Report to the Thirty-Third Legislature
2025 Regular Session

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

Prepared by:

Department of Land and Natural Resources
Division of Aquatic Resources
State of Hawaiʻi

In response to
Section 188F-5, Hawaii Revised Statutes

November 2024

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

Christopher Teague[1], Ashley Wills[1], Camille Barnett[1,2], Zachary Craig[1,2], Ashlynn Overly[1,2], Alexandra Craig[1], Nathan Hayes[1,2], Bryan Ishida[1]

[1] Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawaiʻi
[2] Hawaiʻi Coral Reef Initiative, Social Science Research Institute, University of Hawaiʻi

PURPOSE OF THIS REPORT

This report, which covers the period between 2020 - 2024, is submitted in compliance with Act 306, Session Laws of Hawaiʻi (SLH) 1998, and subsequently codified into law as Chapter 188F, Hawaii Revised Statutes (HRS) - West Hawaiʻi Regional Fishery Management Area. Section 188F-5, HRS requires a review of the effectiveness of the West Hawaiʻi Regional Fishery Management Area to be conducted every five years by the Department of Land and Natural Resources (DLNR), in cooperation with the University of Hawaiʻi (Hawaii Revised Statutes §188F-5)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The nearshore reef environment of West Hawaiʻi is a diverse and complex ecosystem with a wide variety of habitat types, species assemblages, oceanographic contexts, and impacts. These reefs provide the people of West Hawaiʻi and its visitors with a suite of ecosystem services including fishing opportunities, cultural practices, recreation, and tourism. When it passed in 1998, Act 306 directed the Department of Land and Natural Resources to manage the nearshore marine resources of this region using a holistic, ecosystem-based approach. To accomplish this, the Act established the West Hawaiʻi Regional Fishery Management Area (WHRFMA) and called for several specific management actions. Here, we report on the state of coral reef ecosystems in West Hawaiʻi and the Division of Aquatic Resources' (DAR) ongoing programs related to the goals laid out in the Act.

Broadly, the formation of the WHRFMA has provided a framework for rulemaking, community collaboration, monitoring, and research focused on the specific needs of West Hawaiʻi. The establishment of a DAR office located in West Hawaiʻi has allowed DAR to dedicate resources to these tasks and substantially expand operations in the region.

Fishing regulations within the WHRFMA have changed drastically since its inception. While much of the focus has been on the commercial aquarium industry, additional key regulatory changes have included the formation of netting restricted areas, a prohibition on spearfishing while on SCUBA, prohibitions on take of species of special concern (primarily sharks, rays, and pū puhi), and the establishment of the Kaʻūpūlehu Marine Reserve. More recent rulemaking efforts have set regulations for the Miloliʻi Community-Based Subsistence Fishing Area and a two-year moratorium on take of pākuʻikuʻi throughout the WHRFMA.

Fishing activity in West Hawaiʻi is extensive and varied, spanning a wide range of habitats, gear types, and targeted species. Fisher goals and motivations are similarly diverse, with people fishing commercially as well as for subsistence, community, culture, and recreation. Historically, the commercial aquarium trade has also been a substantial component of overall commercial catch in West Hawaiʻi. The aquarium fishery, however, closed following a series of court decisions that culminated in 2017 and has not resumed thus far.

Commercial catch data indicate that in West Hawaiʻi, much of the commercial sector is driven by take of pelagic species and scads (ʻakule and ʻōpelu). Nearshore finfish generally comprise less than 10% of overall commercial catch and is primarily driven by take of menpachi, surgeonfishes, and goatfishes. Previous estimates have suggested that nearshore reef food fisheries on Hawaiʻi island are dominated by non-commercial catch with commercial take being a relatively small component of nearshore catch.

DAR's West Hawaiʻi district staff currently lead several SCUBA-based reef monitoring projects, each with key focal questions and goals. The recently initiated Fish and Habitat Utilization survey

is designed to track trends in fish populations across the WHRFMA. Although this dataset has not been active long enough to detect temporal trends, initial data indicate that the survey methodology will provide important information for several key fish species, families, and functional groups as well as benthic habitats. Longer-term data from the Shallow Water Resource Fish (SWRF) survey suggest declines in observed densities of several surgeonfish species including māikoiko, ʻapi, pākuʻikuʻi, pualu, and umauma lei between 2008 and 2018, though an additional survey round planned for 2025 will be important to assess whether these trends are continuing. Additionally, pākuʻikuʻi, māikoiko, and ʻapi all tend to appear with greater regularity on SWRF surveys compared to other methods, suggesting that continued survey coverage of inshore habitats is necessary to understand the status and trends in these species.

Although the West Hawaiʻi commercial aquarium fishery has been closed since 2017, there is considerable interest in understanding trends in key aquarium species both to better understand past impacts as well as to assess potential risks if the fishery were to reopen. Trends in lauʻīpala densities were highly variable across sites between 1999 and 2024 though patterns were broadly similar across management types. While average observed densities of lauʻīpala have generally increased, much of this was driven by large increases at a handful of key sites. Kole on the other hand has shown more consistent increases across sites, though again there was little to distinguish between trends across management types. Differences in trends between sites, species, and their responses to habitat changes indicate that factors driving trends in these species are complex and difficult to explain by fishing pressure alone.

Nearshore reef habitats across the WHRFMA are highly variable, encompassing aggregate coral reefs, pavement flats, highly structured basalt reefs, and boulder fields. Lobe and finger corals are typically the two dominant species present across monitoring sites with 17 additional species also present, albeit in lower quantities. Long-term data showed substantial declines in live coral cover at nearly all permanent monitoring sites with an average of approximately 50% loss between the baseline surveys and recent years. While recent increases in coral cover at several sites may indicate some level of recovery, other sites have shown continued declines. A new coral restoration program in West Hawaiʻi is underway to help address issues of acute coral damage and decline such as those due to anchoring or cases of heavy bioerosion. A long-term goal of this program is to apply these restoration techniques at larger, ecologically relevant scales.

A key stated purpose of Act 306 was to allow for the substantive involvement of the community in resource management decisions. Since the WHRFMA's inception, the West Hawaiʻi Fishery Council has been a key venue to accomplish this goal. In more recent years, additional community networks have been formed to provide more pathways for communication and advocacy on ocean-resource-related topics. As projects and management goals continue to expand, it will be imperative for DAR to engage with as many voices as possible across West Hawaiʻi.

CHAPTER 1- INTRODUCTION

In 1998, the Hawaiʻi State Legislature passed Act 306, Session Laws of Hawaiʻi 1998 (§188F HRS) directing the Department of Land and Natural Resources (hereafter DLNR or Department) to establish the West Hawaiʻi Regional Fishery Management Area (WHRFMA) along the leeward coast of Hawaiʻi Island. Act 306 was then officially implemented on December 31, 1999 through the passage of Hawaii Administrative Rules (HAR) §13-60.3. The rules established through these processes were the culmination of decades of contention, disagreements, compromises, "gentlepersons' agreements", laws, and rules primarily centered on the commercial aquarium fishery in West Hawaiʻi. The details of this long history deserve a much deeper exploration than can be provided in this report and indeed, this background information has been documented at length previously (DAR, 2000, 2019, 2024a; Walsh et al., 2004). Chapters 1, 4, and 7 of this report contain more abbreviated accounts of this history as well as some of the more recent context of the West Hawaiʻi commercial aquarium fishery.

While the formation of the WHRFMA was initially driven largely by calls to expand regulations on the commercial aquarium industry, Act 306 defined a much broader set of resource management goals, primarily centered on coral reef ecosystems. Act 306 explicitly noted the importance of a regional approach towards effective management of nearshore marine resources, citing the need for such an effort in West Hawaiʻi. The Act outlined a holistic approach to improve the State's management activities regarding both consumptive and non-consumptive aquatic resource uses within the waters off West Hawaiʻi. Key management facets discussed in the act included fisheries, environmental stressors, habitat quality, human use impacts, and community involvement.

The Act laid out specific purposes for the WHRFMA as well as four key management tools to be incorporated within its boundaries; defined as the ocean waters within the State's jurisdiction spanning from ʻUpolu Point in North Kohala to Ka Lae in Kaʻū (Figure 1). Specifically, Act 306 stated that the purposes of the WHRFMA were to:

1. Ensure the sustainability of the State's nearshore ocean resources.
2. Identify areas with resource and use conflicts.
3. Provide management plans as well as implementing regulations for minimizing user conflicts and resource depletion, through the designation of sections of coastal waters in the West Hawaiʻi regional fishery management area as fish replenishment areas where certain specified fish harvesting activities are prohibited, and other areas where anchoring and ocean recreation activities are restricted.
4. Establish a system of day-use mooring buoys in high-use coral reef areas and limit anchoring in some of these areas to prevent anchor damage to corals.
5. Identify areas and resources of statewide significance for protection.

6. Carry out scientific research and monitoring of the nearshore resources and environment.
7. Provide for substantive involvement of the community in resource management decisions for this area through facilitated dialogues with community residents and resource users.

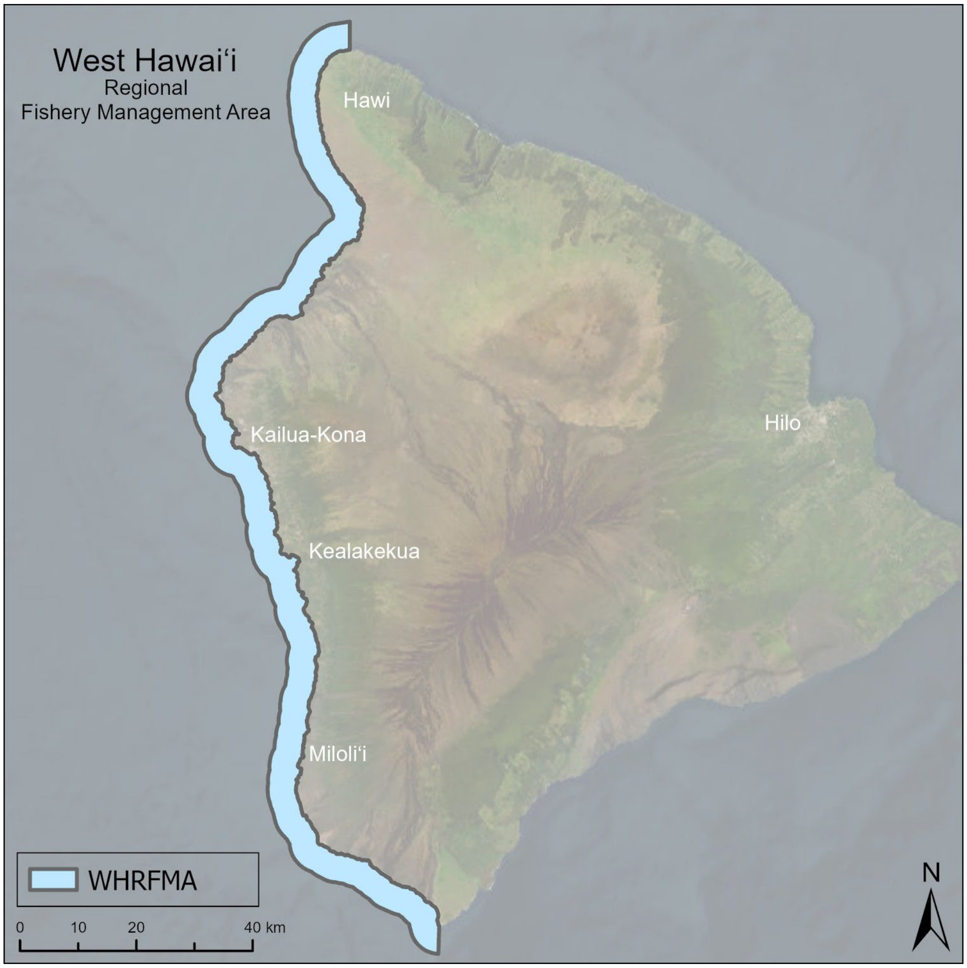

Figure 1*. Map of Hawaiʻi Island depicting the boundaries of the West Hawaiʻi Regional Fishery Management Area (WHRFMA). The WHRFMA extends from ʻUpolu Point in North Kohala to Ka Lae in Kaʻū.*

Further, the Act directed the Department to enact various additional, smaller spatial management areas as well as a day-use mooring buoy system within the WHRFMA. These objectives included the following:

1. Designation of a minimum of thirty per cent of coastal waters as Fish Replenishment Areas (FRAs) in which aquarium fish collection is prohibited.
2. Establishment of a day-use mooring buoy system and designation of some high-use areas where no anchoring is allowed.
3. Establishment of a portion of the fish replenishment areas as fish reserves where no fishing of reef-dwelling fish is allowed.
4. Designation of areas where the use of gill nets as set nets shall be prohibited.

Lastly, the Act required that the Department conduct a review of the effectiveness of the WHRFMA every five years. Taken together, Act 306 laid out specific management actions across a wide swath of priorities, called for research and monitoring of those programs, mandated regular review and reporting, and directed the Department to work closely with the communities of West Hawaiʻi on any and all marine resource management decisions. These activities have primarily fallen under the purview of the DLNR's Division of Aquatic Resources (DAR) and as such, DAR opened a West Hawaiʻi district office largely to accomplish those tasks.

In the years following the passage of Act 306 and its subsequent implementation in HAR §13-60.3, the rules surrounding the WHRFMA were amended several times. These changes are covered in greater detail in Chapter 4; however, they include laynet regulations, additional rules surrounding the commercial aquarium fishery, a SCUBA spearfishing ban, and the establishment of the Kaʻūpūlehu Marine Reserve, among others.

Beyond the specific rules within HAR §13-60.3 and subsequent amendments, the regional management approach in West Hawaiʻi has provided a framework on top of which other rules and initiatives have been developed and implemented. Examples include DAR's reef fish and habitat monitoring activities, a new West Hawaiʻi coral restoration program, and the formation of several stakeholder groups committed to advising DAR on marine resource management activities. Still other programs such as the Miloliʻi Community Based Subsistence Fishing Area (CBSFA) and the Day-Use Mooring system have been in progress since well before the establishment of the WHRFMA, however West Hawaiʻi DAR staff work collaboratively with partners on these projects.

DAR's marine management programs within the WHRFMA highlight the utility of the regional approach laid out in Act 306. The formation of the WHRFMA, as well as DAR's broader shifts towards district-level aquatic resource management, has allowed for statewide initiatives to be tailored to the specific needs of each island or region within the state. Further, it has helped DAR focus resources in the area to work directly with those individuals, communities, and organizations who have close ties and intricate knowledge of the aquatic ecosystems and resources in West Hawaiʻi. Lastly, the breadth of the purposes and rules laid out for the WHRFMA in Act 306 have afforded a high degree of flexibility to enact, revise, and amend initiatives in order to meet the diverse management needs in West Hawaiʻi.

Structure of the Report

Here, we report on the state of coral reef ecosystems in West Hawaiʻi, the current status of DAR's ongoing programs, and measures of the effectiveness of the West Hawaiʻi Regional Fishery Management Area.

Given the wide range of actions and goals established through Act 306, no single metric can completely assess the effectiveness of the WHRFMA. As such, we have structured this report into separate chapters to discuss key components of DAR's management activities in West Hawaiʻi. Chapter 2 gives a characterization of the nearshore reef environment in West Hawaiʻi, noting the resources, habitats, stressors, and human uses within the WHRFMA. Chapter 3 covers an overview of DAR's reef monitoring projects including the objectives and methods. Chapter 4 examines several topics related to reef fisheries including past rulemaking efforts and monitoring data. Chapter 5 reviews the status and concerns around coral reef habitats with topics such as coral bleaching, anchor and vessel damage, the state Day-Use Mooring program, and a new coral restoration project. Chapter 6 discusses DAR's role and activities in providing for substantive involvement of the community in resource management decisions. We end with a chapter on our recommendations for future management initiatives including key remaining data gaps and future departmental needs in order to support the goals of the WHRFMA. Collectively, these chapters address the primary purposes and directives found in Act 306 as well as those of the various programs started subsequently under the aegis of the WHRFMA.

Note regarding names and nomenclature

As many in Hawaiʻi are keenly aware, determining the proper name to use when referring to particular places or species is no small feat. Oftentimes, locations will have one or more Hawaiian name in addition to English or anglicized names. Species also often have Hawaiian names, scientific taxonomic names, and other commonly used names that come from various languages (e.g., Japanese, English, Tahitian, etc.). Fishers, native Hawaiian practitioners, researchers, managers, and other stakeholders often switch seamlessly between these options corresponding to what is most used for a given species. Further, some Hawaiian names for fishes refer to multiple different species whereas other species do not have commonly used Hawaiian names. Given this, it is often impractical to consistently use only one source of names over another and accomplish clear understanding by all readers. In this document, we have sought to strike a balance between precise identification, name recognition, and a respect for traditionally used names. To that end, we used Hawaiian names when possible while switching to common or scientific names either when there was no well-known Hawaiian name available, when one Hawaiian name referred to multiple species, or sometimes when that Hawaiian name is rarely used amongst stakeholders.

CHAPTER 2- REGIONAL DESCRIPTION

The WHRFMA encompasses the entirety of the leeward coast of Hawaiʻi Island from ʻUpolu Point in North Kohala to Ka Lae in Kaʻū. This area spans across three moku (districts; Kohala, Kona, and Kaʻū) and well over 100 ahupuaʻa (land divisions) that divide the western slopes of four volcanos; Kohala, Mauna Kea, Hualālai, and Mauna Loa. The boundaries of the WHRFMA extend along this stretch of the coastline from the highwater mark of the shoreline to the offshore limits of the State's management authority (3 miles seaward of the highwater line).

2.1 West Hawaiʻi Reef Ecosystems

Hawaiʻi Island is the youngest island in the Hawaiian archipelago at an estimated age of 430,000 years (Clague and Dalrymple, 1994). Broadly, the nearshore marine environments of the younger Hawaiian Islands (i.e. Hawaiʻi and Maui) are characterized by steep slopes and rocky, basalt shorelines. Live coral and carbonate structure (dead coral and other calcifying organisms) form a relatively thin veneer atop these basalt substrates as a narrow "apron reef" (Jokiel, 2008). The steep, narrow profile of large portions of these islands leads to a highly compressed pattern of reef zonation compared to other Hawaiian reefs where boundaries between different habitat zones within the reef are relatively distinct (Dollar, 1982).

A typical reef in West Hawaiʻi consists of a basalt cliff extending from 3-7m (10-23ft) above sea level to 3-5m (10-16ft) below (Figure 2). The base of the cliff is primarily basalt boulders on top of a lightly sloping bedrock of basalt which extends offshore beyond the boulders as a relatively flat reef bench. These reef benches range from bare pavement reef to being completely dominated by lobe corals (*Porites lobata* and *P. evermanni* ; Dollar & Tribble 1993). Around a depth of 10m (33ft), the reef bench transitions to a steep slope populated mainly by thickets of finger coral (*P. compressa;* Dollar 1982). At depths ranging from 15-30m (50-100ft), the live finger coral gives way to unconsolidated coral rubble (Dollar and Tribble, 1993). From there, the rubble slope either continues or transitions to a sand plain before extending to much greater depths (Dollar, 1982; Hobson, 1974).

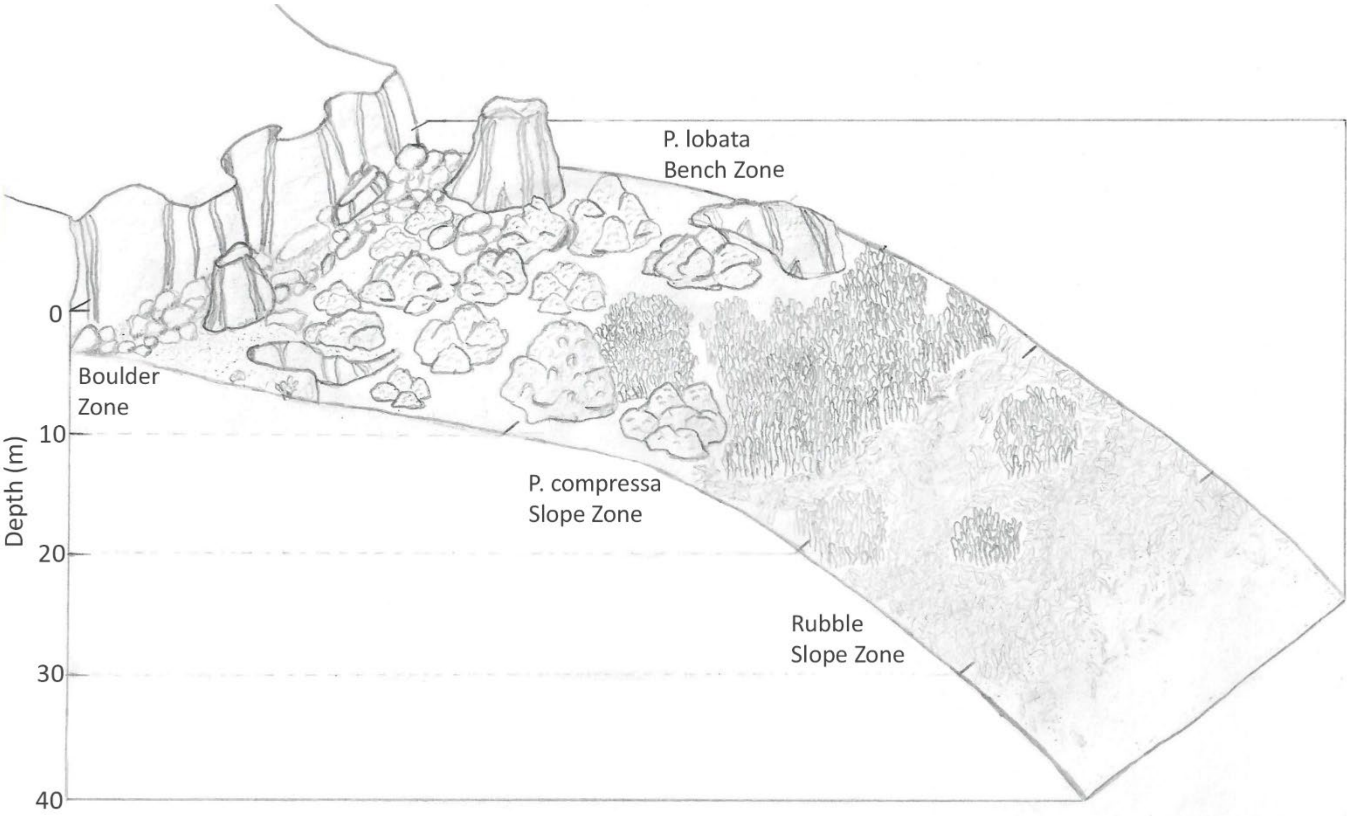

Figure 2. *"Typical" West Hawaiʻi reef profile diagram indicating key habitat zones. Figure adapted from Dollar and Tribble (1993).*

While the above reef description applies to large sections of the West Hawaiʻi coastline, particularly in parts of Kona and Kaʻū, other habitat types that deviate from this model are also present in the region. These include basalt finger reefs, extensive reef flats, spur-and-groove reefs, and protected embayments, among others. The portion of the coast between Keāhole Point and Kawaihae also differs somewhat from other areas in Kona, Kohala, and Kaʻū in that the reef extends further from shore, creating a wider reef bench (Figure 3). This is particularly apparent around Kekaha Kai State Beach, Kaʻūpūlehu, and Kīholo, where the shallow reef (0-30 meters) can extend over one kilometer offshore.

Coral cover is dominated by the genus *Porites* along much of the West Hawaiʻi region. The reef bench is typically dominated by the common lobe coral (*P. lobata*) while a mix of finger coral (*P. compressa*) and lobe coral inhabit the reef slope. Other species are present regularly, with *P. evermanni*, *P. monticulosa*, *P. rus*, and *Pavona duerdeni* making up the majority of the reef-building species in West Hawaiʻi, though typically in lower abundances than *P. lobata* and *P. compressa*. Cauliflower (*Pocillopora meandrina*) and antler (*Pocillopora grandis*) corals are also common, particularly in areas of high wave action or current flow.

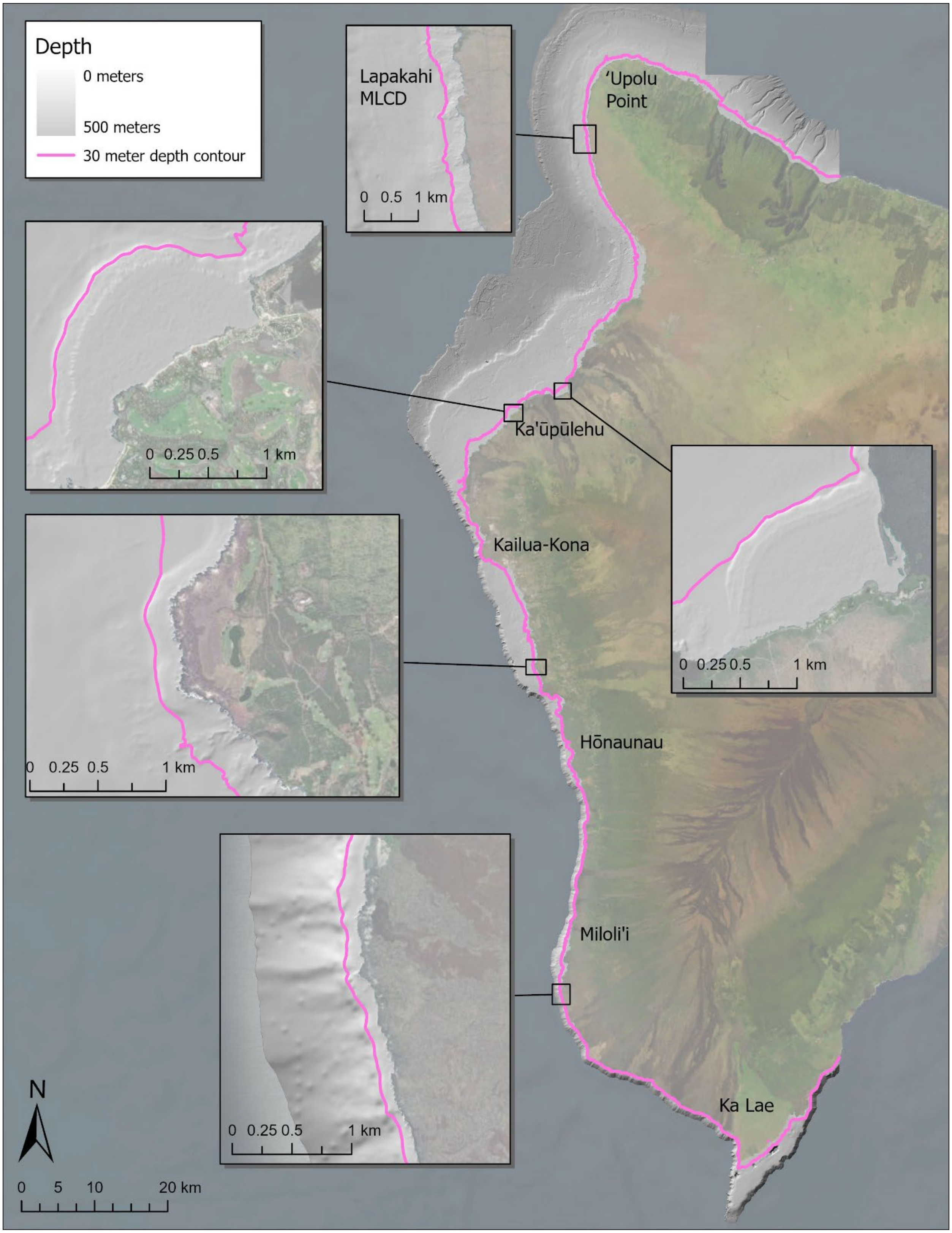

Figure 3. *Map of West Hawai'i showing the seafloor structure and depth. The pink line denotes the 30-meter depth contour.*

2.2 Climate

West Hawaii’s position along the leeward coast of Hawaiʻi Island leaves the region relatively well protected from ocean swells and storms (Kay et al., 1977). Northern winter swells prevalent along the north faces of most of the Hawaiian Islands are often blocked by the more northern islands before reaching the West Hawaiʻi coast (Dollar, 1982). The area is subject, however, to summer south swells generated in the South Pacific and Indian Oceans (Dollar, 1982), North Pacific swells with substantial western components, and “Kona storms” (Blumenstock and Price, 1967). Hurricanes and tropical storms typically do not reach West Hawaiʻi directly as they generally progress in a westward direction in the central Pacific, though storms passing to the south of the island can produce large surf in West Hawaiʻi (Dollar and Tribble, 1993).

Similar to other leeward coasts across the state, West Hawaiʻi exhibits low precipitation relative to other parts of the island. Kohala in particular is one of the driest areas in the state (Luo et al., 2024). Given this low precipitation combined with the porous and permeable nature of the basalt substrate, the majority of the available freshwater is contained as groundwater with little existing within perennial streams or as surface runoff, except in severe weather events (Kay et al., 1977; Street et al., 2008). Groundwater therefore enters the ocean primarily through submarine groundwater discharge rather than stream outflow or runoff, which can impact nearshore salinity, temperature, sediment, and nutrient concentrations (Asner et al., 2024; Gove et al., 2019; Knee et al., 2010; Street et al., 2008).

2.3 Human Activity

Human use and impacts on the nearshore marine environment vary widely both across the state and within West Hawaiʻi (Wedding et al., 2018). The resident population of West Hawaiʻi is generally concentrated along the coastline and around key areas including Kailua-Kona, Kalaoa, Waikoloa Village, and Captain Cook (Gove et al., 2019). Primary human activities on and around reefs in the region include fishing, snorkeling, SCUBA diving, swimming, surfing, and paddling. Additional anthropogenic impacts are wide-ranging and include coastal development, on-site waste disposal, urban, agricultural, and golf course runoff, boating and shipping, and marine debris, among others (Lecky, 2016).

The fishing activities in West Hawaiʻi encompass a broad diversity of fishing communities, fishing modes, methods of access, gear types used, and targeted species (Gove et al., 2019). Nearshore fishing grounds are accessed by shore, boat, canoe, and kayak. Boats typically launch from the main harbors at Kawaihae, Honokōhau, and Keauhou as well as several other launch ramps throughout the region. While shoreline access is impractical across many portions of the coast, fishers utilize numerous county-maintained public access points and other private or informal trails and accesses. Gear types include a variety of line, net, and spear types. Both commercial and non-commercial (i.e., subsistence, cultural, or recreational) harvest modes occur in West Hawaiʻi, though research has indicated that non-commercial take of reef food fish amounts to a much larger proportion of overall catch than commercial fishing (Kittinger et al., 2015; McCoy et al., 2018).

Residents and tourists also engage in various non-fishing activities along West Hawaiʻi. Snorkeling is prevalent at a range of shoreline locations, with Kahaluʻu Beach Park and Hōnaunau Bay as two of the most highly visited locations. A large number of vessel-based snorkel and SCUBA dive charter companies also operate out of West Hawaiʻi harbors, many of whom utilize the system of Day-Use Moorings available in Kona and Kohala. Similar to snorkeling, SCUBA divers and swimmers access various sites across the region from shore, though popular locations differ somewhat between the three activities. Additional shoreline-based activities that utilize a variety of access points include surfing, paddle-boarding, and canoe paddling.

CHAPTER 3- MONITORING OVERVIEW

Resource monitoring provides a basis for assessing the current condition and long-term trends in the populations of reef fish and invertebrates, the status of reef habitats, and the effectiveness of specific fishery regulations. Staff in the West Hawaiʻi DAR office conduct regular monitoring using a range of SCUBA survey methods to examine specific components of the nearshore reef community and fisheries. Broadly speaking, this monitoring work focuses on several key metrics: size and density of reef fish, which can be used to estimate biomass, density of large mobile invertebrates, the percent coverage of various benthic organisms including koʻa (stony coral) and coarse functional groups for limu (algae), and measures of the structural complexity of the reef habitat.

These measures are collected through a handful of different monitoring projects, each of which is designed around a specific management question and targets a defined range of habitats along the West Hawaiʻi coastline (Table 1). The longest continuous dataset obtained through these monitoring efforts is the West Hawaiʻi Aquarium Project (WHAP) dataset, which began in 1999 and is still currently active. The most recently initiated project is the Fish and Habitat Utilization (FAHU) project that was implemented in 2022 with the goal of examining the status and trends of reef fish assemblages and benthic habitat characteristics in West Hawaiʻi at regional or sub-regional (i.e. moku) scales. Below, this section delves into the impetus, purpose, methods, and utility of each of the monitoring projects (Table 1).

Table 1. *Overview of current monitoring projects maintained by the DAR Kona monitoring team. Project title by acronym and the year the project began.*

PROJECT (YEAR ONE)	TARGETED HABITAT	SITE SELECTION	SCOPE OF DATA COLLECTION
WHAP (1999)	Mid depth (10-18 meters) coral rich Habitat	Haphazard Permanent	All fish (taxa, size bin, count) Large mobile invert (taxa, count) Benthic cover (taxa, % cover)
SWRF (2008)	Shallow water (2-6 meters depth)	Systematic	Select fish (taxa, size bin, count) No invertebrates recorded
FAHU (2022)	All hard bottom habitat from Manuka Bay to ʻUpolu Point (2-25 meters depth)	Stratified Random	All fish (taxa, size to cm, count) All large invertebrates (count) Benthic cover (taxa, % cover) Structural complexity (DEM)

3.1 West Hawaiʻi Aquarium Project (WHAP)

The West Hawaiʻi Aquarium Project (WHAP) was principally designed to assess the effectiveness of the system of nine Fish Replenishment Areas (FRAs) that were established along the coastline at the end of 1999 (Tissot et al., 2004). The survey was designed as a Before-After-Control-Impact (BACI) study, with the 'impact' under investigation being the implementation of the FRA system. The intent behind this method was to assess whether fish species targeted by the aquarium trade were increasing at sites inside of these new protected areas relative to adjacent control sites open to fishing. By sampling both before and after implementation of the FRA network as well as both inside and outside of the closed areas, the BACI procedure is designed to control for non-fishing factors that may drive trends in fish differently between sites.

The Before-After component of the analysis allows for evaluation of change between pre-implementation and post-implementation of the FRA system. The Control-Impact portion allows for evaluation of the degree of change can be attributed to the management action by comparing FRA sites to their adjacent control sites. In addition to FRA and open sites, survey locations were included within long-term protected areas (LTPs), such as Fishery Management Areas (FMAs) and Marine Life Conservation Districts (MLCDs), where aquarium collection had been prohibited prior to the establishment of the FRA network. The goal of these sites was to provide an additional point of comparison with sites that had been closed to collection for a longer period of time.

A total of 23 permanent survey sites (Figure 4 & Table 2) were established in March 1999 in order to provide 'Before' data prior to the implementation of the FRA network. Nine sites were located within FRAs, 8 within areas open to aquarium fishing, and 6 located within LTPs. Two additional sites were added at Unualoha Point and the Old Kona Airport MLCD in 2005 and 2007, respectively. Survey sites are assigned to 'FRA Clusters' for analysis to allow FRA and LTP sites to be compared to their nearby open control site (Table 2). Some FRA clusters do not include representation of both an open and LTP survey site due to site placement issues, lack of data from the baseline year, or lack of available management type in reasonable proximity to the FRA survey location.

The location of each survey site was chosen within an area meeting the criteria for habitat type and falling within the designated management zone. Habitats with high coral cover, specifically rich in finger coral (*Porites compressa*), that fell within the 10-18 meters depth range were targeted because of its importance to juvenile lauʻipala (Yellow Tang*, Zebrasoma flavescens*; Tissot et al., 2004).

Table 2*. Sites established for the West Hawaiʻi Aquarium Project monitoring effort listed in order from North to South along the west coast of Hawaiʻi Island. Management status designations include Fishery Replenishment Areas (FRA), areas open to aquarium fishing (Open), and sites with long term protection (LTP) from aquarium fishing: marine life conservation districts (MLCD) and fishery management areas (FMA). Site cluster indicates which sites are paired as control and treatment during analysis.*

Site #	Site Name	Baseline Year	Management Status in 1999	FRA Cluster	Distance (km) to Open Site
1	Lapakahi	1999	Open*	-	
2	Kamilo	1999	Open	North Kohala	
3	Waiaka'īlio	1999	FRA	North Kohala	0.9 km (0.5 mi)
4	Puakō	1999	LTP: FMA	Puakō-Anaehoʻomalu	10.8 km (6.7 mi)
5	Pauoa	1999	FRA	Puakō-Anaehoʻomalu	8.2 km (5.1 mi)
6	Keawaiki	1999	Open	Puakō-Anaehoʻomalu	
7	Kaʻūpūlehu	1999	FRA	Kaʻūpūlehu	7.6 km (4.7 mi)
8	Makalawena	1999	Open	Kaʻūpūlehu	
97	Unualoha Pt.	2005	Open	-	
9	Oʻoma	1999	Open	Kaloko-Honokōhau	
10	Kohanaiki	1999	LTP: FMA	Kaloko-Honokōhau	1.0 km (0.6 mi)
11	Honokōhau	1999	FRA	Kaloko-Honokōhau	4.7 km (2.9 mi)
13	Pawai	1999	LTP: FMA	Kailua-Keauhou	
98	Old Kona Airport	2005	LTP: MLCD	-	
14	S. Oneo Bay	1999	FRA	Kailua-Keauhou	
15	N. Keauhou	1999	FRA	Red Hill	2.4 km (1.5 mi)
16	Kualanui Pt.	1999	Open	Red Hill	
17	Puʻu ʻOhau	1999	LTP: FMA	Red Hill	4.9 km (3.1 mi)
18	Keopuka	1999	Open	Nāpōʻopoʻo-Hōnaunau	
19	Kealakekua Bay	1999	LTP: MLCD	Nāpōʻopoʻo-Hōnaunau	1.4 km (0.9 mi)
20	Keʻei	1999	FRA	Nāpōʻopoʻo-Hōnaunau	3 km (1.9 mi)
21	Kalāhiki	1999	FRA	Hoʻokena	7.9 km (4.9 mi)
22	Kolo	1999	Open	Hoʻokena	
23	Honomolino	1999	FRA	Miloliʻi	10.1 km (6.3 mi)
24	Manukā	1999	Open	Miloliʻi	

*Site was chosen to be in the Lapakahi MLCD but was later realized to be outside of the boundaries and not represent a location closed to aquarium fishing.

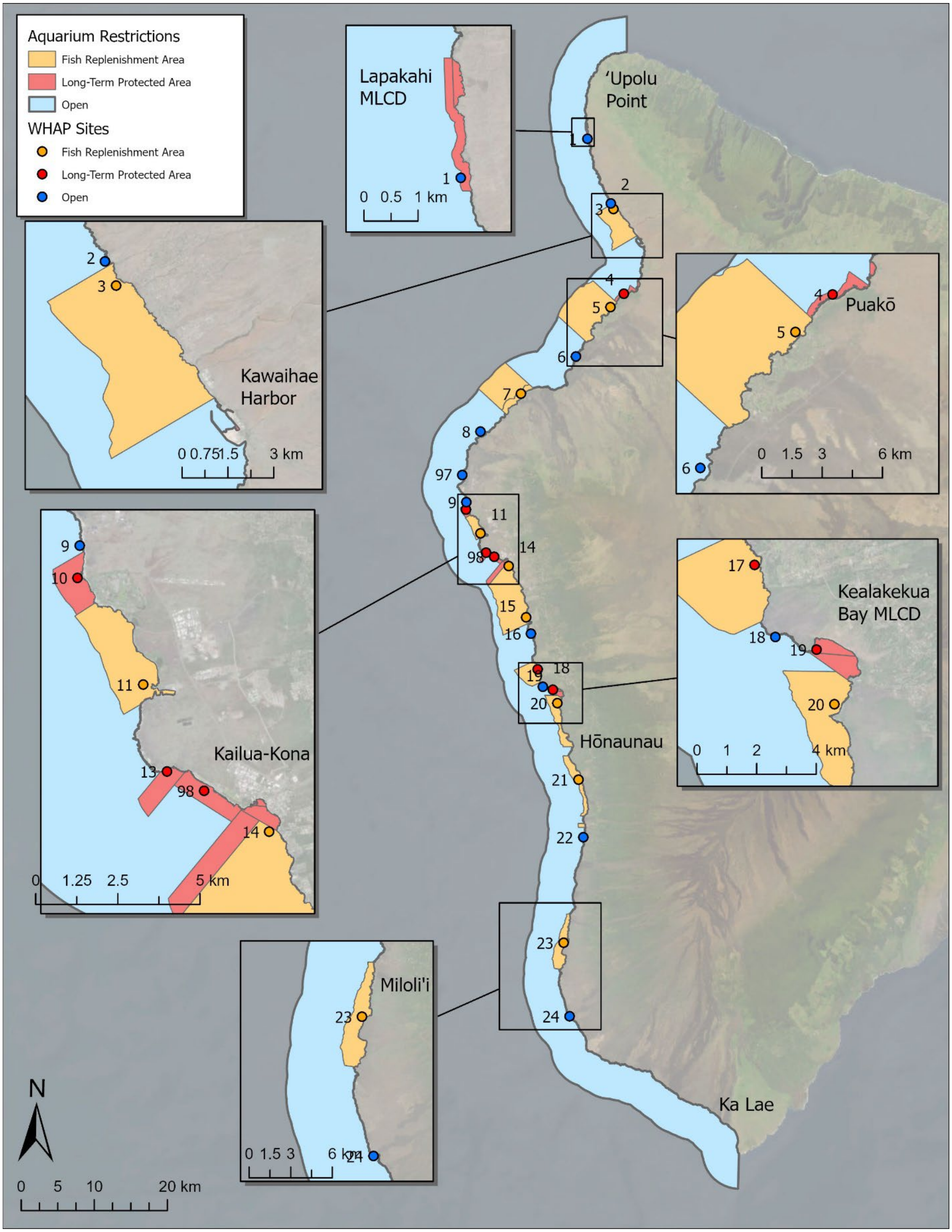

***Figure 4**. Map of permanent survey locations for the West Hawai'i Aquarium Project.*

3.1.1 WHAP Fish and Mobile Invertebrate Methodology

Each site consists of four fixed 4-meter x 25-meter (100-m^2) belt transects that extend in parallel and outward from the center of the site at a minimum of 10-m distance from one another. Permanently affixed bolts mark the start and endpoints of the survey area to ensure that observations are made along the same reef area during each site visit. Survey divers visually estimate the densities of all fishes and select invertebrates (primarily sea urchins and two corallivorous seastars) within the survey area. Two divers swim on either side of the transect line each enumerating fishes and invertebrates along a 2-meter-wide swath. For the first four years of the project, divers recorded each fish as either "adult" or 'juvenile' based on a size cutoff. Beginning in 2003, divers record fish sizes in 5-cm size bins from 0-25 cm and to the nearest 5 cm thereafter. Juvenile fish are identified separately as "recruits" according to species-specific size cutoffs.

For the first six years of the project, all sites were visited approximately bimonthly 5-7 times per year (a full set of visits to all sites is referred to hereafter as a "round"). In 2005, a survey routine of four rounds per year was established with surveys conducted every May, July, September, and November. Surveys followed this cycle through 2021 (albeit with some lost survey rounds due to the COVID-19 pandemic), at which point priority was placed on evaluating a broader range of habitats in West Hawaiʻi. Monitoring surveys for WHAP are now conducted once annually in July.

After data entry, observations from the two divers on each transect are summed together to provide a single count for each species over the full 4m x 25m transect area. The four transects are then averaged together, yielding one mean density estimate for each site. In order to assess the effectiveness of a given closed area (FRA or LTP), it is important to directly compare the site in question with its paired open site. For the purposes of this report, this is accomplished by calculating the simple difference between the closed site and the proximate control site. Values above zero indicate that the observed density is greater at the closed site relative to the site open to fishing.

3.1.2 WHAP Benthic Methodology

In addition to the fish and mobile invertebrate data collected at the WHAP sites, benthic surveys were initiated in 2003 to gather information on the benthic species assemblages at each site. The percentage cover of coral, algae, and other sessile organisms is estimated through the collection of benthic photoquadrat imagery and digital annotation of the images. Benthic surveys are typically conducted every three to four years, however the survey frequency was temporarily increased to an annual basis during 2016 and 2017 to better capture changes in live coral cover following the 2015 widespread coral bleaching event. The benthic monitoring routine then returned to a 3-year cycle with the most recent survey rounds conducted in 2020 and 2023. This dataset allows for a unique opportunity to evaluate site-level trends in benthic condition at these fixed mid-depth, coral rich sites across a period of twenty years.

Photoquadrat surveys are conducted at each of the permanent WHAP sites. Photos of the reef are taken from a fixed height at 1-meter intervals along each transect (26 photos per transect). Benthic cover metrics are extracted from the imagery using digital annotation software. The annotation software has been updated throughout the project to employ the best available technology while staying directly comparable in terms of point overlay and annotation methods. Photogrid was used in 2003, Coral Point Count (CPCe) version 4.1 (Kohler and Gill, 2006) from 2005-2017, and CoralNet 1.0 (Chen et al., 2021) from 2020 through the present.

These programs overlay 20 random points on each image for species identification under each point. Annotators then identify the cover type or organism to the lowest taxon possible. All annotation points along each transect are pooled to calculate benthic percent cover for each transect. The four transects are then averaged together, yielding a single estimate of percent cover for each taxon at each site.

With benthic species and associated classifications undergoing regular taxonomic changes along with noticeable changes in our understanding of groups such as cyanobacteria and Peysonnellids, the monitoring team is conducting quality checks focusing on non-stony coral taxa to ensure the categories of benthic data are not only current but used consistently throughout this long-term dataset. It is anticipated that any changes are likely negligible when looking at the overall trends, particularly regarding stony coral cover. However, some differences are possible in future analyses of this dataset.

3.1.3 WHAP Dataset Caveats and Limitations

Since WHAP sites were selected based on the BACI design with an emphasis on specific habitat requirements, care must be taken when analyzing results from this dataset. Particularly, the site selection scheme was by design not randomly allocated across the survey domain (Gitzen et al., 2012). Instead, sites were chosen for their similarity in depth and prevalence of finger coral as a way to reduce inter-site variability. As such, the sites are not fully representative of all hardbottom habitats in the region and therefore these data should not be used to create extrapolations across the study area at large (e.g., WHRFMA-wide population estimates). Care should also be taken when examining any mean trends by management area type as this may overlook site-level variability which the original study design attempts to control for (DAR, 2024b).

Additionally, individual WHAP sites encompass a small spatial scale (four 100-m^2 transects) relative to their respective management area. Given the inherent heterogeneity of coral reef habitats, trends observed at these sites may not accurately reflect patterns at the scale of a given management area. Similarly, since each site cluster is typically made up of a single site for each management type, trends for any given site cluster may be heavily influenced by small, local-scale conditions.

One assumption of the BACI design is that the control sites provide adequate spatial references for the "impact" sites. Ideally, pairs of sites would be close to each other, located in similar habitats, and subject to similar general conditions (e.g., oceanography, watershed impacts, human use, etc.). The original site selection procedure focused primarily on similarity in habitats, though the specific site selection procedure allowed for some site pairs to have greater distances between them than others (Table 2). Additionally, this design assumes that fishing pressure was similar between paired sites during the before period, that fishing continued in open sites during the "after" period, and that the establishment of the FRAs reduced the effects of fishing pressure at the specific FRA sites. Given that the commercial aquarium reporting zones are quite large (Figure 36) and we therefore have a somewhat low-resolution understanding of the distribution of fishing pressure, there is little opportunity to validate these assumptions.

While the BACI method can accommodate some level of non-impact related differences between site pairs (Osenberg and Schmitt, 1996), the sheer scale of time now contained in the "after" period of the WHAP survey relative to the "before" period has allowed for changes between sites that push beyond that threshold. Of particular importance are long-term changes in coral cover at multiple key sites as well as the widespread marine heatwave and subsequent coral bleaching and mortality event in 2015 (Gove et al., 2019; Kramer et al., 2016). Therefore, it's important to examine trends in coral reef habitat metrics to assess the extent to which they may be influencing the observed trends in the fish assemblages.

Lastly, the West Hawaiʻi commercial aquarium fishery has been closed since 2017, further complicating interpretation of trends in this dataset. The closure effectively splits the monitoring period into three distinct phases: pre-2000 before the establishment of the FRAs, 2000-2017 with FRAs in full effect, and 2017-present post closure. Given that fishing pressure from the commercial aquarium trade is now assumed to be equivalent (i.e., zero) inside and outside of closed areas, we would not expect to observe strong indicators of continued fishing effects following the closure.

3.2 Shallow Water Resource Fish (SWRF) Survey

The Shallow Water Resource Fish (SWRF) survey method was developed to target resource fish species that are prominent in shallow water habitats. Surveys were first conducted in 2008, with 72 sites evenly spaced between Lapakahi and Manukā (Figure 5). Sites are selected along hardbottom habitats using NOAA Hawaiian Island Benthic Habitat maps within depths of 2 to 6 meters (Battista et al., 2007). By focusing on these shallow habitats, the survey targets key species that are not well captured by other monitoring efforts (e.g., pākuʻikuʻi, ʻapi, nenue). Each survey consists of a 10-minute timed swim following the general contour of the reef within the stated depth range. The total distance covered during each survey is measured by collecting waypoints at the start and end of each survey with a diver-towed GPS that is also tracking the route. Divers quantify and record sizes for a set list of fish species observed within the 5-meter-wide survey belt. Only individuals that meet a minimum total length requirement (10-cm or 15-cm depending on the species) are recorded (Table 3).

Surveys for this project were conducted periodically between 2008 and 2018, for a total of five survey rounds to date. Each round consists of 65-72 sites and a full round is typically completed in a two-month timeframe. New site locations were chosen for each of the first four rounds. The 2018 survey round replicated the start points and directions of sites surveyed in 2009, though the distances and precise route varied. DAR monitoring staff will be continuing with an additional round of this survey during the 2025 survey season specifically to assess any potential changes in pākuʻikuʻi densities.

