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

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ABSTRACT

A network of nine Fish Replenishment Areas (FRA) reserves was demarcated in West Hawai'i in 2000 in response to declines of reef fishes taken by aquarium collectors. In 1999, we established 23 study sites in FRAs, areas open to collectors and reference areas (existing protected areas) to collect data both prior to and after the closure of the reserve network in 2000. To date we have conducted 23 bimonthly surveys as well as surveys of the benthic habitats of all sites. Baseline surveys, done prior to reserve closure, document significant effects of aquarium collector harvesting on selected fishes. On average, aquarium fishes were 26% less abundant in newly-established reserves (formerly open) than adjacent reference areas. Analysis of post-closure surveys in 2000-2002 using a Before-After-Control-Impact procedure provided evidence of a significant increase of aquarium fishes in reserves, primarily in the yellow tang (*Zebrasoma flavescens*), the most collected aquarium fish in Hawaii. The recovery of aquarium fishes in the FRAs was probably due to the high number of newly recruited fishes observed in 2001-2002. Large recruitment events are rare in West Hawai'i but are likely to be an important factor determining the effectiveness of marine reserves to help replenish depleted fish populations.

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 17 post-closure surveys conducted in 2000-2002 provided evidence of an increase of aquarium fish stocks in FRAs. There were a statistically significant 26% increase of aquarium fishes in reserves, primarily in the yellow tang (*Zebrasoma flavescens*), the most collected aquarium fish in Hawaii, which increased 74% in FRAs relative to pre-FRA closure. 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 and 2002 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.

PURPOSE

Coral reefs are diverse and productive biological communities that provide 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 2003). 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 of MPAs are replicated (e.g., have more than one reserve), 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 assessment of aquarium fish collecting effects on the island of 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 since then 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 collectively prohibited aquarium fish collecting along 35% of the coast when combined with existing protected areas. The proposed management plan received 93% support at a public hearing, was subsequently approved by the Governor, and the FRAs were officially closed to aquarium collectors on Jan. 1, 2000.

The principle purpose of this paper is to conduct an evaluation of the effectiveness of the nine FRAs to increase the productivity of aquarium fishery resources. 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, and the public.

APPROACH

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 (reference sites). References sites included Marine Life Conservation Districts (MLCDs) and Fishery Management Areas (FMAs), both of which prohibit aquarium fish collecting, along with other activities. A total of 23 study sites were selected in early 1999. The sites were established in six existing reference areas, in eight open areas adjacent to FRAs, and in all nine of the FRAs (Figure 1)

Study sites were selected 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 reference) 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 juvenile aquarium fishes, particularly the yellow tang, *Zebrasoma* *flavescens*, and typically dominates most areas of the west Hawai'i 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 five additional stainless-steel bolts cemented into the bottom, we established four permanent 25 m transects in an H-shaped pattern at each of the study sites . During field surveys, study sites were located by differential GPS and the transect lines were deployed between the eyebolts.

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. 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 reference, FRA, and open area on a single day with the same set of observers. Thus, our transect design was constrained around a maximum total daily bottom time of 2½ hours, or about 50 minutes per site. Other considerations that influenced our design were the 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 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 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 2). 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 (yellow tang) and uncommon (*Chaetodon quadrimaculatus*) aquarium fish did not vary significantly with transect length, nor was their significant variation in the standard error of the estimate (Figure 2). 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).

Power analysis of preliminary fish transect data indicated that our observational design would 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 ($\alpha=\beta=0.10$; see Mapstone 1996) 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).

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 25m 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 2m wide. On the outward-bound leg, larger planktivores and wide-ranging fishes within 4m of the bottom were recorded. On the return leg, fishes closely associated with the bottom, new recruits, 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 (five in 2000). Due to problems with our research vessel surveys were not conducted during the summer of 20022.

We used a quantitative video sampling method to monitor benthic habitats at each study site; 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). 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 (see Brown et al., this volume).

The abundance of coral, non-living substrates and macro algae were estimated at each site using a Sony DCR-TRV900 digital video camera 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) . 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 detect a 10% change in mean coral cover between two surveys ($\alpha=\beta=0.10$). For this paper, habitat data were analyzed to test one assumption of our observational design: that habitat variation was similar among FRA-reference-open areas.

Although all fishes seen were analyzed, species were divided into categories based on high rates of aquarium collecting (10 spp.), any aquarium collecting (58 spp.) and non-collected species (152 spp.). The presence and extent of collecting was based on reports in (Miyasaka, 1997).

We predicted that the density of protected fishes should increase in FRAs after closure, relative to reference areas, due to cessation of collecting. We tested the statistical significance of our predictions using the Before-After-Control Impact (BACI) procedure (Osenberg and Schmidt 1996). This method tested for significant change in fish density by comparing mean FRA-reference differences before closure to mean FRA-reference differences after closure. The same comparison was also made for changes in open-reference differences to examine changes outside of the reserves.

