Evaluation of the effectiveness of Fishery Replenishment Areas in West Hawai`i with recommendations towards the establishment of an MPA network in the state of Hawai`i

Final Report Year 2004
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February 2005

ABSTRACT

A network of nine marine protected areas was established on the west coast of the island of Hawai'i in 2000 in response to declines of reef fishes taken by aquarium collectors. In 1999, we established 23 study sites in MPA areas, areas open to fishing, and control areas (existing protected areas) to collect data both prior to and after the closure of the MPA network in 2000. To date we have conducted 34 bimonthly surveys on over 500,000 fishes from 220 species. Five years after closure of the FRAs, 7 of the 10 most heavily collected fish species have increased overall. Yellow tangs (*Zebrasoma flavescens*) which constitute 84% of all harvested fish increased 49% and chevron tangs (*Ctenochaetus hawaiiensis*) increased 141%. While specific FRAs varied in their effectiveness in increasing fish stocks, overall 7 of 9 showed a positive effectiveness for yellow tangs with four having statistically significant increases in abundance. The effect of the FRAs has also been positive on the fishery. The average number of commercial aquarium collectors, total catch, price per fish, and CPUE during the four years after FRA establishment is higher than the comparable period before FRA establishment and the total economic value of the of the aquarium fishery has reached new heights. Effective replenishment has been linked to the moderately high levels of newly recruiting aquarium fishes observed in 2001-03. Previous work also indicates that habitat characteristics, FRA size, and density of adult fishes are important factors influencing the effectiveness of FRAs. The widespread occurrence of increases of aquarium fishes in FRAs, combined with a large and significant increase in the primary aquarium fish, the yellow tang, indicates that the FRAs are effectively replenishing aquarium fish stocks in Hawai`i after five years of closure.

EXECUTIVE SUMMARY

The West Hawai`i Regional Fisheries Management Area was created by Act 306, Session Laws of Hawaii (SLH) 1998. One of its major mandates was the designation of a minimum of 30% of West Hawai`i coastal waters as Fish Replenishment Areas (FRAs) where aquarium collecting is prohibited. A community advisory group, the West Hawai`i Fisheries Council (WHFC) developed an FRA plan which created a network of nine FRAs comprising 35.2% of the coastline. The FRAs became effective 31 December 1999.

Five years after closure of the FRAs, 7 of the 10 most heavily collected species (representing 94% of all collected fish) have increased in overall density. FRAs have been effective in significantly increasing the abundance of two species relative to already protected control sites (e.g. MLCDs). Yellow tangs which constitute 84% of all targeted fish increased 49% and chevron tangs increased 141%. Several others species, notably the longnose butterflyfish/forcepsfish, four-spot butterflyfish, ornate butterflyfish and Hawaiian cleaner wrasse showed high (>30%) but non-significant increases in FRAs relative to control sites. Four of the top 10 species; kole, Achilles tang, clown tang and multi-band butterflyfish showed insignificant decreases in FRAs relative to control sites.

While specific FRAs varied in their effectiveness in increasing fish stocks, overall

7 of 9 showed a positive effectiveness for yellow tangs with four having statistically significant increases in abundance. Effective replenishment has been linked to the moderately high levels of newly recruiting aquarium fishes observed in 2001-03. Previous work also indicates that habitat characteristics, FRA size, and density of adult fishes are important factors influencing the effectiveness of FRAs. The widespread occurrence of increases of aquarium fishes in FRAs, combined with a large and significant increase in the primary aquarium fish, the yellow tang, indicates that the FRAs are effectively replenishing aquarium fish stocks in West Hawai`i after almost five years of closure. This result is consistent with an earlier published analysis after three years of FRA closure.

The effect of the FRAs on the aquarium fishery itself has been positive. The average number of commercial aquarium collectors working in West Hawai`i during the four years after FRA establishment is higher than the comparable period before. Total catch and the catch of the top two species, yellow tang and kole, is presently the highest it has ever been. The price per fish received by collectors for yellow tangs has increased by an average of 33% subsequent to FRA establishment. Catch per Unit Effort (CPUE) of aquarium fish is higher in West Hawai`i than elsewhere in the State and is maintaining an upward trend. CPUE is the highest it has ever been in Fiscal Year (FY) '04 and the total economic value of the West Hawai`i aquarium fishery has reached new heights.

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 projected 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 (Capitini et al, 2004).

BACKGROUND

The West Hawai\`i Regional Fishery Management Area Plan was conceived to have four separate but complementary components as follows (§188F-4, HRS):

- Designate a minimum of 30% of coastal waters as Fish Replenishment Areas (FRAs) where aquarium collecting is prohibited.
- Establish a day-use mooring buoy system and designate some high-use areas where no anchoring is allowed.
- Establish a portion of the FRAs as fish reserves where no fishing of reef-dwelling fish is allowed.
- Designate areas where the use of gill nets is prohibited.

FRAs were mandated to address concerns over user conflict and localized resource depletion caused by aquarium fish collectors in West Hawai\`i. To address this concern and the specific mandate of the statute, a network of 9 FRAs comprising 35.2% of coastal waters was established in December 1999 (HAR 13-60.3). Aquarium collecting and fish feeding are prohibited in these areas. Scientific research and monitoring on the effectiveness of the FRAs has been underway since 1998 under the aegis of the West Hawai\`i Aquarium Project (WHAP). This Report presents a review of the effectiveness of the FRAs based upon WHAP monitoring data and commercial catch report information. An overview of the aquarium fishery and FRA development is also included.

Accordingly, the objectives of this project were to:

- Evaluate the effectiveness of the FRA network by comparing fish abundances among control, open and FRA study sites;
- Evaluate fish recruitment and population changes in relation to habitat

characteristics for aquarium fishes;

- Document recruitment patterns of aquarium fishes in order to examine the population-level outcomes of an MPA system;
- Compare changes in FRAs to changes in the aquarium fishery.
- Make recommendations on: 1) Effectiveness of the FRAs to enhance the aquarium fishery in west Hawai`i; and 2) Design of MPAs throughout the state of Hawai`i to the West Hawai'i Fisheries Council, DAR, and the legislature.
- Disseminate the results of these studies to coral reef ecosystem managers, the scientific community, the West Hawai'i Fisheries Council, 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). 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 (see Tissot et al, 2004 fro details). 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 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 2004; and 2) by calculating the percent change in the FRA-reference or open-reference difference from 1999 to 2004.

FINDINGS

Aquarium collectors

The marine aquarium fishery in the State of Hawai`i is one of the most economically valuable commercial inshore fisheries with FY 2004 reported landings of 557,673 specimens and a total reported value of $1.08 million. The reported value is considered to be underestimated by a factor of approximately 3 to 5X (Cesar et al. 2002 and Walsh et al. 2003, respectively). The fishery developed initially on O`ahu in the early 1950's, went through a period of expansion in the 70's and has subsequently been declining on O`ahu both in terms of fish catch and overall value.

In contrast to O`ahu, the aquarium fishery on the Island of Hawai`i has undergone substantial and sustained expansion over the past 20 years (Table 1). Presently 81% of fish caught in the State and 70% of the total aquarium catch value come from the Big Island and almost exclusively from West Hawai`i.

The aquarium collecting industry in Hawai`i and especially West Hawai`i has long been a subject of controversy. As early as July 1973, public concern over collecting activities prompted DLNR's then Division of Fish and Game to suspend the issuance of Aquarium Fish Permits. The suspension was lifted one week later. Shortly thereafter, the 10-member State Animal Species Advisory Commission recommended restricting issuance of aquarium fish permits pending "full and extensive study." At a September 1973 meeting called by Fish & Game, a number of university marine scientists recommended the "careful selection of specified sanctuary areas of limited extent and the prohibition of collecting within their confines." It was at this time that aquarium permittees were first required to submit monthly fish catch reports. Unfortunately, no studies were conducted and sanctuary areas were never established.

Over subsequent years as the number of collectors in West Hawai`i began to rise and the numbers of animals collected increased markedly (Figure 2), conflict escalated along the coast, particularly between dive tour operators and collectors. A short-lived informal "Gentleperson's Agreement" was reached in 1987 whereby aquarium collectors agreed to refrain from collecting in certain areas. In return, charter operators agreed not to initiate legislation opposing collecting and to cease harassment. The following year four of the areas from the Gentleperson's Agreement were incorporated into the Kona Coast Fisheries Management Area (FMA) which became effective in 1991.