Table 3. *Fish species recorded during Shallow-Water Resource Fish surveys by each survey diver. Only fish that meet the minimum size requirement are recorded.*

Diver 1 Survey	Diver 2 Survey
Uhu (initial phase)> 15cm *(all species)* **Uhu (terminal phase)> 20cm** *(all species)*	**Select Large Surgeonfishes > 15cm** *(pualu, palani, ʻapi, māikoiko, maiko, na'ena'e, kala lōlō, opelu kala, kala, umaumalei)*
Select Wrasses > 15 cm *(ʻaʻawa, hilu, hīnālea ʻakilolo, poʻou, hīnālea lauhine, hou, rockmover wrasse)*	**Select Small Surgeonfishes > 10cm** *(pākuʻikuʻi, manini, goldrim surgeonfish)*
Select Butterflyfishes > 10 cm *(kīkākapu, kapuhili, reticulated butterflyfish)*	**Select Goatfish Species > 15cm** *(weke 'ula, weke 'a, moano kea, munu, moano, kumu)*
Select Additional Species > 15cm *(wahanui, ʻōmilu, nenue, mū, & lai)*	**Introduced Species > 15cm** *(roi, taʻape, toʻau)*

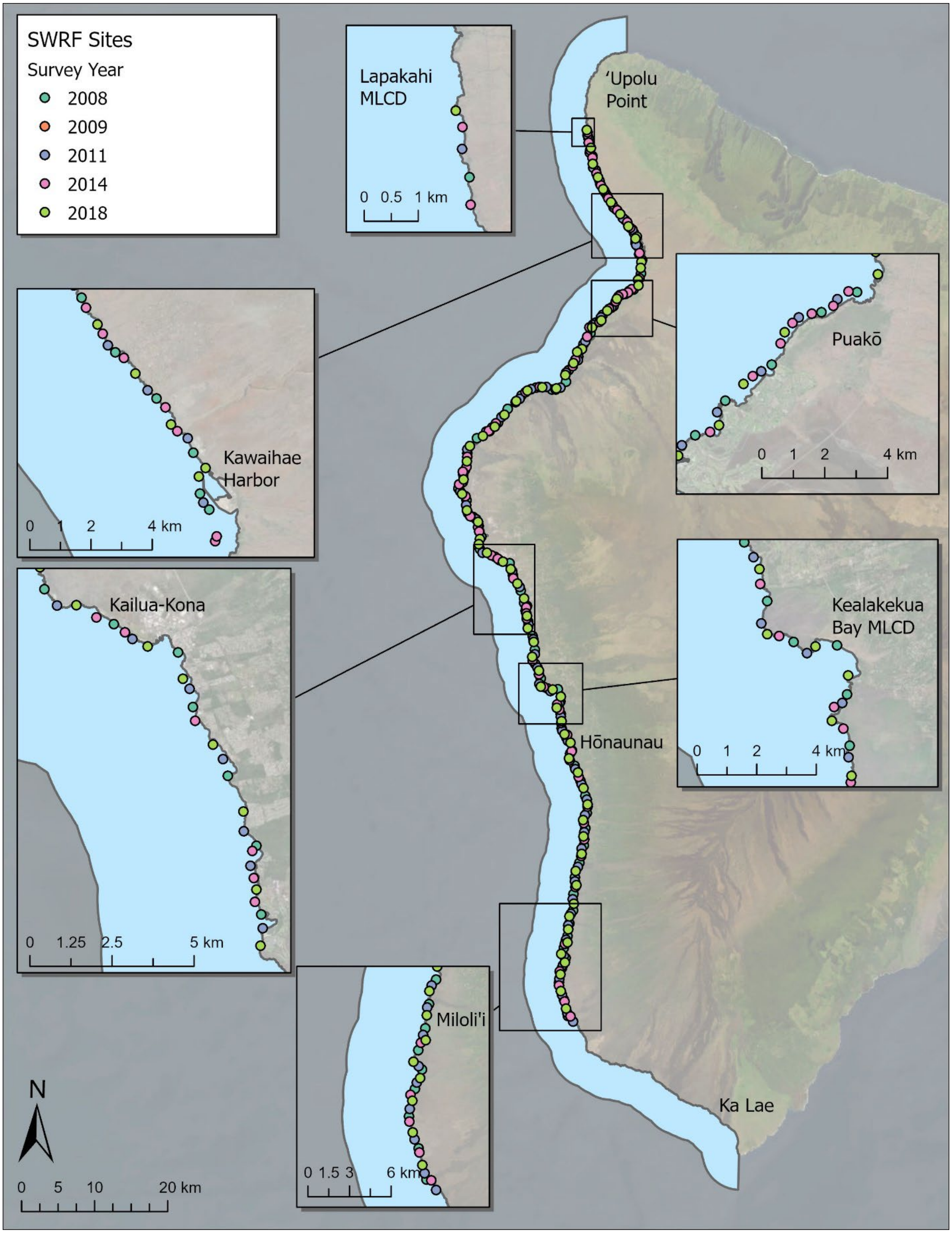

Figure 5*. Map of survey locations for the Shallow Water Resource Fish survey.*

3.1.3 Dataset Caveats and Limitations (SWRF)

The methods utilized by SWRF surveys are unique relative to other methods employed in West Hawaiʻi. Unique components include its design as a timed survey rather than a specified distance as well as the truncated list of species and size classes being recorded. These factors present difficulties in making direct comparisons between this survey method and others (e.g., WHAP and FAHU) which are based on all emergent fishes within a more defined reef survey area. That said, these differences allow surveys to cover a greater area, which may potentially capture some uncommon or mobile species more effectively. While SWRF surveys are standardized by a 10-minute timed swim for each survey, factors such as current, diver fitness, and abundance of fishes to record can all affect the swim speed of the surveyor and distance covered.

Similar to the WHAP survey design, survey locations for this project were not allocated randomly across the survey domain. In this case, site selection followed a systematic approach with even spacing across the coastline. While this allocation scheme allows for an even distribution across the survey domain, it may present challenges in interpretation due to potential spatial biases (Gitzen et al., 2012; Quinn and Keough, 2002). Additionally, the narrow band of targeted habitat and truncated set of sizes recorded means that the method samples a subset of the overall population. Given that, it is likewise inappropriate to use this dataset to provide population estimates across the shallow water habitat of the WHRFMA.

3.3 Fish and Habitat Utilization Project (FAHU)

The goal of the Fish and Habitat Utilization (FAHU) project is to assess nearshore reef ecosystems at a regional scale (i.e., spanning the entirety of the WHRFMA). The FAHU survey effort aims to characterize fish biodiversity, abundance, and size distribution, benthic species assemblages, structural complexity, and density of large mobile invertebrates across the various reef habitats of West Hawaiʻi. This project expands the scope of habitats being targeted by the DAR West Hawaiʻi survey efforts into all hard bottom habitats within logistical survey range.

A stratified random site selection approach was employed to characterize fish assemblages along hard bottom habitats between 2 and 25-meters deep. The strategy of randomly sampling across all hard bottom habitats in West Hawaiʻi allows for the data collected to represent the diversity and variability of the entire sampling region. This was initially planned to cover the full extent of the WHRFMA from ʻUpolu Point in North Kohala to Ka Lae in Kaʻū, however logistical constraints (e.g., distance and ocean conditions) have prevented extensive survey efforts in Kaʻū. Currently, this survey focuses on the region between ʻUpolu Point and Manukā Bay and staff are exploring options to regularly extend coverage in the western portion of Kaʻū.

Strata for site selection are defined by moku and depth bin. The survey region was divided into three moku groupings; 1) South Kona, 2) North Kona, and 3) Kohala (which includes North and South Kohala). Each moku is then further divided into three depth bins: 1) a shallow depth bin from approximately 2 - 8 meters depth 2) a mid-depth bin from 8.1 – 17 meters, and 3) a deep depth bin from 17.1 - 25 meters. The number of sites sampled within each stratum is allocated based on the percentage of total regional reef habitat (i.e., coral or basalt) area located within the stratum. This percentage is referred to as stratum weight (Table 4). Reef area is extracted for these calculations from the NOAA Hawaiian Island Benthic Habitat Layer (Battista et al., 2007). This site allocation procedure operates under the assumption that larger sample sizes are necessary to represent larger areas of hardbottom habitat. Additionally, a minimum of three survey sites per stratum annually was set to avoid under-sampling the smaller strata given that coral reef habitats are highly variable.

***Table 4**. Stratified random survey site allocation (FAHU). Strata are based on a combination of moku and depth bin. The number of sites allocated to each stratum is based on the stratum weight, or the percentage of total survey region hardbottom habitat present in each stratum.*

Stratum Moku	Depth Bin	Depth Range (m)	Hardbottom Area (km^2)	Stratum Weight	Sites Surveyed (2022-2023)
Kohala	*Shallow*	< 8 m	6.02	15 %	25
Kohala	*Mid*	8.1 – 17 m	5.51	14 %	21
Kohala	*Deep*	17.1 – 25 m	3.47	9 %	12
North Kona	*Shallow*	< 8 m	9.35	23 %	36
North Kona	*Mid*	8.1 – 17 m	6.25	15%	36
North Kona	*Deep*	17.1 – 25 m	2.85	7 %	16
South Kona	*Shallow*	< 8 m	2.51	6 %	25
South Kona	*Mid*	8.1 – 17 m	3.06	8 %	31
South Kona	*Deep*	17.1 – 25 m	1.34	3 %	15

The DAR Kona monitoring team is currently in the third year of data collection using this survey methodology and over 300 sites have been sampled to date. The first surveys for the project began as part of a research collaboration with NOAA, the University of Hawaii at Hilo, and Arizona State University during NOAA research expedition SE-22-02, where over 100 sites were sampled within a span of two weeks. This sampling effort extended into Kaʻū moku due to the ability of the ship to provide access to that region for multiple days.

While two years of data collection is not enough to be able to describe any sort of temporal trends in the reef fish populations or habitat metrics, it is a sufficient sample size for generating descriptive statistics and visualization of the diversity present within the study region. A total of 215 random surveys were conducted between ʻUpolu Point and Manukā Bay during the 2022-2023 survey seasons (Figure 6) and all data for fish and invertebrates from these sites are analyzed for this report. Surveys completed in waters off the Kaʻū moku during the 2022 survey round are not included in this analysis due to the small sample size (N = 13). An additional 164 sites have been surveyed during the 2024 survey season, however data were not yet available for inclusion in analyses for this report.

3.3.1 FAHU Fish and Mobile Invertebrate Methodology

At each survey site, a random heading is assigned, and a single 5x25-meter transect is surveyed for fish and large mobile invertebrates. Fish are identified to species and sized to the nearest centimeter (total length) to allow for calculation of biomass estimates. To reduce potential effects of diver disturbance on the survey transect, the transect line is reeled out simultaneously by the fish survey diver while the fish data are recorded. The large mobile invertebrate survey is conducted along a smaller 2-meter belt width, centered along the transect line, so that an invertebrate survey can be performed in a timely manner even when urchins are present in high density. These two surveys are followed by one diver swimming a single lap around the survey area, documenting the presence of fish and invertebrate species located in the immediate area of the survey belt but were not captured on the transect survey. When combined with the "on-transect" observations, this provides an estimate of the overall species richness of the survey location.

3.3.2 FAHU Benthic Methodology

Benthic imagery is collected at a subset of FAHU sites using underwater photogrammetry techniques to generate 3-dimensional (3D) models of the full 5x25-meter area of the fish transect. Overlapping images are collected from approximately 2-3 meters above the substrate covering the entire 125m² survey area (plot). These images are stitched together using Agisoft Metashape Professional (version 1.7.6) to produce an orthorectified photomosaic (orthomosaic) image and a digital elevation model (DEM) of each FAHU transect. The orthomosaic allows for characterization of benthic cover via annotation in CoralNet where 2,000 random points overlay the 125m² plot image. Annotators identify cover type or organism down to the lowest taxon possible. The DEM provides benthic structural characteristics for each site including several measures of rugosity (seafloor complexity; e.g., surface complexity, vector ruggedness measure, profile and planform curvature, and fractal dimension). Each habitat metric is exported at several spatial resolutions (1cm, 2cm, 4cm, 8cm, and 32cm) for each site following the methods described in Fukunaga and Burns (2020). Extracting metrics from the DEMs at various resolutions provides opportunity to look at structural complexity at different scales of interest.

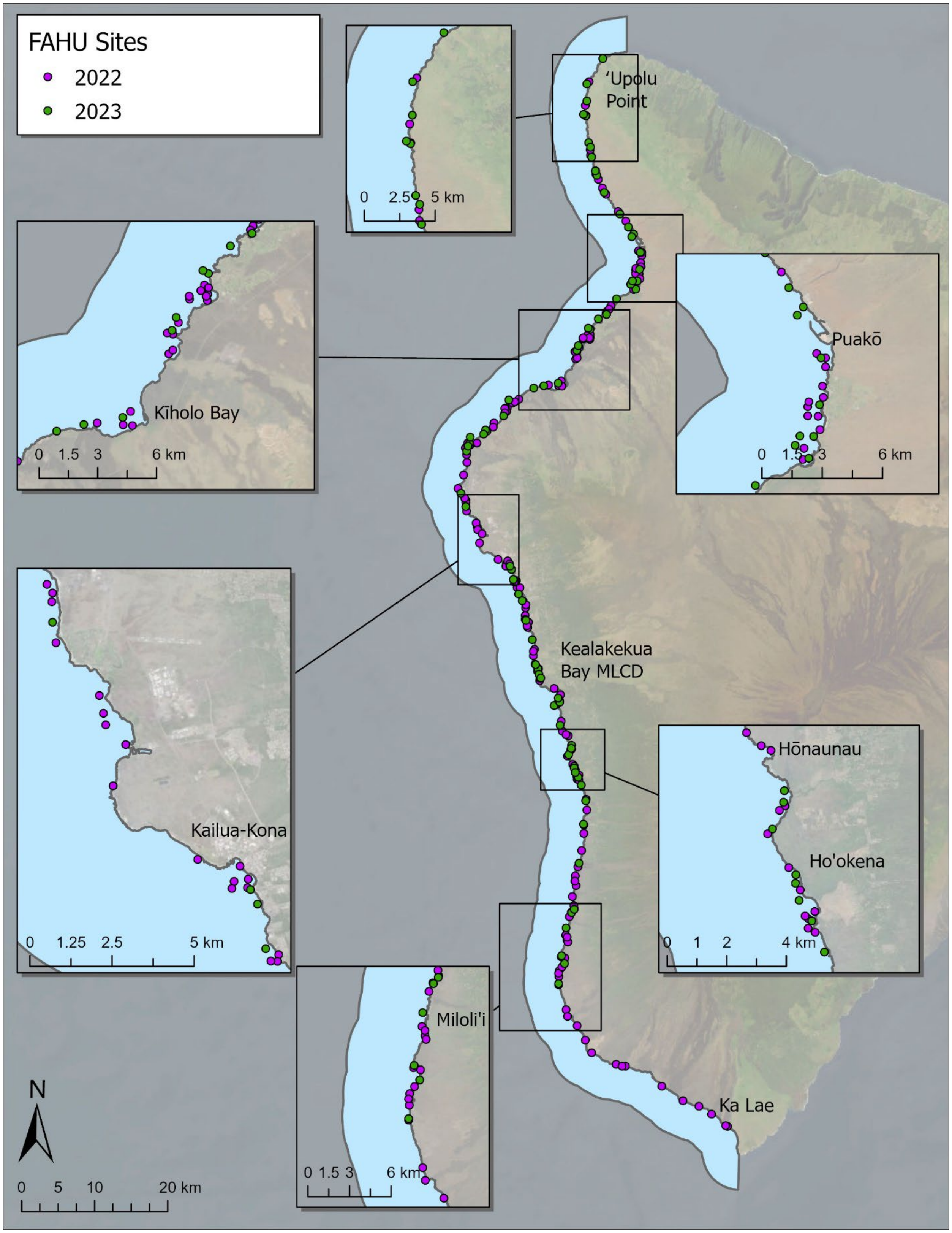

Figure 6. Map of survey locations for the FAHU project during the 2022-2023 survey seasons.

3.3.3 Dataset Caveats and Limitations (FAHU)

The FAHU survey methodology is not without its caveats and limitations. While this survey method is focused on capturing hardbottom habitat, it leaves information of sand associated species (e.g. laenihi) seldom measured. There were also logistical constraints that forced a narrowing of the survey region including unfortunately, omitting Kaʻū from this dataset. It's recognized that this is a major gap in the monitoring effort and is likely that the coastal waters of Kaʻū host unique reef habitats as it is exposed to different oceanographic conditions and is a younger section of the island. The DAR Kona monitoring team is interested in working with partners to find additional collaborative opportunities for conducting another ship or live-aboard based intensive survey effort in this moku.

An additional gap in this FAHU methodology is the limited number of sites that capture the high wave action zones along shoreline. This has been noted to be an important habitat for some species that are not fully captured across many DAR monitoring efforts. There are plans to add an additional survey bin to the FAHU stratification scheme starting in 2025 that will target this habitat and provide data for these shallow water species that are comparable to the rest of the FAHU dataset.

Another key limitation that applies to FAHU as well as other underwater visual survey methods is that all species of fish are not equally captured by these surveys. Species that are captured well are typically non-cryptic species with high site fidelity, while highly mobile species with large home ranges, as well as cryptic or diver-shy species are less likely to be recorded on transect based surveys (Thanopoulou et al., 2018).

Additional limitations were discovered within the benthic coral cover annotation process. Orthomosaic images have a coarser resolution compared to individual 2-dimensional (2D) benthic images raising challenges in identification to lowest taxa for certain benthic organisms. Because of this difficulty, some of the benthic cover categories are identified at higher taxonomic levels. For example, rather than identifying down to species, macroalgae are recorded based on general categories including red, brown, green, and golden algae. Additionally, stony coral genera that are harder to identify at a coarser resolution due their corallite structure, such as *Psammacora spp.* and *Leptastrea spp*., are identified to genus. Soft corals and Zoanthids are also categorized at a higher taxonomic level.

CHAPTER 4- FISHERIES

4.1 Fisheries Regulations in West Hawaiʻi

Prior to the formation of the West Hawaiʻi Regional Fishery Management Area, several area-specific regulations were established by the Department of Land and Natural Resources (DLNR) through the Division of Aquatic Resources (DAR) as well as its preceding agency, the Division of Fish and Game. The first of these Marine Managed Areas (MMAs) was the Kealakekua Bay Marine Life Conservation District (MLCD), established in 1969 (Figure 7; HAR §13-29). The Kealakekua Bay MLCD is one of eleven designated MLCDs throughout the state (although the Waiʻōpae Tidepools MLCD was covered by lava during the 2018 Kīlauea eruption). The general goal of the MLCD program is to conserve and replenish marine resources by restricting most forms of fishing and other consumptive uses. Three additional MLCDs have since been established in West Hawaiʻi, including the Lapakahi MLCD in 1979 (HAR §13-33), the Waialea Bay MLCD in 1985 (HAR §13-35), and the Old Kona Airport MLCD in 1992 (HAR §13-37).

In addition to MLCDs, the Department has established Fisheries Management Areas (FMAs) at various locations along the coast. FMAs are less restrictive than MLCDs but still employ place-specific fishing rules within their boundaries. Typically, these rules place restrictions on the type and amount of gear that may be used (e.g., prohibitions on spearfishing, netting, number of fishing lines, etc.). West Hawaiʻi FMAs include the Kailua Bay FMA established in 1984 (HAR §13-52), the Puakō Bay and Puakō Reef FMA in 1985 (HAR §13-54), the Kawaihae Harbor FMA in 1989 (HAR §13-55), the Keauhou Bay FMA in 1992 (HAR §13-57), and the Kīholo Bay FMA in 1997 (HAR §13-60). Though not designated as an FMA, a broad swath of coastline in South Kona from the Kiʻilae-Kēōkea boundary to the Kapua-Kaulanamauna boundary have specific rules restricting the use of fish or animal bait when fishing for ʻōpelu unless using hook-and-line methods (HAR §13-95-18).

In 1991, the first managed areas specific to the commercial aquarium trade were established as the Kona Coast FMA (Figure 8; HAR §13-58). This FMA encompasses four distinct zones between Oʻoma Beach and Puʻu ʻOhau ("Red Hill") where aquarium collection is prohibited. The four zones are Wawaloli off Oʻoma Beach, Papawai at Pawai Bay at the north end of the Old Kona Airport MLCD, Kailua Bay which extends from the outer boundary of the Kailua Bay FMA, and Red Hill located about two miles north of Kealakekua Bay.

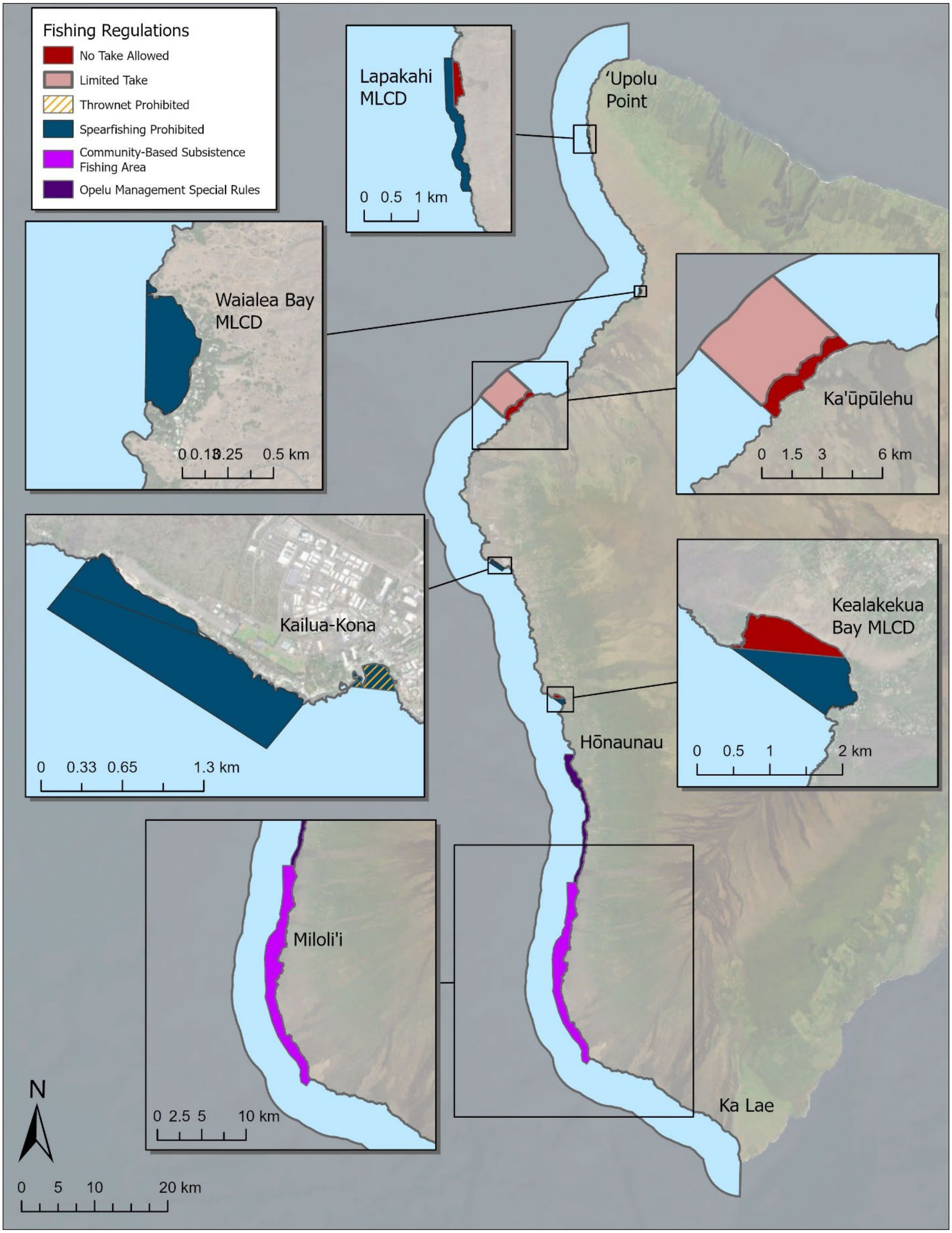

Figure 7. *Non-aquarium or lay net related Marine Managed Areas in West Hawaiʻi.*

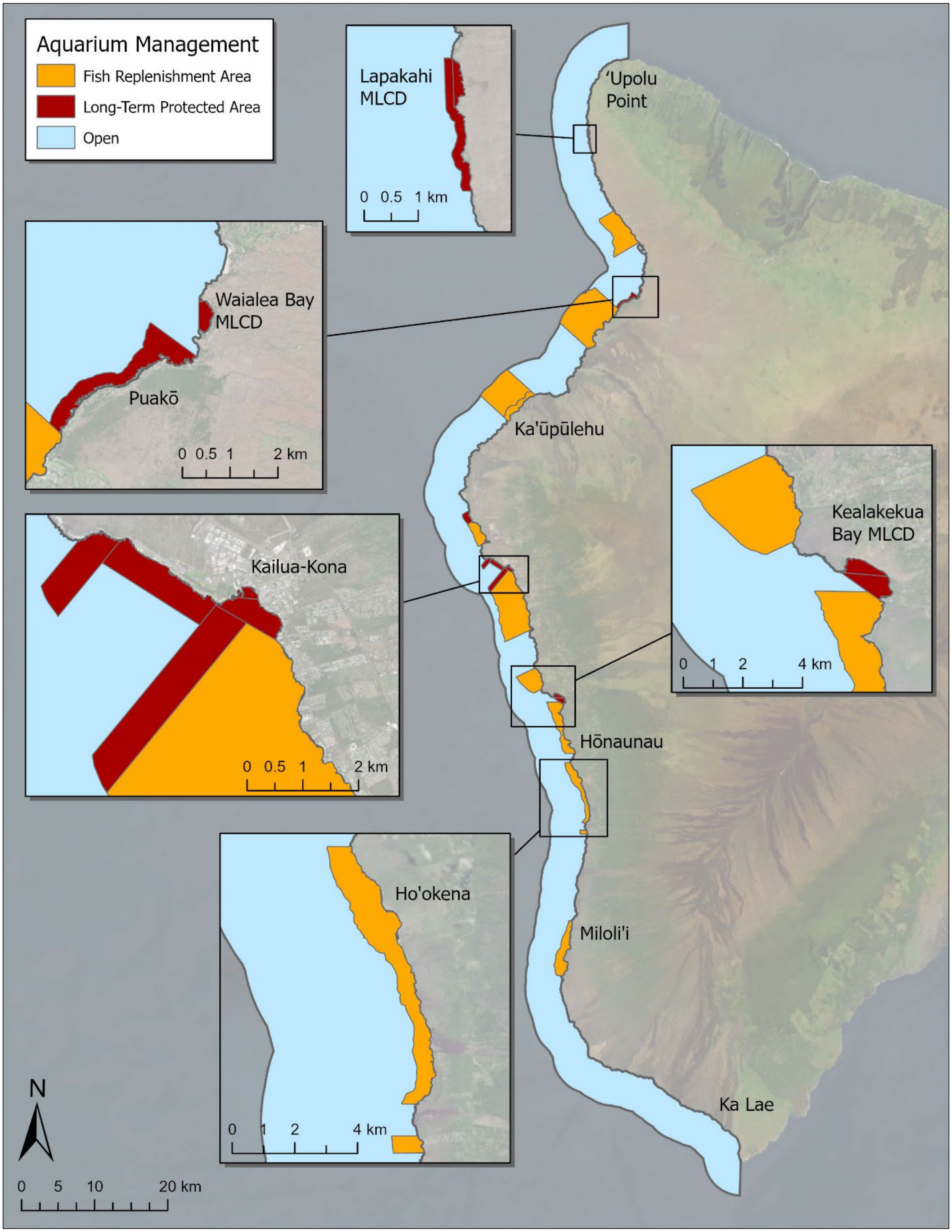

Figure 8. *Map of Fish Replenishment Areas and Long-term Protected Areas (areas closed to aquarium collection prior to 1999). Long-Term Protected Areas include Marine Life Conservation Districts and all Fisheries Management Areas with the exception of the Kīholo Bay FMA.*

The passage of Act 306 and its subsequent implementation in Hawaii Administrative Rules (HAR) §13-60.3 represented the next phase of management of the West Hawaiʻi aquarium fishery. The initial iteration of HAR §13-60.3 focused almost entirely on the establishment of the Fish Replenishment Area (FRA) network. This rule set in place nine separate FRAs between Waiakaʻīlio in North Kohala and Miloliʻi in South Kona where aquarium collection is prohibited (Figure 8). It also prohibits feeding fish for purposes other than fishing within the FRA boundaries.

In 2005, HAR §13-60.3 was amended, placing additional measures on the commercial aquarium fishery within the WHRFMA. The amendment required permit and license requirements, vessel registration, vessel identification, and dive flag usage. It also clarified that aquarium vessels may transit through areas prohibiting collection, however they may not otherwise stop or put collecting gear in the water except in cases of emergency. This amendment also established regulations for lay net fishing, setting requirements for lay net registration, dimensions, identification, and usage. It also established six Netting Restricted Areas (NRAs) where lay net fishing is prohibited (Figure 9). Additionally, the amendment required that any lay net or net-based akule fishing within the Kaloko-Honokōhau FRA must use a locally constructed net of natural fibers.

The next major change to regulations within the WHRFMA came in 2013 with the repeal of HAR §13-60.3 and its replacement by HAR §13-60.4. This amounted to the largest alteration to fishing regulations within the WHRFMA to date. The new additions primarily focused on the aquarium fishery with perhaps the most critical component being the implementation of the "white list". This rule limited all aquarium take within the WHRFMA to forty fish species (Table 5). Take of all other fish and invertebrate species by the aquarium trade was prohibited.

In addition to the "white list", HAR §13-60.4 implemented the West Hawaiʻi Aquarium Permit which is required in addition to the previously required state Aquarium Permit and Commercial Marine License. The new rule established size and/or bag limits for three of the most frequently caught species. Aquarium fishers were limited to a maximum of five lauʻīpala (yellow tang, *Zebrasoma flavescens*) larger than 4.5 inches in total length and five smaller than 2 inches in total length per day. Kole (*Ctenochaetus strigosus*) were restricted to a total of five individuals larger than 4 inches in total length per day. Pākuʻikuʻi (achilles tang, *Acanthurus achilles*) were limited to a total of ten per day. The new rules also included a requirement that nets or containers used by aquarium fishers underwater must be labeled with their Commercial Marine License number. The final aquarium-specific rule was the establishment of a new FRA off Kaʻohe Beach in South Kona.

Beyond the new aquarium rules, HAR §13-60.4 prohibited the take of eleven "species of special concern" which included five species of shark, four species of ray, and two species of pū puhi (large marine snails). Lastly, the new rules prohibited the use of SCUBA while spearfishing.

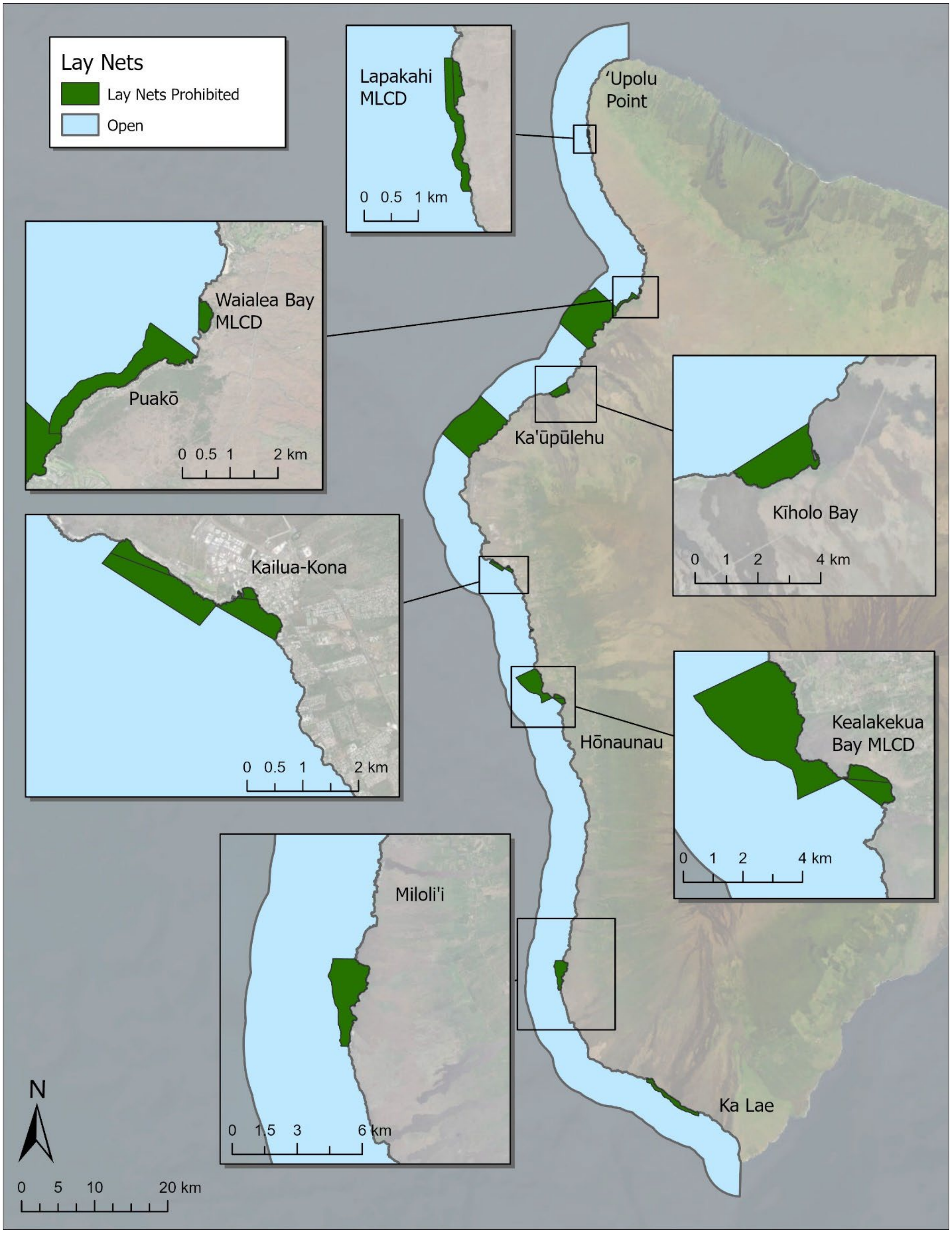

***Figure 9**. Map of areas where use of Lay Nets is prohibited in West Hawai'i. Areas include Marine Life Conservation Districts, Fisheries Management Areas, and Netting Restricted Areas.*

Table 5*. "White list" of 40 fish species allowed for take by aquarium collectors within the WHRFMA.*

Hawaiian Name	Common Name	Scientific Name
pāku‘iku‘i	Achilles tang	*Acanthurus achilles*
palani	Eye-stripe surgeonfish	*Acanthurus dussumieri*
	Goldrim surgeonfish	*Acanthurus nigricans*
mā‘i‘i‘i	Brown surgeonfish	*Acanthurus nigrofuscus*
na‘ena‘e	Orangeband surgeonfish	*Acanthurus olivaceus*
	Thompson's surgeonfish	*Acanthurus thompsoni*
	Black surgeonfish, Chevron tang	*Ctenochaetus hawaiiensis*
kole	Goldring surgeonfish	*Ctenochaetus strigosus*
umauma lei	Orangespine unicornfish	*Naso lituratus*
lau'īpala	Yellow tang	*Zebrasoma flavescens*
kīkākapu	Blacklip butterflyfish	*Chaetodon kleinii*
lauwiliwili	Milletseed butterflyfish	*Chaetodon miliaris*
kīkākapu	Multiband butterflyfish	*Chaetodon multicinctus*
lauhau	Fourspot butterflyfish	*Chaetodon quadrimaculatus*
	Tinker's butterflyfish	*Chaetodon tinkeri*
lauwiliwili nukunuku ‘oi‘oi	Forcepsfish	*Forcipiger flavissimus*
	Pyramid butterfly	*Hemitaurichthys polylepis*
	Psychedelic wrasse	*Anampses chrysocephalus*
	Flame wrasse	*Cirrhilabrus jordani*
hīnālea ‘akilolo	Yellowtail coris	*Coris gaimard*
hīnālea ‘i‘iwi	Bird wrasse	*Gomphosus varius*
la‘o	Ornate wrasse	*Halichoeres ornatissimus*
	Shortnose wrasse	*Macropharyngodon geoffroy*
	Eightline wrasse	*Pseudocheilinus octotaenia*
	Fourline wrasse	*Pseudocheilinus tetrataenia*
	Smalltail wrasse	*Pseudojuloides cerasinus*
hīnālea lauwili	Saddle wrasse	*Thalassoma duperrey*
	Fisher's angelfish	*Centropyge fisheri*
	Potter's angelfish	*Centropyge potteri*
piliko‘a	Redbar hawkfish	*Cirrhitops fasciatus*
hilu piliko‘a	Blackside hawkfish	*Paracirrhites forsteri*
humuhumu ‘ele‘ele	Black durgon	*Melichthys niger*
humuhumu lei	Lei triggerfish	*Sufflamen bursa*
	Gilded triggerfish	*Xanthichthys auromarginatus*
moa	Spotted boxfish	*Ostracion meleagris*
	Hawaiian whitespotted toby	*Canthigaster jactator*
ālo‘ilo‘i	Hawaiian dascyllus	*Dascyllus albisella*
	Peacock grouper, Roi	*Cephalopholis argus*
	Hawaiian longfin anthias	*Compsanthias hawaiiensis*
	Bluestripe snapper, Ta‘ape	*Lutjanus kasmira*

In 2016, HAR §13-60.4 was amended to designate the Kaʻūpūlehu Marine Reserve (Figure 7). This area subsumed the previous Kaʻūpūlehu FRA and set a moratorium on all take shallower than 20 fathoms (120 feet) for a period of ten years. From the twenty-fathom contour to the outer boundary of the State's management authority, take is limited to a subset of species (primarily the "deep seven", pelagic, and introduced fish species as well as kona crab). These rules are effective until June 30, 2026, at which point the Department will implement new long-term fishing rules in collaboration with the Kaʻūpūlehu community.

Fishing regulations within an additional Marine Managed Area, the Miloliʻi Community-Based Subsistence Fishing Area (CBSFA), were established in South Kona in 2022 (Figure 7, HAR §13-60.10). The regulations for this area encompass a range of gear restrictions, size limits, bag limits, and seasonal closures. Several sub-areas within the CBSFA have additional layers of regulations including gear and species restrictions. Lastly, aquarium collection is prohibited throughout the CBSFA.

Following long-standing concerns within DAR and West Hawaiʻi communities regarding the status of pākuʻikuʻi (Achilles tang, *Acanthurus achilles*) in the region, a two-year moratorium on all take of this species was enacted at the end of 2022 (HAR §13-60.41). This rule was established using the Department's adaptive management authority which stipulates that such rules automatically sunset after a period of two years. DAR is currently pursuing rulemaking on longer-term regulations for this species which may include an extended moratorium, bag limits, and a free pākuʻikuʻi fisher registration program.

4.2 Nearshore Reef Food Fisheries

4.2.1 Fishery Descriptions

Fishing effort in West Hawaiʻi can be summarized into two overarching categories: commercial and non-commercial fishing. Within these categories, the nuances of why and how fishers' fish are extensive. Non-commercial fishing encompasses a wide range of specific purposes including subsistence, recreational, and traditional fishing practices with considerable overlap between these general categories. Likewise, commercial fishing is not monolithic in terms of the scale at which they fish commercially. In Hawaiʻi, any fisher intending to sell either part or all of their catch are required to hold a state Commercial Marine License (CML). Some fishers, termed as recreational expense fishers, sell portions of their catch simply to recuperate costs associated with their otherwise non-commercial fishing trip. Others consider themselves to be commercial fishers on a part-time basis while the remainder are considered full-time commercial fishers (Ma and Ogawa, 2016).

While fishing effort by any single non-commercial fisher may be a fraction of that of a full-time commercial fisher, estimates of the non-commercial fisher population are reported to be far greater than the number of licensed commercial fishers (McCoy et al., 2018). This disparity between commercial and non-commercial fishing modes have led to some estimates that catch in nearshore reef fisheries are dominated by non-commercial take (McCoy et al., 2018). There is no requirement for non-commercial fisher licensing for Hawaiʻi residents or reporting of effort and catch, however take by this resource user group is a critical component towards understanding the Hawaiʻi nearshore fisheries as a whole. Broadly, the details of fishery-dependent data in the nearshore waters of Hawaiʻi are complex and nuanced. Here, we present brief discussions of both commercial- and non-commercial datasets for West Hawaiʻi, however a more detailed review is warranted.

Commercial fisheries

Commercial fishing catch reports have been a mandatory requirement for registered commercial fishers since 1948. Reporting throughout the time series has been based on a grid system in which fishers must indicate where fishing and catch occurred (Figure 10). Inshore reporting grids that surround each of the Main Hawaiian Islands extend from the shoreline out seaward approximately two nautical miles, or the estimated average range of the inshore fishing fleet at the time of establishment. In the following summary of West Hawaiʻi commercial inshore fisheries, catch from reporting grid areas 100, 101, 102, and 103 were included. Because area 103 curves around the northern tip of Hawaiʻi Island, some commercial landings reported in this summary may fall outside of the West Hawaiʻi Regional Fishery Management Area.

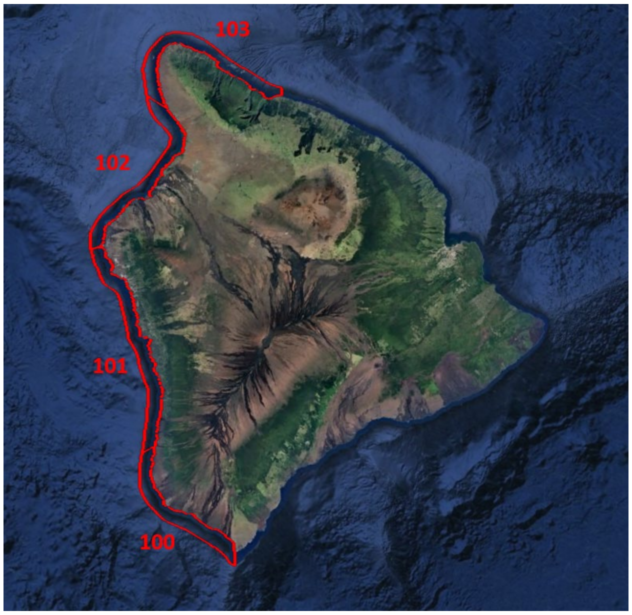

***Figure 10**. Map of inshore commercial fishing reporting grids.*

Commercial catch reported in the West Hawaiʻi inshore grid areas between 1948 and 2023 is composed primarily of scads (ʻakule; *Selar crumenophthalmus* & ʻōpelu; *Decapterus macarellus*) and miscellaneous pelagic species (tunas, billfishes, barracudas, etc.) which together make up 86% of the total landings (Figure 11). In comparison, inshore finfish (squirrelfishes, soldierfishes, surgeonfishes, goatfishes, parrotfishes, snappers and groupers, mullets, wrasses, and uncategorized fishes), i.e., coral reef associated and other shallow water target species, make up approximately 7% of the total reported commercial landings. Because commercial records span a period of 76 years, composition of catch and landings over time vary due to inherent changes in demographics, technology, market demand, and fishing regulations (Figure 12). As the largest components of West Hawaiʻi's inshore fisheries, scad and pelagic species are the primary drivers in overall landings trends over time. Scad landings peaked in the early 1980s, followed by a subsequent rise and peak in pelagic landings in the early 2000s (Figure 12).

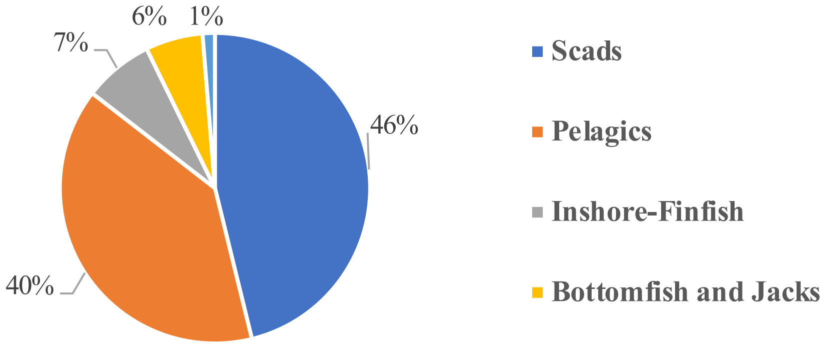

Figure 11. *Composition of species groups in commercial landings reports from 1948-2023 in grid areas 100-103.*

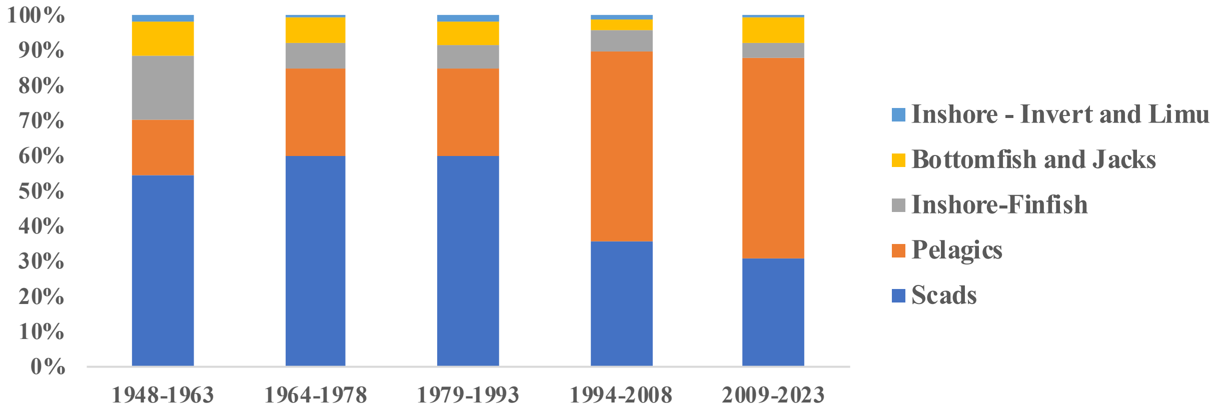

Figure 12. *Percent contribution by species category for commercial landings reports from 1948 to 2023 in areas 100-103.*

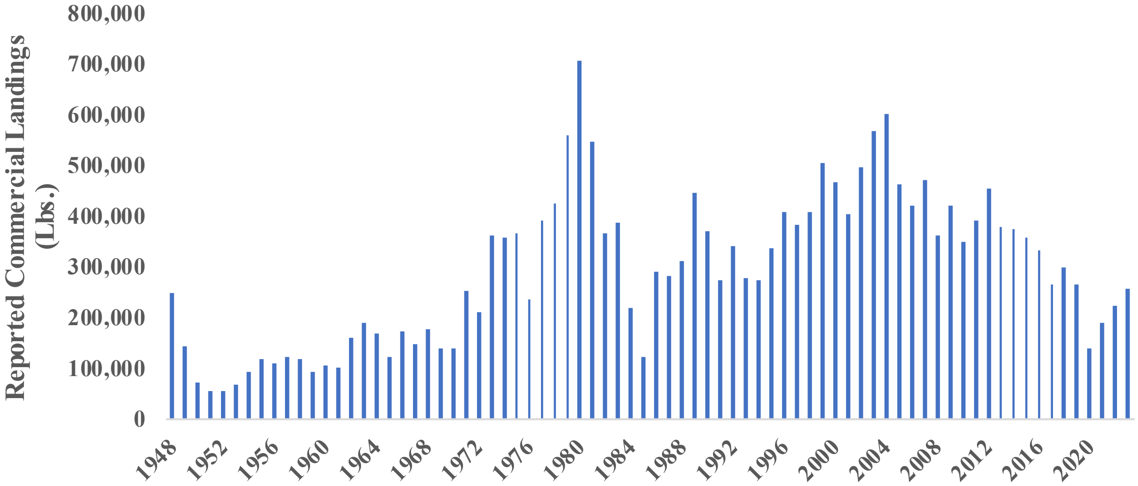

Figure 13*. Annual total weight (lbs) for reported commercial landings in grid areas 100-103.*

The inshore finfish fisheries of West Hawai'i are a consistent fraction of the area's total reported commercial landings (Figures 13 & 14, note scale of each). Composition of reported commercial catch for these fisheries is split between eight different categories, with squirrelfishes (*Holocentridae*; includes ʻūʻū /menpachi) making up the largest component at 32% of all inshore finfish landings from 1948 to 2023. Like West Hawaiʻi commercial landings in general, reported commercial landings of inshore finfish are variable over the time series including multiple distinct peaks in catch during the late 70s, mid 90s, and the mid 2000s (Figure 14). Changing catch and species composition is in part due to shifts in gear usage and their corresponding target species (Figure 15). Net based fisheries were the primary source of inshore finfish commercial landings early on but were progressively phased out as hook and line and dive (spearfishing) fishing modes became dominant (Figure 16).

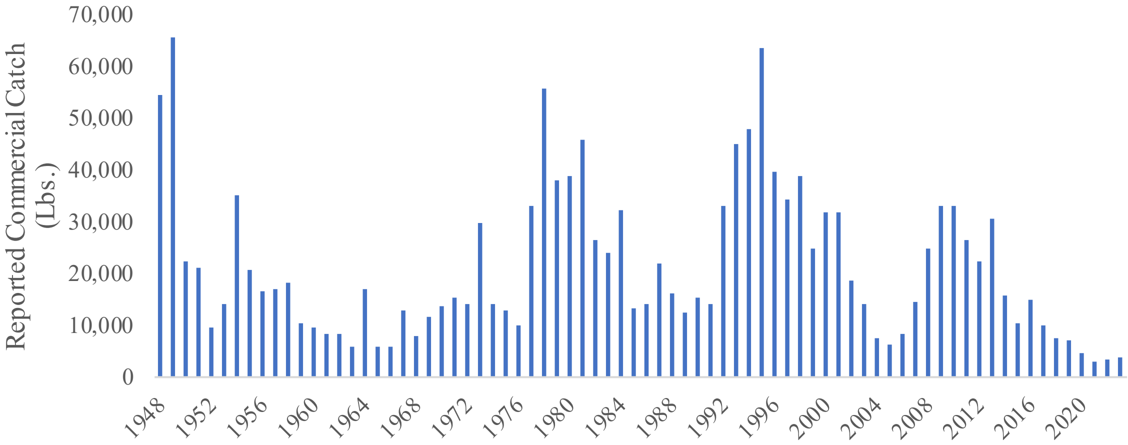

Figure 14*. Annual total weight of reported commercial inshore finfish landings in grid areas 100-103 from 1948-2023.*

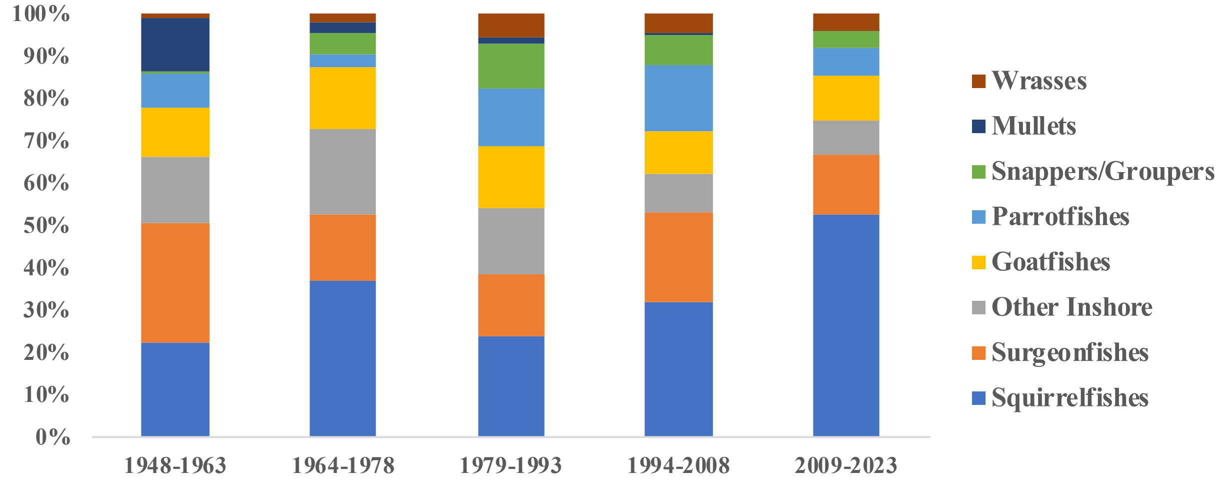

Figure 15. *Changes in percent contribution by inshore finfish category in commercial landings from 1948-2023 reported from grid areas 100-103.*

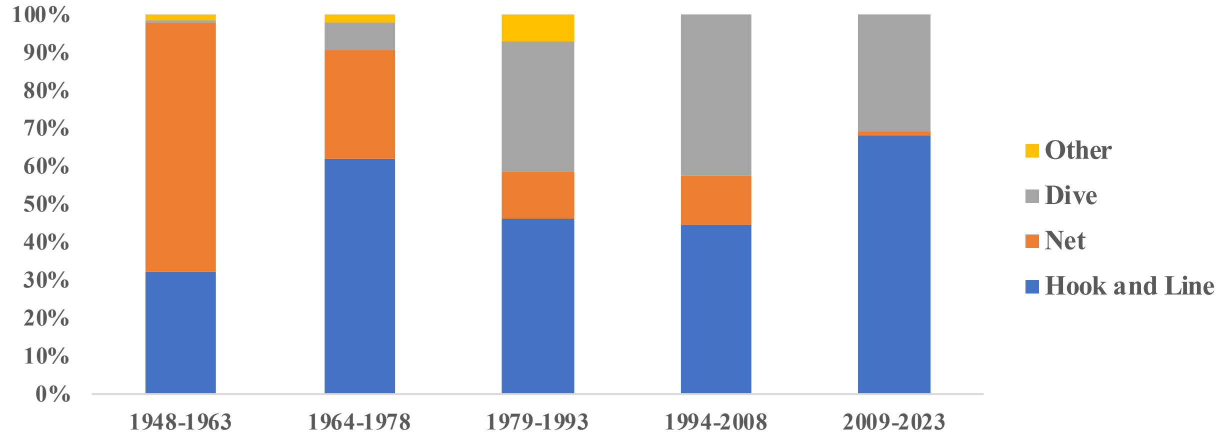

Figure 16. *Gear usage reported in commercial inshore finfish landings from 1948-2023.*

Today, West Hawaii's inshore commercial finfish catch is dominated by squirrelfishes at 61% of total reported commerical fishery catch weight across the last decade (Figure 17). This shift from the long-term species composition is indicative of the change over time to dominance by hook and line boat-based catch. Top ten inshore finfish species caught in the past ten years reflect this, with many of them being species targeted primarily by hook and line fisheries (Table 6). In comparison, top ten inshore finfish caught statewide include a higher representation of fish primarily caught with net based gears such as manini, nenue, palani, and kala (Table 7).

