mm/yr.) of the dominant reef builder *Porites* and the relative contribution of gametes that large colonies provide, it is important to continue monitoring coral disease prevalence as they may have long-term effects on coral populations and community structure (Rodgers & Cox 2003; Forsman et al. 2006, Richmond 1987; Grigg & Maragos 1974, Lough & Barnes 2000).

Why more diseased colonies than total colonies recorded?
Larger colonies tended to occur near the end of survey lines, therefore the number of diseased colonies are greater than total colonies counted due to the methodology employed; coral colonies were counted and sized for the first 10m of each transect, while disease assessments were made along the full 25m line.

Coral community structure

Percent coral cover varied across surveyed sites, ranging from 11.5% at Site 1 (Lapakahi) to 62.0% at Site 14 (South Oneo Bay) (Appendix C). Within all monitoring sites, Poritids were the most abundant corals, while densities of other coral genera were variable across sites. Coral colony density was not significantly related to percent coral cover (Spearman r = -0.2626, p > 0.1). Rather, high coral density reflects an abundance of small colonies (Figure 40).

Spearman rank correlations revealed significant negative relationships between overall colony density and total disease prevalence (r = -0.5276, p = 0.0033). However, total disease prevalence was positively related to percent coral cover (r = 0.4291, p = 0.0202). In other words, higher disease prevalence was observed on reefs with high coral cover and lower colony density, which is likely due to the increase in disease susceptibility with colony size.

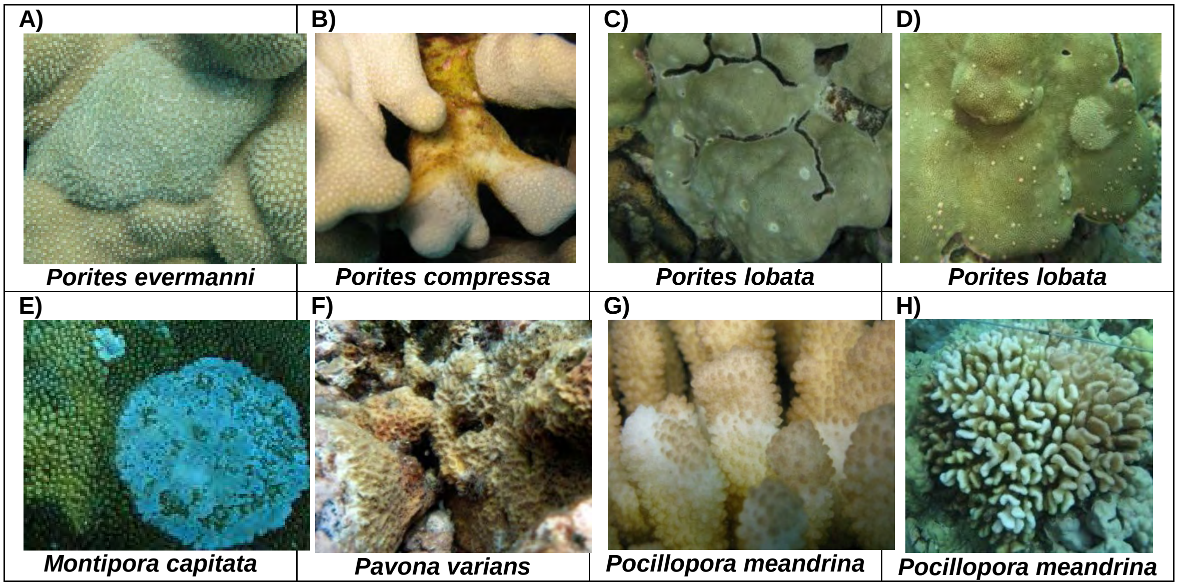
When relationships were analyzed by genus, *Porites* followed the same trend as described above. *Porites* growth anomalies and *Porites* tissue loss syndrome were positively correlated with percent cover of *Porites spp.* (r = 0.4444, p = 0.0178 and r = 0.3804, p = 0.0458) and negatively related to Poritid density (r = -0.7200, p < 0.001 and r = -0.5600, p = 0.0016). Frequency of *Porites* diseases may be attributed to the dominance of Poritid corals in West Hawai‘i reef communities possibly allowing the spread of pathogens or creating a susceptibility to disease within the genus.

Diseases in West Hawai‘i

At 30 sites surveyed in West Hawai‘i, the following diseases were recorded within each specified genus: growth anomalies (GA) of Poritids and Montiporids, *Porites* trematodiasis (TRE), tissue loss syndrome (TLS) within *Porites* and *Pocillopora*, *Porites* multifocal tissue loss (MFTL), and hypermycosis (HYP) of *Pavona* (Figure 41).

The above diseases have been previously described (Coral Disease Working Group 2007, Williams et al. 2010), however we observed a number of cases of a distinct type of tissue loss in *Pocillopora meandrina*. The lesion was characterized by progressive tissue loss from one side of the colony with old algae-covered skeleton grading into recently denuded skeleton to sloughing and into apparently healthy tissue. The tissue loss appears to originate and progress from the base of each branch, with a clear band of freshly denuded skeleton at the lesion margin. We also recorded cases of possible

Pocillopora senescence. This condition is common along West (C. Couch pers. obs.) and East Hawai‘i (B. Vargas-Angel pers. comm.). In most cases colony death originates on one side of the colony and progresses across the colony. Algal covered skeleton is adjacent to paled/bleached tissue, which grades into “normally” pigmented tissue. Samples sent to United States Geological Survey (USGS) Biological Resources Division for analyses revealed atrophy, appearing to be a senescence reaction (or progressive death of the colony, perhaps due to age) (Figure 41).



Porites evermanni

Porites compressa

Porites lobata

Porites lobata

Montipora capitata

Pavona varians

Pocillopora meandrina

Pocillopora meandrina

Figure 41. Examples of coral diseases observed in West Hawai‘i during 2010 baseline surveys: A) *Porites* growth anomaly, B) *Porites* tissue loss syndrome, C) *Porites* multifocal tissue loss, D) *Porites* trematodiasis, E) *Montipora* growth anomaly, F) *Pavona varians* hypermycosis, G) *Pocillopora* tissue loss, H) possible senescence reaction*.*

Disease distribution and prevalence

Consistent with previous coral disease assessments in the Main Hawaiian Islands (Aeby and Cotton 2007, Williams et. al 2010), *Porites* was the most susceptible genus to disease, having the highest disease prevalence (3.76 ± 3.58 %) and most types of diseases compared to other genera. The most widespread diseases observed were growth anomalies, trematodiasis, and tissue loss of *Porites spp*. (Table 8 Figure 42, Appendix A)

Table 8. Occurrence of diseases across ten monitoring stations in survey years 2007 and 2010 in West Hawai‘i. Presence during only one survey year is noted by the year when it was observed, with "X" denoting presence for both survey years.

Disease	SITE 3	SITE 4	SITE 5	SITE 8	SITE 97	SITE 11	SITE 15	SITE 17	SITE 19	SITE 20
Porites trematodiasis	2007	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Porites tissue loss	**X**	2010	2010	**X**	2007	**X**	**X**	2007	**X**	**X**
Porites multifocal tissue loss		X	2007							2010
Porites growth anomaly	2010	**X**	**X**	**X**	2007	**X**	**X**	**X**	**X**	**X**
Pavona hypermycosis		2010		2010					2010	
Montipora white syndrome				2007						
Montipora growth anomaly			2007	**X**	2010					
Pocillopora senescence reaction					2010					
Pocillopora tissue loss										

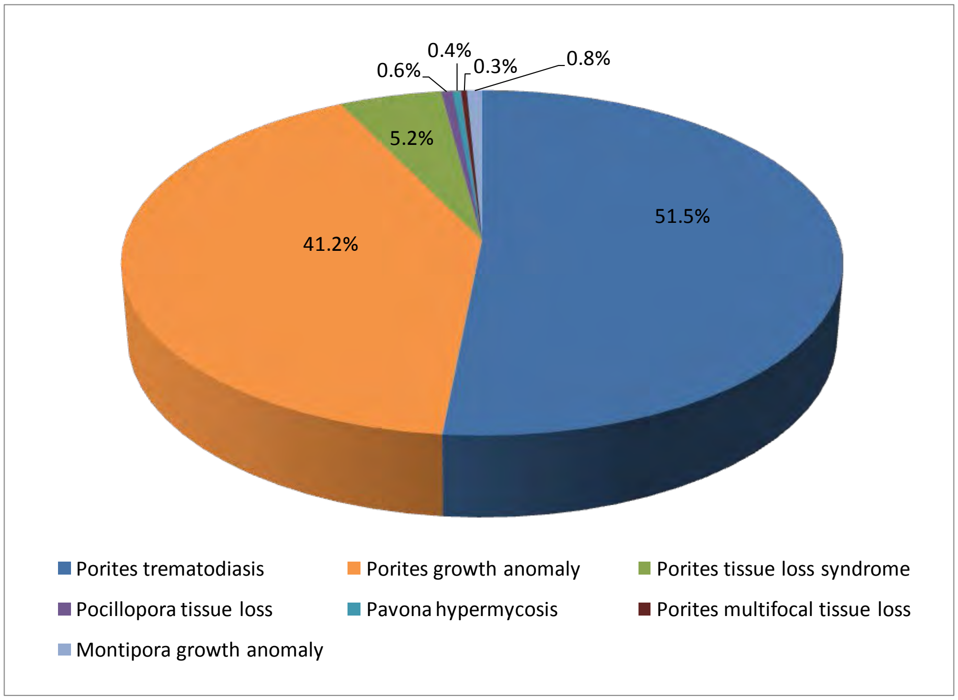


Figure 42. Relative abundance of coral diseases recorded for DAR monitoring sites in West Hawai‘i during surveys conducted in 2010.

Although *Porites* growth anomalies were found at all but two sites (Sites 6, Keawaiki and Site 97, Unualoha Pt.), mean prevalence across all sites was low (1.83 ± 2.15 %), ranging from 0.02 % at Site 10 (Wawaloli Beach) to 7.81% at Site 11 (Honokōhau) (Figure 43).

Porites trematodiasis, the second most common disease, was found at all but the following four sites: Site 2 (Kamilo Gulch), Site 3 (Waiakaʻilio), Site 18 (Keopuka), and Site 21 (Kalahiki Beach). Mean prevalence across all sites was low (1.71 ± 2.17%), ranging from 0.05 % at Site 1 (Lapakahi) to 9.03% at Site 8 (Makalawena) (Figure 43). Porites tissue loss syndrome occurred at all but the following sites: Site 1 (Lapakahi), Site 6 (Keawaiki), Site 7 (Kaʻupulehu), Site 97 (Unualoha Pt.), and Site 17 (Red Hill). Mean prevalence across all sites was low (0.21 ± 0.18 %), ranging from 0.02 at Site 10 (Wawaloli Beach) to 0.65 % at Site 23 (Omakaʻa Bay) (Figure 43).

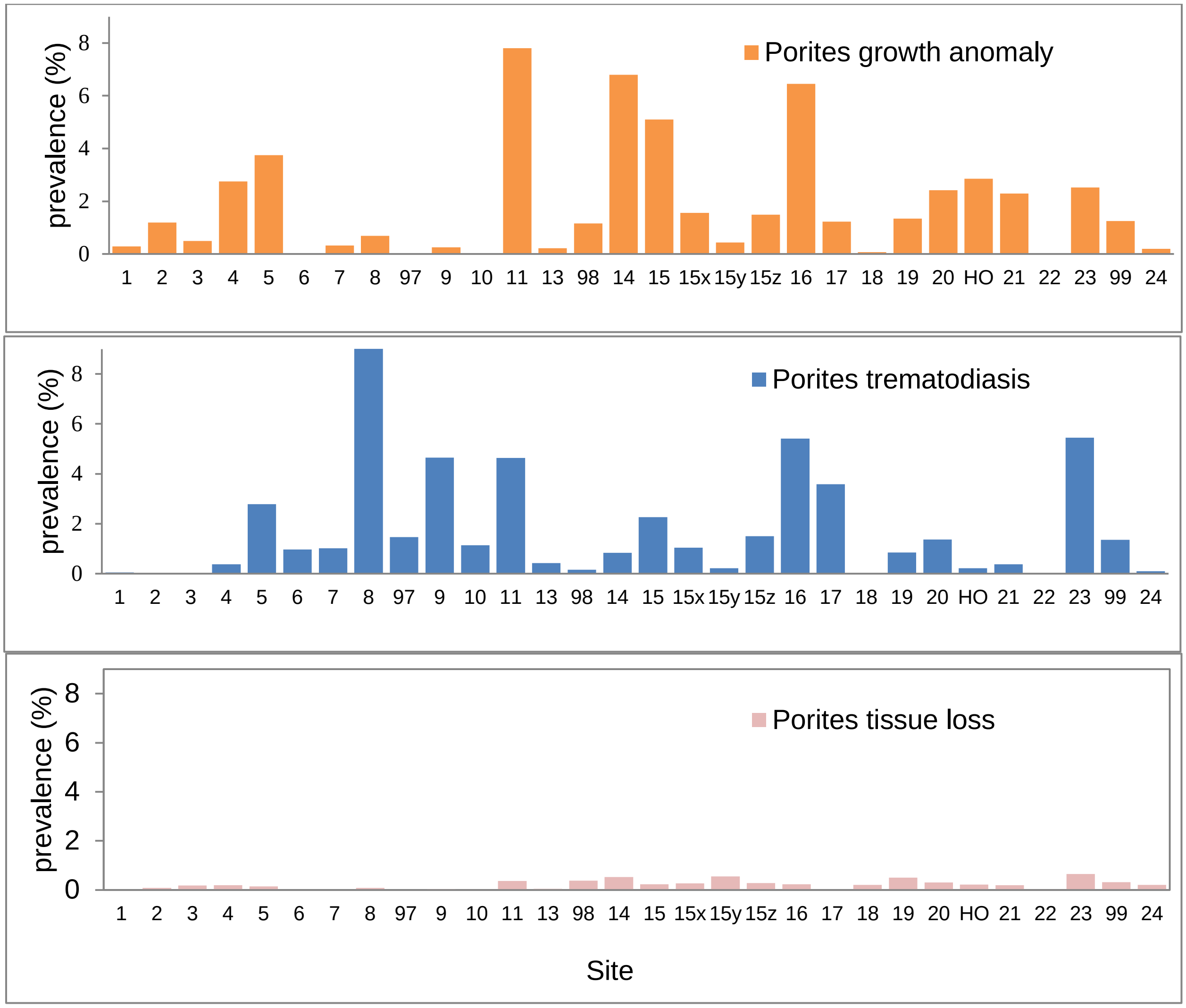


Figure 43. Prevalence of Poritid diseases at each West Hawaiʻi site surveyed in 2010.

Although possible senescence reaction of *Pocillopora meandrina* appears commonly in West Hawai‘i (see section entitled Diseases in West Hawai‘i), this condition was observed at only two sites: 97 (Unualoha Pt.) and 22 (Ho‘okena). This infrequent documentation of cases is likely attributed to the low number of Pocilloporids occurring at DAR monitoring sites, as *P. meandrina* accounts for an average of 0.83% of total coral cover at WHAP sites

Spatial Patterns

Anthropogenic impacts such as coastal pollution are hypothesized to result in physiological stress and altered host-pathogen interactions, leading to changes in coral health and coral reef community structure (Harvell et al. 2007). While the mechanisms underlying the link between coral disease and water quality are poorly understood, diseases such as growth anomalies have been positively associated with high human use and impaired water quality in the Pacific (Yamashiro et al. 2000, Kaczmarsky 2009, Aeby et al. in review).

Due to Hawai’i’s highly porous basaltic rock, terrestrial inputs are transported rapidly through submarine groundwater (Knee et al. 2010). Data collected by Johnson (2008) documented areas with submarine groundwater discharge (SGD) “plumes” between Kawaihae and Hōnaunau. Disease prevalence at DAR monitoring sites was analyzed in relation to these SGD plumes (data were available for a total of 14 monitoring sites within the region documented).

Overall disease prevalence and prevalence of *Porites* growth anomalies were positively correlated with total estimated size of SGD plumes (total prevalence $r = 0.460$, $p = 0.098$, *Porites* GA $r = 0.586$, $p = 0.028$) and number of SGD plumes (total prevalence $r = 0.612$, $p = 0.020$, *Porites* GA $r = 0.744$, $p = 0.002$) located within the vicinity of each site (<1.5 km). These results show high nutrient loading may be affecting West Hawai’i’s coral health.

Additionally, sites surveyed in West Hawai‘i show a significant negative relationship between disease prevalence and distance from harbors/boat ramps (overall disease prevalence: $r = -0.402$, $p = 0.028$) (Figure 44). The most frequently occurring diseases, *Porites* growth anomalies and *Porites* tissue loss syndrome showed decreased prevalence with greater distance to these usage areas (*Porites* GA $r = -0.701$, $p = 0.0001$, *Porites* TLS $r = -0.658$, $p = 0.0001$). Similar to previous findings, the distribution of *Porites* trematodiasis, a disease known to be transmitted by fishes, particularly corallivores, was not associated with these locations (Aeby 2007).

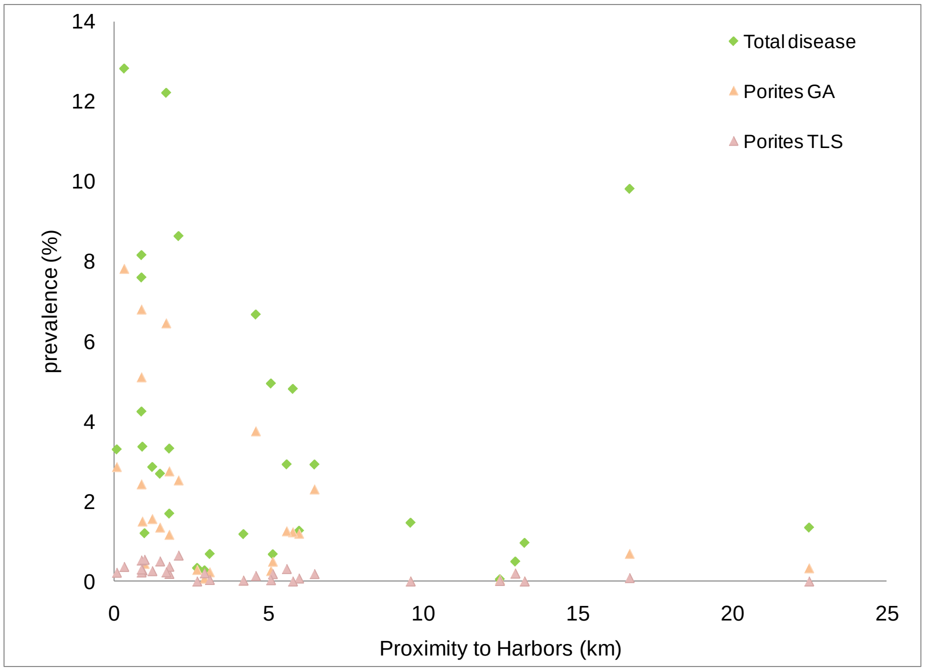


Figure 44. Disease prevalence in relation to site distance from harbors/boat ramps in West Hawai'i for overall disease prevalence (r = -0.402, p = 0.028), *Porites* growth anomalies (GA) (r = -0.658, p = 0.000) and *Porites* tissue loss syndrome (TLS) (r = -0.701, p = 0.000).

Prior studies have also found relationships between abundances of reef fish and prevalence of particular coral diseases. Various fishes are known to impact corals directly (such as the grazing of parrotfish) as well as transmit diseases (such as corallivorous butterflyfish) (Williams et al. 2010). Aeby et al. 1998 also found the highest trematodiasis at sites with intermediate percent coral cover. Using fish abundance data from WHAP surveys, sites were compared for Poritid disease prevalence to corallivorous butterflyfish and parrotfish abundances. However, no statistically significant relationships were found between these fish groups and coral disease prevalence for West Hawai'i's reefs.

Temporal comparisons

Comparisons of disease density (cases per square meter) between 2007 data and 2010 revealed no significant changes in disease densities between survey years (t = -1.46, p = 0.18). Though changes were not significant, *Porites* trematodiasis slightly increased at most sites (Figure 45).

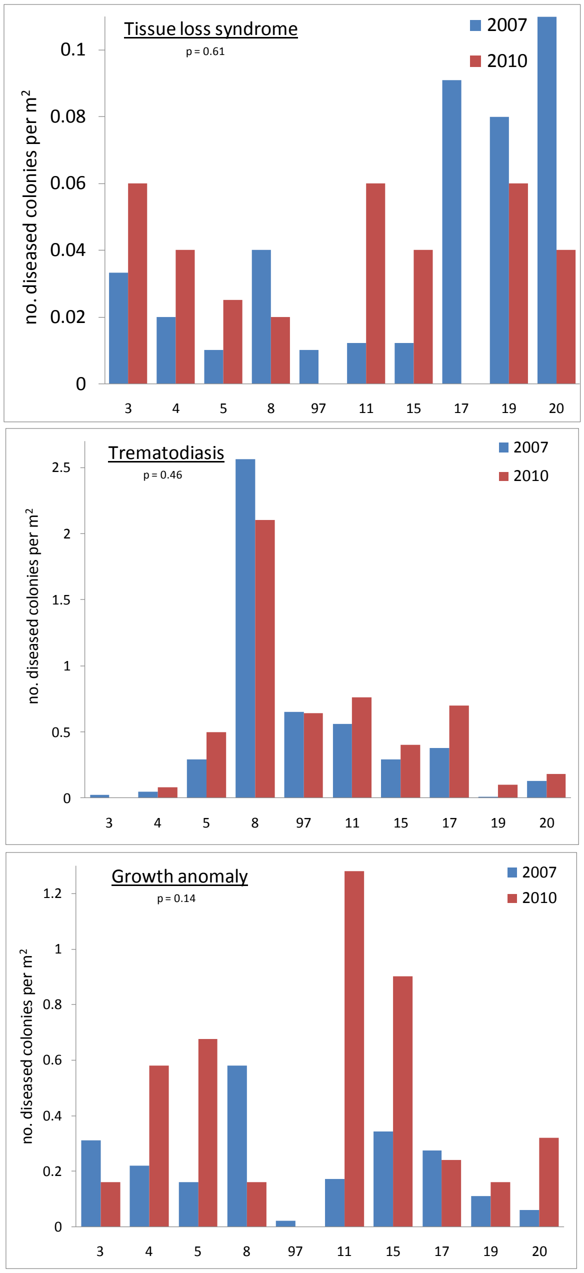


Figure 45. Comparison between survey years (2007 vs. 2010) of diseased colony densities for three types of Poritid conditions at 10 sites in West Hawai‘i.

cases of *Porites* growth anomalies and *Porites* tissue loss syndrome increased (though not significantly) at four sites: Sites 4 (Puakō), 5 (Mauna Lani), 11 (Honokōhau) and 15 (Keauhou). Each of these sites is located in close proximity to harbors and boat ramps. As described in the previous section, diseases have been positively associated with high human use.

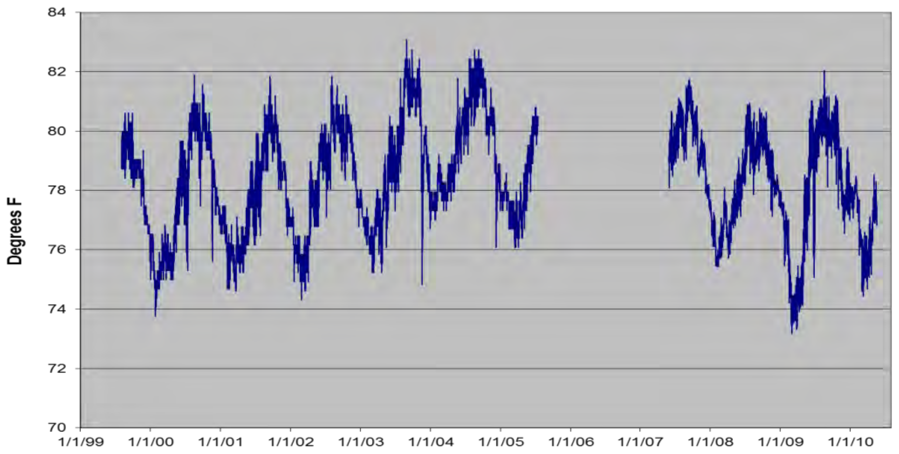
Although no significant change in disease frequency was found, the change in presence or absence of two diseases was noted. *Montipora* white syndrome was not recorded in surveys in 2010, though one case was recorded in 2007. *Pocillopora* tissue loss (including senescence reaction) and *Pavona varians* hypermycosis were not recorded in 2007 surveys, but occurred at multiple sites in 2010. For *Pavona varians* hypermycosis, this includes some sites previously surveyed (Table 8).

Temperature data

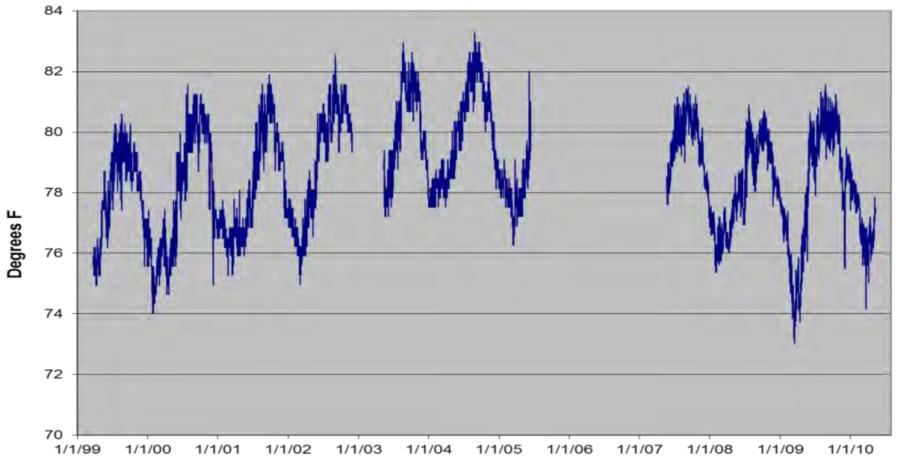
Hobo® temperature loggers (Onset Computer Corporation) were initially deployed at all West Hawai'i Fish Replenishment Area (FRA) sites (Figure 46). They were attached via cable tie to a coral head in the immediate vicinity of the center transect pin. Due to various circumstances including loss and flooding (i.e. multiple Hobo® Water Tem Pro units) a complete temperature record over the last decade is not available for any site. Fortunately fairly comprehensive temperature data exists for several West Hawai'i sites including a northerly site (Waiaka'ilio), a southerly site (Miloli'i) and a central site (Ke'ei) (Figure 47).

Examination of the temperature data reveals a marked similarity in water temperatures along coastal sites separated by considerable distances. From 1999 to 2005 there was a clear trend of increasing water temperatures along the West Hawai'i coastline. Over this 6 year period water temperatures increased by 1.8-2.7°F. For comparison, surface water temperate records at Koko Head, O'ahu indicated an increase of 1.4°F over a 50 year period (NMFS + IGLOSS corrected data provided by Paul Jokiel). Trend analysis suggested that if West Hawai'i water temperatures continued to increase unabated, the lethal thermal limit for corals (i.e. 30 day exposure to mean water temperature of 29.6°C) would likely be reached within a decade. The good news is that waters have not continued to increase and actually have decreased over the past several years.

