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Findings and Recommendations of Effectiveness of the West Hawai'i Regional Fishery Management Area (WHRFMA)

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Findings and Recommendations of Effectiveness of the West Hawaiʻi Regional Fishery Management Area (WHRFMA)

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PURPOSE OF THIS REPORT

This report, which covers the period between 2015 - 2019, is submitted in compliance with Act 306, Session Laws of Hawai′i (SLH) 1998, and subsequently codified into law as Chapter 188F, Hawai′i Revised Statutes (HRS) - West Hawai'i Regional Fishery Management Area. Section 188F-5, HRS, requires a review of the effectiveness of the West Hawai′i Regional Fishery Management Area shall be conducted every five years by the Department of Land and Natural Resources (DLNR), in cooperation with the University of Hawai′i (Section 188F-5 HRS).

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY OF FINDINGS

The Hawaiʻi Division of Aquatic Resources (DAR) has been intensively monitoring West Hawaiʻi reefs since 1999 in conjunction with a number of long-term studies extending over multiple decades. Over the past 20 years of monitoring, a total of 82 survey divers have conducted 8,712 100 m^2 transects for the West Hawaiʻi Aquarium Project (WHAP) alone, in addition to hundreds of other surveys for related projects. This information is utilized to monitor the condition of West Hawaiʻi's reefs and inform management decisions.

The West Hawaiʻi Regional Fishery Management Area (WHRFMA) which spans the entire coastline of West Hawaiʻi, was created by Legislative Act 306 (1998) largely in response to longstanding and widespread conflict surrounding commercial aquarium collecting. The Act's requirement for 'substantive' community input in management decisions was particularly noteworthy and has been described as "revolutionary".

To accomplish the mandates of Act 306, a community advisory group, the West Hawaiʻi Fishery Council (WHFC) was convened by DAR in 1998. The first accomplishment of the WHFC was the designation of a network of nine no-aquarium collecting Fish Replenishment Areas (FRAs). The FRAs, along with other existing aquarium protected areas, comprise 35.2% of the coastline.

In addition to the development of the FRA network, the WHFC has been successful in achieving a number of other notable management actions in West Hawaiʻi including lay gill net rules and spatial restrictions, protection for species of special concern (e.g. sharks/rays), SCUBA spearfishing ban, a no-take Fish Reserve within Kaʻūpūlehu FRA and further comprehensive management of the aquarium fishery. Based on two decades of experience, the WHFC has been a model system for the resolution of issues surrounding reef fisheries resources.

The Hawaiʻi marine aquarium fishery in recent years has been the most economically valuable commercial inshore fishery in the State with Fiscal Year (FY) 2017 average reported landings greater than $2.2 million.

The West Hawaiʻi aquarium fishery has undergone substantial and sustained expansion over the past 30 years. Total catch and market value have increased by 29% and 143% respectively since FY 2000. Approximately 26% of both the total number of aquarium fish caught in the State and value of the catch comes from West Hawaiʻi.

Concerns over continued expansion of the aquarium fishery and over-harvesting in the open areas prompted DAR to establish a 'White List' of 40 species which can be taken by aquarium fishers, which took effect in 2013. All other species of fish and invertebrates are off-limits to aquarium collectors in West Hawaiʻi.

Aquarium catch report validation in 2010 and 2014 for Hawai'i Island did not indicate substantial underreporting of catch by aquarium collectors. Dealer reports of purchases from collectors were 11% and 40% lower than the number reported sold due to the lack of a Hawaiʻi Administrative Rule requiring dealer reports.

In 2012, a lawsuit was filed against the Department of Land and Natural Resources (DLNR) for failing to complete an Environmental Review before issuing aquarium permits. In October 2017, the Hawai′i Circuit Court ruled that, based upon an earlier Hawai′i Supreme Court opinion, existing 'aquarium' permits (for use of fine mesh nets/traps) were illegal and invalid pending a full review of the fishery under the Hawai′i Environmental Policy Act (HEPA). On January 5, 2018 (i.e. FY 2018), DLNR further announced a total prohibition of all commercial aquarium collecting in West Hawai′i until an Environmental Review was completed. The fishery has remained closed in West Hawai′i through the date of this publication.

Of the 40 collected aquarium species taken prior to the closure, Yellow Tang comprise 81.6% and Kole 9.5% of the total catch (FY 2017).

The FRA network (where aquarium collecting is prohibited) was implemented in 1999 and has been very successful in driving an increase in the population of Yellow Tang (*Zebrasoma flavescens*), the most heavily targeted aquarium fish. In the 20 years after the closure, the population of Yellow Tang has increased 165% in the FRAs, 74% in existing Marine Protected Areas (MPAs) and 101% in the Open Areas where all aquarium fishing effort has been directed.

Overall Yellow Tang abundance in the 30'-60' depth range over the entire West Hawai′i coast has increased by over 3.4 million fish (120%) from 1999/2000 to 2017-2018 to an estimated population of 5.7 million fish from Ka Lae to Upolu Point, based on DAR monitoring data and NOAA habitat mapping.

A 2009 study of adult Yellow Tang in their shallow water habitats (10'-20' depths) found no significant differences in the abundance of adult Yellow Tang in open vs. closed areas. Total estimated coastwise population of adult Yellow Tang in this depth range was estimated to be >2.5 million individuals.

Outward movement of adult Yellow Tang from shallow water protected areas into surrounding open areas ('spillover') augments adult stocks in the open areas up to a kilometer or more away.

Yellow Tang populations at two of three long-term monitoring sites in South Kohala (Puakō) and South Kona (Ke′ei) have increased to levels found over three decades ago, prior to the expansion of commercial aquarium collecting in West Hawai′i.

West Hawai′i had a significantly greater percent increase in Yellow Tang density within its planned networked MPAs as compared to two non-networked MPAs in Maui County. Five of the 10 most collected aquarium fish in West Hawai′i were also significantly more abundant in West Hawai′i's Open Areas as compared to Maui MPA closed areas.

Comparative surveys utilizing DAR and NOAA data subsequent to FRA establishment, indicate Yellow Tang are substantially more abundant in West Hawai′i over most size ranges than in any of the other islands in the Main Hawaiian Islands and the Northwestern Hawaiian Islands.

The FRAs have also been very successful in increasing Kole (*Ctenochaetus strigosus*) populations. This species is the second most collected species in the aquarium fishery, representing 9.5% of the total catch. In the 20 years after FRA closures, Kole populations have increased 85% in the FRAs, 120% in the MPAs and 97% in the Open Areas.

Overall Kole abundance in the 30’-60’ depth range over the entire West Hawai′i coast increased by almost 5.2 million fish (118%) since FRA establishment (1999/2000), with a current population of about 9.6 million fish.

In contrast, long-term studies in West Hawai′i have found that Kole populations have decreased 14% in South Kona (Ke′ei) and 71% in South Kohala (Pauoa). Given the length of protection at these sites and the overall decline in habitat quality and fish populations in South Kohala it seems unlikely that the declines are not due primarily to aquarium collecting.

Comparative surveys utilizing DAR and NOAA data subsequent to FRA establishment indicate Kole are substantially more abundant in West Hawai′i over most size ranges than in any of the other islands in the Main Hawaiian Islands or the Northwestern Hawaiian Islands.

The overall mean abundance of the combined top 3-10 collected aquarium species has increased in all management areas since the FRAs were established. These seven species constitute 7.1% of the total FY 2017 West Hawai′i catch and when added to the catch of Yellow Tang and Kole, comprise 98.2% of the total reported catch.

In terms of a species’ abundance between the Open Areas and the FRAs for the top 3-10 collected species, five species were consistently more abundant in the Open Areas than in the FRAs while three species showed no consistent pattern.

Six of seven of the top 3-10 collected species had long-term population increases in one or more of the management areas since FRA establishment (1999/2000). One notable exception was Achilles Tang (*Acanthurus achilles*) which declined in all areas.

WHAP monitoring data show that Achilles Tang have declined in FRAs and Open Areas over the last 20 years. Unlike Yellow Tang and Kole, Achilles Tang have often been more abundant in Open Areas rather than the protected FRAs.

In the most recent decade, Achilles Tang have been more abundant in the MPAs than either the FRAs or Open Areas, perhaps reflecting an increased level of protection in the more restrictive MPAs.

Achilles Tang is the fourth most collected species in the West Hawai′i aquarium fishery although relative to Yellow Tang and Kole, the numbers collected are low (5,473 fish), representing only 1.7% of the total FY 2017 catch.

Commercial aquarium landings of Achilles Tang have been declining in West Hawai′i over the past two decades. This has occurred in association with a 192% increase in the ex-vessel value of the fish since 2008, suggestive of declining availability (i.e. abundance).

Achilles Tang have had very low levels of recruitment (0.12/100m^2) over the past two decades in the 30’-60’ depth range. In contrast, mean Yellow Tang Young-of-Year (YOY) abundance over the last decade was 57 times greater (i.e. 57X) than Achilles Tang YOY and Kole YOY abundance was 54 times greater.

Shallow Water Resource Fish (SWRF) surveys indicate a significant decrease in Achilles Tang biomass in their primary adult habitat since 2008 when the surveys were first conducted. Achilles Tang were observed on 73% of transects in 2008 but only on 38% in 2018.

Data from the long-term studies in South Kohala (Puakō and Pauoa) and South Kona (Ke′ei) also show a pattern of decline in Achilles Tang over the past decades. At Ke′ei in South Kona, the population in the present decade is 18% lower than in the 1980's but this difference is not statistically significant.

Results from the WHAP monitoring program, SWRF surveys and DAR long-term studies suggest there should be concern for the sustained abundance of Achilles Tang. They are a very popular food fish as well as an aquarium fish and thus are being harvested both as juveniles and adults. Low levels of recruitment over the past 11 years appear insufficient to compensate for the existing levels of harvest.

In order to address concerns regarding aquarium impacts on Achilles Tang, a bag limit of 10 fish/person/day was implemented in West Hawai′i at the end of 2013. The bag limit applied *only* to aquarium collectors. It is difficult to precisely project the overall impact of the West Hawai′i Achilles Tang bag limit.

Given the overall evidence for a marked decline in the population of Achilles Tang in West Hawai′i, the existing aquarium-only bag limit appears to be insufficient to stem this decline. A reduction in the aquarium bag limit or a moratorium on aquarium collecting for this species, in conjunction with a conservative bag limit for other fishers should be considered.

Of the 40 fish species on the White List, there are four species for which we do not have WHAP survey data. Three of these, Tinker's Butterflyfish (*Chaetodon tinkeri*), Hawaiian Longfin Anthias (*Pseudanthias hawaiiensis*) and Flame Wrasse (*Cirrhilabrus jordani*) occur in habitats deeper (typically >100') than can be feasibly monitored using traditional SCUBA methods. The other species, the Eyestripe Surgeonfish (*Acanthurus dussumieri*) is usually found during the day over sand habitat, which is not surveyed by WHAP monitoring.

Good survey data are available for 26 other White List species in addition to the top 10 collected species. Ten of these species showed a significant population increase in one or more of the management areas while 11 decreased. Of these 11 species, only the Blackside Hawkfish (*Paracirrhites forsteri*), decreased exclusively in the Open Areas, indicating that factors other than aquarium collecting were affecting the declining populations of the other species.

For most of the species on the White List, collecting impact, in terms of the estimated percentage of the Open Area population being removed annually, is relatively low with 9 species having single digit percent catch (range: 1.62% - 9.24%) and 21 species having catch values of <1% (0,01% - 0.85%) of the total estimated population in the Open Areas (30'-60' depth range).

Besides harvest impacts, species abundances change over time due to both extrinsic and intrinsic factors such as changes in habitat change and reproductive success. This is exemplified by the Multiband Butterflyfish (*Chaetodon multicinctus*) which underwent significant declines in all management areas since 1999/2000.

Of the 40 species on the White List, 11 (27.5%) are considered endemic to Hawaiʻi. This is just slightly above the overall average (25%) of Hawaiʻi marine fish endemism. All but one of the endemic species (Psychedelic Wrasse - *Anampses chrysocephalus*) also occurs at Johnston Atoll.

Endemic fishes are often the most abundant in their genera or families presumably because they have had ample opportunity to become fully adapted to the local environment. A number of Hawaiian endemics are important food species and are harvested in substantial numbers both commercially and non-commercially (e.g. kūmū and uhu uliuli).

Seven of 11 endemic species on the White List are common in suitable habitat. Reported collecting of seven of these species takes < 5% of their estimated Open Area population annually while six of the eight species have < 1% of their population collected annually.

Of the nine endemic species for which we have some survey data, only Kole and the Multiband Butterflyfish are consistently less abundant in the Open Areas relative to the FRAs. Survey data are wholly lacking for Flame Wrasse and Hawaiian Longfin Anthias.

Meaningful trends in catch report data for the four species on the White List which typically occur in deeper water aren't readily apparent due to the high annual variability and/or lack of reported catch. For two of the four species, value per fish has been decreasing which wouldn't be expected if scarcity was affecting prices. For the other two species, value has been generally increasing over time.

Based on deep technical volunteer diver survey observations, Tinker's Butterflyfish and Psychedelic Wrasse are substantially more common in the long-term protected areas (MPAs) while Flame Wrasse and Hawaiian Longfin Anthias are more abundant in the FRAs compared to Open Areas. Sightings for all these species occurred in < 25% of observational dives.

From 2003 to 2017, overall mean coral cover declined less within Open Areas compared to areas closed to commercial aquarium collection, but this difference was not significant. From 2016 to 2017, approximately one year after coral post-bleaching mortality subsided, minimal change in coral cover was documented within aquarium Open Areas, compared to a slight but significant decline in mean coral cover in areas closed to collection. Thus, benthic monitoring at West Hawaiʻi sites indicates that commercial aquarium collecting is not having a measurable negative impact on percent coral cover or change in coral cover over time

In West Hawaiʻi, the aquarium fishery takes 1.8X the number of total reef fishes taken by recreational and other commercial fishers combined. If Yellow Tang, which is primarily harvested at small sizes and not targeted by other fishers, is excluded, the recreational and commercial fisheries take 3X the total number of reef fishes caught by aquarium collectors.

In terms of reef fish biomass caught by the different fisheries in West Hawai′i, considerably more biomass is taken by the combined recreational and commercial fisheries, either including Yellow Tang (2.8X greater) or excluding it (8.6X greater).

The total take of reef fish by commercial and non-commercial ('recreational') fishers on other Main Hawaiian Islands greatly exceeds the total numbers (22X – 571X) and biomass (145X – 446X) of the fish taken by aquarium collectors.

The 2019 West Hawai′i Integrated Ecosystem Assessment Status Report (NOAA) found that the total abundance of nearshore fishes showed a positive trend in all management areas since 2003. Total fish biomass also increased in FRAs by nearly 40% during that period. The most recent survey (2017) indicated that total fish biomass in MPAs was nearly 80% higher compared to FRAs and 100% higher than the biomass in Open Areas.

Adult fish mean length of mature fishes increased by 5.3% in FRAs with no significant change in MPAs or Open Areas since 2003. Adult fish length in 2017 was approximately 11% greater in MPAs and FRAs compared to Open Areas.

Species richness has not changed within each management area over the last 15 years. As with other fish indicators, species richness in 2017 was greatest in MPAs as compared to FRAs and Open Areas.

Administrative and legislative efforts to institute 'Adaptive Management' of the White List (i.e. incorporating management flexibility in the List to respond to the changing situations of the various species have not been successful so far.

Herbivore biomass increased 30.8% in MPAs since 2003 while FRAs and Open Areas have shown no change. Herbivore biomass was approximately 70% greater in MPAs than FRAs and Open Areas in the most recent survey.

There were significant declines in biomass for all resource (food) fish species from 2008 to 2018 and for herbivores from 2014 to 2018. The most marked decline was observed for surgeonfishes, which declined 69% since 2008 and 45% since 2011. This is likely due to pressures from non-commercial ('recreational') fishers in near-shore habitats.

Despite current netting restrictions (prohibited use of lay 'gill' nets) in six designated areas (Netting Restricted Areas or NRA), surgeonfishes continue to decline, with the largest percent declines occurring in NRA. This may indicate that currently other methods of fishing are putting greater pressure on surgeonfish populations than lay netting.

Though the majority of surgeonfish species are in decline, the most notable is Achilles Tang which, despite being a White List species, continues to decline in multiple habitats including shallow water, where they are most abundant as adults. This species is highly targeted for recreational and subsistence fishing as well as for cultural purposes has declined 90% since 2008 and 72% since 2013 in shallow water habitats.

Parrotfish biomass significantly increased from 2009 to all subsequent survey years, with a 43% increase from 2009 to 2018. Effective December 26, 2013, a new administrative rule (HAR 13-60.4) was adopted including a prohibition on SCUBA spearfishing. Parrotfishes, despite not accounting for the majority of speared fish, are considered highly vulnerable targets of SCUBA spearfishing, especially at night when they seek refuge in crevices. This ban seems to have had an overwhelmingly positive effect for the parrotfishes, overall, with many species increasing between the 2011 and 2014 surveys, although there was a non-significant decrease from 2014-2018.

Increases in parrotfish biomass was mainly driven by one species, the Bullethead Parrotfish (*Chlorurus spilurus*), which increased 52% since 2013. This species made up between 27- 46% of total parrotfish biomass from 2008 to 2018. There are species-specific concerns for *Scarus psittacus* (Palenose Parrotfish) and the endemic Spectacled Parrotfish (*Chlorurus perspicillatus*), which declined 56% and 74% respectively since 2013. Species-specific bag limits should be considered for these species showing continued decline.

Beginning in the fall of 2015, West Hawai'i reefs suffered catastrophic coral mortality due to widespread and severe coral bleaching, which affected all fixed monitoring sites. Survey results indicated that coral bleaching prevalence averaged 53.3% and resulted in an average coral cover loss of 49.7% immediately after the event.

The Eyes of the Reef Community Reporting network played a substantial role in helping to document the severity and extent of the bleaching event. More than 200 reports of coral bleaching were reported to the EOR website during the event, helping to characterize the extent and severity of coral bleaching statewide.

Common coral species, such as lobe coral (*Porites lobata*) did not appear to recover from bleaching, while a portion of bleached colonies of the endemic finger coral species (*Porites compressa*) successfully recovered.

Catastrophic loss in cover was observed for the locally common massive smooth mounding coral species, (*Porites evermanni*), and for formerly abundant cauliflower coral (*Pocillopora meandrina*). Special surveys were conducted during the bleaching event to assess post-bleaching mortality for these highly susceptible species. In December 2015, post-bleaching mortality of cauliflower coral averaged 77.8% (total colony mortality) and 95.5% (partial colony mortality). A follow-up survey in May 2016 indicated that total colony mortality had increased to 88.9%. At monitoring site Keauhou, total live surface area of smooth mounding coral was reduced by 92.5% and live colony size frequency was severely truncated.

A large area of extensively bleached plate-and-pillar coral (*Porites rus*) recovered completely following the event, suggesting that reef-areas dominated by this species may be crucial recovery areas for West Hawai'i.

Benthic monitoring surveys conducted in Spring 2017 at fixed monitoring sites indicated continued declines in coral cover at 13 monitoring sites, stable coral cover at six sites, and slight coral cover increases at seven sites when compared to 2016 coral cover. On average, coral cover declined by 7.2% across the region, with severe continued declines at site Puakō (-23.8%). Coral cover has typically been replaced by light algal turf and crustose coralline algae, indicating that local grazers are playing a significant role in controlling macroalgal cover currently.

Collaborative analyses are underway to compare changes in coral cover with available oceanographic, watershed, and reef fish community datasets in order to inform state managers of possible local management strategies.

At the time of this report (October 2019), very high water temperatures surrounding West Hawaiʻi have initiated an Alert Level II designation by the NOAA Coral Reef Watch program, indicating that severe coral bleaching is imminent. Signs of coral bleaching were already detected for numerous coral species, including remaining cauliflower corals. Coral bleaching surveys across fixed monitoring sites are planned for October 2019, and another round of benthic cover image analysis is planned for Spring 2020.

SUMMARY OF MANAGEMENT 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 importance as time progresses. Since the recent inclusion of a new FRA at Ka′ohe (Pebble Beach), South Kona, 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 financially supported by the State of Hawai′i. As of now the monitoring program is wholly dependent on extramural funds (i.e. NOAA) for its continued existence.

3. 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 WHFC should be encouraged and supported by DLNR.

4. Maintain and continue support and implement co-management efforts at Ka′ūpūlehu, Ho′okena, Puakō, Miloli′i, and other interested communities.

5. Experienced facilitators preferably with training in environmental dispute resolution need to work with community advisory groups when addressing complex and contentious marine resource issues. This would also be desirable for DAR when holding particularly contentious community meetings and public hearings.

6. While FRAs are an excellent strategy to manage the most abundant and heavily collected aquarium species, uncommon, rare or ecologically important species require species-specific harvesting limitations in open areas.

7. Legislative authority for the BLNR to adopt ‘Adaptive Management’ is essential for real time response to emerging resource issues. This will become increasing important as the effects of global climate change become manifest.

8. A limited entry aquarium fishery should be established in West Hawai′i to curtail possible unsustainable expansion in the future. Clear legislative authority for such a limited entry program is desirable and possibly necessary.

9. An effective DOCARE enforcement "presence" on the water and along coastal areas is essential for long term sustainability of our marine resources. Legislative authority permitting DOCARE to inspect catch/fish boxes/coolers is imperative for effective enforcement.

10. The effectiveness of the West Hawai′i FRAs for aquarium fish suggests it would be prudent to establish 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 fully protected by MPAs.

11. Species-specific bag limits or spearfishing-restricted areas for commercial and recreational fishers should be considered to stem the overall decline of surgeonfishes and particular species of parrotfishes.

12. MPAs should be large enough for self-recruitment of short distance dispersing propagules (eggs and larvae) and spaced far enough apart that long distance dispersing propagules released from one reserve can settle in adjacent reserves.

13. Given the overall evidence for a marked decline in the population of Achilles Tang in West Hawaiʻi, a reduction in the aquarium bag limit or a moratorium on aquarium collecting for this species, in conjunction with a conservative bag limit for other fishers should be considered.

14. Consideration should be given to removing from White List, the four fish species (Tinker's Butterflyfish, Hawaiian Longfin Anthias, Flame Wrasse and Eyestripe Surgeonfish) whose populations cannot be adequately monitored by DAR.

15. Species-specific bag limits or spearfishing-restricted areas for commercial and recreational fishers should be considered to stem the overall decline of surgeonfishes and particular species of parrotfishes.

16. Thermal stress events driving coral bleaching and mortality are predicted to increase in frequency in the coming decades. Management to enhance reef resiliency and coral recovery are urgently needed, including the reduction of local stressors and enhanced protection of herbivores to improve the condition of reef substrates for coral recovery.

17. Given the likelihood of further periods of thermal stress leading to coral bleaching, DLNR should implement the 2017 Coral Bleaching Recovery Plan.

BACKGROUND

The West Hawai'i Regional Fishery Management Area (WHRFMA) was conceived and established primarily in response to the activities of aquarium collectors along the West Hawai'i coastline.

Aquarium collecting in Hawai'i and especially in West Hawai'i has long been a subject of controversy. Walsh et al. 2003 provides an historical overview of the commercial aquarium fishery in Hawai'i. As the number of collectors in West Hawai'i began to rise in the 1980s and the numbers of animals collected increased markedly (Figure 1), conflict escalated along the coast, most 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. In 1991, four of the areas from the Gentleperson's Agreement were established as the Kona Coast Fisheries Management Area (FMA) within which aquarium collecting is prohibited (HAR §13-58).

In spite of these management efforts, controversy and conflict over aquarium collecting continued unabated. Various meetings were held, and legislative resolutions and bills were drafted to address the issue. A 1996 House Concurrent Resolution (HCR 184) requested that the Department of Land and Natural Resources (DLNR), in conjunction with a citizens' task force, develop a comprehensive management plan to regulate the collection of aquarium fish. A West Hawai'i Reef Fish Working Group (WHRFWG) involving over 70 members of the West Hawai'i community including aquarium collectors and charter operators and other stakeholders held nine meetings over a 15 month period. The WHRFWG opened a dialogue between user groups and community members and provided a forum for the education of its members on social and biological issues involved in resource management.

The WHRFWG identified "hot spots" along the coast where conflict over ocean resources was especially intense and ultimately proposed a wide range of management recommendations, some of which were included in the 1997 DLNR legislative package. Working directly with the people of Ho'okena and Miloli'i, DLNR's Division of Aquatic Resources (DAR) also developed comprehensive FMA rule proposals for each of these communities. To finally begin investigating the biological impact of aquarium collecting, DAR commenced a joint research project with the University of Hawai'i at Hilo. Due in part to opposition by O'ahu aquarium collectors and a lack of agency and political support, only two legislative recommendations of the WHRFWG passed; establishing dealer licenses and increasing commercial license fees. Similarly, recommendations involving the DAR FMA rule proposals languished.

Act 306, Session Laws of Hawai'i (SLH) 1998

In response to the perceived lack of success in adequately dealing with aquarium collecting, a number of citizens, including several members of the WHRFWG formed a grassroots organization, the Lost Fish Coalition (LFC) in 1997, to push for a total ban on aquarium collecting in West Hawaiʻi. They collected almost 4,000 signatures on a petition to ban such collecting. In January 1997, Representative (Rep.) Paul Whalen (R-Kona, Ka'u) introduced legislation (House Bill (HB) 3349) which proposed an outright ban on all collecting between Kawaihae and Miloli'i. Shortly thereafter, Rep. David Tarnas (D-N. Kona, S. Kohala) introduced HB 3457. This bill proposed establishing a West Hawai'i Regional Fishery Management Area (WHRFMA) along the entire 147 mile West Hawai'i coast (Upolu Pt. to Ka Lae) to provide for effective management of marine resources. Among several provisions of this bill was a requirement to set aside 50% of the WHRFMA as Fish Replenishment Areas (FRAs) where aquarium collecting was prohibited. In February 1998, HB 3348 was put on hold. During committee hearings on HB 3457, the 50% provision for FRAs was reduced to "a minimum of 30%." Aquarium collectors and other user groups endorsed the bill and it was passed by the Legislature as Act 306, SLH 1998; effective 13 July 1998. It was subsequently codified as Hawaii Revised Statute – HRS 188F.

Given the longstanding and contentious nature of the aquarium issue in West Hawaiʻi, the importance of legislation in finally addressing the issue cannot be underestimated. It was only when organized and concerted community effort was applied directly via the legislative process that the means for resolution was made possible. It seems highly likely that without the direct legislative mandates of Act 306, little progress would have been made in successfully managing this controversial fishery.

Act 306, SLH 1998 established a West Hawai'i Regional Fishery Management Area along the entire west coast of the Island of Hawai'i (§188F-4, HRS). The overall purpose of Act 306 was to:

Effectively manage fishery activities to ensure sustainability, enhance near shore resources and minimize conflicts of use in the WHRFMA.

There were also four specific management objectives to be accomplished by DLNR:

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

A review of the WHRFMA management plan was to be conducted every five years by DLNR in cooperation with the University of Hawaiʻi. Such reviews were completed for the 2010, 2015 and 2020 Legislatures.

Additionally, Act 306 also provided for "substantive involvement of the community in resource management decisions". This mandate was a unique and key aspect of the legislation which allowed the community to actively participate in the development of resource management actions. This approach was at once both innovative and far-reaching. As noted by Maurin and Peck (2008) "The Act's requirement for 'substantive' community input before management decisions can be taken to achieve the goals has been described as 'revolutionary.' It required, explicitly and for the first time, that the state agency regulating ocean use go beyond the standard public hearings which often occur late in the rule-writing process, and engage in active and ongoing consultation with its constituents.

The West Hawai'i Fishery Council (WHFC)

In order to accomplish the mandates of Act 306, with substantive community input, The West Hawai'i Fishery Council (WHFC) was convened June 16, 1998 under the aegis of DLNR and the University of Hawai'i Sea Grant Program. Consisting of 24 voting members and 6 ex-officio agency representatives from DLNR, Sea Grant, and the Governor's Office, the WHFC's members represented diverse geographic areas and various stakeholder, community and user groups in West Hawai'i. Four aquarium representatives (three collectors and one aquarium shop owner) were members of the WHFC and most of the members were previously on the WHRFWG.

The West Hawai'i Fishery Council provided the vehicle for stakeholders to participate directly in the development of management recommendations. Such participation has important benefits for increasing legitimacy of decisions in the eyes of stakeholders, as well as increasing compliance with decisions and rules subsequently established (Kessler 2004). More detailed information on the background, activities and membership of the WHFC is available on their website: http://westhawaiifisherycouncil.org. The website also has a Science Library which houses numerous articles and scientific paper relating to the WHRFMA, the WHFC, aquarium collecting and the biology of targeted aquarium species.

The first mandate of Act 306 was the establishment of the FRAs. FRAs were mandated to address concerns over user conflict and localized resource depletion caused by aquarium fish collectors in West Hawai'i. Working under a punishing deadline, the WHFC, by determination, consensus and vote, developed an FRA plan consisting of nine separate areas along the coast (Figure 1) encompassing a total of 35.2% of the West Hawai'i coastline (including already protected areas). Perhaps somewhat surprisingly, the areas specifically recommended as FRAs by the aquarium collecting representatives on the Council showed remarkable congruence with those selected by the WHFC as a whole.

The WHFC and the FRA development process have been the focus of a number of in-depth reports and scientific case studies (Walsh 1999, Capitini et al. 2004, Tissot 2005, Maurin and Peck 2008, Tissot et al. 2009, Gregory 2009, Rossiter and Levine 2013), making it one of the most intensively studied community driven management efforts in the State of Hawai'i.

The WHFC's FRA plan was subsequently incorporated by DLNR into administrative rule. The 28 April 1999 public hearing on the FRA Rule (HAR 13-60.3) was the largest public hearing ever conducted by DAR with at least 860 attendees. The draft rule received overwhelming support

(93.5% of 876 testimonies) from a wide range of community sectors. The FRA administrative rule was signed by Governor Benjamin Cayetano on 17 December 1999 becoming effective 31 December 1999.

The FRAs prohibit all collecting of aquarium animals within their boundaries as well as non-fishing related fish feeding. The seaward boundaries of the FRAs extend to a depth of 100 fathoms and distinctive signs mark the boundaries on shore.

In addition to the development of the FRA network, the WHFC, in conjunction with DAR and UH Sea Grant, was successful in achieving a number of other marine resource-related accomplishments. Some of the accomplishments of the WHFC include:

- The Council recommended amendments to the initial FRA rule to enhance enforcement and initiate the implementation of a sustainable, limited entry commercial aquarium fishery.

- The Council has worked with DLNR on the day-use mooring buoy program to site these buoys and inform communities of the value of such moorings to preserve our coral reefs.

- The Council developed rule amendments to provide limited kupuna harvesting of wana (sea urchins) within the Old Kona Airport Marine Life Conservation District (MLCD).

- The Council developed a set of gill net rule recommendations focused on limiting impacts of large-scale commercial netting while providing for subsistence netting. Six no-gill net refuges have been established as well as a Hawaiian cultural netting area (hand constructed, natural fiber nets only). The Council's approach served as a subsequent model for state-wide gill net management.

- The WHFC Youth Council distributed a petition for no-smoking at Kahalu'u Beach Park, wrote a Resolution (with the help of Councilperson Virginia Isbell) which was passed by the Hawai'i County Council and which then drafted an ordinance that was passed unanimously. Kahalu'u Beach Park is now the second beach in the state that is no-smoking.

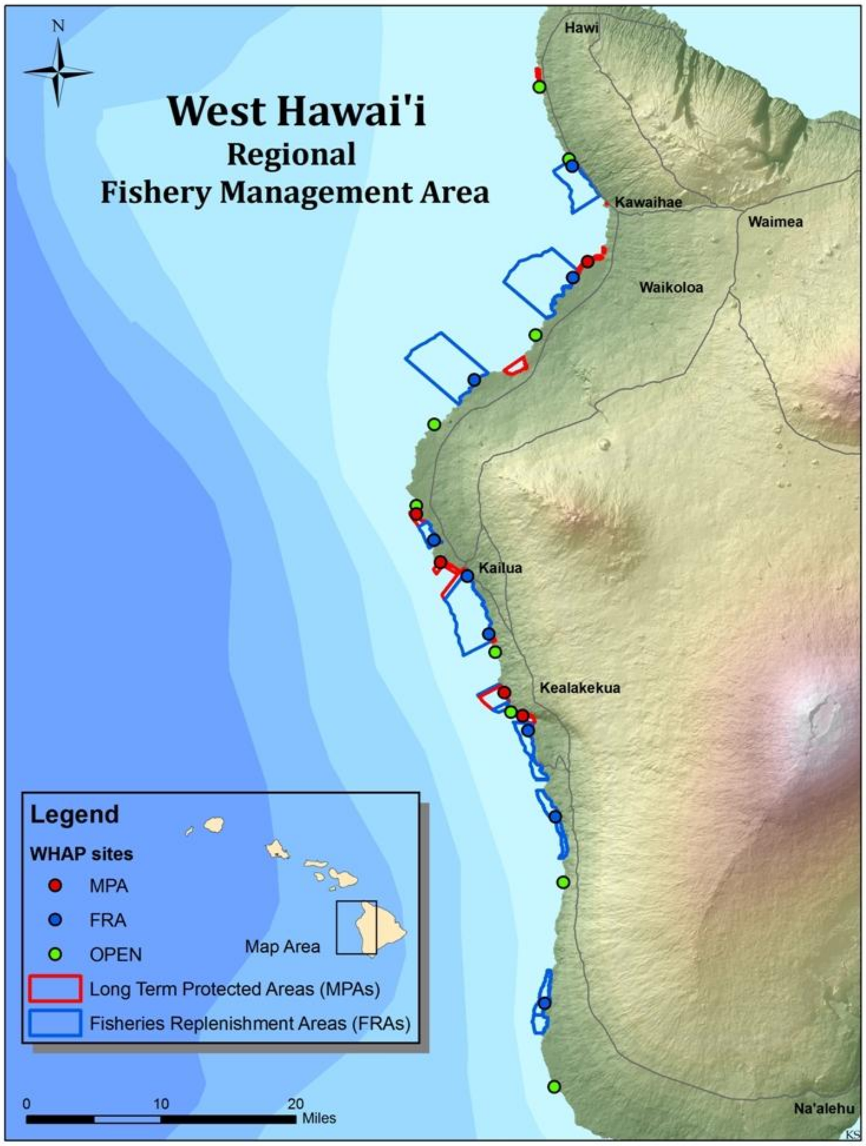


Figure 1. Locations of Fish Replenishment Areas (FRAs) in West Hawai'i and DAR monitoring sites (currently 6 MPAs, 9 FRAs and 10 open sites). Note: MPAs include 2 Marine Life Conservation Districts (MLCDs) and 4 Fishery Management Areas (FMAs).

Of primary importance of WHFC accomplishments was the development of an Aquarium 'White List' specifying which species could be taken for aquarium purposes within the WHRFMA. Working with commercial aquarium collectors, the WHFC established a list of 40 fish species permitted for aquarium take (Table 1). Only those fishes found on the White List can be collected live for aquarium use. All other fishes and all invertebrates are off-limits to collecting. Size and bag limits were also established for three of the species on the White List – Yellow Tang, Kole and Achilles Tang.

The White list, along with other management recommendations (e.g. SCUBA spearfishing prohibition, new Pebble Beach FRA and a no-take listing of 'Species of Special Concern' (primarily sharks and rays) received overwhelming public support and were adopted as a new administrative rule (HAR 13-60.4) effective December 26, 2013.

Table 1. White List' of 40 fish species which can be taken by Aquarium collectors in the WHRFMA.

Common Name	Hawaiian/Local Name	Scientific Name
Yellow Tang	Lauʻipala	*Zebrasoma flavescens*
Goldring Surgeonfish	Kole	*Ctenochaetus strigosus*
Chevron Tang	Hawaiian Kole	*Ctenochaetus hawaiiensis*
Achilles Tang	Pākuʻikuʻi	*Acanthurus achilles*
Goldrim Surgeonfish		*Acanthurus nigricans*
Orangeband Surgeonfish	Naʻenaʻe	*Acanthurus olivaceus*
Eyestripe Surgeonfish	Palani	*Acanthurus dussumieri*
Brown Surgeonfish	Māʻiʻiʻi	*Acanthurus nigrofuscus*
Thompson's Surgeonfish		*Acanthurus thompsoni*
Orangespine Unicornfish	Umauma lei	*Naso lituratus*
Multiband Butterflyfish	Kīkākapu	*Chaetodon multicinctus*
Fourspot Butterflyfish	Lauhau	*Chaetodon quadrimaculatus*
Milletseed Butterflyfish	Lauwiliwili	*Chaetodon miliaris*
Tinker's Butterflyfish		*Chaetodon tinkeri*
Blacklip Butterflyfish		*Chaetodon kleinii*
Pyramid Butterflyfish		*Hemitaurichthys polylepis*
Forcepsfish	Lauwiliwili nukunuku ʻoiʻoi	*Forcipiger flavissimus*
Saddle Wrasse	Hīnālea lauwili	*Thalassoma duperrey*
Flame Wrasse		*Cirrhilabrus jordani*
Shortnose Wrasse		*Macropharyngodon geoffroy*
Ornate Wrasse	Lāʻō	*Halichoeres ornatissimus*
Smalltail Wrasse		*Pseudojuloides cerasinus*
Fourline Wrasse		*Pseudocheilinus tetrataenia*
Eightline Wrasse		*Pseudocheilinus octotaenia*
Bird Wrasse	Hīnālea ʻiʻiwi	*Gomphosus varius*
Psychedelic Wrasse		*Anampses chrysocephalus*
Yellowtail Coris	Hīnālea ʻakilolo	*Coris gaimard*
Potter's Angelfish		*Centropyge potteri*
Fisher's Angelfish		*Centropyge fisheri*
Redbarred Hawkfish	Pilikoʻa	*Cirrhitops fasciatus*
Blackside Hawkfish		*Paracirrhites forsteri*
Black Durgon	Humuhumu ʻeleʻele	*Melichthys niger*
Lei Triggerfish	Humuhumu lei	*Sufflamen bursa*
Gilded Triggerfish		*Xanthichthys auromarginatus*
Spotted Boxfish	Moa	*Ostracion meleagris*
Hi Whitespotted Toby		*Canthigaster jactator*
Hi Dascyllus	ʻĀloʻiloʻi	*Dascyllus albisella*
Hi Longfin Anthias		*Pseudanthias hawaiiensis*
Bluestripe Snapper	Taʻape	*Lutjanus kasmira*
Peacock Grouper	Roi	*Cephalopholis argus*

The creation and functioning of the WHFC is entirely attributable to the volunteer commitment of time, energy and resources of its members. The 79 members of the community who have been members at one time or another of the WHFC have contributed thousands of hours of their own time at no cost to the State. While not directly authorized by state law, this community-based advisory body represents a valuable tool to state government in terms of its approach to and recommendations on marine resource management. These efforts have been assisted by the support of community organizations such as the Hawaiʻi Community Foundation, The Nature Conservancy, Community Conservation Network, the Malama Kai Foundation and especially the Harold Castle Foundation, all of whom recognize the significance and value of the WHFC and its role in assisting in effective management of our marine resources.