We conducted the BACI procedure using a one-way, repeated measure analysis of variance with data from baseline surveys in 1999 (surveys 1-6) and the last six surveys in 2003 (surveys 18-23) in order to estimate the effectiveness of the reserves after three years of closure. Surveys were used as a random, repeated-measure factor. Data for the BACI analysis were limited to the five study areas that had reference, FRA and open sites (Figure 1). We evaluated effectiveness in two ways: 1) by calculating the percent change in mean density from 1999 to 2002; and 2) by calculating the percent change in the FRA-reference or open-reference difference from 1999 to 2002.

Estimates of the effects of aquarium collectors were made by comparing the mean density difference of target fishes in reference-areas relative to FRA-areas using the six baseline surveys from 1999 (see Tissot and Hallacher [2003] for a complete description of this method).

Project Management

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 under the supervision of Tissot. This database is accessible to each of the project participants through the Internet and will is 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.

Findings

Benthic habitat analysis

Analysis of video transects revealed high variation in live coral cover in West Hawai'i (Figure 3). 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). One-way analysis of variance among mean coral cover at reference, FRA, and open areas was not significant ($P > 0.05$).

Effects of collectors

Overall, there were significantly less aquarium fishes in FRAs relative to reference areas in seven of the nine species analyzed during 1999 baseline surveys (Table 1). Overall differences were significantly lower in *Acanthurus achilles* (-56%), *Centropyge potteri* (-42%), *Chaetodon quadrimaculatus* (-97%), *Ctenochaetus strigosus* (-14%), *Forcipiger* spp. (-55%), *Zanclus cornutus* (-49%) and *Zebrasoma flavescens* (-43%). There were no significant differences in *C. multicinctus* or *C. ornatissimus* (Table 1). Overall, aquarium fishes were 26% less abundant in FRAs relative to reference areas.

Effectiveness of FRAs

Overall their was a significant increase in the abundance of aquarium fishes in FRAs after two years of reserve closure (Table 2A). The mean density of aquarium fishes increased 26%, and the mean density in FRAs relative to reference areas increased 50%, between pre- and post-closure surveys (Figure 4). Two of the ten aquarium species examined had significant increases in FRAs relative to reference areas: the yellow tang, *Zebrasoma flavescens* (74%) and Potter's angelfish (*Centropyge potteri)* (80%). In contrast, there were no significant changes in non-aquarium fishes in FRAs (Table 2A, Figure 4).

In areas open to collecting there were no significant overall changes among aquarium or non-aquarium fishes in (Table 2B). However, two of the ten aquarium species had significant increases in abundance in open- relative to reference-areas: *Ctenochaetus strigosus* (51%) and *Forcipinger flavissimus* (61%) (Table 2B)

Recruitment

Although newly recruited individuals were present during the summers of all years, there were higher levels of recruitment of aquarium fishes after reserve closure during the summers of 2001 and 2002 relative to earlier years (Figure 5). In contrast, non-aquarium recruits were more common in 1999 prior to reserve closure, declining in 2000-2002. A two-way BACI ANOVA was not significant among aquarium- and non-aquarium species, before and after closure, nor was there a significant interaction between these two factors (all $P > 0.05$)

Evaluation

Analysis of baseline surveys in 1999 support earlier research documenting significant effects of aquarium collector harvesting on selected fishes in West Hawai'i. Pre-closure surveys indicate that collectors continued to target seven of the nine aquarium species examined in the FRAs prior to closure on Jan. 1, 2000. On average aquarium fishes were 42-97% less abundant, and overall 26% less abundant in FRAs than adjacent reference areas. With the exception of *C. multicinctus* and *C. ornatissimus*, these estimates are remarkably similar to those reported previously by Tissot and Hallacher (2003), which was conducted in 1997-98 at two of the nine general areas surveyed in this study.

Three years after their closure of FRAs there were significant increases in the overall abundance of fishes targeted by collectors. Interestingly, the estimated increase in abundance (26%) is the same amount as the estimated reduction due to collectors prior to FRA closure, suggesting that as a group these fishes may have increased to their pre-exploitation levels. Two species, the yellow tang and Potter's angelfish, showed significant 74-80% increases in FRAs relative to previously protected reference areas. Moreover, several others species, notably *C. multicinctus*, and *F. flavissimus*, showed high (>40%) but insignificant increases in FRAs relative to references area (Table 2). However, other species (*C. ornati*ssimus, *C. quadrimaculatus* and *F. longirostris*), showed high but insignificant decreases in FRAs relative to reference areas. This variation may be random or a response to variation in the intensity of recruitment, mortality or other factors.