<u>Effectiveness of FRAs</u>

As of Fall 2004, WHAP has completed a total of 34 surveys of all study sites, six of which were conducted prior to FRA closure in 1999 (the before- or baseline-surveys) and 28 over the past five years (2000-2004) subsequent to closure (the after-surveys). The surveys have counted a total of 549,019 fishes from 220 species on 3,128 transects.

The general rationale for WHAP's goals was based on the premise that changes in FRAs and open areas can best be estimated by comparing them to geographically adjacent control areas both before and after the closure of the FRAs. This rationale is derived from a well-known statistical procedure known as the BACI (Before-After-Control-Impact) procedure (Tissot et al, 2004) which is the most appropriate and statistically powerful method for examining FRA effectiveness.

FRA effectiveness is measured statistically as the change in the difference between each FRA and control site during each survey (control vs. impact) from baseline to post-baseline surveys (before vs. after). The statistical significant of this change is tested using a two-way repeated-measure analysis of variance. A statistical significant level of α=.10 is used in order to reduce the error level of β (the statistical mistake of concluding FRAs are non-effective when in fact they are). Thus, a statistically significant before vs. after effect in the analysis would indicate that overall fish abundance within FRAs has changed after closure relative to before closure. The degree of change is measured by the Index of FRA Effectiveness (R). R is defined by the following where t = no. of surveys:

$$R = \left[\frac{\sum_{i=1}^{t_{after}} \overline{X}_{control} - \overline{X}_{FRA}}{t_{after}} \right] - \left[\frac{\sum_{i=1}^{t_{before}} \overline{X}_{control} - \overline{X}_{FRA}}{t_{before}} \right] \text{X100} \qquad (1)$$

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

Another measure of change in the FRAs is the absolute percent change in density of the baseline surveys relative to the post-closure surveys. These changes are presented as:

$$\text{Percent change in density} = \frac{\left(\overline{X}_{FRA\text{-}After} - \overline{X}_{FRA\text{-}Before\text{-}}\right)}{\overline{X}_{FRA\text{-}Before}} \times 100 \qquad (2)$$

The BACI procedure attempts to take into account changes that may be affecting the ecosystem but are unrelated to the workings of the FRAs. For example, there could be several years of widespread and plentiful recruitment of aquarium fish to the reefs of West Hawai`i. The numbers of fish would thus increase in the FRAs (as well as other areas) over time, but the increase in a particular FRA may not have anything to do with it being protected from aquarium collecting. Instead, the increase in fish could just be the result of favorable ocean currents or more food available during the fish’s offshore larval stage which results in more young fish recruiting to the reefs. The BACI procedure separates out these factors by comparing the FRAs (or open areas) to control areas which serve as reference points to gauge change. If the population of a particular fish increases over time to the same extent within an FRA and its control, then the effectiveness (R) of the FRA would be zero even though the numbers of fish within have increased over time.

Scientific studies on reef fishes are notoriously difficult due to the very high variability of fish abundance in both time and space. Even with a rigorous statistical design (such as BACI) and six years of study, it is extremely difficult to statistically detect changes in abundances except for the most common species that exhibit large changes (such as yellow tangs). Thus, the ability of this study (and any other that we know of) is limited to only detecting large, significant changes (>50%) in common species, while less common species (99% of aquarium fishes) may still be increasing in abundance but not showing statistical significant changes. As a study such as WHAP continues over time, the ability to detect progressively smaller significant changes increases.

To illustrate the BACI method, presented are two FRAs that have varied in their degree of effectiveness to replenish the most highly targeted aquarium fish in West Hawai`i, the yellow tang. Each graph illustrates the variable nature of yellow tang abundance through time and how changes in the FRAs and open areas occur relative to the control area. Thus, the Kailua-Kona FRA (Figure 3) has shown a statistically significant 146% increase in effectiveness (R) since FRA closure because yellow tang density in the FRA has increased in the last three years proportionally greater from the baseline period than the control has. Indeed, the numbers of yellow tangs within the FRA are presently quite comparable to the control which has been protected for 13 years. In contrast, the Miloli`i FRA (Figure 4) had a non-significant 34% increase in effectiveness even though the number of yellow tangs in the FRA increased. The increase relative to the control area was modest however and therefore not significant.

The overall effectiveness of the FRA network to replenish fish stocks is listed in Table 2. Aquarium fishes in general (65 species) have increased 7% and the top ten harvested fishes (listed individually below) have increased 8%. However, neither of these increases was statistically significant. In contrast, there has been a statistically significant -81% decrease in non-aquarium fishes (145 species) in the overall FRA network, perhaps in response to low recruitment of these species during the study period

Changes for the ten most collected aquarium fishes across all FRAs are shown in Table 3. Seven of the 10 most heavily collected species have increased overall along the West Hawai`i coast since the FRAs have been established. Two of these increases have been large enough to be statistically significant. There have been increases in FRAs relative to respective control site in six of the top ten collected species with two; yellow tangs (49%) and chevron tangs (141%) being significant. Collectively, these two species account for 85% of all collected fishes based on 2004 catch report data.

The top five species which account for 96% of total catch all increased in abundance since the FRAs were established. Each species however has shown variable changes in abundance through time in control, FRA and open areas. For example, of the top five most collected species, yellow tangs (Figure 5) have shown steady increases in abundance in all areas beginning in 2002 (year 3) when large recruitment of juvenile fishes first began occurring. Along with 58% increases in FRAs, control and open areas also increased 77% and 12% respectively, over the course of the study.

Kole (Figure 6) have also shown steady increases across all years. Along with 8% increases in FRAs, control and open areas increased 100% and 10%, respectively over the course of the Study. Achilles tangs (Figure 7) have shown a highly variable pattern with a small gradual increase across years. Along with 34% increases in FRAs, control and open areas also increased 98% and 52%, respectively over the course of the Study. Clown Tangs (Figure 8) have shown an increase in years 4-5. Along with 44% increases in FRAs, controls increased 16% while open areas decreased 1.2% during this time. Chevron tangs (Figure 9) have only shown increases since 2003 (Year 4). However, FRAs increased 2%, controls decreased 35% and open areas increased 22% over the course of the Study. A large part of the relatively high effective value of the FRAs for this species is due to a marked decline in the control areas just prior to FRA establishment.

FRAs have varied in their effectiveness at recovering aquarium fish stocks, as is illustrated for yellow tangs in Figure 10. Overall, 7 of the 9 FRAs have shown a positive effectiveness with four having statistically significant increases in abundance. Given the relatively short time period of FRA existence, this is strong evidence for the widespread effectiveness of the FRAs to enhance aquarium fish populations.

An examination of multiple factors associated with effective FRAs (Tissot et al., 2003) indicates that habitat quality, the size of FRAs, and density of adult fishes are associated with significant recovery of fish stocks. This earlier study indicates two important conclusions from the data: 1) High numbers of juvenile tangs are associated with areas of high finger coral 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 (and other fishes; Walsh, 1987); 2) Large FRAs with wide reefs; and 3) High densities of adult fish (Tissot et al., 2003).

<u>Effectiveness on aquarium fishery</u>

Although there was overwhelming support within the West Hawai`i community for the establishment of the FRAs, a number of collectors expressed concern that the area closures would have negative effects on themselves as well as the fishery as a whole. Although almost 100 species are caught in the fishery, a relatively small handful constitute the bulk of the catch. The top five collected species constitute 96% of the total catch with yellow tangs alone comprising 84%. Yellow tangs are thus a key indicator of the health of the fishery.

After two years of declining yellow tang catch subsequent to the implementation of the FRAs, the catch has increased through 2004 (Figure 11). At this early stage of FRA establishment, this increase is due primarily to successful recruitment of this as well as several other species in the summers of 2002 and 2003 (Figure12). The price per fish received by collectors for yellow tangs has also increased by an average of 33% in the five years after FRA establishment as compared to the four years prior to the FRAs. The average number of commercial aquarium collectors working in West Hawai`i during these same time periods is also higher after the FRAs were established (Figure 2). The overall value of the West Hawai`i aquarium fishery in FY 2004 is the highest it has ever been.