Economics and Monitoring of the West Hawai'i Aquarium Fishery

In recent years the marine aquarium fishery has been the most economically valuable commercial inshore fishery in the State of Hawai'i with FY 2017 reported landings greater than $2.2 million (Figure 2). It should be noted that the dollar value of these fisheries represents only the *ex-vessel* value - what the fishers are paid for their catch, and does not include the value which would be generated by additional dealer and retail sales. The actual economic value of the catch is thus substantially greater than the ex-vessel values shown in figure 2.

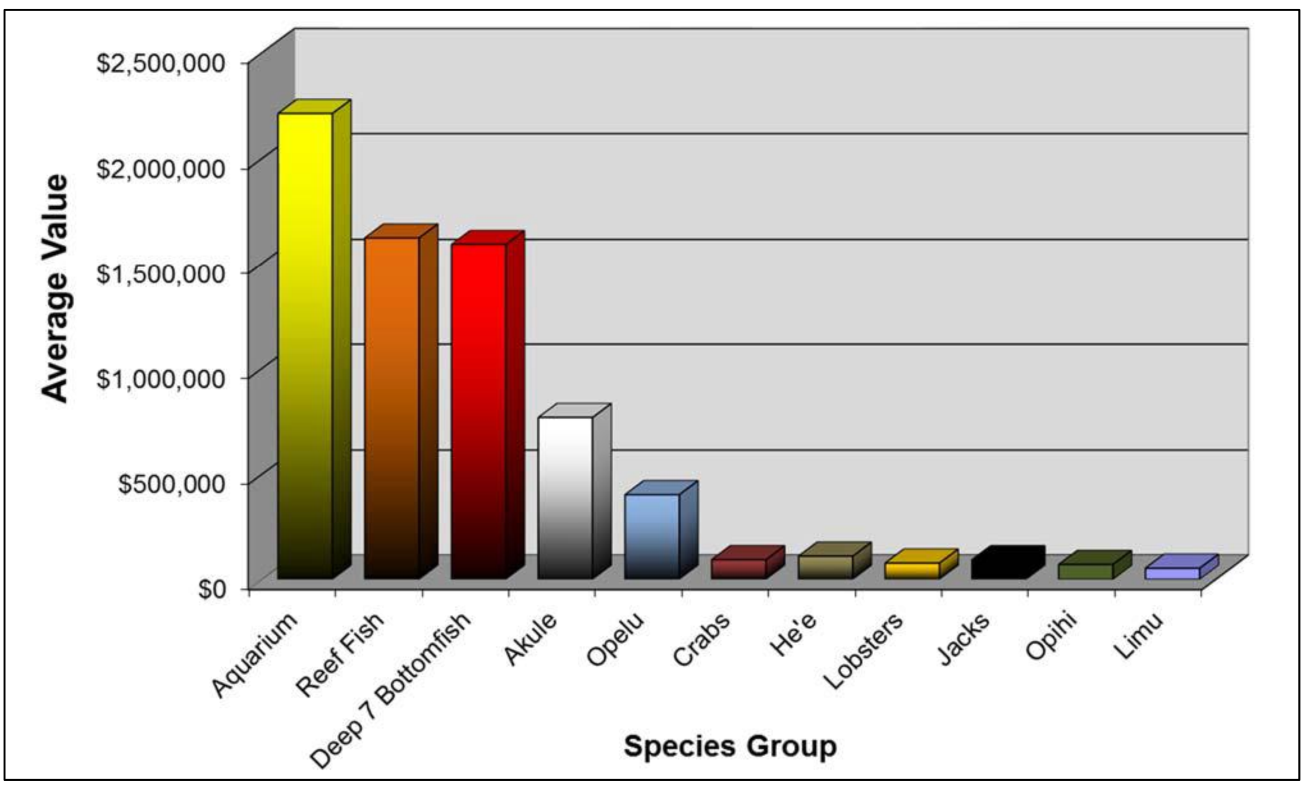


Figure 2. Economic value for various inshore fisheries of the Main Hawaiian Islands. Value ($ adjusted for inflation) averaged over FY 2012-2017.

Although specific export data does not exist for the aquarium fishery, it is clear that most of the aquarium catch is shipped out of the state to dealers on the mainland United States, Europe and Asia (Dierking 2002). This is neither surprising nor atypical for commercial fisheries in Hawai'i. For example, seafood exports of various Hawaiian species exceed 3.7 million pounds annually (Loke et al. 2012).

Data for Fiscal Year 2017 indicate that 78% of fish caught in the State and 68% of the total aquarium catch value came from Hawai'i Island, most of that from West Hawai'i (Table 2). The total aquarium catch and its value increased from 2000 when the FRAs were established, reaching a peak in 2006 (Figure 4). Subsequent catch has declined as has the number of collectors. Note that due to recent court rulings, the statewide aquarium fishery was curtailed in October 2017 (Fiscal Year 2018) and totally stopped in West Hawai'i in January 2018, also FY '18 (see Chronology of Closure section for further details).

Table 2. Changes in West Hawai'i aquarium fishery since implementation of the FRAs.

	FY 2000	**FY 2017**	**Δ**
No. Permits	48	51	6% ↑
Total Catch	252,290	324,565	29% ↑
Total Value	$530,842	$1,290,316	143% ↑
% of State Fish Catch	61%	87%	26% ↑
% of State Fish Value	58%	84%	26% ↑
% of State Total Catch	48%	62%	14% ↑
% of State Total Value	53%	82%	29% ↑

Even though there initially was substantial opposition to the implementation of the FRA network by aquarium fishers and their supporters (Walsh 1999, Capitini et al. 2004, Maurin and Peck 2008), it's clear that overall catch has not declined from the pre-FRA period and recent work (Stevenson et al. 2013) has indicated that the economic status of West Hawai'i aquarium collectors significantly improved since the FRA network was implemented.

Of the 40 fish species on the West Hawai'i White List, two surgeonfishes comprise the overwhelming portion of the catch. Yellow Tang (*Zebrasoma flavescens*) constitute 81.6% of the total catch while the Goldring Surgeonfish (Kole - (*Ctenochaetus strigosus*) made up 9.5% of the total catch in FY 2017 (Table 3). The top 10 collected species comprise 98.2% of all fishes collected and 97.1% of total value.

Table 3. Number and value of West Hawaiʻi White List species caught in FY 2017.

Species	No. caught & kept	Value	% of Total Caught	% of Total Value
Yellow Tang	264,870	$920,186	81.6%	71.3%
Goldring Surgeonfish, Kole	30,901	$75,366	9.5%	5.8%
Orangespine Unicornfish	6,078	$24,738	1.9%	1.9%
Achilles Tang	5,473	$130,853	1.7%	10.1%
Chevron Tang	3,878	$61,764	1.2%	4.8%
Potter's Angelfish	2,245	$18,283	0.7%	1.4%
Ornate Wrasse	1,602	$4,537	0.5%	0.4%
Goldrim Surgeonfish	1,324	$9,654	0.4%	0.7%
Orangeband Surgeonfish	1,293	$3,573	0.4%	0.3%
Brown Surgeonfish	957	$1,498	0.3%	0.1%
Forcepsfish	840	$2,391	0.3%	0.2%
Yellowtail Coris	623	$2,331	0.2%	0.2%
Psychedelic Wrasse	599	$2,573	0.2%	0.2%
Shortnose Wrasse	582	$1,893	0.2%	0.1%
Saddle Wrasse	538	$561	0.2%	0.04%
Multiband Butterflyfish	470	$507	0.1%	0.04%
Fourspot Butterflyfish	319	$881	0.1%	0.1%
Tinker's Butterflyfish	290	$23,380	0.1%	1.8%
Fisher's Angelfish	288	$1,418	0.1%	0.1%
Smalltail Wrasse	278	$573	0.1%	0.04%
Bird Wrasse	265	$1,011	0.1%	0.1%
Thompson's Surgeonfish	148	$316	0.05%	0.02%
Milletseed Butterflyfish	98	$110	0.03%	0.01%
Eightline Wrasse	97	$191	0.03%	0.01%
Hawaiian Dascyllus	89	$159	0.03%	0.012%
Blacklip Butterflyfish	81	$104	0.02%	0.008%
Lei Triggerfish	78	$122	0.02%	0.009%
Spotted Boxfish	57	$302	0.017%	0.023%
Fourline Wrasse	54	$302	0.001%	0.003%
Pyramid Butterflyfish	42	$142	0.013%	0.011%
Blackside Hawkfish	30	$85	0.009%	0.007%
Hawaiian Whitespotted Toby	26	$50	0.008%	0.004%
Redbarred Hawkfish	21	$57	0.006%	0.004%
Gilded Triggerfish	20	$156	0.001%	0.001%
Black Durgon	11	$30	0.001%	0.001%
Eyestripe Surgeonfish	0	$0	0%	0%

Hawaiian Longfin Anthias	0	$0	0%	0%
Flame Wrasse	0	$0	0%	0%
Bluestripe Snapper	0	$0	0%	0%
Peacock Grouper	0	$0	0%	0%
Total	**324,565**	**1,290,316**		

Earlier studies suggested that reported aquarium catch may have been underestimated by a factor of approximately 2X to 5X (Cesar et al. 2002, Walsh et al. 2003). A previously conducted analysis of FY 2010 and FY 2014 aquarium catch data found a good correspondence in reported numbers of animals caught and sold to dealers by aquarium collectors. In FY 2010 there was a 3.5% difference between the numbers of animals reported caught and sold while in FY2014 the difference was only 0.4% (Figure 3). These small differences likely represent both subsequent live releases and mortality.

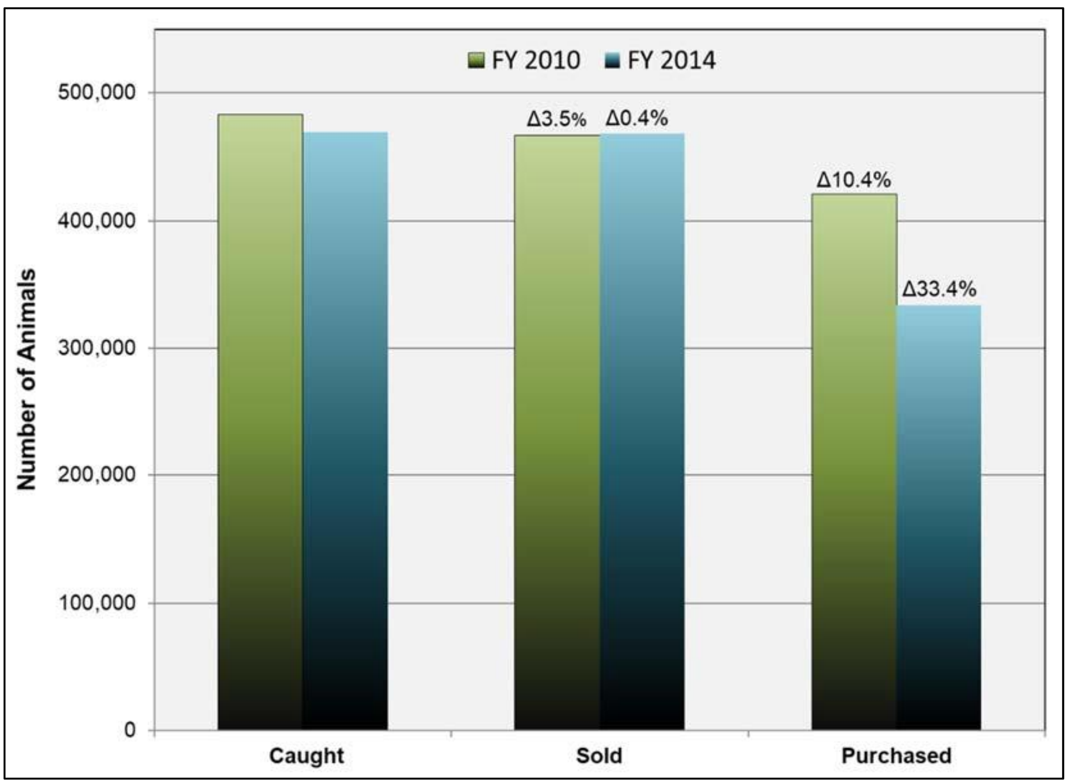


Figure 3. Comparison between Hawai'i Island aquarium collector report data and dealer purchases of aquarium animals from the collectors.

Dealer reports of purchases (including retail sales) from Hawai'i collectors were 10.4% lower in FY 2010 and 33.4% lower in FY 2014 than the number of animals reported sold by collectors. There are two likely reasons for this discrepancy. There has long been statutory authority (HRS

§189-10) for DLNR to establish a Hawai'i Administrative Rule (HAR) requiring primary aquarium marine dealers to be licensed and report aquarium purchases from collectors. However, it was only in January 2018, that the HAR (§13-74-46) was amended to require weekly reporting (Sun-Sat) by commercial aquarium marine dealers. Dealers are required to submit the reports by Tuesday of the following week.

In July 2018, DLNR began an outreach campaign advising all known primary dealers of the new weekly report requirement. Reminder notices were sent to dealers who did not submit any report for a weekly report period. As of the beginning of August 2019, 40% of dealers complied with the weekly report submission deadline while 80% complied by the end of the month. When the new Online Dealer Report (ODR) website application (https://dlnr.ehawaii.gov/odr) comes online on October 14, 2019, the Weekly Report Period report requirement will be enforced using the Civil Resources Violation System - CRVS (DAR Stats Unit, Reginald Kokubun pers. Comm).

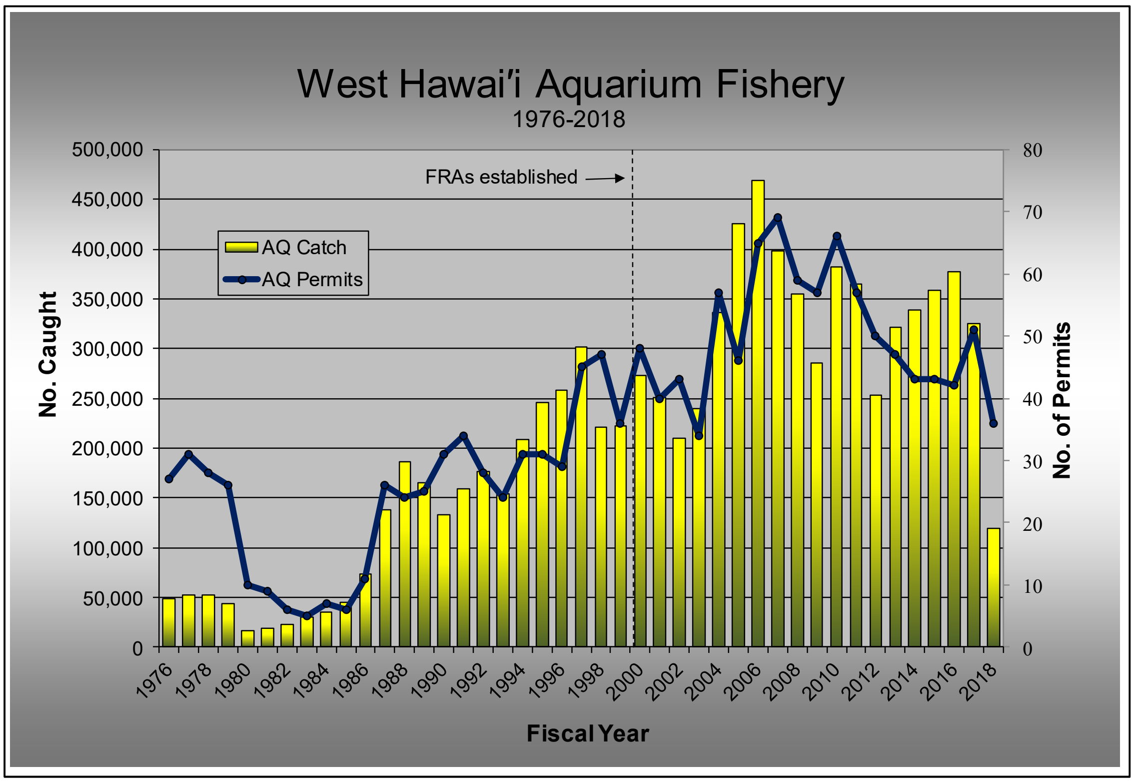


Figure 4. Number of aquarium animals collected, and number of commercial aquarium permits in West Hawai'i for FY 1976-2018.

Another limitation in assessing the accuracy of aquarium catch reporting relates to the fact that the catch of aquarium collectors who sell fish to out of state dealers is not reported since these dealers have no requirement to file dealer reports with DLNR. Even with these onerous limitations in catch report validation, the 2010/2014 comparison did not indicate substantial (i.e. 2X-5X) underreporting of catch by aquarium collectors.

In contrast to other areas in the State, in West Hawai'i, the aquarium fishery has undergone substantial and sustained expansion over the past 30 years (Figure 4). In FY 2017 there were 51 commercial West Hawaiʻi aquarium permits, down from a high of 69 in 2007. Of the issued permits, 33 reported substantial catch (>10K) of Yellow Tang, the primary species in the fishery. The number of permits declined in FY 2018 to 36 as DLNR ceased issuance of aquarium permits in response to a 2017 Hawaiʻi Supreme Court ruling (see following section).

Chronology of the Closure of the West Hawai'i Aquarium Fishery

Aquarium fishing in Hawai'i and especially in West Hawai'i, has long been the subject of controversy and conflict. Over the years there have been repeated efforts by anti-aquarium advocates to shut down the fishery by one stratagem or another. There were a number of legislative initiatives as well as a 2014 Hawaiʻi County Council measure proposing strict regulations on the transport of fish off-island. (West Hawaii Today 2014). All these initiatives were unsuccessful.

In 2012, the first legal action against aquarium fishing was undertaken by three Non-Governmental Organizations (NGO) and several Maui and West Hawai'i residents. Below is a chronology of the legal and administrative decisions leading to the full closure of the West Hawaiʻi aquarium fishery in January 2018. The chronology is based on information on the DAR website and a Honolulu Star Advertiser newspaper article (Perez 2019).

Oct. 24, 2012: Plaintiffs sue the state Department of Land and Natural Resources (DLNR), challenging issuance of 50 aquarium permits. DLNR accused of failing to complete an environmental review before approving permits.

June 24, 2013: Circuit Court determines issuance of aquarium permits is an action not subject to review under Hawaiʻi Environmental Policy Act (HEPA).

July 18, 2013: Plaintiffs appeal to the Intermediate Court of Appeals (ICA).

Aug. 31, 2016: The ICA upholds Circuit Court ruling, affirming that aquarium permits are not subject to environmental review.

Sept. 6, 2017: Hawaiʻi Supreme Court rules that commercial aquarium permits are subject to Hawaii environmental review, but the record is not adequate to determine whether recreational aquarium permits are exempt.

Sept. 7, 2017: DLNR stops issuing new commercial aquarium permits or renewing existing ones.

Oct. 27, 2017: Based on the Supreme Court decision, Circuit Court Judge Jeffrey Crabtree rules that all existing aquarium permits for use of fine mesh nets/traps to catch aquatic life for aquarium purposes were illegal and invalid pending a full review of the fishery under HEPA. Aquarium collecting is still allowed as long as fine mesh nets/traps aren't used.

Jan. 5, 2018: DLNR announces no aquatic life may be taken for commercial aquarium purposes off West Hawai'i until an environmental review is completed.

April 8, 2018: The Pet Industry Joint Advisory Council (PIJAC), representing the aquarium trade, submits Environmental Assessments (EA) to DLNR for the islands of Hawai′i and O′ahu, maintaining that issuing of commercial permits would not have significant environmental impact.

April 12, 2018: Judge Crabtree rules all unexpired recreational permits allowing collection with fine-mesh nets void pending environmental review.

July 26, 2018: DLNR rejects aquarium Environmental Assessments, requiring more rigorous Environmental Impact Statements (EIS). EIS are currently being prepared for West Hawai'i and O'ahu by Stantec Consulting Services, Inc.

The West Hawai′i Aquarium fishery was thus initially impacted in Sept 2017 and ultimately completely closed in January 2018 (both in Fiscal Year 2018).

West Hawai'i Aquarium Project (WHAP)

Although Act 306, SLH 1998, mandated review and evaluation (thus monitoring) of the FRAs in conjunction with UH, no funding was provided to accomplish this. In order to investigate the effectiveness of the FRAs to replenish depleted fish stocks, a consortium of researchers established the West Hawai'i Aquarium Project (WHAP) in early 1999. Funding was secured for the early years of the project through the Hawai'i Coral Reef Initiative Research Program (HCRI-RP), a federal initiative under the aegis of the National Oceanic and Atmospheric Administration (NOAA). Subsequent funding has been provided by Coral Reef Monitoring Grants under NOAA's Coral Reef Conservation Program. The initial project researchers were Dr. William Walsh, DAR/DLNR, Dr. Brian Tissot, Humboldt University, and Dr. Leon Hallacher, University of Hawai′i Hilo. They have been joined in recent years by Dr. Ivor Williams and Dr. Jill Zamzow, National Marine Fisheries Service, Coral Reef Ecosystem Program (NOAA/CREP) and on related projects by Dr. Mark Hixon, University of Hawai′i Mānoa, Dr. Helen Fox, Rare.org. and Dr. Jamison Gove, Ecosystem Sciences Division, NOAA Fisheries.

WHAP initially established 23 study sites (Figure 1) along the West Hawai′i coastline in early 1999 at 9 FRA sites, 8 Open sites (aquarium fish collection areas) and 6 previously established Marine Protected Areas (MPAs) to collect baseline data both prior to and after the closure of the FRAs. The MPAs are Marine Life Conservation Districts (MLCD) and Fishery Management Areas (FMA), which have been closed to aquarium collecting for at least 9 years and were presumed to have close to "natural" levels of aquarium fish abundances. They serve as a reference or ‘control’ to compare with the FRAs and open areas. It should be noted that after several years of study and observation, one of the MPA sites (Lapakahi MLCD – subzone B), was found to really not be closed to aquarium collecting due to its remoteness and poorly defined seaward boundaries (i.e. 500 feet offshore). Collectors were observed on occasion to be working within the MPA. As such, the Lapakahi survey site is considered an Open Area for data analysis. Two additional monitoring sites have subsequently been added to the original 23 sites bringing the total to 25 (6 MPAs, 9 FRAs and 10 open sites – Figure 1).

The overall goals of WHAP were two-fold: **1) To evaluate the effectiveness of the FRA network by comparing targeted aquarium fishes in FRAs and open areas relative to adjacent control sites and, 2) To evaluate the impact of the FRA network on the aquarium fishery.**

Detailed explanations of the study sites and survey methodology are contained in Tissot et al. 2004 and Walsh et al. 2013. To briefly summarize: Densities of all fish and selected invertebrate species are visually estimated along four 25 m X 4 m belt transects at each of the 25 permanent sites in the three types of management areas. All survey divers either have extensive experience in conducting underwater fish surveys in Hawai'i or received training through the UH’s Quantitative Underwater Ecological Survey Techniques (QUEST) training course prior to collecting data (Hallacher and Tissot, 1999). In addition to the transect surveys, a 10 minute ‘free-swim’ survey is also conducted by two divers in the areas surrounding the actual transects. The purpose of this survey is to better census uncommon or rare species and species of particular ecological interest such as Ta′ape, Roi, terminal phase parrotfishes, Cleaner Wrasses and crown-of-thorns starfish. Recently To′au (Black Tail Snapper) and pincushion stars have been added to the free-swim survey.

The scientific information presented in this report represents the cumulative efforts of 82 survey divers (see Acknowledgements) who conducted over 2,100 surveys for WHAP over the past 20 years. All sites are presently surveyed four times a year. During the first five years of the project five to six survey rounds were conducted. Through 2018, 8,712 transects at all study sites have been completed.

FINDINGS AND EVALUATION

Fish Replenishment Areas (FRAs)- Aquarium Collecting Impacts

The overall changes in abundance since FRA establishment for the top 10 most collected aquarium fishes are shown in Table 4. These 10 species represent 98.4% of all the fish collected in West Hawai'i in FY 2017. The ρ value (t-test) in the far right column of Table 3 (and reported elsewhere) is a measure of the significance of the difference between populations, in this case the mean density (i.e. abundance) between the 1999/2000 and 2017/2018 periods. The ρ-value is a number between 0 and 1 and is interpreted in the following way (after Rumsey 2011):

- A small ρ-value (typically ≤ 0.05) indicates strong evidence *against* the hypothesis that there is *no difference* between the populations – in other words, there is a real (i.e. 'significant') difference in the abundance of the two populations.
- A large ρ-value (> 0.05) indicates the opposite; that there is no significant difference in the abundance of the two populations.

Populations of eight of the top 10 species increased significantly in one or more of the management areas (i.e. FRA/Open/MPA) while 2 species declined significantly in both FRA and Open areas. The fact that these two species had declines in both Open and protected areas (FRAs) suggests that factors other than aquarium collecting were also affecting their populations.

The two most heavily collected species, Yellow Tang and Goldring Surgeonfish (Kole) alone account for 91.1% of total FY 2017 fish catch and thus are key indicators of the protective value of the FRAs and the sustainability of the aquarium fishery. Since 1999/2000 both species have increased markedly (and significantly) in the FRAs, MPAs and the Open Areas as well.

Table 4 (next page). Changes in abundance of the top ten most collected aquarium fishes in West Hawai'i between CY 1999-2000 and CY 2017-2018. Colored cells show statistically significant increases (green) and decreases (pink). Note: Young of Year (YOY) not included.

COMMON NAME	**SCIENTIFIC NAME**		**MEAN DENSITY (NO./100M^2)**		**OVERALL % CHANGE IN DENSITY**	ρ
			’99-‘00	**’17-‘18**		
Yellow Tang	*Zebrasoma flavescens*	**FRA**	**12.73**	**33.79**	**+165.4%**	**<0.001**
		Open	**10.24**	**20.53**	**+100.6%**	**<0.001**
		MPA	**23.08**	**40.07**	**+73.6%**	**<0.001**
Goldring Surgeonfish	*Ctenochaetus strigosus*	**FRA**	**28.38**	**52.60**	**+85.4%**	**<0.001**
		Open	**21.18**	**41.65**	**+96.6%**	**<0.001**
		MPA	**28.53**	**62.64**	**+119.6%**	**<0.001**
Orangespine Unicornfish	*Naso lituratus*	FRA	0.81	0.67	-16.8%	0.26
		Open	**1.12**	**1.59**	**+42.6%**	**<0.001**
		MPA	**1.59**	**2.88**	**+81.4%**	**<0.001**
Achilles Tang	*Acanthurus achilles*	**FRA**	**0.26**	**0.05**	**-82.7%**	**<0.001**
		Open	**0.31**	**0.09**	**-70.5%**	**<0.001**
		MPA	0.42	0.22	-48.3%	0.05
Chevron Tang	*Ctenochaetus hawaiiensis*	**FRA**	**0.18**	**0.76**	**+319.2%**	**<0.001**
		Open	**0.17**	**0.84**	**+402.1%**	**<0.001**
		MPA	**0.53**	**0.98**	**+83.7%**	**<0.001**
Potter’s Angelfish	*Centropyge potteri*	**FRA**	**1.38**	**2.28**	**+66.0%**	**<0.001**
		Open	**1.65**	**2.47**	**+49.9%**	**<0.001**
		MPA	**1.54**	**2.39**	**+55.4%**	**<0.001**
Ornate Wrasse	*Halichoeres ornatissimus*	**FRA**	**0.94**	**0.66**	**-30.1%**	**<0.01**
		Open	**2.20**	**1.83**	**-16.6%**	**<0.001**
		MPA	**1.24**	**1.59**	**+28.5%**	**<0.05**
Goldrim Surgeonfish	*Acanthurus nigricans*	FRA	0.04	0.09	+156.6%	0.46
		Open	0.01	0.06	+605.9%	0.42
		MPA	0.11	0.21	+102.4%	0.45
Orangeband Surgeonfish	*Acanthurus olivaceus*	FRA	0.13	0.22	+73.9%	0.24
		Open	**0.31**	**0.50**	**+60.0%**	**<0.01**
		MPA	**0.56**	**0.87**	**+56.3%**	**<0.05**
Brown Surgeonfish	*Acanthurus nigrofuscus*	**FRA**	**8.57**	**13.90**	**+62.1%**	**<0.001**
		Open	**11.20**	**25.77**	**+130.1%**	**<0.001**
		MPA	**7.68**	**22.21**	**+189.3%**	**<0.001**

Species-Specific Findings: Yellow Tang (Zebrasoma flavescens, Lau'ipala)

The overall average changes in Yellow Tang abundance in the three management areas are shown in Figure 5. Prior to the year 2000 (according to 1998/1999 baseline surveys), the areas which would become FRAs were not significantly different than the Open Areas in terms of Yellow Tang abundance. Yellow Tang subsequently exhibited an increase in abundance in all areas following a strong recruitment year in 2002. Relatively low recruitment in six of the following years resulted in subsequent downward trends in all areas. Robust recruitment in 2009 and 2014 has driven further increases in all areas in subsequent years.

The FRAs have clearly been very successful in driving an increase in Yellow Tang populations in West Hawai′i. The most recent findings indicate that since the FRAs were established 19 years ago, the number of Yellow Tang, excluding Young of the Year (YOY), increased by 165% in the FRAs, 74% in the previously protected MPAs and 101% in the Open Areas (1999/2000 – 2017/2018 comparison). Yellow Tang abundance is lower in the Open Areas relative to the FRAs (49.8% for 2017/2018) because aquarium collecting occurs in these areas. Nevertheless, Yellow Tang populations in the Open Areas have increased over the years.

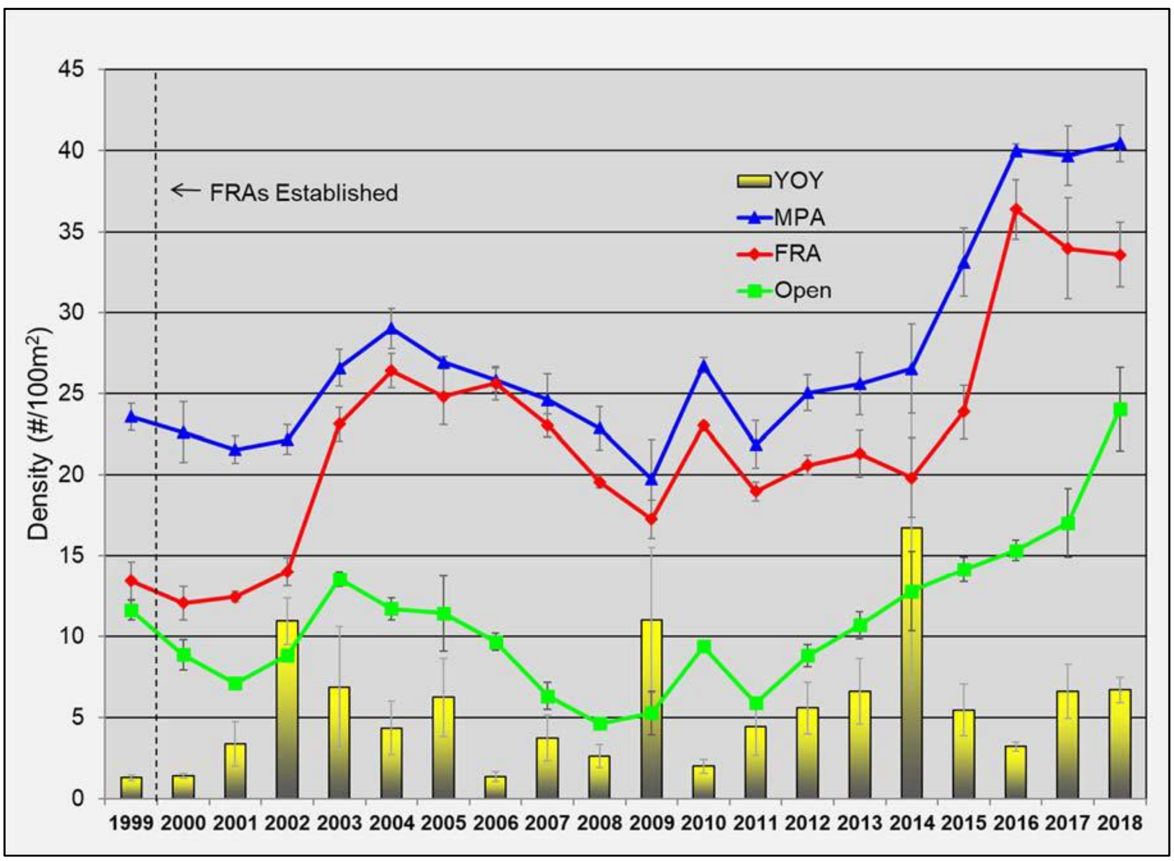


Figure 5. Overall changes in Yellow Tang abundance (Mean ± SE) in FRAs, MPAs and Open areas, 1999-2018. Yellow vertical bars indicate mean density (May -Nov) of Yellow Tang Young-of-Year (YOY). YOY are not included in trend line data.

Population estimates for fish species on West Hawai′i reefs in the 30’-60’ depth zone (where WHAP transects are located) were derived from WHAP fish survey densities and area estimates based on NOAA habitat maps (NOAA 2007). Habitat map data area estimates for "coral reef and hardbottom" habitat were delineated for each of the management regimes (Open Area/FRA/MPA) and the area multiplied by WHAP survey density for the species under consideration (Kosta Stamoulis pers. comm.).

Overall Yellow Tang abundance in the 30’-60’ depth range over the entire West Hawai′i coast is estimated to have increased by over 3.4 million fish from 1999/2000 to 2017/2018 (150% increase) to a current population of about 5.7 million fish within this depth range alone.

The difference in Yellow Tang abundance between the Open Areas and FRAs has been less in recent years likely due to decreases in aquarium catch and effort (Figure 6) and reliable recruitment. Summer 2014 recruitment was the highest recorded since WHAP monitoring began in 1999. Indeed, at a number of locations around the state, 2014 recruitment has been termed ‘biblical’ (Talbot 2014). At the most southerly WHAP survey site (Manukā, Ka′u District), the number of Yellow Tang recruits in July 2014 was 390% higher than on any other previous survey at the site over the last 20 years.

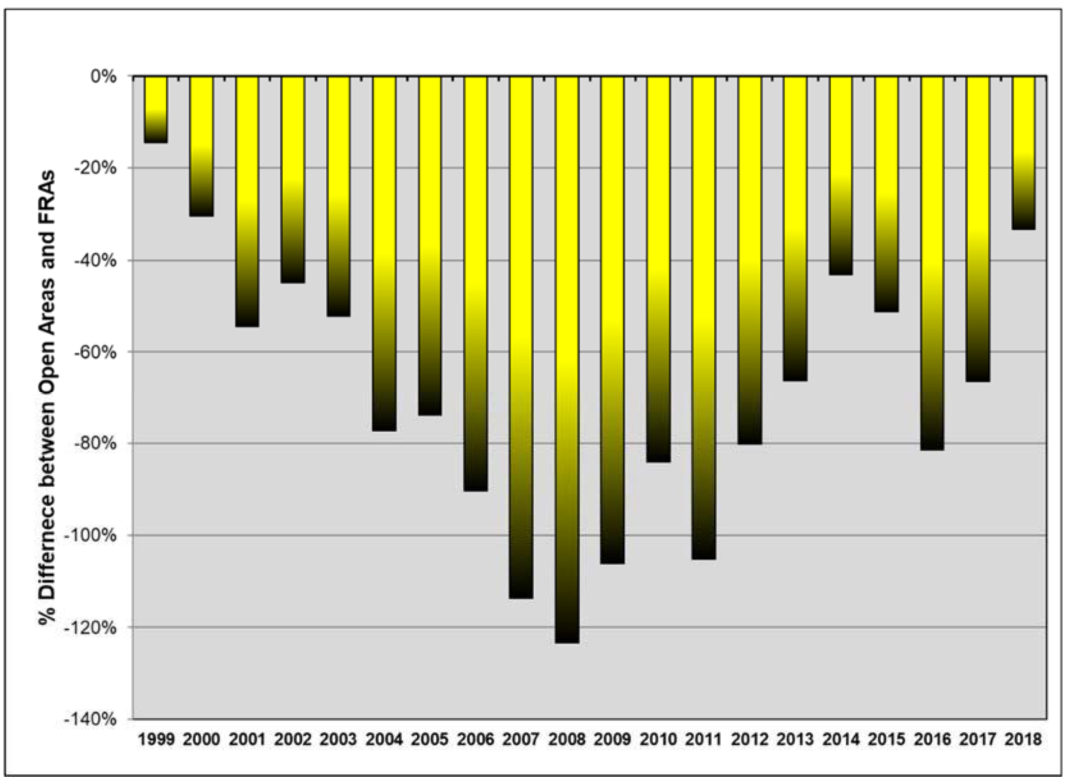


Figure 6. Difference in mean Yellow Tang abundance in West Hawai′i Fish Replenishment Areas (FRAs, n=9) relative to Open Areas (n=10). Bars represent the % difference in abundance for each year from 1999 to 2018. Bars *below* the x axis indicate greater abundance in the FRAs than the Open areas.