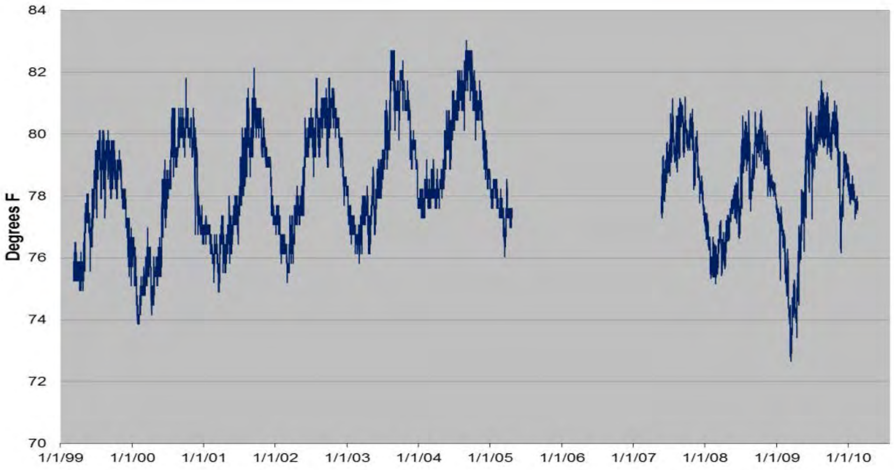
The most recent El Niño event to occur began in June 2009, peaked in November and December of the same year and waned in March 2010. It was effectively over by June 2010 (Jet Propulsion Laboratory http://sealevel.jpl.nasa.gov/science/elninopdo/elnino/). Although El Niño periods are characterized by warmer than usual equatorial waters, West Hawai'i coastal waters were only marginally warmer than the preceding two years. Mean water temperatures for the four month period of Oct 09-Jan10 was 78.9°F which was only 0.4 - 0.5°F warmer than the previous periods (Oct-07-Jan 08 = 78.5°F; Oct 08-Jan 09 = 78.6°F). Examination of the temperature records also shows that water temperatures in several of the previous years (e.g. 2004/2005) were generally higher than during the recent El Niño event.



Waiaka′ilio FRA



Ke′ei FRA



Miloli′i FRA

Figure 46. Temperature (°F) records for three West Hawai'i FRAs.

Fish Survey Methodology

Although the DAR fish survey protocol for West Hawai'i was initially designed to focus primarily on species which are the principal targets of the aquarium fishery it has proven to be a highly useful methodology for general coral reef monitoring and has been adopted by DAR for monitoring on other islands. It's important to note that all fishes are censused, whether they're aquarium species or not. While the protocol is particularly effective for assessing recruits, smaller site-oriented species and those not wary of divers; it also provides highly useful information on other groups including predators, invertebrates and "food" fishes. The specifics of the methodology are detailed in the O'ahu section (pg. 13).

DAR monitored 23 sites in West Hawai'i (Figure 2) bi-monthly, for a total of six surveys per year (five in 2000 due to logistic problems) until Jan. 2005 when the project was revamped at which time surveys became quarterly.

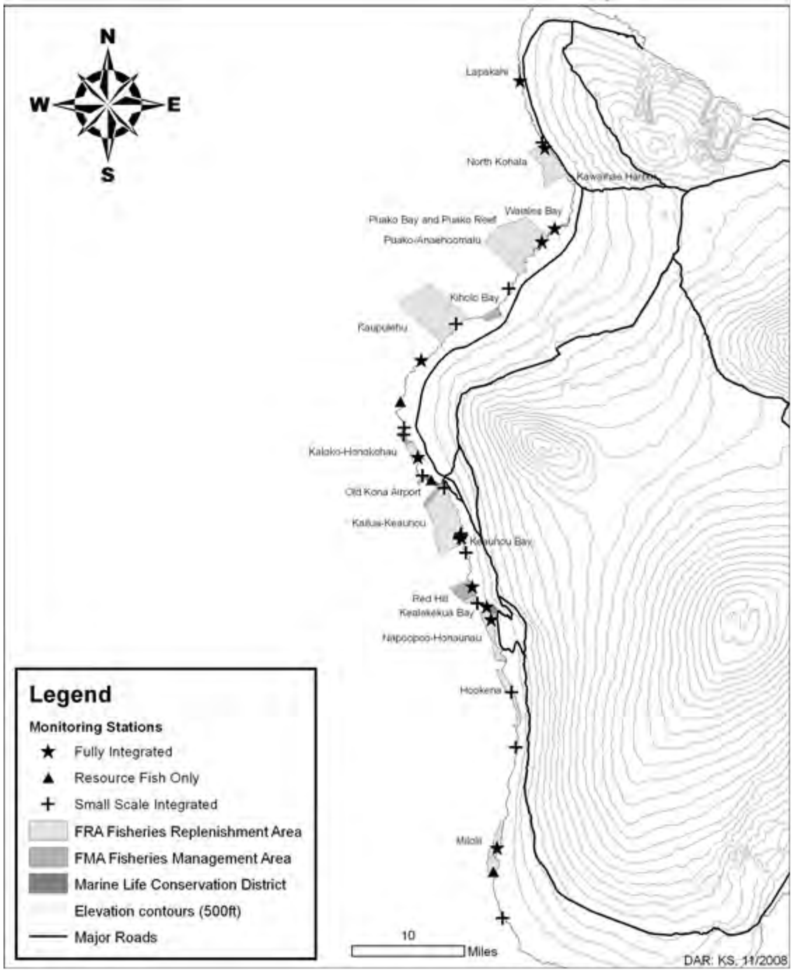


Figure 47. West Hawai'i monitoring sites.

These fixed transect surveys are noted as ‘small scale’ surveys in Table 9. Similar monitoring has also been conducted at three sites in East Hawai’i although on a less systematic schedule.

In addition to the transect surveys, a 10 minute ‘free-swim’ survey is also conducted by two divers in the areas surrounding the fixed transects. The purpose of this survey is to increase the ability to census uncommon or rare species and species of particular ecological interest such as cleaner wrasse (*Labroides phthirophagus*), ta’ape (*Lutjanus kasmira*), roi (*Cephalopholis argus*), crown-of-thorns (*Acanthaster planci*) and all species of terminal phase parrotfishes. Recording of species during the timed free-swim survey that were not observed on the transect surveys augments a site-specific species list.

In order to obtain better data on fish species that are heavily harvested and in demand for both subsistence, recreational and commercial food fisheries (i.e. ‘resource fish’) an enhanced monitoring protocol was newly implemented in 2005 at all new survey sites and at a number of existing monitoring sites (Table 9). ‘Resource fish’ are surveyed by a pair of divers swimming in parallel (10m apart), following a depth contour, for a five minute period. Each diver records all ‘resource fishes’ (main fishery target species) >15cm within a 5m wide belt. Rare, skittish or uncommon fishes such as sharks, rays or carangids which are observed any time throughout the survey dive are noted. Starting points for this survey are based on existing center pin site coordinates. End points are delimited by a diver deploying a surface float at the completion of the 5 minute survey. Sites which include all three types of monitoring are termed “Integrated” (Table 9).

Table 9. West Hawai’i monitoring sites with corresponding coordinates, status and survey type (INT=Integrated monitoring, SS=Small scale, RF=Resource fish only)

Site	District	Latitude	Longitude	Mean Depth (m)	Status	Type
Lapakahi	N. Kohala	20.1600000	-155.9001833	12.1	MLCD	INT
Kamilo Gulch	N. Kohala	20.0810167	-155.8680833	12.8	Open	SS
Waiaka′ilio	N. Kohala	20.0739167	-155.8645167	13.4	FRA	INT
Puakō	S. Kohala	19.9698833	-155.8488000	9.2	FMA	INT
‘Anaeho′omalu Bay	S. Kohala	19.9527500	-155.8661667	10.0	FRA	INT
Keawaiki	N. Kona	19.8911167	-155.9100667	13.3	FRA	SS
Ka′upulehu	N. Kona	19.8439500	-155.9809667	11.4	Open	SS
Makalawena	N. Kona	19.7965000	-156.0328833	10.2	FMA	INT
Ho′ona / Unualoha Pt.	N. Kona	19.7425100	-156.0557500	12.4	Open	INT
Wawaloli Beach	N. Kona	19.7088833	-156.0494951	9.8	Open	SS
Wawaloli	N. Kona	19.7000100	-156.0499100	13.6	Open	SS
Kaloko-Honokōhau	N. Kona	19.6709833	-156.0303333	13.1	FRA	INT
Papawai	N. Kona	19.6472500	-156.0229833	10.4	FMA	SS
Old Kona Airport	N. Kona	19.6421200	-156.0121000	12.2	MLCD	RF
S. Oneo Bay	N. Kona	19.6312000	-155.9930000	12.0	FRA	SS
Keauhou	N. Kona	19.5683833	-155.9693500	12.0	FRA	INT
Keauhou X	N. Kona	19.5733666	-155.9694666	11.6	FRA	SS

Keauhou Y	N. Kona	19.5698000	-155.9703666	15.2	FRA	SS
Keauhou Z	N. Kona	19.5670166	-155.9712666	16.5	FRA	SS
Kualanui Pt. (Red Hill)	N. Kona	19.5482667	-155.9623000	11.3	Open	SS
Red Hill	S. Kona	19.5052833	-155.9528833	13.9	FRA	INT
Keopuka	S. Kona	19.4829167	-155.9460000	10.3	Open	SS
Kealakekua Bay	S. Kona	19.4793000	-155.9327833	8.0	MLCD	INT
Ke′ei	S. Kona	19.4628167	-155.9268000	11.5	FRA	INT
Ho′okena (Kalahiki)	S. Kona	19.3691500	-155.8974000	11.1	FRA	SS
Ho′okena (Auau)	S. Kona	19.2978833	-155.8898833	13.6	Open	SS
Miloli′i/Honomalino	S. Kona	19.1673000	-155.9132500	12.3	FRA	INT
Okoe Bay	Ka’u	19.6421200	-156.0121000	16.5	FRA	RF
Manukā	Ka’u	19.0767167	-155.9039667	12.0	Open	SS

Shallow Water Resource Fish Surveys

Shallow water resource fish surveys collect data on the abundance of resource (desired) fish species in shallow water habitats where they are typically most abundant during the day in West Hawai′i. These surveys were designed to be comparable with our standard

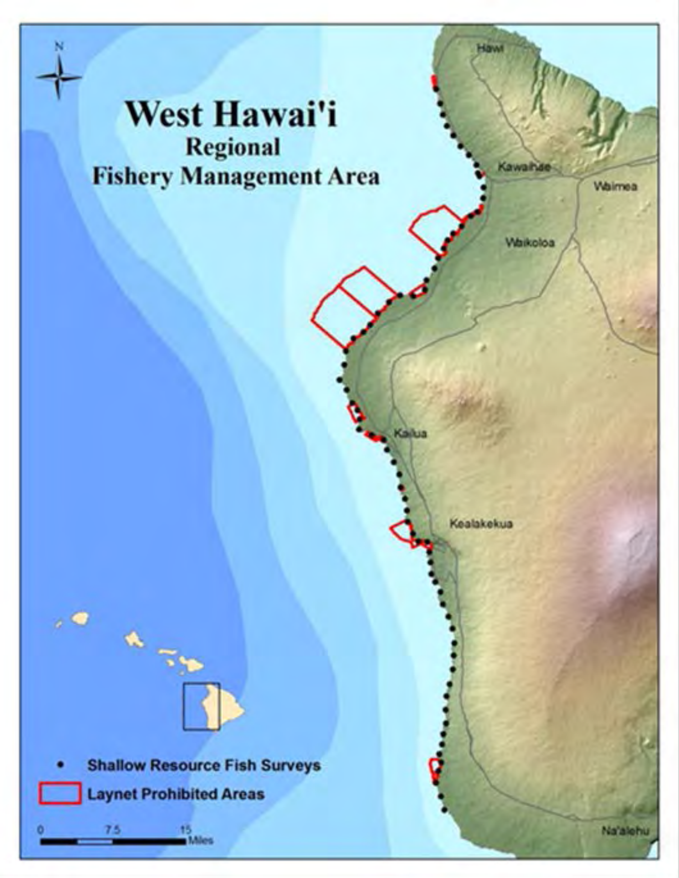


Figure 48. Map showing locations of West Hawai’i shallow water resource fish surveys and laynet prohibited areas.

resource fish surveys occurring in mid-depth habitats, and thus the methodology is very similar. As with the other resource fish surveys, distance covered is measured for every survey so that data can be analyzed on a per unit area basis. Initially 72 sites were selected evenly distributed along the coastline in 2-6m of water between our northern and southernmost permanent study sites (Figure 48). Using a GIS (ArcGIS 9.2), the 72 points were overlaid on a NOAA habitat map for the purpose of adjusting any sites that did not fall on hard-bottom habitat. Direction taken for the survey was predetermined when habitat was an issue. Otherwise survey direction (north or south) from the start point was determined in the field. Each site is surveyed only once.

The survey consists of a timed 10min swim along the coastline with divers being careful to remain in the target depth of 2-6m. When the survey is finished, the boat captain records an end point so that the distance covered can be later calculated. The dive team consists of two divers both surveying a single 5m wide belt. One diver is counting surgeonfish, goatfish, and introduced species above 15cm except for *Acanthurus achilles* and *A. triostegus* for which individuals above 10cm are recorded. The other diver counts parrotfish, wrasses, other resource fish, and selected rare butterflyfish of interest. Large predatory fish appearing off transect are also recorded.

Adult yellow tang surveys

To supplement data from the long-term monitoring program and to investigate the possibility of ‘spillover’ of adult fish from existing protected areas, we survey adult yellow tang populations in their prime daytime habitat, i.e. the deep edge of the shallow pavement zone around 3 to 6 m deep. Along the West Hawai‘i coast, shallow pavement areas generally have a distinct deep boundary where the main reef slope begins and where coral cover increases rapidly, and therefore the target habitat zone for our surveys was mostly well defined. Recognizing that adult yellow tang have highly clumped distributions, we developed a survey approach which allows divers to count yellow tang over long transects running approximately parallel to shore through the prime adult habitat.

There are 4 AYT sites within FRAs, 4 within long-term protected areas (LTP); and 8 in open, i.e. fished, areas. As adults have daily movements between diel and night time areas of up to at least 800 m we assumed that there could be spillover across protected area boundaries over at least that scale. We therefore established 4 open sites as ‘boundary’ sites, centered < 1 km from the nearest protected area boundary, and 4 as ‘open’ sites with mid-points > 2 km from the nearest boundary. Each area was surveyed 5 times in 2006 and 6 times in 2010 and analysis of the latest data will commence in the new year. The survey technique and initial findings of significant spillover of yellow tang from protected to open areas is contained in Williams et al. 2009.

Depth Stratified Random Surveys

In response to a long standing conflict between aquarium fish collectors and the local community at Ka‘ohe (Pebble Beach), South Kona, a DLNR community advisory group, the West Hawai‘i Fisheries Council (WHFC) recently recommended that the area at Ka‘ohe be closed to aquarium collecting. To maintain the existing balance of open and closed areas the WHFC also recommended that a similarly sized protected area be opened at to collecting Keauhou which is presently in an FRA. Considerable disagreement ensued however surrounding the nature and abundance of the resources within the proposed open area so DAR embarked on an effort to accurately assess the populations of a number of species of interest.   72 random, depth stratified, surveys were conducted at Keauhou (Figure 49) in July 2008 to derive area population estimates. Survey methodology closely follows the methodology described above for 25m fixed transects but with two rather than four 25mX4m transects at each random point. The Keauhou survey was repeated in August 2010 and similar surveys have been conducted at Ka'upulehu (August 2009) and Red Hill (April 2009).

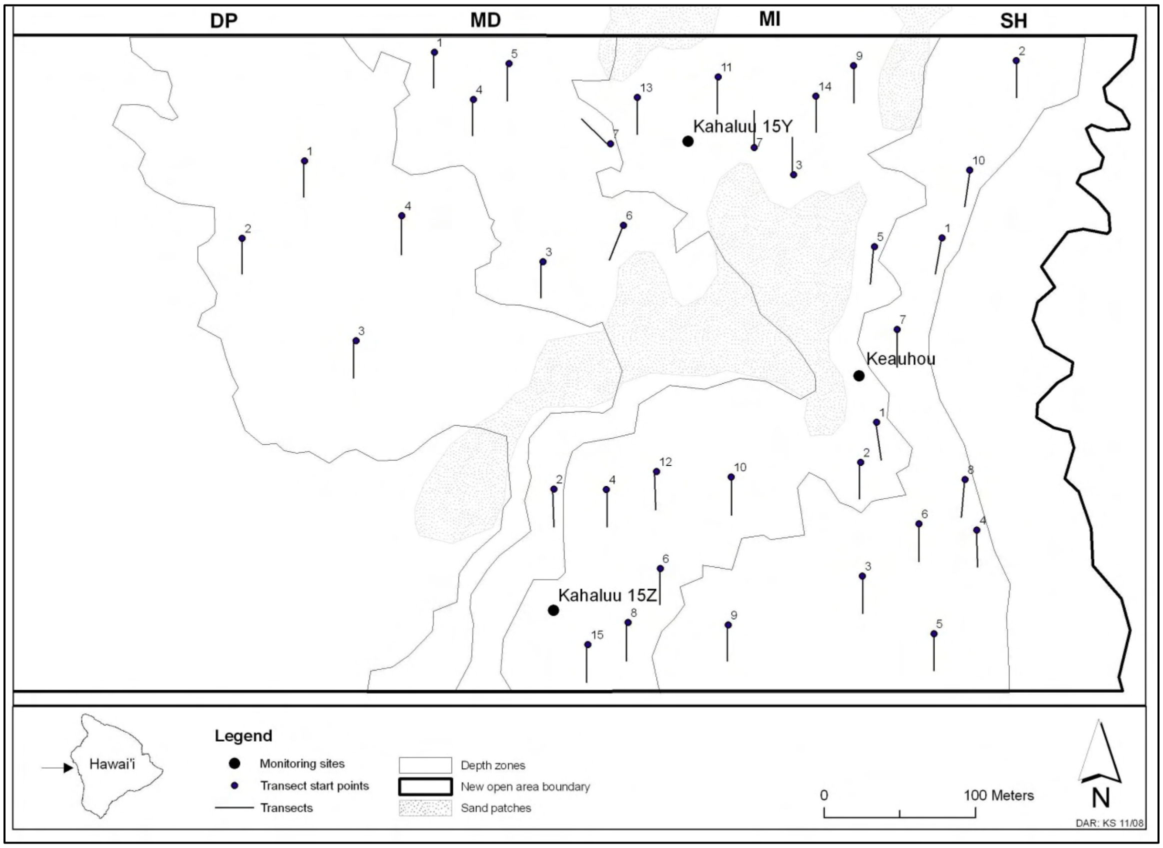


Figure 49. Map showing the locations of Keauhou stratified random fish population survey sites. The stratified depth zones are as follows: DP=24-30m, MD=18-24m, MI=9-18m, SH=3-9m.

Retrospective Surveys

Several long-term retrospective surveys, primarily directed at fish populations, are being conducted at 3 West Hawai'i sites. The sites and the date of the initiation of the original surveys are as follows: Puako, South Kohala (1979), Ke'ei, South Kona (1978) and Honaunau, South Kona (1975). So that new data is comparable with historical data, the same transect locations and survey methodologies are employed as in the original studies. Methods vary by locations, but all are based on standard dimension belts or search areas. Additional benthic data are also being collected. This work is presently under analysis.

Fish Surveys Results

West Hawai'i

Fishes on West Hawai'i reefs may be regarded as falling into three groups based upon human utilization. Resource or 'food' fish such as jacks (Carangidae), goatfishes (mullidae) and parrotfishes (Scaridae) are those targeted for food by recreational and commercial fishers. Aquarium fish are those which are harvested, usually in the smaller size classes, by commercial aquarium collectors. Although there are some species which fall into both groups (e.g. kole, *Ctenochaetus strigosus* and Achilles tang, *Acanthurus achilles*) for the present study these are classified solely as aquarium fishes. The third group ('other') is species which are harvested neither for food nor for aquaria.

The overall number of 'other' fishes, those which are not substantially harvested for either food or for the aquarium trade, did not change significantly at West Hawai'i sites over the last 11 years although individual species within this group may have. In contrast, the abundance of both aquarium and food fishes increased significantly over the same time period (Figure 50). For aquarium fishes it is clear that a substantial part of the increase in overall numbers is due to the implementation in 2000 of a network of

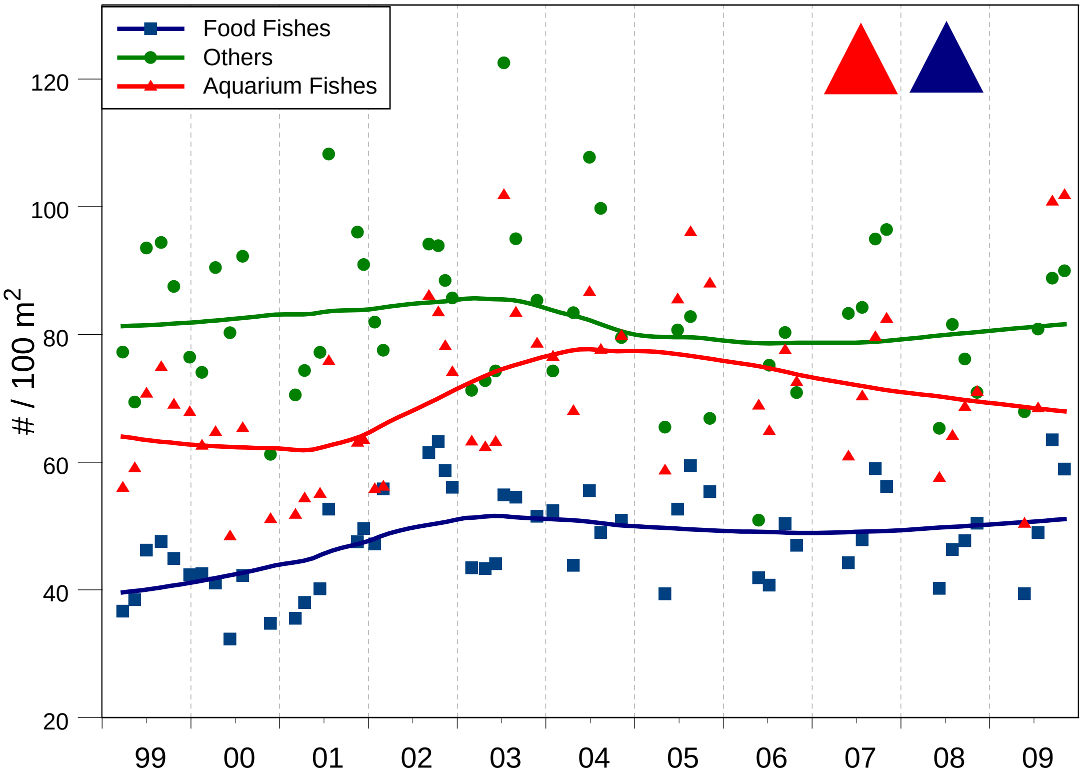
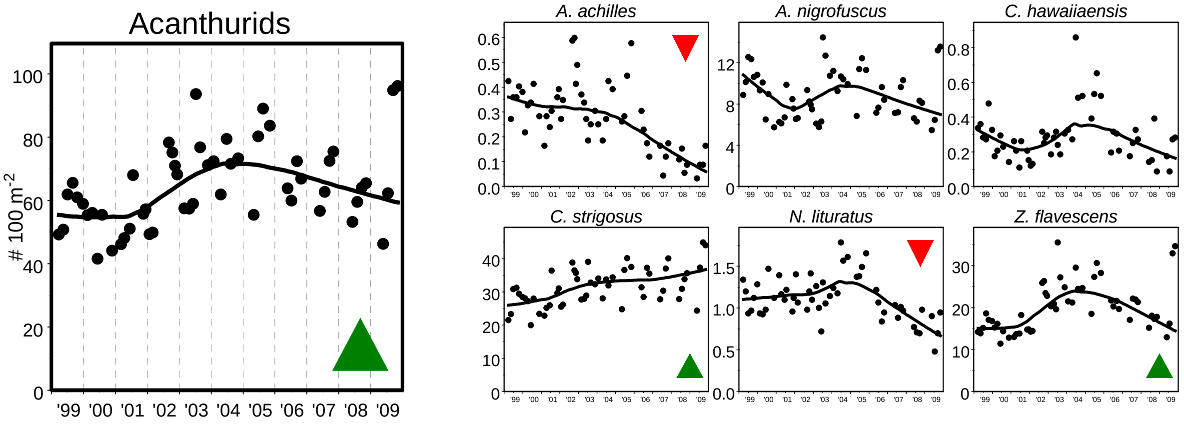
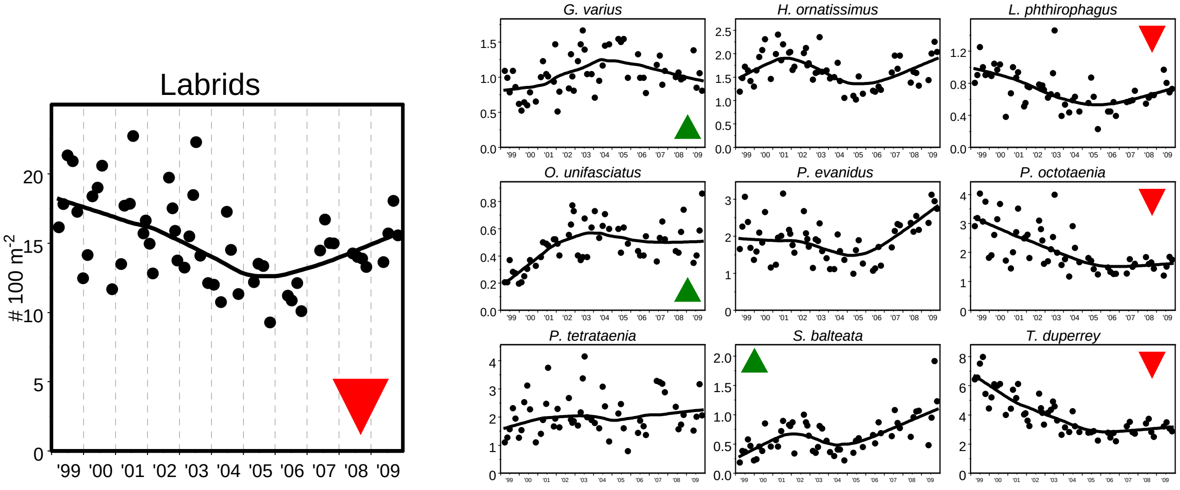


Figure 50. Overall temporal trend in mean fish density of three major fish utilization groups at West Hawai'i sites. Aquarium Fishes represents top 20 collected species. Trend line represents LOESS (locally weighted polynomial regression) smoothing procedure applied to data. Closed triangle = $p<0.05$ (Spearman rank test).

Fish Replenishment Areas (FRAs) along the West Hawai'i coast. The aquarium fishery in Hawai'i is economically the largest inshore fishery in the state and certainly the most conflict filled. The management importance of comprehensive and extensive monitoring such as has been underway in West Hawai'i for over a decade cannot be underestimated when addressing the issue of this highly controversial fishery. In depth analysis of aquarium collecting impacts is contained in a later section (pg. 84).

Examination of the temporal trends of some of the most common reef fish families indicates that acanthurids have been increasing over the past eleven years while labrids have decreased (Figure 51). Overall, chaetodontids and pomacentrids have been relatively stable although some species within the family have either increased or declined.