There is some preliminary evidence (Walsh unpublished data) and anecdotal information that the numbers of yellow tangs in West Hawai`i just prior to FRA establishment were substantially lower than in earlier decades. This heavily collected species has been responding particularly well to FRA protection and given its long life (20+ years, Claisse, pers. comm.), it is likely that stocks will continue to increase in the coming years boding well for the reef community, the aquarium fishery and present and future generations of West Hawai`i.

The trends for the four next most heavily collected species are shown below. Kole (*Ctenochaetus strigosus*) catch (Figure 13) has been consistently increasing since the late 1980's and is now the ranks second in collected fishes both in West Hawai`i and statewide (Walsh et al. 2003). Catch in FY 2004 is the highest it has even been. This species has been increasing in recent years on West Hawai`i reefs and is one of the most common fishes on the reefs. Although it is also harvested somewhat for food, present indications are that with its large population, present collection trends for kole are not problematic.

In contrast, catch of the Achilles tang (*Acanthurus achilles*) has been in decline since FY 1990. This species is a favorite targeted species of both aquarium collectors as well as food fishers and is thus harvested at both ends of its size range. Although the Achilles tang has increased somewhat overall on the reefs over the past five years; the FRAs have not yet been particularly effective in rebuilding populations in protected areas (Table 3).

The clown tang (*Naso lituratus*) catch appears to be following a pattern somewhat similar to the Achilles tang (Figure 14). It reached a peak in the late 80's and then subsequently declined although there was a smaller secondary peak again in the late 90's. As with Achilles tangs, populations are increasing on the reefs but the FRAs have not yet been effective in most areas. Both these species point out the necessity for long term protection in order to maintain the progress of slowly increasing species.

Chevron tangs (*Ctenochaetus hawaiiensis*) were always a minor element of the catch up until 1996. Although the adults are rather inconspicuous, the young are spectacularly colored and highly desired in the aquarium trade with current wholesale prices around $16/fish (P. Masterjohn pers. comm). Recent strong recruitment (Figure 12) has increased populations and catch in recent years. If the market value of this species remains strong, the FRAs will play an increasingly important role over the years in maintaining healthy populations of this species.

Much the same can be said for many of the more uncommon and rare species that are targeted by collectors. Species such as flame angelfish, banded angelfish, Hawaiian lionfish, Tinker's butterfly and *Anthias* species for example, are highly vulnerable to local depletion. While the FRAs will not provide protection for these species in open areas, they do provide a population reservoir to ensure continued presence of the species. Furthermore, since the FRAs encompass many of the areas most utilized by residents and dive/snorkel business, they help to maintain the biodiversity of our reefs people expect and are willing to pay for.

Catch per unit effort (CPUE) is a measure of the number of fish caught during a standard amount of fishing effort and it is often used as a measurement of relative abundance for a particular fish. For the State aquarium fishery, CPUE has historically been the highest in West Hawai`i (Figure 15) due in large part to the abundance of and relative collecting ease of commonly targeted surgeonfishes. The increasing trend in CPUE may be due to increasing expertise and efficiency of West Hawaii's full-time professional collectors as well as to increasing abundances of yellow tangs.

The average CPUE for West Hawai`i over the last ten years (56.7 ±13.3 SD fish/hour) is considerably higher than that reported for other areas such as Australia (20-45 fish/day), Cook Islands (24-36 fish/day), and Sri Lanka (30-50 fish/day) (Wood, 2001). After an initial decrease coincident with FRA establishment, CPUE in West Hawai`i has once again continued a long-term upward trend. As with a number of other indicators of the status of the aquarium fishery, CPUE in 2004 was the highest it has ever has been. It is anticipated that this upward trend will level with time.

Due to uncertainties in the way collecting effort is reported by various fishers, CPUE data is considered to be the weakest component of the aquarium catch report data set and must be viewed cautiously. Indeed one of the caveats implicit with catch report analyses, aquarium or otherwise, is that reported catch accurately reflect what is actually being caught. At present there is no provision or means to verify this information. A recent analysis of the West Hawai`i aquarium catch report data (Walsh et. al. 2003) revealed a substantial number of collectors are not complying with the mandatory reporting requirement of the aquarium fish permit even though failing to comply is grounds for cancellation of the permit. Forty-seven percent of the required reports over the period January 1998 to July 2003 were not filed. Most of the delinquencies were due to short term and/or part time collectors but several of the more active collectors were included. Of all 97 collectors who fished over this period, only 14% filed every required monthly catch report. It is likely that report compliance is as poor or worse on the other islands which have had less attention paid to the fishery.

EVALUATION

Five 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. Significant increases in yellow tangs indicate 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 effect of the FRAs on the aquarium fishery itself has also been positive. Total catch and the catch of the top two species, yellow tang and kole, is presently the highest it has ever been. The price per fish received by collectors for yellow tangs has increased by an average of 33% subsequent to FRA establishment. Catch per Unit Effort (CPUE) of aquarium fish is higher in West Hawai`i than elsewhere in the State and is maintaining an upward trend. CPUE is the highest it has ever been in Fiscal Year (FY) '04 and the total economic value of the of the West Hawai`i aquarium fishery has reached new heights. Compliance by collectors to the FRAs has generally been good and incidents of harassment and conflict between collectors and other ocean users has been markedly reduced. Noncompliance with catch report requirements remains problematic however.

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, and can result in enhancement of nearby fisheries.

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.

RECOMMENDATIONS

Based on the results of this review and evaluation the following recommendations are proposed:

1. Biological and fishery results to date indicate the FRAs are clearly working and are expected to increase in effectiveness as time progresses. With one possible exception, there are no compelling reasons at present to alter the existing network of protected areas.
2. As monitoring and evaluation of the FRAs is required by law and necessary to further understand the dynamics of our coral reef ecosystem, a dedicated monitoring program similar to WHAP needs to be continued

and supported.

3. In order to have sufficient scientific robustness in a monitoring program, sites should be monitored at least 4 times a year with 2 of the surveys during summer recruitment period.
4. Community input and co-management responsibility has proven to be critical in the establishment and legitimacy of the FRA network. Community advisory groups such as the West Hawai`i Fisheries Council should be encouraged and supported by DLNR.
5. While FRAs are an excellent strategy to manage most aquarium species, certain rare or ecologically important species are likely to require species-specific harvesting limitations in open areas.
6. Existing aquarium catch report system should be revised to improve accuracy, remove CPUE ambiguities and provide for verification of catch.
7. The effectiveness of the FRAs for aquarium fish suggests it would be prudent to establish Marine Protected Areas (MPAs) for other resource species throughout Hawai`i as a precautionary measure against overfishing and for restoration of marine resources. Currently, less than 1% of the Main Hawaiian Islands is protected by MPAs (Clark and Gulko 1999).
8. MPAs should be large enough for self-recruitment of short distance dispersing propagules and spaced far enough apart that long distance dispersing propagules released from one reserve can settle in adjacent reserves.
9. An MPA network should encompass the proportion of the biomass necessary to sustain optimal yields of populations of concern.
10. Representative proportions of all habitat types should be included in MPAs, although rare and vulnerable habitats should be represented more fully.
11. MPA efforts must recognize known ecological connections among habitat types, typically from shallow to deeper sites.
12. Diel movement patterns, such as from daytime foraging habitat to nocturnal resting areas must be considered in MPA establishment.
13. As recruitment appears to be an important mechanism influencing the replenishment of nearshore populations, increased monitoring of recruitment and nearshore oceanography is necessary to better understand the dynamics of recruitment processes.
14. MPAs should have unambiguous and geographical distinct boundaries, as they are easier to recognize and enforce.

