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, impact (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 2000 provided no evidence of an increase of aquarium fish stocks in FRAs. In contrast, all aquarium fishes, including those in previously protected areas declined between 1999-2000. Based on the small number of newly recruiting aquarium- and non-aquarium fishes observed in 1999 and 2000, there has been no mechanism to replenish depleted stocks within FRAs (or elsewhere).

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 (impact sites) and those that were not subjected to fish collecting (control sites).

Treatment	Pre-FRA Status	Post-FRA Status
Impact	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, impact (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).

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.

Accordingly, the objectives of this project are:

1. Estimate the impacts of aquarium fish collecting both in and outside of FRA reserves in west Hawai'i.

2. Evaluate the effectiveness of the FRA plan by comparing fish abundances among control, impact and FRA study sites.

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 (Impact, 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 (Figure 5). 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. Based on this method we derived an index of reserve replenishment, *R*, which estimates the difference in mean density between control and FRA areas after reserve closure relative to before closure.

$$R = \overline{\overline{X}}_{after}\left(\overline{X}_{control} - \overline{X}_{FRA}\right) - \overline{\overline{X}}_{before}\left(\overline{X}_{control} - \overline{X}_{FRA}\right) \tag{1}$$

A significant increase in *R* would thus indicate an increase in fish density in reserves 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 eleven fish surveys of all sites (n=1012 transects); six surveys prior to the closure of the reserves which will serve as baseline data and five post-closure surveys. We 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 ongoing quantitative analysis using PointCount. Analyses of these benthic habitat images are 25% complete and will not be described in this report. In east Hawai'i 12 surveys were completed at Kapoho and 8 surveys at Richardson's Ocean Park (Appendix 2). A list of all tasks completed, including outreach, is listed in Appendix 3. A brief description of each study site and a summary of the data collected is included in the attached field guide.

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

There were no significant changes in the most abundantly collected aquarium fishes in control areas before and after reserve closure but significant declines occurred in FRA (10%) and impact areas (14%) (Figure 6). Similarly, there were no significant declines in the abundance of non-aquarium fishes in control areas but significant declines in FRA (11%) and impact (14%) areas. Thus, both collected and non-collected species show similar change in abundance patterns among study sites after reserve closure, suggesting that aquarium fishes in reserves are not increasing or decreasing relative to non-harvested species.

Overall, there was no significant differences in before-after comparisons indicating that aquarium fishes in FRAs were not increasing or decreasing in abundance after reserve closure (Table 3; Figure 6 & 7). In contrast, there were numerous significant differences among FRAs in the estimates of harvesting (control-FRA differences). For all species except *Centropyge potteri* and *Chaetodon multicinctus* there were significantly fewer fishes in FRA relative to control areas (Table 3). This result is essentially a repeat of the analyses presented in Table 2, with the addition of the five post-closure surveys.

Fish Recruitment Patterns

There was seasonal variation in the abundance of newly recruiting aquarium- and non-aquarium fishes (Figure 9). Among aquarium fishes, new recruits were most common from May to September in both 1999 and 2000, with very few individuals seen between December to April. In contrast, although new recruits of non-aquarium fishes were also more common during the summer months, recruits were not uncommon during the fall and winter (Figure 9).

Individual aquarium fish species displayed similar patterns to all aquarium species pooled but differed in the abundance of recruits (Figure 10). In general the magnitude of recruitment of all fishes was very low compared to values observed in Walsh (1987), indicating the lack of strong recruitment that would serve to replenish fishes within FRAs.

Conclusions

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 2000 provided no evidence of an increase of aquarium fish stocks in FRAs. In contrast, all aquarium fishes, including those in previously protected areas (MLCDs and FMAs) declined between 1999-2000. Based on the small number of newly recruiting aquarium- and non-aquarium fishes observed in 1999 and 2000, there has been no mechanism to replenish depleted stocks within FRAs (or elsewhere). Given the low frequency in which large recruitment events occur in west Hawai'i, it will probably be several years until an event of sufficient magnitude will allow a rigorous test of the effectiveness of the marine reserve network in west Hawai'i.

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.

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 Control-FRA differences: 1) before and after reserve closure; 2) among FRAs; and 3) statistical interactions between FRAs and before-after comparisons. P-values are reported for the nine most commonly targeted aquarium fishes and these species pooled.

Taxa	Before-After	FRA	Before-After*FRA
Acanthurus achilles	0.84	>0.01*	0.06
Centropyge potteri	0.93	0.14	0.25
Chaetodon multicinctus	0.33	0.29	0.84
Chaetodon ornatissimus	0.10	>0.01*	0.66
Chaetodon quadrimaculatus	0.56	>0.01*	0.90
Ctenochaetus strigosus	0.78	>0.01*	0.52
Forcipiger spp.	0.66	>0.01*	0.11
Zanclus cornutus	0.15	>0.01*	0.03*
Zebrasoma flavescens	0.14	>0.01*	0.32
Overall	0.52	>0.01*	0.91

 * Significant at $\alpha = 0.05$

Table 4. Estimates of reserve replenishment (*R*): mean difference between pre- and post-closure control-FRA differences. Positive values indicate an increase in mean density (No./100m^2) in fishes in FRAs after closure relative to before closure. Bold face values are statistical significant at P < 0.05 (see Table 3). Bolded values are significant at $\alpha = 0.05$.