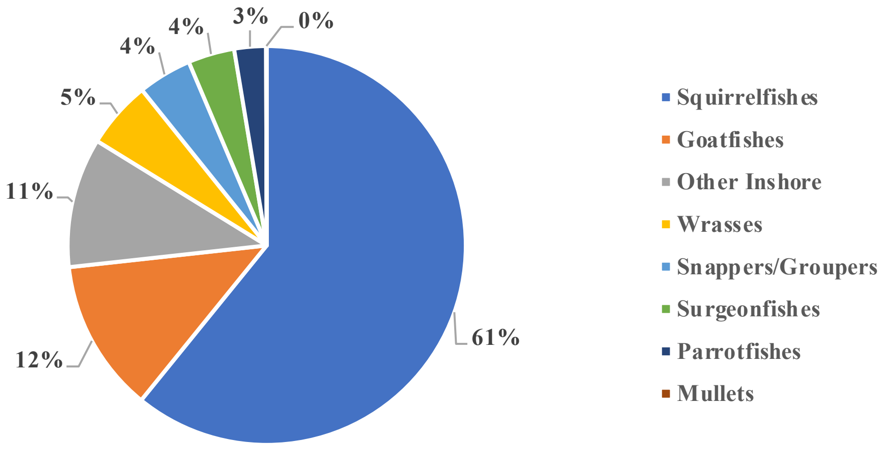

Figure 17. *Percent contribution by species category to total reported inshore finfish commercial landings in grid areas 100-103, 2014-2023.*

Table 6*. Top-10 inshore finfish species by reported commercial landings. Rank is based on proportion (percent) of total catch weight (landings) reported in areas 100-103 during 2014-2023.*

RANK	NAME	SCIENTIFIC NAME	LANDINGS (LBS.)	PERCENT
1	ʻūʻū	*Myripristis spp.*	48,801	60.4%
2	ʻāweoweo	*Priacanthidae*	5,361	6.6%
3	taʻape	*Lutjanus kasmira*	3,286	4.1%
4	moana	*Parupeneus multifaciatus*	2,865	3.5%
5	moana Kali	*Perupeneus cyclostomus*	2,757	3.4%
6	ʻaʻawa	*Bodianus albotaeniatus*	2,281	2.8%
7	uhu	*Scaridae*	2,079	2.6%
8	laenihi	*Iniistius spp.*	1,950	2.4%
9	weke ʻula	*Mulloidichthys vanicolensis*	1,935	2.4%
10	weke nono	*Mulloidichthys pfluegeri*	1,692	2.1%

In the past ten years (2014-2023) reported inshore finfish commercial landings from Hawaiʻi Island grid areas 100-103 were just 2.8% of the statewide total. This low proportion, despite the relatively large area, is driven in part by the lack of market demand compared to that seen on Oʻahu and to a lesser degree Maui. West Hawaiʻi lacks the full time, brick and mortar fish markets capable of absorbing large volumes of fish at a time. High demand, as seen on Oʻahu, influences the usage of certain types of fishing gears and methods that increase capability of larger catches including bag netting and deepwater night scuba spearfishing. The practice of shipping inshore finfish off-island to supply Oʻahu markets does occur, though irregularly. The majority of inshore finfish sold in primary Oʻahu markets are caught in Oʻahu waters. Reported commercial sales of inshore finfish in West Hawaiʻi remain relatively small scale and inconsistent, though there is likely a fair amount of unreported fisher to consumer sales that occur in communities without going through markets.

***Table 7**. Statewide top ten inshore finfish species recorded in commercial landing reports throughout the last decade (2014-2024).*

RANK	NAME	SCIENTIFIC NAME	LANDINGS (LBS.)	PERCENT
1	ʻūʻū	*Myripristis spp.*	470,624	16.1%
2	uhu	*Scaridae*	399,115	13.6%
3	taʻape	*Lutjanus kasmira*	366,109	12.5%
4	palani	*Acanthurus dussumieri*	267,706	9.1%
5	weke ʻula	*Mulloidichthys vanicolensis*	250,746	8.6%
6	kala	*Naso spp.*	161,981	5.5%
7	nenue	*Kyphosus spp.*	104,627	3.6%
8	manini	*Acanthurus triostegus*	103,544	3.5%
9	ʻōʻio	*Albula spp.*	64,875	2.2%
10	naʻenaʻe	*Acanthurus olivaceus*	60,654	2.1%

Non-commercial fisheries

DAR partnered with NOAA fisheries in 2001 to initiate collection of non-commercial shoreline and boat fishing effort and catch data through the Hawaiʻi Marine Recreational Fishing Survey (HMRFS). Data collection occurs through Access Point Angler Intercept Surveys (APAIS) where surveyors gather information from fishers at public fishing access points (e.g., boat ramps and key shoreline fishing locations). Additionally, a Fishing Effort Survey (FES) is distributed through the mail to a portion of Hawaiʻi residents to collect data on the number of trips taken from shore or private boats over a specified period of time. These two surveys are then combined to create an estimate of total non-commercial catch (DAR, 2024c; Ma et al., 2019). The results presented below focus on the APAIS component of this program, however a full examination that includes the FES portion as well may provide greater clarity on nearshore non-commercial fisheries.

Given the lack of defined divisions between sectors of commercial and non-commercial fishing (i.e., recreational expense fishers), there is difficulty in completely separating out commercial vs non-commercial catch data within the HMRFS dataset. Additionally, the APAIS component of this work has some substantial limitations including low spatial coverage of the shoreline, lack of data for night fishing, and non-recording of invertebrate catch (Ma et al., 2019). The limited spatial coverage of the shoreline is likely inadequately sampling certain sectors of the non-commercial nearshore fishery including shore-based spearfishers, net fishers, and kayak-based fishers. HMRFS and NOAA are currently assessing alterations to these methods which would help to alleviate some of these concerns. One key proposed change is the incorporation of roving catch and effort surveys which would greatly expand the spatial coverage of intercept surveys.

Surveys from shoreline fishers between 2018 and 2022 have been summarized to depict some of the platforms and types of gear utilized by the fishers that were interviewed in West Hawaiʻi. It's important to note again that the efforts of APAIS focus on known public fishing locations and is therefore not a comprehensive accounting of all the shoreline access fishing that occurs in West Hawaiʻi. This presents bias towards representation of the fishing that regularly occurs at these known survey locations and may substantially underestimate other fishing activities. For example, a substantial number of anglers may use lesser-known access points for fishing that are not represented in the HMRFS survey data.

Table 8. *Distribution of HMRFS data collection across survey locations during the West Hawaiʻi sampling conducted between 2018 – 2022. "Int. Dates" indicates number of different calendar dates where intercepts were made with fishers and data were collected, "Platforms" shows the number of fishing platforms recorded, but not number of platforms available, and "Gear Types" shows number of gear types recorded in survey data.*

Survey Site	**Int. Dates**	**Platforms**	**Gear Types**
Aliʻi drive	7	1	3
Anaehoʻomalu Bay / Hilton Waikoloa	0	*NA*	*NA*
Four Seasons Resort shoreline	0	*NA*	*NA*
Hōnaunau / Napoʻopoʻo Bay	1	1	2
Honokōhau Harbor	2	1	3
Hualalai / Kua Bay	0	*NA*	*NA*
Kailua Bay	8	3	2
Kapaʻa Park / Mahukona	0	*NA*	*NA*
Kawaihae Harbor	0	*NA*	*NA*
Keauhou Boat Harbor	10	3	2
Kekaha Kai Beach Park	1	1	1
Kīholo Bay	1	1	1
Mauna Lani shoreline	0	*NA*	*NA*
Miloliʻi	6	2	2
Natural Energy Lab (OTEC)	3	3	2
Puakō	2	1	1
Red Hill / Kaiopae / Black Point	0	*NA*	*NA*
South Point	7	2	1
Spencer Beach Park / Coral Flats	0	*NA*	*NA*

There is also a likelihood for platform and gear type recorded through the APAIS surveys to be a influenced by the survey location rather than the true distribution of use by the population of non-commerical shoreline fishers in West Hawaiʻi. A given platform may only be available at some locations and a given gear type may only be utilized from a specific platform so it's possible these nuances lead to over or underrepresentation of certain gear types and platforms in these data. The APAIS survey data reported here were collected through positive intercepts with fishers at 11 survey locations across 48 calendar dates (Table 8). The number of individual fish captures recorded during this effort was 1,059 with 39 unique species of reef fish identified.

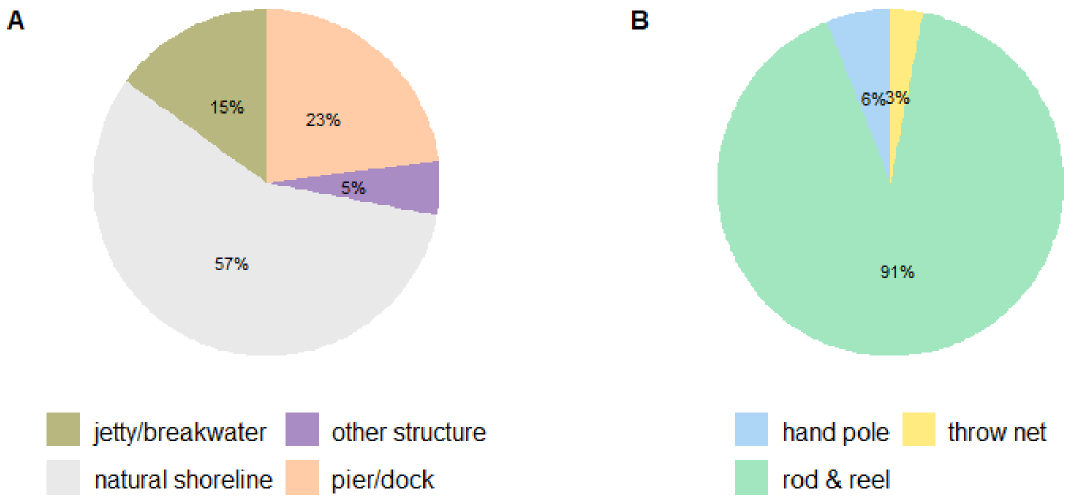

Figure 18. *Non-commercial shoreline fishing gear types and platforms recorded through HMRFS surveys completed in West Hawai'i between 2018 and 2022. Percent shows proportion of total catch that was recorded with the use of each A) fishing platform and B) gear type.*

Most landings recorded were made from natural shoreline as the fishing platform, with rod and reel as the gear type used (Figure 18). The structure of the West Hawai'i shorelines, predominantly composed of basalt cliffs, provides an abundance of natural shoreline fishing opportunities to local fishers. This type of land to ocean interface often provides direct access to deeper water from the shoreline. Almost a quarter of the recorded landings were made from the second most popular platform: piers and docks, though the extent to which this estimate may be affected by the aforementioned sampling bias is unclear. Other platforms recorded as being less frequently used for the recorded landings includes jetties and breakwaters or other structures. Other geartypes recorded by the survey effort include hand pole and thrownet. Notably, records of spearfishing are absent in this dataset, highlighting this limitation in the methodology.

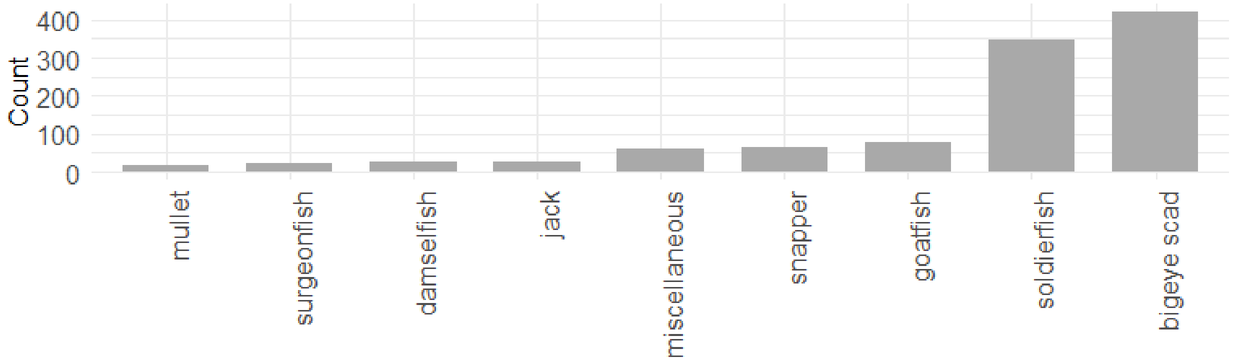

Figure 19*. Fish types recorded through HMRFS surveys completed in West Hawaiʻi between 2018 and 2022. Count (y-axis) shows total number of individual fish landed across all surveys.*

Choice of fishing gear and platform is likely heavily influenced by targeted catch. Shoreline fishers interviewed as part of the HMRFS survey effort are reported to have caught ʻakule (Bigeye Scad) and soldierfishes more often than other targeted species (Figure 19). Without more fisher-dependent data from non-commercial fishers it's difficult to make further inference on how these catch records from shoreline fishers represent the catch of the greater non-commercial fishing population in West Hawaiʻi.

4.2.2 Monitoring Data for Resource Fishes

Across the 215 surveys completed for the Fish and Habitat Utilization Project (FAHU) between 2022 and 2023, a total of 147 species of reef fish were recorded. The mean reef fish species richness (number of species) observed within a given survey transect is 18 ± 1 (±SE) species, with the fewest species recorded being five and the most being forty-four. Twenty species of the family *Acanthuridae* (surgeonfishes) were recorded, with six of these species among the twenty most abundant species observed across all surveys (Figure 20). The twenty most abundant species list also includes species that are not typically targeted as a food resource, such as small damselfishes and wrasses. Ten of these twenty most abundant species, however, have been known to be fished for consumptive purposes in Hawaiʻi (Titcomb, 1972).

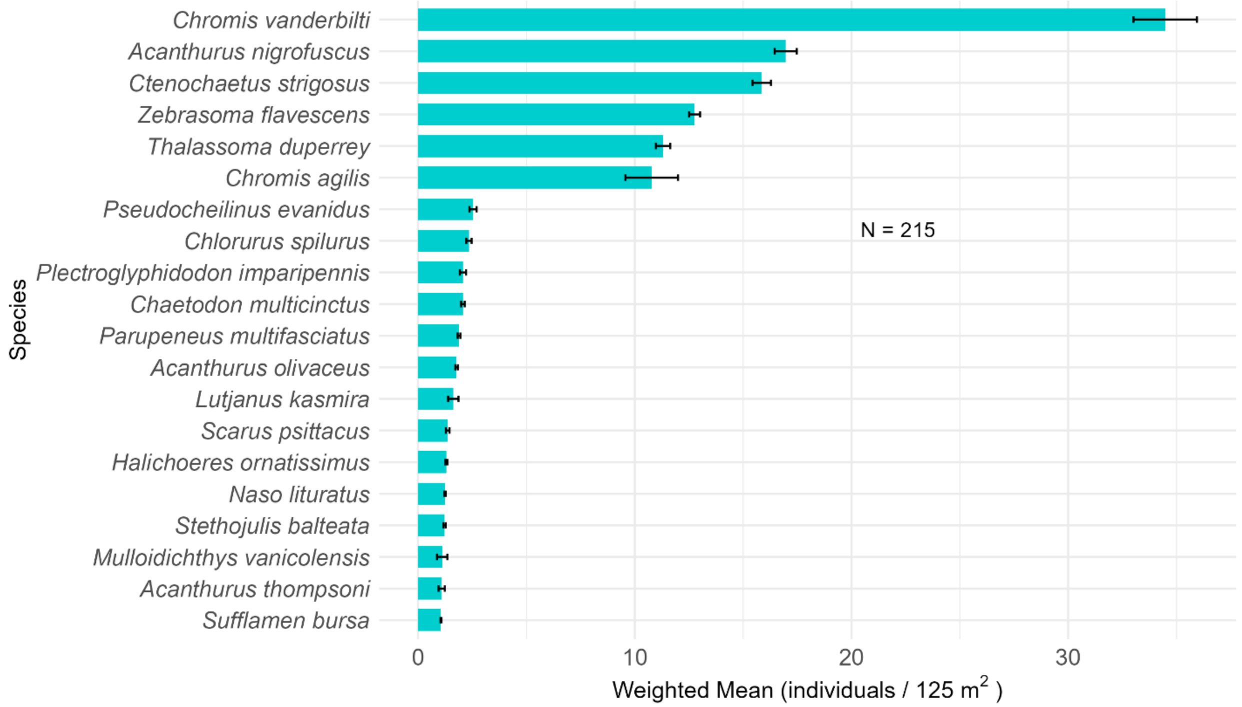

Figure 20. *The 20 most abundant reef fish species recorded during 2022-2023 FAHU surveys. Mean density per transect (125 m^2) weighted by stratum weights with error bars to show weighted standard error for the sample size of 215 surveys across nine strata. Scientific names were used to distinguish species with overlapping Hawaiian names. Translations can be found in Appendix table A-1.*

Surgeonfishes

Surgeonfishes include a range of species that are favored as resource fish in Hawaiʻi (Titcomb, 1972, Figures 15 & 17). Surgeonfishes were one of the most commonly observed families across the FAHU survey locations, occurring at 214 of the 215 survey sites (99%). Three small-bodied species of surgeonfish, kole, maʻiʻi, and lauʻīpala, were observed to be the most abundant species within this family throughout the 2022-2023 FAHU surveys and were frequently sized between 11-14cm (4.3-5.5 inches) in total length (Figure 21). Medium- and large-bodied species of surgeonfish were frequently observed during the survey round as well, though in lesser abundance than the small-bodied species.

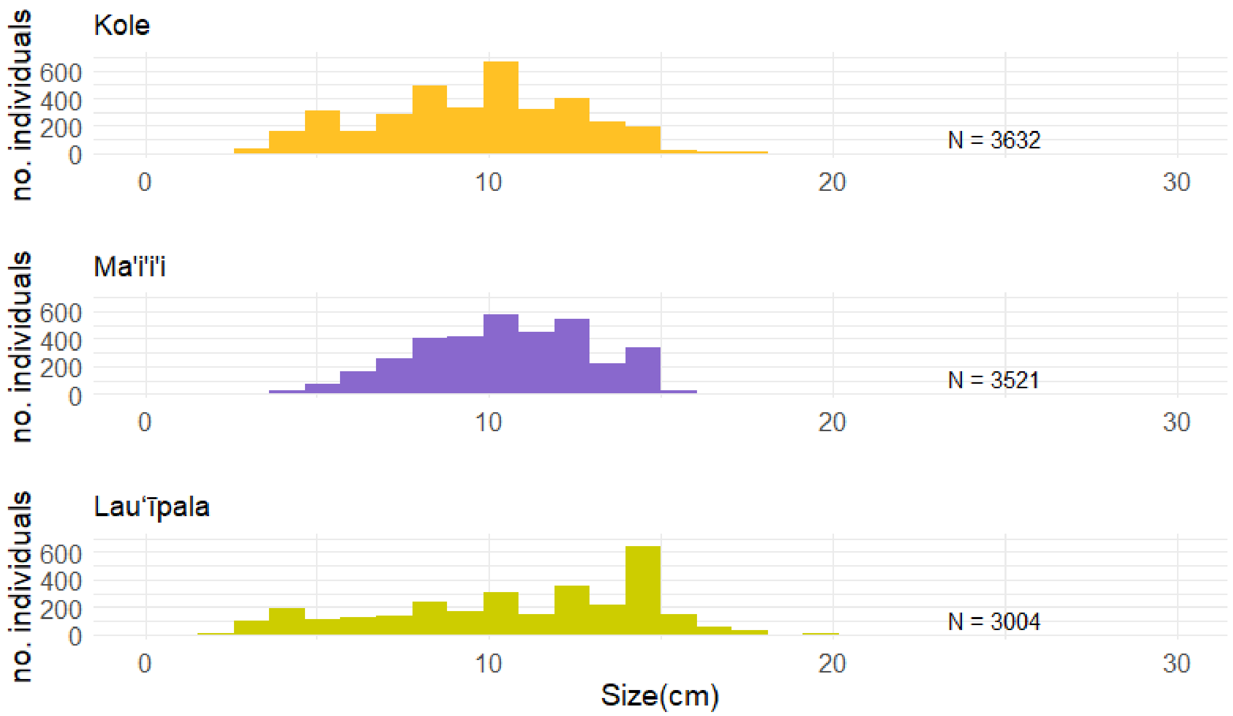

***Figure 21**. Size distribution of the three most abundant surgeon fish species recorded during FAHU surveys. Number of individuals observed (no. individuals) on the y-axis and total length of fish (size) on the x-axis. N represents the total number of individuals of the given species observed during the 215 stratified random surveys conducted along the West Hawaiʻi Coastline in 2022-2023.*

Juvenile surgeonfishes were more commonly observed and generally showed higher densities in the mid and deep depth bins (8-25 meters depth) of the FAHU survey strata. Smaller individuals of the small-bodied surgeonfish group were more frequently observed at deeper sites (> 17 meter depth) and larger individuals were observed more frequently at shallower depths (< 8 meter depth, Figure 22). This relationship between smaller sizes of small-bodied surgeonfishes and deeper sites is likely related to the coral habitat available at those depths, particularly given that finger coral has a tendency to occupy deeper areas that are not subject to high wave action (Dollar, 1982). Lauʻīpala and kole specifically have been noted to recruit and spend time in habitat rich with finger coral (*Porites compressa*) due to the high structural complexity and opportunities for refuge that this species of coral offers (DeMartini and Anderson, 2007; Ortiz and Tissot, 2012). The relationship between fish size and survey depth was less apparent for the medium- and large-bodied subgroups of surgeonfishes (Figure 22). Benthic species composition data processing for FAHU surveys is still in preliminary phases, however once these data are available, the paired benthic and fish surveys will provide opportunities to explore the relationships between key resource species and benthic species assemblages.

***Table 9**. Surgeonfish subgroupings for species commonly observed across West Hawaiʻi monitoring surveys. Common, scientific taxonomic, and Hawaiian names are listed to aid with clarification of species. Maximum sizes are sourced from Shorefishes of Hawaii by John E. Randal.*

Subgroup	*Common*	*Taxonomic*	*Hawaiian*	*Max Size (cm)*
Large	Ringtail Surgeonfish	*Acanthurus blochii*	pualu	42
	Eye-stripe Surgeonfish	*Acanthurus dussumieri*	palani	54
	Orangeband surgeonfish	*Acanthurus olivaceus*	naʻenaʻe	35
	Yellowfin Surgeonfish	*Acanthurus xanthopterus*	pualu	63
	Orangespine Unicornfish	*Naso lituratus*	umauma lei	46
	Sailfin tang	*Zebrasoma veliferum*	māneʻoneʻo	40
Medium	Achilles Tang	*Acanthurus achilles*	pākuʻikuʻi	25
	Whitespotted Surgeonfish	*Acanthurus guttatus*	ʻapi	28
	Whitebar Surgeonfish	*Acanthurus leucopareius*	māikoiko	25
	Bluelined Surgeonfish	*Acanthurus nigroris*	maiko	25
	Thompson's surgeonfish	*Acanthurus thompsoni*		27
	Convict tang	*Acanthurus triostegus*	manini	27
	Black Surgeonfish	*Ctenochaetus hawaiiensis*		28
Small	Goldrim Surgeonfish	*Acanthurus nigricans*		21
	Brown Surgeonfish	*Acanthurus nigrofuscus*	māiʻiʻi	21
	Goldring surgeonfish	*Ctenochaetus strigosus*	kole	24
	Yellow Tang	*Zebrasoma flavescens*	lauʻīpala	20

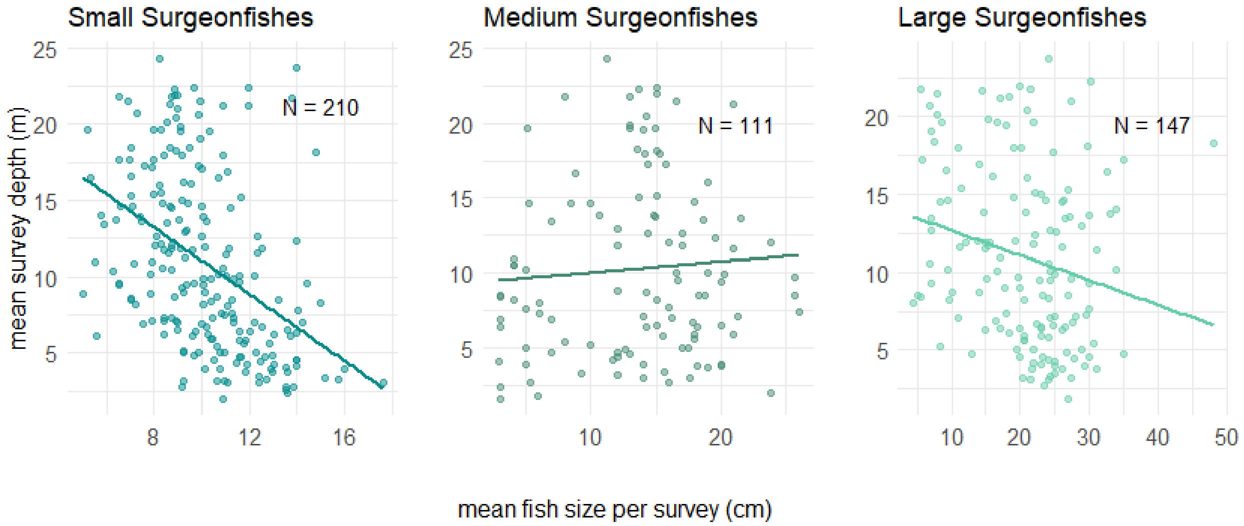

Figure 22. *Size of surgeonfish subgroups plotted against depth of FAHU survey site. Number (N) of FAHU surveys on which individuals of the given subgroup were recorded during the 2022-2023 FAHU survey round. Mean size (cm) of fish within the subgroup per survey transect (x-axis) and mean depth (m) of the survey transect (y-axis). Species included in each subgroup can be found in Table 9.*

The WHAP survey method targets mid-depth, finger coral rich habitat and is therefore likely ideal for observing species of the small-bodied surgeonfish subgroup: kole, lauʻīpala, and maʻiʻiʻi (Figure 23). The densities of kole and maʻiʻiʻi displayed increases at these fixed sites following the substantial fish recruitment event that occurred in 2014 (DAR, 2019; Talbot, 2014). Mean densities of lauʻīpala across sites appear to have increased as well, though this is likely driven by a subset of sites (see Figure 42 in section 4.3.3).

Thompson's surgeonfish (*Acanthurus thompsoni*), a medium-bodied species, also displayed a slight increase in mean density following 2014, influenced by a subset of survey rounds with high variability across individual sites (Figure 24). Following the recruitment event, Thompson's surgeonfish shows a mean density greater than other medium-bodied surgeonfishes, however the large standard deviation for several survey rounds during this time suggests variability across individual sites (Figures 24 & 25). Additional medium and large-bodied surgeonfish densities remained relatively consistent between the years before the recruitment event and the most recent survey round (Figure 25). The black surgeonfish (*Ctenochaetus hawaiiensis*) and umauma lei (orange spined surgeonfish) display a brief and slight increase in density at a subset of sites during the survey rounds surrounding the recruitment event, however this trend was not observed across all WHAP sites. Species within the medium and large-bodied subgroups of surgeonfish are recorded in much lower densities than the common small-bodied surgeonfishes. Along with high variability across sites, this makes it difficult to distinguish reliable trends across WHAP sites. Additionally, while the WHAP dataset presents a robust long-term record at these 25 fixed sites, it does not necessarily reflect regional trends nor trends outside of the targeted mid-depth coral rich habitat.

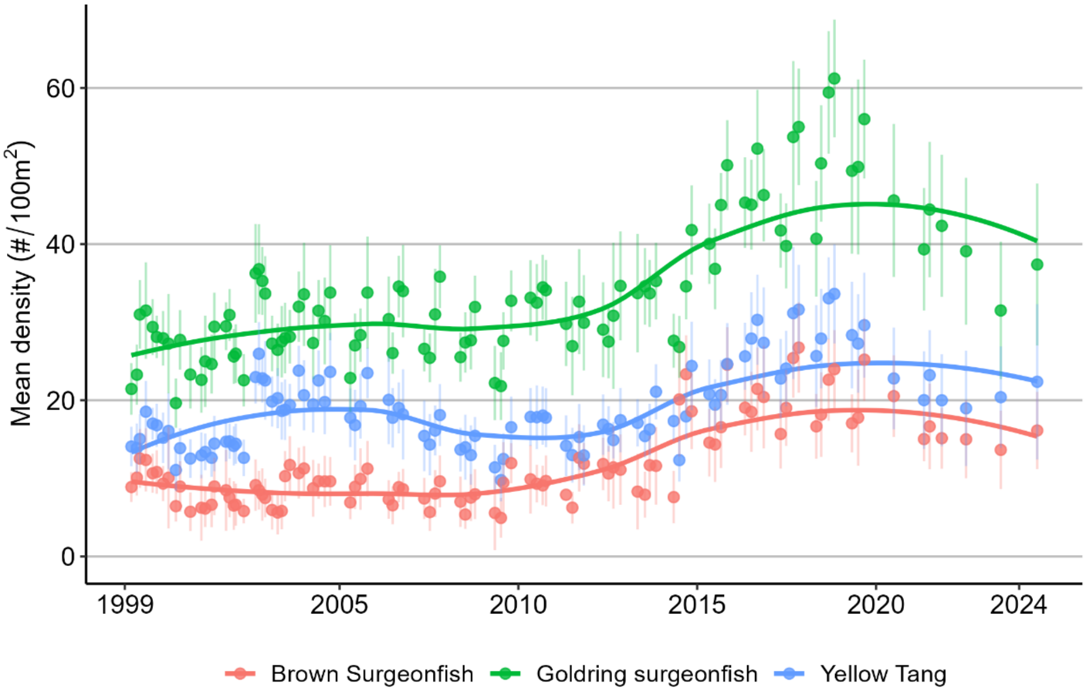

Figure 23. *Mean density of select small surgeonfishes in WHAP surveys. Points represent mean density across 25 WHAP sites for each survey round per species. Error bars represent standard deviation to depict the level of variability between sites. Recruit sized individuals are removed from these data for maʻiʻiʻi (red), kole (green), and lauʻīpala (blue) .*

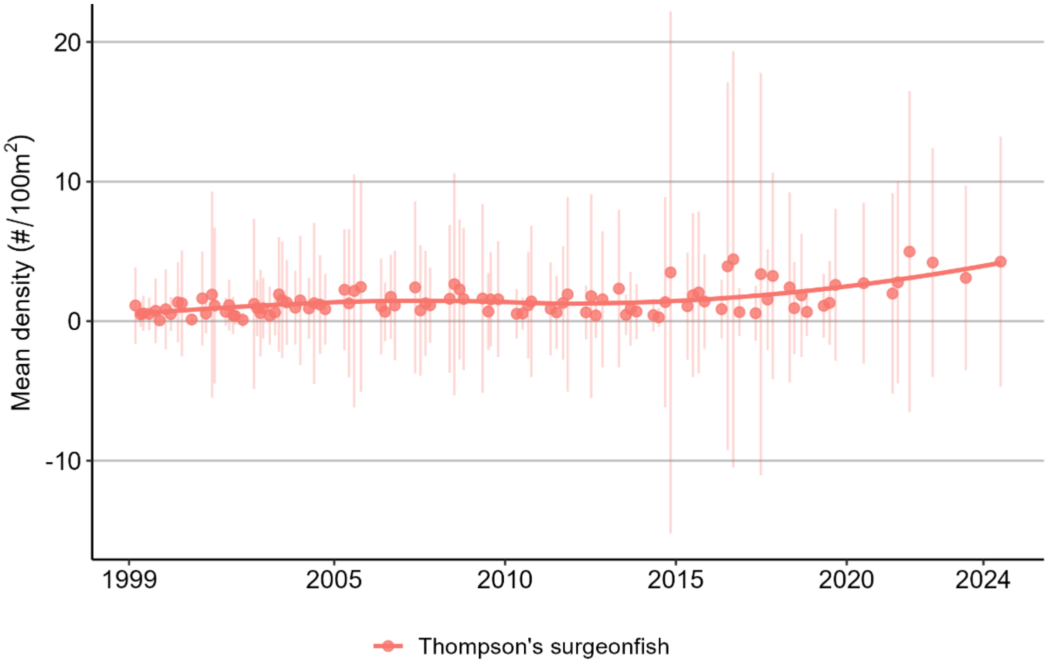

Figure 24. *Mean density of Thompson's surgeonfish observed in WHAP surveys. Points represent mean density across 25 WHAP sites for each survey round per species. Error bars represent standard deviation to depict the level of variability between sites. Recruit sized individuals are removed from these data.*

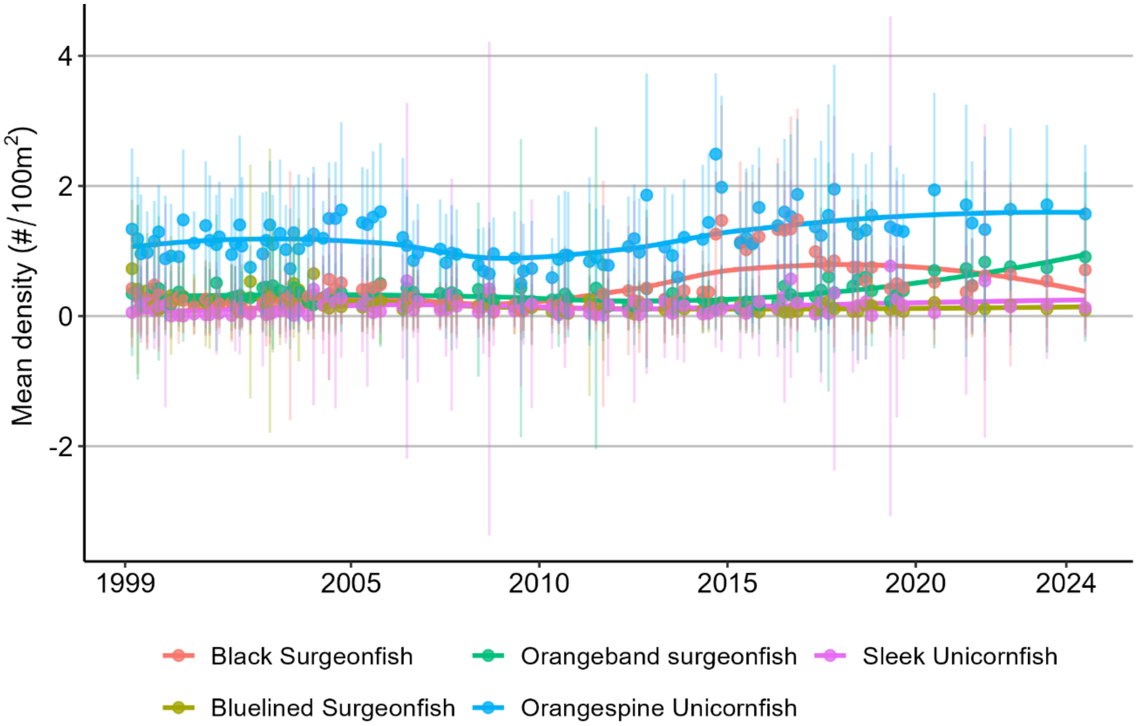

Figure 25*. Mean density of select medium and large-bodied surgeonfishes observed in WHAP surveys Points represent mean density across 25 WHAP sites for each survey round per species. Error bars represent standard deviation to depict the level of variability between sites. Recruit sized individuals are removed from density values. Subgroup and alternative names for these species can be found in Table 9.*

The Shallow-Water Resource Fish (SWRF) survey method is intended to capture the shallow, inshore habitats known to frequently host several species of medium- and large-bodied surgeonfishes often targeted as food resources. Several of these species (māikoiko, ʻapi, pākuʻikuʻi, and manini) were noted to be seen more regularly on SWRF surveys than other methods, however the unique timed survey technique used in the SWRF survey method in addition to the data collection for only select species makes it difficult to directly compare SWRF densities to other area-based survey methods such as FAHU and WHAP (Section 3.2). Eight species of large-bodied surgeonfishes and five species of medium-bodied surgeonfishes have been targeted and recorded through the SWRF survey effort.

Of the medium-bodied surgeonfish subgroup, māikoiko (whitebar surgeonfish) has been recorded at the greatest density compared to other species of the subgroup recorded in SWRF surveys (Figure 26). Manini (Convict tang) has been recorded at the second greatest density in recent years and observed densities have been relatively consistent throughout the course of the monitoring effort (2008-2018). Naʻenaʻe (orangeband surgeonfish) and umauma lei (orangespine unicornfish) are recorded in greatest abundance compared to the other species in the large-bodied surgeonfish subgroup (Figure 27). Naʻenaʻe displayed a consistent density with relatively limited variability across survey years. Several species (māikoiko, ʻapi, pākuʻikuʻi, pualu, and umauma lei) of both the medium and large-bodied subgroups show a decline in observed density over the course of the monitoring period, however the various caveats of the survey method should be considered before the trends of the SWRF data set are considered as representative of the shallow water population for each species (Section 3.2). Additionally, surveys planned for 2025 will be important to determine if these trends are continuing.

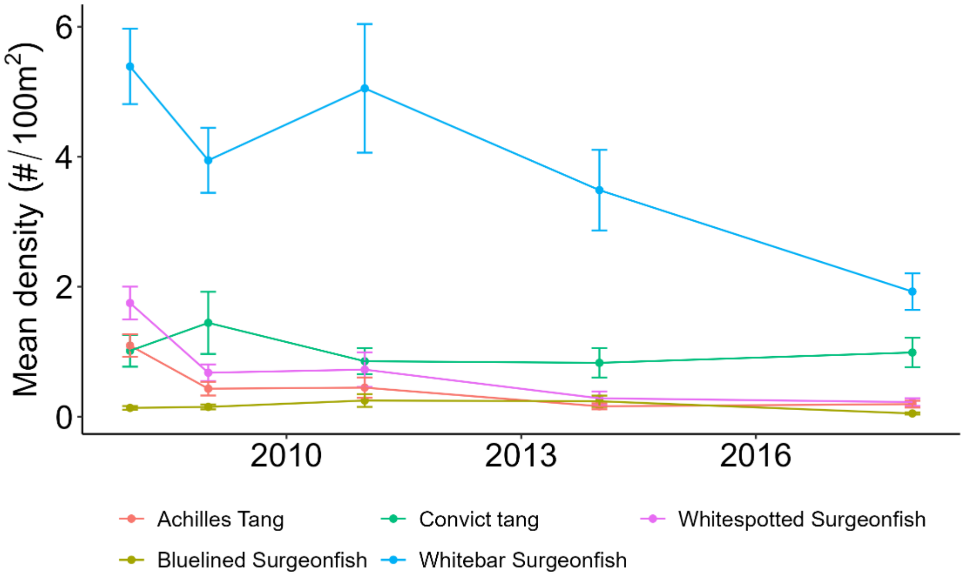

Figure 26*. Mean density of medium-bodied surgeonfishes across SWRF sites for each survey round. Error bars show standard error. Scientific and Hawaiian names for species can be found in Table 9.*

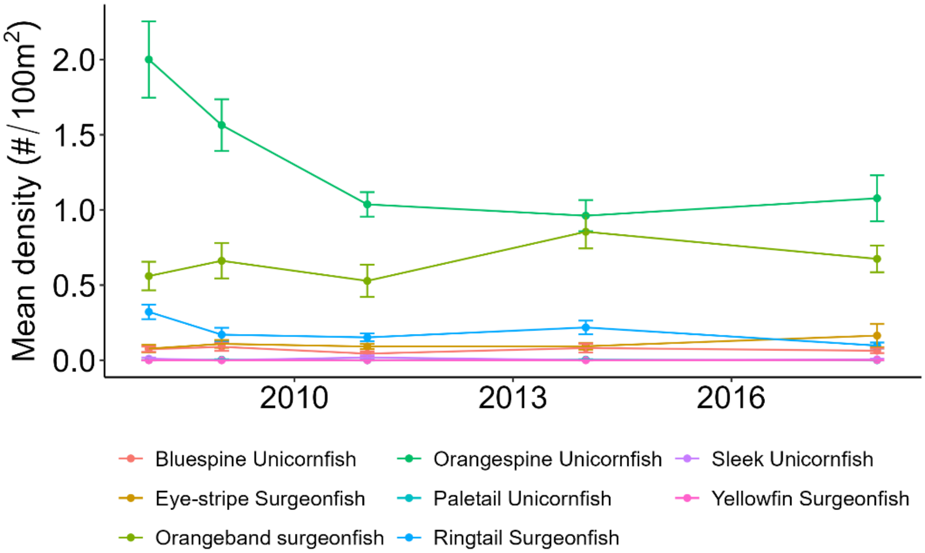

Figure 27*. Mean density of large-bodied surgeonfishes across SWRF sites. Error bars show standard error. Scientific and Hawaiian names for species can be found in Table 9.*

Uhu

Another family of fish that are a popular food resource in West Hawaiʻi are uhu (Parrotfishes) (Table 10). Six different species of uhu (family Scaridae) were observed in FAHU surveys, with two uhu species (bullethead and palenose parrotfish) falling on the FAHU surveys 20 most abundant species list (Figure 20, Figure 28). Uhu were recorded on transect at 61% of the survey sites during the 2022-2023 survey years. Large uhu species are reported to have a large home range (Howard et al., 2013) so it is possible that the 125 m^2 transect scale or the survey method itself does not capture this mobile family well. This low detection rate is not unheard of for large mobile fish species and species that have a reaction to diver presence (Thanopoulou et al., 2018). It has also been documented that different survey techniques accomplish different detection rates, however the detection of large mobile uhu is similar across the techniques that have undergone methods evaluation so long as there are sufficient replicates (Samoilys and Carlos, 2000; Thanopoulou et al., 2018). These caveats to capturing data for the various species of uhu would apply similarly to the FAHU, WHAP, and SWRF survey methods.

***Table 10** 10. Uhu (parrotfish) subgroupings for species commonly observed across West Hawaiʻi monitoring surveys. Common, scientific, and Hawaiian names are listed to aid with clarification of species throughout the section.*

Subgroup	***Common***	***Scientific***	***Hawaiian***
Large	Spectacled parrotfish	*Chlorurus perspicillatus*	uhu ʻahuʻula, uhu uliuli
	Redlip Parrotfish	*Scarus rubroviolaceus*	uhu pālukaluka, uhu ʻeleʻele
Small	Stareye parrotfish	*Calotomus carolinus*	uhu pōnuhunuhu
	Bullethead parrotfish	*Chlorurus spilurus*	uhu
	Regal Parrotfish	*Scarus dubius*	uhu lauia
	Palenose Parrotfish	*Scarus psittacus*	uhu

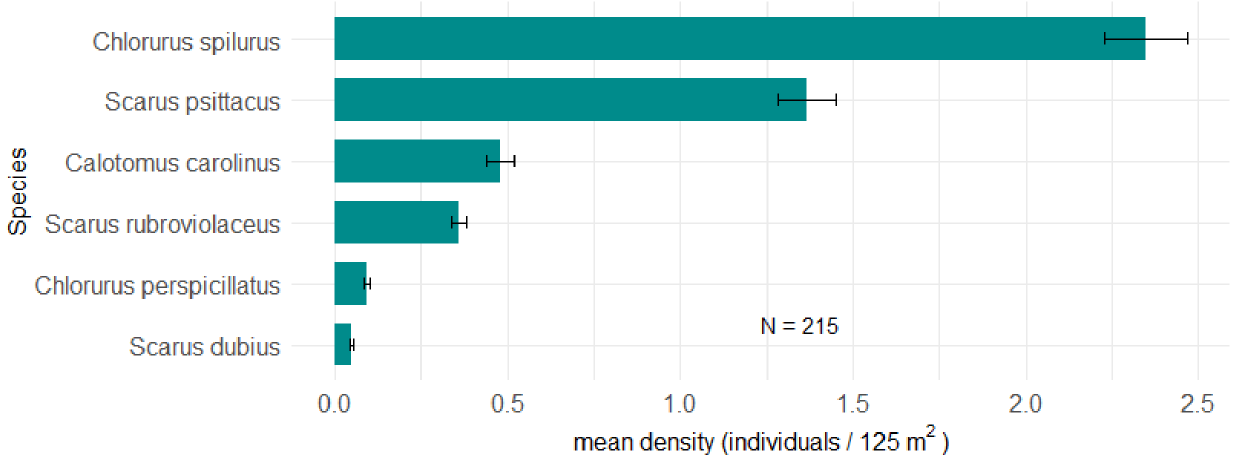

***Figure 28**. Mean uhu (parrotfish) abundance across FAHU surveys. Means are weighted based on FAHU stratum and error bars represent weighted standard error. Subgroups and common and Hawaiian names for uhu species can be found in Table 10.*

A total of 753 individuals of the small-bodied uhu species subgroup and only 105 individuals of the large-bodied uhu species subgroup were observed across the 215 FAHU surveys conducted in 2022-2023. The individual size information collected from these surveys presents an interesting distribution of size frequency for the large-bodied subgroup; there was a high frequency of the smallest sized individuals relative to larger size classes (Figure 29). This may be a function of either the small sample size or the method's likelihood to detect individuals of the large subgroup at different life stages. It's also possible that juvenile uhu are seen in greater abundance than the adults across these surveys due to a high mortality rate that can be expected between life stages of recently recruited individuals and adults (Hixon, 1991). Additionally, there is only one species (uhu pālukaluka, *Scarus rubroviolaceus*) of the large-bodied parrotfish subgroup that is regularly observed in West Hawaiʻi surveys, meaning the low number of observations for this subgroup could be a function of low density and/or its representation by a single species.

The most frequently observed size class for the small-bodied uhu subgroup is around 15-18cm (6-7 inches, Figure 29). Subadults of the small-bodied uhu species, bullethead and palenose parrotfish, are often seen transiting and scavenging in schools of 15-30 individuals throughout the survey region (A. Wills, personal observation). Overall, the FAHU survey method appears to capture the small-bodied subgroup of uhu well and suggests that bullethead and palenose parrotfishes are the mostly commonly occuring uhu species across West Hawaiʻi.

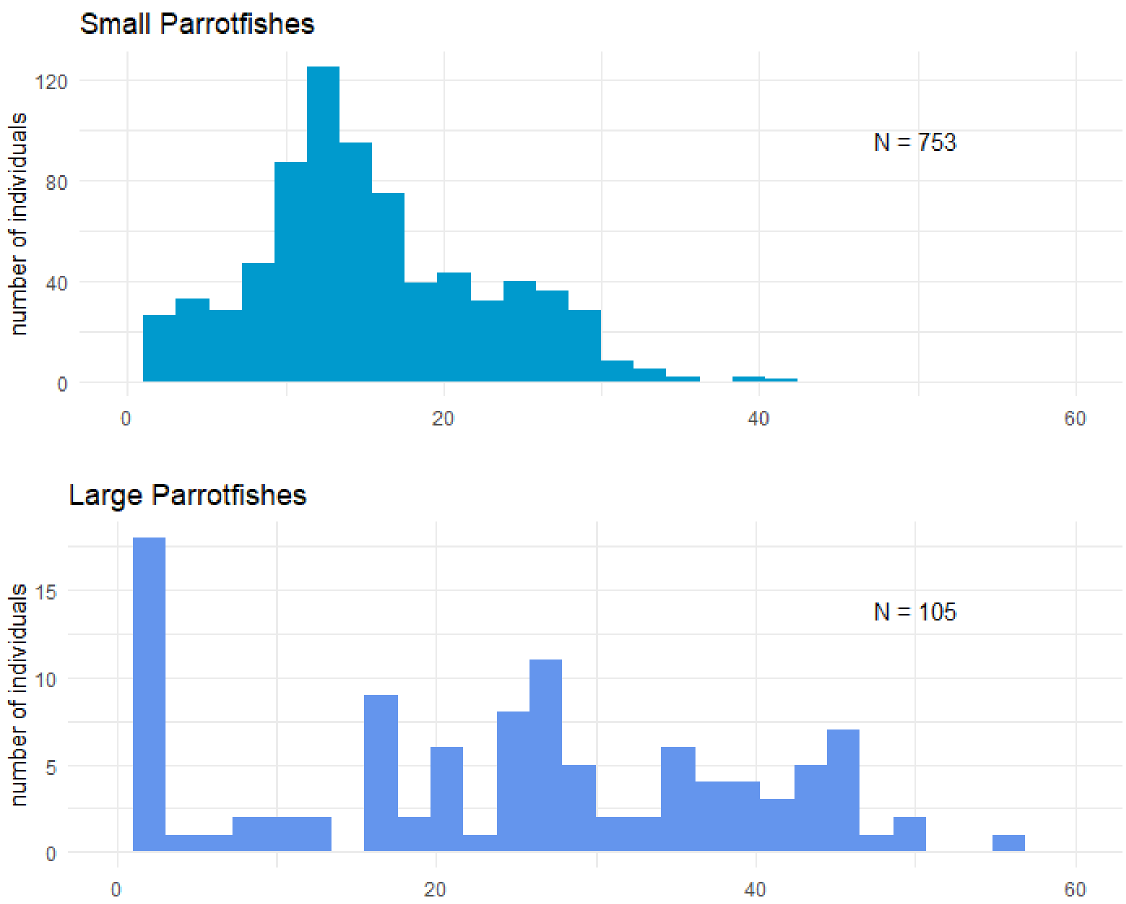

Figure 29. *Size distribution of parrotfish subgroups observed during FAHU surveys. Total number of individuals (N) belonging to the subgroup recorded during the 2022-2023 survey round.*

Bullethead parrotfish are also recorded in greater densities than the other small-bodied uhu species across WHAP surveys, however there are substantial levels of variability across sites (Figure 30). The all-site mean density has remained stable over the course of the survey period with high variability occurring across sites within a survey round. Of the large-bodied subgroup, only the redlip parrotfish (uhu pālukaluka/uhu ʻeleʻele) is observed regularly on WHAP surveys (Figure 31). Considering the low rates of observation for the remaining parrotfish species across numerous sites and rounds, this survey does not provide sufficient data to adequately describe additional species-specific trends.

