

EVALUATING THE EFFECTIVENESS OF A MARINE RESERVE
NETWORK IN WEST HAWAI'I TO IMPROVE MANAGEMENT OF THE
AQUARIUM FISHERY

Final Report Year 2003

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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 30 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 2000-2003 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. Multivariate analyses conducted to explore the relationship between characteristics of the FRAs, with changes in yellow tang population after FRA closure indicated that high numbers of juvenile tangs are associated with areas of high finger coral (*Porites compressa*) cover; and effective FRAs are associated with high numbers of adult fish and large FRAs with wide reefs, that have high finger coral cover

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 22 post-closure surveys conducted in 2000-2003 showed significant increases of aquarium fish stocks in FRAs (Tissot et al., 2004). 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 2001-03 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.

To address the issue of FRA effectiveness a multivariate canonical correlation analysis was conducted to explore the relationship between characteristics of the FRAs, including the depth, rugosity and percent cover of substrates along each transect, as well as the total FRA area, and the width and area of the FRA reef, with changes in yellow tang population after FRA closure, including the total number of adults, juvenile and newly recruited fishes, as well as the before-after changes in abundance. Analyses indicated two important conclusions from the data: 1) high numbers of juvenile tangs are associated with areas of high finger coral (*Porites compressa*) cover; and 2) Effective FRAs (ones with high positive before-after differences) are associated with high numbers of adult fish and large FRAs with wide reefs, that have high finger coral cover. Thus, based on a preliminary analysis of the FRAs the following factors may be important in influencing their effectiveness: 1) high finger coral cover, which is critical habitat for juvenile yellow tangs ; 2) large FRAs with wide reefs; and 3) high densities of adult fish.

Based on current results, it is recommended that monitoring in West Hawai'i continue as the long-term data set is providing extremely valuable insights into MPA effectiveness and important information for the design of future MPAs. 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. Evaluate fish recruitment and population changes in relation to habitat characteristics for aquarium fishes;
3. Document recruitment patterns of aquarium fishes.
4. 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) (see Tissot et al., 2004 for a detailed description of methods and rationale). Reference 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).

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 and 2002).

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.

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 ($\alpha=\beta=0.10$).

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 two-way, repeated measure analysis of variance with data from baseline surveys in 1999 (surveys 1-6) and surveys in 2003 (surveys 25-28) 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 2003; and 2) by calculating the percent change in the FRA-reference or open-reference difference from 1999 to 2003.

To address the issue of FRA effectiveness we used a multivariate canonical correlation analysis to explore the relationship between characteristics of the FRAs, including the depth, rugosity and percent cover of substrates along each transect, as well as the total FRA area, and the width and area of the FRA reef, with changes in yellow tang population after FRA closure, including the total number of adults, juvenile and newly recruited fishes, as well as the before-after changes in abundance

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 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.

Findings

Changes within FRAs

Four years after the closure of FRAs two of the top ten collected aquarium species exhibited significant increases in abundance relative to before FRA closure (Tissot et al., 2004) with yellow tangs (*Zebrasoma flavescens*), which comprises over 70% of the aquarium fishery catch in West Hawai'i, exhibiting the most significant change (Figure 2). Replenishment in FRAs appears to be primarily driven by spatial and temporal variation in recruitment (Figure 3). BACI analysis of before and after changes for yellow tangs reveal significant interactions between FRA and before-after differences, revealing that the degree of FRA change varies among individual FRAs (Table 1). Overall, there was a 52% increase in the abundance of tangs after- relative to before-FRA closure, with significant increases in four of the nine FRAs: Puako (59%), Red Hill (88%), and Honaunau (110%) and Hookena (95%) FRAs (Figure 4). The Kaupulehu FRA exhibited a 50% increase that was marginally significant ($0.01 < P < 0.05$). Thus, five of the nine FRAs are associated with high increases in the abundance of yellow tangs, while the other are not showing significant changes.