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

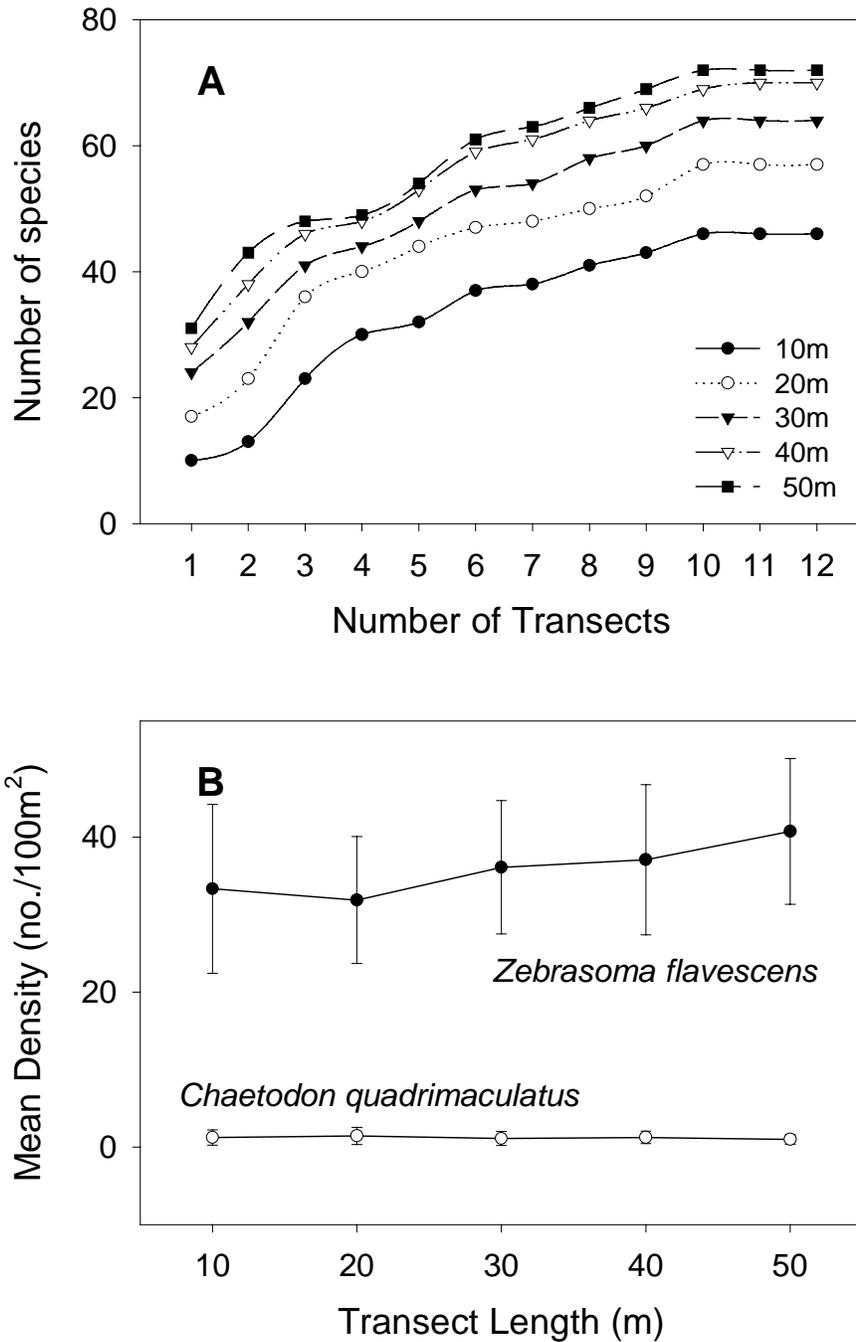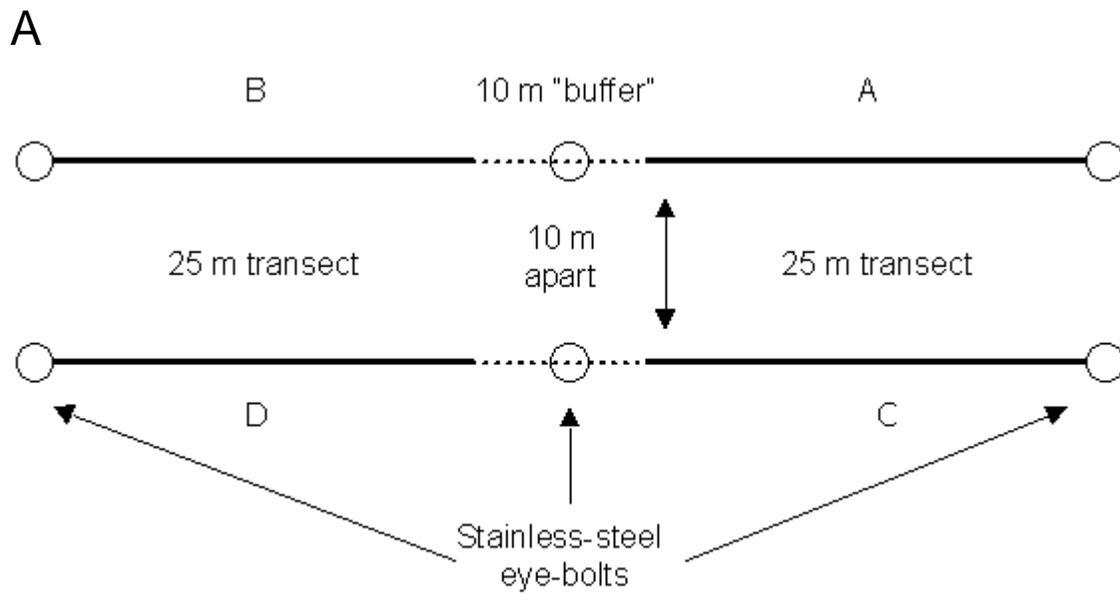| FRA	*Acanthurus achilles*	*Centropyge potteri*	*Chaetodon multicinctus*	*Chaetodon ornatissimus*	*Chaetodon quadrimaculatus*	*Ctenochaetus strigosus*	*Forcipiger flavissumus*	*Zanclus cornutus*	*Zebrasoma flavescens*	*Overall*
N. Kohala	0.1	-0.8	-0.5	**-0.5**	-0.2	-0.9	1.4	0.2	1.5	-0.4
Puako	-0.1	-0.3	-0.5	0.0	0.2	3.2	**-1.1**	0.2	0.0	-1.7
Honokohau	1.0	1.8	0.4	-0.1	0.0	-4.0	0.6	0.0	-1.7	1.9
Red Hill	**-1.0**	-1.4	-0.8	0.4	0.1	-2.8	0.3	-0.2	0.4	4.9
Honaunau	0.2	0.5	0.7	-0.5	-0.2	6.2	-0.4	**-1.0**	-4.2	-1.3
Mean	0.1	>0.1	-0.1	-0.1	>0.1	0.4	0.2	-0.2	-0.8	0.7
SE	0.3	0.6	0.3	0.2	0.1	1.9	0.4	0.2	1.0	1.2
% change	20.1	-0.9	-2.5	-17.0	>0.1	1.2	25.6	-78.2	-5.6	1.2

