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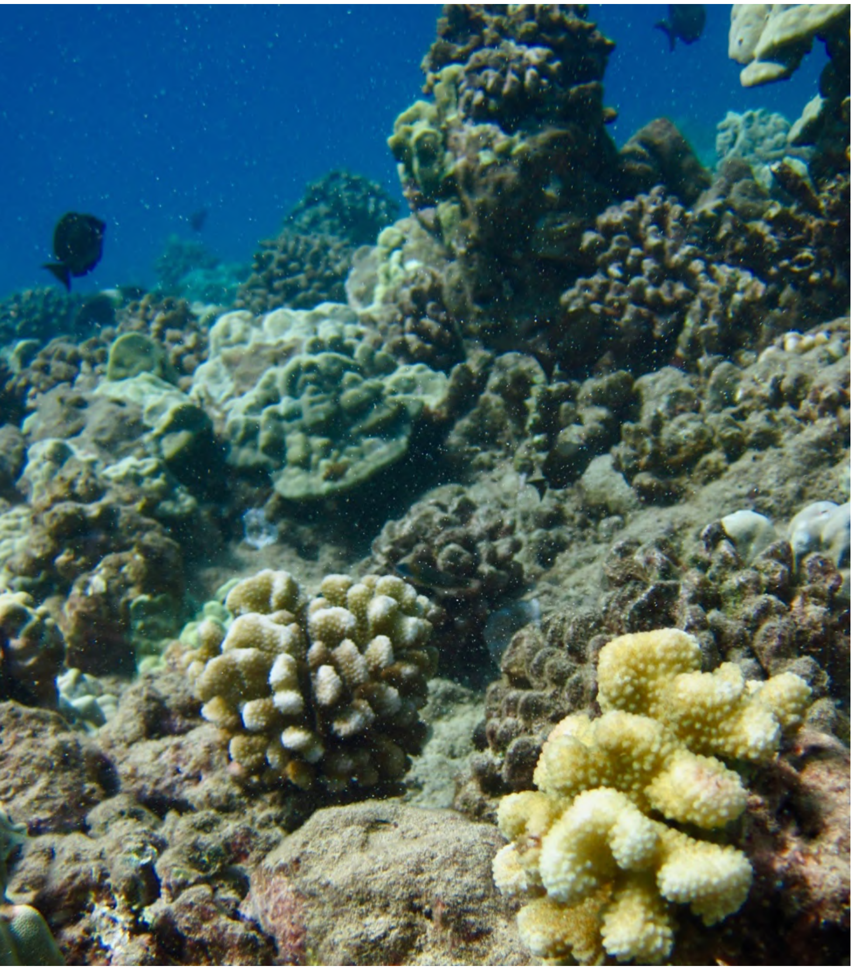
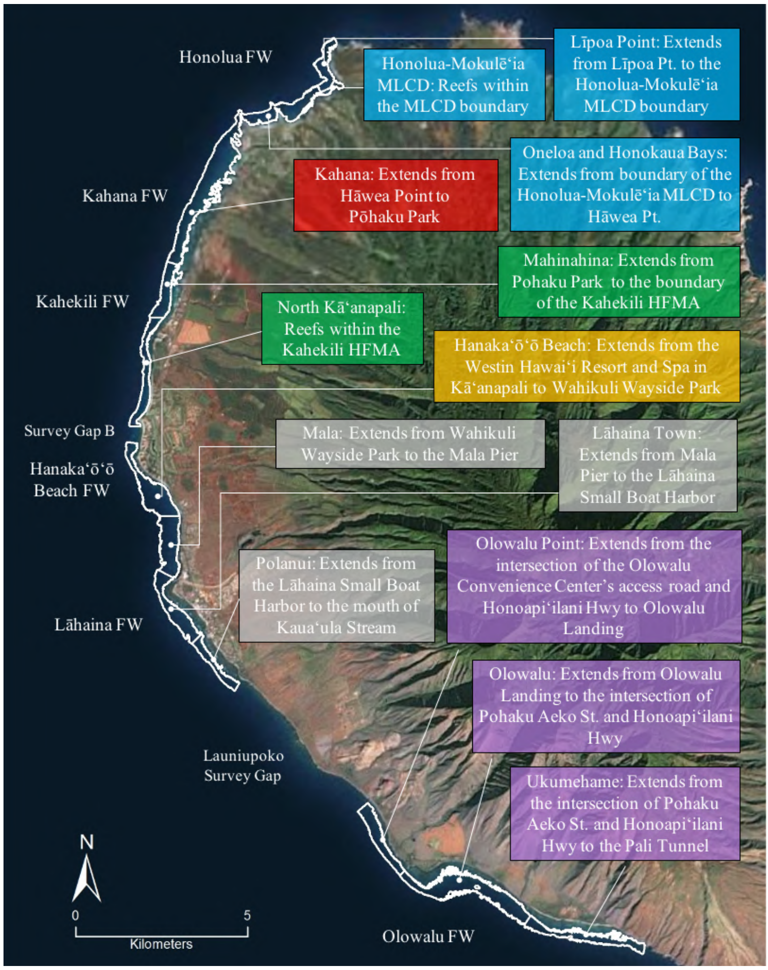
Atlas of the Reefs of West Maui





NOAA CORAL REEF CONSERVATION PROGRAM

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THIS ATLAS IS DEDICATED TO THE PEOPLE OF WEST MAUI, ESPECIALLY THOSE WHO HAVE SPENT THEIR LIVES WORKING TO CONSERVE THE HEALTH AND BEAUTY OF ITS CORAL REEFS. *‘O KA PŪKO‘A KANI ‘ĀINA*, GOES THE SAYING, COMPARING THE BARRIER REEF TO AN INVULNERABLE WARRIOR, MAY WE PROTECT OUR REEFS AS THEY PROTECT AND NOURISH US.

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Acknowledgements

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List of Abbreviations

CCA	Crustose Coralline Algae
CRAMP	Hawai‘i Coral Reef Assessment and Monitoring Program
DAR-Maui	Hawai‘i Division of Aquatic Resources—Maui Office
FW	Focus Window
KHFMA	Kahekili Herbivore Fisheries Management Area
MHI	Main Hawaiian Islands
MLCD	Marine Life Conservation District
SEM	Standard Error of the Mean
TNC	The Nature Conservancy
WWRF	Wastewater Reclamation Facility
WMR	West Maui Region

Executive Summary

The Atlas of the Reefs of West Maui (Atlas) describes the region's coral reefs and their associated fishes based on surveys conducted by numerous public and private organizations between 1999 and 2019. These data have been compiled and analyzed by The Nature Conservancy (TNC) to quantitatively and qualitatively describe the abundance, biomass, and diversity of marine life on the coral reefs of the West Maui Region (WMR). We hope the Atlas can serve as a useful resource to communities and managers in West Maui as they try to better understand the state of their nearshore reefs and develop strategies to work with partners to preserve or restore these special places.

The WMR extends from the Pali Tunnel on Honoapiʻilani Highway (Rte 30) to Līpoa Point and includes 38 km (23.6 mi) of coral reefs, algal flats, sandy beaches, and basalt cliffs (Figure S1). Most of the assembled datasets focused on geographic areas smaller than the entire WMR called Focus Windows (FW), where in-depth analyses of the available data were conducted to yield detailed spatial and temporal information on the benthic and fish assemblages. Two "gap" sections of reef, designated Launiupoko and Gap B, were poorly sampled and thus received no detailed analysis.

Based on information collected at over 2,450 sites, the reefs of the WMR show considerable variation in the abundance and diversity of their coral, macroalgae, and other sessile organisms. Coral cover varied considerably across WMR (Figure S.1), where average coral cover was 16.5 ± 1.3%, and WMR reefs varied from medium-low to high coral cover. Reef tracts with high coral cover tended to have high effective species richness of benthic organisms ($Hill_1$). Across the WMR, *Porites lobata* (lobe coral) was the most abundant coral species, followed by *Montipora capitata* (rice coral), *P. compressa* (finger coral), and *M. patula* (sandpaper coral). These four species tend to be the most abundant corals on a "typical" reef in the Main Hawaiian Islands (MHI).

The Atlas also incorporates information on coral reef fish from over 2,600 sites in the WMR. Like the benthic assemblage, reef fish showed considerable diversity across the WMR, though reef tracts with high fish biomass (Figure S.1) did not necessarily correspond with areas of high coral cover. Average total fish biomass for the WMR was 42.2 ± 3.9 g/m^2. Most reef tracts had roughly average total fish biomass, but the WMR also contained sites at either extreme.

Averages for coral cover (14.4 ± 0.7%), total fish biomass (40.9 ± 2.5 g/m^2), resource fish biomass (22.3 ± 1.8 g/m^2), and prime spawner biomass (3.7 ± 1.0 g/m^2) were calculated for the MHI, to serve as a gauge for how the reefs of the WMR are faring relative to those from around the state. All across the MHI, reefs are affected by overfishing, sediments, land-based pollution, and invasive species. Over the past century, populations of some commercially important reef fish populations have declined by over 90%, and coral cover in some areas has declined by at least 40% in just the last 40 years. For all metrics except prime spawners, reefs in the WMR were consistent with the MHI averages, albeit on the higher side of the range (Figure S.2). The WMR had medium-high prime spawner biomass compared to the MHI, but prime spawner biomass varied considerably among the reef tracts. While there are many reef areas around the state that still have abundant and healthy resources, the current statewide averages used for comparison here certainly reflect substantial declines in resource condition seen broadly across the reefs of the MHI. Reefs in the WMR were consistent with the statewide averages for coral and fish assemblages (see Chapter 1).

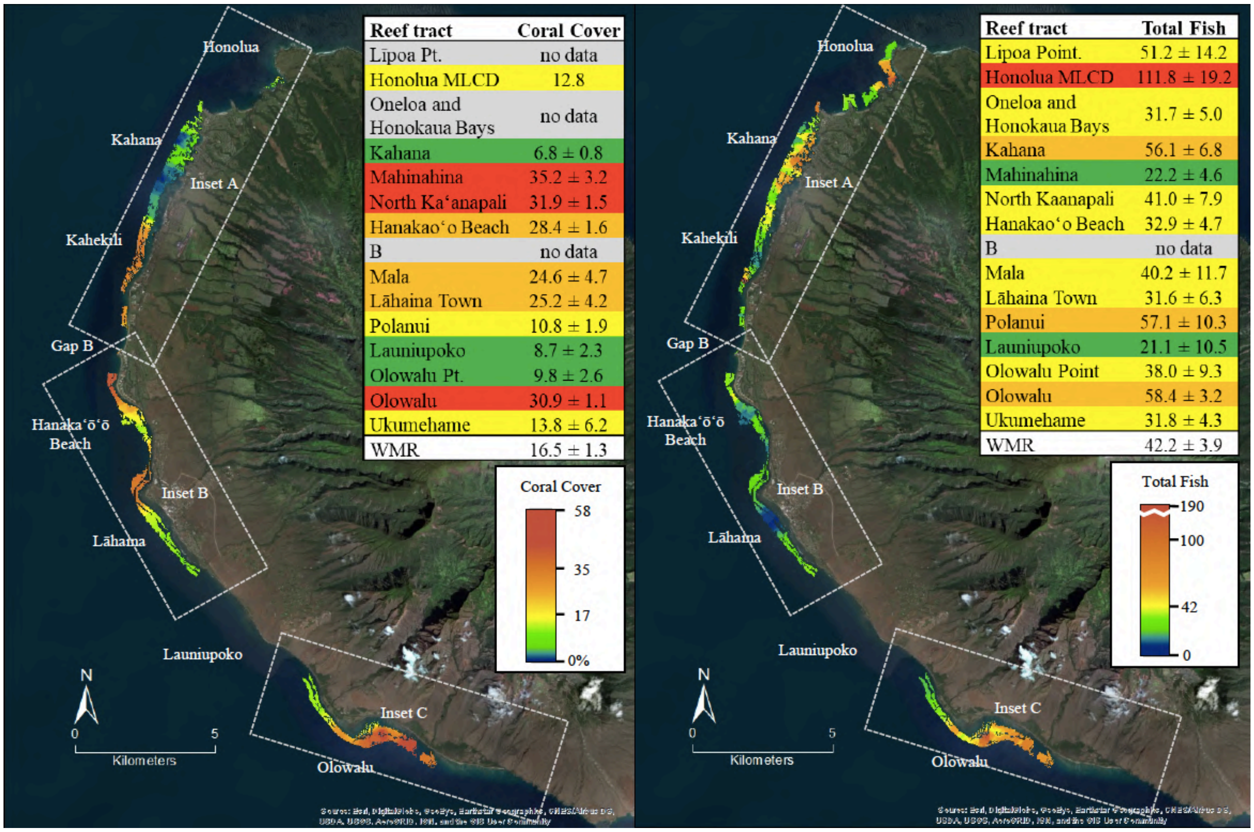

Figure S.1. Percent coral cover (left) and total fish biomass (right) across the WMR. The map is interpolated from 2016-2019 survey data across hardbottom. Map colors are derived from the data for the WMR, such that yellow is the average coral cover or total fish biomass for the FW and red would be considered high coral cover or total fish biomass for the region. Inset box in upper right provides the mean (±SEM) value for each reef tract, arranged from north to south.

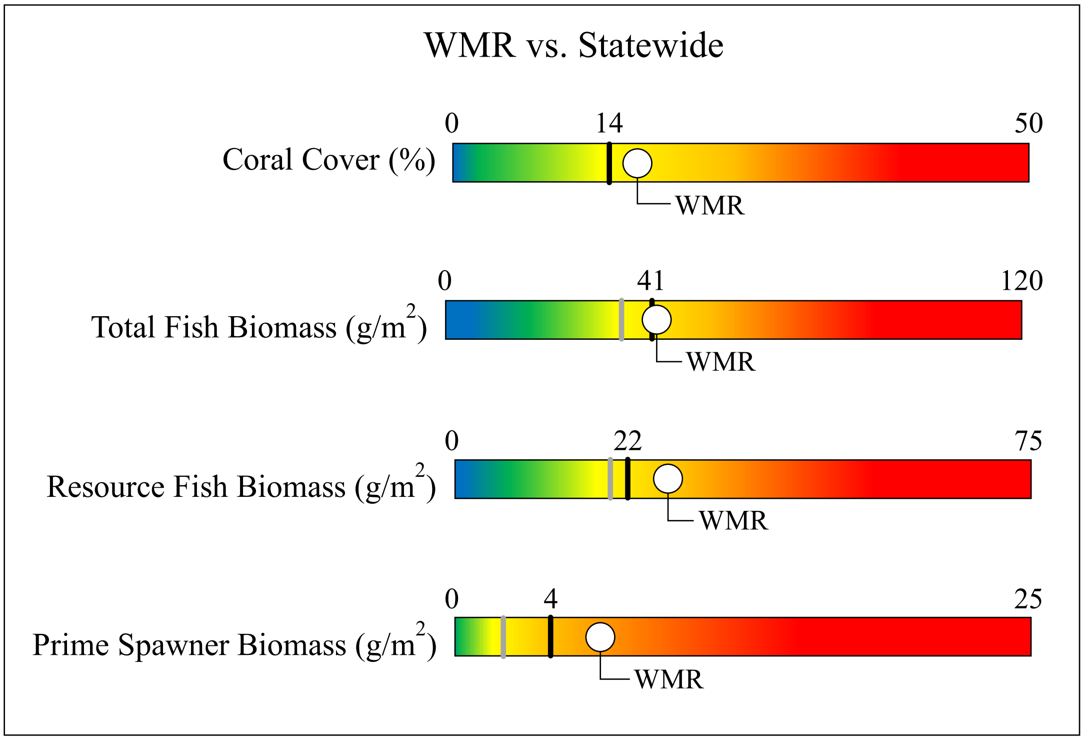

Figure S.2. Comparison of WMR to statewide averages for coral cover (%), total fish, resource fish, and prime spawner biomass (g/m^2). Black vertical line and value denote the statewide average. For the three fish metrics, the grey vertical line is the statewide trimmed mean, which was used to develop the qualitative categories; see the methods (Appendix B) for more details on the use of the trimmed means.

Honolua FW

WMR Context: Reef resources in the Honolua FW show variable levels of condition, tending to have below average coral cover when compared to the WMR. In contrast, benthic diversity was high. The fish assemblage within the Honolua-Mokulēʻia Marine Life Conservation District (MLCD) reef tract had the highest total fish, resource fish, and prime spawner biomass of any reef tract in the WMR, over twice that of the average for the WMR. No other reef tract was characterized as having high total fish biomass. Reef fish diversity was also high.

Statewide Context: The reef tracts within the Honolua FW ranged from average to above average when compared to reefs statewide. The Honolua-Mokulēʻia MLCD had high fish biomass compared to reefs across the MHI, but only average coral cover. While it was not a specific goal of this Atlas to assess the effects of existing marine managed areas, the MLCD appears to be benefitting all fishes inside the boundaries, with possible spillover of resource fish into adjacent reef tracts (*e.g.*, Līpoa Point).

Kahana FW

WMR Context: Reef resources within the Kahana FW are a “mixed bag.” While the fish assemblage had medium-high total fish and prime spawner biomass, resource fish biomass was average and coral cover was the lowest for any of the FWs in the WMR, raising questions about the long-term potential for the reefs at Kahana.

Statewide Context: Reefs within the Kahana FW ranged from below average to above average when compared to reefs statewide. The Kahana FW had medium-low coral cover but above average total fish biomass and high prime spawner biomass compared to reefs in the MHI.

Kahekili FW

WMR Context: Reef resources in the Kahekili FW run the range of condition from poor to good. The North Kāʻanapali reef tract, which lies entirely within the boundary of the Kahekili Herbivore Fisheries Management Area (HFMA), had average to high abundance, biomass, and diversity of both the benthic and fish assemblages compared to other reefs in the WMR, including a rich macroalgal assemblage not found within most other reef tracts. While the Mahinahina reef tract's benthic assemblage had high abundance and diversity, reef fish populations across the Mahinahina reef tract had uniformly low biomass, which ranked it as the worst reef tract in the WMR for total fish, resource fish, and prime spawner biomass.

Statewide Context: Reefs within the Kahekili FW had high coral cover relative to the statewide average but were a "mixed bag" with respect to reef fish. The North Kāʻanapali reef tract had above average resource and high prime spawner biomass compared to other reefs in the MHI, likely due to the management actions associated with the Kahekili HFMA. However, the Mahinahina reef tract was below average for total fish and resource fish biomass and had average prime spawner biomass when compared to other reefs statewide.

Hanakaʻōʻō FW

WMR Context: Reef resources in the Hanakaʻōʻō Beach FW were highly variable and of mixed quality, especially compared to the rest of the WMR. The benthic assemblage had medium high average coral cover and high benthic diversity, but showed a strong north-south gradient. Reefs along the southern end of the FW were fragmented, with low coral cover and species richness when compared to the averages for the WMR. Rounding Hanakaʻōʻō Point, coral cover increased and at the northern end of the FW was high compared to the regional average. The fish assemblage within the Hanakaʻōʻō Beach FW had average abundance, biomass, and diversity when compared to regional averages, but tended to be on the lower end of average range, except for prime spawners.

Statewide Context: The reef tracts within the Hanakaʻōʻō Beach FW ranged from slightly below average to above average when compared to reefs statewide. The Hanakaʻōʻō Beach FW had high coral cover compared to reefs across the MHI, but had slightly below average total and resource fish biomass. Prime spawner biomass was above average when compared to reefs in the MHI, but this was driven primarily by large schools of *Mulloidichthys vanicolensis* (yellowstriped goastfish) observed at two survey sites, and if these two sites were removed, average biomass dropped below the statewide average.

Lahaina FW

WMR Context: The reef tracts within the Lāhaina FW were spatially variable in the abundance, biomass, and diversity of their benthic and fish assemblages, ranging from average to above average. No reef tract had above average abundance, biomass, and diversity of both benthic and fish assemblages. The Polanui reef tract had average coral cover, although it was on the low edge of the average range for the WMR. Total fish biomass and prime spawner biomass were also average in the Polanui reef tract compared to the WMR, but it had medium-high resource fish biomass. Both the Lāhaina Town and Mala reef tracts had medium-high coral cover and benthic diversity and average total and resource fish biomass. Prime spawner biomass in the Lāhaina Town was also average, but prime spawner biomass was high in the Mala reef tract when compared to other reefs in the WMR.

Statewide Context: The reef tracts within the Lāhaina FW ranged from slightly below average to above average when compared to reefs statewide. While the Polanui reef tract had below average coral cover, it had medium-high total fish and resource fish biomass. In contrast, coral cover in the Lāhaina Town reef tract was high compared to other MHI reefs, but had a consistently below average fish assemblage. The Mala reef tract had high coral cover and prime spawner biomass and above average resource fish biomass when compared to reefs statewide.

<u>Launiupoko Survey Gap</u>

WMR Context: Insufficient data exists from the area to conduct an in-depth analysis of the benthic and fish assemblages; hence this area being considered a “gap” area for the Atlas. The data available were used to summarize general conditions and should be treated cautiously due to the low sampling effort in the area. Reef resources in the Launiupoko Survey Gap had medium-low to average abundance, biomass, and diversity for both the benthic and fish assemblages. Coral cover and total fish biomass were both medium-low, while resource fish and prime spawner biomass were average compared to other reefs in the WMR. Resource fish biomass was at the low end of the average range for the WMR. The prime spawner assemblage was surprisingly diverse, but this was likely due to the fragmented nature of the bottom, especially the presence of a mixture of hardbottom and large sandy areas.

<u>Olowalu FW</u>

WMR Context: The reef tracts within the Olowalu FW range from below average to high when compared to regional averages. The Olowalu reef tract consistently ranks among the best reef areas in the WMR, with high coral cover and benthic diversity, and medium-high total fish and resource fish biomass. Coral species richness in particular was exceptional within the Olowalu reef tract, whereas 22 species of coral were observed, which represented 96% of all coral species identified from the WMR. The other reef tracts within the Olowalu FW did not fare as well when compared to the WMR. Data within the Ukumehame reef tract was limited, but it ranked as average for most coral reef parameters compared to other reefs in the WMR, with prime spawners being above average. Olowalu Point tended to have below-average to average reef resources with the notable exception of prime spawner biomass, which was high compared to the WMR.

Statewide Context: The reef tracts within the Olowalu FW ranged from average to above average when compared to reefs statewide. In particular, the Olowalu reef tract generally had high quality benthic and fish resources when compared to other reefs in the MHI. Olowalu Point and Ukumehame reef tracts had consistently average to slightly above-average values for all variables.

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Introduction

The Atlas of the Reefs of West Maui (Atlas) describes the coral reefs and their associated fishes between the Pali Tunnel on Honoapiʻilani Highway (Route 30) and Līpoa Point, approximately 38 km (23.6 mi) of coastline. The information presented in the Atlas is based on surveys conducted by numerous public and private organizations between 1999 and 2019 (Appendix B) that have been compiled and analyzed by The Nature Conservancy (TNC) to quantitatively and qualitatively describe the *abundance*[1], *biomass*, and *diversity* of marine life on the coral reefs of the West Maui Region (WMR).

Most of the assembled datasets focused on geographic areas smaller than the entire WMR, such as the *reef tracts* adjacent to Olowalu, Lāhaina, and Honolua. For these areas, referred to as *Focus Windows* (FW) of the Atlas, in-depth analyses of the available data were conducted to yield detailed spatial and temporal information on the *benthic* and fish *assemblages*. The findings for each FW are described in separate chapters of this atlas.

Marine ecosystems are not isolated from other adjacent, and often distant, ecosystems; instead, they are subject to emigration and immigration of juveniles and adult individuals, sources of external environmental stress, and fluxes of important nutrients from distant marine and terrestrial sources. Equally important, most coral reefs provide important ecological *functions* (biological, chemical, and physical) to other marine and terrestrial ecosystem, and culturally- and economically-important *services* to people. Therefore, effective conservation of coral reefs must consider the role of specific reefs in the broader spatial network of marine and terrestrial ecosystems, and understanding the FW within the larger context of the WMR is crucial if effective place-based management is to occur.

Chapter 1 of the Atlas introduces the reefs of the WMR, providing a brief overview of the abundance, biomass, and diversity of its benthic organisms and coral reef fishes. It will place into this broad context the six FW (Honolua, Kahana, Kahekili, Hanakaʻōʻō Beach, Lāhaina, and Olowalu) and the Launiupoko Survey Gap that will be explored in greater detail in Chapters 2 through 8. Finally, Chapter 1 will provide a standardized lexicon that will be used throughout the Atlas to describe the reef resources of the WMR.

We hope the Atlas can serve as a useful resource to communities and managers in West Maui as they try to better understand the state of their nearshore reefs and develop strategies to work with partners to preserve or restore these special places.

[1] For clarity, specialized and scientific terms used in the Atlas are defined in the glossary (Appendix F). These terms are italicized at first use to indicate their presence in the glossary.

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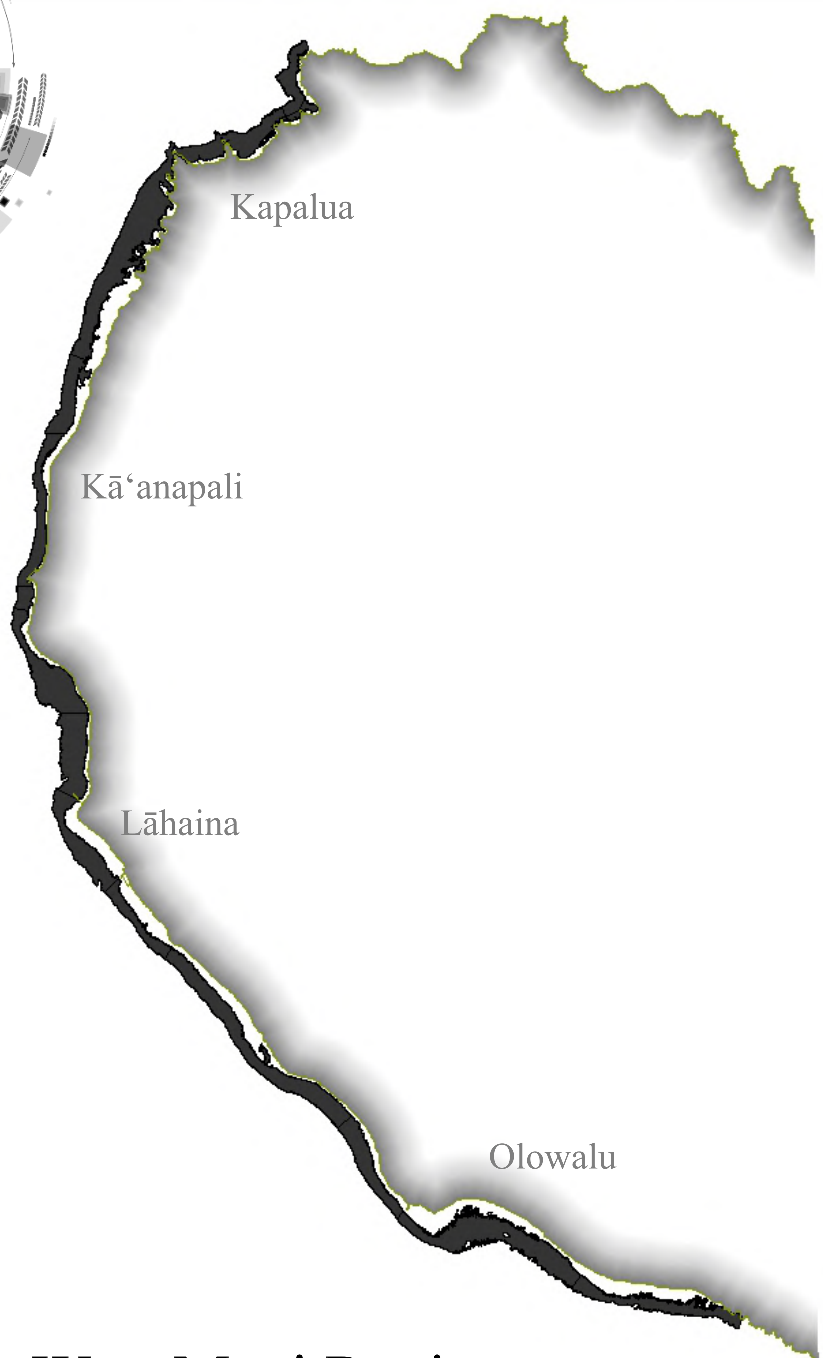

Reefs of the West Maui Region

Geographic Setting

The West Maui Region (WMR) extends from the Pali Tunnel on Honoapiʻilani Highway (Rte 30) to Līpoa Point and includes 38 km (23.6 mi) of coral reefs, algal flats, sandy beaches, and basalt cliffs (Figure 1.1). The coastline is dotted with residential and tourist-based development with concentrations near Lāhaina and Kāʻanapali. Tourism is prominent along much of the coastline north of Lāhaina, with dozens of coastal resorts, golf courses, and significant ocean-based tourism, much of it originating from Lāhaina Harbor. Impervious surfaces and heavily manicured landscapes have promoted runoff of sediment and nutrients into coastal waters and the growing population has created challenges for the WMR's waste disposal systems resulting in nutrient-contaminated groundwater that enters the ocean via submarine discharges. The primary treatment facility in the WMR is the Lāhaina Wastewater Reclamation Facility (WWRF), which currently processes about 15.1 million liters (4 million gallons) of sewage daily, injecting unused water into four injection wells. In addition, thousands of private cesspools and septic systems exist along the coast and uplands of the WMR, where wastewater drains into the ground in the case of a cesspool, and into a tank with a leach field in the case of a septic system.

Upland areas in the WMR were primarily used for agricultural activities during a century of pineapple and sugar cane production, but these crops have been relatively recently phased out, and many of the fields now lie fallow or are being converted to alternative crops. Fallow fields are often covered with invasive grasses and have become prone to wildfires and are sources of non-point source pollution that transports nutrients, sediments, and other agricultural legacy pollutants to coastal waters via surface and groundwater[2].

Coral reefs within the WMR tend to be well-developed, being protected from storm wave impact in many locations, and historically were known for their plentiful fisheries and rich diversity.

