The Effectiveness of Marine Protected Areas and the Impacts of Aquarium Fish Collecting in Hawai'i

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EXECUTIVE SUMMARY

In response to declines in reef fishes due to aquarium collectors, the Hawai'i state legislature, through Act 306, created the West Hawai'i Regional Fishery Management Area in 1998 to improve management of fishery resources. In 1999 the West Hawai'i Fisheries Council, a community-based group of individuals, proposed nine Fish Replenishment Areas (FRAs), along the west Hawai'i coastline that collectively prohibited aquarium fish collecting along 35% of the coast. The FRAs were officially closed on Jan. 1, 2000.

The West Hawai'i Aquarium Project (WHAP) established 23 study sites in early 1999 located at FRA, open (aquarium fish collection areas) and control (existing protected areas) sites to collect baseline data both prior to and after the closure of the FRAs. Analysis of baseline surveys in 1999 support earlier research documenting strong effects of aquarium collector harvesting on selected fishes in west Hawai'i. Pre-closure surveys indicate that collectors continued to target *Acanthurus achilles* *Centropyge potteri*, *Chaetodon quadrimaculatus*, *Ctenochaetus strigosus*, *Forcipiger* spp., *Zanclus cornutus* and *Zebrasoma flavescens* in the FRAs prior to their closure. On average, aquarium fishes were 26% less abundant in FRAs than adjacent control areas.

Analysis of five post-closure surveys conducted in 2001 provided some evidence of an increase of aquarium fish stocks in FRAs. Although there were no statistically significant changes for any single species, aquarium fishes had a significant 0.8% increase in FRAs relative to controls and a significant 15.2% decrease in open areas relative to controls. Thus, the FRAs are enhancing the abundance of aquarium fishes relative to their natural abundances in control areas and also protecting aquarium fish stocks from further declines in abundance. These results appear to be due to the moderately high level of newly recruiting aquarium fishes observed in 2001 relative to 1999 and 2000. Thus, there is evidence that recruitment is an important mechanism replenishing depleted stocks within reserves in Hawaii. Moreover, analysis of the spatial distribution of juvenile yellow tangs suggest that habitat may be an important factor influencing fish abundance and more attention needs to be paid to post-settlement processes in this system.

Based on current results, it is recommended that monitoring in west Hawai'i continue until recruitment levels increase and provide a mechanism to replenish depleted stocks in the newly established reserves and thus provide a rigorous test of the effectiveness of the reserve system to increase the productivity of aquarium fishes. However, we recommend that additional reserves be established in Hawai'i as a precautionary measure against overuse of fishery resources. Further, as recruitment appears to be the primary mechanism driving the replenishment of nearshore fisheries, we recommend that a state-wide monitoring program be instituted to gather fine-scale spatial and temporal information on the extent of newly recruiting fishes. We also advocate for increased study of nearshore oceanography to help better understand the dynamics of recruitment processes. Finally, as habitat appears to be important to newly

recruiting fishes, we need additional studies focused on habitat and management to protect existing habitats critical for juvenile and reproductive fishes.

INTRODUCTION AND PROJECT BACKGROUND

Coral reefs are diverse and productive biological communities and important natural resources in tropical areas. However, reefs in many parts of the world are currently being threatened with a wide variety of anthropogenic disturbances (Richmond, 1993). On the island of Hawai'i, harvesting by the aquarium trade is a major source of overfishing that warrants improved resource management (Clark and Gulko, 1999; Grigg, 1997; Tissot and Hallacher, 1999). This project addresses the implementation and evaluation of a fishery management plan on the island of Hawai'i (Act 306 of 1998) focused on aquarium fish collecting using a network of marine protected areas (MPAs).

MPAs are currently of wide national and international interest (Allison et al., 1998; Bohnsack, 1998; Murray et al., 1999). However, very few studies are replicated, or have statistically rigorous monitoring programs with data collected both before and after closure (Murray et al., 1999). This project represents a unique opportunity to investigate both the effectiveness of MPAs in fishery management and provide an ongoing assessment of aquarium fish collecting impacts in west Hawai'i.

The aquarium collecting industry in Hawai'i has had a long contentious history. As early as 1973, public concern over collecting activities were first addressed by the Hawai'i Division of Aquatic Resources (DAR) by requiring monthly collection reports. However, the industry has been largely unregulated over the last 16 years despite dramatic increases in both the number of issued collecting permits and collected fishes. Further, increases in fish collecting combined with growing public perception of dwindling fish stocks eventually developed into a severe multiple use conflict between fish collectors and the dive tour industry.

In response to declines in reef fishes due to aquarium collectors, the Hawai'i state legislature, through Act 306, created the West Hawai'i Regional Fishery Management Area in 1998 to improve management of fishery resources. One of the requirements of Act 306 mandates that DAR declare a minimum of 30% of the west Hawai'i coastline as Fish Replenishment Areas (FRAs), MPAs where aquarium fish collecting is prohibited. The Act also called for substantive involvement of the community in resource management decisions. In 1998, the *West Hawai'i Fisheries Council*, a community-based group of individuals, proposed nine FRAs along the west Hawai'i coastline that will collectively prohibit aquarium fish collecting along 35% of the coast when combined with existing protected areas (MLCDs: Marine Life Conservation Districts; and FMAs: Fishery Management Areas). The proposed management plan received 93% support at a public hearing, was subsequently approved by Governor Cayetano, and the FRAs were officially closed to aquarium collectors on Dec. 31, 1999.

The principle purpose of our project is to evaluate the effectiveness of the nine FRAs to increase the productivity of aquarium fishery resources. Specifically, our observational design compares FRA sites before and after closure to sites which remained open to aquarium fish collecting (open sites) and those that were not subjected to fish collecting (control sites).

Treatment	Pre-FRA Status	Post-FRA Status
Open	Open to fish collecting	Open to fish collecting
FRA	Open to fish collecting	Closed to fish collecting
Control	Closed to fish collecting	Closed to fish collecting

With our previous two years of funding from the HCRI Research Program we established 23 permanent study sites located in FRA, open (aquarium fish collection areas) and control (existing MPAs) areas to collect baseline data both prior to and after the closure of the FRAs (Appendix 1) . The observational design contains five compete Control-FRA-Impact design blocks which allow rigorous and statistically powerful BACIP (Before-After Control-Impact Procedure) comparisons (Underwood, 1992; Osenberg and Schmitt, 1996). To date we have conducted a total of 15 surveys of all study sites in west Hawai'i including six pre-reserve closure and nine post-reserve closure.

In east Hawai'i there are similar management concerns about overfishing and aquarium fish collecting, particularly in the Kapoho area. A community-based group, the *Wai O'Pae Marine Reserve Committee*, is spearheading efforts to establish a new reserve and has made recommendations to DAR about areas to close. In 1999, we began monitoring two sites at Kapoho, one a proposed reserve and an adjacent control. In 2000 we added an additional site at Richardson's Ocean Park. Continued monitoring at these sites will provide an estimate of baseline conditions to evaluate the response of fish populations to a cessation (or reduction) of fishing pressure in the Kapoho reserve once it is closed. To date we have conducted a total of 24 surveys of study sites at Kapoho and 13 at Richardson's Ocean Park.

Accordingly, the objectives of this project are:

1. Evaluate the effectiveness of the marine reserve network by comparing fish abundances among control, open and FRA study sites.
2. Estimate the impacts of aquarium fish collecting both in and outside of FRA reserves in west Hawai'i.
3. Continue baseline monitoring of potential reserve sites and controls in east Hawai'i.
4. Document recruitment patterns of aquarium fishes.
5. Disseminate the results of our studies to coral reef managers, the scientific community, the West Hawai'i Fisheries Council, and the public.

PROTOCOL DEVELOPMENT

Survey methods were developed specifically for the monitoring of fishes and benthic substrates in west Hawai'i. Fishes were surveyed using visual strip transects, which have been shown to be highly repeatable and reasonably accurate (Brock, 1954;

Sale, 1980). Parameter to be determined included transect length, transect width, and the number of transects sampled at each site. The optimal transect size for a given design will depend on the community being sampled and should be determined empirically (Sale 1980; Sale and Sharp, 1983). As strip transect counts are known to be biased by different observers (e.g., McCormick and Choat, 1987), we created a transect design that would allow us to survey a single Control, FRA, and Impact design block on a single day with the same set of observers. Thus, our transect size was constrained around a maximum total bottom of about 2½ hours per day, or 50 minutes per site. Other considerations that influenced our design were the degree of variability of abundance estimates, the number of species sampled and the statistical power to detect meaningful changes in fish abundance (Mapstone, 1996).

Pilot studies on the design of optimal transect length and number were conducted at Mahukona, Hawai'i during the final survey of the QUEST coral reef monitoring workshop in May of 1995, 1996 and 1997 (Hallacher and Tissot, 1998). Each year, four 50 m transects were established at 7 m and 15 m depths and all fishes were counted at 10 m intervals along 50 m transects by a pair of divers. Sequential 10 m segments of each transect were then pooled to examine the effects of varying transect length on abundance estimates. Based on species accumulation curves the number of different fish species observed along transects increased with transect length and number (Figure 1A). The number of species seen increased dramatically from 10 to 20 m transects, with smaller increases among 20, 30, 40 and 50m transect lengths. Based on these results, longer transects are likely to sample more species, although there did not appear to be much difference between 40 and 50 m transect lengths. In contrast, mean estimates of a common and uncommon aquarium fish did not vary significantly with transect length, nor was their significant variation in the standard error of the estimate (Figure 1B). Thus, accuracy and precision did not appear to vary with transect length. Based on these two results, and the previously mentioned time constraints, we used a design that maximized the number of transects we could reasonably sample with two pairs of divers at a single site in 50 minutes: four 25m transects. Based on previous experience sampling coral reef fishes in Hawai'i we selected a transect width of 2m, which has been shown to produce reasonably precise estimates of fish abundance (Sale and Sharp, 1983; Cheal and Thompson, 1997). Using six stainless-steel bolts permanently cemented into the bottom, we established four permanent 25 m transects in an H-shaped design at each study site (Figure 2A).

Power analysis of preliminary fish transect data indicated that our observational design will detect 10-46% changes in the abundance of the principle targeted aquarium fishes in West Hawai'i during the first year using reasonable error rates (α=0.10; β=0.10; see Mapstone, 1996) (Table 1). After the completion of additional surveys the power of our design will increase and we will be able to detect even smaller changes in fish abundance. Power analyses were based on the ability of a two-sample t-test to detect significant differences between two samples. Our actual design is based on the BACI test (see below) which has even greater power to detect changes between surveys and locations (Underwood, 1992). Based on the estimated levels of the effects due to aquarium collectors reported in Tissot and Hallacher (1999), we will be able to detect significant change in all of the targeted species if population densities within the

FRAs recover to levels similar to adjacent control sites. Thus our design is statistically powerful and capable of testing the hypothesis that the FRA reserve network will enhance the productivity of aquarium fish populations; the major goal of our study.

Another part of our study was the ability to describe the abundance and distribution of benthic habitats at each study site. As a result, pilot studies were also conducted on the optimal design to estimate the abundance of coral, non-living substrates and macro algal cover at each site, and to provide a description of fish habitat . An additional, but secondary goal, was to detect changes in the associated coral reef community.