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.
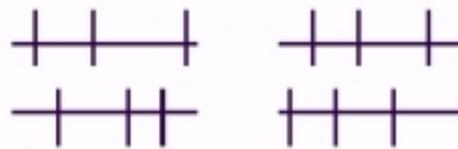
A

B   10 m "buffer"   A

⊙————————————————⊙⊙————————————————⊙

25 m transect   10 m   25 m transect
                       apart

⊙————————————————⊙⊙————————————————⊙

        D   C

                Stainless-steel
                  eye-bolts

B

25 m design   10 m design

———— ————   ┼┼┼ ┼┼┼
———— ————   ┼┼┼ ┼┼┼

N=4 transects   N=12 transects

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.
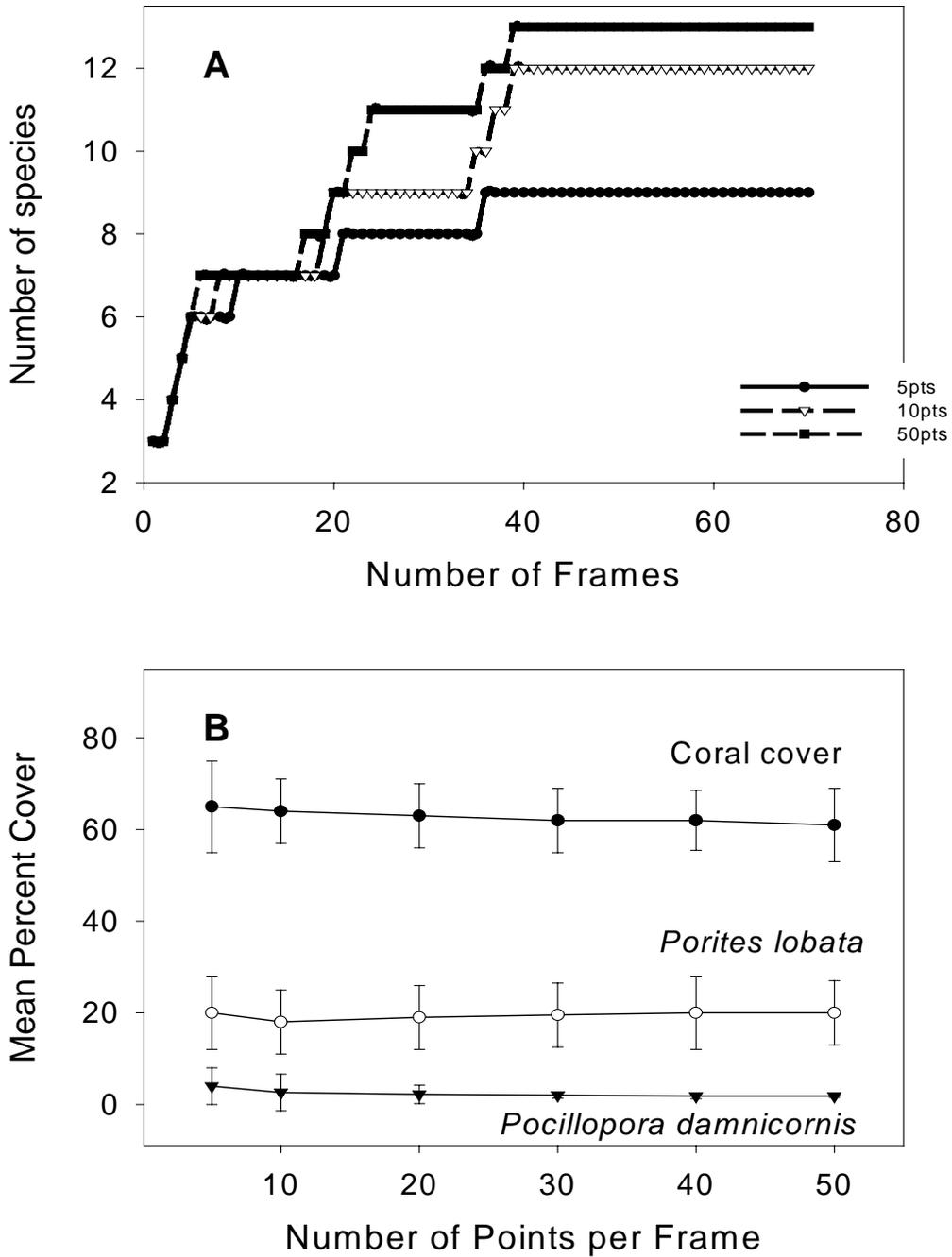
Figure 3. Results of pilot studies using photographic images that varied in the number of frames and the number of points per frame. **A**. The effects of varying frame number and points per frame on the total number of coral/algal species observed. **B**. The