In addition to the WHAP surveys, DAR also conducts three long-term studies which provide a more expansive overview on changes in the abundance of aquarium targeted species over several decades. One of the sites at Hōnaunau in South Kona is being resurveyed for 4 summers beginning in 2018 and is therefore not included in this report.

Another of these long-term studies was conducted at two sites in South Kohala in 2007/2008 (Walsh et al. 2018). One site is at Puakō which has been a Fishery Management Area (FMA) since 1985 in which the use of all nets, except thrownets, is prohibited (thus no aquarium collecting). The other site is 2.5 km to the south at Pauoa Bay which became an FRA in 2000 and was also closed to laynetting in 2005. These sites were originally surveyed in 1979-1981 by the UH Hawaiʻi Cooperative Fisheries Research Unit (Hayes et al. 1982). As can be seen in Figure 4, there was little aquarium collecting occurring in West Hawaiʻi during the time period of the original study, thus population estimates for Yellow Tang at that time represent a largely unfished state given that they are not a highly desired food fish.

Yellow Tang abundance declined by 9% at Puakō but increased by 15% at Pauoa Bay from 1979-1981 to 2007-2008. (Figure 7). Unfortunately, due to how the data were presented in the original study, statistical analysis of this change is not possible. Yellow Tang is one of only a few species which has not undergone substantial declines in both of these areas - indeed it increased somewhat at Pauoa. Both the Puakō and Pauoa sites have suffered major habitat degradation and fish declines over the past three plus decades with marked declines in live coral cover and crustose coralline algae and increases in turf and macroalgae (Minton et al. 2012, Walsh 2013, Walsh et al. 2018).

Aquarium targeted species are not the only ones which have declined but rather major declines were apparent in all trophic levels and most fish families. As noted above, both areas have been off-limits to aquarium collecting for quite some time and thus it is not reasonable to attribute the extensive changes in habitat and fish populations at these sites to aquarium collecting.

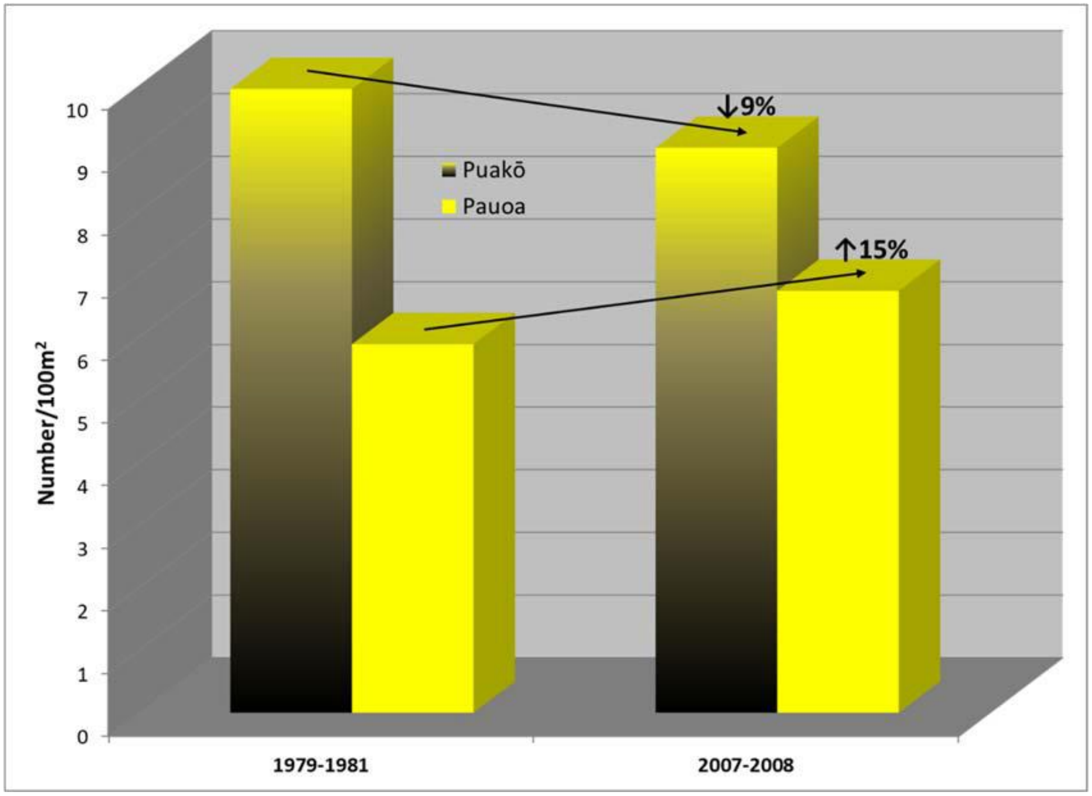


Figure 7. Long-term changes in Yellow Tang abundance at two South Kohala sites.

Another long-term study currently underway at Ke′ei, on the south side of Kealakekua Bay, South Kona provides a more detailed view of decadal changes in fish populations. Surveys have been conducted at this site during 1977-86 and 1998-2019 (307 surveys as of September 2019). As with the South Kohala sites, the earliest surveys (i.e. 1970's) represent a largely unfished population. As aquarium collecting increased in West Hawai′i in the 1980's/90's Yellow Tang populations declined (Figure 8). Ke′ei became an FRA in 2000 and since that time Yellow Tang populations have rebounded to where they are essentially currently the same as in the 1970's. Note the 4% difference between the 1970's and the 2010's is not statistically significant (t-test - ρ=0.6).

The reserve (i.e. FRA/MPA) effects described above in enhancing and sustaining targeted West Hawai'i fish populations are striking, but also of importance are the effects of the reserve network on the breeding populations of these species. While Yellow Tang can occur over a wide range of habitats (Ortiz and Tissot 2008) including the deeper (~70'-130') mesophotic reef (Bogeberg 2014), the bulk of the adult population occurs in relatively shallow reef areas. When Yellow Tang reach sexual maturity, most leave the deeper coral rich reef areas where they settled (and where DAR transects are located) for shallower reef habitat (Claisse et al. 2009). For females, this occurs at approximately 4-5 years of age and for males at age 5-7. To supplement long-term WHAP monitoring, DAR initiated a series of surveys in 2006 using Diver Propulsion Vehicles (DPV) of the shallow reef habitats (10'-20' depths) utilized by adult Yellow Tang.

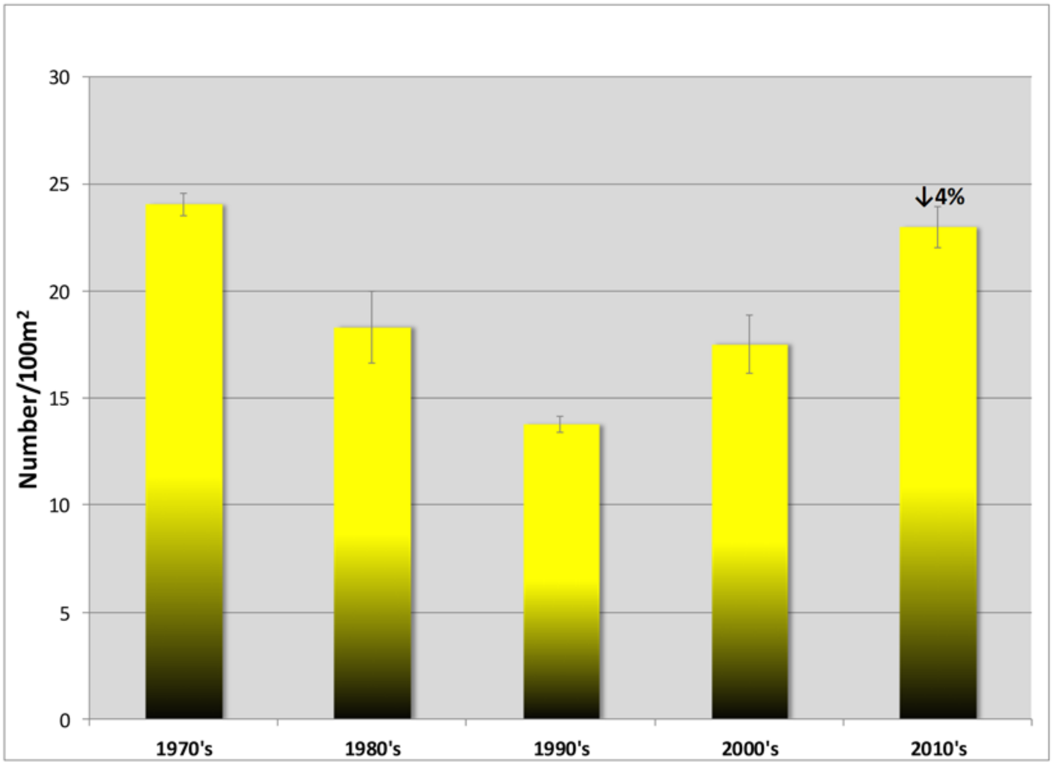


Figure 8. Long-term changes in Yellow Tang abundance at Ke′ei, South Kona.

Adult densities were highest within protected areas and in ’boundary’ areas (open areas adjacent to protected areas) (Williams et al. 2009). Densities were lowest in open areas far from protected areas (Figure 9). The high densities in boundary areas are indicative of ‘spillover’ (outward movement from reserves into surrounding open areas) and demonstrate that protected areas supplement adult stocks not only within their own boundaries, but also in open areas up to a kilometer or more away. Thus, the 35% of the coastline in reserves sustains Yellow Tang (and other similar species) breeding stocks in approximately 50% of the coastline.

If all Open and Protected Areas are considered together, there are no significant overall differences (Figure 10 t-test ρ=0.71) in the abundance of adult Yellow Tang in open vs. closed areas based on shallow reef DPV surveys. Total estimated coastwide population of adult Yellow Tang in this depth range during this period was estimated to be > 2.5 million individuals. It should be noted that with the latest West Hawai′i Regional Fishery Management Area Administrative Rule there is now a bag limit of 5 Yellow Tang per person per day for fish > 4.5” Total Length (TL). This limit applies to all fishers and thus helps to ensure the productivity of the breeding population of Yellow Tang. There is also a similar bag limit which was proposed by the Big Island Association of Aquarium Fishers (2010) for the smallest (< 2”) Yellow Tang which were reported to not survive handling and transport very well.

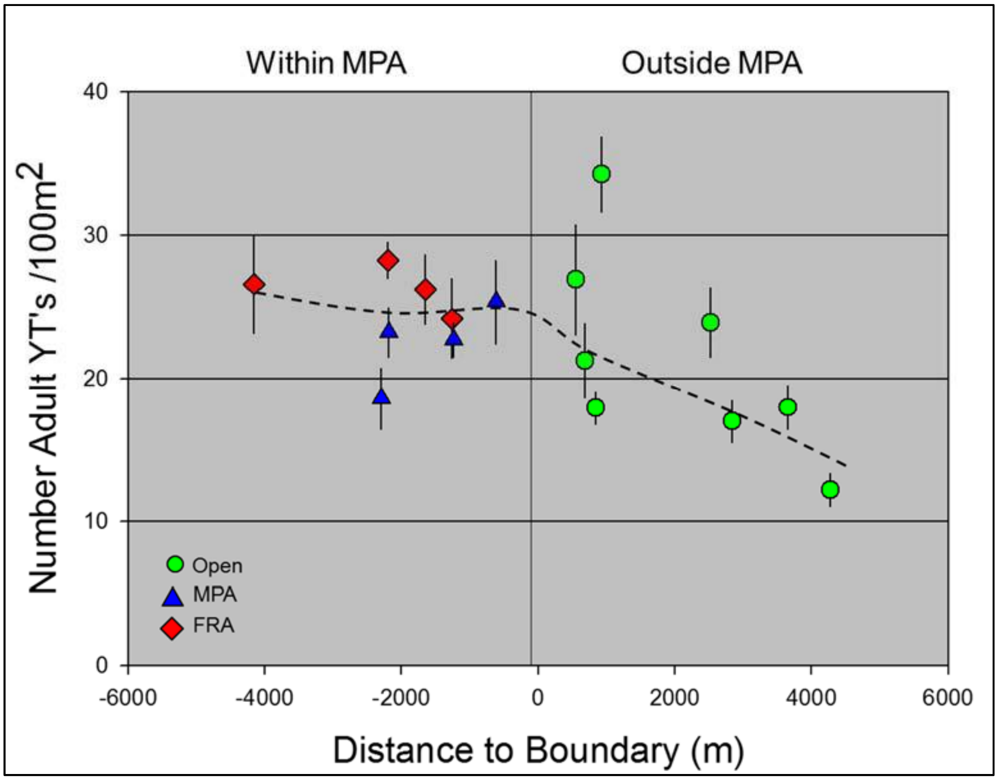


Figure 9. Yellow Tang abundance in adult habitats relative to distance of survey site from nearest protected area boundary. Data points represent mean ± 1 SE by site (n = 5 surveys per site). The trend line was generated using a LOESS smoothing function (after Williams et al. 2009).

For Yellow Tang, populations are robust and have been increasing in protected areas and in some cases have reached levels found decades ago before aquarium collecting expanded along the coast. In the shallower shoreline areas open to aquarium collecting, breeding populations of Yellow Tang in Open Areas are not significantly different than closed areas and in deeper WHAP survey site areas (30'-60') the population of smaller, aquarium-targeted, Yellow Tang has increased significantly over the last 20 years.

The effectiveness of the West Hawai'i FRA network in increasing Yellow Tang populations within the protected areas is clear. The benefit of such increases extend beyond just the FRAs as larvae from a West Hawai'i FRA has been documented to seed unprotected areas (Christie et al. 2010). This demonstrates the high connectivity among populations through larva dispersal and adult movement.

Comparative surveys around the Main Hawaiian Islands utilizing DAR and NOAA Coral Reef Ecosystem Program (CREP) data (2006-2008) indicates that Yellow Tang are substantially more abundant over all size ranges in West Hawai'i than on any of the other Main Hawaiian Islands (Figure 11). Data are for the years 2006, 2007 and 2008 in the NWHI, and 2006 and 2008 for

WHAP and MHI. All sites are forereef sites (30'- 60') surveyed with belt transects for West Hawai'i (WHAP), and by stationary point count (SPC) surveys for other locations (CREP). It should be noted that aquarium collecting in West Hawai'i was at its peak during these years (Figure 4).

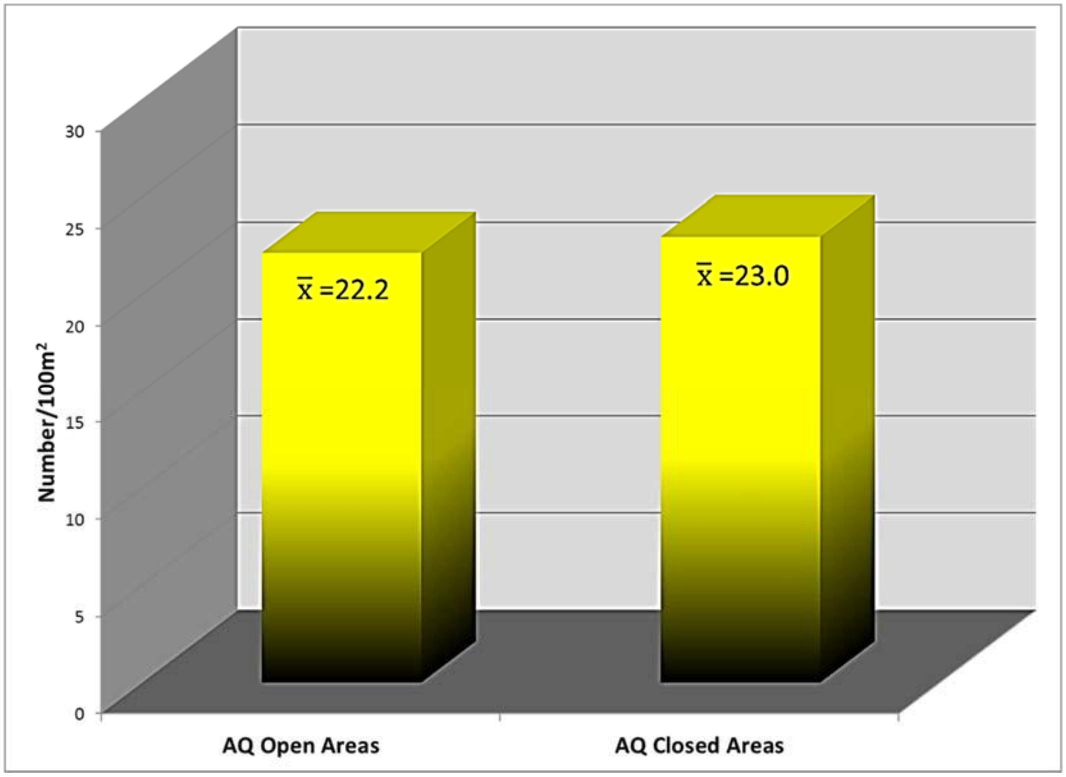


Figure 10. Adult Yellow Tang abundance (Mean ±SE) in West Hawai'i shallow water (10'-20') habitats.

The importance of having multiple planned MPA sites (i.e. network) was also documented by a study (Grorud-Colvert et al. 2014) which compared Yellow Tang abundance in the West Hawai'i planned MPA network with that of two non-networked MPAs in Maui County. The researchers found that West Hawai'i had a significantly greater percent change in Yellow Tang density within the networked MPAs (and Open Areas) before vs. after network establishment as compared to the Maui non-networked sites during the same time period.

A comparison of West Hawai'i with Maui using 2002-2010 WHAP and NOAA-CREP data found that for the 10 most collected aquarium fish in West Hawai'i, all were more abundant in West Hawai'i's o*pen areas* as compared to Maui MPA *closed areas* –Molokini MLCD and 'Ahihi-Kina'u (Figure 13).

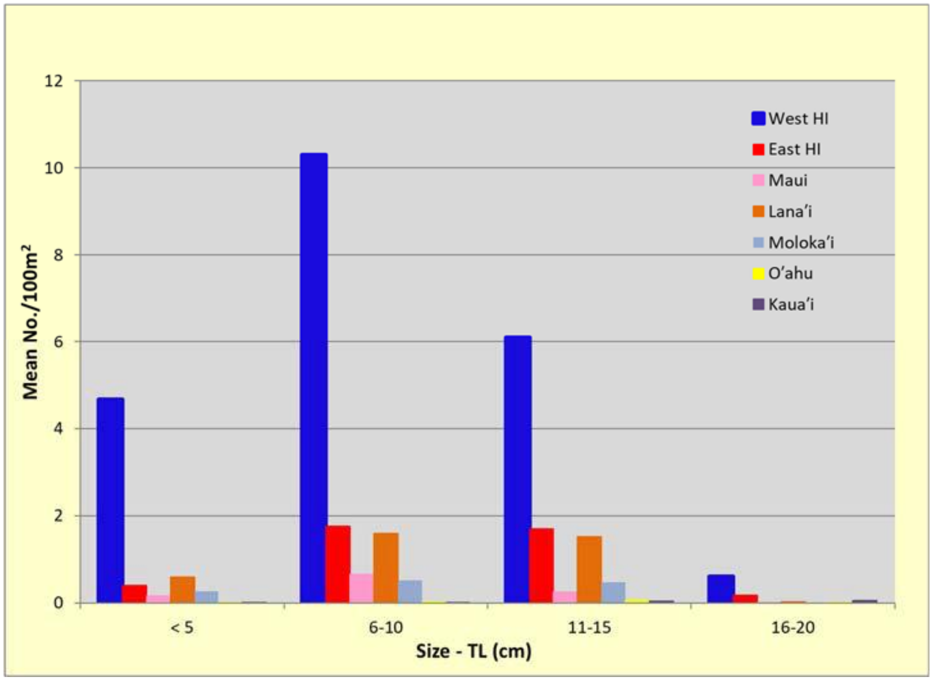


Figure 11. Comparison of size distributions of Yellow Tang at various Main Hawaiian Island (MHI) sites 2006-2008.

Perhaps somewhat surprisingly, all Yellow Tang size classes are also more abundant in West Hawai′i than at any surveyed sites within the unfished Northwestern Hawaiian Islands (Figure 12).

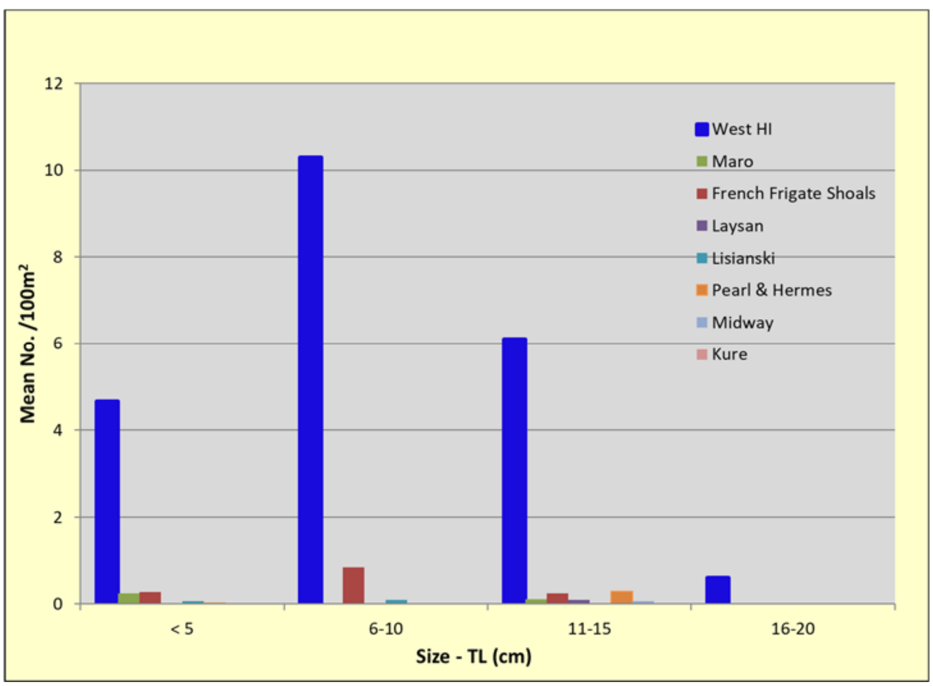


Figure 12. Comparison of size distributions of Yellow Tang at various Northwestern Hawaiian Island (NWHI) and West Hawai′i 2006-2008.

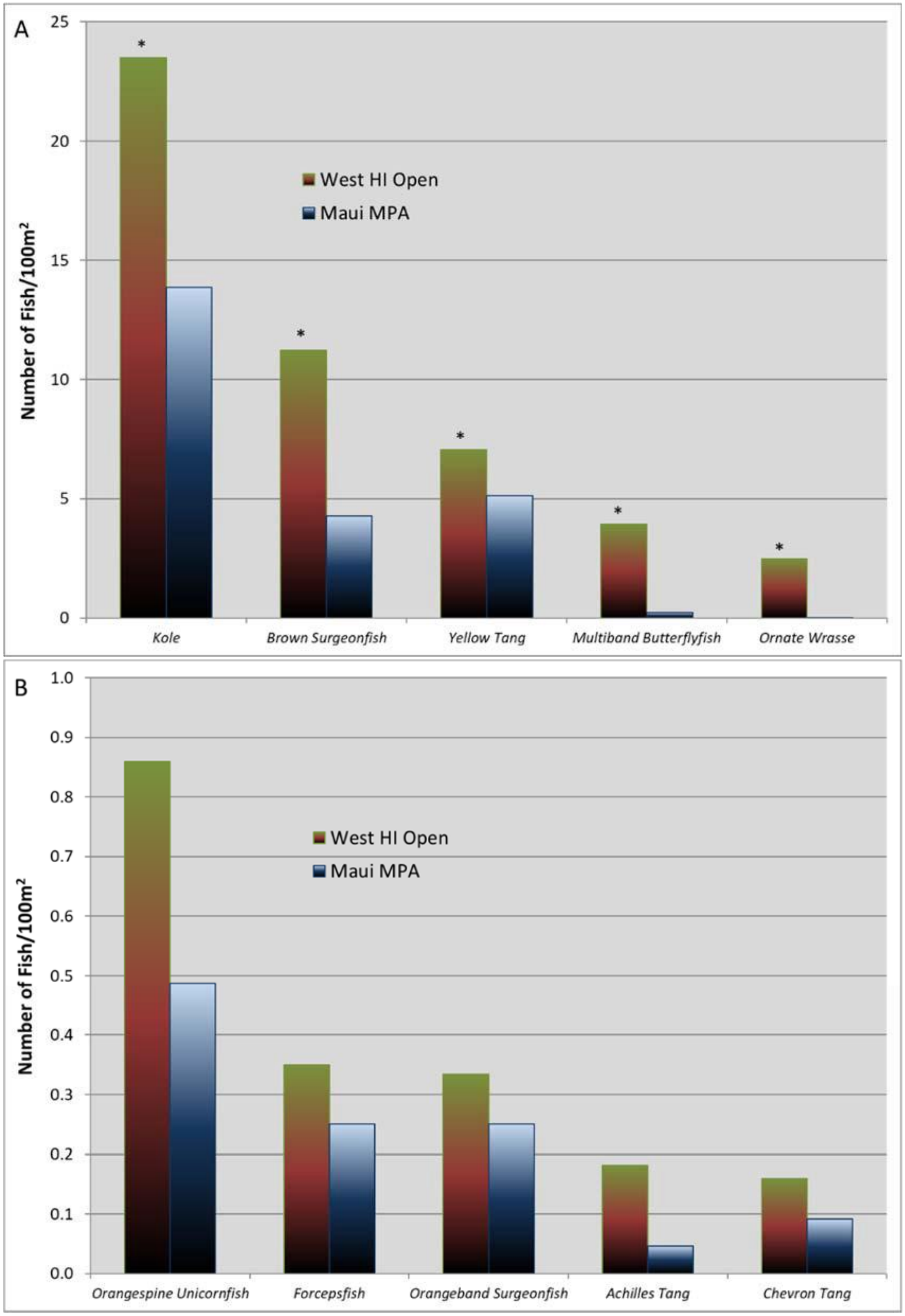


Figure 13. Comparison of aquarium fish abundances in West Hawai'i Open Areas with Maui MPAs 2002-2010. A - Asterisk indicates a statistically significant difference (t – test $\rho \leq 0.005$). Note differences in scale of Y axis in A vs. B.

Goldring Surgeonfish (Ctenochaetus strigosus, Kole)

Kole is the second most collected species in the West Hawai'i aquarium fishery comprising 9.5% of the total catch (FY 2017). Recruitment patterns are markedly similar between Kole and Yellow Tang likely due to similarities in spawning seasonality, location and daily timing (Walsh 1984, 1987). As with Yellow Tang, recruitment of Kole has been variable but generally reliable over the past 15 years (Figure 14).

The FRAs have also been very successful in increasing Kole populations in West Hawai'i. The number of Kole, excluding YOY, increased 85% in the FRAs, 120% in the MPAs and 97% in the Open Areas (1999/2000 – 2017/2018 comparison).

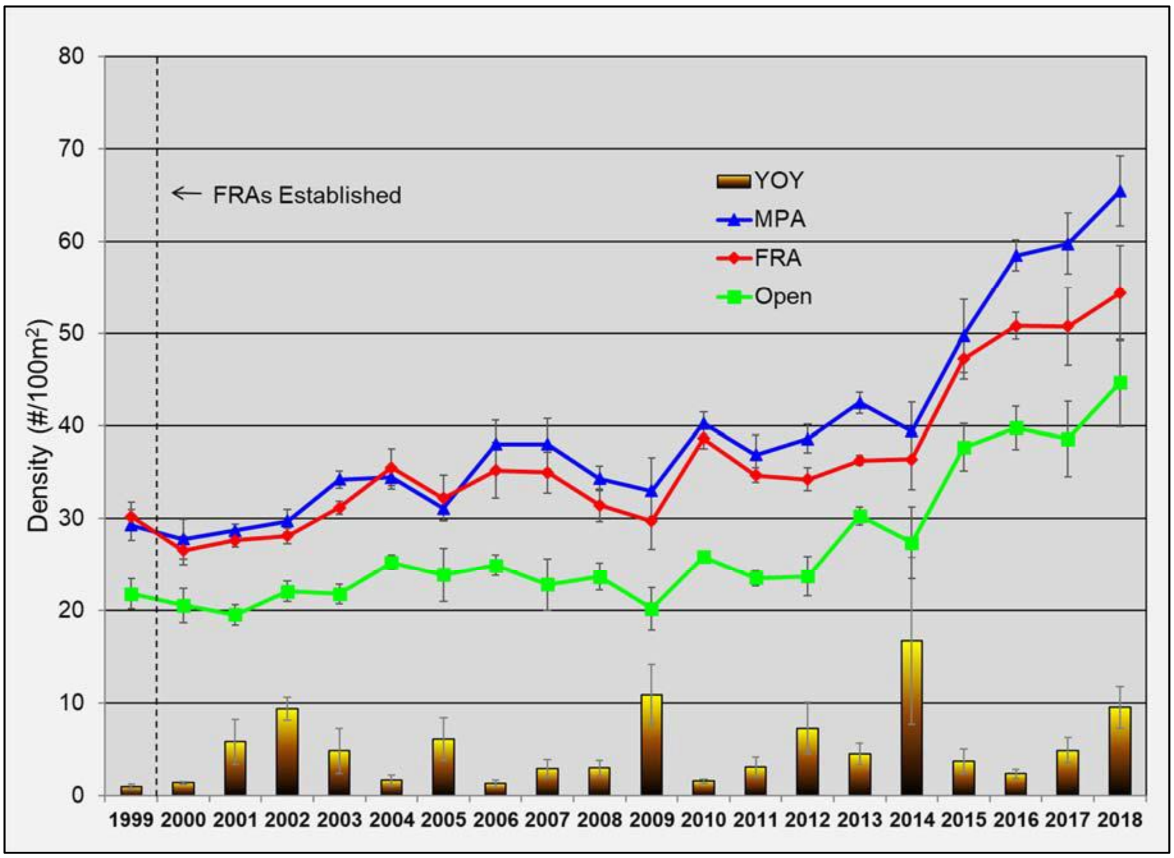


Figure 14. Overall changes in Goldring Surgeonfish (Kole) abundance (Mean ± SE) in FRAs, MPAs and Open areas, 1999-2018. Vertical bars indicate mean density (May-Nov) of Goldring Surgeonfish Young-of-Year (YOY). YOY are not included in trend line data.

Kole abundance is lower (23.4% for 2017/2018) in the Open Areas relative to the FRAs but not as low as for Yellow Tang. This reflects the substantially lower take of this species in the aquarium fishery. The difference in Kole abundance between the Open Areas and FRAs has been largely stable over the years (Figure 15).

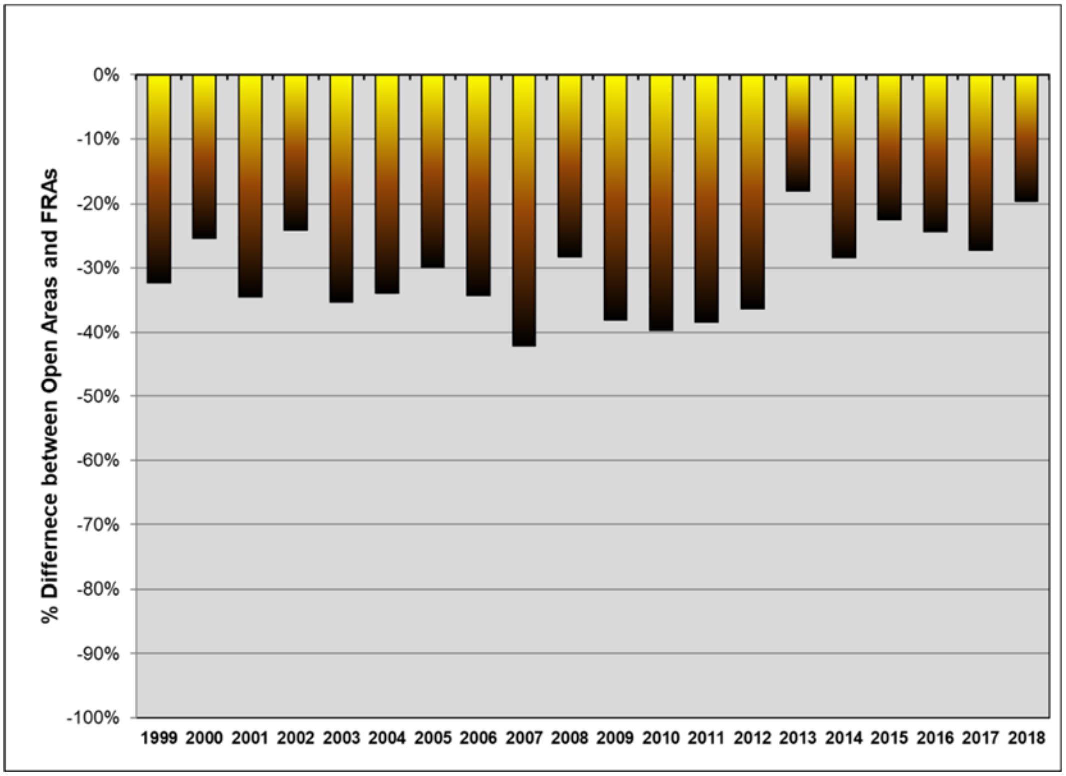


Figure 15. Difference in Kole abundance in West Hawai′i FRAs (n=9) relative to Open Areas (n=10). Bars represent the percent difference in abundance each year from 1999 to 2018. Bars below the x axis indicate greater abundance in the FRAs than the Open areas.

Overall Kole abundance in the 30’-60’ depth range over the entire West Hawai′i coast is estimated to have increased 118% (>5.1 million fish) during this time period with a current estimated population of almost 9.6 million fish. As with Yellow Tang, summer 2014 recruitment for Kole in many areas was very strong. Recruitment at the Manuka survey site for example was 254% higher than on any other previous survey at the site over the last 20 years.

As with Yellow Tang, an effort was made by the West Hawai′i Fishery Council (WHFC) to protect the breeding populations of Kole by establishing a bag limit of 5 Kole per person per day for fish > 4” TL. This limit, which applies only to aquarium collectors, was included in the latest West Hawai′i Regional Fishery Management Area Administrative Rule.

In contrast to the population increases in the WHAP study, two long-term West Hawai′i studies have found Kole to have decreased from earlier periods. The most pronounced decreases occurred at the two South Kohala sites (Figure 16).

The Pauoa FRA has been closed to aquarium collecting for 15 years and lay netting for 10 years. The Puakō FMA has been closed to aquarium collecting (i.e. no nets other than thrownets permitted) for 40 years. Given the length of protection at these two areas and the overall decline in habitat quality (i.e. declines in coral cover and crustose coralline algae and increases in turf and macroalgae) and declines in fish populations at the South Kohala sites (Minton et al. 2012, Walsh 2013, Walsh et al. 2018), it seems highly unlikely that the decline of the Kole population is due primarily to aquarium collecting.

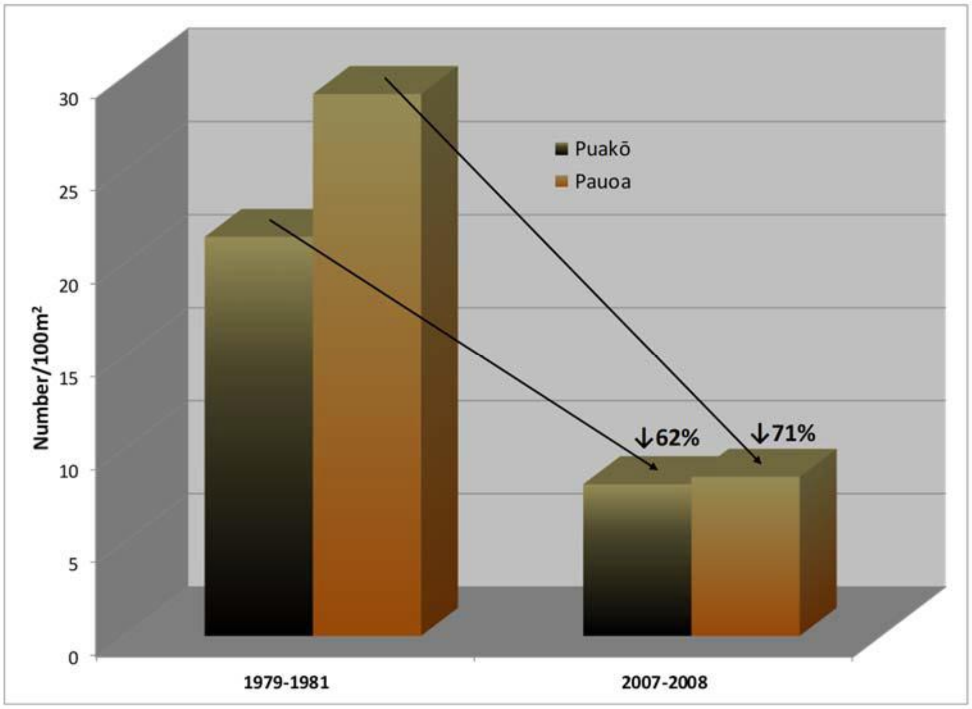


Figure 16. Long-term changes in Kole abundance at two South Kohala sites.