Focus Windows

While the purpose of the Atlas is to describe the marine resources of the entire WMR, the disparity in the types and frequency of data collected between the different areas of this extensive stretch of coastline limited the analyses that could be done for the WMR as a whole. Regions of higher data availability allow for more detailed descriptions of these reef areas. To make the most use of the data available for the Atlas, the WMR was divided into six areas within which the data allowed for in-depth spatial and temporal investigation (Figure 1.1). These areas, referred to as Focus Windows (FW), were primarily selected around reef areas that had been the focus of dedicated survey efforts, with the final boundaries delineated in consultation with staff at the Maui office of the Hawaiʻi Division of Aquatic Resources (DAR-Maui) and other knowledgeable stakeholders. In many cases, large FW were subdivided into two or three smaller areas, referred to as reef tracts. Reef tract boundaries tended to capture the geographic extent of specific datasets while remaining conscious of anthropogenic boundaries, such as marine protected areas, and the locations of neighborhoods, towns, and prominent natural (*e.g.*, headlands, streams, breaks in the reef structure, etc.) and artificial features (*e.g.*, piers, harbor channels, boat ramps, etc.).

[2] Group 70 Int and SRGII (2016) and SRGII (2012)

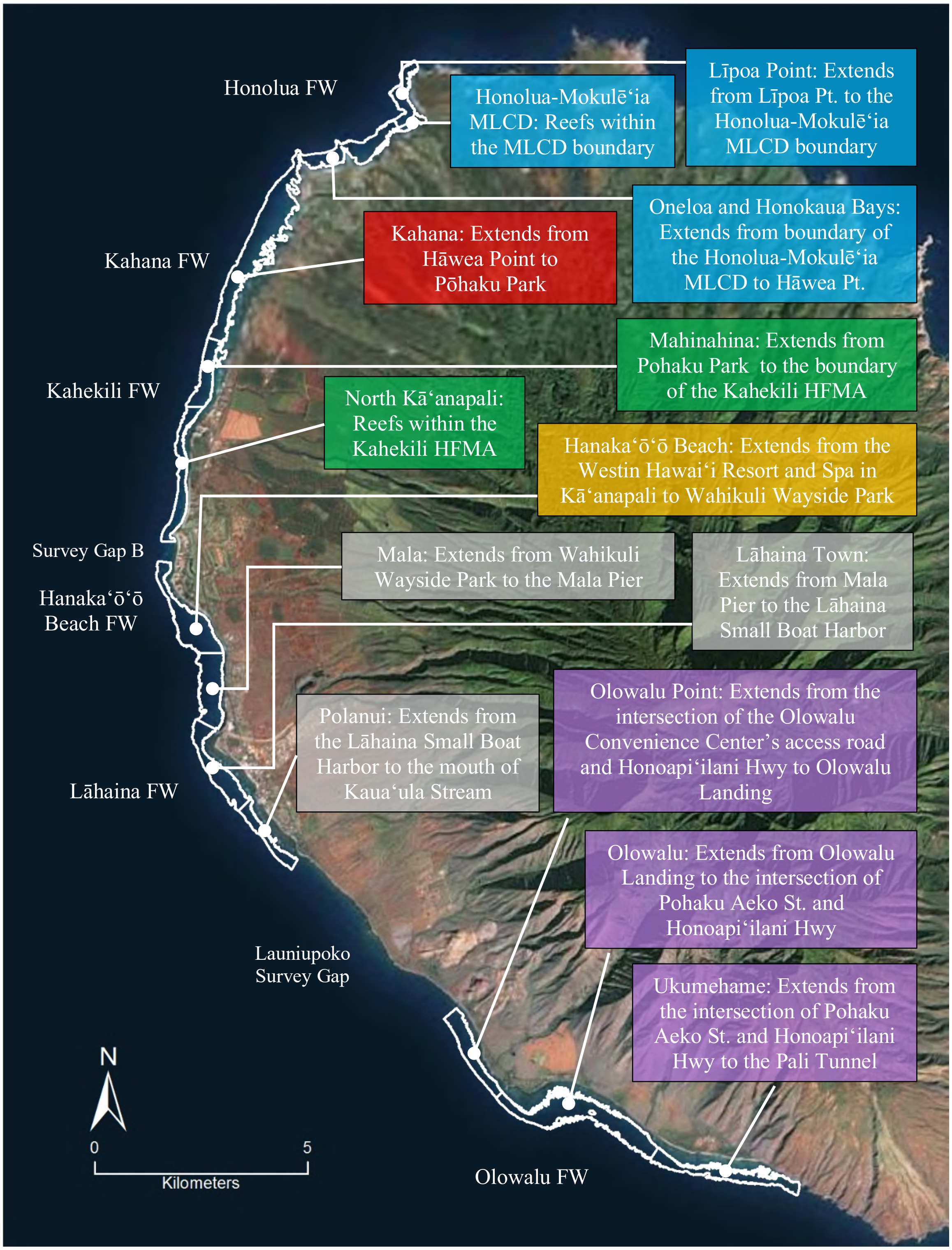

Figure 1.1. The West Maui Region, including its six FWs, two survey gaps, and 13 reef tracts (white polygons and colored boxes). Reef tracts within the same FW share box colors.

The FWs covered 88.5% of the reef area for the WMR. Two "gap" sections of reef, designated Launiupoko and Gap B (Figure 1.1), were poorly sampled and thus received no detailed analysis. Launiupoko, comprising 10.8% of the WMR reef area, contained few recent data (2016-2018), and a pair of the Hawai‘i Coral Reef Assessment and Monitoring Program (CRAMP) long-term monitoring sites (Puamana Deep and Shallow). Nearly annual surveys since 1999 at these CRAMP sites accounted for almost two-thirds of the sampling effort. A limited analysis of the data from the Launiupoko survey gap is presented in Chapter 7. Gap B at Kā‘anapali Beach comprised <1% of the reef area for the WMR, contained no surveys, and is not considered further in the Atlas.

FW boundaries were delineated out of convenience for the Atlas, and do not necessarily represent real, physical boundaries on the reef. While discussion of the reefs within each FW in their respective chapters is conducted in isolation from other reef areas, the coral reefs and their associated fish assemblages are part of the broader WMR coral reef ecosystem, and efforts have been made in every chapter to maintain this broader perspective by: 1) including a discussion of the FW within the broader context of the WMR, and 2) using qualitative language scaled at the regional level to describe the abundance, biomass, and diversity of marine resources. Finally, to provide statewide context, each FW has been examined relative to the statewide average values for several standard coral reef metrics, including the amount of coral and three measures of the amount of fish.

Using regionally-scaled qualitative language contextualizes the marine resources within the FW at the broader WMR-scale. For example, a reef tract with the highest coral cover within a FW may still have average coral within the WMR, a situation that will be important for managers and stakeholders to clearly understand when engaged in conservation planning. Table 1.1 provides the mathematical definitions and a quick reference color scheme that will be used throughout the Atlas for the qualitative terms high, medium-high, average, medium-low, and low and that will be developed in this chapter of the Atlas.

The mathematical definitions used to link the quantitative data with the qualitative terms relies on a *normal probability distribution*. Many of the metrics used to describe abundance, biomass, and diversity of corals reefs (*e.g.*, fish biomass, percent cover, etc.) often do not follow a normal distribution and instead tend to be *right skewed*, meaning that most values tend to be small with a few that are very large. This results in an "inflated" average, which will have the practical result of causing more reef areas to be classified as average or below average. In the context of conservation planning, using a normal distribution for data that are right skewed highlights the relatively few reef areas that have high resource abundance, biomass, or diversity, information critical for developing priorities for conservation and/or management action. In particular, fish data tend to be heavily right skewed due to a few, often very extreme outliers, so to reduce the effects of these outliers, trimmed averages were calculated after removing 5% of the data points from the upper and lower ends of the distribution. The trimmed averages were used in place of normal arithmetic averages.

Maps within the Atlas were generated using a spatial technique called *interpolation*. This technique uses available survey data to generate a complete spatial model of the data by estimating values between the surveys' data using a mathematical algorithm that considers the

Table 1.1. Mathematical definitions and narrative description for the five qualitative categories used in the Atlas to describe abundance, biomass, and diversity of the benthic and fish assemblages of the WMR. The color assigned to each category, with warmer colors representing higher values, is used throughout the Atlas. For all fish metrics, a trimmed mean (described in the text) was used instead of the arithmetic mean.

Term	Definition	"Real World" Description
High	$y > \bar{x} + 1\ s$	A high value is greater than the mean plus one standard deviation. Only reefs with the highest abundance, biomass, or diversity should qualify for this category. Few reefs should fall into this category.
Medium-high	$\bar{x} - ½\ s < y < \bar{x} + 1\ s$	A medium high value falls between the mean plus half the standard deviation and the mean† plus one standard deviation.
Average	$\bar{x} - ½\ s < y < \bar{x} + ½\ s$	An average value falls between the mean plus and minus half of the standard deviation. Most coral metrics are not normally distributed, which should result in most coral reef areas falling to this category or below†.
Medium-low	$\bar{x} - ½\ s < y < \bar{x} + 1\ s$	A medium-low value falls between the mean minus half the standard deviation and the mean minus one standard deviation†.
Low	$y < \bar{x} - 1\ s$	A low value is less than the mean minus one standard deviation. Only reefs with the lowest abundance, biomass, or diversity should qualify for this category†.

† For prime spawners, variability exceeded the mean even after trimming the data. Therefore, for prime spawners, low was defined as $y < 0.1$, medium-low as $0.1 < y < ½\ \bar{x}$, and average as $½\ \bar{x} < y < \bar{x} + ½\ s$.

values of nearby data weighed by their distance away. Areas with a higher density of surveys will produce more "accurate" interpolations than areas with lower survey density. Averages derived from interpolation maps are calculated across all reef areas and typically vary from averages derived from the survey data. Interpolation maps were generated for the Atlas primarily to display general spatial patterns and should not be used to predict exact values at any given location. For example, an interpolation map can, with a high degree of reliability, indicate that one reef tract has more coral than another reef tract, but it should not be used estimate the "exact" coral cover at a specific location within the reef tract. To estimate coral cover, amount of fish, etc., current survey data from the specific location should always be used over the interpolation maps when these data are available.

Benthic Assemblage

The Atlas incorporates benthic information from over 2,450 sites in the WMR (Appendix B). These data were collected between 1999-2019 and were spatially distributed across the entirety of the WMR, although the density of sites varied among the FWs. To give the most accurate picture of the current condition of the benthic assemblage, only data collected after the 2015 mass coral bleaching, totaling 482 sites, were used in most analyses. The coral bleaching event had significant effects on many WMR reefs, and data collected prior to 2015 may not be representative of the current condition of those reefs. When appropriate, older data were incorporated into FW-specific "historical" analyses.

The reefs of the WMR show considerable *spatial heterogeneity*, or variation, in the abundance and diversity of their coral, *macroalgae* (known locally as *limu*), and other *sessile* organisms. *Turf algae* (hereafter, turf) is a short, carpet-like collection of 100+ species that can be an important food source for herbivores (organisms that eat algae), but in large amounts is usually considered an indication of poor reef condition. Turf was the most common component of the benthic assemblage (45.8 ± 0.7%) on WMR reefs.

Coral is the primary structure builder on many reefs in Hawaiʻi and is responsible for creating and maintaining many of the features essential for coral reef fish. Coral cover varied considerably across WMR (Figure 1.2). Average coral cover was 16.5 ± 1.3% (Table 1.2), and WMR reefs varied from medium-low to high coral cover, with the Mala, North Kāʻanapali, and Olowalu reef tracts having high cover.

An *ordination*[3] analysis suggests the primary driver of differences in the benthic assemblage among reef tracts was abiotic substratum (*e.g.*, unconsolidated bottom such as sand) and macroalgal cover, and secondarily the cover of crustose coralline algae (CCA) and turf (Figure 1.3). Other benthic groups contributed less to distinguishing reef tracts from each other. Surprisingly, cover coral appears to be the least important benthic component for describing differences between sites, as shown by its close proximity to the origin in the ordination plot (Figure 1.3). This should not be interpreted as an indication that coral cover is unimportant to the reefs of WMR, however, only that other benthic assemblage components varied more between sites than did coral cover.

Reefs tracts, even ones directly adjacent to each other, tend to be distinct. However, reef tracts extending from Olowalu Point to Mala clustered tightly in the ordination analysis, suggesting similarity in their benthic assemblage structure. These reef tracts (the "SW Cluster") were characterized by higher cover of abiotic substratum (primarily sand), and lower cover of reef building organisms (*i.e.*, CCA and coral) when compared to reefs outside the cluster (Table 1.3). These findings are supported by field and remote sensing observations that indicate a lack of contiguous reef structure along this section of the WMR coastline. Instead this area consists of

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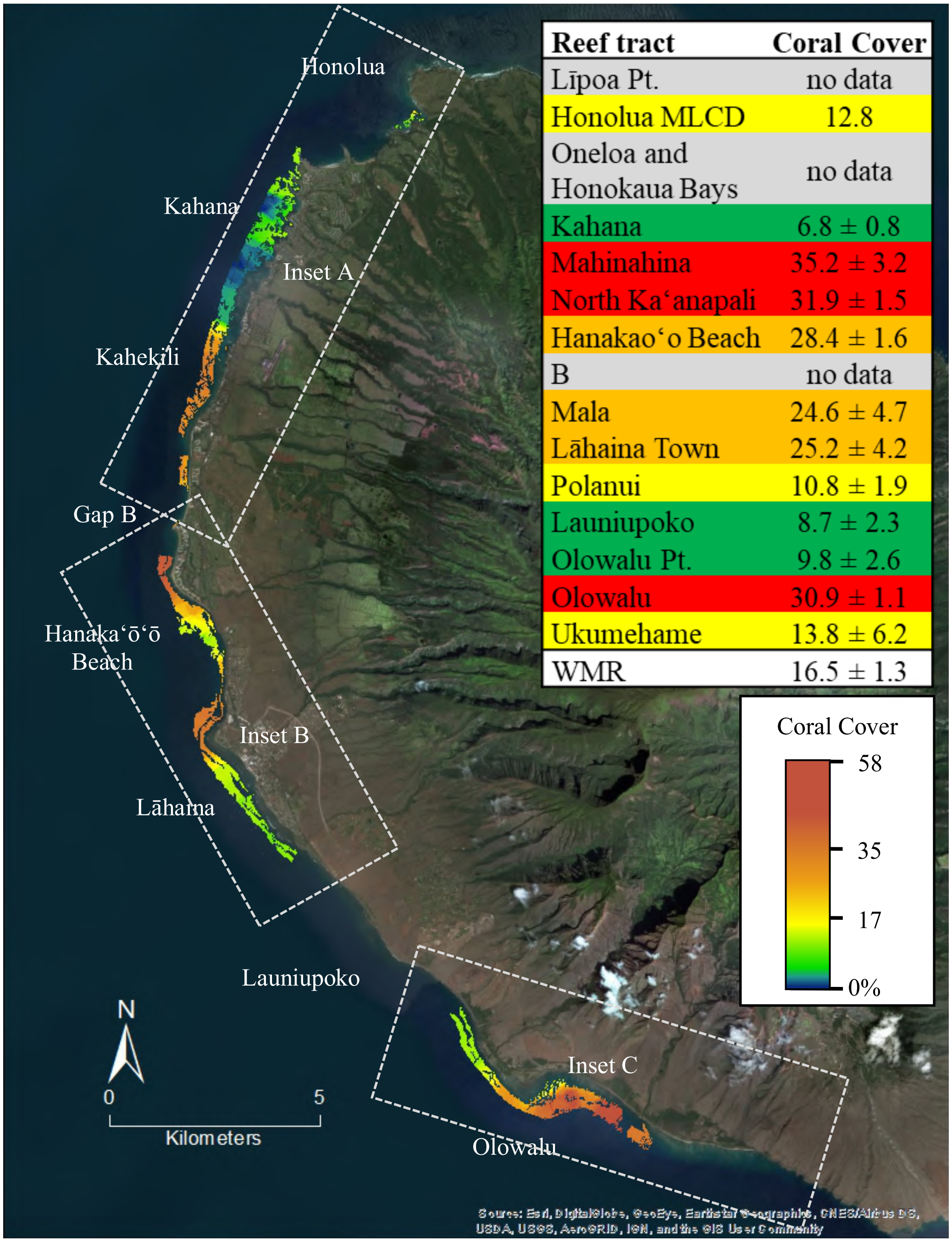
[3]An ordination is a specialized analysis that looks at the similarity of two or more locations using multi-species data. The most common way to display results is through an "ordination plot," in which the sites appear as points on a two-dimensional graph. The proximity of points in the graph is related to their degree of similarity, with points closer together being more similar to each other in their species composition than points farther apart.



Reef tract	Coral Cover
Līpoa Pt.	no data
Honolua MLCD	12.8
Oneloa and Honokaua Bays	no data
Kahana	6.8 ± 0.8
Mahinahina	35.2 ± 3.2
North Ka‘anapali	31.9 ± 1.5
Hanakao‘o Beach	28.4 ± 1.6
B	no data
Mala	24.6 ± 4.7
Lāhaina Town	25.2 ± 4.2
Polanui	10.8 ± 1.9
Launiupoko	8.7 ± 2.3
Olowalu Pt.	9.8 ± 2.6
Olowalu	30.9 ± 1.1
Ukumehame	13.8 ± 6.2
WMR	16.5 ± 1.3

Figure 1.2. Percent cover of coral across the WMR (this page) and with details by coastal sections (next page). The map is interpolated from 2016-2019 survey data across hardbottom. Map colors are derived from the data for the WMR, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the region. Inset box in upper right provides the mean (±SEM) value for each reef tract, arranged from north to south. Lettered inset boxes correspond with the coastal sections displayed on the next page.

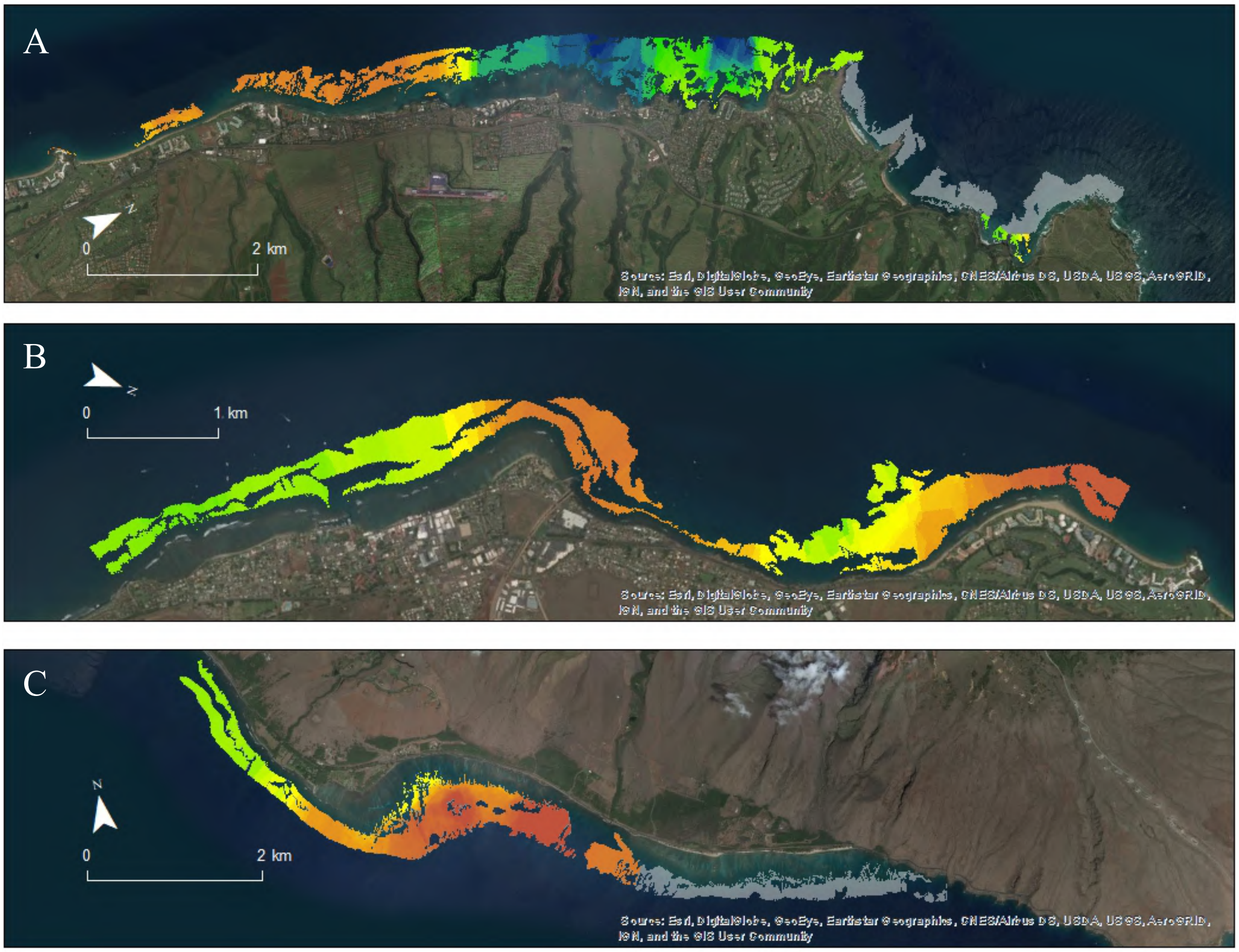


Figure 1.2 (con't). Percent cover of coral across the WMR (previous page) and with details by coastal sections (this page). Values for color ramp match those on the previous page. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom.

Table 1.2. Range of values for coral cover (%) and effective species richness ($Hill_1$) used to categorize a measured value in the Atlas. Colors correspond to those used throughout the Atlas, with warmer colors representing higher values.

	Coral Cover (%)	Richness ($Hill_1$)
High	29.5+	3.5+
Med-High	23.0-29.5	3.1-3.5
Average	10.2-23.0	2.2-3.1
Med-Low	3.8-10.2	1.7-2.2
Low	0-3.8	0-1.7

patchy hardbottom with limited coral growth, interspersed with sand. Other reef tracts showed lower similarity among them, as indicated by their lack of clustering in the ordination plot (Figure 1.3) and higher variability than the SW Cluster (Table 1.3).

Benthic diversity (Figure 1.4) was positively correlated with coral cover (Correlation; $r=0.911$; $p<0.001$); reef tracts with high coral cover tended to have high effective *species richness* of benthic organisms ($Hill_1$). The Kahekili FW had a rich macroalgal assemblage not found within most other reef tracts, whereas 22 species of coral were observed within the Olowalu reef tract, which represented 96% of all coral species identified from the WMR (Appendix E). Across the WMR, *Porites lobata* (lobe coral) was the most abundant coral species, followed by *Montipora capitata* (rice coral), *P. compressa* (finger coral), and *M. patula* (sandpaper coral) (Appendix E). These four species tend to be the most abundant corals on a “typical” reef in the Main Hawaiian Islands (MHI).

Reef Fish Assemblage

The Atlas incorporates information on coral reef fish from over 2,600 sites in the WMR (Appendix B). These data were collected between 1999-2019 and were spatially distributed across the entirety of the WMR, although the density of sites varied among the FWs. To give the most accurate picture of the current condition of the fish assemblage and for consistency with the analysis of the benthic assemblage, only data collected after 2015, totaling 848 sites, were used in most analyses. When appropriate, older data were incorporated into FW-specific “historical” analyses.

Table 1.3. Mean (±SEM) percent cover by benthic group for the SW Cluster (Olowalu Point, Launiupoko, Polanui, Lāhaina, and Mala) and other WMR reef tracts (Olowalu, Hanakao‘o Beach, North Kā‘anapali, Mahinahina, Kahana, and Honolua). Data are from 2016-2018. Insufficient recent data were available for Ukumehame, Oneloa and Honokahua Bays, and Līpoa Point reef tracts.

	SW Clus.	Other Reefs
Turf	51.4 ± 4.5	56.3 ± 7.6
Coral	16.0 ± 3.7	24.3 ± 4.7
Crustose Coralline Algae	1.1 ± 0.2	7.0 ± 1.8
Macroalgae	0.2 ± 0.1	2.6 ± 1.3
Cyanobacteria	<0.1	0.1 ± 0.1
Other	0.1 ± 0.1	0.2 ± 0.1
Abiotic Substratum	31.3 ± 3.4	9.5 ± 3.9

Like the benthic assemblage, reef fish showed considerable diversity across the WMR, but reef tracts with high fish

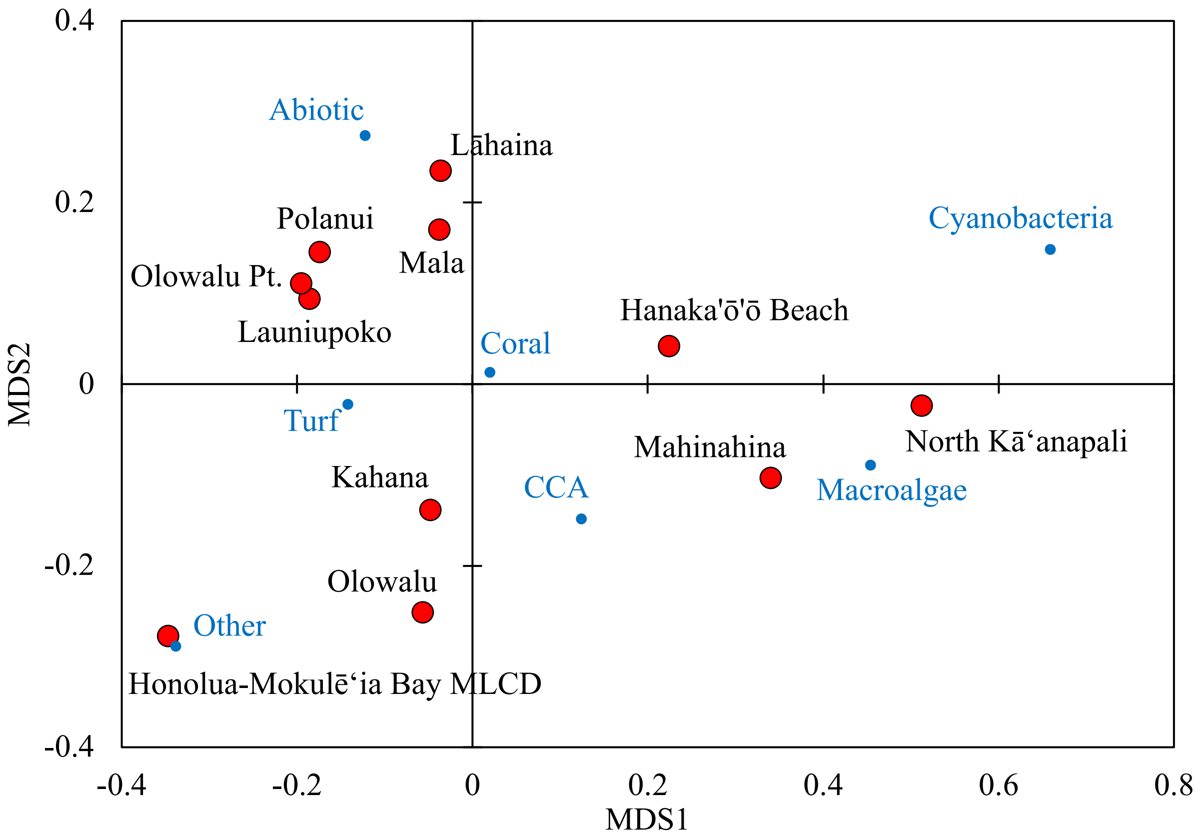


Figure 1.3. Ordination plot (multidimensional scaling) by benthic groups for the WMR reef tracts (red). Smaller blue dots show the direction of influence for each of the seven benthic groups included in the analysis. Data are from 2016-2018 and were insufficient for Oneloa and Honokahua Bays and Līpoa Point reef tracts to plot those tracts here.

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biomass (Figure 1.5) did not necessarily correspond with areas of high coral cover. Average total fish biomass for the WMR was 42.2 ± 3.9 g/m^2 with the reef tracts within the WMR spread across the entire range, from low to high (Figure 1.5). The Honolua-Mokulēʻia Marine Life Conservation District (MLCD) had the highest total fish biomass, over twice that of the average for the WMR. No other reef tract was characterized as having high total fish biomass. Most of the reef tracts had average total fish biomass for the WMR. The Launiupoko survey gap, the section of non-contiguous reef between Olowalu Point and Polanui, had the lowest total fish biomass (Figure 1.5), likely due to this area being low quality reef fish habitat, though the total fish biomass within the Launiupoko survey gap was only slightly lower than the Mahinahina reef tract.

Resource fish[4] biomass showed a similar spatial pattern to total fish biomass, with only the Honolua-Mokulēʻia MLCD reef tract having high resource fish biomass (Figure 1.6 and Table 1.4). Resource fish at Kahana, Olowalu, and especially Polanui dropped closer to the regional

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[4] Resource fish are comprised of species important for consumption and tend to be prized by fishers.