effects of the number of points per frame on mean abundance and variability for total coral cover, a common, and an uncommon coral species.
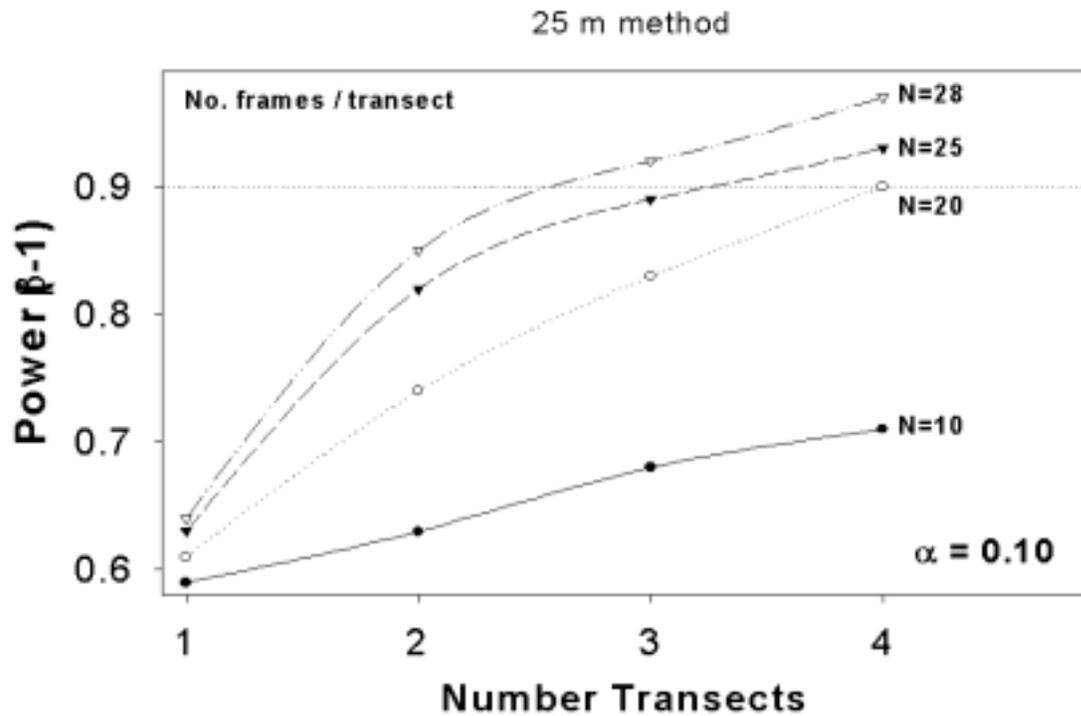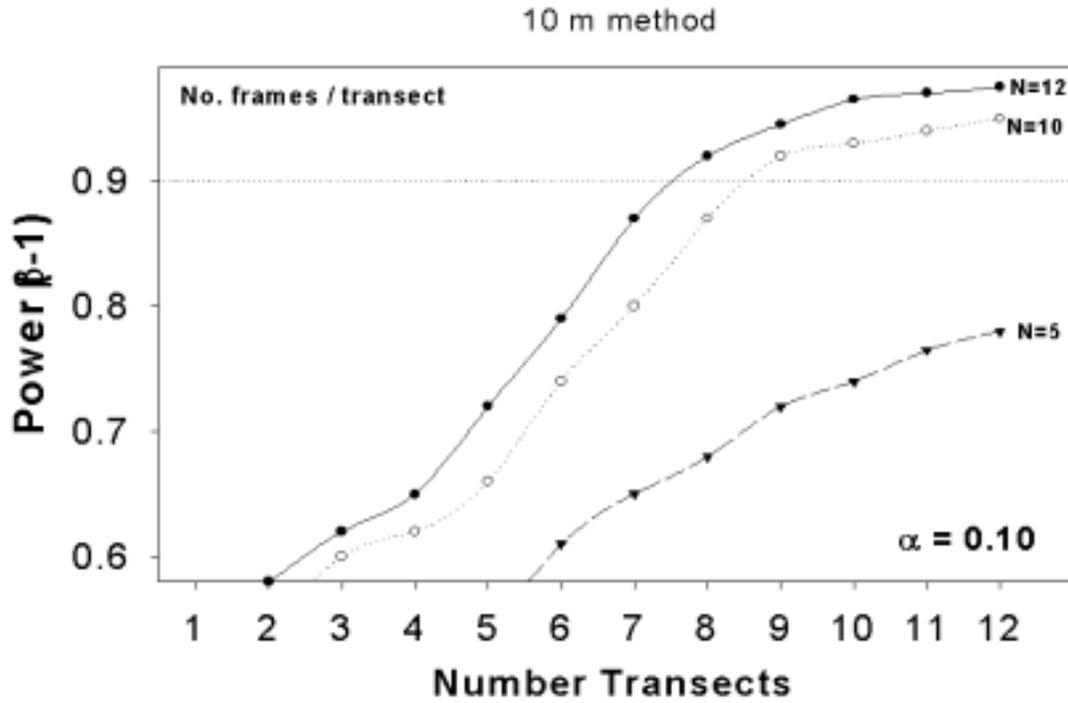
Figure 4. Power analysis of the effects of transect number and frame number to detect a 10% change in total coral cover based on a two-sample t-test between surveys for two alternate transects designs (See text and Figure 2B).

Zebrasoma flavescens

Mean Density (#/100m^2)

28
24
20
16
12
8
0

A

Control

B

FRA

Pre-reserve closure | Post-reserve closure

Mean Density Differnce (#/100m^2)

$\overline{\overline{X}}_{before}\left(\overline{X}_{control} - \overline{X}_{FRA}\right)$

$\overline{\overline{X}}_{after}\left(\overline{X}_{control} - \overline{X}_{FRA}\right)$

