Maui Island Profile

An in-depth look at Maui's nearshore habitats, resources, and management

Executive Summary

Fishing is intertwined within Hawaiian culture. Fishers, or lawaiʻa, use fishing to provide for their community, to continue traditional and customary practices, and to teach the next generation about the important relationship with the ocean. Nearshore habitats including coral reefs, estuaries, and boulders provide habitat for many fish species providing food security to thousands of people.

Coral reefs are the foundation of the nearshore ecosystems in Hawaiʻi. Maui's nearshore waters include many different ecosystems including shallow water reefs, mesophotic reefs, streams, estuaries and artificial reefs. More than 60% of coral reefs in the United States are found within the Hawaiian archipelago. Teeming with life, Hawaiʻi's nearshore habitats are diverse and unique, including hundreds of species of fishes, corals, algae, sea turtles and marine mammals, with many species being found only in Hawaiʻi.

Maui's nearshore coral reef ecosystems have been world renowned for their beauty and abundance, yet many residents have observed declines and degradation within their lifetimes. A recent survey revealed that 76% of Maui residents perceive that the amount of live coral will get worse or much worse in the next 10 years[1]. Out of the 11 sites surveyed for percent coral cover on Maui, almost half showed a decrease in coral cover since the early 2000's. Papaʻula point and Honolua South had the most significant decrease in cover coral (~90% or more) while Olowalu, Kanahena Point, and Honolua South declined by half or more. In the Kahekili Herbivore Fisheries Management Area (FMA), coral cover declines stabilized in 2012 and appeared to slowly increase through 2014, likely due to the establishment of the Fisheries Management Area. Unfortunately, the mass bleaching event in 2015 impacted some of these corals, further decreasing

[1] Allen, M. *et al.* National Coral Reef Monitoring Program Socioeconomic Monitoring Component: Summary Findings for Hawaiʻi, 2020. (2022).

coral cover through 2018. Between 2018 and 2021 in the Kahekili Herbivore FMA, there were significant declines in parrotfish and surgeonfish biomass, coral cover and crustose coralline algae[2].

Estuaries are an important habitat for many species of popular food fish like ʻamaʻama (mullet) and āholehole (flagtails) and serve as critical nursery habitat for juveniles of many nearshore species. Despite this critical role in fish production, many streams in Hawaiʻi have been diverted for agricultural irrigation and ranching. Increasing human population also resulted in more development and urbanization and the accompanying impacts. As a result, many streams in Hawaiʻi today are altered by channelization, diversion, damming, and dumping, resulting in restricted flows, elevated temperatures and an abundance of invasive species.

[2] Pacific Islands Fisheries Science Center. *Kahekili Herbivore Fisheries Management Area: 2022 Results*. 2 (2023).

When looking at the trend of fish biomass, results from the Division of Aquatic Resources (DAR) underwater visual monitoring surveys showed that fish biomass across all habitats increased over time from 2015-2021, but at different rates for areas with highly restrictive fishing regulations compared to areas with very limited regulation (Figure 22 in the Nearshore Fishes section). Modeling results from 2004-2014 survey data show that nine out of 13 moku, district or land division, on Maui had significantly lower total fish biomass compared to areas that highly restricted fishing across the main Hawaiian islands, with only Kahikinui, Kaupō, Hāna and Koʻolau moku biomass estimates overlapping with the estimated biomass of the main Hawaiian Islands no-take areas (Figure 21 in the Nearshore Fishes section).

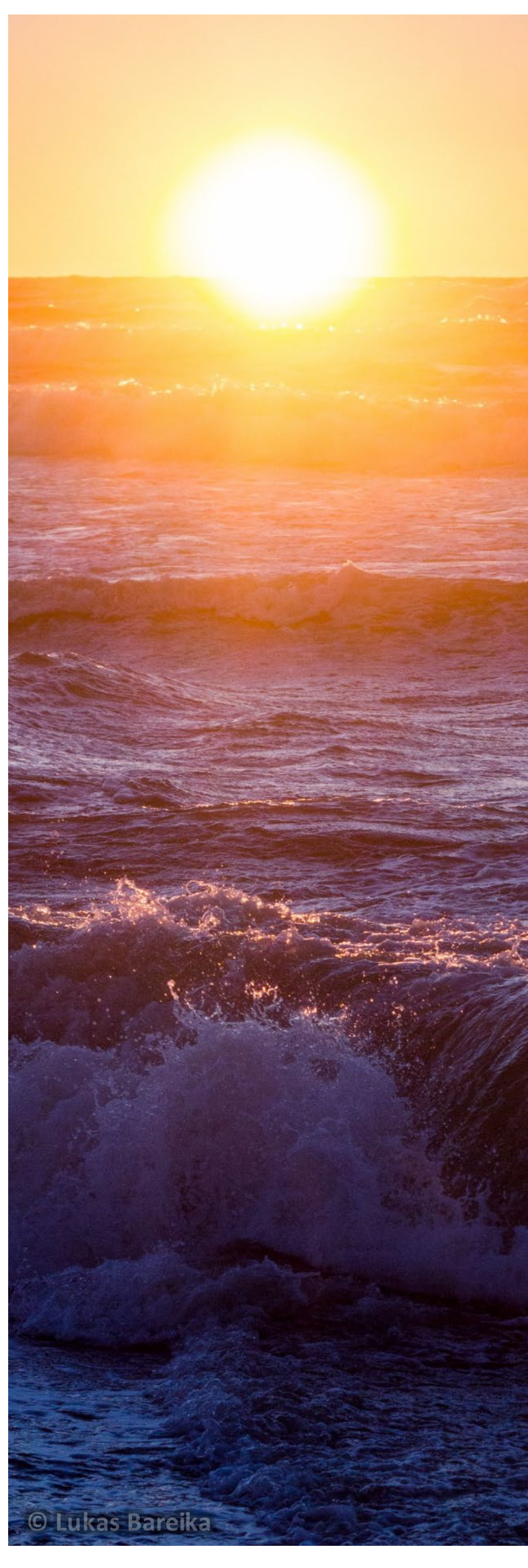
The nearshore fishery is mainly non-commercial (for subsistence or recreation). The top three species caught from shore by non-commercial fishers interviewed by the Hawaiʻi Marine Recreational Fishing Survey, based on actual number of fish caught, were manini (convict tang, a type of surgeonfish), ʻōmilu (bluefin trevally, a type of jack), and nenue (species of chub)[3]. Based on these data, the top three species caught by boat, based on actual number of fish caught, were mahimahi (dorado, a type of dolphinfish), lae nihi (nabeta/razor wrasse), and ono (wahoo, part of the mackerel and tuna family). Kāʻanapali, Lahaina, Launiupoko, Olowalu, Māʻalaea, and Kahului are some of the areas with the highest number of shoreline fishers. Kāʻanapali, Lahaina, Launiupoko, and Māʻalaea are areas with some of the highest fishing effort (defined in this survey as the most gear per fisher).

[3] Division of Aquatic Resources. Hawaiʻi Marine Recreational Fishing Survey results (2023). See non-commercial fishery section starting on page 57 for more information.

Inshore commercial finfish catch around Maui has varied widely from 1948 - 2020, peaking in 1998 with 323,506 lbs. of total catch[4]. Today, Maui contributes about 10% of the state's total annual inshore finfish landings, a value approximately commensurate with the island's population size relative to the entire state. As elsewhere throughout the state, scads (e.g. akule and ʻōpelu) have dominated Maui's inshore commercial landings, with annual landings of scads around Maui being as high as 91% of the total inshore finfish catch for some years. Non-scad inshore commercial catch around Maui has historically been primarily composed of four main species groups including surgeonfishes, goatfishes, jacks, and parrotfishes. Between 2014 and 2015, total reported landings of parrotfishes from Maui's inshore waters (almost entirely via spearfishing) decreased by approximately 80% and have remained low, due to the Maui-specific species regulations, specifically those pertaining to the take of parrotfishes, passed in late 2014. Net-based gears are still the leaders (46%) in terms of combined inshore finfish commercial catch, again primarily due to scads being the principal species targeted. However, spearfishing now contributes a sizable proportion (37%) of the total catch.

[4] Division of Aquatic Resources. Commercial Marine License Reporting Data (2023). See the nearshore commercial fishery section starting on page 63 for more information.

This report discusses the many nearshore habitats where fish are found; the status and recent data regarding Maui's nearshore fish species and fisheries; and potential management options to achieve the vision of healthy marine ecosystems and abundant nearshore resources that allow the people of Hawai'i to enjoy coastal waters, support livelihoods, and feed our families. With effective management, through community and agency collaboration, we can reverse the path of degradation, and reclaim healthy reefs and abundant resources for present and future generations.



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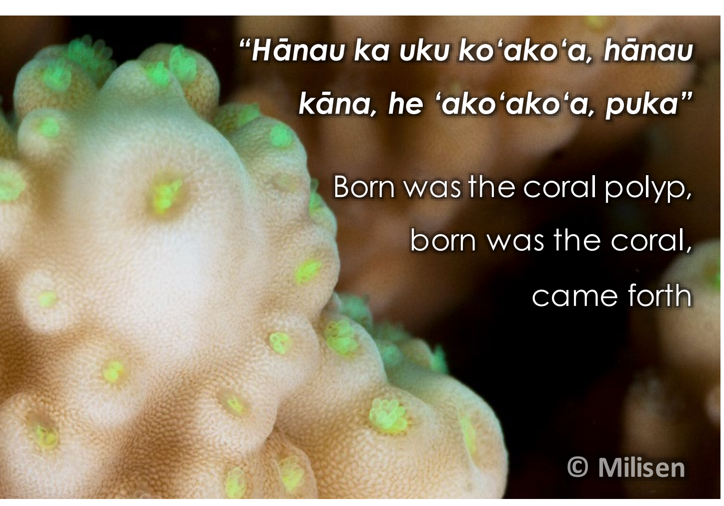
This Report was developed and revised by DLNR, Division of Aquatic Resources (DAR). It was edited and compiled by Stacia Marcoux (DAR/ the Hawai'i Coral Reef Initiative). Formatting and layout were by Leah Volak with the Hawai'i Coral Reef Initiative). Sections were contributed by Laura Gajdzik, Russell Sparks, Paul Murakawa, Brian Kanenaka, Dr. Kimberly Peyton, Anita Tsang, Bryan Ishida, Tom Ogawa, Ricky Tabandera, Trevor Johannsen, and Jesse Boord with DAR. It was developed in consultation with these DAR Aquatic Biologists and staff with expertise in fisheries, monitoring, fisheries management, and coral reef ecology. Additional content was developed in collaboration with and provided by Dr. Mary Donovan and the Hawai'i Monitoring and Reporting Collaborative, Dr. Richard Pyle, Dr. Robert Toonen, Emily Conklin, Cassandra Pardee with Poseidon Fisheries Research, NOAA NCRMP socioeconomic component, Dr. Tye Kindinger with NOAA Ecosystem Sciences Division and the Hawai'i Conservation Alliance.

It was externally reviewed and revised by Cassandra Pardee, a recognized expert in fisheries in Hawai'i.

Fishing in Hawaiʻi is a cultural tradition, continually practiced and passed on through generations of fishers, or lawaiʻa. This cultural connection to resources is also found in the Kumulipo, the Hawaiian creation chant, where coral is the first born and therefore an elder or Kupuna, to the Hawaiian people, thus explaining the importance, respect, and understanding of the role of coral to Hawaiians.

The Importance of Coral Reefs



Since the birth of the koʻa, or coral polyp, the beginning of life according to the Kumulipo, Native Hawaiians have had close connections with the environment, understanding the importance of reciprocal relationships and caring for biocultural resources. If we care for the ʻāina and kai, they will care for us in return. Documentation of the koʻa as one of the first life forms reveals how, hundreds of years ago, Hawaiians recognized the importance of coral reefs and their role in sustaining marine ecosystems and themselves. More than 90% of residents in 2020 (both statewide and Maui individually) agree or strongly agree that coral reefs are important to Hawaiʻi's culture [1].

There are many knowledge systems through which we can better understand the condition of the nearshore habitat and resources. As most Hawaiʻi residents are closely tied to nearshore waters, many have a deep understanding of the current condition or status of the ecosystem and reflect on the current state of the resources, in comparison to their personal observations over time. The socioeconomic team of the National Coral Reef Monitoring Program (NCRMP) monitors socioeconomic information relevant to the benefits of coral reefs and the perceived impacts of society on coral reefs as well as the perceived impacts of coral reef management (See Appendix A for more information on methods). Through an iterative process, scientists developed 13 indicators that could be measured through surveys to monitor and better understand coral reefs through a socioeconomic perspective. For more information on this effort, please visit their website. This team conducted statewide surveys in Hawaiʻi in 2015 and 2020 and some of the results from their most recent survey are shared throughout this document.

Ideally, with proper care and stewardship, many residents envision Hawaiʻi's ocean with crystal clear water, vibrant and healthy corals, and abundant and diverse schools of fish. With population growth, technological advances, and the influx of many new cultures, these reciprocal relationships have weakened and, in some cases, have become disconnected. Human population growth has continued to put a strain on our nearshore waters from impacts including urbanization, land-based sources of pollutants

including sedimentation, and unsustainable extraction. In the 2020 NCRMP socioeconomic survey of Hawaiʻi residents, the people of Hawaiʻi recognized the value of coral reefs to Hawaiʻi's culture, providing food, economic activities and coastal protection. However, more than 76% of Maui and 72% of statewide residents perceived that the condition of coral reefs has gotten worse in the last 10 years and will continue to get worse over the next 10 years [1].

In a 2022 public opinion survey of Hawaiʻi's voters, 96% shared that they agree it is their kuleana, or responsibility, to protect the ocean for future generations[2]. Working together, we can rebuild the relationships between the people of Hawaiʻi and the nearshore waters. With better stewardship and management and through community and agency collaboration, we can reverse the path of degradation, and reclaim healthy reefs and abundant resources for present and future generations.

Nearshore Habitats & Resources

Streams and Estuaries of Maui

Health of streams and estuaries is closely tied to conservation of upland forests and freshwater.

Streams (kahawai) support diverse ecosystems that depend on freshwater. Many of the native species like the ʻoʻopu, ʻōpae, and hīhīwai found in our streams are endemic, meaning they are found nowhere else in the world. Streams play a critical role in maintaining our watersheds and estuaries, and in doing so help to sustain the cultural livelihoods of the islands as well.

Productive streams feed estuaries, and healthy estuaries are needed for sustainable fishing.

Estuaries (muliwai) form where marine, freshwater, and terrestrial ecosystems intermix. A diverse array of aquatic life thrives in estuaries, including species only found in the islands. Young fish (pua) begin their coastal life in estuaries, sustained by an abundance of food that feeds their rapid growth.

As popular recreational and cultural places, estuaries are sought out by residents and visitors for fishing, gathering, boating, birding, surfing, and exploring.

Juvenile āholehole thrive in streams and in estuaries; adults use estuaries and reefs.

What other fish is so at home in fresh, brackish, and salt waters?

DAR is focused on: understanding how streams and estuaries synergize and contribute to coastal fish production in Hawaiʻi; documenting conditions in our estuaries and their streams; and finding solutions that will improve our management of these important freshwater-dependent ecosystems.

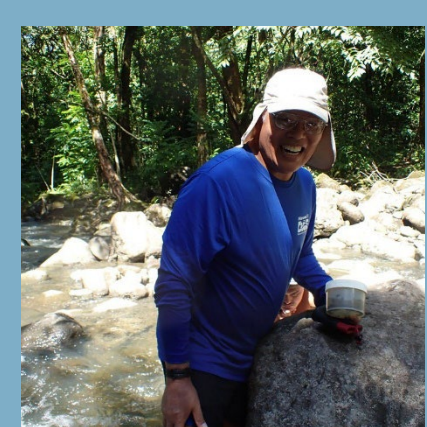
Did you know:

- Hawaiʻi has the most remote streams and estuaries on Earth.
- No other fish in the world can out climb ʻoʻopu ʻalamoʻo, as this goby can ascend great heights to live at the top of our steepest waterfalls.
- Stream species in Hawaiʻi include five ʻoʻopu , two ʻōpae , and the snails hīhīwai and hapawai. Two of the ʻoʻopu, one of the ʻōpaeʻ and hapawai also live in estuaries.
- Estuaries feed many local families with fish that use this resource as nursery and foraging habitats.
- There are so many unusual estuaries in Hawaiʻi that DAR is coining new terminology to describe them.
- On a single day in a small estuary on Maui over 65 species of fish were documented—this is a level of fish diversity that rivals that of our coral reefs.

DAR is monitoring Maui from kahawai to muliwai

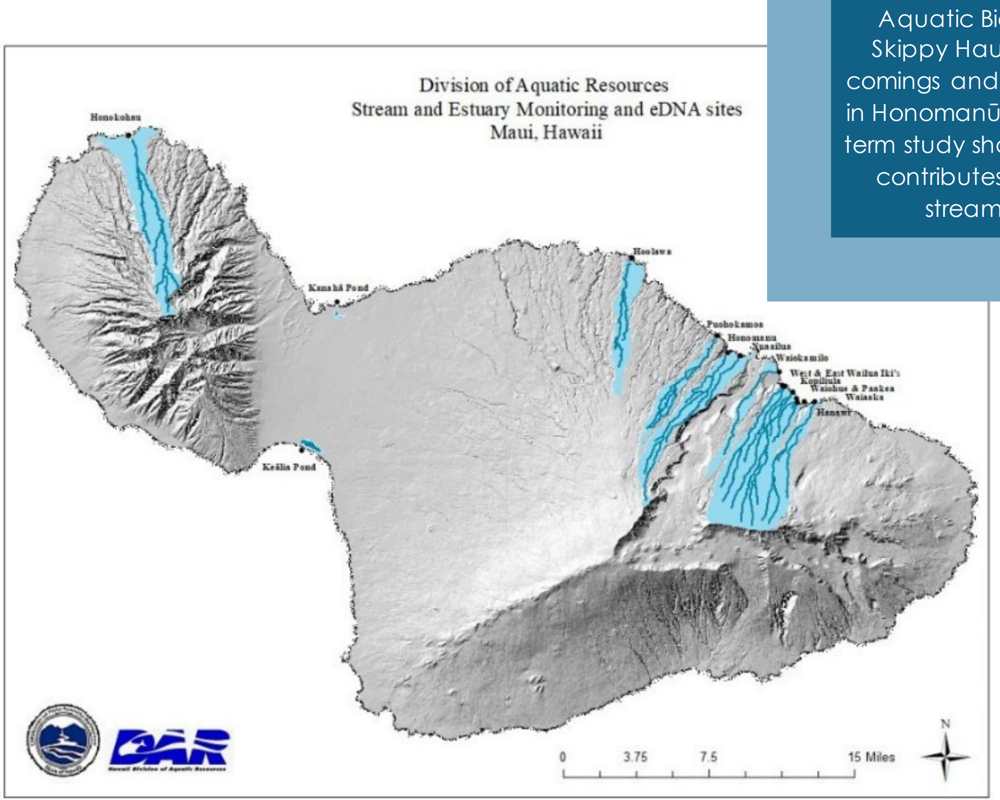
DAR has monitoring studies in streams and estuaries throughout Maui (see map). Results of these efforts are paying off as we gather data on seasonal use of estuaries by many species, document recruitment of freshwater species in streams, improve our understanding of the introduced species plaguing aquatic habitats, and track how aquatic species in both ecosystems respond to recent management actions.

Maui is the first island where streams and estuaries are being monitored together. This coordinated monitoring strategy is designed to enrich our knowledge of these freshwater- dependent ecosystems and result in recovery of areas that have been degraded.



UNCLE SKIPPY

Every month for 20 years Aquatic Biologist (retired) Skippy Hau monitored the comings and goings of hīhīwai in Honomanū Stream. His long-term study shows how this snail contributes to productive streams on Maui.



STREAM MONITORING

Using conventional methods

ʻoʻopu ʻakupa watches as hīhīwai migrate upstream.

Visual stream surveys have been conducted since 2019, recording aquatic species every three months in lower reefs of Honomanū and Honokōhau streams. Snorkeling in preset areas (100 meters long), observers identify species present, record the number of each species, and estimate sizes encountered. At first pass, the preset sites in both streams appear similar, consisting of clear, flowing water running around boulders that create riffles, runs and pools. Interestingly, monitoring shows that freshwater species use these two streams very differently. In Honokōhau abundant ʻoʻopu naniha, ʻoʻopu nākea, and ʻoʻopu ʻakupa are found routinely, while at Honomanū hīhīwai and ʻoʻopu nōpili populate the stream.

Figure 2: Image depicting the connectivity and overlap of habitat by certain native sport and food species. The estuary is the transitional habitat between the lower reaches of the streams and coastal waters and is important nursery habitat for both stream and marine species.

ʻōʻio

ESTUARY MONITORING

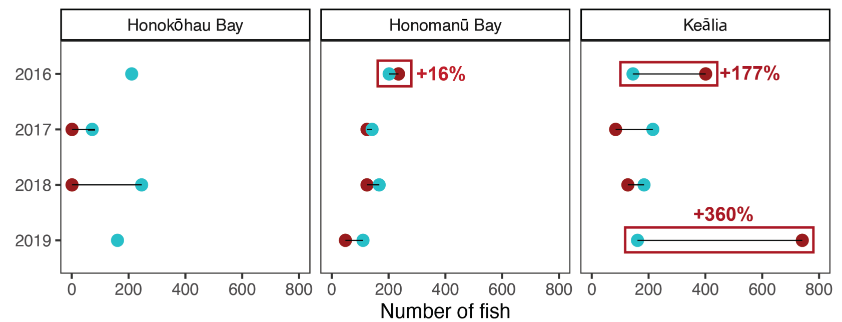
pāpio

Using conventional methods

Cast nets are used to monitor juvenile fish in shallow parts of estuaries. Fish use has been recorded every three months in the estuaries of Honomanū, Honokōhau and Keālia since 2016. Fish are identified, meas-ured, counted, and returned. Of the 50 species recorded by cast netting on Maui, āholehole is the most abundant native fish. Regrettably, monitoring has also revealed eight introduced species that have suc-cessfully invaded Maui's estuaries.

As the figure below illustrates, Keālia has far more problems with introduced species than the other two sites combined. What factors are shaping these results? To a waterbird Keālia is critical wetland habitat. For a fish Keālia is a lagoonal estuary. Native waterbirds have full use of Keālia, whereas native fish have access only when the lagoon mouth is open to the ocean. While water levels naturally fluctuate, limiting freshwater inflow results in a sand bar that closes native fish access for most of the year. Introduced fish, such as tilapia, proliferate under these conditions.

And now for some good news as cast net monitoring finds that Honokōhau is, by far, the least invaded estuary Statewide. Juveniles of native species are abundant and thriving here. This small estuary on the west side with continuous stream flow is teaching us about resilience.



ʻamaʻama

Actual size

Manini ʻōhua settle in estuar-ies as transparent fry. Then they quickly transform, gaining their distinctive stripes.

Not all estuaries have streams. ʻĀhihi-Kīnaʻu Natural Area Reserve, located on the dry slopes of Halea-kalā, has anchialine pools and downstream estuaries that are fed only by coastal groundwater.

Wailua Bay together with East Wailua Iki and West Wailua Iki streams form an estuary.

Figure 3: Estuaries have high diversity, meaning there are many different types of species that use estuaries as habitat. This figure is a compilation of photographs of species commonly found during estuary monitoring. The DAR estuary team has documented well over 100 different species inhabiting estuaries.

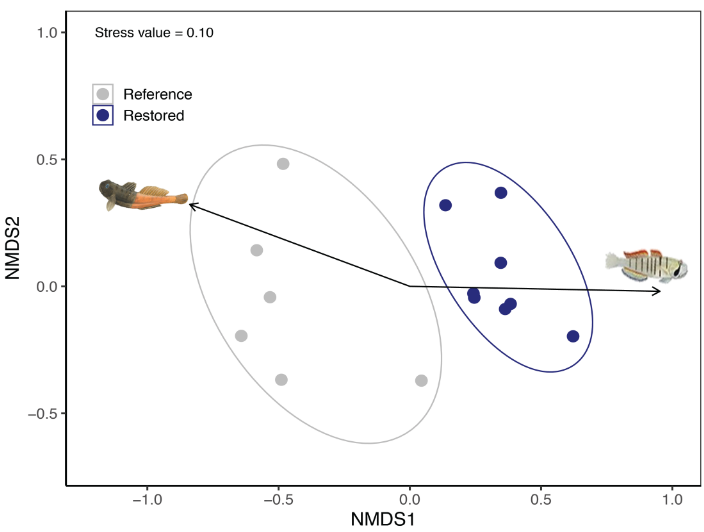
ENVIRONMENTAL DNA

MONITORING BIODIVERSITY IN STREAMS AND ESTUARIES

After more than a century of water diversion, designated streams of Waiohue, West Wailua Iki, and East Wailua Iki in East Maui were returned to natural flow conditions. A monitoring study was funded by the State Legislature to document how aquatic species responded to water restoration.

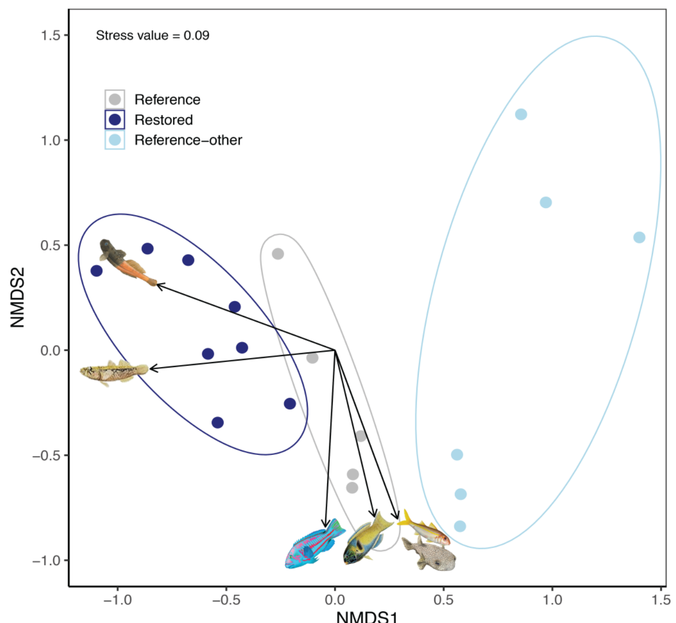
With this opportunity, DAR broadened monitoring to include environmental DNA (eDNA), a new technology that can document species present in an area (=biodiversity). This includes species that are rarely recorded using conventional methods. As one of the planet's biodiversity hotspots, management decisions need monitoring that accounts for our exceptional status. For more details: https://dlnr.hawaii.gov/dar/files/2021/11/DAR_CWRM_East_Maui_Rpt2021.pdf

Fish in streams and estuaries respond to the restoration of freshwater flow.



STREAMS. Analyses of eDNA data using NMDS showed two clear groups based on similarity of species present. Dark blue group contained only streams with restored water flow, while the other group had reference streams only. This result confirms that eDNA is useful for evaluating gains made by ecological restoration.

ESTUARIES. Analyses with estuary eDNA data resulted in 3 groups. Dark blue group contained all estuaries benefiting from restoration of freshwater flow in their contiguous streams. This finding bolsters our understanding that health of our estuaries depends on management decisions for freshwater resources.



What is environmental DNA?

Organisms shed or release parts of themselves into their environment. Someexamples are mucus, skin, or excrement. These cellular particles contain the unique genetic codes of the organisms that shed them and are known as environmental DNA (eDNA). Water that fish and other aquatic organisms live in is the environment that contains their eDNA. By collecting water samples and fil-tering them, eDNA can be collected onto filters. The eDNA of organisms present on those filters can be identified using molecular biology techniques.

Monitoring with eDNA results in a list of species using an area, which enhances our understanding of the communities of species thriving in different ahupua'a.

Nearshore Coral Reefs

Coral reefs are important for providing food, protecting shorelines from erosion and storm surges, and the economy (both from fisheries and tourism)[3]. Coral reefs are the foundation of the nearshore ecosystems in Hawaiʻi. More than 60% of coral reefs in the United States are found within the Hawaiian archipelago. Teeming with life, Hawaiʻi's coral reefs are home to more than 400 species of fish, approximately 70 species of corals, more than 500 species of marine algae (including at least 63 species of limu), as well as sea turtles, monk seals, spinner dolphins, and more. Many of these species are endemic- found only in Hawaiʻi and nowhere else on the planet. About 15% of marine algae and 25% of fish species are endemic.

Figure 3: Perception of the current amount of live coral both statewide and Maui, individually, based on surveys of randomly sampled Hawaiʻi residents (Allen et al. 2022).

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Given their cultural and biological significance, there is concern about the current and future status of coral reefs. More than half of Hawaiʻi residents surveyed in 2020 perceived the current amount of coral cover on reefs to be very bad or bad (Figure 3)[1]. Two factors often considered when measuring or describing the condition of our reefs are percent coral cover (how much coral is present over a given area) and the ratio of calcifying organisms on the reef (like coral and crustose coralline algae) to fleshy algae cover (see Figure 4 for examples of different extents of benthic cover). One collaborative survey effort to monitor coral is called the Hawaiʻi Coral Reef Assessment & Monitoring Program (CRAMP).

Calcified to Fleshy Ratio: The ratio of the proportion of the bottom cover composed of calcified organisms (corals and calcified algae) and fleshy organisms (turf algae and macroalgae), which is an indicator of the overall composition of the benthos. This metric can be a proxy for reef resilience, with areas having a higher ratio (more calcified and less flesh cover), likely being more resilient to stressors and bleaching, due to climate change.

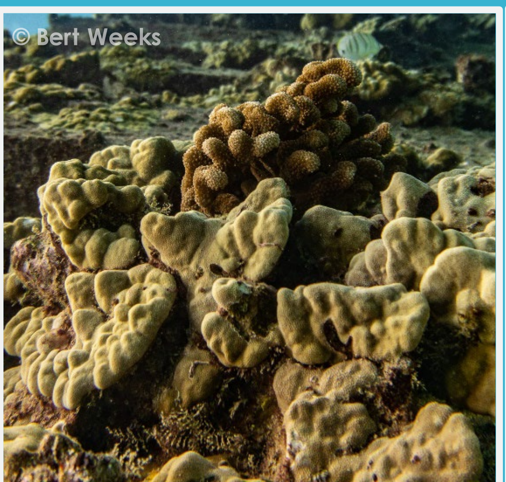


Figure 4: Examples of benthic cover to show areas with a high (left), medium (middle), and low (right) calcified to fleshy ratio. The areas with a high calcified to fleshy ratio are areas that are mostly coral or other calcified organisms like crustose coralline algae. Areas with a low calcified to fleshy ratio are areas dominated by fleshy (macroalgae cover). Many areas are somewhere in between these two ends of the spectrum, with a mix of hard, calcified cover and softer, fleshy macroalgae cover.

The University of Hawai‘i and the Division of Aquatic Resources (DAR) have been collaborating on this monitoring effort since 1998 (monitoring methods summarized in Brown *et al.* 2004, data summarized below is available online Guest *et al.* 2018 [4]), which was the first coral reef long-term monitoring program established in Hawai‘i. This effort allows us to track changes over time at specific monitoring sites. Over the past two decades, percent coral cover at Maui sites varied greatly (Figure 5). Molokini consistently had the highest coral cover (~75%) followed by Mahinahina and Kahekili (varying between ~25 and ~50%), and Kanahena Bay (25%). Out of the 11 sites surveyed, almost half showed a decrease in coral cover since early 2000's (Figure 5, Figure 6). Papa‘ula point and Honolua South had the most significant decrease in cover coral (~90% or more) while Olowalu, Kanahena Point, and Honolua South declined by half or more.

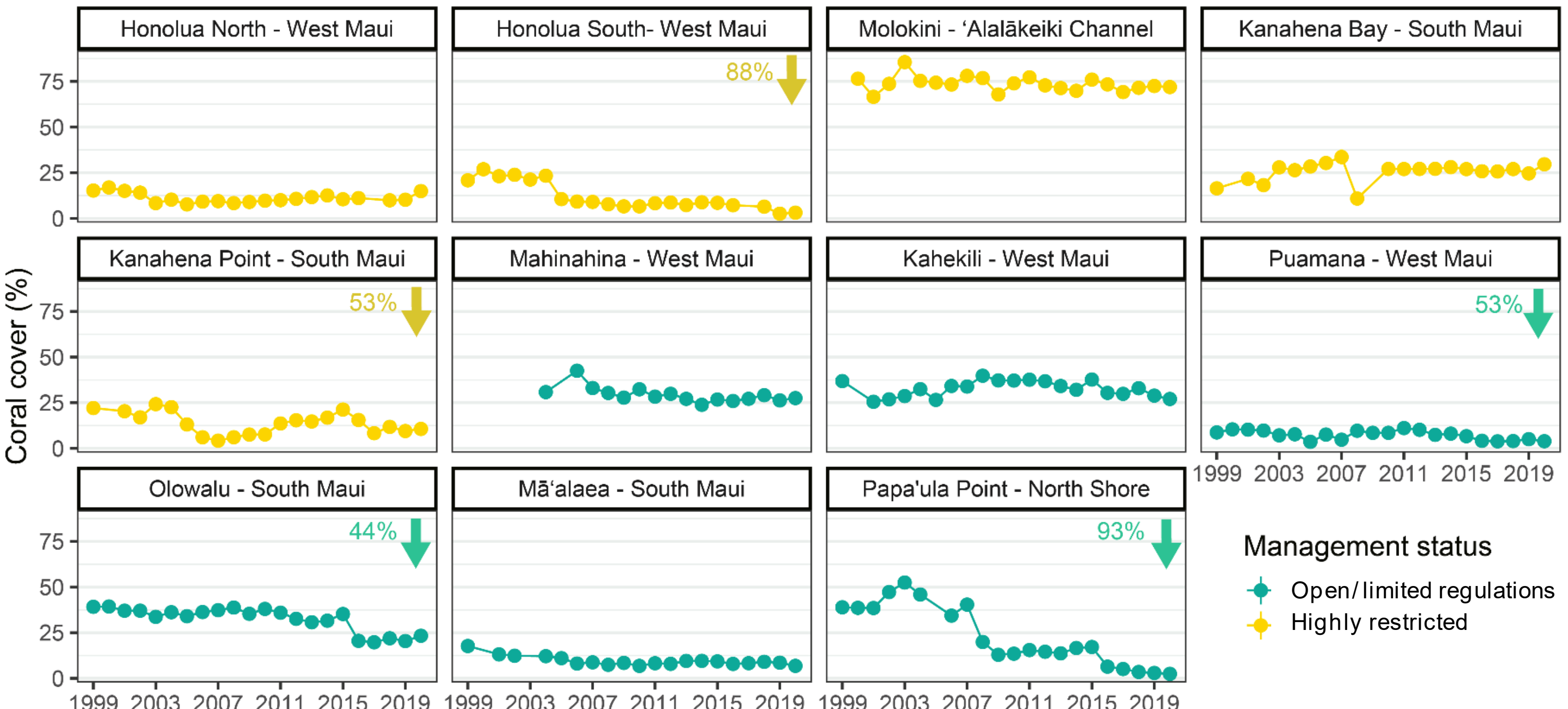


Figure 5: Percent coral cover at 11 sites in the nearshore waters of Maui. Years without data points are years in which surveys were not conducted at those locations. Locations in green are areas where fishing occurs, with minimal fishing regulations in place. Locations in yellow are areas where fishing is either prohibited or highly restricted (such as Marine Life Conservation Districts or Reserves). Differences in coral cover among sites were tested by fitting linear models between the first years and the last years. Arrows depict significant increase or decrease in coral cover from the earliest to the most recent survey year, with the percent change from the two earliest to the two most recent survey years notated for sites with significant declines.

Another scientific resource to help better understand the condition of nearshore resources is the Hawai'i Monitoring and Reporting Collaborative (HIMARC). HIMARC combines monitoring data from multiple large-scale monitoring programs to provide a comprehensive understanding of patterns in nearshore ecosystems statewide. The data are provided by 7 main data sources, which includes DAR. HIMARC then calibrates the data to be analyzed as one large dataset to estimate the condition of different indicators of coral reef condition. The HIMARC figures included in this report share data from 2004-2014 and represent ecosystem condition prior to severe coral bleaching and mortality events. As such, these figures may not reflect current conditions we see today. See Appendix B for more information on HIMARC and the methods used to analyze the combined data.

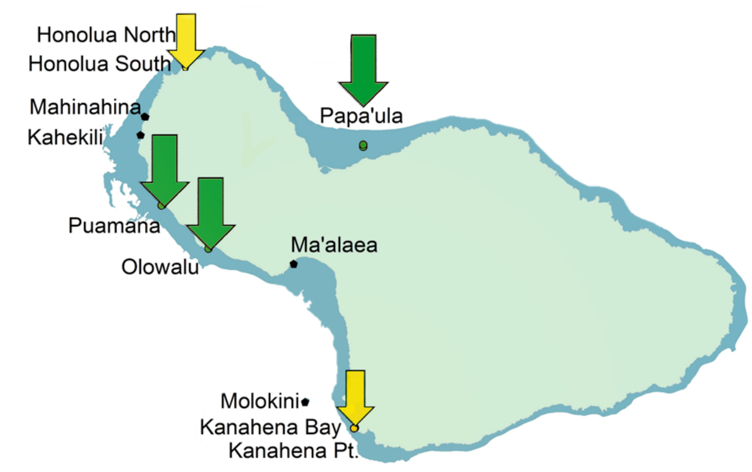


Figure 6: Map of Maui CRAMP sites. Arrows represent sites where there was a significant decrease in percent coral cover from the first year surveyed compared to the most recent year surveyed. Sites labeled in green with an arrow represent sites in areas with limited fishing regulations that experienced a significant decline in percent coral cover. Sites labeled and with an arrow in yellow represent sites in areas with highly restrictive fishing regulations that experienced a significant decline in percent coral cover. Sites labeled in black did not experience a significant increase or decrease in percent coral cover from the first year surveyed compared to the most recent year surveyed, regardless of management status.

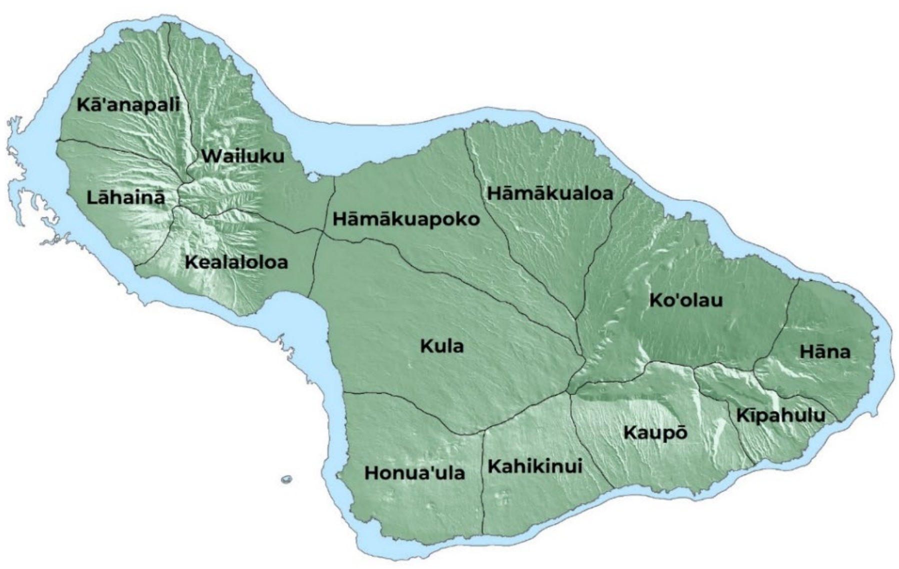


Figure 7: Maui Moku with 50-meter depth contour shown.

At the moku scale (see Figure 7 for map of Maui moku), percent cover is variable across Maui (Figure 8,[5]). Honua'ula in southwest Maui has the highest percent coral cover (~45%) and is significantly higher than the statewide average (~25%). This is likely driven by the remote stretch of shoreline, buffered with forest reserves and preserves, that minimize human impacts to the

area. Ko‘olau in northeast Maui has the lowest percent coral cover of all Maui moku, with an estimated average percent coral cover of 14.3%. When referring to Figure 8, the smaller the error bars, the more confidence there is the estimated average being very close to the true average. Variation across moku is reflected in the extent that the error bars overlap, where overlapping bars reflect similar conditions and separated bars reflect different conditions. Most moku on Maui have similar average coral cover to each other and to the statewide average.

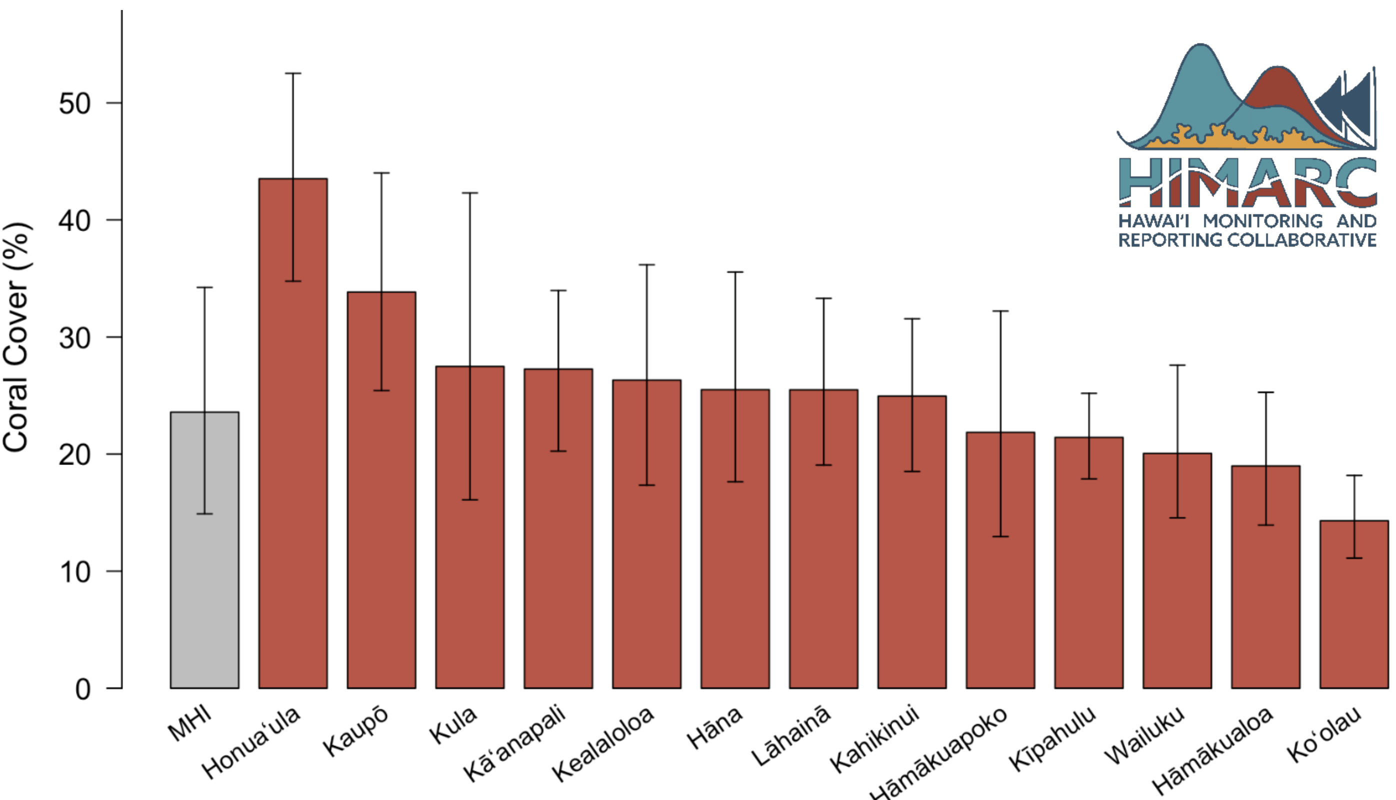


Figure 8: Percent coral cover summarized across moku and compared to the main Hawaiian islands (MHI) values by the Hawai‘i Monitoring and Reporting Collaborative (HIMARC) (Donovan et al., 2023.). Values are based on the best available data from 2004- 2014. Bar heights are means and error bars are 50% intervals of posterior predictions for all hardbottom areas in a given moku. Values are estimates from a Bayesian Hierarchical model that accounts for the relative distribution of habitat and variation in other drivers of the indicator in a given moku. Maui moku are colored red and arranged based on the height of the bars next to the statewide estimate (grey).