In contrast, there were no significant changes among non-collected species within FRAs or in aquarium and non-aquarium species in areas outside of reserves. Furthermore, no aquarium fishes declined in abundance in open areas as might be expected if the intensity of harvested increased outside of the FRAs. In fact, two species displayed significant increases in abundance. These results indicate that reserves can help recover fish abundance without associated decreases in abundance outside of reserves, a common criticism of MPAs (e.g., Chapman & Kramer, 1999)

There was strong interannual variation in the recruitment of all fishes in West Hawai'i. Although there was no significant variation between aquarium and non-aquarium species before or after FRA closure, in general non-aquarium species had higher rates of recruitment before FRAs were closed in 1999, while aquarium species had higher recruitment in 2001 and 2002, after closure. Thus, recovery of aquarium fishes in FRAs was associated with high rates of recruitment, providing evidence that recruitment is an important mechanism replenishing depleted stocks within reserves in Hawaii.

This study documented high temporal variation in recruitment of reef fishes in Hawai'i, a similar result to that found by Walsh (1987) over a five-year period. Thus, although FRAs showed significant recovery in some species after only three years, the frequency of recruitment of protected species is likely to be an important factor determining the recovery of other species in reserves.

The results of this study demonstrate the MPAs can effectively promote recovery of fish stocks depleted by fishing pressures in Hawai'i, without significant declines outside of reserves. Within three years two species, the yellow tang and Potter's angelfish, both reduced by over 40% prior to protection, displayed significant increases inside FRAs relative to reference areas. Yellow tangs, which accounts for over 80% of the aquarium industry in west Hawai'i, increased in density 73% between 1999 and 2003, or about 10.4 fish/100m^2.

Based on these results it would prudent to establish additional reserves throughout Hawai'i as a precautionary measure against overuse of fishery resources. Currently, less than 1% of the main Hawaiian islands is protected by reserves (Clark and Gulko 1999). Further, as recruitment appears to be an important mechanism influencing the replenishment of nearshore populations, we also advocate for increased monitoring of recruitment and nearshore oceanography to help better understand the dynamics of recruitment processes.

Dissemination of Project Results

Scientific Presentations

Tissot, B. N., W, J,. Walsh and L. E. Hallacher. *Evaluating the effectiveness of a Marine Reserve Network in Hawai'i*. Western Society of Naturalists, Monterey, CA. (November 2002)

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

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

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Table 1. Effects of aquarium collecting on nine fishes estimated by mean percent FRA-reference area differences using data from surveys prior to reserve closure (n= 6 surveys). Significant differences between fish density between reference and FRA sites was tested using a two-sample t-test. Mean estimates are compared to the study of Tissot and Hallacher (2003).

Taxa	Overall	Tissot & Hallacher (2003)
Acanthurus achilles	-56*	-58*
Centropyge potteri	-42*	-46*
Chaetodon multicinctus	-4	-38*
Chaetodon ornatissimus	-7	-39*
Chaetodon quadrimaculatus	-97*	-42*
Ctenochaetus strigosus	-14*	-15
Forcipiger spp.	-55*	-54*
Zanclus cornutus	-49*	-46*
Zebrasoma flavescens	-43*	-47*
Overall	-26*	

* Significant at $P < 0.05$

Table 2. Two-way BACI repeated-measure analysis of variance testing for significant changes in before (1999) and after (2002) reserve closure (BA). P-values are reported for the most commonly targeted aquarium fishes, these species pooled and non-aquarium species. **A**. Reference-FRA differences. **B**. Reference-open differences. * Significant at P < 0.05.

A. Reference-FRA differences

Taxa	**Mean density (No/100m^2)**		**% change density**	**% FRA-reference change**	**P (BA)**
	Before	**After**			
Acanthurus achilles	0.22	0.28	+27	+13	0.76
Centropyge potteri	1.16	1.03	-17	+80	**0.03***
Chaetodon multicinctus	4.88	3.92	-20	+76	0.26
Chaetodon ornatissimus	0.95	0.91	-4.2	-112	0.75
Chaetodon quadrimaculatus	0.01	0.02	+100	-61	0.08
Ctenochaetus strigosus	28.1	32.3	+15	+29	0.40
Forcipinger flavissimus	0.61	0.44	-28	+49	0.34
Forcipinger longirostris	0.27	0.45	+67	-47	0.32
Zanclus cornutus	0.27	0.13	-52	+27	0.57
Zebrasoma flavescens	14.2	24.6	+73	+74	**<0.01***
All aquarium fishes	50.6	64.0	+26	+50	**0.01***
All non-aquarium fishes	42.1	47.2	+12	-27	0.12

Table 2 (cont.)