-4
-8
-12

3/99 5/99 7/99 9/99 10/99 12/99 '2/00 '4/00 '6/00 '8/00
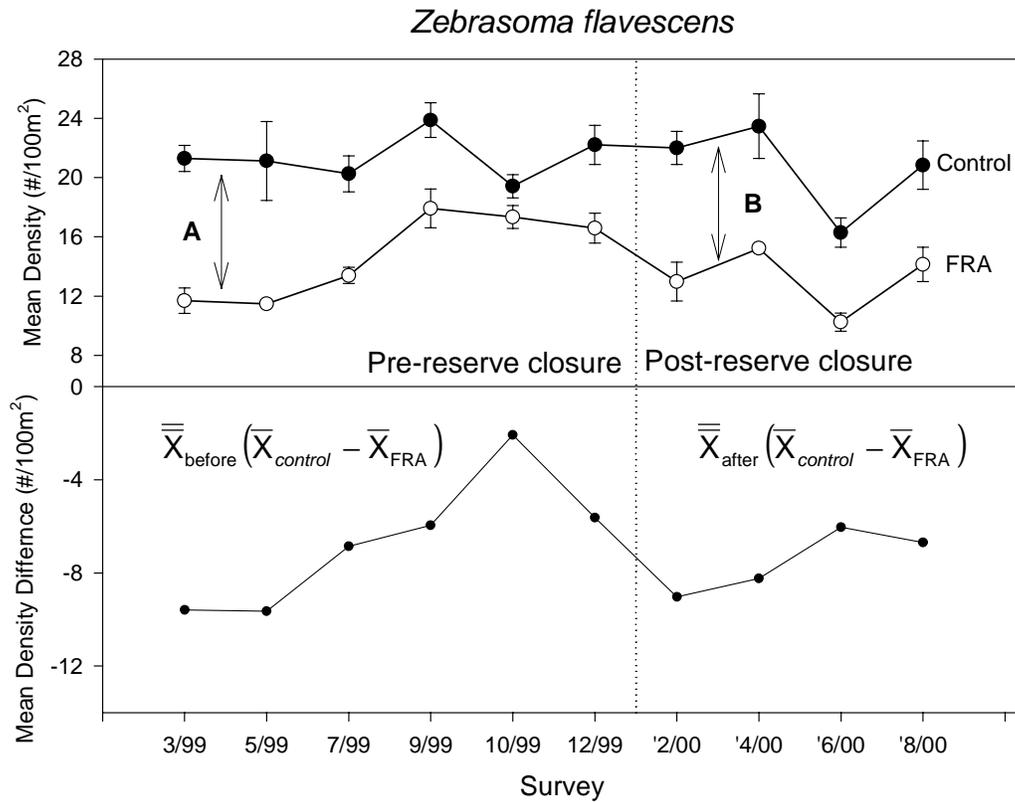
Survey

Figure 5. Graphical illustration of Before-After-Control-Impact Paired Procedure (BACIP). Significant change in fish density in FRA areas are determined by comparing mean Control-FRA differences before reserve closure (arrow A) to mean Control-FRA differences after reserve closure (arrow B).

Control-FRA-Impact Comparisons
Top 10 Aquarium Species Pooled

Control-FRA-Impact Comparisons
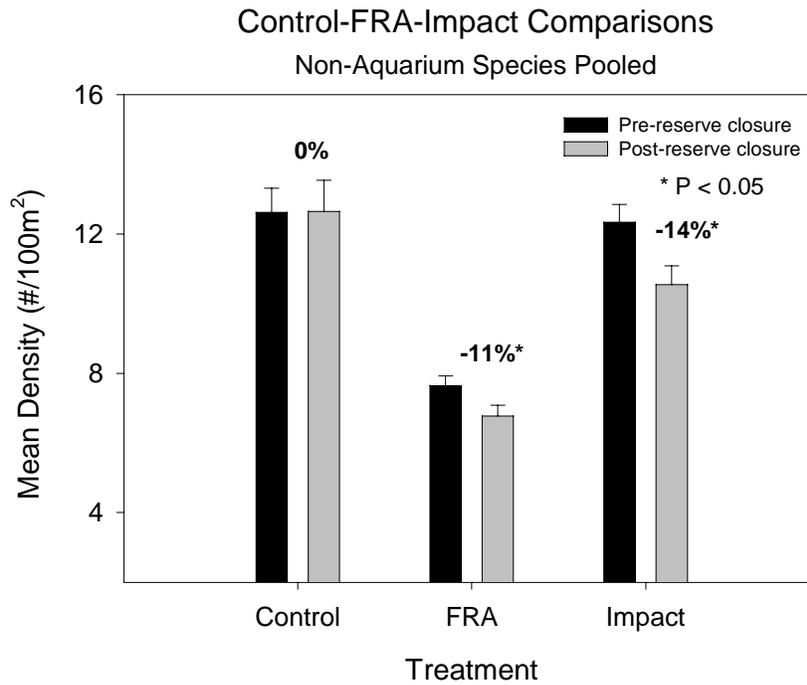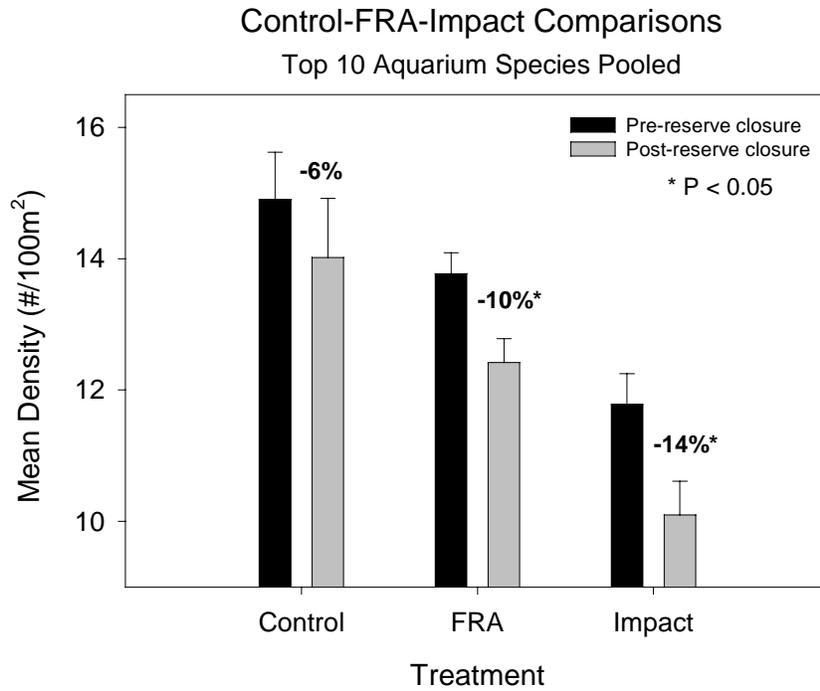### Non-Aquarium Species Pooled