Effectiveness of FRAs

To address the issue of FRA effectiveness a multivariate canonical correlation analysis was conducted to explore the relationship between characteristics of the FRAs, including the depth, rugosity and percent cover of substrates along each transect, as well as the total FRA area, and the width and area of the FRA reef, with changes in yellow tang population after FRA closure, including the total number of adults, juvenile

and newly recruited fishes, as well as the before-after changes in abundance presented in Figure 2-3. Analyses indicated two important conclusions from the data: 1) high numbers of juvenile tangs are associated with areas of high finger coral (*Porites compressa*) cover; and 2) Effective FRAs (ones with high positive before-after differences) are associated with high numbers of adult fish and large FRAs with wide reefs, that have high finger coral cover (Table 2). Thus, based on a preliminary analysis of the FRAs the following factors may be important in influencing their effectiveness: 1) high finger coral cover, which is critical habitat for juvenile yellow tangs (and other fishes; Figure 5); 2) large FRAs with wide reefs; and 3) high densities of adult fish (Figure 6).

Evaluation

Four years after their closure of FRAs there were significant increases in the overall abundance of fishes targeted by collectors, especially the top targeted fish the yellow tang. Overall, four of the nine FRAs in West Hawai'i exhibited significant increases in yellow tangs, indicating the widespread effectiveness of the FRAs to enhance aquarium fish populations. This recovery appears to be associated with strong interannual variation in the recruitment of all fishes in West Hawai'i. 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/100m².

An examination of multiple factors associated with effective FRAs indicates that habitat, the size of FRAs, and the density of adult fishes are associated with significant recovery of fish stocks. These results should be explored further in others species and the results can be used to develop design criteria for creating new, effective FRAs in Hawaii and elsewhere in the tropical Pacific.

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 Publications

Tissot, B. N. and L. E. Hallacher. 2003.. Effects of aquarium collectors on reef fishes in Kona, Hawai'i. *Conservation Biology* 17(6): 1759-1768.

Tissot, Brian, William Walsh and Leon Hallacher. 2004. Evaluating the Effectiveness of a Marine Protected Area Network in West Hawaii to Increase the Productivity of an Aquarium Fishery.. *Pacific Science (In Press)*

Brown, E., E. Cox, P. Jokiel, K. Rodgers, W. Smith, B. Tissot, S. Coles and J. Hultquist. submitted Development of benthic sampling methods for the Coral Reef Assessment and Monitoring Program (CRAMP) in Hawai`i. *Pacific Science (In Press)*

Tissot, Brian. 2004. Integral Marine Ecology: Community-Based Fishery Management in Hawai`i. *World Futures: Journal of General Evolution (in press)*

Scientific Presentations

Tissot, B. N., W. *Integral Ecology: A new tool for fishery management*. Western Society of Naturalists, Monterey, CA. (November 2003)

Ortiz, D. Tissot, B. N., W, J., Walsh and L. E. Hallacher. *Size variation in aquarium fishes in an MPA network in Hawai'i*. Western Society of Naturalists, Monterey, CA. (November 2003)

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

- Progress reports
- New publications
- Posted final reports

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Table 1. Results of BACI two-way repeated-measure analysis of variance on changes in FRAs after four year of post-closure surveys.

<u>Control vs. FRA</u>			
Source	DF	F	P
Before-After (BA)	1	7.10	0.013*
Location	4	76.38	0.001*
BA * Location	4	2.48	0.001*
Times (BA)	26	1.97	0.105*
Error	101		
Total	136		

* - $P < 0.05$

Table 2. Results of canonical correlation analysis comparing characteristics of FRAs to characteristics of yellow tang populations in FRAs after FRA closure, including a measure of reserve effectiveness (before-after = changes in density in FRAs after closure relative to before closure)

	<u>Dim1</u>	<u>Dim2</u>
Canonical R	0.89	0.86
P(Wilks' λ)	<0.01	<0.01
FRA Characteristics:		
Rugosity	-0.01	0.09
Depth	-0.10	0.06
Finger coral cover	<u>0.61</u>	<u>0.45</u>
Lobe coral cover	<u>-0.43</u>	-0.11
Boulders cover	<u>-0.31</u>	0.25
Rubble cover	0.02	-0.23
Total FRA area	-0.12	<u>0.41</u>
Reef width	0.09	<u>0.31</u>
Reef FRA area	0.08	0.11
Yellow tang characteristics:		
No. Adults	<u>-0.39</u>	<u>0.85</u>
No. Juveniles	<u>0.66</u>	-0.22
No. Recruits	0.05	<u>-0.59</u>
Before-After	-0.04	<u>0.58</u>