DISSEMINATION OF PROJECT RESULTS, 1999-2004

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ACKNOWLEDGEMENTS

Many people have played important roles in laying the groundwork for successful and adaptive marine resource co-management in West Hawai`i. David Tarnas is to be especially commended for his innovative and forward looking legislation. Sara Peck of Hawai`i Sea Grant has been involved from the beginning and is instrumental in ensuring community participation and education. Many other people have played and continue to play important roles in West Hawai`i resource co-management. Some of them are listed below:

<u>WHAP Divers & Data Management</u>:

Brent Carman, Steve Cotton DAR, Ivor Williams DAR/HCRI-RP, Delisse Ortiz, Jonathan Hultquist, Kathy Greenwood, Washington State University Vancouver, Mark Albins, Josh Ballauer, Zachary Caldwell, Laura Campbell, Paul Clark, Steve Cotton, Brian Doo, Jeff Eble, Marc Hughes, Karen Geisler, Ranya Henson, Jackie Holbrook, Joe Laughlin, Sara McCutcheon, Scarlet Mraz, Jeff Muir, Shaun Norris, Daniel Okumura, Kara Osada, Richard Osada, Kim Page, Greg Polloi, Linda Preskitt, Noelani Puniwai, Chelsie Settlemier, Allison Suhr, Dan VanRavensway, Cecile Walsh, Todd Wass, Lisa Wedding, Darla White, Charles Wiggins, Rachael Younger, Brian Zyglicynski, University of Hawai'i Hilo

<u>Funding, logistical & other support</u>:

Mike Hamnett, Christine Davidson, Risa Minato HCRI-RP, NOAA-NOS, Jan Marsh, Laura Livnat, Bob Nishimoto, Pete Hendricks, Athline Clark DAR, John Coney, Michael Childers University of Hawai'i Hilo, Dave Pence University of Hawai`i Manoa, Scott Atkinson Community Conservation Network, Larry Basch National Park Service, Eric Kawamoto DOCARE, Linda Paul, Kim Moffie Audubon Society, Virginia Isbell, Collins Tomei, Paul Whalen, Christin Walsh, Tina Owens, Stosh Thompson.

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Table 1. Changes in West Hawai`i aquarium fishery over last twenty Years. Dollar value is adjusted for inflation.

	FY 1984	FY 2004	Δ
No. Permits	7	47	671% ↑
Total Catch	34,706	626,885	942% ↑
Total Value	$173,691	$757,278	436% ↑
% of State Fish Catch	23%	81%	58%↑
% of State Total Catch	19%	59%	40% ↑
% of State Value	30%	70%	40% ↑

Table 2. Overall FRA Effectiveness for fishes.

Group	Overall % Change in Density	R	P
All aquarium fishes	+6%	+7%	0.28
Top 10 aquarium species	+16%	+8%	0.51
Resource fishes	+55%	+20%	0.79
Non-aquarium fishes	**+8%**	**-81%**	**0.01***

* Statistically significant at P < 0.10

Table 3. Overall FRA effectiveness for the top ten most aquarium collected fishes.

COMMON NAME	SCIENTIFIC NAME	MEAN DENSITY (NO/100M^2)		OVERALL % CHANGE IN DENSITY	R
		Before	**After**		
Yellow Tang	*Zebrasoma flavescens*	14.7	21.8	**+48%**	**+49%***
Kole	*Ctenochaetus strigosus*	31.0	33.3	+7%	-3.8%
Achilles Tang	*Acanthurus achilles*	0.24	0.30	+26%	-46%
Clown Tang	*Naso lituratus*	0.75	0.84	+11%	-41%
Chevron Tang	*Ctenochaetus hawaiiensis*	0.22	0.23	**+2%**	**+141%***
Longnose and Forcepsfish	*Forcipiger spp.*	0.73	0.77	+6%	+65%
Fourspot Butterflyfish	*Chaetodon quadrimaculatus*	0.03	0.06	+100%	+116%
Ornate Butterflyfish	*Chaetodon ornatissimus*	0.87	0.75	-14%	+27%
Multiband Butterflyfish	*Chaetodon multicinctus*	5.71	5.02	-12%	-15%
Hawaiian Cleaner Wrasse	*Labroides phthirophagus*	0.88	0.73	-18%	+30%

* Statistically significant at $P < 0.10$

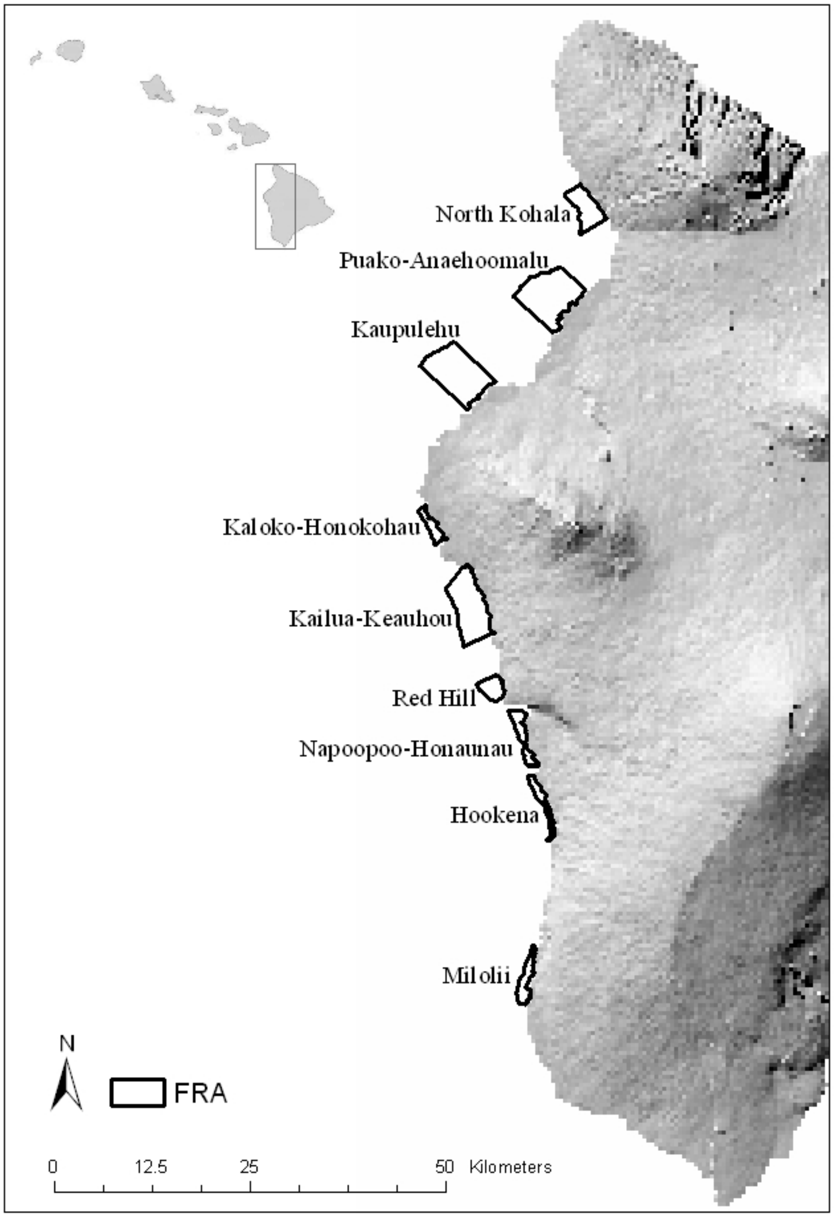

Figure 1. Locations of Fishery Replenishment Areas (FRAs) in West Hawai`i.

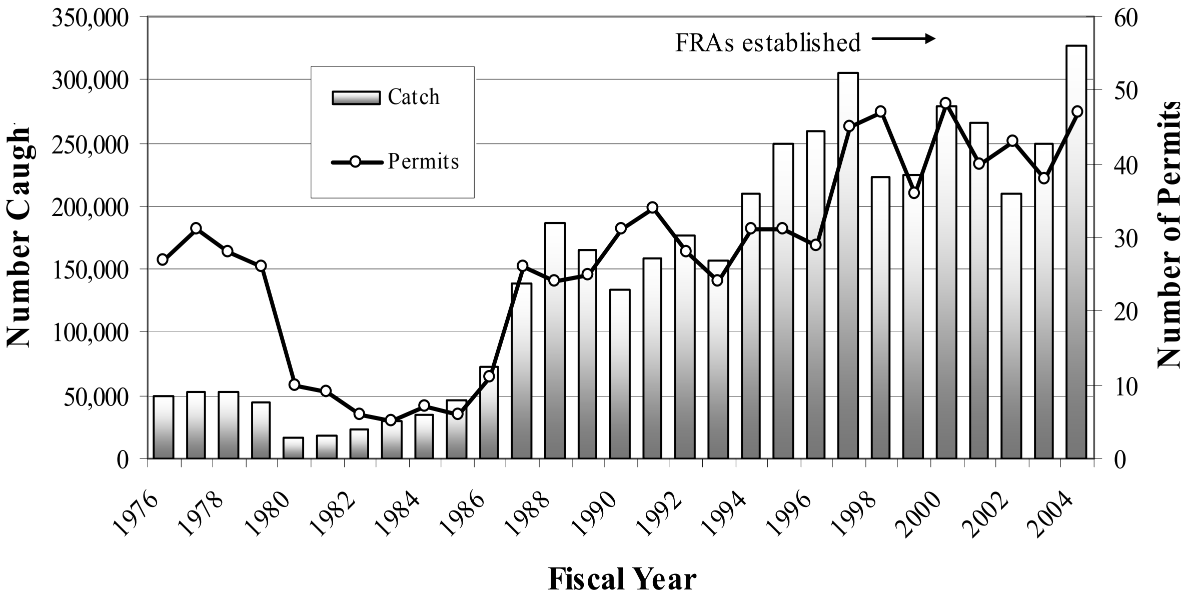

Figure 2. Number of aquarium animals collected and number of commercial aquarium permits in West Hawai`i for Fiscal years 1976-2004.