Figure 6.   Changes in mean density of aquarium (upper graph) and non-aquarium fishes in control (n=6), FRA(n=9), and impact (n=8) areas before and after reserve closure.
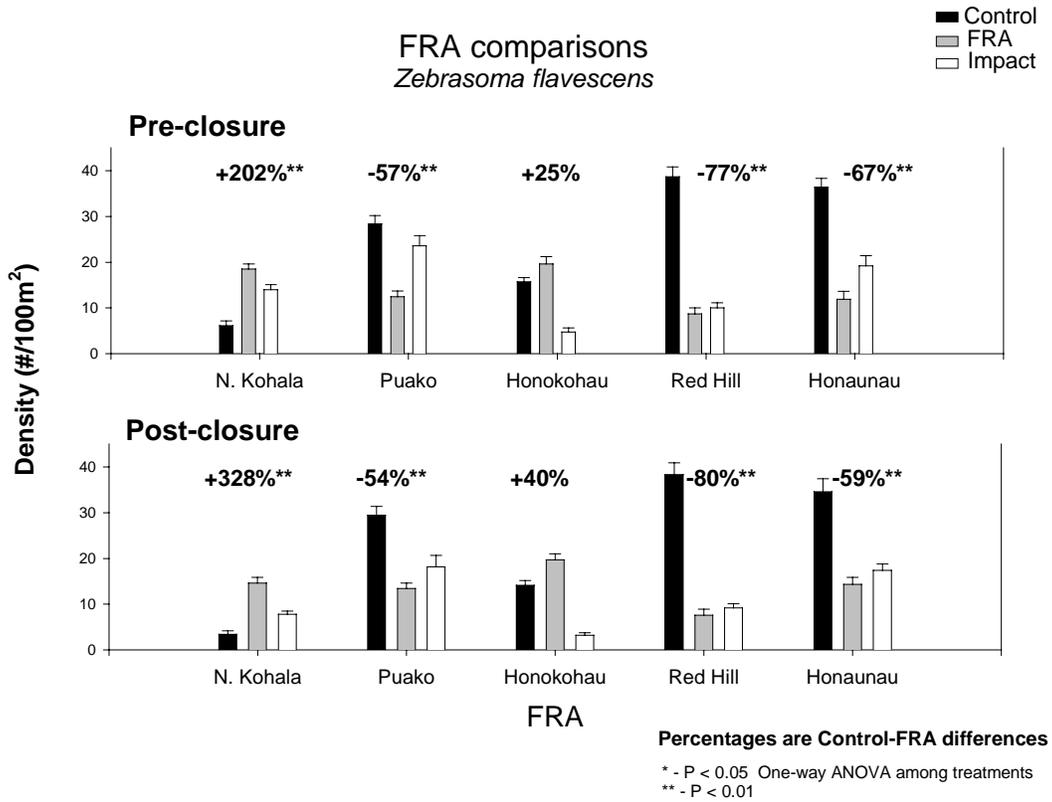
Figure 7.   Changes in the density of the yellow tang, *Zebrasoma flavescens*, at study sites during 1999 pre-closure surveys and 2000 post-closure surveys. Percentages estimate harvesting using differences between control and FRA sites.
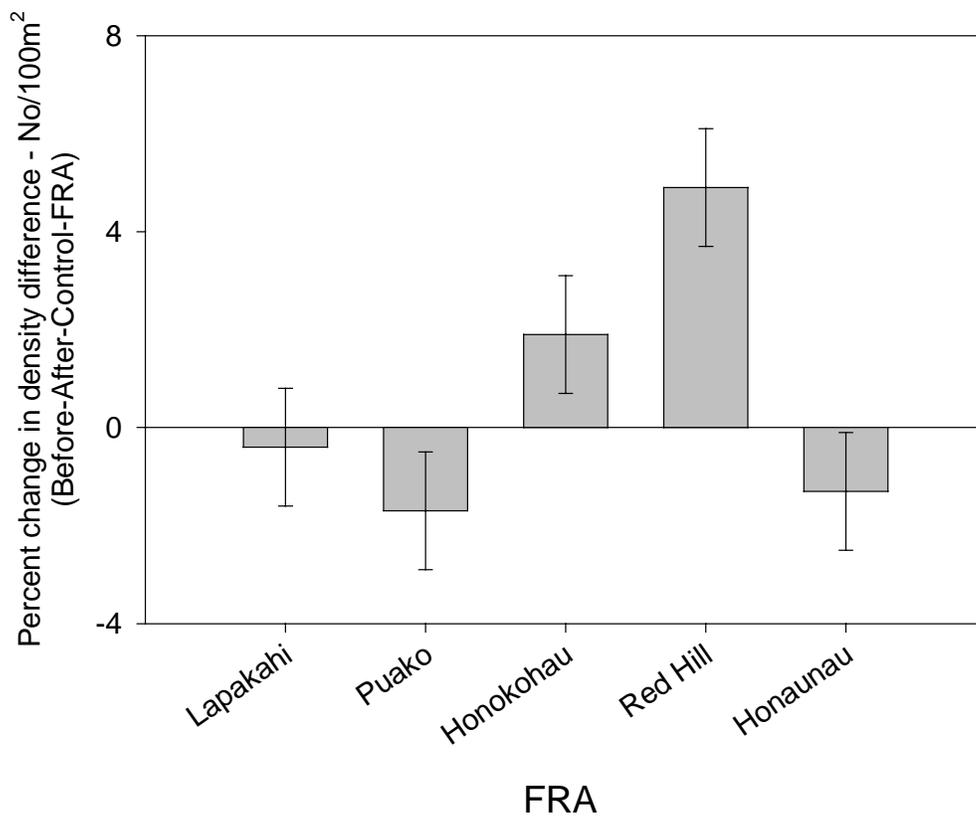