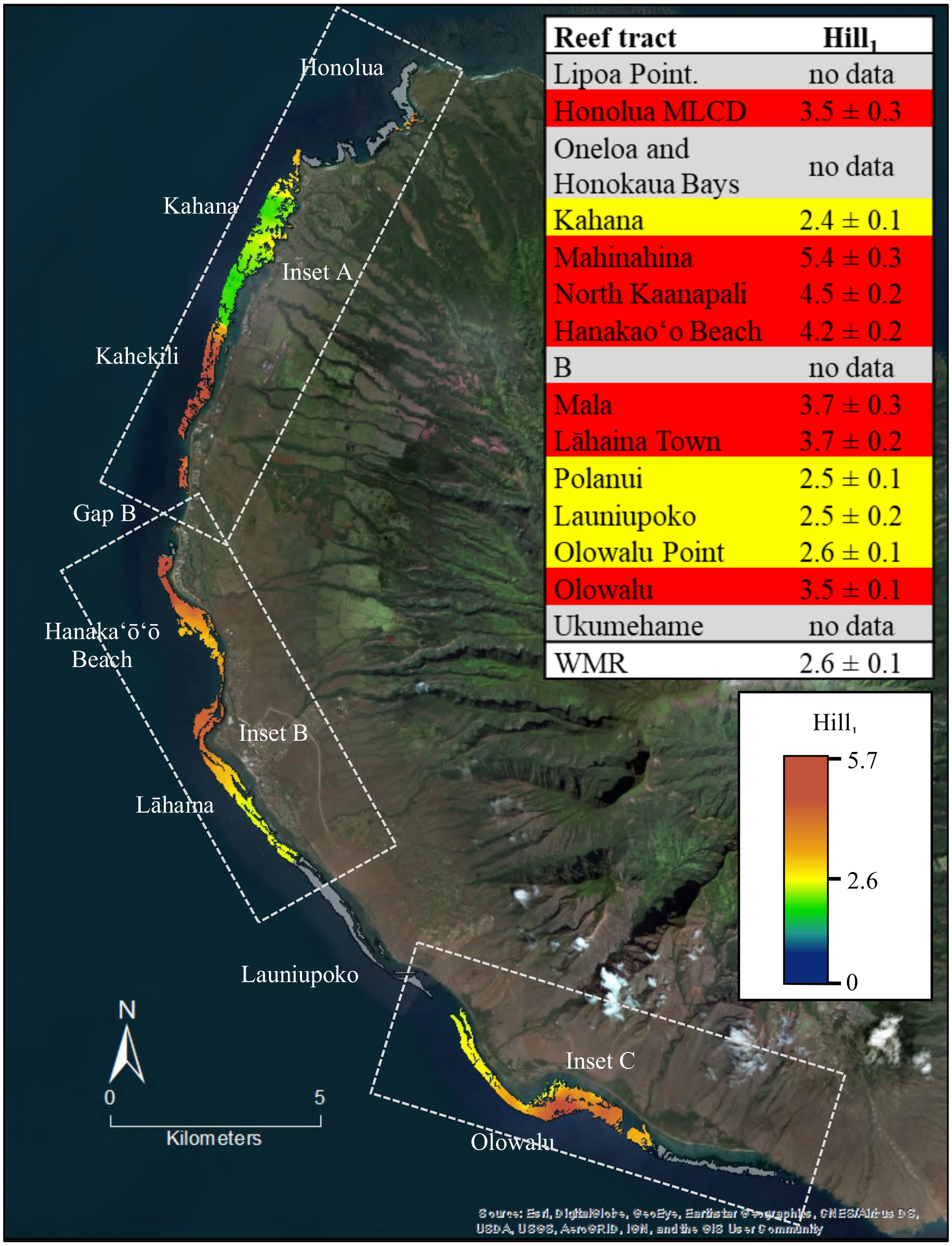


Figure 1.4. Effective species richness (Hill$_1$) for benthic organisms across the WMR (this page) and with details by coastal sections (next page). The map is interpolated from 2016-2019 survey data across hardbottom. Map colors are derived from the data for the WMR, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the region. Inset box in upper right provides the mean (±SEM) value for each reef tract, arranged from north to south. Lettered inset boxes correspond with the coastal sections displayed on the next page.

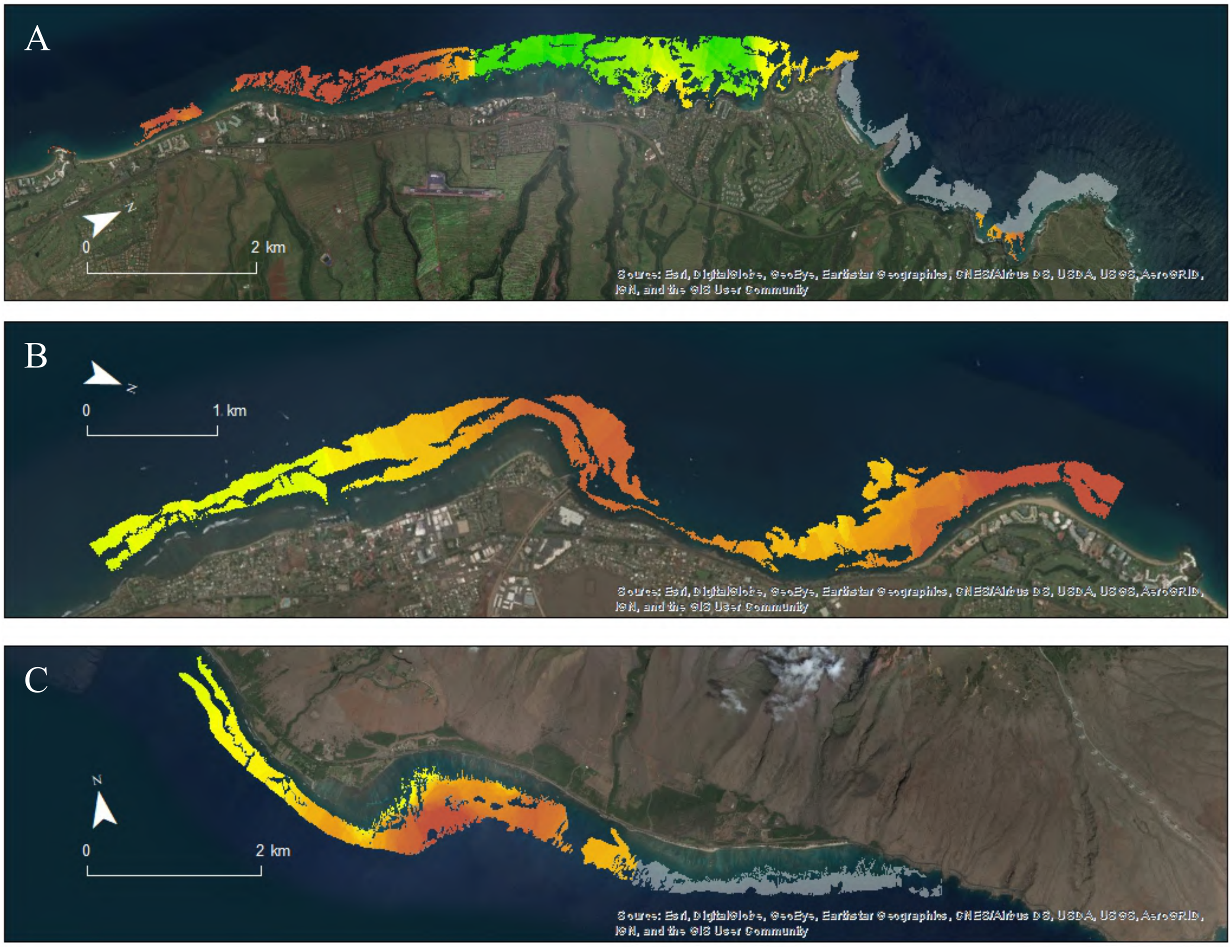


Figure 1.4 (con't). Effective species richness ($Hill_1$) for benthic organisms across the WMR (previous page) and with details by coastal sections (this page). Values for color ramp match those on the previous page. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom.

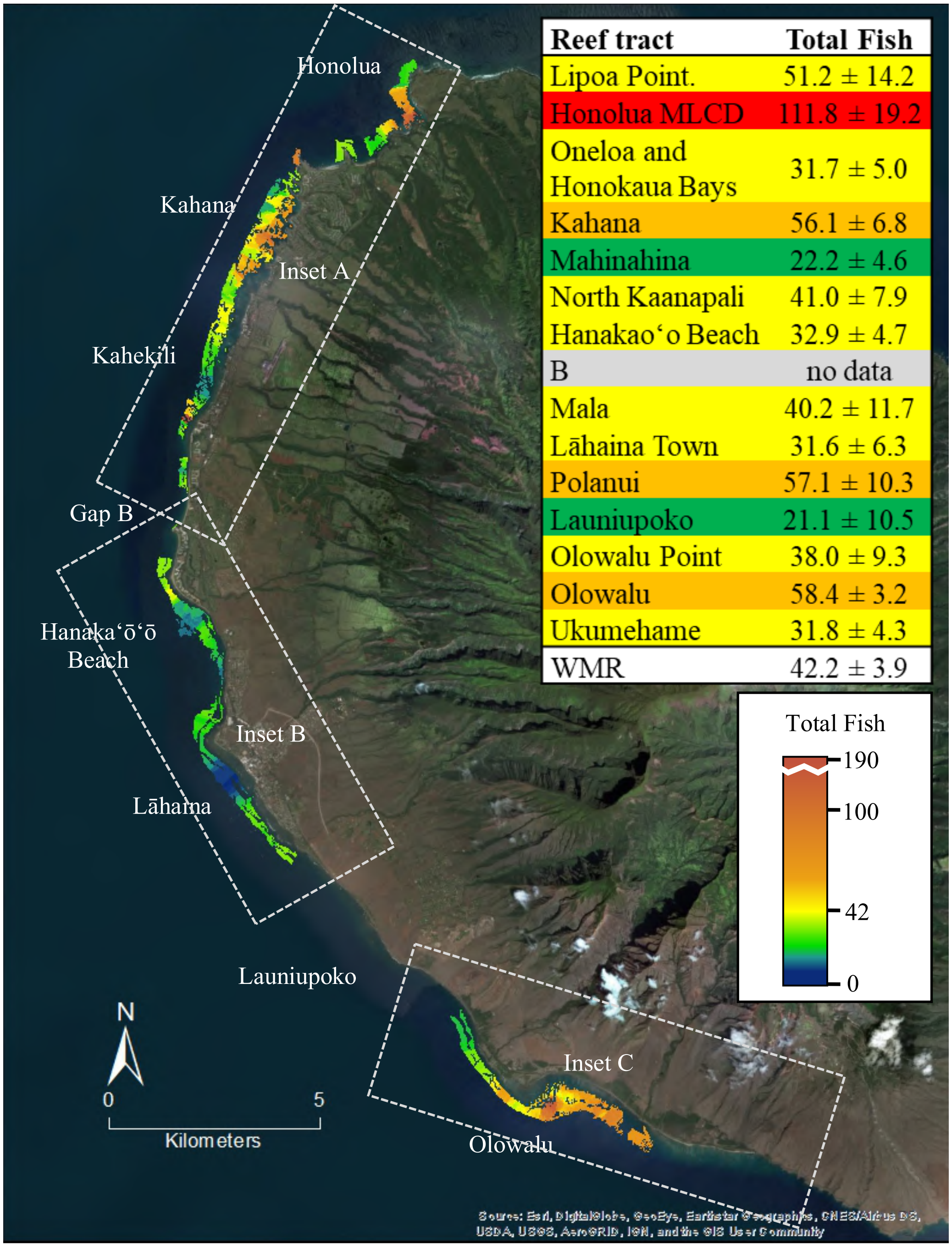


Figure 1.5. Total fish biomass across the WMR (this page) and with details by coastal sections (next page). The map is interpolated from 2016-2019 survey data across hardbottom. Map colors are derived from the data for the WMR, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the region. Inset box in upper right provides the mean (±SEM) value for each reef tract, arranged from north to south. Lettered inset boxes correspond with the coastal sections displayed on the next page.

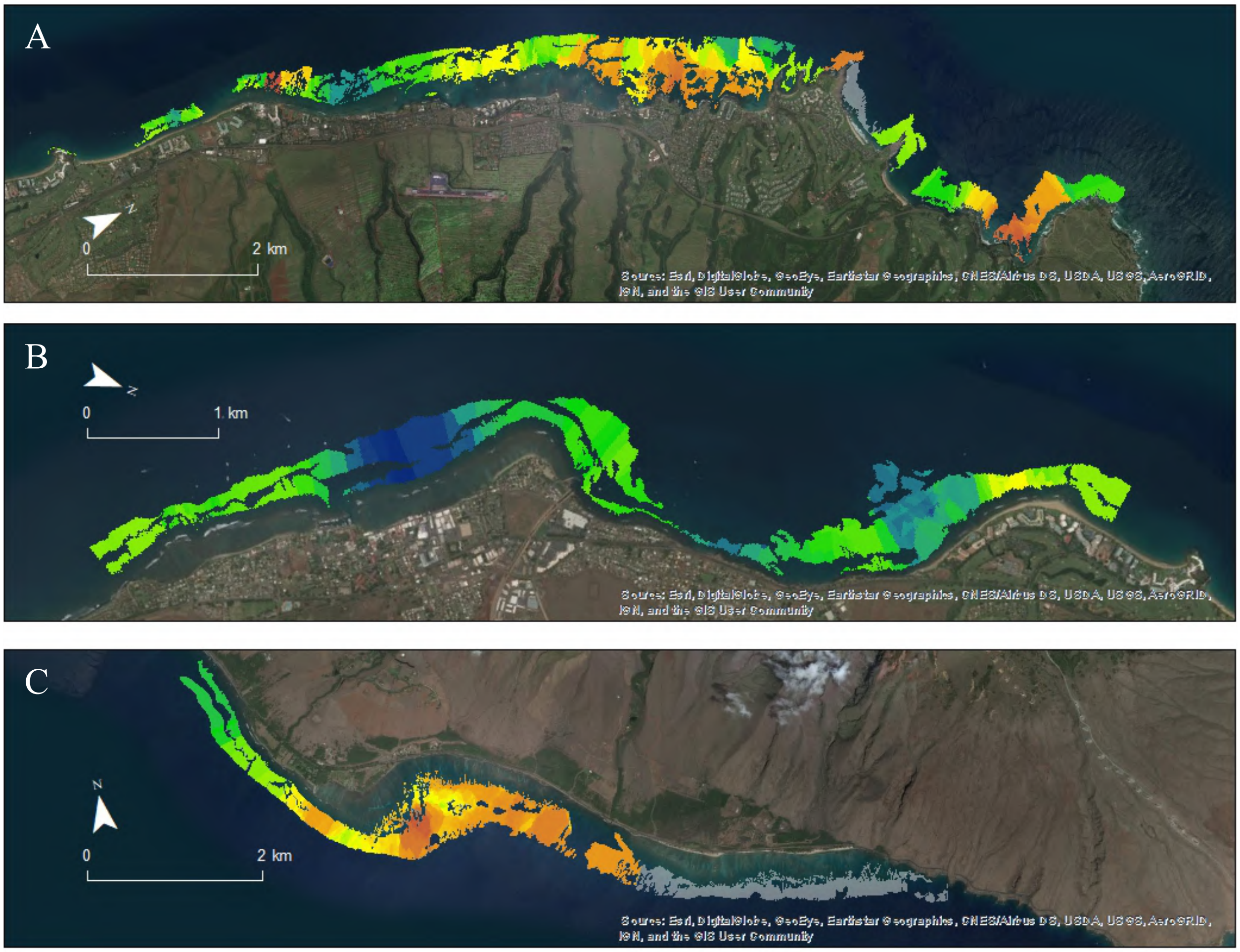
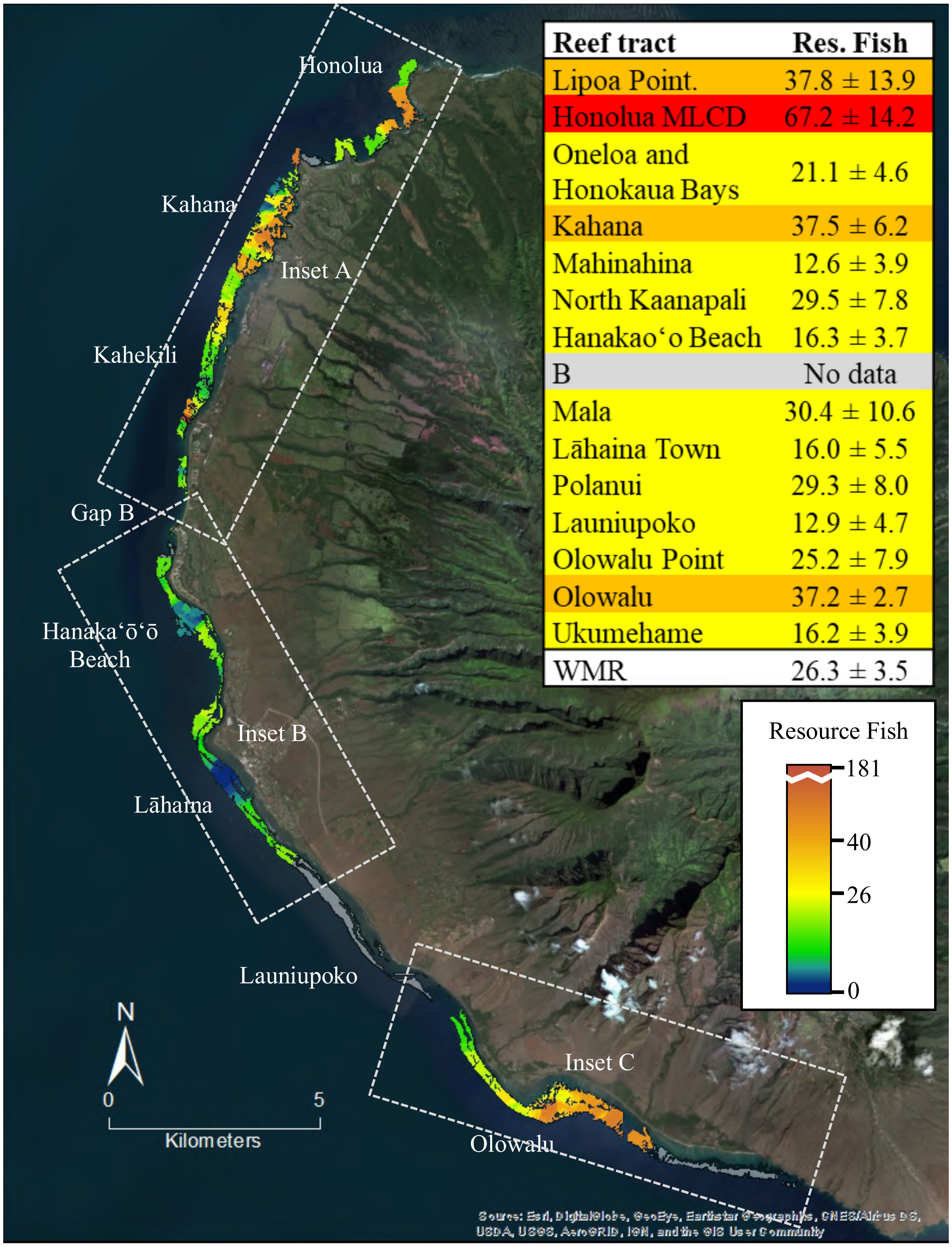


Figure 1.5 (con't). Total fish biomass across the WMR (previous page) and with details by coastal sections (this page). Values for color ramp match those on the previous page. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom.



Reef tract	Res. Fish
Lipoa Point.	37.8 ± 13.9
Honolua MLCD	67.2 ± 14.2
Oneloa and Honokaua Bays	21.1 ± 4.6
Kahana	37.5 ± 6.2
Mahinahina	12.6 ± 3.9
North Kaanapali	29.5 ± 7.8
Hanakao‘o Beach	16.3 ± 3.7
B	No data
Mala	30.4 ± 10.6
Lāhaina Town	16.0 ± 5.5
Polanui	29.3 ± 8.0
Launiupoko	12.9 ± 4.7
Olowalu Point	25.2 ± 7.9
Olowalu	37.2 ± 2.7
Ukumehame	16.2 ± 3.9
WMR	26.3 ± 3.5

Figure 1.6. Resource fish biomass across the WMR (this page) and with details by coastal sections (next page). The map is interpolated from 2016-2019 survey data across hardbottom. Map colors are derived from the data for the WMR, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the region. Inset box in upper right provides the mean (±SEM) value for each reef tract, arranged from north to south. Lettered inset boxes correspond with the coastal sections displayed on the next page.

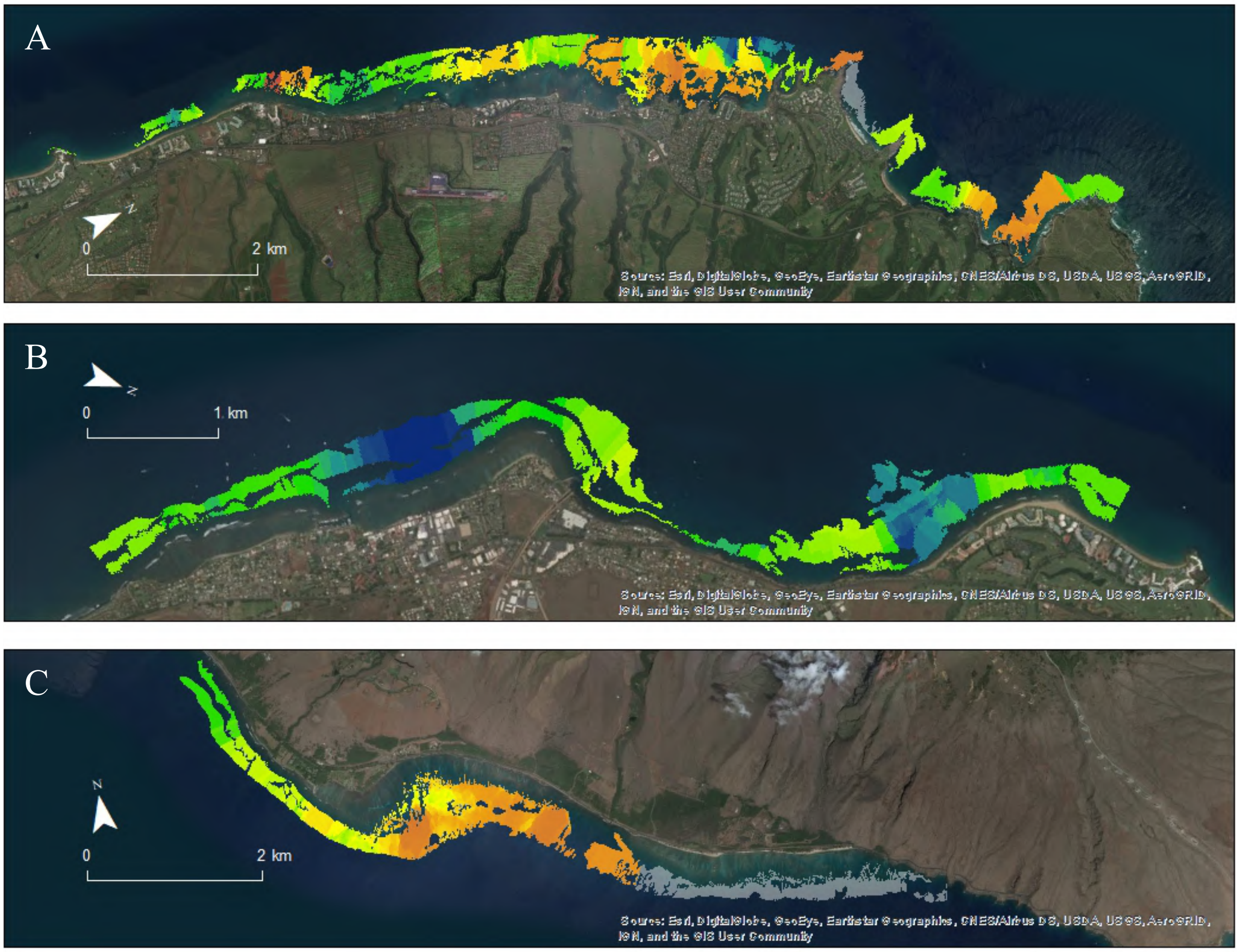


Figure 1.6 (con't). Resource fish biomass across the WMR (previous page) and with details by coastal sections (this page). Values for color ramp match those on the previous page. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom.

Table 1.4. Range of values for total fish biomass (g/m^2), resource fish biomass (g/m^2), prime spawner biomass (g/m^2), and effective species richness ($Hill_1$) for reef fish used to categorize a measured value in the Atlas. Colors correspond to those used throughout the Atlas, with warmer colors representing higher values

	Total Fish (g/m^2)	Resource Fish (g/m^2)	Prime Spawners (g/m^2)	Richness ($Hill_1$)
High	66.1+	41.5+	9.8+	8.3+
Med-High	52.4-66.1	31.3-41.5	6.4-9.8	7.3-8.3
Average	25.1-52.4	10.7-31.3	1.4-6.4	5.3-7.3
Med-Low	11.5-25.1	0.5-10.7	0.1-1.4	4.3-5.3
Low	0-11.5	0-0.5	0-0.1	0-4.3

average, suggesting that fishing may be affecting these locations. Fishing pressure in the WMR is generally high (Figure 1.7) but can vary considerably among the FWs and reef tracts. Examining the ratio of resource fish to non-resource fish (R:NR) can shed light on fishing pressure because areas with high fishing pressure should have a lower R:NR ratio than areas with relatively lower fishing pressure (*i.e.*, harvest of resource fish will lower their numbers while leaving non-resource fish numbers unaltered). North Kāʻanapali and Honolua-Mokulēʻia MLCD reef tracts, both with management designations, had the highest R:NR (Figure 1.8). Only two other reef tracts had R:NR ratios above the WMR average (4.7): Mala and Līpoa Point. The lowest ratios were at Polanui and Lāhaina.

Across the WMR, surgeonfish comprised almost half the resource fish biomass (Figure 1.9), although it varied greatly among the FWs and within reef tracts. Apex predators, such as carangids (jacks) and priacanthids (big-eyes) were relatively rare, accounting for only 2.5% of the resource fish biomass.

Average prime spawner[5] biomass for the WMR was 6.3 ± 1.7 g./m^2 and most reef tracts in the region were average for prime spawners (Figure 1.10 and Table 1.4). Four reef tracts, Honolua-Mokulēʻia MLCD and North Kāʻanapali (both areas with management designations), Mala, and Olowalu Pt. had high prime spawner biomass. Due to the high variability in prime spawner biomass across the WMR resulting in the low and medium-low categories being narrowly defined, no reef tracts were considered to have below average prime spawner biomass. Given this high variability in prime spawner biomass, the number of sites having prime spawners may also be of interest to managers and stakeholders. Only three reef tracts had prime spawners at more than half of the sites surveyed between 2016-2018: Honolua-Mokulēʻia MLCD, Kahana, and North Kāʻanapali. This patchiness in the spatial distribution of prime spawners has resulted in some areas within a reef tract having high prime spawner biomass, notably within the Olowalu and Kahana reef tracts, but due to the limited spatial extent of these prime spawner "hotspots," they are discussed in more detail in the FW chapters.

[5] Prime spawners are individual resource fish >70% of the maximum length for that species.

Table 1.5. Top ten fish families by biomass for 15 WMR reef tracts (numbers represent rank for the reef tract), where a 1 represents most common and a 10 the least common. Reef tracts are abbreviated as follows: LP=Līpoa Point; MLCD=Honolua-Mokulēʻia MLCD; OHB=Oneloa and Honokaua Bays; K=Kahana; M=Mahinahina; NK=North Kāʻanapali; HB=Hanakaʻōʻō Beach; L=Lāhaina; P=Polanui; LSG=Launiupoko Survey Gap; OP=Olowalu Point; O=Olowalu; U=Ukumehame; WMR=West Maui Region. No data were available Survey Gap B (B).

	Honolua			**Kah**	**Kahekili**			**HB**	**Lāhaina**				**Olowalu**			
	LP	**MLCD**	**OHB**	**K**	**M**	**NK**	**B**	**HB**	**Mala**	**L**	**P**	**LSG**	**OP**	**O**	**U**	**WMR**
Acanthuridae	1	1	1	1	1	2		1	1	1	1	1	1	1	1	1
Scaridae	3	3		4	4	3		3	2	5	4	4	7	2	2	2
Balistidae	4	2	2	3	3	4		2	5	2	2	2	2	3	3	3
Mullidae	2	7	4	2	7	1		4	8		7	10	5	6	7	4
Labridae	5	10	3	5	2	5		5	4	4	5	3	3	4	6	5
Chaetodontidae	7		6	9	6	9		8	6	8	8	6	8	5	5	6
Lethrinidae	10					7		10		3	3		9	7		7
Monacanthidae	6	5	5			8		6						8	9	8
Pomacentridae	9		10	10	5	6		7	3	7	6	5	4	10	4	9
Serranidae		8			8	10		9				8	6	9		10
Lutjanidae		9		8					9							11
Carangidae	8		8	7	10					6	10					12
Kyphosidae		4														13
Carcharhinidae				6												14
Holocentridae																15
Zanclidae			7		9				10			9	10		10	16
Diodontidae																17
Cirrhitidae			9												8	18
Kuhliidae		6														19
Tetraodontidae									7	10	9	7				20

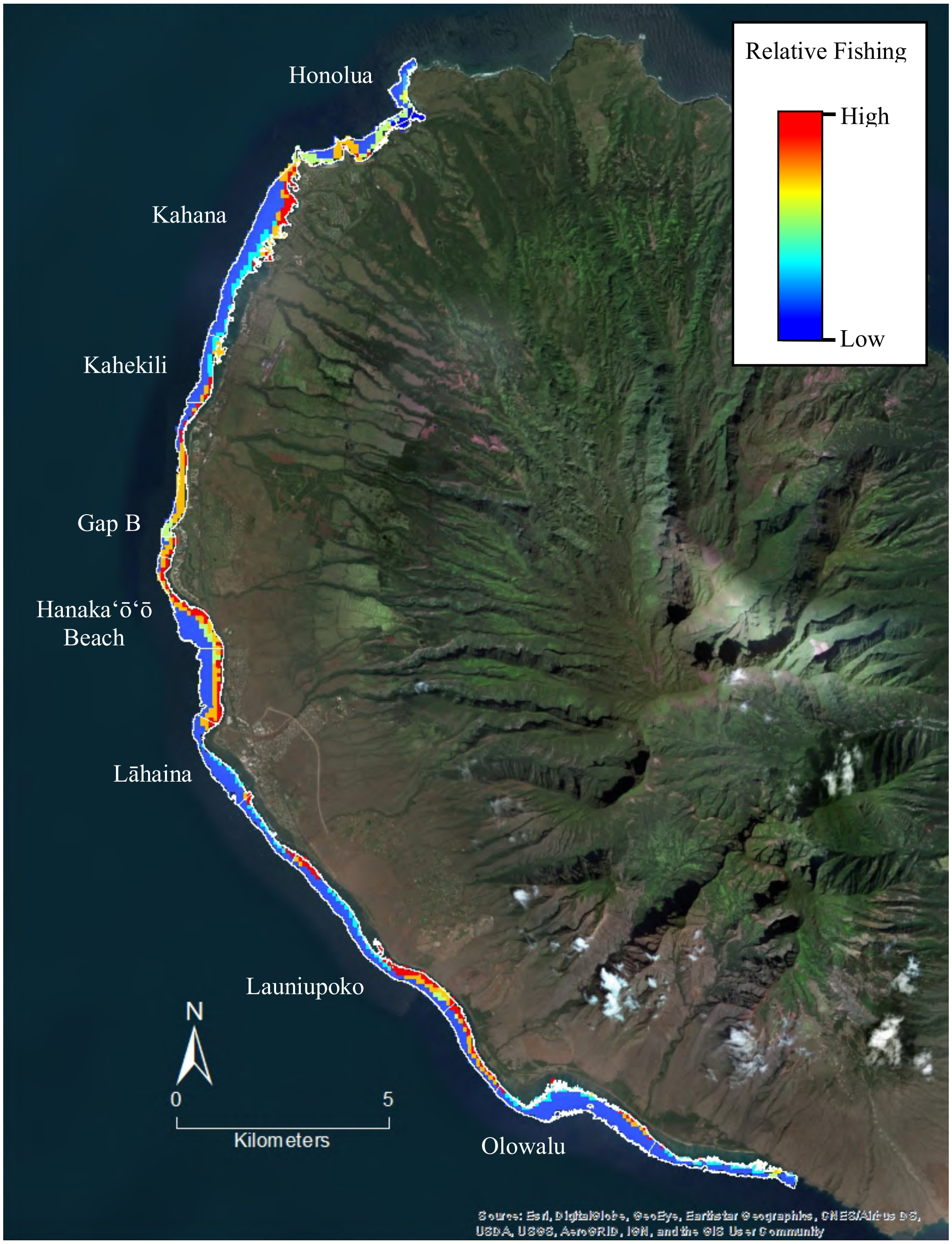


Figure 1.7. Estimated average annual catch for non-commercial fisheries from 2004-2013 for the WMR. These estimates of fishing predate the establishment of the Kahekili Herbivore Fisheries Management Area, which closed the North Kā‘anapali FW to fish for selected species. Estimates for this FW are likely incorrect. Data from The Ocean Tipping Points project (2016) and PacIOOS.