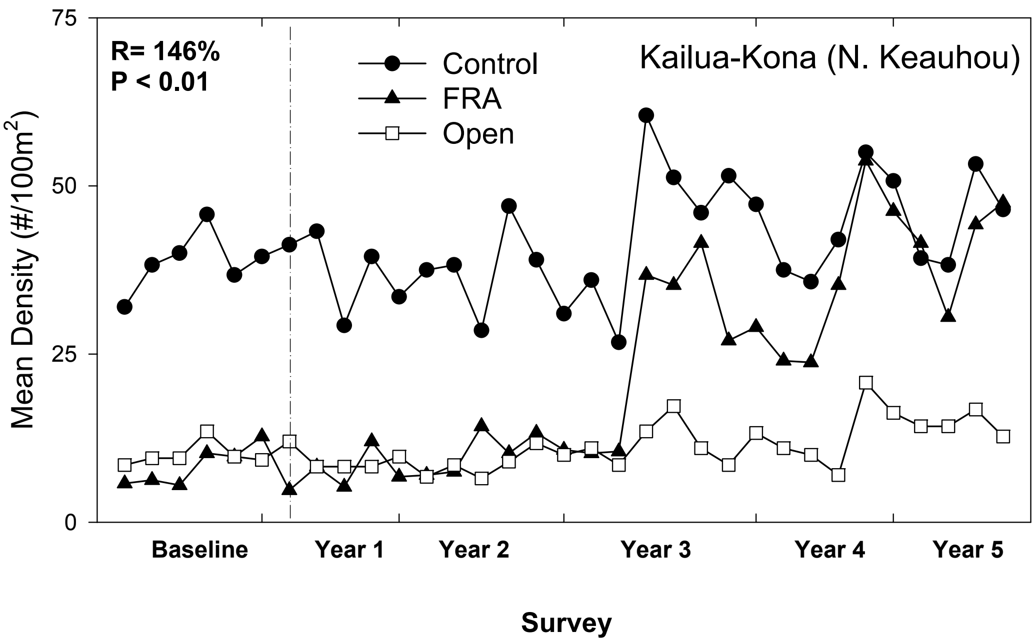

Figure 3. Changes in yellow tangs in the Kailua-Kona FRAs relative to control and open areas.

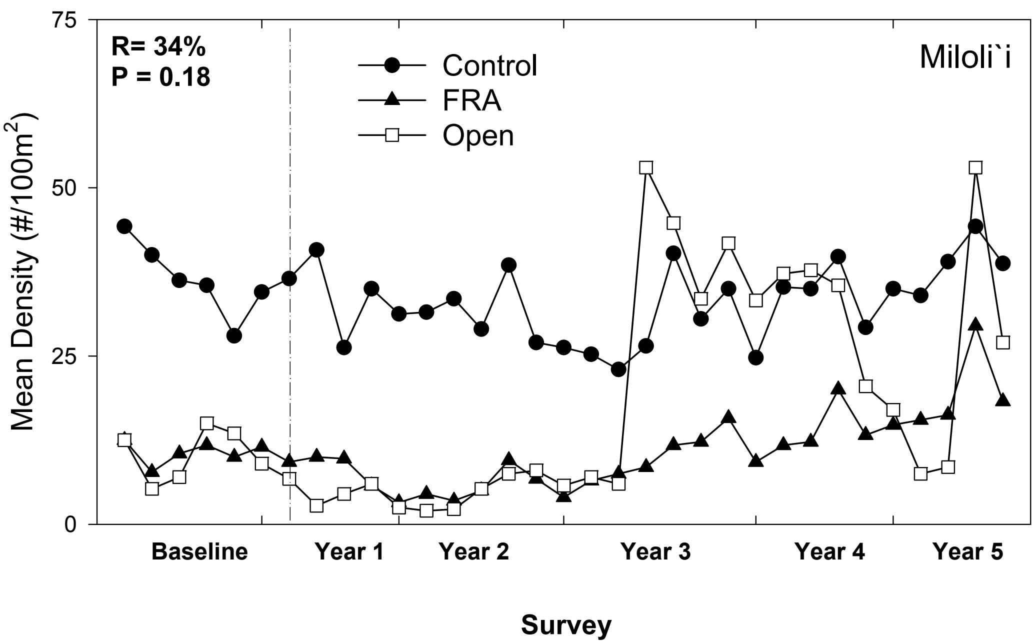

Figure 4. Changes in yellow tangs in the Miloli`i FRAs relative to control and open areas.

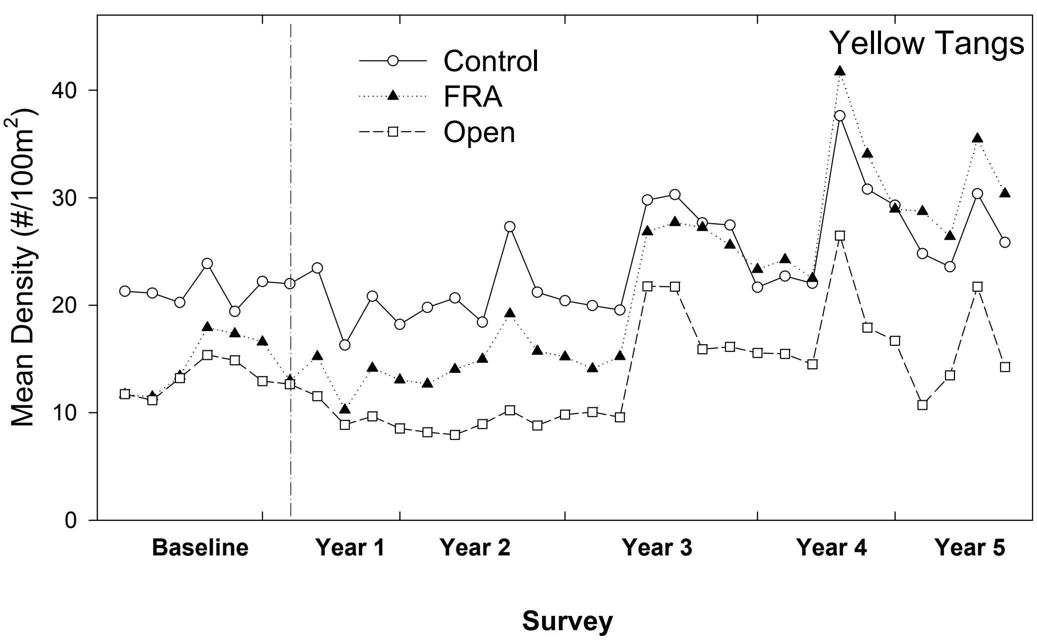

Figure 5. Overall changes in yellow tangs in FRAs, control and open areas, 1999-2004.