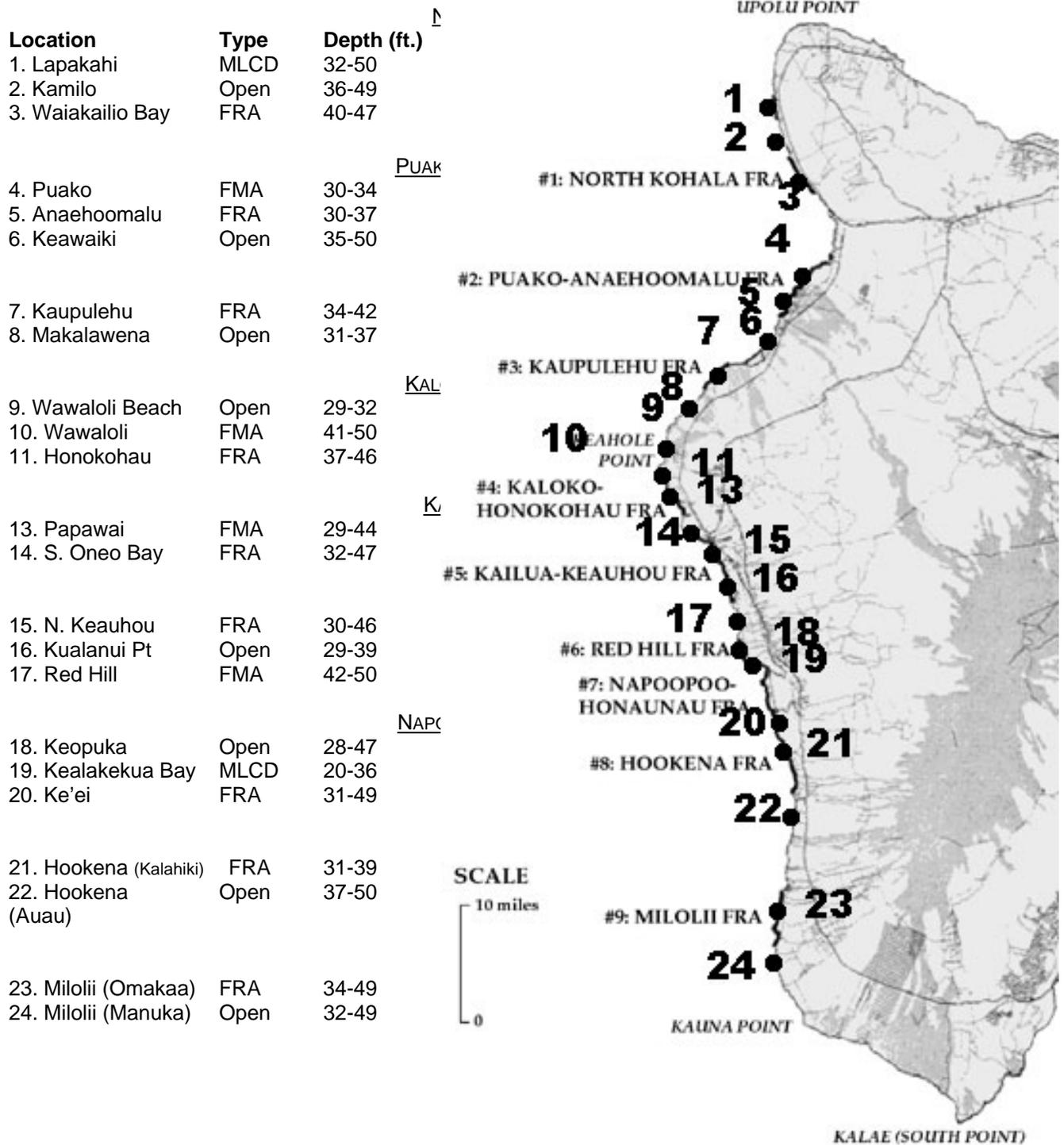


Figure 1. The West Hawaii Regional Fishery Management Area in relation to study sites and observational design assignments.