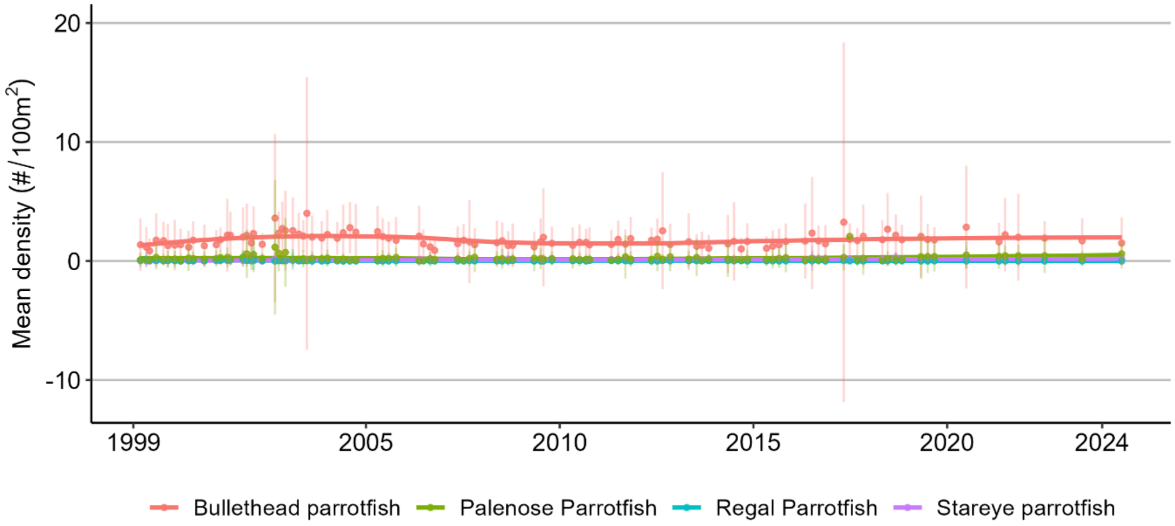

Figure 30. *Mean density of small-bodied uhu across WHAP survey sites. Points represent mean density across 25 WHAP sites for each survey round per species. Error bars represent standard deviation to depict the level of variability between sites. Recruit sized individuals are removed from density values. Subgroup and alternative names for these species can be found in Table 10.*

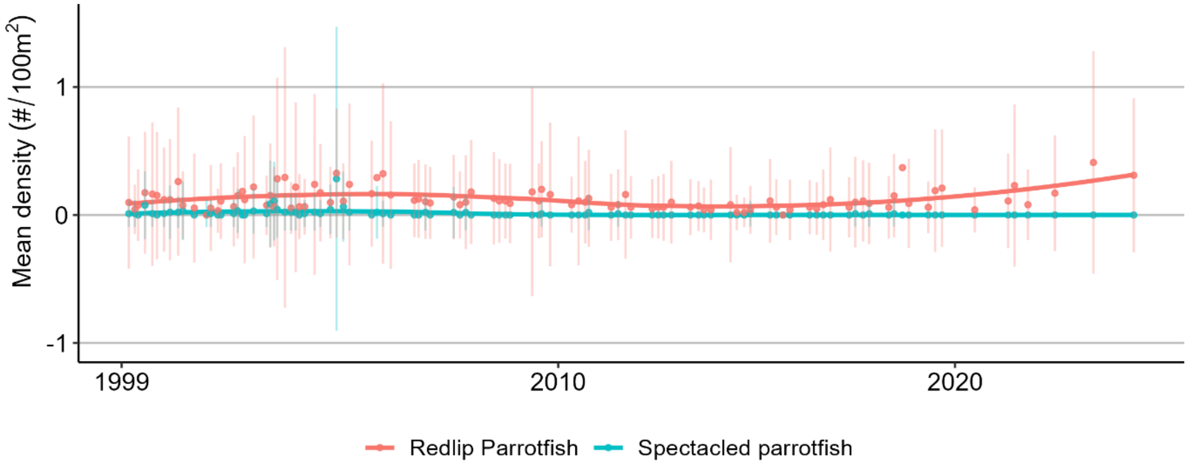

Figure 31. *Mean density of large-bodied uhu across WHAP survey sites. Points represent mean density across 25 WHAP sites for each survey round per species. Error bars represent standard deviation to depict the level of variability between sites. Recruit sized individuals are removed from density values. Subgroup and alternative names for these species can be found in Table 10.*

The uhu density in the SWRF survey dataset echoes the trend of the bullethead and palenose parrotfishes being recorded in greater density than other species of the small-bodied uhu subgroup (Figure 32). The density recorded across the SWRF survey period for these two species appears to be stable between the first and last year of the survey effort with some fluctuation during the survey years in-between. Other species of the small-bodied subgroup were observed at near zero densities throughout the SWRF surveys, suggesting they are uncommon within the observed habitats. One of these species, the stareye parrotfish (pōnuhunuhu) was captured well on FAHU surveys in 2022-2023 (Figure 28). Given the substantial differences in habitat types covered by these two surveys, a likely explanation for this discrepancy is that the SWRF surveys do not encompass the entirety of the preferred habitat of this species and that they are present rather infrequently in these shallow habitats compared to deeper portions of the reef. Additional SWRF surveys planned for 2025 as well as a more detailed examination of habitat use trends in the FAHU dataset may shed additional light for this species.

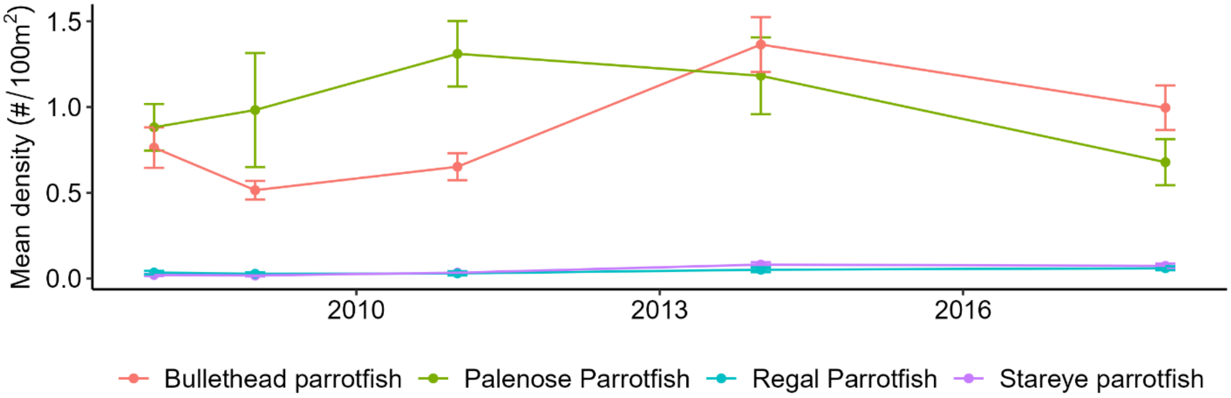

Figure 32. *Density of species of the small-bodied uhu subgroup in SWRF surveys. Density is represented by the mean of all survey transects within a round. Error bars represent standard error.*

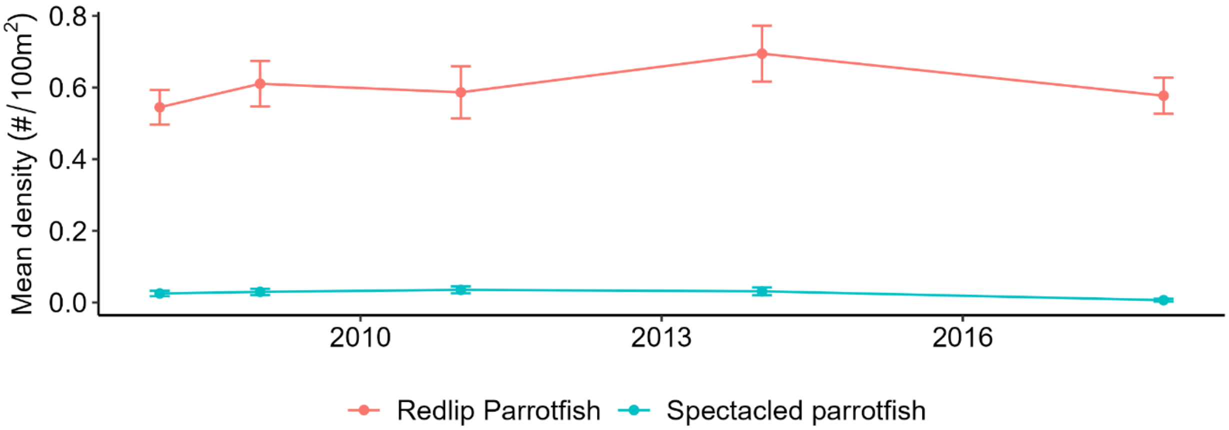

Figure 33. *Density of species of the large-bodied uhu subgroup in SWRF surveys. Density is represented by the mean of all survey transects within a round. Error bars represent standard error.*

Likewise, the Spectacled parrotfish (uhu uliuli) of the large-bodied subgroup is also captured at near zero densities (Figure 33). This species shows up very infrequently throughout the DAR Kona monitoring datasets and is considered a rare species in West Hawaiʻi. Several juvenile and one adult individual of the species was recorded during the 2022 round of FAHU surveys, but the lack of records make it difficult to say anything definitive about the species other than reaffirm the notion that it is rare (Figure 28). The redlip parrotfish shows up in stable and low density across SWRF survey rounds, similar to WHAP survey data, suggesting that individuals of the species occupy the shallow water habitat but in low abundance or are not well captured through the survey method (Figure 33). Again, the caveats of these underwater survey methods should be considered prior to concluding any population trends for these mobile species of interest (See Chapter 3).

4.3 Commercial Aquarium Fishery

4.3.1 Background and Current Status

As noted in Chapter 1, the history of the commercial aquarium trade in Hawaiʻi is long, complex, and highly contentious. Much of this background information is covered in previous reports and publications (DAR, 2000, 2019, 2024a; Walsh et al., 2004). DAR (2024a) provides the most recent accounting, covering many of the major changes in this fishery over the past several decades including the expansion of the fishery in West Hawaiʻi, shifts in demand and consumer preference, and the trends in effort and catch.

The fishery is currently closed following a decision by the Hawaiʻi State Supreme Court on September 6, 2017. The ruling held that commercial aquarium collection using fine mesh nets or traps pursuant to the statewide aquarium permits issued under Hawaii Revised Statutes (HRS) §188-31 are subject to environmental review as described by the Hawaiʻi Environmental Policy Act (HEPA; HRS §343). This was further clarified by the Circuit Court noting on October 27, 2017 that all existing statewide permits are illegal and invalid and that no new permits may be issued until the environmental review process is complete. Since all aquarium collection in West Hawaiʻi requires a statewide aquarium permit, the West Hawaiʻi fishery has been completely closed regardless of the gear type used.

In the years following these rulings, representatives of the aquarium trade have submitted an Environmental Assessment and two iterations of an Environmental Impact Statement (EIS) to the Department. The final revised EIS was deemed accepted by the Board of Land and Natural Resources on July 8, 2021. The Circuit Court injunction prohibiting issuance of permits was then lifted on January 30, 2023 with the court indicating that the environmental review process had been satisfied for the West Hawaiʻi fishery. Although the injunction was lifted, the fishery has not resumed as DLNR has not issued any permits (statewide or for West Hawaiʻi). This process is currently ongoing and evolving with multiple Board of Land and Natural Resources meetings devoted to this topic throughout 2023 and 2024.

4.3.2 Description of the Fishery

The number of reporting aquarium licenses for the West Hawaiʻi fishery has ranged between approximately 10 to 50 since the mid-1970s (Figure 34). While certain time periods (e.g. pre-1986 and the late 1990s) seem to indicate steep declines in fishery participation, it's unclear if these are true trends or an artifact of inaccurate reporting and incomplete recordkeeping prior to 2000 (DAR, 2024a). Reported catch followed a generally increasing trend, from 50,000 fish in the 1970s and early 1980s to a peak of nearly 450,000 fish in 2005. Since 2005, reported catch has ranged between approximately 250,000 and 400,000 fish (Figure 34). Much of this expansion appears to be driven by increased demand for and take of surgeonfishes. Lauʻīpala made up the majority of this trend, however, take of kole also increased during this period (Figure 35).

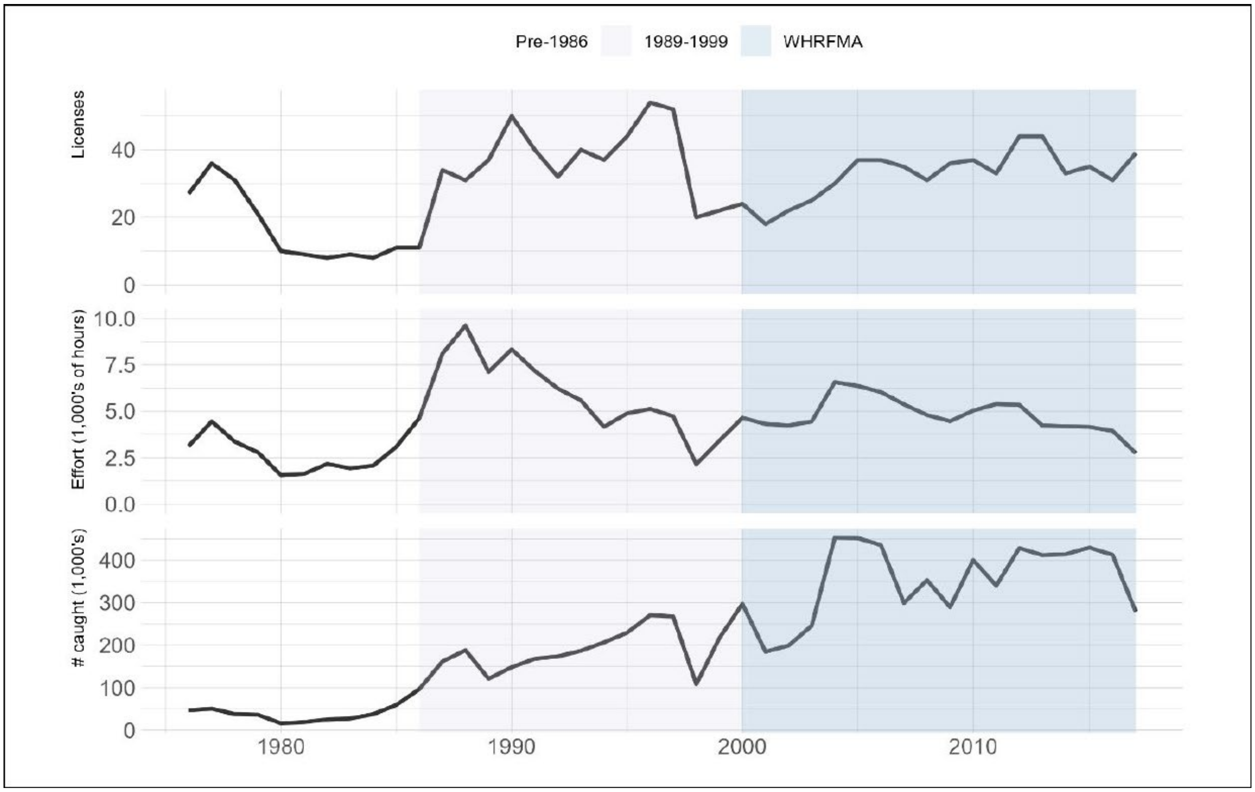

__Figure 34.__ Trends in reporting for the West Hawaiʻi commercial aquarium fishery. Licenses (top), effort (middle), and total reported catch (bottom) Shaded regions reflect three phases of fisheries development. Figure taken from DAR (2024).

The species composition of the reported catch has been largely consolidated to a small number of key species since the 1980s (DAR, 2024a). Between 1999 and 2017, five species have comprised 95% of the overall catch on average. Throughout this time, lauʻīpala has been the primary species targeted, accounting for approximately 81% of the overall catch. Kole had the next highest catch totaling about 9% of total catch. Pākuʻikuʻi, umauma lei, and black surgeonfish have made up the remainder of the top five with 2.2%, 1.8%, and 1.1% of the catch, respectively (Appendix Table B-1).

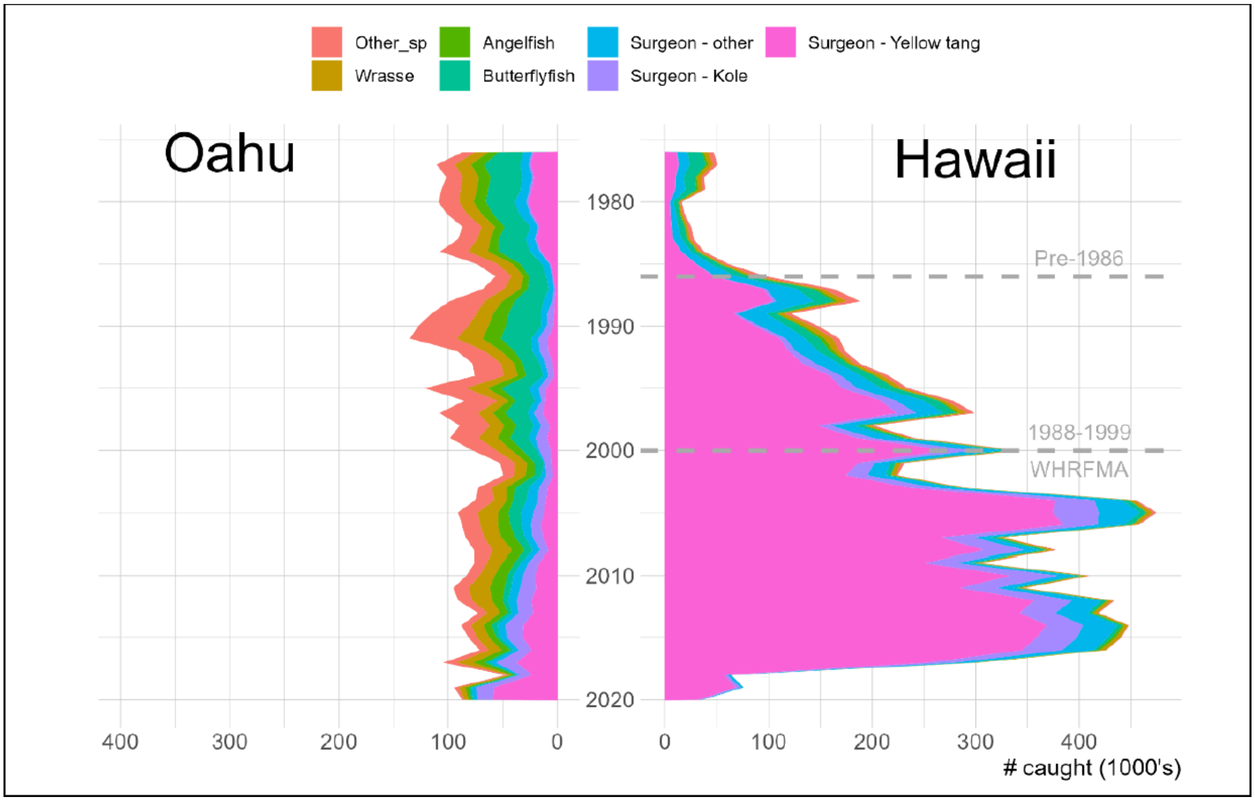

Figure 35. Total catch and composition of main aquarium fish species and/or families for O'ahu and Hawai'i Island. The three phases of the West Hawai'i Aquarium fishery development are highlighted. Note: results reflect catch for all of Hawai'i Island. Figure taken from DAR (2024a).

Several other species made up moderately higher proportions of the reported catch in the early years of the WHRFMA. Three species of butterflyfish (Family *Chaetodontidae*): Forcepsfish, Multiband butterflyfish, and Fourspot butterflyfish collectively made up around 2% of total catch from 1999-2002 but dropped to nearly 0.5% in later years. Moorish idol catch was above one thousand fish per year in 1999, 2000, and 2008 but has otherwise been relatively low. Despite reported catch of over two thousand fish in 1999, Potter's angelfish catch has been relatively low throughout the history of the WHRFMA until later years when it became the 6th most highly caught species (Appendix Table B-1).

The spatial distribution of catch has also shifted somewhat throughout the history of the West Hawai'i aquarium fishery. Most of the reported catch before 2000 occurred in grid 101 which extends from Keāhole Point to Miloli'i (DAR, 2024a and Figures 36 & 37). Following the establishment of the FRA network, commercial aquarium fishing effort declined in this grid and increased in grids 102 and 100. When the fishery closed in 2017, a total of 42% of the WHRFMA shallower than 30 meters was closed to aquarium collection (Figure 38). Although it is currently moot given the inactive status of the fishery, a total of 46% of the WHRFMA shallower than 30 meters has rules prohibiting collection for aquarium purposes (Figure 39).

Figure 36*. Reporting grid areas for the West Hawaiʻi commercial aquarium fishery. Figure taken from DAR (2024a).*

***Figure 37**. Spatial and temporal trends in West Hawaiʻi aquarium fishery catch. Proportion of catch in each catch area during each phase of the West Hawaiʻi aquarium fishery (left) and trends in reporting licenses (right-top), effort (right-middle), and total reported catch (right-bottom) for each area. Confidential data (less than three reporting licenses) were removed from trends. Catch areas are arranged North-South (103-100). The vertical dashed lines indicate the establishment of the Fish Replenishment Area (FRA) network. Figure taken from DAR (2024a).*

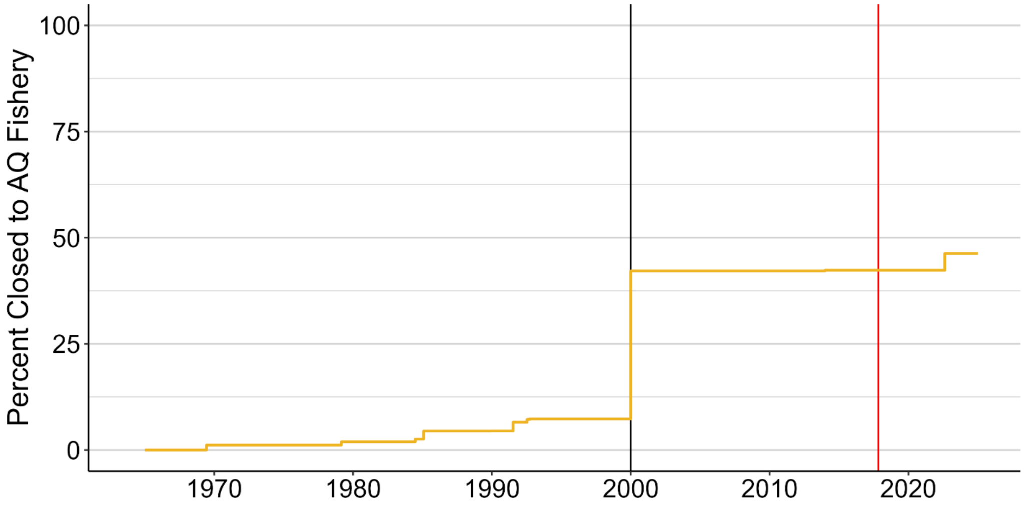

***Figure 38**. Change in percent area of the WHRFMA closed to the aquarium fishery shallower than 30 meters, from 1969-present. The vertical black line indicates the establishment of the FRA network, and the vertical red line indicates the closure of the fishery in 2017.*

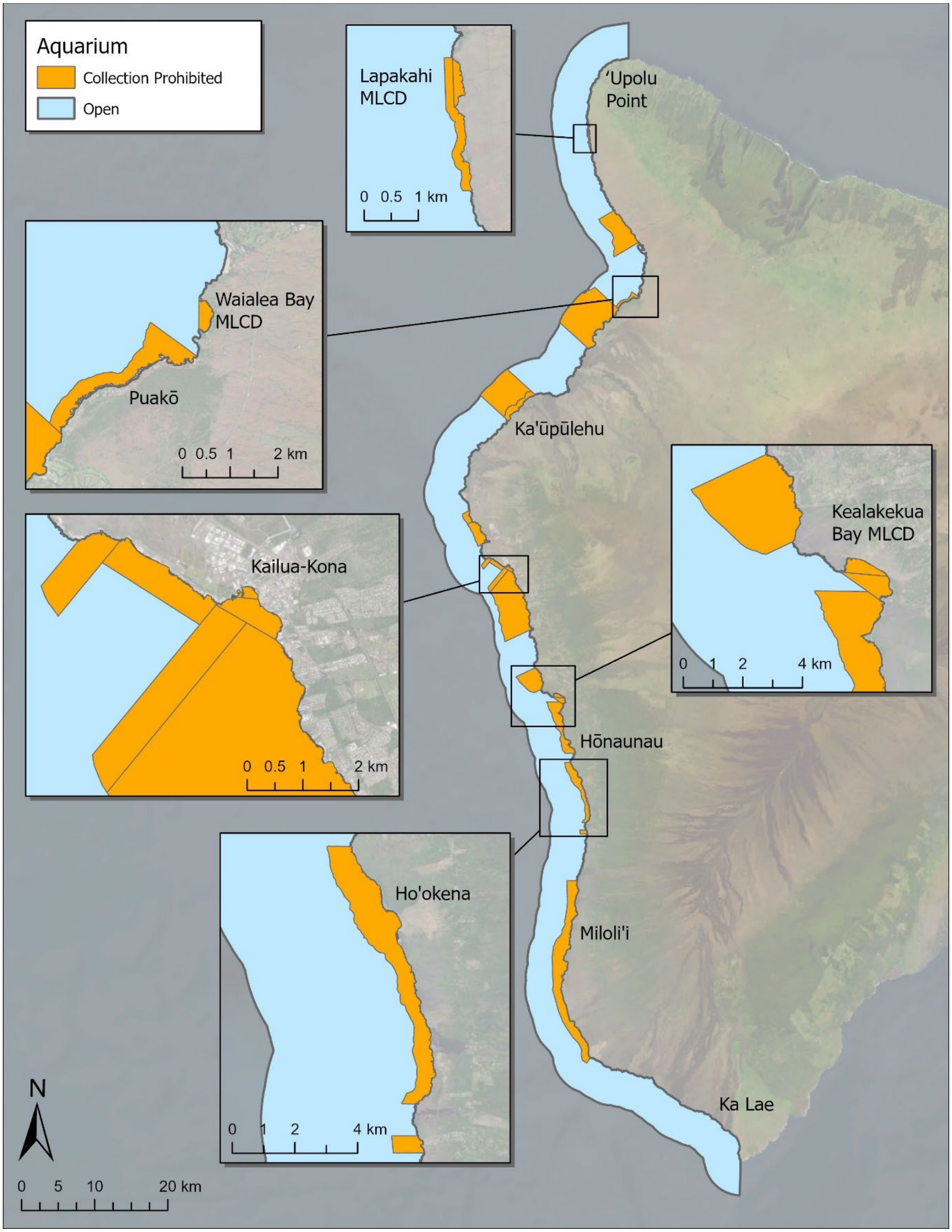

Figure 39. *Map of areas where aquarium collection is prohibited in West Hawaiʻi. Areas include Marine Life Conservation Districts, Fisheries Management Areas, Fish Replenishment Areas, the Kaʻūpūlehu Marine Reserve, and the Miloliʻi Community Based Subsistence Fishing Area.*

4.3.3 Evaluation of the FRA Network

Act 306 outlined two specific goals with regards to the establishment of the FRA network: protection from localized depletion of targeted species due to aquarium collection and the amelioration of user conflicts. The WHAP survey methodology was primarily designed to assess the first goal.

Trends in WHAP data

Although lauʻīpala make up the vast majority of take within the West Hawaiʻi aquarium fishery, it is important to examine the efficacy of the FRA network across a range of species. The species targeted by the fishery (Table B-1) span multiple taxonomic families, life histories, and ecological niches and therefore may respond differently to fishery regulations. Trends in eight species targeted by the aquarium fishery were recently examined in order to assess any broad differences in density between areas open and closed to the commercial aquarium fishery (DAR, 2024b). The eight species included in that work (lauʻīpala, kole, umauma lei, black surgeonfish, potter's angelfish, māʻiʻiʻi, bird wrasse, and Thompson's surgeonfish) were those that have been proposed for inclusion in a "revised white list" by aquarium collectors if the fishery were to reopen. The analysis focused on recruit sized individuals (those that were 5 cm or smaller) to evaluate the input of new fish at WHAP sites as well as juveniles (individuals 5-15 cm) given that they are the primary target size range for the fishery and therefore likely experienced the greatest level of take within the broader population.

This analysis indicated that for those species whose recruits are commonly observed during WHAP surveys, mean annual recruit densities were generally either stable or increasing across WHAP sites (Figure 40). Recruit trends for umauma lei, bird wrasse, and Thompson's surgeonfish were uninformative as recruit densities were generally low for these species on WHAP surveys. It is unclear the extent to which these species exhibit truly low recruitment rates or if the low observed recruit densities are due to other factors including the specific habitat preferences or detectability of these species during their early life history (DAR, 2024b).

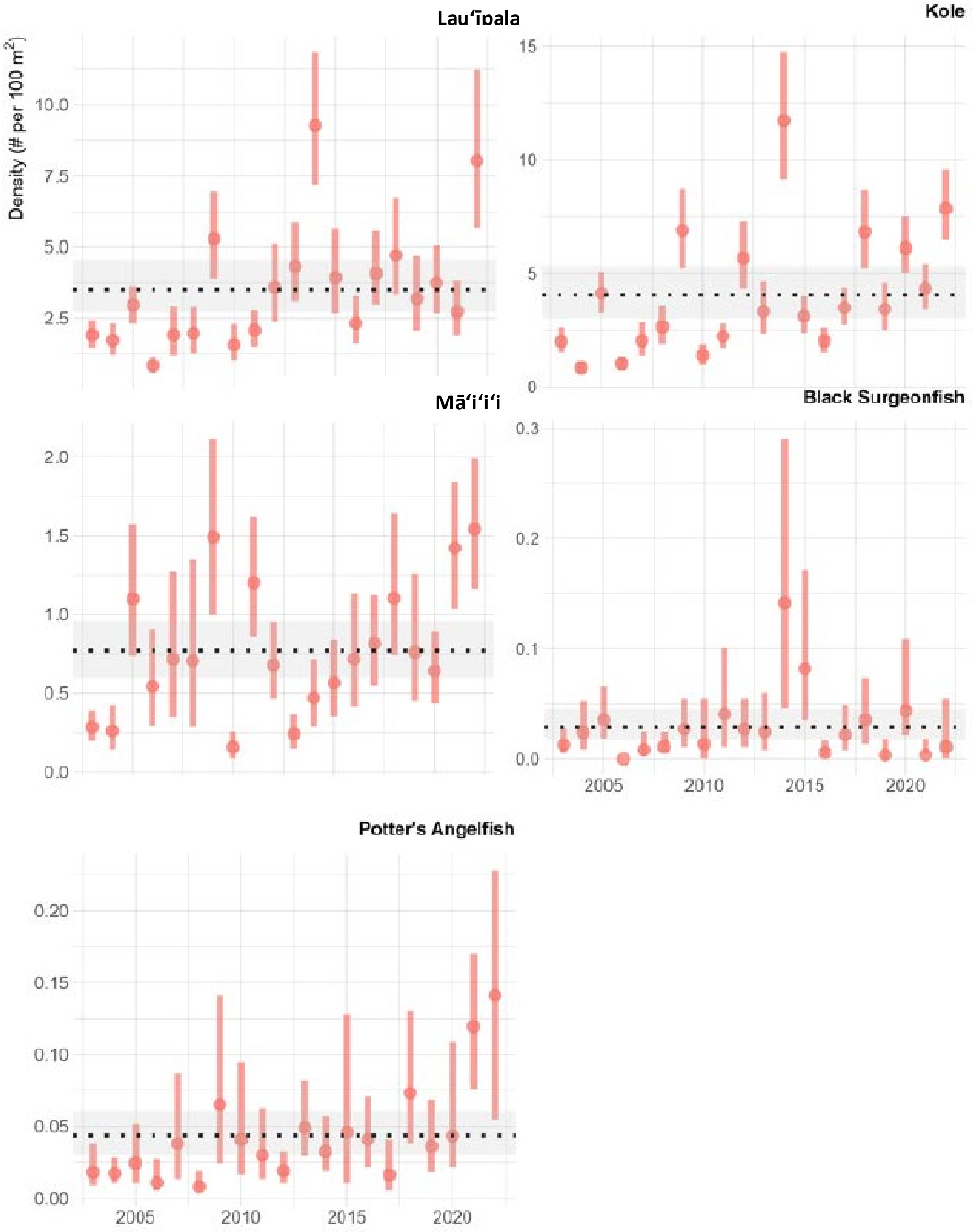

***Figure 40**. Mean annual recruit density within the WHRFMA in the 0-30 m depth range, West Hawai‘i Aquarium Project (WHAP) data 2003-2022. Note* vertical bars denote 90th percent confidence interval, dotted line denotes total mean with grey shading denoting its 90th percent confidence interval. Figure adapted from DAR (2024b).*

Patterns between juvenile densities and management type varied somewhat between species with marginally lower mean densities of lauʻīpala and kole in open areas relative to those closed to fishing and similar or higher mean densities of the other six species in open areas relative to one or both types of closed areas (Figure 41). Despite the lower mean densities of lauʻīpala and kole in sites open to aquarium collection, there was a high level of variability across sites with considerable overlap between management types. The general patterns of the juvenile density trends for each species were broadly similar across management types indicating that juvenile density is likely driven by more than fishing effects alone.

Trends in each species were also examined both for site-level changes in density from 1999-2024 as well as for apparent differences between sites closed to collection and their adjacent control site open to fishing. Consistently higher densities at sites closed to fishing may indicate that closed areas are providing a protective effect on target species populations. Additionally, consistent trends across WHAP sites may be indicative of larger-scale trends in these species, though to reiterate, WHAP data should not be used as a full assessment of population-scale trends across the WHRFMA.

A time series of lauʻīpala density (Figure 42) depicts a high level of variability between sites, with little consistency across sites within a given management type. It has been previously reported that lauʻīpala populations increased considerably across West Hawaiʻi since the inception of the WHRFMA (DAR, 2019). It appears, however, that this was driven primarily by a few sites that showed large increases in observed lauʻīpala densities. FRA sites within the Kaloko-Honokōhau and Hoʻokena clusters both saw substantial increases in observed densities since 2015, however other FRA sites showed either marginal or no increases in density. Manukā, the open site in the Miloliʻi cluster, also showed a somewhat striking increase in density even surpassing the densities seen in the adjacent FRA in recent years. All sites within the Puakō-ʻAnaehoʻomalu cluster have shown declines in lauʻīpala density with recent counts approaching zero.

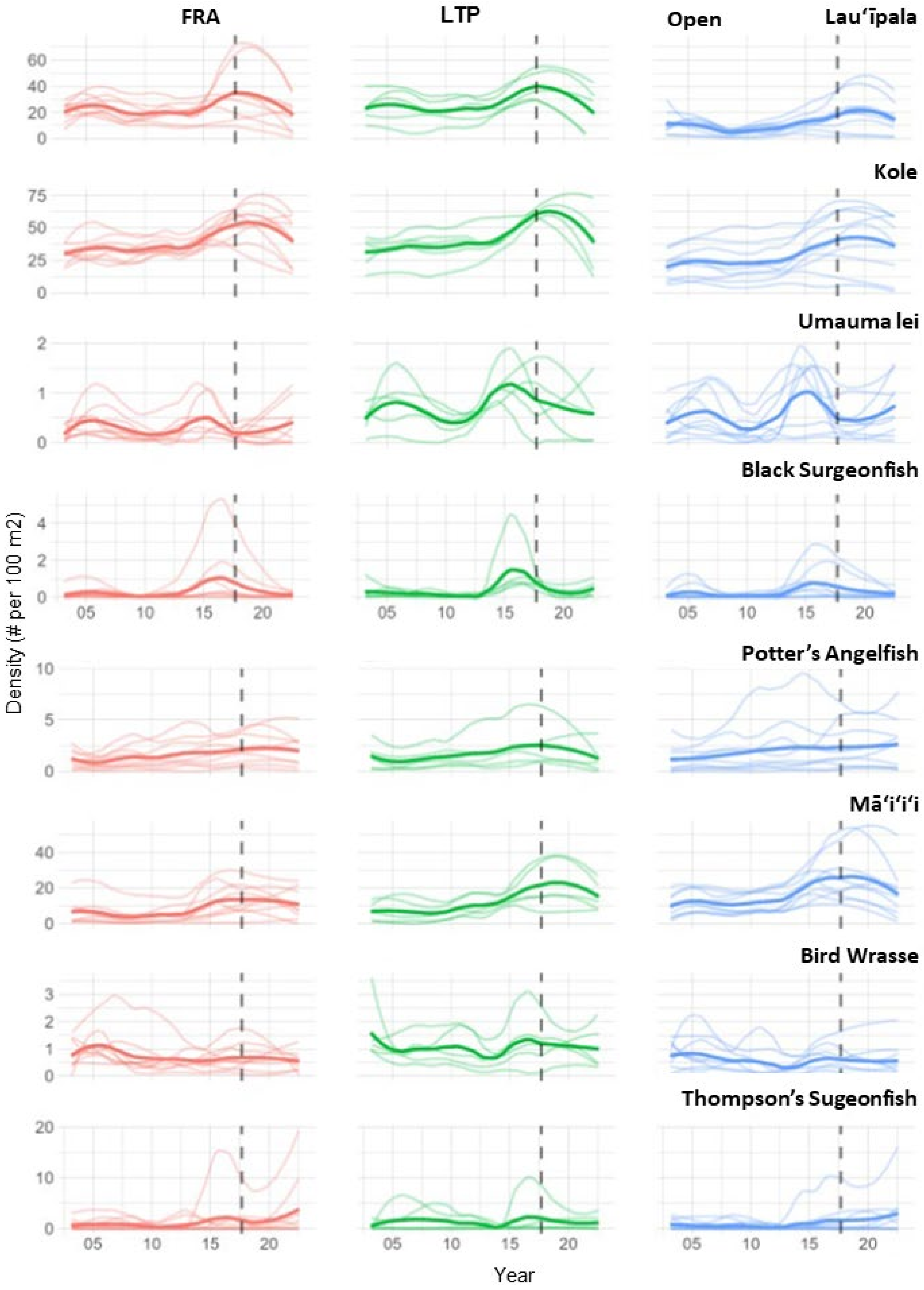

__Figure 41__. Annual mean density by management area (bold lines) and annual site-specific mean density (light lines) in the WHRFMA, WHAP data 2003-2022. Note vertical dashed line represents the closure of the fishery in 2017. Figure taken from DAR (2024b).*

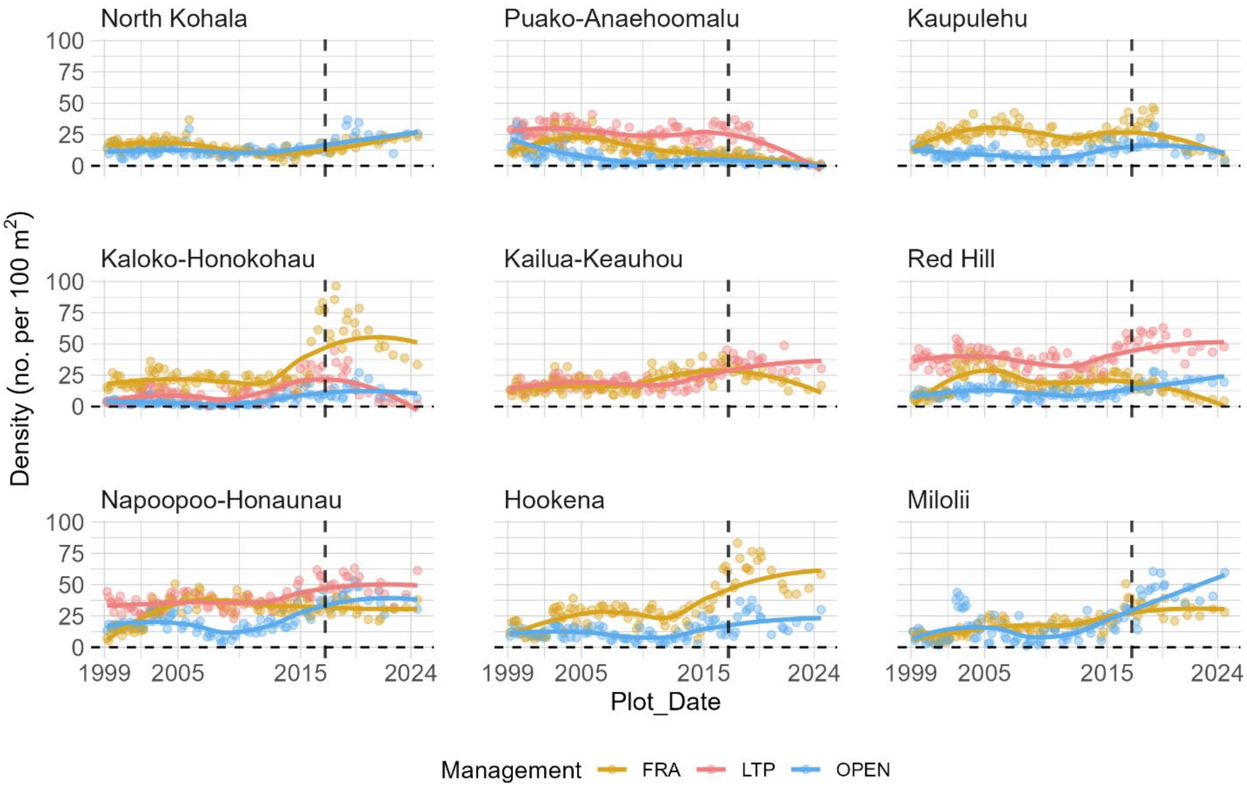

***Figure 42**. Time series of lauʻīpala (yellow tang) density across 23 permanent WHAP sites from 1999-2024. Sites are arrayed by FRA clusters as denoted in Table 3.*

Similar levels of variability are apparent when examining trends in the differences between sites closed to aquarium collection to those open to fishing (Figure 43). Trends in certain site clusters show separation from the zero line indicating potentially different trends between closed and open areas, particularly within the FRA-Open differences in the Kaloko-Honokōhau and Hoʻokena clusters. Other sites including Kaʻūpūlehu and Keʻei (the FRA in the Napoʻopoʻo-Hōnaunau cluster) showed slight departures from zero, though the timing differed from Kaloko-Honokōhau and Hoʻokena. It should be noted that these trend plots do not give any indication of statistical error and as such, we cannot say with certainty whether any divergence from zero is statistically significant. That said, differences between site clusters in the timing, magnitude, and direction of these divergences suggest that multiple mechanisms may be at play beyond any directly related to the commercial aquarium fishery.

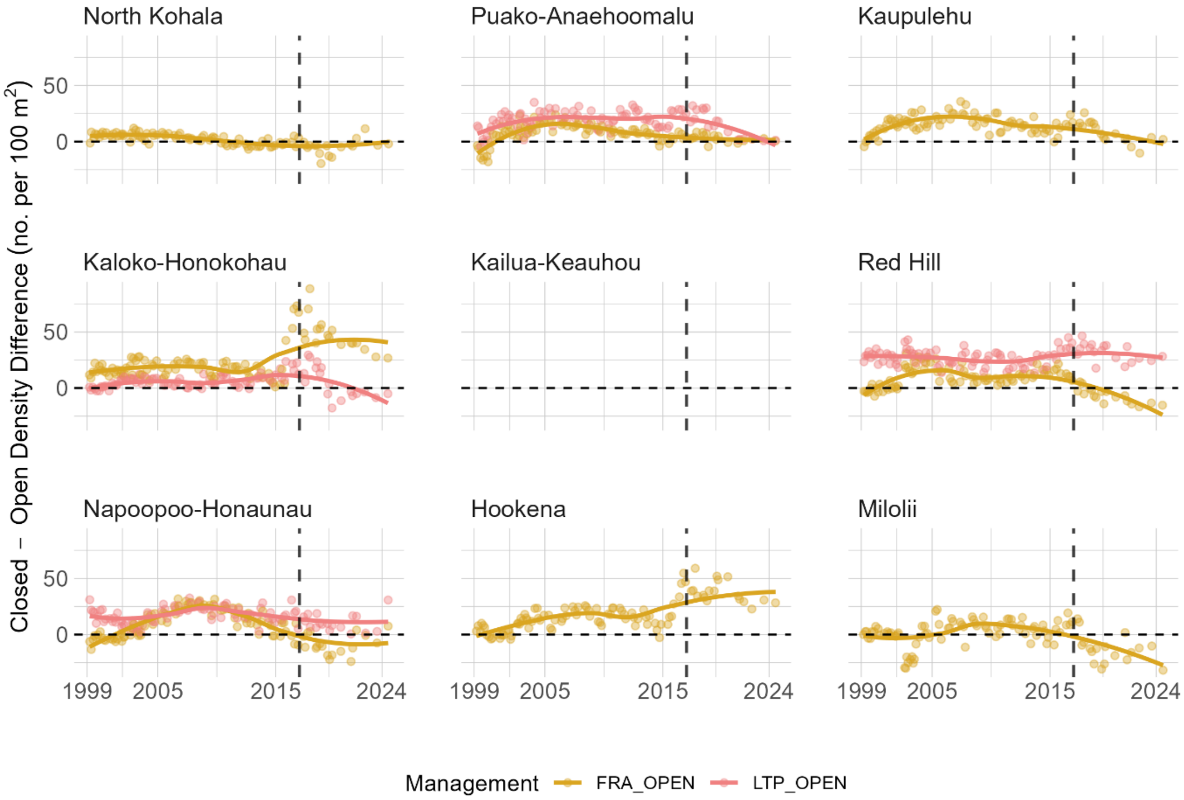

Figure 43*. Time series of the differences in Closed and Open site lauʻīpala densities as a measure of FRA effectiveness. Gold data points and trend lines depict the difference in fish density between the FRA (closed) site and Open site within an FRA cluster. Red points and lines depict the difference in fish density between the LTP (closed) site and Open site within each cluster. Note: no Open site located within Kailua-Keauhou cluster for comparison.*

As noted in Section 3.1.3, it is important to examine these trends alongside any potential changes in coral reef habitat at the WHAP sites. Figure 44 shows trends in live coral cover at the WHAP sites across a period of twenty years. Most sites showed drastic declines in coral cover following the 2015 bleaching event. Several sites, particularly those at the northern end of the WHRFMA, have showed consistent declines that began prior to the bleaching event. Coral cover at the two North Kohala sites have largely tracked each other whereas the trends at the Puakō-ʻAnaehoʻomalu sites are somewhat different from each other. Puakō, the LTP site in the cluster, had a steeper decline in coral cover than the other two sites and has continued to decline in subsequent years. This decline is readily visible when visiting the site since much of the dead carbonate structure has now degraded leaving a distinct lack of structured, complex reef habitat (C. Teague personal observation). It is reasonable to conclude that this large change in coral habitat is an important driver of the low lauʻīpala observations at that site in recent years.

Benthic trends in the Hoʻokena cluster illustrate the difficulty in assigning fishery effects to the observed trends in the lauʻīpala data. This species increased in observed density at the FRA site at a higher rate than the open site (Figures 42 & 43). Around the same time, coral cover increased at the FRA site while declining in the open site since 2015 (Figure 44). Presently, we cannot say with certainty the extent to which the difference in lauʻīpala density between the two sites is due to fishing effects rather than differing trends in coral cover or other factors extrinsic to the commercial aquarium fishery.

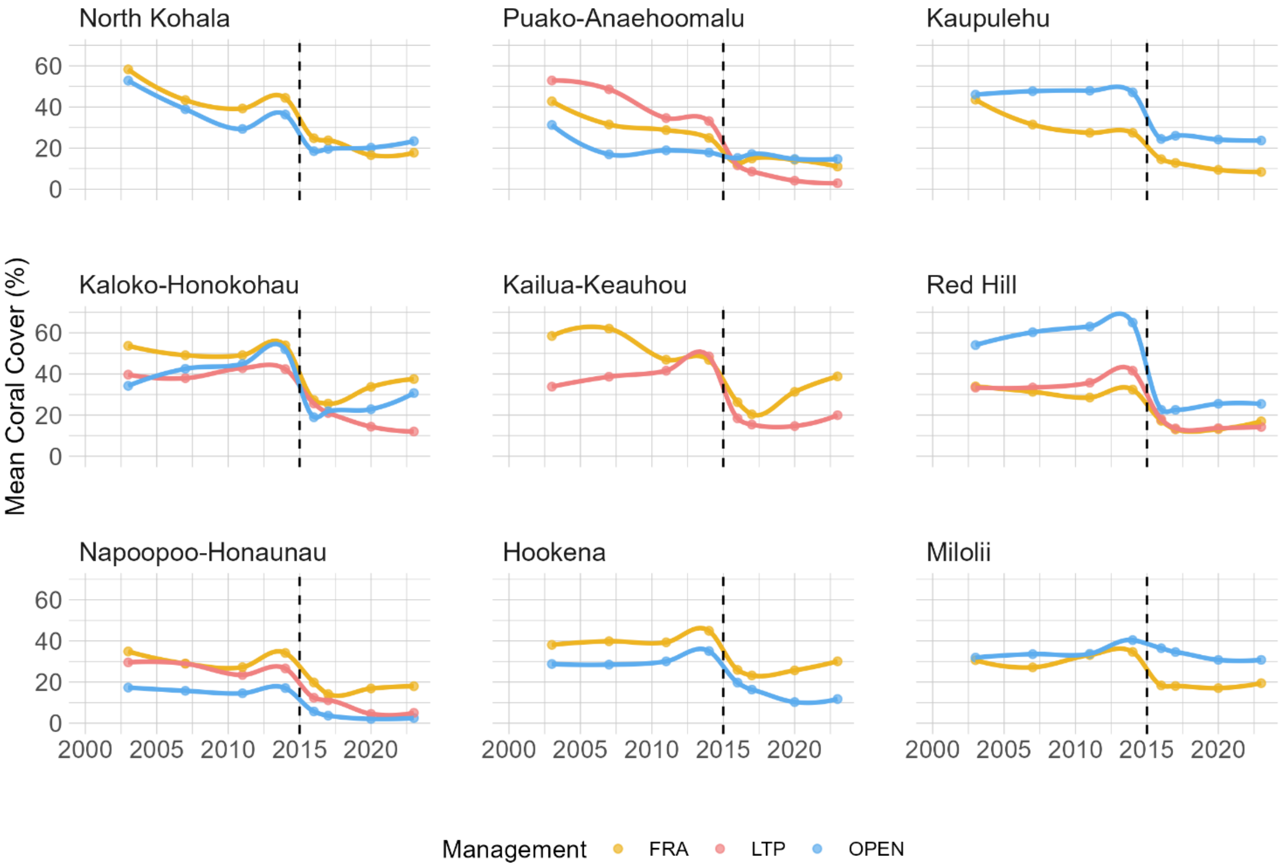

__Figure 44__. Trends in mean coral cover at WHAP sites from benthic surveys conducted between 2003-2023. The vertical dashed line denotes the 2015 mass coral bleaching and mortality event.

Other site clusters present even greater difficulty as there are few readily observable patterns between benthic and lauʻīpala data. For example, coral cover declined at both Kealakekua and Keopuka (Napoʻopoʻo-Hōnaunau cluster LTP and open site respectively), however lauʻīpala density has been relatively stable since 2015. Broadly, this highlights that the patterns of lauʻīpala density are complex at these sites and likely driven by multiple factors. It would seem then, that commercial aquarium collection in open zones and protection from aquarium take in FRAs and LTPs are not the sole drivers of lauʻīpala density trends at these sites.

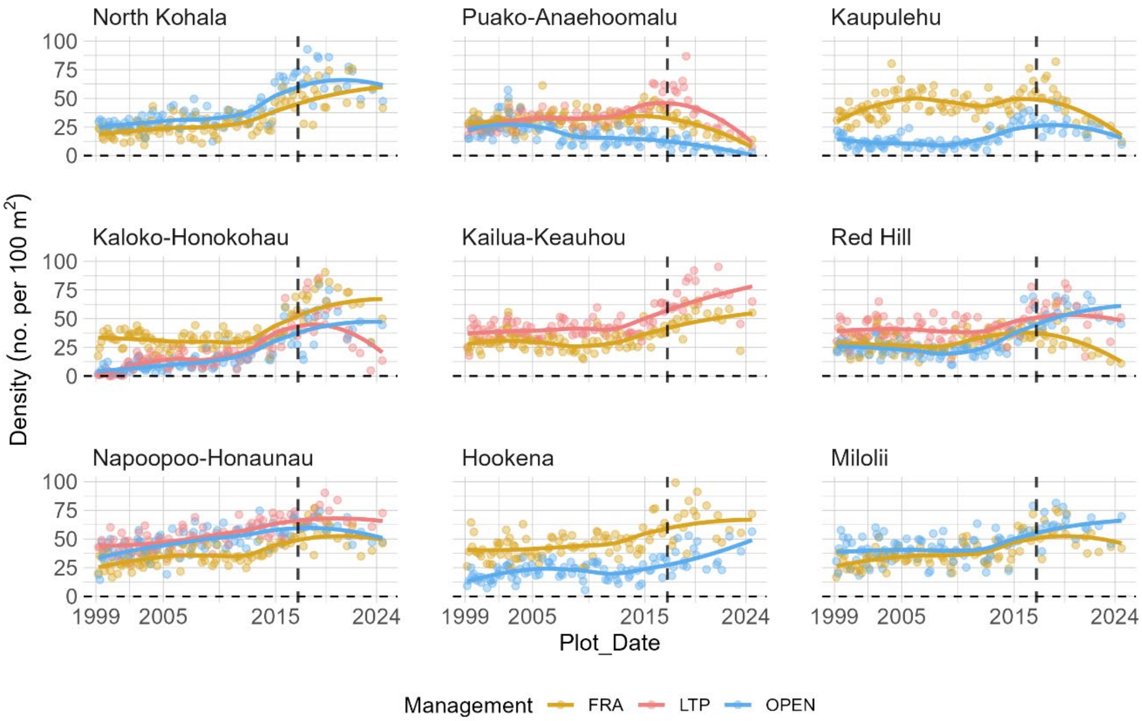

Figure 45. Time series of kole density across 23 permanent West Hawai'i Aquarium Project sites from 1999-2024. Sites are arrayed by FRA clusters as denoted in Table 3.