We used a quantitative video sampling method to monitor benthic habitats in West Hawai'i; an increasingly common method of conducting coral reef surveys (Aronson et al., 1994; Carleton and Done, 1995). Video sampling methods are reasonably accurate and precise and yield the largest quantity of data per unit of field effort (Carlton and Done, 1995; Brown et al., 1999). To ensure consistency with other coral reef survey methods used in the state of Hawai'i, we developed our design in cooperation with the Hawai'i Coral Reef Assessment and Monitoring program (CRAMP) to estimate the abundance, diversity and distribution of benthic habitats (Brown et al., 1999). Parameters to be developed using this method included the number of video transects, number of frames per transect, and the number of random points to sample per frame.

We used data from images taken at Kapoho, Hawai'i to evaluate the number of frames and the number of points per frame. Based on species accumulation curves the number of different coral/algal species sampled increased with the number of points sampled per frame and the number of frames sampled (Figure 3A). The highest number of species sampled occurred when 50 points were sampled on a minimum of 40 frames. Thus, based on these results 40 frames should be sampled per site and analyzed with 50 points each. In contrast, mean estimates of total coral cover and a common and an uncommon species of coral did not significantly vary with the number of points per frame. However, there was a significant decrease in the standard error of the estimate for rare coral species above 30 points per frame relative to 5, 10 and 20 points analyses (Figure 3B). Based on these results and the fact that benthic habitat images could be systemically analyzed in the laboratory where there were no bottom time constraints, we used a design which maximized the diversity of species that could be sampled: a minimum of 40 frames per site each of which is sampled using 50 random points.

The last design criteria to be addressed was the design and number of video transects Using the four-25m transects designed for the monitoring of fishes we devised two alternative methods to sample the benthic habitats at each site using either a ten-10m or four-25m transect configuration (Figure 2B). To evaluate the relative merits of these two designs we used a set of images (n = 112) sampled from a single site at Honokohau, Hawai'i. We compared the two methods using a power analysis of a two-sample t-test to detect a 10% change in mean coral cover between two surveys (α=0.10 and β=0.10). Based on a comparison of the results, both methods were roughly equivalent using different number of frames in the analysis: about 9 frames per transect for the 10m method and 20 frames per transect for the 25m method (Figure 4). However, since the 10m method required setting up new transect lines and the 25m method utilized existing lines, we choose the latter design as it saved time underwater and was thus more cost efficient.

FIELD METHODOLOGY

Study sites were selected in early 1999 within an area of suitable habitat and depth. Sites were selected using a procedure which attempted to minimize among-site habitat variability but yet selected unbiased locations within an area. A diver was towed behind a slow-moving vessel in the area of interest (open, FRA, or control) to search for areas suitable as study sites. Criteria for acceptable sites included a substratum with abundant finger coral (*Porites compressa*) at 10-18 m depths. Finger coral is an important habitat for the most common aquarium fishes, particularly *Zebrasoma flavescens*, and typically dominates most areas of the Kona coast at 10-18 m depths except along exposed headlands and on recent lava flows (Grigg and Maragos, 1974; Dollar, 1982). Within an area of suitable habitat and depth a float with an attached weight was haphazardly thrown off a moving vessel and the ocean-side center transect pin was established at the coral colony nearest to the weight on the bottom. Using 5 additional stainless-steel bolts cemented into the bottom, we established four permanent transects in an H-shaped at each of the 23 sites in west Hawai'i, and the two sites in east Hawai'i (Figure 2A).

During field surveys, study sites were located by differential GPS and the four 25 m transect lines were deployed between the eyebolts. Fish densities of all observed species were estimated by visual strip transect search along each permanent transect line. Two pairs of divers surveyed the lines, each pair searching two of the 25 m lines in a single dive. The search of each line consists of two divers, swimming side-by-side on each side of the line, surveying a column 2 m wide. On the outward-bound leg, larger planktivores and wide-ranging fishes within 4 m of the bottom were recorded. On the return leg, fishes closely associated with the bottom, juveniles, and fishes hiding in cracks and crevices were recorded. All sites were surveyed bi-monthly, weather permitting, for a total of six surveys per year.

The abundance of coral, non-living substrates and macro algae were estimated at each site using a digital video camera. Video sampling was conducted using a Sony DCR-TRV900 housed in an Amphibico® underwater housing. In the laboratory individual contiguous still frames from each transect were extracted from each video and archived for use on CD-ROM. Percent cover estimates of substrate types were then obtained using the program PointCount '99 (P. Dustin, personal communication) which is used by the EPA's Florida Keys Coral Reef Monitoring Project. PointCount projects a series of random dots on each image. An observer then identified the substratum type under each point. Abundance estimates of different substrates were derived by examining the percent of points contacting each substrate within each video frame. Although as many as 40 frames were archived from some transects, we randomly selected 20 frames from each transect as this was a sufficient number of frames to address the questions of our study.

Data Analysis and Methodology

Database

Original underwater data sheets are transcribed and copies are provided to all participating scientists. Originals are archived in DAR's West Hawai'i facility under the supervision of Walsh. Data are entered into a Microsoft® Access relational database developed in cooperation with CRAMP under the supervision of Tissot. This database will be accessible to each of the project participants through the Internet and will also be available to additional coral reef ecosystem managers through the DAR GIS database system and quarterly reports.

The database structure consists of a series of linked tables. Data files are linked by location, survey, transect run, or species code. Thus, fish counts from visual strip transects from each survey are referenced to location information, which provides data on GPS coordinates, management status, historical databases, and a wide-variety of meta-data which serve as a reference to the GIS system. The actual fish transect data are cross-referenced to student observer information, general comments, and taxonomic, ecological, and utilization information on each species. PointCount estimates of benthic substrates are also maintained in the database and linked to location information. These database variables were selected for the current data in order to provide a context based on historical studies conducted in Hawai'i.

Data Analysis

A general prediction of marine reserve theory is that the density of protected organisms should increase in reserves after closure due a reduction in mortality due to reduced harvesting. This prediction assumes that new individuals are entering reserves by recruitment and/or migration. Thus, the density of targeted aquarium fishes should increase in FRAs after reserve closure relative to adjacent control areas if there is new, net immigration into the reserve.

The statistical significance of reserve effectiveness was evaluated using the BACIP (Osenberg and Schmidt, 1996). This method tests for significant change in fish density by comparing mean Control-FRA differences before reserve closure to mean Control-FRA differences after reserve closure. The same comparison can also be made for changes in fish density in open areas by comparing Control-open differences.

Based on this method we derived an index of reserve replenishment, ***R***, which estimates the difference in mean density between control and FRA (or open) areas after reserve closure relative to before closure:

$$R = \left[\frac{\sum_{i=1}^{t_{after}} \overline{X}_{control} - \overline{X}_{FRA}}{t_{after}} \right] - \left[\frac{\sum_{i=1}^{t_{before}} \overline{X}_{control} - \overline{X}_{FRA}}{t_{before}} \right] \qquad (1)$$

Where t_{before} is the number of samples taken prior to reserve closure (n=6) and t_{after} is the number of samples taken after to reserve closure (currently n=9). A significant change in *R* would indicate an increase or decrease in fish density in reserves (or open areas) after closure relative to reserves prior to closure.

The BACIP procedure tests for significant differences in *R* for each reserve using a two-way, repeated measure analysis of variance. Data were limited to the five complete control-FRA design blocks and surveys served as non-independent repeated-measures. This analysis provided a statistically rigorous test of the following factors:

1) <u>Before-after comparisons</u>: tests the overall statistical significance of *R* (all FRAs pooled);

2) <u>FRA/Impact comparisons</u>: tests for significant overall changes in control-FRA and control-impact differences among sites (e.g., the overall magnitude of collector harvesting across all surveys);

3) <u>Statistical interaction between before-after comparisons and each FRA</u>: tests for differences in *R* among FRAs.

Results and Discussion

In west Hawai'i we have conducted a total of 15 fish surveys of all sites (n=1380 transects); six surveys prior to the closure of the reserves which will serve as baseline data and nine post-closure surveys. We have also completed a video benthic habitat survey of all sites and images were extracted and archived from the video on CD-ROM (n=3392 images) for quantitative analysis using PointCount. In east Hawai'i 24 surveys were completed at Kapoho and 13 surveys at Richardson's Ocean Park (Appendix 2). A list of all tasks completed, including outreach, is listed in Appendix 3.

Benthic habitat analysis

Analysis of video transects revealed significant variation in total live coral cover in west Hawai'i (Figure 5). Overall, mean percent coral cover ranged between 27% (Lapakahai) to 78% (Puako). In general, coral cover was higher in sheltered areas (e.g., Puako) and lower in areas located on more wave-exposed headlands (e.g., Keopuka). Of critical importance to the evaluation of FRA effectiveness is the assumption that habitat variation, a known factor influencing fish abundance, is similar among the control-FRA-open areas in each design block. One-way analysis of variance among sites in each design block using total coral cover was non-significant at all FRA blocks except at North Kohala (Figure 6). In this area the percent coral cover was significant lower at the control site, Lapakahi, that at the adjacent FRA and open areas ($P < 0.05$). Thus, fish comparisons in this reserve design block need to be interpreted with caution.

Effects of Aquarium Collectors

Estimates of the impacts of aquarium collectors were made by comparing the mean density difference of target fishes in control relative to FRA areas using the six 1999 baseline surveys (see Tissot and Hallacher [1999] for a complete description of this method). Overall, there were large significant declines in seven of the nine species analyzed (Table 2). Overall differences were significantly lower in FRA relative to control areas in *Acanthurus achilles* (-55%), *Centropyge potteri* (-42%), *Chaetodon* *quadrimaculatus* (--97%), *Ctenochaetus strigosus* (-14%), *Forcipiger* spp. (-55%), *Zanclus cornutus* (-49%) and *Zebrasoma flavescens* (-43%) suggesting strong reductions in abundance due to aquarium collectors prior to reserve closure. There were no overall significant declines in *Chaetodon multicinctus* or *Chaetodon ornatissimus* (Table 2). With the exception of the latter two species, these values are remarkably similar to those reported by Tissot and Hallacher (1999), indicating that active collecting was reducing aquarium fish density in FRAs prior to their closure in early 2000. Overall, aquarium fishes were 26% less abundant in FRAs relative to control areas in west Hawai'i.

Estimates of aquarium collector impacts were also calculated for the five individual complete-block FRAs in west Hawai'i (Table 2). The North Kohala FRA showed no significant negative decline for any species and targeted aquarium fishes were significantly more abundant in the FRA than at the control site. This result is a likely response to the high sand cover and low coral cover of the Lapakahi MLCD, which serves as a control site for the North Kohala FRA (Waiakailio Bay). In contrast, declines due to collectors were significant in the Puako, Red Hill and Honaunau FRAs, while there were no significant overall declines in the Honokohau FRA (Table 2). However, as evidenced above, complete analysis of the benthic habitats of all sites will be critical to a complete evaluation of these patterns.