Variability in coral cover can also be visualized at a higher resolution (Figure 9). Though high percent coral cover areas are found around the island of Maui in most districts (as seen as orange to red colors on the map), the most expansive areas of high percent coral cover are found in the Kihei-Makena district in south/southwest Maui, and at Molokini Crater (Figure 9). Some areas with the lowest percent coral cover include Kahului Harbor, Maʻalaea Bay and east Maui near Keʻanae, Wailua and Nahiku (Figure 9).

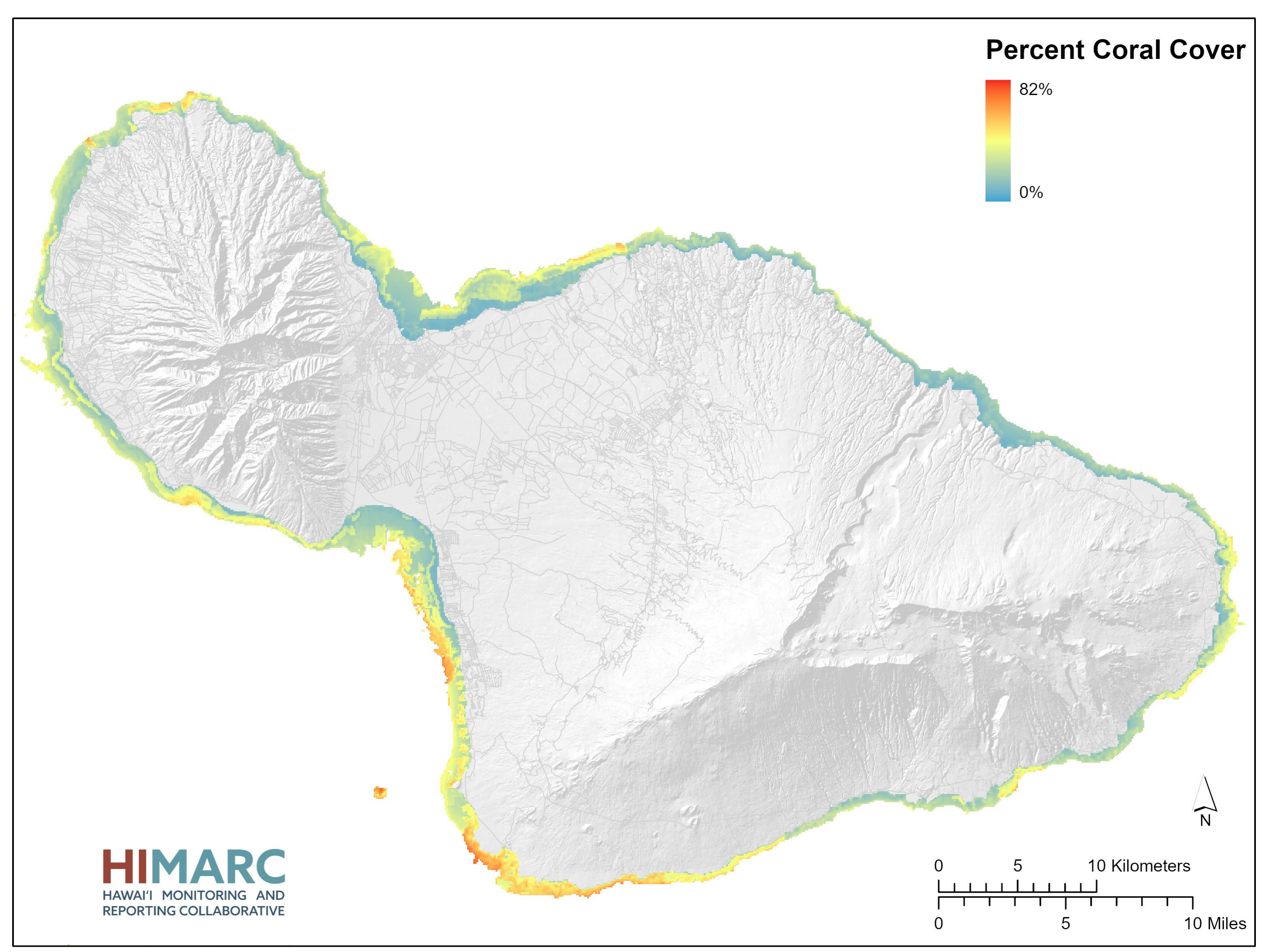


Figure 9: Predicted percent coral cover map with high cover in red and low cover in blue. Values are predicted for hard bottom habitats 0-30 meters depth at a spatial resolution of 100m generated by the Hawaiʻi Monitoring and Reporting Collaborative (HIMARC) (Donovan et al., 2023.) using combined data from 2004-2014 from multiple statewide monitoring programs and comprehensive mapping of drivers in a Bayesian Hierarchical Model.

At the moku scale, the ratio of calcified to fleshy cover (the ratio of how much the bottom is covered by calcifying organisms like coral versus fleshy organisms like algae, see Figure 4) is variable with some moku in a more calcified state (more corals and crustose coralline algae) and some moku in a fleshier state (more macroalgae and turf algae cover than coral). Six of the 13 moku have a higher proportion of fleshy cover than calcified cover (more algae than coral), with only three moku (Hāna, Kaupō and Honuaʻula) having a more dominant calcified state. Reefs with a higher ratio tend to be more resilient to local and global stressors including warming ocean temperatures.

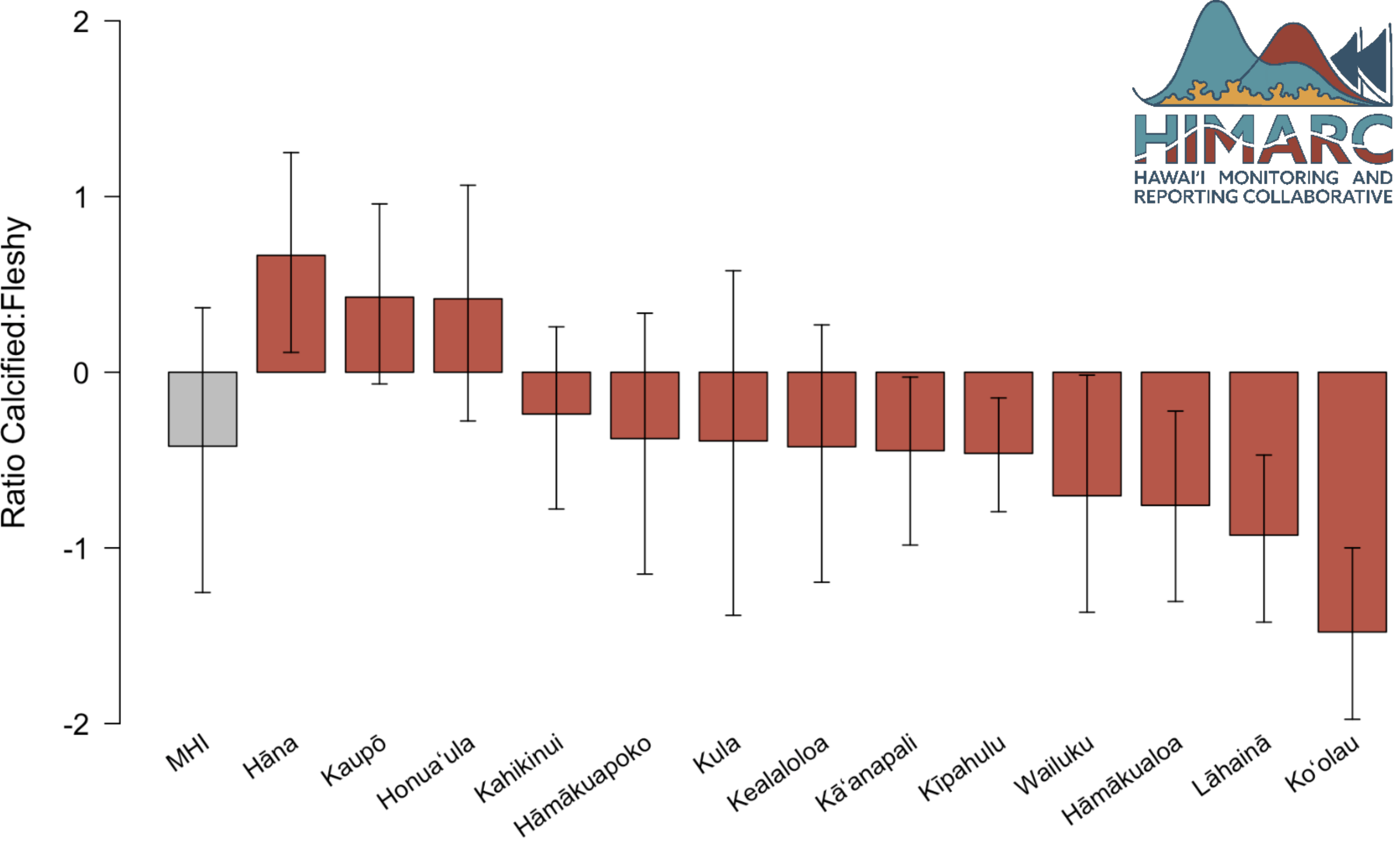


Figure 10: Ratio of calcified to fleshy cover summarized across moku and compared to the main Hawaiian islands (MHI) values by the Hawaiʻi Monitoring and Reporting Collaborative (HIMARC)(Donovan et al., 2023.). Values are based on the best available data from 2004- 2014. Bar heights are means and error bars are 50% intervals of posterior predictions for all hardbottom areas in a given moku. Values are estimates from a Bayesian Hierarchical model that accounts for the relative distribution of habitat and variation in other drivers of the indicator in a given moku. Maui moku are colored red and arranged based on the height of the bars next to the statewide estimate (grey).

Variation is also observed when examining the calcified to fleshy cover ratio at the Maui Island scale (Figure 11). The most calcified areas (for example, areas that have more coral, less algae) are found in the Kihei-Makena district in south/southwest Maui and at Molokini Crater. There is also a high calcified to fleshy ratio along east Maui Hāna moku. Many areas in the Wailuku, Hāmākuapoko and Kula moku are dominated with fleshy cover (for example, more algae, less coral) close to shore, but then have highly calcified areas, farther from shore.

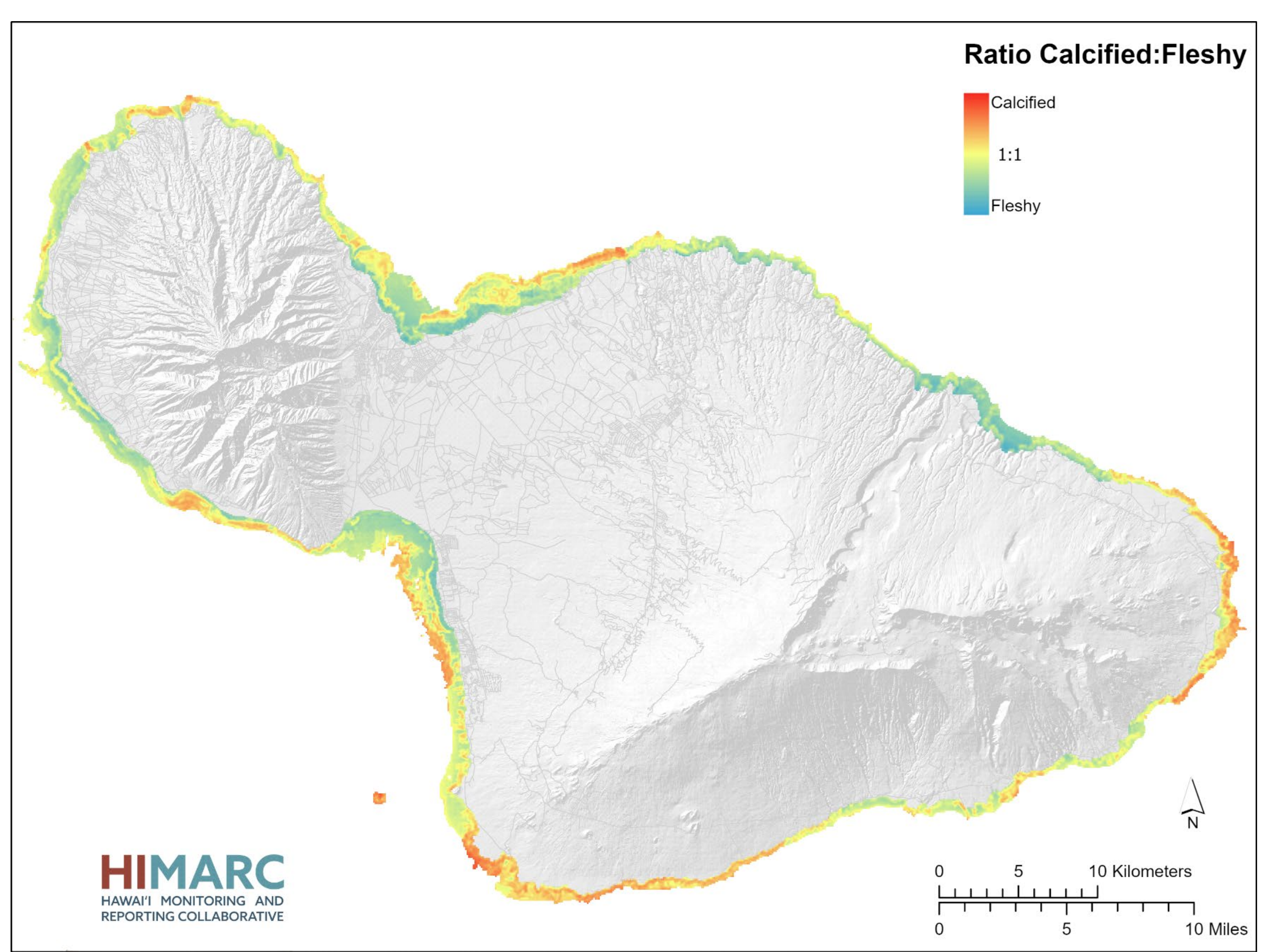


Figure 11: Predicted ratio of calcified to fleshy cover map with areas of high calcified cover (more coral, less algae) in red and high fleshy cover (more algae, less coral) in blue. Values are predicted for hard bottom habitats 0-30 meters depth at a spatial resolution of 100m generated by the Hawaiʻi Monitoring and Reporting Collaborative (HIMARC) (Donovan et al., 2023) using combined data from 2004-2014 from multiple statewide monitoring programs and comprehensive mapping of drivers in a Bayesian Hierarchical Model.

Mesophotic Reefs

Coral reefs that extend from shore to approximately 164 feet (27 fathoms/ 50 meters) in depth are the most monitored and well-understood. Below these depths, from about 30 meters to over 150 meters, there are other, less studied habitats known as mesophotic coral ecosystems (MCE). In 2006, an extensive MCE was discovered off Maui with almost 100% coral cover. These reefs were found to provide habitat for 72 species of frondose macroalgae, including expansive *Halimeda* meadows. Ten species of hard or stony (scleractinian) corals (including four species that are common on adjacent shallow water reefs: *Pocillopora damicornis*, *P. meandrina*, *Porites lobata*, and *Montipora capitata)*, and eight species of black corals (antipatharian) were also observed [6–10]. Representatives of eight additional phyla of invertebrates, and 60 species of fish (on Maui MCE) were also observed with a high rate of endemism (43% for species only found deeper than 30m and 51% for species only found deeper than 70m) (Figure 12)[6]. Many other invertebrate species collected from this study have yet to be identified and may be previously unknown species [6].

Endemic: Organisms that are native to and exist only in a specific place or region and nowhere else in the world.

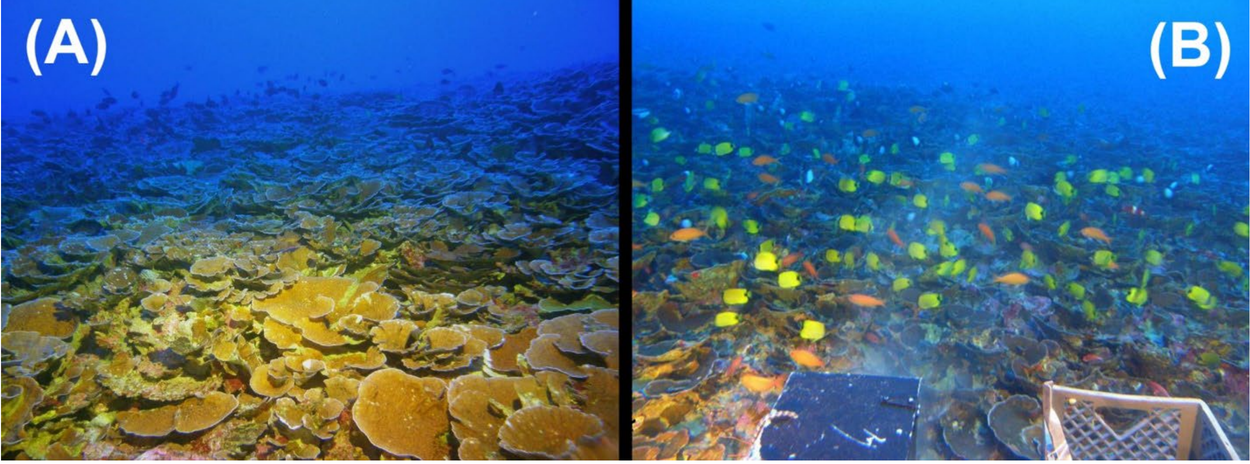


Figure 12: Heterogeneous reef fish distribution on Leptoseris reefs in the ʻAuʻau Channel. (From Pyle et al. 2016).

Reef fish distribution on Leptoseris *reefs in the ʻAuʻau Channel was heterogeneous, with large areas nearly devoid of fishes (A) punctuated with areas of high fish diversity and abundance (B). The fishes seen in the distance in (A) represent a separate localized area of high abundance. All but two of the fishes visible in (B) belong to endemic species (Endemics:* Chaetodon miliaris, Pseudanthias thompsoni, Sargocentron diadema, Dascyllus albisella, Holacanthus arcuatus, Centropyge potteri; *Non-endemic:* Forcipiger flavissimus, Parupeneus multifasciatus*). Photos: HURL.*

Overall diversity is lower in MCE than adjacent shallow water reefs. Coral community composition shifts distinctly with depth. *P. damicornis* and *P. lobata* were only seen at the shallowest MCE (<50 m) and *M. capitata* occurred at depths from 50-80m [11]. At deeper depths, starting around 65m, corals belonging to the genus *Leptoseris* were the most common (Figure 13), becoming dominant from about 80m-130m deep [11]. Some species appear to be deep reef specialists, with *Leptoseris hawaiiensis,* in particular, only being found at depths from 115-125m [12]. It is thought that they host unique symbionts (like the zooxanthellae found in shallow water coral tissues) that help them to metabolize at such deeper depths with limited light availability. This would make them highly specialized and suggest that there is limited connectivity for these specialist species between deep mesophotic reefs and shallow water reefs [12].

Symbiosis: Two different organisms living in close physical association, typically in a mutually beneficial relationship.

Symbionts Organisms living in symbiosis.

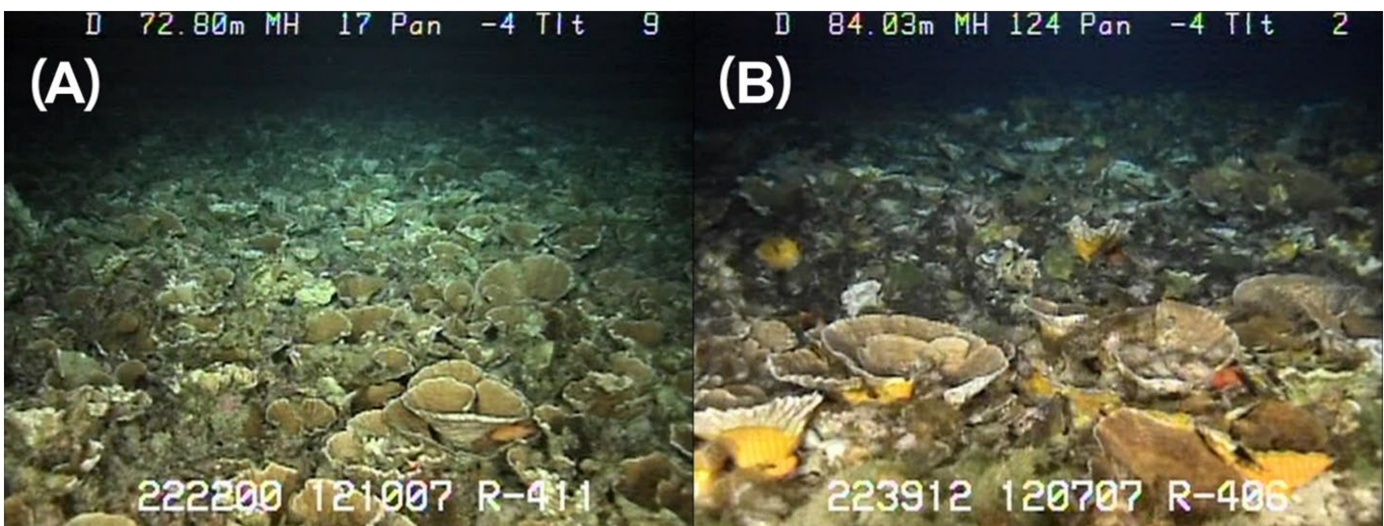


Figure 13: Comparison of Leptoseris*-dominated MCE habitats. (From Pyle et al. 2016) (A) Kaua'i and (B) Maui, showing the close similarity in general structure.*

Generally, the most extensive MCE were found in areas with the clearest water, the ʻAuʻAu channel having between 1.8 to 2.6 times clearer water than nearby areas in West Maui [6]. Many MCE are found near the depth limit where there is just enough light for photosynthesis, so MCE rely on high water clarity that allows limited light to reach the corals. Therefore even small increases in turbidity at the surface (for example caused by an increase in sedimentation or plankton blooms due to increased nutrients), may have greater impacts on MCE than on shallow water reefs, and may be less resilient to these types of stressors [6].

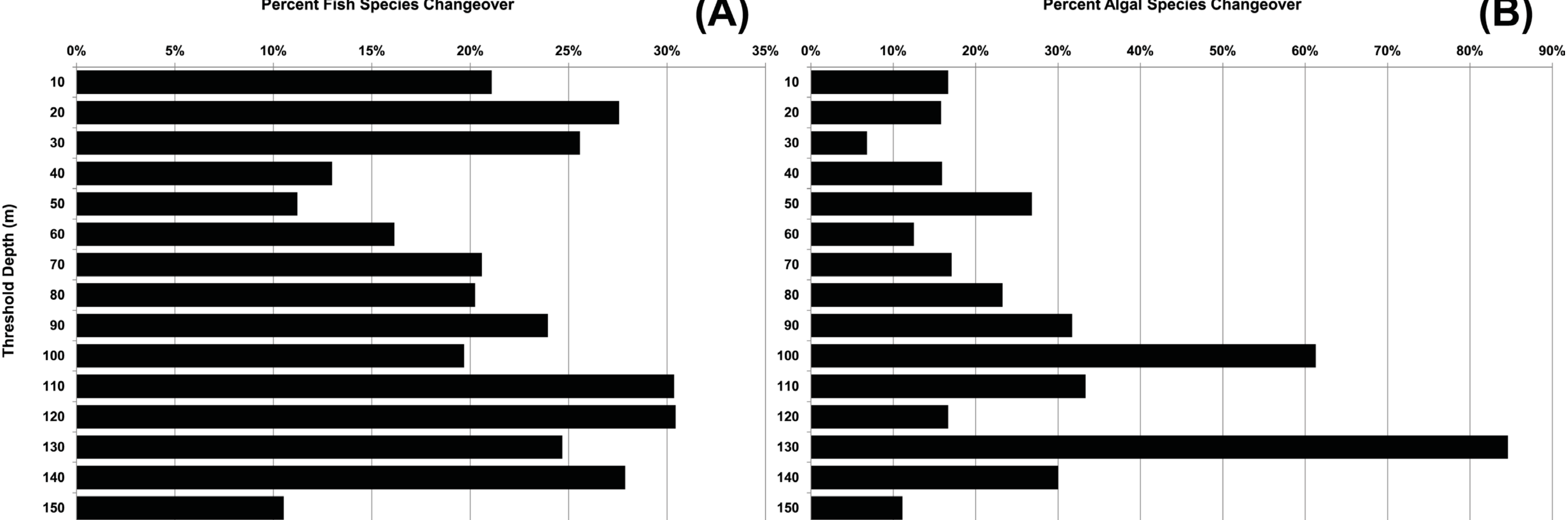


Figure 14: Fish and macroalgal species changeover at 10-m depth intervals. (From Pyle et al. 2016)

The degree of fish (n = 445) changeover (A) and macroalgal (n = 72) species changeover (B) at 10-m depth intervals. Values of each bar represent the number of species with a maximum known depth limit within 10 m above each depth interval plus the number of species with a minimum known depth limit within 10 m below each interval, expressed as a percentage of the total species present at the interval. A high value indicates a more substantial break, and a low value represents a less substantial break.

On black coral beds of the MCE in Maui, 60 species of fish were observed, most of them planktivores (68%), feeding on plankton in the water column [6]. There were relatively few herbivores (7%), omnivores (1%) and piscivores (1%) (feeding on other fish) [6]. Twenty-three percent of fish species were benthic carnivores, meaning they feed on animals found on or associated with the bottom [6]. The shift is less evident in fish community composition in the MHI with depth as with corals in that most fish species (87% of 445 species) observed at depths greater than 30m were also observed on shallower reefs and only 12% of species observed were restricted to MCE.

Mesophotic reefs are unique habitats that are sensitive to many stressors. They harbor a biodiversity of fishes, algae, corals and numerous other invertebrates. The following summarizes key management considerations for MCE from Pyle et al. (2016). There have been discussions among scientists about the possibility that MCE could serve as a refuge for shallow water reef counterparts in the face of thermal stress (rising ocean temperatures causing bleaching and mortality of shallow water corals) and irradiance (sun energy), in that extreme temperature shifts irradiance impacts are less severe at deeper depths. The potential impacts from the increasing frequency of large storm/wave events and ocean acidification on MCE due to climate change are not yet known or fully understood. MCE may be less susceptible to coastal impacts like sedimentation and effluent, as some are farther away from shore. However, it may be that these corals, especially in deeper MCE, are used to the extremely stable environment, making them more sensitive to any type of stress, including thermal and light attenuation from sedimentation or effluent. Despite being farther from shore, some MCE coral species rely on a very limited amount of light available at depth and may be disproportionately susceptible to decreases in water clarity due to sedimentation and nutrient effluent. They would also be vulnerable to disturbances from development occurring in deeper waters, such as undersea cables and offshore windmills, given their depth range and given that the full extent of MCEs in the main Hawaiian islands has not yet been documented. Though there is some overlap in fish species between shallow water reefs and MCE, especially at shallower MCE depths, fish biomass and egg production for some species was lower in MCE than in shallow water reefs, even when considering the increased fishing pressure for this species at shallower depths [6]. This suggests that mesophotic coral and fish populations may be more vulnerable than their shallow water counterparts. However, shallower MCE may serve as a refuge for some reef fish species and coral. Given that there is much to MCE that has yet to be discovered, management actions should be implemented cautiously to preserve these fragile, diverse, and unique habitats.

Refuge at depth: Shallower mesophotic coral ecosystems may serve as a refuge for some species of fishes and corals that are also found on shallower coral reefs, though MCE are more sensitive to disturbance and likely more vulnerable to stressors like warming temperatures and sedimentation.

Other important habitat for reef fishes

Artificial Reefs

Artificial reefs are human-made structures that mimic some characteristics of a natural reef. They can be created from materials such as sunken ships, derelict cars, damaged concrete pipes, and tires. Since 1991, with better environmental awareness, concrete z-shaped ("z-block") modules are primarily used to create artificial reefs in Hawaiʻi. Artificial reefs are becoming more popular in conservation and restoration efforts and are currently being explored as a fisheries management tool to aid in the rehabilitation of degraded ecosystems. They can also be used as a mitigation tool for vessel groundings and other direct impacts that damage coral reefs.

Yet, there are some concerns on the true value that artificial reefs provide. It is unclear whether artificial reefs produce new populations of fish, or are simply attracting existing populations from other reefs [13]. Newly established fish communities around new artificial reefs are usually dominated by transient or opportunistic species that move in from elsewhere or don't stay permanently [14–16]. This supports the concern that artificial reefs may simply aggregate fish from elsewhere. However, these studies focused only on the early stages of biological succession on a reef from the time of deployment to one or two years. This time scale is inadequate, for considerable time must elapse before benthic communities become established and undergo sufficient succession to support resident fishes [17]. Barnett et al. (1991) examined biomass on a 14-year-old artificial reef and found that production of fish on the artificial reef was estimated to be 6.5 times greater than the production of fish on the surrounding sand flats. Therefore, given time to develop stable benthic communities, artificial reefs may support additional marine life. Artificial reefs developed with the "z-block" design provide appropriate stable structures for the recruitment and growth of corals and other benthos. As these benthic communities develop and proceed through succession, they may serve as forage sites for resident fish, enhancing the diversity of local food webs utilized by some fish species [17].

Concerns about the loss of un-colonized hard bottom or sand habitat when an artificial reef is created have also been raised [19]. Hard bottom substrate may serve as recruitment sites for corals, and sand is a feeding/resting area for some fish as well as habitat for other fishes and organisms. It is unlikely, however, that un-colonized hard bottom habitat will grow into a natural aggregate coral reef. If corals could survive in these habitats, they should already be present. In many cases, these mostly flat hard substrates are periodically scoured by sand movement, which may be preventing coral settlement and growth. Artificial reefs can provide enough vertical relief to allow corals to recruit above the level where sand movement (scour) would affect them, providing additional space for corals to settle and grow where they otherwise could not.

Although it is true that sand habitats can change dramatically when an artificial reef is created, sandy areas are very abundant in Hawaiʻi, while complex habitats (which can be provided by artificial reefs) tend to be uncommon. Artificial reefs create appropriate shelter for more diverse, higher standing crops of fishes than would otherwise be found in sand areas or on most natural reef habitats [17]. The establishment of appropriately designed artificial reefs is a proven means of habitat enhancement. Once established, the locus of high fish concentration at the artificial reef site serves as a point source for the production and recruitment of larvae and/or immigration of adults to other locales. Therefore, it can further increase the biological diversity and abundance over an area considerably larger than artificial reef itself [17].

In 1957 the Territory of Hawai'i began looking into the possibility of installing artificial reefs in areas of sparse natural habitat. The State's first artificial reef was created in 1961 at Maunalua Bay, off Kahala, O'ahu (74 acres). In 1963, two more artificial reefs were created off Keawakapu, Maui (54 acres) and Waianae, O'ahu (141 acres) [20]. The entire cost of the modules and its deployment (tug and barge services) was covered through federal funding and concrete material were donated.

The Keawakapu artificial reef was originally created using 150 cars (today there are no visible signs of the cars, as it has disintegrated over the years), 2,250 tire modules, 1435 z-modules, 52 deep water prototypes, 35 concrete slabs, and 1 vessel (the "St. Anthony"). Tire modules were later added in 1989 and 1990 and in 2009, an additional 125 concrete z-modules were dropped to the north of the site. These modules have provided an opportunity to study coral recruitment on artificial reefs and examine the differences in fish assemblage at the artificial reef as compared to a finger coral (*Porites compressa)* dominated reef, as found in other areas around Maui. The artificial reef now hosts a diversity of larger resource fish (uku, mu, kumu, pualu) and white tip reef sharks.

Keawakapu Artificial Reef, Maui

Boundary Coordinates of the Keawakapu Artificial Reef

Coordinate	North Latitude	West Longitude	Depth* Feet	Depth* Meters
A	20° 41.900'	156° 27.300'	72	22
B	20° 41.900'	156° 27.100'	46	14
C	20° 41.610'	156° 27.130'	57	17
D	20° 41.610'	156° 26.930'	52	16

*Depths are approximate and should not be used for navigational purposes. Depths of Coordinates A, B & C were estimated from bathymetry data aggregated from NOAA-NOS Hydrographic Survey Data CD (Version 4.1, Vols. 1 & 2) by the Hawaii State GIS Program. Depth of Coordinate D was estimated from SHOALS LiDAR bathymetry (USACE).

Figure 15: Map of Keawakapu artificial reef location with respect to other coral reef areas.

DAR's Artificial Reef Project's mission is to increase habitat complexity, increase fish biomass and species richness, and enhance fishing opportunities. The State of Hawai'i currently has five artificial reefs on O'ahu and Maui, and multiple fish aggregating devices (FADS) throughout the state in cooperation with the University of Hawai'i's Hawai'i Institute of Marine Biology. Research studies examining the effectiveness of artificial reefs in Hawai'i are mixed, and can be interpreted in multiple ways depending on the management objectives [21–23]. One study conducted at the AR complex off Ewa Beach, O'ahu found that while these structures did support diverse fish communities, they were not comparable to natural reefs and it was mainly dominated by ta'ape (Bluestripe snapper, *Lutjanus kasmira*), a non-native introduced species [22]. Today, Hawai'i's growing population places an ever-increasing fishing pressure on our limited nearshore fishery resources. In response, the State's Artificial Reef program is collaborating on research to enhance reef module design and durability. Determining whether artificial reefs are the best solution will require clear management goals, defined outcomes, and careful consideration of site selection and permitting. Plans to expand O'ahu artificial reef sites are already underway, with DAR actively engaging local fishers to incorporate their input to improve the program. Additionally, enhanced monitoring and research are being planned to assess the ecological effectiveness of these reefs before considering statewide expansion.

Maui's Nearshore Fishes

Coral reefs provide habitat and food for hundreds of species of fish. Healthy reefs and healthy fish populations rely on one another. Coral reefs host some of the highest levels of biological diversity in the ocean, akin to the terrestrial equivalent of rainforests. Coral reef fish populations are increasingly vulnerable to numerous threats including degraded ecosystems, urban run-off, cesspool effluent and fishing pressure.

When residents were surveyed in 2020 about their perception of the condition of the number and variety of fish in Hawai'i, results were divided. Approximately 40% of Hawai'i residents surveyed felt that the condition of the number of fish was bad/very bad, whereas approximately 20% thought that the number of fish was good/very good. Some (28% for Maui specifically and 23% statewide) felt that the condition was neither good nor bad [1]. When asked about the variety of fish, there was a similar split among residents (Figure 16).

DAR monitors coral reef fish at numerous sites around Maui. The survey monitoring method that DAR uses is called the Fish and Habitat Utilization (FAHU), and is similar to the one developed by Dr. Alan Friedlander at the University of Hawai'i [24,25]. Fish, invertebrates, and the benthic organisms that grow on the seafloor, like coral and algae, from eight different habitat types, are monitored in FAHU surveys. For more information about this survey method and habitat types, please see Appendices D and E.

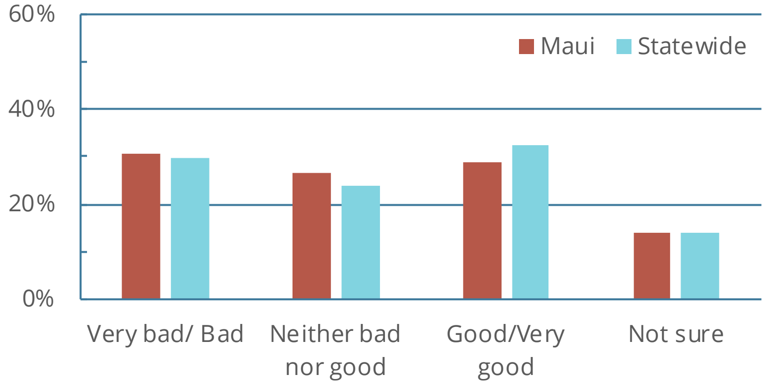
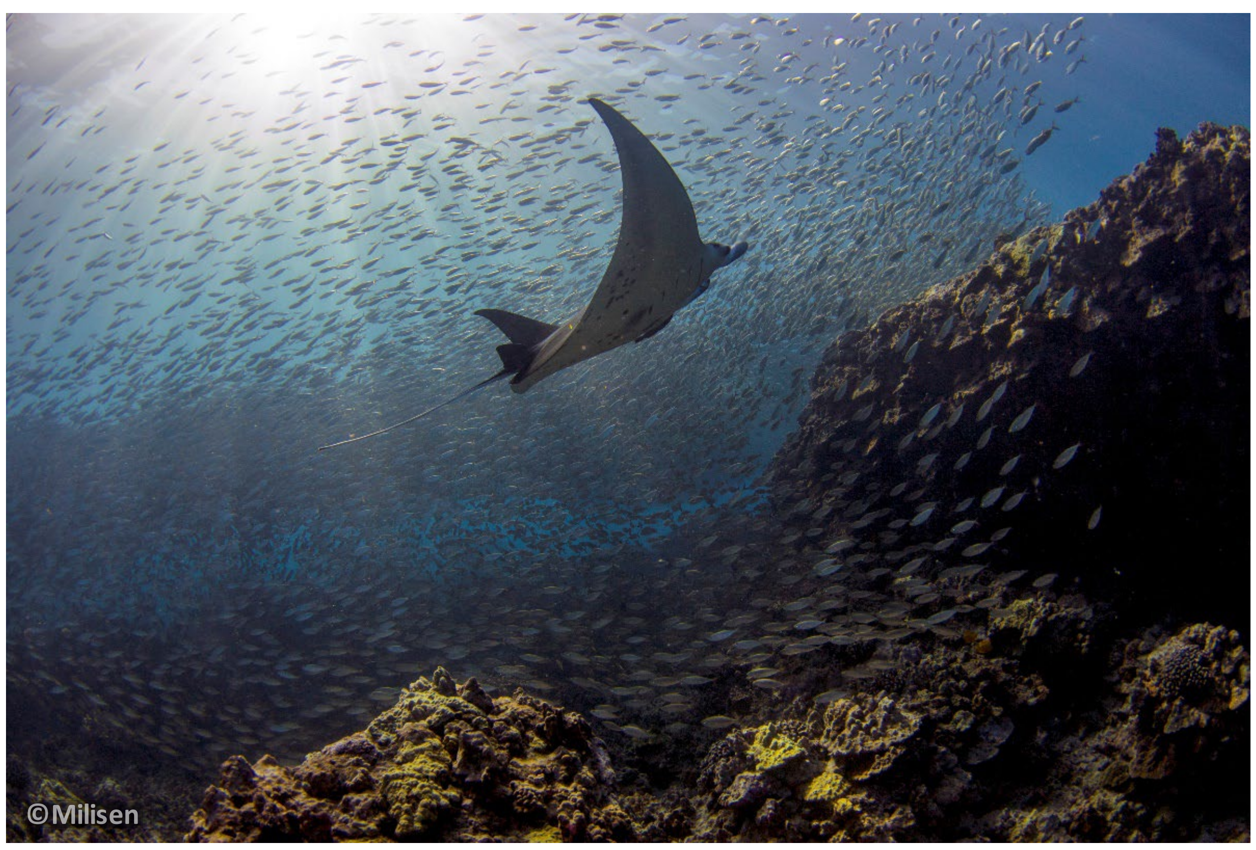


Figure 16: Perception of the current number of fish (top) and variety of fish (bottom) both statewide and Maui, individually, based on surveys of randomly sampled Hawai'i residents (Allen et al. 2022).

One metric that can be estimated from these surveys is species diversity, which can be represented in many ways, including species richness (number of species observed at a site), the Shannon index and the Simpson index. The latter two indices account for both species richness as well as evenness, or the relative contribution or abundance of each species observed in the community overall. A greater number of species on any given reef will support a greater number of critical ecosystem functions, increasing the services that the reef can provide. Species richness at 11 different sites across Maui ranged around 124 species (excluding elusive, roving species such as sharks and manta rays, due to their movement patterns and likelihood to be observed during surveys) per site (Figure 17). Kihei-Makena has the highest species richness (157 species), while Honokōhau had 90 species recorded (no observations of lizard fish, cardinal fish or goatfish, among other species). Interestingly, highly restricted sites did not necessarily harbor the highest number of species. The Kihei-Makena site had the most species overall, but it is not within a marine management area and does not have place-based fishing regulations. Though one potential benefit of more restrictive place-based regulations like marine reserves is increased species diversity, this metric is largely determined by environmental factors such as waves, temperature, and habitat and the efficacy of these reserves depends on the consideration of species-specific environmental and habitat requirements. Thus fisheries management alone cannot effectively conserve species, given the variability of environmental factors and the large number of compounding human-derived threats (such as land-based run-off) [26].