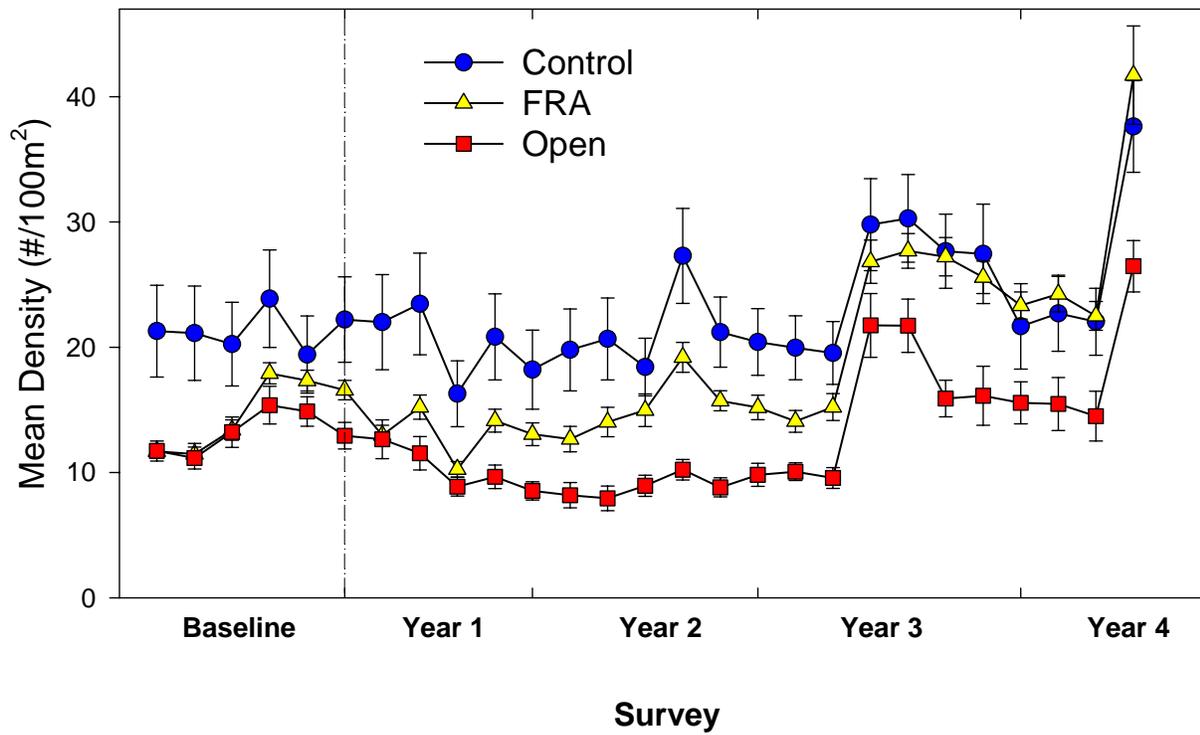


Figure 2. Changes in mean density of yellow tangs (*Zebrasoma flavescens*) in control, open and FRA areas pooled across all surveys before and after reserve closure (± 1 SE). Baseline =1999; Years 1-4= 2000-2003.