At Ke′ei there has been an increasing trend in Kole abundance since 2000 when the area became part of an FRA (Figure 17) but current abundance is still significantly below what it was in past decades (1970's – 2010's $\rho<0.01$).

Kole is regarded as a highly desired food fish by some fishers and targeted accordingly. Given the low aquarium catch of this species relative to its West Hawai′i population in Open Areas (0.58%), it seems inescapable that non-aquarium harvesting activities are an important contributor to observed population declines in West Hawai′i.

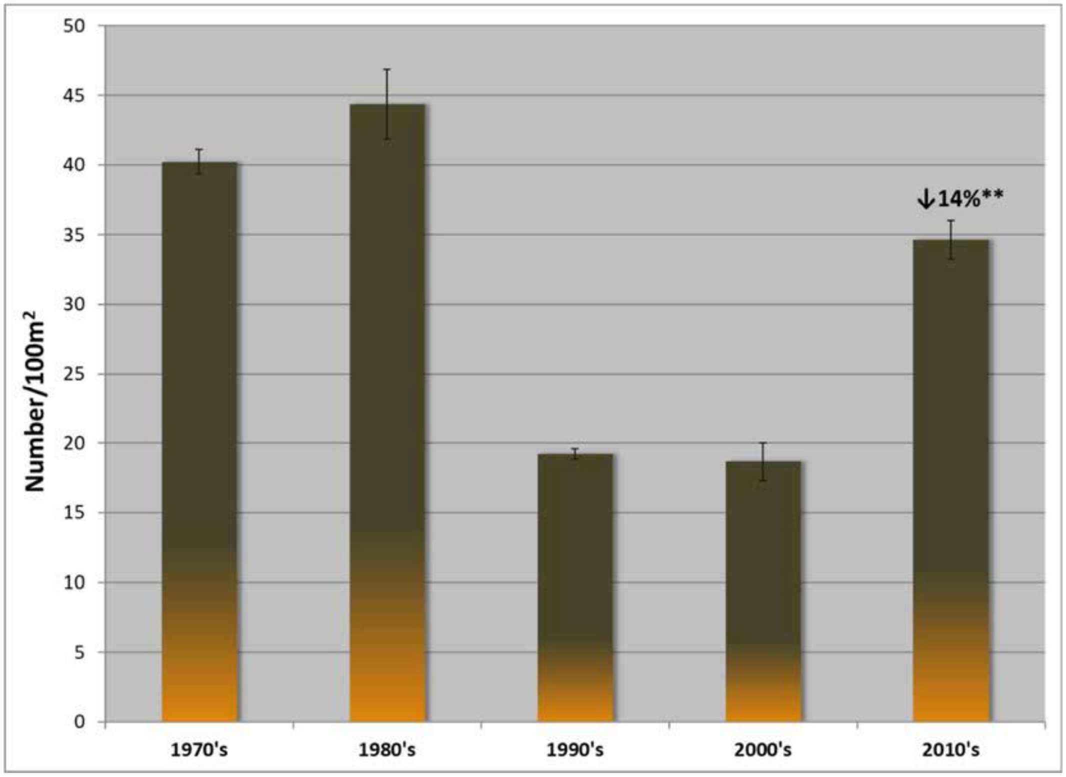


Figure 17. Long-term changes in Kole abundance at Ke′ei, South Kona.

Even with the documented long-term declines in Kole populations in West Hawai′i, the species remains very abundant, at least in the smaller and mid-size ranges. As with Yellow Tang, comparative surveys around the Main and Northwestern Hawaiian Islands utilizing WHAP and CREP data (2006/2008) indicate that Kole are substantially more abundant over most size ranges in West Hawai′i than in any of the other Hawaiian Islands (Figures 18 & 19).

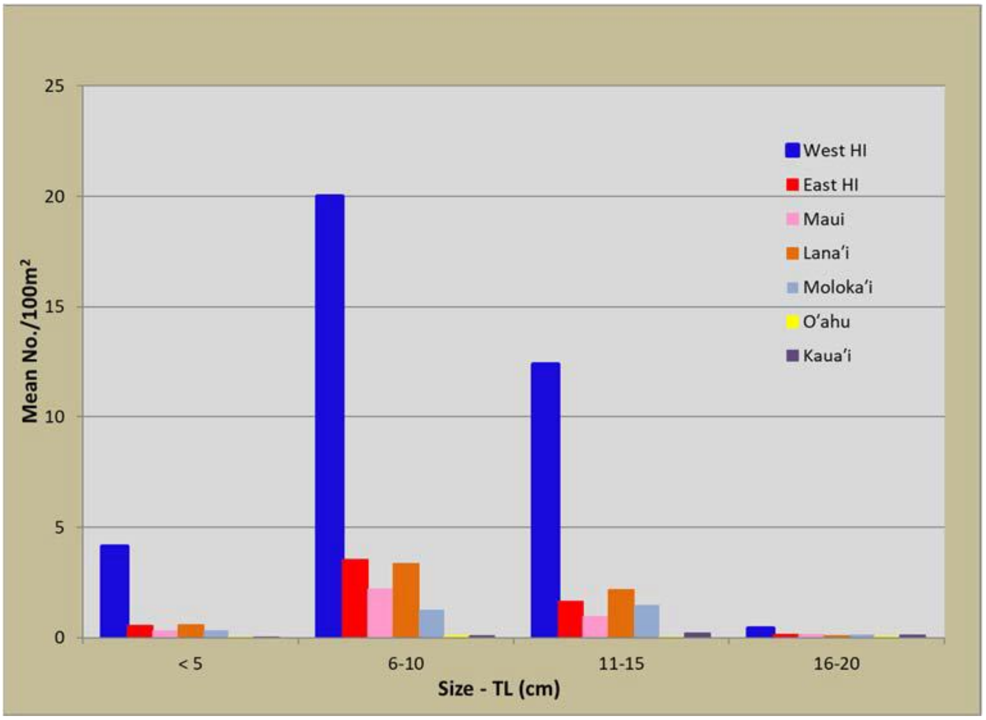


Figure 18. Comparison of size distributions of Kole at various Main Hawaiian Island (MHI) sites 2006-2008.

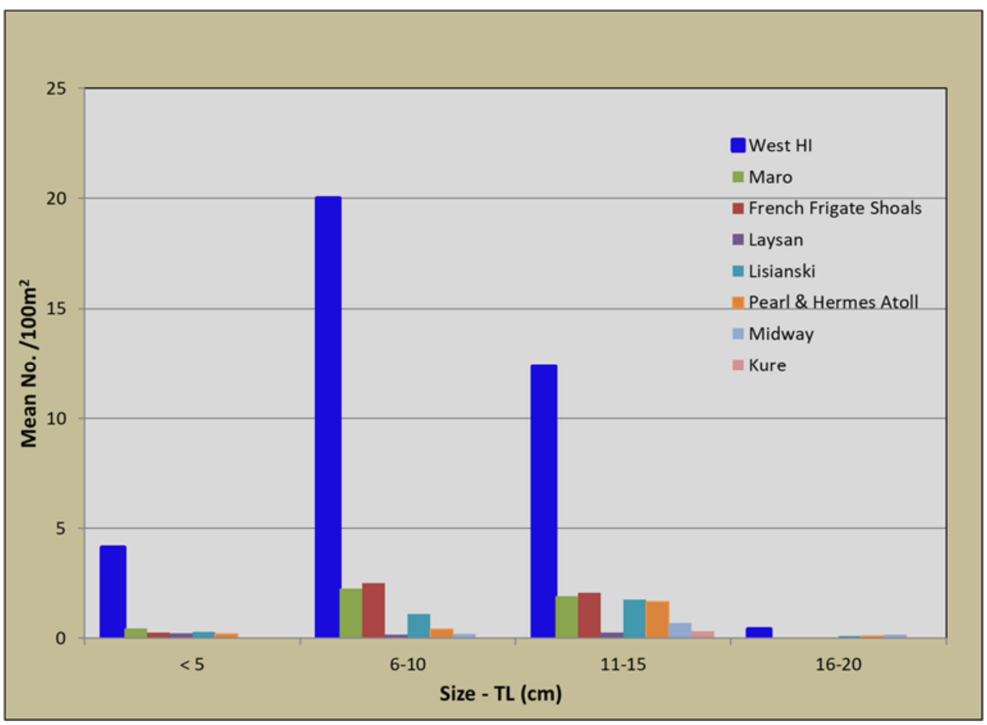


Figure 19. Comparison of size distributions of Kole at various Northwestern Hawaiian Island (NWHI) sites and West Hawai'i 2006-2008.

Other White List Species, Catch ranked 3-10

The overall mean abundance of the combined top 3-10 collected aquarium species (Table 3) increased in all management areas since the FRAs were established (Figure 20). These

seven species constitute 7.1% of the total FY 2017 West Hawai'i catch (Table 3) and when added to the catch of Yellow Tang and Kole, comprise 98.2% of total catch. Interestingly, abundances were consistently higher in the Open Areas for five of these species while there wasn't a consistent pattern for the other three species.

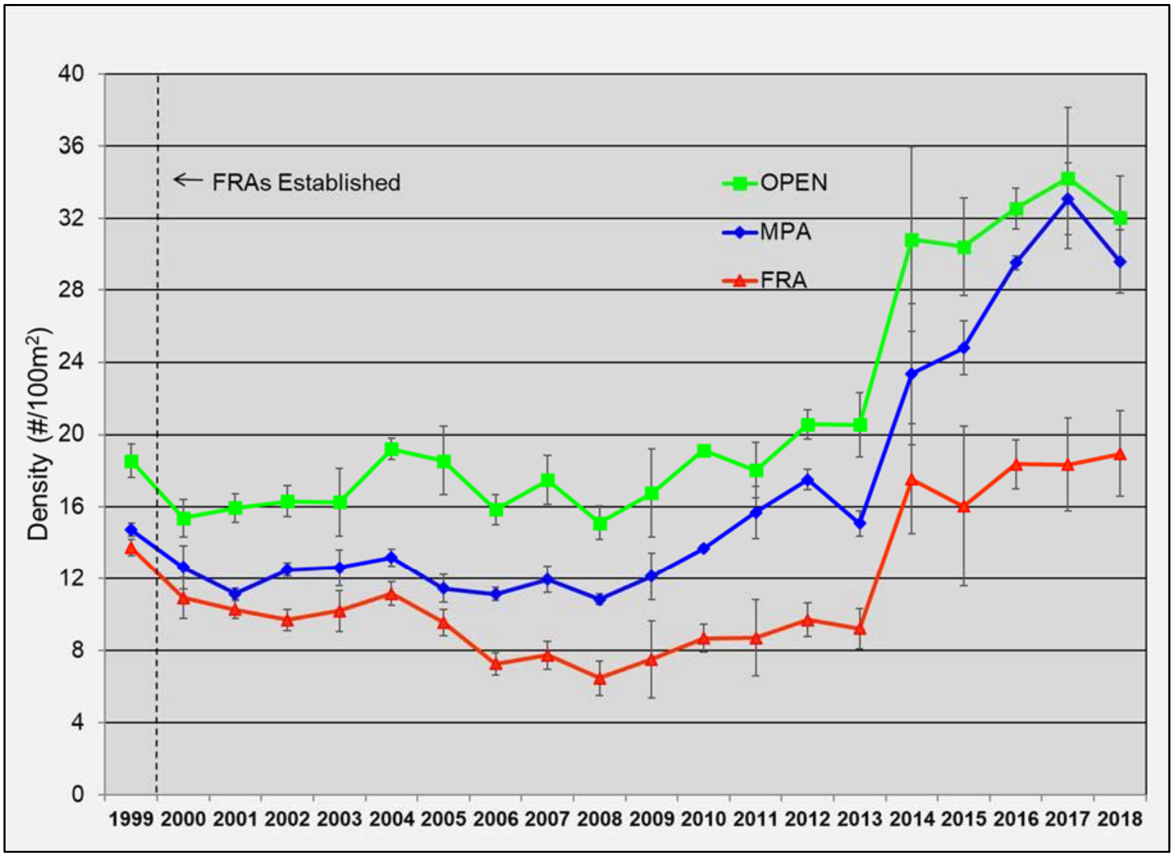


Figure 20. Overall changes in the abundance (Mean ± SE) of the top 3-10 collected aquarium species in Open Areas, MPAs and FRAs, 1999-2018. YOY are not included in trend line data.

Six of seven of the top 3-10 collected species had long-term population increases in one or more of the management areas. One notable exception was Achilles Tang (*Acanthurus achilles*) which declined in all areas, significantly so in Open Areas and FRAs (Table 4).

Achilles Tang (Acanthurus achilles, Pāku'iku'i)

Achilles Tang is the fourth most collected species in the West Hawai'i aquarium fishery although relative to Yellow Tang and Kole the numbers collected are low (5,473 fish), representing only 1.7% of the total FY 2017 catch (Table 3).

Commercial aquarium landings of Achilles Tang have been declining in West Hawai'i over the past two decades. This has occurred in association with a 192% increase in the ex-vessel value of the fish since 2008 (Figure 21). Such opposing trends in catch and value are strongly suggestive of declining availability (i.e. abundance). It should be noted that an aquarium bag limit of 10 fish/person/day was established for Achilles Tang in 2013 which may have affected overall catch in subsequent years.

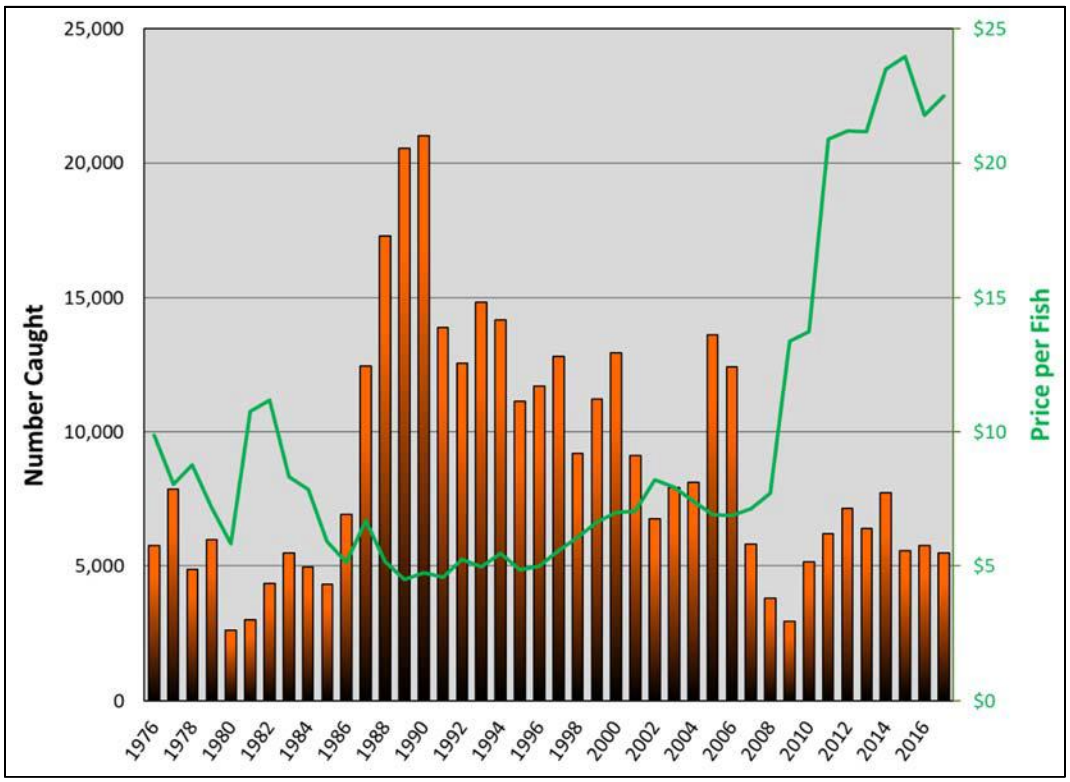


Figure 21. West Hawai'i commercial Achilles Tang aquarium landings and ex-vessel price per fish per fiscal year.

A substantial decline of the Achilles Tang population in West Hawai'i is evident from several data sources. WHAP data show that Achilles Tang have declined significantly in FRAs and Open Areas over the last 20 years (Table 4, Figure 22). A similar declining trend was apparent within MPAs until 2010 when Achilles Tang numbers rebounded somewhat.

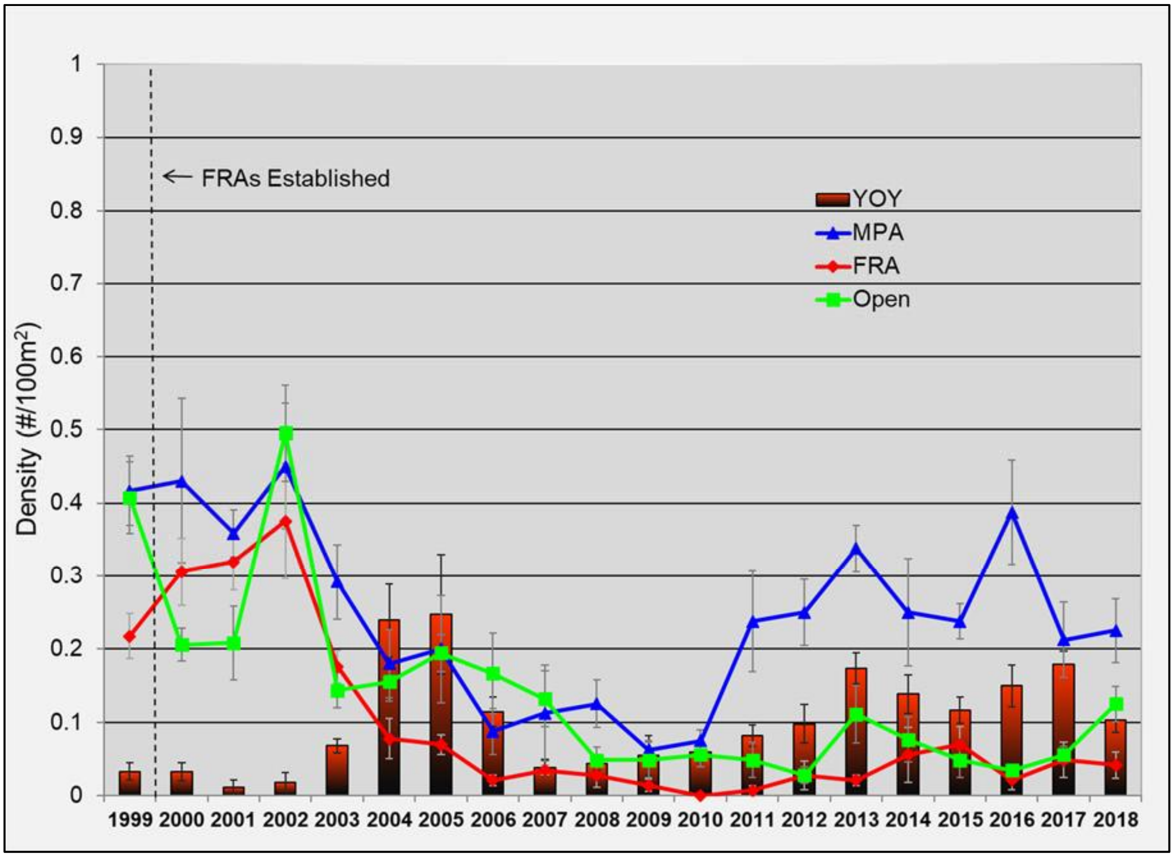


Figure 22. Overall changes in Achilles Tang abundance in FRAs, MPAs and Open areas, 1999-2018. Vertical bars indicate mean density (May-Nov) of Achilles Tang Young-of-Year (YOY). YOY are not included in trend line data.

Achilles Tang has had very low levels of recruitment over the past two decades (Figure 22). The mean density of YOY over the past 10 years for the WHAP sites has only been $0.12/100m^2$. The WHAP sites are in the depth range most typically occupied by Achilles Tang YOY (and juveniles) and are thus well suited for assessing recruitment strength. This long-term low level of recruitment stands in mark contrast to YOY abundance for the two most heavily collected species. Mean Yellow Tang YOY abundance over the last decade was 57X greater ($6.84/100^2$) and Kole YOY abundance was 54X greater ($6.46/100m^2$) than Achilles Tang YOY.

Unlike Yellow Tang and Kole, Achilles Tang have often been more abundant in Open Areas rather than the protected FRAs (Figure 23). The exact meaning of this is unclear at present but may reflect specific habitat differences in the management areas, habitat preferences of Achilles Tang or differential non-aquarium fishing pressure in the various areas. It should also be noted that in the most recent decade, Achilles Tang are more abundant in the MPAs than either the FRAs or Open Areas, perhaps reflecting an increased level of protection in the more restrictive MPAs.

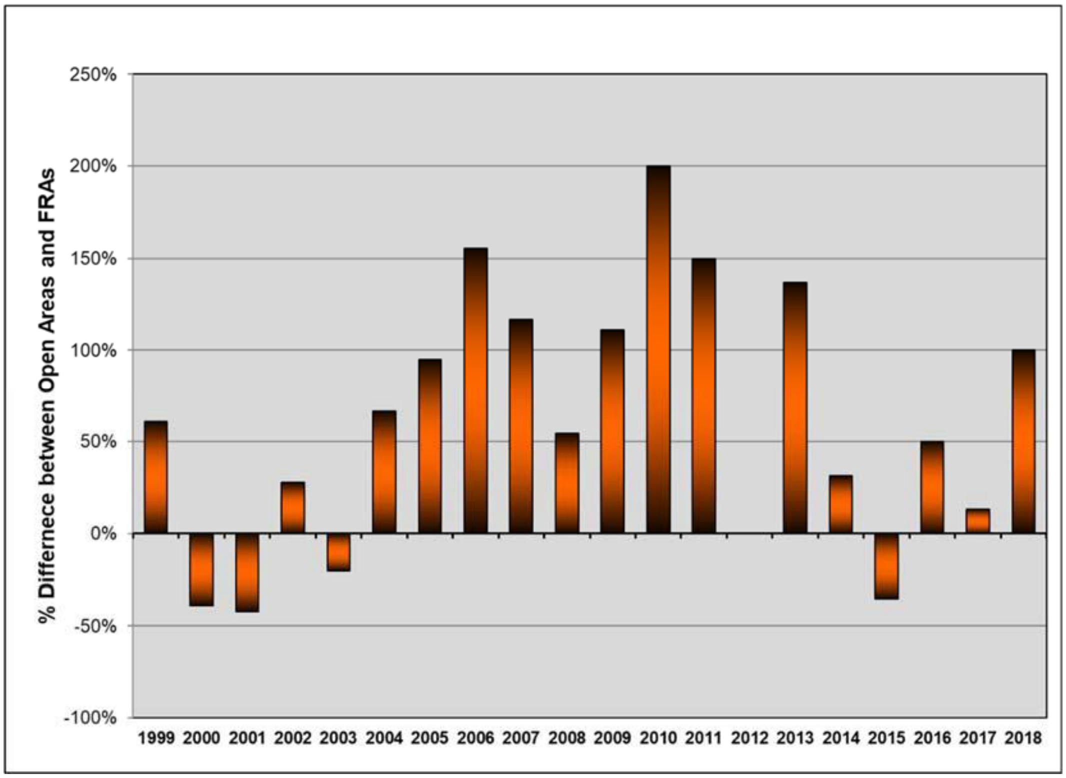


Figure 23. Difference in Achilles Tang abundance in West Hawai'i FRAs (n=9) relative to Open Areas (n=10). Bars represent the percent difference in abundance for each year from 1999 to 2018. Bars above the x axis indicate greater abundance in the Open Areas than the FRAs.

Average densities of Achilles Tang are currently very low ($\overline{x}$ = 0.13/100m^2) on all transects. An important caveat is that the reef areas where the WHAP transects are located are not the prime habitat for adults of this species. Rather, large adults prefer the high energy shallower surge zones more typical of the shoreline drop-offs areas in West Hawai'i (Randall 2007). Presumably algal food resources are more abundant in these areas. As such the bulk of the population is not adequately surveyed by WHAP monitoring. These shallower reef areas are being surveyed however by a different type of monitoring program (Shallow Water Resource Fish Surveys - SWRF) presently conducted by DAR.

SWRF surveys indicate a significant (90%) decrease ($p<0.001$) in Achilles Tang biomass in their primary adult habitat since 2008 when the surveys were first conducted (Figure 24). Achilles Tang were observed on 73% of transects in 2008 but only on 38% in 2018. It should be noted that unlike aquarium fishers in West Hawai'i, there has never been an Achilles Tang bag limit for other fishers.

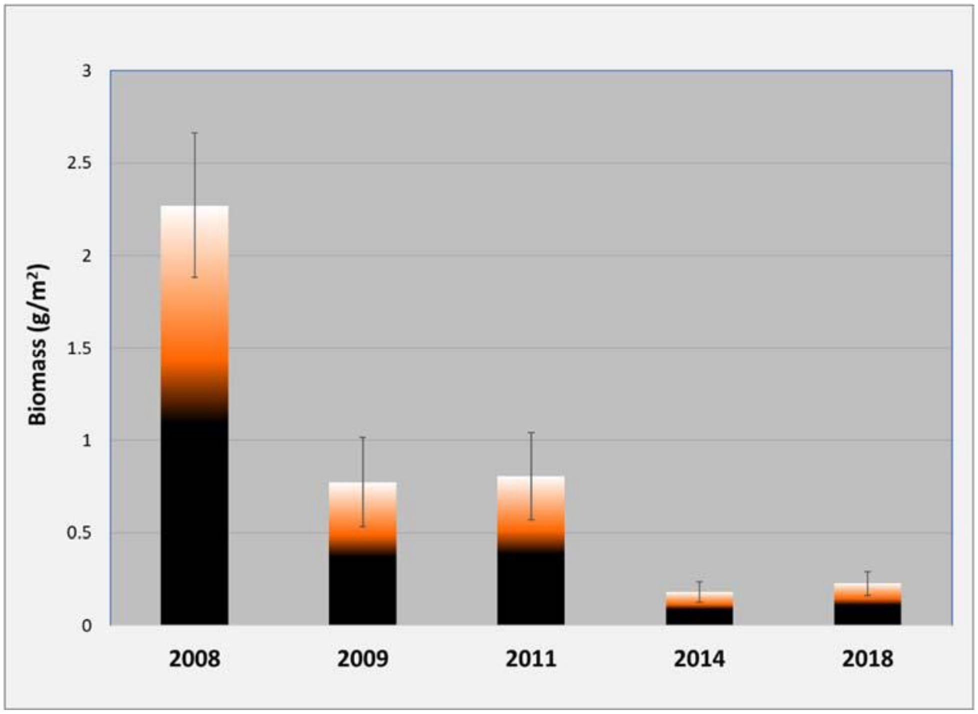


Figure 24. Mean (±SE) biomass of Achilles Tang on SWRF surveys. Mean number of sites surveyed each year was 70 (range 65-73).

Data from the long-term studies in South Kohala and South Kona also show a pattern of decline over the past decades (Figs. 25 & 26).

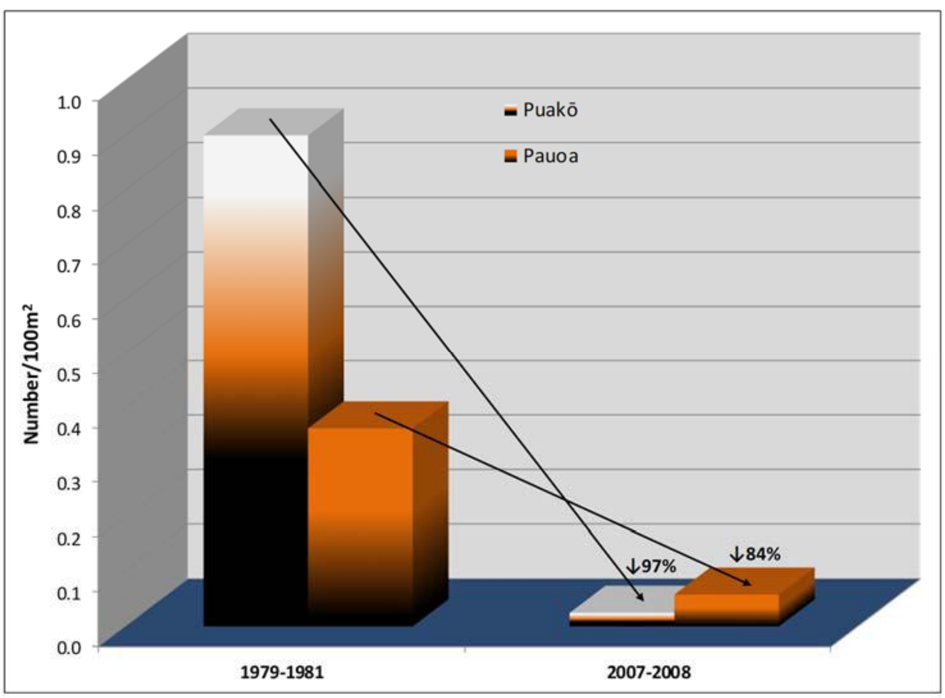


Figure 25. Long term changes in Achilles Tang populations at Puakō and Pauoa.

At Ke′ei, Achilles Tang have not been abundant over the past five decades (Fig. 26) averaging <0.5 fish/100m^2. The population in the present decade is 18% lower than in the 1980's but this difference is not statistically significant (t-test ρ=0.19).

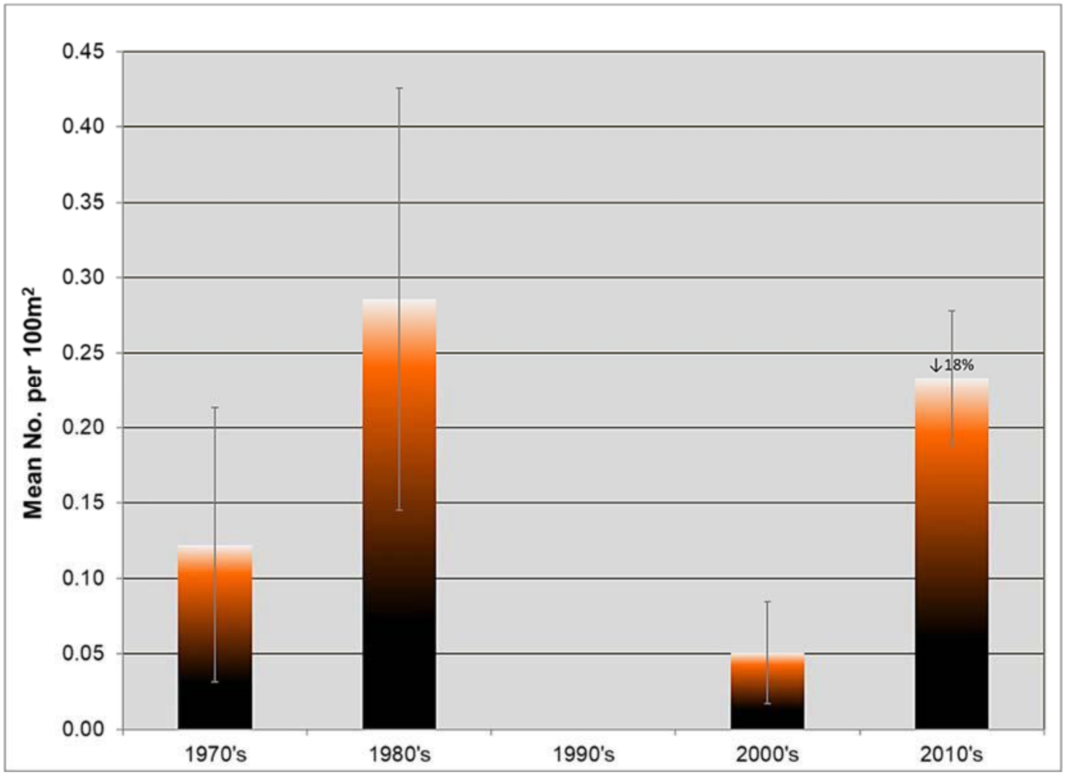


Figure 26. Long term changes in Achilles Tang populations at Ke′ei, South Kona.

Ke′ei notwithstanding, the results from the WHAP monitoring program, SWRF surveys and the long-term study at Puakō/Pauoa suggest there should be concern for the sustained abundance of this species. Achilles Tang are a very popular food fish as well as an aquarium fish and thus are being harvested both as juveniles and adults. Low levels of recruitment (May-Nov $\bar{x}$ = 0.12/100m^2) over the past 11 years appear insufficient to compensate for the existing levels of harvest.

In order to address concerns regarding aquarium impacts on Achilles Tang, a bag limit of 10 fish/person/day was implemented in West Hawai′i at the end of 2013. The bag limit applied *only* to aquarium collectors.

Additionally, beginning in January 2012, DAR's monthly aquarium catch report was converted to a daily aquarium fishing trip report. This daily trip report provided the opportunity to investigate the potential impact of the Achilles Tang daily bag limit.

In West Hawaiʻi in 2012, before the bag limit was implemented, 38 aquarium collectors holding Commercial Marine Licenses (CMLs) collectively caught (and reported) 8,111 Achilles Tang over a total of 515 days effort. There were 6 daily reports (representing 102 Achilles Tang – 1.3% of total catch) which were excluded from the analysis due to multiple day's catch being erroneously reported as a single day. Only 21% of the daily catches per fisher exceeded the proposed daily bag limit, yet they represented 65.8% of the total catch (Figure 27). If the Achilles Tang bag limit had been in effect in 2012 the total catch would have been reduced by 3,227 fish – a 40.3% reduction in catch. Since the bag limit was enacted, the mean annual Achilles Tang catch has decreased by 15.9% (mean of FY11-13 vs. mean of FY15-17).

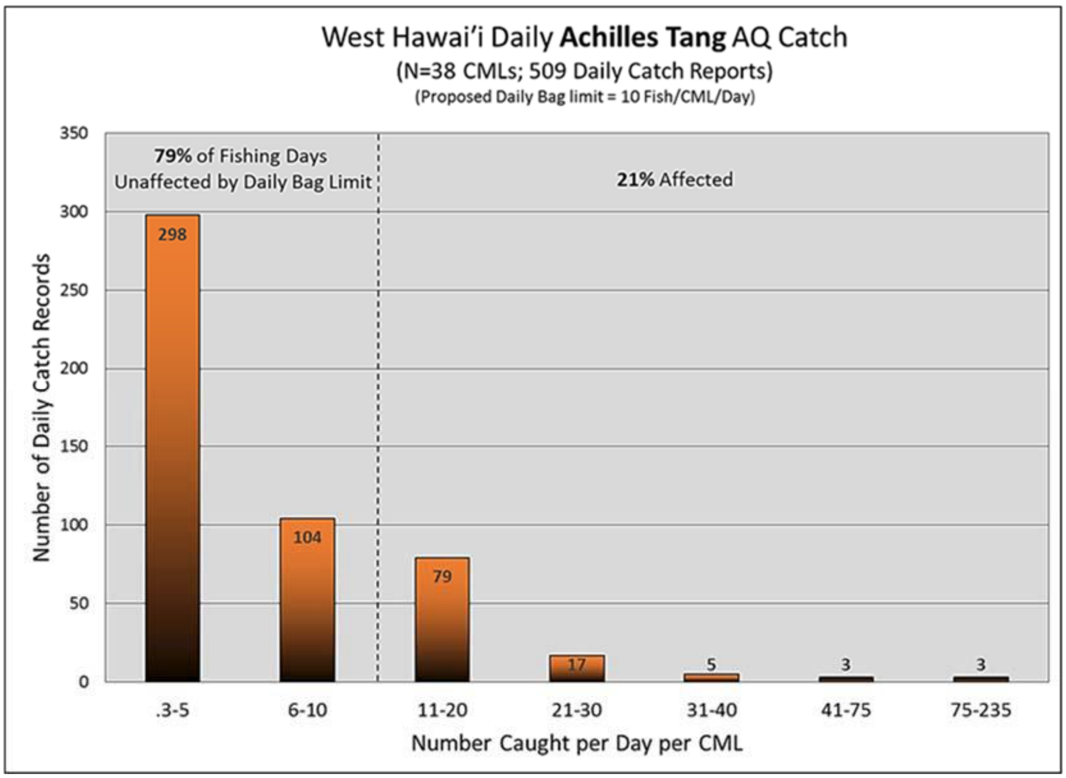


Figure 27. Number of Achilles Tang caught per day by West Hawaiʻi aquarium collectors in FY 2012. The numbers on the bars represents the number of daily catch reports for each category.

It is difficult to precisely project the overall impact of the West Hawaiʻi Achilles Tang bag limit. On the one hand, if there is good compliance with the limit and existing conditions regarding collecting, market forces and population abundances remain relatively stable, then a decrease in overall catch would be anticipated. If targeted effort towards this species increases, even while limited by the bag limit, total catch might increase.

Given the overall evidence for a marked decline in the population of Achilles Tang in West Hawaiʻi, the existing aquarium-only bag limit appears to be insufficient to stem this decline. A reduction in the aquarium bag limit or a moratorium on aquarium collecting for this species, in conjunction with a conservative bag limit for other fishers should be considered.

26 Other White List Species

Of the 40 fish species on the White List, there are four for which we do not have WHAP survey data. Three of these, Tinker's Butterflyfish, Hawaiian Longfin Anthias and Flame Wrasse occur in habitats deeper (typically >100', Randall 2007, Hoover, 2008) than where the WHAP transects are located. The other species, the Eyestripe Surgeonfish is usually found during the day over sand habitat, again not where WHAP transects are located. Two additional species, Psychedelic Wrasse and Fisher's Angelfish also tend to be deeper water species but are recorded on WHAP transects with some regularity. Population estimates for these two species based on WHAP data are thus considered to be substantial underestimates of their actual abundances.