B. Reference-open differences

Taxa	**Mean density (No/100m2)**		**% change density**	**% Open-reference change**	**P (BA)**
	Before	**After**			
Acanthurus achilles	0.53	0.46	-13	+131	0.15
Centropyge potteri	1.62	1.43	-12	+161	0.06
Chaetodon multicinctus	4.70	4.22	-11	-44	0.86
Chaetodon ornatissimus	0.72	0.67	-6.9	-37	0.60
Chaetodon quadrimaculatus	0.53	0.51	-3.8	-127	0.23
Ctenochaetus strigosus	22.4	30.5	+36	+51	**<0.01***
Forcipinger flavissimus	0.46	0.45	-2.2	+61	**0.01***
Forcipinger longirostris	0.36	0.49	+36	-72	0.32
Zanclus cornutus	0.35	0.44	+26	+167	0.06
Zebrasoma flavescens	13.7	13.8	+0.7	-21	0.16
All aquarium fishes	45.0	52.8	+17	+14	0.11
All non-aquarium fishes	60.8	74.8	+23	+0.7	0.94

CAPTIONS TO FIGURES

Figure 1. Locations of study sites established in the West Hawaii Regional Fishery Management Area in relation to observational design assignments. Protection status: MLCDs: Marine Life Conservation Districts; FMAs: Fishery Management Areas; FRAs: Fishery Replenishment Areas; Open: areas open to aquarium harvesting.

Figure 2. Results of pilot studies using visual strip transects that varied in transect length and number. **A**. Effects of varying transect length and number on the total number of fish species observed. **B**. Effects of transect length on mean abundance and standard error of a common and an uncommon aquarium fish species.

Figure 3. 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 Figure 1).

Figure 4. Changes in mean density of fishes in reference, open and FRA areas pooled across all surveys before and after reserve closure (± 1 SE). Top: aquarium fishes; Bottom: non-aquarium fishes.

Figure 5. Changes in mean density of newly recruited fishes in reference, open and FRA areas pooled across all surveys before and after reserve closure (± 1 SE). Top: aquarium fishes; Bottom: non-aquarium fishes.

Site no.	Status	Depth (m)
<u>North Kohala</u>		
1. Lapakahi	MLCD	10-15
2. Kamilo	OPEN	13-15
3. Waiakailio Bay	FRA	12-14
<u>Puako - Anaehoomalu</u>		
4. Puako	FMA	9-10
5. Anaehoomalu	FRA	10-11
6. Keawaiki	OPEN	11-15
<u>Kaupulehu</u>		
7. Kaupulehu	FRA	13
8. Makalawena	OPEN	10-11
<u>Kaloko-Honokohau</u>		
9. Wawaloli Beach	OPEN	10
10. Wawaloli	FMA	12-15
11. Honokohau	FRA	12-14
<u>Kailua-Keauhou</u>		
13. Papawai	FMA	9-13
14. S. Oneo Bay	FRA	10-14
<u>Red Hill</u>		
15. N. Keauhou	FRA	9-12
16. Kualanui Pt	OPEN	9-13
17. Red Hill	FMA	12-15
<u>Napoopoo-Honaunau</u>		
18. Keopuka	OPEN	9-14
19. Kealakekua Bay	MLCD	6-11
20. Ke'ei	FRA	9-15
<u>Hookena</u>		
21. Hookena (Kalahiki)	FRA	9-12
22. Hookena (Auau)	OPEN	11-15
<u>Milolii</u>		
23. Milolii (Omakaa)	FRA	10-15
24. Milolii (Manuka)	OPEN	10-15