Effectiveness of Reserves

Overall their were no significant changes in the most abundantly collected aquarium fishes in control (-6%) and FRA (-6%) areas before and after reserve closure but significant declines occurred in open areas (-16%) (Figure 7). Similarly, there were no significant changes in the abundance of the principal targeted aquarium fish, the yellow tang, *Zebrasoma flavescens*, in control (+1%) and FRA (+2.8%) areas but there was a significant decline in open (-33%) areas. Thus, although reserves did not significantly increase fish stocks relative to pre-reserve levels, they prevented the declines observed in areas open to fish collecting. Moreover, in the case of *Zebrasoma*, abundances in FRAs were increasingly relative to control areas, although this was not statistically significant. This trend can be seen more clearly in Figure 8, which shows increased in yellow tang abundance over time in FRAs relative to control and open populations.

Overall, there was no significant differences in before-after comparisons indicating that aquarium fishes in FRAs and open areas were not increasing or decreasing in abundance after reserve closure relative to control areas (Table 3). In contrast, there were several significant differences among FRAs and open areas indicating significant spatial variation in the abundance of these species among study areas. More importantly, there were several occurrences of significant before-after and FRA interactions terms in the FRAs for the ornate butterflyfish (*Chaetodon ornatissimus*) and the Moorish Idol (*Zanclus cornutus*). Analysis of individual reserve differences for these species (Table 4) indicate that there is variation among reserves in the reserve effectiveness index. In the ornate butterflyfish R varies from 1.6 at the Honaunau FRA to –0.3 at the Red Hill and Puakos FRAs. In contrast, R varies from 0.9

at Honaunau to –0.3 at Honokohau, a value significantly different from zero (Table 4). Overall, there was a significant 0.8% increase (3.6 fish/100m^2) in FRAs relative to controls in aquarium fishes.

In contrast, there were also significant before-after and FRA interactions terms in the open areas for several species (Table 5), indicating differential changes among open areas relative to controls. Overall, there were significant declines in the Achilles tang (*Acanthurus achilles*) at the Honaunau open area (Keopuka) but a significant increase at the Red Hill open area (Kualanui Pt.). Additional significant declines occurred in the longnose butterflyfish *Forcipinger longirostris* in the Lapakahi open area (Kamilo) and in the yellow tang in the Puako open area (Keawaiki). Overall, there was a significant 15.2% decrease (3.5 fish/100m^2) in open areas relative to controls in aquarium fishes (Table 5).

Fish Recruitment Patterns

There was strong recruitment of aquarium fishes during then summer of 2001 relative to the previous two years (Figure 9). Seasonal variation in the abundance of newly recruiting aquarium fishes was strongest from May to September, with very few individuals seen between December to April. Overall, the strongest recruiting fishes were the goldring surgeonfish *Ctenochaetus strigosus*, followed closely by the yellow tang and the multiband butterflyfish, *Chaetodon multicinctus*. (Figure 10). In general the magnitude of recruitment of all fishes during 2001 was moderate compared to values observed in Walsh (1987), indicating that recruitment is occurring but not as strong as has been previously observed in west Hawai'i. However, the increasing trends in abundance of aquarium fishes in FRAs relative to controls, and particularly to open areas, indicates that recruitment is beginning to replenish aquarium fishes in the reserves, although these values are not statistically significant for any single species (Table 4; Figure 8).

Because habitat variation is know to influence newly recruiting fishes, we examined the distribution of recruits relative to the abundance of spatially heterogeneous coral shelter, the finger coral *Porites compressa*. Although there was no significant correlation between the abundance of newly settled yellow tang recruits or adults and the mean percent cover of finger coral ($P > 0.05$) there was a significant correlation between finger coral abundance and juvenile yellow tang abundance (Figure 11, $P < 0.01$). These results suggest that although newly recruiting yellow tangs do not immediately settle into finger coral areas, they are significantly more common in these areas when they reach a larger size. This suggest either post-settlement mortality or movement and is an area for further investigation.

Conclusions

There is significant variation in coral cover in west Hawai'i that appears to be correlated with the degree of exposure to wave action. With the exception of the North Kohala design block, benthic habitats are similar among design blocks to validate statistical comparisons among the BACIP experimental design used in this study.

Analysis of baseline surveys in 1999 support earlier research documenting strong effects of aquarium collector harvesting on selected fishes in West Hawai'i. Pre-closure surveys indicate that collectors continued to target *Acanthurus achilles Centropyge potteri*, *Chaetodon quadrimaculatus*, *Ctenochaetus strigosus, Forcipiger* spp., *Zanclus cornutus* and *Zebrasoma flavescens* in the FRAs prior to closure on Jan. 1, 2000. On average aquarium fishes were 26% less abundant in FRAs than adjacent control areas.

Analysis of five post-closure surveys conducted in 2001 provided some evidence of an increase of aquarium fish stocks in FRAs. Although there were no statistically significant changes for any single species, aquarium fishes had a significant 0.8% increase in FRAs relative to controls and a significant 15.2% decrease in open areas relative to controls. Thus, the FRAs are enhancing the abundance of aquarium fishes relative to their natural abundances in control areas. In contrast, aquarium fishes outside of reserves were experiencing significant declines, probably due to collecting by aquarium fisherman. Thus, in addition to enhancing aquarium fish stocks, the FRAs were also protecting aquarium fish stocks from further declines in abundance.

These results appear to be due to the moderately high level of newly recruiting aquarium fishes observed in 2001 relative to 1999 and 2000. Thus, there is evidence that recruitment is an important mechanism replenishing depleted stocks within reserves in Hawaii. Given the low frequency in which large recruitment events occur in Hawai'i, it will probably be several more years until additional events of sufficient magnitude occur to allow a rigorous test of the effectiveness of the marine reserve network in west Hawai'i. Moreover, analysis of the spatial distribution of juvenile yellow tangs suggest that habitat may be an important factor influencing fish abundance and more attention needs to be paid to post-settlement processes in this system.

Based on the current data analysis, the WHAP monitoring program has shown to provide a rigorous test of changes in fish abundance within the reserve system. It is recommended that monitoring in West Hawai'i continue until recruitment levels increase and provide a mechanism to replenish depleted stocks in the newly established reserves. These results appear to be due to the moderately high level of newly recruiting aquarium fishes observed in 2001 relative to 1999 and 2000. Thus, there is evidence that recruitment is an important mechanism replenishing depleted stocks within reserves in Hawaii. Given the low frequency in which large recruitment events occur in Hawai'i, it will probably be several more years until additional events of sufficient magnitude occur to allow a rigorous test of the effectiveness of the marine reserve network in west Hawai'i. Moreover, analysis of the spatial distribution of juvenile yellow tangs suggest that habitat may be an important factor influencing fish abundance and more attention needs to be paid to post-settlement processes in this system.

We also recommend that additional reserves be established in Hawai'i as a precautionary measure against overuse of fishery resources. Further, as recruitment appears to be the primary mechanism driving the replenishment of nearshore fisheries, we recommend that a state-wide monitoring program be instituted to gather fine-scale spatial and temporal information on the extent of newly recruiting fishes. We also advocate for increased study of nearshore oceanography to help better understand the dynamics of recruitment processes. Finally, as habitat appears to be important to newly recruiting fishes, we need additional studies focused on habitat and management to protect existing habitats critical for juvenile and reproductive fishes.

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Table 1. Power analysis of baseline data comparing the percent detectable change in the abundance of targeted fishes relative to percent changes due to aquarium collectors estimated by Tissot and Hallacher (1999). Power was set at 90% (β=0.10) and α=0.10 for a two-sample T-test to detect significant differences between samples..

Species	**Percent detectable change from baseline (after 1 year)**	**Estimated percent change from collectors (Tissot & Hallacher, 1999)**
*Acanthurus achilles**	46.5	-57.1
Centropyge potteri *	21.2	-46.1
*Chaetodon multicinctus**	11.4	-38.2
Chaetodon ornatissimus	26.6	-39.5
*Chaetodon quadrimaculatus**	16.6	-41.6
*Ctenochaetus strigosus**	9.7	-14.7
*Forcipiger spp.**	32.8	-54.2
*Zanclus cornutus**	41.4	-46.5
*Zebrasoma flavescens**	12.8	-47.3

* Will detect significant change based on baseline data

Table 2. Impacts of aquarium collecting on nine fishes estimated by mean percent Control-FRA differences using data from surveys prior to reserve closure (n= 6 surveys). Significant differences between fish density between control and FRA sites was tested using a two-sample t-test. N/A refers to sites where no individuals were observed at control sites. Mean estimates are compared to the earlier study of Tissot and Hallacher (1999).

Percent Control-FRA Difference

Taxa	N. Kohala	Puako	Honokohau	Red Hill	Honaunau	Overall	Tissot & Hallacher (1999)
Acanthurus achilles	N/A	+400	-100*	-92*	+225	-56*	-58*
Centropyge potteri	-44	-31	-21	-81*	-15	-42*	-46*
Chaetodon multicinctus	+1	-21	+5	-19	+17	-4	-38*
Chaetodon ornatissimus	+344	-36	+27	+24	-78*	-7	-39*
Chaetodon quadrimaculatus	-50	-100	-100	-100*	-100*	-97*	-42*
Ctenochaetus strigosus	+27*	+31*	-17	-31*	-35*	-14*	-15
Forcipiger spp.	+43	-68*	-65*	-73*	-77*	-55*	-54*
Zanclus cornutus	+1100*	+200	-63	-60	-100*	-49*	-46*
Zebrasoma flavescens	+216*	-57*	+25*	-77*	-67*	-43*	-47*
Overall	+60*	-18*	-7	-52*	-48*	-26*	

* Significant at $\alpha = 0.05$

Table 3. Two-way repeated-measure analysis of variance BACIP testing for significant changes in: 1) before and after reserve closure (BA); 2) among study locations (FRA); and 3) statistical interactions between FRA and BA comparisons. P-values are reported for the nine most commonly targeted aquarium fishes and these species pooled. **A**. Control-FRA differences. **B**. Control-Impact differences. * Significant at $\alpha = 0.05$

A. Control-FRA differences

Taxa	BA	FRA	BA * FRA
Acanthurus achilles	0.83	0.09	0.09
Centropyge potteri	0.70	0.17	0.07
Chaetodon multicinctus	0.12	0.17	0.30
Chaetodon ornatissimus	0.84	*0.03	*<0.01
Chaetodon quadrimaculatus	0.46	0.09	0.11
Ctenochaetus strigosus	0.35	*0.03	0.07
Forcipiger flavissimus	0.42	*<0.01	0.92
Forcipiger longirostris	0.51	0.08	0.45
Zanclus cornutus	0.73	0.22	*<0.01
Zebrasoma flavescens	0.23	*<0.01	0.70
All aquarium fishes	0.34	*<0.02	0.11
All non-aquarium fishes	0.32	*<0.01	0.14

B. Control-Open differences

Taxa	BA	FRA	BA * FRA
Acanthurus achilles	0.59	0.20	*<0.01
Centropyge potteri	0.62	*<0.01	0.07
Chaetodon multicinctus	0.34	*0.01	0.71
Chaetodon ornatissimus	0.84	0.08	*0.03
Chaetodon quadrimaculatus	0.42	0.06	*0.02
Ctenochaetus strigosus	0.30	*0.04	0.25
Forcipiger flavissimus	0.18	*<0.01	0.93
Forcipiger longirostris	0.38	0.54	0.07
Zanclus cornutus	0.95	0.11	0.07
Zebrasoma flavescens	0.07	*<0.01	*0.01
All aquarium fishes	0.17	*0.03	0.10
All non-aquarium fishes	0.22	*<0.01	0.05

Table 4. Estimates of reserve replenishment (*R*): mean difference between pre- and post-closure control-FRA differences. Positive values indicate an change in mean density (No./100m^2) in fishes in open areas after closure relative to before closure. Bolded values are significant at $\alpha = 0.05$.