In addition to the top 10 collected species, there is good long-term survey data for 26 other White List species (Table 5). Of these, 10 species showed a significant population increase in one or more of the management areas while 11 decreased. Of these 11 species, only the Blackside Hawkfish decreased exclusively in the Open Areas and thus it is difficult to attribute the observed significant population decrease as being due solely to aquarium collecting. Reported total annual aquarium take of Blackside Hawkfish is so low (Table 6) and constitutes such a minimal percentage of the total Open Area population (0.13%) it's unlikely that aquarium collecting alone could be the cause of this species' population decline in the Open Areas.

Table 5. Changes in abundance of 26 White List species in West Hawai′i over the past 20 years. The comparison is between the mean of 1999-2000 and the mean of 2017-2018. Colored cells show statistically significant changes. Note that all mean density values are rounded to two decimal places which may result in slight differences in the table values between periods. Young of Year (YOY) not included in the analysis.

Common Name	Scientific Name		Mean Density (No./100m^2)		Overall Change in Density	ρ
			'99-'00	**'17-'18**		
Forcepsfish	*Forcipiger flavissimus*	**FRA**	0.41	0.59	+0.19	**<0.05**
		Open	0.41	0.37	-0.04	0.58
		MPA	0.84	0.79	-0.05	0.71
Yellowtail Coris	*Coris gaimard*	FRA	0.17	0.20	+0.02	0.61
		Open	0.13	0.17	+0.04	0.53
		MPA	0.30	0.44	+0.14	0.24
Psychedelic Wrasse	*Anampses chrysocephalus*	FRA	0.01	0.01	0.00	1.00
		Open	0.01	0.01	0.00	1.00

		MPA	0.01	0.03	+0.02	0.63
Shortnose Wrasse	*Macropharyngodon geoffroy*	FRA	0.02	0.01	-0.01	0.73
		Open	0.02	0.03	+0.01	0.77
		MPA	0.01	0.08	+0.06	0.31
Saddle Wrasse	*Thalassoma duperrey*	**FRA**	3.66	2.91	-0.74	**<0.001**
		Open	5.93	4.23	-1.70	**<0.001**
		MPA	4.39	3.93	-0.46	0.17
Multiband Butterflyfish	*Chaetodon multicinctus*	**FRA**	5.20	2.69	-2.51	**<0.001**
		Open	4.00	3.28	-0.71	**<0.001**
		MPA	4.94	3.19	-1.75	**<0.001**
Fourspot Butterflyfish	*Chaetodon quadrimaculatus*	FRA	0.05	0.03	-0.02	**0.65**
		Open	0.54	0.14	-0.40	**<0.001**
		MPA	0.43	0.20	-0.23	**<0.05**
Fisher's Angelfish	*Centropyge fisheri*	FRA	0.00	0.00	0.00	1.00
		Open	0.00	0.55	+0.54	**<0.001**
		MPA	0.00	0.00	0.00	1.00
Smalltail Wrasse	*Pseudojuloides cerasinus*	FRA	0.14	0.16	+0.02	0.78
		Open	0.05	0.16	+0.11	**<0.05**
		MPA	0.04	0.08	+0.03	0.57
Bird Wrasse	*Gomphosus varius*	**FRA**	0.67	0.84	+0.17	**<0.05**
		Open	0.64	0.62	-0.01	0.82
		MPA	1.04	1.53	+0.48	**<0.01**
Thompson's Surgeonfish	*Acanthurus thompsoni*	**FRA**	0.72	1.64	+0.92	**<0.001**
		Open	0.69	2.53	+1.84	**<0.001**
		MPA	0.66	1.55	+0.89	**<0.01**
Milletseed Butterflyfish	*Chaetodon miliaris*	FRA	0.00	0.00	0.00	1.00
		Open	0.04	0.02	-0.02	0.57
		MPA	0.44	0.01	-0.43	**<0.001**
Eightline Wrasse	*Pseudocheilinus octotaenia*	**FRA**	2.20	1.14	-1.05	**<0.001**
		Open	3.31	1.75	-1.56	**<0.001**
		MPA	3.17	1.83	-1.34	**<0.001**
Hawaiian Dascyllus	*Dascyllus albisella*	**FRA**	0.02	0.33	+0.31	**<0.001**
		Open	0.51	0.59	+0.08	0.41
		MPA	0.12	0.15	+0.04	0.70
Blacklip Butterflyfish	*Chaetodon kleinii*	**FRA**	0.00	0.07	+0.07	**<0.05**
		Open	0.00	0.29	+0.29	**<0.001**
		MPA	0.02	0.04	+0.02	0.68
Lei Triggerfish	*Sufflamen bursa*	FRA	0.53	0.69	+0.16	0.07

		Open	0.75	0.86	+0.11	0.24
		MPA	0.57	1.06	+0.50	**<0.001**
Spotted Boxfish	*Ostracion meleagris*	FRA	0.05	0.08	+0.03	0.49
		Open	0.10	0.12	+0.02	0.73
		MPA	0.10	0.19	+0.08	0.25
Fourline Wrasse	*Pseudocheilinus tetrataenia*	**FRA**	1.36	1.81	+0.45	**<0.01**
		Open	1.66	2.12	+0.46	**<0.01**
		MPA	2.95	1.76	-1.19	**<0.001**
Pyramid Butterflyfish	*Hemitaurichthys polylepis*	FRA	0.02	0.07	+0.04	0.37
		Open	0.66	0.35	-0.31	**<0.01**
		MPA	0.59	0.10	-0.49	**<0.05**
Blackside Hawkfish	*Paracirrhites forsteri*	FRA	0.34	0.23	-0.11	0.08
		Open	0.41	0.22	-0.19	**>0.01**
		MPA	0.26	0.26	0.00	1.00
HI Whitespotted Toby	*Canthigaster jactator*	FRA	1.13	1.00	-0.13	0.34
		Open	3.48	2.32	-1.16	**<0.001**
		MPA	2.87	2.14	-0.73	**<0.01**
Redbarred Hawkfish	*Cirrhitops fasciatus*	FRA	0.03	0.04	+0.01	0.84
		Open	0.16	0.06	-0.09	0.63
		MPA	0.06	0.02	-0.04	0.49
Gilded Triggerfish	*Xanthichthys auromarginatus*	**FRA**	0.14	0.03	-0.11	**<0.05**
		Open	0.31	0.03	-0.27	**<0.001**
		MPA	1.26	0.36	-0.90	**<0.001**
Black Durgon	*Melichthys niger*	**FRA**	0.53	0.82	+0.29	**<0.05**
		Open	0.43	0.86	+0.42	**<0.01**
		MPA	2.21	4.36	+2.14	**<0.001**
Blueline Snapper	*Lutjanus kasmira*	**FRA**	0.07	0.80	+0.73	**<0.001**
		Open	0.12	0.31	+0.18	**<0.01**
		MPA	0.19	0.17	-0.02	0.83
Peacock Grouper	*Cephalopholis argus*	FRA	0.57	0.72	+0.16	0.09
		Open	0.57	0.48	-0.09	0.28
		MPA	0.89	0.83	-0.06	0.72

For most of the species on the White List, collecting impact, (the percentage of the population being removed annually from Open Areas) is overall relatively low, with 9 species having single digit percentage catch and 21 species having catch values <1% (Table 6).

Table 6. Open Area population estimates of 'White List' species and % of that population taken annually by aquarium collectors. "Catch" is FY 2017 aquarium catch – the last year without fishing restrictions. 30'-60' Open Area Population" is an estimate (mean of CY 2017/2018) of total numbers of fish (including YOY) in collected Open Areas of hard bottom habitat in 30'- 60' depths. "Catch as % of Population" is the % of the species' population in collected Open Areas taken annually by aquarium collectors.

Scientific Name	Common Name	Catch	30'- 60' Open Area Population	Catch as % of Open Area Population
Psychedelic Wrasse	*Anampses chrysocephalus*	599	1,071*	55.78%
Achilles Tang	*Acanthurus achilles*	5,437	13,796	39.67%
Goldrim Surgeonfish	*Acanthurus nigricans*	1,324	5,966	22.19%
Shortnose Wrasse	*Macropharyngodon geoffroy*	582	3,222	18.07%
Yellow Tang	*Zebrasoma flavescens*	264,870	2,867,048	9.24%
Milletseed Butterflyfish	*Chaetodon miliaris*	98	2,148	4.56%
Chevron Tang	*Ctenochaetus hawaiiensis*	3,878	98,067	3.95%
Yellowtail Coris	*Coris gaimard*	623	18,256	3.41%
Orangespine Unicornfish	*Naso lituratus*	6,078	180,099	3.37%
Orangeband Surgeonfish	*Acanthurus olivaceus*	1,293	53,694	2.41%
Fourspot Butterflyfish	*Chaetodon quadrimaculatus*	319	15,034	2.12%
Forcepsfish	*Forcipiger flavissimus*	840	39,734	2.11%
Smalltail Wrasse	*Pseudojuloides cerasinus*	278	17,182	1.62%
Potter's Angelfish	*Centropyge potteri*	2,245	265,488	0.85%
Ornate Wrasse	*Halichoeres ornatissimus*	1,602	196,879	0.81%
Gilded Triggerfish	*Xanthichthys auromarginatus*	20	3,222	0.62%
Goldring Surgeonfish - Kole	*Ctenochaetus strigosus*	30,901	5,312,745	0.58%
Fisher's Angelfish	*Centropyge fisheri*	288	59,064*	0.49%
Spotted Boxfish	*Ostracion meleagris*	57	12,887	0.44%
Bird Wrasse	*Gomphosus varius*	265	66,581	0.40%
Redbarred Hawkfish	*Cirrhitops fasciatus*	21	6,443	0.33%
Blacklip Butterflyfish	*Chaetodon kleinii*	81	39,734	0.20%
Hawaiian Dascyllus	*Dascyllus albisella*	89	63,359	0.14%
Blackside Hawkfish	*Paracirrhites forsteri*	30	23,625	0.13%
Pyramid Butterflyfish	*Hemitaurichthys polylepis*	42	37,586	0.11%
Saddle Wrasse	*Thalassoma duperrey*	538	140,947	0.10%
Multiband Butterflyfish	*Chaetodon multicinctus*	470	378,843	0.09%
Lei Triggerfish	*Sufflamen bursa*	78	92,354	0.08%
Eightline Wrasse	*Pseudocheilinus octotaenia*	97	187,930	0.05%
Thompson's Surgeonfish	*Acanthurus thompsoni*	148	271,693	0.05%
Brown Surgeonfish	*Acanthurus nigrofuscus*	957	2,980,402	0.03%
Fourline Wrasse	*Pseudocheilinus tetrataenia*	54	227,663	0.02%
Black Durgon	*Melichthys niger*	11	92,354	0.01%

HI Whitespotted Toby	*Canthigaster jactator*	26	249,141	0.01%
Peacock Grouper - Roi	*Cephalopholis argus*	0	51,546	0.00%
Bluestripe Snapper - Taape	*Lutjanus kasmira*	0	33,290	0.00%
Tinker's Butterflyfish	*Chaetodon tinkeri*	290	N/A	-
HI Longfin Anthias	*Pseudanthias hawaiiensis*	0	N/A	-
Flame Wrasse	*Cirrhilabrus jordani*	0	N/A	-
Eyestripe Surgeon	*Acanthurus dussumieri*	0	N/A	-

* - Deeper water species only occasionally recorded on surveys – population underestimated

N/A – Species generally occurs in habitats (generally deeper) not adequately surveyed by transects

It should be kept in mind that scientific studies on reef fishes are notoriously challenging to analyze due to the often high variability of fish abundance in both time and space.

Even with a rigorous statistical design and 20 years of study, it is difficult to statistically detect changes in abundances except for the more common species that exhibit relatively large changes. This is exemplified by the seemingly chaotic patterns of abundance for almost all of the 26 less-collected aquarium species in West Hawaiʻi (Figure 28).

Besides harvest impacts, species abundances can, and do, change over time due to other factors, both extrinsic (e.g. habitat degradation) and intrinsic (e.g. density dependence, reproductive success, etc.). A prime example of this is exemplified by the Multiband Butterflyfish (Figure 28A) which underwent significant declines in all management areas since 1999/2000 (Table 5, Figure 29).

The Multiband Butterflyfish is very lightly collected (0.1% of total catch Table 3) and the catch represents a miniscule portion (0.09%) of the robust population found in mid-depth (30’-60’) Open Areas (Table 6). There is also no commercial food fishery for this species, and it doesn’t appear to be targeted by non-commercial fishers. The cause of the overall declining abundance of Multiband Butterflyfish in protected and unprotected areas is unknown but is highly unlikely to be due to aquarium collecting. Given that Multiband Butterflyfish feed principally on coral polyps, the loss of substantial amounts of live coral due to the 2015 coral bleaching event and subsequent ongoing habitat degradation may play a key role in their population decline in recent years.

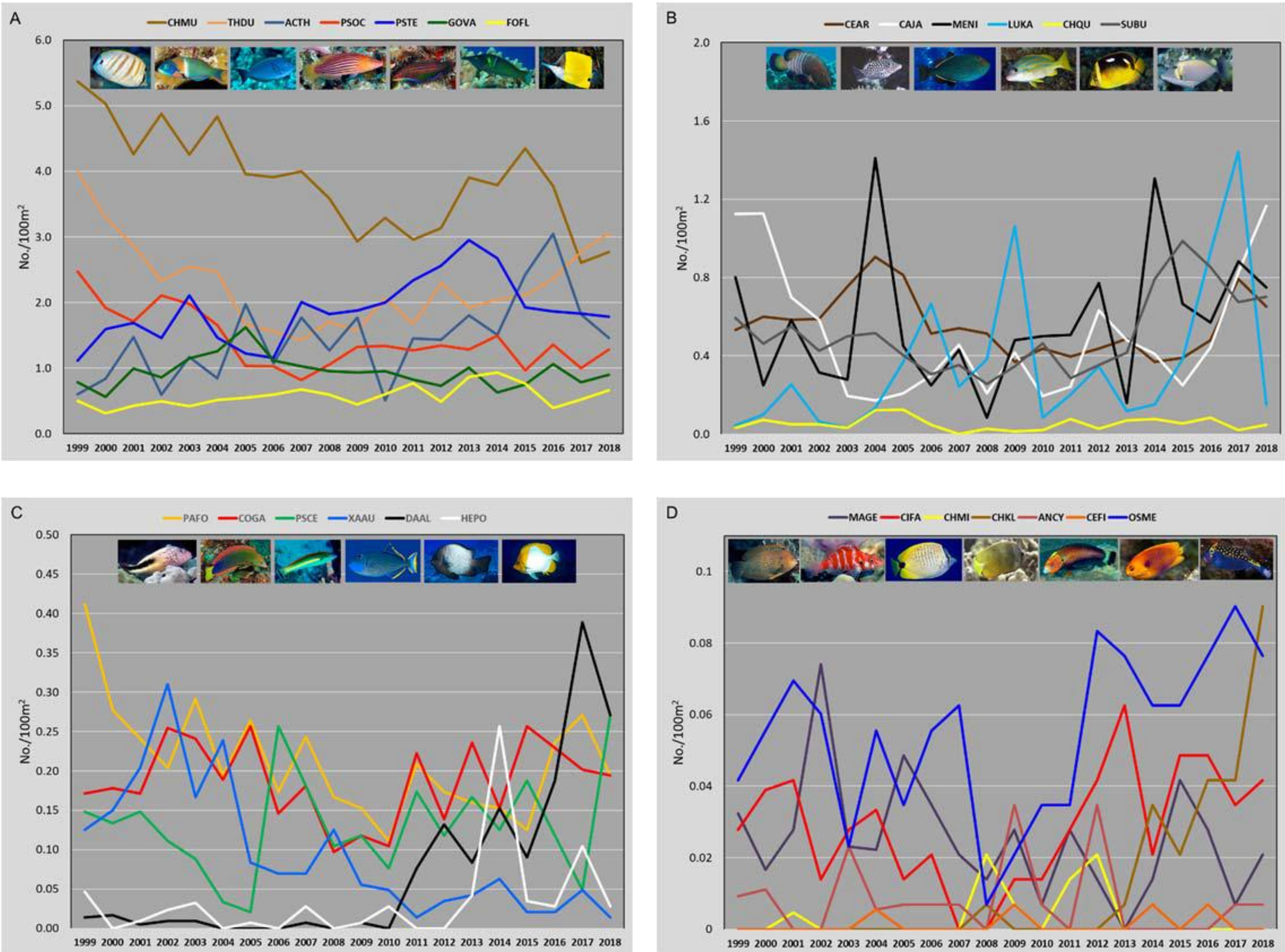


Figure 28. Abundance of 26 White List species in FRAs over WHAP study period. Codes in legend above photos denote first two letters of genus and species. For example; CHMU = *Chaetodon multicinctus* & THDU = *Thalassoma duperrey*. Common names for each species are listed in Table 1.

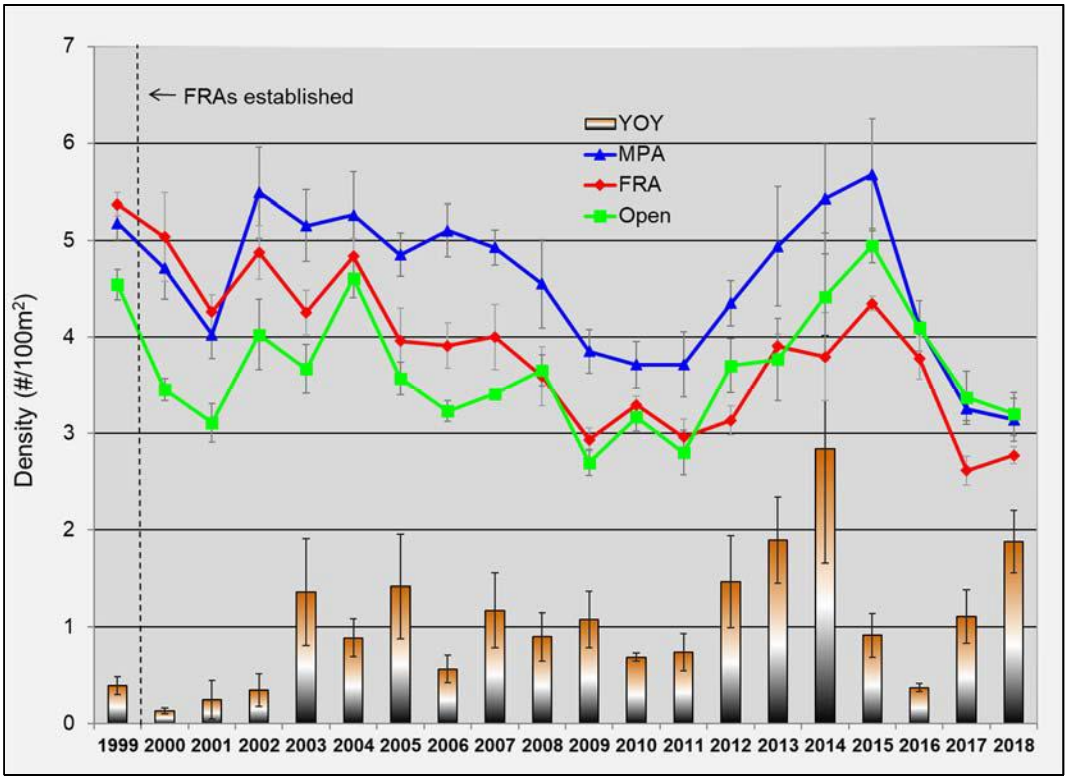


Figure 29. Overall changes in Multiband Butterflyfish abundance in FRAs, MPAs and Open areas, 1999-2018. Vertical bars indicate mean density (June-Nov) of Multiband Butterflyfish Young-of-Year (YOY). YOY are not included in trend line data.

Endemic Species on the White List

An endemic species is one whose presence is restricted to a specific geographic area. Of the 662 species of reef and shore fishes in the Hawaiian Islands, it is currently estimated that 25% of them are endemic (Randall 2007). A number of Hawaiian endemics are important food species and are harvested in substantial numbers both commercially and non-commercially. These include Āholehole, ʻAlaiʻihi ʻĀweoweo, Hāpuʻu, Kole, Kūmū, Mamo, Nabeta, Nohu and Uhu.

Of the 40 species on the WHRFMA White List, 11 (27.5%) are considered endemic to Hawaiʻi (Table 7), only slightly above the average level of overall Hawaiʻi marine fish endemism. All but one of the endemic species (Psychedelic Wrasse - *Anampses chrysocephalus*) also occurs at Johnston Atoll. Note that there is some disagreement in various references as to whether Fisher's Angelfish (*Centropyge fisheri*) is a Hawaiian endemic, but Randall (2007) does not consider it to be endemic.

Several researchers have commented on the relative abundance of endemic fishes. Gosline and Brock (1960) noted *"that many of the endemic fish of the Hawaiian Islands are the most abundant of their genera"* and similarly Hourigan & Reese (1987) state that *"many endemic species are the* *most abundant Hawaiian fishes in their families*." Randall (2007) commented that "*native species have evolved in isolated outposts such as Hawaii for long periods of time and therefore have had ample opportunity to become fully adapted to their environment*."

Table 7. Endemic species on the White List. References relative to abundance are listed below. Listed in the third column are population estimates on West Hawai'i reefs in coral reef and hard bottom habitat in 30'-60' depths. The forth column lists the % of a species population in 30'-60' Open Areas which is taken annually by aquarium collectors (based on FY 17 records).

Species	Abundance	30'-60' Open Area Pop	Catch as % of Open Area Population
Anampses chrysocephalus		1,074*	55.78%
Macropharyngodon geoffroy		3,222	18.07%
Chaetodon miliaris	Most common butterflyfish[1,2]	2,148	4.56%
Centropyge potteri	Most common angelfish[1]	265,488	0.85%
Ctenochaetus strigosus	Very common on HI reefs[1]	5,312,745	0.58%
Dascyllus albisella		63,359	0.14%
Chaetodon multicinctus		378,843	0.09%
Thalassoma duperrey	Most common inshore wrasse[1]	140,947	0.10%
Canthigaster jactator	Most common Toby[1]	249,141	0.01%
Cirrhilabrus jordani	Common in certain habitats[3]	N/A	-
Pseudanthias hawaiiensis	Abundant at 40-199m[4]	N/A	-
* - Deeper water species only occasionally recorded on surveys – population underestimated			
N/A - Species occurs in habitats deeper than transects and thus not recorded on surveys			

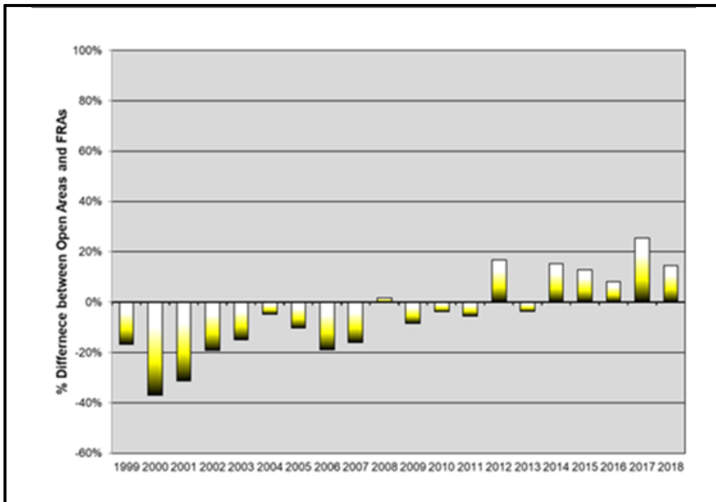
[1]Randall J.E. 2007, [2]Brock V.E. and T.C. Chamberlain. 1968, [3]Hoover J.P. 2008, [4]Chave E.H. and B.C. Mundy 1994.

Seven of 11 endemic species on the White List are common in suitable habitat (Table 7). Aquarium collecting of seven of these species, for which we have adequate survey data, takes <1% of their Open Area population annually.

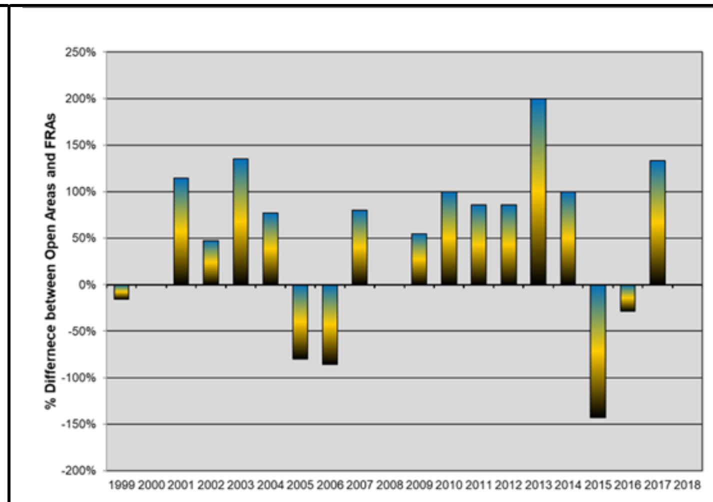
Note that the population estimates presented in Tables 6 & 7 represent only a portion of available habitat where these species occur and populations in MPAs and FRAs are essentially not collected. Thus, total populations in all habitats are invariably considerably higher than indicated for just the Open Areas 30'-60' depth range indicated above.

Figure 30 shows the difference in an endemic species' abundance in West Hawai'i Fish Replenishment Areas (FRAs) relative to Open Areas. Of the 9 endemic species for which we have survey data, only Kole are consistently less abundant in the Open Areas relative to the FRAs. Kole are currently 23.4% less abundant in Open Areas than in FRAs (Figure 15, avg. 2017-2018).

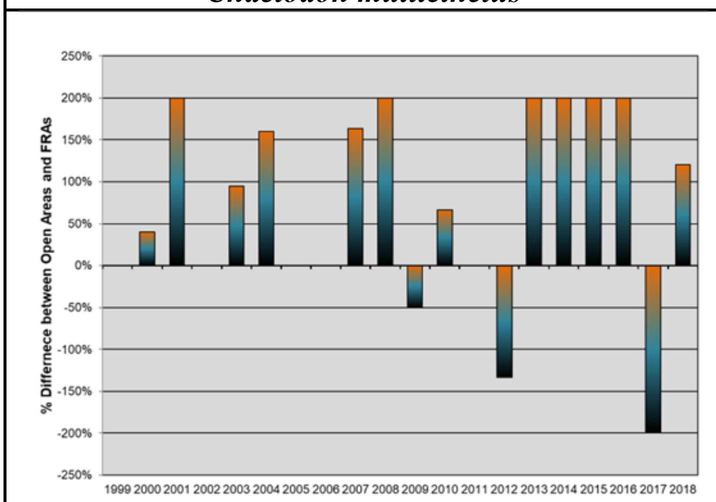
The Multiband Butterflyfish (*Chaetodon multicinctus*) was consistently less abundant in the Open Areas in the past, but this difference has decreased in recent years and now they are 19.5% more abundant in the Open Areas (Figure 29, avg. 2017-2018). The percentage of the Open Area population of both these species taken by aquarium collectors in recent years is <0.6% (Table 7).



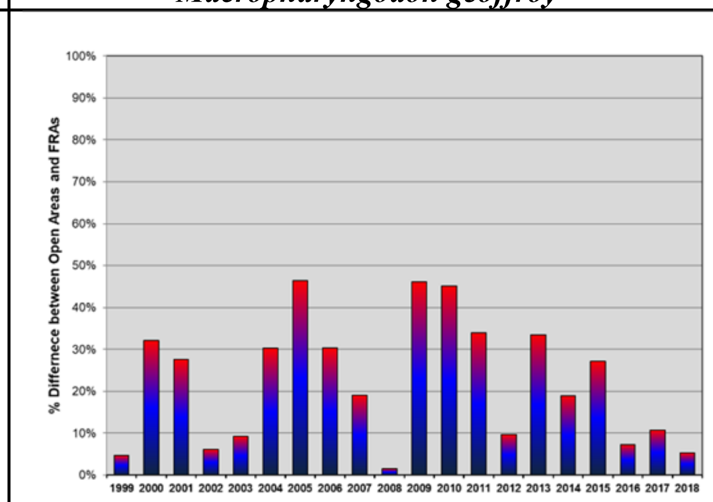
Chaetodon multicinctus



Macropharyngodon geoffroy



Anampses chrysocephalus



Centropyge potteri

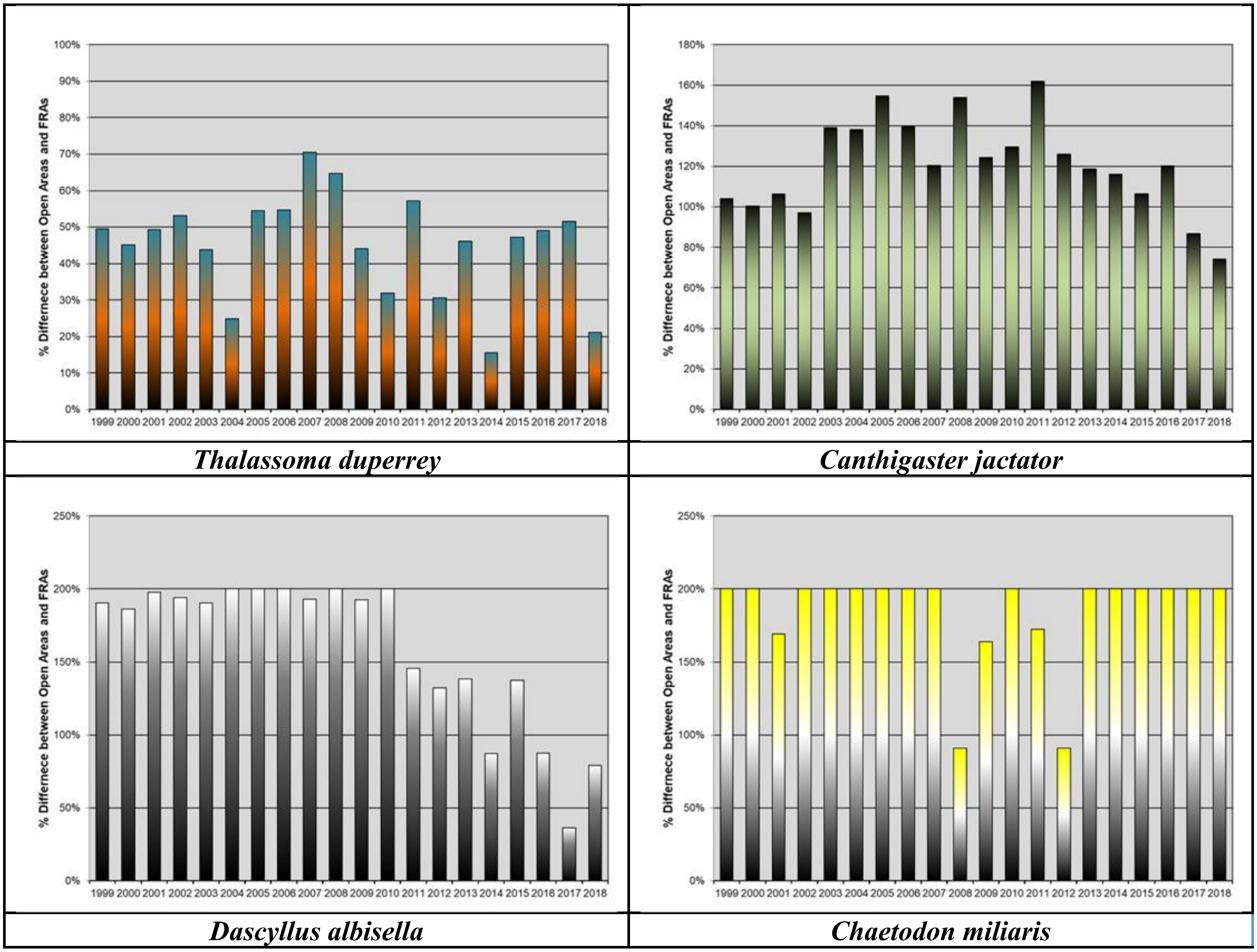


Figure 30. Difference in the abundance of Endemic White List species in West Hawaiʻi Fish Replenishment Areas (FRAs, n=9) relative to Open Areas (n=10). Bars represent the % difference in abundance for each year from 1999 to 2018. Bars above the x axis indicate greater abundance in the Open Areas than the FRAs. Bars below the axis indicate greater abundance in the FRAs than the Open Areas.

For three endemic species on the White List, Psychedelic Wrasse (*A. chrysocephalus*), Hawaiian Longfin Anthias (*Pseudanthias hawaiiensis*) and Flame Wrasse (*Cirrhilabrus jordani*), we do not have adequate population estimates, due to their deeper water habitats, to accurately assess the impact of continued aquarium collection. There is also another non-endemic species, Tinker's Butterflyfish (*Chaetodon tinkeri*), for which data is similarly lacking.

Other sources of data can sometimes be utilized to monitor the status of such species and their continued inclusion on the White List. Figure 31 shows the West Hawaiʻi aquarium catch and price paid per fish (adjusted for inflation using Honolulu Consumer Price Index - CPI) for the four species noted above. Meaningful trends in catch report data for these species aren't readily apparent due to the high annual variability and/or lack of reported catch (e.g. *Pseudanthias hawaiiensis*). For two of the four species, value per fish has been decreasing which wouldn't be expected if scarcity was affecting prices. For the other two species, value has been generally increasing over time.

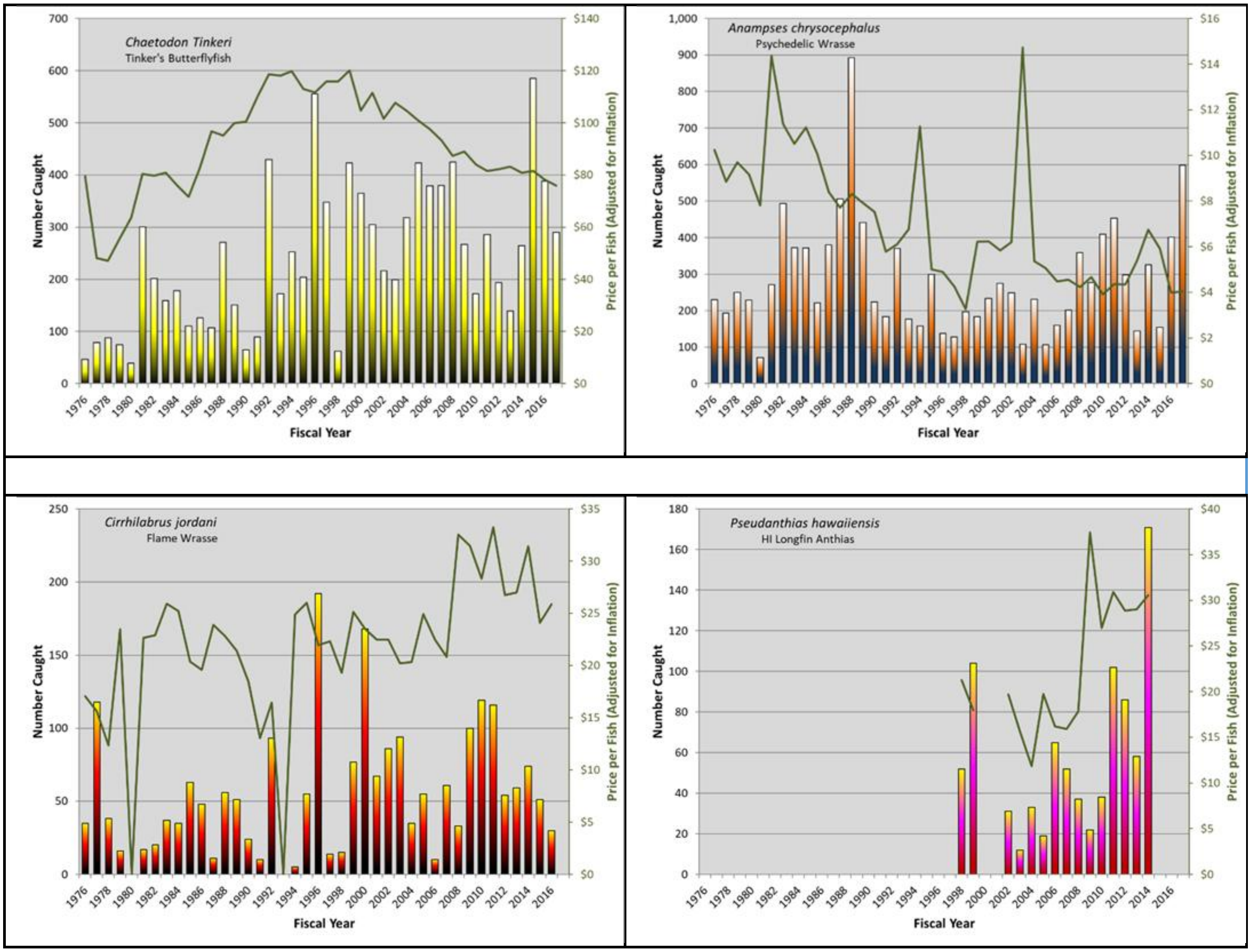


Figure 31. West Hawai'i aquarium catch (vertical bars) and ex-vessel price per fish of selected species.

The only other relevant sources of information on these four species are observations at depth from the dive logs of local technical divers Gerard and Dr. Vicky Newman. Dives (n= 1127 dives) ranged from a minimum depth of 60 feet to a maximum depth of 331 feet. Figure 32 presents Gerard Newman's observations as percentage of dives on which a particular species was observed within a given type of management area over the period 2002 - 2011.