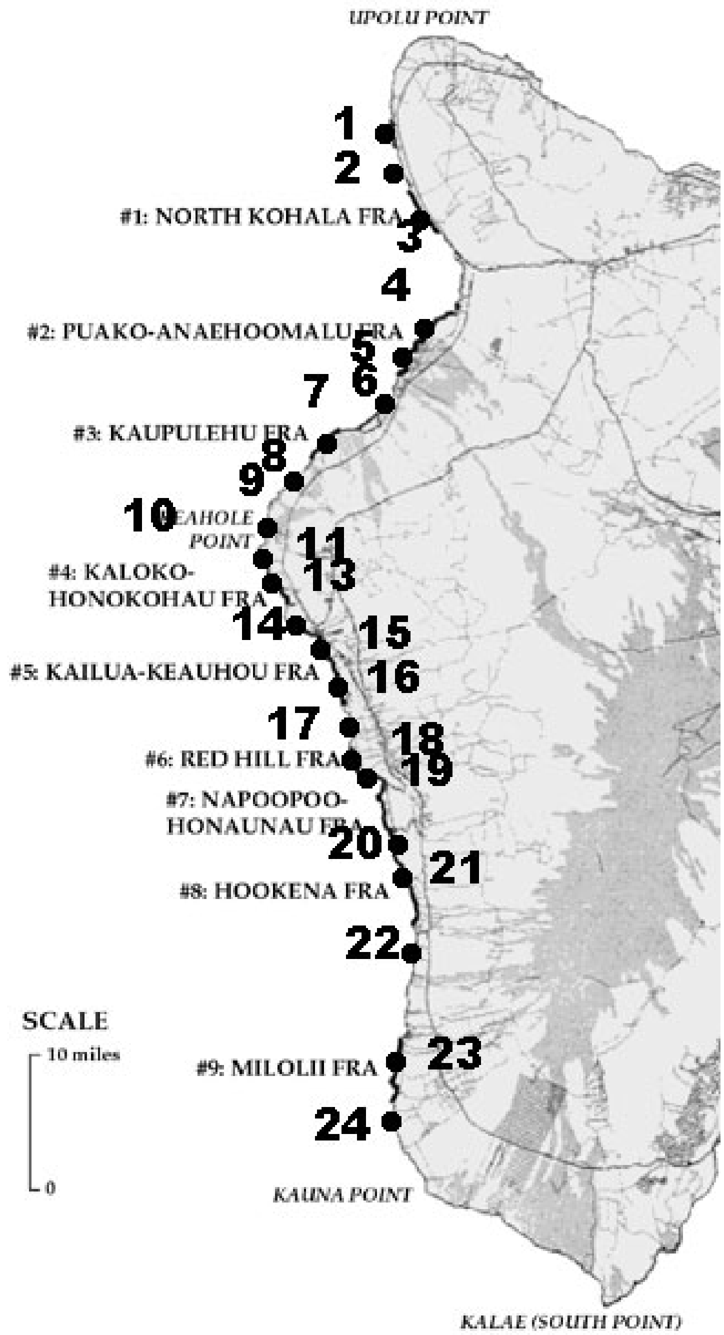

Figure 1

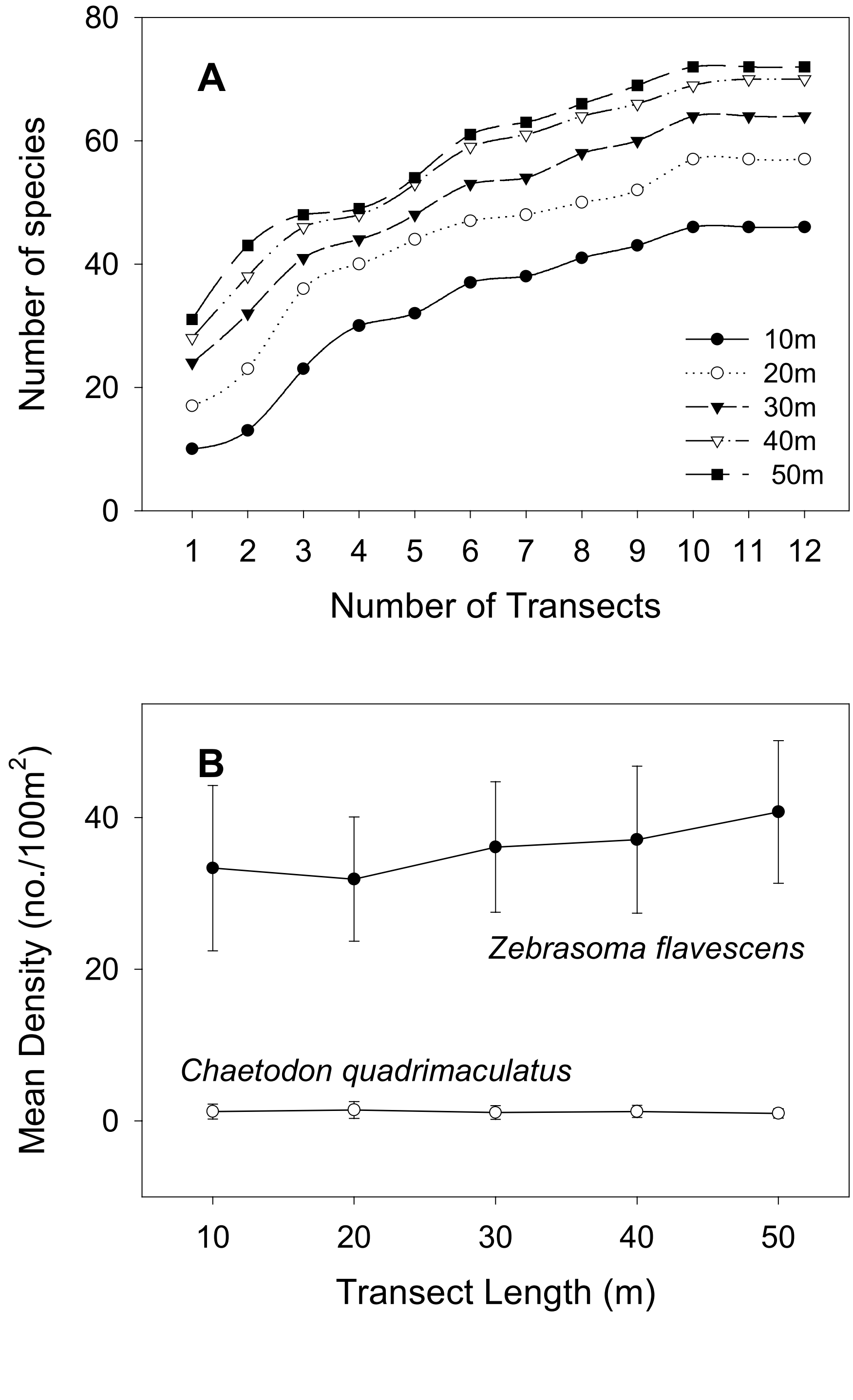
A
Number of species
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12
Number of Transects
10m
20m
30m
40m
50m
B
Mean Density (no./100m²)
40
20
0
10 20 30 40 50
Transect Length (m)
Zebrasoma flavescens
Chaetodon quadrimaculatus