Figure 8.   Changes in the density of the top aquarium fishes in FRAs in post-relative to pre-closure surveys using the reserve effectiveness index (*E*) (see text).
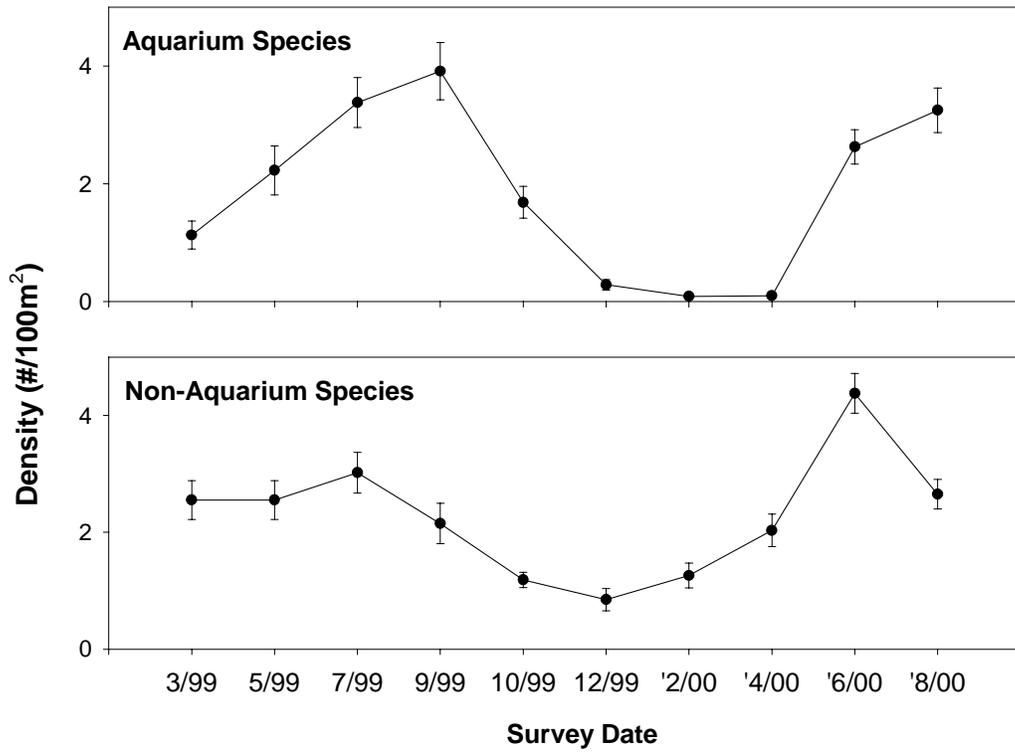
Figure 9.   Density of newly recruiting fishes for aquarium fishes and non-aquarium fishes. Individuals from all sites are pooled.
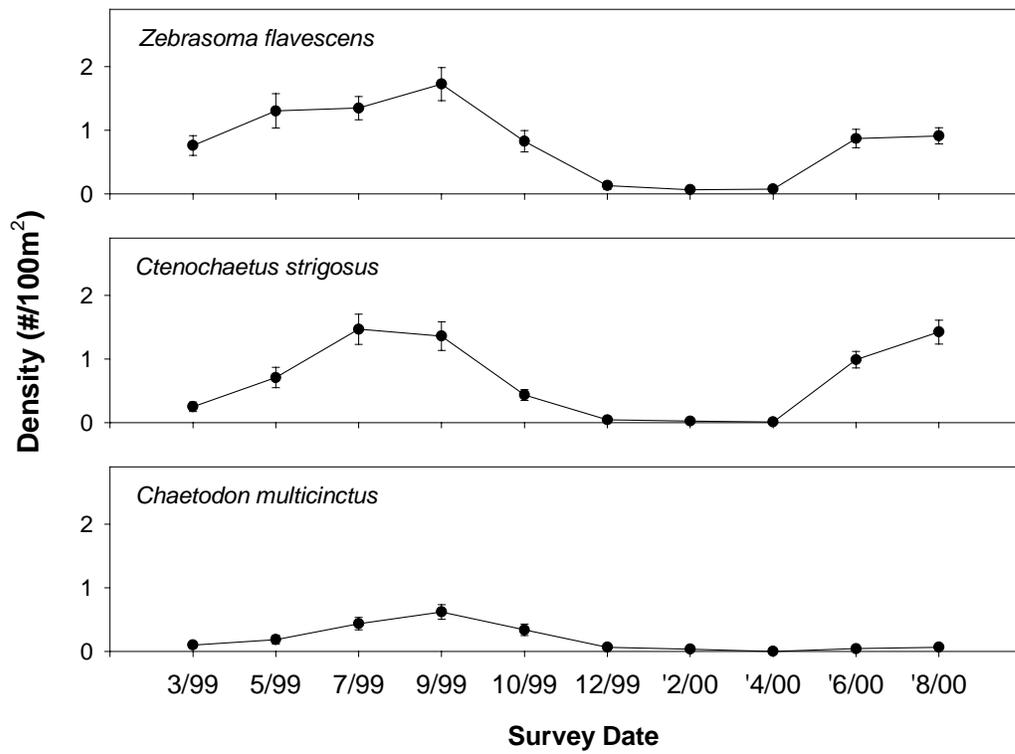
Figure 10.   Density of newly recruiting fishes for three common aquarium fishes. Individuals from all sites are pooled.