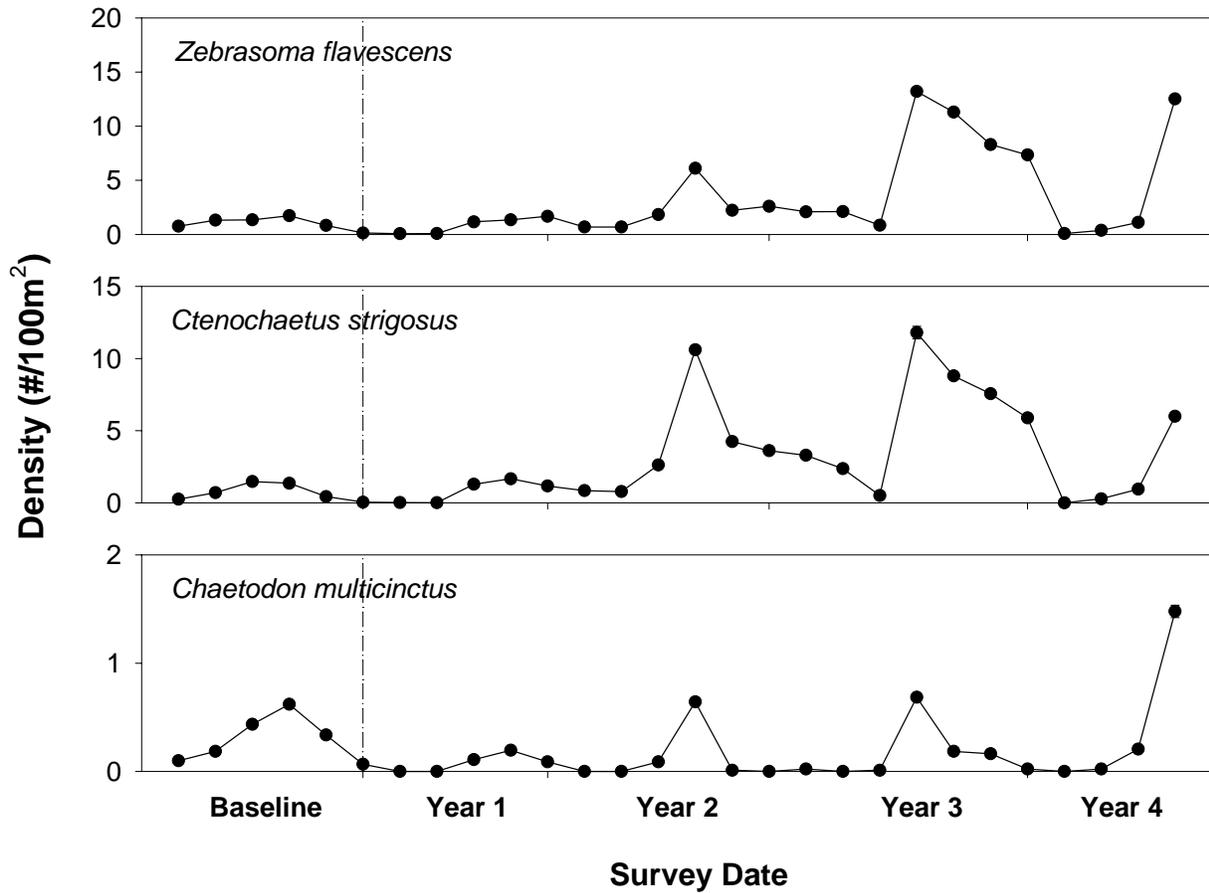


Figure 3 . Changes in mean density of young-of-the-Year yellow tangs (*ZebraSoma flavescens*), Kole (*Ctenochaetus strigosus*) and Multi-banded Butterflyfish (*Chaetodon multicinctus*) pooled across all areas in West Hawai'i (± 1 SE). Baseline =1999; Years 1-4= 2000-2003.