Mean Change in Control-FRA difference (# fish/100m^2)

FRA	*Acanthurus achilles*	*Centropyge potteri*	*Chaetodon multicinctus*	*Chaetodon ornatissimus*	*Chaetodon quadrimaculatus*	*Ctenochaetus strigosus*	*Forcipiger flavissumus*	*Forcipiger longirostris*	*Zanclus cornutus*	*Zebrasoma flavescens*	Aquarium fishes	Non-Aquarium fishes
Lapakahi	-0.1	0.6	0.3	0.2	0.1	3.7	0.3	-0.7	-0.3	-0.6	7.3	3.5
Puako	0.0	0.1	0.5	-0.3	-0.2	-4.6	0.4	0.5	-0.2	2.3	-1.3	-1.5
Honokohau	-0.8	-1.2	-0.4	0.1	-0.1	0.8	0.4	-0.1	**-0.3**	-0.2	-5.9	-1.9
Red Hill	**0.9**	0.9	-0.5	-0.3	-0.5	4.2	0.0	-0.1	0.0	2.6	9.7	7.7
Honaunau	-0.1	0.3	0.0	1.6	0.5	-1.7	0.4	-0.1	0.9	6.1	8.2	7.2
Mean	0.0	0.2	0.0	0.2	0.0	0.5	0.3	-0.1	0.0	2.0	3.6	3.0
SE	0.3	0.4	0.2	0.3	0.2	1.7	0.1	0.2	0.2	1.2	3.0	2.0
% change	-2.2	9.2	**-15.9**	181.5	-11.1	0.8	38.0	-34.7	33.3	14.8	**0.8**	10.8

Table 5. Estimates of open area replenishment (*R*): mean difference between pre- and post-closure control-open differences. Positive values indicate a change in mean density (No./100m^2) in fishes in FRAs after closure relative to before closure. Bolded values are significant at $\alpha = 0.05$.

Mean Change in Control-Open difference (# fish/100m^2)

FRA	*Acanthurus achilles*	*Centropyge potteri*	*Chaetodon multicinctus*	*Chaetodon ornatissimus*	*Chaetodon quadrimaculatus*	*Ctenochaetus strigosus*	*Forcipiger flavissumus*	*Forcipiger longirostris*	*Zanclus cornutus*	*Zebrasoma flavescens*	Aquarium fishes	Non-Aquarium fishes
Lapakahi	-0.6	0.6	-0.6	-0.1	0.0	5.1	0.3	**-1.1**	-0.4	-1.9	4.8	1.4
Puako	-0.1	0.3	-0.7	-0.5	-0.2	0.0	0.5	0.4	0.1	**-12.2**	-14.3	-12.4
Honokohau	-0.7	-0.7	-1.2	0.1	-0.4	-4.7	0.3	-0.5	0.0	-0.8	-22.9	-8.5
Red Hill	**1.1**	1.0	1.0	-0.1	-0.1	3.4	0.2	-0.1	0.2	-0.3	2.0	6.3
Honaunau	**-1.0**	1.4	0.0	1.1	0.2	8.4	0.6	0.0	0.4	3.7	13.1	14.7
Mean	-0.2	0.5	-0.3	0.1	-0.1	2.4	0.4	-0.3	0.1	-2.3	-3.5	0.3
SE	0.4	0.4	0.4	0.3	0.1	2.2	0.1	0.3	0.1	2.6	6.6	4.9
% change	-293.3	131.2	-77.8	31.5	-177.8	23.7	54.8	-78.3	37.0	-20.5	**-15.2**	1.3

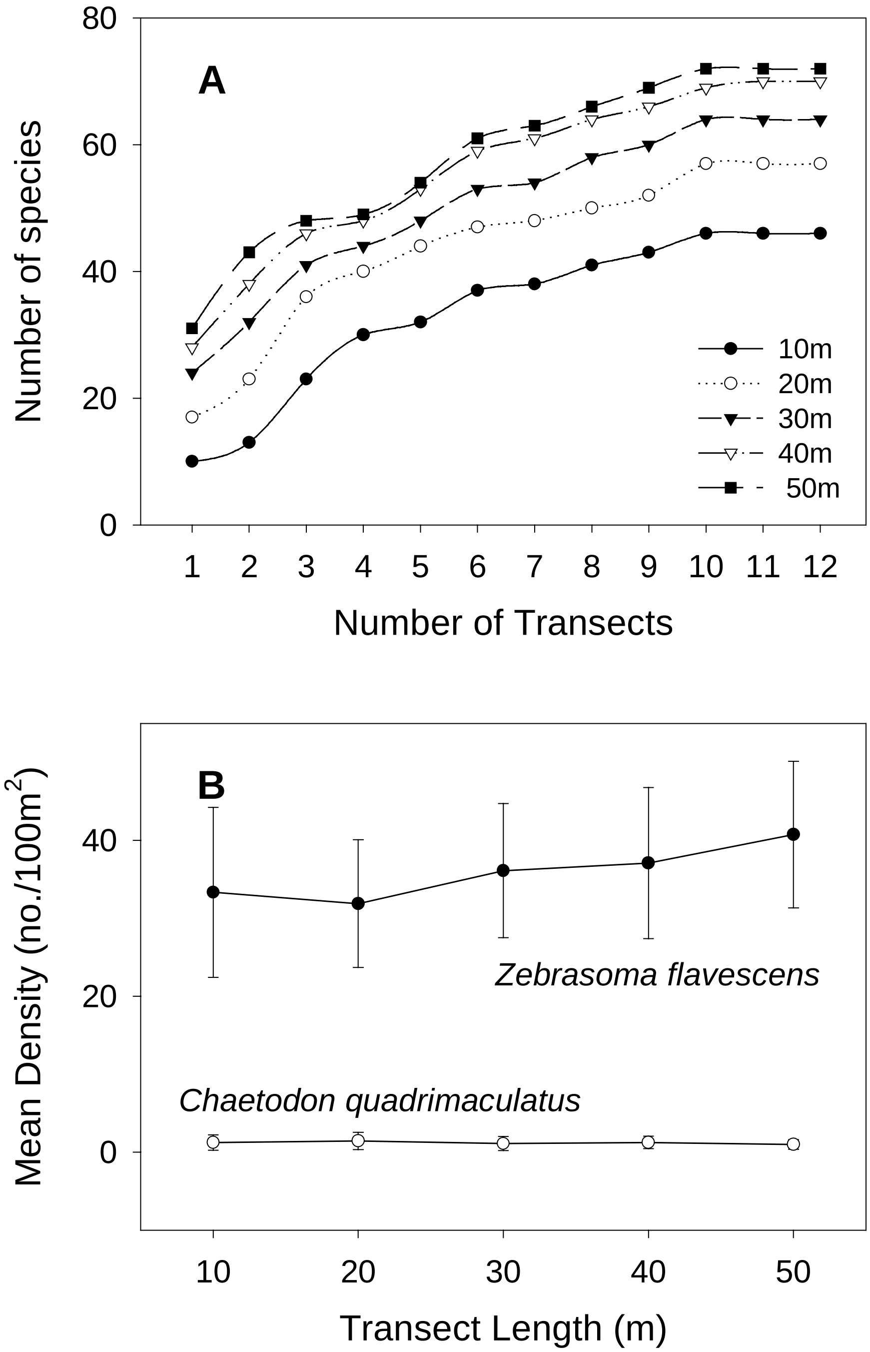
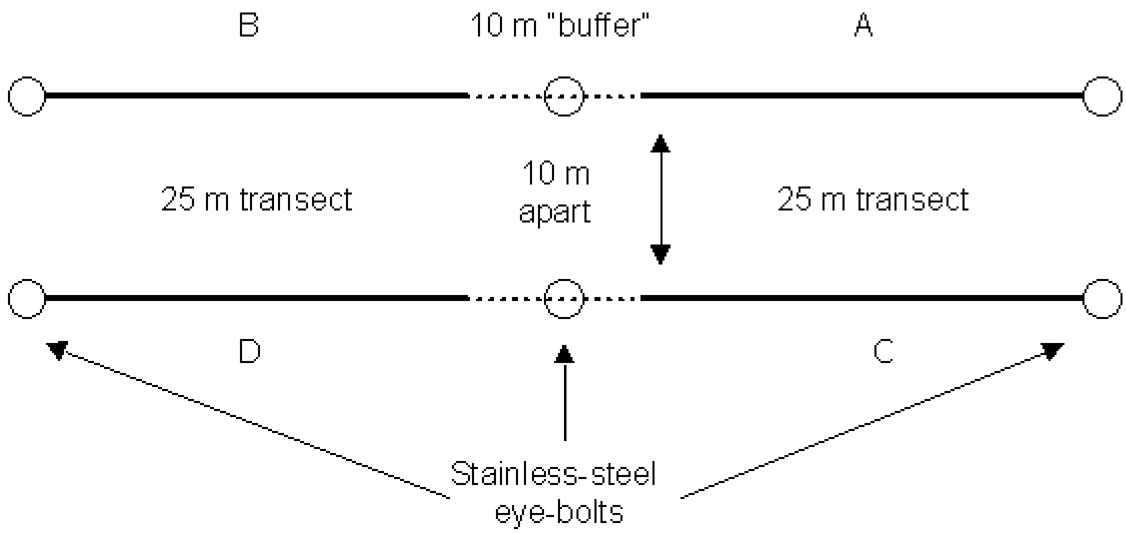


Figure 1. Results of pilot studies using visual strip transects that varied in transect length and number. **A**. The effects of varying transect length and number on the total number of fish species observed. **B**. The effects of transect length on mean abundance and variability of a common and an uncommon aquarium fish species.