Trends in kole densities were somewhat more consistent than lau'īpala between sites (Figure 45). Sites in six of the nine clusters showed increases in observed density, particularly after 2015. Similar to lau'īpala, kole densities appear to be declining at sites in the Puakō cluster. Trends of the differences in kole densities between closed and open sites were variable across site clusters (Figure 46). No consistent patterns were observed in these differences with some clusters showing higher densities in the FRA site compared to its reference site while others showed the reverse. For many sites, this difference remained relatively constant across the time series, however the two potential exceptions to this were the Ka'ūpūlehu and Red Hill clusters. At Ka'ūpūlehu, this divergence appears to be driven by both an increase at the FRA site and a decrease at the open site in the early years of the study (Figure 45). Kole densities at these sites have converged in recent years as densities in the FRA site have declined while densities in the open site increased prior to the fishery's closure. At Red Hill, there has been a recent increase in kole density at the open site and decreases at the FRA site. This is somewhat surprising given the large decline in coral cover at the Red Hill open site following 2015 (Figure 44).

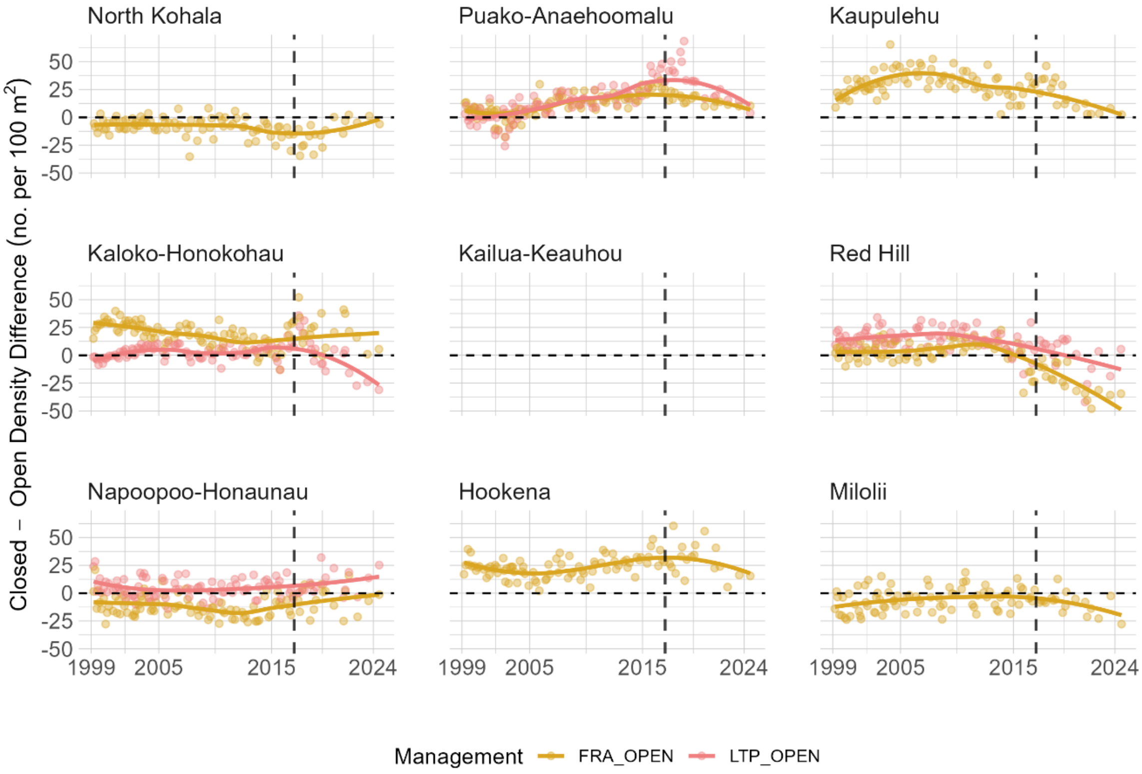

***Figure 46**. Time series of the differences in Closed and Open site kole densities as a measure of FRA effectiveness. Gold data points and trend lines depict FRA - Open site differences. Red points and lines depict LTP - Open site differences. Note: no Open site located within Kailua-Keauhou cluster for comparison.*

After lauʻīpala and kole, the other species making up the top ten caught by the commercial aquarium fishery in West Hawaiʻi since 1999 were pākuʻikuʻi, umauma lei, black surgeonfish, forcepsfish, laʻo, multiband butterflyfish, potter's angelfish, and fourspot butterflyfish (Appendix Table B-1). Density time series (Appendix C) for these species at many of the WHAP sites were rather uninformative with either high levels of variability or observed densities close to zero, both of which present difficulties in observing any clear trends. Broadly, the plots of differences between closed and open sites for these species show either similarly high variability or differences close to zero indicating that the closed and open sites generally tracked each other.

The complexity in these data underscores the difficulty in developing a single, straightforward narrative regarding the effects of the commercial aquarium trade on targeted species as well as the effectiveness of the FRA network in increasing fish abundance. Individual species differed across sites in terms of density trends as well as the difference between paired closed and open sites. Coral cover is likely an important factor driving fish abundance and differences in coral cover between FRA sites and adjacent control sites within an FRA cluster may obfuscate potential trends related to fishing effects. Future analyses should explicitly incorporate benthic data as a way to separate out these effects from those of the FRAs.

These data also show substantial variation between species with density trends differing even at the same sites. One example of this can be observed by comparing density trends of māʻiʻi and lauʻīpala at the Honokōhau FRA site (Figure 47). As previously noted, lauʻīpala densities at this site have increased somewhat dramatically, particularly after 2015. Conversely, māʻiʻi has had low densities at that site throughout the length of the study. It is possible that differences in species-specific habitat preferences between these two species are driving this disparity. This aligns with previous work indicating that māʻiʻi and lauʻīpala display differences in habitat usage, particularly with māʻiʻi recruits associating with deeper rubble habitats along the reef slope (Ortiz and Tissot, 2012). Other potential factors could include differences in recruitment, spawning, or life history as well as interspecific competition.

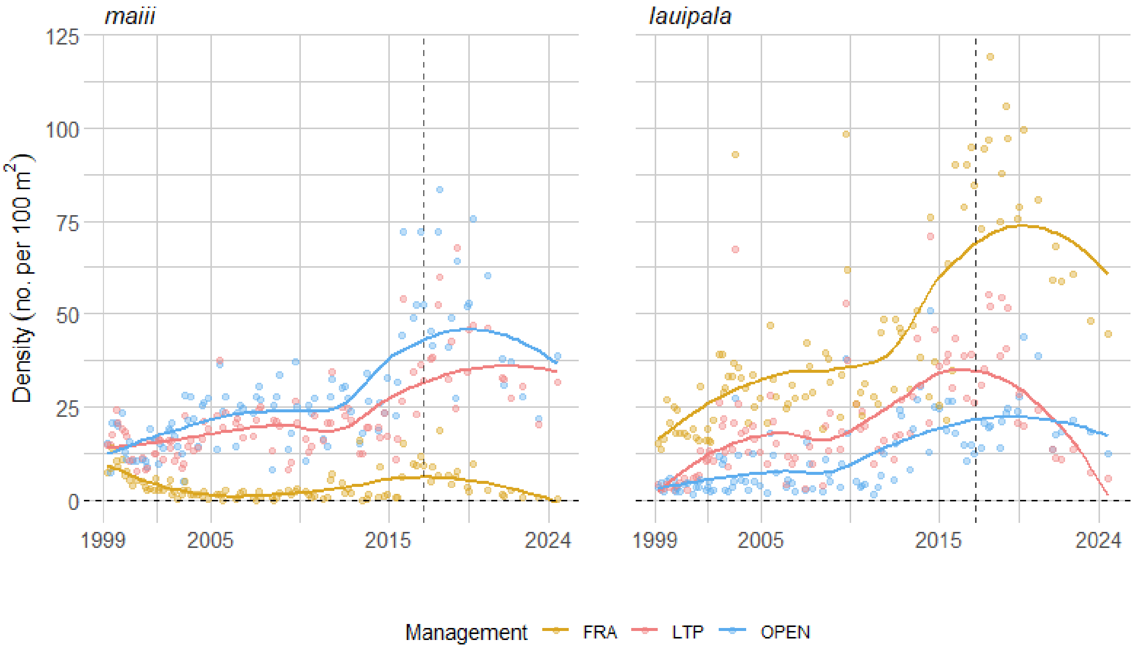

***Figure 47**. Comparison of density time series between māʻiʻi and lauʻīpala at sites in the Kaloko-Honokōhau FRA cluster.*

FRAs and user conflict

One of the primary goals of the FRA network as specified in Act 306 was to alleviate conflicts between different user groups. Originally, much of this conflict was between dive tour operators and aquarium collectors (DAR, 2019). As the fishery and the controversy surrounding it continued to expand, the set of stakeholders opposed to the fishery grew to include the native Hawaiian community, recreational ocean users, fishers, and other businesses (Maurin and Peck, 2008). Members of these various groups on both sides of the issue formed the West Hawaiʻi Fishery Council (WHFC, see Chapter 6) just as Act 306 was being finalized. From its inception, the WHFC set targets for representation by a multitude of user groups including five membership seats for commercial aquarium collectors.

The first goal of the WHFC was to delineate the boundaries for the FRA network as specified by Act 306. Each member of the WHFC used a set of selection criteria to generate a map of tentative sites for the FRAs that would cover at least 30% of the WHRFMA. Fish collectors were then asked to identify those areas that they felt were crucial to their operations, however it should be noted that many collectors declined to participate in this component of the process however several still did provide input (Capitini et al., 2004; Maurin and Peck, 2008). These maps were then combined into a final proposal. By including all stakeholders in this process, the goal was to ensure that the specific locations were selected to reduce conflicts and gain consensus among these groups (Capitini et al., 2004).

This level of separation between aquarium collection and areas frequented by other ocean users via the establishment of the FRAs likely led to some decline in direct conflicts, at least between dive operators and aquarium collectors (DAR, 2004). There was, however, a continued sentiment that the dispute was not fully resolved despite the FRA network (Capitini et al., 2004). Beyond the direct user conflicts, there remain substantial unresolved disagreements regarding the aquarium fishery. These extend further than the sustainability of the fishery and spatial separation of user groups and are rather driven more by fundamental disagreements about the practice of aquarium collection in its entirety. This is exemplified by repeated calls to curtail the fishery via the legislative, judicial, and executive branches of the Hawaiʻi state government, extensive public testimony on the subject from both sides of the issue, and efforts by aquarium collectors and their representatives to reopen the fishery since its closure in 2017. At present, it appears that disputes at this level are likely to continue.

CHAPTER 5- CORAL REEF HABITAT

5.1 West Hawaiʻi Coral Reefs

As described in Chapter 3, two of the major monitoring projects conducted in the WHRFMA collect benthic data as a routine survey component (i.e., WHAP and FAHU). Benthic survey data collected through WHAP can provide long-term trend information for the 25 permanent sites surveyed, however it does not provide information on the variability of reef habitats across the extent of the WHRFMA. A newly implemented survey design (FAHU) is anticipated to provide region-scale estimates, but these surveys have only been conducted for three years thus far, precluding their ability to provide long-term trends. The WHAP data are used to evaluate long-term benthic trends at these selected sites which will be discussed in section 5.2 of this chapter. The FAHU data are used to describe the broader survey region and look at the overall benthic species composition and habitat complexity as well as the variability of these metrics across habitats.

The benthic data that comes from the FAHU monitoring effort are twofold: 1) habitat complexity metrics and 2) percent cover of benthic species assemblages. Both benthic habitat complexity and benthic taxa cover data are extracted from the reefscape model that is built using the photogrametry survey images for each site. Three-dimensional (3D) models have been successfully built for a total of 209 FAHU sites surveyed during the 2022 and 2023 field seasons. Six models were unable to be built due to inconsistencies in the survey imagery, thus leading to a discrepancy in the number of sites available for fish and invertebrate data analyses (N=215) compared to benthic data (N=209).

The 3D structural metrics are important components in reef monitoring as they provide information about the benthic habitat that is fundamental to species distribution, abundance, and biodiversity (Fukunaga et al., 2020; Fukunaga and Burns, 2020). Structural complexity metrics have been calculated from the Digital Elevation Models (DEMs) of all 209 sites, with 90 of those sites having been fully annotated to produce benthic species cover information. As data collection and analyses are ongoing, means for species assemblages from the FAHU data may undergo shifts in future reporting with the addition of more samples. Because the three depth bins (shallow, mid-depth, and deep) are not fully represented within the 90 sites that have been annotated thus far, stratification was simplified to three moku (Kohala, North Kona, South Kona), instead of nine strata, for calculating weighted mean benthic cover for this survey region (see Section 3.3).

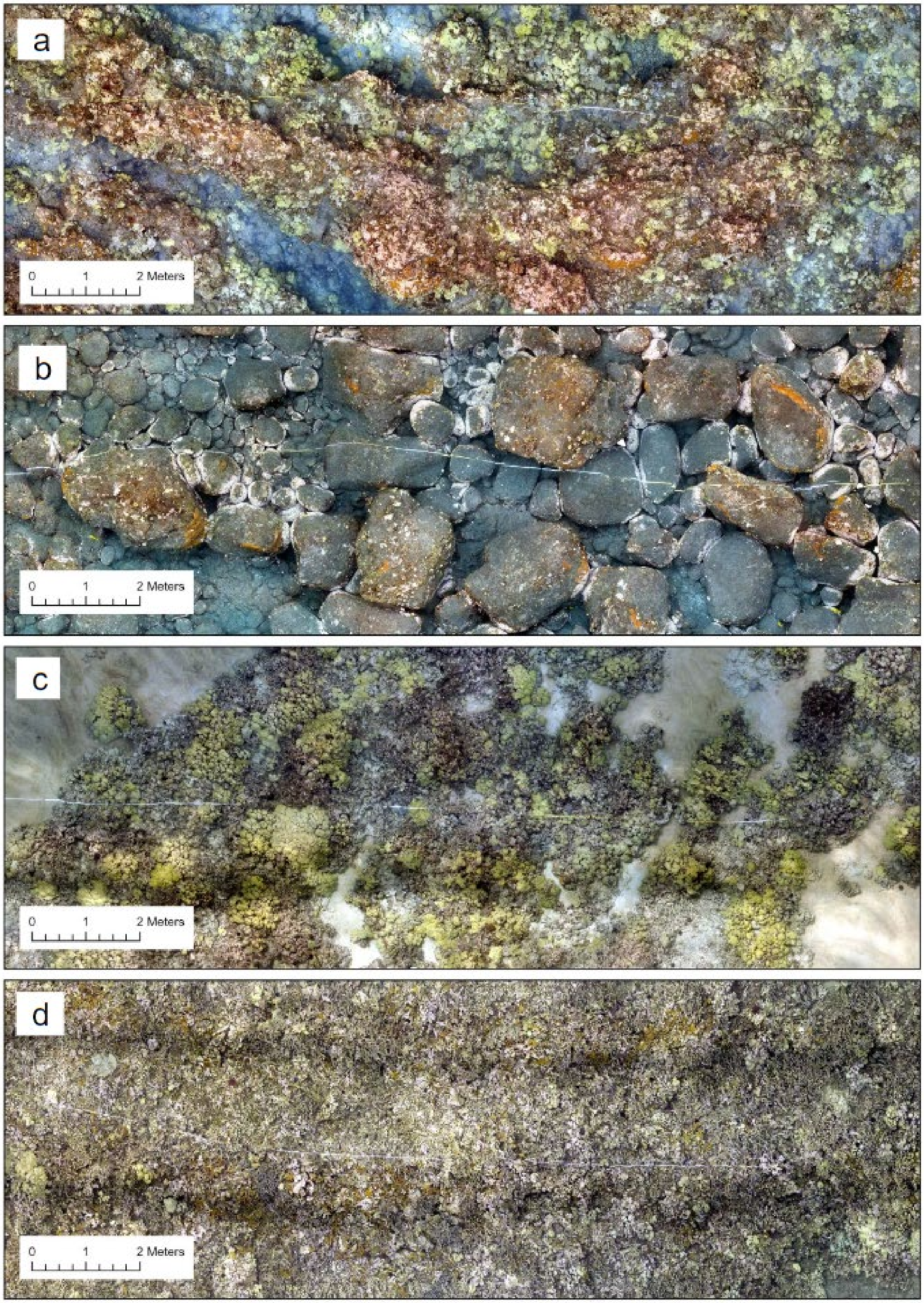

***Figure 48**. Examples of the variability in benthic structure and composition across West Hawaiʻi FAHU dataset (2024). A) aggregate reef (North Kona, shallow), B) boulders (South Kona, shallow), C) patch reef (North Kona, shallow), and D) aggregate reef (Kohala mid-depth).*

The marine hardbottom habitats in West Hawaiʻi are diverse, ranging from aggregate coral reefs to pavement flats, to highly structured zones of basalt, boulders, or consolidated calcifying organisms (Figure 48). Benthic cover data shows the presence of ten major taxonomic categories: turf algae, stony coral, sand, crustose coralline algae (CCA), cyanobacteria, encrusting algae, macroalgae, sessile invertebrates, soft coral, and bare basalt (Figure 49). Species that were unable to be identified during annotations were categorized as unknown. The 'turf algae' label used in FAHU benthic monitoring represents a broad category that includes light algal turf as well as mixed groups of algal turf with CCA, cyanobacteria, or cropped macroalgae. Turf algae is frequently found covering bare or grazed substrate that has not been colonized by coral or other established benthic organisms.

Turf algae was the dominant benthic category observed with a mean cover of 69.52% ± 2.21(SE) across these 90 FAHU sites. Stony coral was observed with a mean cover of 14.01% ± 2.70 (SE), followed by CCA (8.30 ± 1.99%) (Figure 49). Corals and other calcifying organisms (CCA and encrusting algae) are reef building organisms and are critical in the creation and preservation of the topographical structure of a reef ecosystem. While the amount of substrate occupied by mixed, grazed, and unidentifiable low relief algal cover (turf) outweighs the coverage of these reef builders, it will be important to track the coverage metrics of the reef builders through time as indicators of increasing or declining reef structure as well as overall coral reef health.

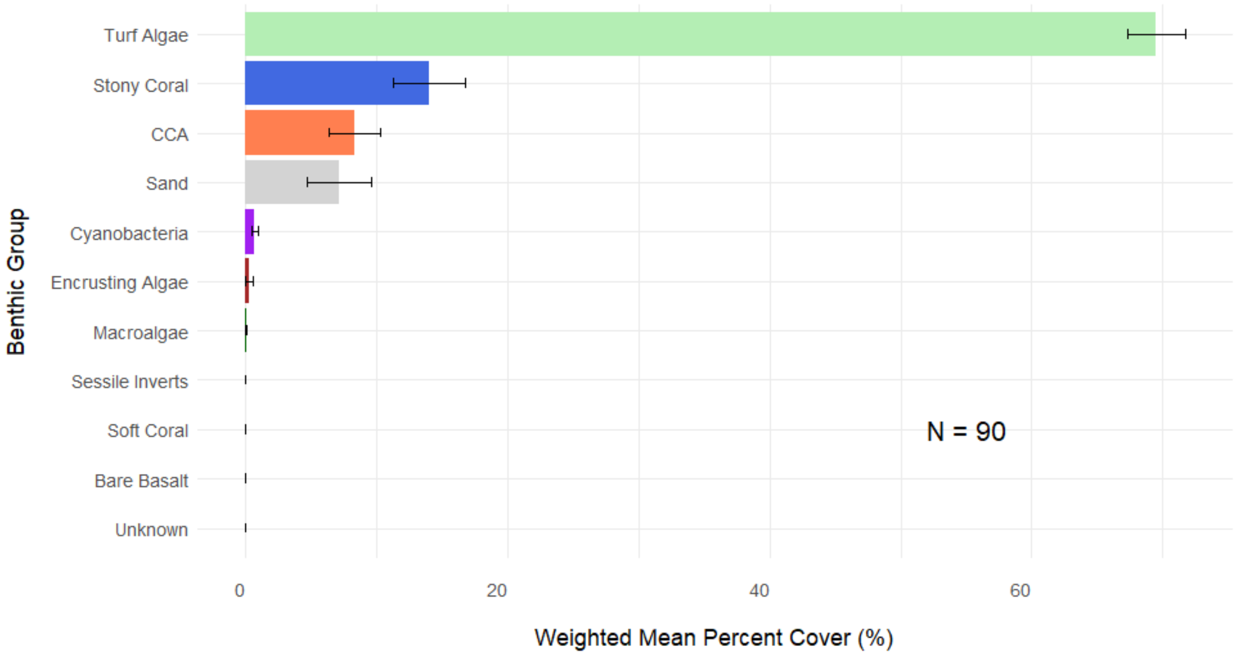

***Figure 49**. Mean percent cover of benthic groups across FAHU surveys. Mean percent cover and standard error bars are weighted by moku (Kohala, North Kona, and South Kona).*

A total of 15 species across seven genera of stony coral were observed throughout the 90 FAHU surveys (Figure 50). A mean species richness of 4 ± 0.1(SE) species of stony coral were observed across survey sites with a maximum of six species and a minimum of one species at a given site. Lobe coral (*Porites lobata)* was the dominant coral species observed, followed by finger coral (*P. compressa*), which was recorded at a mean cover of about half that of lobe coral (Figure 50). Lobe coral was also the most frequently occurring coral species across these 90 FAHU surveys with presence at 99% of the sites (89 of the 90 surveys), and a single site maximum percent cover of 37.37%. Finger coral was recorded at only 68% (62 of 90) of the sites, however, was recorded at a single site maximum percent cover greater than lobe coral at 42.89% percent cover finger coral. Though less commonly occurring than lobe coral across these survey sites, finger coral shows high coverage particularly at mid-depths (Figure 51).

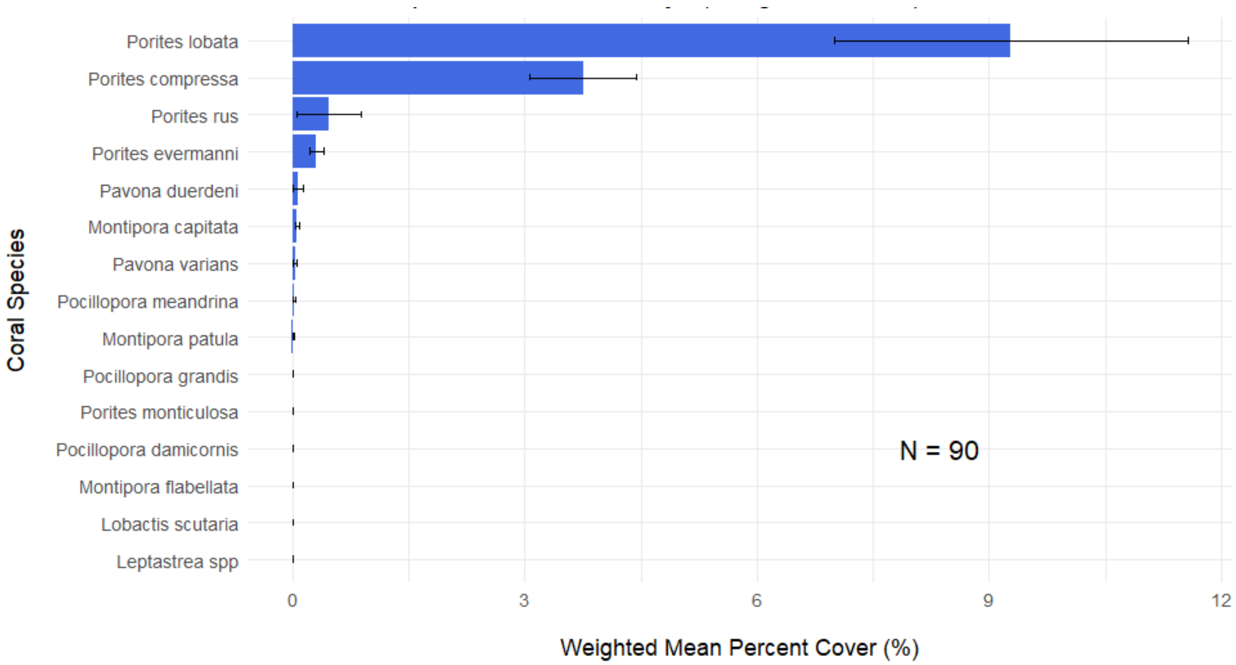

Figure 50. *Percent cover of coral species across FAHU surveys. Mean percent cover weighted by moku weights with error bars to show weighted standard error for the sample size of 90 surveys across three moku in West Hawai'i, 2022.*

The specific growth form of *P. compressa* has implications for estimating relative coral cover as measured by the FAHU and WHAP survey protocols (as well as many other survey methodologies). *P. compressa*, grows round finger-like branches and expands primarily upward with new extensions of structure occupied by live coral tissue while allowing the base of the branches to perish and become occupied by other benthic organisms. When images are annotated, these spaces between the live coral branches are recorded as the organism occupying that particular space. As such, even the healthiest, most intact *P. compressa* reef will likely exhibit substantially less than 100% coral cover. Conversely, mounding and plating coral forms consist of contiguous living tissue across the surface of the colony and therefore may reach higher levels of estimated coral cover due to their morphology and the technique used for assessing benthic cover. With these differences in growth patterns considered, the difference in live coral cover displayed between the two most common species is at least in part a reflection of morphological characteristics rather than differences in structural contribution to a given reef.

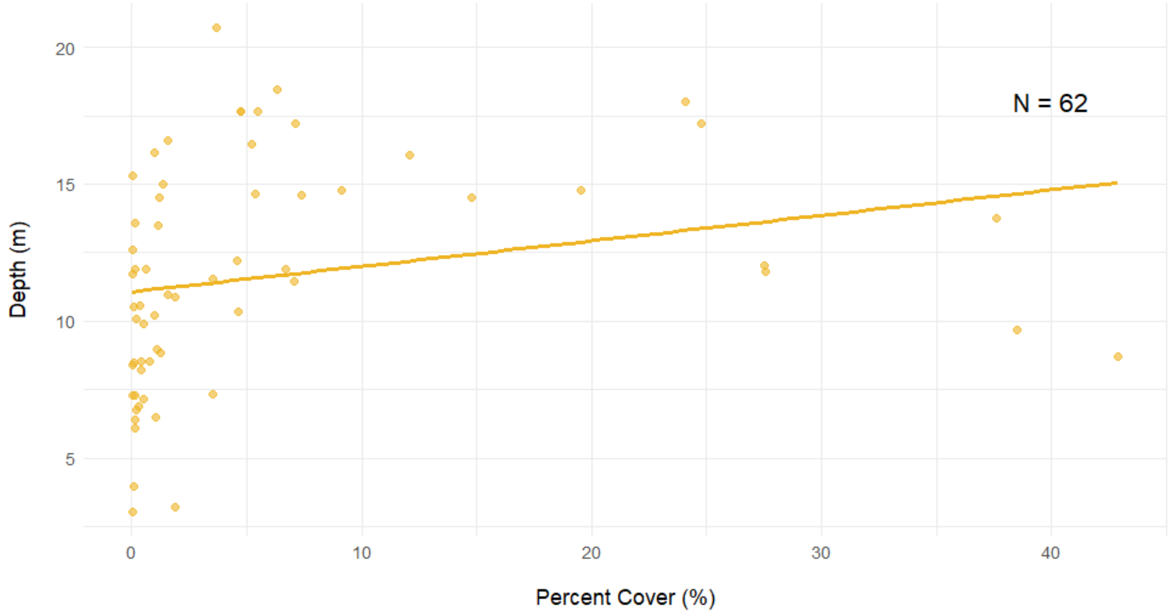

***Figure 51**. Mean percent coral cover of Porites compressa plotted against depth (meters). Number (N) of sites with P. compressa recorded during the 2022 FAHU survey round.*

Plate and pillar coral (*P. rus*) accounted for the third highest mean coral cover across survey sites, though it accounts for substantially less than *P. lobata* and *P. compressa* (Figure 50). *P. rus* appears to be relatively uncommon across survey locations, having been observed at only 3 of the 90 sites, but when it is present it is quite abundant at the given location. For example, one site in North Kona displayed 34.03% cover of *P. rus* during the 2022 FAHU survey effort.

Brown lobe coral (*P. evermanni*) also occurs in a notable abundance across the survey region (Figure 50) and was recorded to be present at 67 of the 90 survey sites. These descriptive statistics suggest a pattern the opposite of *P. rus*, that *P. evermanni* is common but not abundantly recorded at individual FAHU survey sites. Prior to the 2015 coral bleaching event, this species occurred as two- to three-meter-wide healthy colonies in various areas along the Kona coast. Currently, the species is still frequently observed, but massive colonies are not often encountered (A. Wills, personal observation).

Live coral cover is an indicator of coral reef health and function, however measures of habitat structural complexity add another layer of key information to gain a better understanding of the quality of habitat. More complex reefs provide a wider range of specific habitat spaces, allowing the reef to support a greater abundance and diversity of organisms. This complexity creates refuge for prey organisms, habitat for cryptic species, foraging grounds for predators, and space for other benthic organisms.

Various measures of habitat structural complexity (rugosity) can be calculated from the DEM of the survey transect area (plot) including surface complexity, vector ruggedness measure (VRM), profile and planform curvature, and fractal dimension (see Section 3.3.2). Although all of these assess a similar concept of reef complexity, utilizing multiple metrics at a range of spatial scales can yield a more complete understanding of the reef than any single measure by characterizing different aspects of reef structure (Fukunaga et al., 2020; Fukunaga and Burns, 2020). Although the scope and scale of utility of all metrics has not yet been fully realized, DAR staff have begun extracting these metrics and using them to examine the range of topographic complexity across survey locations.

Surface complexity, calculated as the ratio of the three-dimensional surface area to the planar two-dimensional area, was extracted at 1 cm resolution to depict this range across the 209 sites surveyed in 2022-2023 (Figure 52). Three example reefs were then chosen to show how this complexity metric maps onto reef structure. The three examples represent a flat, low complexity reef, an aggregate reef with sand channels, and a high complexity aggregate reef.

Vector Ruggedness Measure (VRM) is another metric that can be used to characterize specific reef components at different spatial scales. VRM is a measure of terrain ruggedness that compares individual pixels of the DEM with its neighboring pixels to estimate differences in the shape of the reef. Previous work has shown that VRM can effectively characterize different coral morphologies with 1 cm resolution capturing branching corals, encrusting corals at 2 cm resolution, and mounding corals at 4cm resolution (Fukunaga and Burns, 2020). Figure 53 shows the distribution of VRM values at multiple spatial scales across the 209 FAHU sites, while Figure 54 shows a positive relationship between VRM and *P. compressa* at 1cm resolution.

Combining these various DEM-derived habitat metrics with information on benthic cover can provide a holistic view of the complexity and diversity of reef habitats across West Hawaiʻi. By tracking these metrics through time, DAR staff will be able to monitor changes in reef complexity across the survey domain and within moku. Beyond monitoring, these tools can provide crucial information necessary to pursue analysis for delineation of important habitat features for key fish and invertebrate species, modeling species distributions and identifying locations that may offer some level of resilience to changing climatic conditions. All of which are pertinent to management efforts and providing an ability to make informed decisions.

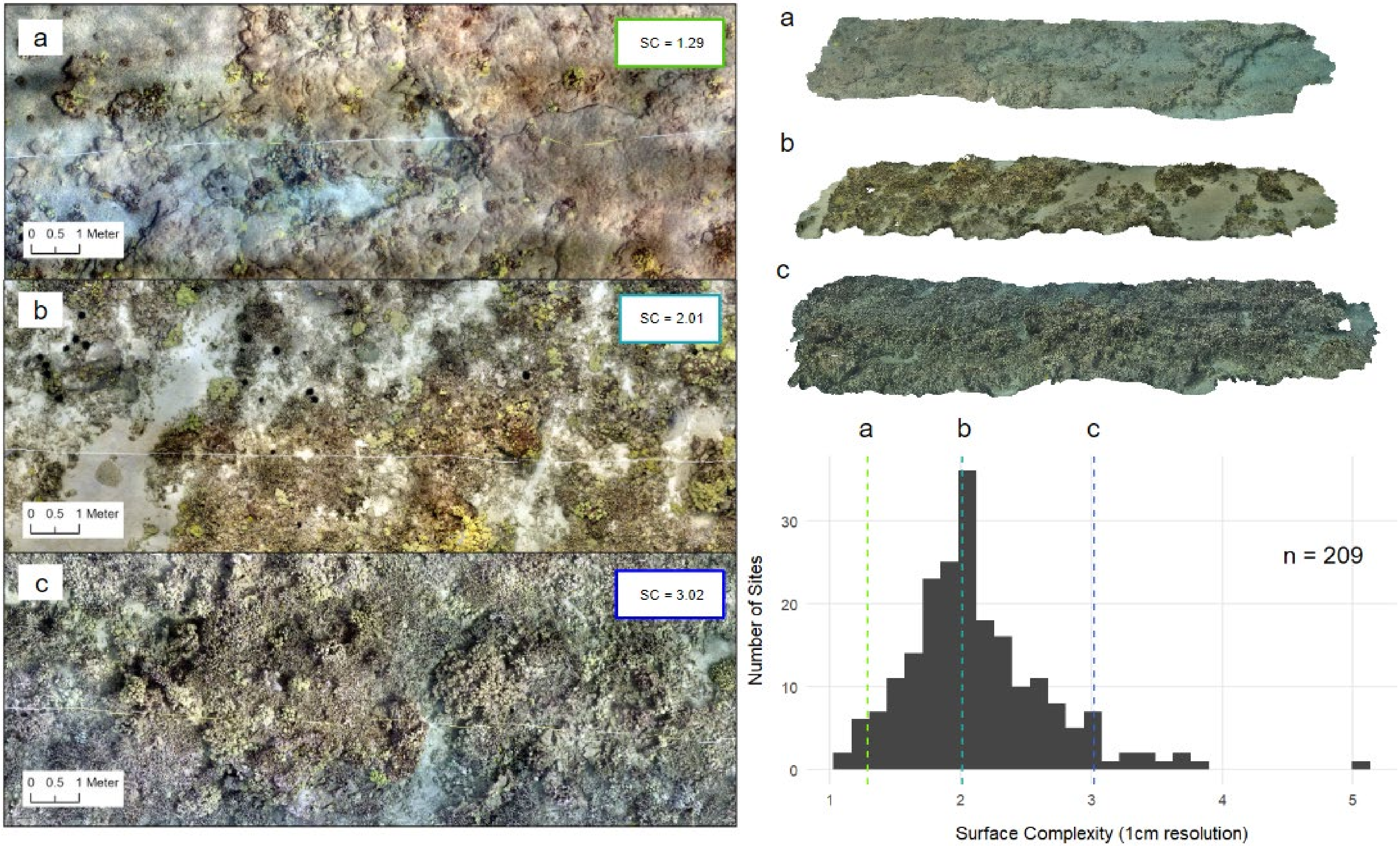

Figure 52. *Benthic surface complexity (SC) at 1cm resolution with habitat examples. Number (N) of sites surveyed in 2022-2023, FAHU data. A) pavement flat (Kohala, shallow), B) aggregate reef with sand channels (Kona, mid-depth), and C) aggregate reef (Kohala, mid-depth).*

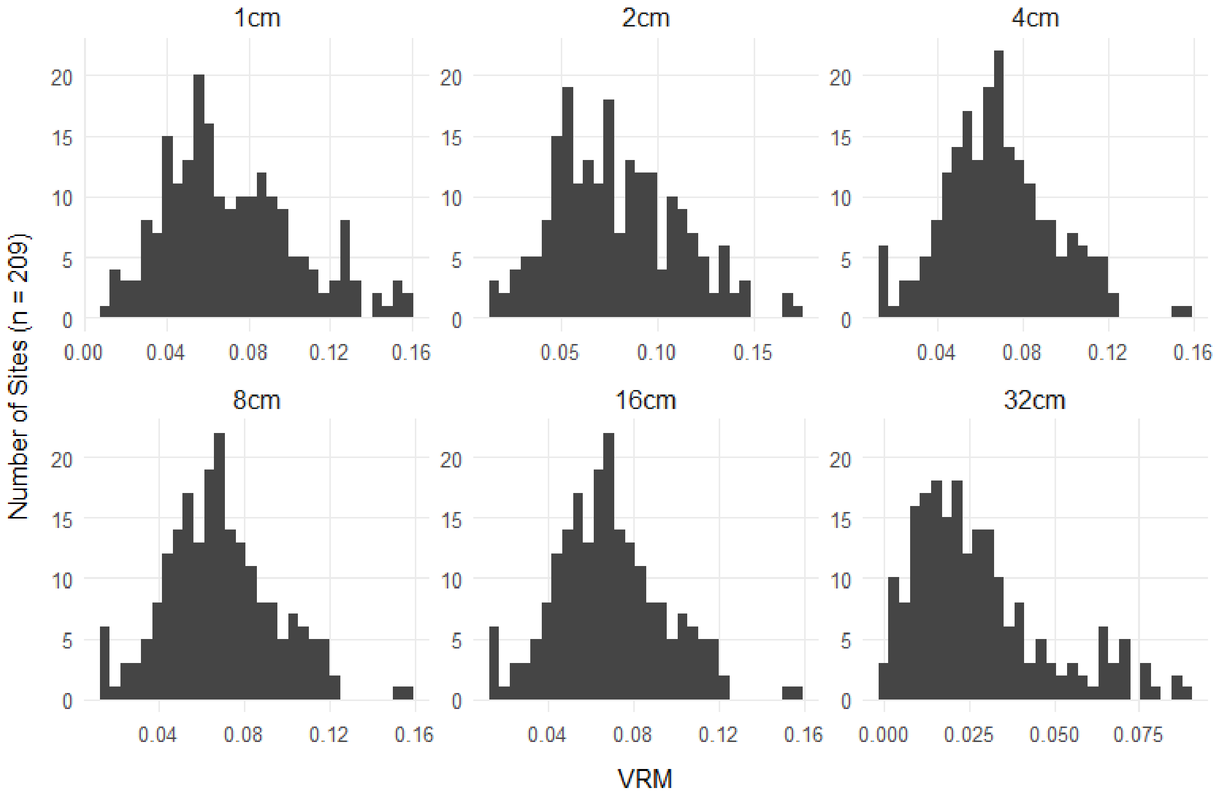

Figure 53. *Distribution of vector ruggedness measures (VRM) at six different resolutions (1cm, 2cm, 4cm, 8cm, 16cm, and 32cm) across FAHU surveys. Number (N) of sites surveyed during the 2022-2023 FAHU survey round.*

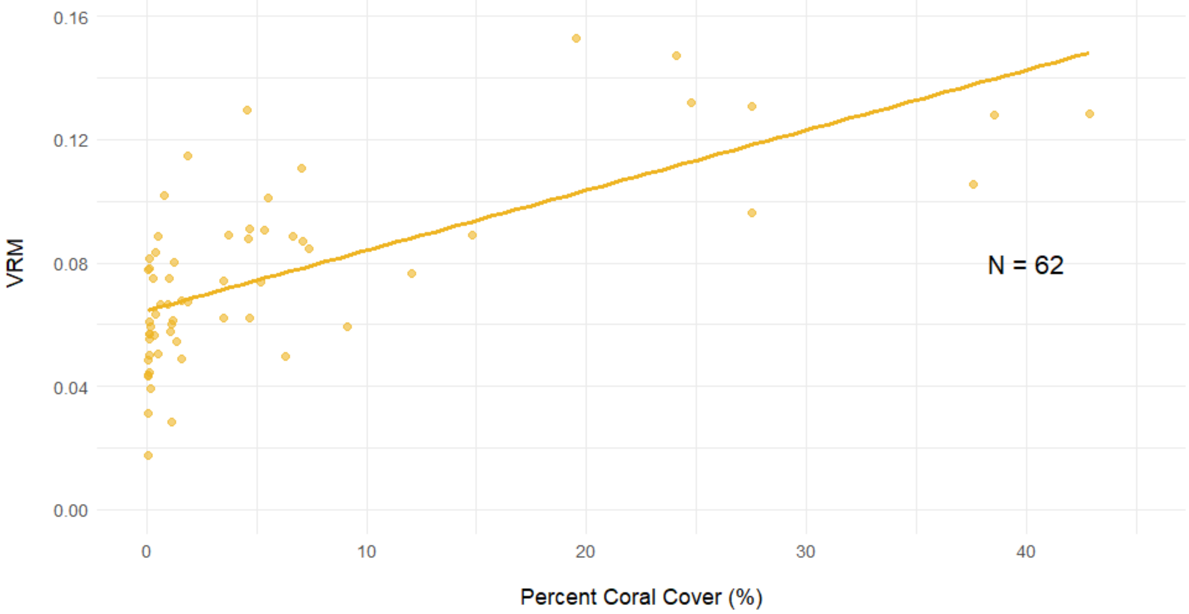

Figure 54. *Mean percent cover of P. compressa across VRM at 1cm resolution. Number (N) of sites is the subset of FAHU sites with annotation data, including only those where species was present.*

5.2 Long-term Benthic Trends

5.2.1 Environmental Stressors

Though multiple stressors such as sedimentation, water quality, storm events and coral diseases are known to have an impact on coral health in West Hawaiʻi, thermal stress has appeared to be the most notable and damaging factor over the past two decades (Couch et al., 2014; Gove et al., 2019). In 2015, West Hawaiʻi experienced greater thermal stress than any other region of the Hawaiian archipelago according to NOAA Coral Reef Watch (Maynard et al., 2016) due to combined effects of a powerful El Nino, a warm phase of the Pacific Decadal Oscillation (PDO), and locally weak wind patterns producing the warmest ocean temperatures on record for this region (Gove et al., 2019). A study of the South Kohala and North Kona focus region by Maynard et al., (2016) revealed high levels of coral bleaching and mortality due to the prolonged marine heatwave. Catastrophic post-bleaching coral mortality was also documented at fixed sites by DAR's West Hawaiʻi monitoring staff in 2015 (Kramer et al., 2016).

The compromised reef structure is further challenged by larger and stronger storms. A severe storm with large swells caused extensive coral damage along the West Hawai'i coast north of Keāhole Point in January 2004 (Walsh et al. 2013). These types of severe weather events have caused increasingly more damage throughout the monitoring period and are of particular concern due the loss of reef framework and increased fragility of the reef structure post 2015. For example, a "historic swell" in July 2022 resulted in live rock, coral and additional benthic organisms tossed onto south and west facing shorelines, with broken pieces of coral observed at and near study sites (Jones, 2022; C. Barnett & A. Pugh, personal observation). While a changing global climate is manifesting as the foremost current threat to Hawaii's reefs, sedimentation, storm events, and additional anthropogenic stressors such as effluent, phosphorous and nitrogen flux, presence of development, and commercial and recreational fishing, also impact coral health and ecosystem structure and resilience in West Hawaiʻi (Couch et al., 2014; Gove et al., 2023; Maynard et al., 2016; Walsh et al., 2013, 2018).

5.2.2 Long-term Benthic Monitoring (WHAP)

Benthic monitoring has been conducted at fixed sites established by the West Hawaiʻi Aquarium Project (WHAP) at semi-regular intervals since 2003, with the most recent data collected in 2023 (see Section 3.2.1). Although individual WHAP sites are small in scale, they offer valuable insights into changes in benthic cover at sites selected for coral richness over the past twenty years.

Trends in Coral Cover from 2003-2023

Benthic monitoring at 25 WHAP sites has shown a substantial decline in percent stony coral (koʻa) cover between baseline survey years (2003 (n=23)/2005 (n=2)) and the most recent surveys conducted in 2023 (n = 25). Mean percent cover across all sites (n=25) during the baselines years was 39.5% ± 2.3%(SE), and has since declined to 18.3% ± 2.2%(SE) in 2023; a mean relative loss of 53.2% between the baseline and most recent survey rounds (Figures 55 & 56, Table 11). Changes in relative cover at each site are shown from North to South in Figure 56. The greatest loss occurred at the Puakō site (site 4), while the Manukā site (site 24) showed the least amount of loss (Figure 56). Fifteen of the 25 WHAP sites exhibited a loss in relative coral cover greater than 50% and only one site (site 24) exhibited a loss of less than 10% between the baseline survey year and the most recent survey round. The survey years between the baseline and most recent round provide additional context on the timing of these changes over the course of the 20-year period.

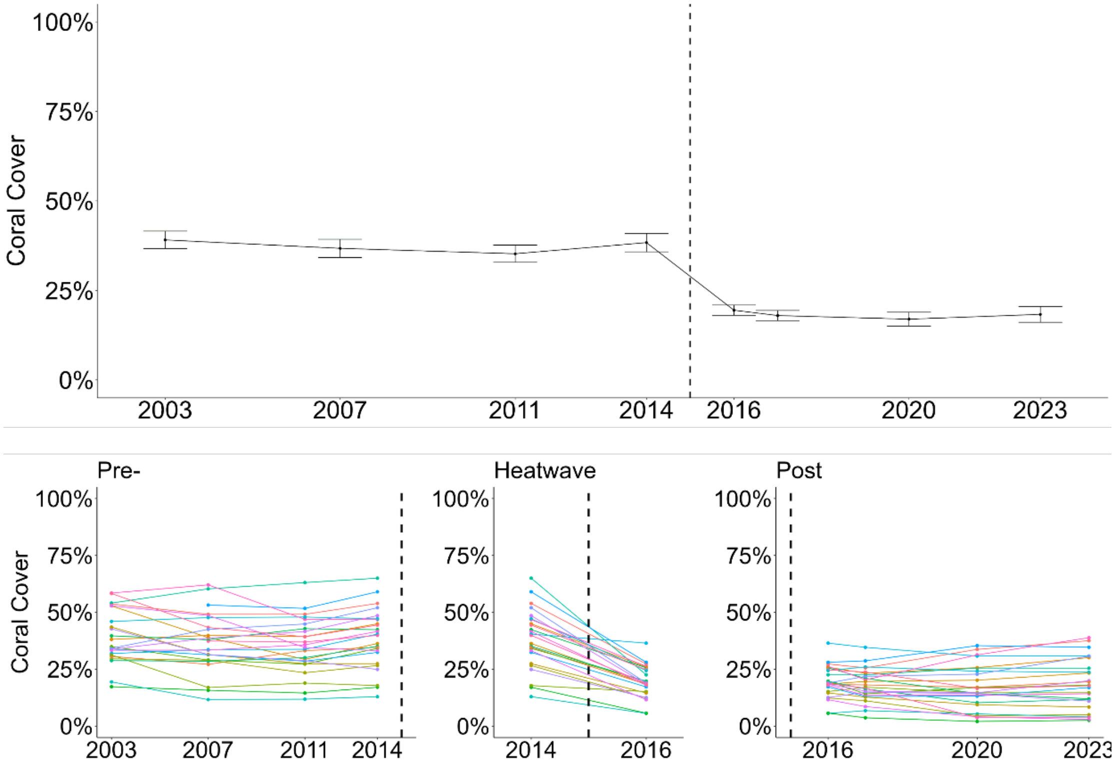

Figure 55*. Annual mean percent coral cover across 25 long-term monitoring sites 2003-2023 (WHAP). Top: Overall mean coral cover (%) across all sites. Bottom: Site specific annual means, West Hawaiʻi Aquarium Project (WHAP) data. Note* dashed line represents marine heatwave.*

Table 11. *Mean coral cover (%) from benthic surveys across 25 long-term monitoring sites (2003-2023, WHAP data). Sites are listed from North to South. *Baseline data collected in 2005 for Sites Unualoha (Site 97) and Old Kona Airport (Site 98).*

Site No	Location	Mean Depth (m)	2003/2005 (Mean ± SE %)	2007 (Mean ± SE %)	2011 (Mean ± SE %)	2014 (Mean ± SE %)	2016 (Mean ± SE %)	2017 (Mean ± SE %)	2020 (Mean ± SE %)	2023 (Mean ± SE %)
1	**Lāpakahi**	11	19.43 ± 2.67	11.65 ± 3.21	11.84 ± 4.6	12.94 ± 3.11	5.62 ± 1.66	6.80 ± 1.05	5.34 ± 0.85	4.08 ± 0.86
2	**Kamilo**	11	52.82 ± 2.24	38.92 ± 1.84	29.31 ± 1.91	36.3 ± 1.97	18.51 ± 1.64	19.62 ± 1.38	20.18 ± 3.08	23.35 ± 3.11
3	**Waiakaʻilio**	14	58.28 ± 0.75	43.36 ± 4.44	39.25 ± 3.84	44.4 ± 3.74	24.79 ± 2.31	23.75 ± 1.37	16.57 ± 0.42	17.74 ± 2.12
4	**Puakō**	10	52.87 ± 3.75	48.59 ± 3.25	34.59 ± 3.48	33.13 ± 4.57	11.62 ± 0.83	8.57 ± 1.25	4.13 ± 0.89	2.91 ± 1.1
5	**Pauoa**	10	42.75 ± 2.06	31.46 ± 1.21	28.76 ± 1.72	24.91 ± 1.54	12.53 ± 1.45	14.93 ± 1.01	14.28 ± 2.14	11.00 ± 1.67
6	**Keawaiki**	14	31.25 ± 0.55	16.96 ± 1.87	18.91 ± 2.99	17.82 ± 3.14	15.19 ± 2.17	17.10 ± 3.00	14.69 ± 3.18	14.67 ± 1.43
7	**Kaʻūpūlehu**	12	43.52 ± 3.17	31.43 ± 4.27	27.42 ± 4.95	27.44 ± 6.7	14.59 ± 3.99	12.77 ± 4.25	9.42 ± 3.16	8.39 ± 2.53
8	**Makalawena**	10	45.99 ± 1.76	47.68 ± 4.27	47.92 ± 1.88	47.13 ± 3.71	24.42 ± 5.95	25.99 ± 8.00	24.12 ± 10.53	23.67±10.06
97	**Unualoha Point**	12	36.8 ± 0.9*	37.38 ± 1.68	36.96 ± 3.06	39.89 ± 3.29	18.79 ± 1.73	16.70 ± 1.91	3.75 ± 1.57*	3.93 ± 1.26
9	**Oʻoma**	10	34.22 ± 3.54	42.52 ± 3.22	44.86 ± 4.28	52.00 ± 5.57	18.94 ± 1.55	21.88 ± 1.34	22.83 ± 1.83	30.71 ± 1.33
10	**Kohanaiki**	14	39.67 ± 1.77	37.95 ± 2.77	42.82 ± 2.97	42.37 ± 3.21	25.64 ± 2.41	21.00 ± 1.23	14.35 ± 2.79	12.00 ± 2.95
11	**Honokōhau**	12	53.70 ± 6.29	49.12 ± 1.53	49.14 ± 2.98	53.92 ± 3.47	27.30 ± 1.06	25.60 ± 1.07	33.71 ± 0.67	37.53 ± 2.14
13	**Pawai**	11	33.82 ± 3.36	38.66 ± 1.88	41.57 ± 2.43	48.54 ± 2.38	18.41 ± 3.53	15.40 ± 4.70	14.65 ± 4.03	19.93 ± 7.72
98	**Old Kona Airport**	14	50.7± 1.7*	53.2 ± 1.89	51.72 ± 1.28	59.02 ± 1.82	28.05 ± 4.84	28.68 ± 5.08	35.36 ± 6.49*	34.64 ± 3.05
14	**S. Oneo Bay**	11	58.47 ± 1.01	62.06 ± 1.66	45.88 ± 4.02	46.82 ± 3.17	26.27 ± 5.13	20.36 ± 3.85	31.67 ± 5.55	38.83 ± 6.34
15	**N. Keauhou**	12	33.93 ± 7.06	31.33 ± 6.12	27.44 ± 4.15	32.41 ± 4.04	17.23 ± 3.20	13.01 ± 3.01	13.15 ± 2.79	16.96 ± 4.47
16	**Kualanui Point**	11	54.06 ± 5.47	60.3 ± 1.89	63.06 ± 4.18	65.00 ± 1.50	22.56 ± 3.14	22.53 ± 3.45	25.5 ± 5.30	25.43 ± 4.48
17	**Puʻu Ohau**	14	33.35± 4.09	33.4 ± 4.04	35.73 ± 1.82	41.58 ± 3.95	17.95 ± 2.63	13.49 ± 1.79	13.64 ± 2.58	14.24 ± 3.14
18	**Keopuka**	11	17.32 ± 2.73	15.75 ± 1.96	14.55 ± 2.62	17.08 ± 4.05	5.70 ± 1.94	3.67 ± 1.49	2.06 ± 0.92	2.53 ± 1.4
19	**Kealakekua Bay**	8	29.57 ± 3.91	28.94 ± 5.61	23.46 ± 2.22	26.62 ± 3.43	12.37 ± 3.05	11.14 ± 3.10	4.54 ± 1.30	5.03 ± 2.84
20	**Keʻei**	11	34.90 ± 6.06	29.02 ± 5.24	27.25 ± 3.83	34.17 ± 2.20	19.80 ± 2.67	14.18 ± 1.56	16.89 ± 3.00	17.98 ± 4.36
21	**Kalāhiki**	11	38.11 ± 1.63	39.85 ± 3.20	39.33 ± 1.64	44.95 ± 3.00	25.92 ± 4.54	23.23 ± 3.96	25.70 ± 2.77	30.09 ± 3.04
22	**Kolo**	14	28.80 ± 2.45	28.48 ± 3.73	30.07 ± 2.05	35.10 ± 2.65	19.73 ± 3.78	16.34 ± 3.79	10.27 ± 1.26	11.74 ± 3.87
23	**Honomalino**	14	30.65 ± 2.78	27.16 ± 3.77	33.15 ± 3.53	34.66 ± 4.45	18.41 ± 2.67	18.10 ± 4.50	17.07 ± 5.98	19.46 ± 6.79
24	**Manukā**	12	31.92 ± 7.42	33.60 ± 6.87	33.76 ± 7.35	40.43 ± 4.74	36.47 ± 5.55	34.62 ± 6.18	30.79 ± 4.01	30.80 ± 6.01
	All WHAP Sites (N)		25	25	25	25	25	25	25	25
	All WHAP Sites (Mean ± SE)		39.48 ± 2.29	36.75 ± 2.53	35.24 ± 2.39	38.35 ± 2.58	19.47 ± 1.42	17.98 ± 1.41	16.97 ± 1.94	18.31 ± 2.22

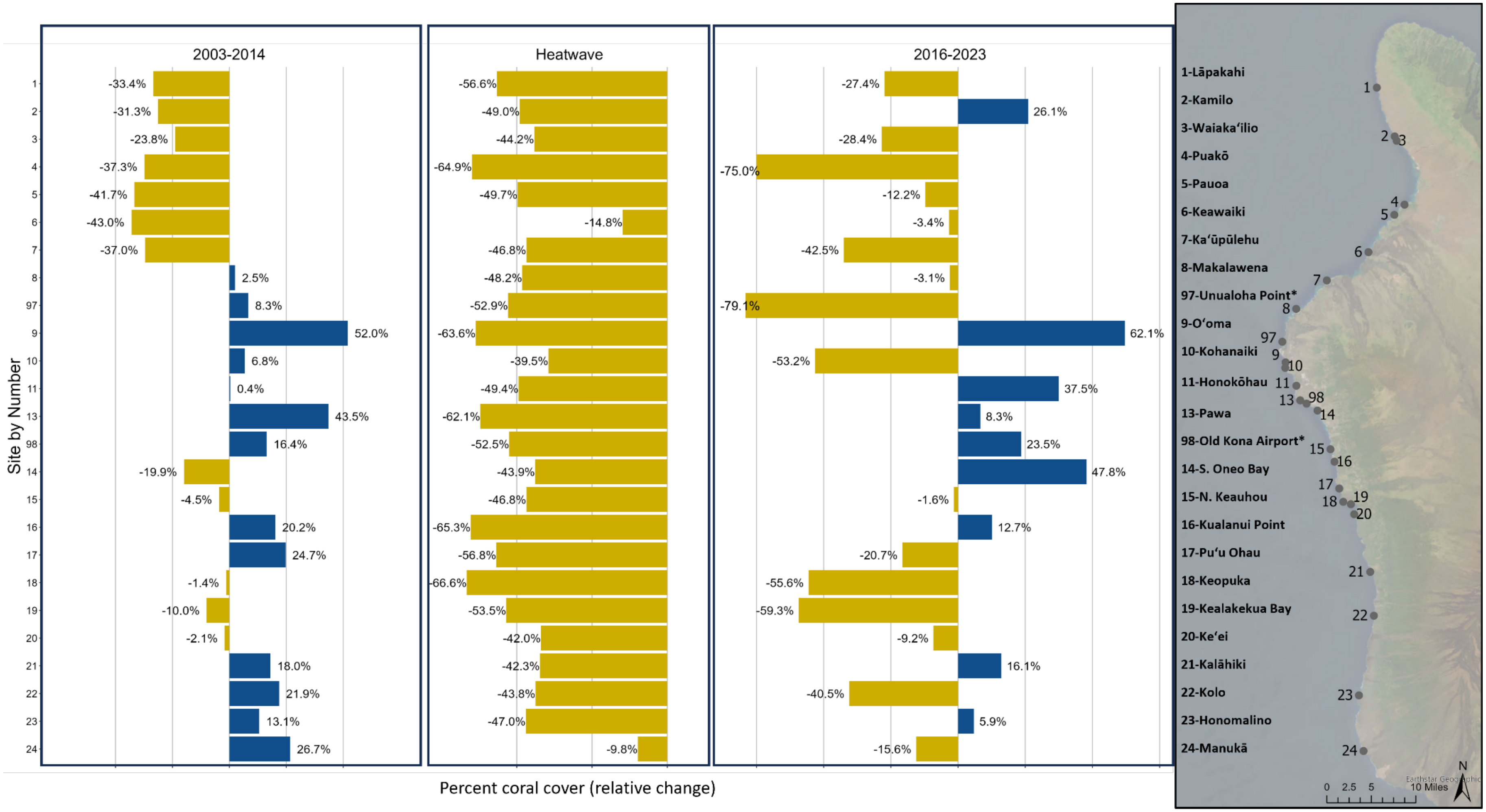

***Figure 56**. Relative change in percent coral cover at 25 long-term monitoring sites 2003-2023, West Hawaiʻi Aquarium Project (WHAP) data. *Note benthic data for Sites 97 & 98 were collected in 2005.*

From the baseline years through 2014, minimal shifts were observed in the mean coral cover across all sites (Table 11). However, trends in coral cover at individual sites showed noteworthy variability: ten sites showed a loss in coral cover, eleven sites showed an increase in coral cover and four sites showed an absolute relative change of less than 3% (Figure 56). Nine sites located in North and South Kona exhibited increases of greater than 10% relative coral cover. Relative coral cover increases included up to 52.0% at the Oʻoma site (site 9), followed by 43.5% increase at the site at Pawai (site 13). The seven northernmost sites (located in Kohala and North Kona) underwent declines between 23.8-43.0% loss in coral cover during this period, with the greatest relative loss in coral cover occurring at the Keawaiki site (site 6). The four southernmost sites showed increases in relative coral cover from 13-27%. This demonstrates that while the all-sites-mean during this timeframe did not change substantially, it's necessary to look at the site level changes to understand the range in coral growth and loss that occurred among these sites and across moku.