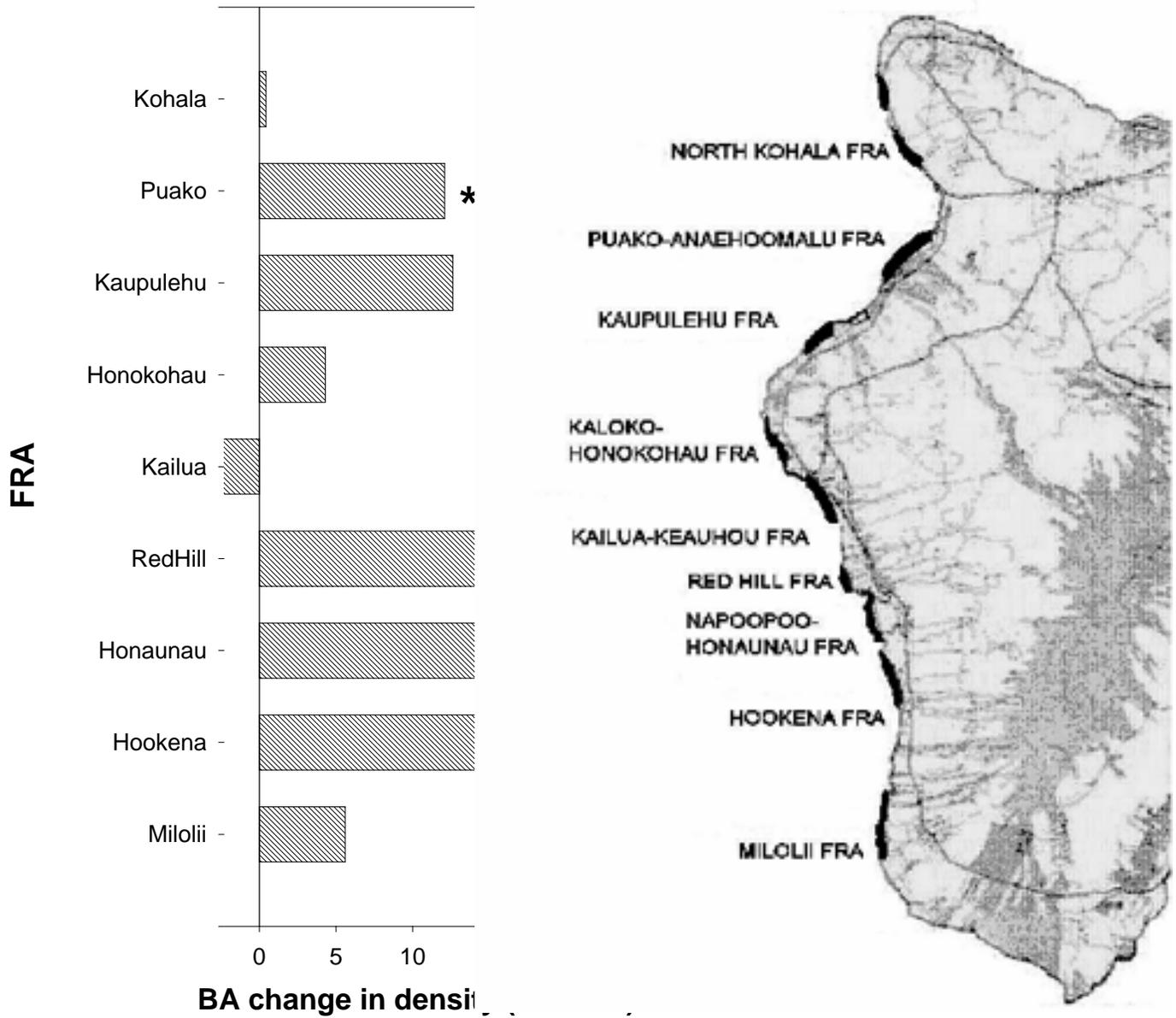


Figure 4. Evaluation of before-after changes in density in FRAs relative to adjacent control areas between 1999-2003 surveys. BA = Before-After change in density in FRA site relative to adjacent control site. Bars indicated with an asterisk (*) are significant using a paired t-test at $\alpha = 0.05$.