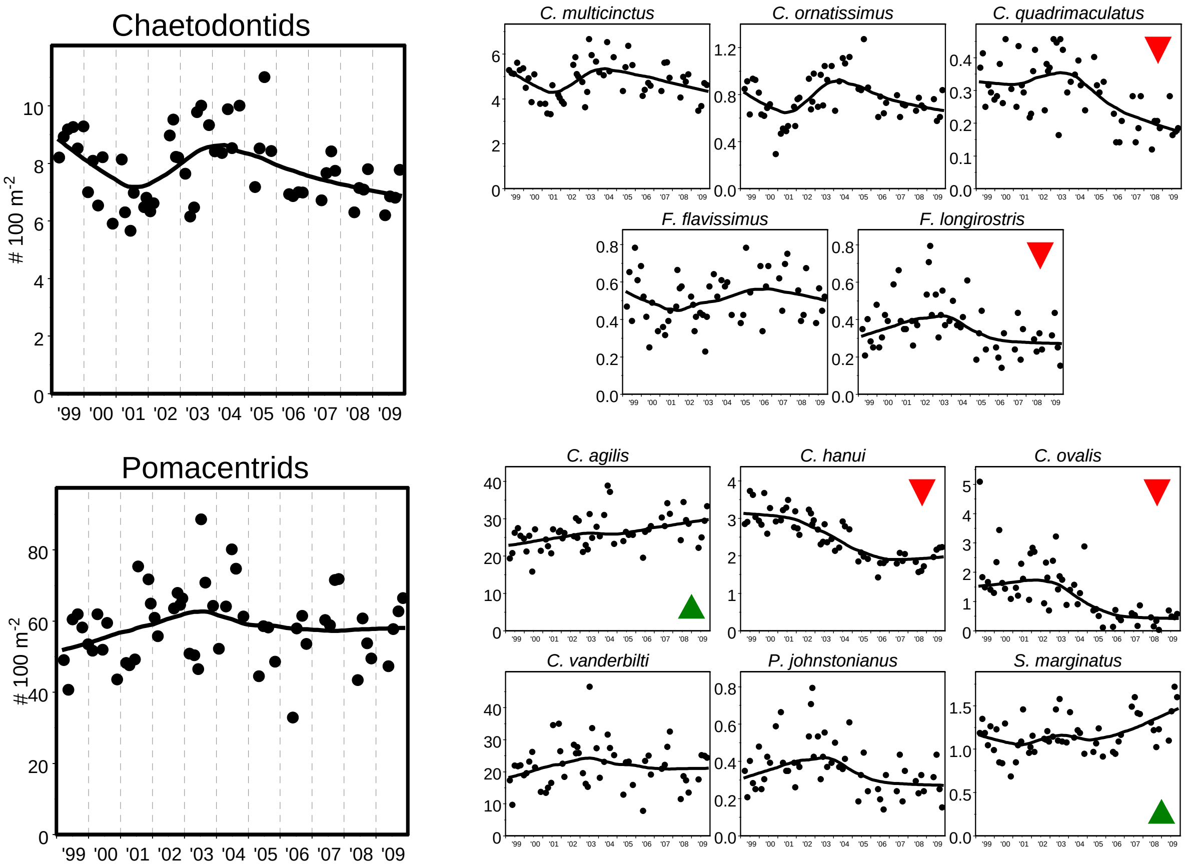


Figure 51. Temporal trend in mean fish density for four families on West Hawai'i sites. Trend line represents LOESS (locally weighted polynomial regression) smoothing procedure applied to data. Open triangle = p<0.1, Closed triangle = p<0.05 (Spearman rank test).

As noted, the species within each family can vary substantially in temporal trends as exemplified by the wrasses where three species increased, two decreased and three remained stable. The reasons for such differences are not clear but it does appear that with only a single exception (*Stethojulis balteata*) most wrasses are in a period of decreasing abundance, undoubtedly influenced by low levels of recent recruitment. Among the acanthurids the two species exhibiting the most substantial increases (*Zebrasoma flavescens* and *Ctenochaetus strigosus*) are also the most heavily collected aquarium species comprising approximately 91% of the total catch. It is also apparent however that a number of less abundant aquarium-targeted species such as the moorish Idol (*Zanclus cornutus*) and lei triggerfish (*Sufflamen bursa*) have not responded to the increase in protected areas and have actually decreased in West Hawai'i since 1999 (Figure 52).

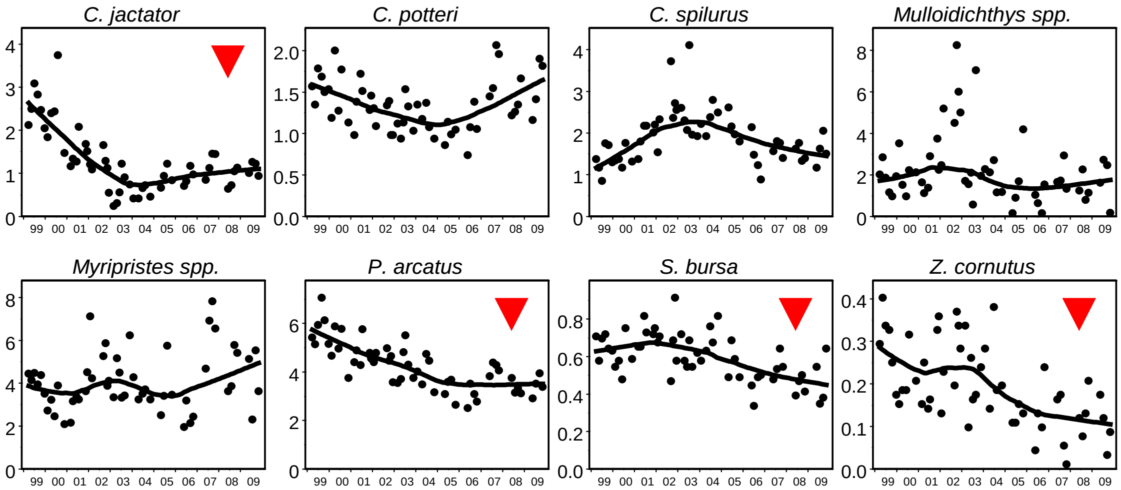


Figure 52. Temporal trend in mean fish density for various fish species of interest at West Hawai'i sites. Trend line and triangles as above.

Introduced Species

Ta'ape

From their initial introductions, ta'ape have clearly undergone an expansive period of population growth. Ta'ape were only introduced to the island of O'ahu but have subsequently spread widely throughout the islands of the archipelago. Based on free swim site surveys there was a trend for increasing numbers from 1999 to 2004 followed by a subsequent of unknown cause.

Transect data reflects overall low abundance of this species in the reef areas of the study sites (2007-2009 mean = $0.23/100m^2$). Similarly ta'ape are rarely found in the shallower water where resource fish surveys are conducted (mean = xx/100m2). While Ta'ape are numerous in some locales usually along drop-offs and deeper reef areas, their distribution is highly patchy (characteristic of a schooling species) and they are not at all abundant in many reef areas in West Hawai'i. Similar to West Hawai'i, at some shallow reef locations such as in Kāne'ohe Bay, ta'ape numbers also appear to have declined from earlier periods (George Losey, pers. comm.).

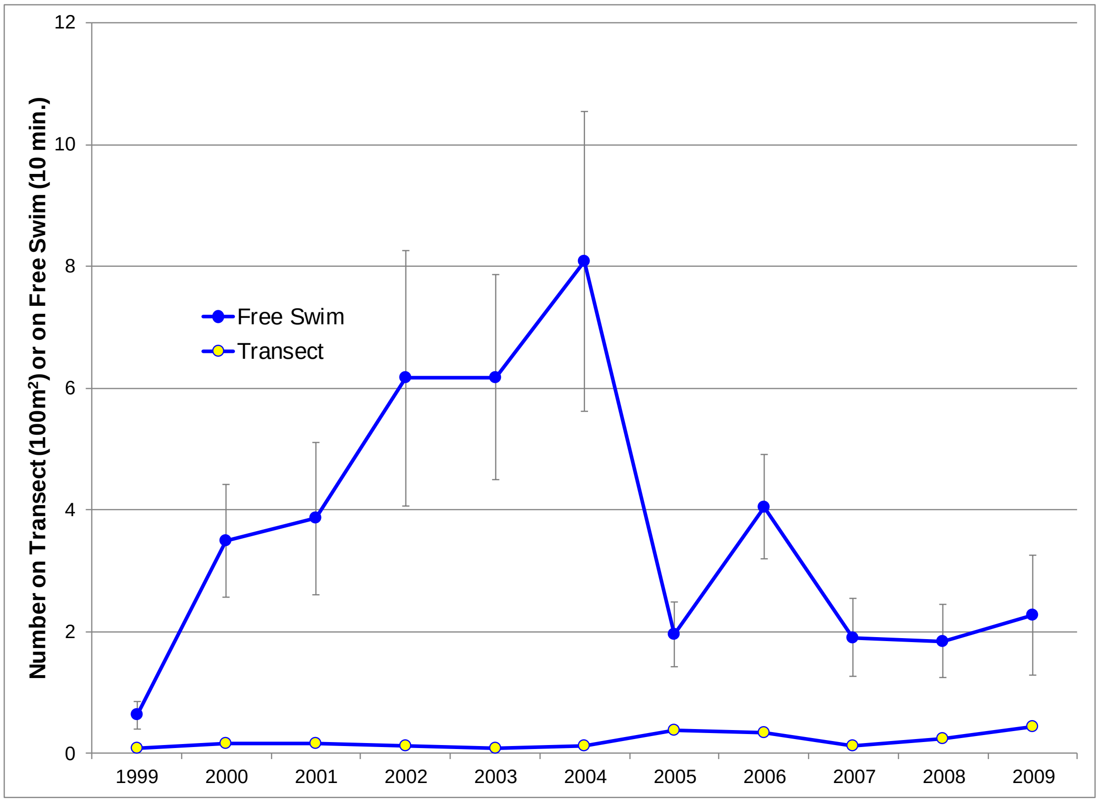


Figure 53. Ta′ape density trends on West Hawai'i transects and 10 minute free swim surveys.

Roi

Of the six species of groupers (family Serranidae) introduced to Hawai'i only roi, *Cephalopholis argus* has become established. There were more roi introduced (n=2385) than any other grouper and it was the only species introduced to the Island of Hawai'i (400 fish from Moorea in 1956). It now occurs on all the main Hawaiian Islands and in low numbers on some of the Northwest Hawaiian Islands.

As evidenced by transect and free-swim data (Figure 15) overall roi abundance at West Hawai'i sites was increasing since at least 1999 to 2004. West Hawai'i retrospective studies at Hōnaunau and Ke'ei indicate that roi populations only began to increase in the 1990's, three decades after their initial introduction. Randall notes in 1987 that "This fish (roi) has not become abundant. It has not developed a population approaching that of its native stock in the Society Islands."

Since 2004 however there has been a marked downturn in observed overall roi abundance both on West Hawai'i transect (56% decrease) and free swim surveys (55% decrease) (Figure 54). These declines occurred at 20 of 23 surveyed sites.
This recent decline may be related in part to an unusual fish die off in West Hawai'i which first became apparent in May 2006. At that time seven dead roi were found washed up on the beach at `Anaeho`omalu, North Kona (Travis Hall, pers. Comm.).

Several other species were also noted at this time including several goatfish (*Mulloidicthys sp*.), a surgeonfish (*Acanthurus dussumieri*) and a moray eel. Over the next five months there were numerous reports of dead and dying fishes, typically floating or struggling at the surface, along a wide stretch of the West Hawai'i coastline. In most instances the fish had distended swim bladders which prevented still live fish from returning to the bottom. Individuals of three species (*C. argus*, *C. sordidus* and *A. olivaceus*) were observed underwater live but having difficulty maintaining equilibrium. Roi were by far the most commonly involved species in the die off incidents but a number of other species also perished comprising a wide range of families, feeding types and depth ranges (Table 10). Similar undocumented reports of floating fish (typically roi) were also received from Maui, O'ahu and Moloka'i.

Ten specimens of nine species were collected and sent to the National Wildlife Health Center, U.S. Geological Survey in Honolulu for necropsy. Diagnostic Case Report findings typically indicated swim bladder distension, a variety of incidental lesions and, in two cases, atrophy of the liver. No gross or microscopic lesions were considered severe enough to cause death and the cause of death remains unknown (Thierry Work, pers. Comm.).

Table 10. List of fishes collected or reported in West Hawai'i die-off.

Family	Species	Common Name
Acanthuridae	*Acanthurus dussumieri*	eyestripe surgeonfish
Acanthuridae	*Acanthurus olivaceus*	orangeband surgeon
Acanthuridae	*Acanthurus triostegus*	convict surgeonfish
Acanthuridae	*Ctenochaetus hawaiiensis*	black surgeonfish
Acanthuridae	*Naso hexacanthus*	sleek unicornfish
Acanthuridae	*Zebrasoma flavescens*	yellow tang
Balistidae	*Melichthys niger*	black durgon
Balistidae	*Rhinecanthus aculeatus*	lagoon trigger
Balistidae	*Rhinecanthus rectangulus*	reef triggerfish
Chaetodontidae	*Chaetodon auriga*	threadfin butterflyfish
Chaetodontidae	*Forcipiger flavissimus*	forcepsfish
Kuhliidae	*Kuhlia sandvicensis*	Hawaiian flagtail
Lutjanidae	*Lutjanus kasmira*	ta'ape (blueline snapper)
Mullidae	*Mulloidichthys sp.*	goatfish
Muraenidae	*Gymnothorax sp.*	moray eel
Scaridae	*Chlorurus sordidus*	bullethead parrotfish
Scaridae	*Scarus rubroviolaceus*	redlip parrotfish
Serranidae	*Cephalopholis argus*	roi (Peacock grouper)
Serranidae	*Epinephelus quernus*	Hawaiian grouper

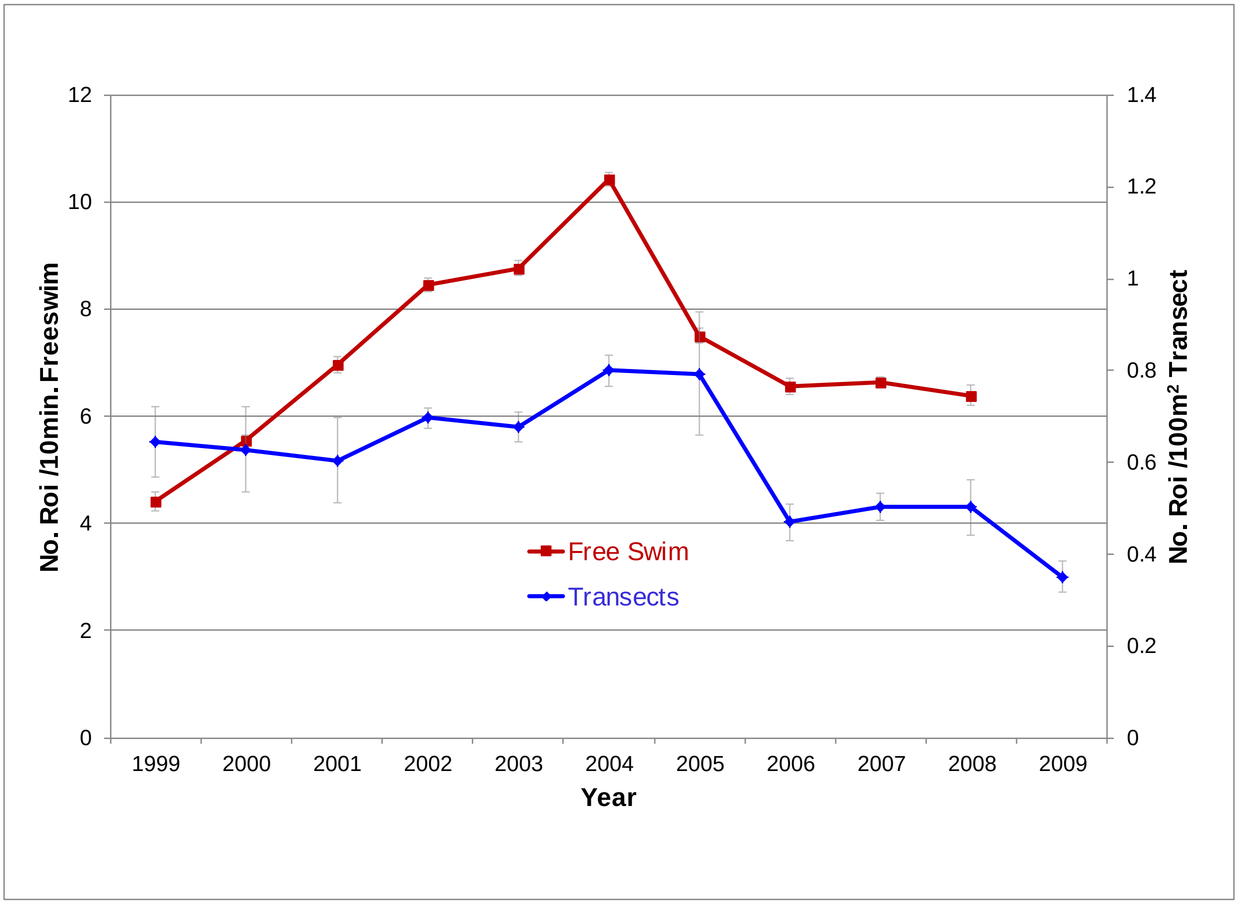


Figure 54. ***C. argus*** **density trends in West Hawai'i. Data based on two types of underwater visual surveys at 23 long-term monitoring stations spread over approximately 100 miles of coastline. Each site was surveyed 4-6 times a year.**

The following year in 2007 only a single fish was reported or found suffering similar conditions, that being the deep-sea swallower *Kali indica* (Fig 55).

Figure 55. Deep-sea swallower, *Kali indica* with inflated swim bladder.

Puffer Die-Off

Early in 2010 a die-off of large puffers, with external symptoms quite similar to the previous mortalities, began to occur on Maui and Hawai'i Island. Over the ensuing months low numbers of dead and dying puffers increased (Figure 56) and were progressively reported up the island chain as far as Kaua'i (Oct. 2010). The overall reported numbers of dead puffers decreased as fall approached. Greater than 95% of all reported mortalities were of the stripebelly puffer, *Arothron hispidus* with a few porcupine fish (*Diodon hystrix*), Hawaiian Whitespotted toby (*Canthigaster jactator*) and spotted puffer (*Arothron meleagris*) (Thierry Work, pers. comm.)

A network of concerned citizens and agency people were actively involved in this incident, filing reports of mortalities and shipping dead fish to Dr. Thierry Work, Wildlife Disease Specialist with the U.S. Geological Service (USGS) in Honolulu. As of Nov. 18, 2010 a total of 106 puffers had undergone both gross and microscopic examination. All assays for viruses (including electron microscopy) have so far come up negative and all attempts to incriminate any other infectious agent as a cause have come to naught. At present, the current last hypothesis is that these fish are being exposed to some sort of environmental toxin, probably natural given the widespread extent of mortalities.

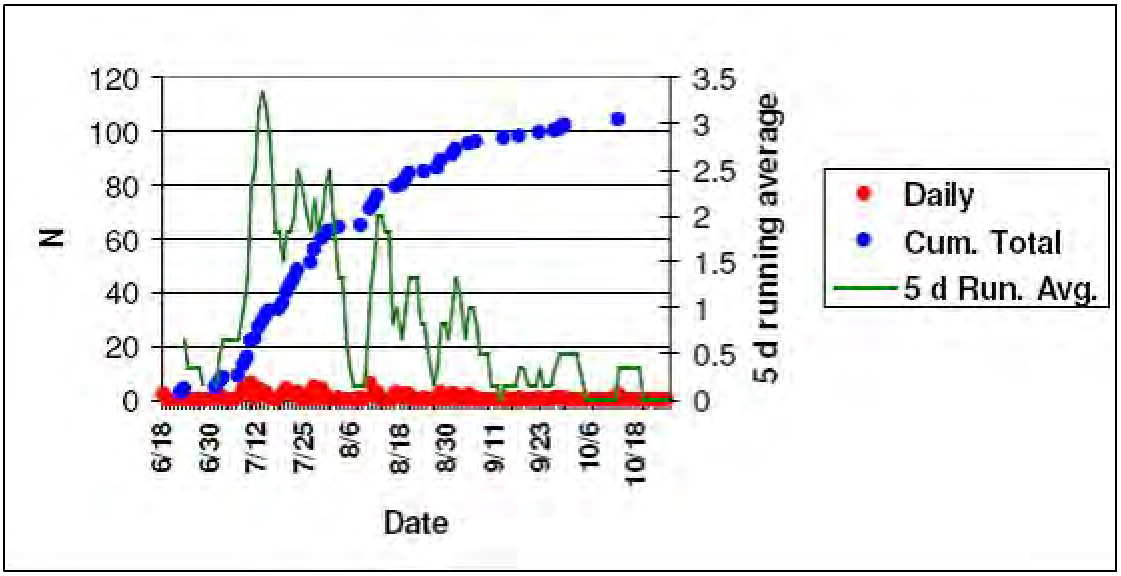


Figure 56. Number of dead puffers examined as USGS Honolulu Field Station.

West Hawai'i monitoring data indicates a substantial decline has occurred in the spotted puffer (*A. meleagris*) with a precipitous drop in 2009/2010 (Figure 57). Other large puffer species were too infrequently counted on transects to determine changes in abundance. The decline in *A. meleagris* is somewhat perplexing in that this species did not constitute a substantial portion of the reported and examined mortalities. It is of interest to note that two separate dead puffers of this species were found face down underwater at Ke'ei (photo in Fig p) and in a Wai o Pae tide pool (Jennifer Turner, pers. comm.). In a somewhat similar vein, West Hawai'i monitoring data indicates that the Hawaiian spotted toby (*C. jactator*) declined substantially over the past decade. It's unknown whether similar sorts of mortalities are responsible.

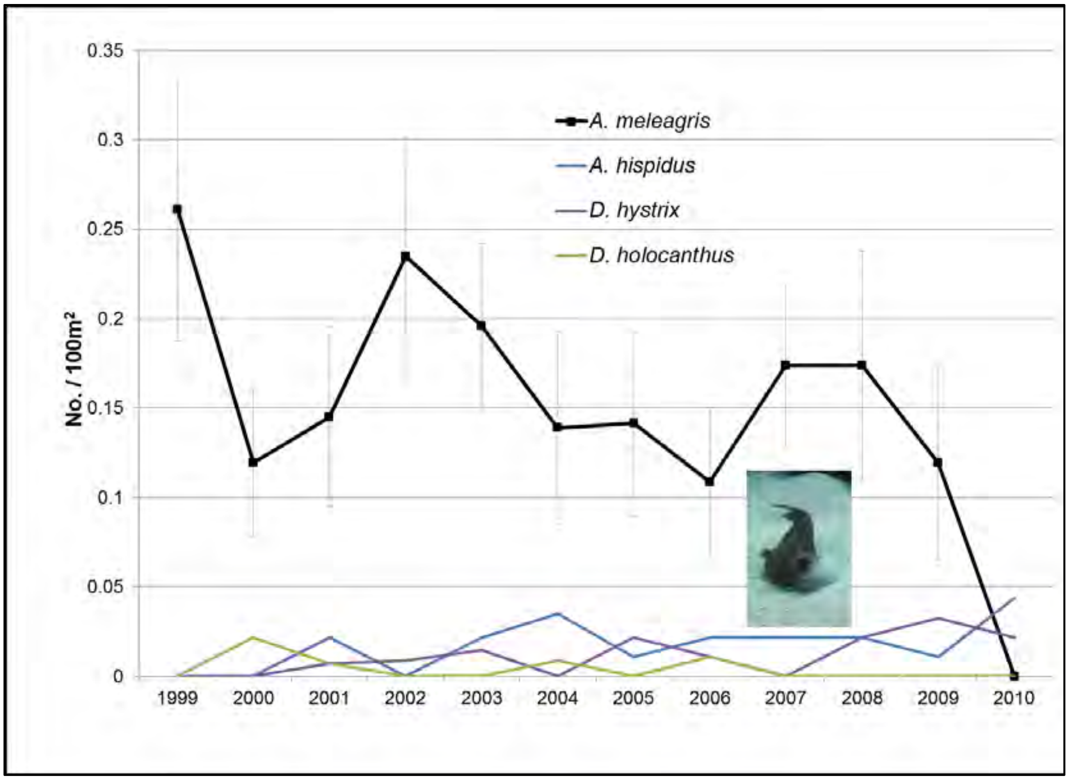


Figure 57. Pufferfish abundance trends in West Hawai'i.

Roi impacts

As previously noted, although roi was introduced to augment declining populations of food and game fishes it has not been well received by most Hawai'i fishermen due to concerns about ciguatera and more recently about negative impacts to native fish populations. As with ta'ape, roi have been blamed for a multitude of problems on the reefs, including a decline in important aquarium fish such as the yellow tang *Zebrasoma flavescens*. Concern has also been expressed over putative impacts on food fishes and invertebrates

The marked decline in the numbers of West Hawai'i roi in recent years provides an unprecedented opportunity (i.e. a 'natural' experiment) to examine responses of the reef fish community to a >50% reduction in the roi population. This work is currently planned for the coming year. It is anticipated that if roi are having major impacts on the abundances of other species they prey upon there would be detectible and consistent temporal relationships between roi and prey species abundance. An examination of roi and two of the most abundant species in roi's prime habitat the yellow tang (*Zebrasoma flavescens*) and kole (*Ctenochaetus strigosus*) fails indication direct negative impact on either species. From 1999 to 2004 as roi populations were increasing, both kole and yellow tang populations were increasing. Subsequent to 2004 as roi populations decreased yellow tans similarly decreased whereas kole numbers were fairly stable (Figure 58). This is not the pattern that would result if roi abundance was a major determinant of the abundance of these other two species.

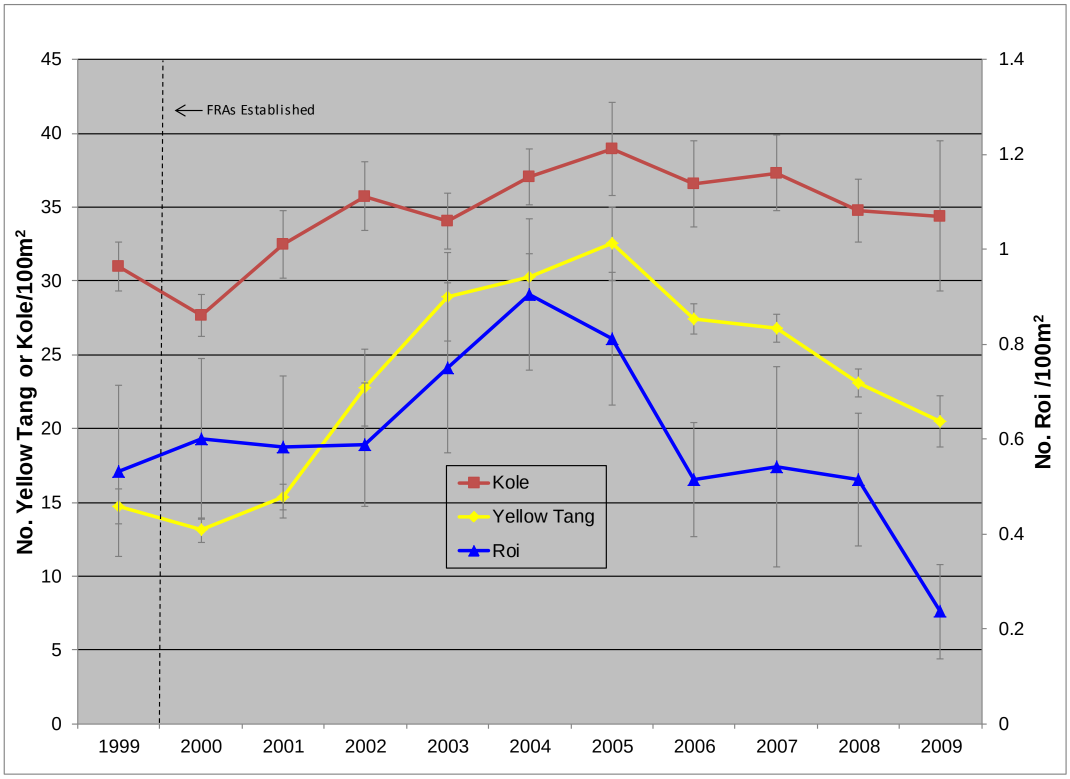
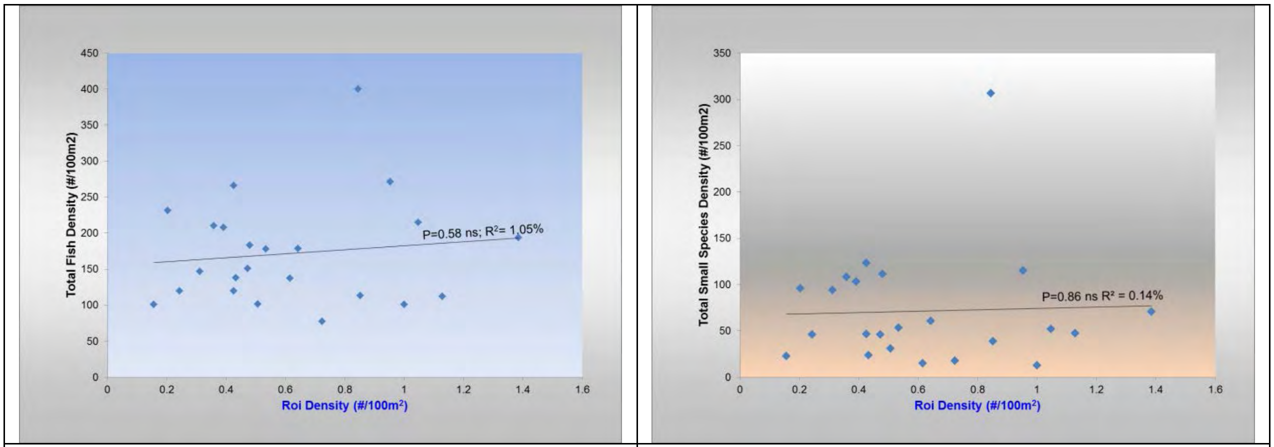


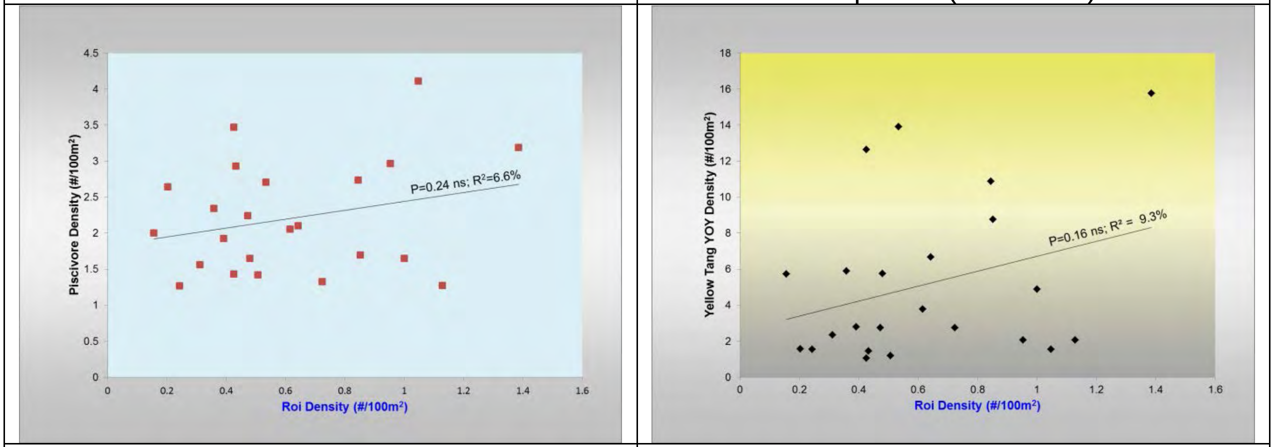
Figure 58. Temporal trends of the numbers of kole, yellow tang and roi in FRAs. Young of Year (YOY) not included.