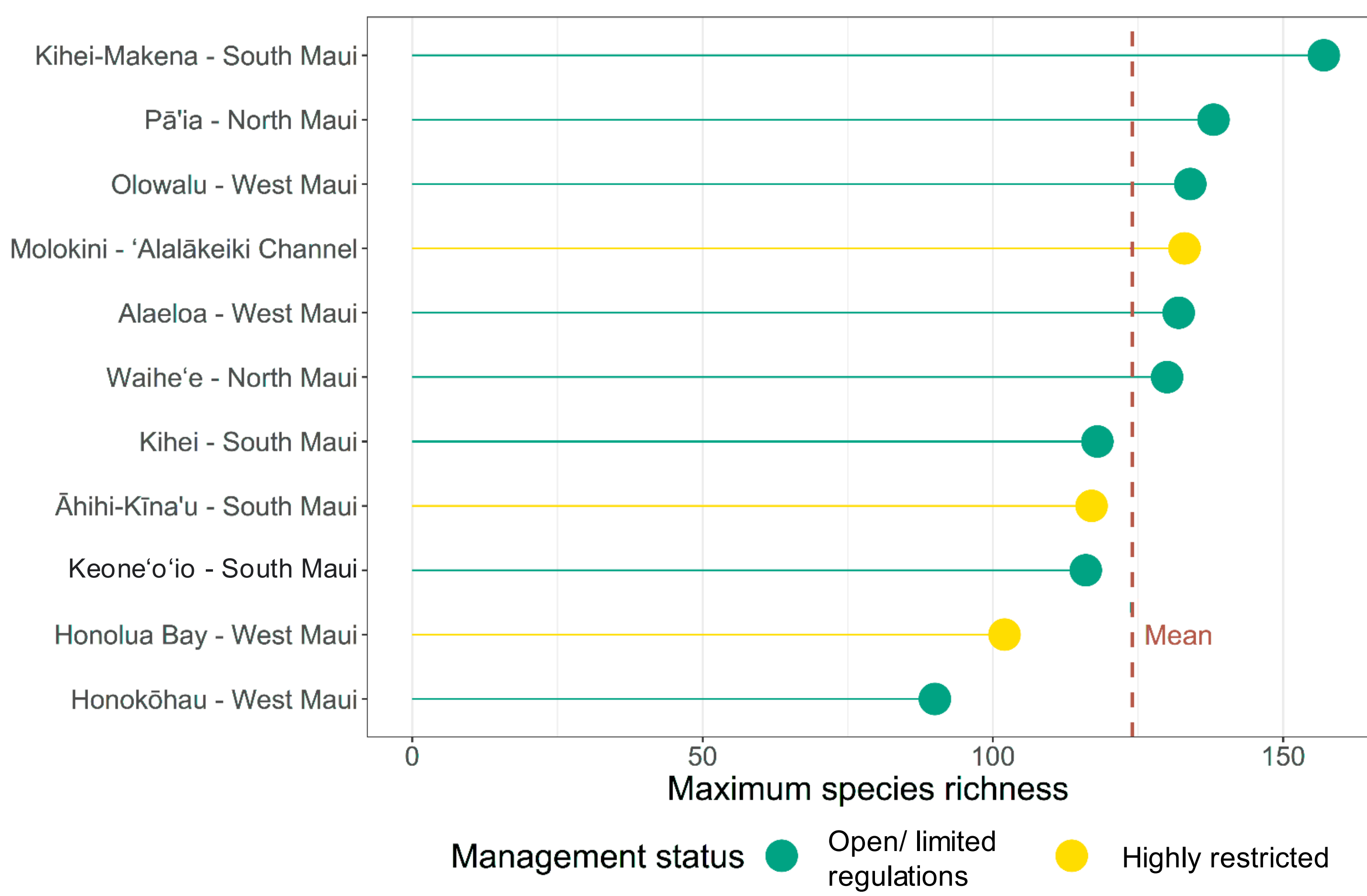


Figure 17: Total species richness was estimated for each site across all years and represented the highest number of species recorded at that site at all times. The green plots represent survey data at sites that have no, or very limited, fishing regulation and the yellow plots represent sites where fishing is either prohibited or highly restricted. The red dotted line represents the average among all DAR monitoring sites in highly restricted areas, across survey years from 2015- 2021.

Another measure of species diversity is the Shannon's Diversity Index, which accounts for both the number and evenness of species (the commonness or rareness of species being observed). Values range from 0, indicating the presence of one species, to 1, indicating that all species present are evenly represented. Based on 2004-2014 data, ten of the 13 Maui moku had fish diversity values that are comparable to the value of no-take areas across the main Hawaiian islands and four of those were significantly higher than the average of no-take areas on Maui. Three Maui moku (Lahaina, Honuaʻula, and Hāmākuapoko) had significantly lower fish species diversity than no-take areas across the main Hawaiian islands.

HIMARC
HAWAIʻI MONITORING AND REPORTING COLLABORATIVE

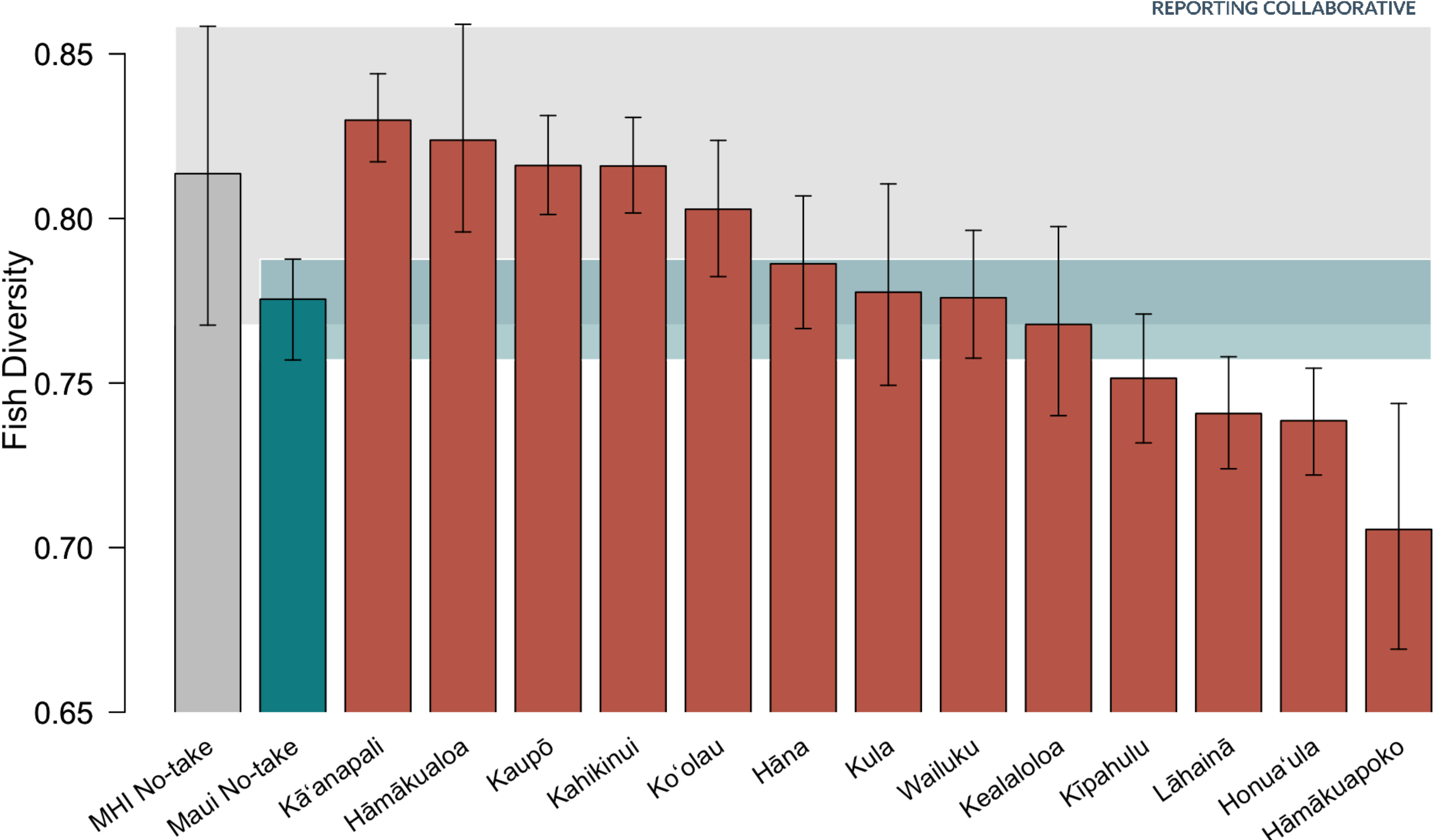


Figure 18: Fish species diversity (Shannon's Diversity Index) summarized across Maui moku by HIMARC, where monitoring surveys occurred, compared to fish species diversity inside Marine Life Conservation Districts (MLCDs) in the main Hawaiian islands (MHI) and Maui. MLCDs highly restrict fishing and can serve as a no-take baseline. Bar heights are means and error bars are 50% intervals of posterior predictions for all hardbottom areas in a given moku based on best available data from 2004-2014. Values are estimates from a Bayesian Hierarchical model that accounts for the relative distribution of habitat and variation in other drivers of the indicator in a given area. 50% intervals for no-take baselines are shaded grey for the statewide values, and blue for Maui. Error bars for moku that do not overlap the shaded areas have significantly lower biomass compared to no-take baselines.

Total fish biomass (all fish combined) is highly variable across the main Hawaiian Islands (MHI) by moku. Moku in the most remote locations furthest away from humans (for example, on Kahoʻolawe and Niʻihau) have the highest biomass, whereas 6 of the 8 moku with the lowest levels of fish biomass are on Oʻahu, where there is high human population and urbanization. Maui moku varied between relatively high and low fish biomass compared to other moku statewide (represented by red bars in Figure 20). The variability seen among Maui moku follows the statewide patterns in that areas with the highest fish biomass were generally in remote locations and were furthest from humans. Areas with low total fish biomass were generally near areas with higher populations of both residents and tourists and were closer to other land-based impacts such as run-off from golf courses.

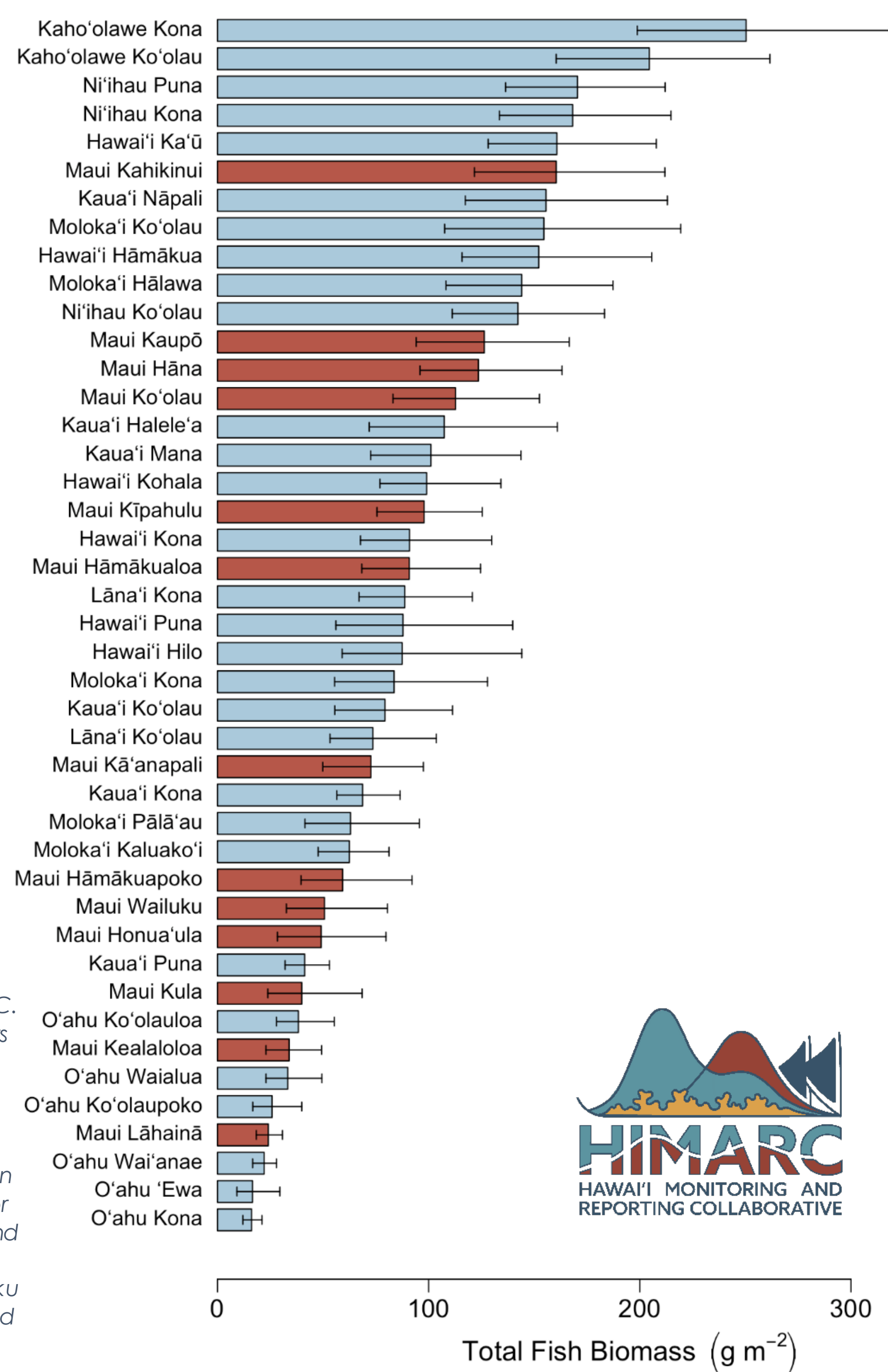


Figure 19: Total fish biomass summarized across moku by HIMARC. Bar lengths are means and error bars are 50% intervals of posterior predictions for all hardbottom areas in a given moku based on best available data from 2004-2014. Values are estimates from a Bayesian Hierarchical model that accounts for the relative distribution of habitat and variation in other drivers of the indicator in a given moku. Maui moku are colored red and arranged based on the height of the bars.

The variation in total fish biomass across Maui moku can be compared with values from different areas that have varying levels of management, to provide context about the relative state of fish assemblages in each moku. Drivers included in the model for producing these drivers include measurements within categories of land-based pollution, fishing pressure, physical oceanography, and habitat, and as such the estimates account for the variability in these categories among moku (more details are found in Appendix B: HIMARC Introduction and Methods). Marine Life Conservation Districts (MLCDs) either prohibit or highly restrict fishing, and thus serve as a baseline to compare biomass levels across moku. The estimated total fish biomass inside Maui MLCDs ranged from 88.1 g/m^2 to 164.3 g/m^2 (with a 50% chance that the true value is within this range). The estimated no-take average for Maui was approximately a third lower than the average of no-take areas across the main Hawaiian Islands (116.1 vs 197.2 g/m^2). Nine out of 13 Maui moku had significantly lower biomass compared to areas that highly restrict fishing across the

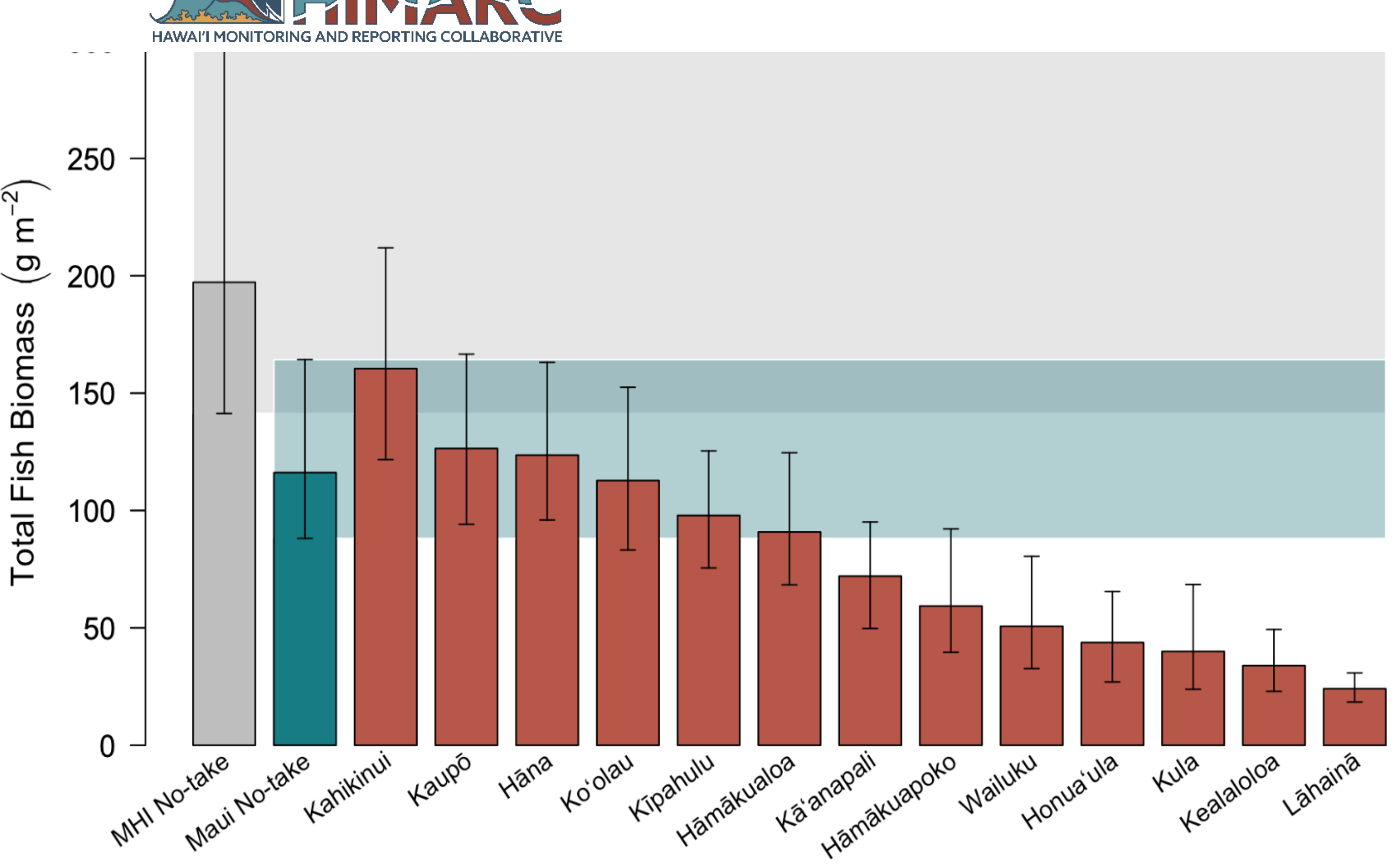


Figure 20: Total fish biomass summarized across Maui moku, where monitoring surveys occurred, compared to total fish biomass inside Marine Life Conservation Districts (MLCDs) in the main Hawaiian islands (MHI). MLCDs highly restrict fishing and can serve as a no-take baseline. Bar heights are means and error bars are 50% intervals of posterior predictions for all hardbottom areas in a given moku based on best available data from 2004-2014. Values are estimates from a Bayesian Hierarchical model that accounts for the relative distribution of habitat and variation in other drivers of the indicator in a given area. 50% intervals for no-take baselines are shaded grey for the statewide values, and blue for Maui. Error bars for moku that do not overlap the shaded areas have significantly lower biomass compared to no-take baselines.

main Hawaiian islands, with Kahikinui, Kaupō, Hāna and Koʻolau moku overlapping with the no-take baseline (Figure 20). These two moku have low human population and are difficult to access from shore, lessening the effects of human impacts. Wailuku, Honuaʻula, Kula, Kealaloloa, and Lahaina were also significantly lower than the no-take baseline for Maui. These areas have large human population centers, large numbers of hotels and are more impacted by run-off from storms and land-based sources of pollutants.

Fish biomass measured from DAR's FAHU surveys across different management regimes increased over time (Figure 21), but at different rates (R^2=0.21, $p<0.01$). On average, biomass was higher for highly restricted sites (2019 mean = 113 and 2021 mean = 159) compared to sites with open/limited fishing regulation (2015 mean = 67 and 2021 mean = 104). The slope of biomass for sites with limited fishing regulation showed a steady increase over time, while sites where fishing is prohibited or highly restricted increased during the first two years but then plateaued. The increase in biomass over time between the different management categories might be explained by various factors, including Maui-specific fishing regulations (i.e. laynet restrictions, parrotfish, or goatfish regulations), pulse of fish recruits, a decrease in human in-water presence due to the COVID-19 pandemic, and differences in natural carrying capacity of different habitats. See Appendix D for details on survey and statistical methods.

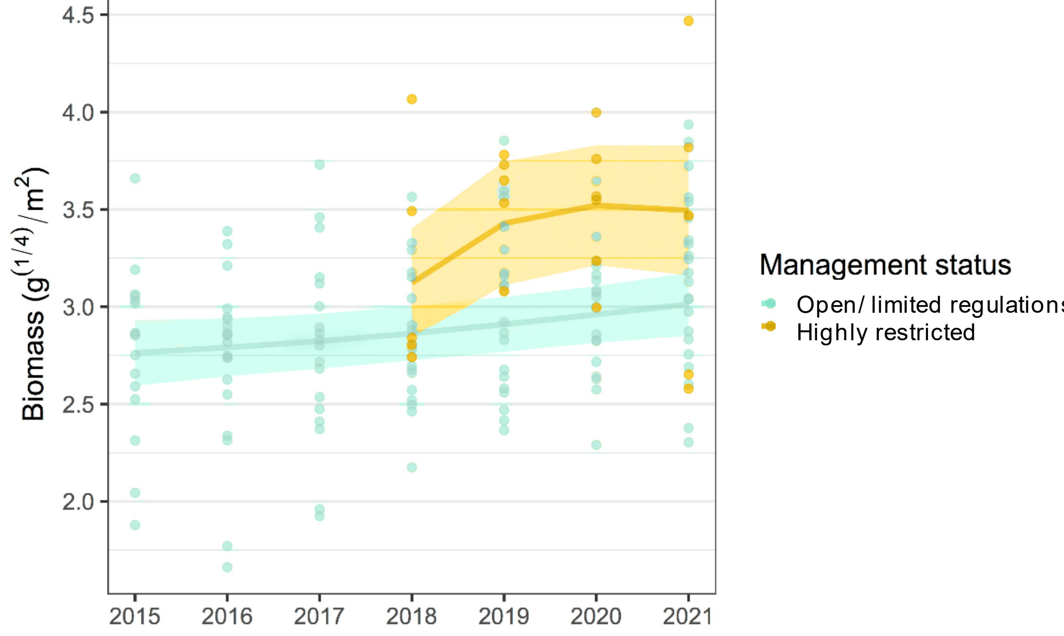


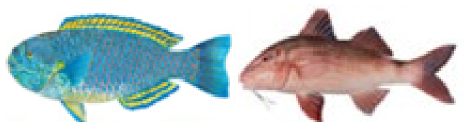
Figure 21: Total fish biomass from DAR FAHU monitoring surveys (plotted as the fourth-root transformed values) over time in sites that are open to fishing or have limited regulations (green) and sites where fishing is highly restricted (yellow). Fish biomass (fourth root transformed) across all habitats increased over time, but at different rates by management status (R^2=0.21, $p<0.01$).

Total fish abundance in areas with limited fishing regulation and areas with highly restrictive fishing regulation stayed relatively stable (Figure 21). The areas where fishing is highly restricted may seem to have a greater increase in abundance than the other areas, but the range of the data overlaps between years so increases are not considered meaningfully different from year to year. Specific groups such as herbivorous and resource (species commonly targeted as food) fish showed

Maui Rules!

Did you know? There are additional regulations implemented in Maui's nearshore waters that are different than those in the rest of the state. For example, lay net fishing is prohibited around the entire island of Maui. There are also separate rules (implemented in 2014) for uhu, parrotfishes, and several species of goatfishes that are different than the statewide rules elsewhere.

For more information on the specifics for Maui and statewide, please visit our website.



significantly higher biomass in 2020 and 2021 at sites with highly restrictive fishing regulation, compared to areas with limited fishing regulation (Figure 22).

These additional categories of fish biomass, resource fish and herbivorous fish are additional indicators of nearshore condition. Resource fish biomass can help to better understand the health of the fishery and fishing pressure. If resource fish species are declining and other species less targeted or not targeted for food do not share the same patterns over time, this could be an indication that fishing pressure is not sustainable. Often, fishing is focused on larger individuals, and over time this removal of the largest individuals can reduce the resource fish biomass and average size of fish.

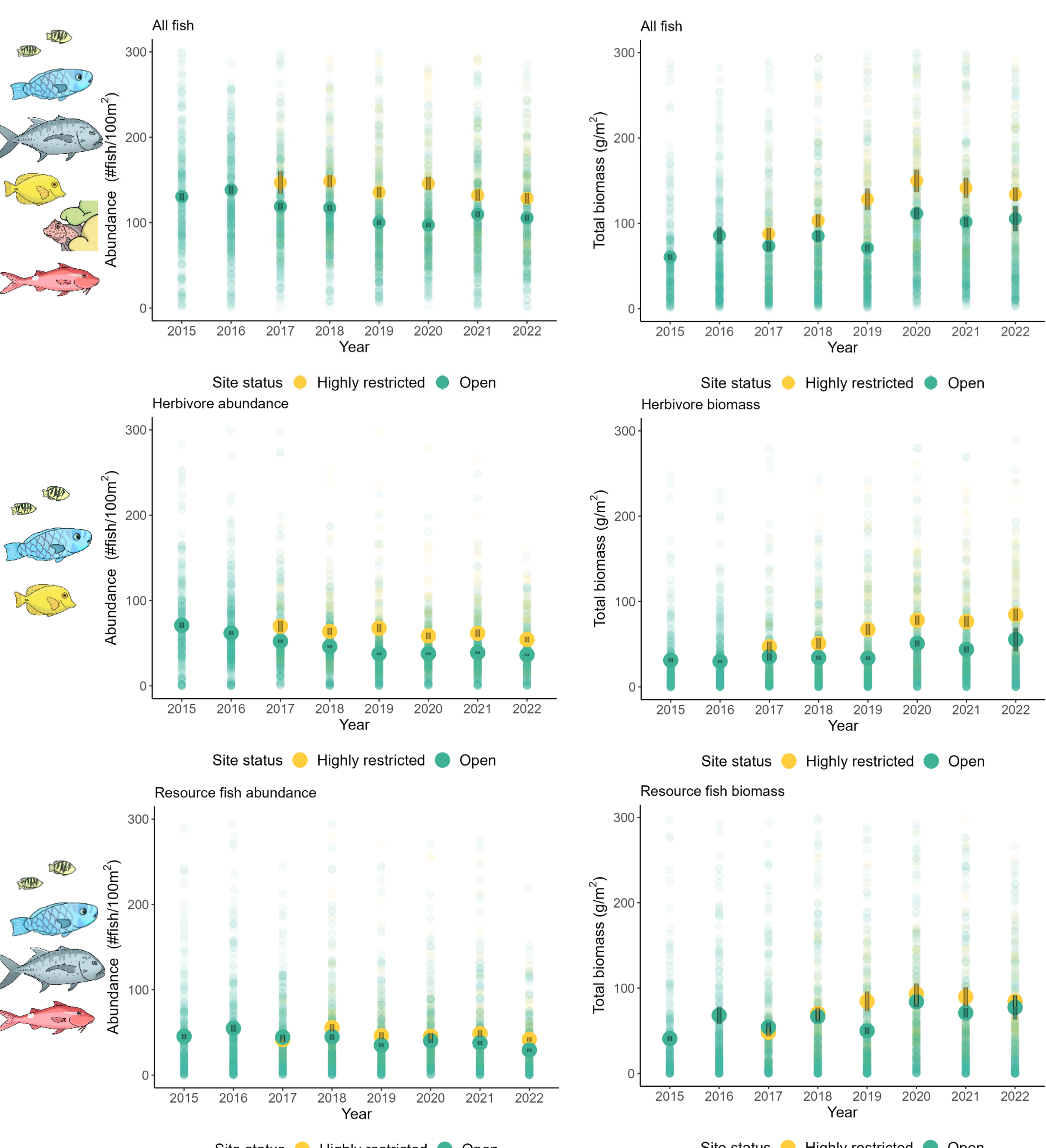


Figure 22: Data from DAR FAHU monitoring surveys for fish biomass (metric using number and size of fish to estimate weight) and abundance (number of fish) for 3 categories: All fish species, herbivorous fish species and resource (species highly targeted as food) fish species. The green plots represent survey data at sites that have very limited fishing regulation, and the yellow plots represent sites where fishing is either prohibited or highly restricted. The dots represent the data for each transect per year, the bold dots represent the mean (average) value among sites each year and the solid vertical line represents the standard error.

For both resource fish biomass and average fish size indicators, Lahaina, Kula and Kealaloloa had predicted values significantly lower than both the main Hawaiian island and the Maui no-take baselines, as well as significantly lower than six of the 13 Maui moku (Figure 23 and Figure 24). Kāʻanapali, Wailuku and Honuaʻula moku also had significantly lower resource fish biomass than both the main Hawaiian island and Maui no-take baselines (Figure 23). Five of the 13 Maui moku (Kahikinui, Hāna, Kaupō, Koʻolau and Hāmākualoa) had comparable resource fish biomass to the main Hawaiian island no-take baseline, or areas that highly restrict fishing and generally had much higher biomass than at least four of the other Maui moku and somewhat higher than two (Kāʻanapali and Wailuku) (Figure 23).

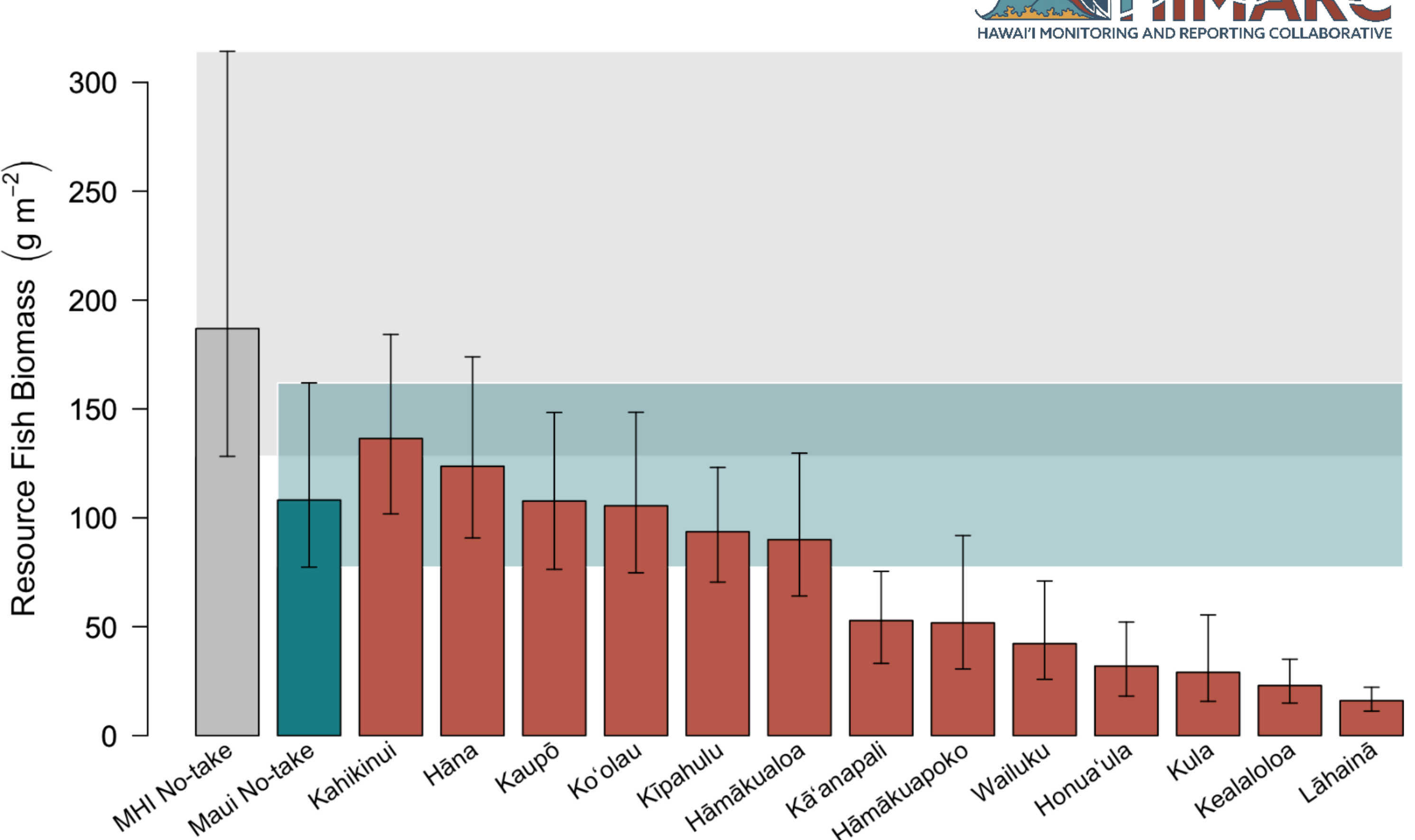


Figure 23: Resource fish biomass summarized across Maui moku provided by HIMARC, where monitoring surveys occurred, compared to resource fish biomass inside Marine Life Conservation Districts (MLCDs) in the main Hawaiian islands (MHI). MLCDs highly restrict fishing and can serve as a no-take baseline. Bar heights are means and error bars are 50% intervals of posterior predictions for all hardbottom areas in a given moku based on best available data from 2004-2014. Values are estimates from a Bayesian Hierarchical model that accounts for the relative distribution of habitat and variation in other drivers of the indicator in a given area. 50% intervals for no-take baselines are shaded grey for the statewide values, and blue for Maui. Error bars for moku that do not overlap the shaded areas have significantly lower biomass compared to no-take baselines.

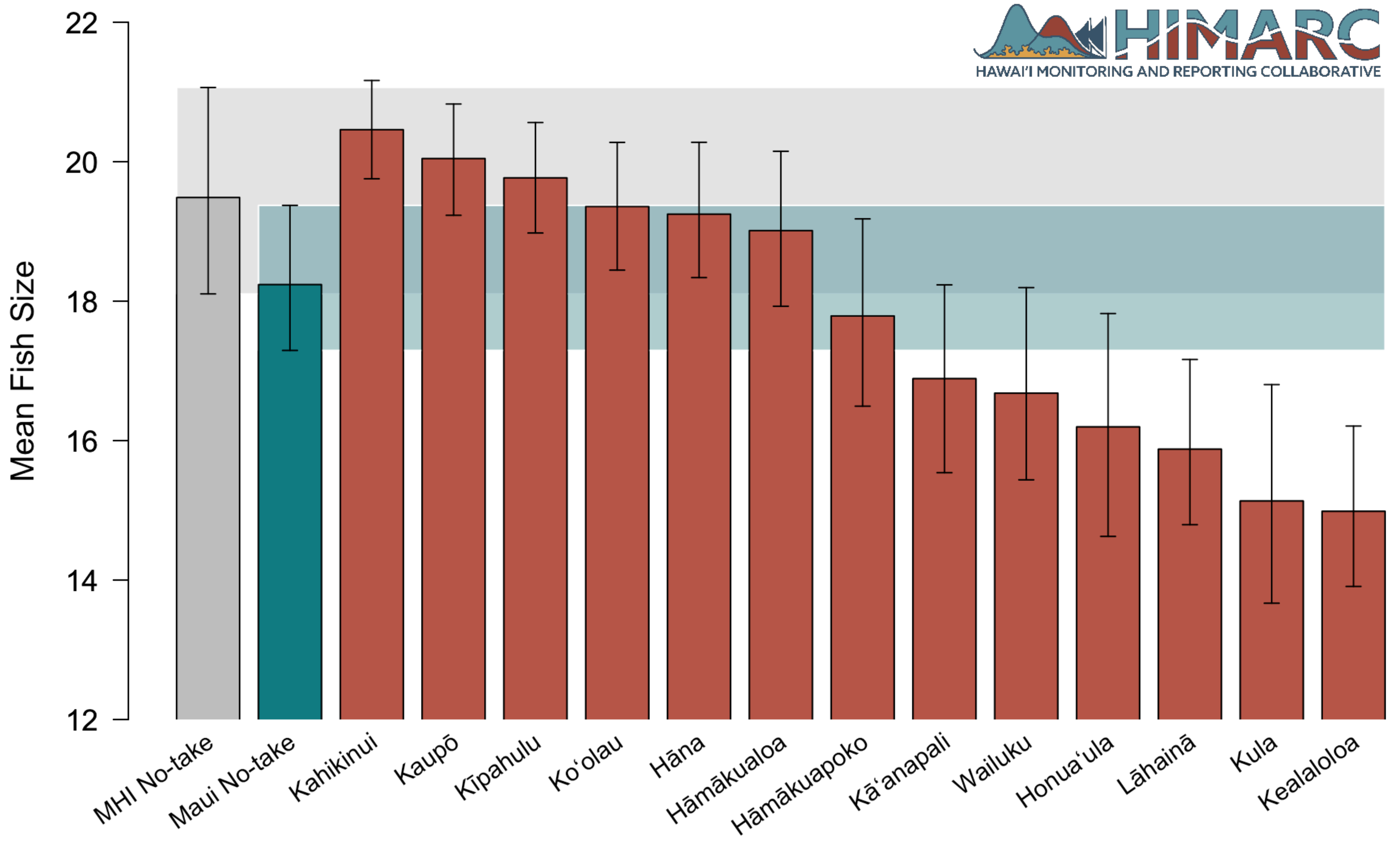


Figure 24: Average fish size summarized across Maui moku provided by HIMARC, where monitoring surveys occurred, compared to resource fish biomass inside Marine Life Conservation Districts (MLCDs) in the main Hawaiian islands (MHI). MLCDs highly restrict fishing and can serve as a no-take baseline. Bar heights are means and error bars are 50% intervals of posterior predictions for all hardbottom areas in a given moku based on best available data from 2004-2014. Values are estimates from a Bayesian Hierarchical model that accounts for the relative distribution of habitat and variation in other drivers of the indicator in a given area. 50% intervals for no-take baselines are shaded grey for the statewide values, and blue for Maui. Error bars for moku that do not overlap the shaded areas have significantly lower biomass compared to no-take baselines.

Herbivore fish biomass is also a useful indicator to better understand the condition of nearshore reefs. Not only are many herbivorous fish food favorites, they also are important for helping to improve reef condition. Herbivores help to graze, browse or scrape algae (fleshy cover) from the reef opening up room for new corals to grow and keeping the fleshy cover at manageable levels so that it does not out-compete the corals, especially when the corals are already stressed from impacts such as excess nutrients coming from land and warming ocean temperatures. Because of the role herbivores play in keeping a balanced, calcified reef, the measure of herbivore biomass is also a measure of reef resilience.

Seven of 13 Maui moku had herbivore biomass significantly lower than the main Hawaiian island no-take baseline and four of those (Kula, Honuaʻula, Kealaloloa and Lahaina) were also significantly lower than the Maui no-take baseline (Figure 25), based on 2004-2014 data [5]. Herbivore biomass in Lahaina was the third lowest of all moku in the main Hawaiian islands[5]

HIMARC
HAWAIʻI MONITORING AND REPORTING COLLABORATIVE

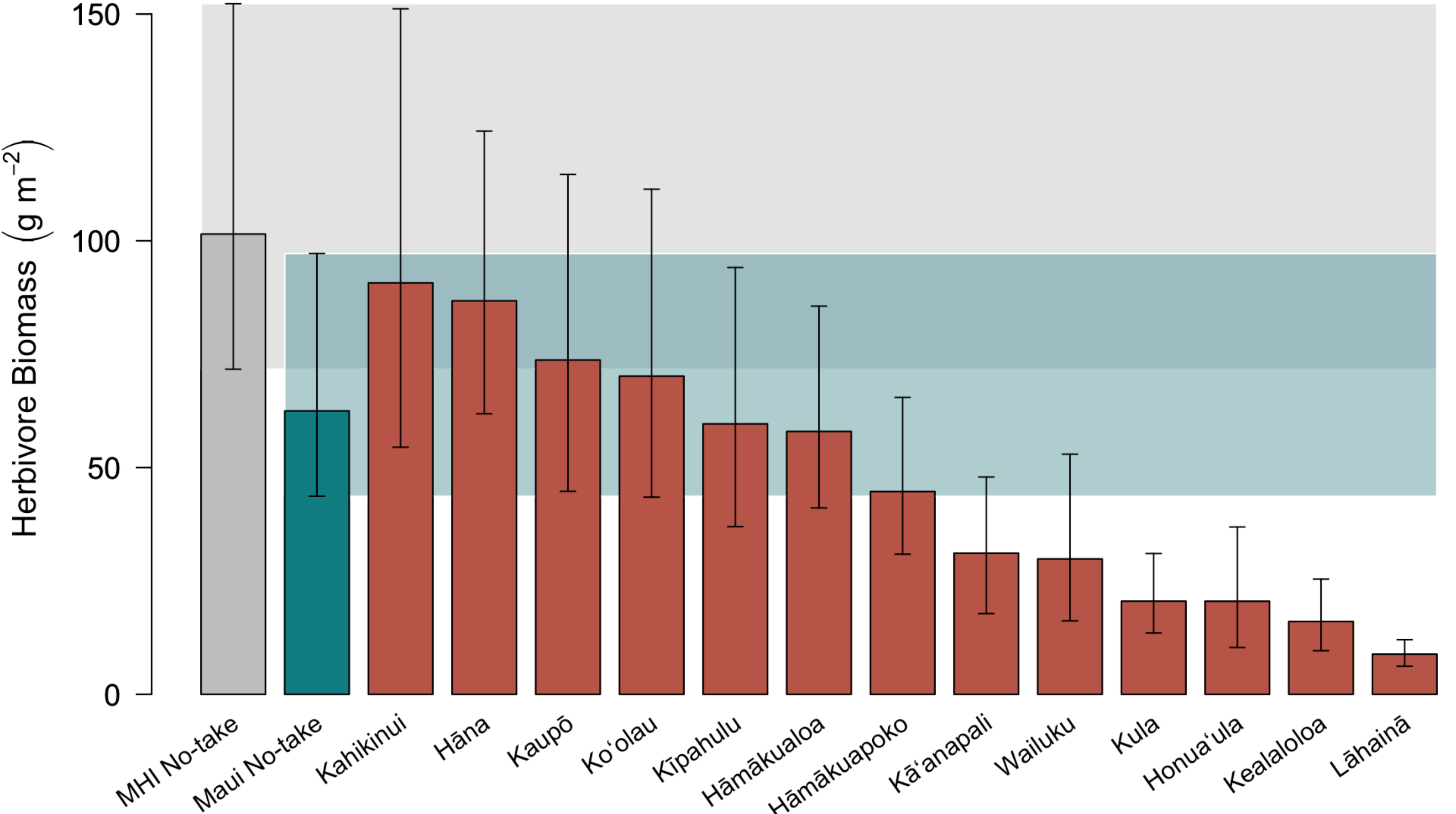


Figure 25: Herbivore fish biomass summarized across Maui moku provided by HIMARC, where monitoring surveys occurred, compared to resource fish biomass inside Marine Life Conservation Districts (MLCDs) in the main Hawaiian islands (MHI). MLCDs highly restrict fishing and can serve as a no-take baseline. Bar heights are means and error bars are 50% intervals of posterior predictions for all hardbottom areas in a given moku based on best available data from 2004-2014. Values are estimates from a Bayesian Hierarchical model that accounts for the relative distribution of habitat and variation in other drivers of the indicator in a given area. 50% intervals for no-take baselines are shaded grey for the statewide values, and blue for Maui. Error bars for moku that do not overlap the shaded areas have significantly lower biomass compared to no-take baselines.