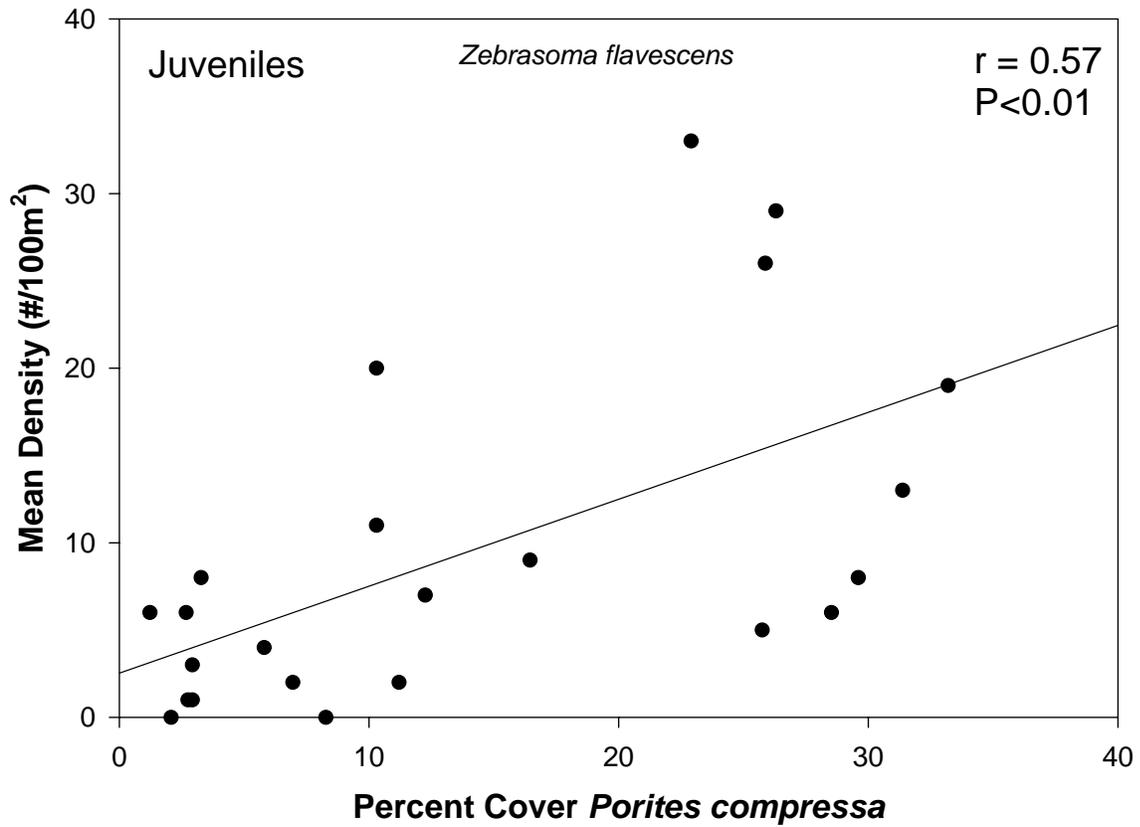


Figure 5. Mean density of juvenile yellow tangs in relation to the percent cover of finger coral (*Porites compressa*) across all sites in West Hawai'i.