Another complementary way of examining the extent and magnitude of potential roi impacts on West Hawai'i reef fish populations is to examine the relationship between roi abundance at each of the monitoring sites with the abundance of various species and functional groups at the sites. Figure 59 illustrates this approach for six different groups of fish; none of which show a significant negative relationship with roi abundance. In other words having more roi in an area does not result in having less; A) total fish (p=0.58), B) small prey fish (p=0.86), C) other piscivores (p=0.24), D) yellow tang YOY (0.16), E) kole YOY (p=0.79) or F) all YOY (p=0.86).



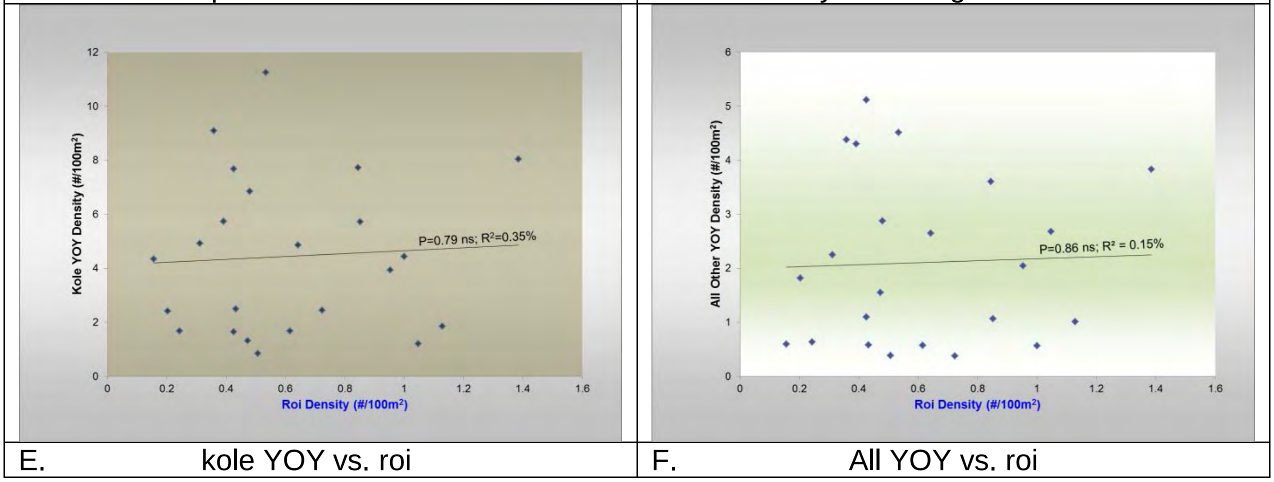
A. All fish vs. roi

B. Small fish species (<15cm TL) vs. roi



C. All piscivores vs. roi

D. yellow tang YOY vs. roi



E. kole YOY vs. roi

F. All YOY vs. roi

Figure 59. Relationship between Roi and various West Hawai'i fish population parameters.

Aquarium Species

The aquarium collecting industry in Hawai'i and especially in West Hawai'i has long been a subject of controversy. In contrast to other areas in the State, the West Hawai'i aquarium fishery has undergone substantial and sustained expansion over the past 30 years (Figure 60). Approximately 75% of fish caught in the State and 67% of the total aquarium catch value comes from the Big Island and almost exclusively from West Hawai'i (Table 11).

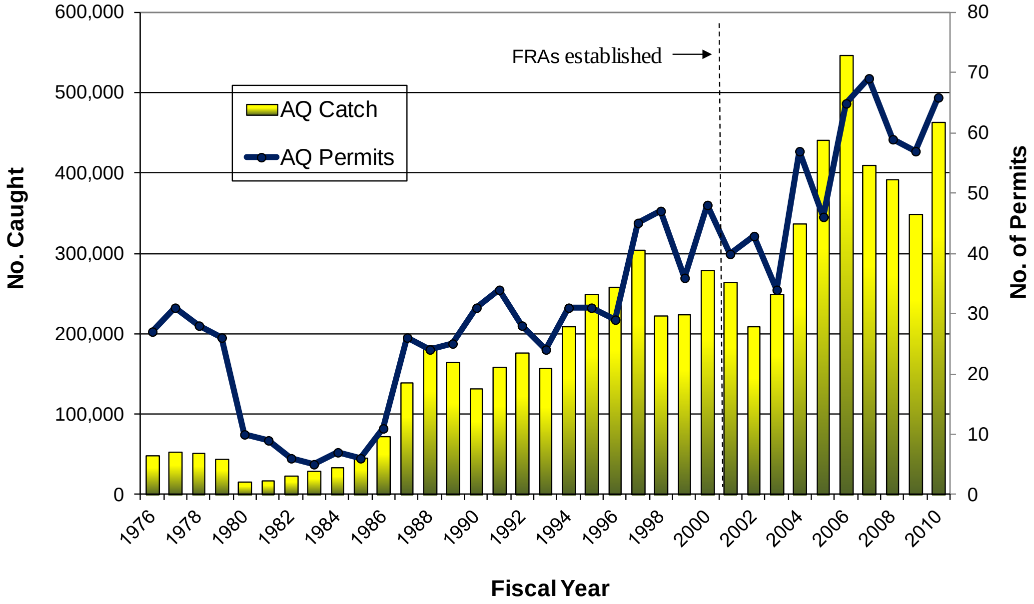


Figure 60. Number of aquarium animals collected and number of commercial aquarium permits in West Hawai'i for fiscal years 1976-2009.

Table 11. Changes in West Hawai'i aquarium fishery since implementation of the FRAs. Dollar value is adjusted for inflation.

	FY 2000	FY 2009	Δ
No. Permits	48	57	19% ↑
Total Catch	279,606	349,250	25% ↑
Total Value	$745,129	$1,271,329	71% ↑
% of State Fish Catch	70%	75%	5% ↑
% of State Fish Value	67%	69%	2% ↑
% of State Total Catch	55%	63%	8% ↑
% of State Total Value	59%	67%	8% ↑

The West Hawai'i Regional Fishery Management Area, which spans the entire West Hawai’i coastline, was established in 1998 primarily in response to the activities of aquarium collectors working the coastline. Overall, the marine aquarium fishery in the State of Hawai'i is one of the most economically valuable commercial inshore fisheries with FY 2009 reported landings of 557,673 specimens and a total value of $1.08 million. The reported values may be underestimated by a factor of approximately 2 to 5X (Cesar et al. 2002, Walsh et al. 2003). Walsh et al. 2003 provides an historical overview of the commercial aquarium fishery in Hawai'i.

In 1999, DAR in conjunction with a citizen's advisory group, the West Hawai'i Fisheries Council (WHFC), established a network of 9 Fish Replenishment Areas (FRAs) where aquarium collecting was prohibited. Along with existing protected areas 35.2% of the coastline was off limits to collecting.

In order to investigate the effectiveness of the FRAs to replenish depleted fish stocks, a consortium of researchers established the West Hawai'i Aquarium Project (WHAP) in early 1999. Funding was secured for the early years of the project through the Hawai'i Coral Reef Initiative Research Program (HCRI-RP), a federal initiative under the aegis of the National Oceanic and Atmospheric Administration (NOAA). Subsequent funding has been provided by Coral Reef Monitoring Grants under NOAA's Coral Reef Conservation Program. The initial project researchers were Dr. Brian Tissot, Washington State University, Dr. William Walsh, DAR/DLNR and Dr. Leon Hallacher, University of Hawai'i-Hilo. They have been joined in recent years by Dr. Ivor Williams, National Marine Fisheries Service, Dr. Mark Hixon, Oregon State University and Dr. Helen Fox, World Wildlife Fund.

WHAP established 23 study sites (Figure 47, Table 9) along the West Hawai'i coastline in early 1999 at 9 FRA sites, 8 open sites (aquarium fish collection areas) and 6 previously established Marine Protected Areas (MPAs) to collect baseline data both prior to and after the closure of the FRAs. The MPAs are MLCDs and Fishery Management Areas (FMAs), which have been closed to aquarium collecting for at least 9 years and were presumed to have close to "natural" levels of aquarium fish abundances. They serve as a reference or 'control' to compare with the FRAs and open areas.

The overall goals of WHAP were two-fold: 1) To evaluate the effectiveness of the FRA network by comparing targeted aquarium fishes in FRAs and open areas relative to adjacent control sites and, 2) To evaluate the impact of the FRA network on the aquarium fishery.

The general rationale for WHAP's goals was based on the premise that changes in FRAs and open areas can best be estimated by comparing them to other areas which have been protected for relatively long periods of time. These areas (MPAs) serve as control areas against which the FRAs are measured both before and after the closure of the FRAs. This rationale is derived from a well-known statistical procedure known as the BACI (Before-After-Control-Impact) procedure (Tissot et al, 2004) which is an especially appropriate and statistically powerful method for examining FRA effectiveness.

For this study FRA effectiveness (R) is measured statistically as the change in the difference between each FRA and the mean of all MPA sites during each survey (control vs. impact) from before (1991-2000) vs. after (2007-2009) FRA establishment. Details on study methodology and this procedure are covered in (Tissot et al, 2004, Division of Aquatic Resources 2004).

R measures the changes within the FRA as a percent of the baseline abundance relative to control sites. In the case of this study, R is a measure of the effectiveness or 'protective value' of the FRAs. That is, what effect is increased protection having on targeted fish?

Scientific studies on reef fishes are notoriously difficult due to the very high variability of fish abundance in both time and space. Even with a rigorous statistical design (such as

BACI) and 11 years of study, it is difficult to statistically detect changes in abundances except for the most common species that exhibit relatively large changes.

Fish Replenishment Areas (FRAs)

Changes in density for the ten most collected aquarium fishes across all FRAs are shown in Table 12. Yellow tang density increased markedly (and significantly) in the FRAs while seven of 10 decreased (Achilles tang, multiband butterflyfish and brown surgeonfish decreased significantly). However these seven species represent <6% of the total West Hawai'i aquarium catch.

The FRAs were 'effective' (increases in FRAs relative to long term MPAs) for eight of the top 10 collected species with three being statistically significant. As with density there were significant decreases in effectiveness for the multiband butterflyfish and brown surgeonfish. Both of these species are not very heavily collected averaging <2000 individuals per year over the last 5 years (Table 14) and are fairly abundant on the reef. It's thus not clear why their numbers are declining in the FRAs. These two species exhibited overall declines in all three types of areas with the greatest decrease in the protected areas (FRAs and MPAs). For the brown surgeonfish this may be the result of a competitive interaction with yellow tang and/or goldring surgeonfish (aka kole). As their numbers have increased the brown surgeonfish's has decreased. Both yellow tang and brown surgeonfish are herbivore browsers with quite similar diets (Jones 1968). In a possibly similar relationship Barlow (1974) found the numbers of brown surgeonfish and manini (*Acanthurus triostegus*) to be negatively correlated and this was attributed to the aggressive dominance of the brown surgeonfish.

Table 12. Overall FRA effectiveness for the top ten most aquarium collected fishes. 'Before' = Mean of 1999-2000; 'After' = Mean of 2007-2009. YOY not included.

Common name	Scientific name	Mean density (No/100m^2)		Overall% change in density	ρ	R	ρ
		Before	**After**				
yellow tang	*Zebrasoma flavescens*	12.73	19.95	**+57%**	0.01	**+77%**	<0.01
goldring surgeonfish	*Ctenochaetus strigosus*	28.38	32.01	+13%	0.23	+83%	0.39
Achilles tang	*Acanthurus achilles*	0.26	0.05	**-81%**	0.01	+2%	0.09
clown tang	*Naso lituratus*	0.81	0.59	-27%	0.10	+2%	0.37
black surgeonfish	*Ctenochaetus hawaiiensis*	0.18	0.16	-12%	0.77	+3%	0.41
longnose and forcepsfish	*Forcipiger spp.*	0.64	0.84	+32%	0.13	**+4%**	0.03
multiband butterflyfish	*Chaetodon multicinctus*	5.20	3.49	**-33%**	0.02	**-5%**	<0.01
brown surgeonfish	*Acanthurus nigrofuscus*	8.58	4.06	**-53%**	0.03	**-26%**	0.01
orangeband surgeonfish	*Acanthurus olivaceus*	0.13	0.10	-20%	0.63	+3%	0.45
ornate wrasse	*Halichoeres ornatissimus*	0.94	0.65	-31%	0.08	+2%	0.14

Bold = statistically significant at $\rho \leq 0.05$

With only a single exception all of the FRAs have proven to be effective (positive R value) in enhancing yellow tang stocks (Figure 61). Seven of the eight increases were statistically significant. The single FRA which was ineffective was Waiaka'ilio Bay in North Kohala. This FRA had very low yellow tang recruitment throughout the study period and additionally the area may have been impacted by a sedimentation event in October 2006 on nearby reefs.

An examination of multiple factors associated with effective FRAs (Tissot et al., 2004) found that habitat quality, FRA size (especially reef width) and density of adult fishes are associated with significant recovery of fish stocks. Of particular importance are areas of high finger coral (*Porites compressa*) cover which is critical habitat for juvenile yellow tang and other fishes (Walsh, 1987). Live coral cover at Waiaka'ilio declined 12% between 2003 and 2007 (Table 7).

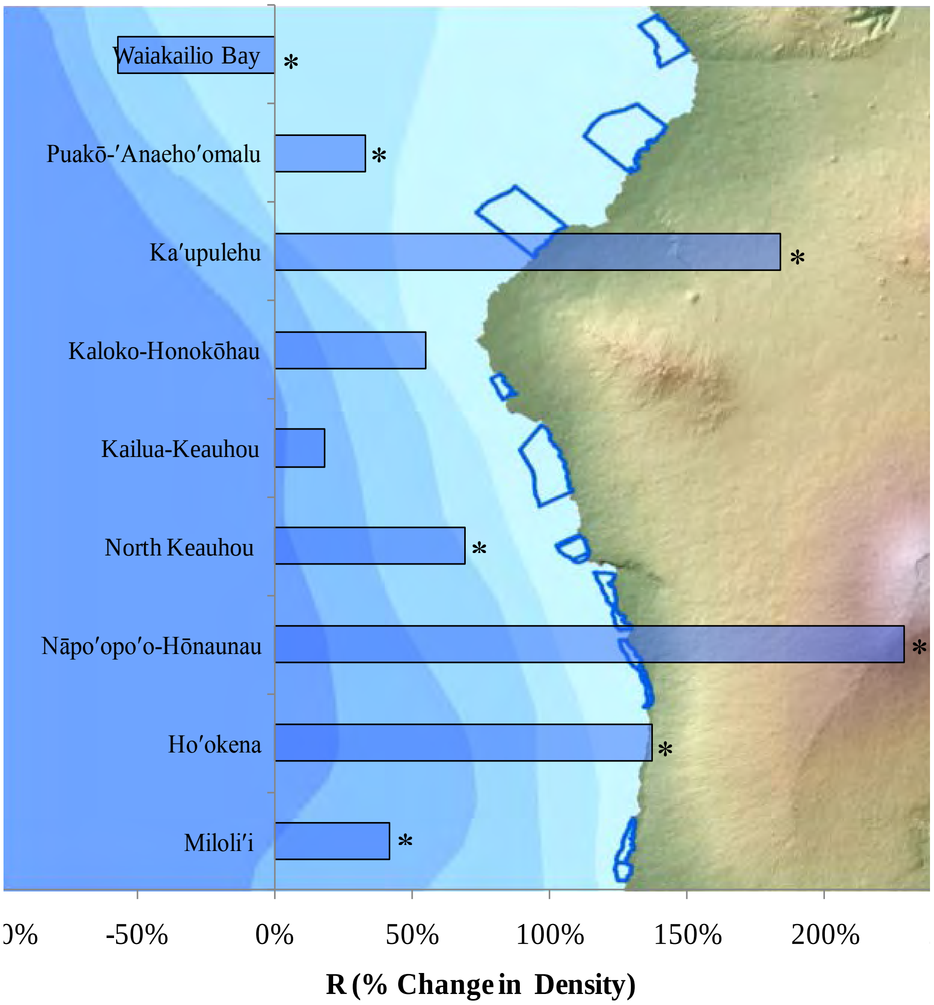


Figure 61. Effectiveness of individual FRAs to replenish yellow tang, 1999-2009.
***= Statistically significant at $\rho \leq 0.05$**

The overall average changes in yellow tang abundance in the three management areas are shown in Figure 62. Yellow tang exhibited a delayed increase in abundance in all areas following a strong recruitment year in 2002. Relatively low recruitment in 5 of the 7 following years resulted in subsequent downward trends in all areas. Even with low recruitment in 6 of the past 11 years the number of adult yellow tang increased by 57% in the FRAs since they were established (Table 12).

Recent work (Claisse et al. 2009) has shown that when yellow tang reach sexual maturity they leave the deeper coral rich reef areas where they settled (and where DAR transects are located) for shallower reef habitat. For females this occurs at approximately 4-5 years of age and for males at age 5-7. Thus in the absence of substantial input of Young-of-the-Year fish, (i.e. low recruitment) yellow tang populations will invariably decline over time due to the emigration of mature fish in addition to natural mortality. This apparently is what has occurred over the last six years in the protected areas.

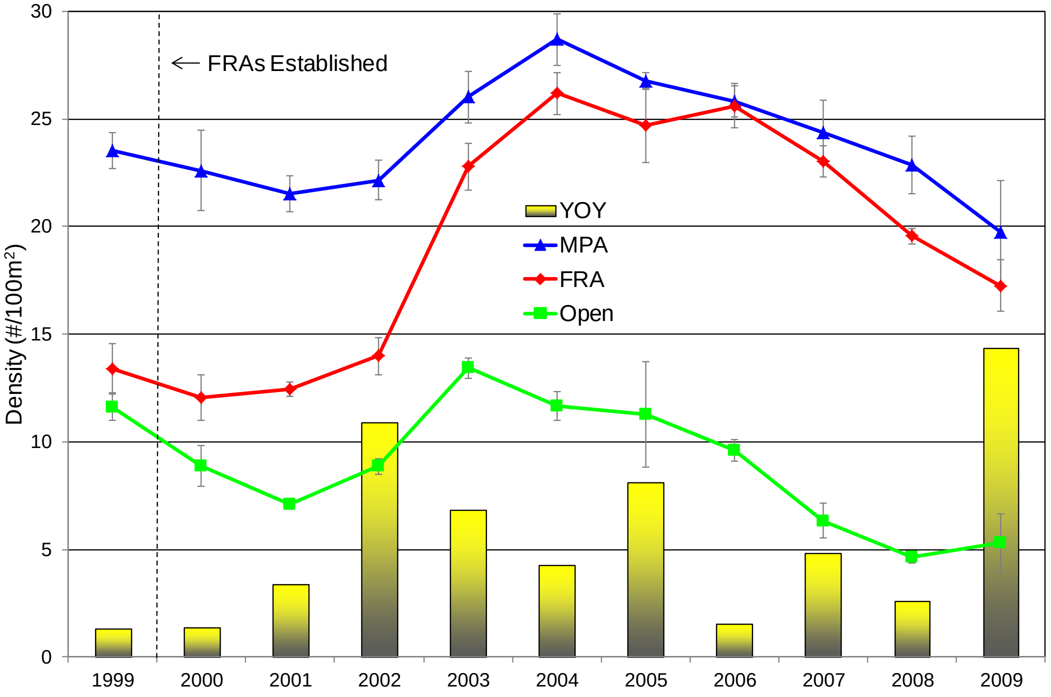


Figure 62. Overall changes in yellow tang abundance (Mean ± SE) in FRAs, MPAs and Open areas, 1999-2009. Yellow bars indicate mean density (June-Nov) Yellow tang Young-of-Year (YOY). YOY are not included in trend line data.

The decrease of yellow tang in open areas to below baseline levels is attributable to the above factors as well as an increase in the number of aquarium collectors and collected animals relative to the period when the FRAs were established (Figure 60). The continuing decline of yellow yang in areas open to collecting has prompted several additional proposed management actions including restricting which species can be collected (See Species of Special Concern section pg.103) and the establishment of a limited entry program for the fishery. Recruitment in 2009 was the highest in the past 11 years which is likely to ameliorate current downward trends at least over the short term.

The fishing/reserve (i.e. FRA/MPA) impacts described above are striking, but of greater significance to the role such reserves have in enhancing and sustaining West Hawai'i populations and the fishery which depends on those, are effects of the reserve network on Yellow tang breeding stocks. Based on adult yellow tang ‘jet boot’ surveys (Williams et al. 2009) it was found that adult densities were highest within protected areas and in ’boundary’ areas (open areas adjacent to protected areas). Densities were lowest in open areas far from protected areas. The high densities in boundary areas are evidence of ‘spillover’ (outward movement from reserves into surrounding open areas) and indicate that protected areas supplement adult stocks not only within their own boundaries, but also in open areas up to a kilometer or more away. Thus, the 35% of the coastline in reserves helps to sustain yellow tang breeding stocks in about 50% of the coastline.

Goldring surgeonfish or kole exhibited trends (Figure 63) quite similar to yellow tang but since they are more abundant and much less collected than the tang, open areas have been relatively stable. Overall, kole have increased by 13% since FRA establishment (Table 3). As with yellow tang, recruitment levels have been relatively high thus enabling densities to increase in the protected areas. It is unknown at present if kole make a habitat change as they reach sexual maturity. Recruitment patterns are markedly similar between the two species, likely due to similarities in spawning seasonality, location and daily timing (Walsh 1984, 1987).

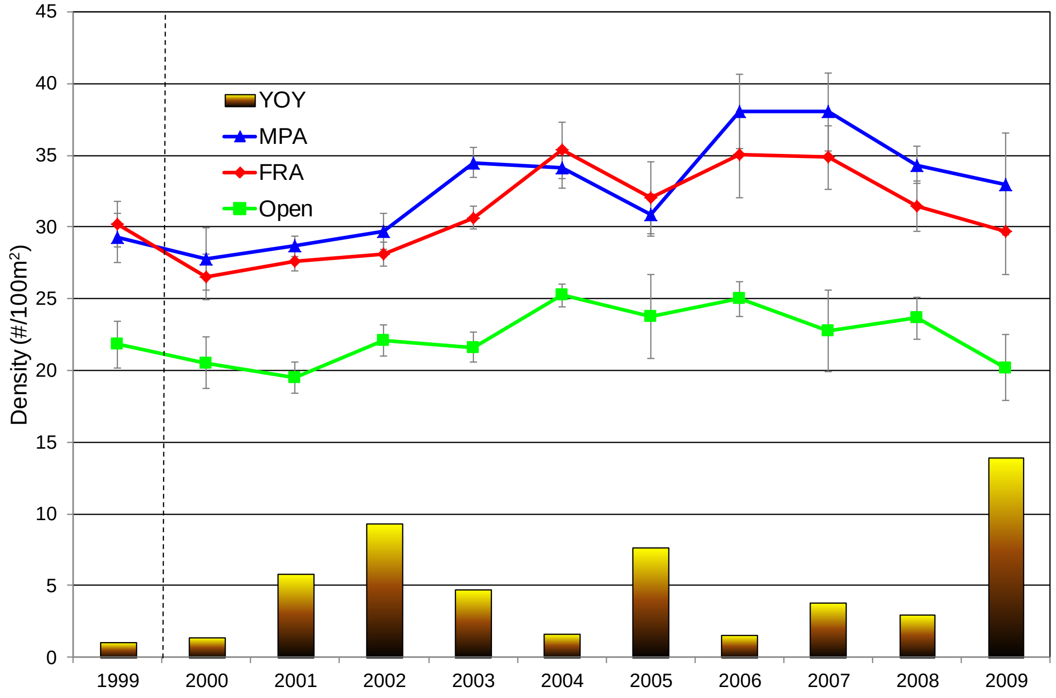


Figure 63. Overall changes in goldring surgeonfish (aka kole) abundance (Mean ± SE) in FRAs, MPAs and Open areas, 1999-2009. Bars indicate mean density (June-Nov) of goldring surgeonfish Young-of-Year (YOY). YOY are not included in trend line data.

Achilles tang (Figure 64) has generally shown a highly variable pattern in all management areas in the early years of the study with an overall decline in the last seven years. Average densities of this species is very low ($\bar{x}$ = 0.26/100m^2) on all transects. The deeper reef areas where the DAR transects are located is not the prime habitat for adults of this species. They prefer the high energy shallower surge zones more typical of the shoreline drop-offs areas in West Hawai'i. Presumably algal food resources are more abundant in these areas. These areas reef areas are surveyed by means of the shallow water resource surveys conducted by DAR. Initial results from this program and other ancillary longer terms studies suggest there should be concern for the sustained abundance of this species. Achilles tang are a very popular food fish as well as an aquarium fish and thus are being harvested both as juveniles and adults. Low levels of recruitment over the past 11 years ($\bar{x}$ (Jun-Nov) = 0.09/100m^2) appear insufficient to compensate for the existing levels of harvest. DAR is currently in the process of developing a comprehensive package of size and bag limits for a number of popularly targeted species. There is a recommended bag limit of 10 Achilles tang/person/day which would apply to all harvesters including commercial fishers and aquarium collectors.