Connectivity: How Nearshore Places and Populations are Connected and Replenished

Larval Connectivity

Connectivity is the way a population is linked across different geographic areas through the exchange of larvae and adults- the ways that a population is connected, even when individuals may be far apart. In Hawaiʻi, connectivity seems to be mostly limited to the island-scale, as there is very limited connectivity between most islands, with the exception of the islands within Maui Nui (Maui, Molokaʻi, Lānaʻi, and Kahoʻolawe)[27]. The amount of larvae that replenish an area itself (self-seeding) and the extent (quantity and distance) to which larvae can seed other areas (larval source areas), depends on the reef size and length of time that a species spends in its larval life stage. Looking at replenishment is important because it can contribute to reef resilience within a network of MMAs [28]. The distance larvae travel from the time of spawning to the time of settlement is highly variable depending on the species (Figure 26)[29]. Warming ocean temperatures can decrease the survival of coral larvae and decrease the distance that larvae will likely move prior to settling, potentially reducing connectivity [30]. This reduced

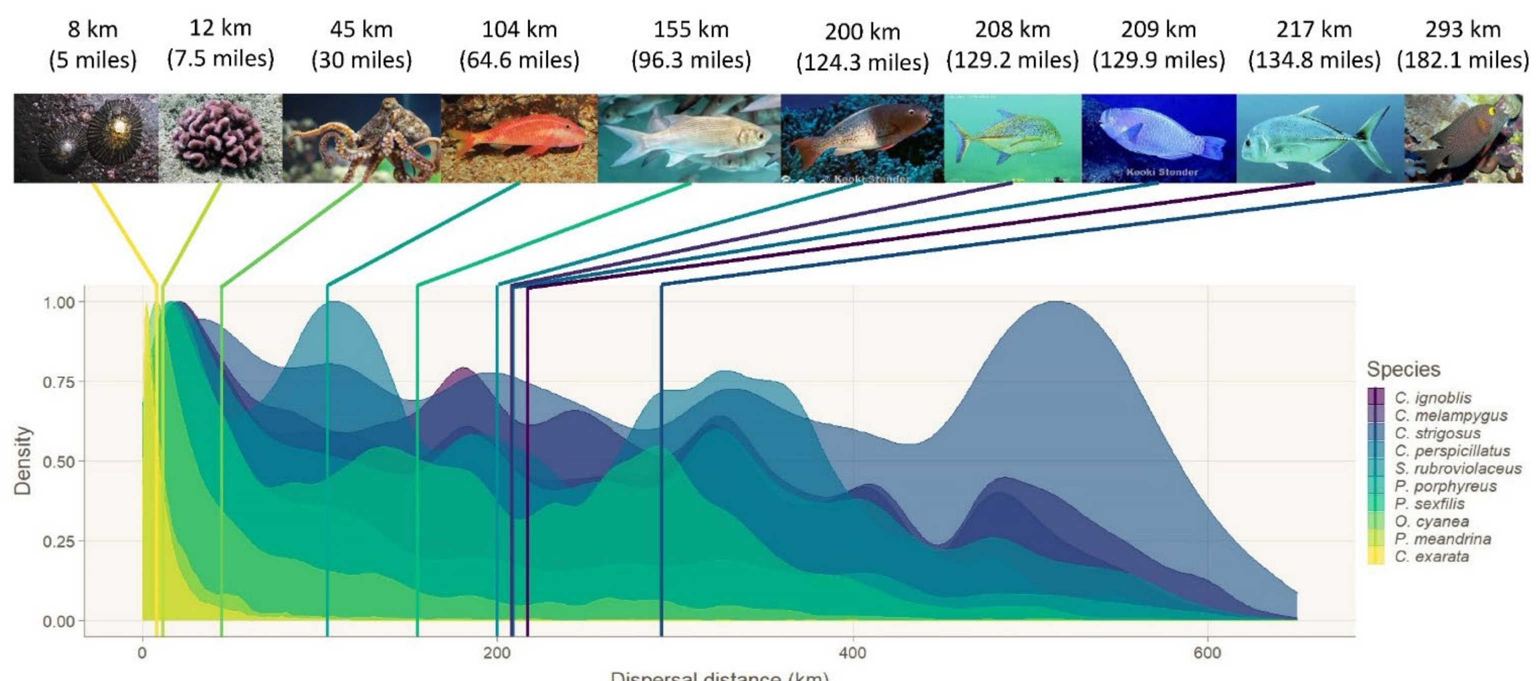
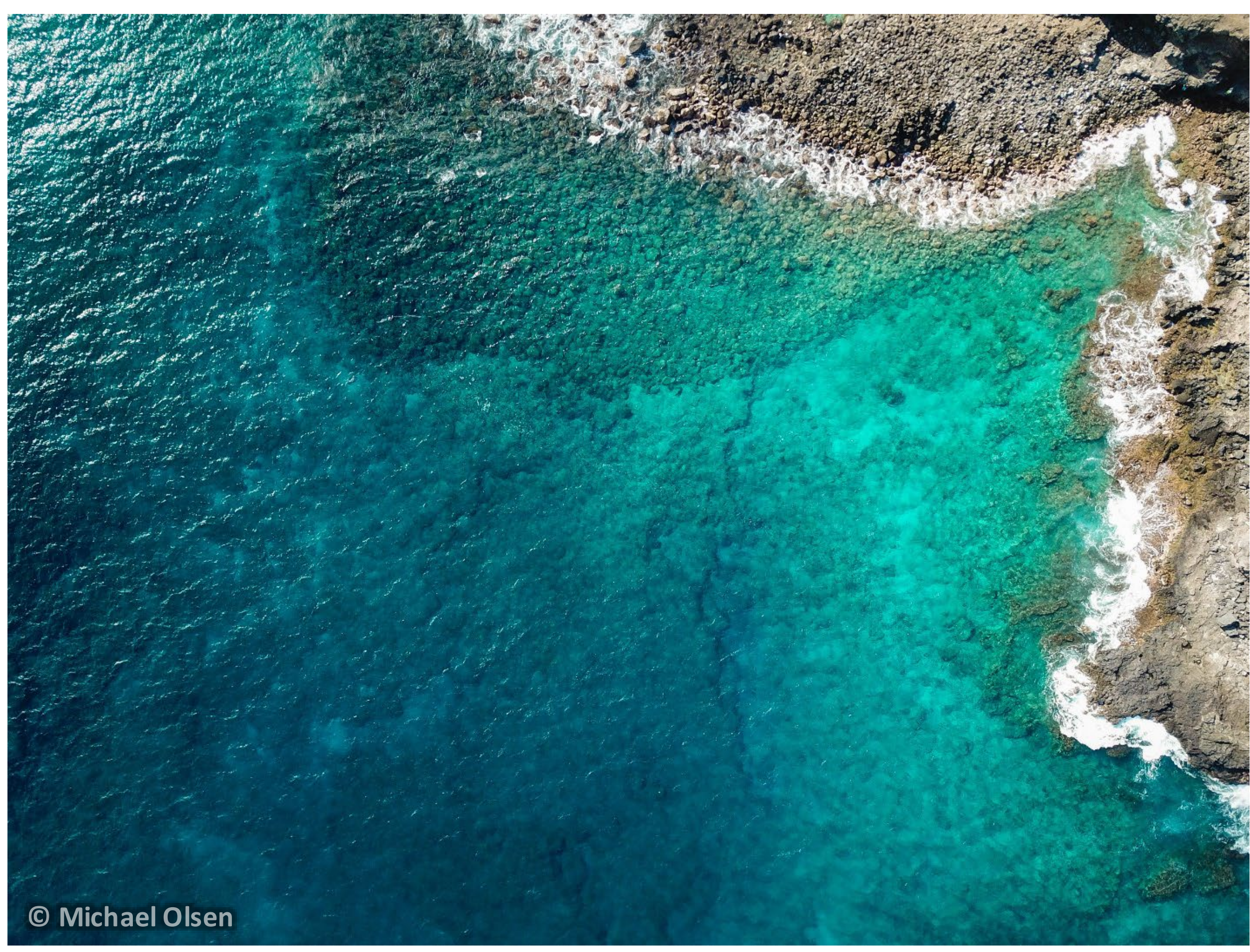


Figure 26: Summary of dispersal distance for all modeled species from Conklin, Neuheimer and Toonen, in prep. Species are shown at the top, arranged in order of dispersal distance. Dispersal distance is measured in kilometers, and represents the straight-line distance between where a modeled larva spawned and where it settled. The distribution of these distances is shown for each species, where distance is shown on the horizontal axis and density is shown on the vertical axis. Peaks close to zero kilometers show larvae settling back to the same island where they spawned, while further peaks show settlement to other islands. Each species' median dispersal

connectivity may especially impact reefs that rely on other areas as larval sources because of low self-seeding.

Although larvae are difficult to track, models may be used to estimate where they are likely to end up settling on the reef to better understand connectivity for different species across places (Figure 26). Estimates of larval flow in Hawaiʻi were made using a fine-scale (1-km resolution) oceanic current model of the main Hawaiian islands, built using oceanographic data[29]. The model included ocean depth, as well as the speed and direction of currents. Ocean currents were modeled for a period of about two and half years to include seasonal current patterns. Researchers simulated spawning events for ten different Hawaiian reef species, incorporating life history traits such as habitat preferences, spawning type, spawning season, moon phase and time of day of spawning events, buoyancy of eggs and larvae, and amount of time the larvae of each species typically spend at sea before settling back to the reef as juveniles (pelagic larval duration). For each species, the model simulated the release of between 6 and 10 million eggs over the length of the model run. Simulated eggs were released from appropriate habitat around each island, hatched into larvae, and drifted in ocean currents until the end of their pelagic larval duration. At this time, larvae that were close to appropriate habitat were marked as successfully settled. For every surviving larva in the model, the spawning location, settlement location, and distance traveled to estimate species-specific patterns of larval flow around the islands were marked (Figure 27)[29].



For all modeled species[29], on average, Honuaʻula moku, waters which include the 'Āhihi-Kīna'u Natural Area Reserve, and Hāna moku, have the highest centrality, or are central points to the Maui network - key places of connectivity for multigenerational flows of larvae (Figure 27). Other important locations for larval dispersal are the nearshore waters of Olowalu and Ukumehame, which are generally areas of high self-seeding (local populations are replenished by larvae produced in these waters) and are a larval source (providing larvae to other places around the island) (Figure 27). For ʻopihi, the key larval source and high centrality areas are in Ukumehame and Hāna. For moi and ʻōmilu, there are several areas around the island identified as being larval sources, exporting more larvae than they import. For moi the highest centrality points are in the moku of Honokahua and Kula, with several other locations being moderately high. The highest centrality points For ʻōmilu include the moku of Kula, Koʻolau and Ukumehame, with several other moderately high points especially in North and South Maui (Figure 27). Areas are low self-seeding and larval sinks (areas that rely on other areas around the island for larval replenishment) are Hāmākuapoko moku and East Maui for moi, and northern Lahaina moku and East Maui for ʻōmilu.

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Locations of high centrality should be carefully considered in management planning, as they are key for maintaining larval connectivity and supporting fish replenishment and abundance.

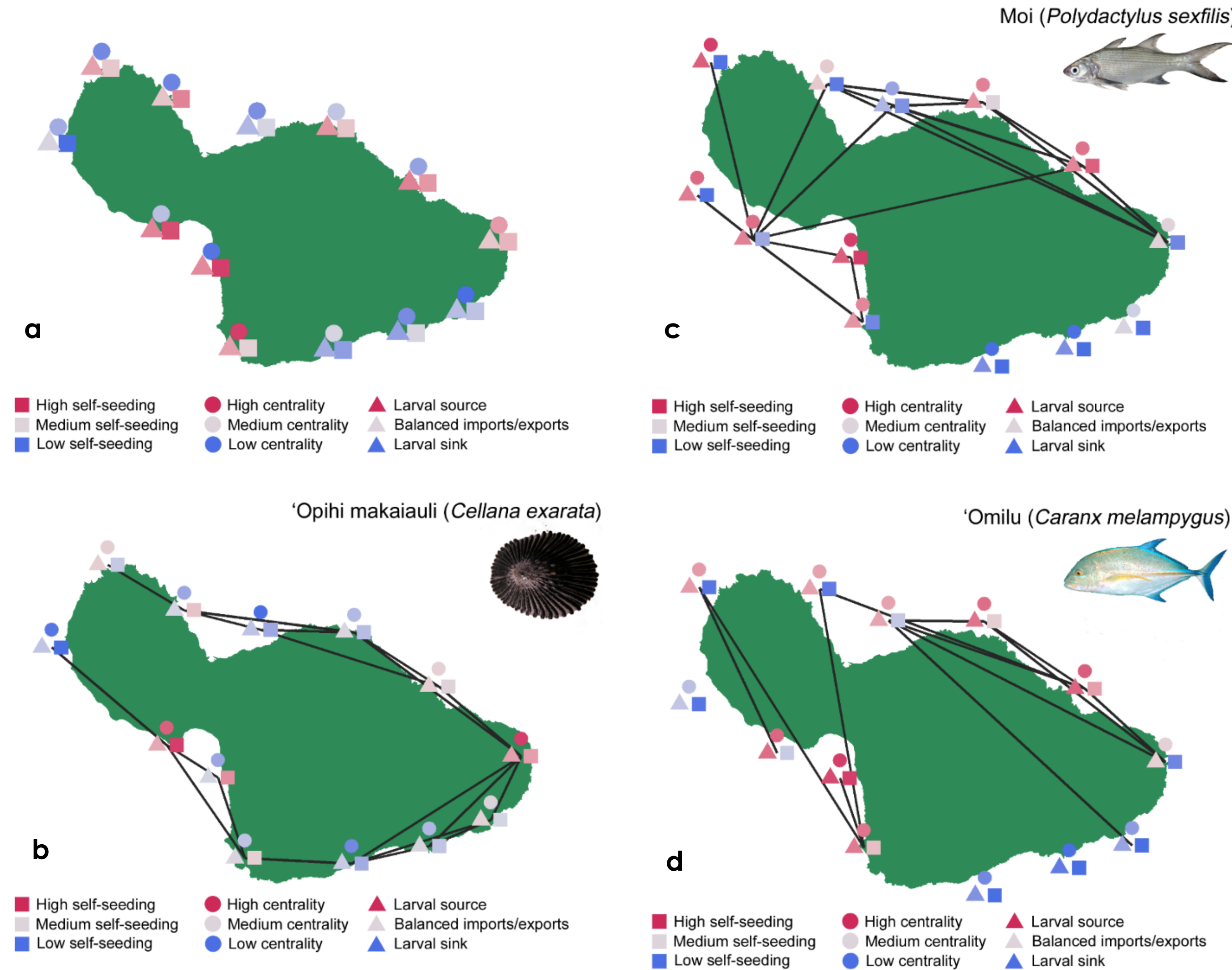

Figure 27: Summary of larval flow patterns and moku-level measures for the average of all modeled species from Conklin, Neuheimer and Toonen, in prep, (a), 'opihi makaiauli (Cellana exarata) (b), moi (Polydactylus sexfilis) (c), and 'ōmilu (Caranx melampygus) (d). These figures were selected as examples of species with a short, medium, and long pelagic larval duration, respectively. Each moku is represented by a cluster of three markers around Maui 's coastline. Black lines between moku represent a strong connection between moku in at least one direction, accounting for 5% or more of all larvae settled to that moku. For each moku, three measures were calculated: centrality, self-seeding, and source-sink index.

Centrality (circles) measures how central a moku is to the whole network, and moku with high centrality can be thought of as important multigenerational "chokepoints". Self-seeding (squares) measures where a moku gets most of its larvae. A moku with high self-seeding provides most of its own larvae, while a moku with low self-seeding relies mostly on other moku for its larvae. Source-sink index (triangles) measures whether a site is more of an "exporter" of larvae (source) or more of an "importer" of larvae (sink). Larval sources export more larvae than they import, while larval sinks import more larvae than they export. For all measures, high values are shown in red, medium values are shown in light gray, and low values are shown in blue.

Fish Movement and Habitat Connectivity

Once fish settle and grow, they can move throughout their home range for the rest of their life. Research on habitat use and fish movement patterns are extremely useful and important to incorporate into marine management area (MMA) planning, as the size of the MMA should ensure that resident fishes can grow, reproduce, and travel safely within it. If an MMA is too small, it would not protect fish that travel larger distances into unprotected or fished areas where they may be captured, thereby hindering the effectiveness of an MMA. When considering the size of an MMA, it is therefore critical to identify clear objectives and assess what are the targeted species you are aiming to protect. Based on a synthesis of empirical studies examining 210 coral reef fish species and larval dispersal patterns, it has been recommended that marine management areas should be more than twice the home range of the focal species [31]

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Many studies in Hawai'i have suggested that relatively small MMAs that encompass <2 km of coastline could provide effective, long-term protection for reef fishes [32–35]. Research has shown that several species of reef fish in Hawai'i have relatively small home ranges and exhibit high site fidelity, with one study showing between 0.2- 1.6 km (generally less than a mile) of coastline being used by 11 species [36]. Another study of 23 species in a Hawai'i MMA found that 85% of tagged fish were recaptured within 0.05 km (~0.03 mi) from the release site [37]. Similar findings showing high site fidelity and traveling maximum distances of up to 2 km (~1.2 mi) have been shared from Hawai'i for pualu (Ringtail Surgeonfish/ *Acanthurus blochii*) [36], several species of parrotfishes [35,36], kala (Bluespine Unicornfish/ *Naso unicornis*) [34], weke or weke 'ā (Yellowstripe Goatfish/ *Mulloidichthys flavolineatus*) [32], kūmū (Whitesaddle Goatfish/ *Parupeneus porphyreus*) [33], moano kea (Blue goatfish/ *Parupeneus cyclostomus*) [36], and lau'īpala (Yellow Tang/ *Zebrasoma flavescens*) [38]. However, larger-scale MMAs should be considered to protect larger predator species that are highly mobile, such as 'ōmilu (Bluefin Trevally/ *Caranx melampygus),* ulua aukea (Giant Trevally/ *Caranx ignobilis*), uku (Green Jobfish/ *Aprion virescens*), and manō (sharks). Hawai'i-based research have shown that these predator species can travel more than 10 km [39–43], which means MMAs need to be big enough in size to protect mobile predators as well if that is a management objective.

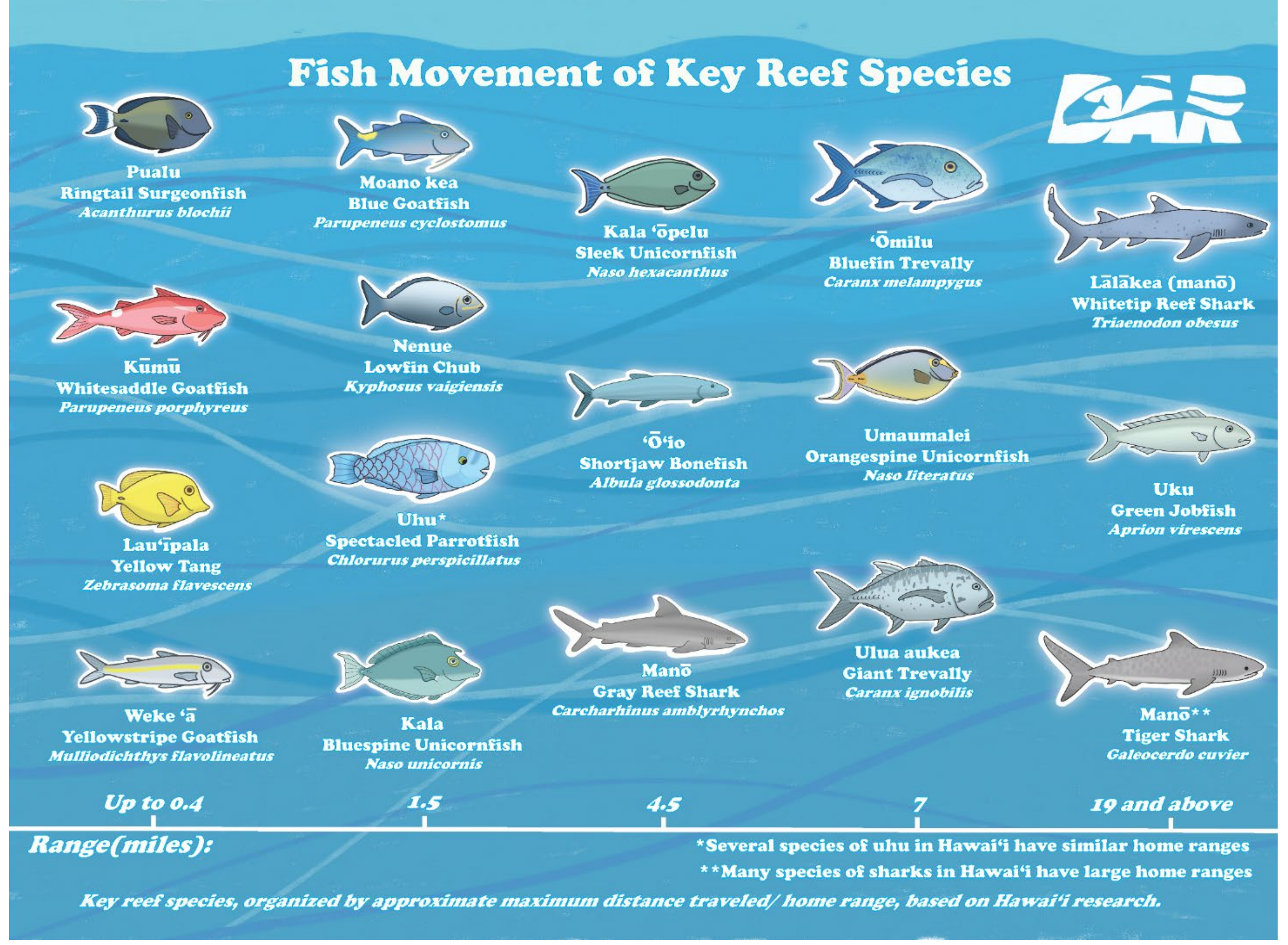

Figure 28: Fish movement of key reef species, organized by approximate maximum distance traveled/ home range, based on Hawai'i research. Figure illustrated and designed by Avery Williams.

We are still learning more about potential home ranges, maximum travel distances, and movements of reef fish species. It should be noted that many of the Hawaiʻi based studies have relatively small sample sizes which should be taken into consideration if these values are used for management planning, and several research has revealed exceptional movements for a few individuals. For example, while most nenue (*Kyphosus* species) studies reveal average home ranges of ~1 to 1.5 km [44–46], some individuals have been found to travel much farther, displaying trans-island movement of hundreds of kilometers around Hawaiʻi Island [44]. Similar uncharacteristic behaviors or outliers have also been detected for umaumalei (Orangespine Unicornfish/*Naso literatus*) and ʻōʻio (Bonefish/*Albula* species). The calculated average maximum linear distance for umaumalei in one study was 2.8 km, however, an exceptional movement from one individual was detected 10.9 km away, emigrating from the marine protected area study site [36]. Another study for ʻōʻio found that while more than 78% of recaptures were within 1 km of the original tagging location, the furthest movement recorded from one individual was more than 75 km away [47], highlighting the need for carefully consideration of MMA boundaries to incorporate these potentially larger movements. Additionally, it is noteworthy to include that habitat breaks and topographic features could also affect fish movement and act as natural barriers, such as sudden depth changes due to drop-offs, or interruptions in reef habitat due to sand patches or channels [32,33,36]. Therefore, examining benthic composition and habitat types, such as whether the area of interest has contiguous reef or is heterogeneous, should also be taken into consideration when planning MMA boundaries.

Furthermore, data from both short-term and long-term tracking methods should be utilized and combined, as significant differences in movement from the same species have been reported depending on method employed [39,43,48]. Overall, research and information on the residency, habitat use, and spatial movement patterns of fishes should be used as a key tool in designing effective networks of MMAs and to ensure protection of focal species in management objectives.

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Maui's Nearshore Fisheries

Coral reefs provide important habitat for abundant nearshore fisheries. In 2020, Maui residents agreed or strongly agreed (86%) that coral reefs in good condition provide food for coastal communities to eat (Figure 29)[1] The nearshore fishery in Hawai'i provides over 7 million meals per year to Hawai'i's families and makes up 8.2% of the total value of all fisheries in Hawai'i [49]. On Maui, non-commercial catch makes most of the total catch.

Figure 29: 86% of residents in 2020 (both statewide and Maui, individually) agree or strongly agree that coral reefs in good condition provide food for coastal communities to eat (Allen et al. 2022).

Many locals frequently eat seafood, with almost 60% of Maui residents in 2020 reporting eating seafood at least once per week [1]. Much of this seafood is most likely from pelagic species (like 'ahi and ono), not coral reef fish. Only 8% of 2020 residents reported eating seafood from local coral reefs at least once per week (Figure 30)[1].

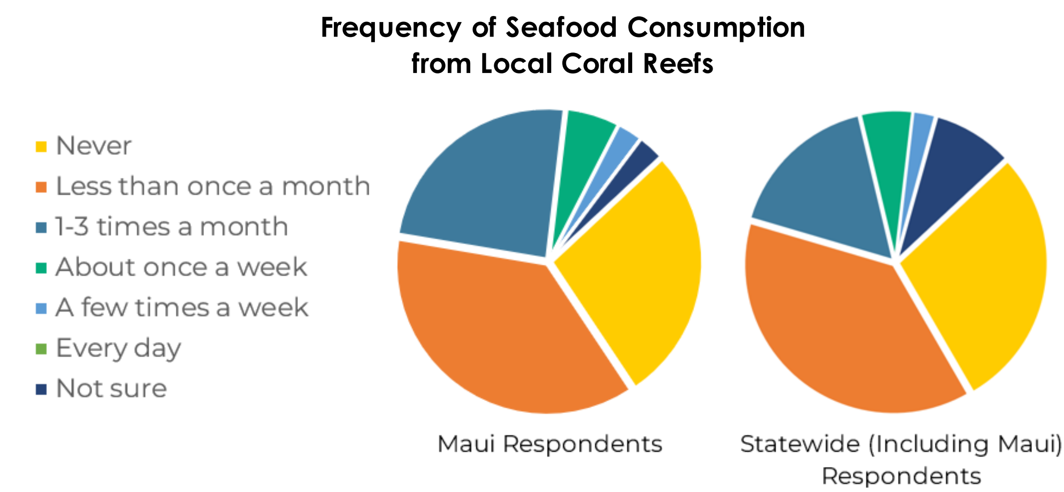


Figure 30: Frequency of seafood consumption in 2020 from local coral reefs, based on surveys of randomly sampled Hawai'i residents (Allen et al. 2022).

Nearshore Non-Commercial Fishery

Hawai‘i Marine Recreational Fishing Survey

Data from fisheries-dependent fishing effort and catch is important to estimate not only what is being taken, but to determine the total biomass of extraction from Hawai‘i's inshore reef ecosystem.

The Hawai‘i Marine Recreational Fishing Survey (HMRFS), a collaboration between DAR and NOAA Fisheries, compiles information from both non-commercial shoreline and private boat fishers through a voluntary, in-person creel survey. Information is captured directly from fishers about their catch, but the number of interviews is constrained by logistics and a limited number of personnel. Currently there are nine HMRFS sites on Maui where data are collected (Figure 31).

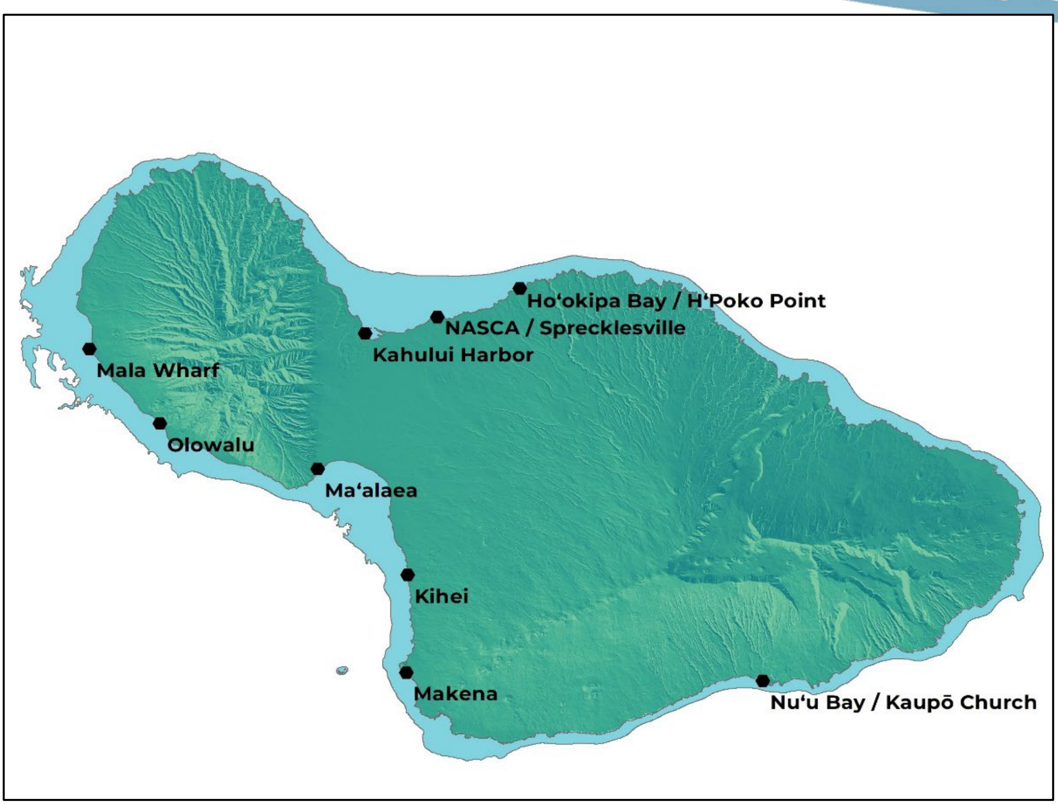


Figure 31: Current HMRFS sample sites on Maui.

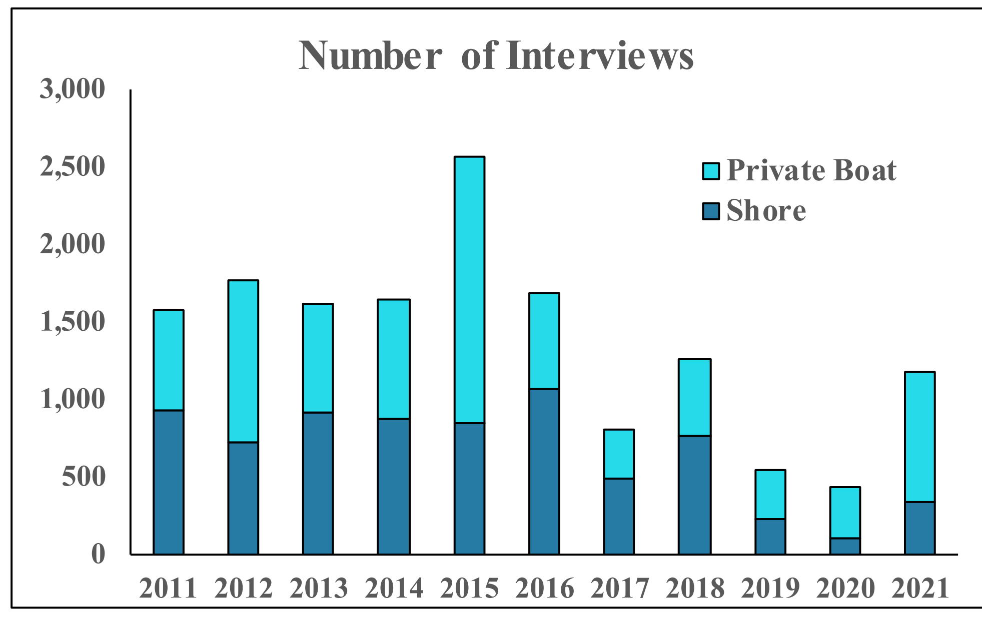


Figure 32: Number of shore-based and boat-based interviews conducted by HMRFS from 2011 or 2021.

From 2011-2021 there were a total of 1,994 shore-based interviews conducted with an annual average of 181 interviews per year. For boat-based interviews during the same time frame, there were a total of 1,826 interviews with an average of 166 interviews per year (Figure 32).

Based on the survey sites, the primary gear type used by fishers interviewed by HMRFS is "rod and reel" for both shore-based (84%) and boat-based (92%) surveys (Figure 33). It is important to note, that HMRFS effort is focused near harbors and other key points of entry and therefore likely underestimates certain gear types, such as spearfishing, that do not rely on these areas to fish. The 2020 NCRMP socioeconomic survey showed that more than one-third (41.5% for Maui individually and 33.3% statewide, combined) of residents (not just fishers) participate in fishing from shore or boat using a pole, line or net (Figure 34, Allen et al. 2022).

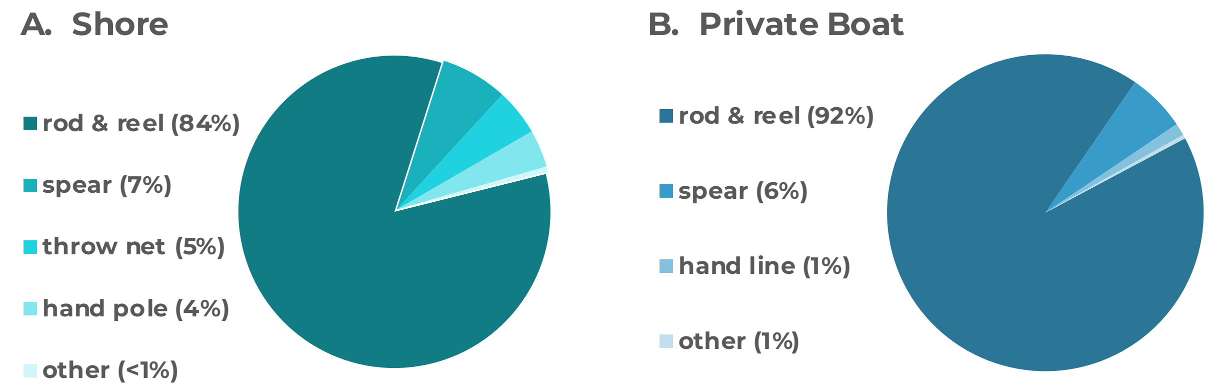


Figure 33: Gear types used by Maui shore (A) and private boat fishers (B) from 2011-2022.

Maui residents participate in various extractive activities: 41.5% of residents reported fishing from boat or shore using a pole, line or net, 27.2% reported gathering of marine resources (such as limu, ʻopihi and wana), and 23.2% reported participating in spearfishing [1]. When looking at how often Maui residents fished for key species groups, 39.8% fished for jacks, 12.7% fished for parrotfishes and 20.1% fished for surgeonfish (Figure 35, Allen et al. 2022). Almost a quarter of residents (24.1%) in 2020 reported harvesting ʻopihi and 34.1% harvesting heʻe, when they were participating in extractive activities (Figure 35, Allen et al. 2022). The statewide average of residents in 2020 who fish for parrotfish is higher than the average for Maui residents [1], which may be due to the stricter fishing regulations on uhu in Maui waters with a bag limit of 2 total regardless of species, a no-take rule for all blue (terminal male) parrotfish, and higher minimum size limits for the two large-bodied species.

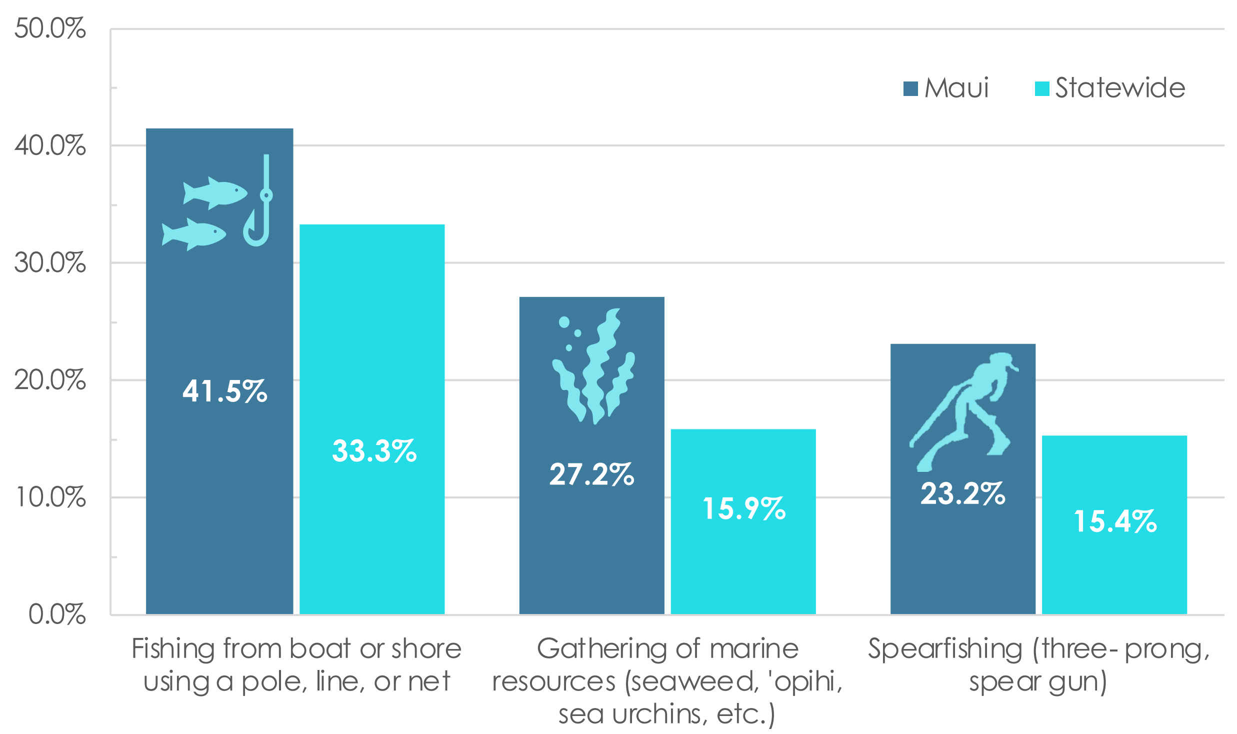


Figure 34: Proportion of participation in extractive activities for Maui, individually, and statewide, based on surveys in 2020 of randomly sampled Hawaiʻi residents (Allen et al. 2022).

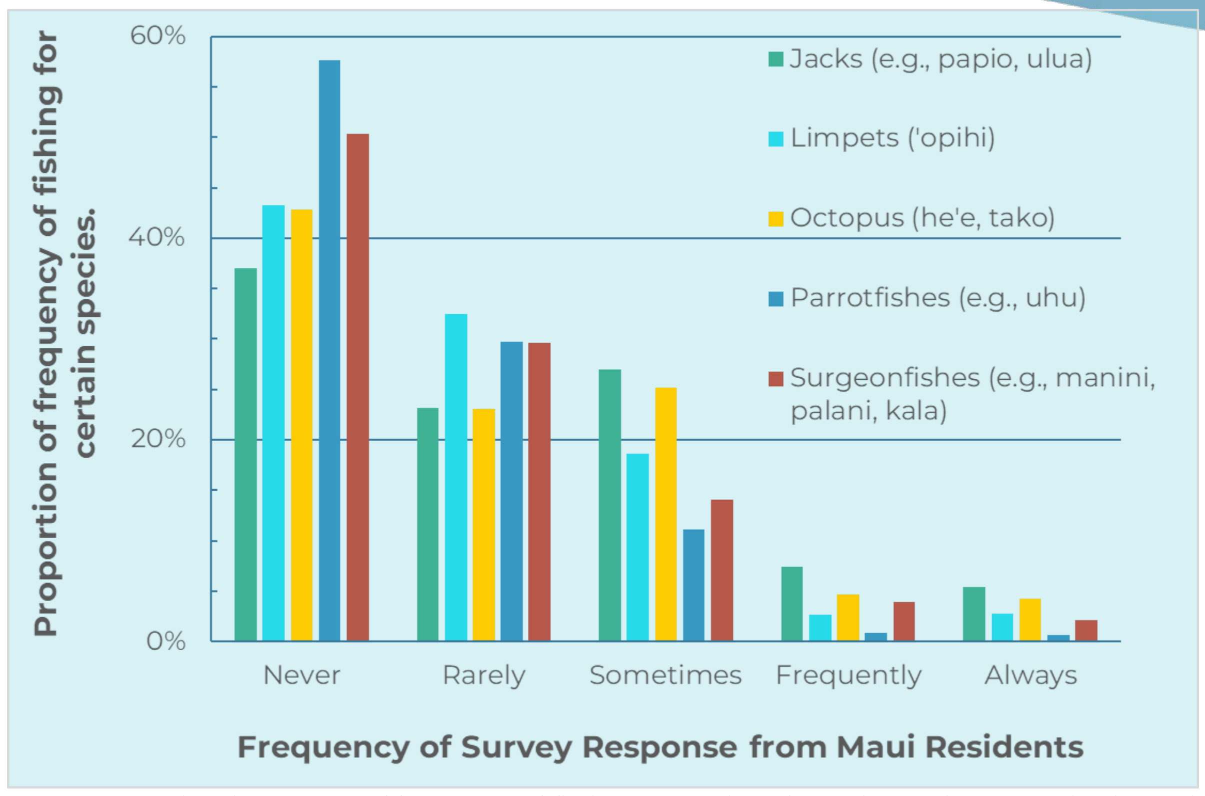


Figure 35: Proportion (in percent) of frequency of fishing/ harvesting of certain species by Maui residents in 2020 according to survey results based on surveys of randomly sampled Maui residents (Allen et al. 2022).

Based on the HMRFS data, the top three species caught from shore, based on the actual number of individual fish (not estimated), by non-commercial fishers (Figure 36) were manini (convict tang, a type of surgeonfish), ʻōmilu (bluefin trevally, a type of jack), and nenue (species of chub). The top three species by boat, also based on the actual number of individual fish, were mahimahi (dorado, a type of dolphinfish), lae nihi (nabeta/razor wrasse), and ono (wahoo, part of the mackerel and tuna family).

	A. Shoreline Top 10 Finfish
1.	manini
2.	ʻōmilu
3.	nenue
4.	halalu/akule
5.	ulua (giant trevally)
6.	āholehole
7.	lai
8.	ʻōʻio
9.	moano
10.	moi

	B. Private Boat Top 10 Finfish
1.	mahimahi
2.	nabeta
3.	ono
4.	uku
5.	ʻahi
6.	aku
7.	ʻōpakapaka
8.	taʻape
9.	ʻaʻawa (table boss)
10.	yellowspot papio

Figure 36: Top 10 most common finfish caught non-commercially by Maui shore (A) and private boat fishers (B) from 2011-2021 (based on the proportion of total fishing trips where at least one of a particular species was caught). Note only fish that were verified by HMRFS staff and kept for home consumption were included in the tables.