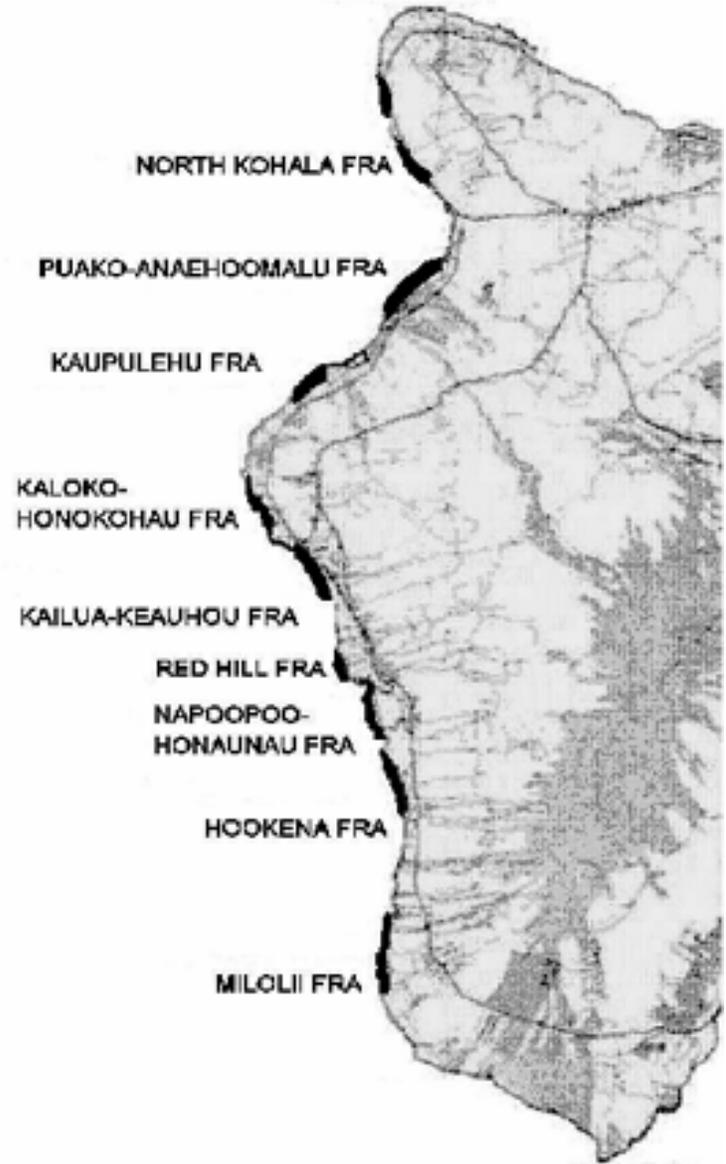
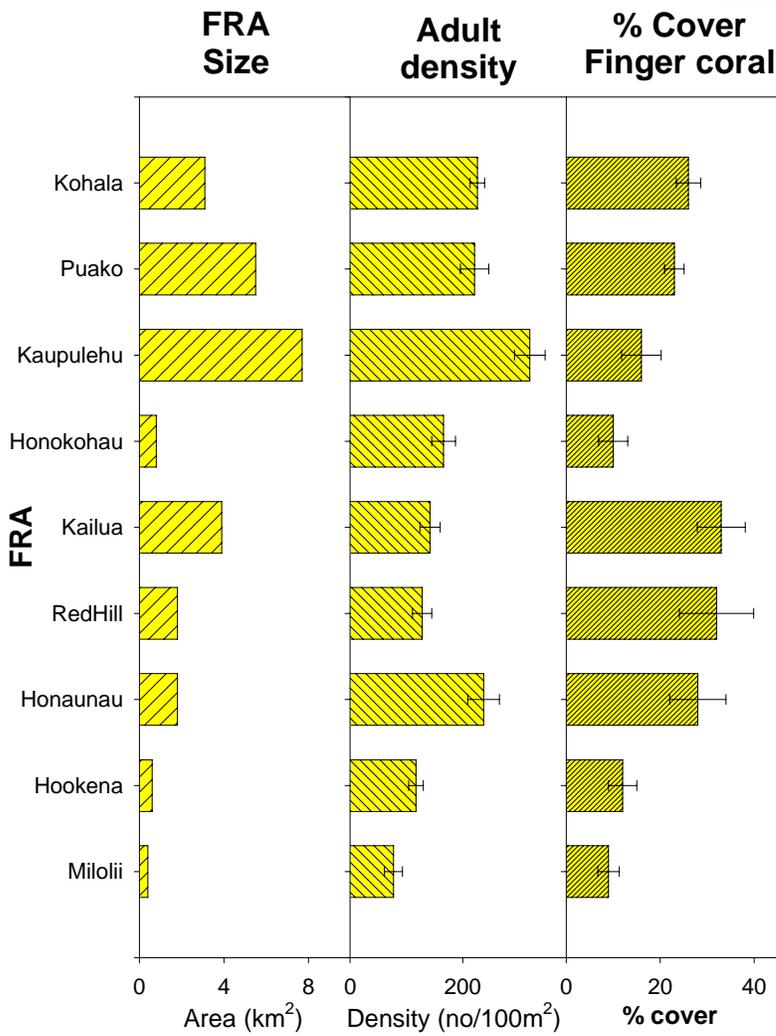


Figure 6. Important characteristics of FRAs associated with effective replenishment of yellow tangs based on canonical correlation analysis (Table 2). FRAs that displayed significant before and after changes in tang density were associated with large FRAs (Puako and Kaupulehu), high adult densities ((Puako Kaupulehu, and Honaunau), or high cover of finger coral (Red Hill).

PRINCIPLE INVESTIGATOR

DATE