Figure 2

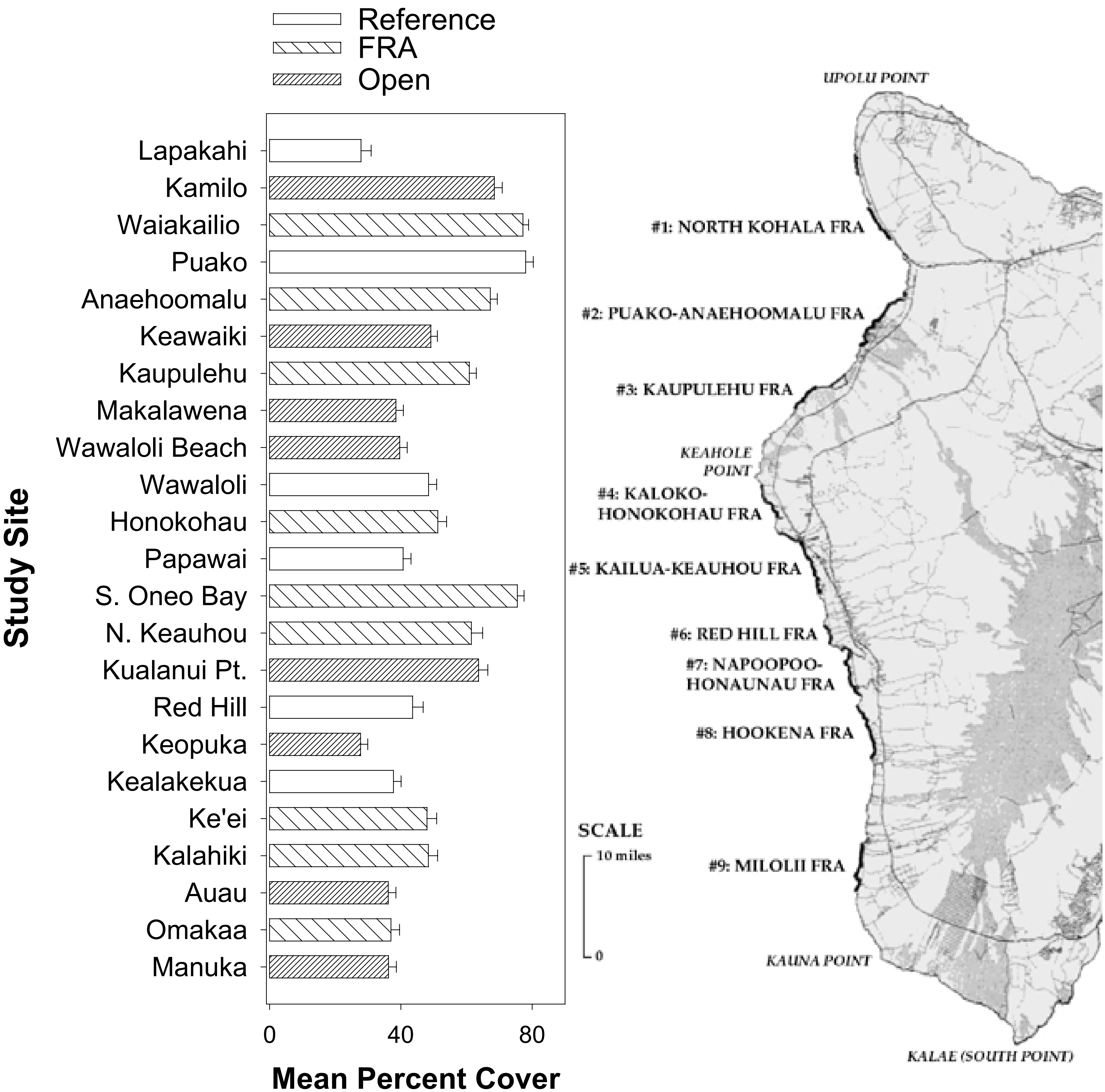
Reference
FRA
Open
Study Site
Lapakahi
Kamilo
Waiakailio
Puako
Anaehoomalu
Keawaiki
Kaupulehu
Makalawena
Wawaloli Beach
Wawaloli
Honokohau
Papawai
S. Oneo Bay
N. Keauhou
Kualanui Pt.
Red Hill
Keopuka
Kealakekua
Ke'ei
Kalahiki
Auau
Omakaa
Manuka
0
40
80
Mean Percent Cover
UPOLU POINT
#1: NORTH KOHALA FRA
#2: PUAKO-ANAEHOOMALU FRA
#3: KAUPULEHU FRA
KEAHOLE POINT
#4: KALOKO-HONOKOHAU FRA
#5: KAILUA-KEAUHOU FRA
#6: RED HILL FRA
#7: NAPOOPOO-HONAUNAU FRA
#8: HOOKENA FRA
SCALE
10 miles
0
#9: MILOLII FRA
KAUNA POINT
KALAE (SOUTH POINT)