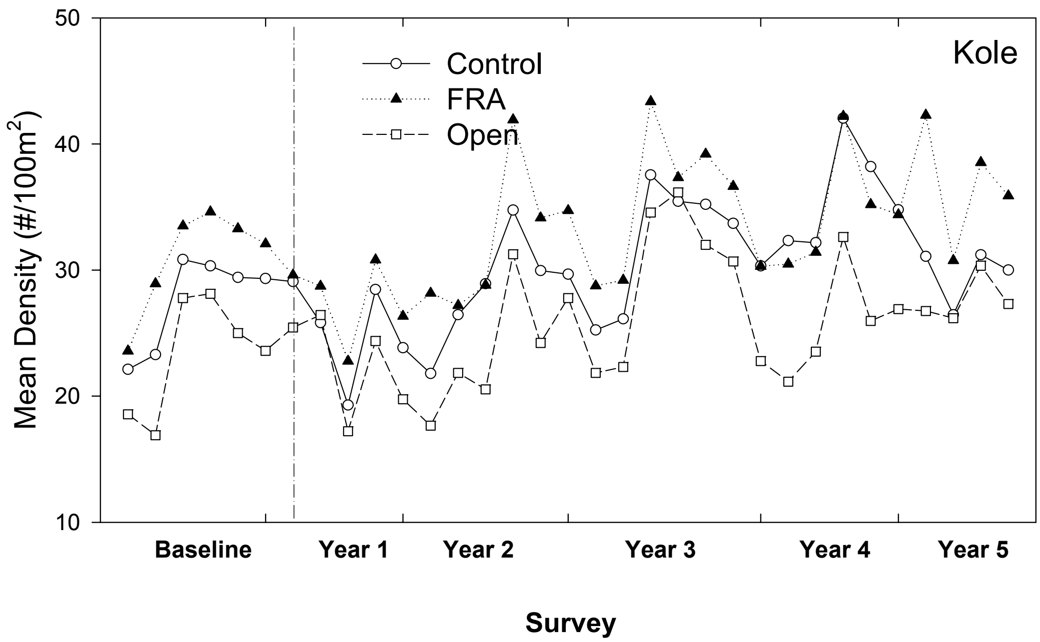

Figure 6. Overall changes in Kole in FRAs, control and open areas, 1999-2004.

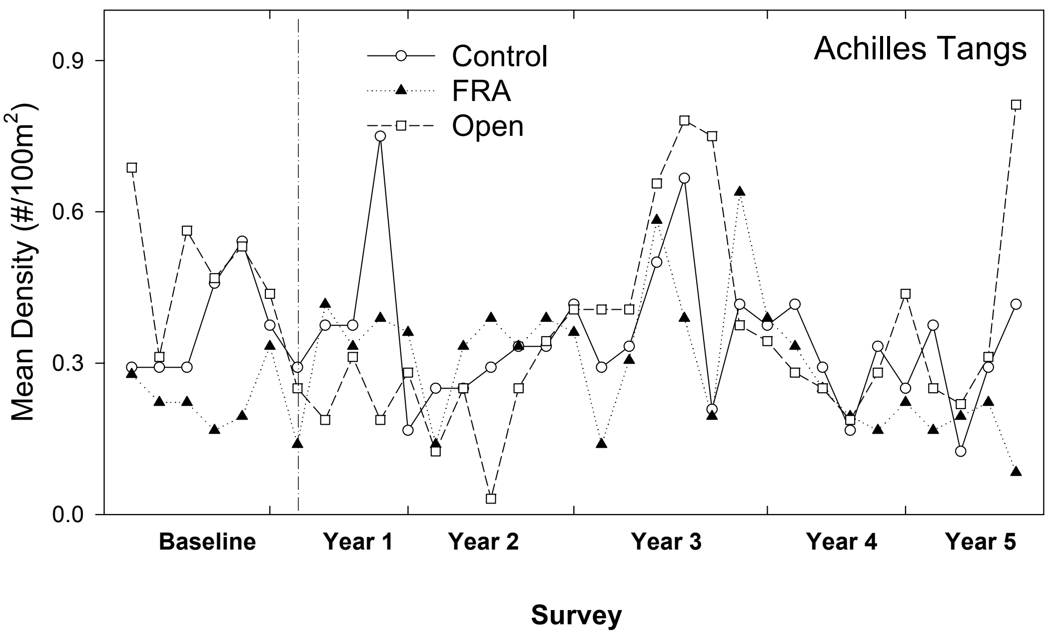

Figure 7. Overall changes in Achilles tangs in FRAs, control and open areas, 1999-2004.

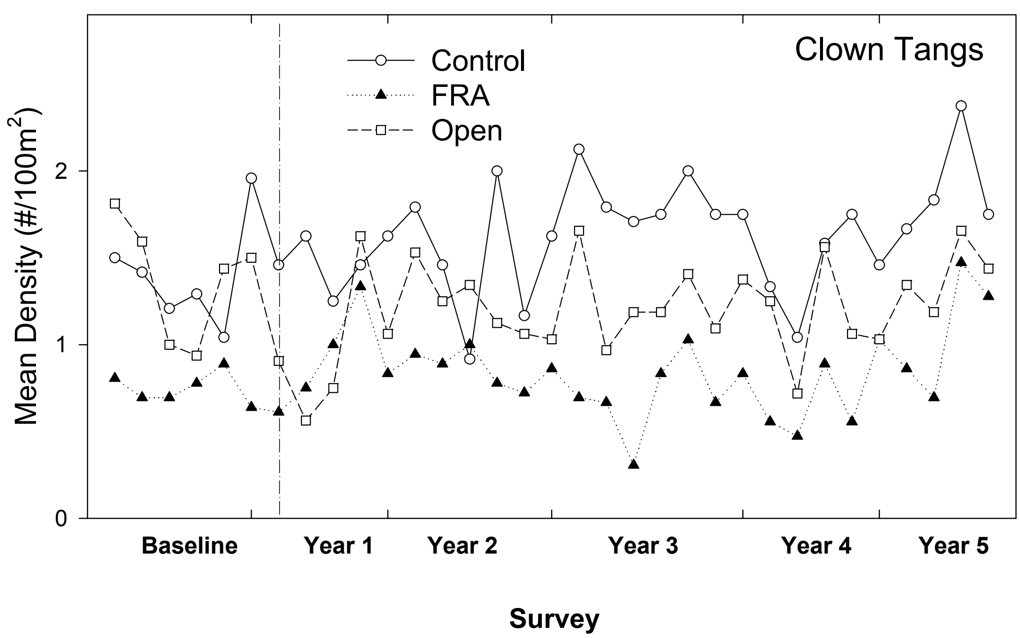

Figure 8. Overall changes in clown tangs in FRAs, control and open areas.

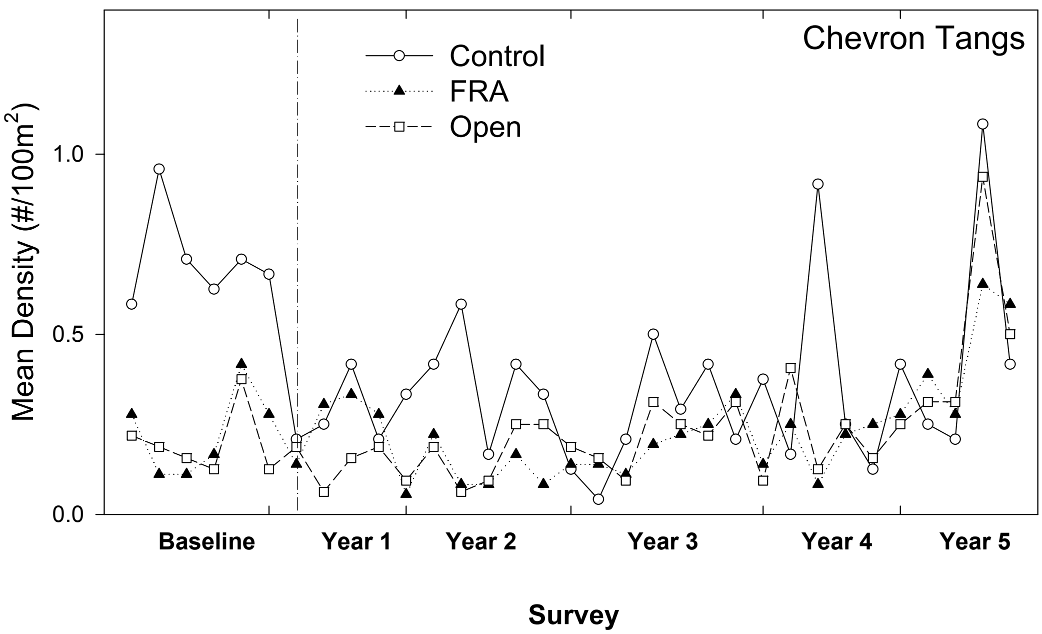

Figure 9. Overall changes in Chevron tangs in FRAs, control and open areas, 1999-2004.