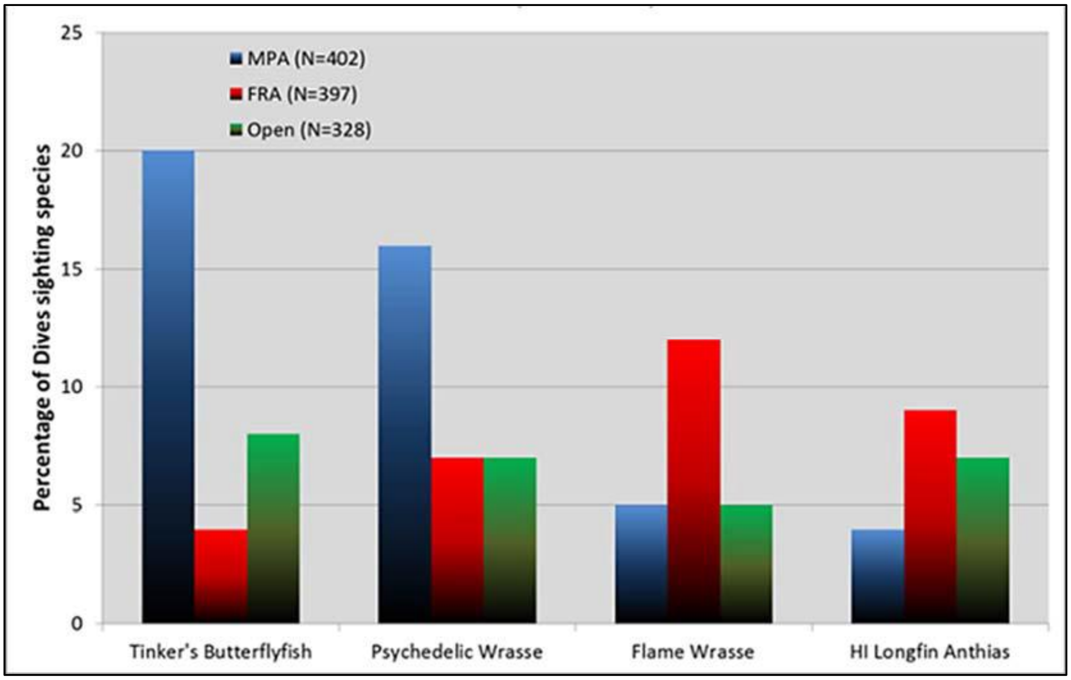


Figure 32. Deepwater sightings of White List species by West Hawai′i technical divers.

Tinker's Butterflyfish and Psychedelic Wrasse were substantially more common in the long term protected areas (MPAs) while Flame Wrasse and Hawaiian Longfin Anthias were more abundant in the FRAs. Sightings for all these species in all management areas did not exceed 25% of observational dives.

Given the lack of adequate survey data on 4 deep-water species (Figure 32) as well as for the Eyestripe Surgeonfish, it would seem to be prudent to remove them from the White List of permitted aquarium species since their population status cannot be assessed. For the Wrasse, Anthiid and Surgeonfish there wasn't any reported catch in FY17.

Impact of Commercial Aquarium Collecting on West Hawai′i Coral Cover

Most aquarium collecting in West Hawai′i involves the use of barrier nets which are deployed along the bottom, against which targeted fish are trapped and hand-netted. As such, there is a potential for aquarium divers to make inadvertent or careless contact with live corals and therefore damaging them.

To assess possible aquarium-related impacts on coral cover, digital photographic images (0.30 m^2) were collected each meter along the four 25 m permanent transects at each WHAP site in the spring of 2003, 2007, 2011, 2014, 2016, and 2017. Images were analyzed using CPCe software, version 4.1 (Kohler and Gill 2006), which generated 20 randomized points overlaid on each image. To analyze benthic cover, an experienced observer identified the taxa underneath each randomized point to the lowest possible taxonomic level. Identifications to the species level were made whenever possible. Following image analysis, summary data were exported into Microsoft Excel with benthic cover averaged by category and by site.

Coral cover was compared between sites where commercial aquarium fish collection was occurring ("YES") or not occurring ("NO") (Table 6). Management zones in the WHRFMA where aquarium fish collection is prohibited include Fish Replenishment Areas (FRAs), Fishery Management Areas (FMAs,), Marine Life Conservation Districts (MLCDs) and one Marine Reserve. Statistical analysis compared mean coral cover and mean change in coral cover between sites open and closed to aquarium collection.

Table 8. Description of spatial management at each DAR permanent WHAP monitoring site.

SITE #	SITE	AQ Occurring?	FRA Status	FMA Status	MLCD Status
01	Lapakahi[1]	**YES**	NO	NO	NO
02	Kamilo	**YES**	NO	NO	NO
03	Waiaka'ilio	NO	YES	NO	NO
04	Puakō	NO	NO	YES	NO
05	Anaeho'omalu	NO	YES	NO	NO
06	Keawaiki	**YES**	NO	NO	NO
07	Ka'ūpūlehu[2]	NO	YES	NO	NO
08	Makalawena	**YES**	NO	NO	NO
09	Wawaloli Open	**YES**	NO	NO	NO
10	Wawaloli FMA	NO	NO	YES	NO
11	Honokohau	NO	YES	NO	NO
13	Papawai	NO	NO	YES	NO
14	S. Oneo	NO	YES	NO	NO
15	N. Keauhou	NO	YES	NO	NO
16	Kualanui	**YES**	NO	NO	NO
17	Red Hill	NO	YES	YES	NO
18	Keopuka	**YES**	NO	NO	NO
19	Kealakekua	NO	NO	NO	MLCD
20	Ke'ei	NO	YES	NO	NO
21	Kalahiki	NO	YES	NO	NO
22	Au Au/Ho'okena	**YES**	NO	NO	NO
23	Omaka'a	NO	YES	NO	NO
24	Manuka	**YES**	NO	NO	NO
97	Unualoha	**YES**	NO	NO	NO
98	Old Kona Airport	NO	NO	NO	MLCD

[1]The DAR monitoring site is outside of the offshore boundaries of subzone B of the MLCD. Aquarium collecting is known to occur in this area.
[2]The portion of the FRA shoreward of the 120' depth contour is a no-take Marine Reserve.

Coral cover and change in coral cover datasets met normality and homogeneity of variance requirements for parametric analysis, and were compared using a one-way analysis of variance (ANOVA) with coral cover and change in coral cover as the response variable, and site management (open ("YES") vs. closed ("NO") to commercial aquarium collection) as the factor using Minitab statistical software (version 14.0).

Coral cover was slightly higher within areas closed to the commercial aquarium fishery compared to open areas (Fig. 33), but this difference was not statistically significant for any year of monitoring (2003: $p = 0.276$; 2007: $p = 0.275$; 2011: $p = 0.496$; 2014: $p = 0.554$; 2016: $p = 0.673$; 2017: $p = 0.782$). Additionally, there was no apparent trend of declining coral cover in the open areas for periods 2003 to 2014 or 2016 to 2017. The slight (but statistically insignificant) higher coral cover in areas closed to aquarium collecting is likely because protected areas were often selected for their high-quality habitat (i.e. high coral cover).

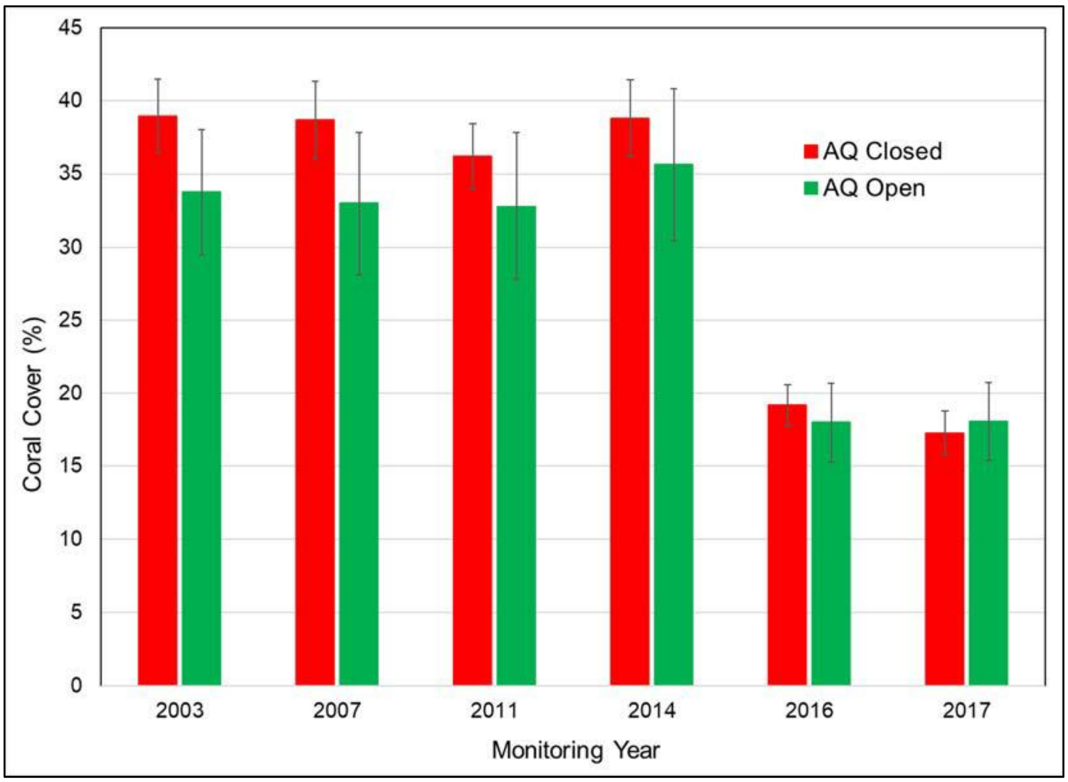


Figure 33. Mean coral cover (%) at DAR WHAP monitoring sites by year, averaged by aquarium fishery management restrictions and by year. Error bars represent standard error of the mean.

The decline in live coral cover in 2016/2017 is related to a severe thermal stress event in West Hawai'i from 2014 to 2016, with a peak in the fall of 2015 during which water temperatures approached 30°C. Severe and prolonged elevated sea surface temperatures throughout West Hawai'i caused region-wide coral bleaching and subsequent mortality, resulting in a relative loss in coral cover of -49.4% over all monitoring sites (Kramer et al. 2016). Over this time period, overall mean coral cover decline was slightly less in the areas open to commercial aquarium collection, but again, the difference was not significant (Closed areas: -19.6 % ± 6.0 %; Open areas: -17.6 % ± 1.3 %; p = 0.605) (Figure 34).

From 2003 to 2017, overall mean coral cover declined less within Open Areas compared to areas closed to commercial aquarium collection (Closed areas: -22.5% ± 3.4%**;** Open Areas: -15.5% ± 2.3%), but this difference in change in coral cover was not significant (p = 0.093) (Fig. 34).

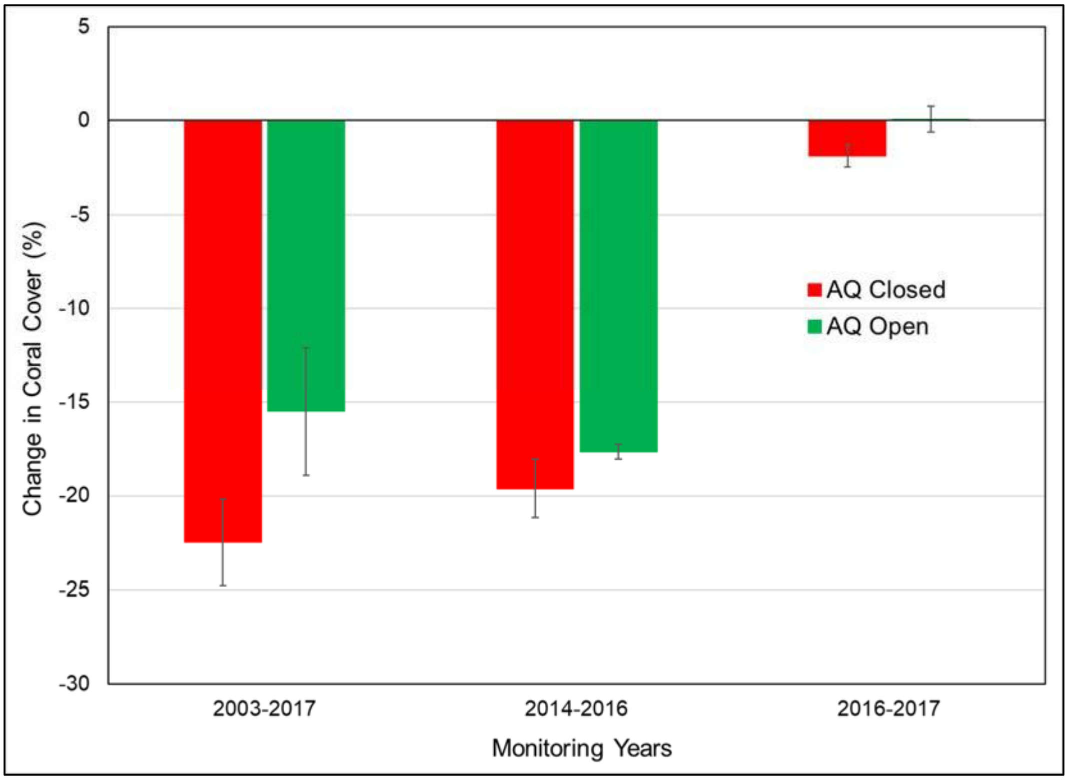


Figure 34. Mean change in coral cover (%) at DAR WHAP monitoring sites, averaged by aquarium fishery management restrictions and by year. Error bars represent standard error of the mean.

From 2016 to 2017, approximately one year after coral post-bleaching mortality subsided, minimal change in coral cover was documented within areas open to commercial aquarium collection (Open areas: 0.07 % ± 2.1 %), compared to a slight decline in mean coral cover in areas closed to collection (Closed: -1.94 % ± 2.3 %), and this difference was statistically significant (p = 0.038) (Fig. 34).

The DAR benthic monitoring protocol was not explicitly designed to investigate possible impacts of aquarium collecting on benthic cover (i.e. structural damages to coral). Nevertheless, fifteen years of benthic monitoring at 25 permanent West Hawai'i monitoring sites indicates that commercial aquarium collecting is not having a measurable negative impact on percent coral cover or change in coral cover over time.

Aquarium Reef Fish Catch vs. Non-aquarium Catch

The role of herbivorous fishes in maintaining reef resiliency by exerting strong top-down pressure on macroalgae growth on coral reefs has been well documented (Williams, et al. 2019). Of particular importance are the abundance of large herbivores such as parrotfishes (Ong and Holland 2010).

Both the Open Areas and FRAs permit all fishers (except aquarium collectors) almost unrestricted take of herbivores such as surgeonfishes and parrotfishes with few size limits (all minimum sizes) and no bag limits. In contrast, the MPAs have additional restrictions affecting herbivore take including a few highly protected or no-take areas. Other types of fishing (i.e. food fishing) are likely responsible for observed differences between these areas and the more protected MPAs. A WHRFMA SCUBA spearfishing ban instituted in December 2013 will likely provide additional coast-wide protection for important herbivores especially parrotfishes which are especially vulnerable at night.

In order to gain a more balanced perspective on the generalized impact on reef fishes by aquarium collecting relative to other types of reef fishing activities, an effort was made several years ago to compare reef fish catch by aquarium collectors with the catch of reef fish by other commercial fishers and non-commercial 'recreational' fishers. Both aquarium collectors and other commercial fishers are required by law and Administrative Rule to submit catch reports and thus island specific reef fish catch data is available for each group. As noted previously (Figure 3), a prior analysis suggests that aquarium catch reports appear to fairly accurately reflect actual catch. Unfortunately, similar assurance isn't available for other commercial catch reports and there is information suggesting that commercial catches for other fisheries are likely substantially underestimated (Milne 2012).

Non-commercial (i.e. recreational fishers) in Hawai'i are not required to submit catch reports but such catch data have been collected since 2003 by the Hawai'i Marine Recreational Marine Fishing Survey (HMRFS) and subsequently since 2007 by NOAA's Marine Recreational Information Program (MRIP). Species-specific recreational catch data on a statewide basis is available online: http://www.st.nmfs.noaa.gov/st1/recreational/queries/custom_time_series.html. All MRIP catch data from 2008 thru 2010 was decreased by a factor of 81.96% (i.e., 1/1.22) because of a count error made by NOAA in the population household numbers for Maui County (Hongguang 2012).

MRIP data are presented on a state-wide basis. The number of reef fishes caught statewide by the recreational and commercial sectors has been quite comparable averaging 1,511,025/yr. for recreational fishers and 1,554,010/yr. for commercial (i.e. non-aquarium) fishers. The combined catch however is 6.7X (i.e. 6.7 times) the total statewide take (455,845/yr.) of aquarium fishes.

Averaged over the period 2008-2011, the estimated total average statewide yearly biomass of reef fish caught by both commercial and non-commercial fishers (2,359,857 lbs./yr.) was also similar for both commercial fishers (1,199,520 lbs.) and recreational fishers (1,160,337 lbs.).

Note that a recent study (McCoy et al. 2018) covering the period 2004 – 2013, had a fairly comparable biomass estimate of overall "reef-associated" fishery catch (2,574,463 lbs./yr.) but with a lower estimate for commercial fishers (407,659 lbs./yr.) and a higher estimate for non-commercial reef fish catch (2,166,804 lbs./yr.).

To compare total reef fish catches for the various fishing sectors on a more localized area basis, it was necessary to apportion the recreational catch among island areas. An adjustment factor was calculated based on the percentage of statewide commercial reef fish landings reported from each area (generally island or county as well as West Hawai′i). A separate adjustment factor was derived for both number of reef fishes caught and biomass. Biomass was estimated for aquarium fish catch by specifying a targeted size or typical maximum size of collected species based on information provided by active collectors (n = 7) and Stevenson et.al. (2011). Size data was then converted to weight utilizing length to weight conversion factors (DAR database, Fishbase).

In West Hawai′i, the recreational (i.e. non-commercial) fishery is substantially greater than the commercial fishery both in terms of numbers of reef fish caught (Figure 35) and total biomass of reef fish caught (Figure 36).

Over the analysis period (2008-2011), the West Hawai′i aquarium fishery collected 1.8X the number of reef fishes taken by recreational and commercial fishers combined. If Yellow Tang, which is primarily harvested at small sizes and not targeted by other fishers, is excluded, the recreational and commercial fisheries combined to take 3X the number of reef fishes caught by aquarium collectors (Figure 35, Table 9).

In terms of reef fish biomass caught by the different fisheries in West Hawai′i, considerably more biomass is taken by the combined recreational and commercial fisheries either including Yellow Tang (2.8X) or excluding it (8.6X) (Figure 36, Table 9). Additionally, unlike the aquarium fishery which targets mostly immature fish, the other fisheries selectively target the larger breeding portion of the population which has profound implications for the sustainable usage of the resource. This is reflected in Figure 36.

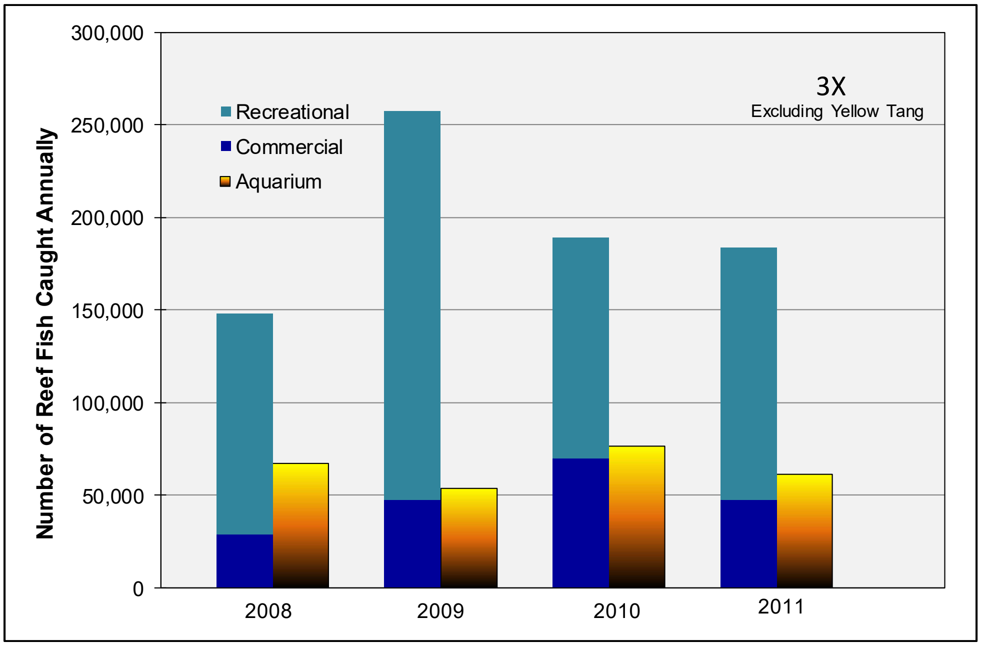


Figure 35. Comparison of the number of reef fishes, excluding Yellow Tang, caught by recreational, commercial and aquarium fishers in West Hawai'i.

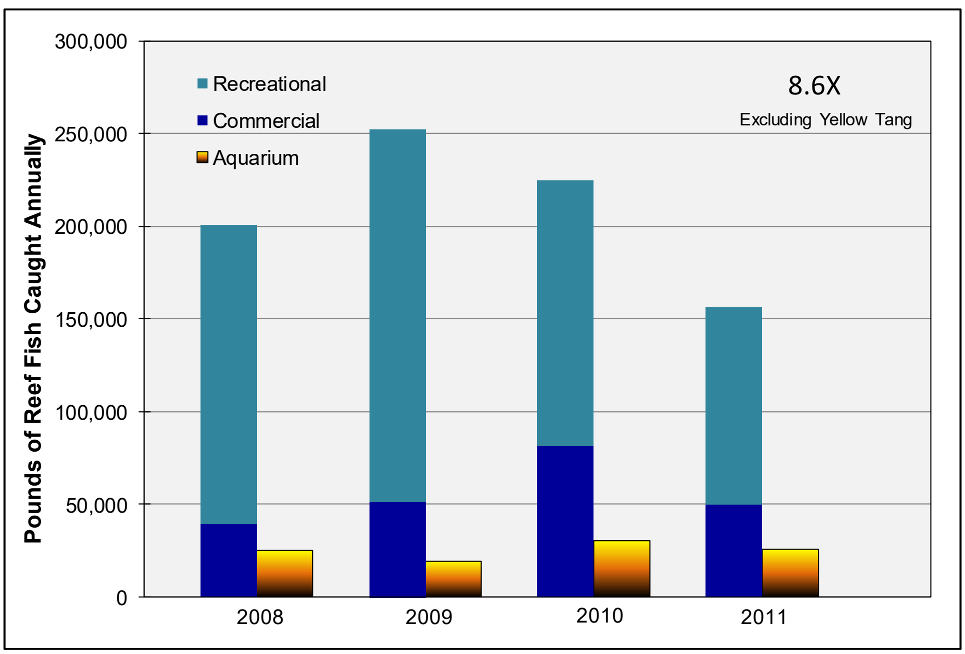


Figure 36. Comparison of the biomass of reef fishes excluding Yellow Tang, caught by recreational, commercial and aquarium fishers in West Hawai'i.

As in West Hawai'i (excluding Yellow Tang), the total take of reef fish by commercial and non-commercial ('recreational') fishers on other islands also greatly exceeds the numbers and biomass of the fish taken by aquarium collectors (Table 9). Note that in recent years the aquarium catch on Maui has declined markedly as several collectors moved off island. FY14 Maui aquarium catch (3 collectors) totaled 278 organisms.

Table 9. Island comparison of the number and pounds of reef fishes caught by recreational and commercial fishers relative to aquarium collectors 2008-2011. The far right column represents Total Non AQ catch of reef fish relative to the catch taken by aquarium collectors.

Reef Fish Catch Numbers					
	Recreational	Commercial	Total Non AQ	Aquarium	Non AQ/AQ
West Hawai'i	146,176	48,498	**194,674**	**343,729**	**0.6X**
West Hawai'i w/o YT	146,176	48,498	**194,674**	**64,815**	**3X**
Maui	218,474	71,730	**290,204**	**13,316**	**22X**
'Oahu	675,520	196,417	**871,936**	**81,514**	**11X**
Kaua'i	218,423	93,223	**311,645**	**546**	**571X**
Reef Fish Catch Biomass (lbs.)					
West Hawai'i	153,193	55,468	**208,661**	**75,274**	**2.8X**
West Hawai'i w/o YT	153,193	55,468	**208,661**	**25,248**	**8.6X**
Maui	342,769	122,268	**465,037**	**3,217**	**145X**
'Oahu	496,132	242,812	**738,945**	**36,119**	**20X**
Kaua'i	215,685	63,794	**279,479**	**626**	**446X**

NOAA West Hawai'i Integrated Ecosystem Assessment

In 2019, a multidisciplinary team of Hawai'i scientists and managers published a report on the status of the West Hawai'i marine ecosystem (Gove et al. 2019). This collaborative report represents a compilation of 30 ecosystem indicators that track the status of the region's marine ecosystem. Indicators include climate and oceanic drivers of ecosystem change, the states of ecological communities, and the activities and relationships between people and marine resources in West Hawai'i. Major highlights and the full report can be found on the following webpage: West Hawai'i IEA Ecosystem Status Report.

A number of the findings relating directly to the West Hawai'i aquarium fishery which have not been covered elsewhere in this report follow. Note that Figures and Tables are adapted from the IEA Status Report.

- The commercial aquarium fishery is the second most valuable commercial fishery in West Hawai'i comprising nearly 25% of the revenue generated from all commercial fishing activities in the region. Average annual revenue from aquarium collecting was $1.35 million over the last 14 years.

- The average total number of organisms caught was approximately 360,000 per year since 2003. More recently, total revenue has increased to an average of $1.58 million per year over the last 5 years with no significant change in the number of fishes caught.

- The total abundance of nearshore fishes has shown a positive trend in all management areas - MPAs, FRAs, and Open Areas - across West Hawaiʻi since 2003 (Figure 37). Total abundance has increased by 28.9%, 36.0%, and 34.9% in MPAs, FRAs, and Open Areas, respectively (Table 10). Total abundance of fishes differed based on management status. For example, the total abundance of fish in 2017 was greater in MPAs compared to FRAs and Open Areas by 61.4% and 34.8% (Table 11).

- Total fish biomass (i.e. weight of the entire reef-fish assemblage per unit area) increased in FRAs by nearly 40% since 2003 (Figure 37, Table 10). The most recent survey (2017) indicated that total fish biomass in MPAs was nearly 80% higher compared to FRAs and 100% higher than the biomass in Open Areas (Table 11).

- Adult fish length of mature fishes increased by 5.3% in FRAs with no significant change in MPAs or open areas since 2003. Adult fish length in 2017 was approximately 11% greater in MPAs and FRAs compared to Open Areas.

- Species richness (total number of species present per survey), has not changed within each management area over the last 15 years. As with other fish indicators, species richness in 2017 was greatest in MPAs as compared to FRAs and Open Areas.

- Herbivore biomass (total weight of herbivorous fishes per unit area), increased 30.8% in MPAs from 2003 to 2017. FRAs and Open Areas have shown no change in herbivore biomass over the same time period. Herbivore biomass was approximately 70% greater in MPAs than FRAs and Open Areas in the most recent survey. Of note, herbivores in West Hawaiʻi constitute roughly half of the total biomass in each of the management areas.

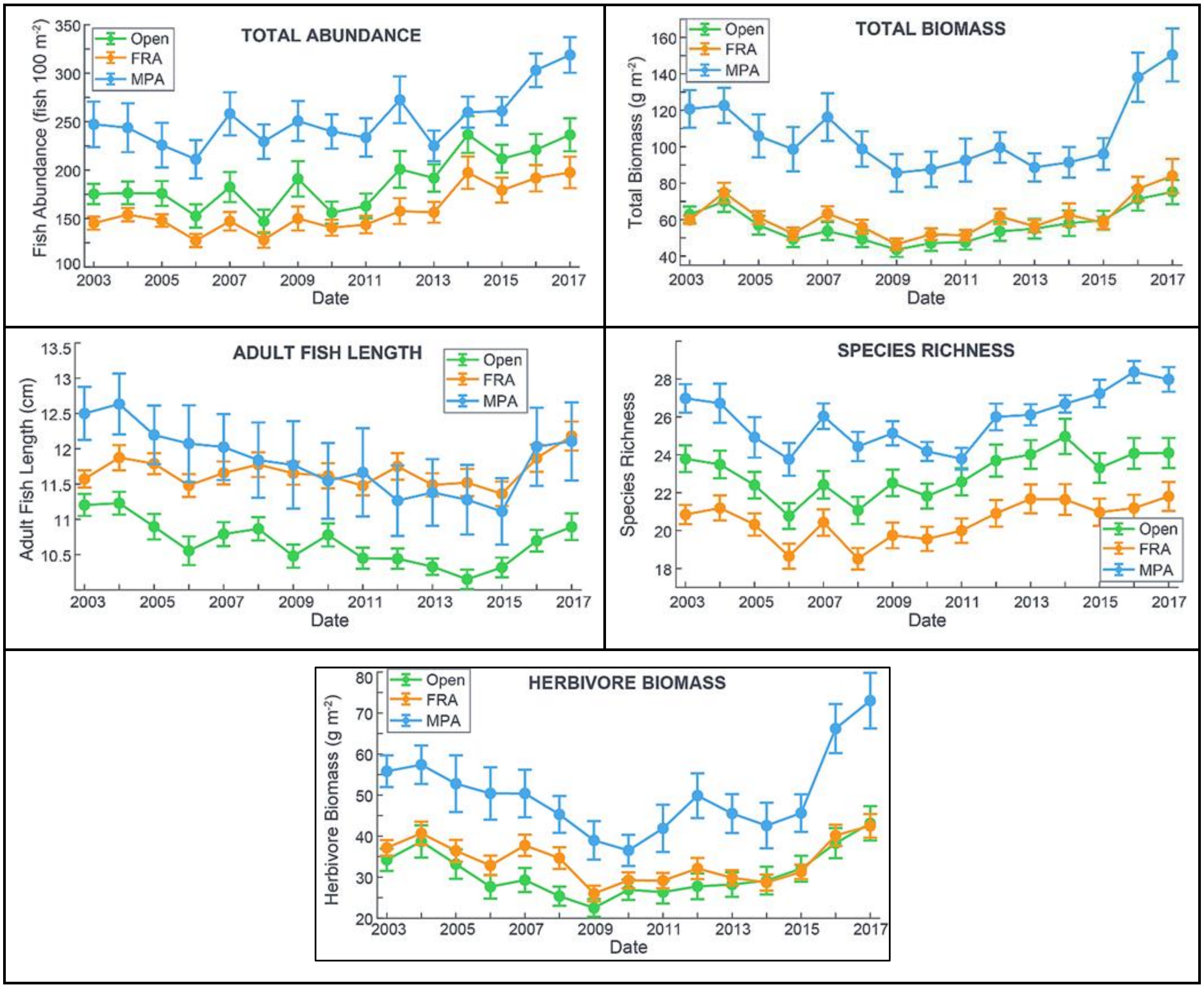


Figure 37. Reef fish indicators for West Hawaiʻi include total fish abundance, fish biomass, adult fish length, species richness and herbivore biomass. Error bars represent ±1 standard error. Data Source: DAR WHAP (Figures from Gove et al. 2019).

Table 10. Changes in mean reef fish and benthic coral reef community indicators by management status from 2003 to 2017. Indicators are grouped by management status (MPA, FRA, Open Area). Bold values represent statistically significant differences ($p<0.05$).

INDICATOR	MANAGEMENT STATUS	2003	2017	PERCENT CHANGE
Total Fish Abundance (number of fish/100 m²)	MPA	247.26	318.82	**+28.9%**
	FRA	145.30	197.54	**+36.0%**
	Open	175.35	236.46	**+34.9%**
Total Fish Biomass (g/m²)	MPA	120.73	150.34	+24.5%
	FRA	59.90	84.03	**+40.3%**
	Open	62.77	75.18	+19.8%
Mean Adult Fish Length (cm)	MPA	12.50	12.11	-3.1%
	FRA	11.57	12.18	**+5.3%**
	Open	11.20	10.89	-2.8%
Species Richness (number of species/survey)	MPA	26.98	27.98	+3.7%
	FRA	20.85	21.81	+4.6%
	Open	23.79	24.10	+1.3%
Herbivore Biomass (g/m²)	MPA	55.81	73.01	**+30.8%**
	FRA	37.15	42.50	+14.4%
	Open	34.22	43.11	+26.0%
Juvenile Yellow Tang (number of fish/100 m²)	MPA	14.95	26.89	**+79.8%**
	FRA	18.90	30.78	**+62.9%**
	Open	10.06	16.18	**+60.8%**
Coral Cover (%)	MPA	35.29	16.77	**-52.5%**
	FRA	40.96	17.30	**-57.8%**
	Open	33.76	17.31	**-48.7%**
Total Algal Cover (%)	MPA	40.84	56.59	+36.5%
	FRA	37.26	54.31	**+43.5%**
	Open	48.99	58.79	+18.6%
Calcifying:Non-Calcifying Ratio	MPA	1.11	0.79	+36.5%
	FRA	1.57	0.79	**+43.5%**
	Open	0.94	0.59	+18.6%

Table 11. Relative difference in reef fish and benthic coral community indicators by management status in 2017. Indicators are grouped by management status (MPA, FRA and Open Area). Bold values represent statistically significant differences ($p<0.05$). See Table 10 for indicator values.

INDICATOR	2017 DIFFERENCE IN MANAGEMENT STATUS (%)		
	MPA – FRA	MPA – Open	FRA – Open
Total Abundance	**+61.4**	**+34.8**	-16.5
Total Biomass	**+78.9**	**+100.0**	+11.8
Adult Fish Length	-0.6	**+11.1**	**+11.8**
Species Richness	**+28.3**	**+16.1**	**-9.5**
Herbivore Biomass	**+71.8**	**+69.3**	-1.4
Juvenile yellow tang	-12.7	**+66.2**	**+90.2**
Coral Cover	-3.1	-3.2	0.0
Total Algal Cover	+4.4	-3.9	-7.9
Calcifying: Non-Calcifying Ratio	0.2	34.6	34.4

- The average annual commercial aquarium catch differs greatly along West Hawaiʻi. For example, 80–85 thousand fish (25% of the total catch) are caught on average per year in the area from Keāhole Point to Waikoloa. In contrast, fewer than 10,000 fish were caught from Keahole Point to Kailua-Kona (Figure 38).

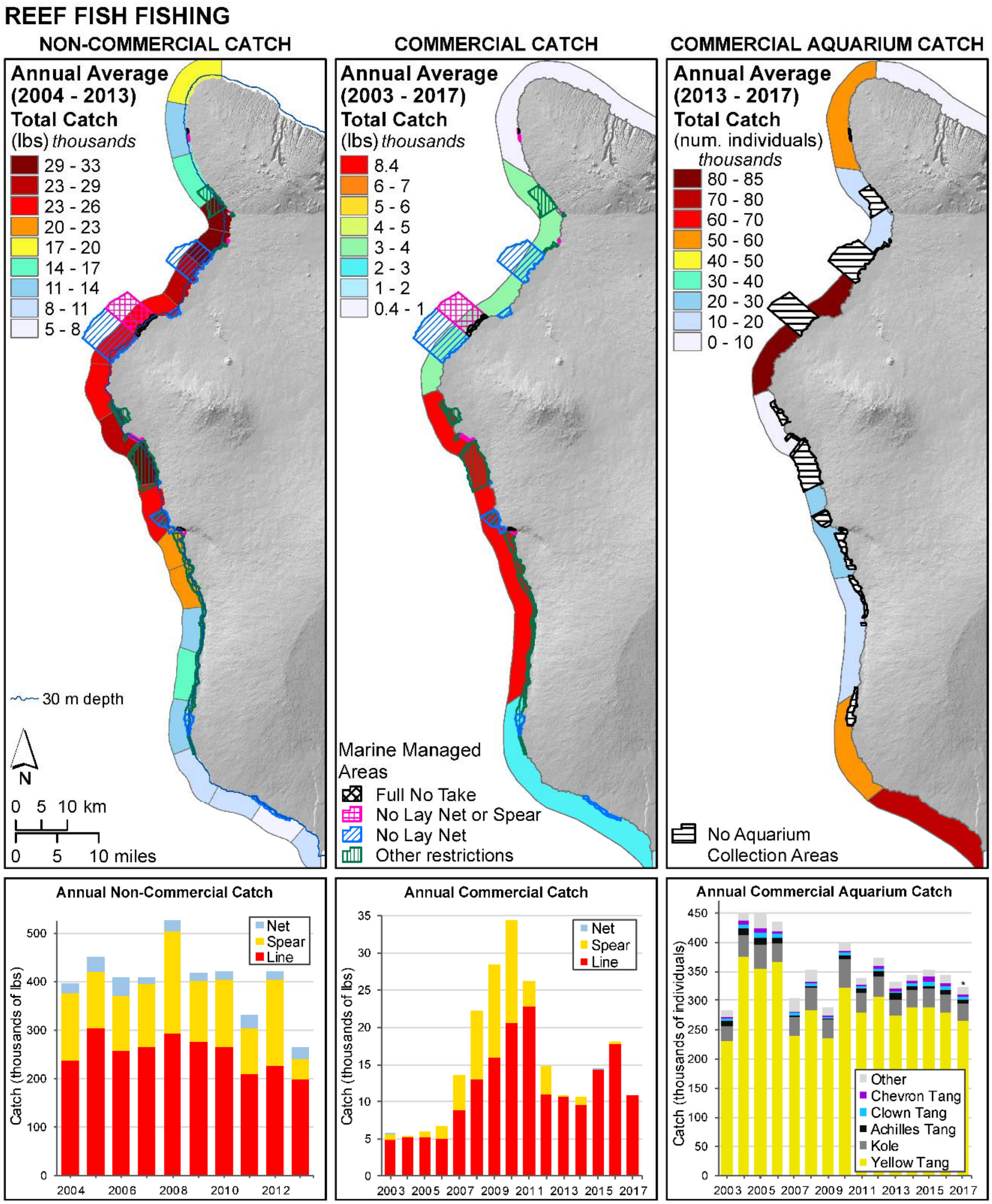


Figure 38. Maps of West Hawai'i indicating the spatial distribution of average annual reef fish catch, including non-commercial catch, commercial catch, and commercial aquarium catch. Coastal segments are shown for the purposes of visualization only and do not represent the outward spatial extent over which catch was enumerated. Below each map are annual values for the total catch of reef fish from 2003/2004 to 2017/2018.