A



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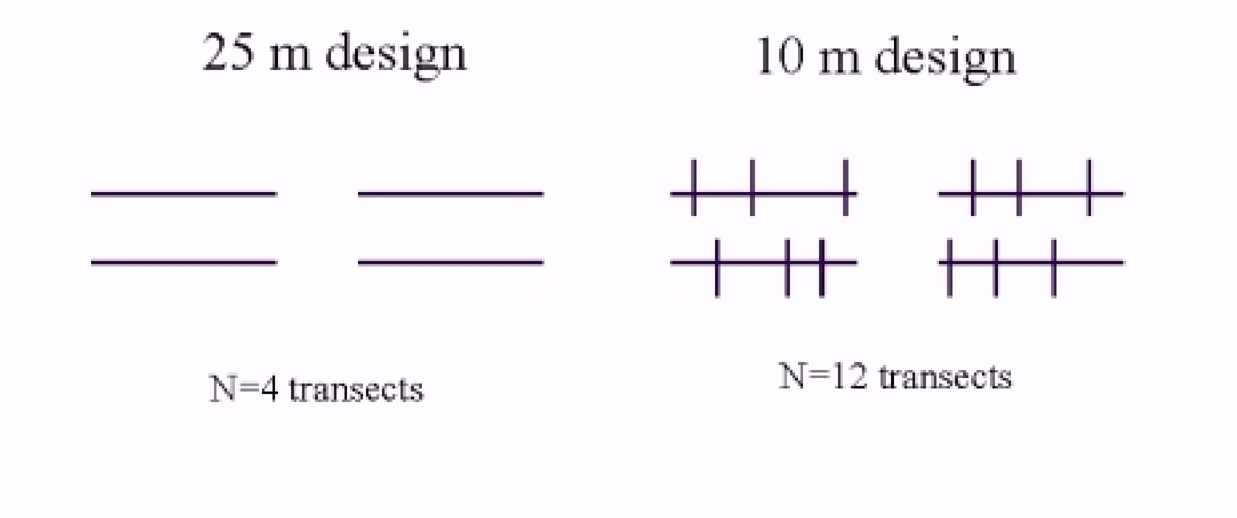
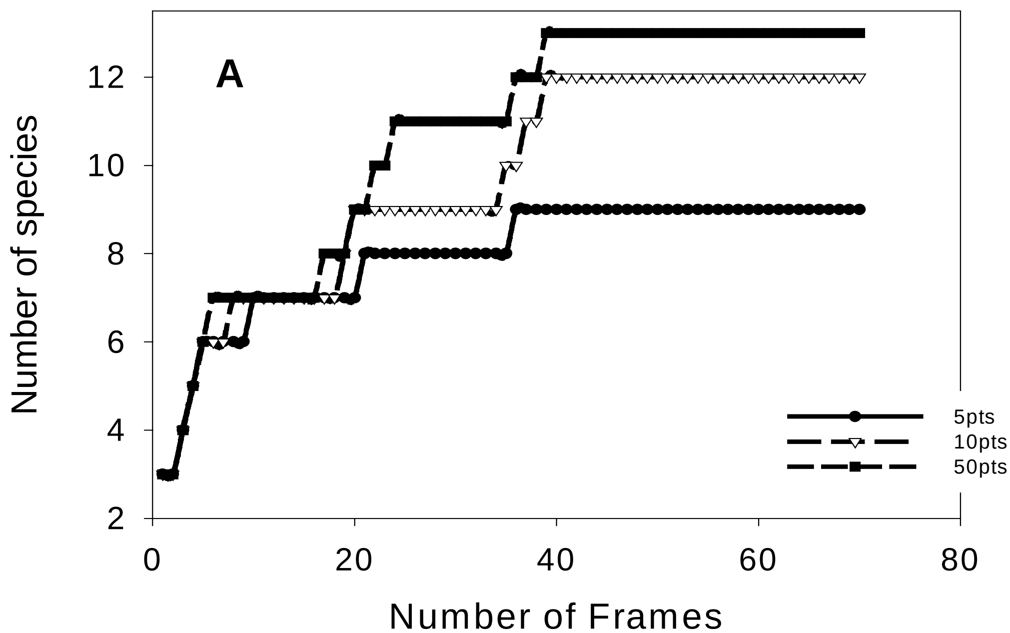


Figure 2. Design of permanent transects established at each site. **A**. H-shaped transect design created at each study site to conduct visual strip transects for fishes. Two 60 m transect tapes were positioned along six permanent stainless-steel eyebolts. Divers surveyed four 25 m transects separated by 10 m buffer areas between replicates. **B**. Alternate transects designs evaluated for benthic habitat sampling.



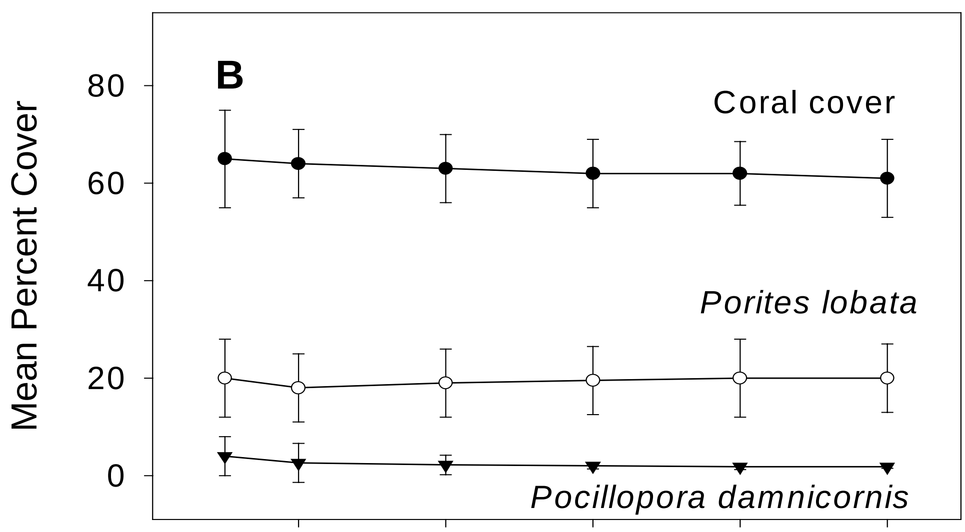


Figure 3. Results of pilot studies using photographic images that varied in the number of frames and the number of points per frame. **A**. The effects of varying frame number and points per frame on the total number of coral/algal species observed. **B**. The effects of the number of points per frame on mean abundance and variability for total coral cover, a common, and an uncommon coral species.

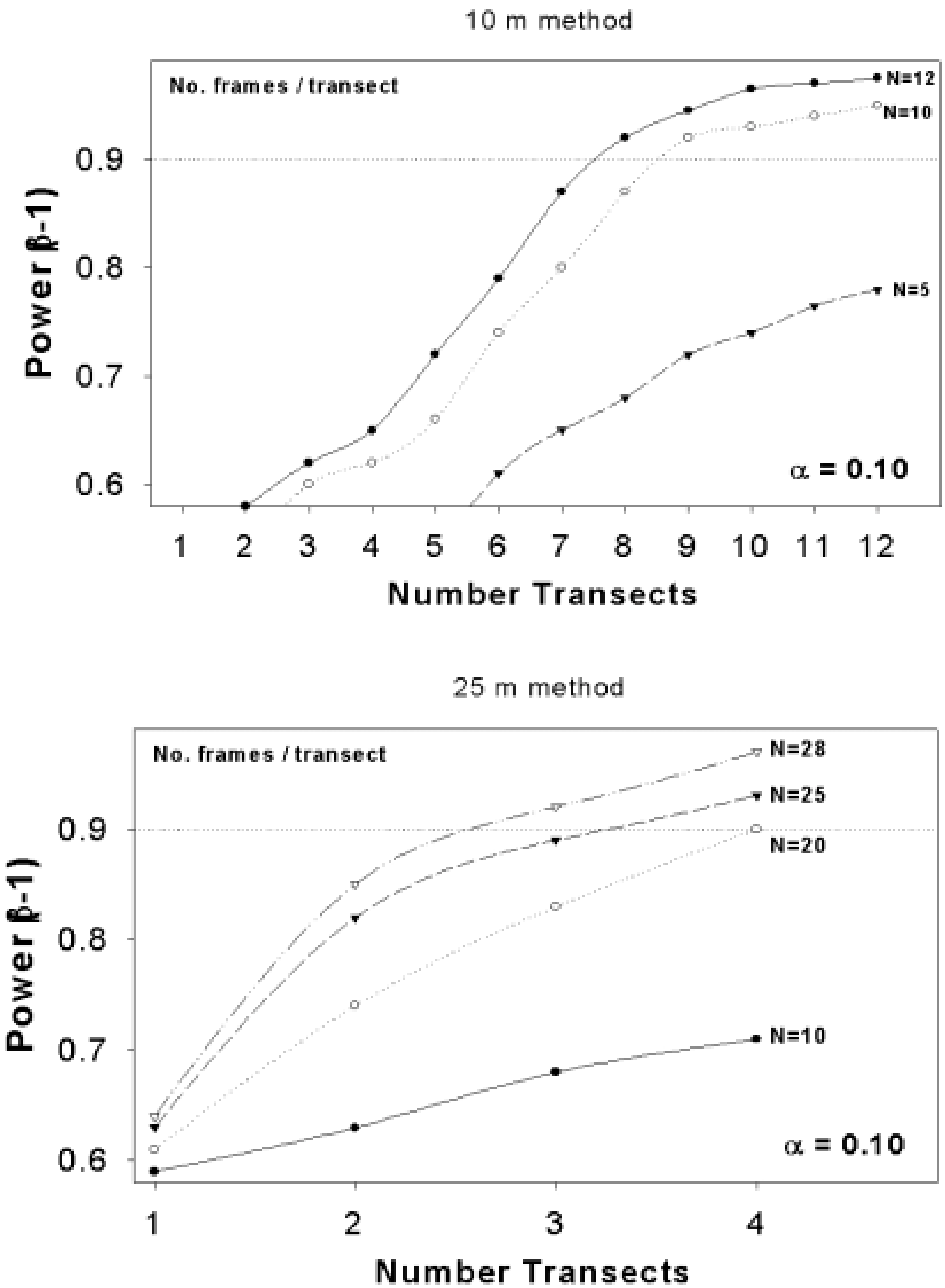


Figure 4. Power analysis of the effects of transect number and frame number to detect a 10% change in total coral cover based on a two-sample t-test between surveys for two alternate transects designs (See text and Figure 2B).