Figure 3

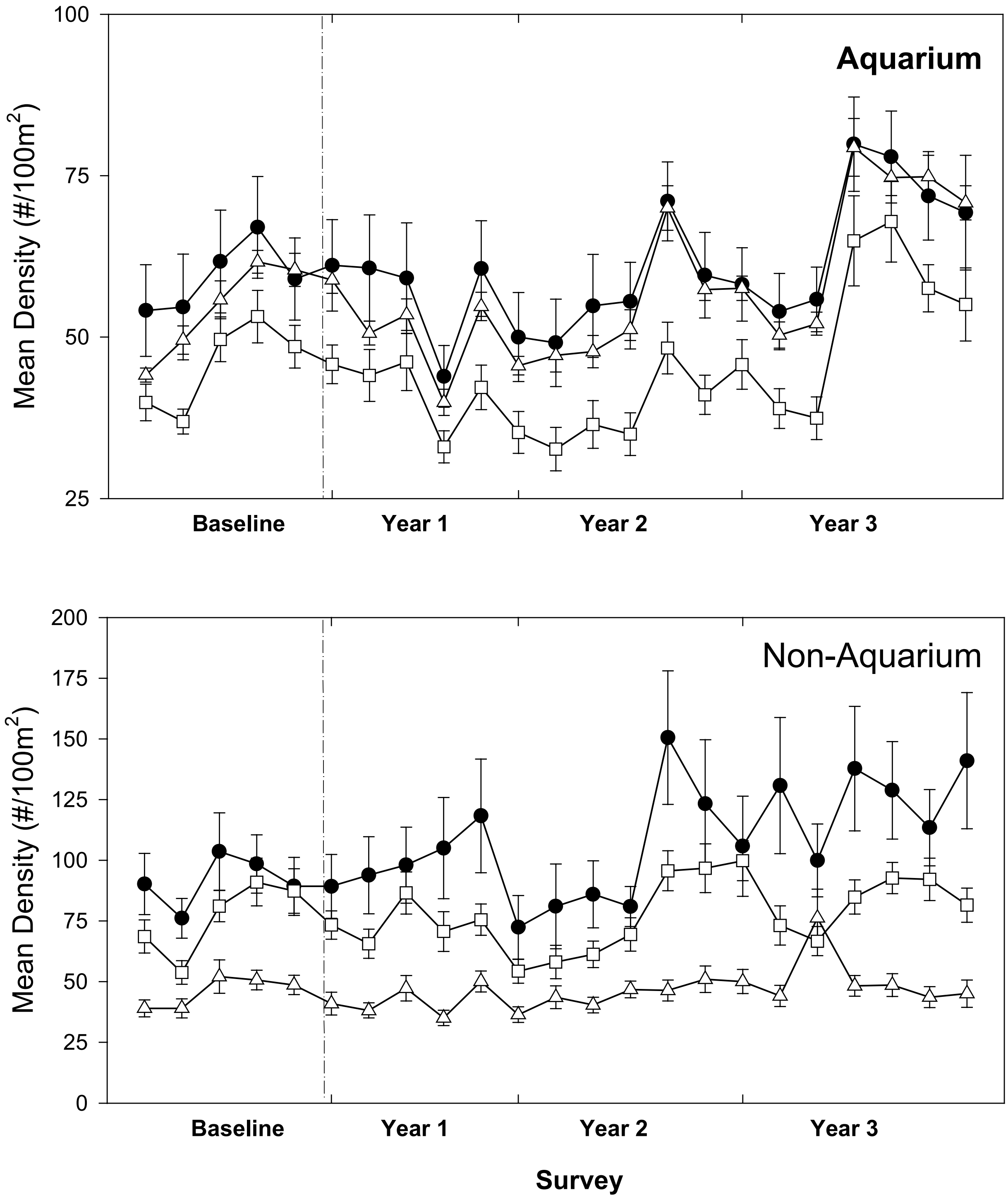
Aquarium
Non-Aquarium
Mean Density (#/100m2)
Mean Density (#/100m2)
100
75
50
25
200
175
150
125
100
75
50
25
0
Baseline
Year 1
Year 2
Year 3
Baseline
Year 1
Year 2
Year 3
Survey