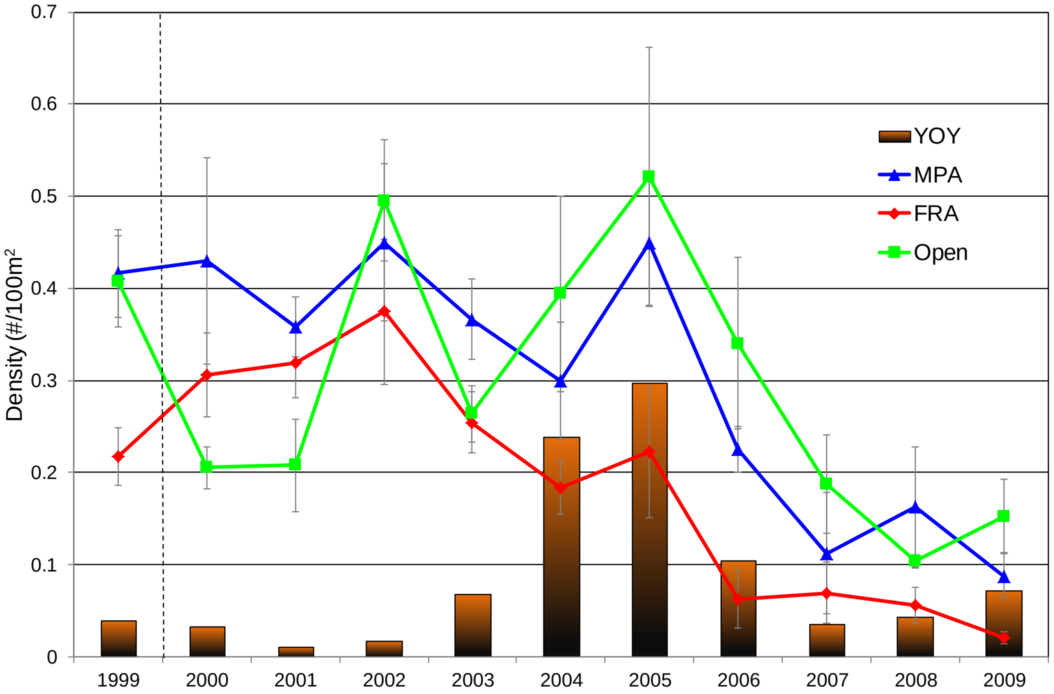


Figure 64. Overall changes in Achilles tang abundance in FRAs, MPAs and Open areas, 1999-2009. Bars indicate mean density (June-Nov) of Achilles tang Young-of-Year (YOY). YOY are not included in trend line data.

The abundance/recruitment trends of the clown tang and black surgeonfish, the fourth and fifth most collected species, are somewhat similar to Achilles tang (Figures 65 & 66). Here again the primary adult habitat is not the deeper, coral rich areas, where the DAR transects are located. Additionally the clown tang is also widely taken as a food fish as well as being an important aquarium fish. The abundance of both these species on the transects closely tracks recruitment with an upturn during 2004/2005 when there was somewhat higher recruitment followed by declining trends in subsequent years that had low recruitment. Overall, recruitment has been minimal over the last decade for both clown tang ($\bar{x}$ = 0.05/100m^2) and black surgeonfish ($\bar{x}$ = 0.05/100m^2).

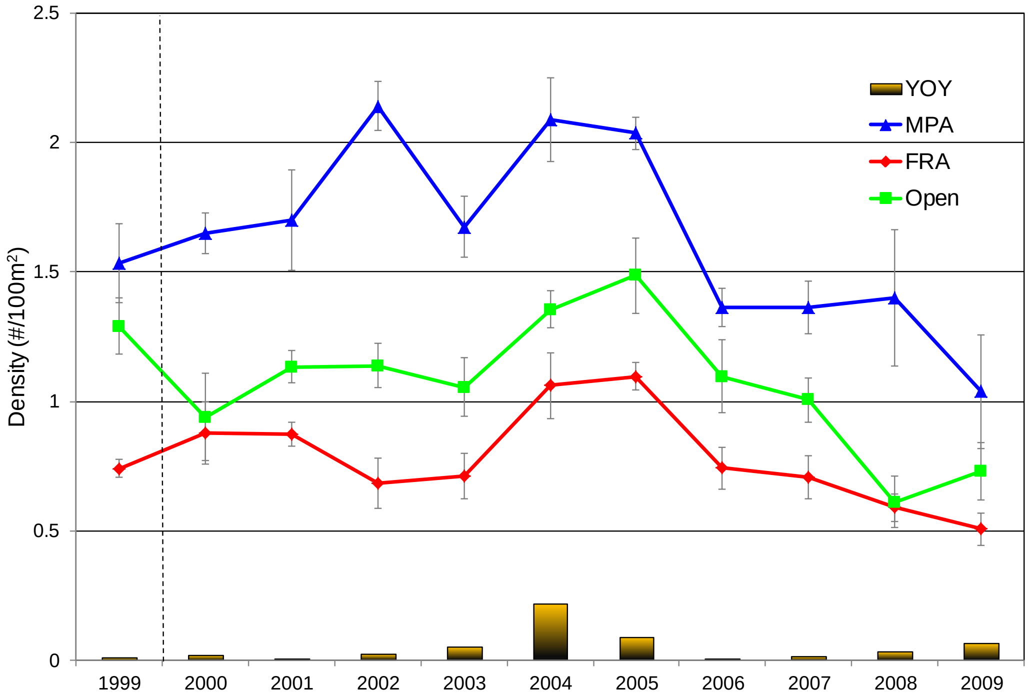


Figure 65. Overall changes in clown tang abundance (Mean ± SE) in FRAs, MPAs and Open areas, 1999-2009. Bars indicate mean density (June-Nov) of clown tang Young-of-Year (YOY). YOY are not included in trend line data.

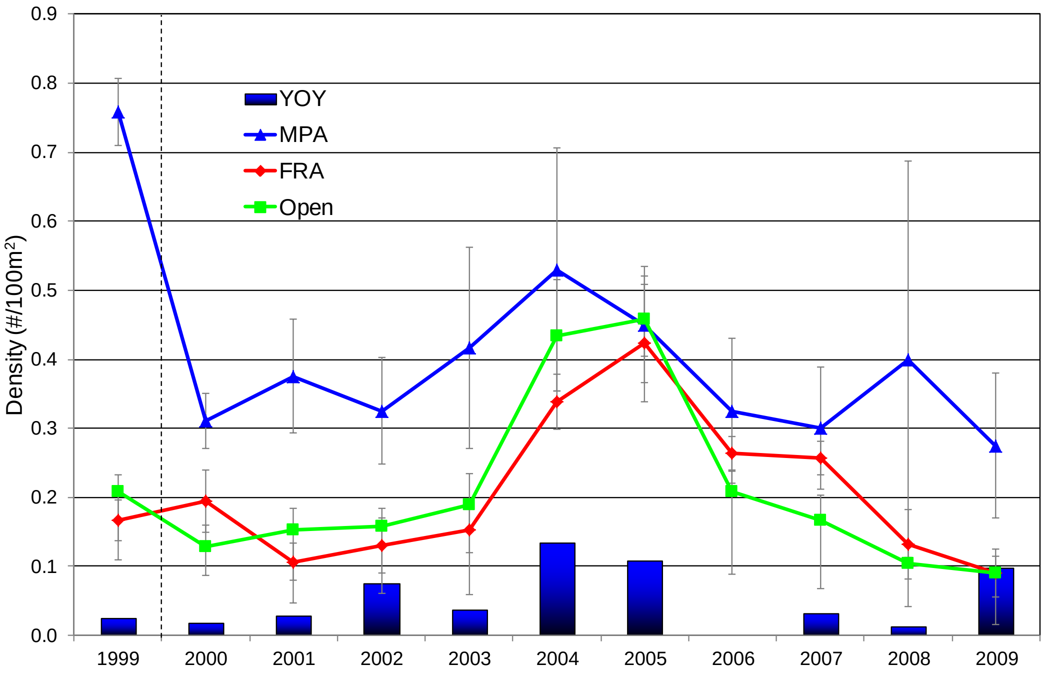


Figure 66. Overall changes in black surgeonfish abundance (Mean ± SE) in FRAs, MPAs and Open areas, 1999-2009. Bars indicate mean density (June-Nov) of black surgeonfish Young-of-Year (YOY).

As observed in previous work (Walsh 1987) and emphasized again in this work, for some species, recruitment can be highly variable between years and repeated low levels of recruitment is a regular occurrence. Without substantial input of the YOY, overall abundances on the deeper reef transects decrease over time due to ontogenetic movement out of settlement habitat and natural mortality. This decrease can occur even in areas which are not subject to aquarium collecting pressure (i.e. FRAs and MPAs).

Although only a few species comprise the bulk of the West Hawai'i aquarium fishery, over 200 different species of fishes and invertebrates have been collected from the reefs over the last five years. Some of these species are uncommon or even rare and presumably have a low resilience to harvesting pressure. Even in protected areas a considerable amount of time may be required for populations of these species to increase. A good example seems to be the flame angelfish, *Centropyge loricula*. This very attractive but uncommon species is highly desired in the aquarium trade. Demand far exceeds the supply Hawai'i can provide so substantial numbers of this species are imported to Hawai'i (for subsequent reshipping) from other locales (e.g. Christmas Island).

Flame angelfish were rarely sighted on transect or free swim surveys during the first seven years of the study (Figure 67). Beginning in 2006 however they have become noticeably more abundant presumably due to one or more years of good recruitment. The recruits are apparently cryptic so not readily surveyed.

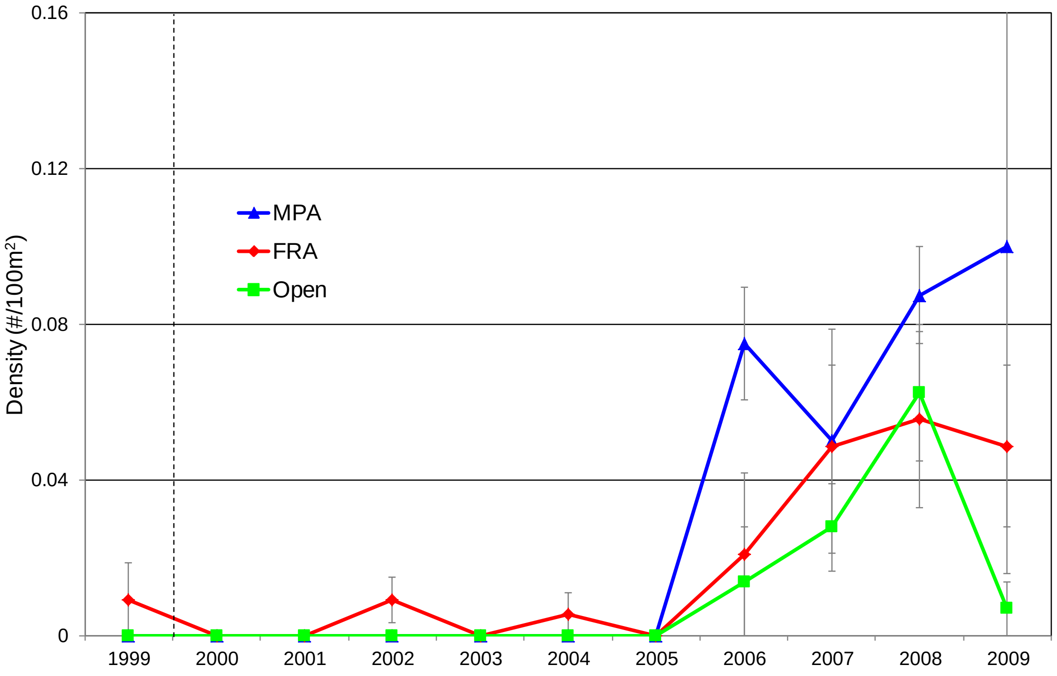


Figure 67. Sightings of flame angelfish in FRAs, MPAs and Open areas, 1999-2009. Species of Special Concern

Coral reef animals have multiple values and they serve fundamental biodiversity and ecosystem functions. They're important not only to aquarium collectors and other fishers but also to the commercial ocean recreation industry, their visitors and Hawai'i ocean users in general. Management of this resource needs to balance these values and uses. A number of reef fish species are particularly vulnerable to depletion because they may be naturally uncommon or rare but command high prices in the aquarium trade and are thus highly sought after by collectors. Examples include the dragon moray (*Enchelycore pardalis*),Tinker's butterflyfish (*Chaetodon tinkeri*), and bandit angelfish (*Desmoholacanthus arcuatus*). All of these species (and others) are worth more (sometimes considerably more) than $50 each when collected. In a retail aquarium shop in Connecticut the author recently observed a bandit angel that sold for $3,500.

For uncommon or rare species or those that occur in deeper reef habitats, it is difficult and/or unfeasibly expensive to gather solid information on their status and trends. Nevertheless for some of these species such as the Hawaiian turkeyfish there is considerable anecdotal evidence that they have declined in recent decades. It's also clear from a number of our long term studies at Puakō, Ke'ei and Hōnaunau that a number of fairly conspicuous species have likewise declined in abundance over time – most obviously several species of butterflyfish and, in particular, the bandit angelfish.

FRAs are a key component of the sustainable management of the West Hawai′i aquarium fishery. They encompass many of the areas most utilized by residents and dive/snorkel business, and help maintain the biodiversity of our reefs people expect and visitors are willing to pay for. The FRAs do not of course provide protection for species in the open areas. While they do provide a population reservoir, intensive fishing pressure on species with low natural abundances across most of West Hawai′i's reefs is problematic. Concerns over continued expansion of the fishery (up 25% in the last decade) and harvesting effects in the open areas (65% of the coast), necessitate additional management measures.

To address such issues DAR in conjunction with The West Hawai′i Fisheries Council (WHFC) developed a 'white list' of species which could be taken by aquarium fishers (Table 13). The approach taken by the WHFC was based on the fact that the West Hawai'i aquarium fishery is very heavily focused on a relatively small number of species. Six species (yellow tang, goldring surgeonfish, Achilles tang, clown tang, black surgeonfish and Tinker's butterfly) make up 96% of the total catch value averaged over the last 5 years. The 40 species on the white list make up 99% of the total catch value so the great majority of species taken (over 180 species) have very little individual or collective value; nonetheless they are important components of the reef ecosystem. It should be noted no invertebrates are included on the white list.

The white list is part of a Hawai'i Administrative Rule (HAR 13-60.3) Amendment that is currently being processed. Although the list has been recommended and supported by the WHFC and recently approved by the newly formed Big Island Association of Aquarium Fishers (BIAFF) there nevertheless has been some criticism directed at the list. Most of the concern is generally directed to why this species or that species is included on the list (i.e. allowed to be collected). Concerns have been articulated about collecting impacts on the species' populations and sometimes as to suitability and survivability of the species in captivity.

Aquarium Open vs. FRA Trend Analysis

In order to more comprehensively explore the 40 white list species and the current and potential impact to their populations on the reefs by aquarium collecting two different analyses were undertaken.

The first analysis examined the trends in the % difference in density between areas open to collecting and the FRAs (closed to collecting) for the species on the white list. Density was based on the overall average density of each species for the last three years (2007-2009) at all open and FRA survey sites. The % difference in fish densities between open and FRAs areas for a species was calculated as: $(\text{Density}_{OPEN} - \text{Density}_{FRA})/\text{Density}_{OPEN})$ X 100.

Table 13. Proposed ‘White List’ of species which can be taken by aquarium collectors within the West Hawai'i Regional Fisheries Management Area.

Common Name	Scientific Name	Common Name	Scientific Name
Achilles tang	*Acanthurus achilles*	Potter’s angelfish	*Centropyge potteri*
goldrim surgeonfish	*Acanthurus nigricans*	pyramid butterflyfish	*Hemitaurichthys polylepis*
yellow tang	*Zebrasoma flavescens*	lei triggerfish	*Sufflamen bursa*
psychedelic wrasse	*Anampses chrysocephalus*	Hi dascyllus	*Dascyllus albisella*
chevron tang	*Ctenochaetus hawaiiensis*	redbarred hawkfish	*Cirrhitops fasciatus*
milletseed butterflyfish	*Chaetodon miliaris*	Hi whitespotted toby	*Canthigaster jactator*
forcepsfish	*Forcipiger flavissimus*	Thompson’s surgeonfish	*Acanthurus thompsoni*
fourspot butterflyfish	*Chaetodon quadrimaculatus*	saddle wrasse	*Thalassoma duperrey*
clown tang	*Naso lituratus*	brown surgeonfish	*Acanthurus nigrofuscus*
yellowtail coris	*Coris gaimard*	black durgon	*Melichthys niger*
shortnose wrasse	*Macropharyngodon geoffroy*	fourstripe wrasse	*Pseudocheilinus tetrataenia*
gilded triggerfish	*Xanthichthys auromarginatus*	eightstripe wrasse	*Pseudocheilinus octotaenia*
goldring surgeonfish	*Ctenochaetus strigosus*	bluestripe snapper	*Lutjanus kasmira*
spotted boxfish	*Ostracion meleagris*	peacock grouper	*Cephalopholis argus*
Orangeband Surgeonfish	*Acanthurus olivaceus*	Eyestripe Surgeonfish	*Acanthurus dussumieri*
smalltail wrasse	*Pseudojuloides cerasinus*	Tinker’s butterflyfish	*Chaetodon tinkeri*
blackside hawkfish	*Paracirrhites forsteri*	blacklip butterflyfish	*Chaetodon kleinii*
bird wrasse	*Gomphosus varius*	Fisher’s angelfish	*Centropyge fisheri*
multiband butterflyfish	*Chaetodon multicinctus*	flame wrasse	*Cirrhilabrus jordani*
ornate wrasse	*Halichoeres ornatissimus*	Hi longfin anthias	*Pseudanthias hawaiiensis*

There were 7 species which had distributions and/or behaviors which precluded obtaining accurate density estimates in the survey areas. *Chaetodon Kleinii* is a planktivore which typically feeds above the reef often near drop-offs or in deeper water. *Lutjanus kasmira* is a schooling species more likely to be found in deeper water at reef/sand interfaces while *Centropyge fisheri, Chaetodon tinkeri, Cirrhilabrus jordani and Pseudanthias hawaiiensis* inhabit deeper (generally >50’) waters. *Acanthurus dussumieri* were rarely recorded on fixed line transects and appeared to be associated with sand areas. Individuals of this species which are encountered are invariably of very large size and small fish (e.g. YOY) are essentially rarely if ever seen. These 7 species were excluded from the analyses.

The results of this analysis are presented in the following graphs (Figures 68-70). Given the controversial nature of all aspects of managing the aquarium fishery and the current relevance of the issue, available data for all species are presented.

The columns (bars) represent the % difference in density between open and FRA areas for each year since 1999. Bars below the x axis indicate densities which are lower in the open areas relative to the FRAs and similarly bars above the x axis indicate densities which are higher in the open areas relative to the FRAs. The number to the right of the species name represents the 3 year ('07-'09) % difference.

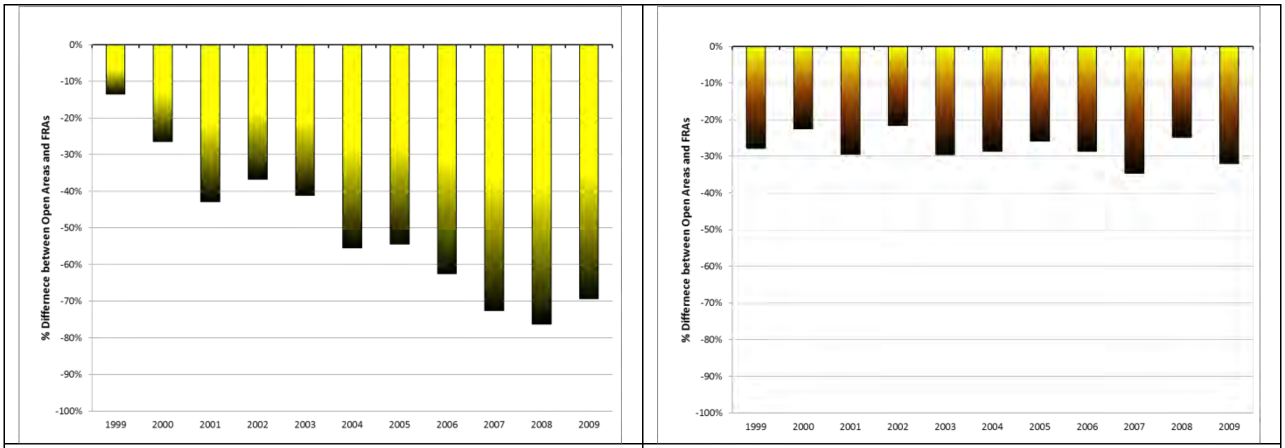
The white list species can be classified into three groups based on their densities in the open areas relative to FRAs. Group 1 species (6 spp., Fig 68) had consistently lower densities in the open areas. The yellow tang, *Zebrasoma flavescens* is particularly noteworthy as the disparity between the open areas and the FRAs is substantial and continually increasing. Averaged over the past three years ('07-'09) yellow tang are 73% less abundant in the open areas as compared to the FRAs. Yellow tang are by far the most heavily targeted species in West Hawai'i and over the past decade the numbers of aquarium collectors and collected fish have increased substantially (Figure 60). A substantial and increasing impact of collecting is clear on yellow tang indicating the need for additional management measures.

The second most collected species, the kole, *Ctenochaetus strigosus*, also exhibits a collecting impact but in contrast to yellow tang the disparity between open and protected areas has not been increasing. For kole, open areas contain 30% fewer fish than the FRAs. Roi, *Cephalopholis argus* is, also less abundant in the open areas but this is not due to aquarium collecting as very few individuals of this species are collected (Table 14). There is some indication that aquarium collectors kill this grouper on occasion or as a matter of course which may explain the difference between areas.

Group 2 species (11 spp. Figure 69) did not exhibit any consistent pattern of differences in abundance in open vs. FRAs. In some years densities were higher in the FRAs while in other years they were higher in the open areas. In some years there were essentially no differences between areas.

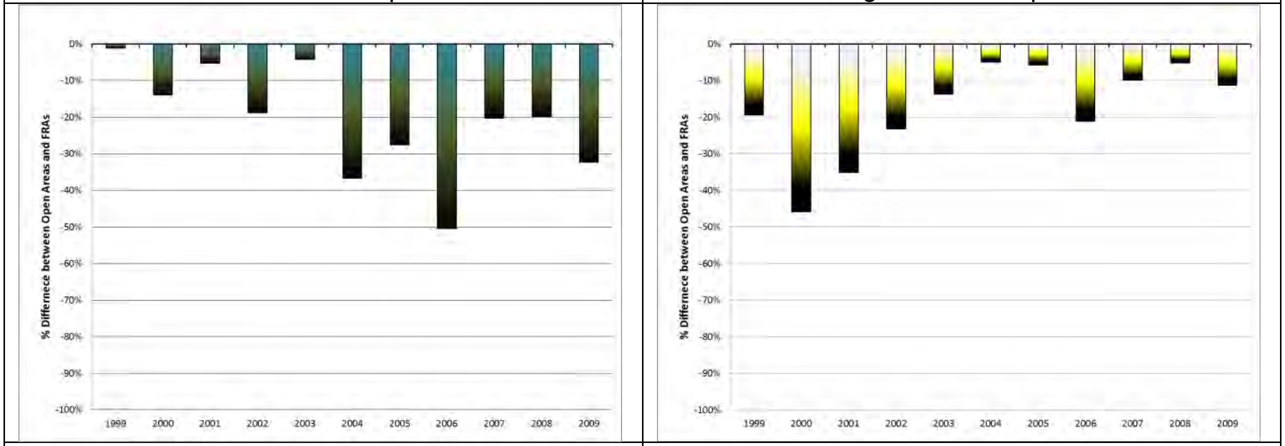
Group 3 species (16 spp., Figure 70) had consistently greater densities of fishes in the open areas vs. the FRAs. This pattern, as with Group 2 species, appears to relate to the comparatively low number of fishes collected relative to the size of their population on the reefs (see Table 14).

In summary, there was clear evidence of collecting impact for only 5 species of the 33 white list species which were analyzed. Four of the 5 (not *G. varius*) were all among the 10 most heavily collected species in the fishery (Walsh 2010). For the others, it appears that, at least based on the past 11 years data, inclusion on the white list poses little or no threat to their populations. The caveat is that this assumes collecting preferences will remain similar to the past decade and the amount of collecting effort (i.e. number of collectors) does not substantially increase. Furthermore these findings do not mean that aquarium collecting may not be having major impacts on species not on the white list especially uncommon, rare and valuable species.



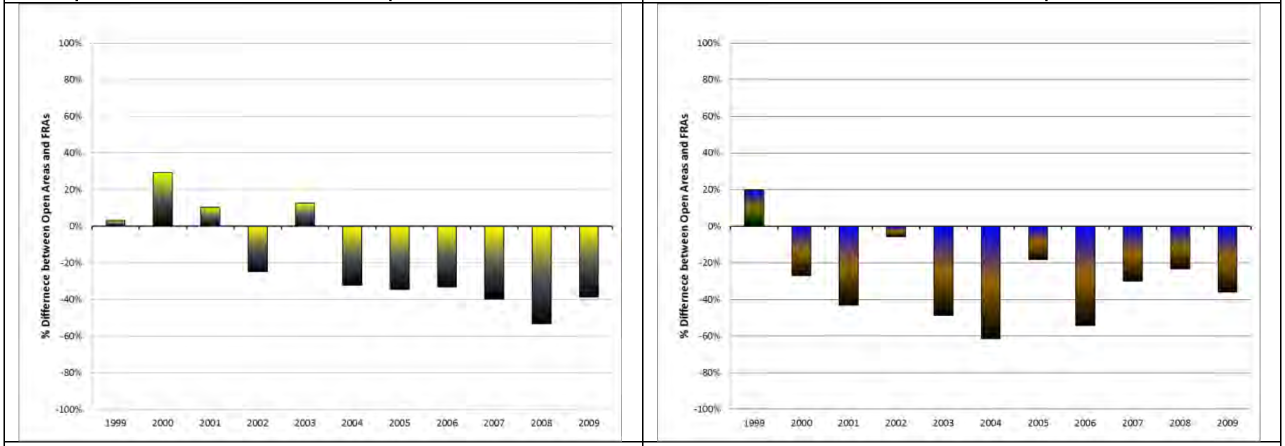
Zebrasoma flavescens Open-FRA diff. **-73%**

Ctenochaetus strigosus Open-FRA diff. **-30%**



Gomphosus varius Open-FRA diff. **-24%**

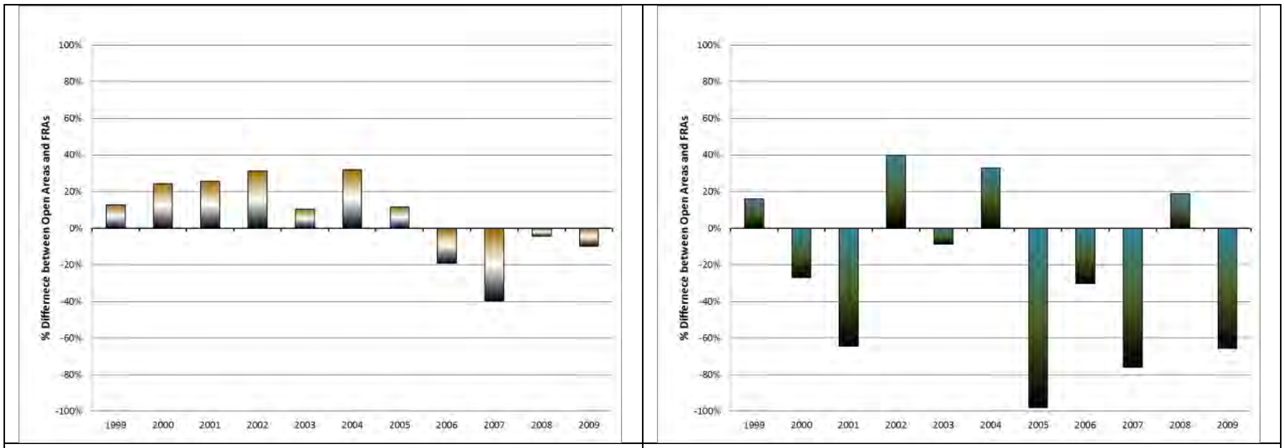
Chaetodon multicinctus Open-FRA diff. **-9%**



Forcipiger flavissimus Open-FRA diff. **-44%**

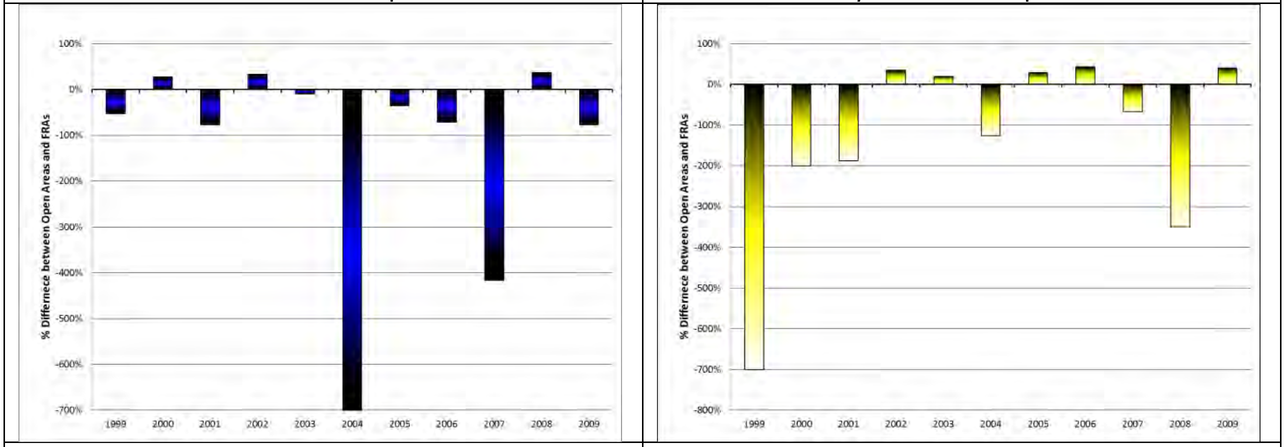
Cephalopholis argus Open-FRA diff. **-30%**

Figure 68. White list species showing fairly consistent lower densities in areas open to aquarium collecting. The graph columns represent the % difference in density between open and FRA areas. Bars below the x axis indicate densities are lower in the open areas relative to the FRAs.