The most extreme changes across this twenty-year monitoring period occurred between survey years 2014 and 2016, with a nearly 50% loss in overall relative mean coral cover (Figure 56). This catastrophic coral mortality resulted from the marine heatwave and subsequent severe coral bleaching event of 2015. Between survey years 2014-2016, twenty-four out of the twenty-five WHAP sites experienced severe loss in coral cover. Of those, twenty-two sites experienced greater than 40% loss in relative cover, with ten sites exceeding a 50% loss (Figure 56). Mean coral cover across all WHAP sites was reduced from nearly 40% to less than 20% between 2014 and 2016 survey rounds (Table 11). This thermal event effectively established 2016 as new baselines for considering coral cover across these sites, particularly when considering relative changes into future years.

In looking at the coral cover over the survey years following the mass mortality event (2016 to 2023), the overall mean coral cover across sites indicated relatively little change on average (Table 11). Site-level trends, however, denote a high level of variability between locations with some sites exhibiting continued declines and others showing substantial rebounds in coral cover. Substantial (>10%) continued loss in relative coral cover has occurred across the four moku (North Kohala, South Kohala, North Kona, South Kona) at 12 sites between 2016 and 2023 (Figure 56). Conversely, several sites do show an increase in coral cover with the largest increase being a relative change of 62.2% at the Oʻoma site in North Kona (Figure 56). This is the same site that displayed the largest increase in relative coral cover during the 2004-2014 period. Trends of substantial increase in coral cover occurred at four additional sites in North Kona: S. Oneo Bay, Honokōhau, Old Kona Airport, and Kualanui Point, and at Kamilo in North Kohala and Kalāhiki in South Kona during this survey period (Figure 56). Less than ±10% relative change occurred at two sites in South Kona and at four sites in North Kona.

Between 2003 and 2023, percent coral cover at WHAP sites has decreased to approximately half the initial condition. With an overall estimated loss of -57.60 ± 4.23% in relative coral cover over the monitoring period, the most striking decline of -49.6 ± 1.8% occurred between survey years

2014 to 2016, after the highest prolonged sea surface temperatures on record for the Hawaiian Islands in 2015 (Gove et al., 2019, Table 2). Although several sites have seen increases in coral cover in recent years, none of the sites have reached or surpassed their baseline cover levels. Though there is extreme variability across sites, the presence of sites with increasing coral cover may be indicative of some thermal tolerance and/or recovery along areas of West Hawaii's reefs.

Diversity and trends among corals

Originally selected for coral richness, long-term monitoring of WHAP sites showed a distinct decline of two important reef building species at these mid-depth sites between 2003-2023. Overall decline in percent coral cover is primarily due to loss of the two dominant reef building corals in the genus *Porites* (Figure 57). The common species *Porites lobata* (lobe coral) declined from an all-site mean of 23.11% ± 1.07(SE) in 2003, to 9.37% ± 1.33(SE) in 2023. The endemic coral species *P. compressa* showed a relative loss of 23.9% between 2014-2016, but otherwise showed minimal overall change in mean percent cover in subsequent years; 11.4% ± 1.1 (SE) in 2003, 8.11% ± 1.0(SE) in 2016, and 7.9% ± 1.3(SE) in 2023.

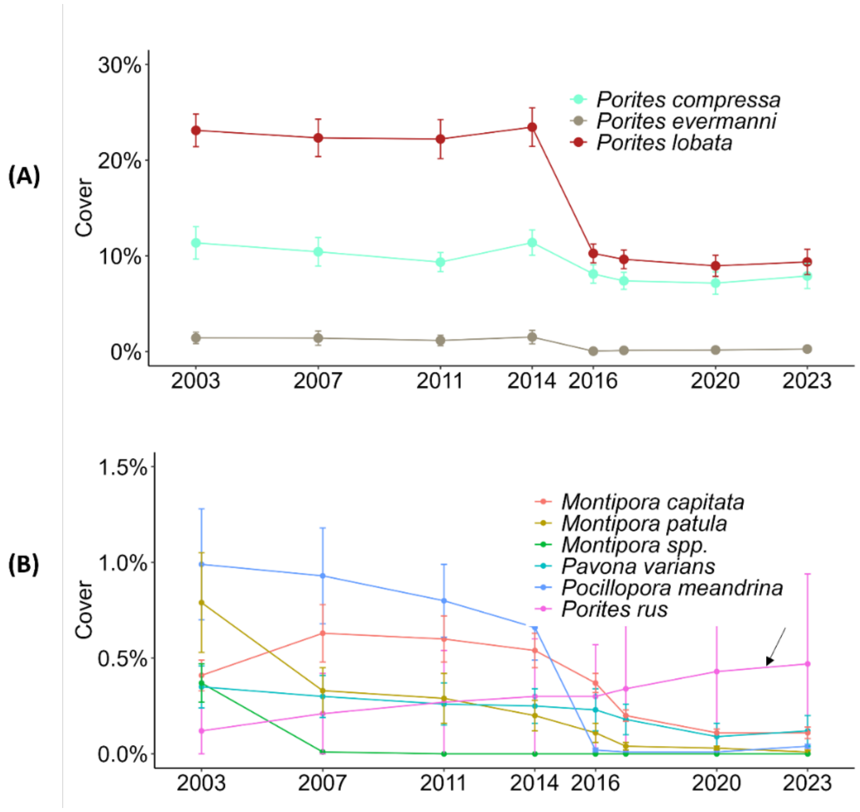

***Figure 57**. Annual mean percent coral cover of common coral species at 25 long-term monitoring sites from 2003-2023, West Hawaiʻi Aquarium Project (WHAP) data. Note the different scales between (A) dominant reef building species, as compared to (B) less abundant species. *Arrow indicates Porites rus trendline driven by Site 8.*

Including the two previously mentioned dominant *Porites* species, 19 total species from 7 different genera of stony coral were detected across the 25 sites over the twenty-year monitoring period (Figure 58). Though a relatively common coral on West Hawaiʻi reefs, *Porites evermanni* was not abundant along transects at WHAP sites due to the initial selection criteria which targeted *P. compressa* (2003 mean cover = 1.39% ± 0.6%(SE)). In the years surrounding the heatwave of 2015, percent cover of *P. evermanni* was reduced from an all-sites mean of 1.52% ± 0.7(SE) in 2014 to 0.05% ± 0.02(SE) in 2016, followed by a small increase in 2023 (0.27% ± 0.1(SE)). Other stony corals occur in very low abundance at WHAP sites. Corals of the genus *Pocillopora* (*P. grandis, P. meandrina, P. damicornis*) decreased from 1.07% ± 0.3(SE) in 2003 to 0.01 ± 0.01 (SE) in 2023, with the most significant change occurring between 2014-2016 (-96% relative change). Corals of the genus *Montipora* decreased continuously from 1.58% ± 0.4%(SE) in 2003 to 0.12% 0.03% across WHAP sites. Observations of *Pavona* also declined throughout the monitoring period, while *Lobactis, Psammocora, and Leptastrea* were each represented by infrequent occurrences and are not abundant enough at these sites to track trends in cover.

The site at Makalawena is unique in that it is the only WHAP site to host a large assemblage of *Porites rus*; a species that appears in abundance where it is present though it is relatively infrequent coastwide (see Section 5.1). *P. rus* was observed to be extensively bleached at this site in November 2015 following the marine heatwave event (Kramer et al., 2016), however coral cover analyses indicates that minimal mortality occurred for this species post-bleaching, with a relative decrease of -8.51% between 2014 and 2016. The *P. rus* cover at Makalawena has since exhibited a continual increase during years after the bleaching event (2016 = 6.88%, 2017 = 8.3%, 2020 = 10.7%, 2023 = 11.6%). Throughout the entire project period (2003-2023) live cover of *P. rus* has increased to over three times the percent cover detected during the baseline survey year at the Makalawena WHAP site.

Despite catastrophic losses of *P. lobata* and *P. compressa* after severe bleaching in 2015, *P. rus* has shown both the ability to recover from bleaching (Kramer et al., 2016) and an increase in recent years. As a result of climate change, it is anticipated that ocean temperatures will continue to increase in the coming decades. It is estimated that ocean temperatures similar to those that caused the severe coral bleaching in 2015 will occur on an annual basis by 2040 in West Hawaiʻi (Gove et al., 2019). In this scenario with increased temperatures and continued declines in corals, the potentially higher thermal stress tolerance of *P. rus* may make this species of increasing importance for future reef structure in West Hawaiʻi.

Other Benthic Groups (Non-stony Coral)

Corresponding with the decline in live stony coral cover from 2003-2023, benthic substrate was increasingly composed of other benthic categories across these 25 WHAP sites (Figures 58). The major taxonomic categories identified and discussed here are crustose coralline algae (CCA), cyanobacteria, macroalgae (>2cm height), octocoral, Peyssonnellia, Zoanthids, and algal turf. Algal turf is a broad category encompassing light turf, cropped macroalgae (<2cm height), and highly mixed assemblages of light turf, CCA, and cyanobacteria.

Between 2003 and 2023, WHAP sites showed a pronounced increase of the all-site mean algal turf cover from 44.4% ± 11.4 (SD) to 65.8% ± 14.5 (SD). Data from 2003 showed CCA comprising 8.5% ± 3.9 (SD) overall mean cover, with fluctuations through survey year 2014. Relative cover of CCA then increased from 8.0% ± 4.3 (SD) in 2014 to 16.6% ± 9.5 (SD) in 2016, a relative increase of over one hundred percent, followed by a return to baseline levels through 2023 (8.5% ± 6.2 (SD)). Percent cover of cyanobacteria also showed fluctuations after the 2015 thermal event (0.6% ± 0.5 (SD) in 2003, increasing to 3.5% ± 2.7 (SD) in 2016, and 2.2% ± 1.4 (SD) in 2023). Percent cover of macroalgae has shown slight temporal fluctuations, though remained at less than 1% for all survey years across WHAP sites.

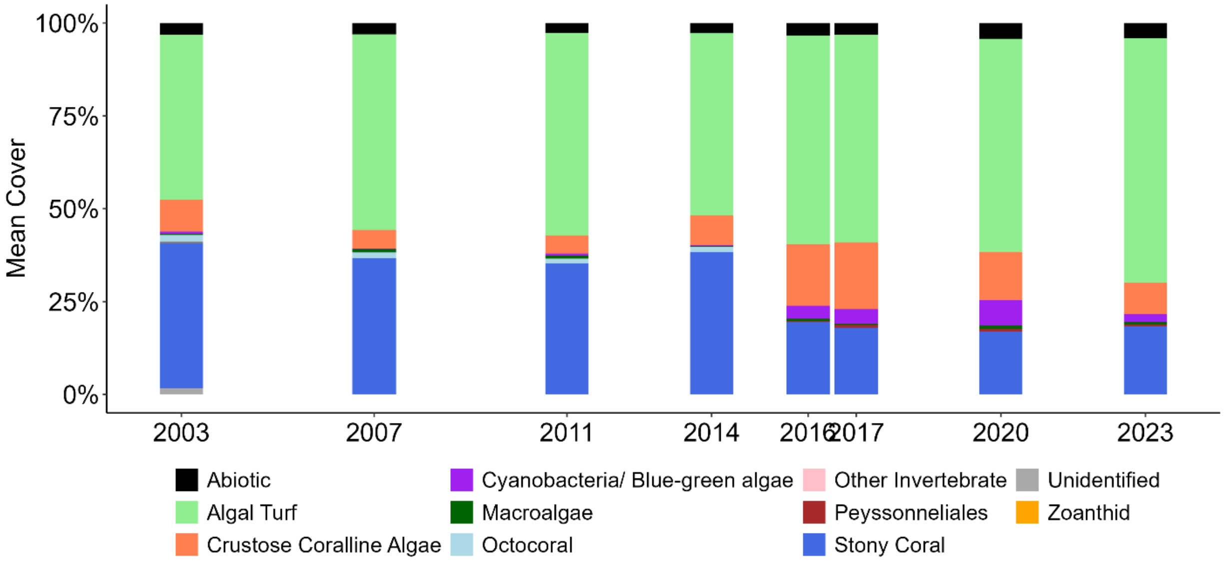

***Figure 58**. Annual mean percent cover of ten major taxonomic categories across 25 long-term monitoring sites (2003-2023, WHAP data).*

Following the post-bleaching coral mortality, declines in coral cover appear to have led to increases in light algal turf and crustose coralline algae (CCA; Figure 59). CCA in particular can be important for coral settlement and tissue growth. Algal turfs can negatively impact coral settlement and early survivorship, but if they are kept relatively low through herbivory, they tend to have little effect (Williams et al., 2019). It is important to note that the methodology employed for annotating 2D benthic images gives a top-down view. This view does not evenly distribute points throughout the complex 3D structure of a coral reef, thereby possibly underrepresenting the more cryptic species. However, a lack of macroalgal growth detected across these mid-depth sites indicate local grazers are playing an important role in controlling growth of benthic macroalgae, which remained at less than one percent in 2023 (Figure 58).

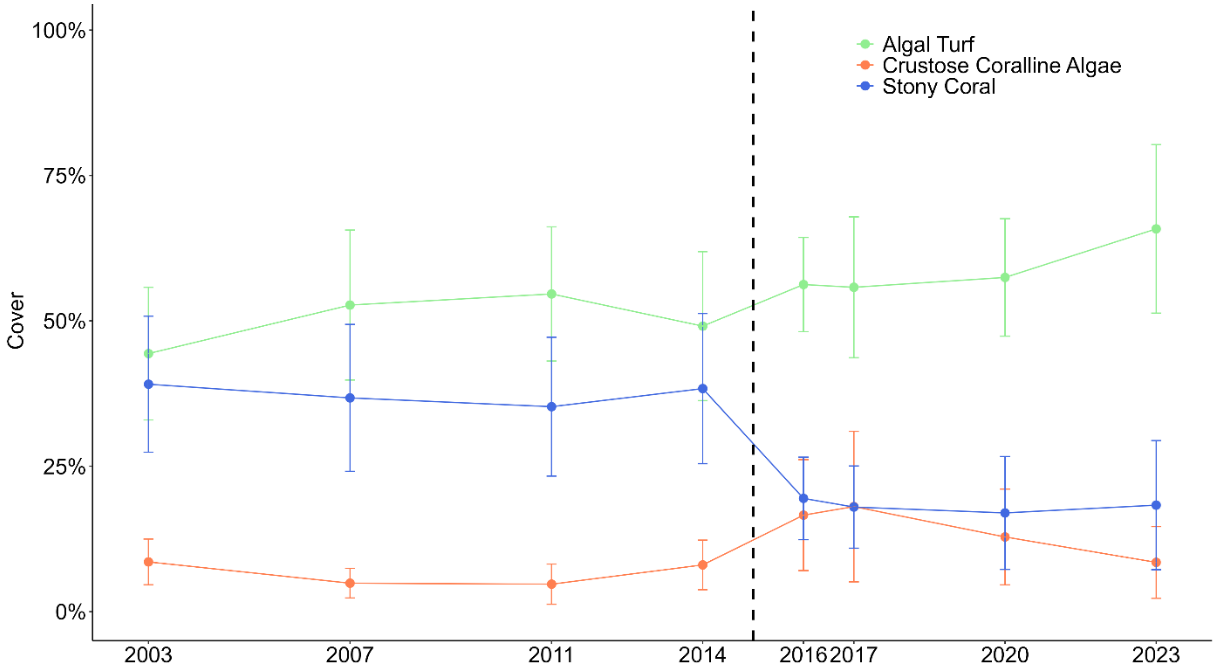

Figure 59. *Annual mean percent cover of the dominant benthic taxonomic categories across 25 long-term monitoring sites (2003-2023, WHAP data). Error bars are SD of the annual mean to show inter-site variability. Survey year 2003, n =23 with n = 25 for all other years.*

With changes in reef structure, cryptic or previously overlooked species may become more apparent to survey image annotators. Once thought to be infrequently occurring, *Ramicrusta hawaiiaensis* has become a species of interest due to its noticeable presence on reefs in West Hawaiʻi, leading to sampling and proper taxonomic identification (Grady et al. 2022). The benthic identification both of *Ramicrusta spp*. and other members of *Peysonnellialis*, a larger taxonomic category that includes nine species and five genera in Hawaiʻi, have been recorded in WHAP annotations (Sherwood et al. 2021). While some Peyssonnelids are known to actively overgrow live corals in other regions, the role of these species in West Hawaiʻi is not well understood. To date, percent cover of *R. hawaiiensis* is relatively low, accounting for less than 1% mean cover across WHAP sites.

Interestingly, benthic monitoring revealed a strong temporal influence on the endemic blue octocoral *Sarcothelia edmondsoni* across WHAP sites over the monitoring period. Known as a bioindicator of anthropogenic influences in Hawaiʻi (Tsang 2021), this species accounted for a small portion of benthic cover across all WHAP sites in 2003, with a notable amount of cover at the Pawai site. Observed at a survey round maximum of 13 sites in 2007, presence of *S.*

edmondsoni trended downward in both spatial occurrence and percent cover during the years to follow, with a substantial decline after the thermal stress event in 2015. Over the course of the 20-year project, this species of interest began with a relatively low mean percent cover of 1.67 ± 1.03% across WHAP sites in 2003, and years 2020 and 2023 did not yield a single notation of the endemic blue octocoral *Sarcothelia edmondsoni* through the photo annotation method.

5.3 Bioerosion

Declines in stony corals (koʻa), particularly after rapid mortality, destabilize the coral reef framework and causes reefs to become more vulnerable to degradation from other disturbances such as sedimentation, eutrophication, pollution, temperature extremes, predation, and wave action. Bioerosion, or the weakening and breakdown of the calcareous coral reef structure can also further compromise the functionality of the ecosystem (Glynn and Manzello, 2015).

Shifts in environmental conditions such as increasing ocean temperatures, can alter bioerosion rates, with local scale environmental variability of particular importance to the coral reef accretion-erosion balance in the main Hawaiian Islands (Silbiger et al., 2017). Changes in coral reef structure and benthic composition have been documented across West Hawaiʻi reefs through the long-term benthic monitoring at fixed WHAP sites (see section 5.2.2). Significant coral mortality over the past two decades has transformed these sites both in terms of benthic composition as well as structure and stability. Loss of live coral cover paired with wave action from regular and seasonally strong storm events has created expanses of unconsolidated rubble at a number of permanent monitoring sites, creating concerns for further degradation and bioerosion.

5.3.1 Mobile benthic invertebrates (Sea Urchins)

Grazing by herbivorous fishes and sea urchins plays a critical role in controlling the growth of macroalgae (limu) and clearing substrate for new corals to attach and grow. While sea urchins account for a large percentage of herbivore biomass and control of algae in Hawaiʻi, an imbalance and overpopulation may lead to overgrazing, impacting reef structure and contributing to bioerosion (Wabnitz et al., 2010). The substantial increase in abundance of these grazers is of growing interest on the reefs of West Hawaiʻi, as both an indicator of a changing habitat and a potential contributor to further bioerosion, particularly along reef slopes because destabilized structures up slope can become loose and damage healthy coral structures downslope (Johansson et al., 2010).

From 1999-2024, an overall increase in sea urchin abundance has been documented along with an overall decline in coral cover (Figures 60 & 62). It is not necessarily the large abundance of urchins, but the change in abundance that is important to consider across these West Hawaiʻi sites. Baseline surveys conducted in 1999 displayed a mean density of 20 individuals per 100-m^2 at WHAP sites, ranging from a density of 3 individuals per 100-m^2 (Site 18 Keopuka) to 69 (Site 6 Keawaiki). In contrast, surveys conducted in 2024 showed an increase to a mean density of 99 individuals per 100-m^2 across all WHAP sites, with counts ranging from 3 (Site 22 at Kolo) to a startling 501 individuals per 100-m^2 at Puakō (Site 4). This overall positive trend has been driven by substantial increases of wana (*Diadema spp.* and *Echinothrix spp.*) and extreme increases of hāʻukeʻuke ulaʻula (*H. mammillatus*) and hāwaʻe maoli (*T. gratilla*) at various sites (Figure 61). Abundance of the rough-spined sea urchin (*C. gigantea)* remained in relatively low density across the monitoring period.

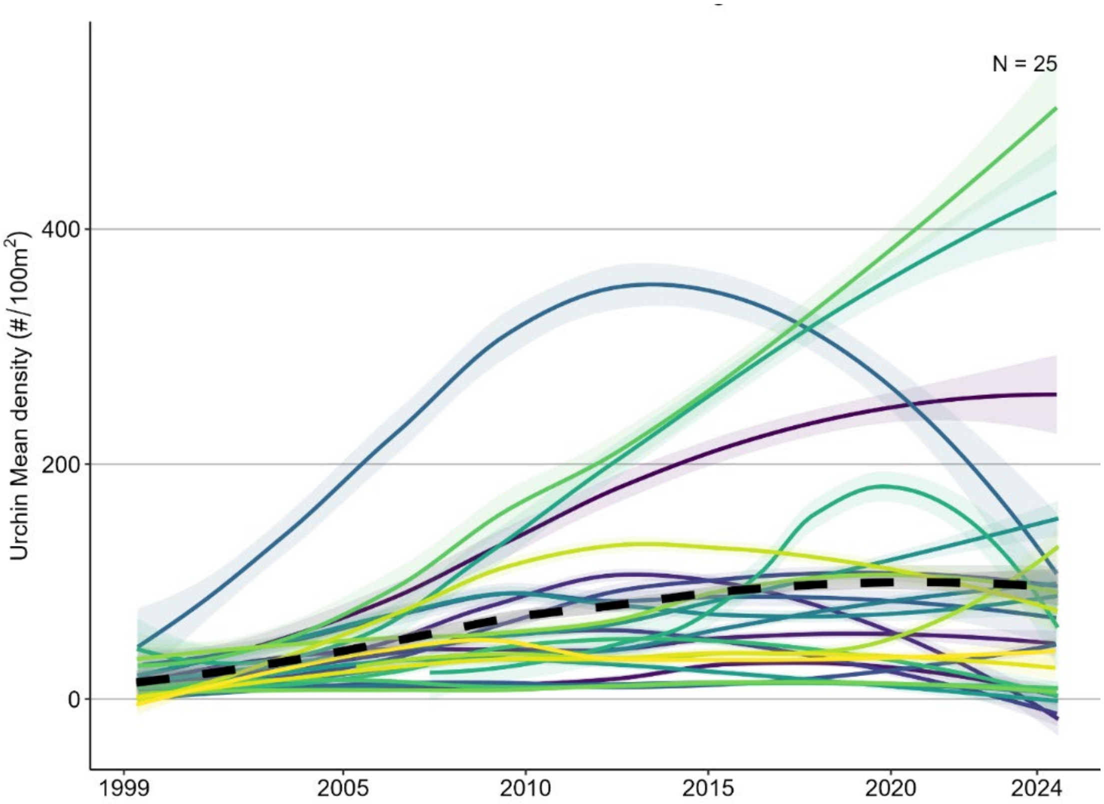

Figure 60*. Long-term trends in sea urchin density across WHAP sites (1999-2024). Density curves for individual sites (solid lines) are based to mean urchin density across four transects (N =4) at each survey site during each survey round. Number of rounds per year ranged from 1-6. Trend line for all-sites mean (dashed line) includes all sites surveyed each round. Number of fixed WHAP sites (N) each round is 23 from 1999-2005, 24 from 2005-2007 and 25 from 2007 until the most recent survey round in 2024.*

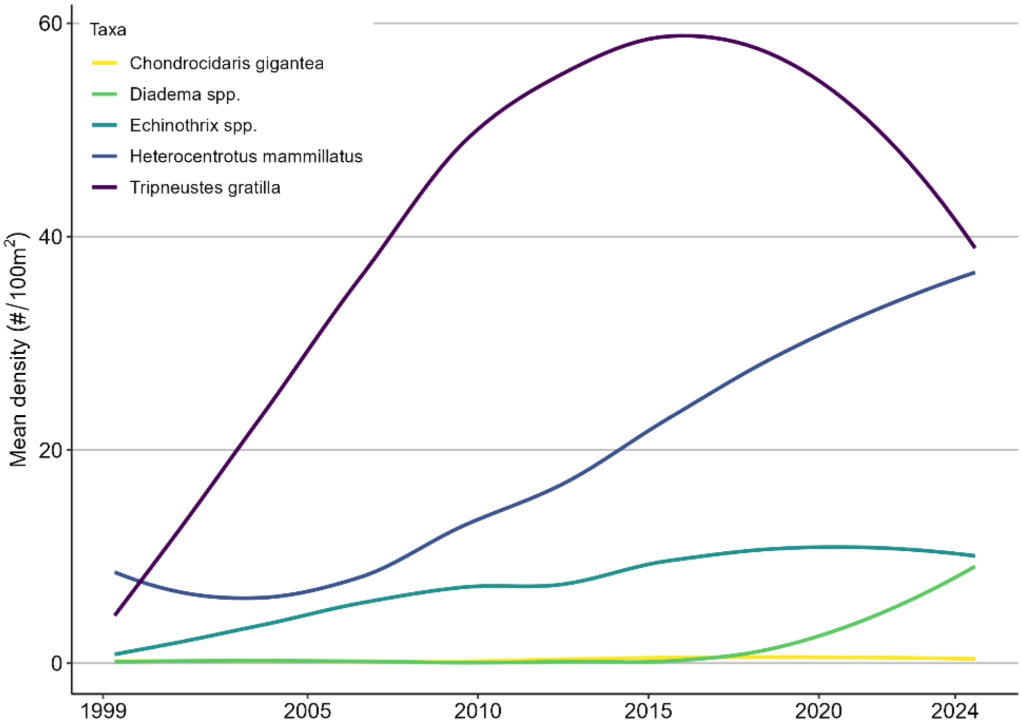

***Figure 61**. Long-term trends in sea urchin densities by species across WHAP sites (1999-2024). Density (y-axis) is mean of all survey sites within a survey round. Number of survey rounds per year ranged from 1-6 and number of fixed WHAP sites (N) each round is 23 from 1999-2005, 24 from 2005-2007 and 25 from 2007 until the most recent survey round in 2024.*

While the general pattern showed an overall increase in urchin abundance over the monitoring period, the 25 sites showed considerable variability in the scale of that increase with seven sites driving the bulk of the overall trend: extreme increases were documented for the following four sites: Puakō, Pauoa, Keawaiki (sites 4, 5, 6) and N. Keauhou (site 15), and notable increases occurred at sites at Old Kona Airport, Unualoha Point, and Makalawena (sites 98, 97, 8) (Figures 60 & 62).

When looking at mean percent coral cover and urchin density across WHAP sites and survey years, urchin densities under 100 individuals per 100-m^2 appear to be associated with a wide range of coral cover (Figures 62 & 63). However, as urchin densities increase above 100 individuals per 100-m^2, increasing abundance appears to be associated with decreasing amounts of coral cover. At sites Puakō (site 4) and N. Keauhou, the greatest densities of sea urchins documented for any WHAP site were observed during the most recent surveys in 2024 (501 and 419 individuals per 100-m^2). While both sites initially consisted of expanses of finger coral (*Porites compressa)* and lobe coral (*P. lobata)*, drastic coral mortality and accompanying benthic structural changes have occurred across the monitoring period, resulting in both sites currently primarily composed of loose (non-living) coral rubble.

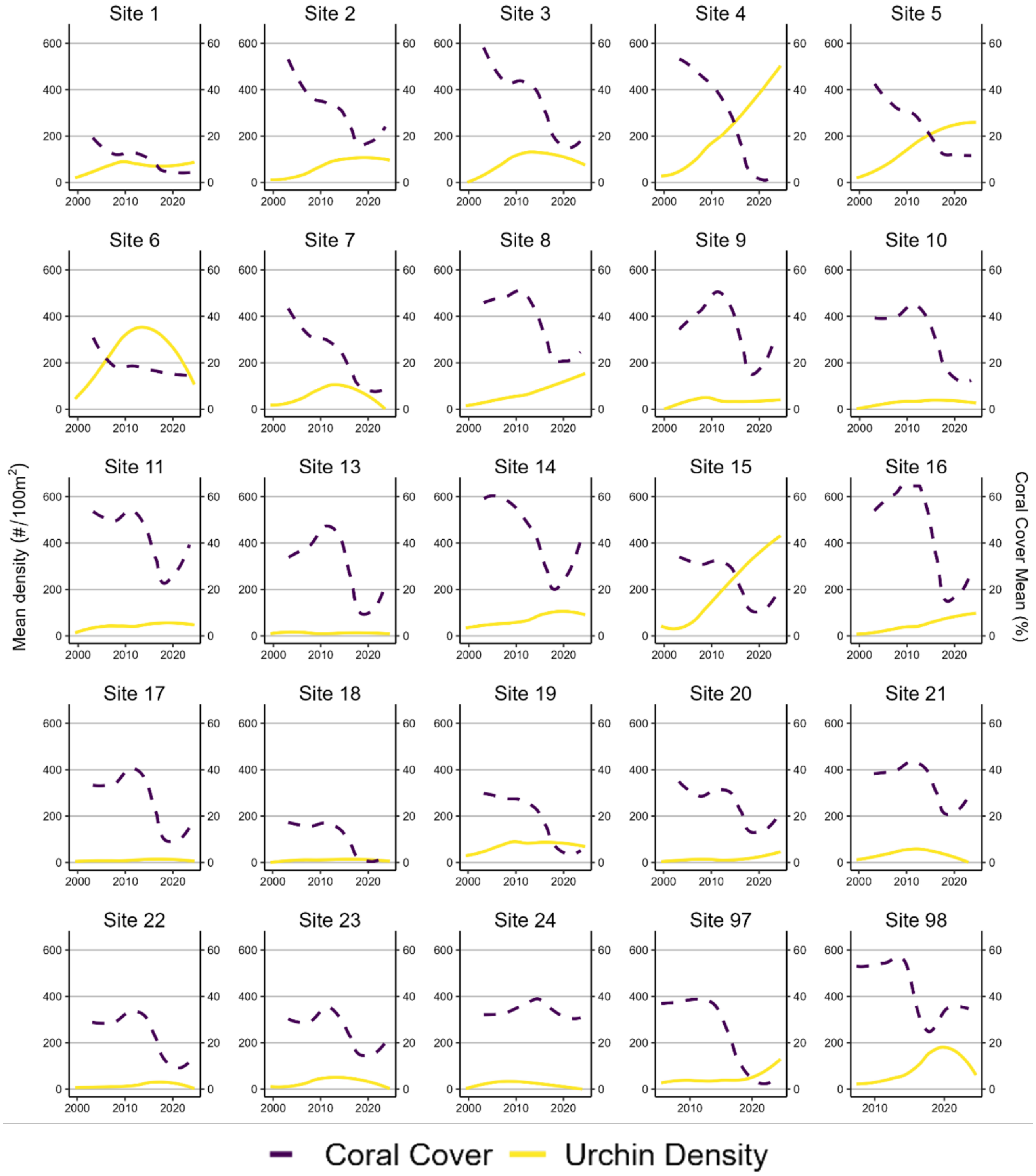

***Figure 62**. Trends in sea urchin abundance and coral cover at 25 long-term monitoring sites (WHAP data). Sea Urchin data were collected continuously from 1999-2024, while coral cover data was collected for survey years 2003 (n=23), 2005 (n =2), and for 2007, 2011, 2014, 2016, 2017, 2020, 2023 (n = 25).*

The site at Keawaiki (site 6) also showed a similar trend of substantial increase in urchins corresponding to dramatic coral loss and benthic structural changes, though this occurred earlier in the monitoring period 2003-2014. This site was the main driver of the large increase of *T. gratilla* visible in the overall trend during that timeframe (Figures 61 & 62). The site at Unualoha (site 98) has also undergone drastic reduction in coral and is situated at the top of a steep slope with large basalt features near one end of the site. These types of vertical features are preferred by diademids (a family encompassing both *Echinothrix spp* and *Diadema spp.),* though expanses of coral rubble with high *Diadema spp*. density have been observed at this site (C. Barnett, personal observation; Hoover, 1998).

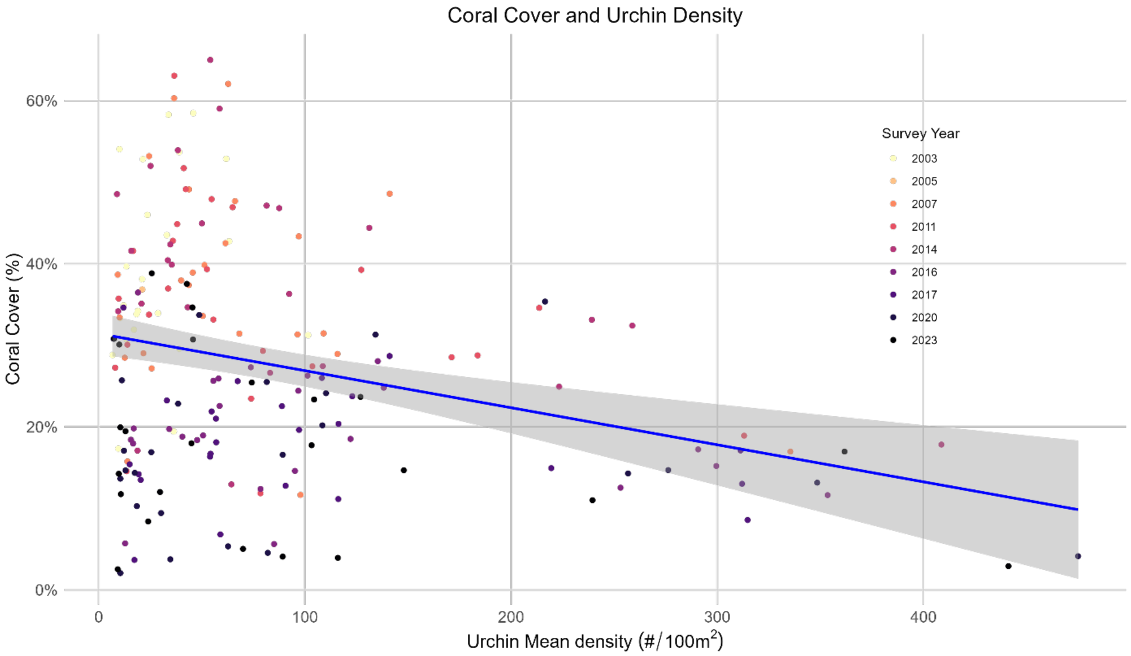

Figure 63*. Trends in stony coral cover and sea urchin density at WHAP sites, 2003-2023. Mean annual coral cover (y-axis) and mean urchin density (x-axis) at each site during each survey round. Data are for 25 long-term WHAP monitoring sites (N=25) and each site is plotted nine times – once for each survey round. 2003-2023.*

While an increase in urchin abundance alone is not necessarily cause for alarm, and the data from the WHAP sites cannot fully represent the entirety of the WHRFMA, the rise in populations of sea urchins coupled with declines in stony coral cover suggests a changing ecosystem. The immediate increase in crustose coralline algae cover during surveys in 2016 (after the thermal-stress event of 2015), indicated a potential for reef-binding algae to provide structural stability and substrate for coral recovery. However, the ongoing loss of coral cover, increasing turf algae, and observed degradation of habitat suggest that coral calcification may not be exceeding the rate of bioerosion at numerous WHAP sites.

There are, however, a number of WHAP sites that showed large declines in coral cover but did not have substantial changes in urchin abundance. This variability highlights the complexity of these mid-depth habitats and the need for further sampling and data analysis (Figure 62). Additional data are currently being collected across West Hawaiʻi using a stratified random sampling design. These recently added FAHU monitoring surveys include a broad depth range and expand substrate selection to include all hardbottom habitats. After the processing of the full 2022-2024 datasets, further investigations utilizing a full suite of habitat complexity metrics and benthic cover data may yield a better understanding of the relationships among species assemblages and habitat structure across West Hawaiʻi reefs.

5.4 Coral Damage

In addition to user conflict and concerns surrounding declining reef fish populations, the legislature highlighted the issue of physical damage to reef ecosystems from anchoring and novice divers in Act 306. The Act called for the establishment of a day-use mooring buoy (DMB) system along the coastline of the WHRFMA to include installation of DMBs in high-use coral reef areas in order to prevent anchor damage to corals.

5.4.1 Day-Use Mooring Buoys

Day-use mooring buoys have been in use within West Hawaiʻi since 1990, though their management has shifted somewhat over the years. An initial set of 46 moorings were installed in 1990 through a collaborative partnership of community members, vessel operators, non-governmental organizations, and the University of Hawaiʻi Sea Grant Program. In 1995, the Department established an official statewide DMB program via HAR 13-257 which is administered by the Department's Division of Boating and Ocean Recreation (DOBOR). Since then, the number of DMBs in West Hawaiʻi has grown to a total of 80 with an additional 7 proposed for installation. Of the 80 existing DMBs, at least five are lacking functional rigging at this time (Malama Kai Foundation, pers. communication). The actual number of operational moorings varies, as maintenance depends on the inspection and reporting by DMB users and the repair schedule of partner entities.

While all current DMBs have been permitted through the U.S. Army Corps of Engineers, only the original 46 moorings have ever been officially listed in HAR §13-257. An effort to expand coverage of all permitted moorings under HAR §13-257 is currently underway as this would ensure that the rules associated with DMBs apply equally to those moorings currently in existence. These rules include a 2.5-hour time limit for DMB use, prohibition of overnight use (except in cases of emergencies or by enforcement or rescue craft), and prohibition on anchoring within 100 yards of a DMB (though anchoring in the broader DMB zone is allowed if abiding by previously stated rules and if the anchor and chain are not located in areas where live coral exists).

Historically, the West Hawaiʻi DMBs have been maintained primarily by non-governmental entities. Notably, the Malama Kai Foundation has been an integral part of the West Hawaiʻi DMB program since its inception and continues to be the primary entity responsible for maintaining and repairing the majority of DMBs in West Hawaiʻi. The Malama Kai Foundation is funded for this work primarily through independent donations and grants. DAR is currently piloting a program to provide state funding for DMB maintenance on Maui and there are plans to expand this program statewide using funding obtained by the Aloha i ke Kai Ocean Stewardship Fee program. Overall, many organizations, businesses, and ocean users utilize and support the DMB program both statewide and within West Hawaiʻi, justifying a continued and expanded level of support by the State.

5.4.2 Ship Anchor Damage and Vessel Groundings

Day-use mooring buoys are primarily meant for use by small- to medium-sized private and charter vessels but are not suitable for larger ships. Large vessels, including yachts well over 100 feet in length, often visit West Hawaiʻi and require safe anchorages. However, given the steep slope of the nearshore seafloor and relative lack of large, flat sandy areas, such anchorages are not common in West Hawaiʻi. Mariners operating such large vessels are expected to consult a variety of available maps and DLNR representatives are available for contact in the area to provide information on ideal anchor locations. While some have done this level of due diligence, others have failed to do so, sometimes resulting in large-scale coral damage.

There have been three such high-profile incidents within West Hawaiʻi since 2018. Two involved large luxury yachts, 197 and 164 feet in length, which anchored along sections of coral reef in Kailua Bay. In both cases, hundreds of coral colonies were damaged by the ships' anchor and anchor chain. In the incident with the 164' ship, the anchor chain was observed draped on top of approximately 20 meters of live coral reef. The third was a 52-foot sailing vessel that anchored within the waters of the Kaloko-Honokōhau National Historical Park, damaging over 150 specimens of coral and live rock. Though not anchor-related, another incident in Kailua Bay involving temporary moorings for a sporting event occurred in 2023 when over 50 coral colonies were damaged.

There is a clear concern about continued damage within the Kailua Bay area, given the frequency of preventable damage events occurring there. This seems to be due to the combined effects of the area being widely used by mariners and a lack of awareness by operators of the extent of coral reef habitats in the bay. DAR staff are currently examining ways to help alleviate the latter issue for the future including working with NOAA's Office of Coast

Survey to delineate reef areas in official charts and conducting outreach with private chart plotting companies like Garmin to clearly denote coral reef areas on their devices. Additionally, DAR staff are planning to create clear habitat maps of the bay that can be distributed to mariners when they contact the Department.

5.5 Coral Restoration

5.5.1 DAR West Hawaiʻi Coral Restoration Program

The coral restoration program in West Hawaiʻi was initially conceived to address and respond to coral damage incidents in West Hawaiʻi. Historically, there has been a lack of capacity within DAR's West Hawaiʻi district to fully document these incidents, conduct emergency coral restoration activities, and track the long-term success of those endeavors. Additionally, mass bleaching events in the past decade have led to decreases in coral cover and subsequent bioerosion and reductions in the stability of the reef structure. Together, these have highlighted a broader need for coral restoration work within West Hawaiʻi.

Recent funding through federal Congressionally Directed Spending has allowed for the initiation of this new coral restoration work. This program aims to develop best practices for stabilizing corals and reef substrates that have become dislodged through anthropogenic (e.g., anchor damage) or natural (e.g., storms) causes, as well as transplanting corals growing on man-made structures such as day-use moorings, seawater intake pipes, and fish net pens. Additionally, best practices will be developed for propagating corals in a land-based nursery, outplanting nursery-reared corals back to the reef, and incorporating resilience methodologies into restoration protocols.

This work is being conducted through collaborations with several key groups in West Hawaiʻi and throughout the State. Community leaders in Kealakekua and Kahaluʻu have been instrumental in the development of these projects from their inception. DAR and The Nature Conservancy are both conducting pilot-scale coral stabilization within Kealakekua Bay. The teams have worked together to identify areas in need of restoration and have delineated focal areas for piloting this research. Staff from both organizations have assisted and will continue to assist with restoration efforts within each project area.

DAR and Arizona State University (ASU) have been working together to develop a restoration strategy within Kahaluʻu Bay. One of the strategies being implemented is stabilization of the many corals of opportunity (COO), or dislodged, living coral colonies and fragments, that can be found within the bay. Staff from each organization have established a schedule to conduct collaborative restoration days. DAR will create a site map to clearly communicate which areas have stabilized corals and which areas are still in need of stabilization effort. Community members will be able to assist with these efforts in several ways including transporting the corals, monitoring the outplants, and potentially assisting in fragmentation events.

DAR and ASU are also collaborating on a land-based coral nursery. The Ridge to Reef Restoration Center (3RC) is a large-scale nursery that can facilitate multiple coral research and propagation projects. DAR is focusing on coral rehabilitation and propagation. ASU is focusing on resilience research and assisted sexual reproduction. Staff from both groups have been working together on many of the different aspects surrounding reef restoration and research.

Lastly, DAR currently operates a large-scale restoration facility at the Ānuenue Fisheries Research Center on Oʻahu. As the West Hawaiʻi program continues to grow, communication between these teams will become increasingly critical to ensure that information on successes and potential pitfalls are shared. A new coral restoration operation is also being started by DAR staff on Kauai, which will warrant an expanded level of intra-divisional collaboration.

Coral restoration is currently being conducted at a pilot scale in West Hawaiʻi. Small-scale applications allow for changes to be made during the next iteration. Once the methodology has been refined, DAR plans to explore ways to scale coral restoration to an extent that is more ecologically relevant. In order to accomplish this, DAR staff are aiming to increase the efficiency of operations, expand and strengthen community partnership, and integrate sexual propagation techniques for nursery-grown corals.

5.5.2 Coral Stabilization

Following the bleaching events, some reef substrates have turned into unconsolidated rubble mixed with corals of opportunity (COO), which are loose colonies that are no longer attached to the reef. If these corals remain unstable, they are unable grow new tissue to reattach to the reef. The COOs being collected are also a risk due to their mobility, which could damage other corals or lead them to settle in the sand. Staff identify optimal outplanting areas with viable open substrate for attaching these transplants (Figure 65). The substrate is cleaned with a wire brush, adhesive is applied to the base of the coral (avoiding live tissue), and the COO is then secured to the reef. Photos are taken to monitor the survival and growth of these colonies. In some cases, Structure from Motion (SfM) photogrammetry are being used to track metrics like percent coral cover and rugosity. Staff will revisit these restoration sites for ongoing monitoring of coral survivorship, health, and growth. DAR staff have also begun testing various adhesives for reattachment, including different cement mixtures, all-fix epoxy, and Z-Spar epoxy.

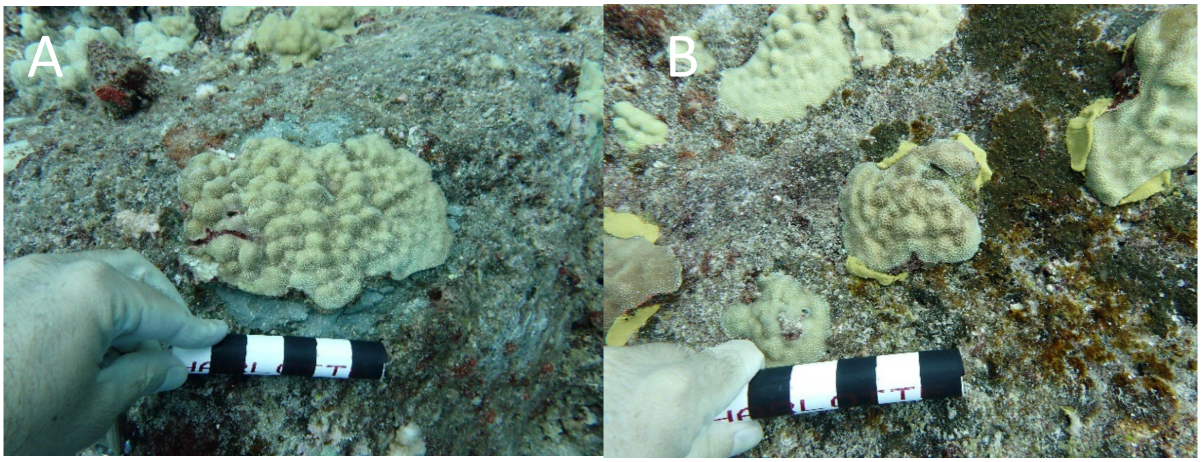

Figure 64. Porites lobata corals of opportunity (COOs) transplanted with A) cement and B) epoxy.

5.5.3 Rubble Stabilization

Another stabilization approach involves areas of the reef that are composed primarily of unconsolidated rubble, where coral recruitment has been less successful likely due to constantly moving substrate. DAR staff are testing stabilization methods such as pinning mesh over the rubble (Figure 66). Once secured, divers will attach COOs to the mesh to promote natural stabilization and growth. Various materials, including basalt fiber mesh and stainless-steel threaded rods, are being tested. Restoration staff will continue to monitor these stabilized areas to ensure that the mesh is still secure, check if coral recruitment is increasing, and record observations of natural coral growth and stability. The metrics used to determine success of rubble stabilization projects usually include changes in coral cover as well as structural complexity (Ceccarelli et al, 2020).