Figure 4

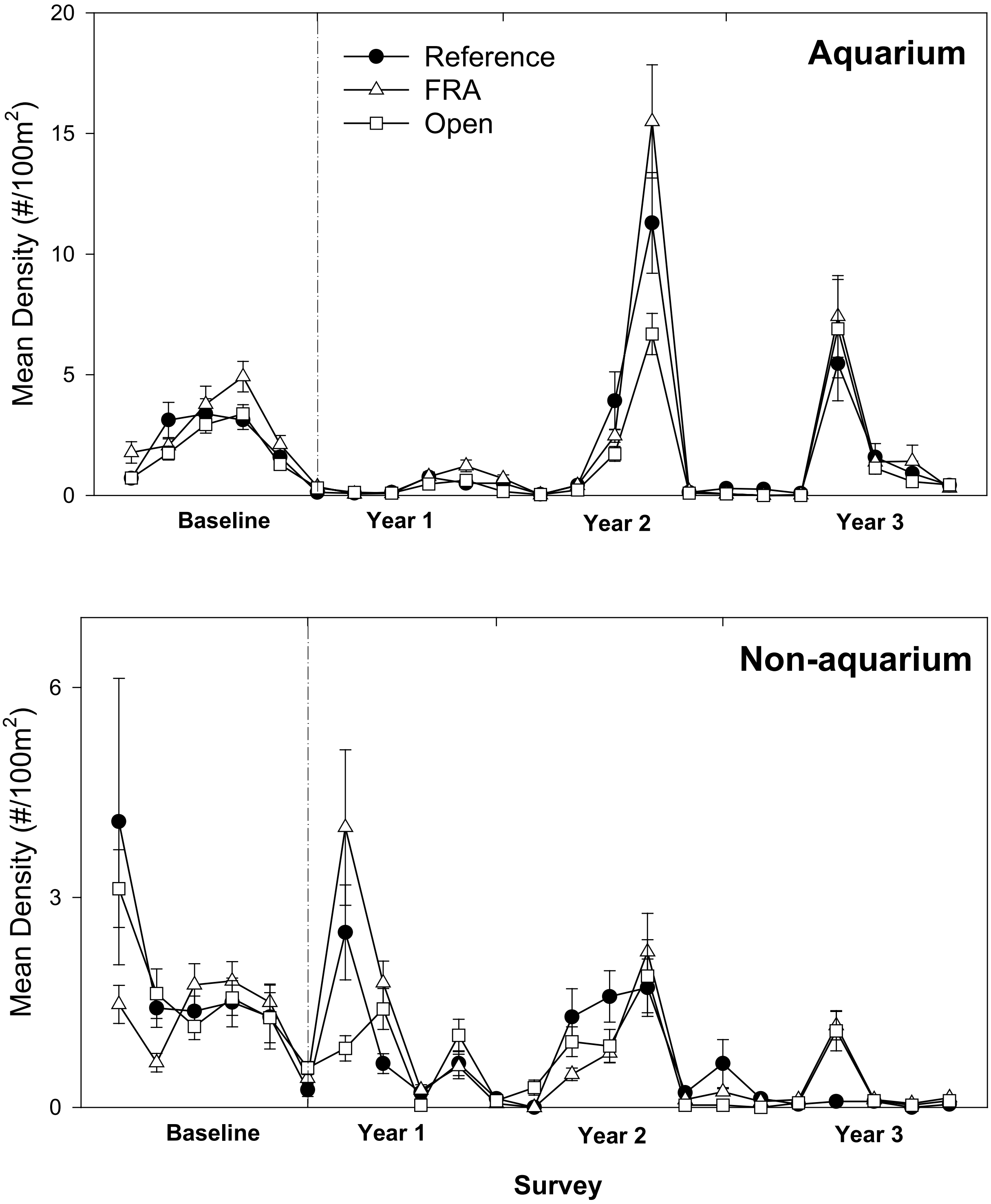
Aquarium
Reference
FRA
Open
Mean Density (#/100m²)
20
15
10
5
0
Baseline
Year 1
Year 2
Year 3
Non-aquarium
6
3
0
Survey

Figure 5