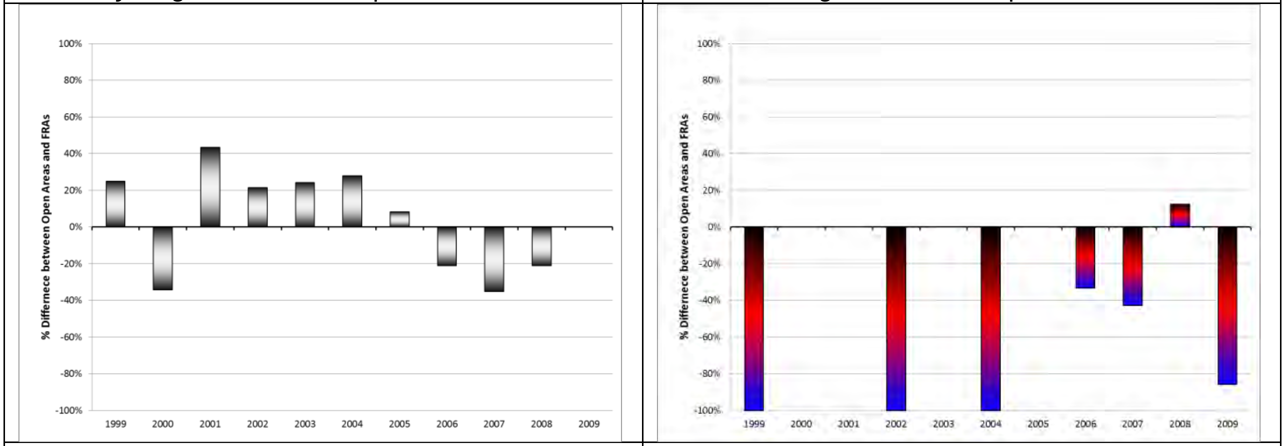
Paracirrhites forsteri Open-FRA diff. **-18%**

Acanthurus thompsoni Open-FRA diff. **-41%**



Melichthys niger Open-FRA diff. **-152%**

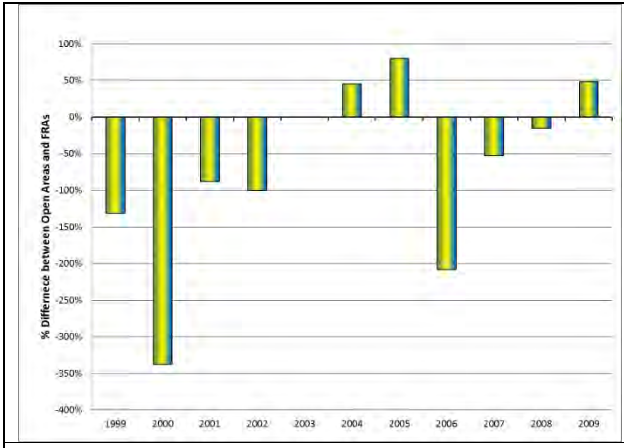
Acanthurus nigricans Open-FRA diff. **-126%**



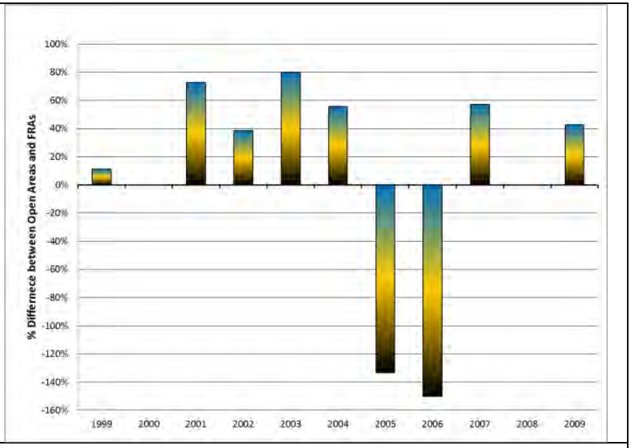
Ctenochaetus hawaiiensis Open-FRA diff. **-19%**

Centropyge loricula Open-FRA diff. **-39%**

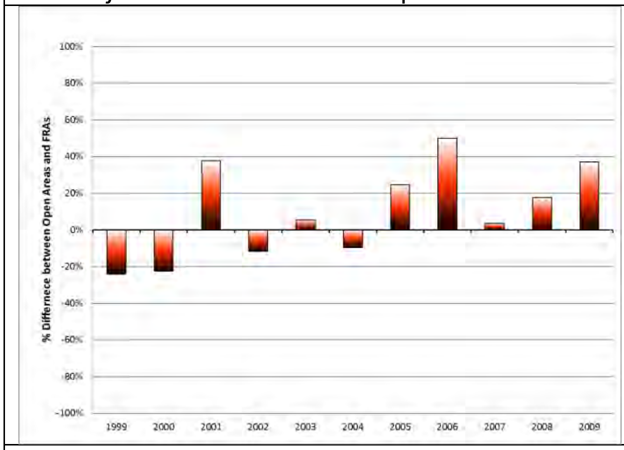
Figure 69. White list species exhibiting inconsistent differences in density between areas open to aquarium collecting and FRAs. The graph columns represent the % difference in density between open and FRA areas. Bars below the x axis indicate densities are lower in the open areas relative to the FRAs. Note different Y axis scale for *M. niger* and *A. nigricans*. Note *C. loricula* (flame angelfish) is *not* on white list and graph is shown just for comparison.



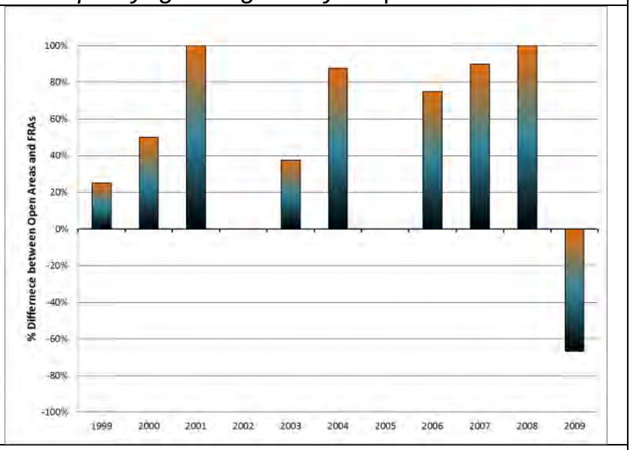
Pseudojuloides cerasinus Open-FRA diff. **-7%**



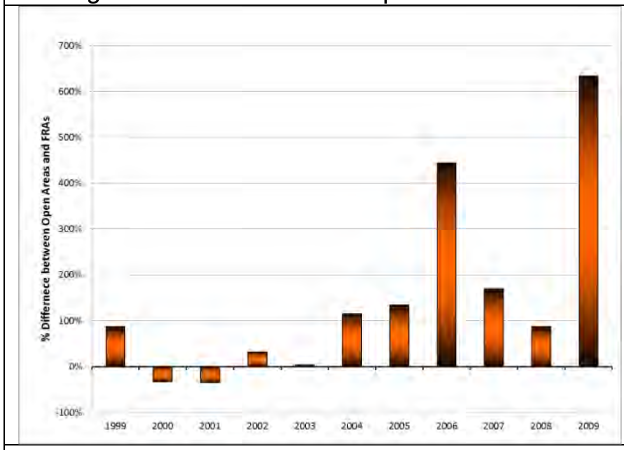
Macropharyngodon geoffroy Open-FRA diff. **33%**



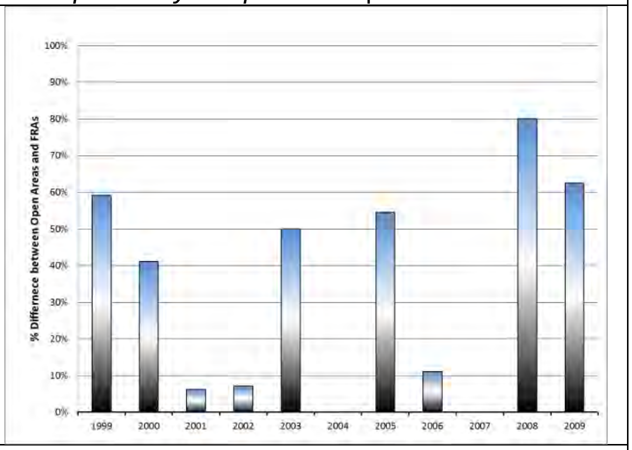
Coris gaimard Open-FRA diff. **+19%**



Anampses chrysocephalus Open-FRA diff. **+41%**

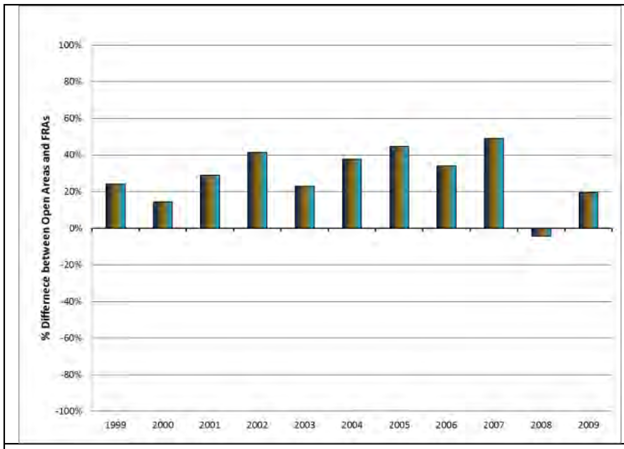


Acanthurus achilles Open-FRA diff.**+ 297%**

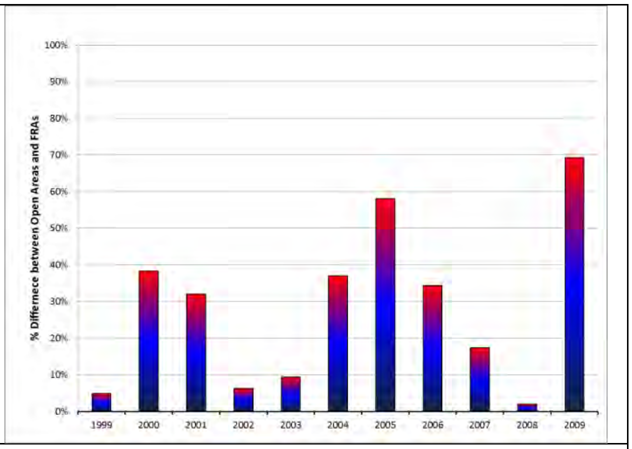


Ostracion meleagris Open-FRA diff. **+48%**

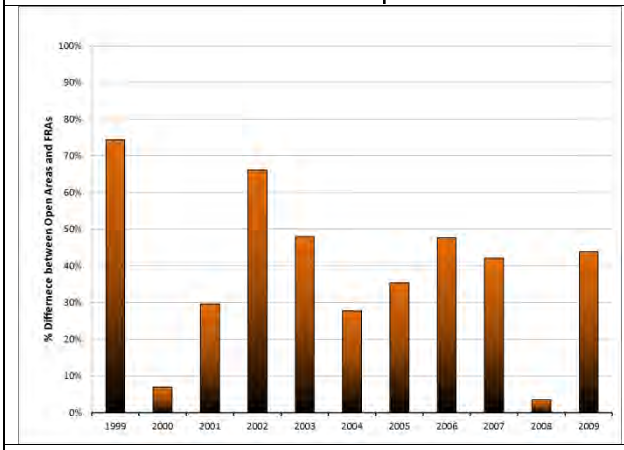
Figure 69 con't. White list species exhibiting inconsistent differences in density between areas open to aquarium collecting and FRAs. The graph columns represent the % difference in density between open and FRA areas. Bars below the x axis indicate densities are lower in the open areas relative to the FRAs. Bars above the x axis indicate densities are higher in the open areas relative to the FRAs. Note different Y axis scale for *P. cerasinus* and *M. geoffroy*.



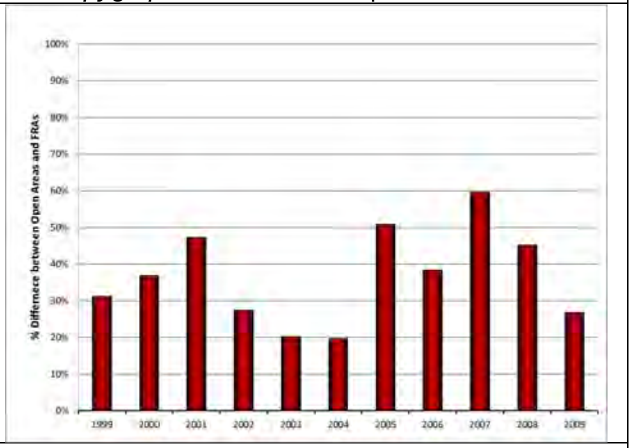
Pseudocheilinus tetrataenia Open-FRA diff.**+ 21%**



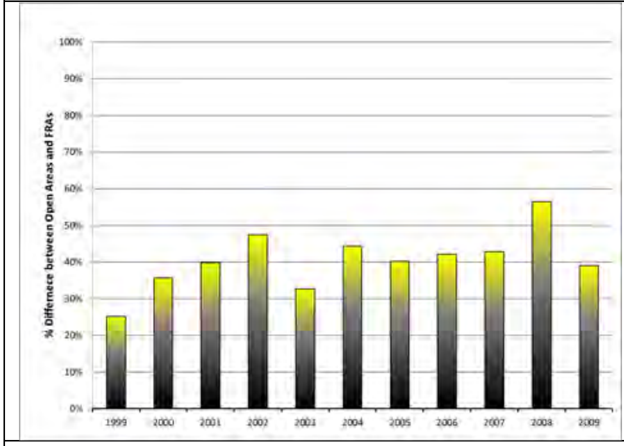
Centropyge potteri Open-FRA diff. **+30%**



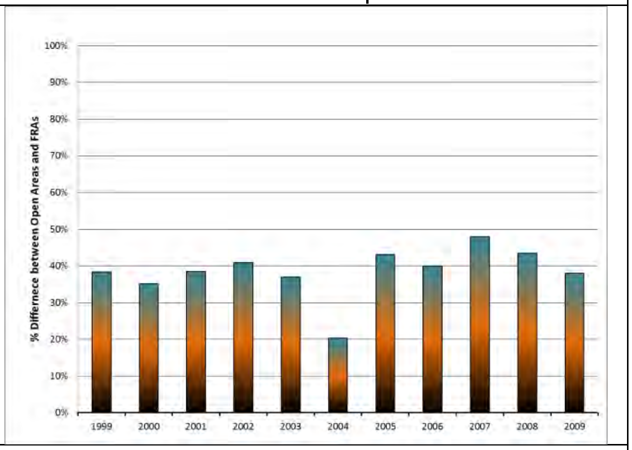
Naso literatus Open-FRA diff. **+30%**



Pseudocheilinus octotaenia Open-FRA diff.**+ 44%**

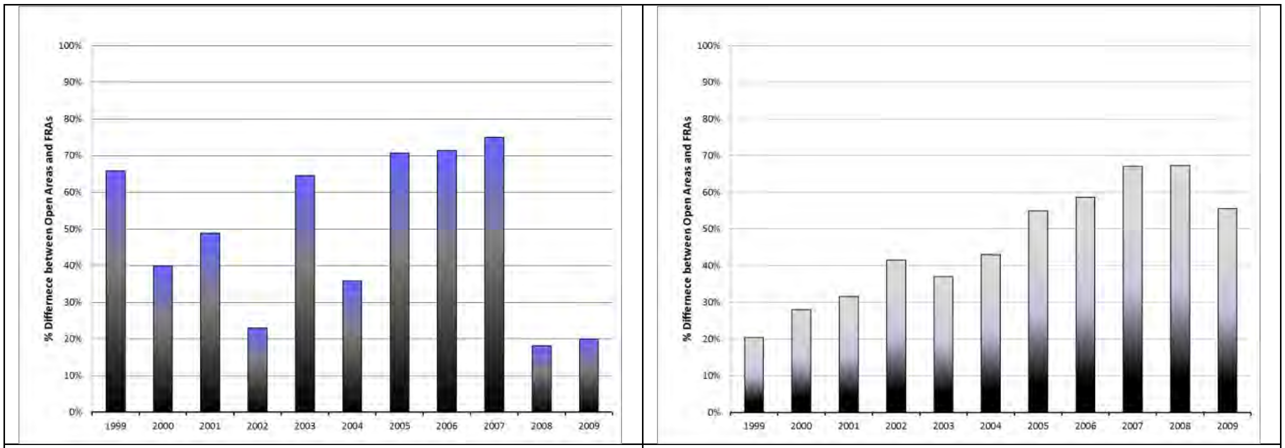


Sufflamen bursa Open-FRA diff. **+40%**

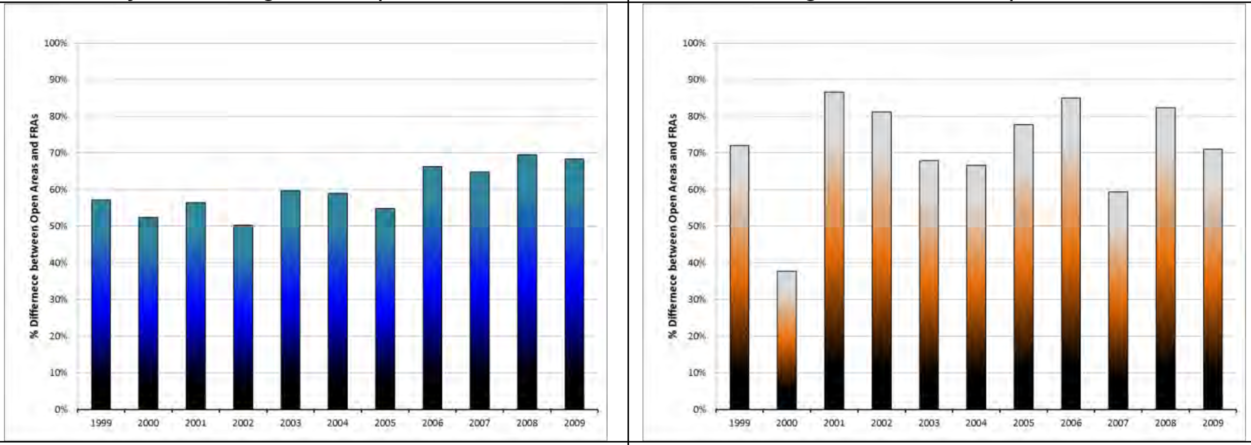


Thalassoma duperrey Open-FRA diff. **+43%**

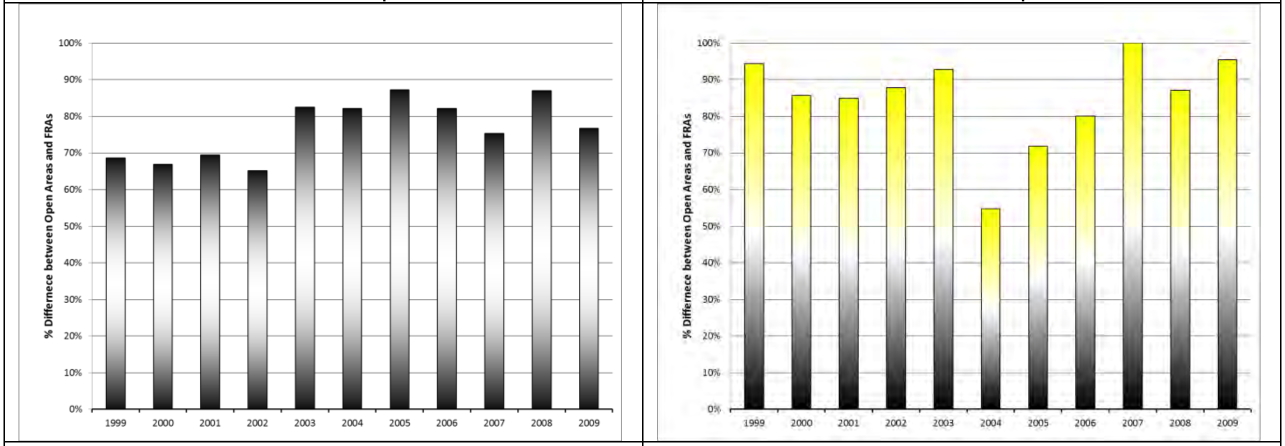
Figure 70. White list species exhibiting higher population densities in areas open to collecting relative to FRAs. The graph columns represent the % difference in density between open and FRA areas. Bars above the x axis indicate densities are higher in the open areas relative to the FRAs.



Xanthichthys auromarginatus Open-FRA diff. **+38%** | *Acanthurus nigrofuscus* Open-FRA diff. **+63%**

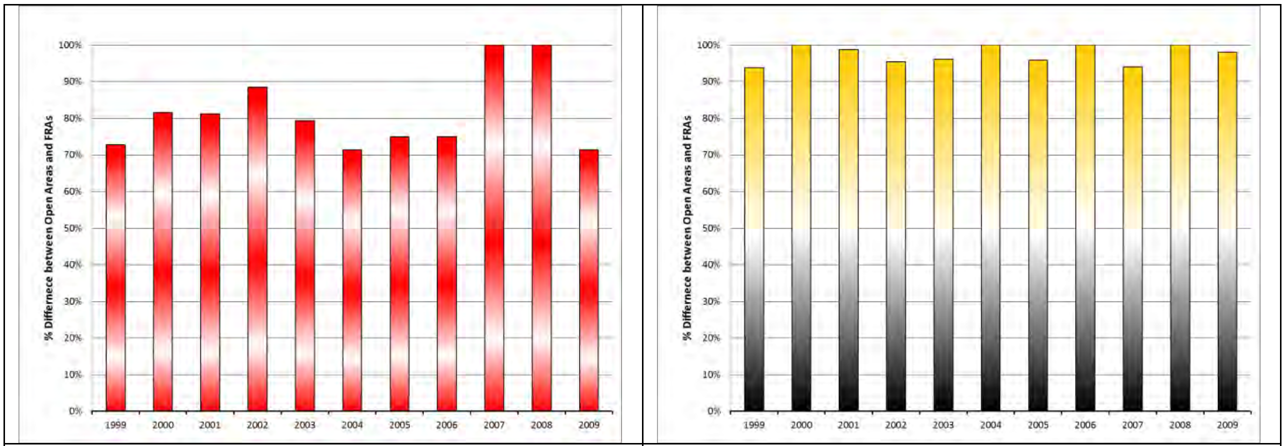


Halichoeres ornatissimus Open-FRA diff. **+68%** | *Acanthurus olivaceus* Open-FRA diff.**+ 71%**



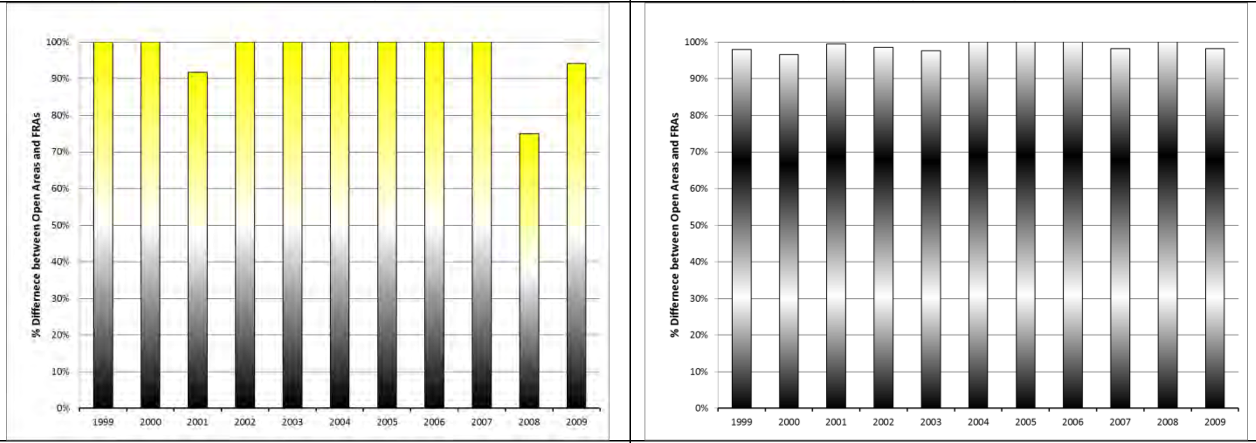
Canthigaster jactator Open-FRA diff. **+80%** | *Chaetodon quadrimaculatus* Open-FRA diff. **+94%**

Figure 70 con't. White list species exhibiting higher population densities in areas open to collecting relative to FRAs. The graph columns represent the % difference in density between open and FRA areas. Bars above the x axis indicate densities are higher in the open areas relative to the FRAs.



Cirrhitops fasciatus Open-FRA diff. **+90%**

Hemitaurichthys polylepis Open-FRA diff. **+97%**



Chaetodon miliaris Open-FRA diff. **+90%**

Dascyllus albisella Open-FRA diff. **+99%**

Figure 70 con't. White list species exhibiting higher population densities in areas open to collecting relative to FRAs. The graph columns represent the % difference in density between open and FRA areas. Bars above the x axis indicate densities are higher in the open areas relative to the FRAs.