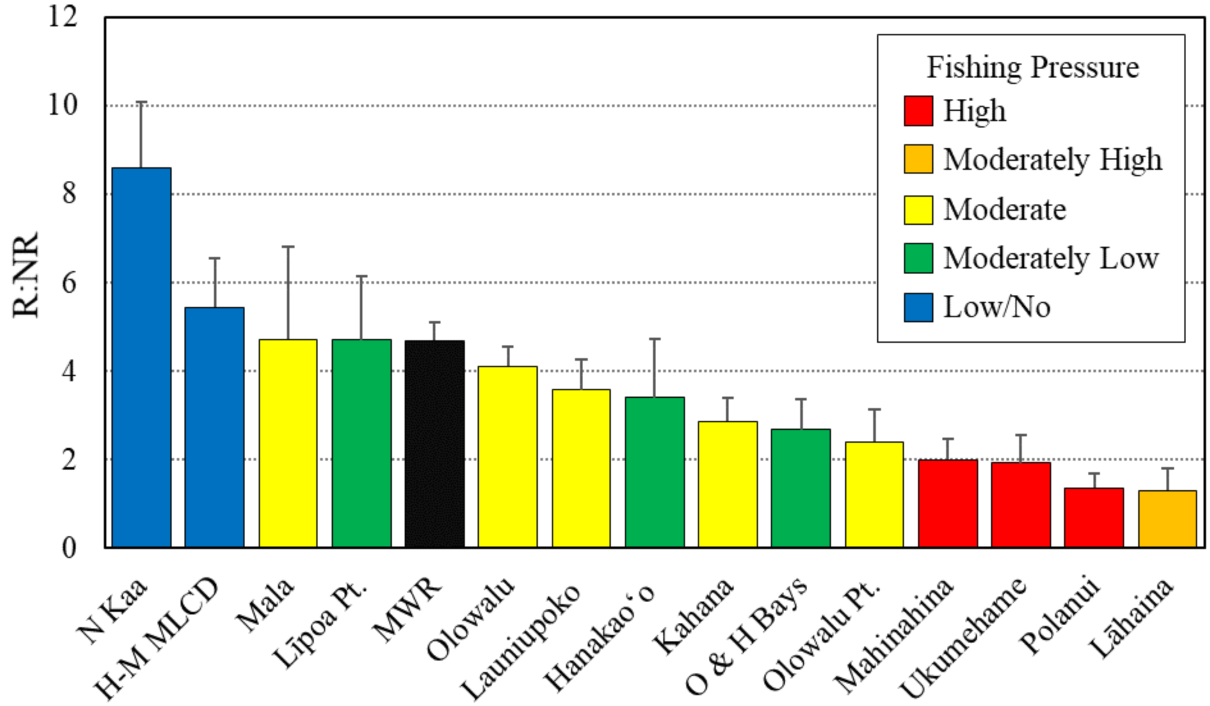


Figure 1.8. The ratio of mean resource fish biomass to non-resource fish biomass (R:NR) for reef tracts in the WMR. Average for the WMR was 4.7. Honolua-Mokulēʻia MCLD (H-M MLCD) and North Kāʻanapali (N Kaa) are fishery management areas. Fishing pressure was derived from the expert opinion of fishing effort within each reef track provided by DAR-Maui staff.

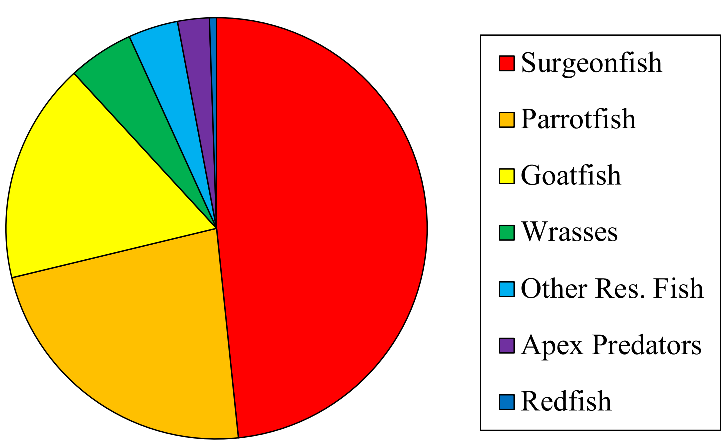


Figure 1.9. Resource fish composition (% of total resource fish biomass) for the WMR. Data are from 2016-2018.

Effective species richness for reef fishes varied between medium-low and medium-high, with no sites occupying the extremes (Figure 1.11 and Table 1.4). A more in-depth analysis (not shown) of the reef fish assemblage structure showed that survey sites did not cluster by reef tracts. Sites from divergent reef tracts tended to cluster together, suggesting no clear spatial pattern was present at the reef tract scale, and that other underlying factors might be driving similarity among survey sites. Two potential factors could be fish habitat composition (*e.g.*, the composition of the benthos, local stressors such as proximity to stream inputs, etc.) and quality (*e.g.*,

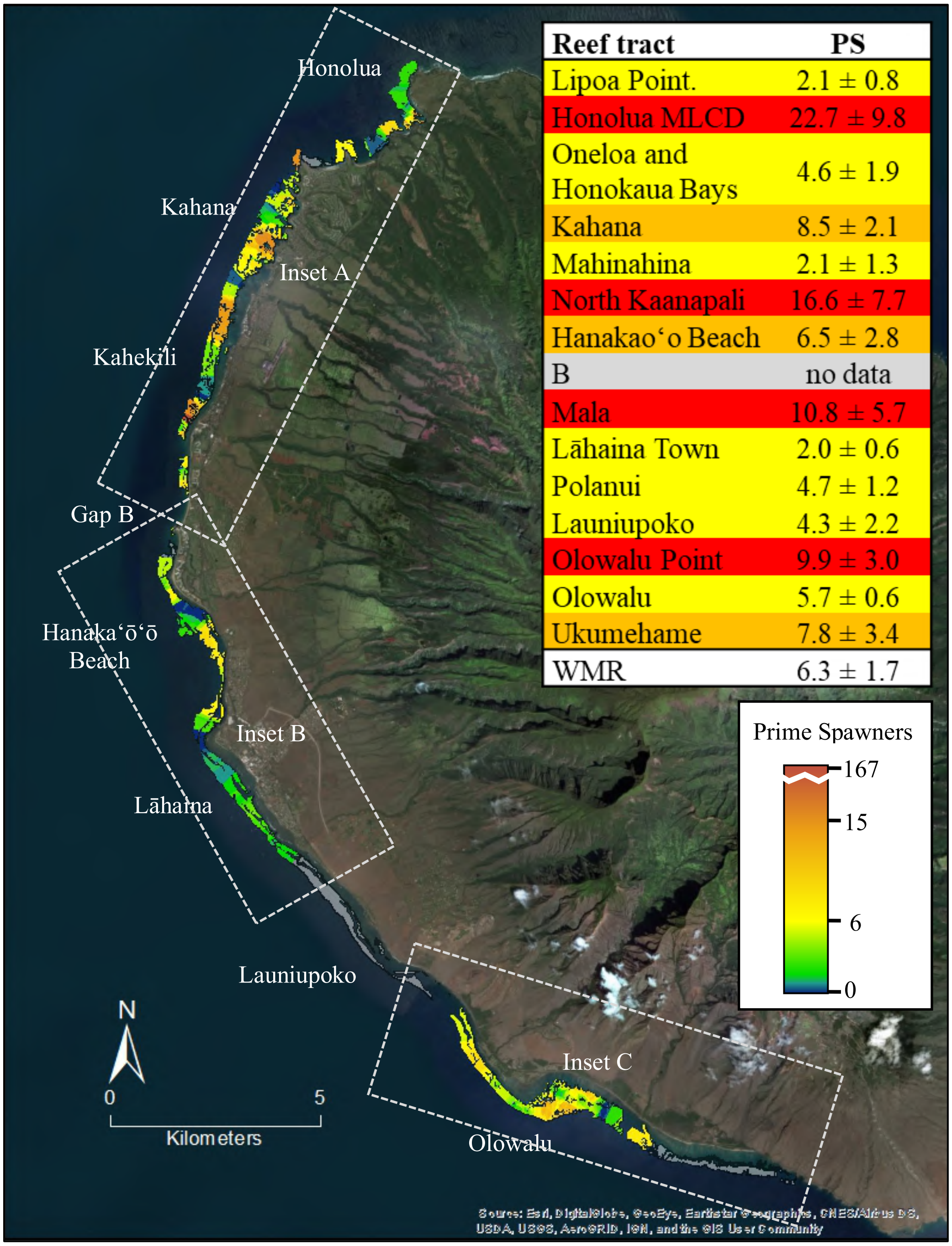


Figure 1.10. Prime spawner biomass across the WMR (this page) and with details by coastal sections (next page). The map is interpolated from 2016-2019 survey data across hardbottom. Map colors are derived from the data for the WMR, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the region. Inset box in upper right provides the mean (±SEM) value for each reef tract, arranged from north to south. Lettered inset boxes correspond with the coastal sections displayed on the next page.

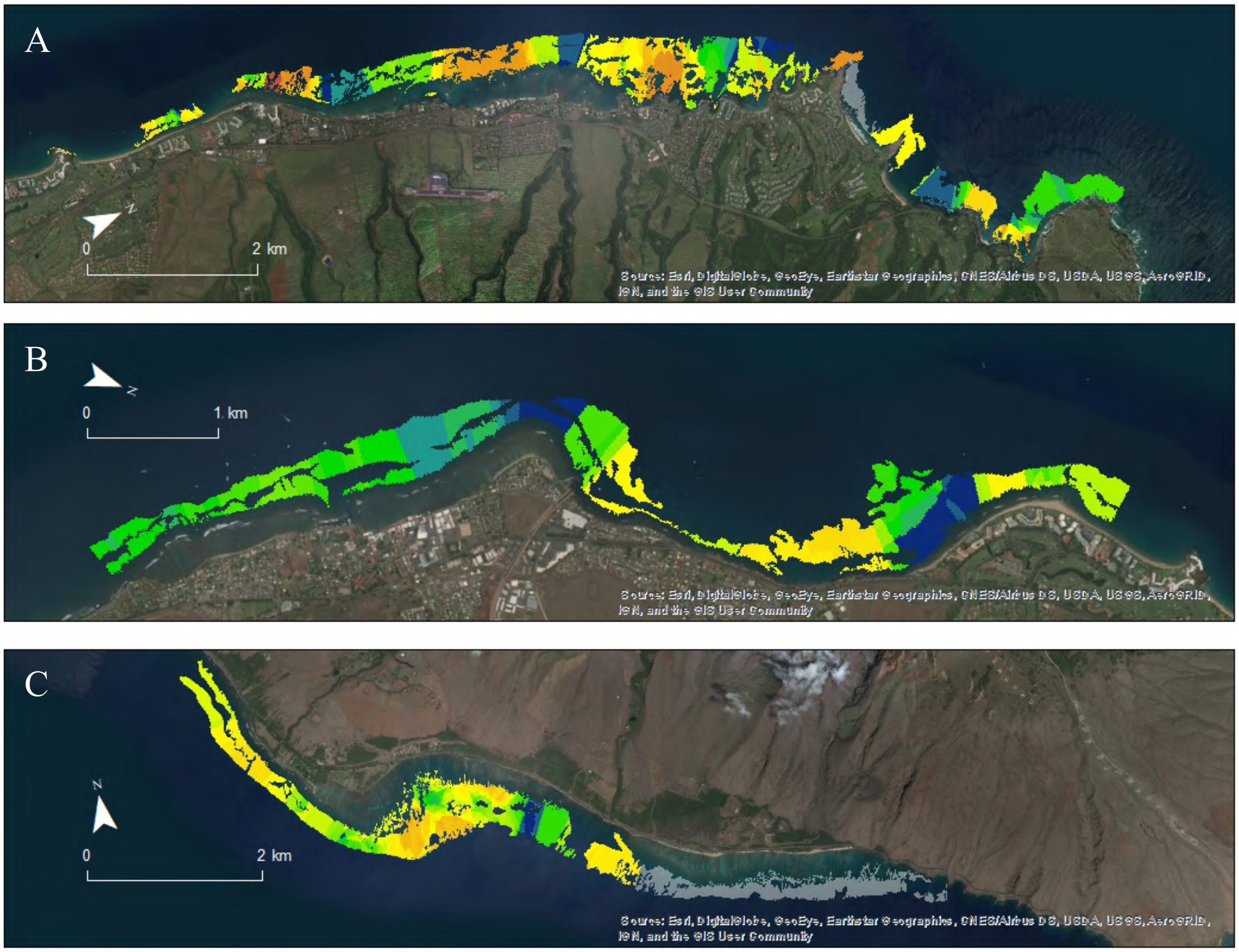


Figure 1.10 (con't). Prime spawner biomass across the WMR (previous page) and with details by coastal sections (this page). Values for color ramp match those on the previous page. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom.

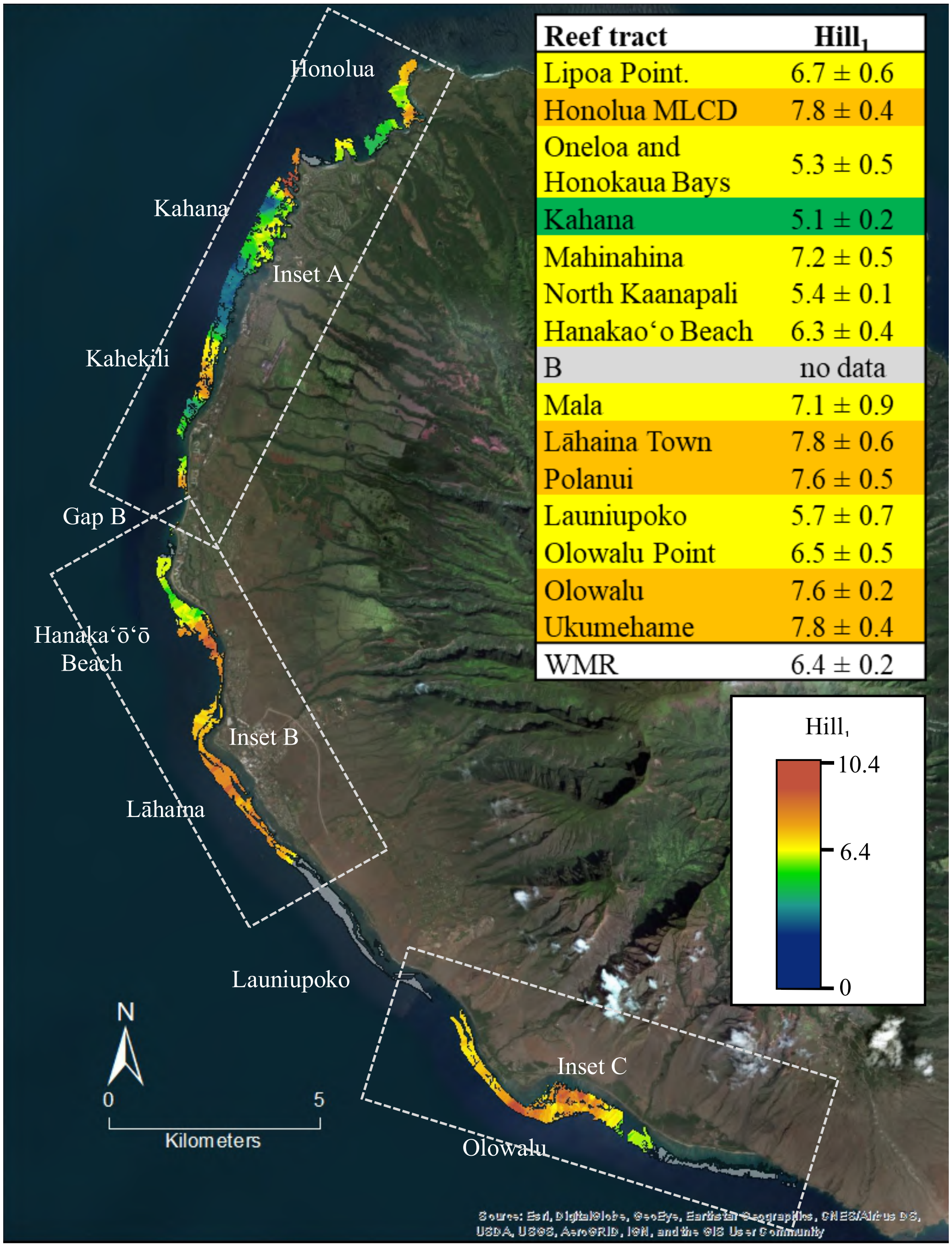


Figure 1.11. Effective species richness (Hill$_1$) for fish across the WMR (this page) and with details by coastal sections (next page). The map is interpolated from 2016-2019 survey data across hardbottom. Map colors are derived from the data for the WMR, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the region. Inset box in upper right provides the mean (±SEM) value for each reef tract, arranged from north to south. Lettered inset boxes correspond with the coastal sections displayed on the next page.

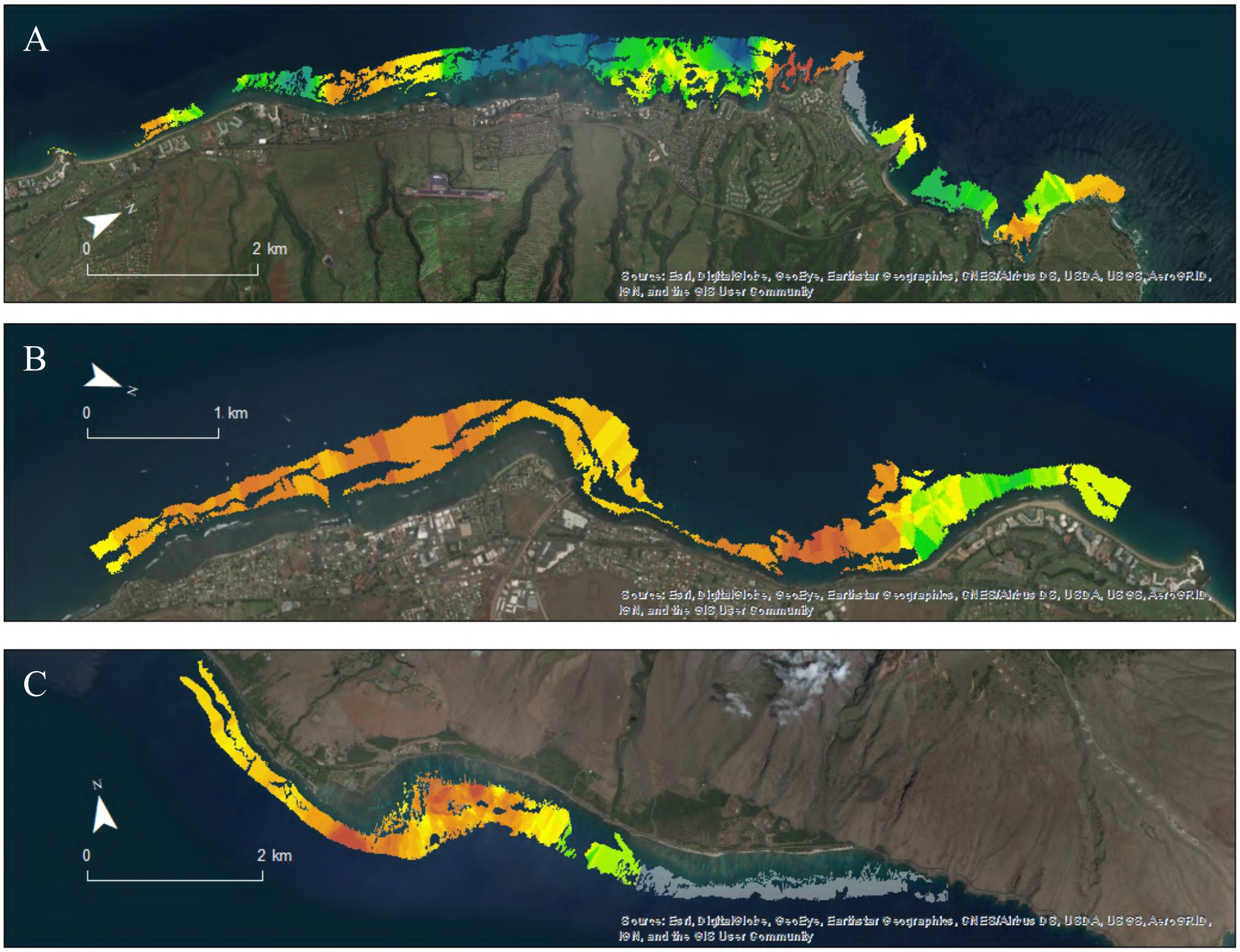


Figure 1.11 (con't). Effective species richness (Hill$_1$) for fish across the WMR (previous page) and with details by coastal sections (this page). Values for color ramp match those on the previous page. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom.

proximity to local stressors such as sediment or nutrients). For example, sites with greater than average cover of sand are expected to have a different composition of reef fish than sites with no sand, and this "high" sand site would tend to be more similar to another "high" sand site regardless of reef tract than the "high" sand would be to the fish assemblage of a "low" sand site within the same reef tract. This lack of clustering at the reef tract scale also indicates the reef fish of the WMR are likely a single, well-mixed assemblage whose composition, which would be expected across a relatively small spatial area comprised of predominantly contiguous reef, such as West Maui, and has been supported by genetic studies.

However, the difference in the benthic assemblage (*i.e.*, habitat composition) among the reef tracts is considerable, so it is not surprising that fish assemblages also differed among reef tracts in their species composition (Appendix D) and the relative biomass of fish families (Table 1.5). Most reef tracts had a similar core of common fish families that included surgeonfish (Acanthuridae), parrotfish (Scaridae), triggerfish (Balistidae), goatfish (Mullidae) and wrasses (Labridae). Acanthurids had the highest biomass for all reef tracts except North Kāʻanapali, where a few sites had high biomass of goatfish (Chapter 4). The five most abundant fish families across the WMR are families common on most reefs in the MHI.

The Big Picture

Averages for coral cover (14.4 ± 0.7%), total fish biomass (40.9 ± 2.5 g/m^2), resource fish biomass (22.3 ± 1.8 g/m^2), and prime spawner biomass (3.7 ± 1.0 g/m^2) were calculated for the MHI, to serve as a gauge for how the reefs of the WMR are faring relative to those from around the state. All across the MHI, reefs are affected by overfishing, sediments, land-based pollution, and invasive species. Over the past century, populations of some commercially important reef fish populations have declined by over 90%, and coral cover in some areas has declined by at least 40% in just the last 40 years. For all metrics except prime spawners, reefs in the WMR were consistent with the MHI averages, albeit on the higher side of the range (Figure 1.12). The WMR had medium-high prime spawner biomass compared to the MHI, but prime spawner biomass varied considerably among the reef tracts. This variability in the condition of reefs across the WMR is explored in greater detail in subsequent chapters of the Atlas.

Synthesis

In general, coral reefs north of Hanakaʻōʻō Beach tend to have higher abundance, biomass, and diversity than their counterparts to the south, with the Olowalu reef tract being a notable exception (Figure 1.13). While not explicitly examined, a general spatial pattern has emerged highlighting hotspots of marine resources on reefs around prominent points of land. Many of these reef areas are relatively small, however, and at the WMR-spatial scale, tend to have only a small effect on the abundance, biomass, and diversity of entire FWs or even reef tracts. These "hotspots" are examined in more detail in the individual FW chapters.

While it was not a specific goal of this Atlas to assess the effects of existing marine management areas, the effect of the Kahekili Herbivore Fisheries Management Area (KHFMA) and the Honolua-Mokulēʻia MLCD were detectable in the reef fish community, with the two reef tracts

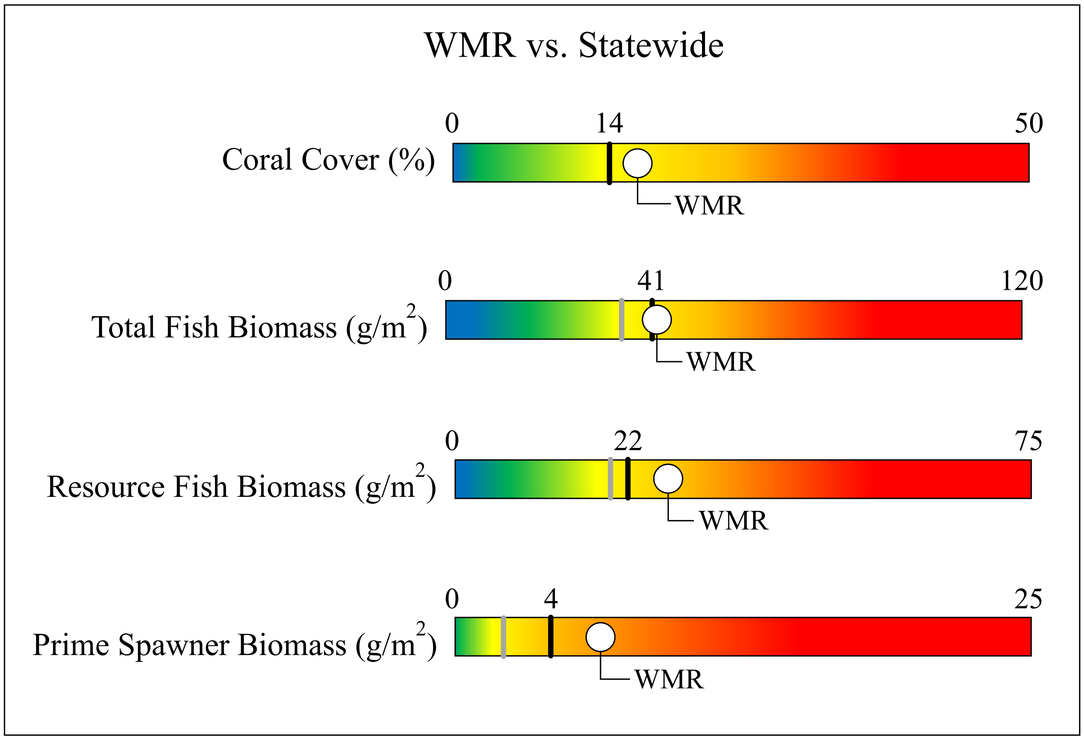


Figure 1.12. Comparison of WMR to statewide averages for coral cover (%), total fish, resource fish, and prime spawner biomass (g/m^2). Black vertical line and value denote the statewide average. For the three fish metrics, the grey vertical line is the statewide trimmed mean, which was used to develop the qualitative categories; see the methods (Appendix B) for more details on the use of the trimmed means.

(North Kāʻanapali and Honolua-Mokulēʻia MLCD) having the highest prime spawner biomass. Honolua-Mokulēʻia MLCD in particular appeared to benefit all fishes both inside the MLCD, and possibly with some resource fish spillover into adjacent reef tracts (*e.g.*, Līpoa Point).

Benefits of these protected areas on the benthic assemblages were less clear, but the management actions within the two areas focus primarily on fisheries, and benefits to the benthic assemblage would need to occur indirectly, which is often slow to happen and can be difficult to detect. This effort was complicated in the Honolua FW by the lack of current benthic data. While little difference was seen between the North Kāʻanapali reef tracts and adjacent areas, recent studies[6] have attributed initial changes in its benthic condition (*i.e.*, increased crustose coralline algae) to the recently created KHFMA in a comprehensive examination of the effectiveness of the management area. This reef tract was examined in greater detail in Chapter 4.

The Olowalu reef tract stood in contrast to other southern reefs and was in many ways one of the gems of the WMR. It possessed an abundant and diverse coral assemblage and medium-high total fish and resource fish biomass without the benefit of additional fishery management. Olowalu has long been known to be a place treasured by its community and a top snorkeling and

[6] For example, see Williams *et al.* (2016).

diving destination. The Olowalu FW showed signs of stress from climate change, land-based sources of pollution, and fishing, and in recent years has become the focus of community efforts to prevent additional sources of land-based pollution and strengthen marine management.

The Lāhaina FW is heavily affected by fishing and has obvious issues associated with land-based sources of pollution, yet still had patches of benthic and reef resources that were above average for the WMR. Coral cover and benthic diversity in the Lāhaina and Mala reef tracts were above average but tend to be associated with reef areas around Puʻunoa Point and the Mala Pier. The Polanui reef tract had medium-high fish biomass, although only average resource fish biomass and along with Lāhaina had the lowest R:NR (Figure 1.8), suggesting significant effects from fishing. The Mala reef tract had high prime spawner biomass, although the diversity of prime spawners tended to be low (Chapter 6). Polanui appeared to have considerable potential both historically and currently to support abundant resources. More detailed analyses and discussions of spatial and temporal trends for each of the FWs and reef tracts can be found in the chapters that follow.