Shoreline Fishing Effort Surveys

Currently, the HMRFS project is dedicated to collecting fisheries-dependent data. However, data gaps remain for areas in between HMRFS survey locations. To address the data gaps, the Maui DAR team records fishing effort covering a larger area, to complement HMRFS efforts. A survey schedule is randomly generated in coordination with the HMRFS project, to determine survey locations. Surveys are conducted on weekdays and weekends. At each location, number of fishers and gear type are recorded. Gear types may include pole and line (dunking, whipping or hand pole), spear (three prong or speargun), and net (throw net or lay net). Other methods may also be noted such as surround (hukilau) net, scoop net, kayak/surfboard trolling, hand gathering, fly fishing, bow fishing, and more. Most of the eastern Maui region is not currently covered by these surveys.

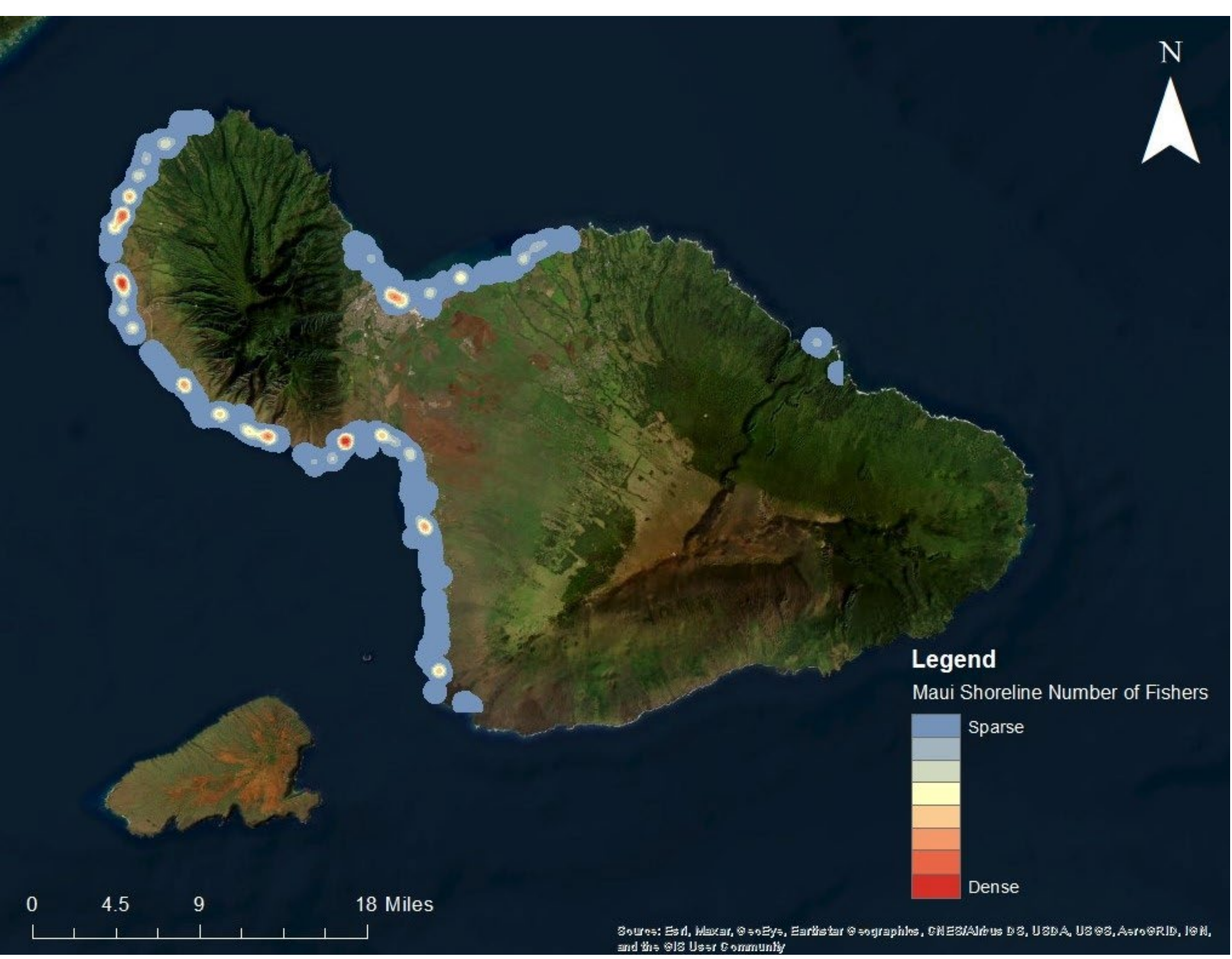


Figure 37: Kernel density heat map depicting number of fishers recorded on Maui from April 2020 to July 2022. Color gradation illustrates the density, with cooler tones representing sparse values, and warmer colors depicting higher density. Colors represent the extent of where shoreline fishing effort surveys were conducted- regions on the map that are not colored means these areas were not surveyed.

Some of the locations with the highest numbers of fishers (Figure 37) are along the coasts of Kāʻanapali, Lahaina, Launiupoko, Olowalu, Māʻalaea, and Kahului, which are areas with relatively high population density (more people live in these areas). Though this pattern is similar when looking at fishing effort (the amount of gear per person), the intensity is lower, especially in Olowalu and Kahului, meaning that though some of these areas had a high number of fishers, they were using less gear (Figure 38). Kāʻanapali, Lahaina, Launiupoko, and Māʻalaea are some of the areas with the highest fishing effort.

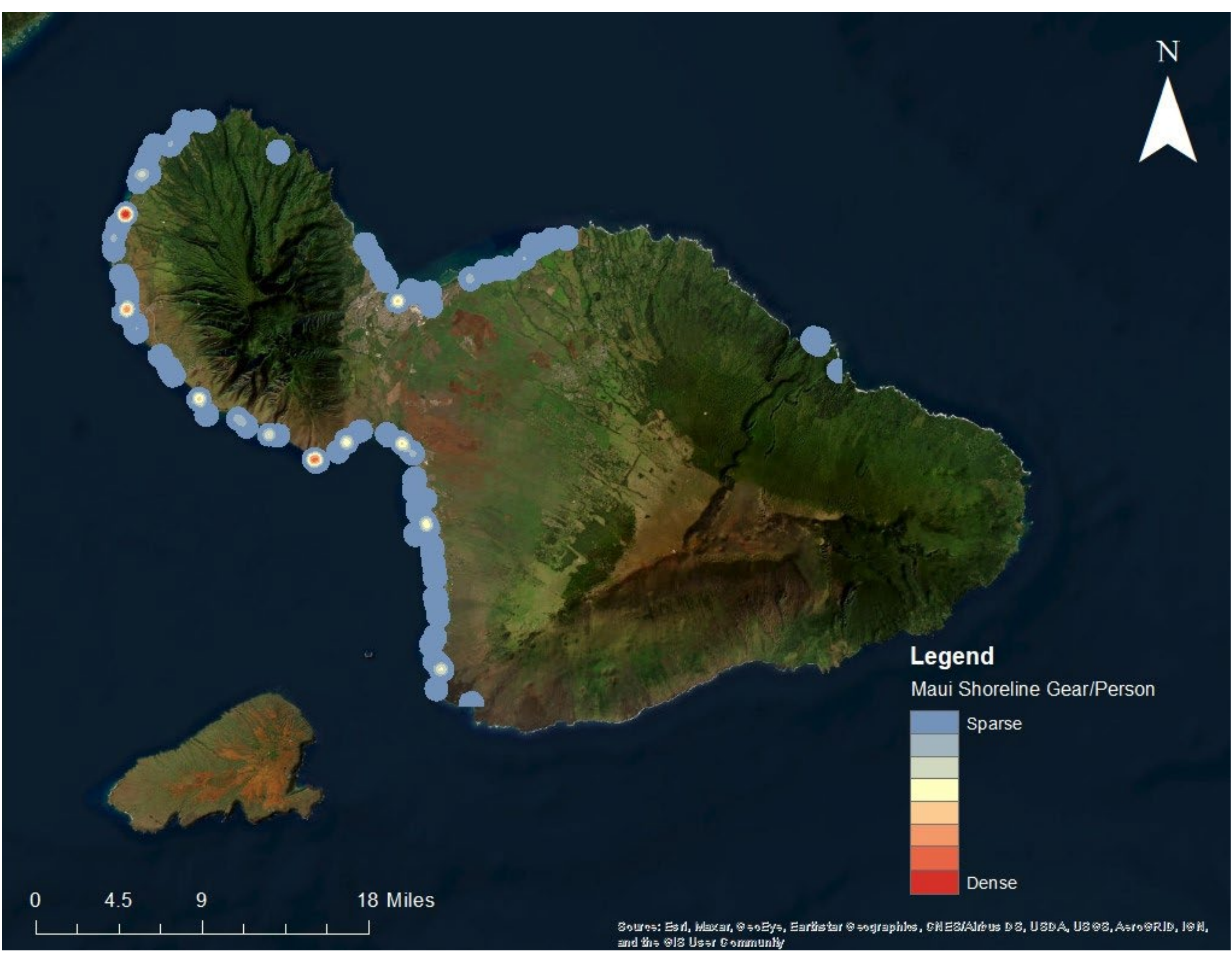


Figure 38: Kernel density heat map depicting fishing effort (gear/person) recorded on Maui from April 2020 to July 2022. Color gradation illustrates the density, with cooler tones representing less effort, and warmer colors depicting greater effort. Colors represent the extent of where shoreline fishing effort surveys were conducted- regions on the map that are not colored means these areas were not surveyed.

Nearshore Commercial Fishery

The nearshore fishery is dominated by non-commercial catch (subsistence or recreational), yet many Maui residents still purchase seafood at a store or restaurant (always- 15.7%, frequently- 34.4%, or sometimes- 28.9%) and others purchase their seafood at a market or roadside vendor (frequently-17.9%, or sometimes-29.1%) [1]. This highlights the importance of the commercial fishery to Hawaiʻi residents.

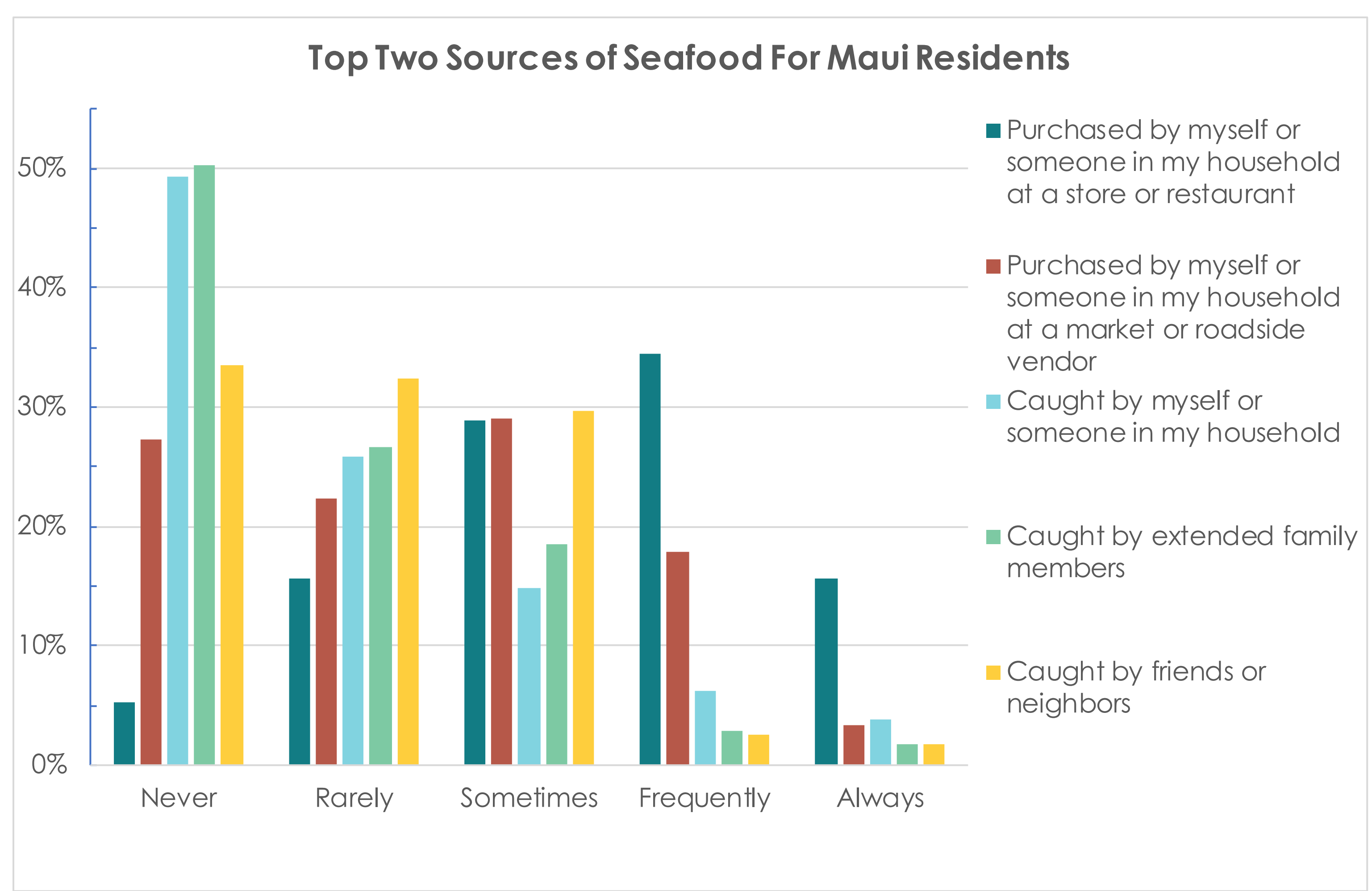


Figure 39: Top two sources of seafood for Maui residents in the 2020 NCRMP Socioeconomic study (Allen et al. 2022).

Area Coverage and Divisions for Nearshore Commercial Fishing Reports

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 they fished (Figure 40). Inshore reporting grids that surround each of the Main Hawaiian Islands extend from the shoreline to approximately two nautical miles seaward, which was based on the estimated average range of the inshore fishing fleet at the time of establishment. In the following summary of Maui inshore commercial finfish fisheries, "inshore" areas are defined by grid area numbers 300 to 305 (Figure 40). While commercial reporting is mandatory, it is acknowledged that under-reporting and illegal commercial fishing do occur. It is therefore recommended that all landings shown herein be viewed as a baseline. It should also be noted that reporting compliance likely varied across the 73-year time series as enforcement, outreach, and other factors may have changed.

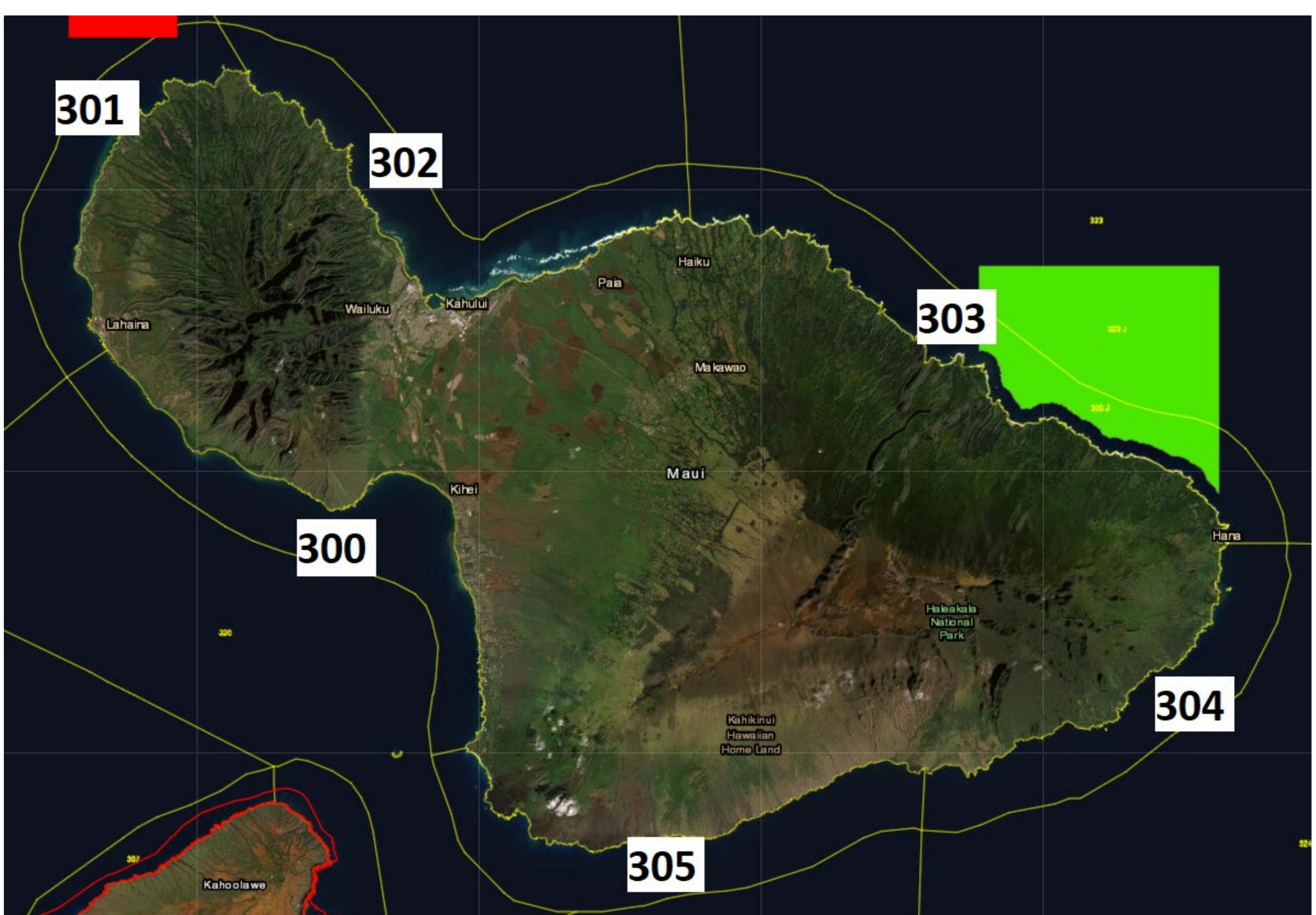


Figure 40: Map of commercial inshore reporting areas around the island of Maui.

Nearshore Commercial Catch History

Inshore commercial finfish catch around Maui varied widely throughout the time series, peaking in 1998 with 323,506 lbs. of reported total catch (Figure 41). As elsewhere throughout the state, scads have dominated Maui's inshore commercial landings (Figure 42). Annual landings of scads around Maui have been as high as 91% of the total inshore finfish catch. Most of this catch is akule (*Selar crumenophthalmus*) while ʻōpelu (*Decapterus macarellus*), the other targeted scad species in the State, is not as heavily fished in the inshore waters surrounding Maui. Akule are a highly sought after foodfish that form dense seasonal aggregations in inshore waters, making them susceptible to net gears (specifically surround nets, seine nets, and bag nets). Because nets are the primary gear used to target scads, it is not surprising that they are the primary gear types used for commercial fishing in Maui's inshore waters. The akule fishery across the state is highly driven by highliners, or skilled fishers with the expertise to make large catches. The large, irregular peaks depicted in Figure 41 are almost entirely the result of large catches of akule by highliners.

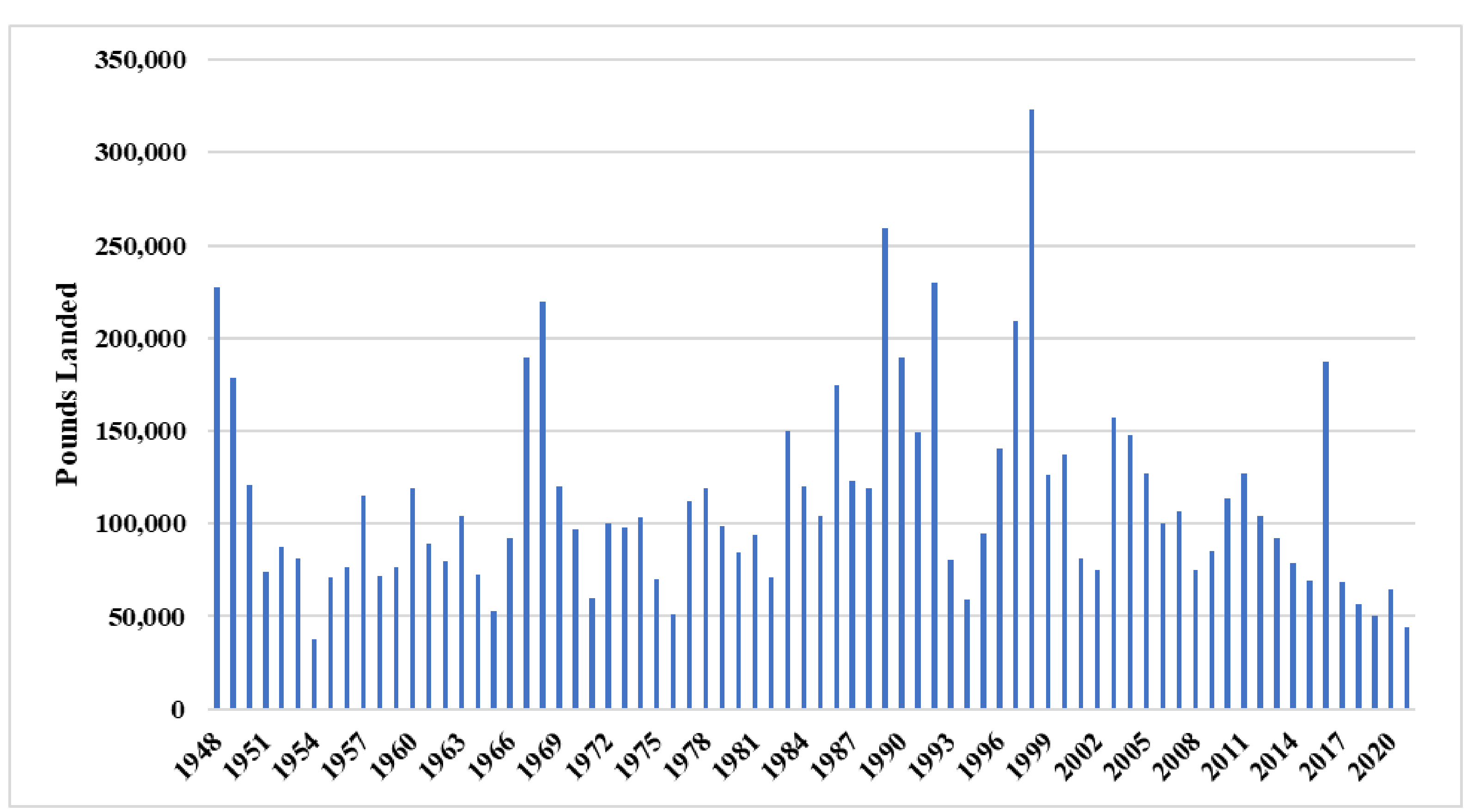


Figure 41: Total commercial inshore finfish catch reported in areas 300-305, 1948-2021

Non-scad inshore commercial catch around Maui has historically been composed primarily of four main species groups, which include surgeonfishes, goatfishes, jacks, and parrotfishes. Each of the main Hawaiian Islands have a distinct set of inshore fisheries based on their markets, active highliners, and unique customs. For example, the fish trap, a dominant gear type used to target non-scad inshore species on Oʻahu until the early 1990s, is largely absent in Maui's nearshore fisheries. Primary gears used to target non-scad species around Maui have varied throughout the time series. Non-scad catch was primarily composed of hook-and-line and net gears until the late 1970's when spearfishing first became commonly adopted as a means of commercial harvest. Spearfishing grew in commercial use as fishers used the gear more commonly to target species such as large-bodied surgeonfishes and parrotfishes more efficiently, especially when using SCUBA.

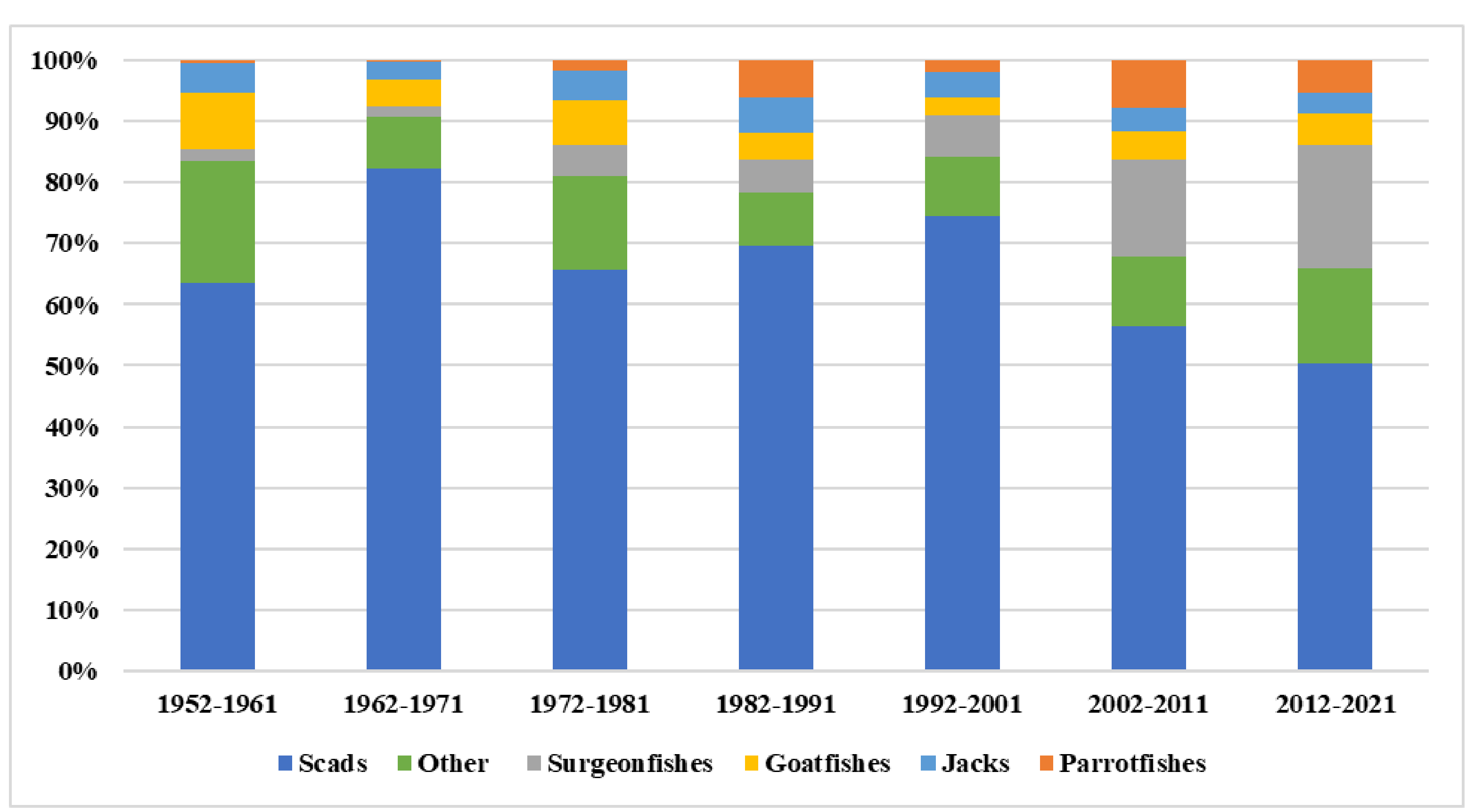


Figure 42: Inshore commercial finfish catch composition by species groups

Nearshore Commercial Catch Today

Maui currently contributes about 10% of the state's total annual commercial inshore finfish landings, a value approximately commensurate with the island's population size relative to the entire state. In the past ten years, Maui has contributed 20% of the state's inshore surgeonfish catch, 10% of the state's inshore scad catch, 10% of the state's inshore goatfish catch, and 9% of the state's inshore parrotfish catch (Figure 43). The Maui-specific species regulations passed in late 2014, specifically those pertaining to the take of parrotfishes, appeared to cause an immediate decrease in reported catch (Figure 44). Between 2014 and 2015, total reported landings of parrotfishes from Maui's inshore waters (almost entirely via spearfishing) decreased by approximately 80% and have remained low. Though limited legal harvest and some amount of unreported (unlawful) take of uhu still persist despite the restrictions, the Maui-specific species regulations will likely prevent significant future expansion of the uhu fishery on the island.

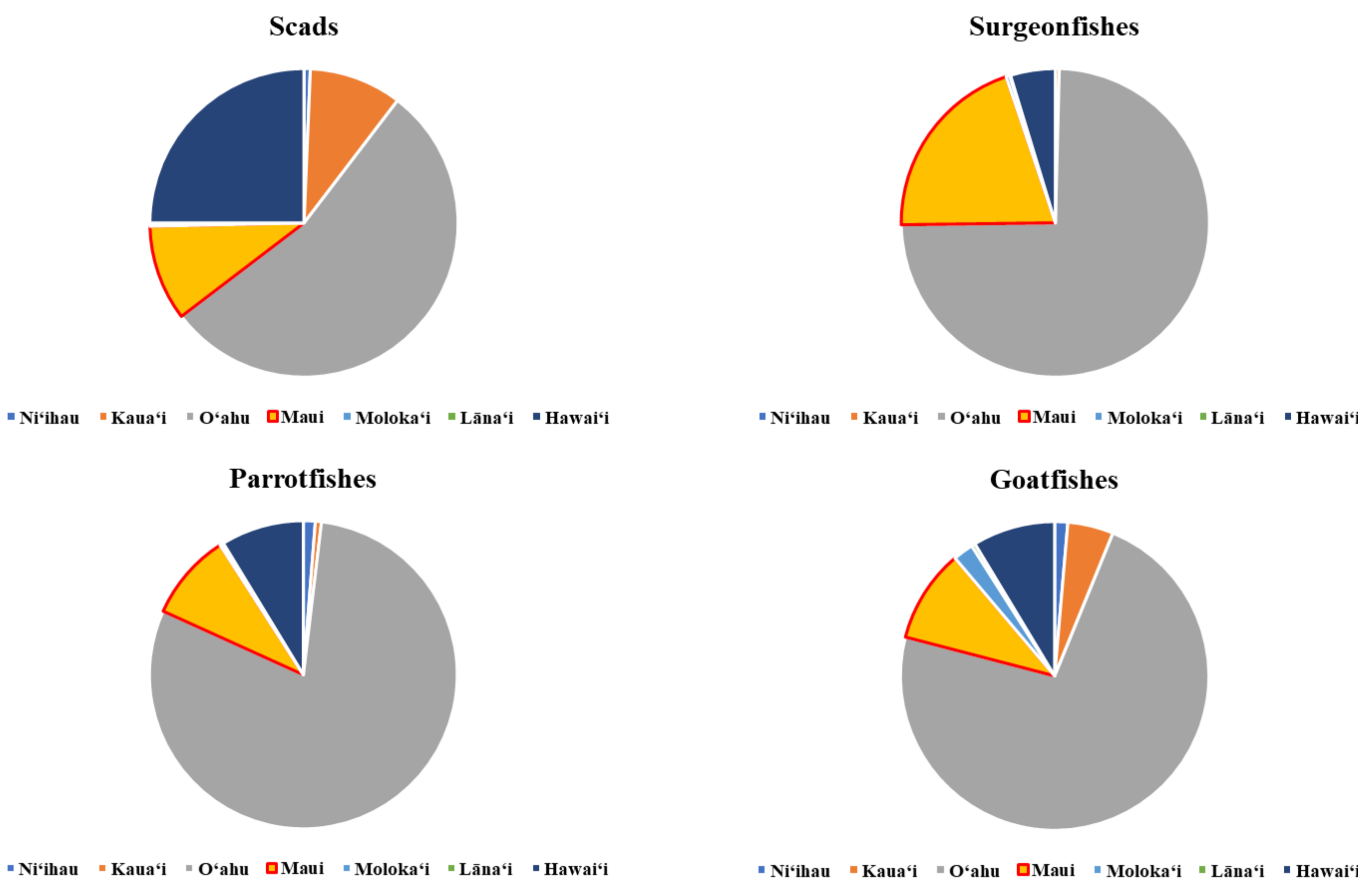


Figure 43: Percent commercial landings by island for four main inshore targeted species groups, 2012-2021

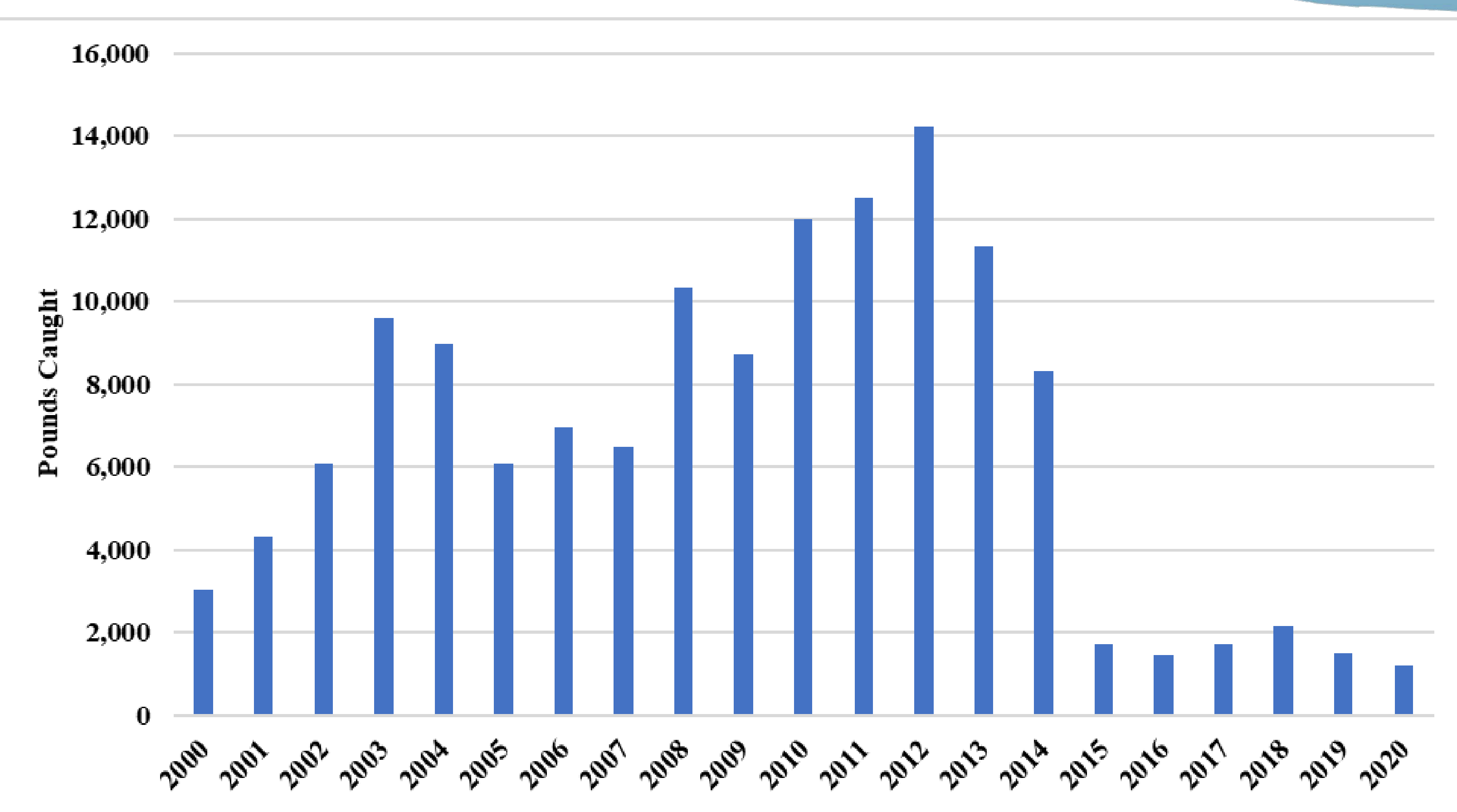


Figure 44: Reported Maui commercial parrotfish landings, 2000-2020. Note 2021 landings withheld due to confidentiality.*

Approximately 70% of Maui's inshore finfish landings in recent years have come from reporting area 300 which spans the coastline from Puʻu Olaʻi to Lahaina and includes the city of Kihei at its center (Figure 45). The coastline from Nakalele Point to Kuiaha Point (grid area 302), is the second most reported area for inshore finfish catch with 15% of landings coming from this area between 2012 and 2021. Both of these areas (300 and 302) are likely leaders in reported catch due to their proximity to major Maui population centers and markets, and open shoreline access including boat ramps.

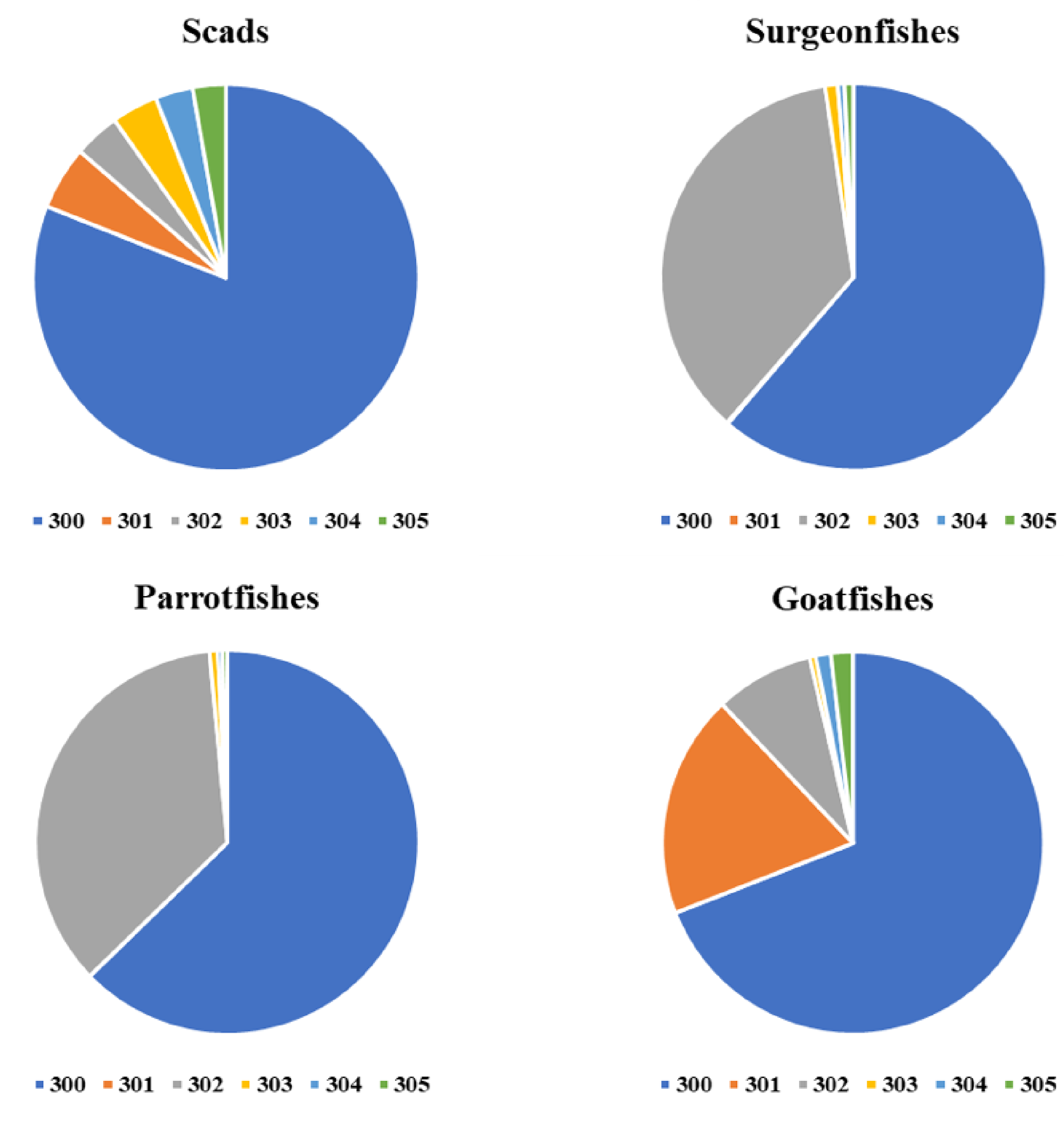


Figure 45: Percent commercial landings by Maui inshore grid area for four inshore species groups, 2012-2021

Today, net-based gears are still the leaders for fishing methods (46%) in terms of combined inshore finfish commercial catch, again primarily due to scads being the principal species group targeted. However, spearfishing now contributes a sizable proportion of the total catch (37%). Though the 2007 Maui laynet ban may have had an effect on commercial catch, its total impact on commercial landings was likely small due to the fact that the ban did not prohibit net gears such as surround nets, seine nets, or bag nets, which are common in the commercial fishery.

Between 2017 and 2021 the sale of inshore finfish has brought an average ex-vessel value of approximately $176,000 per year to Maui's economy. Ex-vessel value refers to revenues from the first point of sale only (money to fishers), and does not include revenues from retail sales at restaurants, fish markets, wholesalers, etc. DAR does not collect economic data beyond the first point of sale, but it is likely that the total value of inshore species is much higher than the ex-vessel value alone. Scads make up about 50% of all revenue from inshore species per year which is not surprising given that they make up about 50% of the current inshore landings per year (Figure 46). Other than surgeonfishes, the other inshore species groups rarely exceed $20,000 per year in ex-vessel value in recent years.