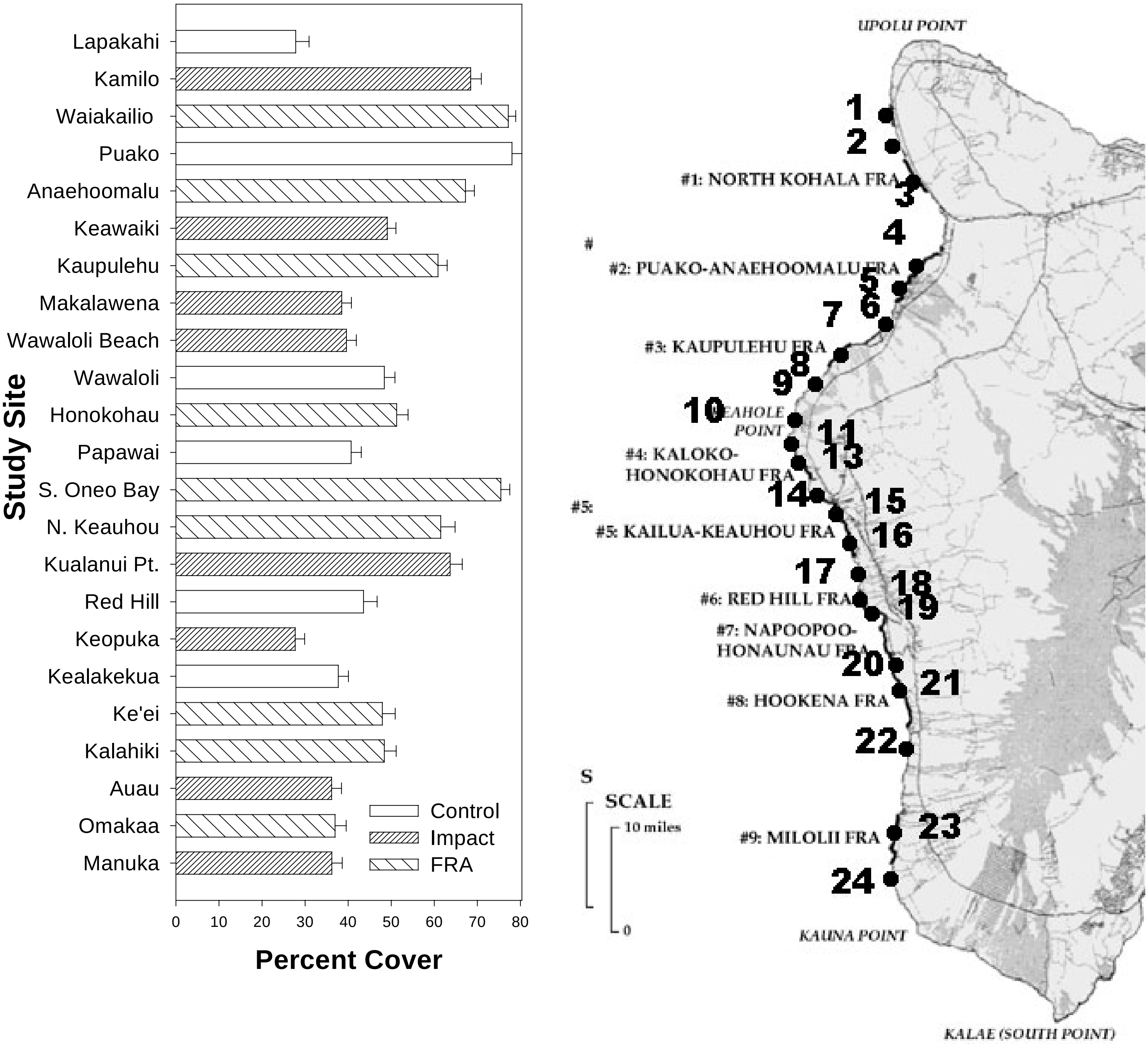
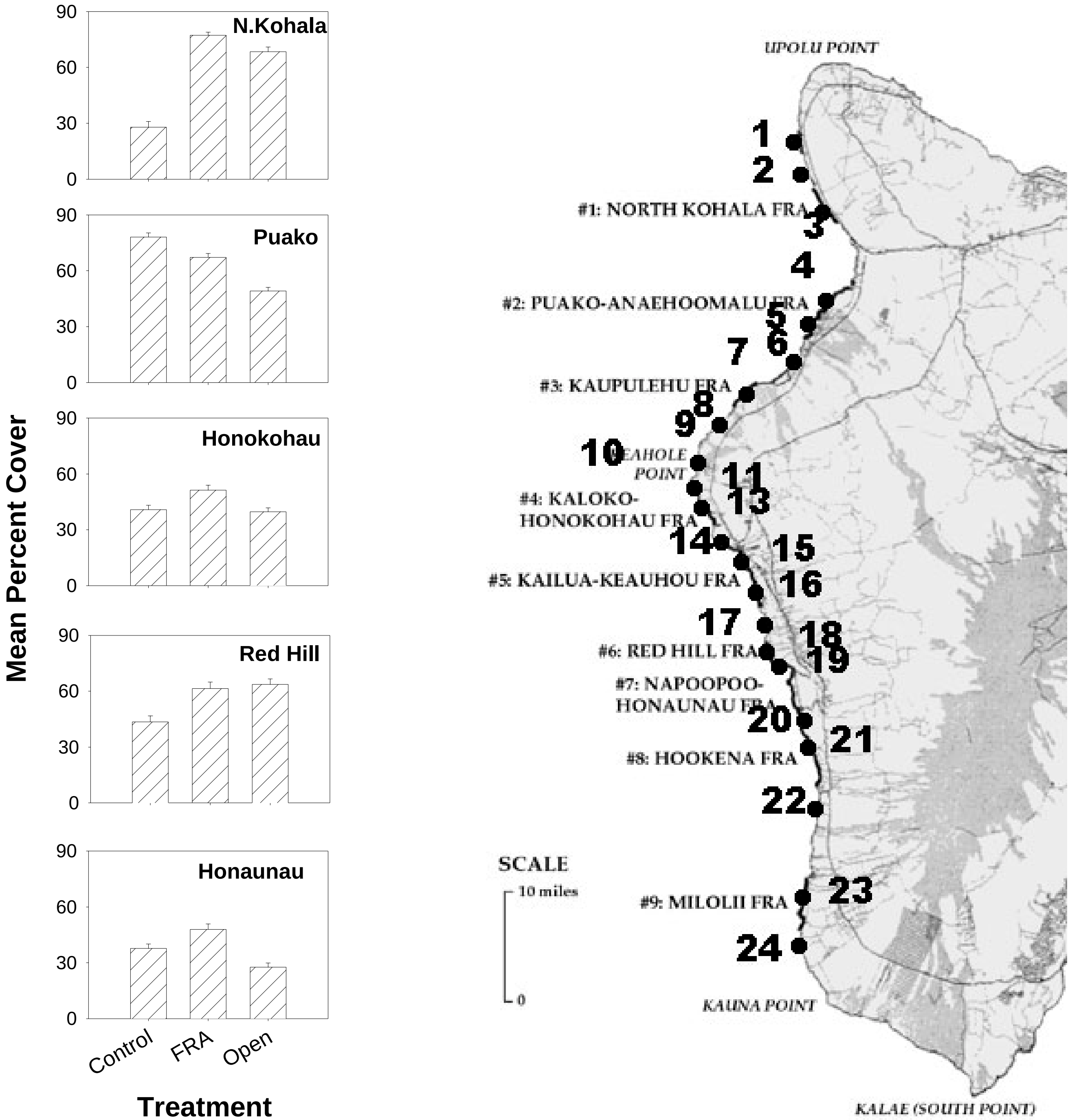


Figure 5. Mean percent live coral cover at study sites in West Hawai'i (± 1 SE). Site locations occur approximately opposite of their geographic locations on the map (see Appendix 1).



Fi[…] cover at control, FRA and open design blocks in West
Ha[…] cur approximately opposite of their geographic
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tre[…] hala control site which has significantly lower coral
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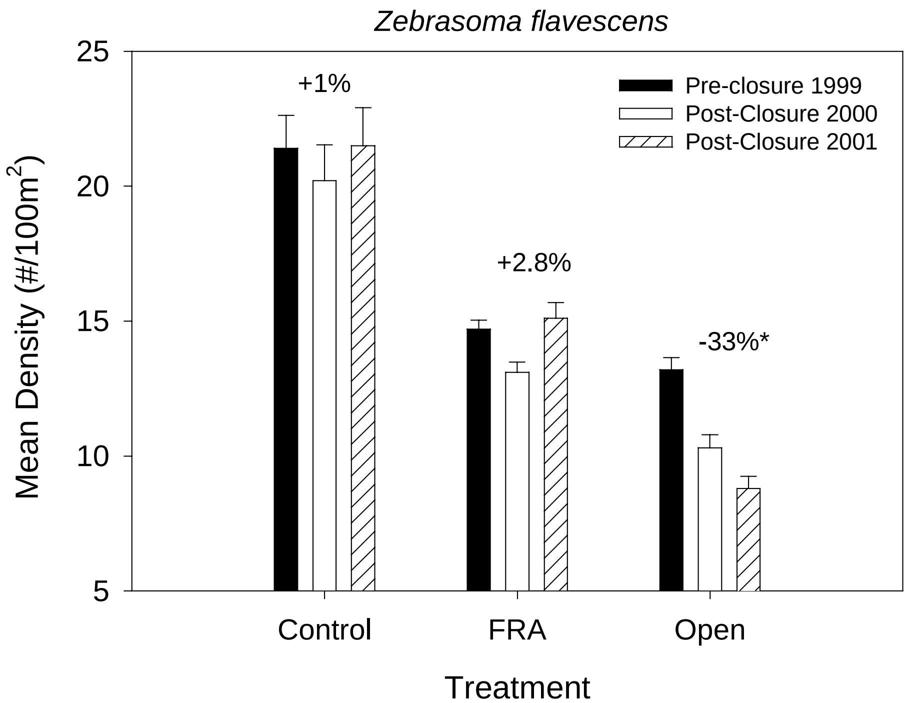


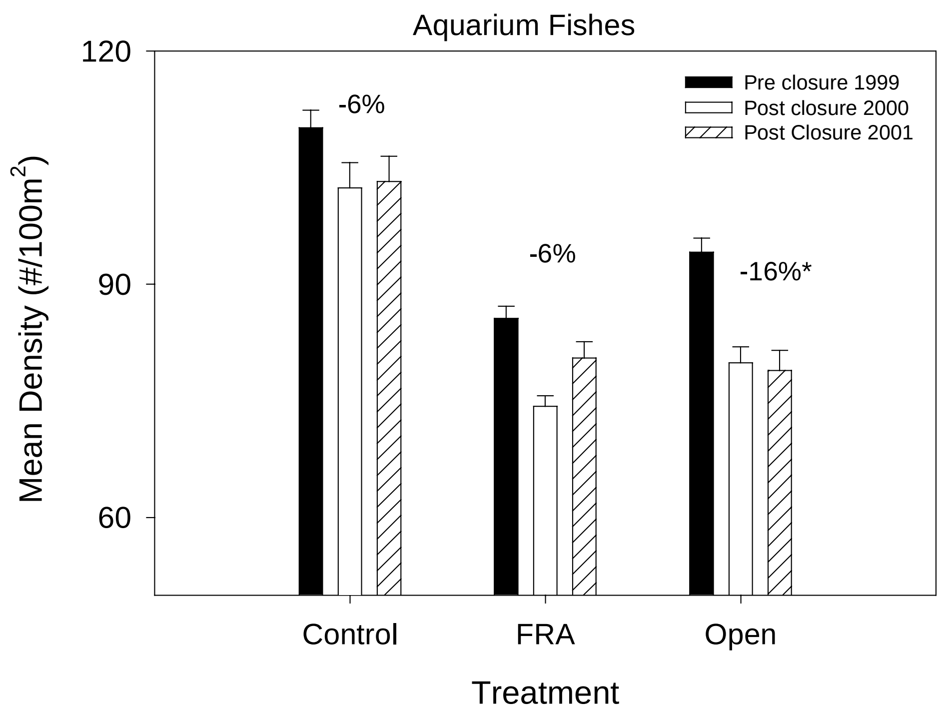


Figure 7. Broad comparisons of pre-closure and the two post-closure years 2002 and 2001. Top: the main aquarium fish *Zebrasoma flavescens*. Bottom: All aquarium fishes pooled. Percentages are two sample comparisons between 1999 and 2001 data (* values are significant at $\alpha = 0.05$).