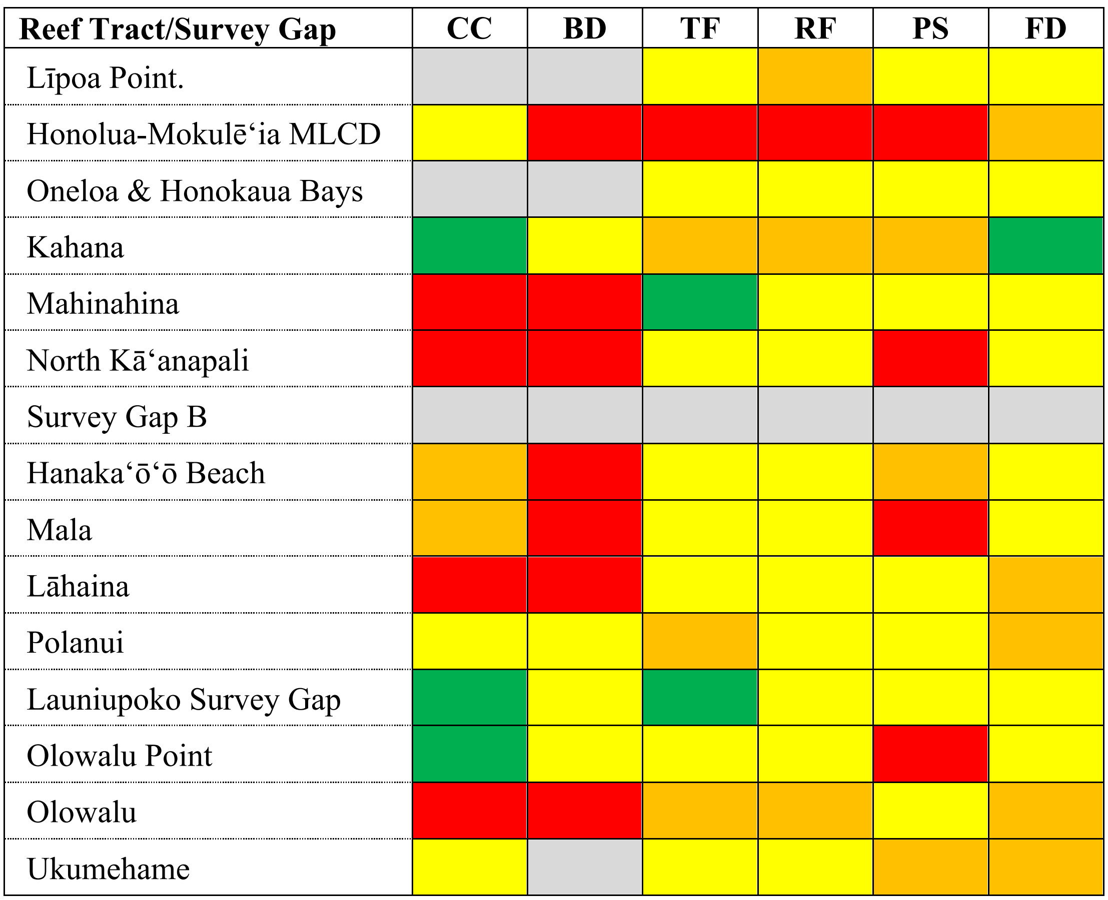
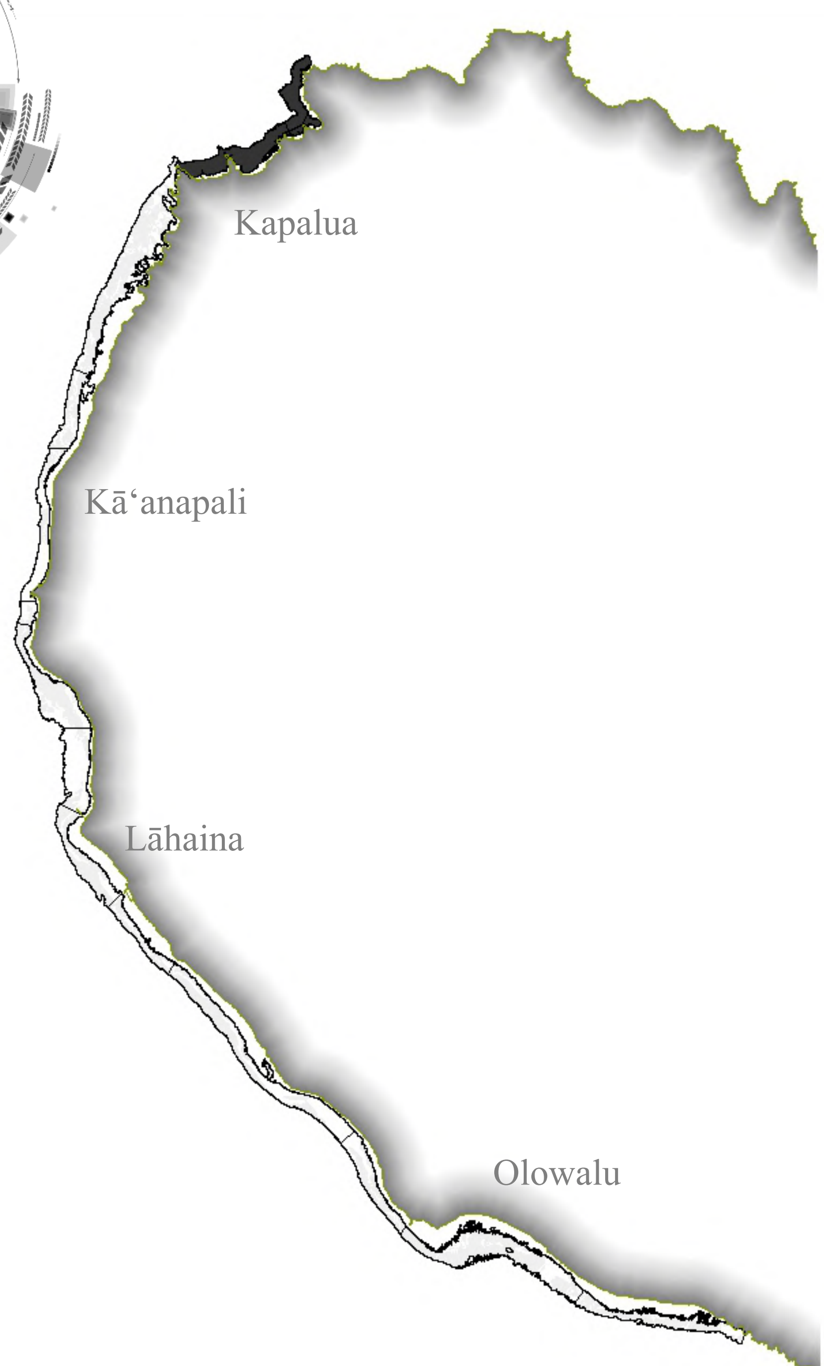


Figure 1.13. Summary of the qualitative categories for the WMR reef tracts and survey gaps for coral cover (CC), benthic diversity (BD), total fish biomass (TF), resource fish biomass (RF), prime spawner biomass (PS), and reef fish diversity (FD). Grey indicates data were not available for the reef tracts or survey gap and colors correspond with those in Table 1.1.

2



Reefs of Honolua

Geographic Setting

The Honolua Focus Window (FW) extends from the most northwesterly tip of Līpoa Point southward to Hāwea Point and encompasses four embayments separated by often narrow, rocky points of land. Within three of the bays are white sand beaches. The fringing reef is fragmented by several wide, sandy areas fed by intermittent streams that drain into three of the four bays. Coastal development is diverse, with numerous condominiums, tourist resorts, and golf courses, predominantly in the southern half of the FW and agricultural and conservation lands toward the north[7]. Land ownership of the agricultural and conservation lands is highly consolidated with Maui Land and Pineapple owning 80% of these lands. Legacy agricultural practices such as pushing dirt off fields and into stream gulches, impervious surfaces, and heavily manicured landscapes have promoted surface runoff of sediment and nutrients into coastal waters, contributing to high turbidity[8]. Papua Gulch and Honolua Stream are likely the largest contributors of sediment to Honolua Bay, which has the highest turbidity in the FW[9].

The Data

The Honolua FW is comprised of three reef tracts (Figure 2.1):

- **Līpoa Point** reef tract extends ~0.8 km (0.5 mi) from the most northwesterly tip of Līpoa Point to the northern boundary of the Honolua MLCD. This reef tract was surveyed several times between 2002 and 2018, with the highest survey effort occurring in 2016 and 2018 (Table 2.1). Unlike other reef tracts in the Honolua FW, considerably fewer benthic surveys than fish surveys were conducted. In March 2018, TNC assessed one reef resilience site (Līpoa Point) within this reef tract.
- **Honolua-Mokulēʻia Marine Life Conservation District (MLCD)** reef tract comprises the area within the boundary of the Honolua-Mokulēʻia MLCD. For some analyses in this chapter, this reef tract has been subdivided into Mokulēʻia Bay and Honolua Bay (Figure 2.1). This reef tract was surveyed multiple times between 1999 and 2019 (Table 2.1), with the greatest survey effort occurring before 2008. Two Hawaiʻi Coral Reef Assessment and Monitoring Program (CRAMP) long-term monitoring sites have been surveyed nearly annually from 1999-2016. In 2018, TNC assessed two reef resilience sites (Honolua North and Honolua South) within this reef tract.
- **Oneloa and Honokahua Bays (O&H Bays)** reef tract extends 2.9 km (1.8 mi) from the southern boundary of the Honolua-Mokulēʻia MLCD to Hāwea Point. It encompasses Oneloa and Honokahua Bays. This reef tract was surveyed multiple times between 2002 and 2018, with the highest survey effort occurring prior to 2008 (Table 2.1).

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[7] Group 70 Int and SRGII (2016)
[8] The Hawaiʻi Department of Health and more recently Hui O Ka Wai Ola have maintained sampling sites at Oneloa (2006-2016), DT Fleming Beach in Honokahua, Mokulēʻia Bay and Honolua Bay (2006-2016). Water quality assessments reveal that turbidity is particularly high in Honolua Bay especially as related to storm events, but nitrate is comparatively low. To learn more about Hui O Ka Wai Ola and download raw data, please visit huiokawaiola.com.
[9] Falinski (2016) and Stock (2019).

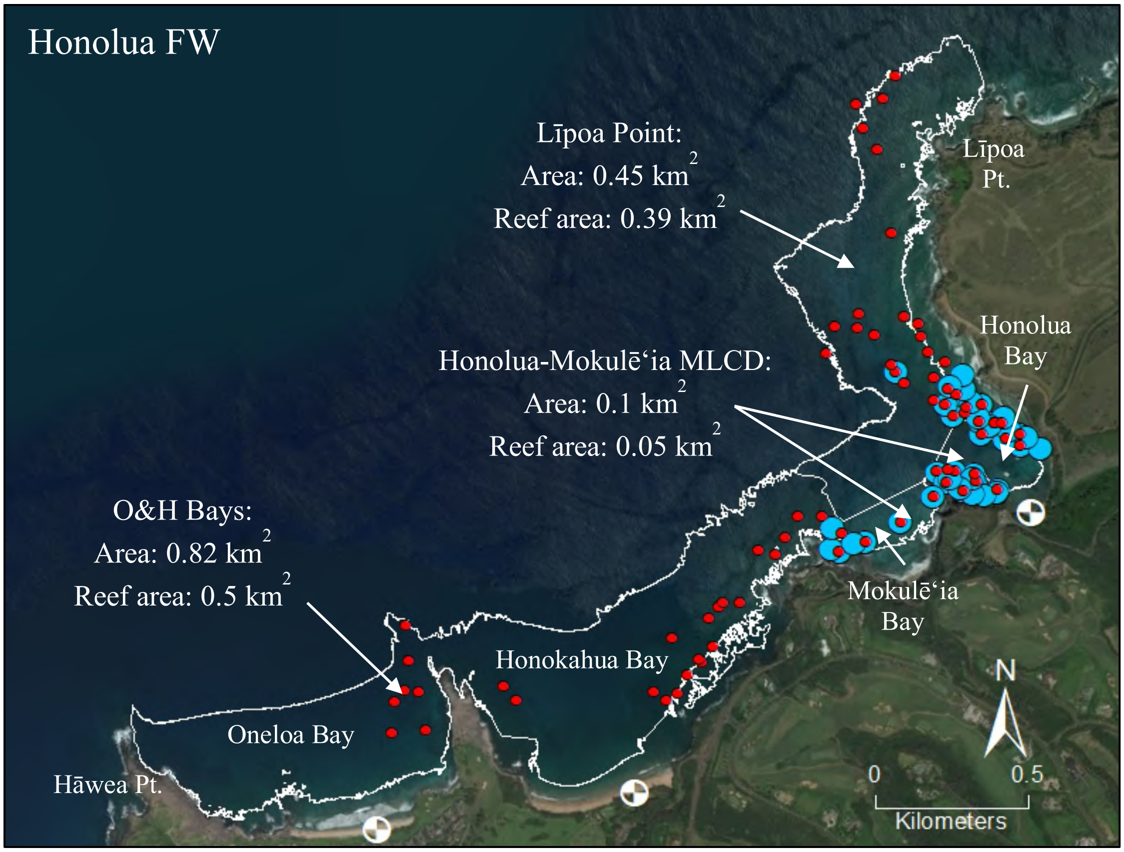

Figure 2.1. Reef tracts within the Honolua FW. Dots indicate 2016-2019 survey efforts for the benthic (blue) and fish (red) assemblages within the FW. White quadrant circles along the shore (west to east) are the Oneloa, DT Fleming Beach, Mokulē‘ia Bay (not pictured), and Honolua Bay long-term water quality monitoring sites.

Maps within the Atlas were generated using a spatial technique called interpolation. This technique uses available survey data to generate a complete spatial model of the data by estimating values between the surveys' data using a mathematical algorithm that considers the values of nearby data weighed by their distance away. Areas with a higher density of surveys will produce more "accurate" interpolations than areas with lower survey density. Averages derived from interpolation maps are calculated across all reef areas and typically vary from averages derived from the survey data. Interpolation maps were generated for the Atlas primarily to display general spatial patterns and should not be used to predict exact values at any given location. For example, an interpolation map can, with a high degree of reliability, indicate that one reef tract has more coral than another reef tract, but it should not be used estimate the "exact" coral cover at a specific location within the reef tract. To estimate coral cover, amount of fish, etc., current survey data from the specific location should always be used over the interpolation maps when these data are available.

Table 2.1. Benthic and fish assemblage survey effort (number of survey sites) in the Honolua FW between 1999 and 2019. The FW has three reef tracts: Līpoa Point, Honolua-Mokulēʻia MLCD, and O&H Bays.

Reef Tract	Survey Year	Benthic	Fish
Līpoa Point		10	33
	2002	3	2
	2006	2	2
	2007	1	2
	2016		13
	2018	3	14
	2019	1	
Honolua-Mokulēʻia MLCD		124	109
	1999	2	
	2000	2	2
	2001	2	
	2002	31	26
	2003-2005	6 (2/year)	
	2006	28	26
	2007	26	26
	2008-2012	10 (2/year)	
	2013	2	1
	2014-2015	4 (2/year)	
	2016	2	4
	2018	7†	24
	2019	2†	
O&H Bays		77	100
	2002	25	25
	2006	26	24
	2007	24	25
	2012	2	
	2016		16
	2018		10
TOTAL		211	242

†In addition to the sites inside the reef tract, 12 (2018) and 13 (2019) sites directly adjacent to, but outside of the reef tract boundary, were used to anchor the interpolations, but were not used to calculate average coral cover and benthic diversity for the reef tract.

Benthic Assemblage

Current Spatial Patterns: Benthic

Information on the benthic assemblage collected after the 2015 mass bleaching is limited for the Honolua FW (Table 2.1), making it difficult to describe the current composition and condition of its coral reefs. Since 2016, only nine sites have been surveyed within the MLCD, with six sites inside Honolua Bay and three inside Mokulēʻia Bay. While the Maui office of the Hawaiʻi Division of Aquatic Resources (DAR-Maui) conducted extensive surveys within and adjacent to the MLCD in 2018 and 2019 (n=42), much of the hardbottom within the MLCD is in shallow water and most of the sites surveyed were shallower than the 3 m minimum depth limit used throughout the Atlas. (Table 2.1). Fifty-six percent (2018) and 85% (2019) of the 2018-2019 survey sites were just shoreward of the reef tract's Atlas boundary. However, comparisons of the benthic assemblages at sites inside and just outside of the Honolua MLCD reef tract boundary showed differences, suggesting the results for the benthic assemblage discussed below are likely an accurate representation of the current condition of the reefs within the Honolua MLCD.

In addition, four 2018-2019 sites have been surveyed outside the MLCD, all within the Līpoa Point reef tract. However, three of these four sites were directly adjacent to the MLCD boundary (Figure 2.1). Given this sampling distribution, these sites are unlikely to be representative of the entire Līpoa Point reef tract and therefore have not been summarized in the Atlas. With the scarcity of recent data across the FW (*i.e.*, 13 total sites across the three reef tracts, with some supplemental data for the Honolua-Mokulēʻia MLCD), descriptions of the current condition of the benthic assemblage are restricted to the Honolua-Mokulēʻia MLCD reef tract and should be considered preliminary, even if they currently represent the best available information.

Turf was the dominant benthic organism within the Honolua-Mokulēʻia MLCD reef tract, covering 84.0 ± 3.3% of the hardbottom. Coral cover within the Honolua-Mokulēʻia MLCD reef tract was 12.4 ± 3.1%, and comprised nine coral species (Table 2.2), with *Porites lobata* (lobe coral) being the dominant coral. Other important species in the coral assemblage were *Pocillopora meandrina* (cauliflower coral), *Montipora patula* (sandpaper coral), and encrusting *M. capitata* (rice coral). As an assemblage, these coral species are typical of wave-exposed reefs in Hawaiʻi. While survey data are limited, coral cover in Honolua Bay (14.9 ± 4.4%) was twice that in Mokulēʻia Bay (7.5 ± 2.0), and the assemblage structure appears to differ. *Porites lobata* was the dominant coral in Honolua Bay, whereas *Pocillopora meandrina* dominated the coral assemblage in Mokulēʻia Bay. Both coral cover (Figure 2.2) and benthic diversity (Figure 2.3) were highest on the north side of Honolua Bay, where it averaged approximately 17%. Coral cover on the south side of Honolua Bay was approximately 8% and was similar to that found in the Mokulēʻia Bay. This would consistent with the north side of Honolua Bay being more sheltered from winter swells relative to the south side of the bay, as well as prevailing longshore currents moving potential stream inputs into the bay toward the south.

The largest spatial dataset for the Honolua FW predates the 2015 coral bleaching event by almost a decade (combined years 2006 and 2007), but given the limited data available post-2015, it may still be valuable to consider it to understand the relative structure of the benthic assemblages

Table 2.2. Average (±SEM) percent cover of benthic groups and taxa for the Honolua-Mokulēʻia MLCD reef tract (n=9) and the two bays that comprise the reef tract: Mokulēʻia Bay (n=3) and Honolua Bay (n=6). Data are from 2018-2019. Insufficient data were available to characterize the benthic assemblage for the Līpoa Point and O&H Bays reef tracts.

	MLCD	**Mokulēʻia Bay**	**Honolua Bay**
Turf	84.0 ± 3.3	87.7 ± 2.9	82.2 ± 4.8
Coral	12.4 ± 3.1	7.5 ± 2.0	14.9 ± 4.4
Porites lobata	5.4 ± 1.9	1.5 ± 0.3	7.4 ± 2.5
Pocillopora meandrina	2.9 ± 0.9	4.9 ± 1.9	1.9 ± 0.8
Montipora patula	2.1 ± 1.0	0.7 ± 0.1	2.8 ± 1.5
Montipora capitata	1.2 ± 0.7	0	1.7 ± 1.0
Porites compressa	0.4 ± 0.3	0	0.6 ± 0.4
Leptastrea bewickensis	0.2 ± 0.2	0	0.3 ± 0.3
Leptastrea purpurea	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Pavona varians	0.1 ± 0.1	0	0.1 ± 0.1
Pocillopora damicornis	0.1 ± 0.1	0.3 ± 0.3	0
Crustose Coralline Algae	1.9 ± 0.4	2.3 ± 1.1	1.7 ± 0.4
Macroalgae	<0.1	0	0.1 ± 0.1
Cyanobacteria	0	0	0
Other	0.6 ± 0.2	0.7 ± 0.4	0.6 ± .3
Abiotic	1.0 ± 0.5	1.9 ± 1.3	0.6 ± 0.3
Sand	1.0 ± 0.5	1.9 ± 1.3	0.6 ± 0.3
Other	0	0	0

throughout the FW prior to the bleaching event. These older data likely do not accurately reflect the current state of the benthic assemblage of these reefs. Indeed, comparing benthic cover of coral and turf within the two bays of the Honolua-Mokulēʻia MLCD finds lower coral and high turf cover post-2015 compared to 2006-2007 (Table 2.2 compared to Table 2.3). However, the relative cover between the two bays is similar in both data sets, suggesting the "spatial relationship" of the two bays is similar between the two sampling periods. This may indicate that broad spatial patterns that existed in the mid-2000s may still be relevant today, and managers may be able to derive some inference on the current condition of the reefs in the O&H Bays and Līpoa Point reef tracts from these older data. However, this would assume that the local environmental conditions across the Honolua FW have not changed significantly over the last decade, *e.g.*, sediment reduction has occurred in one but not the other bays.

Sampling effort from 2006-2007 was robust within the O&H Bays and Honolua-Mokulēʻia MLCD reef tracts (Table 2.1) and is likely to present an adequate description of the benthic assemblage over those years. Sampling in the Līpoa Point reef tract is low and spatial restricted to near the MLCD boundary, which will likely create a poor characterization of the entirety of this reef tract and thus is not summarized here.

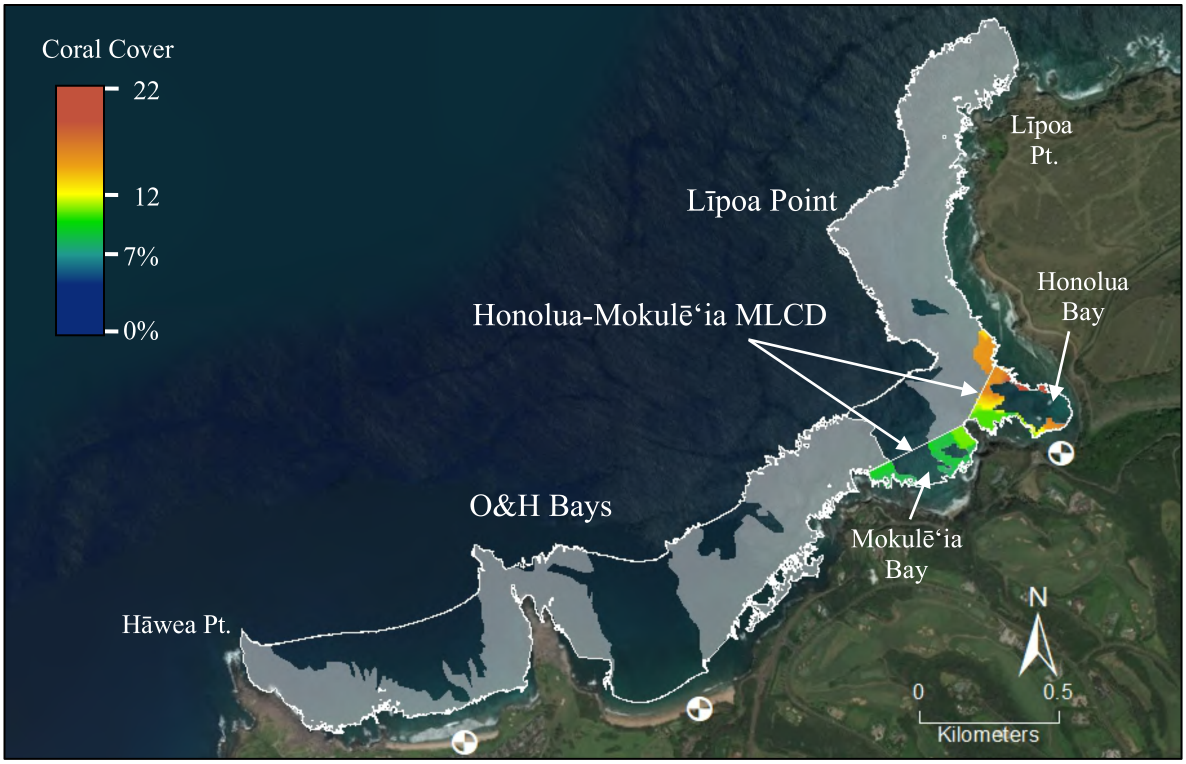

Figure 2.2. Coral cover across the Honolua FW. The map is interpolated from 2016-2019 survey data across hardbottom. White lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. White quadrant circles along the shore (west to east) are the Oneloa, DT Fleming Beach, Mokulē‘ia Bay (not pictured), and Honolua Bay long-term water quality monitoring sites. Note: Due to lack of data across most of the FW, no accompanying graph has been provided.

These pre-bleaching data show that the benthic assemblages in the two bays within the Honolua-Mokulē‘ia MCLD reef tract were different (Figure 2.4). Coral cover was significantly higher in Honolua Bay compared to Mokulē‘ia Bay (t-test; t_{82}=5.53; p<0.005). At a broad scale, coral cover in Honolua Bay (and presumably the most southerly part of the Līpoa Point reef tract) was twice that of the reefs in Mokulē‘ia Bay and the O&H Bays reef tract (Table 2.3), a finding consistent with the current (2018-2019) data. Lower coral cover south of Honolua Bay was offset by higher turf and macroalgal cover.

In the mid-2000s, benthic assemblages appear to be influenced more by factors other than the MLCD designation; the reefs in the two bays inside the MLCD were more similar to the adjacent reefs outside the protected area than with the other reefs inside the MLCD. Inside the MLCD, a wide sand channel bisected the reef, creating two distinct contiguous reef areas (Figure 2.4). The reefs in Mokulē‘ia Bay were part of the reef area extending to the southwest while those on the north side of Honolua Bay were contiguous with the reef extending northward toward Līpoa Point.

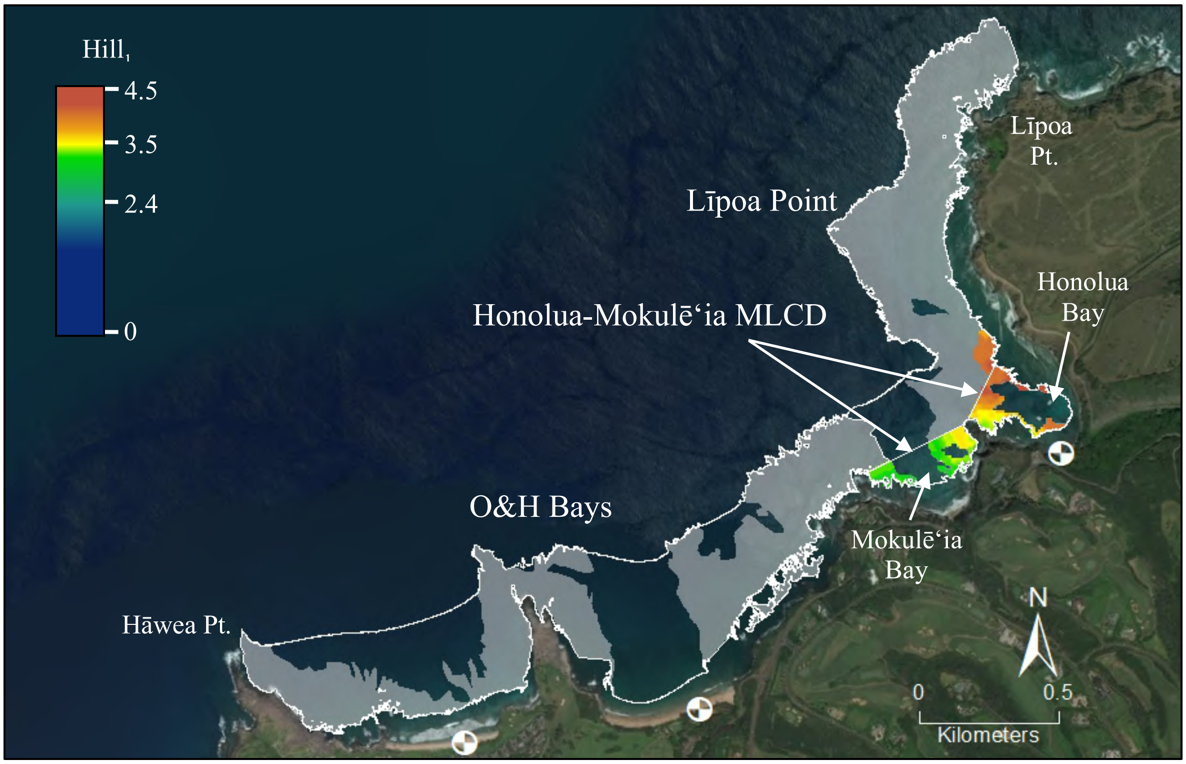

Figure 2.3. Effective species richness ($Hill_1$) across the Honolua FW. The map is interpolated from 2016-2019 survey data across hardbottom. White lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. White quadrant circles along the shore (west to east) are the Oneloa, DT Fleming Beach, Mokulēʻia Bay (not pictured), and Honolua Bay long-term water quality monitoring sites. Note: Due to lack of data across most of the FW, no accompanying graph has been provided.

Because of historical sediment deposits from its pineapple agriculture days and its relatively large size, the Honolua watershed is one of the highest sediment-exporting watersheds in the West Maui Region (WMR)[10]. Recent events have deposited many tons of sediment into the bay, and turbidity levels are consistently among the highest in the region[11]. Curiously, coral cover both in the mid-2000s (2006-2007) and over recent years (2016-2019) appears to be higher in Honolua Bay than in either Mokulēʻia Bay (which has no stream input) or within the O&H Bays reef tract, although strong evidence exists suggesting sediment impacts have caused substantial declines in coral cover within Honolua Bay in recent decades (discussed below). Longshore currents in this area typically move from north to south[12], and fresh, sediment-laden water wraps around the point separating Mokulēʻia Bay from Honolua Bay, which may explain the lower coral cover observed downstream of the Honolua watershed. This might provide some

[10] Falinski (2016)
[11] Hui O Ka Wai Ola (2018)
[12] Storlazzi *et al.* (2003)

Table 2.3. Average (±SEM) percent cover of benthic groups from 2006-2007 in O&H Bays (n=50) and the Honolua-Mokulēʻia MLCD (n=54) reef tracts. Values are also provided for the two bays that comprise the MLCD: Mokulēʻia Bay (n=20) and Honolua Bay (n=34). Insufficient data were available for the Līpoa Point reef tract.