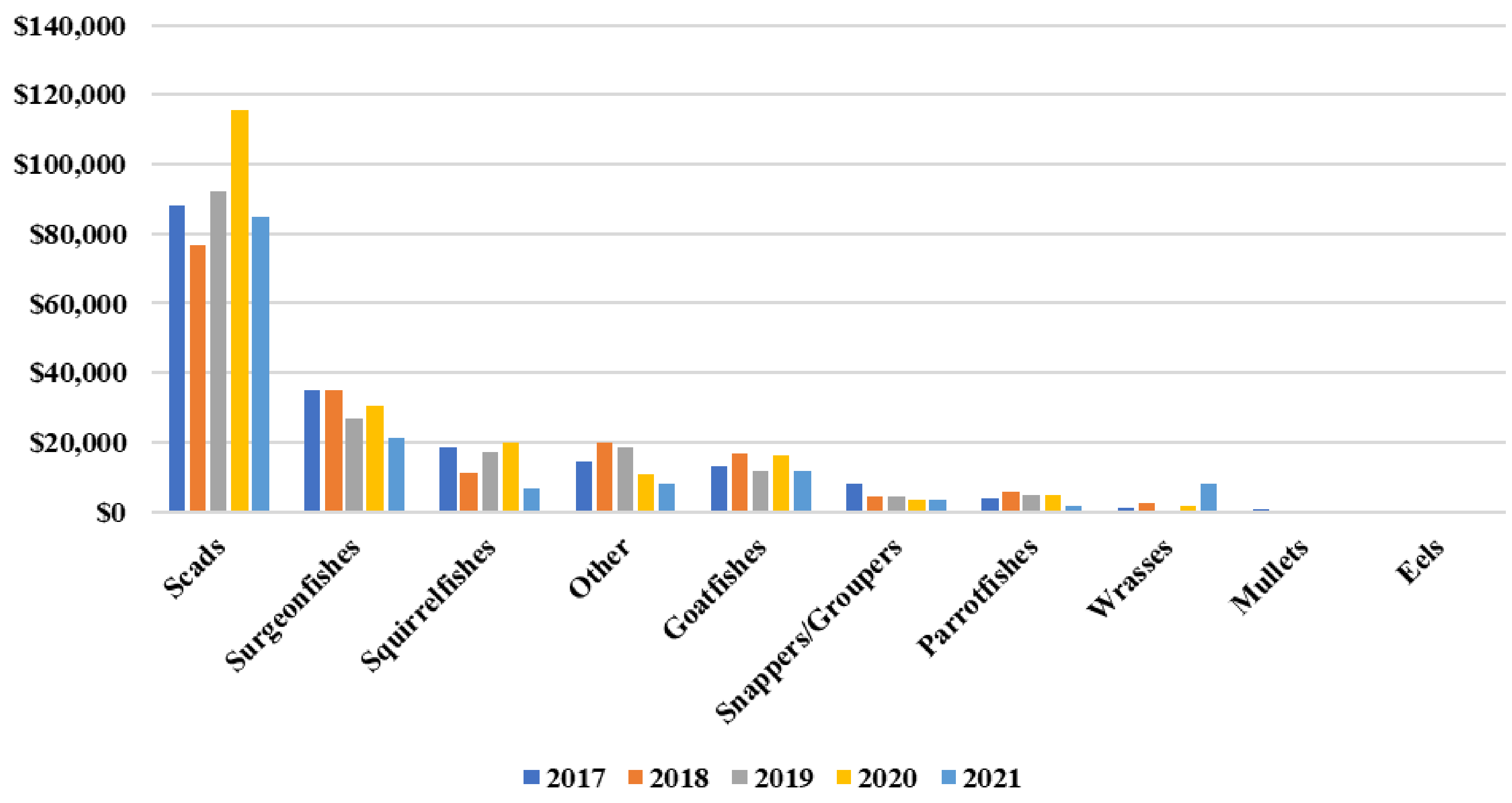
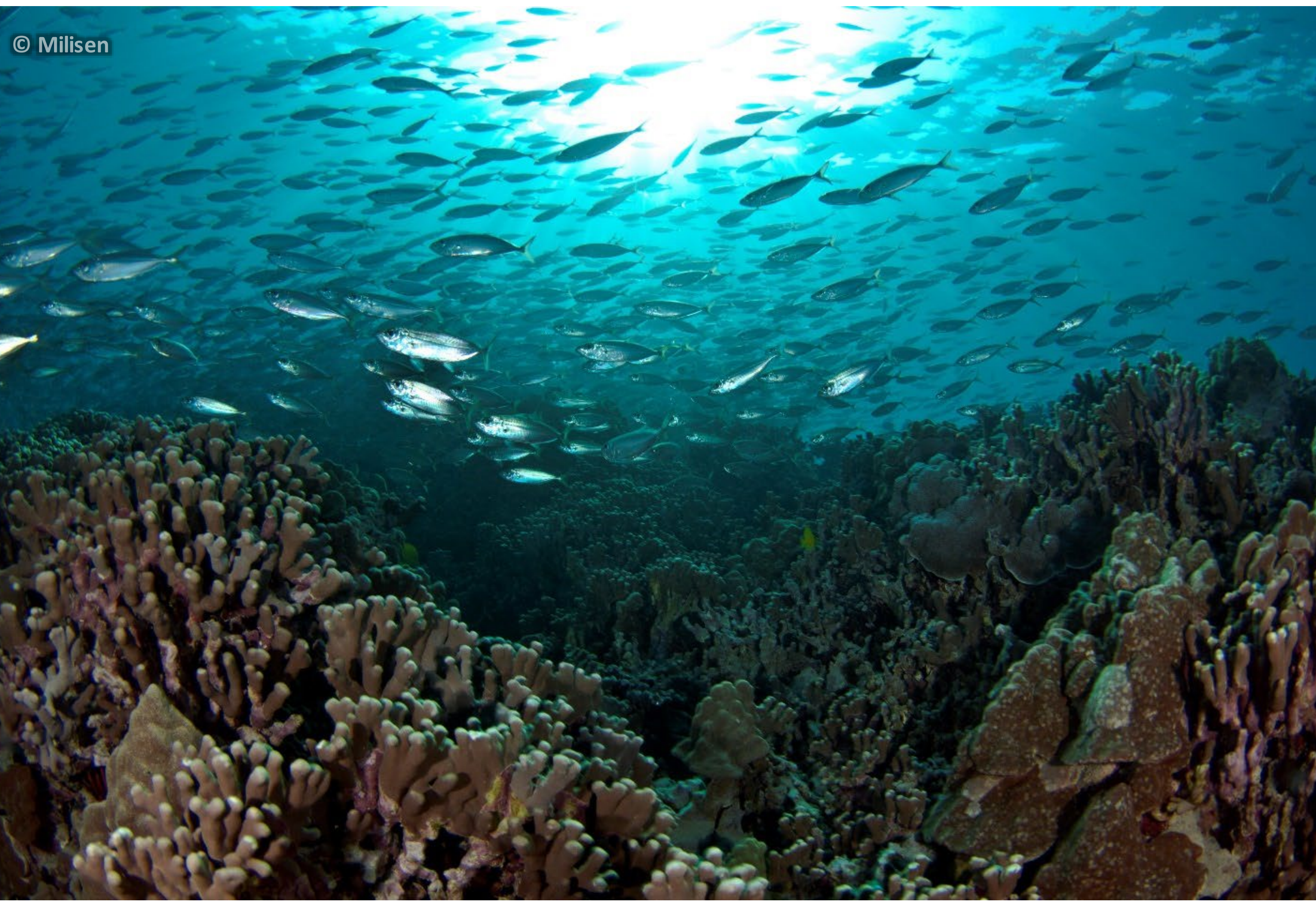


Figure 46: Estimated annual ex-vessel values for inshore species sold on Maui, 2017-2021.

Compared to O‘ahu, Maui’s commercial fresh seafood retail infrastructure is today quite limited though much more substantial than that of Kaua‘i, Lānai and Moloka‘i. Between 10 and 14 Maui-based registered dealers typically report inshore species purchases in recent years, with the population centers of Kahului and Wailuku being the main hubs for commercial sales. Cash sales, or direct sales between fisher and consumer also happen at a higher rate on Maui than on O‘ahu. A higher rate of cash sales is typical of the outer islands versus O‘ahu, again likely due to the limited market infrastructure in the less-populated areas. Movement of inshore fish between islands, primarily between outer islands and O‘ahu retailers, does occur. Reported exports of fish from Maui to O‘ahu are currently relatively low, likely due in part to the presence of established dealers on-islands. Outer-island fishers who export to O‘ahu are often at a disadvantage in that they may receive a lower price per pound to account for shipping costs or may be required to pay for shipping themselves.



Reported participation and effort in Maui's inshore commercial fisheries have shown a steady decline over the past ten years, with total landings falling accordingly (Figure 47). This is not surprising, as many of Hawai'i's fisheries, both inshore and offshore, have been experiencing a similar trend. Changing market demand, competing fisheries, the rising cost of living, increased fishing regulations, and aging of the commercial fleet are just some of the factors likely playing a role in these gradual declines. The inshore commercial finfish fisheries around Maui will certainly persist into the future to fill demand brought overwhelmingly from the island's kama'āina population. However, these fisheries will likely continue to be constrained by limited on-island demand and market infrastructure relative to O'ahu.

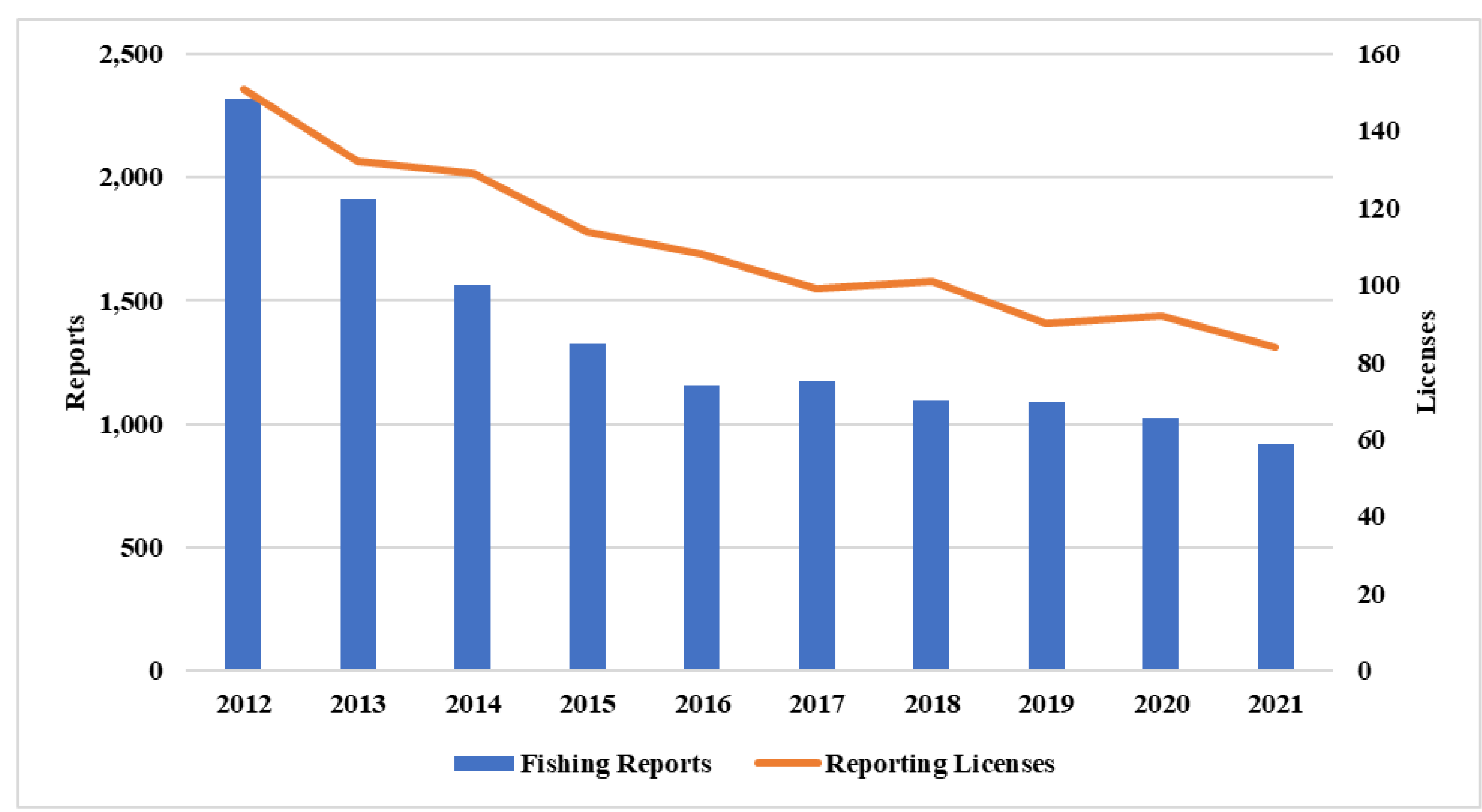


Figure 47: Reports and licenses reporting in Maui's inshore finfish fisheries, 2012-2021

Current Threats to the Marine Ecosystem and Fisheries

Because of the strong connections and relationships the people of Hawai'i have with the marine environment, most residents understand the threats and pressures on the ecosystem [1,2]. Based on voter surveys, a majority of Maui residents perceived land based sources of pollution such as (dirt, pollutants, and sewage) as a major threat to the nearshore waters and coral reefs [2]. Other major threats identified were climate change (which is one of the major drivers of coral bleaching), overuse/crowding of marine areas, and overfishing [2,50].

Coral Bleaching

Coral bleaching occurs when corals are stressed due to changes in environmental conditions such as temperature, light, or nutrients, which causes them to expel the symbiotic algae living in their tissues, often causing them to turn completely white. When these conditions persist over long periods and do not allow for enough recovery time, the corals will die. Coral bleaching events throughout Hawai'i have increased in frequency and severity as ocean temperatures continue to rise; three large scale bleaching events occurred over a 6-year period beginning in 2014 [51]. After the 2019 bleaching event, Maui overall reported up to 25% bleaching across survey areas, similar to the rest of the state. However, North and South Maui sites specifically had significantly less bleaching than the rest of Maui and the state as a whole [51].

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Land Based Sources of Pollution

Rainfall and heavy storm events can cause increased runoff of water that carries land-based sources of pollution into the ocean. Runoff can include pollutants such as overflowing cesspools, sewers, fertilizers, pesticides, chemicals, and other debris, which can be harmful to coastal ecosystems and humans [52]. When heavy rain events cause excessive runoff of water carrying land-based pollution into the oceans, the Clean Water Branch issues a brown water advisory indicating a threat to coastal coral ecosystems [53] and human health. Wastewater inputs during these events have a cumulative impact on the coastal environment reducing ecosystem health, function, and resilience. Increased nutrients can cause increased macroalgal cover and filter feeders, and reduced coral cover [54,55]. Added sediments also increase the turbidity of coastal waters which can alter primary production (including symbiotic algae within corals), feeding behaviors, reproduction, and survival of species [56]. Reducing urban runoff can have the greatest positive impact on coral reefs, particularly along West Maui coastlines where there is a lot of commercial development, resorts, and golf courses [51].

The disposal of treated sewage effluent into subsurface injection wells in West Maui and Kihei have been shown to contribute substantial nutrient loads, resulting in impaired water quality within the coastal waters [57–59]. The Lahaina and Kihei injection wells release 3.4 and 2.5 million gallons of partially treated wastewater effluent per day, respectively [60]. The total coral cover over four sites in West Maui waters decreased by 37% from 1995-2012, due to the discharge of wastewater from these injection wells. By analyzing coral cores and getting a historical perspective on water quality throughout a reef's life, a direct link between the wastewater injection wells discharge from the Lahaina Wastewater Reclamation Facility and water quality on West Maui reefs has been documented [59]. Maui County was found to be in violation of the Clean Water Act for all four injection wells in Lahaina and face similar litigation in Kihei.

Overcrowding on Coral Reefs

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Heavy human use has a significant impact on the nearshore environment. High visitor use was correlated with reduced water visibility, lower percent coral cover and increased coral breakage and sediment accumulation in Hanauma Bay [61]. Heavy human use within Molokini was shown to have a negative effect on coral reef predators such as sharks and jacks [50]. During the COVID-19 lockdown, fish biomass within the Molokini MLCD exhibited a significant rebound in fish biomass [62]. Once tourism resumed, ōmilu and other large predators were once again displaced [62]. SCUBA divers and snorkelers overcrowding MMAs may also directly damage live substrates such as coral, coralline algae, or sessile invertebrates while swimming along the bottom or standing in the shallows [63]. Divers and swimmers also introduce sunscreens to the environment containing UV-filter drugs such as oxybenzone, avobenzone, octocrylene, and others which have been shown to be detrimental to corals and the surrounding ecosystem [64].

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Invasive Species

Historically, Maui has experienced less negative impact from aquatic invasive species (AIS) compared to Oʻahu due to Honolulu Harbor being the entry point for many shipping vessels that act as vectors for AIS. However, AIS that occur on Oʻahu have been known to make their way to Maui and other neighboring islands. The two major invasive algae species that have impacted Maui's near-shore reefs in the past are prickly seaweed (*Acanthophora spicifera*) and hook weed (*Hypnea musciformis*). Populations for both species experienced rapidly increasing cover until around 2017 when the outbreaks subsided, possibly from an unusually cloudy winter. It can be very difficult and often impossible to eradicate alien invasive species after introduction. Because of this, Maui emphasizes efforts to prevent the introduction of species to the island, rather than reducing invasive species already present. Below are some of the invasive species that are already well established or of concern for Maui.

Non-native Fish Species

The State of Hawaiʻi introduced eleven species of shallow water snappers and groupers to Oʻahu and the island of Hawaiʻi as potential food fish between 1955 and 1961 [65]. Of these, three species roi (Peacock Grouper, *Cephalopholis argus*), taʻape (Blueline Snappper, *Lutjanus kasmira*) and toʻau (Blacktail Snapper, *Lutjanus fulvus*) became established in Hawaiʻi's nearshore waters. There are also several species of fish that were unintentionally or accidentally introduced to Hawaiian waters including (with the first two pictured below) Kanda (Marquesan mullet, *Osteomugil engeli*), tilapia (several species), mollies (multiple species species) and mosquitofish (*Gambusia affinis*), common in some estuaries and stream mouth estuaries. Some of these non-native fish species are now so widespread that eradication at the island or islands scale is not likely and they have varying degrees of impact on nearshore fish populations and communities.

Black chin Tilapia

Marquesan Mullet

Blueline Snapper

Taʻape (Blueline Snapper, *Lutjanus kasmira*): Though introduced in the 1950s to provide additional fishing opportunities, there was not much of a demand for them by local fishers so the population rapidly expanded its population and is now found in high abundance on many nearshore reefs. This species of snapper is delicious and sustainable seafood. It was featured in an article in Honolulu Magazine called, "Eat me because I'm pretty". Given its abundant and ubiquitous occurrence throughout much of the main Hawaiian islands' nearshore waters, targeting this species is ideal for sustainable seafood.

Blacktail Snapper

Toʻau (Blacktail Snapper, Lutjanus fulvus): This species was also purposefully introduced in the 1950s on Oʻahu as an effort to enhance fishing opportunities, as the species is a popular food fish elsewhere in its native range. It did not reproduce as quickly as the taʻape and has low abundance on nearshore reefs in Hawaiʻi.

Roi Peacock Grouper

Roi (Peacock Grouper, *Cephalopholis argus*): Roi never became a successful food fishery because in Hawai'i it is associated with ciguatera, toxic to humans when consumed. Many studies have sought to find a relationship between ciguatera "hot spots" in an attempt to predict areas where fish may be more or less toxic. Fishers, tour operators and other ocean users have expressed frustration and concern over the perceived impact of this large, predatory species on native fish species and community composition. Roi in Hawai'i are opportunistic predators, with a large variety of prey species in its stomach. Roi potentially have low metabolism, with many caught individuals having empty stomachs. They have low food intake needs, compared to other native predators such as jacks [66]. Therefore, the impact of roi on native fish assemblages is likely less than perceived, but in high abundance the species could have a significant impact on reef assemblage [66]. Many fishers have responded by calling for "roi roundups" or directed fishing pressure on the species to lower its abundance in specific areas. Unfortunately, these efforts are not likely to increase native fish populations in the long term (4.5 years), despite increases in prey species in the short term (18 months)[67], and must be combined with other management options to enhance the sustainability of nearshore fish communities.

Established Invasive Species

Crown of Thorns

Crown of thorns (COTS) is a **NATIVE** species to Hawai'i, but different environmental factors can cause unnatural population explosions. COTS are corallivores, meaning they eat corals and are able to significantly alter reef ecosystems. At natural population levels, COTS don't cause large scale damage to natural reefs, but they can cause extensive loss to corals when outbreaks occur in high numbers.

Prickly Seaweed

Hook Weed

Prickly seaweed and hook weed are known to occur on Maui and have at times, been considered invasive. Currently, the surveys by the Hawai'i Division of Aquatic Resources (DAR) don't show large areas of high algal coverage on Maui, but nutrient influxes could cause future outbreaks.

Species of Concern

Report immediately if seen

Gorilla Ogo

Gorilla Ogo has not yet been found on Maui but has spread to Molokaʻi. Native *Gracilaria* species are present on Maui, however, *Gracilaria salicornia*, also known gorilla ogo, has become a major problem on Oʻahu reefs because this species smothers large areas of nearshore coral. Preventing further spread is a high priority for DAR.

Leather Mudweed

Leather mudweed is a species of great concern because it traps sediments, turning nearshore sandy flats into mud flats. It has not been documented on Maui but has caused extensive damage on Oʻahu and preventing the spread of this species is of high importance.

Smothering Seaweed

Euchema and Kappaphycus spp. are similar species collectively known as smothering seaweed. They were introduced to Oʻahu for aquaculture purposes. Unfortunately, they quickly spread across Kāneʻohe Bay, where they were first established and are now the most wide-spread invasive algae affecting the patch reefs within the Bay. They have not been documented on Maui but preventing the spread of this species is also of great concern.

Coral Disease

Although not considered an invasive species, coral diseases are an emerging issue in marine conservation. The known coral diseases present in Hawaiʻi don't typically cause extensive damage to coral reefs. However, the spread of Stony Coral Tissue Loss Disease (SCLTD; pictured left), currently spreading in Caribbean reefs, is of great concern and prevention is key. If the disease were to be brought to Hawaiian reefs, the outcome could be catastrophic.

Preventative Measures

It is easier to prevent an introduction of an alien species than to eradicate it once it has become established. To prevent the spread of alien and invasive species, DAR promotes the practice of "**Clean, Drain, Dry**" when entering and leaving the water, especially when moving between watersheds.

CLEAN off visible aquatic plants and sediment from all equipment before leaving the water or moving between different bodies of water. Soak or spray equipment with diluted (1-2%) bleach.
DRAIN watercraft bilge, live-well, motor, and other water containing devices before leaving the water access.
DRY everything for at least five days.

Visit www.stopaquatichitchhikers.org for more information.

Early Detection

Successful eradication of alien species often depends on the early detection and rapid response to introductions. Once a species becomes established, it is extremely difficult and often impossible to fully eradicate. We ask the public to report any sightings of alien species that are observed outside of their known range or in usually high abundance to DAR so that a rapid response can be initiated. In the past, DAR has been successful in eradicating introduced species as long as the species has been brought to DAR's attention before the species can become widespread and established.

Report Sightings

Please report sightings of species of concern to dlnr.ais@hawaii.gov or your local DAR office for immediate response.

Sightings of established species can also be reported to iNaturalist, (www.inaturalist.org) under the DAR AIS Project, as well as through Eyes of the Reef (www.eorhawaii.org) .

Nearshore Resource Management

Traditional Hawaiian Fishery Management

Historically Hawai'i had several management regimes. At the ahupuaʻa (traditional land divisions based on watersheds) level, konohiki (resource managers) coordinated with the people of the land, local elders, and expert fishermen to determine when it was appropriate to place kapu (ban/taboo) on different fish species [68]. Kapu represented a type of closure that was usually based on spawning seasons of certain species, to protect resource replenishment [69]. Adherence to the closure was motivated by shared cultural, social, and spiritual values [70], as well as a potential penalty of death [71]. If there was balance and harmony between the ahupuaʻa residents and konohiki, the land and sea would be abundant [68].

In the 1839 Declaration of Rights and the Constitution of 1840, konohiki fishing rights were given written recognition, designating fishing grounds for the konohiki and the people of that ahupuaʻa [72]. In 1845, it was documented that the privilege of the konohiki putting kapu exclusively on one kind of fish was exchangeable for the right of kapu over all fish within a konohiki's fishing ground for a certain length of time [70]. In 1850, the Kuleana Act granted fee simple titles for kuleana lands to ahupuaʻa residents upon proving two-year occupancy of the land, providing two corroborating witnesses who "knew" the land, and acquiring approval of the konohiki [73]. In 1859, the laws were codified, but the written acknowledgement of the kapu now only included the season "for the protection of such fishing grounds the minister of the interior may taboo the taking of fish thereon at certain seasons of the year"[74].

Another important aspect of historical regulations and distribution of catch was the practice of giving and sharing. A fisher's catch was typically shared with the kūpuna (elders), the konohiki, and the broader community [70]. It was easier for all to see the amount that was being taken out of the ocean because it was shared by the community. In fact, it was illegal in the kanawai (laws) to deny a hungry person a fish from your pile [70,71,75].

Contemporary Fishery Management

The mission of DAR is to work with the people of Hawaiʻi to manage, conserve and restore the state's unique aquatic resources and ecosystems for present and future generations. There are many management tools that DAR can use to achieve this mission. These tools fall into two main categories, regulatory and non-regulatory actions.

Regulations can be implemented to limit and/or prevent unsustainable harvest, ultimately providing better fishing opportunities for the future. Regulations can be implemented proactively to ensure sustainability prior to observations of declines in a fishery. This promotes maximum fishing opportunities by not waiting for the stock to be depleted before pursuing regulations. The most commonly used regulations for recreational fisheries management worldwide are bag limits, which limits the total catch per person per day, and size limits, which limits the minimum or maximum size needed for a fish to be legally harvested [76]. For additional information on coral reef fisheries management strategies, refer to "A perspective on the management of coral reef fisheries" in Ecology of Fishes on Coral Reefs by Alan Friedlander (2013).

Ecosystem: A biological community of interacting organisms and their physical environment.

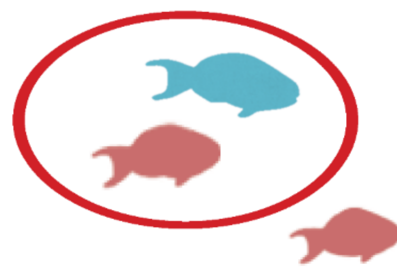
Ecosystem-Based Management (EBM): An integrated, science-based approach to the management of natural resources that aims to sustain the health, resilience, and diversity of ecosystems while allowing for sustainable use by humans of the goods and services they provide.

DAR has the authority to regulate fisheries. HRS section 187A-5 gives DLNR the authority to make the following kinds of regulations concerning aquatic life:

- Bag limits
- Size limits
- Seasonal closures
- Area regulations/ Marine Management Areas
- Gear regulations

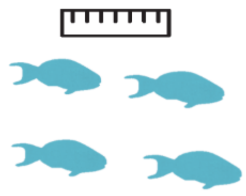
Activities related to boating, recreation, and other human activities in state waters are regulated by the Division of Boating and Ocean Recreation, DLNR (HAR 234), and regulations on water quality are set by the Department of Health (HAR 11-54).

The Division of Aquatic Resources has the authority to ensure sustainable harvest based on the following principles:



Take only what you need

Bag Limit



Let the keiki grow

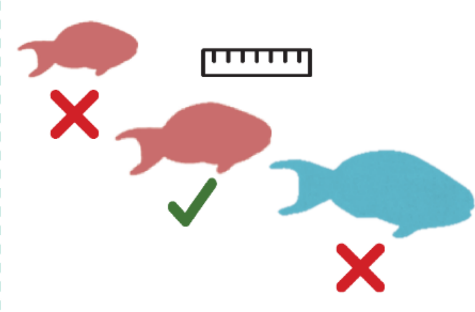
Size Limit

Let the fish reproduce

Closed Season

Use the right gear

Gear Regulations



The sweet spot: catch medium fish

Slot Limit

Respect Local Rules

Marine Management Areas

Bag Limits

A bag limit is one management method that reduces the amount of fish harvested by limiting the total number of fish caught per person per day. Bag limits are helpful in situations where fish are being removed from the population faster than they can be replaced by the next generation. Bag limits generally allow for fishers to use any legal gear type, making this form of regulation more inclusive as it does not exclude select fishers from being able to harvest a particular species. From an ecological point of view, bag limits are more effective at reducing post-release mortality by eliminating the extra time and handling needed to measure fish due to a size restriction [76]. Bag limits also allow for the harvest of the species at all times of the year by any gear type. Sustainable results can be increased further when combining bag limits with another type of regulation such as size limits or gear restrictions [78].

Size Limits

Size limits set size requirements for the harvest of a species and may be set for a minimum or maximum size, or both. Minimum size limits aim to protect the juvenile fish population until they've reached a size of maturity where they can reproduce at least once. Size at maturity is typically used to set minimum size limits to give fish the opportunity to reproduce. Since every individual is a little different, size at maturity is often estimated and described as the L50 value (the length at which at least half of the population is able to reproduce). A maximum size limit aims to protect the bigger fish, which can produce exponentially more offspring than a newly mature fish [79]. In some species, like uhu where the largest individuals are male, maximum size limits can also ensure that the population will have large male spawners. Minimum and maximum sizes can also be combined to create a slot limit, which means that only individuals sized in between the minimum and maximum size limit may be caught. Both minimum and maximum size limits aim to conserve the reproductive potential on either side of the size spectrum.

Definition of Size/Length/Age at Maturity:

> The size, length or age at which individuals are reproductively active and producing [80]

Definition of L50:

> The size/length at which at least 50% of the individuals in a population are reproductively active and producing[80]

Size limits may have less of a socioeconomic impact compared to bag limits by encouraging more fisher participation. Sometimes size limits may be preferred to bag limits, as size limits do not dictate the number of fish caught. Size limits also allow fishers to continue fishing, making sure that food is on the table, traditions continue being passed on, and the connection of community are maintained through sharing of fish [81,82].

While bag limits may only affect the most efficient fishers, size limits can help reduce the impact on the fishery of all fishers [76]. Size limits are popular for the dual goal of limiting overfishing and improving the fishing quality [83].

Size limits can also help fishing communities attain optimal yields, even under high fishing pressure [84]. For most fishes, the size at which optimum yield is achieved can be simply approximated by multiplying a species' length at maturity (L50) by a factor of 1.2 [85]. There are limitations to the benefits of size limits: size-restricted fish may experience stress, injury or even death when released if they are below or above the regulated size limit. Additionally, some gear types like spearfishing do not allow for catch and release, therefore catch outside of the legal limit will likely be discarded and wasted.

Seasonal and Area Closures

Seasonal closures refer to prohibiting the harvest of certain species during certain times of the year, usually based on spawning seasons. Closures can be variable depending on location and species. In general, these regulations are most appropriate for certain species if individuals aggregate when spawning, making them easy to target in large numbers. There are limitations to the benefits of seasonal restrictions: seasonally restricted fish may experience stress, injury or even death when released if they are accidentally caught out of season.

Area regulations are regulations that are specific to a place and may include seasonal closures, gear restrictions, or certain size and bag limits that may be more restrictive than statewide regulations.

Although kapu and seasonal closures were used regularly in ancient Hawaiian times, they were done at ahupuaʻa and moku (island) level, and as such, are not applicable for statewide regulations. Because there can be variation in spawning seasons between places, seasonal spawning closures for certain species should be at a place-based scale for management in the future. Seasonal closures may not always have conservation benefits to the fishery if the area selected is too small or the closure period is too short. The use of seasonal closures or other place-based regulations may also lead to increased pressure in other areas or lead to a derby effect, with a lot of targeted pressure, just before or soon after the closure.

Marine Management Areas

Another option for place-based regulations is a marine management area (MMA). An MMA is a place in state marine waters that is designated by statute or administrative rule for the purpose of managing how people use the geographic area and the ecologically and culturally important marine resources within its boundaries. The resources may include any type of marine life (e.g. fishes, invertebrates, algae) and their habitats. The goal of an MMA may also include preservation of cultural or historical resources or serve to resolve user conflicts.

Each MMA has its own set of legally designated marine resource regulations, which may include fishing regulations, such as restrictions on gear type, size and catch limits, or take of specific species. A collection of individually managed areas that are ecologically connected in a network, such as through larval dispersal, provide benefits that are greater than can be achieved by single management areas [86].

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Gear Regulations

There are many different fishing gear types used in Hawaiʻi's nearshore fishery. Some types are more effective at catching large numbers of fishes or other aquatic organisms quickly. Therefore, regulations on specific gears and methods of fishing can help to minimize higher catch rates and may even limit or eliminate the harvest of particular species or life stages. For example, there are regulations in Hawaiʻi that prohibit smaller mesh nets, as larger mesh sizes allow smaller juvenile fishes to escape, giving them a chance to reach maturity.

Many existing MMAs have gear regulations, and there are also statewide gear regulations. Current gear regulations can be found here: https://dlnr.Hawaiʻi.gov/dar/fishing/fishing-regulations/gear-restrictions/. MMAs are often ranked by their level of protection based on the restrictiveness of gear regulations in place [74,87].

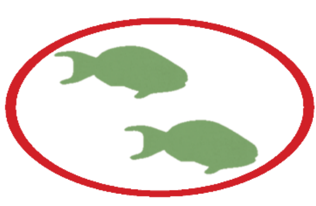
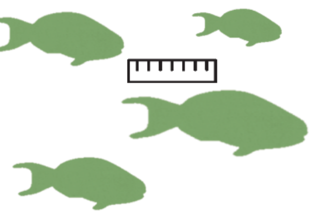
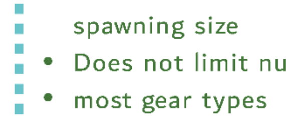
Addressing Overly Efficient Gear (SCUBA and Nighttime Spearfishing)

Across the board there are certain gear types or fishing methods that are more efficient in comparison to other gear types. SCUBA spearfishing and nighttime spearfishing are two examples of gear/fishing types that are particularly effective.

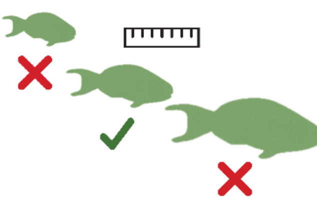
Many Pacific Island countries ban the use of SCUBA while spearfishing [88]. Banning nighttime spearfishing or SCUBA spearfishing is a significant way to control fishing pressure [89]. SCUBA spearfishing is banned in American Samoa and this regulation has relatively high compliance [89]. In American Samoa, there was a documented 15 fold increase in catch of parrotfishes with the introduction of SCUBA in 1994, leading to a harvest of 18.7% of the standing stock [90]. This was the basis for the country's ban of SCUBA spearfishing through Executive Order [90].

Fishers in Hawai'i have expressed that SCUBA spearfishing can be too efficient, and nighttime spearfishing may be considered unfair because sleeping fishes are defenseless, and other fishes are easily disoriented with a night divers light [91]. SCUBA spearfishing was banned within the West Hawai'i Regional Fishery Management Area (WHRFMA) boundaries from 'Upolu Point to Ka Lae (South Point) on Hawai'i Island in December of 2013. Since the implementation of this ban, the probability of observing parrotfish outside of no-take reserves as increased and biomass in these areas and fishery management areas has slightly increased[5].

Fishing regulations help to ensure sustainable harvest.

	Benefits	Drawbacks
Bag Limits 	• Reduces excessive take • Reduces fishing pressure • Allows all gear types • Promotes sustainable catch Adjustable • based on resource health and fisher need	• Different bag limits for different species may be difficult to remember • Targets gear types which catch large amounts of fish very easily • Statewide bag limits are difficult to determine because of variability between places
Size Limits  	• Immature fish are allowed to reach spawning size • Does not limit number caught Allows • most gear types	• Fish size can be difficult to estimate while underwater • Different size limits for different species may be difficult to remember • Catch and release for undersized fish is not practical for some gear types like a spear or some nets

Closed Season	• If during spawning season, protects reproductive individuals
	• Reduces fishing pressure
	  • Reproductive fish are less stressed
	  • Chance to rest and grow larger
		• Spawning seasons are highly variable by place
		• Life history could change with changing conditions
		• Reduces access at certain times

Gear Regulations	• Allows for a variety of species to still be caught • Can limit take of certain life stages or types of fish while still allowing fishing	• Excludes fishers who prefer specific gear types, if that gear is regulated
Slot Limits 	• Minimizes take of the population that haven't yet reproduced • Minimizes take of large very reproductive individuals • Older fish reproduce in much larger amounts than smaller fish • Allows for most gear types	• Can be difficult to estimate in water • Different size limits for different species may be difficult to remember • May limit catch of a desired size range
Place-based Regulations	• Incorporates traditional knowledge at local scales into management actions • Aligns regulations with unique characteristics of a place • Protects entire local ecosystem • Ensures broad size range of herbivores • Can replenish nearby fished areas via spillover of adult fish and seeding by larvae.	• Fishers can have a hard time remembering the rules for each place • May increase pressure in non-regulated areas • May limit access to preferred local fishing areas

Compliance and Enforcement of Fishing Regulations

Promoting compliance and upholding conservation rules are essential to increase management effectiveness and improve the overall health of nearshore environments. The Division of Conservation and Resources Enforcement (DOCARE) is the law enforcement agency of DLNR. DOCARE is responsible for enforcing existing regulations and any new fisheries regulations that are implemented and their mission is to protect, conserve, and manage the unique and limited natural, cultural, and historical resources. DAR works closely with DOCARE when developing and proposing new rules. DOCARE is also currently working to increase its enforcement capacity by filling officer vacancies through its Academy and Field Training Program. An additional 42 new officers were added in early 2023, increasing its ranks by 50%. DOCARE is also providing updated training on natural resources rules, and ensuring they have enough vessels, vehicles, and equipment to carry out enforcement responsibilities. In the 2021 legislative session, their inspection authority was expanded so that officers now have the authority to inspect catch, when fishing or harvesting activity is believed to be occurring, allowing them to ensure that pono and legal fishing practices are followed.

Knowing that officers cannot be everywhere all the time, the public can now report resource violations through the DLNR Tip App. Data reported on this app helps officers better address "hot spots" for violations and work more closely with concerned communities where problems are identified. Violations may incur criminal and civil penalties. These fees are assessed per violation. For example, if there are multiple fish caught below a minimum size limit, as set by the regulation, each fish caught could result in individual and separate penaltyies and fines. The tables below highlight the different fees for marine resource violations:

Table 1: Schedule of criminal and civil fines for marine resource violations. Fines increase if there is no response within 21 days. Fines are assessed per violation.

	1st Offense		2nd Offense		3rd Offense	
Violation	**Criminal Fine**	**Civil Fine**	**Criminal Fine**	**Civil Fine**	**Criminal Fine**	**Civil Fine**
Fishing Within a MLCD	$250-$1,000	Up to $200	$500-$1,000	Up to $400	$1,000	Up to $600
Fishing in Prohibited Area	$100-$1,000	Up to $200	$200-$1,000	Up to $400	$500-$1,000	Up to $600
Gear Restriction Violation	$100-$1,000	Up to $200	$200-$1,000	Up to $400	$500-$1,000	Up to $800
Size Limit Violation	$100-$1,000	Up to $200	$200-$1,000	Up to $400	$500-$1,000	Up to $800
Bag Limit Violation	$100-$1,000	Up to $200	$200-$1,000	Up to $400	$500-$1,000	Up to $800

DOCARE is also expanding its educational program Makai Watch. The Makai Watch program empowers community leaders to take ownership in the protection of their local marine resources. Makai Watch partners with local communities to educate the public on pono behavior. The program trains community members to take active roles in managing their resources by teaching them how to: (1) spot unlawful uses of marine resources (2) educate users regarding correct practices, and (3) contact enforcement authorities as appropriate. By enhancing outreach and education efforts, Makai Watch promotes compliance with existing rules and allows enforcement to focus on resource users who choose to evade proper regulations.

Other Management Options

DAR recognizes that fishing regulations are just one part of the solution. Effective management can be achieved only through addressing the many other factors that affect the health of our nearshore resources through a holistic and comprehensive strategy. In addition to fishing regulations, additional management options include:

Education: People are more likely to follow regulations that are easy to understand, easy to follow, and if the justification is well-understood. Education and outreach are critical components of any management strategy so that the public has a solid understanding of the ecosystem threats, potential solutions and how certain management actions are likely to help. With this shared understanding, there is a general increase in overall compliance and a shared desire to do what is right for the natural resources.

Outreach and Proper Signs: Proper signs help to provide education and outreach about regulations, practices, and the history of an area. This can help all who visit the area abide by the same standards and follow the same regulations, since they will be more aware of what is expected at a given place. It can also help to share information about any practices or sensitivities visitors should be aware of before entering an area to perpetuate place-based pono knowledge, traditions, and practices.

Enhance Habitat

Reef Habitat Plan: This is part of the statewide Hawai'i Coral Reef Strategy Makai Restoration Action Plans. The plan's goal is to improve nearshore fish habitat in areas of need. Guided by fisher input, restoration methods already identified include creating artificial reefs, coral outplanting, invasive limu removal, research into the impacts of invasive roi, taʻape and toʻau, as well as working with other agency partners to address freshwater quality and quantity issues.

Coral Restoration: DAR has created a one-of-a-kind land-based Coral Restoration Nursery to fast-grow Hawaiian corals under strict biosecurity protocols. Through a suite of unique restoration tools and procedures, DAR can produce a couple hundred large coral colonies per year for outplanting to damaged or degraded reef areas. There are several sites with outplanted colonies on Oʻahu and coral restoration projects are currently being planned for West Hawaiʻi.

DAR Sea Urchin Hatchery: The DAR Sea Urchin Hatchery plays a key role in controlling invasive seaweed and reef restoration efforts in Kāneʻohe Bay, Oʻahu. DAR cultivates hāwaʻe maoli, (*Tripneustes gratilla* or the native collector sea urchin) at the Ānuenue Fisheries Research Center. The urchins are raised from on-site spawning and grown up to 3/5 inch (15 mm) in diameter, at which time they are released into Kāneʻohe Bay to control invasive algae [92].

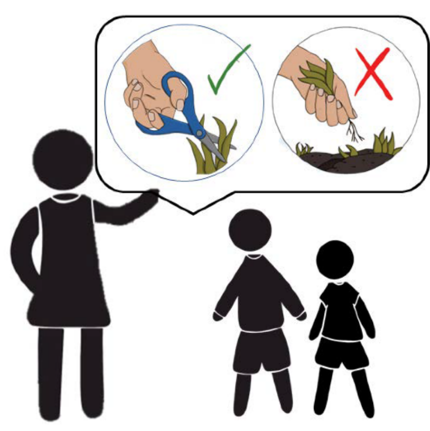
The first hatchery raised urchins were released in 2011. Since then, the hatchery has outplanted over 500,000 of these urchins that eat invasive algae. Using urchins as a biological control agent has now been able to control the invasive algae that once smothered the coral reefs in Kāneʻohe Bay. They are able to eat algae that grow in small spaces or crevices in the reef, reclaiming important coral habitat for young fishes and other small organisms.

As a result of DAR's efforts, invasive seaweed in Kāneʻohe Bay has decreased significantly in the last five years. DAR habitat managers continue to strategically deploy urchins wherever invasive seaweed is found. This prevents a full-scale reinvasion from taking root again and preserves the integrity of coral reef habitat. DAR is now also outplanting these urchins at the Waikīkī MLCD and FMA to control invasive algae in that area.