Aquarium Population and Catch Analysis

The second approach to assessing white list inclusion estimated actual populations of the species on the list and related those numbers to the aquarium catch of that species. Most aquarium collecting in West Hawai'i occurs primarily in mid-depth ranges. While abundance and conditions can and will alter collecting depths, Tissot and Stevenson (2010) reported that the majority of aquarium fishers collect between 41'- 59'. A population estimate was thus made based on a depth range of 30'-60' (open area = 7.08 km^2) which makes fixed transect data highly appropriate (Table 14). Added advantages are that survey sites span a considerable portion of the West Hawai'i coastline and include both open and closed areas.

Mean densities for the same 34 species on the white list for which adequate data existed were calculated for the period 2007-2009 at open survey sites. A GIS was used to determine the total area of hard bottom reef in the 30' -60' depth range that was open to aquarium collecting. Open areas at the extreme north and south parts of the West Hawai'i coast were excluded due to the remoteness of the areas and the difficulty of operating and collecting there. Total populations were the product of open area density

Table 14. Population estimates and % of population taken by aquarium collectors of 'White List' species. 'E' indicates an endemic species, Catch is the average aquarium catch over FY' 06-'10 and Population is an estimate of total numbers of fish in collected open areas of hard bottom from 30'-60' depths. Catch as % of Population is the % of the species' population in collected open areas taken annually by aquarium collectors.

Scientific Name		Catch	30'-60' Population	Catch as % of Population
Acanthurus achilles		8,477	10,655	79.56%
Zebrasoma flavescens		324,211	536,842	60.39%
Ctenochaetus hawaiiensis		3,926	8,524	46.06%
Acanthurus nigricans	E	794	2,951	26.91%
Naso lituratus		5,972	55,405	10.78%
Anampses chrysocephalus	E	229	2,623	8.73%
Forcipiger flavissimus		2,643	33,604	7.87%
Macropharyngodon geoffroy		170	2,623	6.48%
Chaetodon quadrimaculatus		982	16,556	5.93%
Coris gaimard		678	11,802	5.74%
Acanthurus olivaceus		1,039	25,080	4.14%
Chaetodon miliaris		228	5,573	4.09%
Ostracion meleagris		112	3,606	3.11%
Ctenochaetus strigosus		36,244	1,841,492	1.97%
Pseudojuloides cerasinus		175	10,327	1.69%
Gomphosus varius		512	55,733	0.92%
Chaetodon multicinctus	E	1,877	291,288	0.64%
Centropyge potteri		796	123,925	0.64%
Xanthichthys auromarginatus		67	11,802	0.57%
Dascyllus albisella	E	164	29,014	0.57%
Halichoeres ornatissimus		1,040	187,034	0.56%
Paracirrhites forsteri	E	60	11,147	0.54%
Sufflamen bursa		221	42,292	0.52%
Melichthys niger		53	11,474	0.46%
Lutjanus kasmira		26	7,376	0.35%
Thalassoma duperrey		766	257,848	0.30%
Cirrhitops fasciatus	E	11	4,098	0.27%
Acanthurus thompsoni		229	86,059	0.27%
Acanthurus nigrofuscus	E	1,551	892,060	0.17%
Hemitaurichthys polylepis	E	39	22,949	0.17%
Canthigaster jactator		186	123,597	0.15%
Pseudocheilinus octotaenia		118	136,055	0.09%
Pseudocheilinus tetrataenia		119	189,165	0.06%
Cephalopholis argus		2	26,063	0.01%
Chaetodon tinkeri		395	NA	NA
Acanthurus dussumieri	E	473	NA	NA
Chaetodon kleinii		98	NA	NA
Centropyge fisheri		89	NA	NA
Cirrhilabrus jordani		54	NA	NA
Pseudanthias hawaiiensis		39	NA	NA
		Total	5,076,643	

X open area (7.08 km^2). This population was then related to the average catch of the species for the period 2005-2009.

Based on this analysis aquarium collecting is having a major impact on Achilles and yellow tang with aquarium fishing mortalities of 80% and 60% respectively. Achilles tang has had low levels of recruitment over the past decade (Figure 64) and substantial numbers of larger fish (i.e. ‘breeders’) are taken for human consumption. Given these factors, population declines and a substantial aquarium impact are not surprising. Yellow tang has generally recruited reliably but the numbers of collectors and aquarium take has risen substantially over the past decade (figure 60). For most of the white list species collecting impact, in terms of the % of the population being removed annually, is relatively low with 10 species having single digit % catch and 19 species having % catch values <1%.

To put the issue of putative roi impacts and community eradication attempts into better perspective, the above analysis estimated the roi population in West Hawai’i at 30’ – 60’ depths to be 58,839.

Gill net management

As mandated by Legislative Act 306 (SLH 1998) ,a laynet (i.e. gill net) management plan was developed over four years by the WHFC and DAR. The recommended plan became

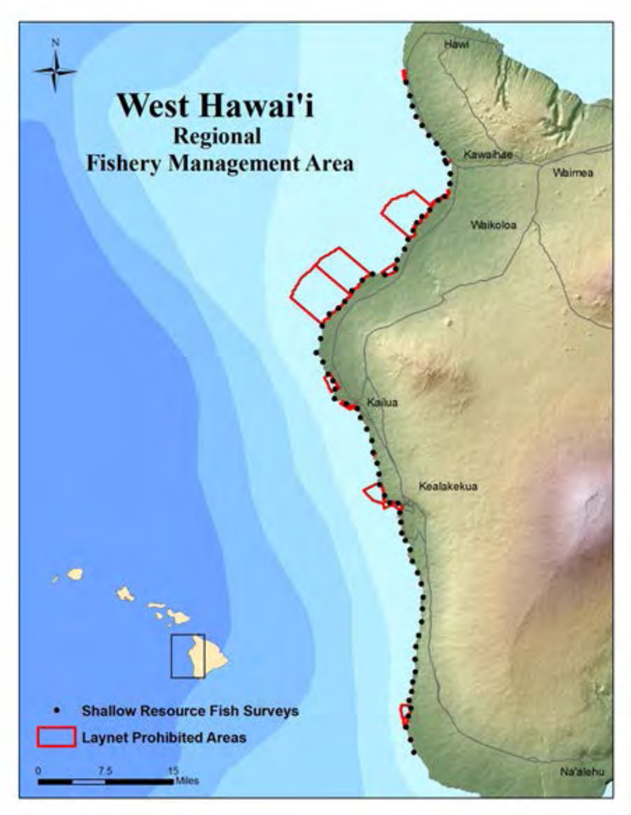


Figure 71. Locations of laynet prohibited areas in West Hawai'i and shallow water resource fish survey sites.

a Hawai'i Administrative Rule in 2005. The rule provides for continued small-scale subsistence-level netting while effectively controlling large-scale commercial netting. Eight areas have been designated where the use of gill nets is prohibited. Along with existing no gill-netting areas, approximately 25% of the coastline now prohibits the use of such nets (Figure 71).

Additional provisions of the rule were designed to encourage responsible net use and enhance enforcement. These include requirements such as net registration and numbered identification (floats and tags), maximum soak time of four hours and maximum net length of 125'. One area (Kaloko-Honokōhau FRA) was designated a Hawaiian cultural netting area where only locally constructed handmade nets of natural fibers may be used. The West Hawai'i laynet rules served as a model for the rest of the state and have generally been adopted elsewhere except for Maui which completely banned their use

Transects conducted in shallow water habitats most likely to be impacted by lay gill netters (Figure 71) indicate there is presently little difference in the biomass of targeted food fishes between areas open to netting and those prohibiting netting either beginning in 2005 or MPAs which have had longer (>10 years) prohibitions on laynetting (Figure 72).

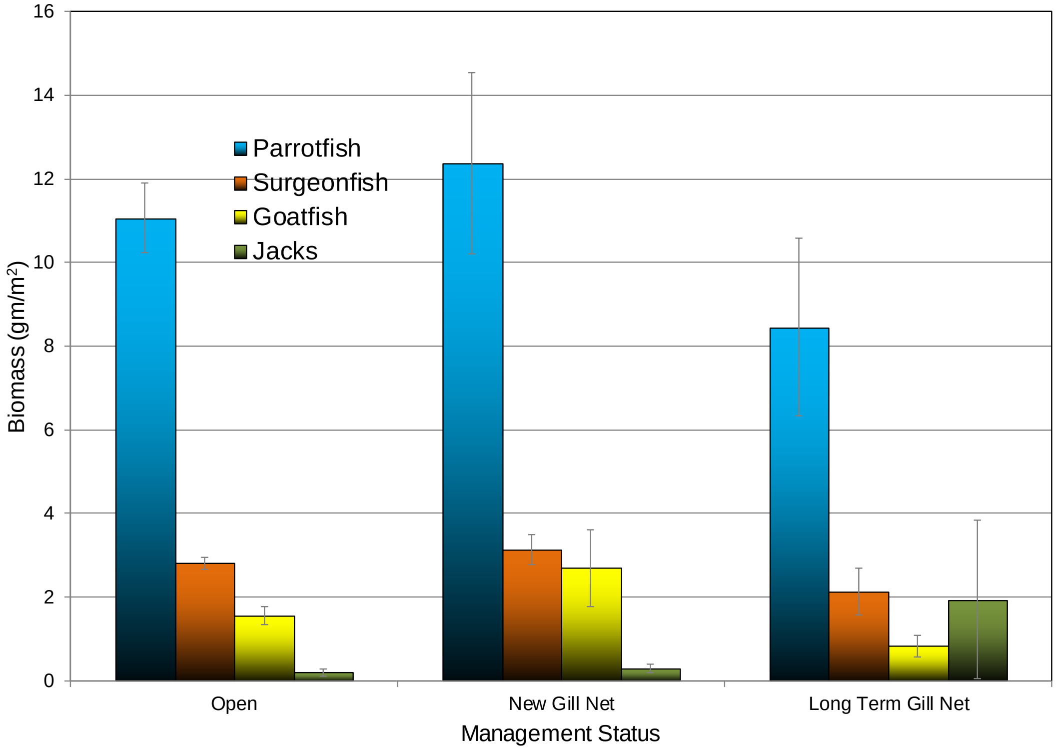


Figure 72. Biomass of 'Resource' (i.e. food) fish on shallow water transects. Only fish > 15 cm TL are censused. 'Open' denotes surveys (n=99) in areas where lay gill netting is permitted. 'New Gill Net' are survey areas (=32) which were closed to gill netting in 2005 and 'Long Term Gill Net' are survey sites (n=11) within MPAs which have prohibited netting for >10 years.

The reasons for the lack of differences between open and laynet protected areas may relate to one or more of several factors: (i) the newly protected areas haven't had sufficient time to work; (ii) the protected areas are not effectively enforced; (iii) the sites of many of the shallow water resource transects may be areas where netting is impractical (i.e. rocky shorelines, sharp reef drop-offs, etc.) and (iv) the overall level of laynet fishing is relatively low. This last factor is supported by the low number of lay gill nets registered in West Hawai'i (52 as of Dec. 2009) as compared to the other islands (e.g. 796 on O'ahu).

Invertebrates - Crown of thorns (COTS)

While *Acanthaster planci* is native to Hawai'i and not an introduced species it nevertheless is of substantial concern to the general public due to its reputation as a 'coral killer' and the publicity generated by massive outbreaks on other Pacific islands. The last reported large-scale occurrence in Hawai'i of the crown-of-thorns starfish, was in August 1969 when approximately 20,000 starfish were observed off the south shore of Moloka`i. Since that time there have only been scattered reports of COTS aggregations and all have been of considerably lesser magnitude. COTS have been implicated in recent coral declines on Maui.

Data from both transect and free-swim surveys reflect the low absolute abundance on the West Hawai'i reefs and indicate a previous increasing trend in COTS abundance has been reversed over the last four years (Figure 73).

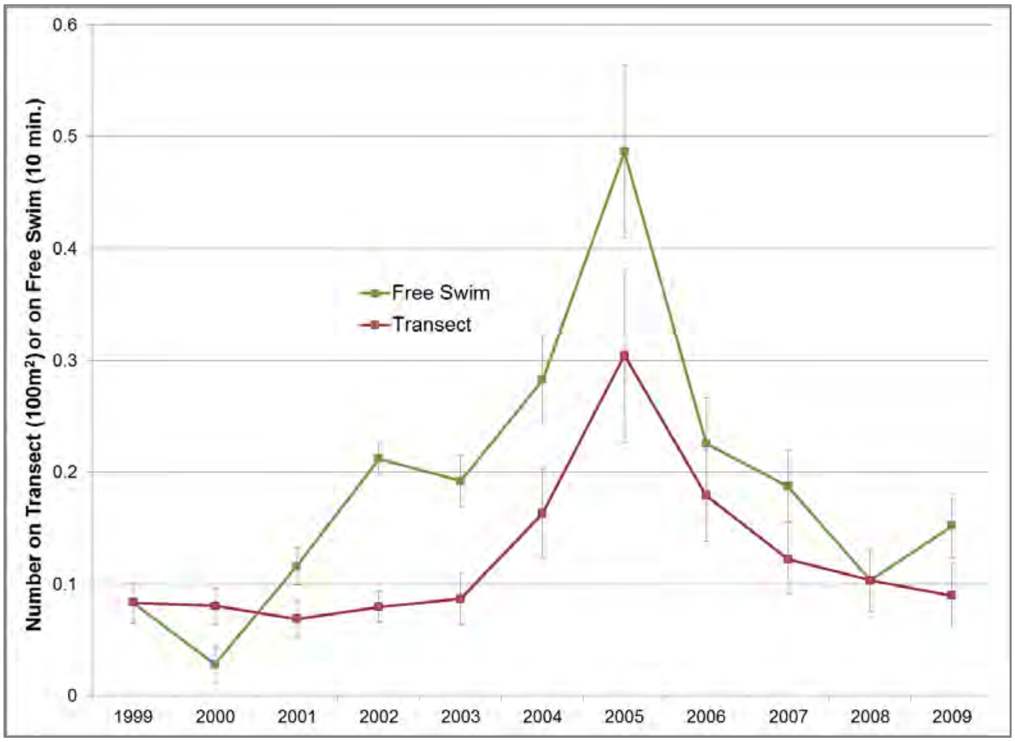


Figure 73. Overall Crown-of-Thorns abundance on West Hawai'i transects and 10 minute free swim surveys.

Urchins

Three of more common surveyed urchin species have increased in West Hawai'i since monitoring began in 1999 with the collector urchin (*Tripneustes gratilla*) showing the greatest increase (figure 74). This increase does not appear to be related to a substantial increase in food supply (i.e. benthic algae) along the coast. Likewise there is no indication that potential food competitors such as herbivorous fishes (e.g. acanthurids) have markedly decreased. In actuality some of the most abundant surgeonfish have increased along with the urchins.

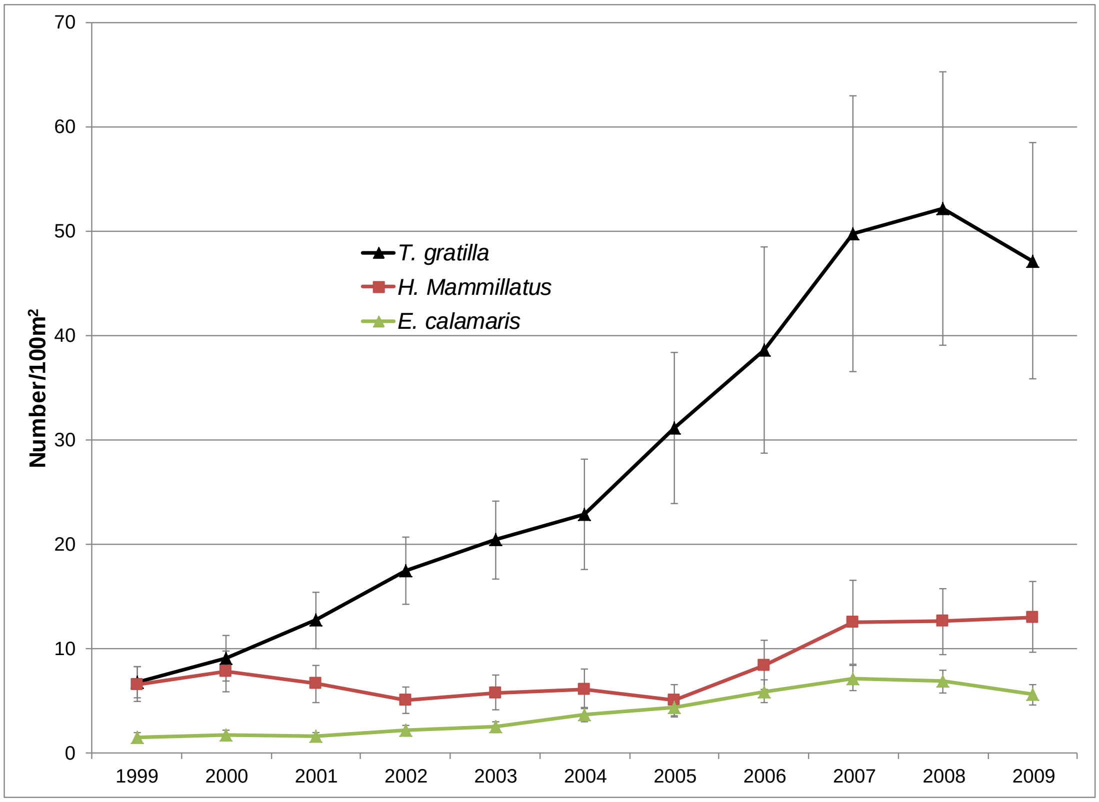


Figure 74. Abundance (*Mean ± SE) of* collector urchin *Tripneustes gratilla,* red pencil urchin *Heterocentrotus mammillatus* and banded urchin *Echinothrix calamaris* on transects.

East Hawai'i Fish Survey Results

To date, abundance of fishes among sites is significantly different, being more abundant at both Waiopae sites than at Richardson's Ocean Center (Figure 75 A). Species richness among sites is also significantly different among sites, being higher on MLCD transects compared to ROC (Figure 75 B). There are no among-site differences in species diversity (p= 0.435) (Figure 75 C). The MLCD and ROC sites have the highest similarity in their fish communities, and the OPEN and ROC communities have the lowest similarity (Table 15).

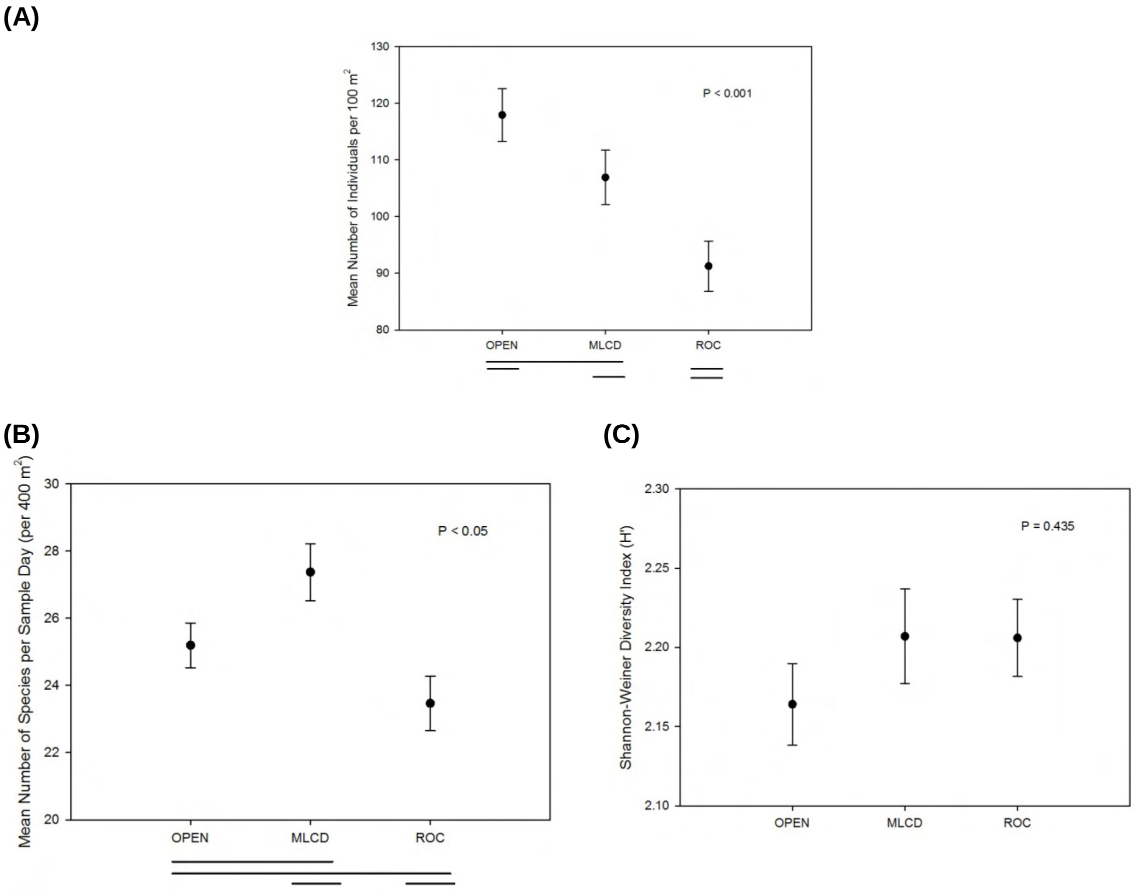


Figure 75. Fish community parameters at Waiopae (MLCD & OPEN) and Richardson's Ocean Center (all survey years pooled) Data are means and standard errors. (A) abundance; (B) Species richness; (C) S-W Diversity.

Table 15. Percent Similarity from pairwise site comparisons.

Location	Percent Similarity
MLCD vs. OPEN	69.3%
MLCD vs. ROC	72.7%
OPEN vs. ROC	53.1%

Over the twelve years of surveying of fishes at Waiopae and Richardson's, there appears to have been a slight increase in fishes observed between 1999 and 2006, followed by a three-year decline, with an upturn on fishes seen so far in 2010 (Figure 70). There is generally good concordance in the year-to-year abundance of fishes among survey sites (Figure 70). Since the delineation of the Waiopae MLCD on June 16, 2003, no net increase in fish abundance has been observed.

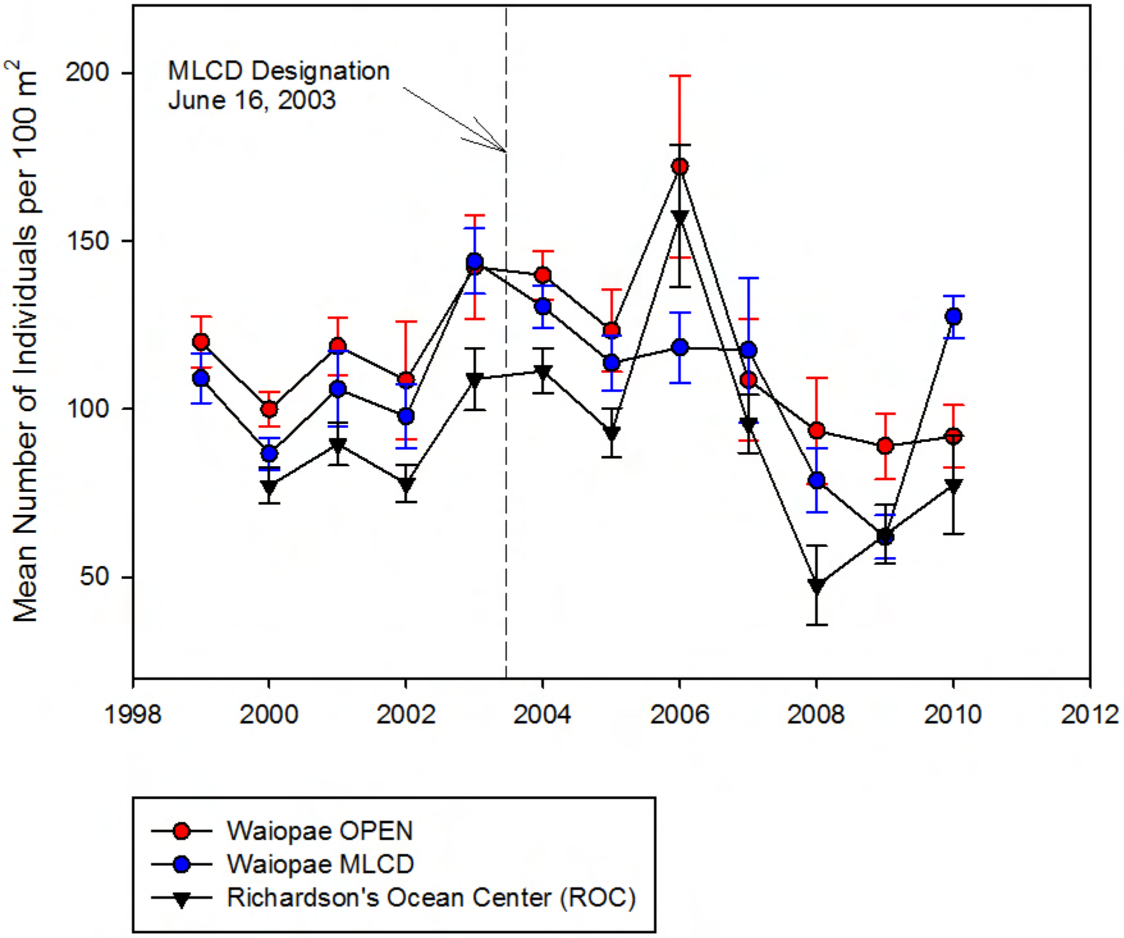


Figure 76. Annual mean abundance (+SE) of fishes at Waiopae and Richardson's Ocean Center.

Of the 136 species recorded on transects at the three locations, most individuals are from one of six families: Labridae, Scaridae, Acanthuridae, Pomacentridae, Tetraodontidae, and Chaetodontidae (Table 15, Figure 71). Labrids and pomacentrids were particularly abundant at all three sampling areas, but scarids were only abundant on Waiopae Open transects. All of the transect lines in this area are deeper than other sites and two traverse a level area with abundant turf algae which appears to attract large numbers of scarids. Species densities at the three East Hawai'i sites are listed in Appendix G.

Table 16. Individuals per 100 m^2 by family at East Hawai'i sites (n = 224 transects at Waiopae Sites; n = 172 at Richardson's Ocean Center).