		Honolua-Mokulēʻia MLCD		
	O&H Bays	**MLCD**	**Mokulēʻia Bay**	**Honolua Bay**
Turf	46.2 ± 2.0	47.1 ± 2.5	55.4 ± 3.0	42.3 ± 3.3
Coral	9.0 ± 1.2	21.0 ± 2.0	10.9 ± 1.9	26.9 ± 2.4
CCA	6.4 ± 0.7	10.6 ± 1.0	12.6 ± 1.9	9.4 ± 1.2
Macroalgae	17.8 ± 1.6	7.1 ± 1.1	9.1 ± 1.8	5.9 ± 1.3
Abiotic	18.6 ± 1.6	12.7 ± 2.4	9.5 ± 2.1	14.6 ± 3.7

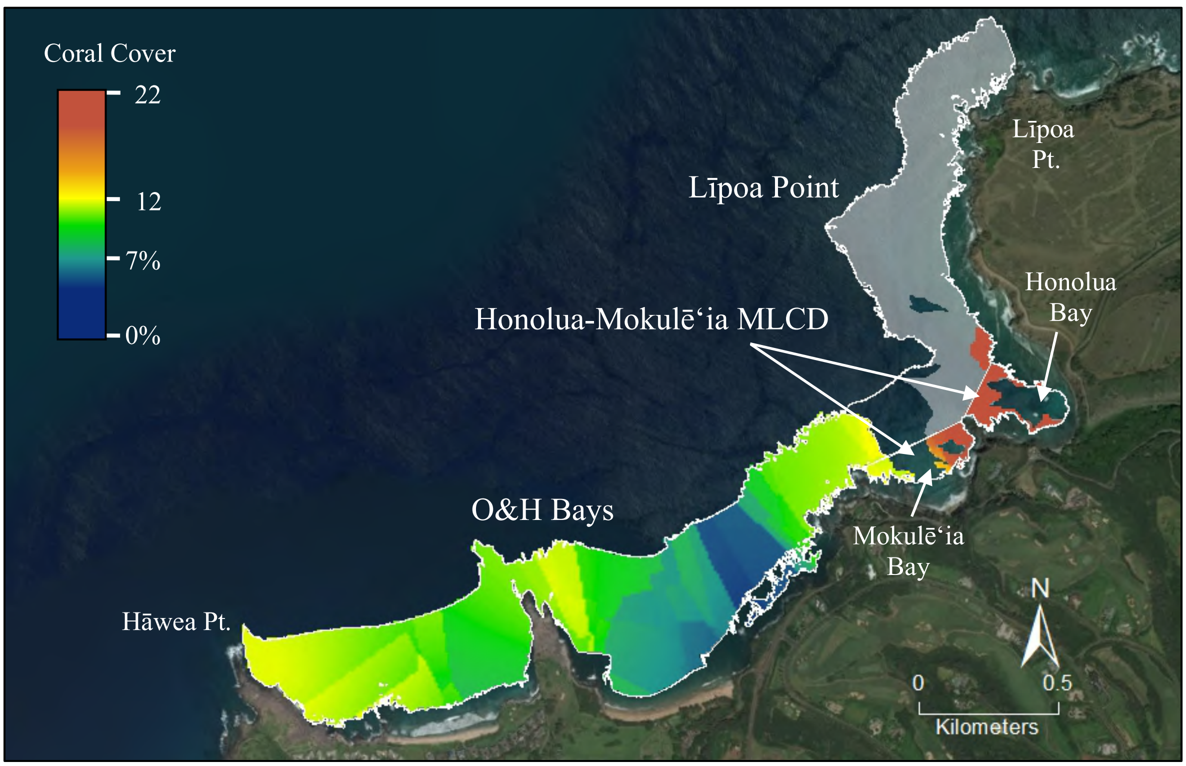

Figure 2.4. Coral cover within the Honolua FW from the mid-2000s; data were combined from surveys in 2006 and 2007. Surveys of the Līpoa Point reef tract were limited in number (n=3) and spatially restricted to the southern end of the reef tract, so the northern part of this reef tract has been excluded from the figure.

explanation of the differences between sites, even though Mokulē'ia Bay does not have a stream to input sediment. Assessments[13] conducted at a handful of sites just prior to the onset of the mass coral bleaching event in 2015 noted that all three of their sites in this FW appeared compromised by stressors associated with human activity, but specifically identified evidence of sediment impairment at their site in Honokahua Bay (O&H Bays reef tract). Water quality monitoring since 2006 also indicates that the O&H Bays reef tract experiences elevated nutrients (likely from development, landscaping, and golf courses).

Historical Patterns: Benthic

An 18-year time series of data (1999-2016) is available for two permanent reef monitoring sites in Honolua Bay. Unlike other locations that are part of the Hawai'i Coral Reef Assessment and Monitoring Program (CRAMP), the two sites in Honolua Bay are not a shallow/deep depth-pair, but instead are at similar depth (3 m) on opposite sides of the bay. The sites are designated "Honolua South" and "Honolua North."

Both sites indicate reef degradation has occurred in Honolua Bay since 1999, resulting in a 65% and 27% reduction of coral at the Honolua South and Honolua North sites, respectively (Figure 2.5). Initially, coral cover at the Honolua South site was ~30% greater than the Honolua North site and maintained this level of cover through 2004, after which it declined sharply. In contrast, Honolua North appears to have undergone a less precipitous decline in cover from 15% to 11%

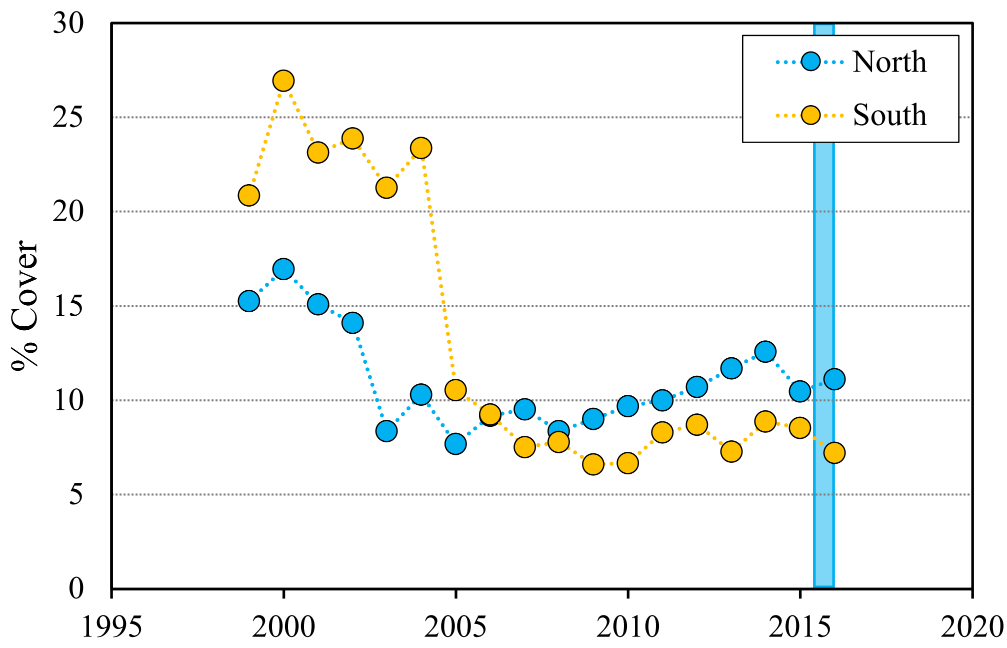

Figure 2.5. Coral cover at the Honolua North (blue) and Honolua South (gold) CRAMP monitoring sites within the Honolua Bay from 1999-2016. The blue bar signifies the approximate months over which the 2015 mass coral bleaching event affected Maui reefs.

[13] PIFSC (2017)

coral cover over a similar timeframe. Since 2005, coral cover has fluctuated between 8-12% at both sites, with the Honolua South site having lower cover than the Honolua North every year since 2007. This pattern is consistent with those expected from sediment events in Honolua Bay. Longshore currents would carry sediment onto the reef along the south side of the bay, and the precipitous drop from 2004 to 2005, suggests one or more large sediment events may have occurred during this time period. The last half of 2004 and first half of 2005 were notable for extended and severe rainfall events across the Hawaiian Islands[14], including Maui, which indicates conditions were present that could have facilitated a large sediment event at Honolua.

While the two long-term monitoring sites provide insufficient spatial coverage from which to draw rigorous conclusions, the 2015 mass bleaching event does not appear to have had a large effect on the reefs in Honolua Bay. The 2015 bleaching event affected many of the reefs in the Main Hawaiian Islands (MHI), especially on Maui, where it reduced coral cover by 20-40% in the WMR[15] and altered coral species composition. Coral such as *P. meandrina* were particularly affected, and on some reefs, colony mortality was >90%[16]. These losses, along with the potential for future losses from bleaching, prompted a petition from the Center for Biological Diversity to list the species in Hawaiʻi under the Endangered Species Act (CBD 2018). However, *P. meandrina* appeared to be relatively abundant in the Honolua area in 2018 (Table 2.2), including many large colonies, which would have been present during, and thus survived, the 2015 coral bleaching event. The prevalence and severity of bleaching is often spatially heterogenous, and may be mitigated by local environmental and oceanographic conditions such as the upwelling of cool water, freshwater inputs, water clarity, etc. While it would be desirable to attribute some benefit to the reef during the bleaching event associated with the protections afforded by the MLCD, the lack of data preclude such determination either way, and so while it is conceivable that the MLCD was beneficial to reef resilience, it is currently unclear why the 2015 coral bleaching event had little observable effect on the reefs at Honolua.

Coral Health and Reef Resilience

In March 2018, a reef resilience assessment of leeward Maui was conducted by The Nature Conservancy (TNC) and its partners. These assessments were intended to quantify the relative resilience of Maui's reefs to the effects of climate change. Resilience is the ability of a reef to resist, recover from, and adapt to a climate-related event (*e.g.*, coral bleaching) to maintain a diverse, coral-rich state that provides key ecological functions and services to people[17]. Given the integral role of reefs to the people of Hawaiʻi, reef resilience is closely linked with social resilience, which is the ability of human communities to adapt to social, political, environmental, or economic change[18].

Two shallow-water and one deep-water (Table 2.4) reef resilience sites were surveyed within the Honolua FW. The complete results of TNC's Maui Reef Resilience assessment are detailed

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[14] For example, see Chu *et al.* (2009)
[15] SSRI (2017)
[16] Minton *et al.* (2018b)
[17] Nystrom and Folke (2001)
[18] Adger (2000)

Table 2.4. The three reef resilience (RR) sites within the Honolua FW. "RR Rank" is the relative reef resilience rank among 31 shallow and 20 deep sites along leeward Maui, with 1 being the most resilient and higher numbers indicating less resilience. "Dis. Prev." is the percent of colonies presenting at least one disease. "ALOG" is the percentage of colonies being overgrown by benthic algae. "Paling/Bleaching" is the percent of colonies showing signs of tissue paling or bleaching. Average values for the WMR (italics) are presented for comparison.

RR Site	Reef Tract	RR Rank	Dis. Prev.	ALOG	Paling/ Bleaching
Shallow	*WMR Average*		*2.4 ± 0.5*	*9.6 ± 1.5*	*18.2 ± 4.8*
Honolua South	Honolua-Mokulēʻia MLCD	S17/31	0.3	8.7	1.1
Honolua North	Honolua-Mokulēʻia MLCD	S5/31	0.9	5.1	1.6
Deep	*WMR Average*		*1.4 ± 0.3*	*7.2 ± 1.5*	*19.9 ± 6.4*
Līpoa Point	Līpoa Point	D11/20	1.3	3.1	2.0

elsewhere[19], so only the coral health and resilience findings for the sites in the Honolua FW are summarized here.

The prevalence of coral disease and bleaching (Table 2.4) were low at all three sites when compared to the WMR average. At two of the resilience sites, prevalence of coral disease was <1% of colonies, and paling/bleaching never exceeded 2% of the colonies at any of the three sites. Overgrowth by algae was more prevalent than disease or bleaching, but still below the average for the WMR.

As part of the reef resilience assessment, the 31 shallow-water and 20 deep-water sites were assigned a relative reef resilience rank, based on several indicator variables, including coral cover, coral disease prevalence, coral diversity, coral recruitment, reef builder ratio (ratio of calcifying species to non-calcifying species), rugosity, and herbivorous fish biomass. Among the sites in the Honolua FW, the Honolua North reef resilience site was categorized as having high potential resilience and Honolua South site as having medium-low resilience in comparison to the other 31 shallow-water sites. These relative resilience ranks are interesting given the historical patterns at these two locations, specifically the large decline in coral cover at the Honolua South site between 2004 and 2005, but no similar decline at the Honolua North location. The Līpoa Point reef resilience site ranked in the lower half for resilience among the leeward Maui deep sites and was categorized as medium-low.

[19] Maynard *et al.* (2019)

Fish Assemblage

Current Spatial Patterns: Fish

Total fish biomass in the Honolua FW was highest on the reef areas within the Honolua-Mokulēʻia MLCD (Figure 2.6), especially those within Honolua Bay and on the reefs adjacent to the rocky point that separates Honolua Bay from Mokulēʻia Bay. Total fish biomass within the Honolua-Mokulēʻia MLCD reef tract (111.8 ± 19.2 g/m^2) was more than twice that of the adjacent Līpoa Point reef tract (51.2 ± 14.2 g/m^2) and almost 4-times that of the O&H Bays reef tract (31.7 ± 5.0 g/m^2). While higher biomass was observed for most fish families within the Honolua-Mokulēʻia MLCD compared to the two other reef tracts (Table 2.5), the largest difference among the reef tracts was in surgeonfish (Acanthuridae), which was the most abundant family and had nearly 3-times more biomass within the Honolua MLCD than within either of the other two reef tracts. Potential effects of the MLCD on the fish assemblage are discussed in detail below. Fish biomass was low in Honokahua Bay and around Makaluapuna Point into Oneloa Bay, where current data are sparse (Figure 2.6). Given this lack of data, the status of the reef fish assemblage in Oneloa Bay is unclear and represents an information gap.

Resource fish biomass, which is comprised of species important for consumption[20] and that tend to be prized by fishers, showed a spatial pattern similar to total fish biomass (Figure 2.7). The Honolua-Mokulēʻia MLCD (67.2 ± 14.2 g/m^2) reef tract had over 3-times the resource fish biomass as O&H Bays (21.1 ± 4.6 g/m^2) and nearly twice that of the Līpoa Point (37.8 ± 13.9 g/m^2) reef tracts. Variability in resource fish biomass was high, especially within the Honolua-Mokulēʻia MLCD and Līpoa Point reef tracts, and was driven by several sites with very high resource fish biomass.

Resource fish composition and relative biomass differed among the three reef tracts (Figure 2.8), but most notably between Līpoa Point and the other two reef tracts. No single resource fish group dominated the Līpoa Point reef tract; instead three groups, surgeonfish, parrotfish, and goatfish comprised 95% of the resource fish biomass. In contrast, surgeonfish alone comprised 90% of the resource fish biomass in the O&H Bays reef tract, and 75% of the Honolua-Mokulēʻia MLCD reef tract. The Honolua-Mokulēʻia MCLD was the only reef tract in the FW to have all resources groups. Notably, redfish were only observed inside the MLCD, and apex predators had 7-times greater biomass inside compared to reef tracts outside the MLCD. Apex predator richness was also higher, including three species of jack (*Caranx melampygus* [bluefin trevally], *Carangoides orthogrammus* [island trevally], and *Scomberoides lysan* [doublespotted queenfish]) as well as the snapper *Aprion virescens* (green jobfish).

Prime spawners are individual resource fish >70% of the maximum length for that species. These individuals tend to exert a disproportionately large effect on population dynamics due to their considerably higher fecundity and egg quality compared to smaller individuals[21]. Conservation of prime spawners is important to maintaining sustainable fisheries and ecosystems.

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[20] See Appendix B for a list of resource and non-resource species
[21] Birkeland and Dayton (2005) and Hixon *et al.* (2014)

Table 2.5. Average (±SEM) fish biomass (g/m^2) by family O&H Bays (n=26), Honolua-Mokulēʻia MLCD (n=28), and Līpoa Point (n=27) reef tracts. Data are from 2016-2018.

	O&H Bays	**Honolua-Mokulēʻia MLCD**	**Līpoa Point**
Acanthuridae	22.3 ± 4.7	56.8 ± 14.6	17.4 ± 3.4
Balistidae	4.5 ± 0.9	10.0 ± 2.6	5.8 ± 0.7
Scaridae	0.1 ± .10	8.8 ± 2.3	6.6 ± 2.5
Kyphosidae	0	8.1 ± 6.6	0.1 ± 0.1
Monacanthidae	0.5 ± 0.3	4.3 ± 1.3	1.9 ± 1.1
Kuhliidae	0	3.8 ± 3.8	0
Mullidae	0.9 ± 0.3	3.1 ± 1.2	14.1 ± 13.6
Serranidae	0	3.0 ± 1.3	0.1 ± 0.1
Lutjanidae	0	2.8 ± 1.7	0.1 ± 0.1
Labridae	1.5 ± 0.3	2.3 ± 0.5	2.5 ± 0.5
Chaetodontidae	0.4 ± 0.1	2.2 ± 0.4	1.2 ± 0.4
Pomacentridae	0.2 ± 0.1	1.4 ± 0.7	0.2 ± 0.1
Carangidae	0.4 ± 0.3	1.2 ± 0.4	0.4 ± 0.3
Mugilidae	0	1.1 ± 1.1	0
Lethrinidae	0.2 ± 0.2	1.0 ± 1.0	0.2 ± 0.1
Holocentridae	0	0.6 ± 0.5	0
Aulostomidae	<0.1	0.4 ± 0.3	0.1 ± 0.1
Diodontidae	0	0.3 ± 0.3	0
Zanclidae	0.4 ± 0.1	0.2 ± 0.1	0.1 ± 0.1
Cirrhitidae	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Tetraodontidae	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Fistulariidae	0	0.1 ± 0.1	0.1 ± 0.1
Ostraciidae	<0.1	<0.1	0
Blenniidae	<0.1	<0.1	<0.1
Apogonidae	<0.1	<0.1	0
Caracanthidae	<0.1	0	<0.1
Gobiidae	<0.1	0	0
Malacanthidae	<0.1	0	0
Microdesmidae	<0.1	0	<0.1
Pomacanthidae	0	0	<0.1
Synodontidae	0	0	<0.1
Total Fish Biomass	**31.7 ± 5.0**	**111.8 ± 19.2**	**51.2 ± 14.2**

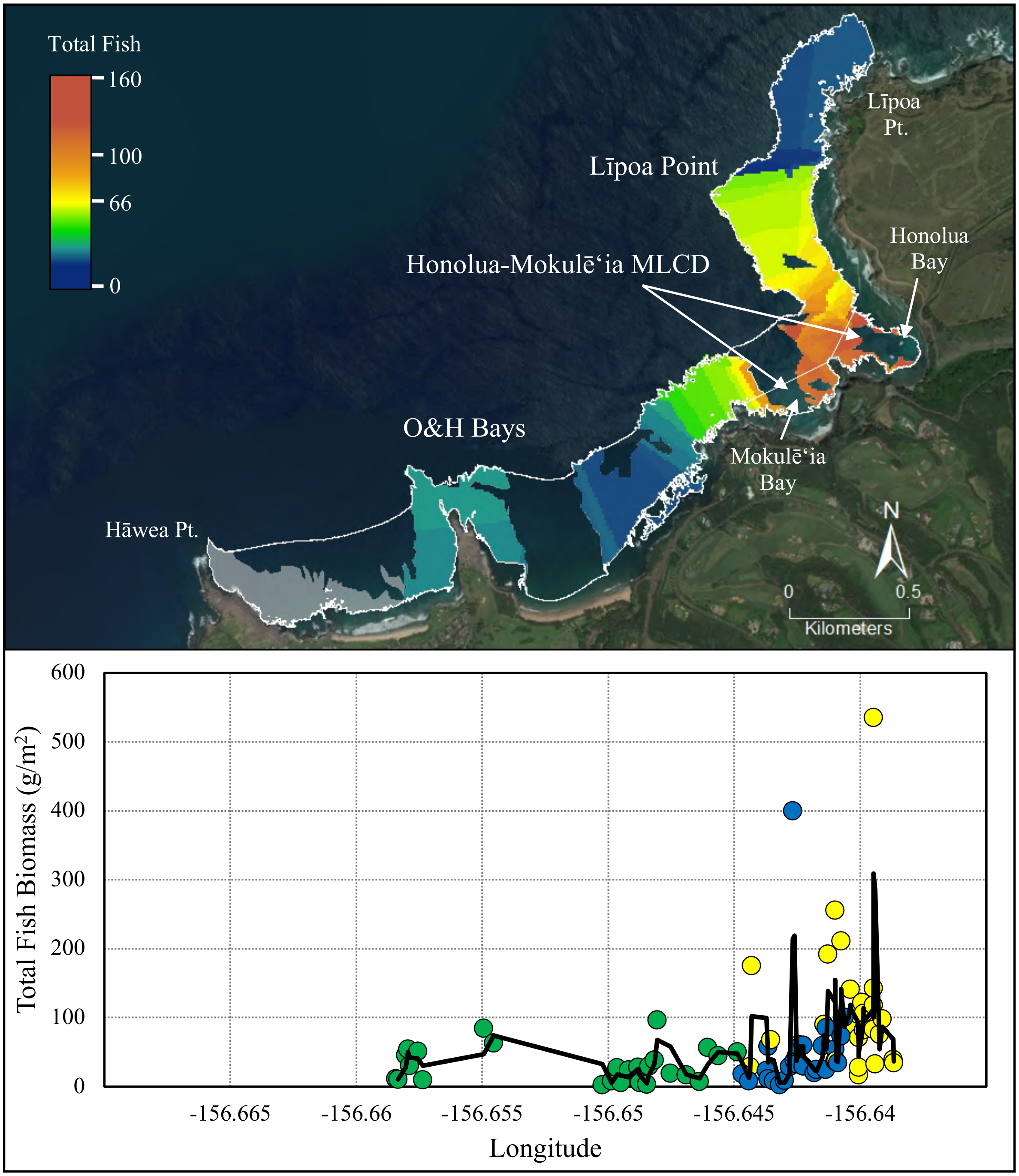


Figure 2.6. Total fish biomass across the Honolua FW. The map (top) is interpolated from 2016-2018 survey data across hard hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of total fish biomass across at consecutive survey sites along the east-west axis. Colored points in the graph correspond with the O&H Bays (green), Honolua-Mokulēʻia MLCD (yellow), and Līpoa Point (blue) reef tracts.

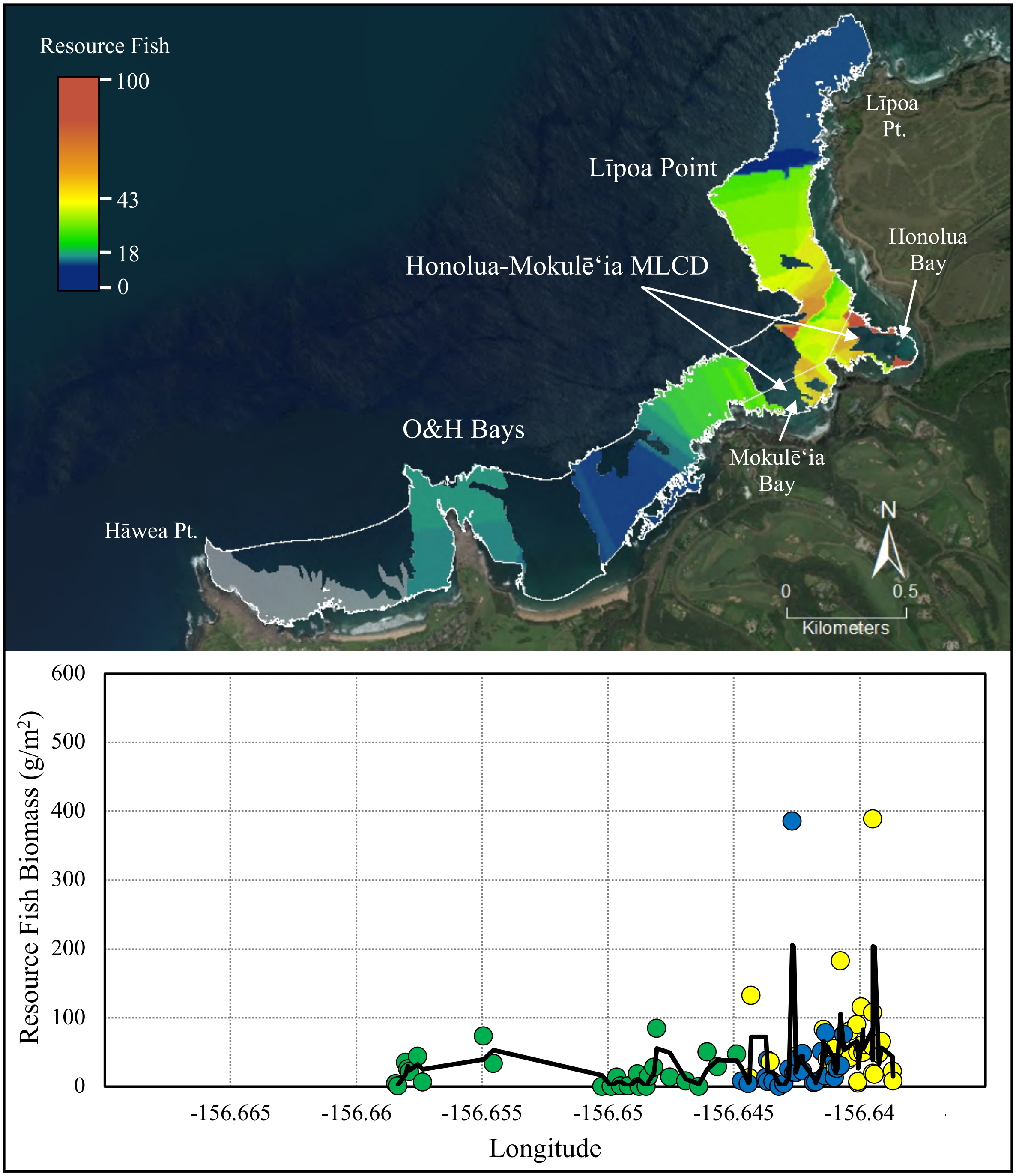


Figure 2.7. Resource fish biomass across the Honolua FW. The map (top) is interpolated from 2016-2018 survey data across hard hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of resource fish biomass across at consecutive survey sites along the east-west axis. Colored points in the graph correspond with the O&H Bays (green), Honolua-Mokulēʻia MLCD (yellow), and Līpoa Point (blue) reef tracts.

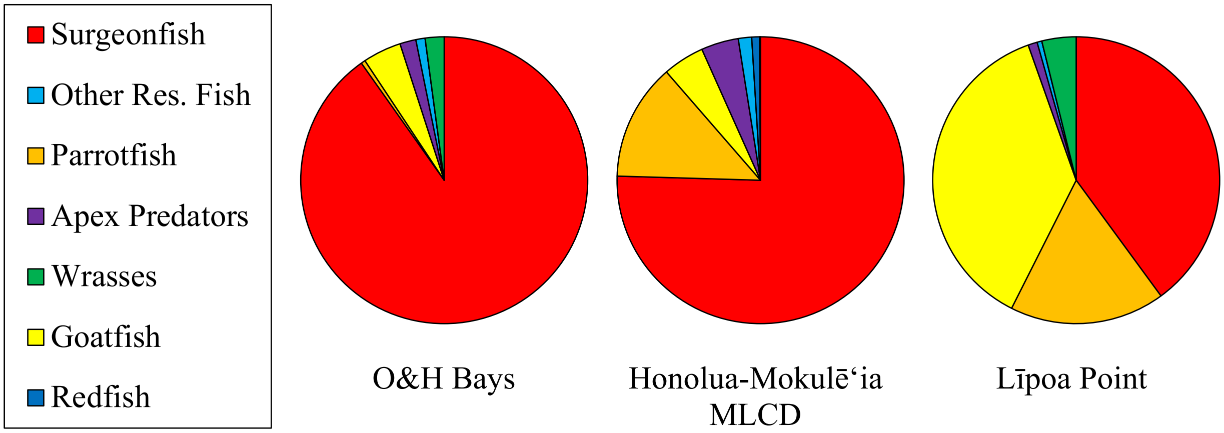


Figure 2.8. The relative composition (percent of total resource fish biomass) of the resource fish by group for the O&H Bays, Honolua-Mokulēʻia MLCD, and Līpoa Point reef tracts. Data are from 2016-2018.

The Honolua-Mokulēʻia MLCD reef tract had higher average prime spawner biomass (22.7 ± 9.8 g/m^2) than either the Līpoa Point (2.1 ± 0.7 g/m^2) or O&H Bays (4.6 ± 1.9 g/m^2) reef tracts. Compared to some other FWs in the WMR (*e.g.*, Olowalu, Kahekili), diversity of prime spawners was relatively low across the Honolua FW, totaling only 11 species in three families (Acanthuridae, Mullidae, and Scaridae). No apex predator prime spawners were observed. Outside the Honolua-Mokulēʻia MCLD, two surgeonfish, *Acanthurus olivaceus* (orangeband surgeonfish) and *Naso lituratus* (orangespine unicornfish), comprised about 70% of the prime spawner biomass. Inside the MLCD, *A. blochii* (ringtail surgeonfish) and *A. triostegus* (convict tang) were dominant, accounting for almost 77% of the prime spawner biomass.

Prime spawner variability is often high and generally results from many "zeroes," *i.e.*, survey sites at which no prime spawners were observed. While many zero sites were present for all three reef tracts in the Honolua FW, the Honolua-Mokulēʻia MLCD reef tract had fewer zero sites (50%) than either the Līpoa Point (70%) or O&H Bays (65%) reef tracts, and also more sites with high prime spawner biomass; of the ten sites with highest prime spawner biomass in the FW, eight were within the Honolua-Mokulēʻia MLCD reef tract.