Adaptive Management of the Aquarium Fishery

When the White List of aquarium fish species permitted for collection was being formulated by DAR and the WHFC, it was understood that the dynamics of marine ecosystems are complex and often poorly understood. Species populations can wax and wane over time and often this variability is unpredictable. It was thus considered essential to incorporate some management flexibility in the White List to respond to the changing situations of the various species. Such an approach can be termed "Adaptive Management" (McGraw-Hill 2005).

To accomplish such adaptive management, the draft WHRFMA rule amendment incorporated a provision allowing the Board of Land and Natural Resources (BLNR) to impose a moratorium on further collecting of a White List species. The moratorium would be triggered if DAR could provide sufficient data to the BLNR to indicate that the population of a particular species in West Hawai'i might be jeopardized (e.g. substantial decline in numbers) by aquarium collecting or other factors. A similar BLNR moratorium provision (regarding urchin harvesting) was incorporated in another West Hawai'i rule (HAR 13-37 Old Kona Airport MLCD) which was amended in 2005. Somewhat similar BLNR prerogatives exist in other DLNR rules as well (e.g. HAR §13-94-11 – regarding bottomfish).

Although both the DAR legal fellow and DLNR's Deputy Director (a former Deputy AG himself) concurred with the board moratorium approach in the rule, the Deputy AG reviewing the rule would not approve such a moratorium and ultimately it was removed. The Deputy AG asserted that any such changes to the rule (i.e. a species-specific moratorium) could only be made by amending the rule via Hawai'i Administrative Rule making (Chapter 91). Such a process can take many years to accomplish thereby obviating any real-time adaptive management.

Following this setback to effective management, an alternative strategy was attempted whereby WHFC/DAR would seek specific legislative authorization to institute a moratorium process in West Hawai'i (only). Such bills were introduced in 2012 (HB2129) and 2013 (HB 185) by Representative Cindy Evans (and others). These bills authorized the Board of Land and Natural Resources (BLNR) to impose temporary aquarium management measures (i.e., bag limits, closed seasons or moratoriums) within the WHRFMA without the need to go through the lengthy administrative rule-making process. It also required DLNR to establish a limited entry program for commercial aquarium fishers. Neither of these bills was approved by the Legislature and thus adaptive management of the West Hawai'i aquarium fishery is still not possible.

Nearshore (Shallow-Water) Resource Fishery

Shallow water resource fish (SWRF) surveys were conducted to collect data on the abundance of resource fish species (i.e. food fish) in shallow water (2 m–6 m) habitats. Timed 10-minute surveys along a 5 m transect belt followed the contour of the coastline from predetermined, randomly selected, start points. These surveys were conducted in 2008, 2009, 2011, 2014 and 2018 at sites spanning the West Hawai'i coastline (Figure 39). The same 72 sites were surveyed in 2009 and 2018 to allow for direct comparisons. Only resource and a few introduced species were counted and individuals were sized within 5 cm bins. Fish were counted only if they were 15 cm or larger with the exception of three smaller surgeonfish species (Achilles Tang (*Acanthurus achilles*), Goldrim Surgeonfish (*A. nigricans*) and Convict Tang (*A. triostegus*), which were recorded when larger than 10 cm in total length. Biomass was standardized per meter squared using total distance covered as calculated using start and end waypoints from a diver-towed GPS unit.

Throughout the five years surveyed, a total of 68 total species were recorded with 20 of those being counted in only one of the five years. Based on percent abundance over all five years, the five most abundant species in decreasing order were the Whitebar Surgeonfish (*Acanthurus leucopareius*), Orangespine Surgeonfish (*Naso literatus*), Palenose Parrotfish (*Scarus psittacus*), Convict Tang, Bullethead Parrotfish (*Chlorurus spilurus*) and Whitespotted Surgeonfish (*A. guttatus*).

There was a significant ($p < 0.05$) decline in biomass for all fish species counted in surveys from 2008 to 2009, 2011 and 2018 and a more significant decline ($p < 0.01$) from 2014 to 2018 (Figure 40). Herbivores make up nearly 90% of the total biomass of resource fish each year, and as such, mirror the decline of all fish species between years with significant declines from 2008 to 2009, 2011 and 2018 and from 2014 to 2018 ($p < 0.05$). Herbivores were dominated by surgeonfishes in 2008 and 2009, making up 70% and 65% of herbivore biomass in 2008 and 2009, respectively, but this percentage decreased to 43% by 2018.

Parrotfishes and surgeonfishes combined made up over 90% of total herbivore biomass. Parrotfish biomass increased significantly ($p < 0.5$) in surveys from 2009 to 2011, 2014 and 2018 (Figures 40 and 41), with the most significant increase from 2009 to 2014 ($p < 0.00001$). This increase followed a slight, non-significant decrease from 2008 to 2009. Parrotfishes made up just 25% of total fish biomass in 2008 and increased to 41% in 2014 and 44% in 2018.

In contrast, there was a significant decline ($p < 0.01$) in biomass for resource species of surgeonfishes between 2008 and all other years and between 2018 and all other years (Figures 40 and 41).

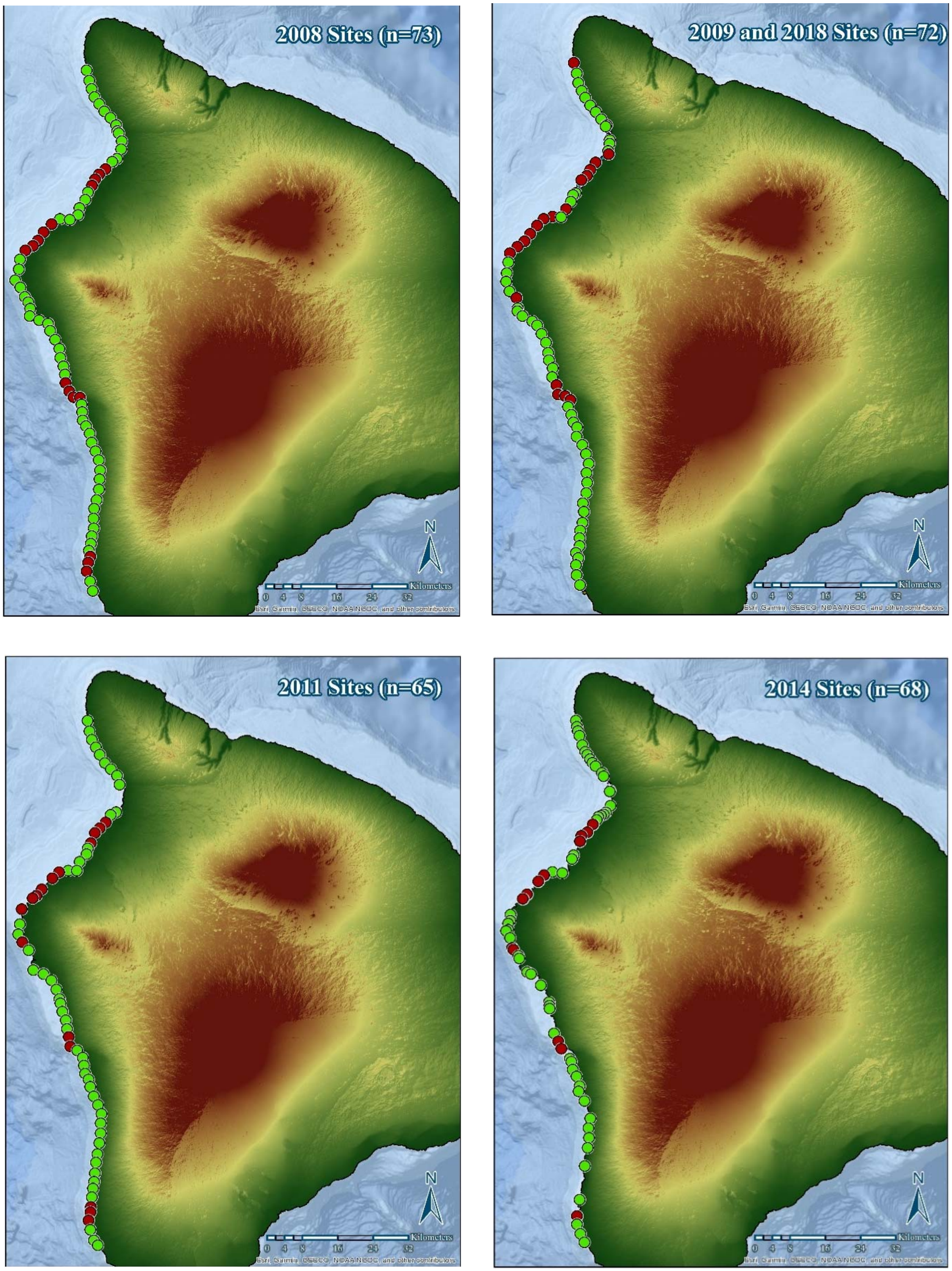


Figure 39. Maps of West Hawai'i Shallow Water Resource Fish (SWRF) survey sites for each of the survey years. Sites within Netting Restricted Areas are represented by red circles, whereas sites outside of these areas are represented by green circles. Note that survey sites were the same for 2009 and 2018.

Table 12. List of species represented in surveys for all five years, listed from most abundant to least abundant. Surgeonfish species are highlighted in orange and parrotfish species are highlighted in green. Species on the WHRFMA "White List" are noted with an asterisk.

Common Name	Scientific Name	Number of Individuals Counted					
		2008	2009	2011	2014	2018	All Years Combined
Whitebar Surgeonfish	*Acanthurus leucopareius*	4405	3602	3780	2215	1487	15489
Orangespine Surgeonfish*	*Naso literatus*	1626	1382	814	605	795	5222
Palenose Parrotfish	*Scarus psittacus*	701	780	1029	751	500	3761
Convict Tang	*Acanthurus triostegus*	810	939	672	561	719	3701
Bullethead Parrotfish	*Chlorurus spilurus*	603	474	508	879	754	3218
Whitespotted Surgeonfish	*Acanthurus guttatus*	1417	575	527	183	167	2869
Yellowfin Goatfish	*Mulloidichthys vanicolensis*	422	709	651	622	251	2655
Orangeband Surgeonfish*	*Acanthurus olivaceus*	457	531	419	547	507	2461
Redlip Parrotfish	*Scarus rubroviolaceus*	449	555	457	441	431	2333
Achilles Tang*	*Acanthurus achilles*	881	377	359	103	136	1856
Sea Chubs	*Kyphosus spp.*	286	521	318	132	566	1823
Manybar Goatfish	*Parupeneus multifasciatus*	252	199	221	169	238	1079
Ringtail Surgeonfish	*Acanthurus blochii*	263	134	118	150	78	743
Blueline Surgeonfish	*Acanthurus nigroris*	110	140	172	173	42	637
Yellowstripe Goatfish	*Mulloidichthys flavolineatus*	75	49	74	298	113	609

Goldrim Tang*	*Acanthurus nigricans*	184	105	0	74	123	486
Eyestripe Surgeonfish*	*Acanthurus dussumieri*	65	109	70	57	99	400
Doublebar Goatfish	*Parupeneus insularis*	106	54	50	70	107	387
Yellowtail Coris*	*Coris gaimard*	62	92	71	58	46	329
Bluespine Unicornfish	*Naso unicornis*	57	79	34	51	49	270
Bluestripe Snapper*	*Lutjanus kasmira*	66	33	7	25	99	230
Peacock Grouper*	*Cephalopholis argus*	33	40	45	51	25	194
Stareye Parrotfish	*Calotomus carolinus*	16	16	26	52	58	168
Blue Goatfish	*Parupeneus cyclostomus*	43	25	33	36	27	164
Regal Parrotfish	*Scarus dubius*	31	24	21	33	45	154
Spectacled Parrotfish	*Chlorurus perspicillatus*	20	30	29	21	5	105
Smalltooth Jobfish	*Aphareus furca*	15	16	21	32	15	99
Reticulated Butterflyfish	*Chaetodon reticulatus*	19	15	29	13	8	84
Saddleback Butterflyfish	*Chaetodon ephippium*	18	13	12	18	15	76
Ringtail Wrasse	*Oxycheilinus unifasciatus*	12	13	15	24	10	74
Bigeye Emperor	*Monotaxis grandoculis*	5	23	12	15	17	72
Bluefin Trevally	*Caranx melampygus*	10	9	28	12	10	69
Blacktail Snapper	*Lutjanus fulvus*	7	7	10	4	40	68
Spotted Queenfish	*Scomberoides lysan*	8	8	21	4	1	42

Sleek Unicornfish	*Naso hexacanthus*	8	1	13	1	3	26
Old Woman Wrasse	*Thalassoma ballieui*	1	1	7	4	3	16
Hawaiian Hogfish	*Bodianus albotaeniatus*	3	3	1	2	5	14
Surge Wrasse	*Thalassoma purpureum*	3	0	0	4	6	13
Great Barracuda	*Sphyraena barracuda*	1	1	1	0	1	4

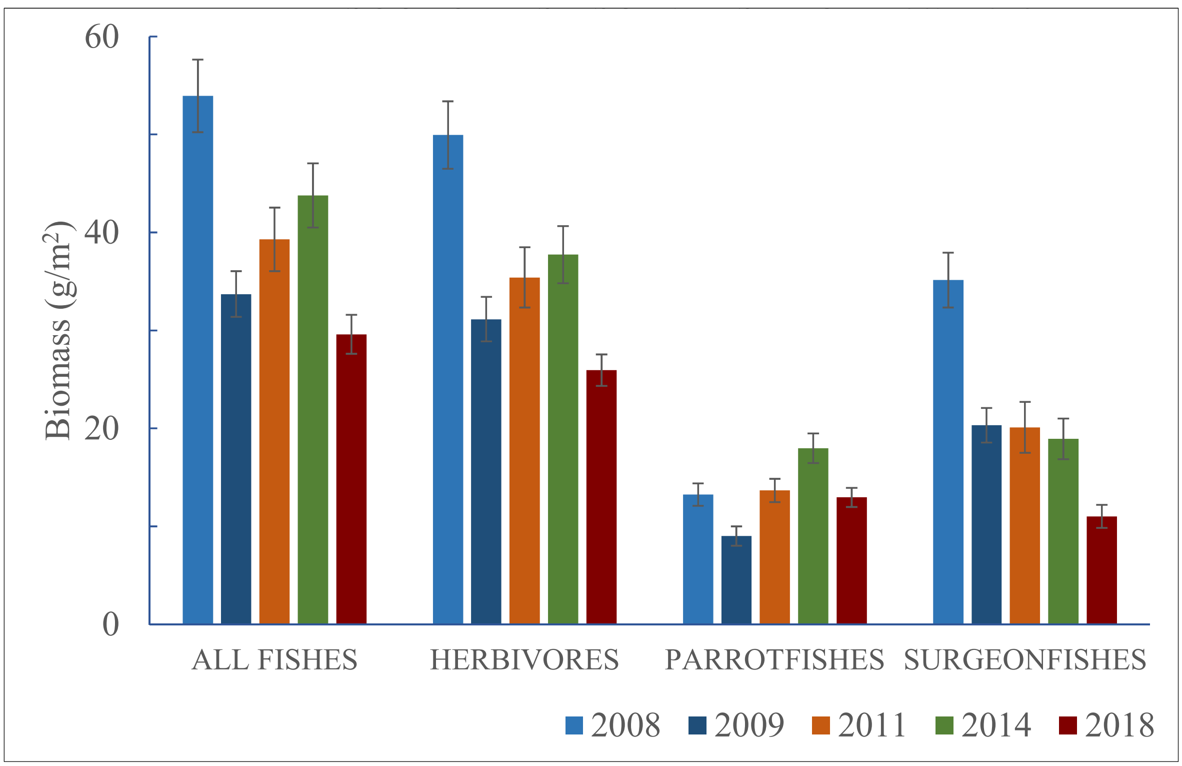


Figure 40. Average biomass per site (± SE) of All Fishes, Herbivores, Parrotfishes and Surgeonfishes counted in each of the survey years. There was a statistically significant decline from 2008 to 2009 and a further decline from 2009 to 2018 in all groups except Parrotfishes. Parrotfishes experienced a significant increase from 2009 to 2018, despite a slight, non-significant decline from 2014 to 2018.

When comparing 2009 to 2018 where the sites surveyed were the same, there were no significant differences in the total fish biomass ($p = 0.79$) nor the biomass of all herbivores ($p = 0.56$). There were significant differences in biomass of surgeonfishes ($p < 0.01$) and the biomass of parrotfishes ($p < 0.5$) between 2009 and 2018, with surgeonfishes declining dramatically (46% decline) and parrotfishes increasing (43% increase) (Figures 40 and 41).

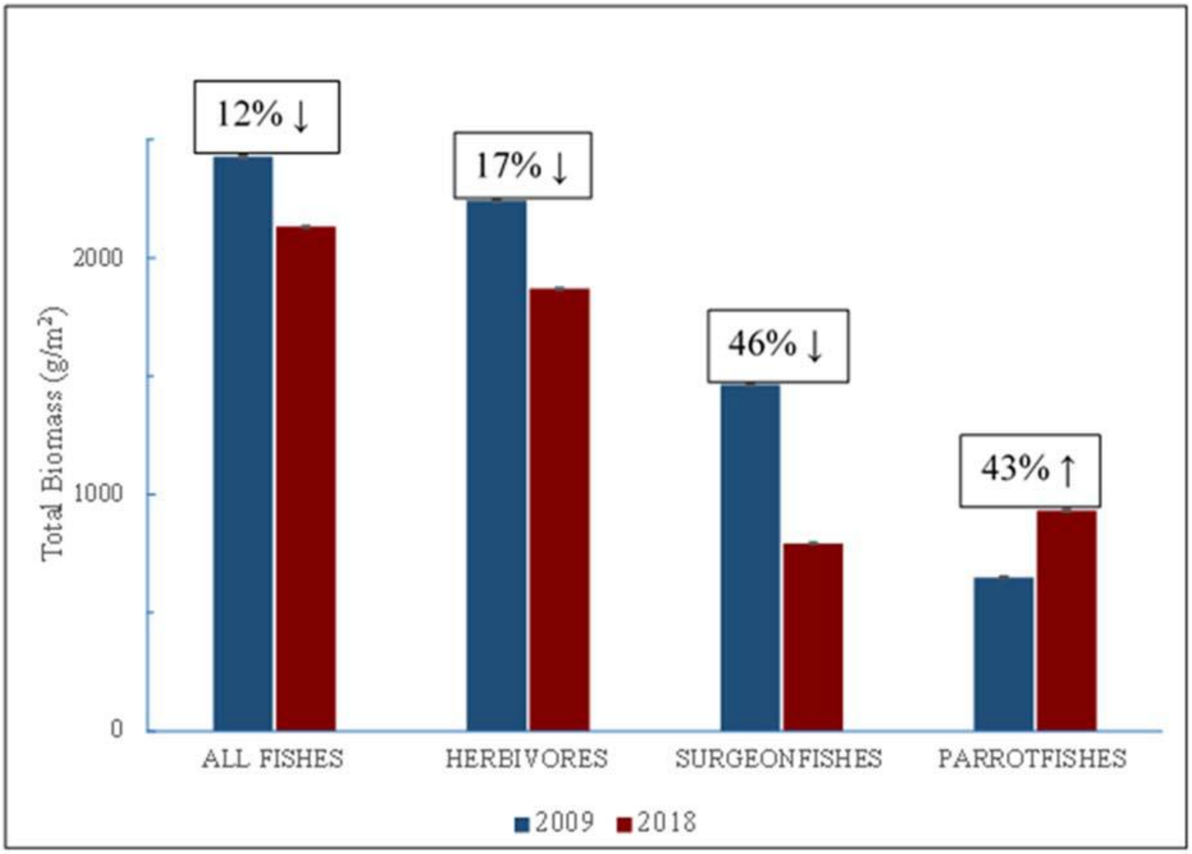


Figure 41. Total biomass of fishes (± SE) across 72 surveyed sites in 2009 and 2018. Significant differences were found in parrotfishes and surgeonfishes with parrotfishes increasing and surgeonfishes declining.

There are six designated Netting Restricted Areas (NRAs) throughout the WHRFMA where fishing with a lay net is generally prohibited. To examine the differences between areas with Netting restrictions (NRAs) and those without, fish biomass was compared across all five survey years at sites in fully open areas (SWRF survey sites within MLCDs, FMAs or FRAs that did not have netting restrictions were not included in this analysis) and sites within NRAs. There were no significant differences between open areas and NRAs for total fish biomass ($p = 0.34$) nor for all herbivores biomass ($p = 0.15$) (Figure 42, Table 13).

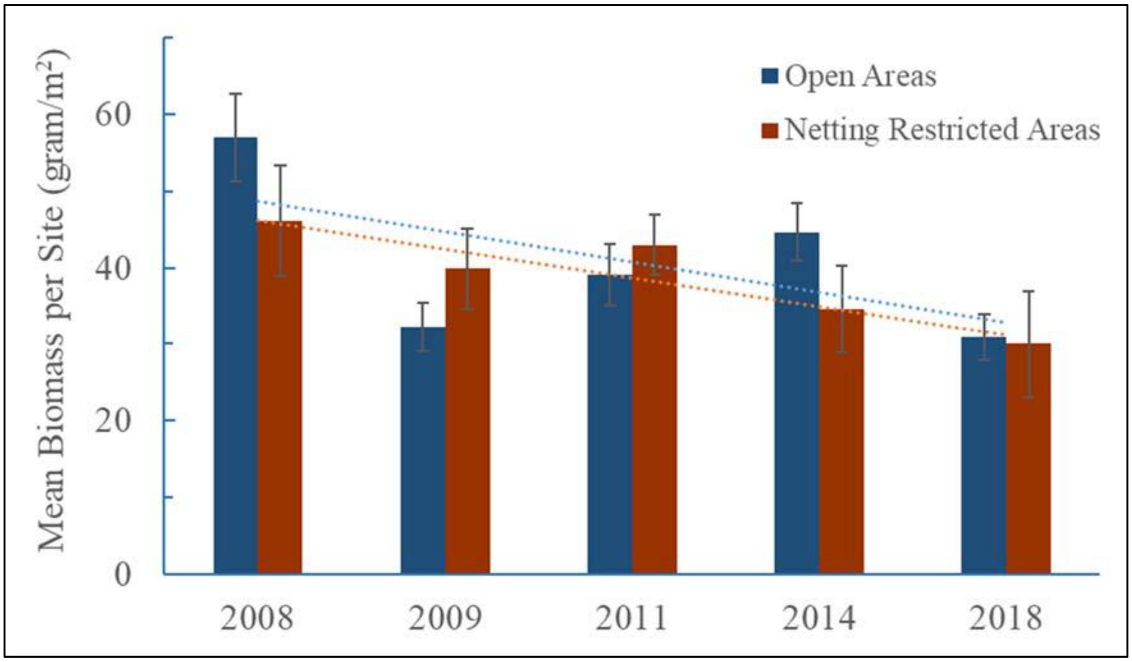
There were also no significant differences in total fish or total herbivore biomass (of all counted fish species) between 2009 and 2018 (Figure 41) nor between open areas and NRAs. There were significant differences however (Figure 41) in the biomass of parrotfishes (43% increase, $p < 0.001$), and surgeonfishes (46% decrease, $p < 0.001$).

Table 13. Mean biomass of all resource fish species and all herbivores across all five survey years in open areas and NRAs. There were significant declines in mean biomass between years but no significant differences between the two management types for these groups.

Species Group	Management Type	Mean Biomass (gm/m^2 per site)					Overall % Change in Biomass Since 2008	Overall % Change in Biomass Since 2013
		2008	2009	2011	2014	2018		
All Resource Fish	Open	56.94	32.23	39.09	44.66	30.93	-45.68	-20.88
	Net-restricted	46.10	39.86	42.98	34.58	30.03	-34.87	-30.15
	Total (All Sites)	53.93	33.70	39.28	43.76	29.59	-45.13	-24.67
All Herbivores	Open	54.11	29.34	35.48	39.26	28.82	-46.74	-18.79
	Net-restricted	42.29	36.67	38.78	30.79	21.69	-48.71	-44.07
	Total (All Sites)	49.94	31.13	35.41	37.73	25.94	-48.07	-26.75

When comparing all five years surveyed, there was no significant difference in parrotfish biomass in open areas versus NRAs ($p = 0.52$). The percentage change in parrotfish biomass was greater (larger increase in biomass) in open areas ($n = 29$) than in NRA ($n = 19$) from 2008 to 2018 (Figure 43, Table 14). There was a significantly higher biomass of parrotfish in NRAs than open areas in both 2009 and in 2018, ($p < 0.05$). This difference was more pronounced in 2009 than in 2018.

Increases from 2009 to 2018 in parrotfish biomass in open areas and NRAs were mainly driven by one species of parrotfish, *Chlorurus spilurus* (Bullethead Parrotfish), increasing 52% since 2013. *Calotomus carolinus* (Star-eyed Parrotfish) and the endemic *Scarus dubius* (Regal Parrotfish), while accounting for relatively low numbers overall, also showed large increases (99% and 86%, respectively since 2013). There are species-specific concerns for *Scarus psittacus* (Palenose Parrotfish) and the endemic *Chlorurus perspicillatus* (Spectacled Parrotfish), which declined 56% and 74% respectively since 2013 (Table 15).



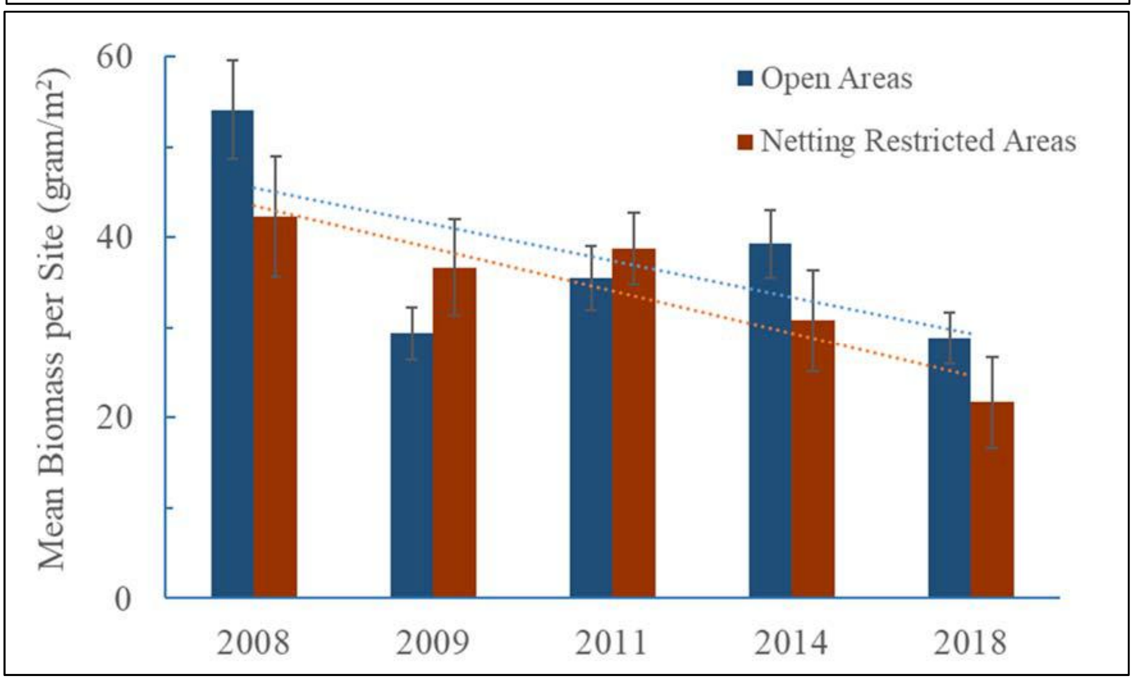


Figure 42. Mean biomass (± SE) per site of All Resource Fish Species (top) and All Herbivores across five survey years. Biomass was compared between sites with and without netting restrictions. There were no significant differences between management type for either of these groups.

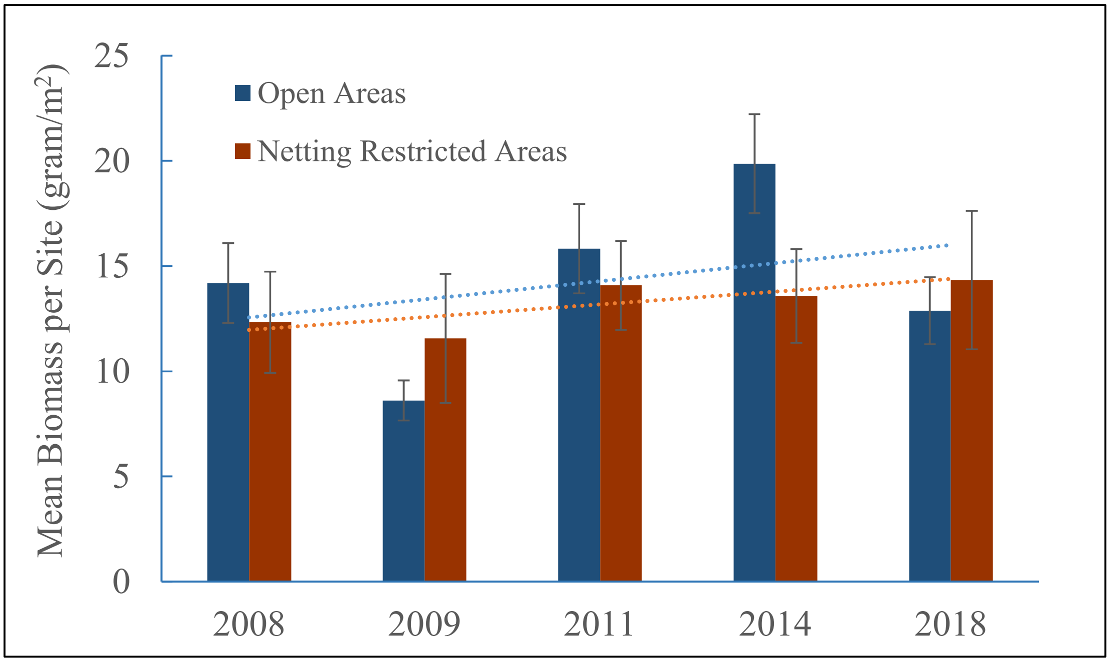


Figure 43. A comparison of mean biomass per site of all Parrotfishes in shallow water habitats in Open management areas and Netting Restricted Areas from 2008 to 2018.

When considering all five years in which the surveys were conducted, the biomass of surgeonfishes in open areas was higher than that of NRAs with marginal significance ($p = 0.05$). The percentage change in surgeonfish biomass was greater in NRAs than in open areas, with a larger decline of surgeonfish in NRAs (Figure 44, Table 15). Surprisingly, there were significant declines for both management types between 2008, 2009 and 2018 ($p < 0.001$). The majority of surgeonfish species are in decline (Table 15). Most notably *Acanthurus achilles* (Achilles Tang) which, despite being a White List species, continues to decline in multiple habitats including shallow water, where they are most abundant as adults. This species has declined 90% since 2008 and 72% since 2013. Despite netting restrictions, many surgeonfish species continue to experience major declines in the shallow water environment where they are heavily targeted for recreational and commercial fishing as food fish.

Table 14. Mean biomass of Parrotfishes in shallow water habitats across five years of surveys. Percentage change listed from 2008, as this was the first year of the surveys, and since 2011, which was the last year of surveys prior to the beginning of the ban on SCUBA spearfishing.

Common Name	Scientific Name	Management Type	Mean Biomass (gm/m^2 per site) 2008	2009	2011	2014	2018	Overall % Change in Biomass Since 2008	Overall % Change in Biomass Since 2013
All Parrotfish	Family *Scaridae*	Open	14.19	8.61	15.83	19.86	12.87	-9.28	-18.66
		Net-restricted	12.33	11.56	14.09	13.58	14.34	16.31	1.79
		Total (All Sites)	13.25	9.00	13.66	17.98	12.95	-2.25	-5.20
Spectacled Parrotfish	*Chlorurus perspicillatus*	Open	0.30	0.43	0.49	0.76	0.29	-2.50	-40.51
		Net-restricted	0.69	0.24	0.70	0.01	0.00	-100.00	-100.00
		Total (All Sites)	0.43	0.30	0.45	0.34	0.12	-72.35	-73.63
Palenose Parrotfish	*Scarus psittacus*	Open	4.87	1.29	6.78	4.86	3.07	-37.02	-54.74
		Net-restricted	3.55	5.69	5.27	3.60	2.02	-43.14	-61.68
		Total (All Sites)	3.70	2.45	5.39	4.71	2.39	-35.54	-55.67
Redlip Parrotfish	*Scarus rubroviolaceus*	Open	4.05	4.28	4.52	4.91	4.83	19.35	6.85
		Net-restricted	4.68	2.40	4.11	3.20	3.03	-35.26	-26.30
		Total (All Sites)	4.41	3.66	3.64	4.26	4.00	-9.33	9.97
Bullethead Parrotfish	*Chlorurus spilurus*	Open	4.84	2.49	3.69	8.87	4.24	-12.40	14.69
		Net-restricted	3.15	3.14	3.88	6.44	8.88	181.84	129.08
		Total (All Sites)	4.55	2.46	3.94	8.25	5.98	31.53	51.69
Regal Parrotfish	*Scarus dubius*	Open	0.07	0.10	0.23	0.28	0.29	347.59	27.94
		Net-restricted	0.11	0.08	0.11	0.17	0.31	171.23	182.95
		Total (All Sites)	0.09	0.10	0.18	0.26	0.34	288.04	85.87
Stareye Parrotfish	*Calotomus carolinus*	Open	0.04	0.03	0.11	0.16	0.15	283.09	36.10
		Net-restricted	0.01	0.02	0.02	0.15	0.11	723.16	360.65
		Total (All Sites)	0.03	0.03	0.07	0.17	0.13	337.96	99.07

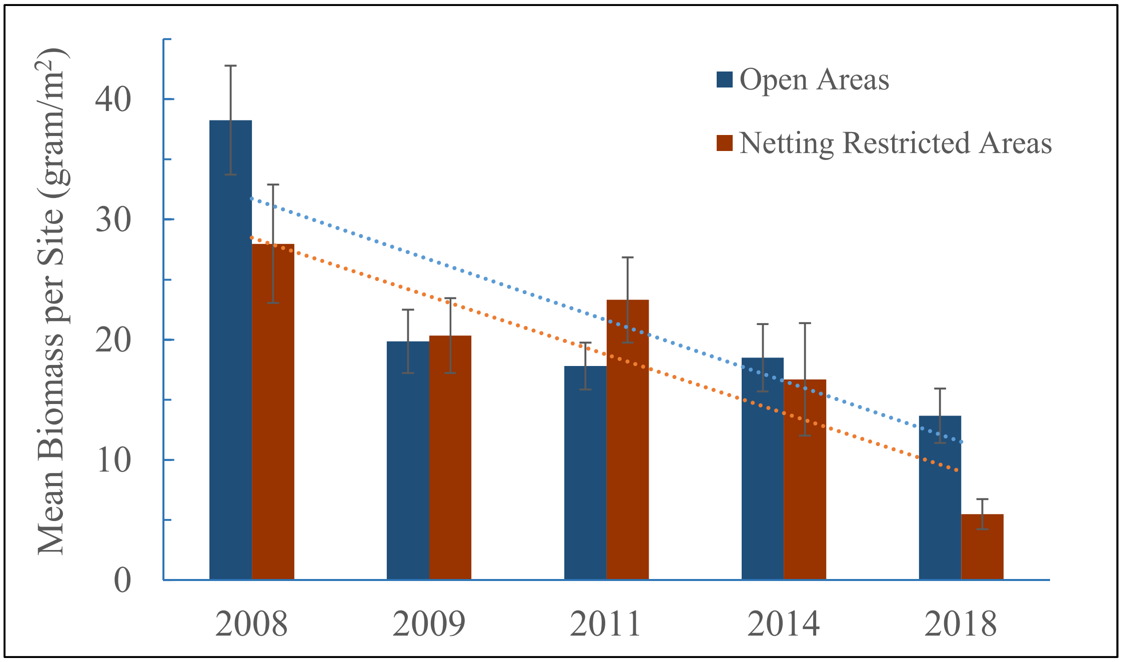


Figure 44. A comparison of mean biomass per site of all surgeonfishes in shallow water habitats in Open management areas and Netting Restricted Areas from 2008 to 2018.

In December 2013, the West Hawai′i Regional Fishery Management Area (WHRFMA) Hawai′i Administrative Rule (HAR) was amended to include a ban on SCUBA spearfishing within the WHRFMA. Parrotfishes, despite not accounting for the majority of speared fish, are considered highly vulnerable targets of SCUBA spearfishing, especially at night when they seek refuge in crevices. This ban seems to have had an overwhelmingly positive effect for the parrotfishes, overall, with many species increasing between the 2011 and 2014 surveys. There are some species that may be in need of additional protections as their numbers continue to decline despite Netting Restrictions and the SCUBA spearfishing ban.