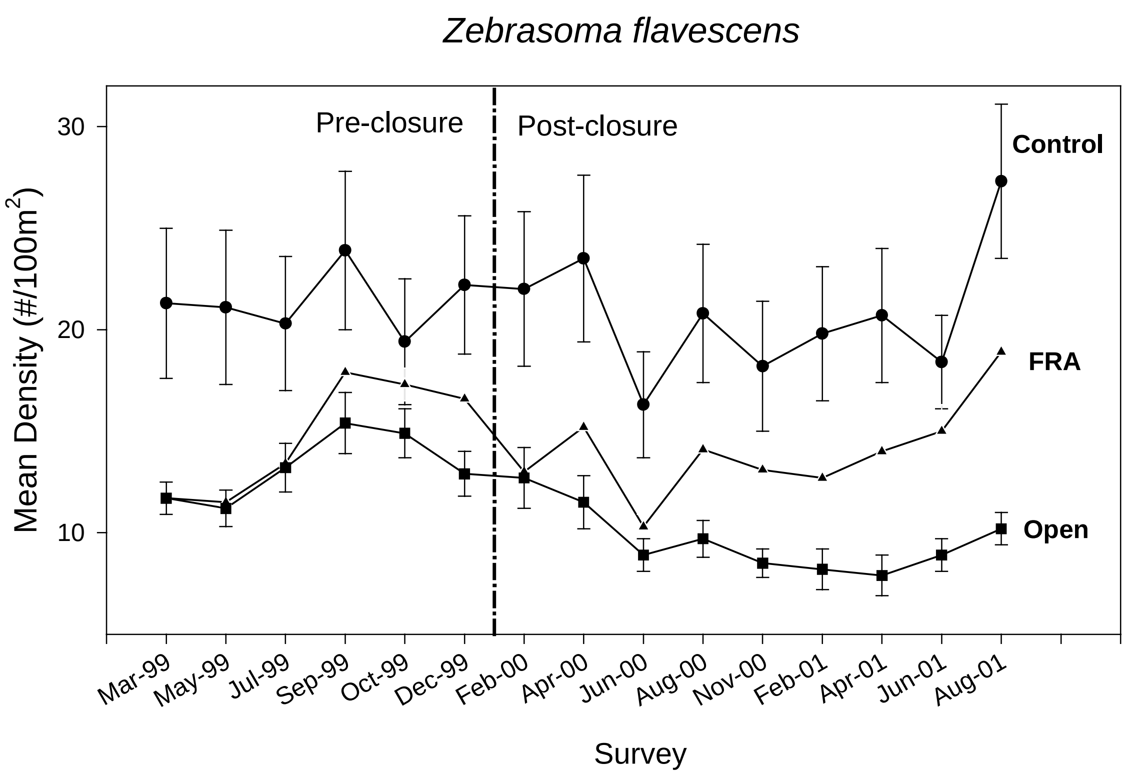


Figure 8. Changes in mean density of the yellow tang, *Zebrasoma flavescens*, in control, open and FRA areas pooled across all surveys before and after reserve closure.

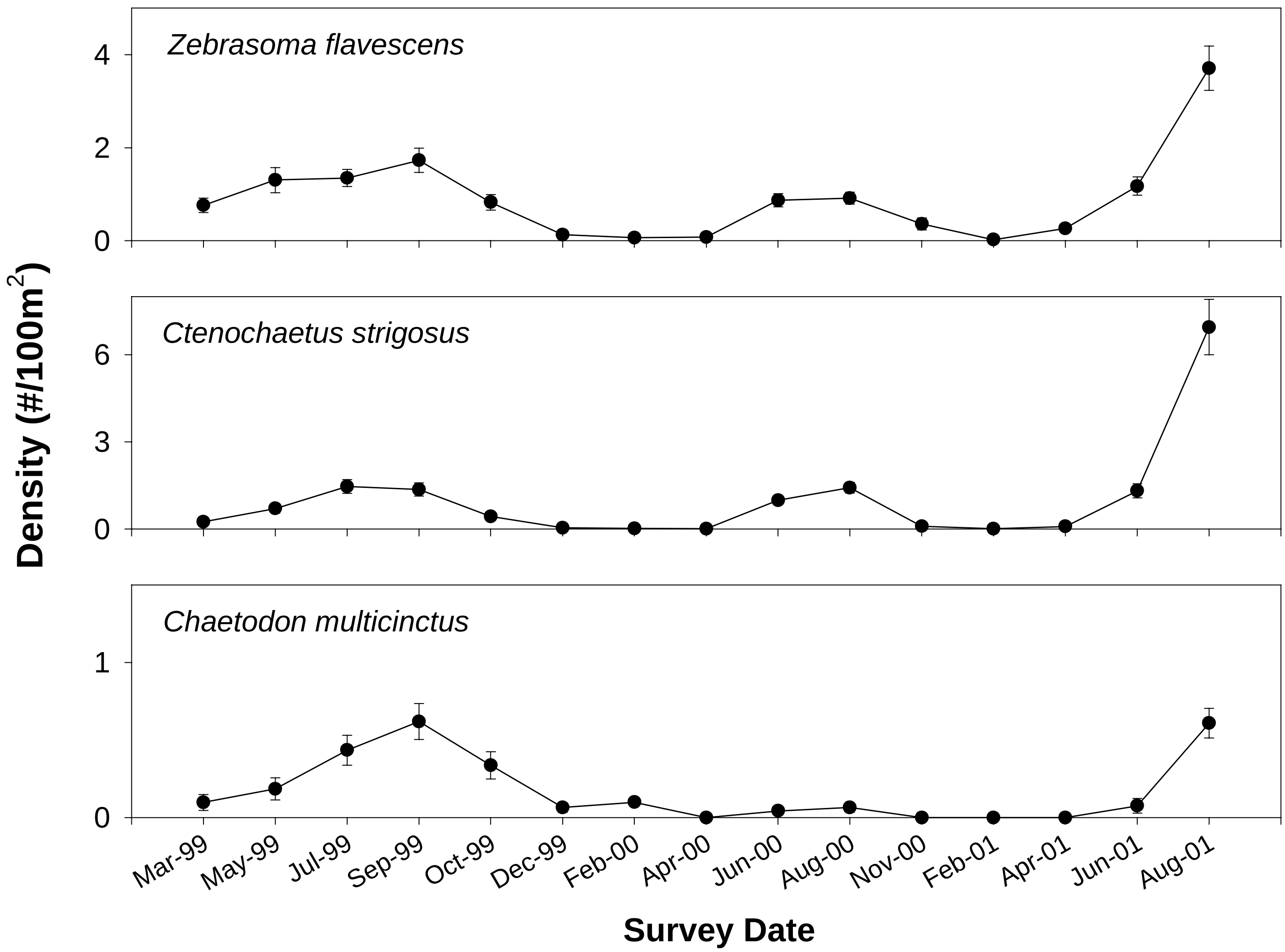


Figure 9. Mean density of newly recruiting fishes pooled for all study sites for three commonly collected aquarium fishes across all surveys.

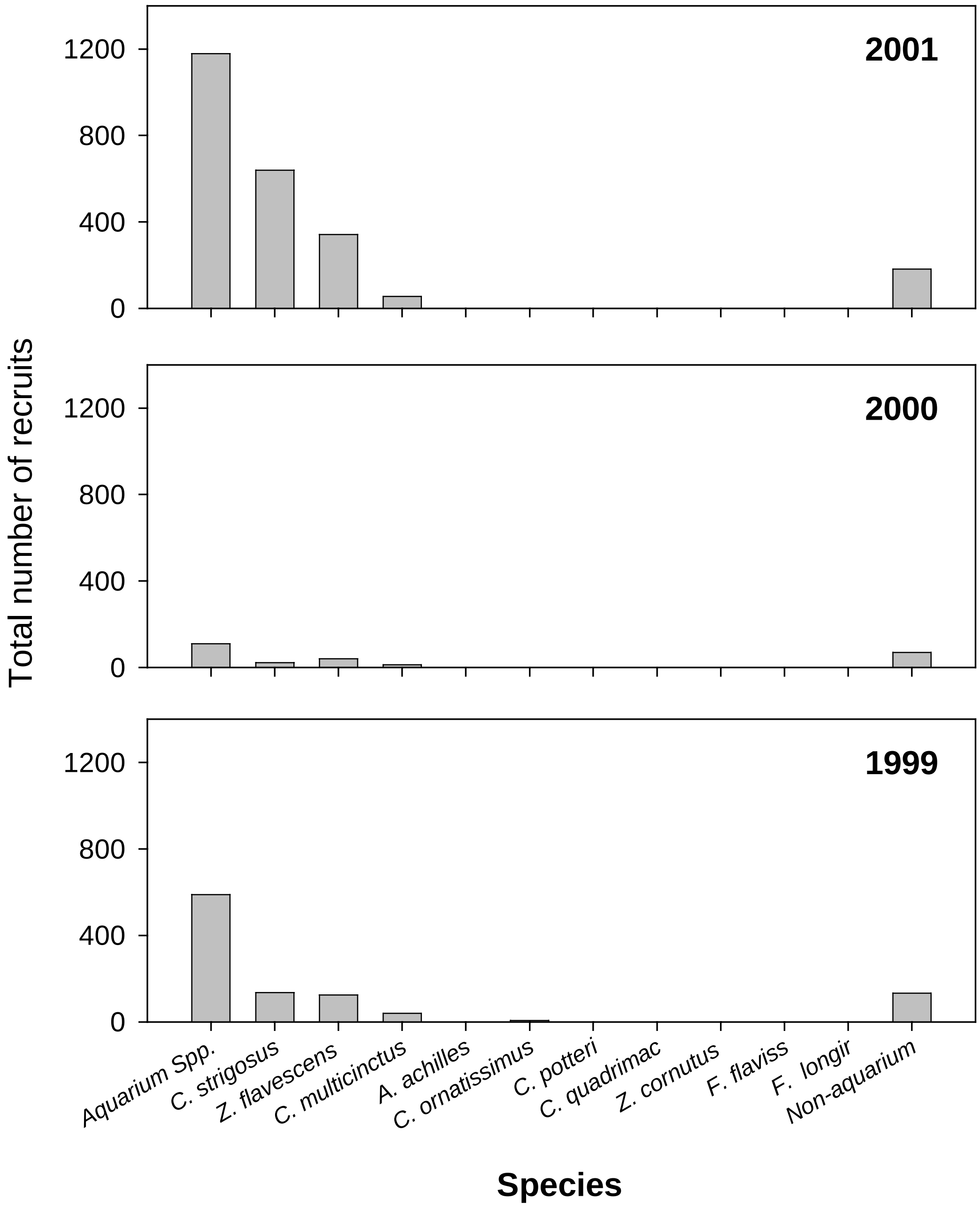


Figure 10. Total number of newly recruiting fishes at all study sites for aquarium fishes pooled, targeted aquarium fishes, and non-aquarium fishes pooled in July of 1999, 2000 and 2001.