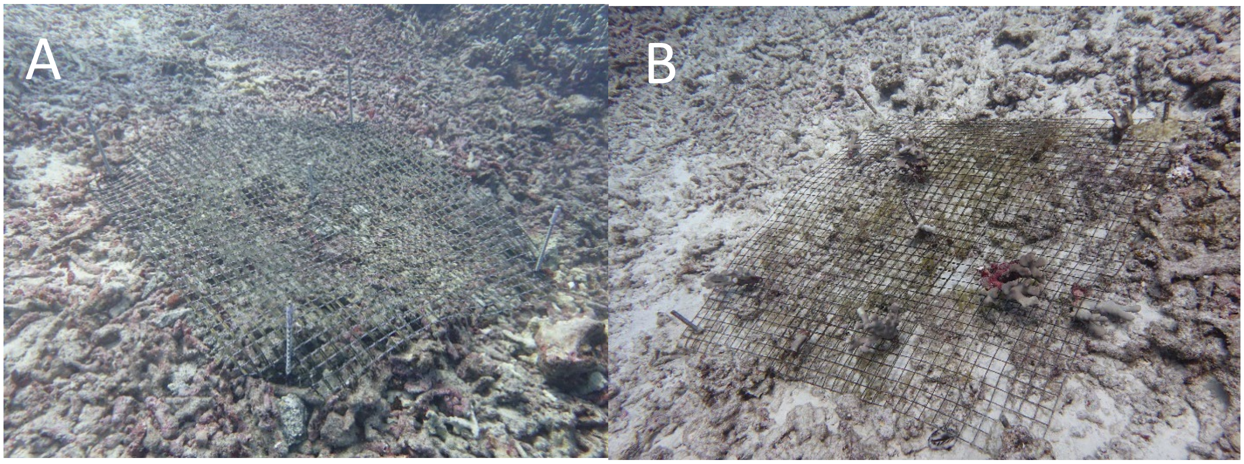

***Figure 65**. Reef rubble stabilization with the use of mesh. A) Basalt fiber mesh recently installed onto a rubble field. B) Stainless steel mesh 2 months after installation with new corals of opportunity attached. Restoration site for reef stabilization in Kealakekua Bay, 2024.*

5.5.4 Post-Restoration Monitoring

A comprehensive monitoring protocol is being developed for restoration sites to ensure that appropriate metrics are tracked, and the effectiveness of methodologies can be quantified. Staff will return to outplanting sites to capture images of reattached corals and record observations of health condition. A photogrammetry survey will be performed at some sites or larger survey plots to later build and analyze metrics for live coral cover and rugosity. These data will help assess the effectiveness of stabilization and reattachment across different reefs in West Hawaiʻi. Monitoring will occur at 2-5 weeks, 6 months, and 12 months after initial outplanting. The first monitoring event will determine whether any changes to the reattachment strategy significantly affect coral survival and success. Subsequent visits will allow staff to observe long-term survival, growth, and other environmental impacts, such as changes in fish assemblages and reef rugosity.

5.5.5 Land-Based Coral Nursery

The DAR Kona team is collaborating with ASU to develop a large-scale land-based coral restoration nursery located within the Hawaiʻi Ocean Science and Technology (HOST) Park. The 3RC nursery features 72 raceways, each with a capacity of 200 gallons (Figure 67). The park supplies water for a flow-through system, enabling optimal quarantine conditions for corals in the tanks. DAR staff are refining the fragmentation process for each coral species commonly found in Hawaiʻi, aiming to identify methods that maximize survival and accelerate growth for rapid tissue recovery (Knapp et al., 2022). The fragments grown in the nursery will be outplanted back to the reef, spaced at distances that will facilitate growth and fusion into sexually mature colonies in a fraction of the time it would take for the original corals to reach sexual maturity. Beyond fragmentation and propagation, this facility can support additional restoration-focused efforts including assisted sexual reproduction, thermal resilience testing, asexual propagation, and numerous other research projects. Additionally, staff at the nursery are working to enhance capacity and knowledge of coral husbandry, endeavoring to facilitate the growth of restoration efforts throughout Hawaiʻi.

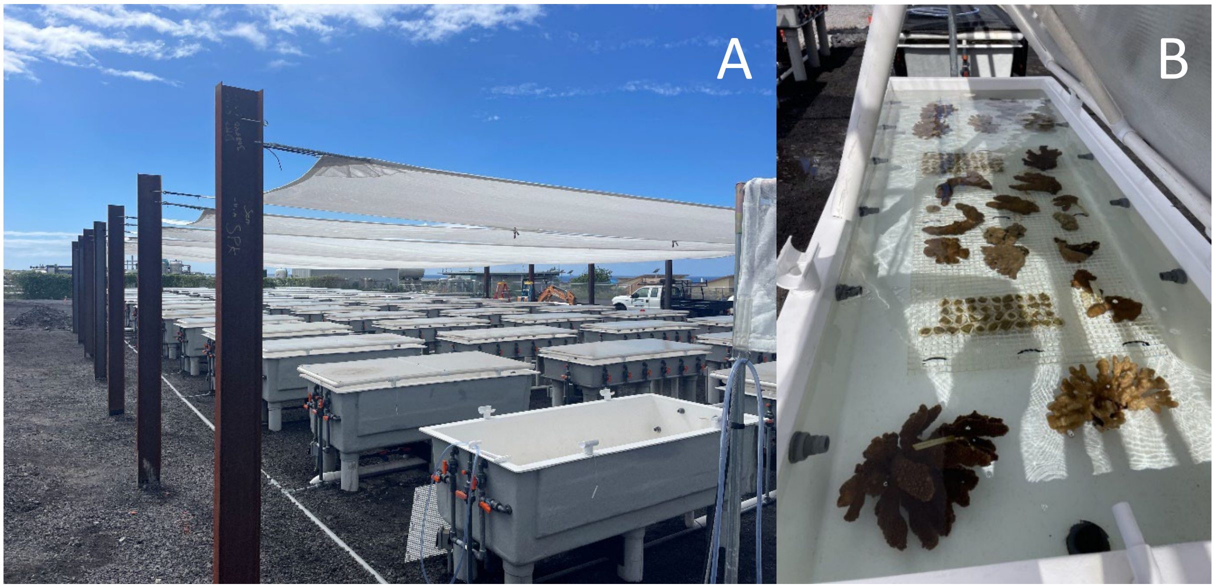

Figure 66. *The Ridge to Reef Restoration Center (3RC) in West Hawai'i: A) view of the coral nursery, and B) corals being held in a tank for restoration purposes.*

CHAPTER 6- SUBSTANTIVE COMMUNITY INVOLVEMENT

One of the key purposes of the WHRFMA was to “provide for substantive involvement of the community in resource management decisions” (§188F-3 HRS). This purpose was included in order to explicitly gather feedback from the broader West Hawai‘i community well prior to the public hearing process, as many had felt the opportunity for community input occurred far too late in the rulemaking process (Maurin and Peck, 2008).

This need had been identified to some extent prior to Act 306. Continued controversy surrounding the commercial aquarium fishery in West Hawai‘i following the formation of the Kona Coast Fisheries Management Area (Section 4.1) led the Hawai‘i House of Representatives to pass House Concurrent Resolution 184 in May of 1996. This resolution called for the designation of a working group (dubbed the West Hawai‘i Reef Fish Working Group, WHRFWG) to provide advice on DAR’s management of the commercial aquarium fishery (Capitini et al., 2004). This group disbanded, however, after little progress was made on a variety of proposed rules and legislative actions (Maurin and Peck, 2008).

As noted briefly in Section 4.3.3, the West Hawai‘i Fishery Council (WHFC) was formed in 1998 around the same time that Act 306 was passed (Maurin and Peck, 2008). The WHFC is seen as a direct successor to the WHRFWG, particularly given considerable overlap in membership between the two groups. Initially, the WHFC’s major task was to assist DLNR in accomplishing the mandates set forth in Act 306. Of particular importance was the WHFC’s inclusion of a variety of stakeholders, with the goal of meeting the “substantive community input” component with broad representation of interests within the West Hawai‘i community (DAR, 2019).

Although DAR and partners in the University of Hawai‘i Sea Grant College Program helped to form the group, the WHFC was never recognized by the legislature as an official entity. Further, there was a conscious decision in the early days for the WHFC to not be supported through state funding in order to maintain autonomy from the government (Maurin and Peck, 2008). Instead, the WHFC has been funded by grants from multiple entities over the years including the National Fish and Wildlife Foundation, the Coastal Zone Management program, the Harold K.L. Castle Foundation, the Hawai‘i Community Foundation, the Malama Kai Foundation, and UH Sea Grant. Recently, however, much of the organization’s activities are funded individually by Council members.

The WHFC has been an important venue for community feedback on DAR’s management decisions since its inception. DAR staff continue to regularly attend the monthly meetings to answer questions and inform the Council on upcoming priorities, decisions, and projects. Over the past 25 years, the WHFC has been heavily involved in a number of key regulatory changes within the WHRFMA. These include:

- Development of the FRA network
- Establishment of the Netting Restricted Areas as mandated by Act 306
- Siting of new Day-Use Moorings and community outreach about the program at large
- Amendment of the regulations within the Old Kona Airport MLCD to allow for limited harvest of wana (sea urchins)

The WHFC was also instrumental in the passage of the revised WHRFMA rules (HAR 13-60.4) in 2013 (Section 4.1). This revision included some of the largest changes to the WHRFMA regulations to date including the implementation of the “white list”, size and bag limits for aquarium take of lauʻīpala, kole, and pākuʻikuʻi, establishment of the new Pebble Beach FRA, prohibition of take of several “Species of Special Concern”, and the prohibition of SCUBA spearfishing.

In more recent years, additional community networks have been formed in West Hawaiʻi to achieve goals broadly similar to those of the WHFC. Although they differ in priorities and membership, they share a focus on gathering input from the communities they represent and help to inform and advise DAR on management decisions. Three such networks are currently active in West Hawaiʻi and DAR staff regularly participate in meetings. The Kai Kuleana Network, currently facilitated by The Nature Conservancy (TNC) connects around 15 communities in West Hawaiʻi with a focus on coral reefs. The South Kohala Coastal Partnership focuses on mauka to makai efforts to manage and restore coastal and marine ecosystems in South Kohala. This group has been funded and supported by NOAA, DAR, UH Sea Grant, and TNC. The Hawaiʻi Fisherman’s Alliance for Conservation and Tradition is a statewide group with a contingent on Hawaiʻi Island that is focused primarily on education, information exchange, and advocacy for fishers.

Beyond these larger community networks, there are many groups and non-profits focused on issues facing nearshore reefs in specific communities. Staff in DAR’s West Hawaiʻi district make efforts to interface with as many of these groups, organizations, and networks as possible, however historically there has not been sufficient capacity to do so effectively. While recent increases in staffing have helped to alleviate this, additional capacity is warranted to ensure the voices comprising these varied organizations are heard and proper consultation is achieved.

A remaining question is how well all user groups are represented within each of these entities and across all organizations. It has become clear through a variety of public meetings in recent years that substantial portions of ocean users tend to be less active in organized groups as well as in DAR-hosted public scoping sessions and public hearings. Notably, these potentially underrepresented user groups include many shore-based, non-commercial fishers including spear, net, and pole/line-based fishers. While many groups do include individuals participating in these activities, DAR staff often hear that a substantial number of these fishers are either unaware, uninterested, or unwilling to participate in these types of dialogue.

DAR’s Holomua Initiative may provide an opportunity to resolve some of these issues. The Holomua process has been progressing on Maui over the past two years and plans are to initiate this process on Hawaiʻi Island in the near future. This will involve the formation of a community-nominated “Navigation Team” that would develop management recommendations for Hawaiʻi Island. One scenario could capitalize on this process by asking a broad range of user groups as well as each of those groups listed previously on how best to ensure their voices, expertise, and knowledge are considered, and how to foster meaningful collaboration among different groups. Through these types of inclusive collaborations, DAR’s Holomua Initiative hopes to provide an avenue to recognize common goals that can be aligned and incorporated into management actions, such as drafting island and/or region wide management plans.

Considering the aforementioned, DAR’s West Hawaiʻi staff have identified the following needs and goals to more effectively meet the “Substantive Community Input” purpose of Act 306:

1) Work to build stronger relationships with fishers through various means including fisher-dependent monitoring activities such as HMRFS, fishing tournaments, collaborative research, information sessions, and one-on-one “talk-story” opportunities.

2) Through the Holomua process, work with individuals, communities, advocacy groups, and networks to better understand how best to engage productively on marine management topics and encourage collaboration.

3) Expand capacity within DAR’s West Hawaiʻi district for the following categories:
   a) Education- Currently there is one education specialist for all of Hawaiʻi Island, based in DAR’s Hilo office. While that staff member is active in West Hawaiʻi, there are simply too many needs for outreach, education, and connection with communities for a single specialist to cover. Additional capacity could provide an effective conduit between fishers and West Hawaiʻi district staff while also helping to increase our ability to host educational and outreach-focused events, thereby helping to address Goals 1 and 2.

   b) Fisheries research- There is a general need to bolster the fisheries-focused knowledgebase within the West Hawaiʻi district office and help to increase capacity for topics discussed in Chapter 4. This could also help to address Goal 1 above by engaging directly with fishers through the development of pilot collaborative research projects.

CHAPTER 7- MANAGEMENT RECOMMENDATIONS

Based on the findings above, the following recommendations are proposed:

1. Continue current fish and invertebrate monitoring programs while incorporating additional methods and sampling locations to fill key data gaps (e.g., shallow shoreline surveys, camera-based methods, hook-and-line methods).

2. Continue benthic monitoring at long-term fixed sites (WHAP and FAHU) as these data are crucial to assess changes in reef habitats and associated reef organisms. With continued thermal stress events forecasted, monitoring data generated by these projects will continue to provide important information on spatial and temporal patterns of coral mortality and recovery.

3. As monitoring and evaluation of the West Hawaiʻi Regional Fishery Management Area is a requirement of Act 306 and is a key component of understanding changes to nearshore fisheries and ecosystems, DAR's monitoring activities in West Hawaiʻi should be financially supported by the State of Hawaiʻi as much as possible. Currently, this work is funded in part by the State via staff time and in part by the NOAA Coral Reef Conservation Program.

4. Work to build stronger relationships with fishers through various means including fishery-dependent monitoring activities (e.g., HMRFS), fishing tournaments, collaborative research, information sessions, and one-on-one "talk-story" opportunities.

5. Through the Holomua process, work with individuals, communities, advocacy groups, and networks to better understand how best to engage on marine management topics and encourage collaborations.

6. Support ongoing community co-management activities by providing clear guidance to community partners on roles and responsibilities.

7. Continue to support the expansion of coral restoration activities in West Hawaiʻi including coral damage response, community restoration projects, water quality linkages, and large-scale restoration.

8. Produce mapping products to educate mariners on best practices when anchoring in West Hawaiʻi, particularly around Kailua Bay.

9. Expand support for the West Hawaiʻi day-use mooring buoy system to ensure timely maintenance and repair.

10. Support and expand ongoing initiatives to understand, mitigate, and reduce land-based sources of pollution including but not limited to wastewater projects at Puakō and Kealakehe, ungulate removals, and sediment flow in Kohala.

11. Collaborate with DAR’s Fisheries program to produce a report on the state of fishery-dependent monitoring information for West Hawaiʻi acknowledging key needs and data gaps.

12. Produce detailed monitoring plans for each active monitoring project, outlining the design, scope, methodology, and analytical procedure. Monitoring plans should clearly define the limitations of the datasets.

13. Expand capacity within DAR’s West Hawaiʻi district and the Division at large for the following broad categories:

    a. Education - Currently there is one education specialist for all of Hawaiʻi Island, based in DAR’s Hilo office. While that staff member is active in West Hawaiʻi, there are simply too many needs for outreach, education and connection with communities for a single specialist to cover. Additional capacity could provide an effective conduit between fishers and West Hawaiʻi district staff while also helping to increase our ability to host educational and outreach-focused events.

    b. Fisheries Research - There is a general need to bolster the fisheries-focused knowledgebase within the West Hawaiʻi district office and help to increase capacity for topics discussed in Chapter 4. This would also help to address Recommendation 6 above by engaging directly with fishers through the development of pilot collaborative research projects.

    c. Land-based sources of pollution and water quality - Additional capacity focused on these issues would allow us to better collaborate with partners working in this space and provide an effective link to our ongoing monitoring, restoration, and management work.

    d. Social science - Expertise in social science and socioeconomics would be valuable for the Division to better understand the motivations, drivers, and sentiments surrounding resource uses and ensure proposed management actions are both aligned with resources uses and likely to achieve their stated goals.

14. Support the expansion of the Division of Conservation and Resource Enforcement (DOCARE) to build the capacity to ensure that regulations are enforced across the extent of the WHRFMA.

ACKNOWLEDGEMENTS

Mahalo nui to the numerous individuals, organizations, and partners that have played and continue to play important roles in the aquatic resource co-management of West Hawai'i. Many have laid the groundwork and many more continue to work towards a successful and collaborative future. Invaluable contributions have been made by those who are listed here and by many others who care for these resources.

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). Funding since 2019 has been provided from NOAA awards NA19NOS4820051, NA21NOS4820017, and NA23NOS4820148. Coral Restoration has been funded thus far through federal Congressionally Directed Spending under NOAA awards NA22NMF4690311 and NA23NOS4690269.

The administration of the above grants would not have been possible without support by the Hawai'i Coral Reef Initiative Research Program (HCRI-RP). HCRI-RP was established in 1998 through the University of Hawaiʻi Social Science Research Institute to support scientific research and monitoring to enhance the state's capacity to manage its coral reef resources.

Thank you to the many community groups, researchers, and partners who provide continual support and stewardship: NOAA, the University of Hawaiʻi, The Nature Conservancy, Arizona State University, Conservation International Hawai'i, Hui Aloha Kīholo, Kalanihale, Kai Kuleana, Hoʻāla Kealakekua Nui, and the West Hawaiʻi Fishery Council. Our appreciation is extended for the technical training, support, and collaboration from the Multiscale Environmental Graphical Analysis (MEGA) Lab and the Hawaiʻi Monitoring and Reporting Collaborative (HIMARC).

We would like to express our sincere gratitude to Dr. William J. Walsh (aka DB) for his unwavering dedication and tireless efforts in establishing a strong foundation for the management of marine resources in West Hawaiʻi. His extensive contributions, including the development of collaborative processes and the implementation of large-scale data collection methods, have been instrumental in supporting ongoing efforts.

Mahalo to the many contributors and data collectors for the West Hawaiʻi DAR projects over the past 25 years, including those the individuals who contributed to data collection during this reporting period: Devon Aguiar, Akara Blaies, Camille Barnett, Alli Craig, Zack Craig, Bryant Grady, Cynthia Hankins, Nathan Hayes, Neal Hoogenboom, Laura Jackson, Lindsey Kramer, Megan Leatherman, Sydney Lewis, Keelee Martin, Ashlynn Overly, Linda Preskitt, Shannon Shea, Nikki Smith, Chris Teague, Ashley Wills.

REFERENCES

Asner, G.P., Vaughn, N.R., Heckler, J., 2024. Operational Mapping of Submarine Groundwater Discharge into Coral Reefs: Application to West Hawaiʻi Island. Oceans 5, 547–559. https://doi.org/10.3390/oceans5030031

Battista, T.A., Costa, B.M., Anderson, S.M., 2007. Shallow Water Benthic Habitats of the Main Eight Hawaiian Islands (NOAA Technical Memorandum No. NCCOS 61). NOAA Biogeography Branch.

Blumenstock, D., Price, S., 1967. Climate of Hawaii, in: Climates of the States, No. 60-51, Climatography of the United States. U.S. Department of Commerce.

Capitini, C.A., Tissot, B.N., Carroll, M.S., Walsh, W.J., Peck, S., 2004. Competing Perspectives in Resource Protection: The Case of Marine Protected Areas in West Hawaiʻi. Society & Natural Resources 17, 763–778. https://doi.org/10.1080/08941920490493747

Chen, Q., Beijbom, O., Chan, S., Bouwmeester, J., Kriegman, D., 2021. A New Deep Learning Engine for CoralNet, in: 2021 IEEE/CVF International Conference on Computer Vision Workshops (ICCVW). Presented at the 2021 IEEE/CVF International Conference on Computer Vision Workshops (ICCVW), IEEE, Montreal, BC, Canada, pp. 3686–3695. https://doi.org/10.1109/ICCVW54120.2021.00412

Clague, D.A., Dalrymple, B.G., 1994. Tectonics, Geochronology, and Origin of the Hawaiian-Emperor Volcanic Chain, in: A Natural History of the Hawaiian Islands. University of Hawaii Press, pp. 5–40. https://doi.org/10.1515/9780824844264-003

Couch, C.S., Garriques, J.D., Barnett, C., Preskitt, L., Cotton, S., Giddens, J., Walsh, W., 2014. Spatial and temporal patterns of coral health and disease along leeward Hawai'i Island. Coral Reefs 33, 693–704. https://doi.org/10.1007/s00338-014-1174-x

DAR, 2024a. History of the West Hawaii Commercial Aquarium Fishery. Division of Aquatic Resources.

DAR, 2024b. Data Review and Management Brief for the West Hawaiʻi Commercial Aquarium Fishery. Division of Aquatic Resources.

DAR, 2024c. Hawaii Marine Recreational Fishing Survey [WWW Document]. Division of Aquatic Resources. URL https://dlnr.hawaii.gov/dar/fishing/hmrfs/

DAR, 2019. Findings and Recommendations of Effectiveness of the West Hawaii Regional Fishery Management Area (WHRFMA). Division of Aquatic Resources.

DAR, 2004. Findings and Recommendations of Effectiveness of the West Hawaii Regional Fishery Management Area (WHRFMA). Division of Aquatic Resources.

DAR, 2000. Aquarium Collecting in West Hawaii: A Historical Overview. Division of Aquatic Resources.

DeMartini, E.E., Anderson, T.W., 2007. Habitat associations and aggregation of recruit fishes on Hawaiian coral reefs. Bulletin of Marine Science 81.

Dollar, S.J., 1982. Wave stress and coral community structure in Hawaii. Coral Reefs 1, 71–81. https://doi.org/10.1007/BF00301688

Dollar, S.J., Tribble, G.W., 1993. Recurrent storm disturbance and recovery: a long-term study of coral communities in Hawaii. Coral Reefs 12, 223–233. https://doi.org/10.1007/BF00334481

Fukunaga, A., Burns, J.H.R., 2020. Metrics of Coral Reef Structural Complexity Extracted from 3D Mesh Models and Digital Elevation Models. Remote Sensing 12, 2676. https://doi.org/10.3390/rs12172676

Fukunaga, A., Burns, J.H.R., Pascoe, K.H., Kosaki, R.K., 2020. Associations between Benthic Cover and Habitat Complexity Metrics Obtained from 3D Reconstruction of Coral Reefs at Different Resolutions. Remote Sensing 12, 1011. https://doi.org/10.3390/rs12061011

Gitzen, R.A., Millspaugh, J.J., Cooper, A.B., Licht, D.S. (Eds.), 2012. Design and analysis of long-term ecological monitoring studies. Cambridge University Press, Cambridge New York.

Glynn, P.W., Manzello, D.P., 2015. Bioerosion and Coral Reef Growth: A Dynamic Balance, in: Birkeland, C. (Ed.), Coral Reefs in the Anthropocene. Springer Netherlands, Dordrecht, pp. 67–97. https://doi.org/10.1007/978-94-017-7249-5_4

Gove, J.M., Lecky, J., Walsh, W.J., Ingram, R.J., Leong, K., Williams, I.D., Polovina, J.J., Maynard, J., Whittier, R., Kramer, K.L., Schemmel, E., Hospital, J., Wongbusarakum, S., Conklin, E., Wiggins, C., Williams, G.J., 2019. West Hawai'i Intergrated Ecosystem Assessment Ecosystem Status Report (No. SP-19-001), PIFSC Special Publication. Pacific Island Fisheries Science Center.

Gove, J.M., Williams, G.J., Lecky, J., Brown, E., Conklin, E., Counsell, C., Davis, G., Donovan, M.K., Falinski, K., Kramer, L., Kozar, K., Li, N., Maynard, J.A., McCutcheon, A., McKenna, S.A., Neilson, B.J., Safaie, A., Teague, C., Whittier, R., Asner, G.P., 2023. Coral reefs benefit from reduced land–sea impacts under ocean warming. Nature 621, 536–542. https://doi.org/10.1038/s41586-023-06394-w

Hixon, M.A., 1991. Predation as a Process Structuring Coral Reef Fish Communities, in: The Ecology of Fishes on Coral Reefs. Elsevier, pp. 475–508. https://doi.org/10.1016/B978-0-08-092551-6.50022-2

Hobson, E.S., 1974. Feeding Relationships of Teleostean Fishes on Coral Reefs in Kona, Hawaii. Fish Bull 72, 915–1031.

Hoover, J.P., 1998. Hawai'i's sea creatures: a guide to Hawai'i's marine invertebrates. Mutual Pub, Honolulu, Hawaii.

Howard, K.G., Claisse, J.T., Clark, T.B., Boyle, K., Parrish, J.D., 2013. Home range and movement patterns of the Redlip Parrotfish (Scarus rubroviolaceus) in Hawaii. Mar Biol 160, 1583–1595. https://doi.org/10.1007/s00227-013-2211-y

Johansson, C., Bellwood, D., Depczynski, M., 2010. Sea urchins, macroalgae and coral reef decline: a functional evaluation of an intact reef system, Ningaloo, Western Australia. Mar. Ecol. Prog. Ser. 414, 65–74. https://doi.org/10.3354/meps08730

Jokiel, P.L., 2008. Biology and Ecological Functioning of Coral Reefs in the Main Hawaiian Islands, in: Riegl, B.M., Dodge, R.E. (Eds.), Coral Reefs of the USA. Springer Netherlands, Dordrecht, pp. 489–517. https://doi.org/10.1007/978-1-4020-6847-8_12

Kay, E.A., Lau, L.S., Stroup, E.D., 1977. Hydrologic and Ecologic Inventories of the Coastal Waters of West Hawaii.

Kittinger, J.N., Teneva, L.T., Koike, H., Stamoulis, K.A., Kittinger, D.S., Oleson, K.L.L., Conklin, E., Gomes, M., Wilcox, B., Friedlander, A.M., 2015. From Reef to Table: Social and Ecological Factors Affecting Coral Reef Fisheries, Artisanal Seafood Supply Chains, and Seafood Security. PLoS ONE 10, e0123856. https://doi.org/10.1371/journal.pone.0123856

Knee, K.L., Street, J.H., Grossman, E.E., Boehm, A.B., Paytan, A., 2010. Nutrient inputs to the coastal ocean from submarine groundwater discharge in a groundwater-dominated system: Relation to land use (Kona coast, Hawaii, U.S.A.). Limnology & Oceanography 55, 1105–1122. https://doi.org/10.4319/lo.2010.55.3.1105

Kohler, K.E., Gill, S.M., 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. Computers & Geosciences 32, 1259–1269. https://doi.org/10.1016/j.cageo.2005.11.009

Kramer, K.L., Cotton, S.P., Lamson, M.R., Walsh, W.J., 2016. Bleaching and catastrophic mortality of reef-building corals along west Hawaii Island: Findings and future directions. Presented at the 13th International Coral Reef Symposium, Honolulu, Hawaii.

Lecky, J.H., 2016. Ecosystem Vulnerability and Mapping Cumulative Impacts on Hawaiian Reefs. University of Hawaii, Mānoa.

Luo, X., Frazier, A.G., Diaz, H.F., Longman, R., Giambelluca, T.W., 2024. Routine Climate Monitoring in the State of Hawaiʻi: Establishment of State Climate Divisions. Bulletin of the American Meteorological Society 105, E1045–E1061. https://doi.org/10.1175/BAMS-D-23-0236.1

Ma, H., Ogawa, T., Lowe, K., Voorhees, D., Sminkey, T., Yau, A., Quach, M., O'Malley, J., Dukes, S., Opsomer, J., Lesser, V., Matthews, T., Sabater, M., Torres, A., Tibbatts, B., 2019. Developing Certified Surveys for the Hawaii Marine Recreational Fishing Survey: MRIP Workshop Summary Report (NOAA Administrative Report No. H-19-06). National Oceanic and Atmospheric Administration.

Ma, H., Ogawa, T.K., 2016. Hawaii Marine Recreational Fishing Survey : a summary of current sampling, estimation and data analyses. (NOAA-TM-NMFS-PIFSC-55), NOAA Technical Memo. U.S. Department of Commerce.

Maurin, P., Peck, S., 2008. The West Hawaiʻi Fisheries Council Case Study Report. University of Hawaii Sea Grant College Program.

Maynard, J., Conklin, E., Minton, D., Most, R., Couch, C.S., Williams, G.J., Gove, J.M., Dieter, T., Schumacher, B., Walsh, W.A., Harper, D. (Douglas R., Jayewardene, D., Parker, B.-A.A., Watson, L.M., 2016. Relative resilience potential and bleaching severity in the West Hawai'i Habitat Focus Area in 2015. https://doi.org/10.7289/V5T43R4Z

McCoy, K.S., Williams, I.D., Friedlander, A.M., Ma, H., Teneva, L., Kittinger, J.N., 2018. Estimating nearshore coral reef-associated fisheries production from the main Hawaiian Islands. PLoS ONE 13, e0195840. https://doi.org/10.1371/journal.pone.0195840

Ortiz, D.M., Tissot, B.N., 2012. Evaluating ontogenetic patterns of habitat use by reef fish in relation to the effectiveness of marine protected areas in West Hawaii. Journal of Experimental Marine Biology and Ecology 432–433, 83–93. https://doi.org/10.1016/j.jembe.2012.06.005

Osenberg, C.W., Schmitt, R.J., 1996. Detecting Ecological Impacts Caused by Human Activities, in: Detecting Ecological Impacts. Elsevier, pp. 3–16. https://doi.org/10.1016/B978-012627255-0/50003-3

Quinn, G.P., Keough, M.J., 2002. Experimental Design and Data Analysis for Biologists. Cambridge University Press.

Samoilys, M.A., Carlos, G., 2000. Determining Methods of Underwater Visual Census for Estimating the Abundance of Coral Reef Fishes. Environmental Biology of Fishes 57, 289–304. https://doi.org/10.1023/A:1007679109359

Silbiger, N.J., Donahue, M.J., Brainard, R.E., 2017. Environmental drivers of coral reef carbonate production and bioerosion: a multi-scale analysis. Ecology 98, 2547–2560. https://doi.org/10.1002/ecy.1946

Street, J.H., Knee, K.L., Grossman, E.E., Paytan, A., 2008. Submarine groundwater discharge and nutrient addition to the coastal zone and coral reefs of leeward Hawai'i. Marine Chemistry 109, 355–376. https://doi.org/10.1016/j.marchem.2007.08.009

Talbot, R., 2014. "Biblical" Spawning Event of Hawaiian Reefs [WWW Document]. Coral Magazine. URL https://www.coralmagazine.com/2014/08/29/biblical-spawning-event-on-hawaiian-reefs/ (accessed 10.27.24).

Thanopoulou, Z., Sini, M., Vatikiotis, K., Katsoupis, C., Dimitrakopoulos, P.G., Katsanevakis, S., 2018. How many fish? Comparison of two underwater visual sampling methods for monitoring fish communities. PeerJ 6, e5066. https://doi.org/10.7717/peerj.5066

Titcomb, M., 1972. Native use of fish in Hawaii, 2nd ed. University Press of Hawaii, Honolulu.

Wabnitz, C., Balazs, G., Beavers, S., Bjorndal, K., Bolten, A., Christensen, V., Hargrove, S., Pauly, D., 2010. Ecosystem structure and processes at Kaloko Honokohau, focusing on the role of herbivores, including the green sea turtle Chelonia mydas, in reef resilience. Mar. Ecol. Prog. Ser. 420, 27–44. https://doi.org/10.3354/meps08846

Walsh, W., Cotton, S., Barnett, C., Couch, C., Preskitt, L., Tissot, B., Osada-D'Avella, K., 2013. Long-Term Monitoring of Coral Reefs of the Main Hawaiian Islands. Division of Aquatic Resources.

Walsh, W.J., Cotton, S.S.P., Dierking, J., Williams, I.D., 2004. The Commercial Marine Aquarium Fishery in Hawai'i 1976-2003. Status of Hawaii's coastal fisheries in the new millennium, revised. A.M. Friedlander (ed.) Proceeding of the 2001 fisheries symposium sponsored by the American Fisheries Society, Hawaii Chapter, Honolulu, Hawaii. pp 129–156.

Walsh, W.J., Zamzow, J.P., Kramer, L., 2018. Continued long-term decline of the coral reef biota at Puakō and Pauoa, West Hawai'i (1979 – 2008). Division of Aquatic Resources.

Wedding, L.M., Lecky, J., Gove, J.M., Walecka, H.R., Donovan, M.K., Williams, G.J., Jouffray, J.-B., Crowder, L.B., Erickson, A., Falinski, K., Friedlander, A.M., Kappel, C.V., Kittinger, J.N., McCoy, K., Norström, A., Nyström, M., Oleson, K.L.L., Stamoulis, K.A., White, C., Selkoe, K.A., 2018. Advancing the integration of spatial data to map human and natural drivers on coral reefs. PLoS ONE 13, e0189792. https://doi.org/10.1371/journal.pone.0189792

Williams, I.D., Kindinger, T.L., Couch, C.S., Walsh, W.J., Minton, D., Oliver, T.A., 2019. Can Herbivore Management Increase the Persistence of Indo-Pacific Coral Reefs? Front. Mar. Sci. 6, 557. https://doi.org/10.3389/fmars.2019.00557

Appendix A

Table A-1 Species list of commonly observed fish in West Hawai‘i. This list has been shortened to represent fish species commonly observed in fish surveys and is not a comprehensive list of all fish species documented in West Hawai‘i.

Family	Hawaiian Name	Common Name	Scientific Name
Angelfishes		Fisher’s angelfish	*Centropyge fisheri*
		Flame angelfish	*Centropyge loricula*
		Potter’s angelfish	*Centropyge potteri*
Barracudas	kākū	Great barracuda	*Sphyraena barracuda*
	kawele‘ā	Heller‘s barracuda	*Sphyraena helleri*
Bigeyes	‘āweoweo	Common bigeye	*Heteropriacanthus cruentatus*
	‘āweoweo	Hawaiian bigeye	*Priacanthus meeki*
Butterflyfishes	kīkākapu	Threadfin butterflyfish	*Chaetodon auriga*
	kīkākapu	Saddleback butterflyfish	*Chaetodon ephippium*
	kīkākapu	Blacklip butterflyfish	*Chaetodon kleinii*
	kīkākapu	Racoon butterflyfish	*Chaetodon lunula*
	kapuhili	Oval butterflyfish	*Chaetodon lunulatus*
	lauwiliwili	Milletseed butterflyfish	*Chaetodon miliaris*
	kīkākapu	Multiband butterflyfish	*Chaetodon multicinctus*
	kīkākapu	Ornate butterflyfish	*Chaetodon ornatissimus*
	lauhau	Fourspot butterflyfish	*Chaetodon quadrimaculatus*
		Reticulated butterflyfish	*Chaetodon reticulatus*
	lauhau	Teardrop butterflyfish	*Chaetodon unimaculatus*
	lauwiliwili nukunuku ‘oi‘oi	Forcepsfish	*Forcipiger flavissimus*
	lauwiliwili nukunuku ‘oi‘oi	Big longnose butterflyfish	*Forcipiger longirostris*
		Pyramid butterflyfish	*Hemitaurichthys polylepis*
		Thompson’s butterflyfish	*Hemitaurichthys thompsoni*
Cardinalfishes	upāpalu	Iridescent cardinalfish	*Pristiapogon kallopterus*
Chubs	nenue	Chub	*Kyphosus spp.*
Cornetfishes	nūnū	Bluespotted cornetfish	*Fistularia commersonii*
Damselfishes	mamo	Hawaiian sergeant	*Abudefduf abdominalis*
		Indo-pacific sergeant	*Abudefduf vaigiensis*
		Agile chromis	*Chromis agilis*
		Chocolate-dip chromis	*Chromis hanui*
		Whitetail chromis	*Chromis leucura*
		Oval chromis	*Chromis ovalis*
		Blackfin chromis	*Chromis vanderbilti*
		Threespot chromis	*Chromis verater*
	ālo‘ilo‘i	Hawaiian dascyllus	*Dascyllus albisella*
		Bright-eye damselfish	*Plectroglyphidodon imparipennis*
		Blue-eye damselfish	*Plectroglyphidodon johnstonianus*
		Hawaiian gregory	*Stegastes marginatus*
Emperors	mū	Bigeye emperor	*Monotaxis grandoculis*
Filefishes	loulu	Scrawled filefish	*Aluterus scriptus*
	‘ō‘ili	Barred filefish	*Cantherhines dumerilii*
	‘ō‘ili lepa	Squaretail filefish	*Cantherhines sandwichiensis*
	‘ō‘ili	Shy filefish	*Cantherhines verecundus*
	‘ō‘ili	Yellowtail filefish	*Pervagor aspricaudus*
Flagtails	āholehole	Reticulated flagtail	*Kuhlia sandvicensis*
	āholehole	Hawaiian flagtail	*Kuhlia xenura*

Goatfishes	wekeʻā	Square-spot goatfish	*Mulloidichthys flavolineatus*
	wekeʻula	Yellowfin goatfish	*Mulloidichthys vanicolensis*
	moano ukali ulua	Blue goatfish	*Parupeneus cyclostomus*
	munu	Island goatfish	*Parupeneus insularis*
	moano	Manybar goatfish	*Parupeneus multifasciatus*
	malu	Sidespot goatfish	*Parupeneus pleurostigma*
	kūmū	Whitesaddle goatfish	*Parupeneus porphyreus*
Groupers & Anthias		Peacock grouper, roi	*Cephalopholis argus*
		Hawaiian longfin anthias	*Compsanthias hawaiiensis*
		Bicolor anthias	*Pseudanthias bicolor*
Hawkfishes	pilikoʻa	Redbar hawkfish	*Cirrhitops fasciatus*
	poʻopaʻa	Stocky hawkfish	*Cirrhitus pinnulatus*
	pilikoʻa	Arc-eye hawkfish	*Paracirrhites arcatus*
	hilu pilikoʻa	Blackside hawkfish	*Paracirrhites forsteri*
Lizardfishes	ʻulae	Lizardfish	*Synodus spp.*
Milkfish	awa	Milkfish	*Chanos chanos*
Moorish Idol	kihikihi	Moorish idol	*Zanclus cornutus*
Mullets	ʻamaʻama	Stripped mullet	*Mugil cephalus*
	uouoa	Sharpnose mullet	*Neomyxus leuciscus*
Parrotfishes	pōnuhunuhu	Stareye parrotfish	*Calotomus carolinus*
	uhu	Yellowbar parrotfish	*Calotomus zonarchus*
	uhu ʻahuʻula (initial), uhu uliuli (terminal)	Spectacled parrotfish	*Chlorurus perspicillatus*
	uhu	Bullethead parrotfish	*Chlorurus spilurus*
	lauia	Regal parrotfish	*Scarus dubius*
	uhu	Palenose parrotfish	*Scarus psittacus*
	uhu pālukaluka (initial), uhu ʻeleʻele (terminal)	Ember parrotfish	*Scarus rubroviolaceus*
Porcupinefishes	kōkala	Longspine porcupinefish	*Diodon holocanthus*
	kōkala	Giant porcupinefish	*Diodon hystrix*
Pufferfishes	ʻoʻopu hue	Stripebelly puffer	*Arothron hispidus*
	ʻoʻopu hue	Spotted puffer	*Arothron meleagris*
		Ambon toby	*Canthigaster amboinensis*
	puʻu olau	Crowned toby	*Canthigaster coronata*
		Hawaiian whitespotted toby	*Canthigaster jactator*
Snappers	wahanui	Forktail snapper	*Aphareus furca*
	uku	Green jobfish	*Aprion virescens*
		Blacktail snapper, toʻau	*Lutjanus fulvus*
		Bluestripe snapper, taʻape	*Lutjanus kasmira*
Squirrelfishes & Soldierfishes	ʻūʻū	Bigscale soldierfish	*Myripristis berndti*
	ʻūʻū	Epaulette soldierfish	*Myripristis kuntee*
	ʻalaʻihi	Spotfin squirrelfish	*Neoniphon sammara*
	ʻalaʻihi	Crown squirrelfish	*Sargocentron diadema*
	ʻalaʻihi	Peppered squirrelfish	*Sargocentron punctatissimum*
	ʻalaʻihi	Longjaw squirrelfish	*Sargocentron spiniferum*
	ʻalaʻihi	Bluestripe squirrelfish	*Sargocentron tiere*
	ʻalaʻihi	Hawaiian squirrelfish	*Sargocentron xantherythrum*
Surgeonfishes & Unicornfishes	pākuʻikuʻi	Achilles tang	*Acanthurus achilles*
	pualu	Ringtail surgeonfish	*Acanthurus blochii*
	palani	Eye-stripe surgeonfish	*Acanthurus dussumieri*
	ʻapi	Whitespotted surgeonfish	*Acanthurus guttatus*
	māikoiko	Whitebar surgeonfish	*Acanthurus leucopareius*
		Lined surgeonfish	*Acanthurus lineatus*
		Goldrim surgeonfish	*Acanthurus nigricans*

Surgeonfishes & Unicornfishes	māʻiʻiʻi	Brown surgeonfish	*Acanthurus nigrofuscus*
	maiko	Bluelined surgeonfish	*Acanthurus nigroris*
	naʻenaʻe	Orangeband surgeonfish	*Acanthurus olivaceus*
		Thompson’s surgeonfish	*Acanthurus thompsoni*
	manini	Convict tang	*Acanthurus triostegus*
	pualu	Yellowfin surgeonfish	*Acanthurus xanthopterus*
		Black surgeonfish	*Ctenochaetus hawaiiensis*
	kole	Goldring surgeonfish	*Ctenochaetus strigosus*
	kala lōlō	Paletail unicornfish	*Naso brevirostris*
	ʻōpelu kala	Sleek unicornfish	*Naso hexacanthus*
	umauma lei	Orangespine unicornfish	*Naso lituratus*
	kala	Bluespine unicornfish	*Naso unicornis*
	lauʻīpala	Yellow tang	*Zebrasoma flavescens*
	māneʻoneʻo	Sailfin tang	*Zebrasoma veliferum*
Triggerfishes		Finescale triggerfish	*Balistes polylepis*
	humuhumu ʻeleʻele	Black durgon	*Melichthys niger*
	humuhumu hiʻu kole	Pinktail durgon	*Melichthys vidua*
	humuhumunukunukuāpuaʻa	Lagoon triggerfish	*Rhinecanthus aculeatus*
	humuhumunukunukuāpuaʻa	Reef triggerfish	*Rhinecanthus rectangulus*
	humuhumu lei	Lei triggerfish	*Sufflamen bursa*
	humuhumu mimi	Bridled triggerfish	*Sufflamen fraenatum*
		Gilded triggerfish	*Xanthichthys auromarginatus*
		Blueline triggerfish	*Xanthichthys caeruleolineatus*
Trumpetfishes	nūnū	Trumpetfish	*Aulostomus chinensis*
Wrasses		Psychedelic wrasse	*Anampses chrysocephalus*
	ōpule	Pearl wrasse	*Anampses cuvier*
	ʻaʻawa	Hawaiian hogfish	*Bodianus albotaeniatus*
	kūpoupou	Cigar wrasse	*Cheilio inermis*
	malamalama	Lined coris	*Coris ballieui*
	hilu	Blackstripe coris	*Coris flavovittata*
	hīnālea ʻakilolo	Yellowtail coris	*Coris gaimard*
	hīnālea ʻiʻiwi	Bird wrasse	*Gomphosus varius*
	laʻo	Ornate wrasse	*Halichoeres ornatissimus*
	laenihi	Peacock razor wrasse	*Iniistius pavo*
	laenihi	Blackside razor wrasse	*Iniistius umbrilatus*
		Hawaiian cleaner wrasse	*Labroides phthirophagus*
		Shortnose wrasse	*Macropharyngodon geoffroy*
		Rockmover wrasse	*Novaculichthys taeniourus*
	poʻou	Ringtail wrasse	*Oxycheilinus unifasciatus*
	mālamalama	Disappearing wrasse	*Pseudocheilinus evanidus*
		Eightline wrasse	*Pseudocheilinus octotaenia*
		Fourline wrasse	*Pseudocheilinus tetrataenia*
		Pencil wrasse	*Pseudojuloides cerasinus*
	ōmaka	Belted wrasse	*Stethojulis balteata*
	hīnālea lauhine	Old woman wrasse	*Thalassoma ballieui*
	hīnālea lauwili	Saddle wrasse	*Thalassoma duperrey*
	hou	Surge wrasse	*Thalassoma purpureum*
		Fivestripe wrasse	*Thalassoma quinquevittatum*
	ʻawela	Christmas wrasse	*Thalassoma trilobatum*

Appendix B

Table B-1 Reported commercial aquarium catch for each species from 1999-2017. Species highlighted in blue are those on the "white list". Confidential data (entries representing fewer than three reporting licenses) were removed. Total values highlighted in red are have been recalculated using only non-confidential data. The difference between these recalculated values and the actual reported values amounted to fewer than 300 individual fish across all species and all years.