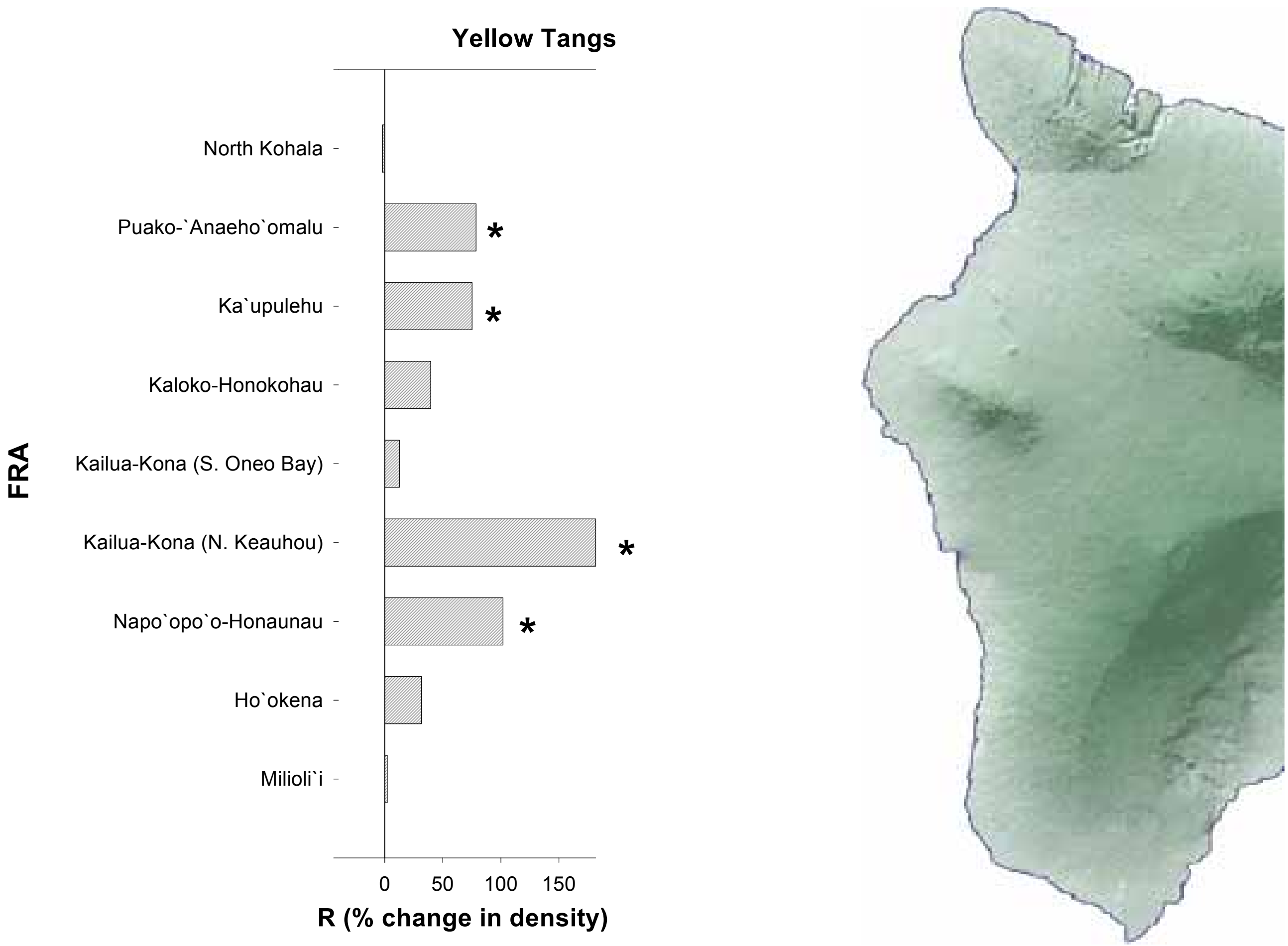

Figure 10. Effectiveness of individual FRAs to replenish yellow tangs, 1999-2004. * = Statistically significant

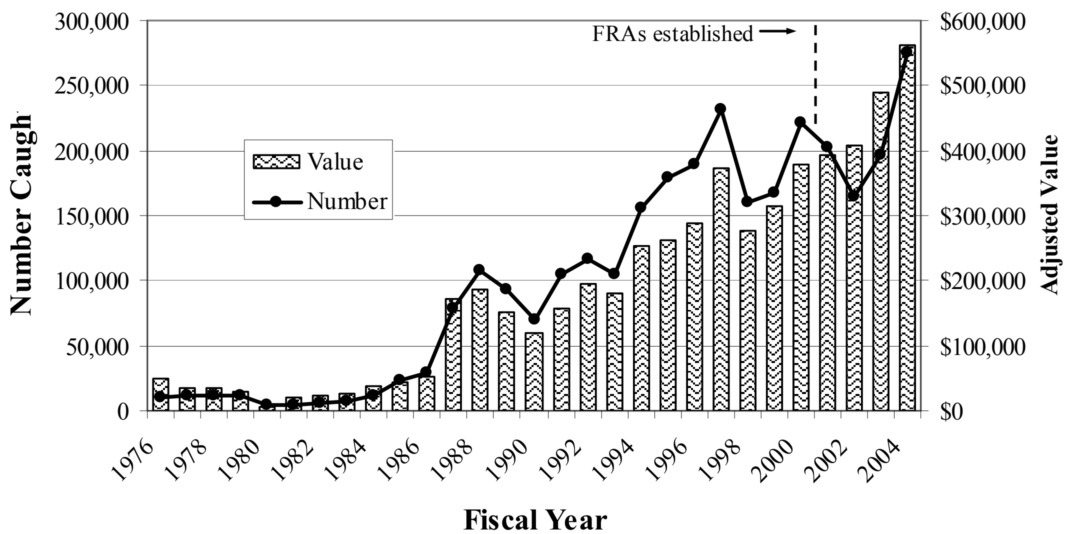

Figure 11. Number and value (adjusted for inflation) of yellow tangs caught in West Hawai'i per fiscal year.