Appendix 1

North Kohala

Location	Type	Depth (ft.)
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
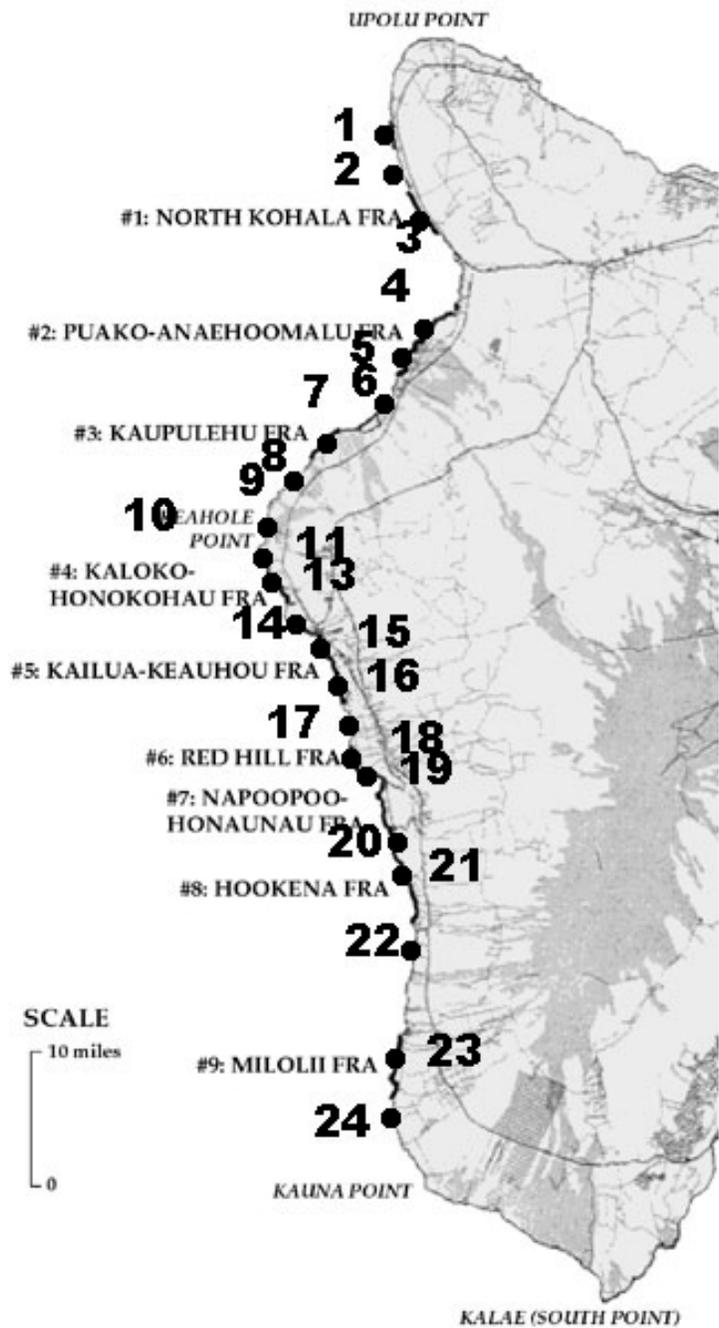
The West Hawaii Regional Fishery Management Area in relation to study sites and observational design assignments.

Appendix 2

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

<u>West Hawai'i sites</u>

Survey	Field surveys	Data entry and verification
1	Mar. 10 - Apr. 13, 1999	May 4, 1999
2	May 4 - 26, 1999	July 15, 1999
3	June 3 - Aug. 3, 1999	Jan. 12, 2000
4	Aug. 4 - Sept. 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	June 5 - June 15, 2000	Oct. 2, 2000
10	Jul. 17 - Aug. 17, 2000	Nov. 17, 2000
11	Oct. 31-Dec. 19, 2000	Feb. 2, 2001

<u>East Hawai'i sites: Kapoho</u>

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 |

East Hawai'i sites: Kapoho

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

Appendix 3

<u>Completed Task List</u>

A. Field surveys:

<u>Fish transects</u>

- West Hawai'i: 6 surveys of all sites (n=460 transects)
- East Hawai'i: 12 surveys of Kapoho sites; 8 of Richardson's (n = 80 transects)

<u>Habitat transects</u>

- West Hawai'i: one survey of all sites (n=91 transects; 3392 quadrats)

B. Data management:

- Data entry and verification for 5 west Hawai'i surveys; 20 east Hawai'i surveys
- Extraction and archive of all benthic habitat imagery (n=3392 images)

C. Data analysis

- Preliminary quality assurance analysis of benthic habitat imagery
- Power analysis of benthic habitat imagery using 10 vs. 25 m transects
- Quantitative analysis of benthic habitat of four study sites

D. Public Outreach:

<u>Public WHAP Talks</u>

- Walsh W. J., Hawaii Operational Safety Team (US Coast Guard Auxiliary). January.
- Walsh W. J., University of Hawai'i Zoology Dept. Seminar on "*Polyps and Politics*" January.
- Walsh W. J., Waikoloa HS Ocean Explorers. January.
- Hallacher, L.H. Kapoho Community Association. February.
- Walsh W. J., National Ocean Service Field team, March.
- Walsh W. J., Marine Option Program Symposium Keynote address. May.
- Walsh W. J., Maritime Industry Day 2000 Conference. May.
- Hallacher, L.H. Richardson's Ocean Park. June.
- Walsh W. J., SeaGrant ReefTalk, July.
- Walsh W. J., Keauhou Community Association, September
- Walsh W. J., Kawaihae Bay Boating Club. September

Scientific Presentations on WHAP

- Tissot, B. N. *The emerging role of marine protected areas in ecosystem management: contrasts between Oregon and Hawai'i.* Washington State University, Pullman, WA. September.
- Tissot, B. N., W, J,. Walsh and L. E. Hallacher. *Adaptive Community-based Management of a Marine Reserve Network in Hawai'i.* Ninth International Coral Reef Symposium, Bali, Indonesia. October.
- Tissot, B. N. *The role of coral reef monitoring programs: working towards a synthesis of science, management, and policy.* Ninth International Coral Reef Symposium, Bali, Indonesia. October.

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

- Progress reports
- Updated brochure

Appendix 4

<u>Field Guide to study sites</u>