scientific_name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	% of total catch
Zebrasoma flavescens	166,201	223,273	144,951	153,917	200,616	371,068	354,848	355,829	230,177	283,347	235,328	321,422	275,583	305,728	285,900	290,188	299,110	304,556	221,422	5,023,464	81.16%
Ctenochaetus strigosus	14,691	21,964	13,163	18,508	21,048	37,455	40,441	31,178	28,716	37,462	30,509	45,611	34,757	33,592	29,830	30,215	35,079	35,520	24,382	564,121	9.11%
Acanthurus achilles	9,571	13,737	4,490	6,032	7,657	10,451	13,553	9,428	3,820	3,429	3,024	7,279	6,685	8,017	9,538	6,481	5,097	6,575	4,085	138,949	2.24%
Naso lituratus	7,087	9,972	5,959	5,437	4,054	7,485	9,014	6,737	3,488	4,199	2,464	4,521	4,538	4,541	4,616	5,057	7,313	8,223	4,159	108,864	1.76%
Ctenochaetus hawaiiensis	1,724	820	820	2,563	2,994	5,468	7,114	4,307	1,603	1,774	1,871	2,242	1,640	4,925	3,960	6,805	7,002	5,144	2,691	65,467	1.06%
Forcipiger flavissimus	2,325	2,620	2,045	2,122	1,394	2,726	2,053	2,853	3,069	2,531	1,587	1,420	1,264	1,378	1,061	1,136	885	873	578	33,920	0.55%
Halichoeres ornatissimus	502	529	12,847	1,206	696	1,323	1,244	985	955	892	716	815	845	946	627	942	1,357	1,650	1,196	30,273	0.49%
Chaetodon multicinctus	1,235	1,392	1,348	840	849	1,017	1,920	2,368	1,798	2,125	1,133	1,544	1,054	1,077	704	512	565	315	478	22,274	0.36%
Centropyge potteri	2,359	1,006	540	528	413	413	580	436	942	1,232	783	908	692	708	1,012	1,361	3,105	2,847	1,381	21,246	0.34%
Chaetodon quadrimaculatus	1,665	1,893	551	996	1,009	1,573	1,213	1,048	836	695	491	468	562	948	593	782	858	388	239	16,808	0.27%
Acanthurus olivaceus	358	259	222	782	636	743	1,676	1,396	459	845	691	990	513	950	825	630	773	1,811	910	15,469	0.25%
Acanthurus nigrofuscus					85		1,200	793	2,437	2,790	818	1,254	614	350	142	28	161	1,322	590	12,712	0.21%
Zanclus cornutus	1,818	1,141	730	761	337	457	1,620	252	326	1,530	657	465	161	429	363					11,047	0.18%
Thalassoma duperrey	632	803	691	254	254	856	838	813	683	684	505	626	729	491	357	453	425	612	344	11,050	0.18%
Coris gaimard	612	717	452	453	430	651	798	577	623	763	482	639	727	326	224	448	655	735	441	10,753	0.17%
Acanthurus nigricans	384	199	99	209	209	552	916	852	457	830	398	406	253	530	361	603	650	1,642	773	10,323	0.17%
Labroides phthirophagus	841	1,413	1,082	795	348	716	318	340	512	495	603	604	338	836	708					9,949	0.16%
Gomphosus varius	220	462	191	364	220	398	620	538	530	441	289	407	341	277	135	176	244	308	160	6,321	0.10%
Chaetodon tinkeri	385	354	204	220	205	439	399	351	449	313	176	227	207	221	182	454	490	311	231	5,818	0.09%
Anampses chrysocephalus	264	229	205	155	119	232	118	133	219	313	373	349	395	250	269	240	199	628	337	5,027	0.08%
Canthigaster jactator	492	565	1,006	542	121	284	262	204	75	113	68	133	117	29	15			26	26	4,078	0.07%
Macropharyngodon geoffroy	15	58			26	160	145	113	225	184	189	204	285	218	273	391	516	574	385	3,961	0.06%
Sufflamen bursa	153	53	101	160	42	216	191	252	150	194	246	275	163	190	121	171	274	175	57	3,184	0.05%
Ostracion meleagris	348	350	415	250	133	104	85	82	79	140	167	89	151	219	118	158	112	34	40	3,074	0.05%
Acanthurus dussumieri						341	2,133	129					115							2,975	0.05%
Pseudojuloides cerasinus	29	27		28	23	95	128	117	140	325	252	262	202	181	119	99	252	420	206	2,905	0.05%
Acanthurus thompsoni					61	61	987	31		52	186	102	40	208	99	346	116	153	152	2,779	0.04%
Naso spp.						428	736	241												2,618	0.04%
Acanthurus nigroris						130	197	257	118	332	285	420	287	252	235	20				2,548	0.04%
Chaetodon unimaculatus	149	311	63	145	177	251	322	234	137	213	108	75	55	186	113					2,539	0.04%
Hemitaurichthys polylepis	133	43	131	92	124	62	33	11	10	88	227	176	80	117	70	579	271	111		2,358	0.04%
Pseudocheilinus octotaenia	327	570	91	13	25	43	163	75	70	160	107	138	80	85	15	34	129	131	48	2,304	0.04%
Thalassoma trilobatum						11	111	156	119	590	473	528	233							2,298	0.04%
Paracirrhites arcatus	45	37	45	69	126	132	284	222	138	309	209	212	159	120	93					2,200	0.04%
Dascyllus albisella	187	92		26	39	165	97	94	142	164	173	158	135	64	27	31	194	101	50	1,939	0.03%
Centropyge fisheri				55	18	24	169	36	108	78	76	72	52	55	40	94	227	285	183	1,630	0.03%
Chaetodon miliaris	55	8	58		43	11	48	21	24	94	110	329	155	165	40	15	194	95	69	1,534	0.02%
Melichthys niger	164	120	21	69	72	110	38	12	61	50	110	40	54	188	70	39	56	28	5	1,307	0.02%
Cirrhilabrus jordani				118			13		49		142	70	93	41	78	76	60	7		1,254	0.02%
Centropyge loricula		53		21		7	45	53	148	169	141	148	135	133	92					1,229	0.02%
Pseudocheilinus tetrataenia				12		23	65	115	117	151	84	98	82	26	35	65	77	47	38	1,066	0.02%
Chaetodon kleinii	26	38			25	87	117	48	164	120	22	99	32	31				70	67	1,022	0.02%
Abudefduf abdominalis																					0.00%
Acanthuridae (family)	25			51	9	41	58	20	9	18		26	14	31	28	6				336	0.01%
Acanthurus blochii						122	37			50										216	0.00%
Acanthurus guttatus																				36	0.00%
Acanthurus leucopareius							5	26				10		10						100	0.00%
Acanthurus triostegus																				60	0.00%
Acanthurus xanthopterus																				515	0.01%
Aluterus scriptus																				20	0.00%
Amblycirrhitus bimacula																				12	0.00%
Anampses cuvier		11		17	13	17	17	14			25	12	14							166	0.00%
Antennariidae (family)				16			15	10	9	17	14	12	13		4					157	0.00%
Apogon erythrinus																					0.00%

scientific_name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	% of total catch
Apogonidae (family)																					0.00%
Apolemichthys arcuatus	155	172		31	21	53	40	32	42	54	24		27	36	21					766	0.01%
Arothron hispidus																				6	0.00%
Arothron meleagris																				118	0.00%
Aulostomus chinensis	6					25	24	18	16	28	27	15	10	41	27					282	0.00%
Balistidae (family)						5														115	0.00%
Blenniidae (family)							13				10	15		9						220	0.00%
Bodianus bilunulatus											24	9								61	0.00%
Bodianus sanguineus																					0.00%
Bothidae (family)																					0.00%
Cantherhines dumerilii						7	4					7			3					60	0.00%
Cantherhines sandwichiensis																				9	0.00%
Canthigaster amboinensis																				4	0.00%
Canthigaster coronata	36					4	13	21	13											330	0.01%
Canthigaster epilampra																					0.00%
Caracanthus typicus																				15	0.00%
Cephalopholis argus								4												28	0.00%
Chaetodon auriga					3		7													73	0.00%
Chaetodon citrinellus												0								99	0.00%
Chaetodon ephippium																				13	0.00%
Chaetodon fremblii	12		6	0		43	11			5	7			9						153	0.00%
Chaetodon lineolatus																					0.00%
Chaetodon lunula	125	105	35	6	27	58	41	38	156	20	72	24	22	8	8					745	0.01%
Chaetodon lunulatus							85													85	0.00%
Chaetodon ornatissimus	146	21					58	7												257	0.00%
Chaetodon reticulatus	3						3													181	0.00%
Chaetodon trifascialis																				67	0.00%
Chaetodontidae (family)																					0.00%
Cheilio inermis																				3	0.00%
Chromis agilis																					0.00%
Chromis hanui																				10	0.00%
Chromis ovalis																				22	0.00%
Chromis vanderbilti																				32	0.00%
Chromis verater									8											15	0.00%
Cirrhitidae (family)												9								176	0.00%
Cirrhitops fasciatus		23			4	18		16	18								8	17	14	177	0.00%
Cirrhitus pinnulatus																					0.00%
Cirripectes obscurus																				7	0.00%
Coris ballieui																					0.00%
Coris flavovittata																				17	0.00%
Coris venusta						6		3						9						69	0.00%
Cymolutes lecluse																					0.00%
Dendrochirus barberi																				6	0.00%
Diodontidae (family)																					0.00%
Doryrhamphus excisus																					0.00%
Echidna nebulosa																				74	0.00%
Enchelycore pardalis									15	31				4						124	0.00%
Exallias brevis						3	5													44	0.00%
Forcipiger longirostris																				24	0.00%
Gobiidae (family)																				9	0.00%
Grammistinae (subfamily)																					0.00%
Gymnomuraena zebra				4																30	0.00%
Gymnothorax eurostus	7		7				13													78	0.00%
Gymnothorax meleagris								19												52	0.00%
Hemitaurichthys thompsoni										6										22	0.00%
Heniochus diphreutes																				9	0.00%
Heteropriacanthus cruentatus																				7	0.00%
Holocentridae (family)					16	15	68		13		4		3							150	0.00%
Hyporthodus quernus																					0.00%
Iniistius pavo																					0.00%
Iniistius umbrilatus																				14	0.00%
Istiblennius zebra																				238	0.00%
Kyphosus bigibbus																					0.00%
Labridae (family)				243	205	38	136	35				25								838	0.01%
Lactoria diaphana																					0.00%

scientific_name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	% of total catch
Lutjanus kasmira							6				103						20			330	0.01%
Malacanthus brevirostris																					0.00%
Melichthys vidua	32	28		5		15		9	9	11	14			6						151	0.00%
Microcanthus strigatus																					0.00%
Microdesmidae (family)																					0.00%
Monacanthidae (family)																				35	0.00%
Monotaxis grandoculis																					0.00%
Mullidae (family)																				20	0.00%
Mulloidichthys vanicolensis					7		39													70	0.00%
Muraenidae (family)																				22	0.00%
Myripristis amaena							16	6		39			18							114	0.00%
Myripristis berndti																				58	0.00%
Myripristis kuntee																					0.00%
Naso brevirostris																				130	0.00%
Naso hexacanthus											8									9	0.00%
Naso unicornis			22	61	6															146	0.00%
Novaculichthys taeniourus	32	60	22	6	24	25	45	15	28	35	15	13	17	11	15					363	0.01%
Ophichthidae (family)																					0.00%
Ostorhinchus maculiferus																					0.00%
Ostracion whitleyi		36	8	11		6	12	12	21	9	7	7	11	14	6					180	0.00%
Oxycheilinus bimaculatus																				3	0.00%
Oxycheilinus unifasciatus							14			60			15							183	0.00%
Oxycirrhites typus																				194	0.00%
Paracirrhites forsteri	40	83	25	10	14	45	77	41	25	88	56	62	33	29	34	31	32	40	17	782	0.01%
Parupeneus multifasciatus							15					22								113	0.00%
Parupeneus porphyreus																				9	0.00%
Pervagor aspricaudus																				20	0.00%
Pervagor spilosoma					8	13	9	8		19	9									198	0.00%
Plectroglyphidodon imparipennis																					0.00%
Plectroglyphidodon johnstonianus						22	36		6		4	16	7	16						140	0.00%
Plectroglyphidodon sindonis																					0.00%
Pleuronectidae (family)																					0.00%
Poecilia sphenops																					0.00%
Polydactylus sexfilis																					0.00%
Pomacanthidae (family)																					0.00%
Pomacentridae (family)					57	89	70	51	34											460	0.01%
Pristiapogon kallopterus																					0.00%
Pseudanthias bicolor							22													132	0.00%
Pseudanthias hawaiiensis																				865	0.01%
Pseudanthias thompsoni																				41	0.00%
Pseudocheilinus evanidus							53		38	30	12		15	30	8					236	0.00%
Pterois sphex												7								59	0.00%
Rhinecanthus aculeatus																					0.00%
Rhinecanthus rectangulus																				55	0.00%
Sargocentron xantherythrum										10										56	0.00%
Scaridae (family)	33	15	9			17	23													128	0.00%
Scorpaenidae (family)																					0.00%
Scorpaenopsis cacopsis																				4	0.00%
Scorpaenopsis diabolus																				5	0.00%
Scuticaria tigrina																					0.00%
Sebastapistes coniorta																					0.00%
Stegastes fasciolatus																					0.00%
Stethojulis balteata	49	53	20	10	32	40	161	78	25	81	90	76	52	33	29					829	0.01%
Syngnathinae (subfamily)																					0.00%
Synodontidae (family)											6									14	0.00%
Taenianotus triacanthus							3			19	6		9	10						74	0.00%
Tetraodontidae (family)																				17	0.00%
Thalassoma ballieui																				4	0.00%
Thalassoma lunare																					0.00%
Thalassoma lutescens																				6	0.00%
Thalassoma purpureum																				65	0.00%
Uropterygius macrocephalus																				72	0.00%
Xanthichthys auromarginatus	50	40	39	43	67	56	62	128	34	87	29	32	34	35	9	7	13	20		785	0.01%
Xanthichthys mento																				10	0.00%
Zebrasoma veliferum															0					136	0.00%

Appendix C
Pākuʻikuʻi

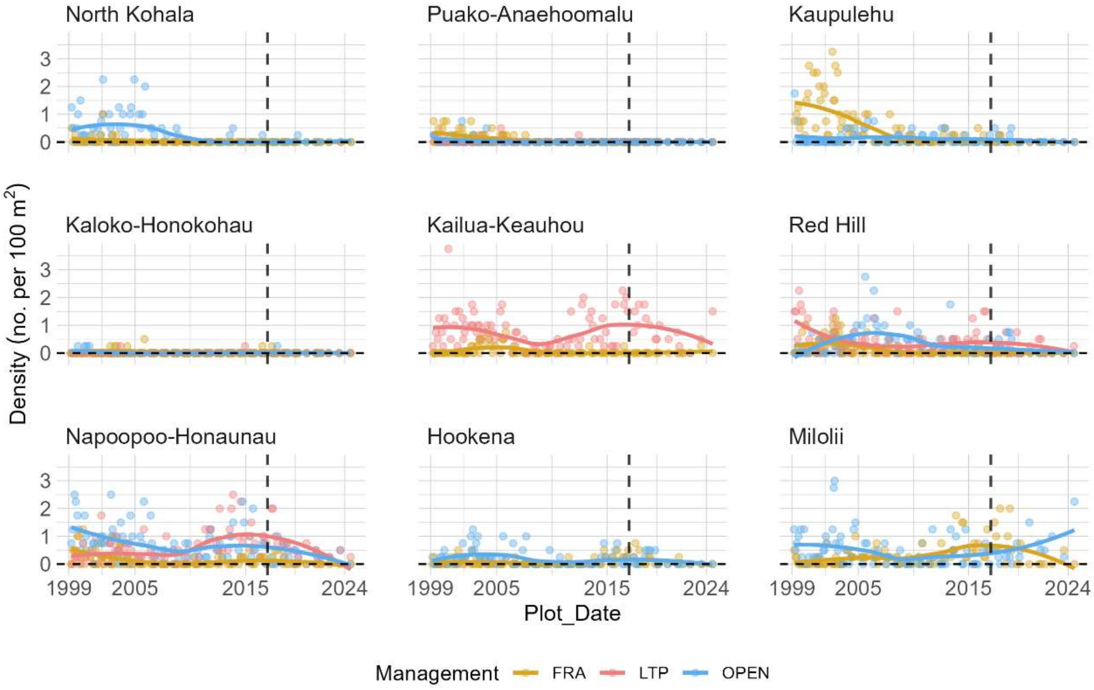

***Figure C-1**. Time series of pākuʻikuʻi density across 23 permanent West Hawaiʻi Aquarium Project sites from 1999-2024. Sites are arrayed by FRA clusters as denoted in Table 3.*

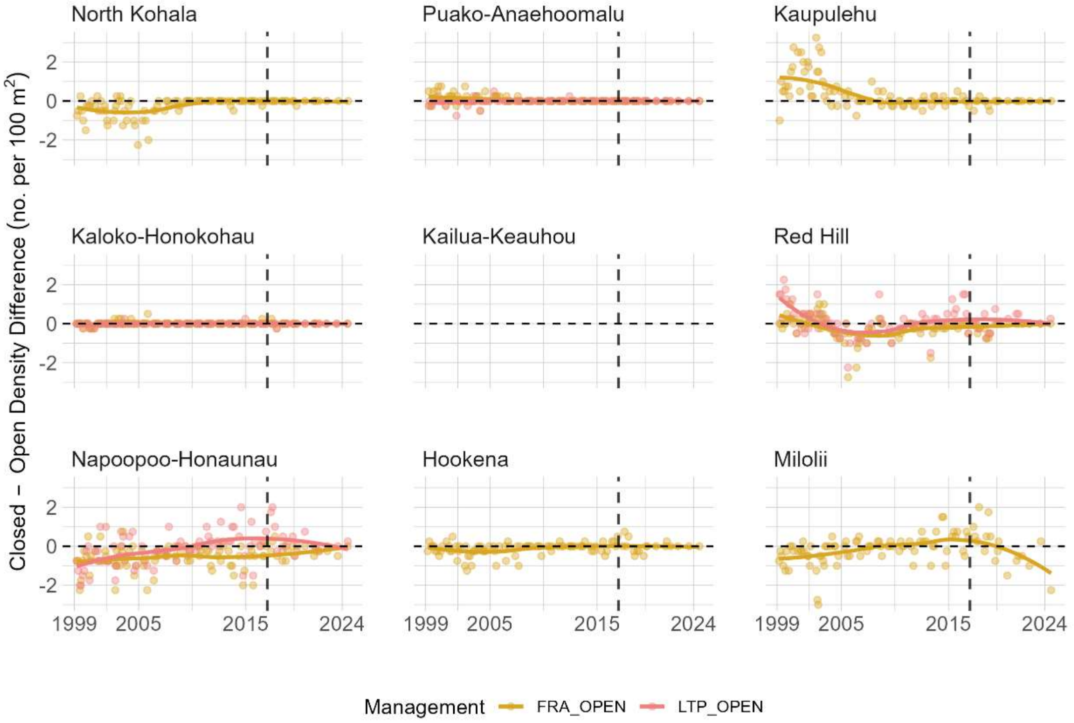

***Figure C-2.** Time series of the differences in Closed and Open site pākuʻikuʻi densities as a measure of FRA effectiveness. Gold data points and trend lines depict FRA - Open site differences. Red points and lines depict LTP - Open site differences.*

Umauma lei

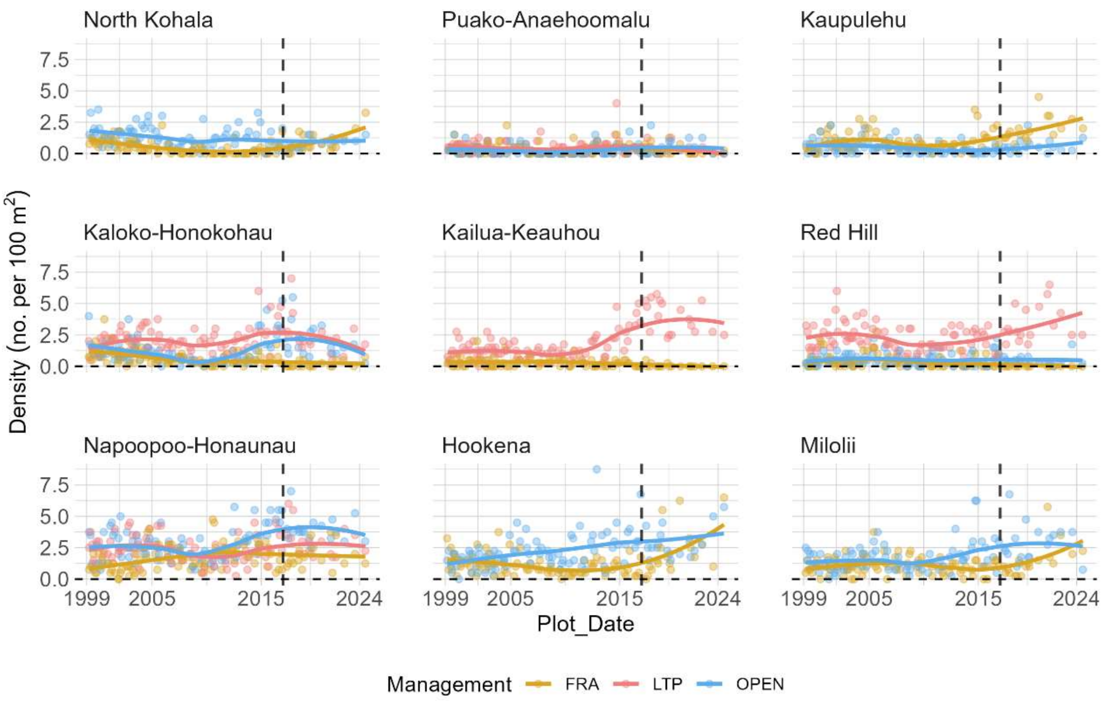

Figure C-3. *Time series of umauma lei density across 23 permanent West Hawai'i Aquarium Project sites from 1999-2024. Sites are arrayed by FRA clusters as denoted in Table 3.*

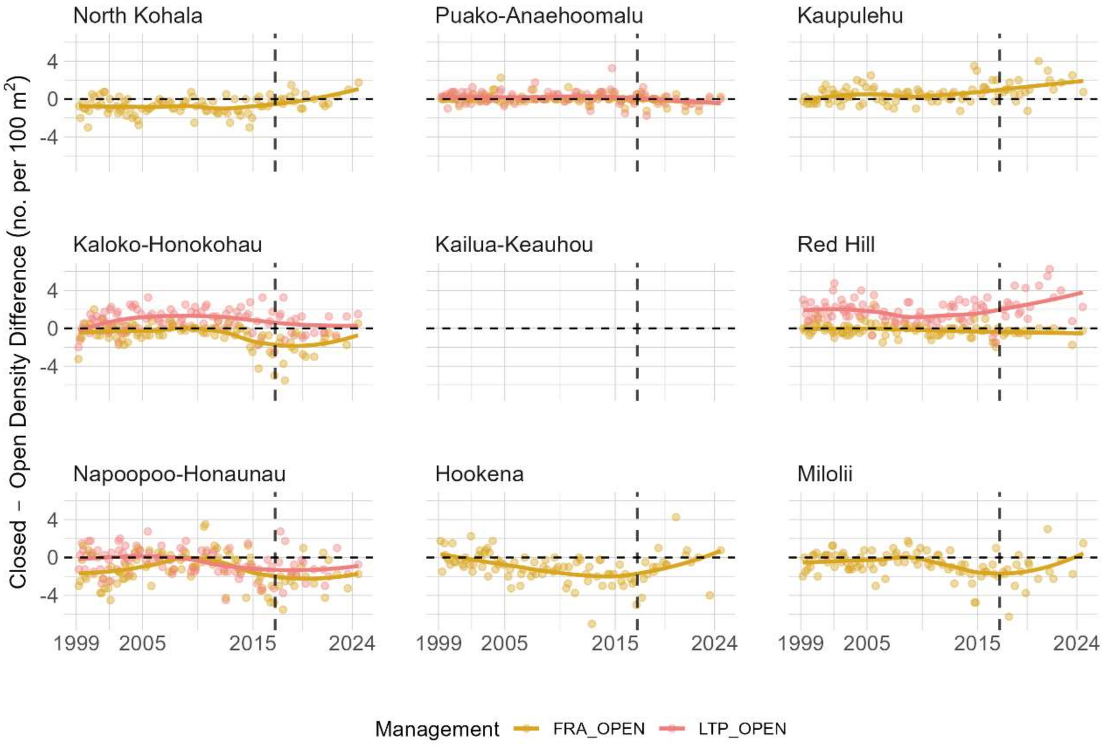

Figure C-4. *Time series of the differences in Closed and Open site umauma lei densities as a measure of FRA effectiveness. Gold data points and trend lines depict FRA - Open site differences. Red points and lines depict LTP - Open site differences.*

Black Surgeonfish

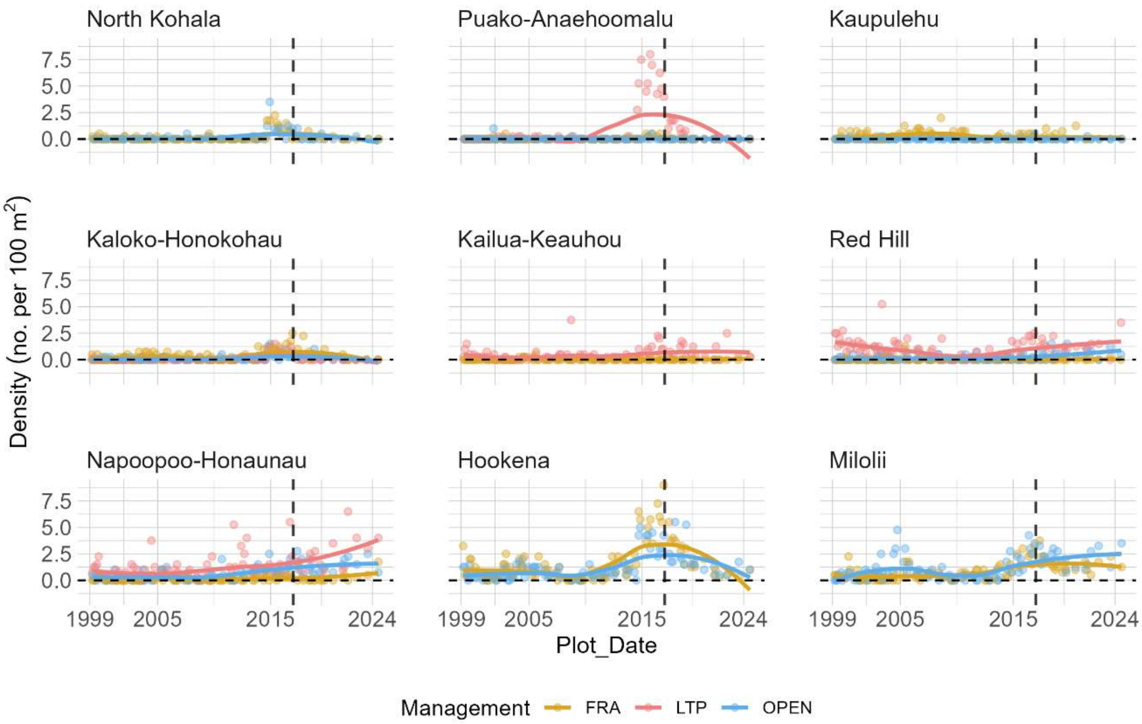

Figure C-5. *Time series of black surgeonfish density across 23 permanent West Hawai'i Aquarium Project sites from 1999-2024. Sites are arrayed by FRA clusters as denoted in Table 3.*

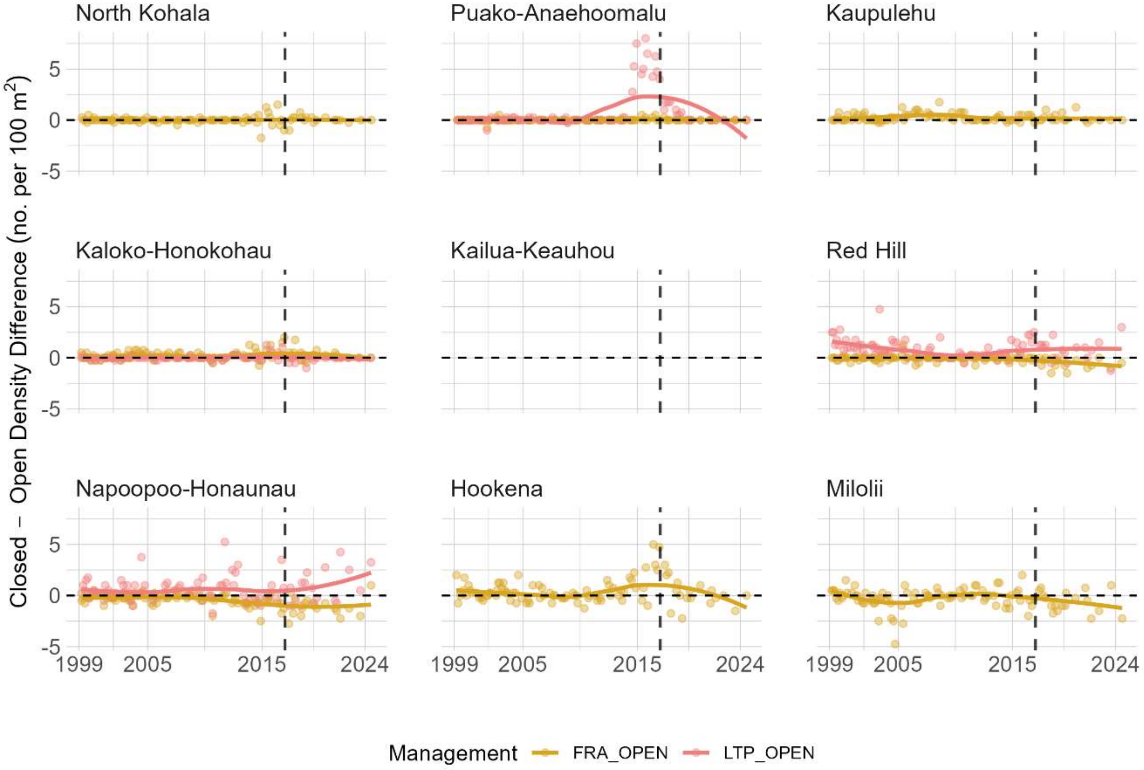

Figure C-6. *Time series of the differences in Closed and Open site black surgeonfish densities as a measure of FRA effectiveness. Gold data points and trend lines depict FRA - Open site differences. Red points and lines depict LTP - Open site differences.*

Forcepsfish

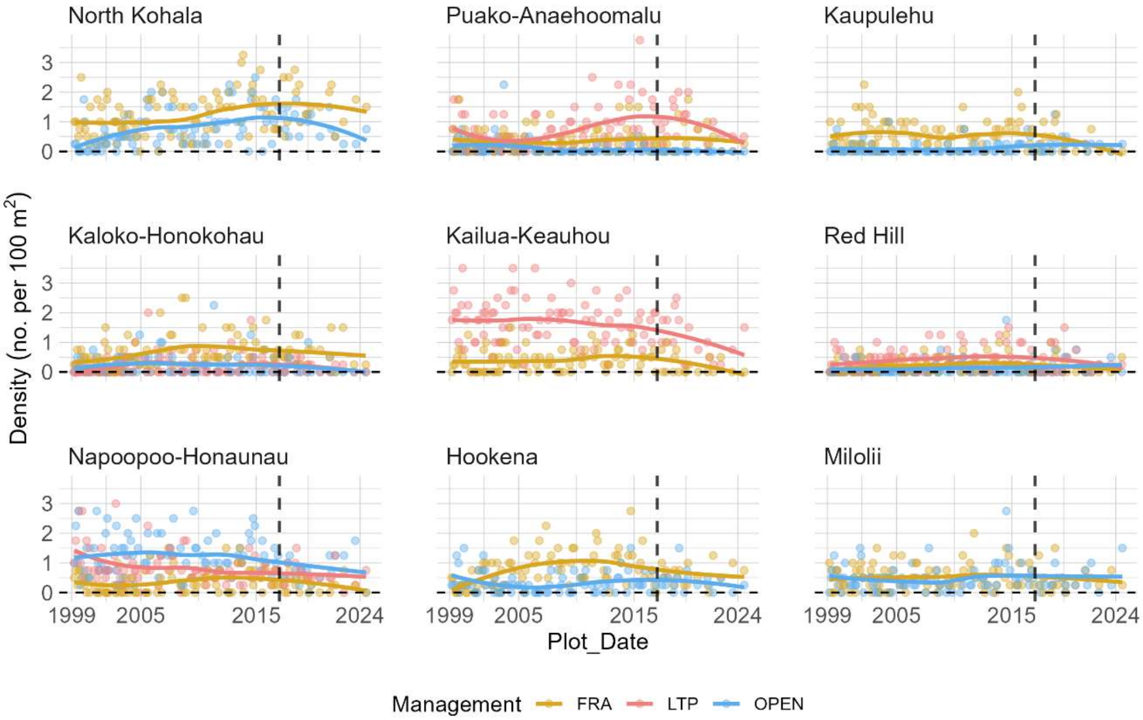

***Figure C-7**. Time series of forcepsfish density across 23 permanent West Hawaiʻi Aquarium Project sites from 1999-2024. Sites are arrayed by FRA clusters as denoted in Table 3.*

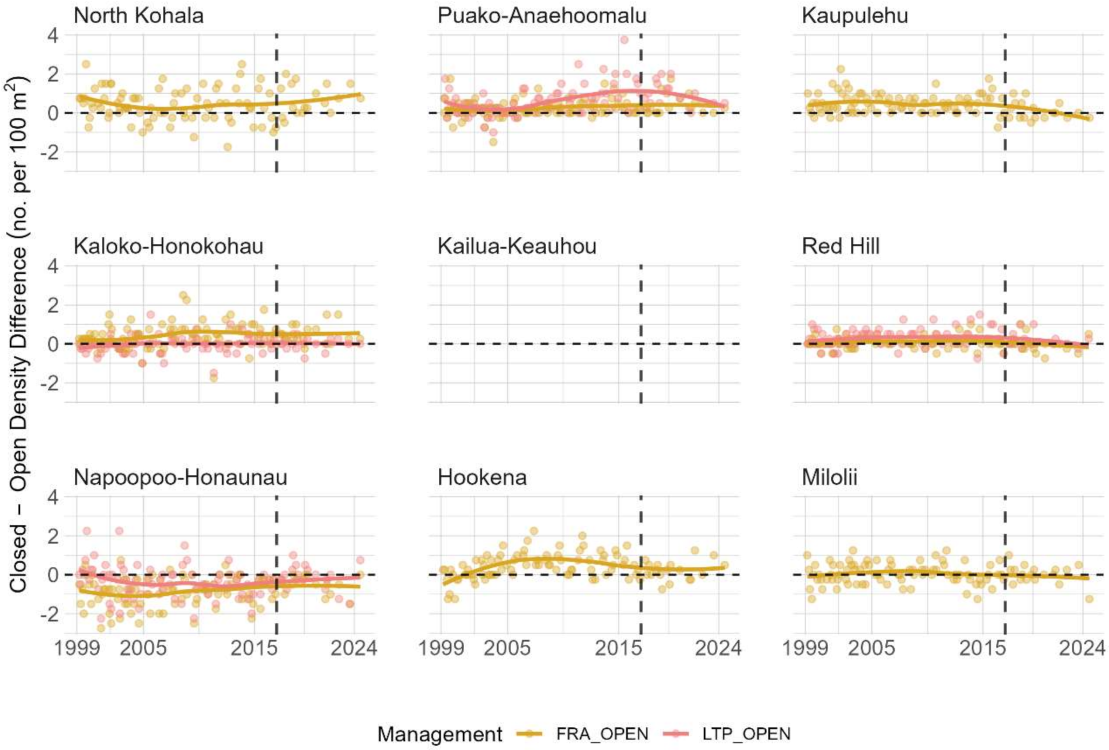

***Figure C-8.** Time series of the differences in Closed and Open site forcepsfish densities as a measure of FRA effectiveness. Gold data points and trend lines depict FRA - Open site differences. Red points and lines depict LTP - Open site differences.*

La‘o

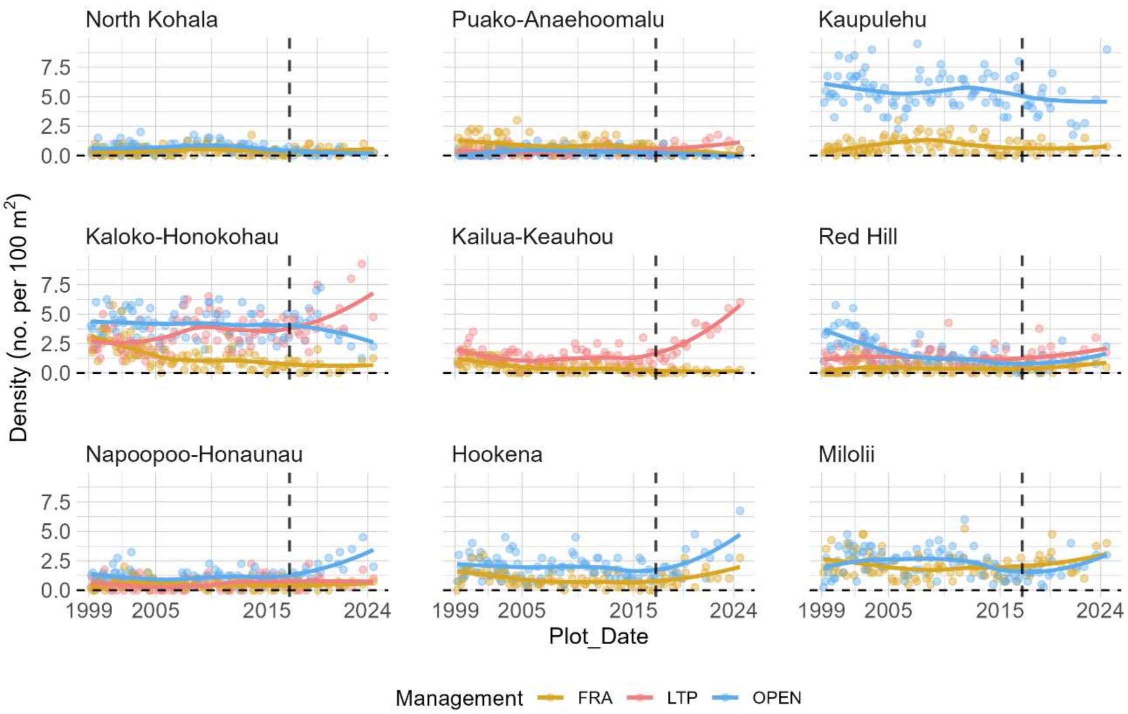

Figure C-9. *Time series of la‘o density across 23 permanent West Hawai‘i Aquarium Project sites from 1999-2024. Sites are arrayed by FRA clusters as denoted in Table 3.*

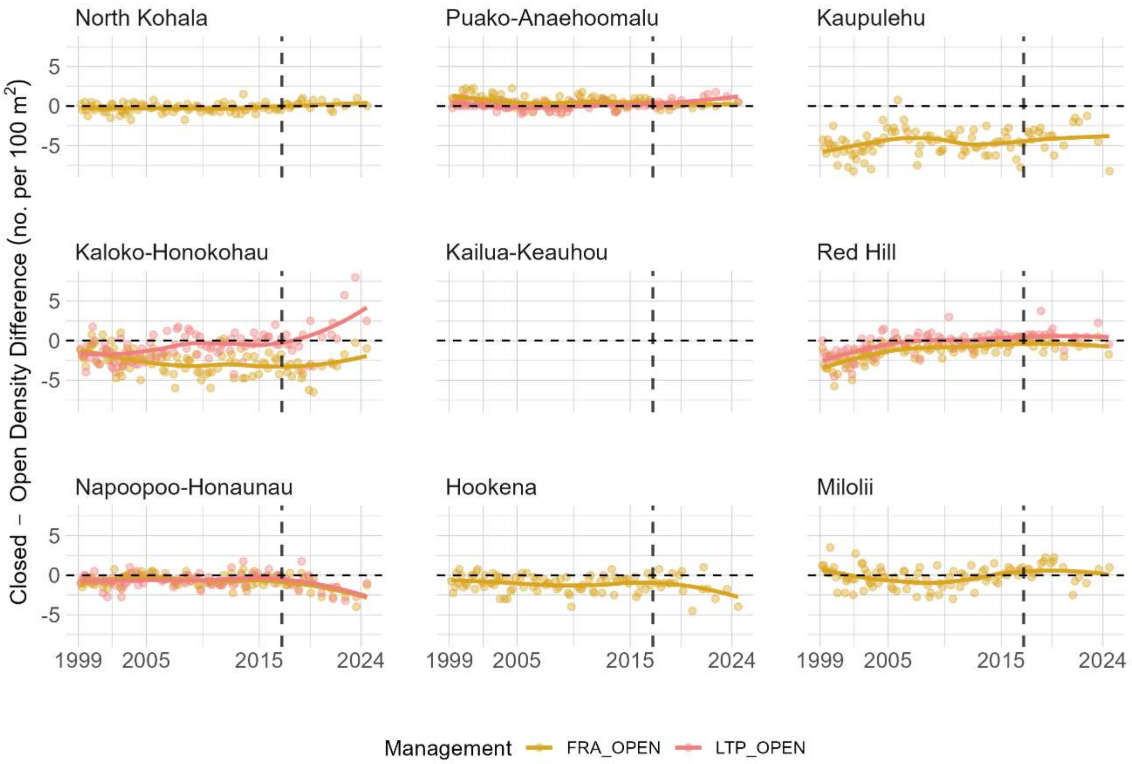

Figure C-10. *Time series of the differences in Closed and Open site la‘o densities as a measure of FRA effectiveness. Gold data points and trend lines depict FRA - Open site differences. Red points and lines depict LTP - Open site differences.*

Multiband butterflyfish

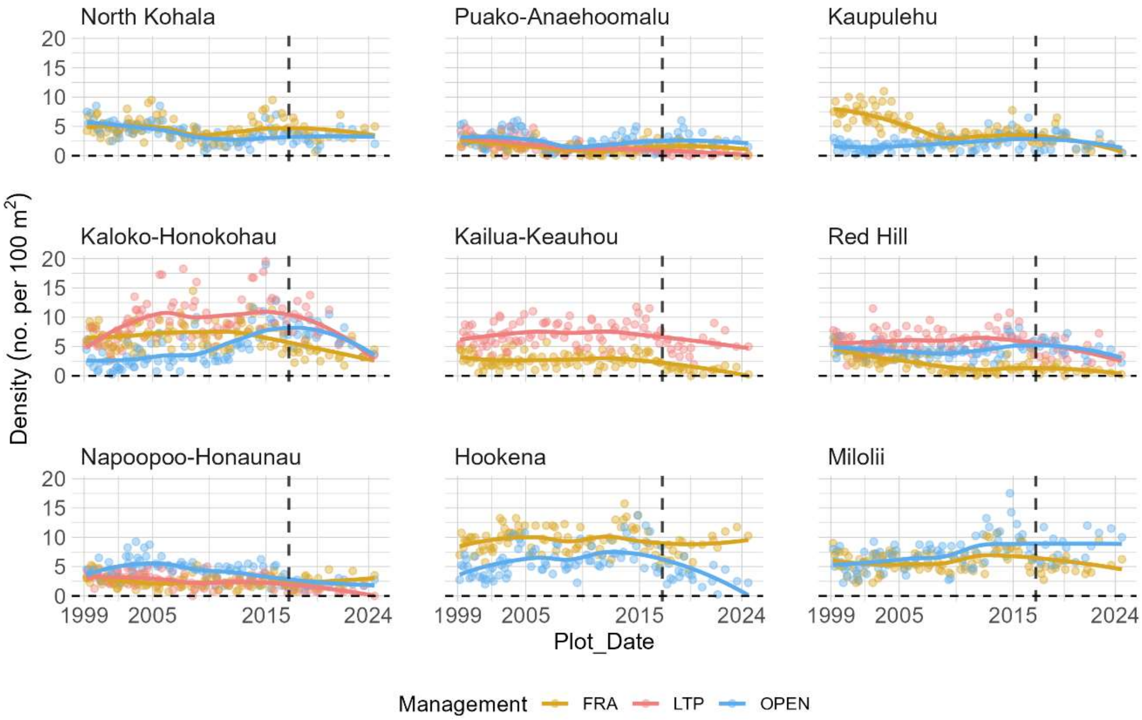

***Figure C-11**. Time series of multiband butterflyfish density across 23 permanent West Hawai'i Aquarium Project sites from 1999-2024. Sites are arrayed by FRA clusters as denoted in Table 3.*

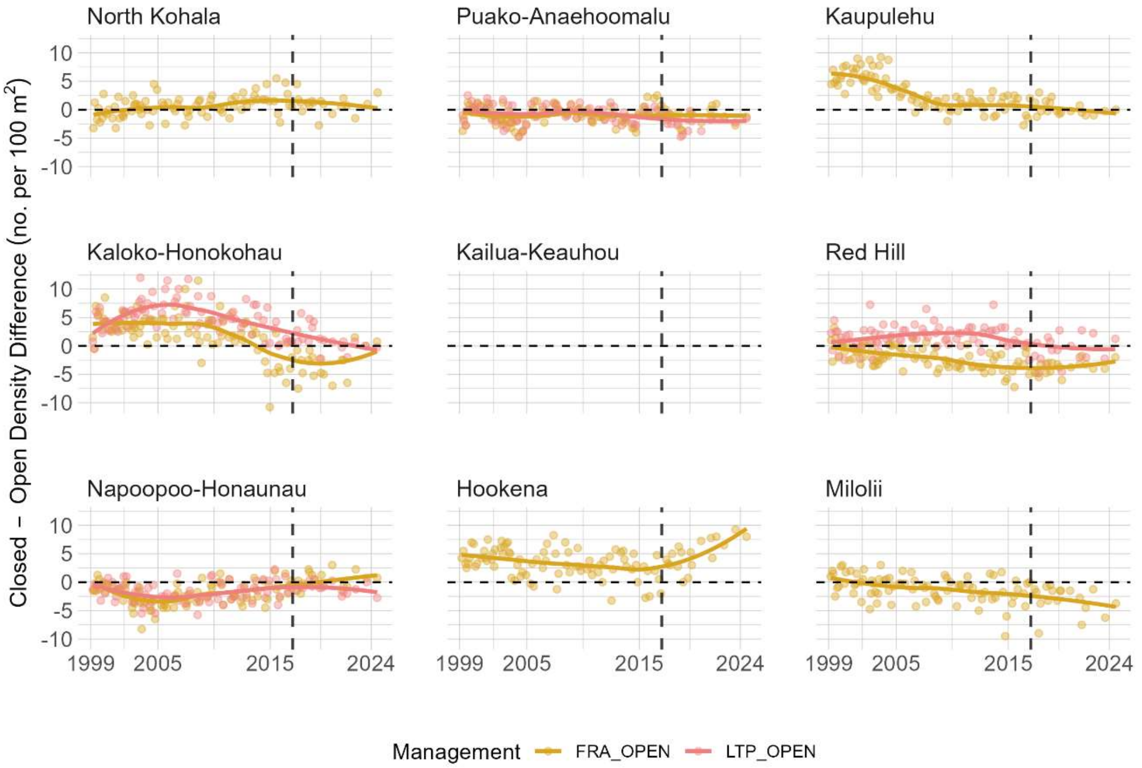

***Figure C-12.** Time series of the differences in Closed and Open site multiband butterflyfish densities as a measure of FRA effectiveness. Gold data points and trend lines depict FRA - Open site differences. Red points and lines depict LTP - Open site differences.*

Potter’s angelfish

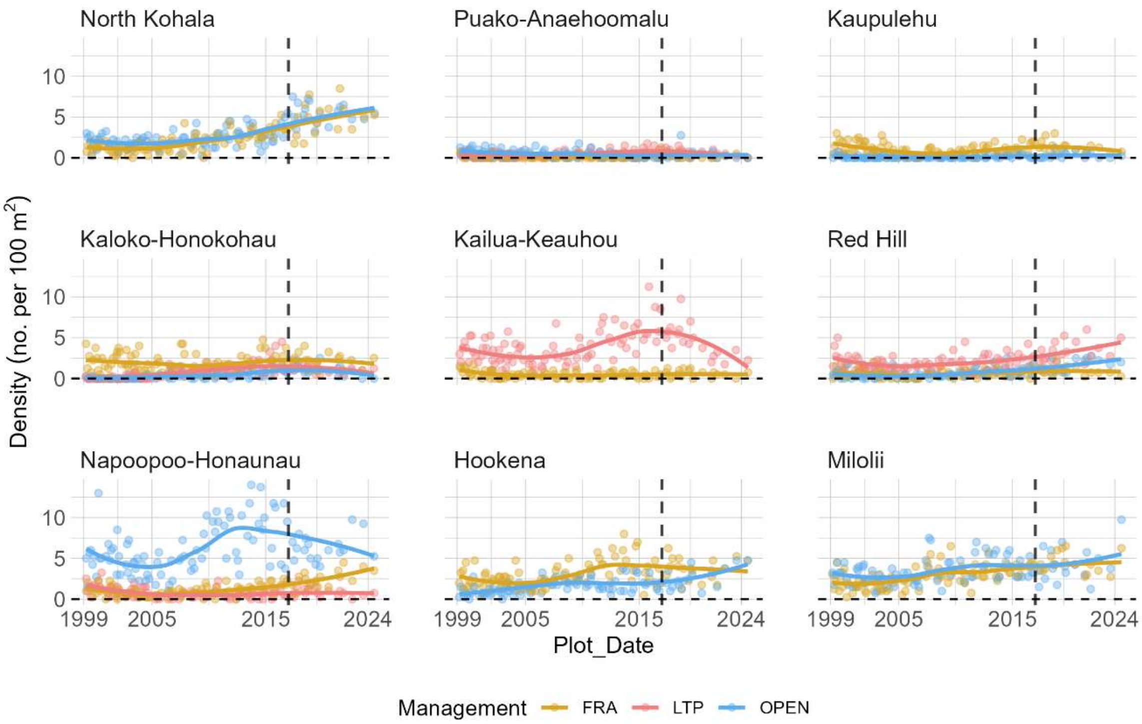

Figure C-13*. Time series of potter’s angelfish density across 23 permanent West Hawaiʻi Aquarium Project sites from 1999-2024. Sites are arrayed by FRA clusters as denoted in Table 3.*

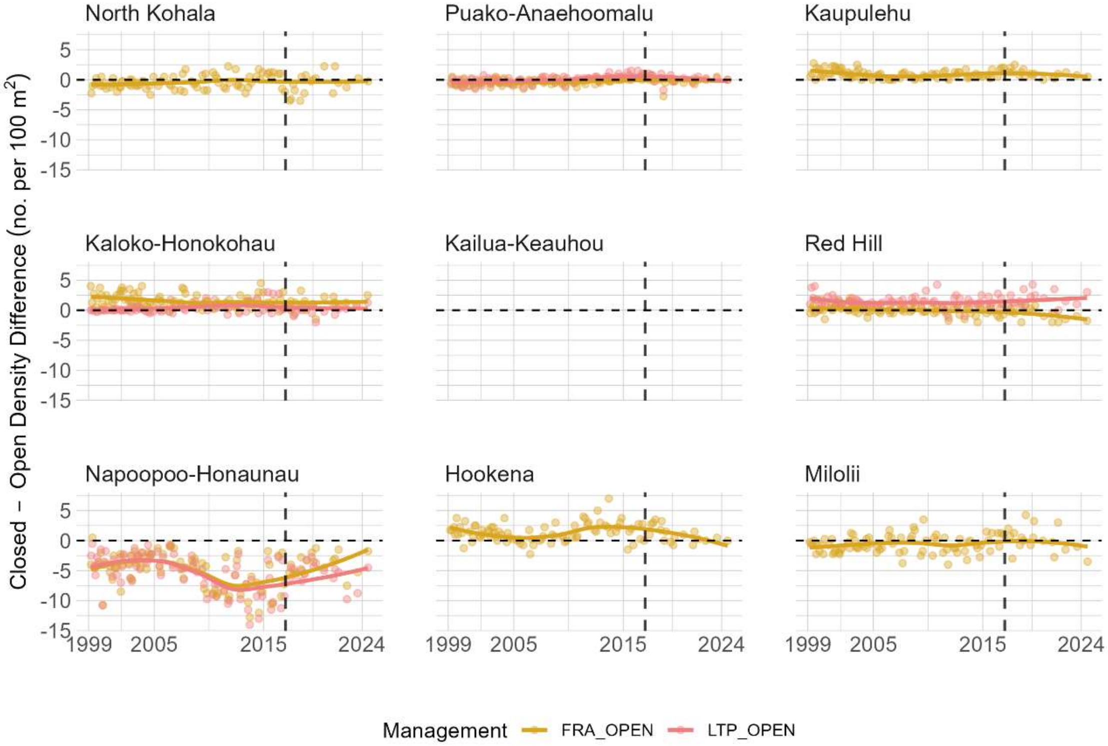

Figure C-14. *Time series of the differences in Closed and Open site potter’s angelfish densities as a measure of FRA effectiveness. Gold data points and trend lines depict FRA - Open site differences. Red points and lines depict LTP - Open site differences.*

Fourspot butterflyfish

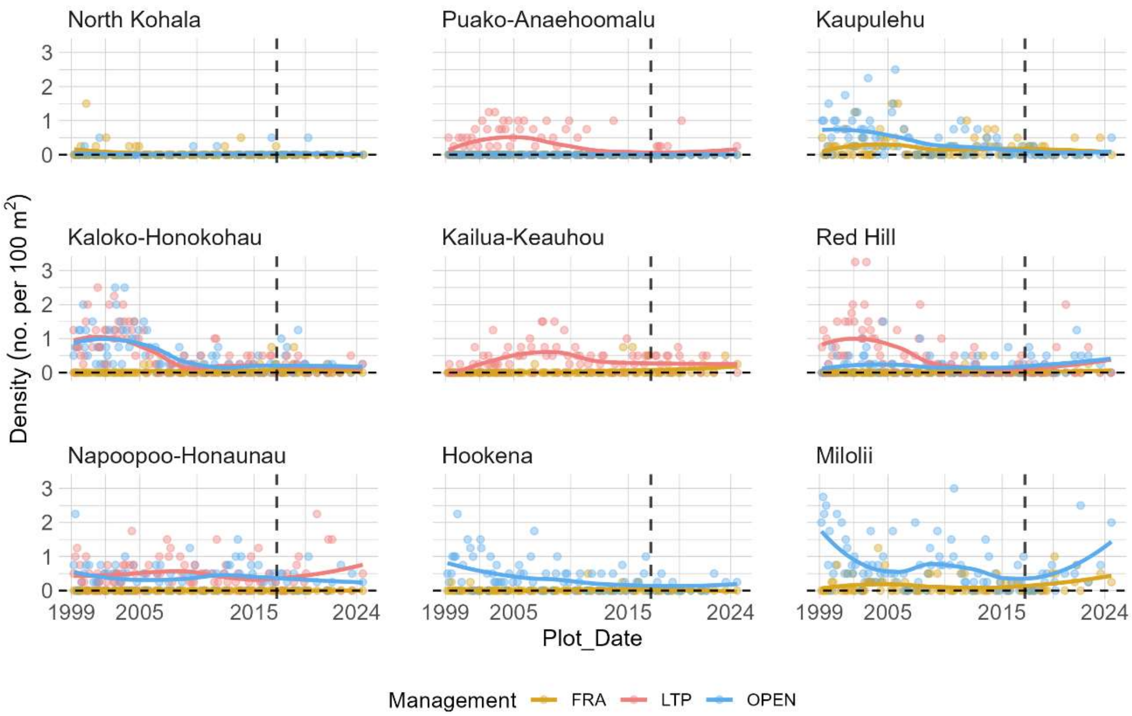

__Figure C-15__. Time series of fourspot butterflyfish density across 23 permanent West Hawaiʻi Aquarium Project sites from 1999-2024. Sites are arrayed by FRA clusters as denoted in Table 3.

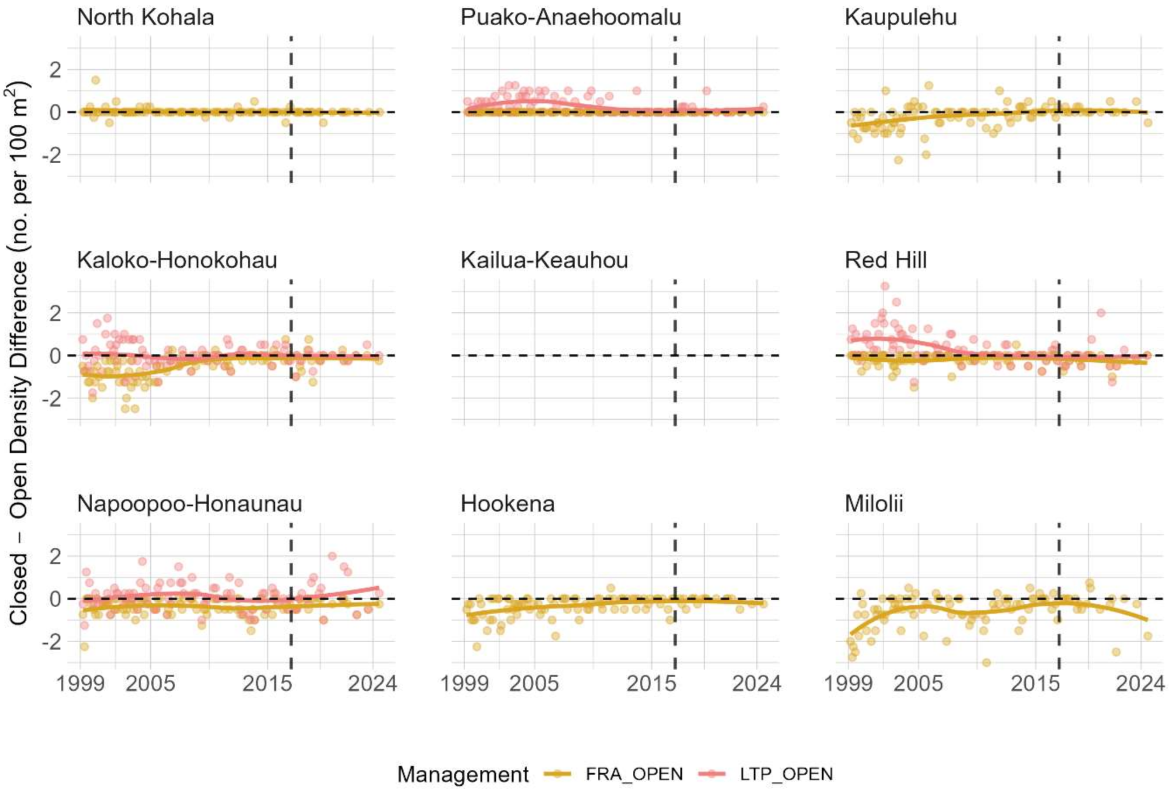

***Figure C-16.** Time series of the differences in Closed and Open site fourspot butterflyfish densities as a measure of FRA effectiveness. Gold data points and trend lines depict FRA - Open site differences. Red points and lines depict LTP - Open site differences.*