Stream and Estuary Monitoring:

DLNR Commission on Water Resource Management (CWRM) is working to restore stream flow across the islands, including some that have been diverted for over a century. They also create interim stream flow standards (setting the minimum quantity, flow or depth at water that is required for a given stream). Streams are important to supplying freshwater to Hawai‘i’s estuaries, which serve as nursery grounds for many species of food fish. As these changes are implemented and natural stream flow is returned to coastal waters, stream and estuary monitoring will help to track the response of the ecosystem, including many important species of fish and invertebrates. See the section on stream and estuary monitoring starting on page 13 for more information about DAR’s stream and estuary monitoring program.

Other management actions that complement fishing regulations to ensure healthy reefs and abundant resources

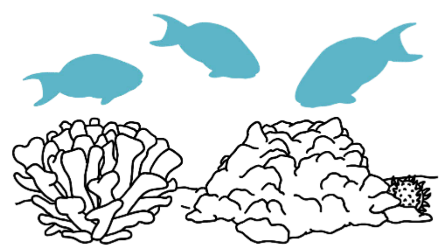


Get the word out

Education/Outreach

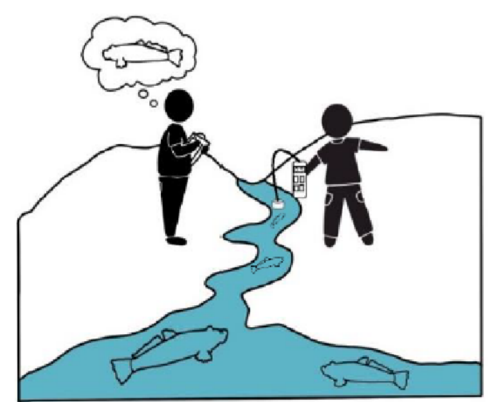
Keep People Informed

Signage



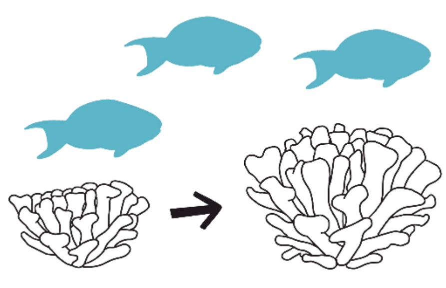
Repair and Prevent Damage

Enhance Habitat



Track Changes of Recovering Watersheds

Stream and Estuary Monitoring



Track Progress and Changes

Enhanced Monitoring

Work Together Towards Solutions

Community and Agency Partnerships

Examples include:
- Restoring stream flow
- Addressing overuse/ over-tourism
- Increasing enforcement
- Reducing sedimentation
- Addressing run-off and land-based sources of pollution

Graphics illustrated by Avery Williams

Monitoring:

Monitoring is an essential component that measures and documents current conditions, tracks environmental responses following implementation of new management approaches, and uses data to identify areas where management actions need to be further adapted. Monitoring provides a way to measure the changes occurring and if implemented actions are effective. Monitoring can help not only to track the response of species or habitats to management actions or regulations, but also can track the changes in human use or threats over time, including changes in fishing pressure, coral bleaching or bleaching related die-off, ocean acidification, run-off, sedimentation and visitation to a certain area. These factors can also help to inform future adaptive management.

While DAR has an extensive monitoring program, particularly regarding fishes and coral, there are several data gaps in monitoring of nearshore resources. With compounding threats targeting these important subsistence resources, such as ʻopihi and limu, expanding monitoring efforts is critically important to gather data to better inform management and planning at the local and statewide level. One important effort to increase monitoring for these species is through DAR partnering and supporting communities that engage in community-based monitoring. This provides support for place-based monitoring efforts of resources prioritized by specific communities.

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Community and Agency Partnerships:

DAR is committed to creating and maintaining partnerships and collaborations with other agencies, non-governmental organizations, and communities in order to address some of the concerns and impacts to nearshore resources that are beyond its jurisdiction and authority. There are many examples of collaborations already in progress to help address some of these multi-faceted and multi-jurisdictional impacts to the nearshore environment. Below are some examples that could serve as models for incorporating collaborations and partnerships into management planning to find solutions to complex concerns.

'Opihi Rest Areas

The 'Opihi Rest Areas along the eastern coastline of Maui are examples of a successful protection and restoration initiative through community-based management. In response to the decline in 'opihi numbers, community groups Nā Mamo O Mū'olea and Kīpahulu 'Ohana worked to revive the traditional Hawaiian practice of resting an area from 'opihi harvest. This allows them to grow larger and produce more larvae that can then spread to repopulate both the rested area along with neighboring areas. The communities asked fishers to avoid any harvest in these areas and encouraged voluntary compliance through outreach and education without any enforcement measures. After three years of surveys, significant increases in 'opihi abundance were observed both within and down current from both rest areas[93]. Projects like these showcase the effectiveness of community efforts to replenish native resources through education and outreach without the need of enforcement agencies.

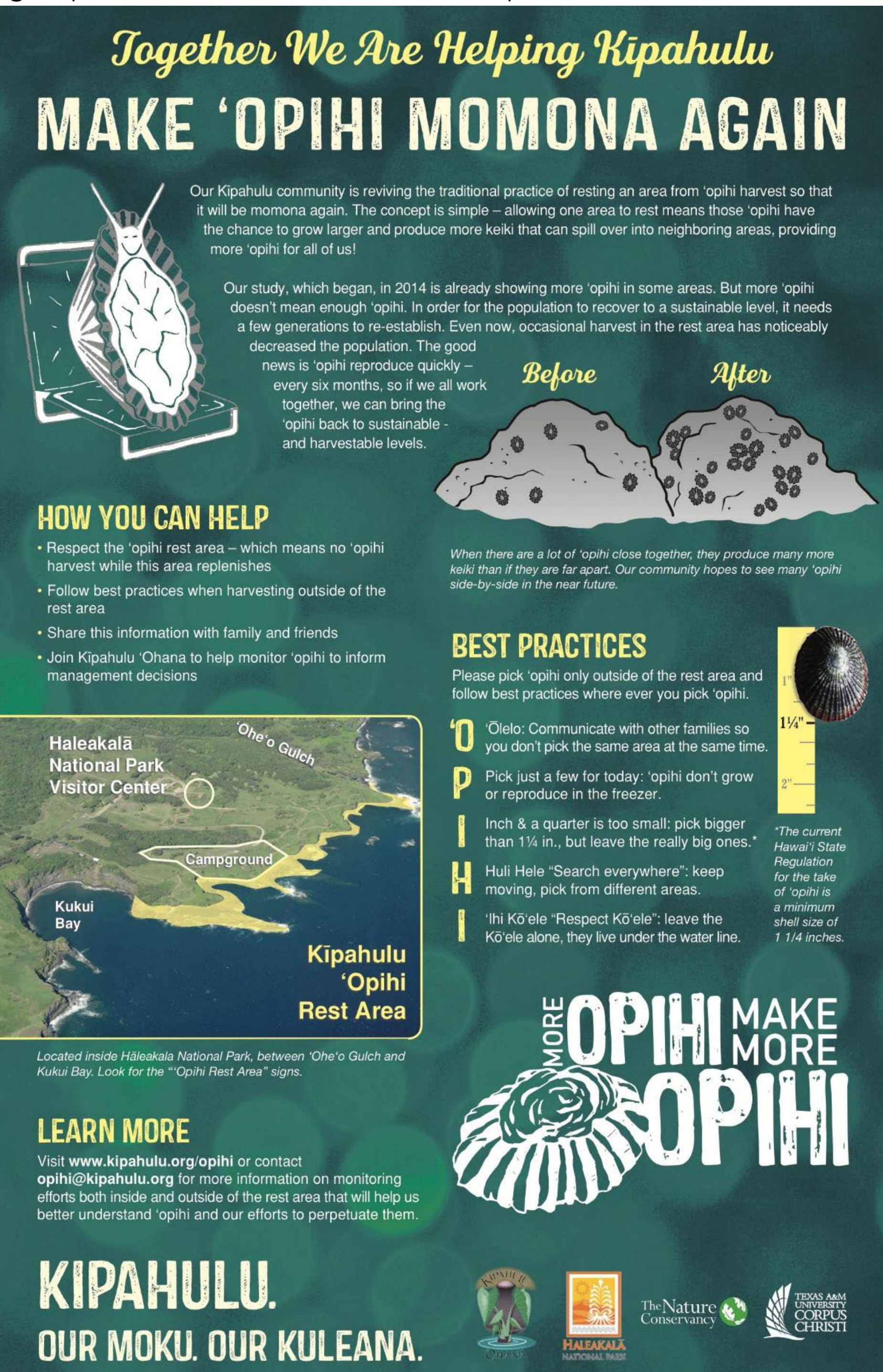

Figure 48: Poster to support 'opihi rest area inside Haleakala National Park https://kipahulu.org/whatwedo/malamaikekai/opihi/

Waiheʻe Limu Restoration

The Waihe'e Limu Restoration is another example of a community organization working to restore natural resources. Volunteers come together and use the knowledge of local fishers to help revive, replant, and restore Hawaiʻi's native limu and preserve Hawaiian cultural practices from mauka to makai. The group is now able to cultivate a greater awareness through education and public outreach events teaching the importance of limu to help replenish fish stocks and restore balance in the ecosystem. They also monitor water quality, limu growth, and fish populations to help protect the northern coastline of Maui.

Stream Restoration

After more than a century of freshwater diversion for commercial agriculture use, the State Water Commission returned three streams in East Maui (Waiohue, East Wailua iki and West Wailua iki) to natural water flow conditions. This unprecedented shift of water usage restored habitat for nine endemic species found in Hawaiian streams [94]. The order was the culmination of a 2001 petition which was filed by the Native Hawaiian Legal Corporation and Maui Tomorrow. These groups were able to invoke a legal ruling to help restore freshwater inputs to these watersheds. Now, these productive streams can feed estuaries which are needed to provide critical habitat for juvenile fish and help sustainable fishing.

Coral Reef Alliance - Mauka to Makai

The Coral Reef Alliance is an environmental NGO working in Maui to preserve and protect coral reefs by restoring West Maui's watersheds. These water sheds are a significant source of land-based pollution to the ocean and this group is taking a mauka-to-makai approach to help keep coral reefs healthy. Also known as a ridge-to-reef approach, focusing on restoring the watershed to its natural state will allow future runoff to first be naturally filtered, thus reducing levels of nutrients, sediments, and harmful chemicals that reach the reefs.

The Coral Reef Alliance is working to plant native plants and restore forests along the Wahikuli and Honokowai watersheds. These areas were identified by the U.S. Coral Reef Task Force as high priority because large amounts of sediment move through the watershed resulting in smothered coral reefs. The added vegetation will help hold soil in place and reduce sediments reaching streams to be transported to the coast. Native seeds are grown locally on Maui in greenhouses and nurseries before being out-planted at the restoration sites. Sediment accumulation and grain size are then monitored to determine the effectiveness of the restoration. The Coral Reef Alliance also teamed up with TNC and DAR to monitor coral reef sites to show what effect the watershed restoration is having on the reef ecosystem. These efforts are paving the way for future efforts to successfully restore local watersheds and coastal environments.

Paniaka Restoration Project

Beachfront development along South Maui has drastically shifted the ecological balance of the historical wetlands in the area. Native flora have been restricted by many invasive species that have shifted the physical landscape of these culturally and ecologically important lands. Introduced predators have also hindered the recovery of endangered birds and other species. Environmental groups are working to preserve these wetlands within Mākena State Park through the Paniaka Wetland Restoration Project. These groups plan to retore the water table by removing invasive kiawe trees, plant native vegetation to help restore habitat for birds and other wetland species and install fencing to protect the native vegetation from grazing animals and birds from predators.

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These are just a few examples of work that can be done through collaboration and partnership to address impacts to the nearshore ecosystems that are beyond the jurisdication of DAR but are important components to effective nearshore management.

Connecting ʻĀina and Kai through Management

Traditionally in Hawaiʻi, natural resources were managed at local (ahupuaʻa) and district (moku) levels, and management was integrated ma uka to ma kai. Currently there are management and stewardship efforts for ʻāina and kai, but rarely are these efforts integrated, even though impacts on land often extend to impact the nearshore waters. Hawaiʻi's watersheds are relatively steep and narrow, connected by streams, rivers, and run-off allowing the resulting effects of disturbances throughout the watersheds to directly affect the nearshore environment. Given this interconnectedness, when designing place-based management strategies, it is best to align terrestrial management and conservation efforts with coastal and marine efforts so that there is management along the entire watershed, reflective of traditional natural resources management practices in Hawaiʻi.

Terrestrial Management and Conservation

Before humans voyaged to the Hawaiian islands, it is estimated that 85% of the land was covered in vegetation, including both wet and dry habitats/ forests. Today less than half of that native vegetation remains [95]. Various statewide and local programs are working to restore these vegetated terrestrial ecosystems, including State Conservation District, Hawaiʻi's Natural Area Reserves System, watershed partnerships, Hawaiʻi Land Trust, Kamehameha Schools, and numerous others. Presently at least 35% of terrestrial areas have been assigned some sort of formal protection designation (Figure 49). Native forests in watersheds can help absorb water increasing groundwater and improving our freshwater supply. Protection and restoration of these forests can help to reduce sedimentation and run-off, which can directly impact nearshore ecosystems.

© Jeff Bagshaw/DOFAW

The Division of Forestry and Wildlife (DOFAW) manages the statewide Natural Area Reserves System (NARS). The system was established to preserve in perpetuity specific land and water areas that are relatively unmodified, which support natural floral and faunal communities, as well as geological sites, of Hawaiʻi. It consists of reserves on five islands and encompasses the State's most unique ecosystems. They additionally coordinate the 30×30 Watershed Initiative to protect 30% of Hawaiʻi's priority watershed forests by the year 2030. Approximately 20% of total land area has been identified as priority watersheds in Hawaiʻi and this initiative aims to protect these watersheds by controlling damaging invasive species (including ungulates) and diseases, planting trees, preventing wildfires, and educating the community about the importance of our forests.

© DOFAW

In addition to state designation status such as State Conservation Districts or Natural Area Reserves, various stakeholders including agency, non-governmental organizations and private landowners have come together to create partnerships to co-manage terrestrial ecosystem across ownership boundaries. These are voluntary alliances that protect and manage over 2 million acres of forest in Hawaiʻi [95]. The Hawaiʻi Association of Watershed Partnerships connect 10 independent island-based partnerships and work collaboratively with more than 90 public and private partners across 5 islands to protect watershed lands.

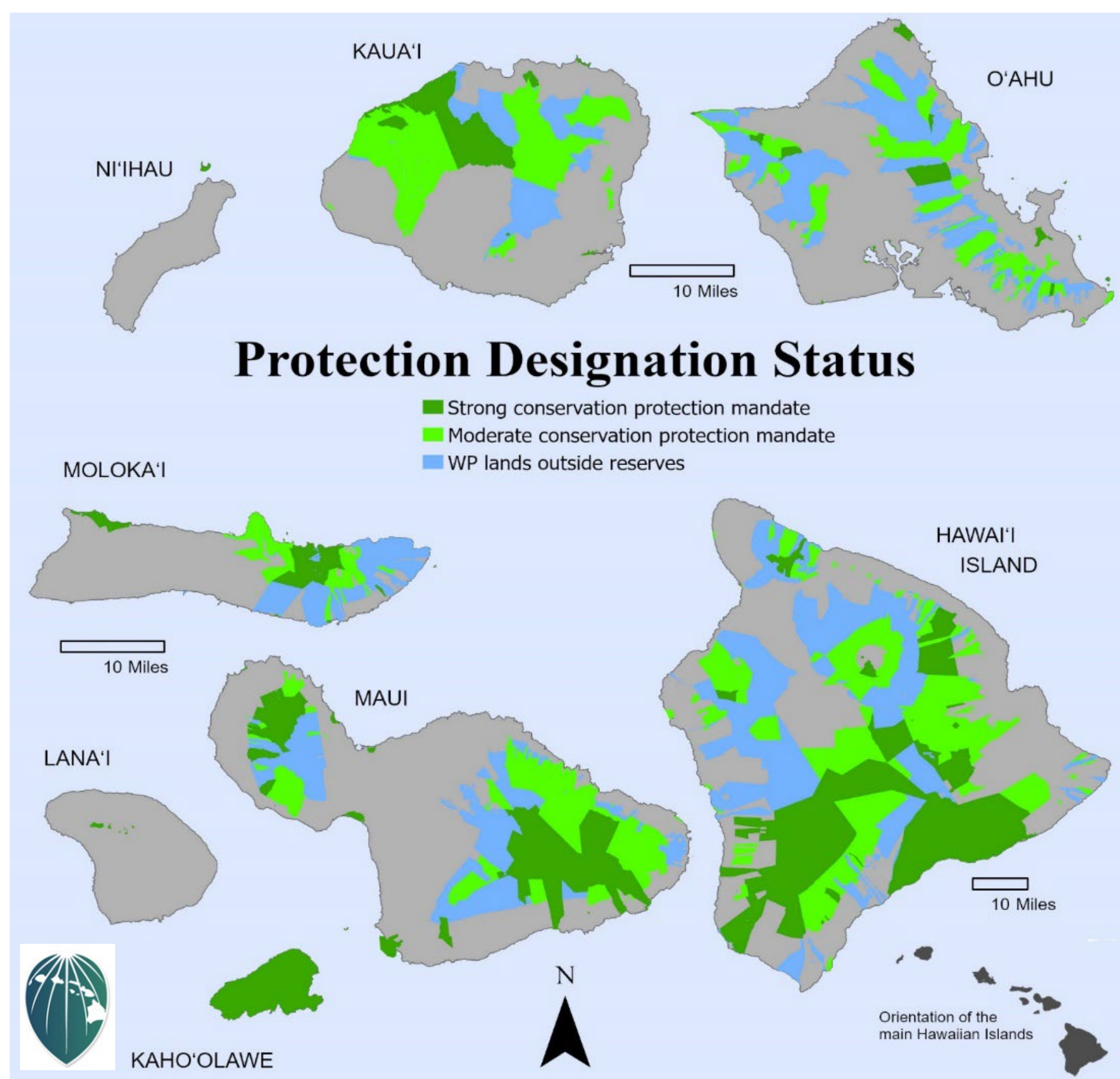

Figure 49: Status of terrestrial conservation protection areas on the main Hawaiian Islands. Data source: Provided with permission by the Hawaiʻi Conservation Alliance.

Strong protection areas include permanent mandates for biocultural resource conservation (e.g., National Parks and Wildlife Refuges, State Natural Area Reserves and Wildlife Preserves). Moderate protection areas have short-term protection designation and mandates for multiple use including conservation (e.g., State Forest Reserves, private conservation areas). Watershed partnerships have strong commitments for conservation management but may include areas with limited or no long-term commitment for conservation protection.

In addition to formal designations and partnerships, there are many organizations that work to steward and co-manage the nearshore environment (Figure 50). The motivation for community-led natural resource management is growing. Initially, many of these community-led efforts were focused on coastal management, but now they are expanding to terrestrial ecosystems as well.

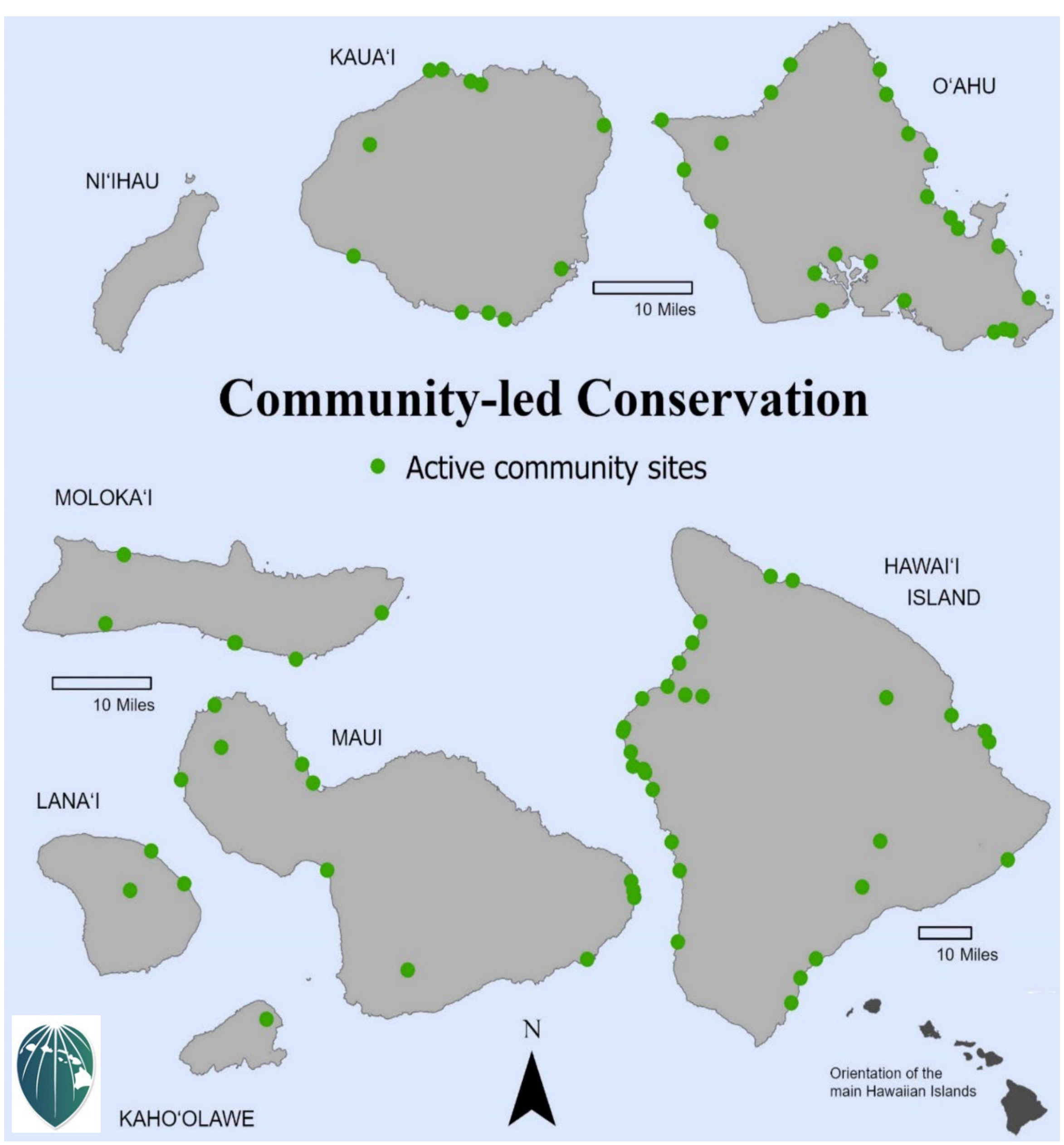

Figure 50: General locations of community-led biocultural conservation efforts across the state. Data from KUA (Kevin Chang), figure provided with permission by the Hawaiʻi Conservation Alliance.

An example of this is the increasing interest in creating Community-Based Subsistence Fishing Areas (CBSFA). CBSFAs are unique marine areas co-managed between DAR and the local community to protect fishing practices customarily and traditionally exercised for purposes of native Hawaiian subsistence and culture. This type of marine management area seeks to balance the needs of the community with the needs of the fisheries and the ecosystem. The community of Hāʻena, Kaua'i developed the first officially adopted CBSFA rules package. The rules package for Miloliʻi CBSFA was adopted in 2022 and spans much of South Kona on Hawaiʻi Island. Kīpahulu CBSFA was designated on Maui in 2024. Other communities have engaged in co-management with DAR and initiated similar efforts including Ka'ūpūlehu and Kealakekua on Hawaiʻi Island, along with several others.

Existing Marine Management Areas

There are several types of MMA that are managed or co-managed by the Department of Land and Natural Resources (DLNR), including Natural Area Reserves, Marine Life Conservation Districts, Fisheries Management Areas and CBSFAs (Figure 51). Approximately 4% of Maui is currently managed as part of an MMA with six existing MMA areas: Honolua-Mokulēʻia Marine Life Conservation District (MLCD), ʻĀhihi-Kīnaʻu Natural Area Reserve (NAR), Molokini Shoal MLCD, Kahekili Herbivore Fisheries Management Area (FMA), Kahului Harbor FMA, and Kīpahulu Moku CBSFA (the newest Maui MMA, formally designated in 2024).

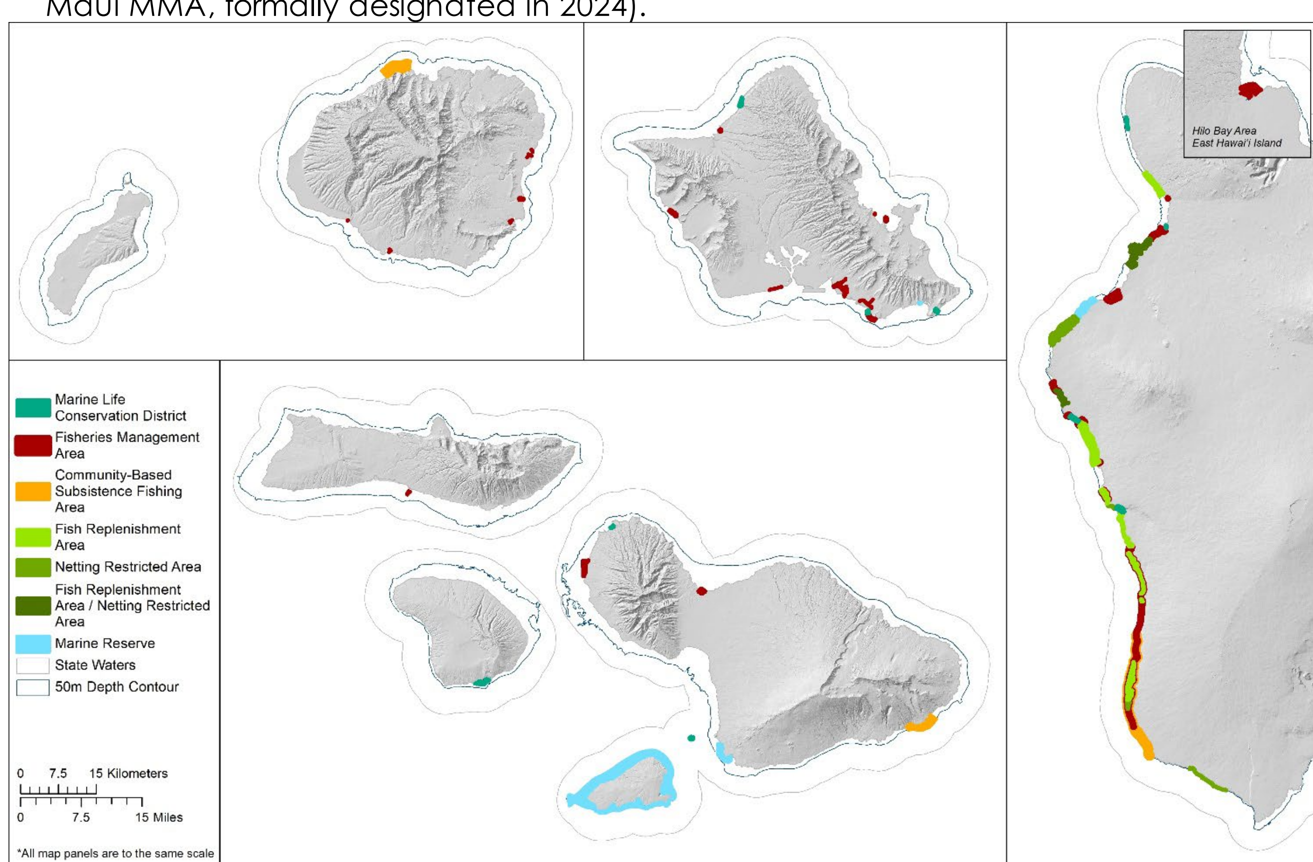

Figure 51: Statewide map of existing DLNR MMAs that overlap with nearshore waters.

Natural Area Reserve System (NARS)

The Natural Area Reserves System was established to preserve, as relatively unmodified as possible, in perpetuity specific land and water areas that support the natural flora, fauna, and geological sites of Hawai'i. The diverse areas found in the NARS range from marine and coastal environments to lava flows, tropical rainforests, and even an alpine desert. Within these areas, one can find rare endemic plants and animals, many of which are on the edge of extinction. Currently, the state of Hawai'i has 21 reserves on five islands, encompassing 123,810 acres of the state's most unique ecosystems. 'Āhihi-Kīna'u Natural Area Reserve is the only NARS that is considered an MMA because it encompasses both terrestrial and marine ecosystems.

'Āhihi-Kīna'u Natural Area Reserve Established 1973

Location: 'Āhihi-Kīna'u shore waters include the waters seaward of Cape Kīna'u, a distance of 2000 to 3000 feet as shown.

Highlights: 'Āhihi-Kīna'u NAR is the oldest MMA on Maui and has one of the highest diversity of corals in such a limited area in the state [96,97]. The area also has over 75 species of fish (17 endemic) within its boundaries [96,97]. These two points makes 'Āhihi-Kīna'u NAR the most effective fully protected MMA in the state of Hawai'i based on total resource fish biomass to management size [98].

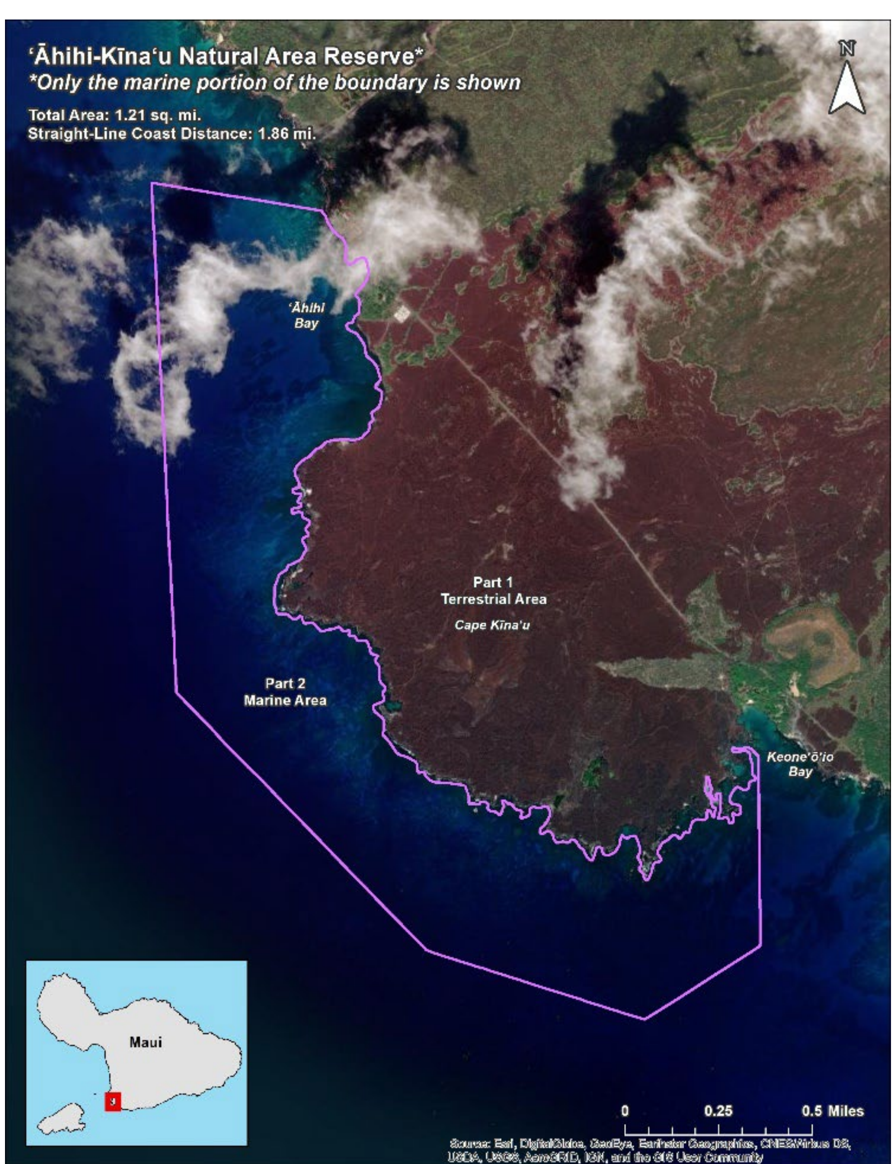

Figure 52: Map of 'Āhihi-Kīna'u Natural Area Reserve

Marine Life Conservation Districts

Marine Life Conservation Districts (MLCD) were introduced in 1967 with the establishment of the Hanauma Bay MLCD on Oʻahu and continue to be an important tool to manage the valuable ecosystems in our nearshore waters today. They are designed to conserve and replenish marine resources to the greatest extent possible by providing fish and other aquatic life with a protected area in which to grow and reproduce. The taking of any type of living material (fishes, eggs, shells, corals, algae, etc.) and non-living habitat material (sand, rocks, coral skeletons, etc.) is generally highly restricted, if permitted at all. There are 2 MLCDs on Maui: Molokini Shoal Marine Life Conservation District and Honolua-Mokulēʻia Bay Marine Life Conservation District. Both areas are popular places for snorkeling, diving, and underwater photography.

Molokini Shoal Marine Life Conservation District
Established: 1977

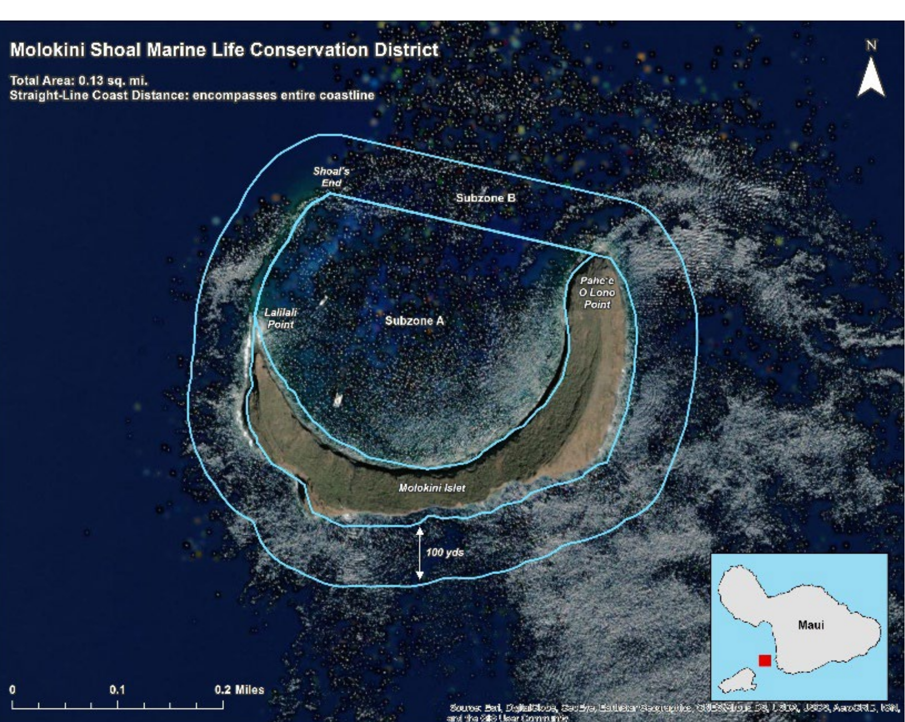

Figure 53: Map of Molokini Shoal Marine Life Conservation District

Location: The Molokini Shoal Marine Life Conservation District is located offshore of Molokini Shoal, about three miles from the southwestern coast of Maui. "Subzone A" includes the waters and submerged lands within the crater bounded seaward by a straight line from the end of the submerged ridge extending off Lalilali Point to Paheʻe O Lono Point. "Subzone B" includes the waters and submerged lands 100 yards seaward of Molokini Shoal and Subzone A as shown.

Highlights: Molokini has high species diversity, richness, and biomass which includes dominant resource species such as surgeonfish, jacks, and parrotfish. Fish surveys at Molokini have found more apex predators, herbivores, and larger resource fish than in other comparable open access areas on Maui [25,99]. Aside from the ecological/biological benefits, Molokini MLCD also has economic benefits. It is the second most visited MPA in the state of Hawaiʻi; recreational activities in the MLCD bring in over $20 million annually [100].

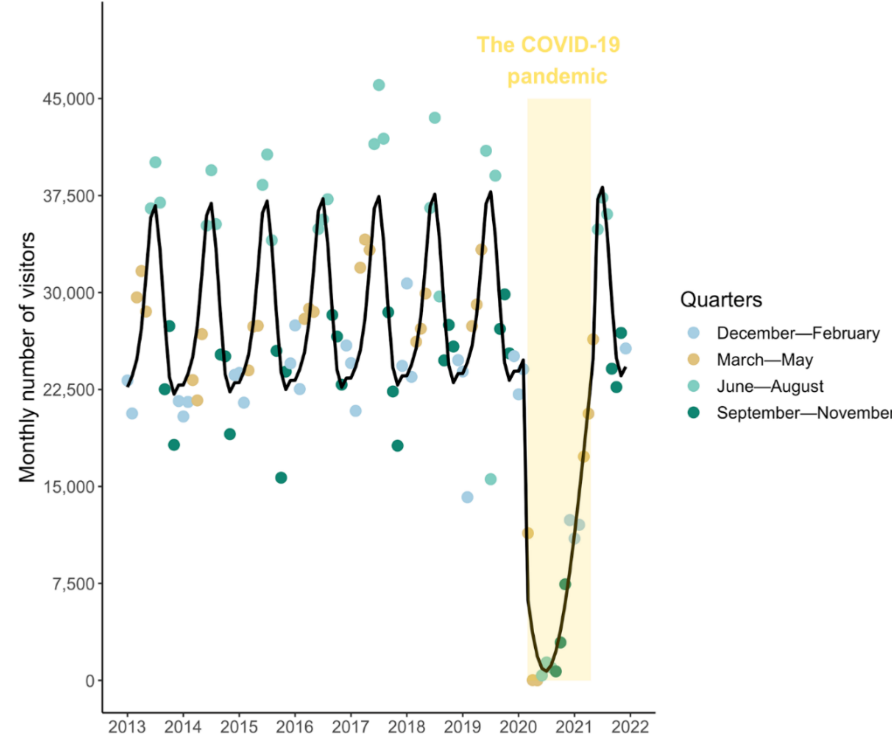

Figure 54: Monthly variation in number of people visiting Molokini MLCD since 2013, published in Weng et al. 2023. Circles show monthly counts of people at Molokini and are colored by quarters that corresponds to a 3-month period. The black line is the result of the GAM model. The yellow box denotes the period of travel restrictions associated with the COVID-19 pandemic (from March 2020 to May 2021).

Lockdowns and travel restrictions imposed by the State of Hawai'i during the COVID-19 pandemic resulted in a steep decline in visitors, which allowed researchers a unique opportunity to study marine resources at the Molokini MLCD in the relative absence of humans. Since 2012, commercial vessel users (not private boat users) have provided detailed reporting of their visits to the Molokini MLCD to the Maui Division of Aquatic Resources. These reports showed the monthly number of visitors in Molokini remained similar between 2013-2019. In 2020 and in 2021 visitor numbers dropped significantly (Figure 54). In contrast, fish biomass increased during that period in both shallow and deep aggregate reefs before dropping in 2021 when the number of visitors started to return to the pre-pandemic level (Figure 54, Figure 55)[101].

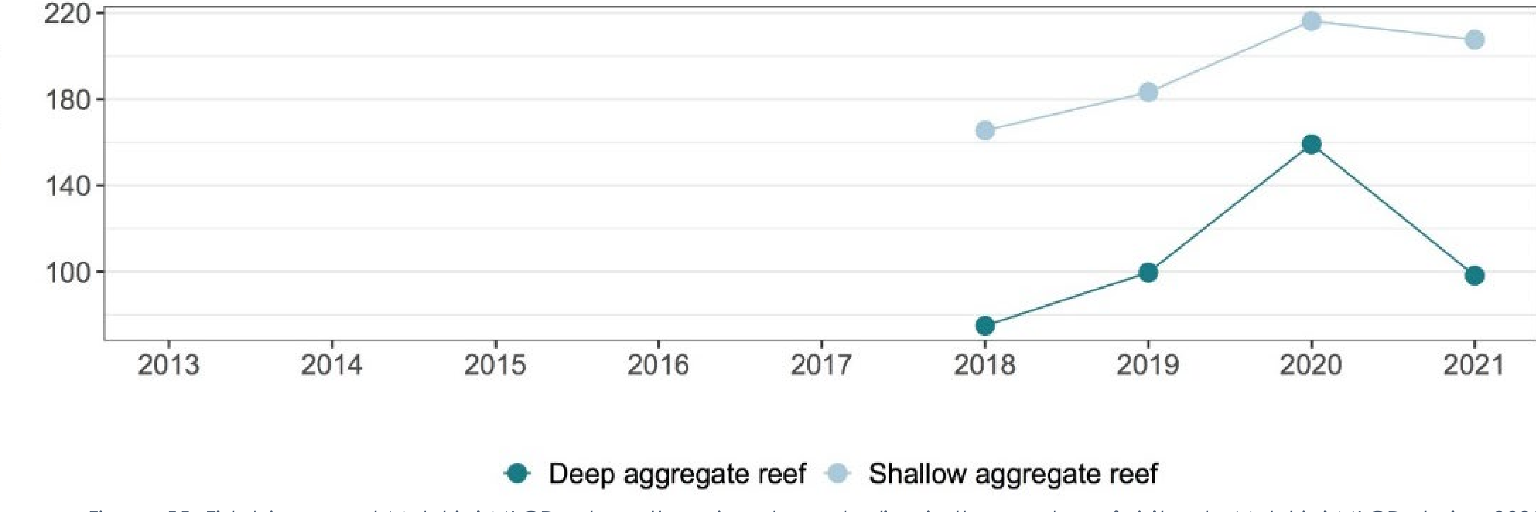

Figure 55: Fish biomass at Molokini MLCD, where there is a steep decline in the number of visitors to Molokini MLCD during 2020 (Figure 54), due to the State restrictions during the COVID-19 pandemic and a significant increase in fish biomass at both deep and shallow aggregate reef habitats (Weng et al. 2023).

Honolua-Mokulēʻia Bay Marine Life Conservation District
Established: 1978

Location: The Honolua-Mokulēʻia Bay Marine Life Conservation District is located along the northwestern coast of Maui, bounded seaward by a line from ʻAlaelae Point to Kalaepiha Point, then to the point at the northwestern corner of Honolua Bay as shown.