Prime spawner biomass was not uniformly distributed within the Honolua MLCD (Figure 2.9). Mokulēʻia Bay had lower prime spawner biomass than Honolua Bay, but the low sampling effort in Mokulēʻia Bay makes it difficult to conduct a detailed assessment. Of the five survey sites in Mokulēʻia Bay, only one had prime spawners (20%). In contrast, 57% of the survey sites in Honolua Bay had prime spawners, often with biomass well in excess of that found at the single Mokulēʻia Bay site where they were also present. Not surprisingly, prime spawner diversity was lower in Mokulēʻia Bay, but this may be an artifact of the low sampling effort. The dominant structure of the prime spawner assemblage was similar between the two bays—*i.e.*, *A. blochii* was the most common in both bays, with the "rare" primer spawner species being absent from

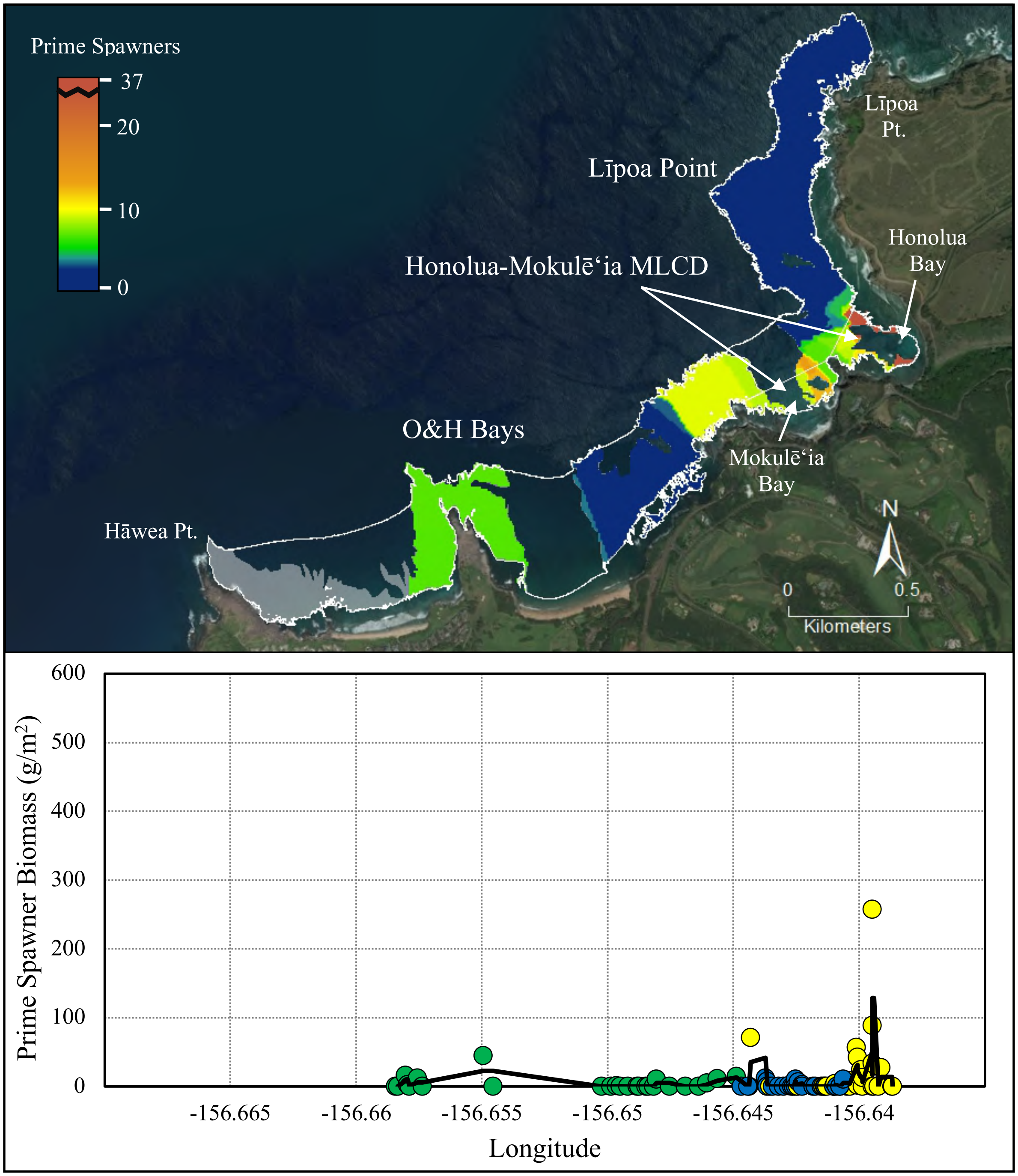


Figure 2.9. Prime spawner biomass across the Honolua FW. The map (top) is interpolated from 2016-2018 survey data across hard hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of prime spawner biomass across at consecutive survey sites along the east-west axis. Colored points in the graph correspond with the O&H Bays (green), Honolua-Mokulē'ia MLCD (yellow), and Līpoa Point (blue) reef tracts.

Mokulēʻia Bay. As with total fish and resource fish biomass, Mokulēʻia Bay likely has lower prime spawner biomass than Honolua Bay, but the biomass is still considerably greater than that found outside the MLCD.

In general, effective species richness (measured as $Hill_1$ number) for fish was higher on the north side of the FW (Figure 2.10). The Līpoa Point reef tract (6.9 ± 0.5) had higher average effective species richness than O&H Bays reef tract (5.3 ± 0.5), with the highest effective species richness for the entire Honolua FW occurring at the most northerly sites off Līpoa Point. While the waters off points of land are often areas of high fish abundance, biomass, and diversity (*e.g.*, Hāwea Point, Makaluapuna Point in the O&H Bays reef tract), Līpoa Point is also the farthest location in the WMR from a major population center such as Wailuku, Lāhaina, and Kihei.

The highest average effective species richness for fish was within the Honolua-Mokulēʻia MLCD reef tract (7.6 ± 0.4). This high fish diversity is likely a result of the protected area but may also be associated with better quality of reef fish habitat compared to other reef tracts in the FW.

Fishing effects can often be detected by examining the average individual size of species by their importance in the fishery. High fishing pressure should lower the average size of more heavily-fished than less-heavily fished species, assuming other potential non-fishing stressors affect the species similarly[22]. Therefore, a ratio of average individual size can be used to compare fish populations between two reef areas and infer the relative effects of fishing versus non-fishing effects on those fish assemblages. The size of 20 common species was compared across the three reef tracts in the Honolua FW, and no significant differences were found between the Honolua-Mokulēʻia MLCD and either the O&H Bays or Līpoa Point reef tracts for resource, non-resource, or moderately-prized species (Figure 2.11); however, the MLCD showed a trend toward larger sized larger fish, especially compared to the O&H Bays reef tract (Figure 2.11b).

Historical Patterns: Fish

While a time series of fish data exists for the Honolua FW, it is sporadically distributed through time (2002, 2006, 2007, and 2018[23]), which can make interpretation difficult, especially for fish because they have naturally high spatial and temporal variability. Analysis of the Honolua FW is also complicated by the Honolua-Mokulēʻia MLCD, which was established in 1978, nearly 25 years before the first surveys in the time series. Twenty-five years is long enough to expect many of the benefits expected from the protected area to have accrued, which could make interpretation of the time series results difficult.

[22] This assumption is generally true, but it is important to note that reef fish species have different habitat requirements and thus would display a differential response to environmental stressors or changes in environmental conditions. However, when averaged over many species, these species-specific differences should be reduced.

[23] The 2016 data include only four surveys conducted inside the Honolua-Mokulēʻia MLCD, so this data set was removed from the analysis, but is addressed during the discussion of temporal change within the Honolua-Mokulēʻia MLCD.

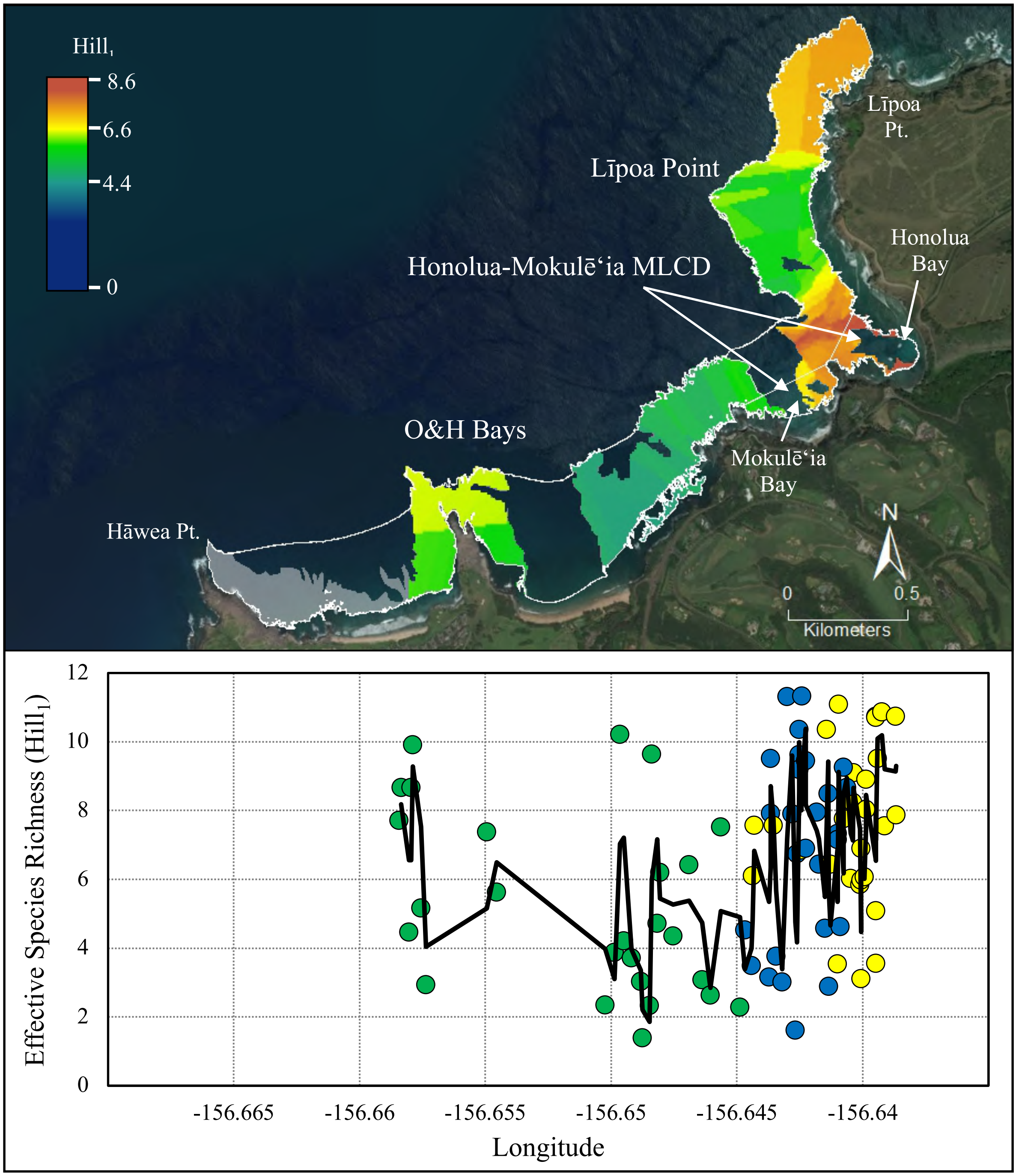


Figure 2.10. Effective species richness for fish (Hill$_1$) across the Honolua FW. The map (top) is interpolated from 2016-2018 survey data across hard hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of effective species richness across at consecutive survey sites along the east-west axis. Colored points in the graph correspond with the O&H Bays (green), Honolua-Mokulēʻia MLCD (yellow), and Līpoa Point (blue) reef tracts.

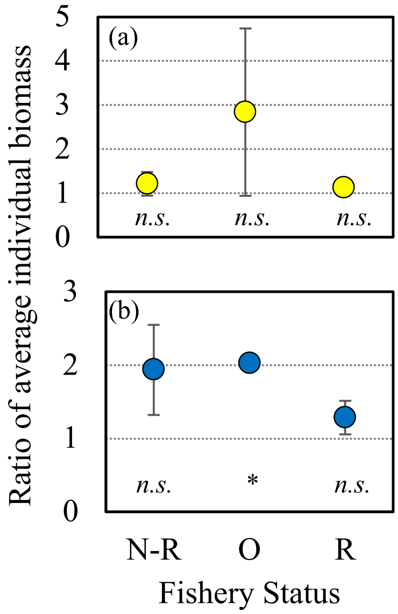


Figure 2.11. Comparison of fish size (ratio of average individual biomass) between (a) Honolua-Mokulēʻia MLCD and Līpoa Point and (b) Honolua-Mokulēʻia MLCD and O&H Bays reef tracts. A ratio=1 means the fish in the two reef tracts were of approximately equal size within the two reef tracts, a ratio>1 means fish within the Honolua-Mokulēʻia MLCD reef tract were larger on average than the other reef tract, and a ratio<1 indicates fish within the Honolua-Mokulēʻia MLCD reef tract were smaller on average than the other reef tract. N-R=non-resource fish (8 species), O=other moderately-prized fish (4 species), R=resource fish (10 species). Significance was tested using a 1-sample t-test. *=not enough species shared by the two reef tracts to conduct a statistical test.

While our analysis found a marginally-significant difference among survey years for total fish biomass (ANOVA; $F_{4, 192}$=2.6, p=0.051), follow up comparisons could detect no differences among the years, suggesting any change in total fish biomass that may have occurred through time within the Honolua FW is small (Figure 2.12a). We also detected no difference in the temporal trend for fish inside versus outside the MLCD; neither assemblage appears to have noticeably changed in total fish biomass since 2002. A similar pattern holds for resource fish (Figure 2.12b); while an effect was found between the years (ANOVA; $F_{4, 192}$=3.0, p=0.033), it was sufficiently small that it could not be detected among the years, suggesting changes through time are likely small. However, prime spawner biomass has significantly decreased since 2002 (ANOVA; $F_{4, 192}$=7.6, p<0.001), with prime spawner biomass in 2018 being significantly lower than in previous years (Figure 2.12c). Data also suggest that declines in prime spawners have been larger inside the Honolua-Mokulēʻia MLCD than outside. Reasons for this decline are unclear, but it occurred both inside and outside the MLCD.

Effect of the Honolua-Mokulēʻia MLCD

The purpose of this report is not to assess the effectiveness of the Honolua-Mokulēʻia MLCD; however, the potential effects of this marine life conservation district cannot be ignored when examining the fish assemblage within Honolua FW. The Honolua-Mokulēʻia MLCD was established in 1978 and restricted the take all of fish and the possession of fishing gear (with some permitted exceptions) within the MLCD boundary. Previous studies of the effectiveness of the MLCD have been weakened by a lack of rigorous pre-closure data and have focused on comparisons of the fish assemblage inside and outside the MLCD. These comparisons are complicated by the potential confounding caused by differences in fish habitat quality that are difficult to account for without pre-closure information.

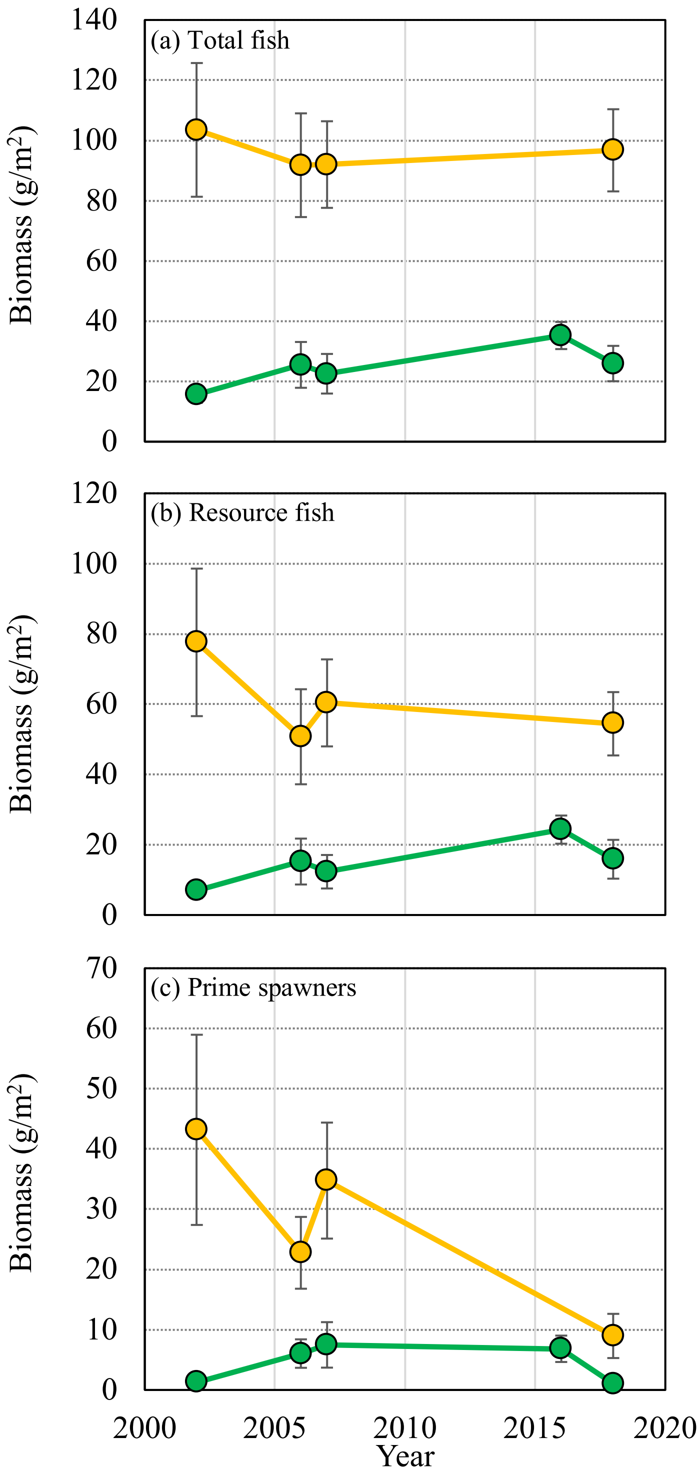


Figure 2.12. (a) Total fish, (b) resource fish, and (c) prime spawner biomass within the Honolua-Mokulēʻia MLCD (orange) and O&H Bays (green) reef tracts between 2002 and 2018. Too few data were collected within the Honolua-Mokulēʻia MLCD reef tract in 2016 and were excluded from the figure.

While this study is limited by these same important caveats, the Honolua-Mokulēʻia MCLD appears to be having positive effects on the fish assemblage. Total fish (ANOVA; $F_{1,\,192}$=108.4, p<0.001), resource fish (ANOVA; $F_{1,\,192}$=86.2, p<0.001), and prime spawner (ANOVA; $F_{1,192}$=66.1, p<0.001) biomass are all significantly higher inside the MLCD than outside and appear to be spilling over the boundary onto the adjacent reef (Figures 2.6, 2.7, and 2.9). However, non-resource fish biomass was also greater inside than outside the MLCD (ANOVA; $F_{1,3}$=84.5, p<0.001), suggesting habitat may also be responsible for or contributing to this pattern. Resource fish biomass over the past 16 years has been nearly 6-times greater inside compared to outside the MLCD, whereas non-resource fish biomass has been about 2.5-times greater. If the fishery management actions have no effect on the biomass pattern, the ratio of both resource and non-resource should be similar (a 2.5-times increase). Resource fish biomass also increases more rapidly than non-resource fish biomass when approaching the MLCD boundary (Figure 2.13), suggesting a management effect, while also providing supporting evidence that resource fish are spilling over the boundary. The larger response of resource fish compared to non-resource fish to the MLCD suggests they have gained additional benefit from the protected area above any habitat effect when compared to their lightly-fished counterparts.

The Big Picture

Within the context of the WMR, reef resources in the Honolua FW show variable levels of condition. Recent benthic data (2016-2019) were spatially limited to the reefs in and near the Honolua-Mokulēʻia MLCD, and these reefs were variable, tending to have below average coral cover when compared to the WMR. In contrast, benthic diversity was high. Ample evidence exists suggesting the condition of coral and the benthic assemblage more broadly has declined across the Honolua FW since the early 2000s. Even so, some of the areas appear to have maintained high potential reef resilience to climate change, and efforts to better identify these reef areas and enact actions to improve their resilience would be warranted. Currently, data suggest these resilient reefs are within the Honolua-Mokulēʻia MLCD reef tract, but others may exist elsewhere within the FW. The Honolua FW would benefit from benthic surveys conducted across a broader spatial scale, and especially within the O&H Bays and Līpoa Point reef tracts.

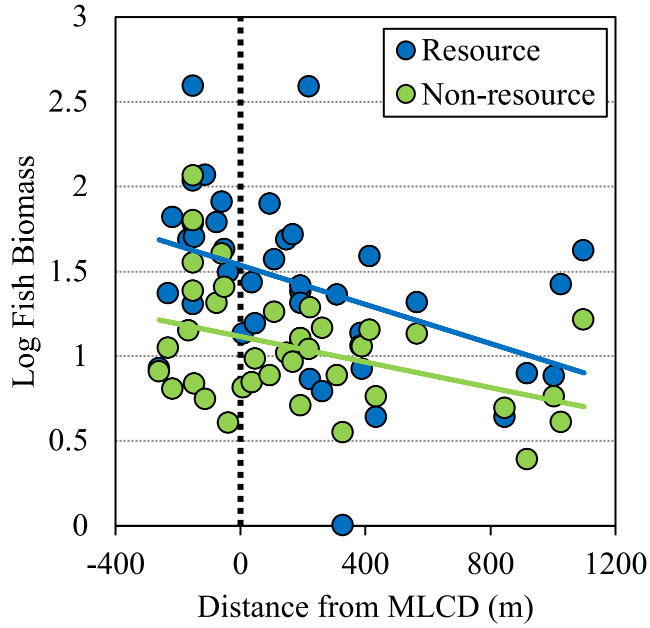


Figure 2.13. Resource and non-resource fish biomass ($\log_{10}$[biomass+1]) versus distance from the boundary of the Honolua-Mokulēʻia MLCD for 39 sites on the contiguous reef along the north side of Honolua Bay and extended into the Līpoa Point reef tract. Negative distance values are inside the MLCD. Linear trendlines are provided to aid with visual interpretation.

The fish assemblage within the Honolua-Mokulēʻia MLCD reef tract had the highest total fish, resource fish, and prime spawner biomass of any reef tract in the WMR (see Chapter 1). Reef fish diversity was also high. The reef fish assemblage in both the O&H Bays and Līpoa Point reef tracts were close to the WMR average for total fish, resource fish, and prime spawner biomass, although the Līpoa Point reef tract may be benefiting from spillover from the MLCD and what appears to be relatively low fishing effort when compared to other reefs in the WMR (Ocean Tipping Points 2016, Chapter 1).

Statewide Context

Averages for coral cover (14.4 ± 0.7%), total fish biomass (40.9 ± 2.5 g/m^2), resource fish biomass (22.3 ± 1.8 g/m^2), and prime spawner biomass (3.7 ± 1.0 g/m^2) were calculated for the MHI, to serve as a gauge for how the reefs of the WMR are faring relative to those from around the state. All across the MHI, reefs are affected by overfishing, sediments, land-based pollution, and invasive species. Over the past century, populations of some commercially important reef fish populations have declined by over 90%, and coral cover in some areas has declined by at least 40% in just the last 40 years. While there are many reef areas around the state that still have abundant and healthy resources, the current statewide averages used for comparison here certainly reflect substantial declines in resource condition seen broadly across the reefs of the MHI. Reefs in the WMR were consistent with the statewide averages for coral and fish assemblages (see Chapter 1). However, considerably variability in the condition of reefs exists across the WMR, and the reef tracts within the Honolua FW ranged from average to above average when compared to reefs statewide (Figure 2.14). The Honolua-Mokulēʻia MLCD had high fish biomass compared to reefs across the MHI, but only average coral cover. While current information on the benthic assemblage were not available for the O&H Bays and Līpoa Point, these reef tracts tended to have roughly average biomass for the three fish metrics, but with Līpoa Point having above average resource fish biomass.

Synthesis

The reefs within the Honolua FW are heavily influenced by the Honolua-Mokulēʻia MCLD, historic and present land management, and their relative remoteness when compared to other reefs in the WMR. The existing protected area, established nearly 25 years ago, appears to have benefited the reef fish assemblage inside the MLCD and to a more limited extent through

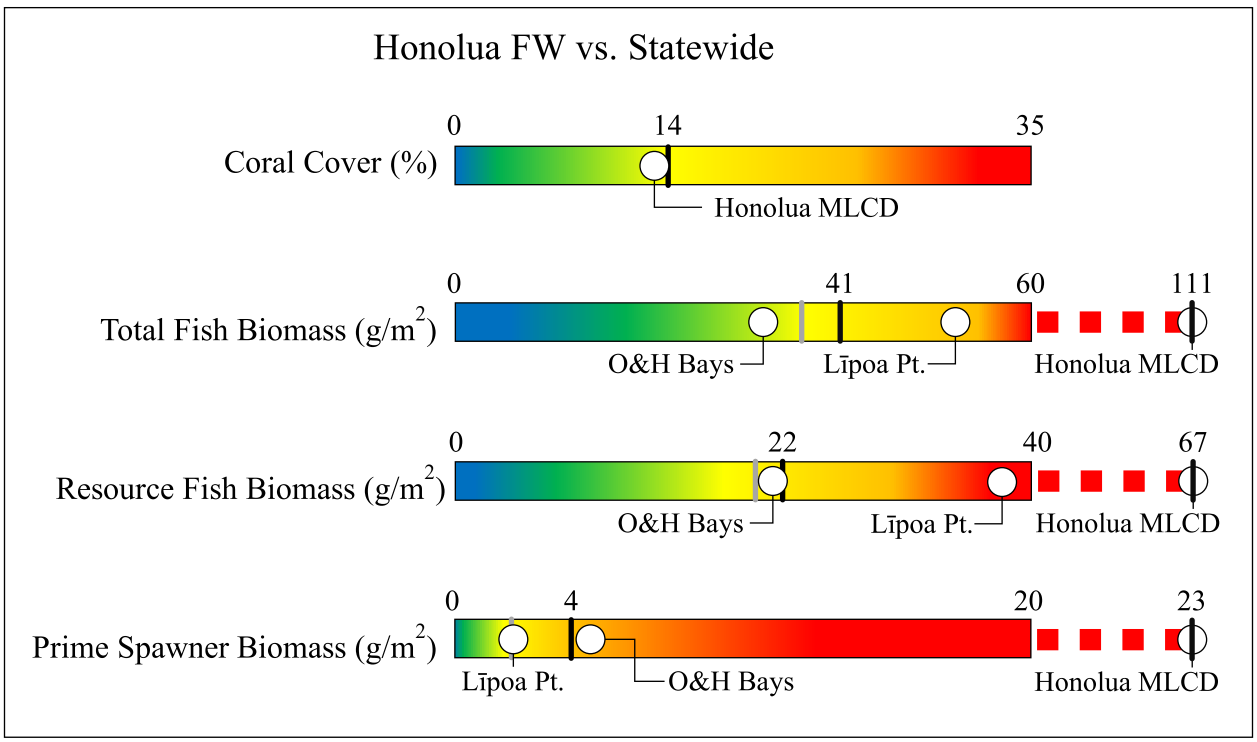


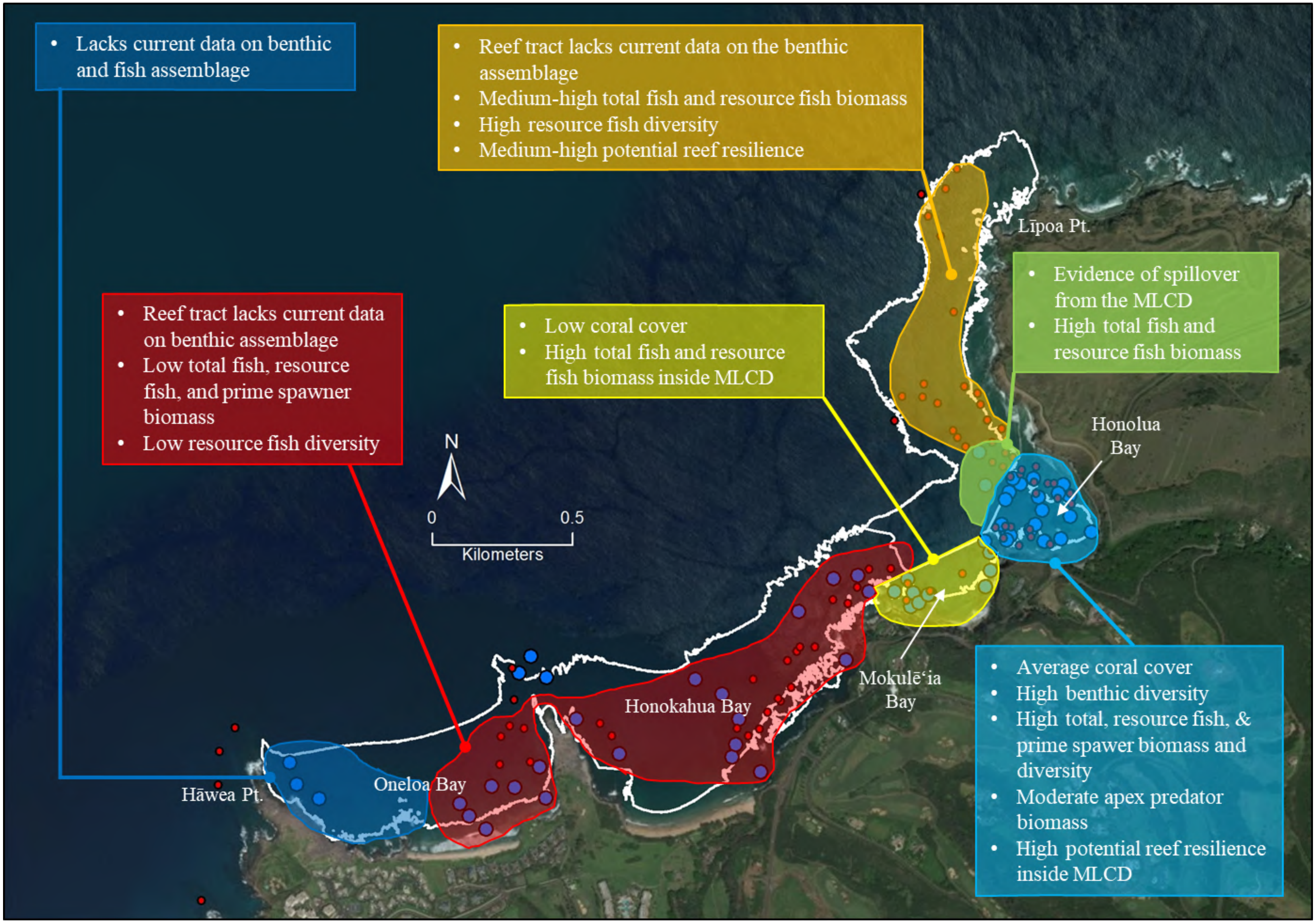
Figure 2.14. Comparison of reef tracts in the Honolua FW to statewide averages for coral cover (%), total fish, resource fish, and prime spawner biomass (g/m^2). Black vertical line and value denote the statewide average. For the three fish metrics, the grey vertical line is the statewide trimmed mean, which was used to develop the qualitative categories; see the methods (Appendix B) for more details on the use of the trimmed means.

spillover, the adjacent reefs, especially to the north of the protected area. Due to a lack of current data both inside and outside the MLCD boundary, it is not possible to assess the effects of the MLCD on the benthic assemblage.