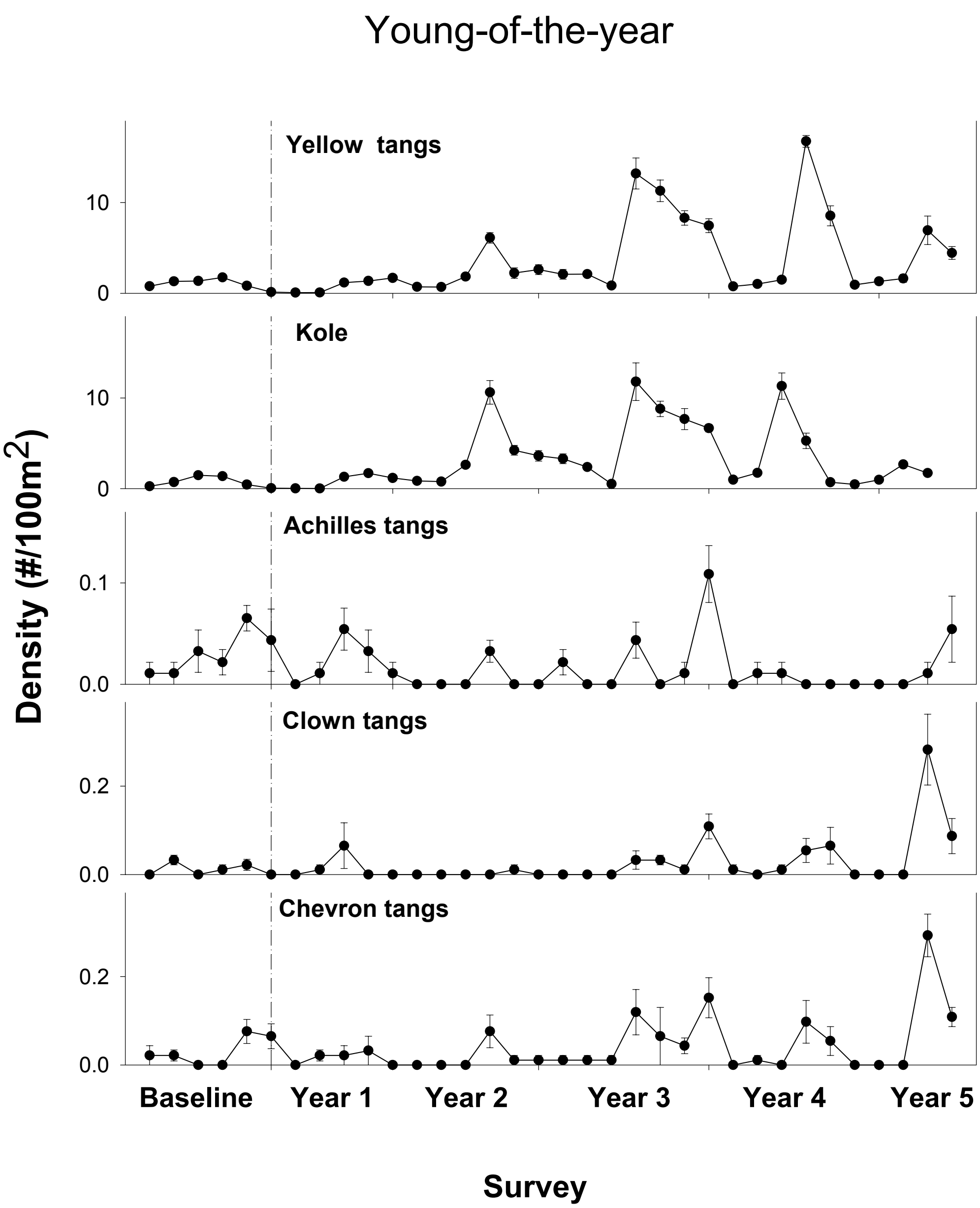

Figure 12. Recruitment trends for top 5 collected aquarium fish. Note: 'Young-of-the-Year' refers to fish which have recruited during each year's major summer recruitment period.

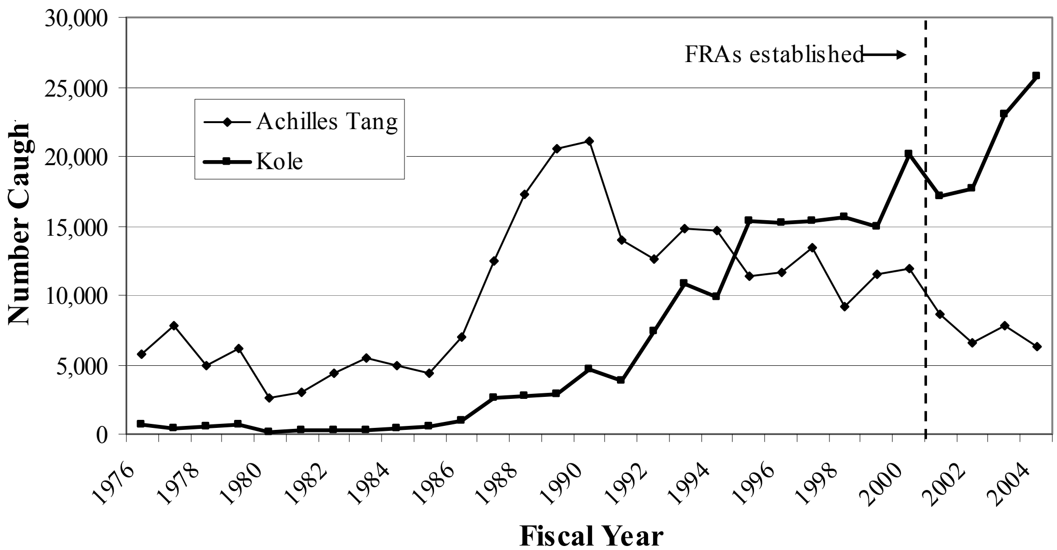

Figure 13. Number caught of top 2nd and 3rd West Hawai`i species per fiscal year.

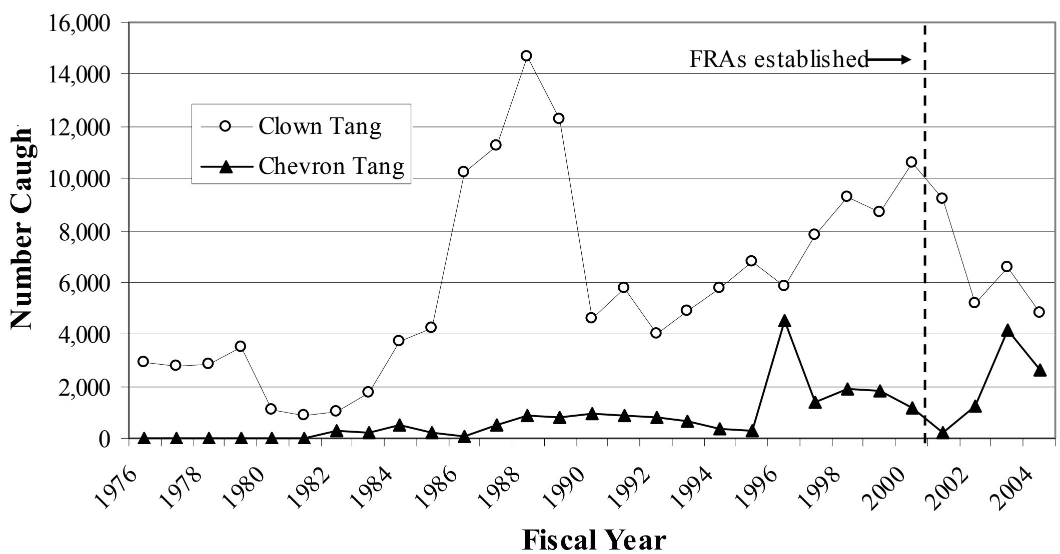

Figure 14. Number caught of top 4th and 5th West Hawai`i species per fiscal year.

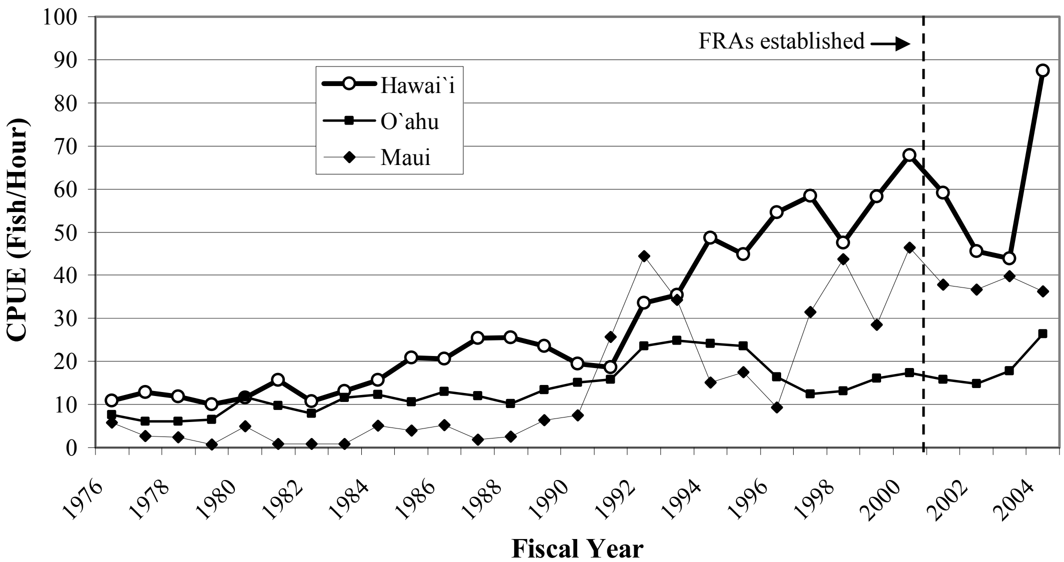

Figure 15. Catch per unit effort for Hawai`i collecting areas. Maui includes the of Maui, Moloka`i and Lana`i.