Family	OPEN	MLCD	ROC
Acanthuridae	13.10	6.12	9.88
Apogonidae	0.02	0.00	0.00
Aulostomidae	0.05	0.02	0.01
Balistidae	0.04	0.05	0.13
Belonidae	0.00	0.10	0.09
Blenniidae	1.30	1.06	0.35
Caracanthidae	0.00	0.01	0.04
Chaetodontidae	2.33	2.99	1.26
Cirrhitidae	0.11	0.40	1.41
Diodontidae	0.00	0.00	0.00
Fistulariidae	0.33	0.09	0.06
Gobiidae	0.03	0.01	0.00
Holocentridae	0.03	0.04	0.01
Kyphosidae	0.00	0.59	0.00
Labridae	48.54	52.46	39.52
Lutjanidae	0.04	0.40	0.00
Monacanthidae	0.02	0.01	0.01
Mugilidae	0.00	0.01	0.11
Mullidae	0.62	0.14	0.05
Muraenidae	0.09	0.14	0.14
Myliobatidae	0.00	0.00	0.00
Ophichthidae	0.00	0.00	0.00
Ostraciidae	0.05	0.19	0.05
Pomacanthidae	0.00	0.00	0.00
Pomacentridae	16.91	33.54	33.31
Scaridae	29.29	4.12	1.31
Scorpaenidae	0.00	0.07	0.23
Serranidae	0.15	0.41	0.01
Synodontidae	0.03	0.03	0.03
Tetraodontidae	4.12	4.11	2.72
Zanclidae	0.06	0.10	0.03
Pooled Individuals/100 m^2 =	117.3	107.2	90.7

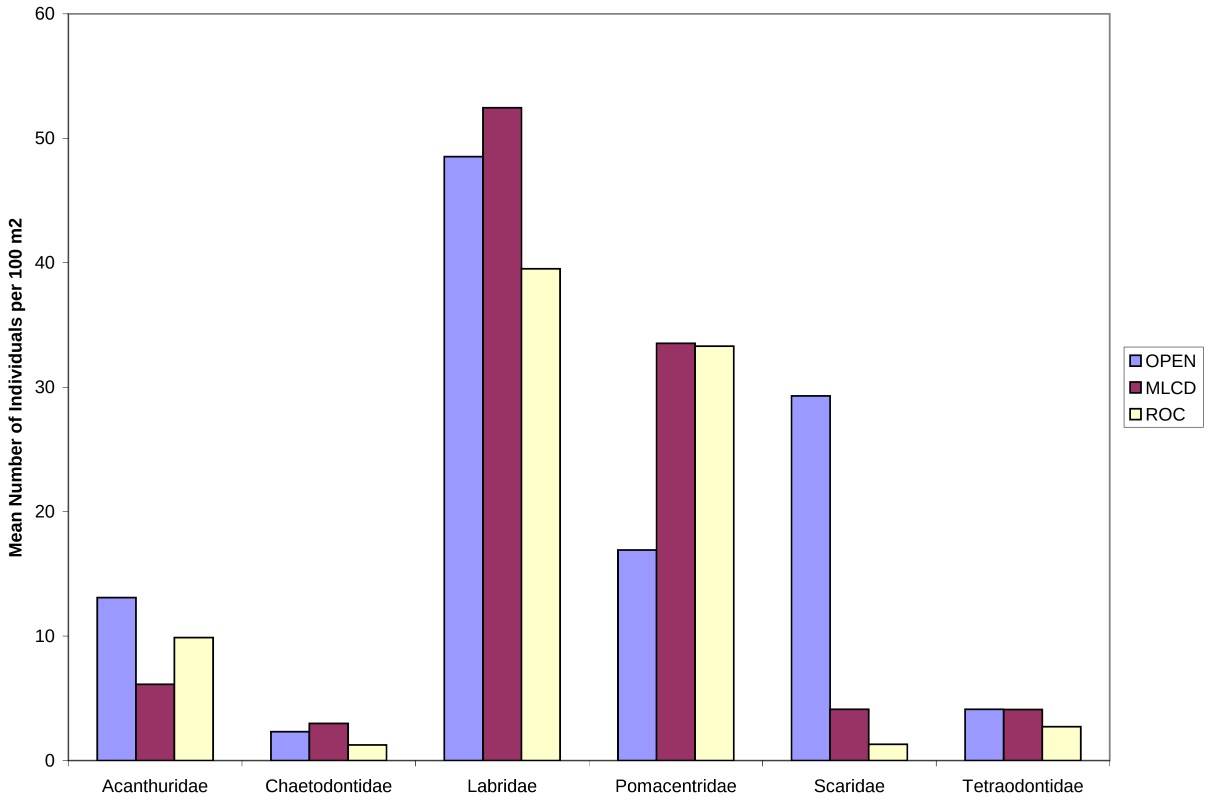


Figure 77. Wai Opae Open/MLCD and ROC fish abundance by family (all years pooled).

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Appendix A

Occurrences of eight coral diseases documented across 30 monitoring sites in West Hawaiʻi (GA = growth anomaly, TRE = trematodiasis, TLS = tissue loss syndrome, MFTL = multifocal tissue loss, HYP = hypermycosis).

ID	Site	*Porites* GA	*Porites* TRE	*Porites* TLS	*Porites* MFTL	*Pavona* HYP	*Montipora* GA	*Pocillopora* senescence reaction	*Pocillopora* TLS
SITE1	Lapakahi	**x**	**x**						
SITE2	Kamilo Gulch	**x**		**x**					
SITE3	Waiakaʻilio Bay	**x**		**x**					
SITE4	Puakō	**x**	**x**	**x**		**x**			
SITE5	Mauna Lani	**x**	**x**	**x**					
SITE6	Keawaiki		**x**			**x**			
SITE7	Kaʻupulehu	**x**	**x**						
SITE8	Makalawena	**x**	**x**	**x**		**x**	**x**		
SITE97	Unualoha Pt.		**x**				**x**	**x**	
SITE9	Wawaloli Beach	**x**	**x**	**x**					
SITE10	Wawaloli FMA	**x**	**x**	**x**			**x**		
SITE11	Kaloko-Honokōhau	**x**	**x**	**x**					
SITE13	Papawai	**x**	**x**	**x**					
SITE98	Old Kona Airport	**x**	**x**	**x**					
SITE14	S. Oneo Bay	**x**	**x**	**x**		**x**			
SITE15	Keauhou	**x**	**x**	**x**					
SITE15x	Keauhou X	**x**	**x**	**x**		**x**			
SITE15y	Keauhou Y	**x**	**x**	**x**	**x**				
SITE15z	Keauhou Z	**x**	**x**	**x**					
SITE16	Kualani Pt. (Red Hill)	**x**	**x**	**x**	**x**		**x**		
SITE17	Red Hill	**x**	**x**						
SITE18	Keopuka	**x**		**x**					
SITE19	Kealakekua	**x**	**x**	**x**		**x**			
SITE20	Keʻei	**x**	**x**	**x**	**x**				
HO	Hōnaunau drop off	**x**	**x**	**x**					
SITE21	Hoʻokena (Kalahiki)	**x**	**x**	**x**	**x**				
SITE22	Hoʻokena (Auau)	**x**		**x**				**x**	**x**
SITE23	Omakaʻa Bay	**x**	**x**	**x**			**x**		
SITE99	Okoe Bay	**x**	**x**	**x**					
SITE24	Manukā	**x**	**x**	**x**					

Appendix B. West Hawai’i Benthic Cover 2007 Surveys

Broad Benthic Categories

Survey Site	Coral	Turf-Bare	Crustose Coralline	Encrusting Macroalgae	Macroalgae	Sand	Sessile Invert	Other
‘Anaeho’omalu	31.5%	56.9%	7.1%	0.1%	0.3%	2.4%	0.1%	1.6%
Ho’okena	28.4%	57.7%	4.8%	2.3%	6.3%	0.1%	0.1%	0.3%
Honokōhau	48.5%	31.6%	3.3%	0.5%	0.3%	2.4%	12.9%	0.1%
Kalahiki	39.6%	48.3%	5.2%	2.2%	1.5%	2.0%	0.0%	1.2%
Kamilo	38.2%	51.0%	7.1%	0.3%	0.2%	0.7%	0.0%	2.3%
Ka’upulehu	31.2%	59.9%	5.8%	0.2%	0.0%	1.8%	0.0%	1.3%
Keawaiki	16.7%	74.9%	5.7%	0.4%	0.2%	0.3%	0.1%	1.7%
Kealakekua	28.6%	65.0%	4.1%	0.7%	0.1%	0.1%	0.0%	1.4%
Ke’ei	28.7%	58.4%	3.6%	0.4%	6.9%	0.3%	0.0%	1.7%
Keopuka	15.6%	75.8%	4.1%	1.3%	0.1%	1.8%	0.1%	1.2%
Kualanui	59.8%	33.4%	3.7%	0.1%	1.3%	0.3%	0.1%	1.1%
Lapakahi	11.4%	56.7%	1.6%	0.9%	0.2%	28.6%	0.1%	1.4%
Makalawena	47.6%	47.5%	1.9%	0.1%	0.0%	1.8%	0.2%	0.6%
Manukā	33.2%	52.9%	9.7%	1.2%	0.1%	1.5%	0.0%	1.5%
N. Keauhou	31.1%	61.4%	5.0%	0.4%	0.4%	0.5%	0.1%	1.1%
Omaka'a	27.1%	61.8%	2.5%	0.2%	0.2%	7.7%	0.0%	0.5%
Papawai	38.3%	39.9%	3.1%	0.6%	4.0%	1.9%	11.0%	1.2%
Puakō	47.8%	42.0%	6.7%	0.6%	0.2%	0.3%	0.0%	2.4%
Red Hill	33.2%	59.4%	2.2%	1.8%	0.1%	2.7%	0.0%	0.6%
S. Oneo	61.9%	31.7%	3.7%	0.9%	0.1%	1.2%	0.1%	0.0%
Waiaka’ilio	42.5%	47.7%	5.5%	0.5%	0.1%	1.2%	0.1%	2.2%
Wawaloli	37.5%	55.3%	3.1%	0.1%	0.0%	0.4%	3.1%	0.5%
Wawaloli Beach	42.3%	52.8%	0.3%	0.0%	0.0%	3.1%	0.3%	1.3%
Keauhou X	57.6%	37.6%	3.3%	0.3%	0.1%	0.6%	0.5%	0.3%
Keauhou Y	40.3%	55.0%	3.0%	0.1%	0.2%	1.0%	0.0%	0.4%
Keauhou Z	42.5%	45.9%	6.6%	0.4%	0.1%	1.2%	2.6%	0.7%
Okoe Bay	34.0%	55.3%	6.0%	0.0%	0.1%	3.3%	0.0%	1.3%
Old Kona Airport	53.2%	25.2%	2.4%	0.3%	0.1%	10.8%	8.0%	0.0%
Unualoha	36.8%	57.3%	1.1%	0.1%	1.1%	1.4%	0.3%	1.8%

Appendix C. West Hawai’i Coral Cover By Species 2007 Surveys

Survey Site	***Montipora capitata***	***Montipora patula***	***Pavona varians***	***Pocillopora meandrina***	***Porites compressa***	***Porites evermanni***	***Porites lobata***	**Other**
Anaeho’omalu	1.1%	0.8%	0.6%	0.3%	14%	0.0%	14.2%	0.4%
Ho’okena	3.5%	0.2%	0.0%	2.3%	3.4%	0.4%	19.4%	0.0%
Honokōhau	0.2%	0.0%	0.0%	0.3%	16.0%	0.5%	31.4%	0.4%
Kalahiki	0.1%	0.0%	0.0%	0.3%	13.6%	1.0%	25.5%	0.1%
Kamilo	0.6%	0.1%	0.1%	0.0%	17.1%	0.0%	20.5%	0.2%
Ka’upulehu	0.2%	0.1%	0.1%	0.2%	2.8%	0.0%	27.6%	0.2%
Keawaiki	0.7%	1.6%	1.9%	0.0%	7.4%	0.0%	4.9%	0.1%
Kealakekua	0.1%	0.0%	1.1%	0.2%	11.9%	0.2%	14.9%	0.4%
Ke’ei	0.2%	0.0%	0.1%	0.1%	20.2%	1.5%	6.7%	0.0%
Keopuka	0.2%	0.3%	0.0%	4.8%	1.6%	0.6%	8.2%	0.1%
Kualanui	0.1%	0.4%	0.1%	0.7%	3.2%	18.7%	36.8%	0.0%
Lapakahi	0.1%	0.0%	0.0%	0.0%	1.7%	0.2%	9.4%	0.1%
Makalawena	2.0%	2.6%	1.7%	1.5%	6.2%	0.1%	27.8%	5.7%
Manukā	0.3%	0.0%	0.0%	0.3%	9.9%	1.0%	22.2%	0.1%
N. Keauhou	0.0%	0.0%	0.3%	0.0%	21.2%	0.1%	9.7%	0.0%
Keauhou X	0.1%	0.0%	0.1%	0.0%	18.8%	2.9%	35.7%	0.0%
Keauhou Y	0.1%	0.1%	0.0%	0.0%	26.1%	0.0%	13.2%	0.0%
Keauhou Z	0.0%	0.0%	0.0%	0.1%	24.0%	0.5%	19.1%	0.0%
Okoe Bay	0.3%	0.0%	0.0%	0.3%	4.5%	2.6%	26.3%	0.0%
Old Kona Airport	0.2%	0.0%	0.0%	0.5%	14.1%	0.6%	38.0%	0.0%
Omaka'a	0.9%	0.1%	0.1%	1.2%	7.7%	2.3%	14.9%	0.1%
Papawai	0.2%	0.1%	0.1%	0.4%	3.5%	1.8%	32.4%	0.3%
Puakō	1.3%	0.7%	0.2%	0.5%	17.2%	0.3%	27.2%	1.0%
Red Hill	1.0%	0.2%	0.1%	1.4%	10.2%	1.7%	19.4%	0.0%
S. Oneo	0.2%	0.5%	0.6%	0.3%	30.5%	1.7%	28.2%	0.0%
Unualoha	1.0%	0.1%	0.0%	3.3%	4.5%	0.3%	26.5%	0.2%
Waiaka’ilio	0.5%	0.4%	0.5%	0.3%	14.7%	0.0%	26.4%	0.1%
Wawaloli	0.5%	0.0%	0.1%	3.9%	4.0%	0.3%	28.0%	0.9%
Wawaloli Beach	1.1%	0.0%	0.0%	0.9%	4.0%	1.4%	34.8%	0.0%

Appendix D. West Hawai`i Benthic Cover 2003 Surveys

Broad Benthic Categories

Survey Site	Coral	Turf-Bare	Crustose Coralline	NCC Macroalgae	Macroalgae	Sand	Sessile Invert	Other
‘Anaeho’omalu	41.2%	38.8%	8.6%	0.6%	0.0%	3.3%	0.0%	7.5%
Ho’okena	28.5%	55.3%	6.1%	4.3%	0.2%	1.0%	0.3%	4.3%
Honokōhau	48.3%	18.5%	6.8%	0.5%	0.1%	1.7%	11.6%	12.4%
Kalahiki	37.1%	45.6%	5.4%	2.8%	0.3%	3.1%	0.0%	5.7%
Kamilo	49.5%	29.1%	7.4%	3.9%	1.2%	1.1%	0.0%	7.9%
Ka’upulehu	40.9%	40.7%	8.5%	0.3%	0.0%	1.6%	0.0%	7.9%
Keawaiki	29.9%	51.7%	9.4%	0.0%	0.6%	0.2%	0.0%	8.1%
Kealakekua	27.7%	51.1%	8.0%	2.5%	0.0%	0.0%	0.0%	10.7%
Ke’ei	31.3%	40.0%	14.3%	0.9%	0.0%	0.2%	0.0%	13.4%
Keopuka	16.5%	62.5%	8.2%	1.8%	0.0%	1.3%	0.0%	9.6%
Kualanui	53.3%	36.0%	4.6%	0.7%	0.0%	0.4%	0.2%	4.7%
Lapakahi	19.5%	53.8%	1.4%	0.9%	0.0%	23.0%	0.0%	1.3%
Makalawena	45.2%	44.8%	4.0%	0.3%	0.0%	2.3%	0.1%	3.3%
Manukā	30.8%	50.4%	9.0%	2.7%	0.1%	2.1%	0.0%	4.8%
N. Keauhou	32.9%	41.5%	15.1%	0.4%	0.0%	0.2%	1.3%	8.5%
Omaka'a	30.2%	52.2%	4.2%	0.7%	0.0%	8.4%	0.0%	4.3%
Papawai	32.8%	30.1%	6.2%	0.5%	0.0%	3.0%	19.8%	7.6%
Puakō	49.9%	32.2%	7.5%	0.9%	0.0%	0.9%	0.0%	8.6%
Red Hill	31.5%	40.9%	6.6%	3.9%	0.2%	5.3%	0.8%	10.7%
S. Oneo	57.0%	23.3%	10.5%	0.3%	0.1%	2.1%	0.2%	6.6%
Waiaka’ilio	54.4%	29.1%	5.3%	0.9%	0.8%	1.3%	0.1%	8.1%
Wawaloli	37.9%	45.8%	2.3%	0.2%	0.3%	2.0%	2.5%	9.0%
Wawaloli Beach	33.8%	51.9%	2.4%	0.2%	0.0%	7.1%	0.3%	4.3%

Appendix E. West Hawai`i Coral Cover By Species 2003 Surveys

Survey Site	*Montipora capitata*	*Montipora patula*	*Pavona varians*	*Pocillopora meandrina*	*Porites compressa*	*Porites evermanni*	*Porites lobata*	Other
‘Anaeho’omalu	0.8%	2.2%	1.0%	1.1%	15.2%	0.2%	19.6%	1.2%
Ho’okena	1.6%	0.7%	0.0%	2.0%	2.0%	0.3%	19.3%	2.4%
Honokōhau	0.0%	0.0%	0.0%	0.2%	14.4%	1.8%	31.8%	0.0%
Kalahiki	0.0%	0.0%	0.0%	0.2%	13.4%	0.0%	22.9%	0.6%
Kamilo	0.8%	0.2%	0.1%	0.2%	23.3%	0.1%	24.3%	0.4%
Ka’upulehu	0.2%	0.1%	0.0%	0.3%	6.7%	1.1%	31.9%	0.4%
Keawaiki	0.5%	3.8%	1.4%	0.9%	12.7%	0.0%	8.9%	1.6%
Kealakekua	0.1%	0.3%	1.9%	0.2%	10.6%	0.0%	13.7%	0.8%
Ke’ei	0.1%	0.0%	0.1%	0.0%	19.6%	1.8%	9.4%	0.1%
Keopuka	0.0%	0.1%	0.1%	4.2%	1.0%	0.0%	9.6%	1.6%
Kualanui	0.5%	0.5%	0.1%	0.1%	3.0%	13.7%	34.3%	1.2%
Lapakahi	0.2%	0.0%	0.0%	0.6%	3.1%	0.0%	15.4%	0.1%
Makalawena	1.0%	4.0%	1.0%	1.0%	6.4%	0.5%	26.5%	4.7%
Manukā	0.2%	0.0%	0.0%	0.4%	7.6%	0.4%	21.5%	0.7%
N. Keauhou	0.0%	0.0%	0.6%	0.0%	16.2%	0.0%	15.0%	1.0%
Omaka’a	0.5%	0.4%	0.1%	0.2%	6.8%	2.3%	18.4%	1.4%
Papawai	0.2%	0.1%	0.0%	0.8%	1.8%	0.8%	28.1%	1.0%
Puakō	0.4%	1.7%	0.3%	0.7%	16.9%	0.2%	28.5%	1.3%
Red Hill	0.6%	0.1%	0.1%	0.6%	10.0%	2.0%	16.9%	1.1%
S. Oneo	0.2%	0.6%	0.4%	0.2%	27.2%	1.9%	25.4%	1.0%
Waiaka’ilio	0.6%	2.3%	0.1%	0.7%	19.4%	0.0%	30.5%	0.8%
Wawaloli	0.1%	0.1%	0.0%	5.5%	3.5%	0.0%	27.3%	1.3%
Wawaloli Beach	0.4%	0.1%	0.0%	1.5%	3.2%	1.7%	26.1%	0.7%

Appendix F.

Table 2003 and 2007 Octocoral Percent Cover Comparison

Sites (North to South)	2003	2007	P=
Lapakahi (01)	0.0%	0.0%	N/A
Kamilo (2)	0.0%	0.0%	N/A
Waiaka’ilio Bay (03)	0.0%	0.0%	N/A
Puakō (4)	0.0%	0.0%	N/A
‘Anaeho'omalu (05)	0.0%	0.0%	N/A
Keawaiki (06)	0.0%	0.0%	N/A
Ka'upulehu (07)	0.0%	0.0%	N/A
Makalawena (8)	0.0%	0.0%	N/A
Wawaloli Beach (09)	0.4%	0.3%	0.908
Wawaloli (10)	2.3%	3.1%	0.232
Honokōhau (11)	10.6%	12.7%	0.592
Papawai (13)	18.2%	10.9%	0.018
S. Oneo Bay (14)	0.2%	0.1%	0.058
N. Keauhou (15)	1.2%	0.1%	0.13
Kualanui Pt. (16)	0.1%	0.1%	0.231
Red Hill (17)	0.5%	0.0%	0.262
Keopuka (18)	0.0%	0.0%	N/A
Kealakekua Bay (19)	0.0%	0.0%	N/A
Ke'ei (20)	0.0%	0.0%	N/A
Ho'okena (Kalahiki) (21)	0.2%	0.0%	0.141
Ho'okena (Auau) (22)	0.0%	0.0%	N/A
Miloli’i (Omaka’a) (23)	0.0%	0.0%	N/A
Miloli’i (Manuka) (24)	0.0%	0.0%	N/A

APPENDIX G.

Table X3. Individuals per 100 m^2 by species at East Hawai’i sites (n = 224 transects at Waiopae; n = 172 at Richardson's Ocean Center).

Taxa	OPEN	MLCD	ROC
Abudefduf abdominalis	0.09	0.74	3.20
Abudefduf sordidus	0.00	0.22	0.03
Abudefduf vaigiensis	0.00	0.04	0.05
Acanthurus achilles	0.00	0.04	0.01
Acanthurus blochii	0.02	0.00	0.00
Acanthurus leucopareius	0.03	0.25	0.25
Acanthurus nigrofuscus	10.35	2.92	6.18
Acanthurus nigroris	0.00	0.04	0.02
Acanthurus triostegus	1.83	2.48	3.36
Aetobatis narinari	0.00	0.00	0.00
Aluterus scriptus	0.00	0.00	0.00
Anampses chrysocephalus	0.00	0.00	0.00
Anampses cuvier	0.03	0.00	0.01
Apogon kallopterus	0.01	0.00	0.00
Apogon menesemus	0.00	0.00	0.00
Arothron hispidus	0.03	0.02	0.01
Arothron meleagris	0.08	0.24	0.07
Asterropteryx semipunctatus	0.03	0.00	0.00
Aulostomus chinensis	0.05	0.02	0.01
Belonidae	0.00	0.01	0.01
Blenniella gibbifrons	0.02	0.01	0.03
Blenniidae	0.00	0.00	0.00
Bodianus bilunulatus	0.03	0.00	0.00
Calotomus carolinus	0.01	0.00	0.00
Cantherhines dumerilii	0.01	0.01	0.01
Canthigaster amboinensis	0.36	1.18	1.06
Canthigaster jactator	3.65	2.67	1.58
Canthigasteridae	0.00	0.00	0.00
Caracanthus typicus	0.00	0.01	0.04
Centropyge potteri	0.00	0.00	0.00
Cephalopholis argus	0.15	0.41	0.01
Chaetodon auriga	0.10	0.05	0.04
Chaetodon lineolatus	0.00	0.00	0.00
Chaetodon lunula	1.50	2.15	0.70
Chaetodon lunulatus	0.00	0.00	0.04
Chaetodon miliaris	0.03	0.00	0.00
Chaetodon multicinctus	0.00	0.00	0.00
Chaetodon ornatissimus	0.12	0.22	0.03
Chaetodon quadrimaculatus	0.49	0.48	0.44
Chaetodon unimaculatus	0.08	0.00	0.00
Cheilio inermis	0.00	0.00	0.00
Chlorurus perspicillatus	0.38	0.04	0.00

Chlorurus sordidus	16.30	1.93	0.63
Chromis agilis	0.09	0.01	0.14
Chromis ovalis	0.78	0.02	0.00
Chromis hanui	0.00	0.00	0.02
Chromis vanderbilti	10.01	9.33	2.82
Cirrhitops fasciatus	0.01	0.04	0.64
Cirrhitus pinnulatus	0.01	0.13	0.14
Cirripectes vanderbilti	0.89	0.54	0.18
Coris flavovittata	0.00	0.01	0.01
Coris gaimard	0.33	0.47	0.41
Coris venusta	0.02	0.08	0.32
Ctenochaetus hawaiiensis	0.00	0.00	0.00
Ctenochaetus strigosus	0.41	0.31	0.00
Dascyllus albisella	0.19	0.03	0.01
Dendrochirus barberi	0.00	0.00	0.00
Diodon hystrix	0.00	0.00	0.00
Echidna nebulosa	0.02	0.00	0.00
Exallias brevis	0.01	0.04	0.02
Fistularia commersonii	0.33	0.09	0.06
Forcipiger flavissimus	0.01	0.06	0.00
Forcipiger longirostris	0.00	0.02	0.00
Gnatholepis anjerensis	0.00	0.00	0.00
Gomphosus varius	4.88	5.74	1.23
Gymnomuraena zebra	0.01	0.02	0.03
Gymnothorax eurostus	0.00	0.04	0.01
Gymnothorax flavimarginatus	0.02	0.03	0.02
Gymnothorax melatremus	0.00	0.00	0.00
Gymnothorax meleagris	0.01	0.04	0.05
Gymnothorax sp.	0.02	0.01	0.02
Gymnothorax undulatus	0.01	0.00	0.00
Halichoeres ornatissimus	0.04	1.04	0.58
Hemitaurichthys thompsoni	0.00	0.00	0.00
Kyphosus bigibbus	0.00	0.28	0.00
Kyphosus sp.	0.00	0.26	0.00
Kyphosus vaigiensis	0.00	0.04	0.00
Labroides phthirophagus	1.50	0.97	0.05
Lutjanus fulvus	0.02	0.00	0.00
Lutjanus kasmira	0.02	0.40	0.00
Lutjanus sp.	0.00	0.00	0.00
Macropharyngodon geoffroy	0.00	0.05	0.06
Melichthys vidua	0.00	0.01	0.00
Mulloidichthys flavolineatus	0.04	0.01	0.03
Mulloidichthys vanicolensis	0.04	0.00	0.00
Myrichthys magnificus	0.00	0.00	0.00
Naso lituratus	0.07	0.05	0.04
Naso unicornis	0.03	0.00	0.01
Neomyxus leuciscus	0.00	0.01	0.11
Neoniphon sammara	0.01	0.00	0.00

Novaculichthys taeniourus	0.01	0.01	0.02
Ostracion meleagris	0.05	0.19	0.05
Oxycheilinus unifasciatus	0.07	0.02	0.02
Paracirrhites arcatus	0.08	0.19	0.58
Paracirrhites forsteri	0.00	0.04	0.05
Parupeneus bifasciatus	0.15	0.07	0.00
Parupeneus cyclostomus	0.05	0.01	0.01
Parupeneus multifasciatus	0.34	0.02	0.02
Parupeneus porphyreus	0.00	0.03	0.00
Pervagor aspricaudus	0.01	0.00	0.00
Plagiotremus ewaensis	0.04	0.05	0.05
Plagiotremus goslinei	0.34	0.41	0.07
Platybelone argalus	0.00	0.09	0.08
Plectroglyphidodon imparipennis	1.58	2.98	8.22
Plectroglyphidodon johnstonianus	0.96	1.07	1.42
Plectroglyphidodon sindonis	0.00	0.00	0.02
Priolepis aureoviridis	0.00	0.00	0.00
Pseudocheilinus evanidus	0.03	0.02	0.02
Pseudocheilinus octotaenia	0.14	0.06	0.00
Pseudocheilinus tetrataenia	0.13	0.14	0.01
Pseudojuloides cerasinus	0.00	0.00	0.00
Pterois sphex	0.00	0.00	0.00
Rhinecanthus rectangulus	0.04	0.04	0.13
Sargocentron diadema	0.01	0.00	0.00
Sargocentron punctatissimum	0.02	0.00	0.01
Sargocentron xantherythrum	0.00	0.03	0.00
Scarus dubius	0.29	0.02	0.01
Scarus psittacus	11.69	1.85	0.47
Scarus rubroviolaceus	0.62	0.28	0.20
Scuticaria tigrinus	0.00	0.01	0.00
Sebastapistes coniorta	0.00	0.06	0.22
Stegastes fasciolatus	3.21	19.10	17.38
Stethojulis balteata	5.04	7.98	14.18
Synodus binotatus	0.00	0.01	0.03
Synodus sp.	0.02	0.02	0.00
Synodus ulae	0.00	0.01	0.00
Synodus variegatus	0.01	0.00	0.00
Taenianotus triacanthus	0.00	0.01	0.00
Thalassoma ballieui	0.02	0.04	0.05
Thalassoma duperrey	36.21	35.76	22.38
Thalassoma purpureum	0.00	0.01	0.01
Thalassoma quinquevittatum	0.02	0.00	0.00
Thalassoma trilobatum	0.04	0.06	0.15
Zanclus cornutus	0.06	0.10	0.03
Zebrasoma flavescens	0.35	0.03	0.01
Pooled Individuals/100 m^2 =	117.3	107.2	90.7