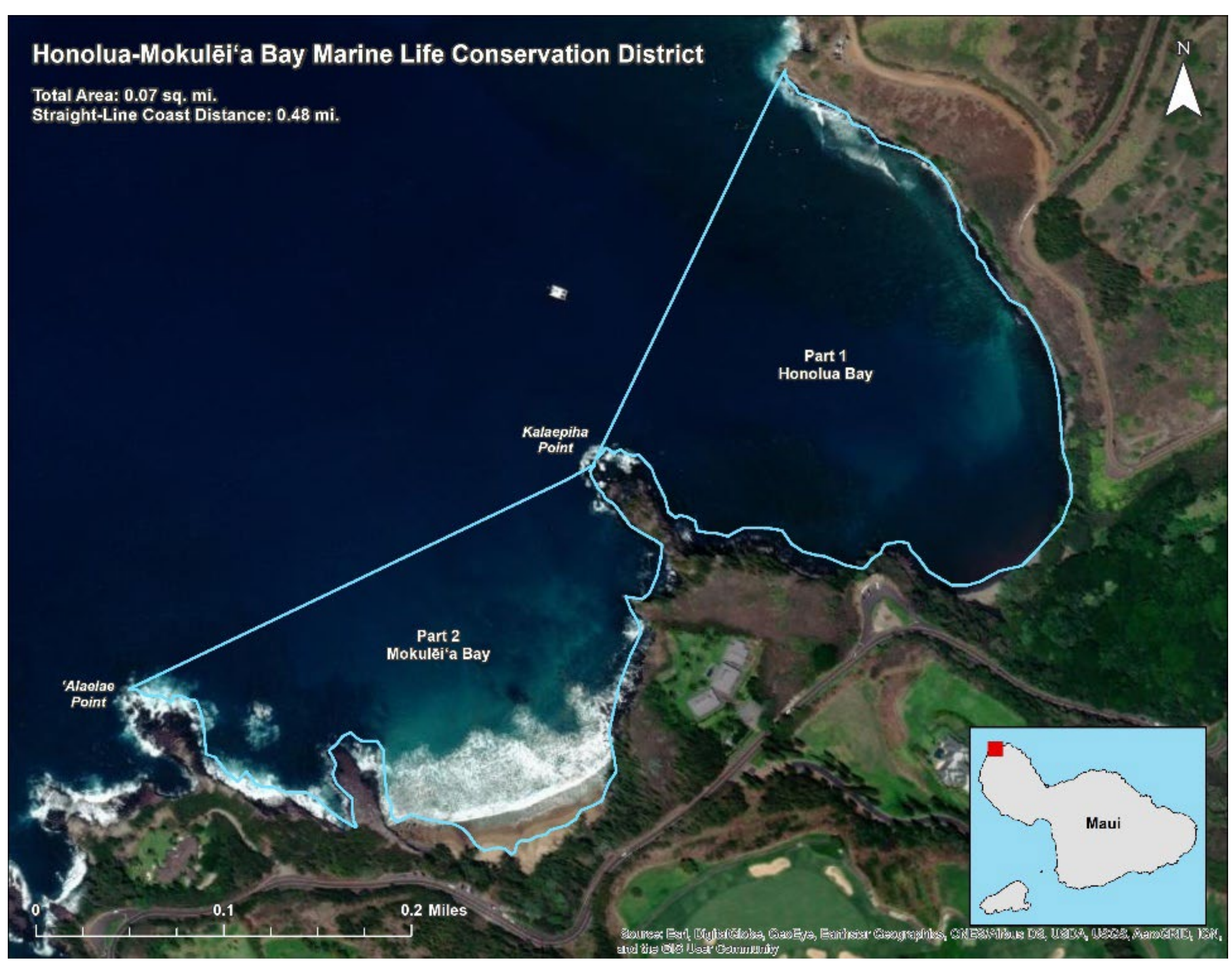

Figure 56: Map of Honolua-Mokulēʻia Marine Life Conservation District

Highlights: The total fish biomass, resource fish biomass, and prime spawner biomass inside the Honolua-Mokulēʻia MLCD is 2.5 times higher than the average of other reef tracts in the West Maui Region [102]. Additionally, apex predators (jacks and sharks) had 7 times greater biomass inside the MLCD compared to reef tracts outside the MLCD [25,102]. Not only does the Honolua-Mokulēʻia MMA have a positive effect for fish biomass within the boundaries of the MLCD, but it appears the effects are spilling over into adjacent reefs [102].

Fisheries Management Areas

Fishery Management Areas (FMA) manage or enhance fisheries for long-term sustainability of the resources and help to resolve conflict between diverse resource users. There are two FMAs on Maui: the Kahekili Herbivore Fisheries Management Area and Kahului Harbor Fisheries Management Area.

Kahekili Herbivore Fisheries Management Area
Established: 2009

Location: Kahekili Herbivore Fisheries Management Area is located off north Kāʼanapali. The northern boundary is a straight line extending 1292 yards west from Honokōwai Beach Park, the southern boundary is a straight line extending 335 yards west from Hanakaʼōʼō Beach, and the seaward boundary is a straight line connecting the seaward endpoints of the northern and southern boundaries.

Figure 57: Map of Kahekili Herbivore Fisheries Management Area

Highlights: The Kahekili Herbivore FMA is the first MMA in Hawaiʻi where fish stocks are being managed for the specific goal of improving the health and resilience of the coral reef – not just the fishes. The FMA has average to high abundance, biomass, and diversity of both benthic and fish species compared to other reefs in the West Maui Region [102]. Parrotfish biomass has been steadily increasing since the FMA was established in 2009 [103]. Parrotfish biomass is currently more than three times greater within the FMA than outside the FMA in the adjacent Mahinahina reef tract [102]. Resource fish were also 50-100% larger inside the FMA than outside [102].

Kahekili Herbivore Fisheries Management Area Monitoring Summary

The Kahekili Herbivore Fisheries Management Area (KHFMA) was established on Maui in 2009 along an approximately two-mile section of the north Kāʻanapali coastline in West Maui. Rules established in this area prohibited the take of herbivores, including both fishes (chubs, surgeonfishes and parrotfishes) and urchins, while continuing to allow all other forms of fishing. KHFMA is the first place in Hawaiʻi where fish stocks are being managed for the specific goal of improving the health and resilience of the coral reef itself – not just the fishes. Leading up to the establishment of the KHFMA, state monitoring results showed that coral cover along this section of coastline had declined dramatically and that reefs were periodically overgrown by blooms of algae. There were concerns about injection wells and the need to control high nutrient inputs in the area contributing to these algae blooms. The condition of the reef was particularly concerning in 2005 and 2006, when dense summer blooms of the alien algae *Acanthophora spicifera* appeared to be accelerating the ongoing declines in coral cover. Survey data from this time also showed that the herbivore fish biomass within this area was low compared to similar habitats around other parts of Maui.

These regulations protected all important reef herbivores from harvest and stopped the long-term practice of fish feeding (a practice that alters fish composition, behavior and normal grazing practices). Routine fish and habitat surveys were conducted on the reefs in the KHFMA and compared with survey results from other similar reefs around Maui.

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Nine years after the rules were implemented, average parrotfish biomass increased by nearly 400% and average surgeonfish biomass increased by 71% [104]. In 2018, biomass of parrotfishes larger than 10 inches in total length was more than 10 times the 2008 level [104]. The change in urchin density varied by species, with some staying relatively stable and some declining. This suggests that they weren't heavily targeted/harvested prior to the new rules and could be a result of the reduction in their food source, macroalgae.

Improving and sustaining conditions that support coral cover long-term is especially important in Hawaiʻi because the majority of our coral species (*Porites* spp.) are slow-growing (only 1-3 cm/year [105]) and have very low recruitment rates. Coral cover declines in the KHFMA stabilized in 2012 and appeared to slowly increase through 2014. Unfortunately, the mass bleaching event in 2015 impacted some of these corals, driving coral cover downward through 2018. However, the study found that crustose coralline algae (CCA), a foundational building block for coral recruitment and growth, increased by more than 11% and macroalgae cover remained low [103,104].

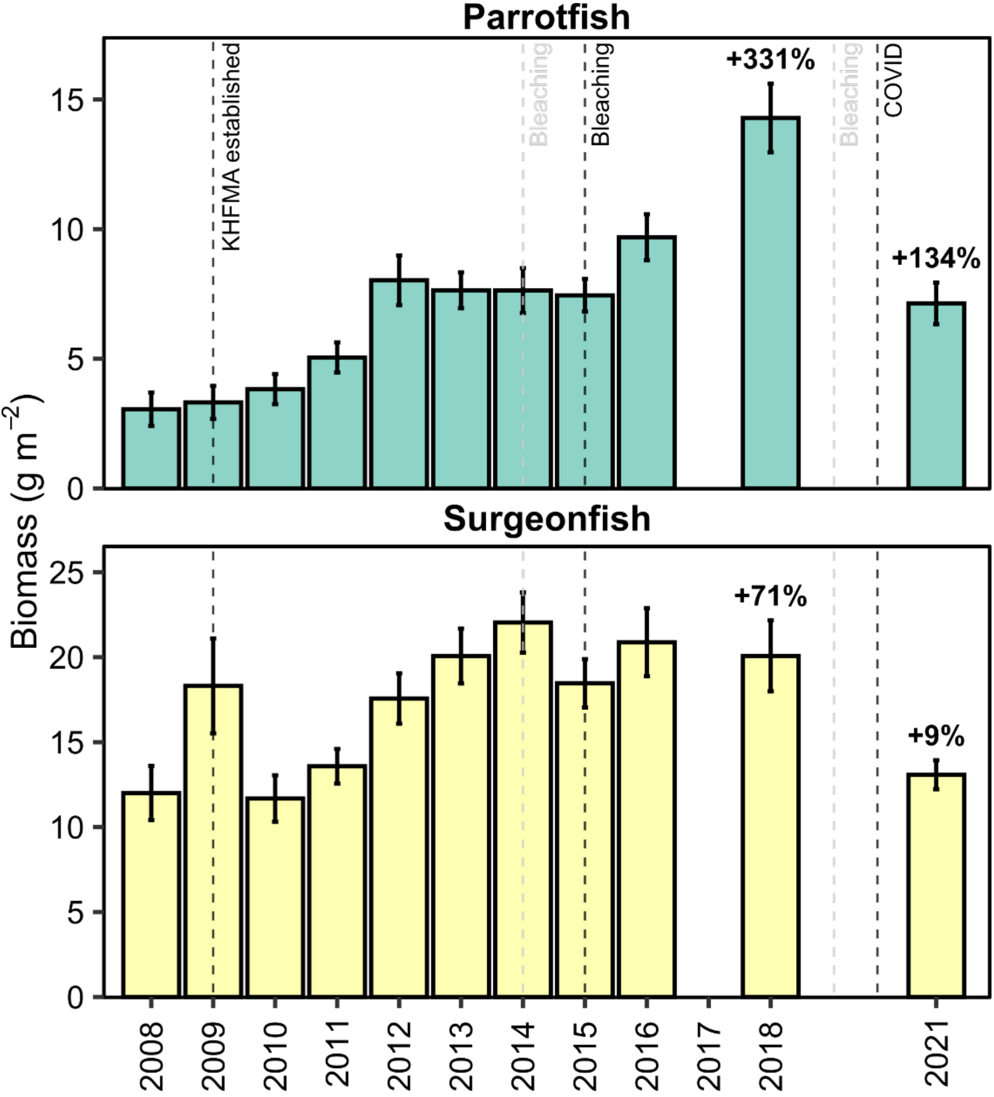

Figure 58: Trends in surgeonfish and parrotfish biomass from 2008 (pre-implementation) to 2021 in Kahekili Herbivore Fisheries Management Area. Time references for KHFMA implementation in 2009, the severe coral bleaching event in 2015 and COVID-19 pandemic in 2020 are indicated by vertical dotted lines.

Despite the initial increase in parrotfishes and surgeonfishes, preliminary results show significant declines in parrotfish and surgeonfish biomass (Figure 58), coral cover and crustose coralline algae between 2018 and 2021[106]. For parrotfishes, biomass was not significantly different post-2015 bleaching, but then there were step-wise declines in the Beach Park habitat closest to shore from 2016-2021 (Figure 59). The deeper and farther off-shore habitats (deeper reef and spur-groove) also experienced declines from 2018-2021, but biomass after these declines was similar to the 2016 levels, whereas the biomass at the beach park was significantly lower than in 2016. This may be related to

changes/declines in reef condition and
lack of compliance to the KHFMA regulations.
Areas close to shore experience greater pressure from
human impacts, including fishing. The density of *Tripneustes gratilla*, a collector urchin well-known for being a productive grazer of macroalgae, has also decreased since 2018 (Figure 61). The driver of these changes is unknown, but given the rapid and significant response to herbivore populations and the reef after the rules were initially implemented in 2009, it is clear that continued compliance is critical to maintain the high levels of herbivores and positive trends in reef condition overtime. DAR, in collaboration with NOAA, will continue to monitor this site in the future to assess changes over time.

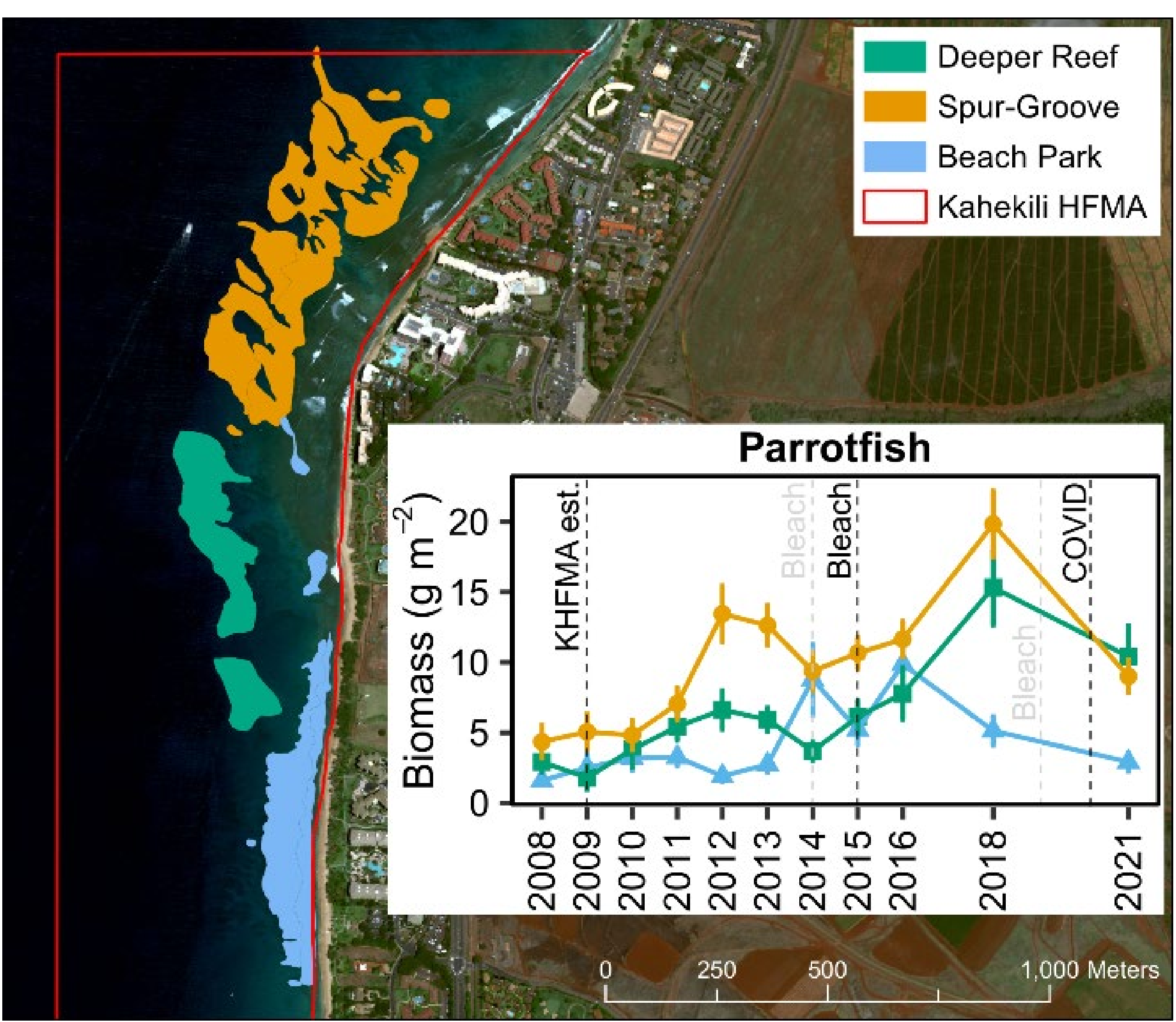

Figure 59: Trends in parrotfish biomass by KHFMA reef area. Dotted vertical lines indicate the implementation of KHFMA, major and minor bleaching events and the COVID-19 pandemic in 2020 for reference.

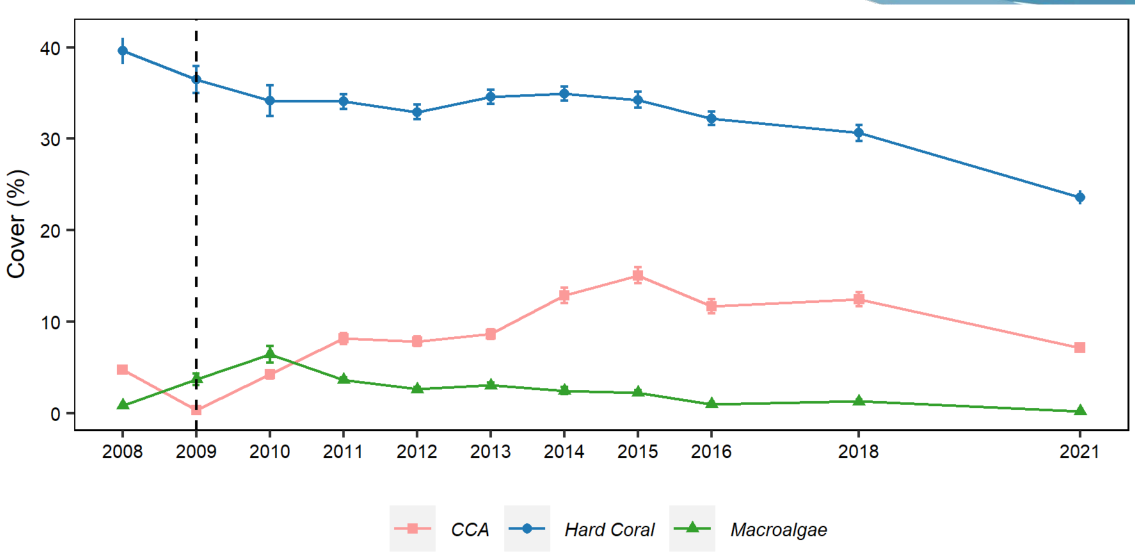

Figure 60: Percent cover of crustose coralline algae, hard coral and macroalgae at Kahekili Herbivore Fisheries Management Area from 2008 (pre-implementation) to 2021.

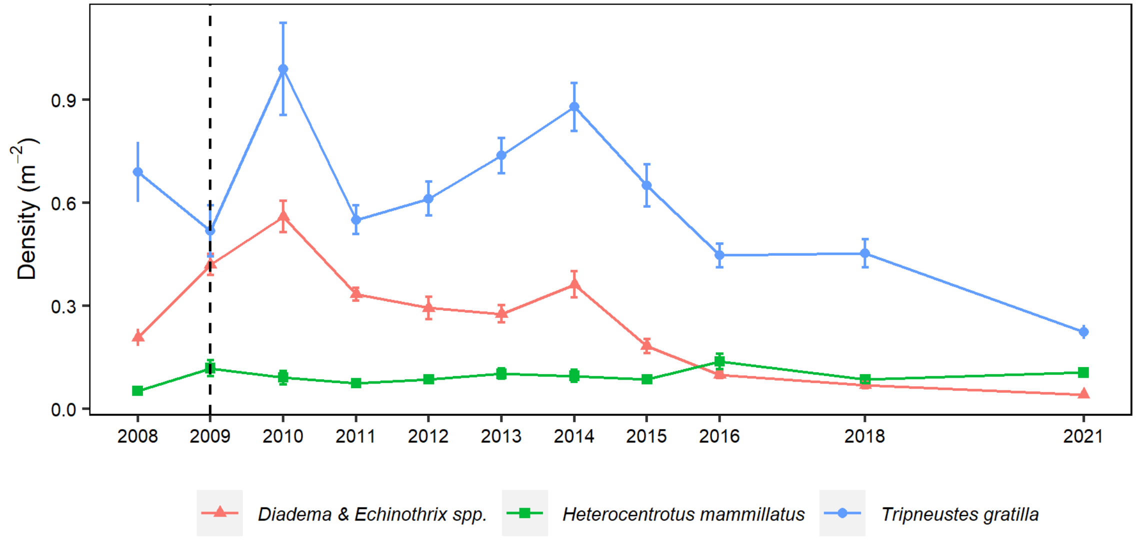

Figure 61: Density of urchins at Kahekili Herbivore Fisheries Management Area from 2008 (pre-implementation) to 2021.

Kahului Harbor Fisheries Management Area
Established: 2009

Location: Kahului Harbor is the primary port on the northern coast of Maui. The Fisheries Management Area is bounded by a line between the seaward edges of the breakwaters, as shown.

Highlights: Unfortunately, most FMAs including Kahului Harbor are not monitored on a consistent basis so it is difficult to determine the biological/ecological successes of the FMA [107]. However, on a social scale, local community members have been actively involved in helping to manage the FMA. In 2010, a local group of community members established the Wailuku Community Managed Makai Area (CMMA). Between 2012-2014, the Wailuku CMMA engaged the community and stakeholders by holding regular meetings, walking beaches and fishing areas, and engaging with fishermen about the FMA regulations and how to properly abide by them [108]. In 2016, the Wailuku CMMA worked with scientists, fishers, managers, and other stakeholders in Kahului to develop a Community Action Plan and developed Objectives and Strategic Actions to achieve a healthy harbor fishery [108].

Figure 62: Map of Kahului Harbor Fisheries Management Area

Community-Based Subsistence Fishing Areas

Community-Based Subsistence Fishing Areas, or CBSFAs, are unique marine areas co-managed between DAR and the local community to protect fishing practices customarily and traditionally exercised for purposes of native Hawaiian subsistence, culture, and religion. This type of marine management area seeks to balance the needs of the community with the needs of the fisheries and the ecosystem. Currently there are 3 CBSFAs in the State, with several other communities working towards their designation. CBSFAs promote place-based traditional Hawaiian fishing practices for subsistence consumption, community sharing, and restoring fisheries for future generations to continue living off the resources.

Kīpahulu Moku Community-Based Subsistence Fishing Area
Established: March 25, 2024

Figure 63: Map of Kīpahulu Community-Based Subsistence Fishing Area

Location: The Kīpahulu Community-Based Subsistence Fishing Area (CBSFA) is located on the southeast coast of Maui and includes the waters and submerged lands from Kālepa Gulch in the west to Puaʻaluʻu Gulch in the east, from the shoreline out to approximately 60 meters depth. It includes two sub-zones, as shown. This area encompasses the entirety of the moku boundary, consistent with traditional Hawaiian management practice. There are two subzones. The ʻOpihi Rest Area, where the harvest of ʻopihi is prohibited, is located between Oheo Gulch and Kaʻū Bay. The Kukui Bay Sanctuary is bounded by three points going from Kukui Bay interior to Submarine Point to Pulilele Point. It is prohibited to harvest any marine life within the Kukui Bay Sanctuary boundaries.

Highlights: The newly designated Kīpahulu CBSFA is the first CBSFA to be designated on Maui and the first MMA in East Maui. The community started planning for this area in 2010 through iterative consultations with the local East Maui community, kupuna, fishers, scientists and DLNR. The intention is to help ensure high quality fishing now, and in the future, while reaffirming customary fishing traditions.

Closing Message

The people of Hawaiʻi and its nearshore resources are intricately connected. Given the unprecedented threats to these resources and their ecosystems from the effects of climate change, fishing pressure, land-based sources of pollution, sedimentation and run-off, development, and overuse, strategic management action is urgently needed. It is the hope that future planning efforts will bring fishers together in collaboration with DAR to share this kuleana of being ocean stewards. By working together with the Maui community to develop management solutions, we can build a brighter future and ensure the sustainability of Maui's nearshore resources and provide fishing opportunities and traditions for present and future generations.

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Appendices

Appendix A: National Coral Reef Monitoring Program (NCRMP) Socioeconomic Monitoring Component Methods (Excerpt from Methodology section from Allen et al. 2022)

The Socioeconomic Component of the NCRMP collects and monitors socioeconomic information, including human use of coral reef resources, knowledge, attitudes, and perceptions of coral reefs and coral reef management, and demographics of the populations living in coral reef areas. The overall goal of the socioeconomic monitoring component is to track relevant information regarding each jurisdiction's population, social and economic structure, the benefits of coral reefs and related habitats, the perceived impacts of society on coral reefs, and the impacts of coral management on communities. NOAA's Coral Reef Conservation Program uses the information to improve programs designed to protect coral reefs at local, regional, and national levels, as well as to inform continuing research and communication products. Survey indicators were developed in consultation with local stakeholders, partners, and other scientists.

The NCRMP socioeconomic survey instrument is composed of one consistent set of questions for all U.S. coral reef jurisdictions, as well as a subset of jurisdiction-specific questions relevant to local management needs. NCRMP socioeconomic data are collected using a variety of modes as appropriate to the context in each jurisdiction with methodology that generally follows Dillman's Tailored Design Method [109]. For all jurisdictions, the aim is a representative sample of the population that meets a 95% confidence level with a minimum of a +/-5% margin of error. All survey questions are periodically approved for use by the Office of Management and Budget (OMB) under OMB#0648-0646. Surveys are planned to be repeated in each U.S. coral reef jurisdiction approximately once every five to seven years. For the Hawai'i jurisdiction, the first cycle of data collection occurred in 2015 and the second in 2020.

Following the first cycle of monitoring (2015 for Hawai'i), the NCRMP Socioeconomic team coordinated a series of expert panels and workshops to determine how each of the 13 socioeconomic indicators would be measured using primary data collected through the NCRMP resident surveys and existing secondary data. In 2019, the team published an indicator development report (Abt Associates, Inc. 2019) that presented guiding methodology for each monitoring cycle's indicator score development, as well as the calculated indicator scores for the first round of monitoring. Following the completion of each monitoring cycle, the 13 socioeconomic indicator scores will be recalculated using the 2019 foundational methodology. Tracking indicator scores over time will allow CRCP to monitor trends in human connections to U.S. coral reef ecosystems.

More information on indicator development, secondary data, as well as summary findings and methods can be found at the project website: www.coris.noaa.gov/monitoring/socioeconomic.html.

A telephone and online web survey of residents aged eighteen and older within Hawaiʻi Island (further stratified by East and West), Kauaʻi, Maui, and Oʻahu was conducted from March to June 2020. The survey instrument is included in Allen et al. 2022. Residents were invited to take an online web survey through mailed invitational letters and reminder post-cards with telephone follow up calls. Residents could also choose to complete the survey via telephone. All surveys were offered to residents in English. Of the 23,501 individuals contacted, a total of 2,700 surveys were completed (293 completed telephone surveys and 2,407 completed online web surveys), yielding an overall response rate of 11.5%. For more information on data collection procedures, please see Appendix B.1 in Allen et al. 2022. Data were weighted to resident populations with slight differences caused by weight trimming. For more details on data weighting and trimming protocols, please see Appendix B.2 in Allen et al. 2022.

Appendix B: HIMARC Introduction and Methods

The Hawaiʻi Monitoring and Reporting Collaborative (HIMARC) manages a database of monitoring data from large-scale monitoring programs, monitoring at specific sites, and one-off surveys by individual researchers. The data are provided by 7 main data sources: (1) Fisheries Ecology Research Lab, University of Hawaiʻi (FERL); (2) The Nature Conservancy Hawaiʻi Marine Program (TNC); (3) the National Park Service (NPS); (4) Fish Habitat Utilization Study, NOAA Biogeography (FHUS); (5) National Coral Reef Monitoring Program (NOAA); (6) Division of Aquatic Resources, State of Hawaiʻi (DAR); and (7) Coral Reef Assessment and Monitoring Program, University of Hawaiʻi (CRAMP).

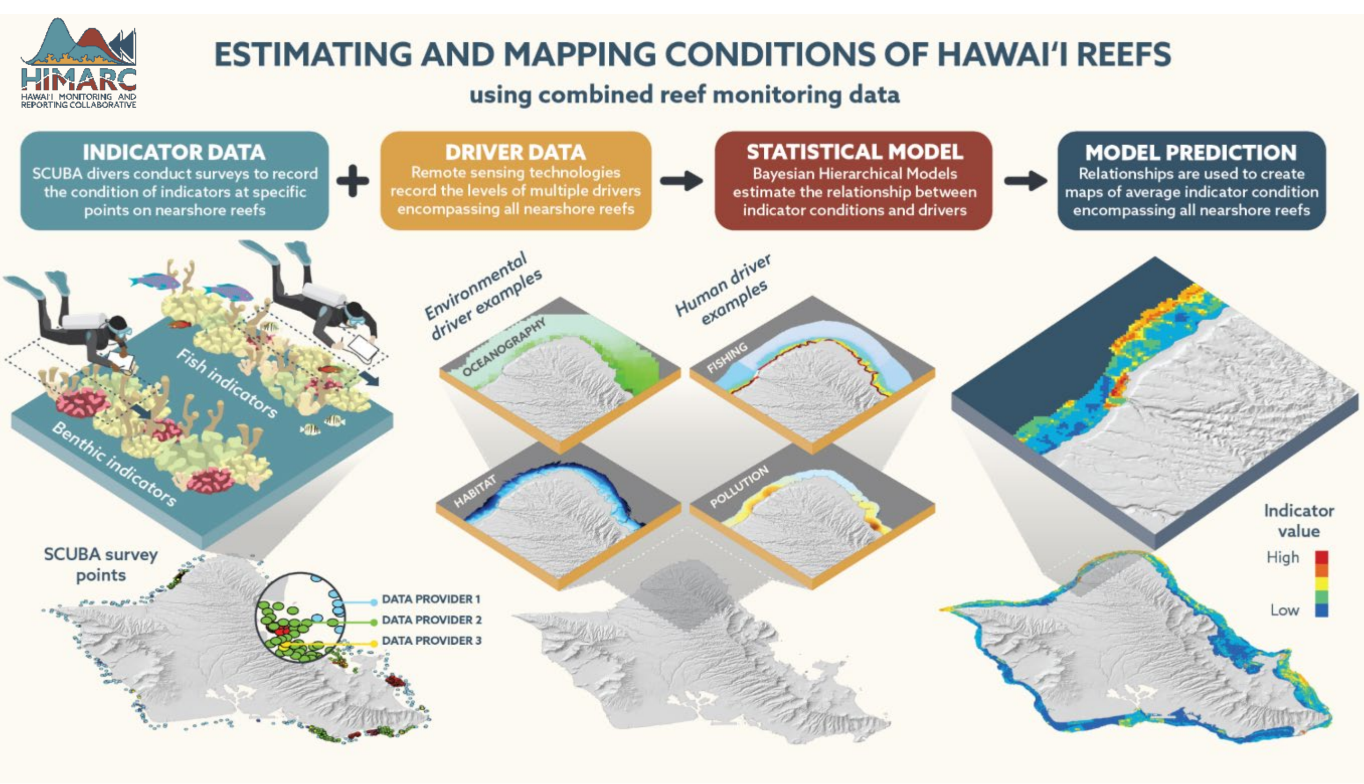

Figure 64: Methods used by the Hawaiʻi Monitoring and Reporting Collaborative to model the condition of nearshore reefs in the Main Hawaiian Islands. SCUBA surveys conducted by multiple data providers measure benthic and fish indicator variables that are included in HIMARC analyses (left). The indicator surveys are combined with 27 driver layers that are hypothesized to influence indicator condition, including environmental and human drivers (middle). Both datasets are combined in a statistical model to understand the relationship between indicators and drivers, and are used to make predictions of indicator condition for hardbottom areas at a scale of 100m extending from the shoreline to 30 m depth (right).

These disparate datasets are first compiled into a single database such that synthetic analyses can be conducted across different components of the coral reef assemblage. Each dataset is acquired from partners, transformed into a consistent format, checked rigorously for errors, and formatted in a common framework while retaining important metadata that is needed for analysis. During the data quality assurance and quality control process (QA/QC,) HIMARC engages the data providing organizations in an extensive back-and-forth review process. This process accounts for any potential errors in data collection. The clean dataset is then combined into a larger dataset for analysis of reef indicator condition.

Indicator condition is modeled by analyzing survey data (like number and size of fish or percent coral cover in an area during a survey) with driver data (Figure 64). Drivers are factors that we know are connected to the condition of given indicators such as land-based pollution, oceanography, habitat and harvest.

Appendix C: DAR Methods for FAHU Monitoring Surveys at Artificial Reef Sites

DAR uses the FAHU method to monitor the artificial reef sites for fish assemblage and benthic condition. Transects within each artificial reef location are pre-selected in the office using module condition information for each location. The vessel will use a GPS unit to locate the transect site. Once the transect is located, the following methodology is employed. There are two members on a survey team consisting of a fish and benthic surveyor. The bearing is determined when the fish diver gets to the bottom (0°, 90°, 180°, 270°), allowing the divers to stay on modules or hardbottom substrate. The fish surveyor spools the 25m transect line out, while recording, species, size (total length in centimeters) and the number of individual fishes to 2.5m on each side of the transect line (5m width). To allow for larger, fast-moving fishes a minimum observation time of 10-minute is required per transect. The benthic surveyor adjusts the white balance setting on the digital camera and completes the metadata on the survey identification datasheet. To avoid interference or alter fish behavior, the benthic diver waits until the fish surveyor is approximately 5m along the line before taking four digital pans of the seascape, with an approximate 60 (benthic habitat)/40 (water column) split, in the cardinal directions (N, W, E, S) to get an overview of the station and the habitat. A photo of the transect site is taken from the slate. A total of 26 benthic photos are then taken of the transect at every meter along the 25m line keeping the monopod perpendicular to the bottom to avoid parallax. Benthic photos are analyzed with software such as coral point count (CPCe) or CoralNet. The benthic diver counts all urchin species in a 1m wide belt. Urchins may be counted concurrently with the benthic photos as the benthic diver follows the fish diver or may be counted on the return swim, back to the start position. The fish diver reels in the line and the survey is completed.

Appendix D: DAR Methods for FAHU Monitoring Surveys and for Statistical Analyses

Fish and Habitat Utilization Survey (FAHU) was used to monitor fish in 11 sites along the coastline of Maui. This method first started in 2015 and is currently in use. In the field, FAHU surveys are conducted as follows. During five to 10 minutes, a scuba diver swam a 25 x 5 m transect at a constant speed while identifying all fishes to species level in 5-m band width centered around the transect tape. The surveyor also estimated the total lengths and recorded the habitat types. A maximum of 20 transect replicates are conducted at each site at a depth varying between 22 to 53 feet. Length estimates of fishes from visual censuses were converted to weight using the following length-weight relationship: $W = aSL^b$ where the parameters a and b are constants for the allometric growth equation and SL is standard length in mm and W is weight in grams. Total length was converted to standard length by multiplying standard length to total length-fitting parameters obtained from FishBase. Elusive, pelagic species- including manta rays and sharks- were removed from downstream analysis as well as juveniles and recruits since the focus was to detect changes in fish biomass for adult fish that are conspicuous, resident members of Hawaiʻi's coral reef ecosystems.

For analysis, sites were grouped per management status: "open/limited fishing" (comprising areas with only limited regulation for a small subset of fish species) and "highly restricted" areas (only those that are no-take where fishing is prohibited or where fishing is highly restricted). There are also eight habitat types, and the acronyms and descriptions can be found in the table below. Only shallow aggregate reef (SAG), deep aggregate reef (DAG), and Mixed Medium Depth (MMX) are common habitat types to the two management categories sites.

All statistical analyses and plots were done in R with the following packages: doBy, Rmisc, stats, car, vegan, dplyr, reshape2, fishualize, ggplot2, tidyr, forcats, patchwork, and mgcv.

Generalized additive mixed models (GAMM) were used to assess any trends in fish biomass and abundance over time between open/limited fishing and highly restricted sites. The models were fitted with a Gaussian error distribution. Smoother functions for continuous covariates (calendar year) were fitted with cubic regression splines and a number of knots (4) that optimizes the "wiggliness" of the smoother parameter's curve. The covariate over time, with autocorrelation of habitat type per site per year, was also conducted because our data are not independent. An ARMA (1,1) residual autocorrelation structure was added after visually checking the partial and autocorrelation function plots. Validation protocols were followed (e.g. checking normality of residuals).

Appendix E: Benthic Habitat Categories

Habitat	Description	Photo
Pavement (PAV)	Limestone or basalt substrate with low relief, complexity (<1m/3ft), and coral cover	
Pavement with sand channels (PSC)	Limestone or basalt substrate with large sand channels	
Pavement with ledges (PAL)	Limestone or basalt substrate with caves, lobster holes, undercuts, which have >1m/ 3ft vertical relief	
Aggregate reef: Shallow (SAG) and Deep (DAG)	Consolidated highly rugose substrate; at usually a depth of <10 m/30 ft for SAG; at usually a depth of >7-10 m/22-30 ft for DAG	

Spur and groove (SPG)	Uniform spurs/groves or coral peninsula > 1m/3ft mainly are exposed to moderate wave energy.	
Rock rubble (RRB)	Small to Mid sized rocks and rubble, may consist of dead coral pieces or coral rubble (<25cm diameter). High rubble:sand.	
Mixed medium depth (MMX)	Mixed substrate with rubble, sand, and degraded areas and with patches of higher coral cover at typically a depth of 3-8 m	

Appendix F: Maui Shoreline Fishing Effort Summary Methods

Kernel density maps were created using ArcGIS ArcMap 10.6.1.
Maui shoreline effort data from April 7, 2020 to July 23, 2022 was provided by Linda Castro, and data was re-formatted and analyzed by Anita Tsang. Only roving effort data was used, interview/intercept data was not evaluated, as most, if not all, of the information from interviews should be captured in the roving data. Fishing effort was calculated by dividing total gear recorded by the total number of fishers in each entry, which is the same methodology used to generate Oʻahu's shoreline effort heat maps created by Jake Reichard (Oʻahu Monitoring Technician). Locations where zero fishers were recorded are included and depicted in the maps to represent extent of survey areas. Entries that had blanks for number of fishers, "closed," or "no fishing" were converted to zero. Specifications/settings for map outputs are as follows:

- Projection used= NAD_1983_UTM_Zone_4N
- Cell output size= 100
- Search radius= 2,000

Appendix G: Designing marine management area networks

Place-based management through marine management area (MMA) designation is one option as an effective tool to promote sustainability of nearshore resources. DAR biologists, in collaboration with other researchers and experts, have developed a set of seven ecological design principles that aim to maximize ecological goals or objectives of MMAs. These principles account for key bio-physical processes (including resilience to climate change). Design principles are scientific guidelines that describe how to create effective networks of MMAs. These include areas that are the right size, spaced appropriately, and can work individually while still being ecologically connected to achieve conservation goals, such as bigger and more fish. Below are the seven ecological design principles, which can be considered "best practices" for MMA network design.

1) Representation of diverse coastal habitats

a) Inclusion of representative habitat types of nearshore waters (e.g., seagrass meadows, coral reefs, or estuaries), recognizing the importance of these habitats for specific life stages of targeted fish species (i.e., nursery habitat, spawning areas, and foraging areas)
b) Replication of these different habitat types
c) Inclusion of rare and/or unique features and/or species
d) MMAs in both leeward and windward side of islands

2) Size and shape of MMA designed to optimize management and fisheries benefits.

a) Size is at least 1.5 miles (2 km) straight-distance along coastline
b) MMAs have compact shapes and clear boundaries
c) Consideration of movement patterns and home ranges of species to be prioritized for protection
d) Include both juvenile and adult preferred habitats in the network and ensure MMA boundaries encompass areas that connect these key habitats utilized throughout different life stages

3) Connected network of individual MMAs at an island scale

a) Spatially close enough and evenly distributed to best support connectivity between MMAs within the network
b) Include connectivity nodes and use oceanographic features to support larval dispersal and recruitment

c) Optimize larval production of prioritized species by including measures that protect the larger, older, reproductive females, especially in key larval source locations.

4) *Uka* and *kai* collaborations and partnerships for a holistic management approach

a) MMAs are adjacent to terrestrial and estuarine areas that are already well-managed
b) Consider influences of land-based impacts and coordinate marine planning with land-based efforts to optimize outcomes.
c) Coordinate networks of areas that have active management and/or stewardship across land and sea for an integrated approach
d) Collaborate with local communities and other organizations that are adjacent to MMAs to provide support with outreach, compliance and enforcement

5) Prioritization of areas that could have the highest possible benefit from management and/or restoration

a) Select "healthy" areas that generally have low levels of threats/pressures and host higher biodiversity
b) Select areas that may be degraded but could benefit the most from management and restoration efforts (e.g., coral outplanting, sea urchin release to remove invasive algae that can suffocate corals, collaboration with land-based efforts to reduce sedimentation or effluent)
c) Carefully consider areas near/with multiple or compounding threats (e.g., pollution, sedimentation, high levels of human development and population, invasive algae), prioritizing areas that have fewer threats whenever possible

6) Inclusion of areas that are shown to be resilient (both resistance to and recovery from disturbance) in the face of global stressors such as climate change

a) Representation of thermally resilient coral reefs, including reefs in areas that have naturally high temperature variability
b) Inclusion of coral reefs in areas with low levels of human impacts (e.g., minimal run-off, less sedimentation, good water quality, fewer boating and recreational activities)
c) Prioritization of areas with natural temperature buffers, such as cold groundwater discharge or upwelling

d) Inclusion of areas that have high coral recruitment
e) Inclusion of areas that have high herbivore diversity, abundance, and biomass

7) Long-term planning that allows for evaluation and adaptation to current conditions

a) Designation of MMA boundaries is not time-bound and does not include rotational closures
b) Long-term planning utilized to create a comprehensive monitoring plan, establish a framework for review, and allow for time to evaluate responses to management actions, in which regulations may be adapted and amended to reflect current conditions
c) MMAs co-located with existing long-term monitoring sites

Appendix H: Socio-cultural Design Principles

To create a more holistic approach, frameworks for coastal resource management need to acknowledge social, cultural, and ecological factors in the planning and evaluation of MMAs. The Holomua Marine initiative plans to utilize and incorporate socio-cultural measures throughout the process, from planning to using these measures for evaluation of success. There are also socio-cultural design principles to help guide effective management and measure the social and cultural connections that humans have with the environment and how these connections are impacted by the implementation of management.

1) Place-Based Knowledge and Education

a) Perpetuate place-based pono knowledge, traditions, and practices
b) Provide education between generations in the nearshore area that reflect the ecosystem, traditions, and history of the place

2) Physical, Mental, and Spiritual Well-being

a) Provide a place to practice and strengthen mental, physical, and spiritual well-being
b) Ensure appropriate access and sustain the quality of experience in nearshore area

3) Community Relationships, Engagement, and Commitment

a) Empower and grow community efforts to mālama ʻāina and kai
b) Provide a place where relationships within family and community are supported and maintained

4) Efficacy and Equitable Governance

a) Utilize transparent and collaborative processes to address impacts to the nearshore area
b) Manage the number and impact of visitors on the nearshore area
c) Maintain resources and habitat that provide food