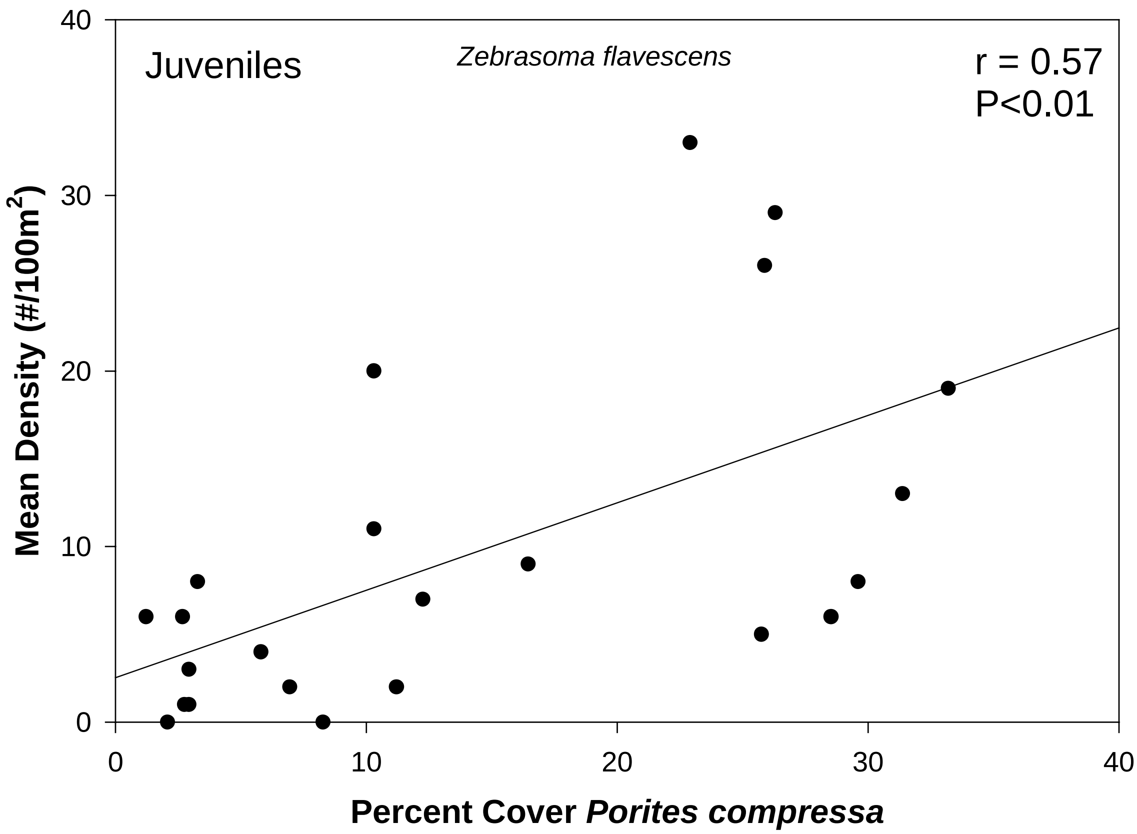
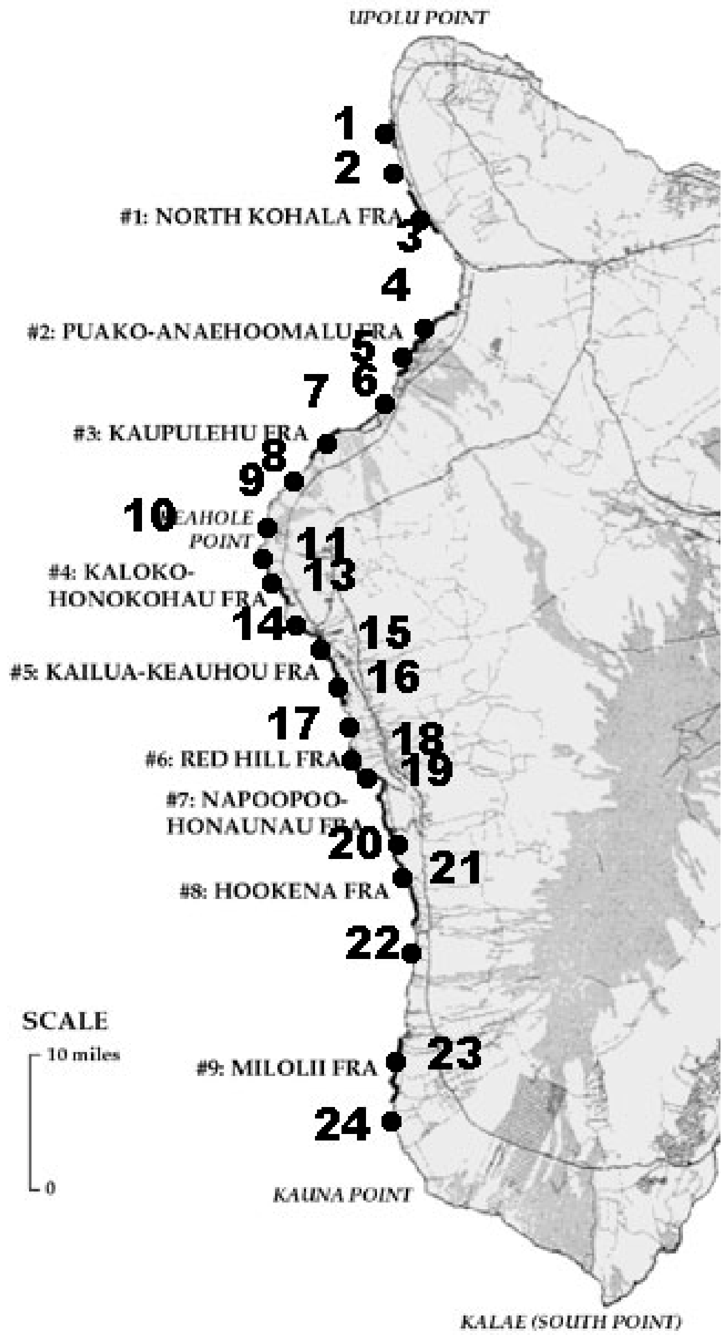


Figure 11. Density of juvenile yellow tangs, *Zebrasoma flavescens*, in relation to the mean percent cover of finger coral, *Porites compressa* across all study sites.

Appendix 1

Location	Type	Depth (ft.)
North Kohala		
1. Lapakahi	MLCD	32-50
2. Kamilo	Impact	36-49
3. Waiakailio Bay	FRA	40-47
PUAKO - ANAEHOOMALU		
4. Puako	FMA	30-34
5. Anaehoomalu	FRA	30-37
6. Keawaiki	Impact	35-50
KAUPULEHU		
7. Kaupulehu	FRA	34-42
8. Makalawena	Impact	31-37
KALOKO-HONOKOHAU		
9. Wawaloli Beach	Impact	29-32
10. Wawaloli	FMA	41-50
11. Honokohau	FRA	37-46
KAILUA-KEAUHOU		
13. Papawai	FMA	29-44
14. S. Oneo Bay	FRA	32-47
RED HILL		
15. N. Keauhou	FRA	30-46
16. Kualanui Pt	Impact	29-39
17. Red Hill	FMA	42-50
NAPOOPOO-HONAUNAU		
18. Keopuka	Impact	28-47
19. Kealakekua Bay	MLCD	20-36
20. Ke'ei	FRA	31-49
HOOKENA		
21. Hookena (Kalahiki)	FRA	31-39
22. Hookena (Auau)	Impact	37-50
MILOLII		
23. Milolii (Omakaa)	FRA	34-49
24. Milolii (Manuka)	Impact	32-49



The West Hawaii Regional Fishery Management Area in relation to study sites and observational design assignments.

Appendix 2

List of all surveys conducted to date at east and west Hawai'i study sites with dates of data entry and verification.

West Hawai'i sites

Survey	Field surveys	Data entry and verification
1	Mar. 10 - Apr. 13, 1999	May 4, 1999
2	May 4 - 26, 1999	Jul. 15, 1999
3	Jun. 3 - Aug. 3, 1999	Jan. 12, 2000
4	Aug. 4 - Sep. 28, 1999	Jan. 25, 2000
5	Oct. 12 - Nov. 3, 1999	Feb. 2, 2000
6	Nov. 24, 1999-Jan. 25, 2000	Mar. 22, 2000
7	Jan.27 - Mar. 1, 2000	Mar. 31, 2000
8	Mar. 22 - May 2, 2000	Aug. 25, 2000
9	Jun. 5 - Jun. 15, 2000	Oct. 2, 2000
10	Jul. 17 - Aug. 17, 2000	Nov. 17, 2000
11	Oct. 31- Dec. 19, 2000	Feb. 2, 2001
12	Feb. 21 - Mar. 20, 2001	Jun. 8, 2001
13	Apr. 3 - Apr. 26, 2001	Jun. 27, 2001
14	Jun. 5 - Jun. 26, 2001	Aug. 15, 2001
15	Jul. 3 - Aug. 10, 2001	Sept. 15, 2001
16	Oct. 30 - Dec. 4, 2001	In progress

East Hawai'i sites: Kapoho

Survey	Field surveys	Data entry and verification
1	Jul. 22, 1999	Oct. 1, 1999
2	Aug. 5, 1999	Oct. 1, 1999
3	Aug. 26, 1999	Feb. 23, 2000
4	Sep. 30, 1999	Feb. 23, 2000
5	Oct. 14, 1999	Feb. 23, 2000
6	Oct. 28, 1999	Feb. 23, 2000
7	Nov. 12, 1999	Aug. 24, 2000
8	Dec. 3, 1999	Feb. 24, 2000
9	Jan. 5, 2000	Feb. 24, 2000
10	Feb. 11, 2000	Feb. 24, 2000
11	Mar. 10, 2000	Mar. 24, 2000
12	Apr. 7, 2000	Aug. 3, 2000
13	May 27, 2000	Aug. 3, 2000

14	Jul. 5, 2000	Oct. 8, 2000
15	Aug. 18, 2000	Oct. 8, 2000
16	Sep. 29, 2000	Nov. 30, 2000
17	Oct. 20, 2000	Jan. 11, 2001
18	Nov. 10, 2000	Jan. 11, 2001
19	Dec. 18, 2000	Jan. 26, 2001
20	Jan. 5, 2001	Jan. 18, 2001
21	Feb. 2, 2001	Apr. 2, 2001
22	Mar. 2, 2001	Apr. 2, 2001
23	May 4, 2001	Sep. 28, 2001
24	Jul. 13, 2001	Jul. 27, 2001

East Hawai'i sites: Richardson's Ocean Park

Survey	Field surveys	Data entry and verification
1	Apr. 14, 2000	Aug. 3, 2000
2	Jun. 9, 2000	Aug. 3, 2000
3	Jul. 7, 2000	Oct. 8, 2000
4	Aug. 18, 2000	Oct. 8, 2000
5	Sep. 29, 2000	Nov. 30, 2000
6	Oct. 20, 2000	Jan. 11, 2001
7	Nov. 10, 2000	Jan. 11, 2001
8	Dec. 18, 2000	Jan. 18, 2001
9	Jan. 5, 2000	Jan. 18, 2001
10	Feb. 2, 2001	Apr. 2, 2001
11	Mar. 2, 2001	Apr. 2, 2001
12	May 4, 2001	Sep. 28, 2001
13	Jul. 13, 2001	Jul. 27, 2001

Appendix 3

Completed Task List

A. Field surveys:

Fish transects

- West Hawai'i: 5 surveys of all sites East Hawai'i: 5 surveys of Kapoho sites; 4 of Richardson's

B. Data management:

- Data entry and verification for 5 west Hawai'i surveys; 9 east Hawai'i surveys
- Data entry of all benthic habitat imagery (n=3392 images)

C. Data analysis

- Quality assurance analysis of benthic habitat imagery
- Quantitative analysis of benthic habitats at all 23 study sites (n > 90,000 random points)

D. Public Outreach:

Scientific Presentations on WHAP

- Tissot, B. N., W, J,. Walsh and L. E. Hallacher. *Measuring the effectiveness of a Marine Reserve Network in Hawai'i*. Western Society of Naturalists, Ventura, CA. (November)

Website updates: http://coralreefnetwork.com/kona/

- Progress reports
- Posted final reports and field guide
- Updated brochure