From 2003-2011, commercial spearfishers took more pounds of surgeonfishes than any other family (Walsh 2013a). Though it is likely that both parrotfishes and surgeonfishes could experience increased protection from the SCUBA spearfishing ban, surgeonfishes face greater spearfishing pressure overall. The majority of these species are in rapid decline in shallow water habitats. Many species of surgeonfish are important for food and some as cultural resources. They were once the most dominant group of herbivores and now that dominance is shifting as their numbers continue to decline. Promoting herbivore management areas to reduce fishing pressures may be necessary protect this valuable resource for the future.

Table 15. Mean biomass of surgeonfishes in shallow water habitats across five years of surveys. Percentage change listed from 2008, as this was the first year of the surveys, and since 2011, which was the last year of surveys prior to the beginning of the ban on SCUBA spearfishing.

Common Name	Scientific Name	Management Type	Mean Biomass (gm/m² per site) 2008	2009	2011	2014	2018	Overall % Change in Biomass Since 2008	Overall % Change in Biomass Since 2013
All Surgeonfishes	*Family Acanthuridae*	Open	38.27	19.85	17.81	18.50	13.66	-64.30	-23.28
		Net-restricted	27.98	20.34	23.30	16.70	5.49	-80.39	-76.46
		Total (All Sites)	35.14	20.33	20.09	18.93	11.02	-68.63	-45.13
Achilles Tang*	*Acanthurus achilles*	Open	2.47	0.55	0.66	0.12	0.30	-87.79	-54.41
		Net-restricted	1.70	1.43	1.55	0.32	0.10	-94.18	-93.59
		Total (All Sites)	2.27	0.77	0.81	0.18	0.23	-89.94	-71.64
Whitespotted Surgeonfish	*Acanthurus guttatus*	Open	7.79	2.28	1.57	1.43	1.21	-84.46	-22.95
		Net-restricted	5.68	2.06	4.43	1.04	0.24	-95.73	-94.53
		Total (All Sites)	7.04	2.12	2.40	1.04	0.83	-88.26	-65.51
Ringtail Surgeonfish	*Acanthurus blochii*	Open	0.77	0.32	0.19	0.84	0.17	-78.37	-10.46
		Net-restricted	0.58	0.11	0.33	0.48	0.07	-87.65	-78.23
		Total (All Sites)	0.82	0.33	0.25	0.53	0.17	-79.78	-33.37
Orangespine Surgeonfish*	*Naso literatus*	Open	11.04	5.89	3.62	2.77	2.92	-73.52	-19.31
		Net-restricted	7.29	5.08	3.56	3.16	1.19	-83.73	-66.71
		Total (All Sites)	8.83	4.89	3.19	3.17	2.35	-73.32	-26.24
Goldrim Tang*	*Acanthurus nigricans*	Open	0.35	0.19	0.00	0.15	0.159	-54.62	15.85
		Net-restricted	0.14	0.06	0.00	0.03	0.028	-80.48	2.81
		Total (All Sites)	0.21	0.09	0.00	0.10	0.10	-52.45	10.07
Whitebar Surgeonfish	*Acanthurus leucopareius*	Open	11.82	6.91	8.67	7.89	5.81	-50.81	-32.93
		Net-restricted	7.35	7.26	9.18	6.47	1.05	-85.66	-88.51
		Total (All Sites)	11.72	7.68	10.20	8.66	4.13	-64.73	-59.49
Orangeband Surgeonfish*	*Acanthurus olivaceus*	Open	2.38	1.64	1.62	3.47	1.34	-43.94	-17.52
		Net-restricted	2.95	1.23	1.46	2.51	0.98	-66.79	-33.11
		Total (All Sites)	2.32	2.04	1.60	3.20	1.60	-30.95	0.53
Eyestripe Surgeonfish*	*Acanthurus dussumieri*	Open	0.14	0.28	0.17	0.33	0.24	74.92	42.85
		Net-restricted	0.17	0.47	0.09	0.24	1.22	627.56	1198.90
		Total (All Sites)	0.19	0.31	0.15	0.36	0.46	137.50	208.08

West Hawai'i Coral Reef Decline Due to Severe Thermal Stress Events (Coral Bleaching)

In the fall of 2015, leeward reefs of Hawai′i Island suffered catastrophic coral mortality due to widespread and severe coral bleaching (Figure 45). Large-scale coral bleaching events are increasingly causing mass coral mortality and associated reef declines globally (Donner et al. 2005, Hoegh-Guldberg et al. 2007). From August to November 2015, extreme and prolonged thermal stress conditions occurred within West Hawai′i coastal waters, with water temperatures exceeding 30° C at several monitoring sites (Eakin 2016, W. Walsh pers. comm.). Beginning in August 2015, a massive coral bleaching event affected the majority of coral species across reef zones. The severity of this event was unprecedented for Hawai′i Island according to previous DAR monitoring reports (Walsh et al. 2012), and was preceded by less severe events in 2006 and 2014, affecting primarily the Northwestern Hawaiian Islands (Kenyon and Brainard 2006) and certain areas of the Main Hawaiian Islands (Bahr et al. 2015). To better understand the impact of this event and possible local management strategies, DAR Kona conducted coral bleaching prevalence and severity surveys just after the forecasted peak thermal stress (Eakin 2016), and post-bleaching coral mortality was determined in the spring of 2016. The Eyes of the Reef Community Reporting network played a substantial role in helping to document the severity and extent of the bleaching event, along with scientific data collected by the DAR Coral reef monitoring program.

From October to November 2015, coral bleaching surveys were conducted at 8 selected fixed monitoring sites. Three 10 m^2 belt transects were surveyed per site, and all coral colonies within each belt were scored for bleaching condition and severity and any signs of algal turf overgrowth of bleached tissue. Mean total coral bleaching prevalence was 53.3 $\pm$ 5.3% and severe bleaching prevalence (more than 25% of a colony white bleached) was 39.2 $\pm$ 4.0%. Relatively higher severe bleaching was observed for northern and central coast sites. Importantly, based on coral mortality estimates, coral bleaching severity may have continued to increase post-survey. Severe algal turf overgrowth of bleached corals (>50% of colony affected), a condition which tended to precede coral mortality, ranged from 5.1 $\pm$ 1.5% to 14.2 + 4.2% prevalence, and was highest for sites Puakō (14.2 $\pm$ 4.2%) and South Oneo (12.2 $\pm$ 0.6%). This condition was weakly positively correlated with total dissolved nitrogen based on a single grab sample (Pearson correlation= 0.660, p=0.075). Total dissolved nitrogen exceeded 40 µm for sites Puakō and S. Oneo, suggesting that impaired watersheds may have reduced coral recovery from bleaching.

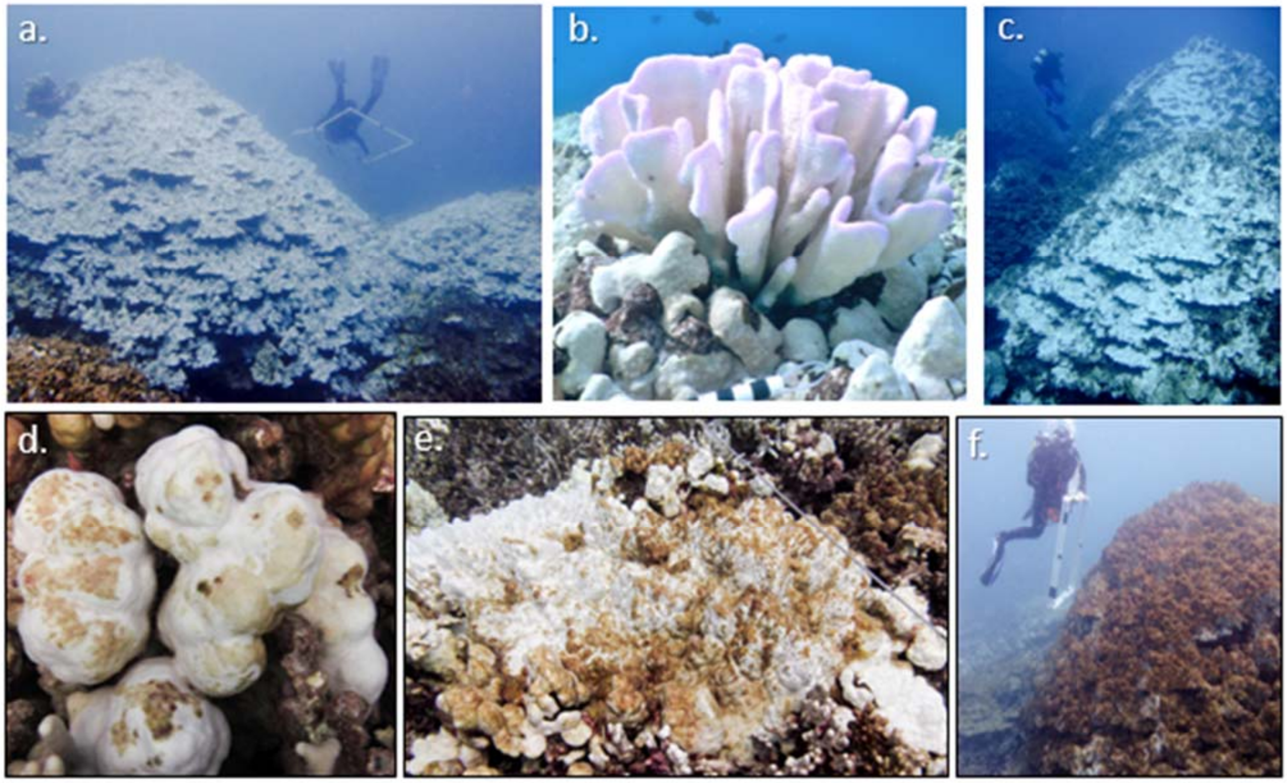


Figure 45. Images from coral bleaching survey sites in West Hawai'i during the fall 2015 coral bleaching event; a) severely bleached *Porites evermanni* colonies at N. Keauhou, b) severely bleached *Pocillopora eydouxi* and *Porites lobata* colonies at Honokōhau, c) initial algal turf colonization on P. evermanni at N. Keauhou; d) and e) initial algal turf colonization on *P. lobata* at Honokōhau, and f) algal turf colonization of recently dead *P. evermanni* at N. Keauhou (post-bleaching mortality).

Based on qualitative observations, severe coral bleaching affected common coral species, *Pocillopora meandrina* (cauliflower coral), and in December 2015, 8 shallow reef sites with high densities of *P. meandrina* were selected for rapid health surveys. In December 2015, post-bleaching mortality of *P. meandrina* averaged 77.8% (total colony mortality) and 95.5% (partial colony mortality), based on a weighted mean according to the total number of colonies surveyed at each site. A follow-up survey at Kealakekua Bay in May 2016 indicated that total colony mortality had increased to 88.9%. Focused predation by *Acanthaster plancii* and *Drupella* spp. on remaining live *P. meandrina* was frequently observed at this and other sites, and likely contributed to continued mortality of this species post-bleaching.

Severe coral bleaching was also observed for locally abundant coral species, *P. evermanni*, but was not detected in permanent monitoring site surveys. To quantify *P. evermanni* post-bleaching mortality, a previously mapped reef area with relatively high-density *P. evermanni* was surveyed in June 2016 (adjacent to the North Keauhou permanent monitoring site). Total live surface area of *P. evermanni* decreased from 1879 m^2 to 140.2 m^2 post bleaching at the surveyed site adjacent to North Keauhou (a loss of 92.5% cover), and live colony size frequency was severely truncated (Table 3). In August 2014, 193 live colonies were observed with an average percent live of 81.7 ± 0.7%. Post-bleaching (June 2016), 41 colonies were observed with an average percent live of 3.1 ± 0.8% (Table 3). Similar catastrophic mortality of this species was observed qualitatively in other areas and resulted in the loss of enormous (and very old) colonies.

Benthic cover was analyzed at 26 permanent monitoring sites from January to April 2016 (just after the bleaching event) using benthic image analysis. Severe post-bleaching coral mortality had occurred at all but one site and resulted in an average relative coral cover loss of -49.7 ± 2.7% from 2014 to 2016 (Figure 45, Table 16). Relative loss in coral cover ranged from -10.5 % (site Manukā) to -70.5% (site Acropora Gardens). For common coral species *Porites lobata*, coral bleaching prevalence was 57.8 ± 8.6% and post-bleaching relative mortality was estimated at -57.6%, suggesting that minimal bleaching recovery occurred for this species (Table 17). For endemic species *P. compressa*, coral bleaching prevalence was 54.8 ± 8.2% and post-bleaching relative mortality was -32.1%, suggesting that a portion of bleached colonies successfully recovered (Table 18). Mean gross cover of uncommon species coral *Pavona varians* increased (+ 0.22%) following the bleaching event, suggesting recovery from observed bleaching prevalence of 25.2 ± 8.9%.

Table 16 (next page). Results of fall 2015 coral bleaching surveys, and spring 2014 and 2016 benthic cover surveys. Monitoring sites are listed from North to South. Change in coral cover is expressed as mean relative coral loss (± SE), and 2014 and 2016 datasets were compared using a paired t-test. Statistical differences in coral cover between 2014 and 2016 are represented as, * $p \leq 0.05$, ** $p \leq 0.005$, and *** $p \leq 0.001$. Significant differences between sites are represented by superscripts (a, b, c).

Site	Mean Depth (m)	Latitude	Longitude	Coral Bleaching Survey Date	Benthic Cover Survey Dates (2014;2016)	Total Bleaching Prevalence (Mean ± SE %)	Severe Bleaching Prevalence (Mean ± SE %)	Pre-bleaching Coral Cover: 2014 (Mean ± SE %)	Post-bleaching Coral Cover: 2016 (Mean ± SE %)	Relative Coral Loss: 2014-2016 (Mean ± SE %)
Lapakahi	11	20.16000	-155.90018		3/14/2014; 1/13/2016			12.8 % ± 3.1 %	5.6% ± 1.6%	-55.4% ± 11.4% *
Kamilo	11	20.08102	-155.86808		4/14/2014; 1/13/2016			34.9 % ± 1.8 %	17.9% ± 1.6%	-48.7% ± 3.8% ***
Waiaka'īlio	14	20.07392	-155.86452	10/20/2015	4/14/2014; 1/13/2016	51.3% ± 2.8%	42.2% ± 2.3%	43.2 % ± 3.8 %	23.7% ± 2.2%	-44.8% ± 3.8% *
Puakō	10	19.96988	-155.84880	10/23/2015	4/07/2014; 2/04/2016	55.8% ± 5.8%	42.2% ± 4.4%	32.2 % ± 4.5 %	11.0% ± 0.8%	-64.2% ± 4.3% *
Anaeho'omalu	10	19.95275	-155.86617		4/07/2014; 2/04/2016			24.1 % ± 1.5 %	12.3% + 1.4%	-49.2% ± 5.6% **
Keawaiki	14	19.89112	-155.91007		4/07/2014; 2/04/2016			17.5 % ± 3.1 %	14.7% ± 2.1%	-14.3% ± 6.5%
Ka'ūpūlehu	12	19.84395	-155.98097		4/14/2014; 4/05/2016			27.0 % ± 6.6 %	14.2% ± 3.9%	-47.6% ± 4.3% *
Makalawena	10	19.79650	-156.03288		4/14/2014; 2/01/2016			46.1 % ± 3.3 %	24.1% ± 5.9%	-49.3% ± 8.5% **
Unualoha Point	12	19.74251	-156.05575		4/14/2014; 2/01/2016			38.8 % ± 3.3 %	18.4% ± 1.7%	-52.7% ± 1.6% **
Wawaloli Open	10	19.70888	-156.04950		4/04/2014; 1/14/2016			51.3% ± 5.4%	18.6% ± 1.5%	-61.6% ± 7.5% *
Wawaloli FMA	14	19.70001	-156.04991		4/04/2014; 1/14/2016			42.0% ± 3.2%	24.9% ± 2.4%	-40.8% ± 2.4% ***
Honokōhau	12	19.67098	-156.03033	10/9/2015	4/03/2014; 1/14/2016	47.3% ± 4.7%	36.7% ± 4.1%	53.2% ± 3.4%	26.2% ± 1.0%	-49.9% ± 4.7% *
Papawai	11	19.64725	-156.02298		2/21/2014; 2/09/2016			47.7% ± 2.5%	18.0% ± 3.4%	-61.6% ± 7.9% *
Old Kona Airport	14	19.16730	-155.91325		2/21/2014; 2/02/2016			57.2% ± 2.0%	26.7% ± 4.6%	-52.9% ± 9.2% *
S. Oneo Bay	11	19.63120	-155.99300	10/16/2015	2/21/2014; 4/05/2016	66.4% ± 10.8%	52.1% ± 6.3%	46.0% ± 3.3%	24.8% ± 4.5%	-45.7% ± 9.5% *
N. Keauhou	12	19.56838	-155.96935	10/15/2015	4/07/2014; 4/07/2016	45.1% ± 2.5%	32.2% ± 1.0%	31.9% ± 3.9%	16.4% ± 3.0%	-49.8% ± 4.0% ***
Kualanui Point	11	19.54827	-155.96230		4/01/2014; 3/24/2016			64.5% ± 1.6%	22.2% ± 3.0%	-65.4% ± 5.1% **
Acropora Gardens	8	na	na		1/17/2014; 4/19/2016			25.0% ± 6.2%	7.4% ± 2.4%	-71.0% ± 6.8% *
Red Hill	14	19.50528	-155.95288		4/07/2014; 3/24/2016			41.2 % ± 3.9%	17.8% ± 2.6%	-57.3% ± 3.8% **
Keopuka	11	19.48292	-155.94600		2/21/2014; 2/17/2016			16.8 % ± 3.9%	5.7% ± 1.9%	-68.8% ± 4.2% *
Kealakekua Bay	8	19.47930	-155.93278	10/13/2015	2/21/2014; 2/17/2016	49.2% ± 2.6%	38.5% ± 2.7%	25.7% ± 3.3%	12.1% ± 3.0%	-53.2% ± 8.4% *
Ke'ei	11	19.46282	-155.92680		2/21/2014; 2/17/2016			32.8% ± 2.4%	19.0% ± 2.6%	-41.5% ± 8.3% *
Kalahiki	11	19.36915	-155.89740	10/27/2015	1/17/2014; 4/07/2016	50.9% ± 3.3%	35.1% ± 5.3%	44.2% ± 3.0%	24.8% ± 4.1%	-42.5% ± 10.6% *
Au'Au, Ho'okena	14	19.29788	-155.88988		1/17/2014; 3/29/2016			34.2% ± 2.6%	19.6% ± 3.7%	-43.5% ± 8.1% *
Omaka'a, Miloli'i	14	19.16730	-155.91325	11/13/2015	2/21/2014; 3/22/2016	60.4% ± 9.6%	34.9% ± 5.6%	34.1% ± 4.4%	18.1% ± 2.6%	-46.3% ± 5.1% *
Manukā	12	19.07672	-155.90397		2/21/2014; 3/22/2016			39.4% ± 4.7%	35.3% ± 5.4%	-11.4% ± 5.6%
					Mean	**53.3% ± 2.4%**	**39.1% ± 1.8%**	**37.1% ± 1.4%**	**18.4% ± 0.86%**	**-49.6% ± 1.8% ***

Table 17. Change in coral cover (%) from 2014 to 2016 for the common coral species, *Porites lobata* (mean ± SE), following the 2015 coral bleaching event. Coral bleaching prevalence for each species was determined during fall 2015 bleaching surveys. Statistical differences in coral cover (%) by species from 2014 to 2016 are represented as, * p ≤ 0.05, ** p ≤ 0.005, and *** p ≤ 0.001.

Site	*P. lobata* pre-bleaching cover: 2014 (%)	*P. lobata* post-bleaching cover: 2016 (%)	*P. lobata* bleaching prevalence (%)	Relative change in *P. lobata* cover (%)
Waiaka'ilio	27.9 % ± 2.6 %	11.9 % ± 1.2 %	52.4 % ± 1.0 %	-57.5 % ± 2.6 % **
Puakō	20.7 % ± 3.0 %	5.6 % ± 2.2 %	59.1 % ± 11.0 %	-73.2 % ± 7.8 % *
Honokōhau	31.2 % ± 2.5 %	11.0 % ± 1.3 %	48.1 % ± 4.1 %	-64.2 % ± 4.7 % **
S. Oneo	23.7 % ± 5.0 %	9.0 % ± 1.4 %	69.9 % ± 15.7 %	-59.3 % ± 5.9 % *
N. Keauhou	9.2 % ± 1.9 %	7.4 % ± 1.2 %	50.3 % ± 13.6 %	-10.0 % ± 25.4 %
Kealakekua Bay	15.6 % ± 2.9 %	5.5 % ± 1.4 %	40.4 % ± 1.6 %	-65.6 % ± 7.7 % *
Kalahiki	27.7 % ± 4.5 %	9.9 % ± 2.1 %	60.4 % ± 15.4 %	-61.9 % ± 9.4 % *
Omaka'a Bay	18.2 % ± 1.7 %	8.3 % ± 0.5%	81.6 % ± 6.0 %	-53.9 % ± 2.9% *
Mean	**21.8 % ± 1.6 %**	**8.6 % ± 0.6 %**	**58.0% ± 4.1%**	**-55.7 % ± 4.7 % *** **

Table 18. Change in coral cover (%) from 2014 to 2016 for the common coral species, *P. compressa* (mean ± SE), following the 2015 coral bleaching event. Coral bleaching prevalence for each species was determined during fall 2015 bleaching surveys. Statistical differences in coral cover (%) by species from 2014 to 2016 are represented as, * p ≤ 0.05, ** p ≤ 0.005, and *** p ≤ 0.001.

Site	*P. compressa* pre-bleaching cover: 2014 (%)	*P. compressa* pre-bleaching cover: 2016 (%)	*P. compressa* bleaching prevalence (%)	Relative change in *P. compressa* cover (%)
Waiaka'ilio	14.1 % ± 1.5 %	11.3 % ± 1.4 %	67.0 % ± 2.7 %	-19.2 % ± 6.8 %
Puakō	10.8 % ± 3.3 %	4.8 % ± 1.6 %	66.9 % ± 9.0 %	-57.5 % ± 13.1 %
Honokōhau	20.4 % ± 1.6 %	15.0 % ± 1.5 %	42.6 % ± 7.3 %	-26.7 % ± 3.4 % **
S. Oneo	18.7 % ± 1.6 %	13.6 % ± 3.5 %	84.5 % ± 6.2 %	-27.2 % ± 15.6 %
N. Keauhou	22.2 % ± 4.1 %	8.9 % ± 1.8 %	50.4 % ± 12.3 %	-59.7 % ± 6.1 % *
Kealakekua Bay	8.9 % ± 3.3 %	6.3 % ± 3.1 %	49.3 % ± 3.3 %	-33.6 % ± 12.6 % *
Kalahiki	15.9 % ± 2.2 %	13.9 % ± 5.2 %	34.1 % ± 10.5 %	-17.7 % ± 20.1 %
Omaka'a Bay	12.1 % ± 3.4 %	9.0 % ± 2.8 %	43.6 % ± 14.1 %	-21.5 % ± 10.8 %
Mean	**15.4 % ± 1.2 %**	**10.3 % ± 1.1 %**	**54.3 % ± 4.3 %**	**-32.9 % ± 4.7% *** **

Site Makalawena hosts a large assemblage of *Porites rus*, which was observed to be extensively bleached in November 2016. Coral cover analyses for transect D at this site (the sole transect with high *P. rus* abundance) indicated that minimal mortality had occurred for this species post-bleaching (*P. rus* cover: 2014 = 28.9%; 2016 = 27.0%).

In summary, the 2015 coral bleaching event resulted in catastrophic coral mortality for West Hawai′i reefs, with a loss of approximately half of the total stony coral cover. Algal turf overgrowth of bleached coral tissue generally preceded mortality and was weakly positively correlated with total dissolved nitrogen. This finding suggests that local watershed management can play a role in bleaching recovery, and additional water sampling is needed, particularly for sites with little watershed nutrient data available. Common coral species *Porites lobata* did not appear to recover from bleaching, while a portion of bleached colonies of the endemic species *P. compressa* successfully recovered (Tables 17 and 18). *Pavona varians* cover increased post-bleaching, and despite its relatively low cover and encrusting morphology, may serve as an important player in reef recovery, working to cement reef structure throughout future thermal stress events. A large area of *P. rus* recovered fully from the event, suggesting that *P. rus* dominated reef zones may be crucial recovery areas for West Hawai′i.

Beginning in early 2016 in response to this catastrophic loss in coral cover, DAR developed a plan to determine the best possible management strategies to promote coral recovery. This effort included: 1) issuing a survey to collect expertise and information from more than 80 coral bleaching scientists globally, 2) conducting a comprehensive review of scientific literature discussing coral bleaching management, and 3) convening a series of local workshops with more than 40 Hawai´i-based scientists and mangers to discuss survey outcomes and management recommendations. The outcome of this series of activities was summarized in the Coral Bleaching Recovery Plan (DLNR/DAR 2017). Top management strategies developed in this process included, 1) the establishment of a network of permanent, fully-protected, no-take Marine Protected Areas (MPAs), 2) the reduction of land-based stressors, and 3) the effective management of herbivore populations. At that time, DAR was committed to timely implementation of management actions to promote coral reef recovery, but unfortunately, formal management response strategies were not implemented.

Benthic monitoring surveys conducted in Spring 2017 at fixed monitoring sites indicated continued declines in coral cover at 13 monitoring sites, stable coral cover at 6 sites, and slight coral cover increases at 7 sites when compared to 2016 coral cover (Figure 46). From Spring 2016 to Spring 2017, several high swell events were observed to cause severe physical damage to remaining reef structure and to generate high volumes of coral rubble across fixed sites (Walsh et al., personal communication). On average from Spring 2016 to Spring 2017, coral cover declined by 7.2% across the region, with severe continued declines at site Puakō (-23.8%). Coral cover has typically been replaced by light algal turf and crustose coralline algae, indicating that local grazers are playing a significant role in controlling macroalgal cover currently.

Future analyses of coral bleaching and mortality datasets will include contributions to statewide datasets with collaborators and comparisons with available oceanographic (SST, light stress damage indices) (Eakin 2016), watershed (nutrients), and reef fish assemblage datasets available for each site. Findings will be used to inform local managers of best practices to promote coral recovery from this event.

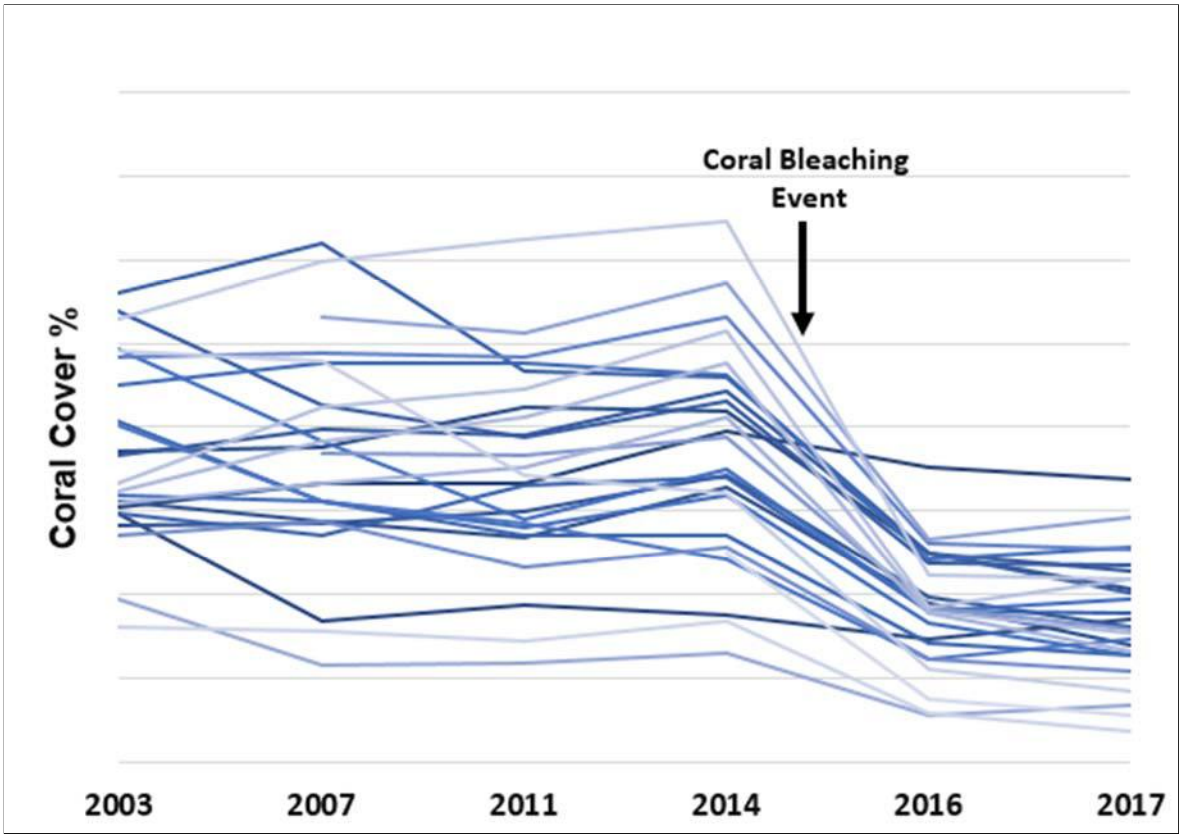


Figure 46. Change in coral cover (%) across the 25 DAR Kona fixed monitoring sites from 2003 to 2017. A regional-scale coral bleaching event caused catastrophic declines in coral cover in the fall of 2015.

At the time of this report (October 2019), very high water temperatures surrounding West Hawai´i had initiated an Alert Level II designation by the NOAA Coral Reef Watch program, indicating that severe coral bleaching is imminent. Signs of coral bleaching were already detected for numerous coral species, including remaining cauliflower corals (*P. meandrina*) and several species of massive/ mounding corals (Poritids). Coral bleaching surveys across fixed monitoring sites are planned for October 2019, and another round of benthic cover image analysis is planned for Spring 2020.

Other Issues of Concern within the WHRFMA (2014-2019)

Marine debris

Plastic pollution is an ever-increasing problem along our ocean and shores statewide, and there is no exception for West Hawaiʻi. When possible, DAR Kona staff will assess any larger debris items or grounded vessels (abandoned and derelict or after storm events / incidents) for both ecosystem damage and potential vectors for spreading aquatic-invasive species (AIS) into Hawaiian Waters. Any grounding work has been done in concert with and with guidance from the DAR response person, David Gulko, who is based out of Oʻahu at the DAR Ānuenue Fishery Research Station.

In addition, DAR Kona staff have provided guidance to local fishermen who are interested in locating and safely collecting marine debris in Hawaiian waters and has been involved since 2014 in the statewide Hawaiʻi Marine Debris Action Plan network (coordinated by the National Oceanic & Atmospheric Administration's Marine Debris Program). First in the nation, Hawaiʻi's Marine Debris Action Plan was created as a cooperative declaration and continues with biennial meetings with numerous state, county, federal, academic and nonprofit partners that come together in a concerted effort to reduce, remove, research, and prevent marine debris in Hawaiʻi. DLNR DAR has been a partner of this HI-MDAP since it was first declared in January 2010. More information can be found about this program at: https://marinedebris.noaa.gov/report/hawaii-marine-debris-action-plan.

With collaboration from local nonprofit organization, Hawaiʻi Wildlife Fund (HWF), and in coordination with the DLNR's Division of Boating and Ocean Recreation (DOBOR) land manager at Honokōhau harbor, DAR Kona assisted HWF to install a derelict fishing net and line bundle receptacle outside the office in January 2018. A similar receptacle (5' x 3' x 2' fish box) was installed outside the Wailoa Fisheries Station in Hilo. Together and with support from local boat fishermen, shoreline users and scuba dive vessels, and with cooperation from DOBOR, over 10 truckloads (2 from the Hilo site) of nets weighing over 8,000 pounds were removed from the ocean and shoreline with this program. This effort costs the state no additional money and is a great example of coordination and cooperation with community groups, fishermen, divers and local businesses operating around the harbor.

Fish Aggregation Devices (FAD)

The State of Hawaiʻi Fish Aggregation Device (FAD) program is managed by the UH Sea Grant Program at the University of Hawaiʻi at Mānoa. According to their website (http://www.himb.hawaii.edu/FADS/), "the State of Hawaiʻi has placed Fish Aggregating Devices (FADs) in the waters surrounding the main Hawaiian Islands. These buoys attract schools of tuna and other important pelagic fishes, such as mahimahi, ono and billfish. FADs allow fishermen to easily locate and catch these species."

Unfortunately, these FADs (large metal buoys) sometimes break free from their mooring chains and float with the currents in towards the shoreline and nearshore reefs. When possible, DAR Kona staff helps to assist in the communication and coordination to ensure a safe recovery of these devices, and to monitor for native and non-native aquatic species that may be hitchhiking or attached to them like corals and other invertebrates. According to the FAD program website: "The State of Hawaiʻi FAD program is operated by Hawaiʻi Institute of Marine Biology (HIMB), SOEST, University of Hawaiʻi in cooperation with the State of Hawaiʻi's Division of Aquatic Resources (DAR). The program is directed by Dr. Kim Holland of HIMB. Principle funding for the system is derived from the Dingle-Johnson Federal Funds, disbursed through DAR. The daily management of the FAD system is supervised by Mr. Warren Cortez."

Recent shark finning incidences

DAR Kona staff were recently sited in a press release about multiple incidents of shark finning on Hawaiʻi Island. The full article is available at: https://governor.hawaii.gov/newsroom/latest-news/dlnr-news-release-shark-finning-raises-concerns-on-hawaii-island-july-31-2019/.

From the article: "Dramatic photographs of two oceanic whitetip sharks, lacking fins, along with photographs of a dead, three-and-a-half-foot long whitetip reef shark is raising concern among marine biologists on Hawaiʻi Island. The two oceanic whitetip sharks, a species listed as threatened under the Endangered Species Act, were observed alive off the coast of West Hawaiʻi and were photographed and reported by dive tour operators. Stacia Marcoux, a Fish & Habitat Monitoring Technician with the DLNR Division of Aquatic Resources (DAR) commented, 'Shark finning is not a new phenomenon, but the recent number of incidents is concerning. This is especially true for the threatened oceanic whitetip. We hope that once people see these photos, they will join us in condemning and discouraging this kind of activity regardless of its legality.'

In June, DAR colleague Megan Lamson found a whitetip reef shark, finned and dead, at Kaʻaluʻalu Bay. In addition to missing its dorsal fin it had been gutted. While the finning of the two oceanic whitetip sharks in West Hawaiʻi was reported to the DLNR Division of Conservation and Resources Enforcement (DOCARE) it's difficult to investigate without knowing when it happened and who may be responsible. Marcoux received photos provided by Big Island Divers and Aquatic Life Divers of the fin-less oceanic whitetips. She said, ‘It’s heartbreaking to see these terrible wounds on these individuals. Sharks deserve our respect and we’re encouraged that most tour operators are educating their clients about this issue. No one wants to see an injured shark swimming by.’

Marcoux and Lamson indicate, ‘Sharks are apex predators and vital contributors to a healthy marine ecosystem. Many shark species are long-lived, they reproduce slowly, and anything that happens to threaten them can lead to sudden populations declines.’ They added that pono fishing practices include shark protection because they help sustain healthy fish communities and a balanced marine ecosystem. Additionally, certain shark species are culturally and spiritually important.

People can help sharks remain a keystone species in Hawaiian waters by discouraging shark feeding, fishing, finning or harassing activities…. Currently state law prohibits the take, killing, possession, sale, or offer for sale of whitetip reef shark and other shark species in West Hawaii. Take means to fish for, catch, or harvest or attempt to fish for, catch or harvest aquatic life. It is illegal to intentionally catch a whitetip reef shark to remove a fin within the West Hawaii Regional Fishery Management Area (HAR 13-60.4-4). Additionally, it is illegal to possess, sell, offer for sale, trade or distribute shark fins anywhere in Hawaiʻi (HAR 188-40.7). Anyone who sees any of these activities is asked to call the DLNR hotline at 643-DLNR (643-3567) or to report it via the free DLNR Tip app available for both iPhones and android devices.”

Local interest in coral restoration

Due to dramatic changes in coral cover over the past few years, there has been an uptick in local businesses (both for-profit and non-profit organizations) that have expressed interest in being involved with coral restoration efforts along the West Hawaiʻi coastline. Numerous businesses have expressed interest in collaborating with DAR Kona in coral "outplanting" activities. DAR Kona has encouraged these businesses and individuals to apply for a Special Activity Permit (SAP).

There is currently a strong need for scientifically-based "best practices" to guide appropriate and effective coral restoration activities, and DAR is working with partners in the scientific community to initiate and develop practices that would be feasible (and scientifically credible) for implementation in the Hawaiian Islands. During this critical time, when coral reefs are especially vulnerable (e.g. catastrophic loss following the 2015 bleaching event, increasing ocean acidification, and increasing local stressors due to a growing shoreline population), it is important to ensure that all potential “reef restoration” activities are being performed by competent and well-trained organization. Any state-approved coral restoration effort should be based on the best available science. Due to the high volume of requests for meetings and guidance, we are currently focused on discussions and collaboration with science-based efforts. In the coming decades, scale-appropriate coral restoration activities will be a crucial part of effective local management of coral reef ecosystems.

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Since 2002, the West Hawaiʻi coral reef monitoring program has been funded by the National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Conservation Program under the National Centers for Coastal Ocean Science (NOAA/NCCOS).

Many people have played important roles in laying the groundwork for successful and adaptive marine resource co-management in West Hawaiʻi. David Tarnas is to be especially commended for his innovative and forward looking legislation. Sara Peck of UH Sea Grant College Program was involved from the beginning and was instrumental in ensuring community participation and education. Special acknowledgement goes out to Marni Herkes who passed on this year. Marni played a key role as the first recording secretary for the West Hawaiʻi Fishery Council (WHFC).

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