The reef area on the southern end of the Līpoa Point reef tract appears to have higher abundance, biomass, and diversity than those farther north, likely a result of its close proximity to the Honolua-Mokulēʻia MLCD and change in environmental condition, such as exposure. Fish biomass declines with distance from the MLCD boundary, especially for prime spawners. However, the reefs off Līpoa Point harbor a diverse reef fish assemblage, especially among resource fish. Given the remoteness of this reef tract from Maui's population centers and its proximity to the diverse areas of the Honolua-Mokulēʻia MLCD reef tract, the Līpoa Point reef tract appears to have considerable potential to increase its benthic and reef fish resources with more effective fishery and land management.

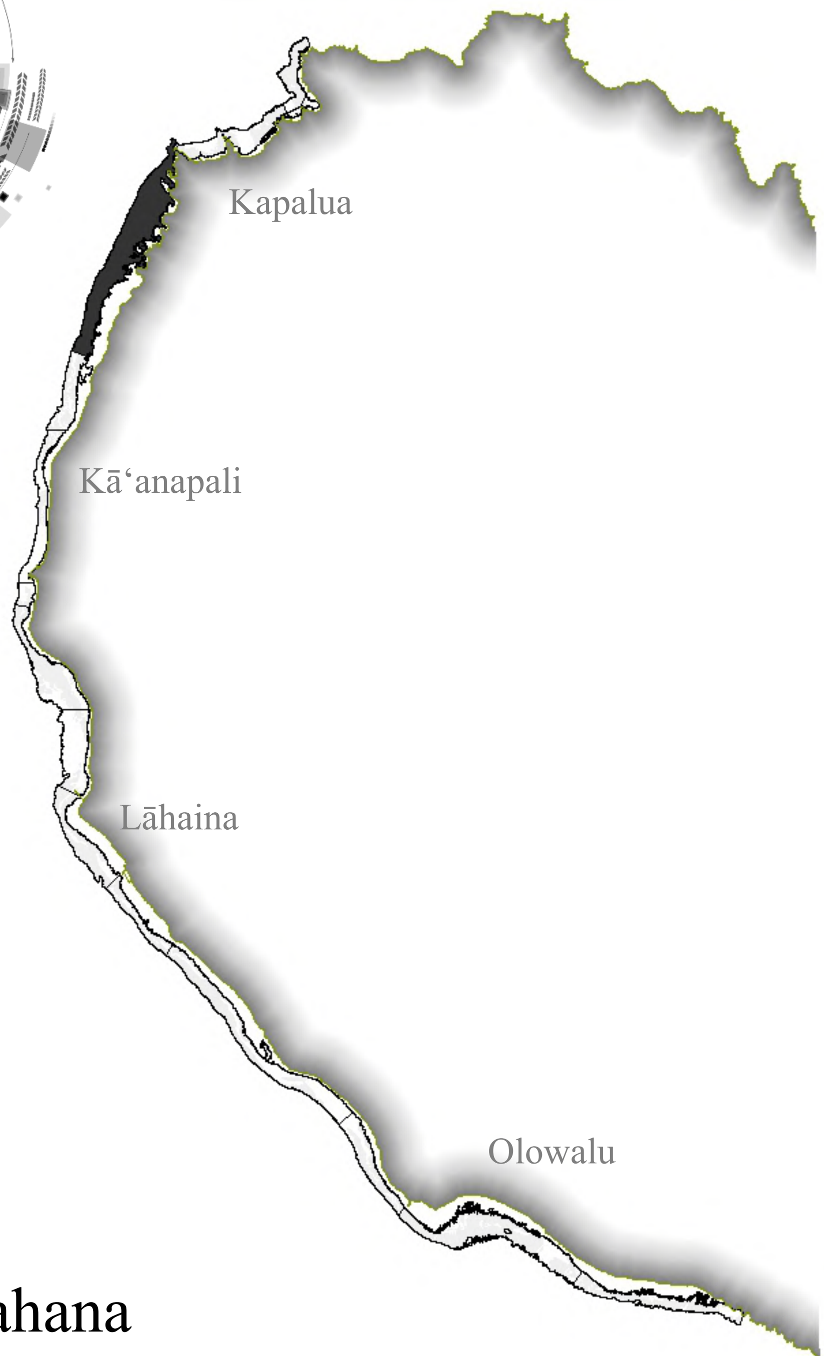
The Honolua-Mokulēʻia MLCD reef tract is comprised of Mokulēʻia and Honolua Bays. The benthic and fish assemblages in Honolua Bay appear to have higher abundance, biomass, and diversity than those in Mokulēʻia Bay. This spatial pattern does not appear to be associated specifically with bays, however, and reef quality appears to decrease from northeast to southwest within the reef tract. The reefs on the north side of the Honolua Bay have higher abundance, biomass, and diversity that those on the south. Likewise, the reef on the northeast side of the Mokulēʻia Bay, which extends into Honolua Bay and northward toward Līpoa Point, appears generally to have greater abundance, biomass, and diversity of fish than the reef on the southeast side of the bay.

Data for the O&H Bays reef tract is not evenly distributed across both Oneloa and Honokahua Bays, and the lack of data in Oneloa Bay makes it difficult to assess the current condition of its benthic and fish assemblages. While high fish biomass has been documented off Hāwea Point (see Chapter 3), it is unlikely that similarly high biomass occurs within the bay itself, which is supported by information around Makaluapuna Point, which showed higher fish biomass on reefs at the seaward tip of the point, but not in adjacent areas inside either Oneloa or Honokahua Bays. In general, both benthic and fish resources appear to be in poorer condition in the O&H Bays reef tract than within either of the other reef tracts in the Honolua FW.



• Lacks current data on benthic and fish assemblage
• Reef tract lacks current data on the benthic assemblage
• Medium-high total fish and resource fish biomass
• High resource fish diversity
• Medium-high potential reef resilience
Līpoa Pt.
• Evidence of spillover from the MLCD
• High total fish and resource fish biomass
• Reef tract lacks current data on benthic assemblage
• Low total fish, resource fish, and prime spawner biomass
• Low resource fish diversity
• Low coral cover
• High total fish and resource fish biomass inside MLCD
N
0
0.5
Kilometers
Honolua Bay
Mokulēʻia Bay
Honokahua Bay
Oneloa Bay
Hāwea Pt.
• Average coral cover
• High benthic diversity
• High total, resource fish, & prime spawer biomass and diversity
• Moderate apex predator biomass
• High potential reef resilience inside MLCD

3



Reefs of Kahana

Geographic Setting

The Kahana Focus Window (FW) extends from Hāwea Point southward to Pōhaku Park and includes several small bays and slender, rocky points of land. This FW is almost entirely within the Kahana watershed, which has a mixture of urban, agricultural and conservation land[24]. Within many of the embayments are sandy beaches, backed by large tourist resorts, condominiums, and golf courses. Given the diversity of land uses, coastal waters in the Kahana watershed are subject to sedimentation from agricultural fields, and nutrient and pollutant runoff from impervious surfaces, heavily manicured landscapes, and historical agricultural fields. Data collected from a network of 20 water quality monitoring stations across the West Maui Region (WMR)[25] showed the Kahana FW had the "dirtiest" coastal waters in the region, with stations at Pōhaku Park, Kahana Village, and Ka'opala Bay (Figure 3.1) all having among the highest turbidity levels. In addition, high nutrients levels were found at Pōhaku Park (highest in the WMR) and Ka'opala Bay.

The Data

The Kahana FW is comprised of a single contiguous reef tract extending ~5.6 km (3.5 mi) from Hāwea Point to Pōhaku Park (Figure 3.1). The Kahana FW was surveyed multiple times between 2002 and 2018, including six years with >20 sites surveyed (Table 3.1). In 2018, TNC assessed one reef resilience site (Alaeloa Point) within the Kahana FW.

Maps within the Atlas were generated using a spatial technique called interpolation. This technique uses available survey data to generate a complete spatial model of the data by estimating values between the surveys data using a mathematical algorithm that considers the values of nearby data weighed by their distance away. Areas with a higher density of surveys will produce more "accurate" interpolations than areas with lower survey density. Averages derived from interpolation maps are calculated across all reef areas and typically vary from averages derived from the survey data. Interpolation maps were generated for the Atlas primarily to display general spatial patterns and should not be used to predict exact values at any given location. For example, an interpolation map can, with a high degree of reliability, indicate that one reef tract has more coral than another reef tract, but it should not be used estimate the "exact" coral cover at a specific location within the reef tract. To estimate coral cover, amount of fish, etc., current survey data from the specific location should always be used over the interpolation maps when these data are available.

Benthic Assemblage

Current Spatial Patterns: Benthic

The benthic assemblage within the Kahana FW was characterized primarily by its high cover of turf (72.8 ± 1.3%), low cover of coral (6.8 ± 0.8%), and low benthic diversity (Table 3.2).

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[24] Group 70 Int and SRGII (2016)

[25] Hui O Ka Wai Ola and the State Department of Health collect water quality data at 20 sites in the WMR, including four locations in the Kahana FW: Kapalua Bay, Napili Bay, Ka'opala Bay, Kahana Village, and Pōhaku Park. To learn more about Hui O Ka Wai Ola and download raw data, please visit huiokawaiola.com.

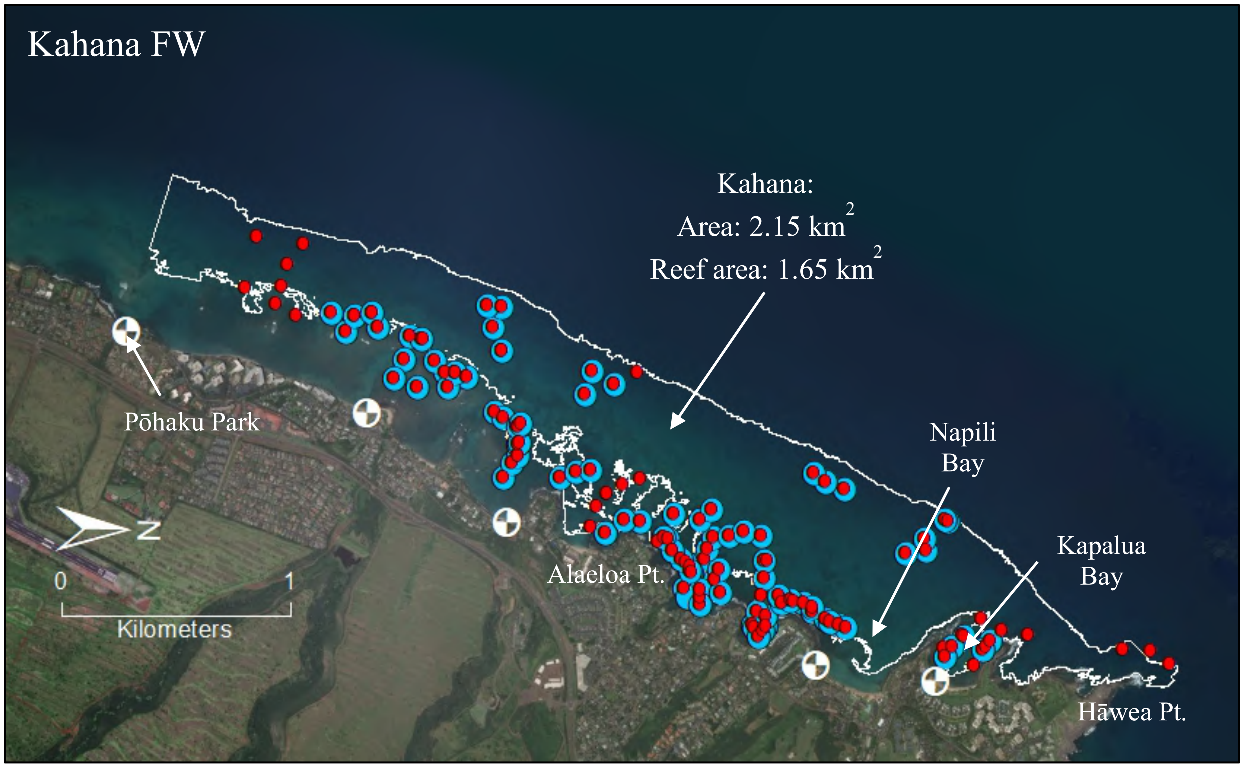

Figure 3.1. Survey effort for the benthic (blue) and fish (red) assemblages within the Kahana FW from 2016-2018. White quadrant circles along the shore are (north to south) the Kapalua Bay, Napili Bay, Ka'opala Bay, Kahana Village, and Pōhaku Park long-term water quality monitoring sites.

Table 3.1. Benthic and fish assemblage survey effort (number of survey sites) in the Kahana FW between 2002 and 2018.

Reef Tract	Survey Year	Benthic	Fish
Kahana		276	287
	2002	21	22
	2005		1
	2006	20	22
	2007	20	22
	2008	1	
	2010	3	
	2012	4	
	2013	1	
	2015	77	70
	2016	74	96
	2017	54	53
	2018	1	1

Table 3.2. Average (±SEM) percent cover of benthic groups and taxa in the Kahana FW (n=130) and by shallow (n=85) and deep (n=15) sites. Some sites in the FW had no associated positional or depth information, which accounts for the discrepancy between the number of surveys in the depth categories and the FW. Data are from 2016-2018.

	Kahana	**Deep**	**Shallow**
Turf	72.8 ± 1.3	72.9 ± 4.0	71.8 ± 1.6
Coral	6.8 ± 0.8	0.5 ± 0.2	8.2 ± 1.0
Porites evermanni/lutea	1.3 ± 0.3	0	1.3 ± 0.4
Montipora capitata	1.1 ± 0.3	<0.1	1.5 ± 0.4
Porites lobata	1.0 ± 0.2	0.2 ± 0.1	1.4 ± 0.3
Montipora patula	0.8 ± 0.1	0	0.9 ± 0.2
Porites rus	0.6 ± 0.4	0	0.8 ± 0.5
Porites compressa	0.5 ± 0.1	0	0.5 ± 0.2
Pocillopora meandrina	0.4 ± 0.1	0.2 ± 0.1	0.5 ± 0.1
Pocillopora ligulata	0.3 ± 0.1	0	0.3 ± 0.1
Montipora flabellata	<0.1	0	<0.1
Pavona varians	<0.1	0	<0.1
Cyphastrea ocellina	<0.1	0	<0.1
Leptastrea purpurea	<0.1	0	<0.1
Porites brighami	<0.1	0	<0.1
Pavona duerdeni	<0.1	0	<0.1
Porites c.f. *bernardi*	<0.1	0	<0.1
Unidentified coral	<0.1	0	<0.1
Crustose Coralline Algae	1.4 ± 0.5	0	2.2 ± 0.8
Macroalgae	8.1 ± 0.8	3.0 ± 0.6	8.6 ± 0.9
Cyanobacteria	0	0	0
Other	0.3 ± 0.1	0.4 ± 0.2	0.4 ± 0.1
Abiotic	10.6 ± 1.0	23.3 ± 3.9	8.9 ± 1.1
Sand	9.7 ± 1.0	23.3 ± 3.9	7.9 ± 1.1
Other	0.9 ± 0.1	0	0.9 ± 0.1

Variability in the cover of turf was surprisingly low (coefficient of variation = 0.21), but the variability within other benthic groups was high (CV>1.0), suggesting these other benthic groups were patchily distributed across the FW. This pattern also suggests that much of the reef in the Kahana FW may be in relatively “poor” condition and may provide low-quality habitat for reef fish and other associated organisms. However, areas of modest coral cover (>12%); Figure 3.2) and benthic diversity (Figure 3.3) do exist, notably in the shallow waters off Alaeloa Point, along the north side of Napili Bay, and wrapping around the rocky point into Kapalua Bay.

Coral cover within the Kahana FW displayed an unusual pattern with depth. Coral cover was correlated with depth (Correlation; r_{222}=-0.344; $p<0.001$), with higher coral cover in shallower

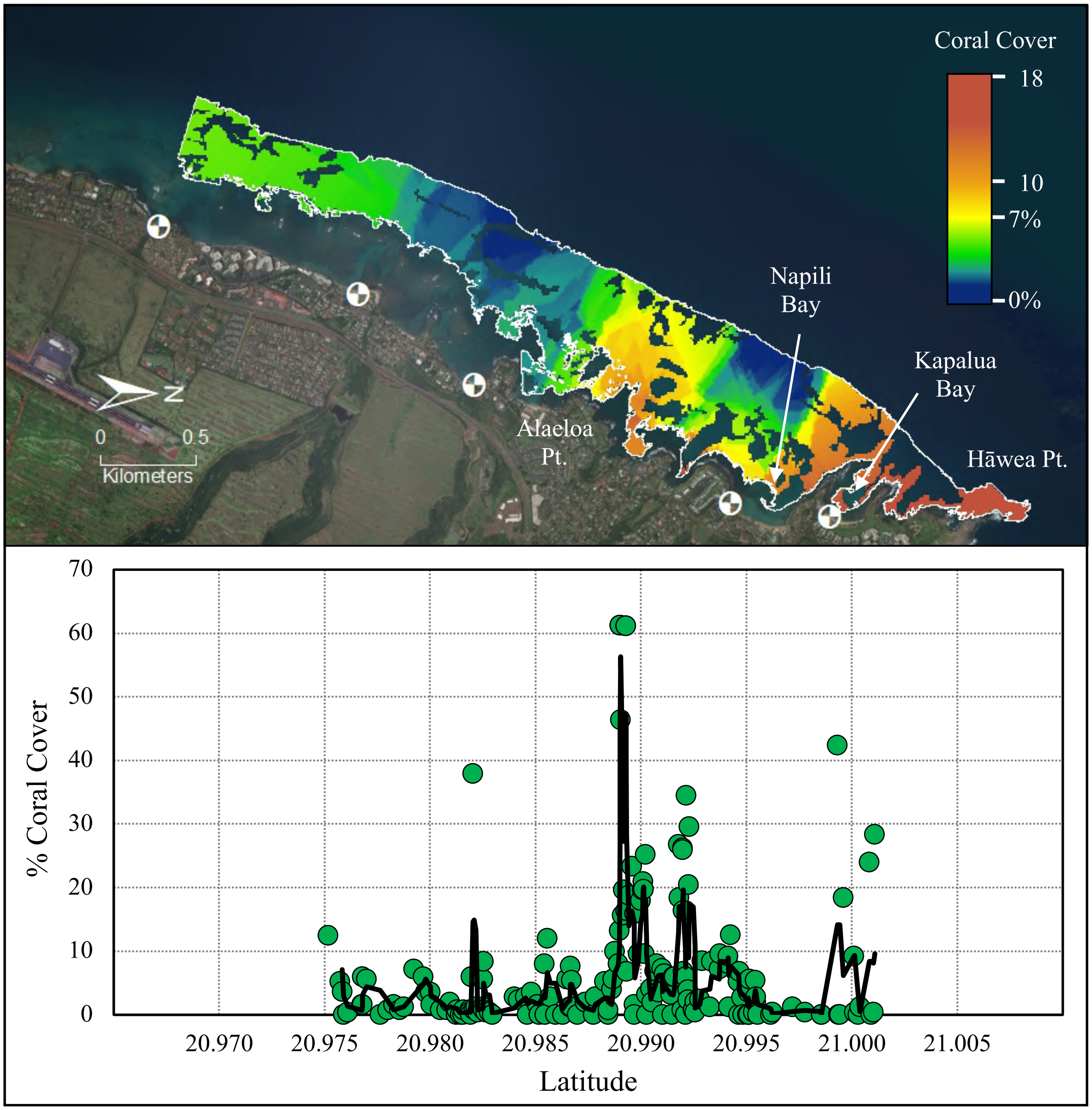

Figure 3.2. Coral cover across the Kahana FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of coral cover at consecutive survey sites along the north-south axis. White quadrant circles along the shore are (north to south) the Kapalua Bay, Napili Bay, Kaʻopala Bay, Kahana Village, and Pōhaku Park long-term water quality monitoring sites.

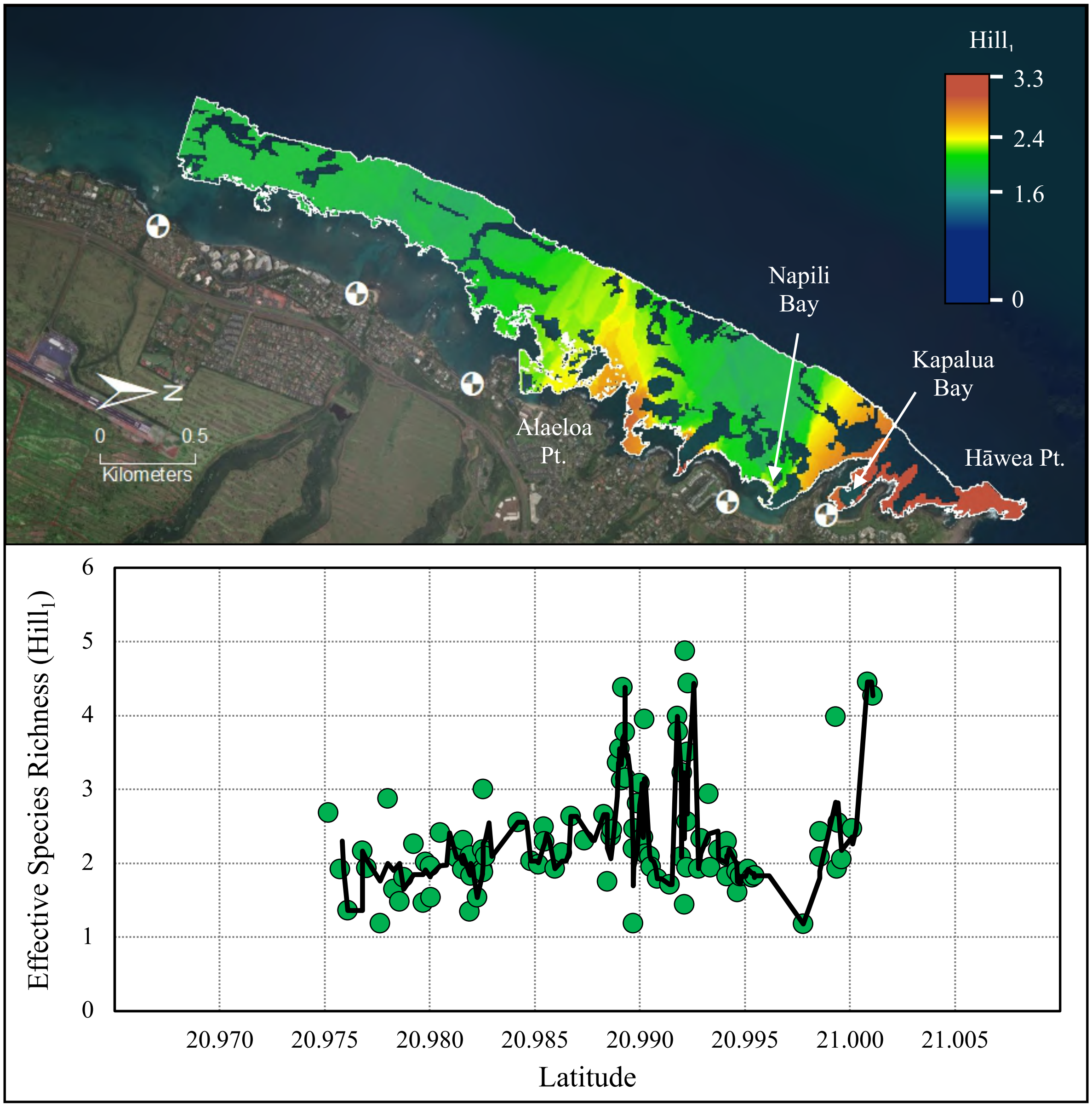

Figure 3.3. Effective species richness (Hill$_1$) across the Kahana FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average species richness for the FW and red would be considered high species richness for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of effective species richness at consecutive survey sites along the north-south axis. White quadrant circles along the shore are (north to south) the Kapalua Bay, Napili Bay, Ka‘opala Bay, Kahana Village, and Pōhaku Park long-term water quality monitoring sites.

waters and a pronounced depth "threshold" at approximately 6 m (20 ft). Beneath this threshold, coral never exceeded 3.2% cover (Figure 3.4a). At shallower depths, individual survey sites could reach values up to 46.4%, though average coral cover remained low (8.2 ± 1.0%). Some of these sites were spatially clustered, forming coral "hotspots" within the Kahana FW, but even these reef areas tended to have coral cover well below many other reefs in the WMR (Chapter 1), and likely do not represent exceptional reef or fish habitat at the regional scale.

While coral cover was low, coral species richness was robust, totaling 16 species (Table 3.2), and no single species dominated the assemblage. *Porites evermanni/lutea* (hump coral) was the most abundant, covering 1.3 ± 0.3% of the bottom and accounting for almost a fifth (19%) of all coral, but *Montipora capitata* (rice coral) and *P. lobata* (lobe coral) also covered more than 1% of the bottom. Most species were rare, with eight averaging <0.1% cover. Differences in coral species richness were also found with depth. Deep reef sites (>6 m) had only three coral species, compared to the shallow sites, where 16 species were found (Table 3.3).

Differences in the benthic structure between shallow and deep sites extended beyond coral (Figure 3.5). The benthic assemblage at depth was primarily turf-covered hardbottom interspersed with sand (abiotic) and the macroalgae *Halimeda* spp. Together, these accounted for >99% of the cover at sites deeper than 6 m. Shallow sites tended to have higher diversity, but coral, turf, and sand still accounted for most of the cover (89%). Like coral, species richness of macroalgae was greater at shallow compared to deep sites (Table 3.3), totaling seven common taxa in the shallow-water assemblage compared to only one in the deep-water assemblage.

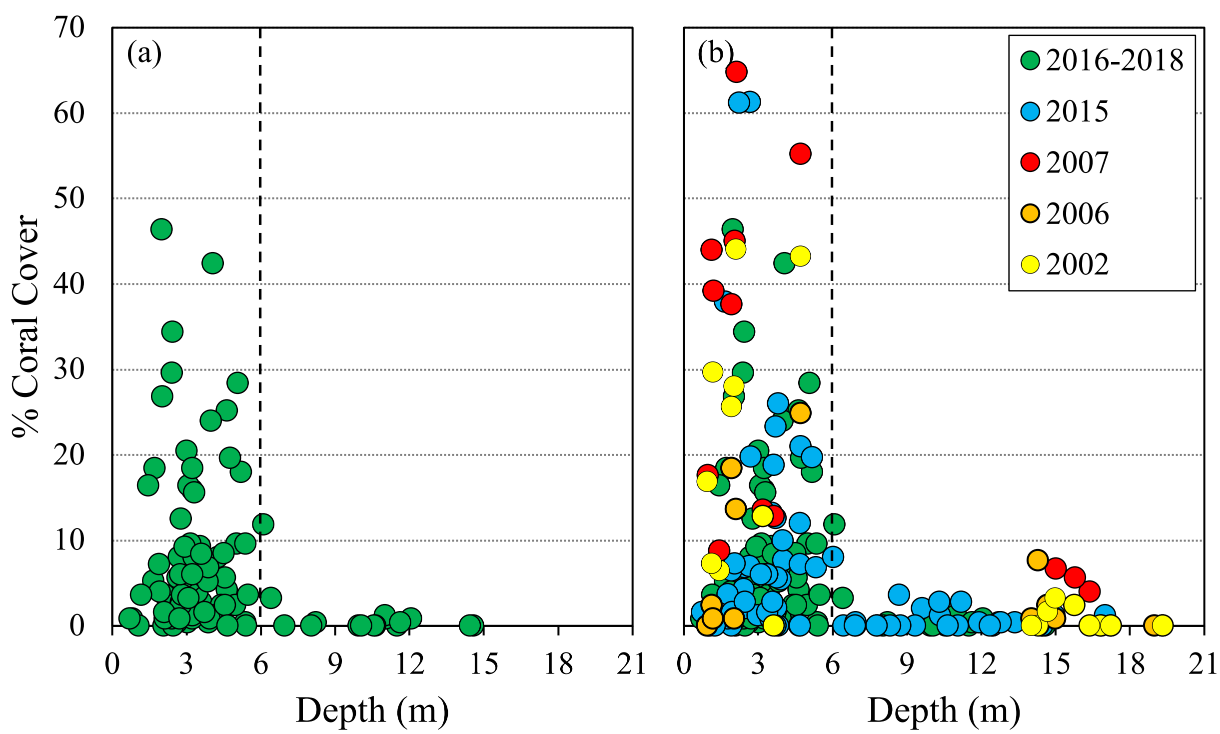

Figure 3.4. Coral cover by depth in the Kahana FW for (a) 2016-2018 and (b) 2002-2018. Dotted line represents the "6 m threshold" beneath which high coral cover sites do not occur.

Table 3.3. Species richness of coral and algae at shallow (<6 m) and deep (>6 m) sites in the Kahana FW. Data are from 2016-2018.

	Shallow	**Deep**
Coral	*Cyphastrea ocellina*	*Montipora capitata*
	Leptastrea purpurea	*Pocillopora meandrina*
	Montipora capitata	*Porites lobata*
	Montipora flabellata	
	Montipora patula	
	Pavona duerdeni	
	Pavona varians	
	Pocillopora ligulata	
	Pocillopora meandrina	
	Porites c.f. *bernardi*	
	Porites brighami	
	Porites compressa	
	Porites evermanni/lutea	
	Porites lobata	
	Porites rus	
	Unidentified coral	
Algae	*Asparagopsis taxiformis*	*Halimeda* spp.
	Chlorophyta sp.	
	Dictyota spp.	
	Halimeda spp.	
	Liagora spp.	
	Phaeophyta sp.	
	Rhodophyta sp.	

Historical Patterns: Benthic

A 17-year time series of data (2002-2018) is available for the Kahana FW (Table 3.1), with robust datasets existing for 2002, 2006, 2007, 2015, 2016, and 2017. A mass coral bleaching event affected West Maui's reefs in 2015. This global scale event caused considerable coral mortality on many reefs in the Hawaiian Islands, including on Maui and Hawaiʻi Island[26]. The 2015 surveys in the Kahana FW were conducted in May and August, which would have been before or during the early stages of the bleaching event, and likely before any significant coral mortality could have occurred. Therefore, pre-bleaching data at Kahana was considered to be information collect in the years 2002-2015 and post-bleaching data were those collected between 2016-2018.

[26] For more information on bleaching-related mortality for reefs on Maui, see SSRI (2017) and for Hawaiʻi Island see Kramer *et al.* (2016) and Minton *et al.* (2018b).

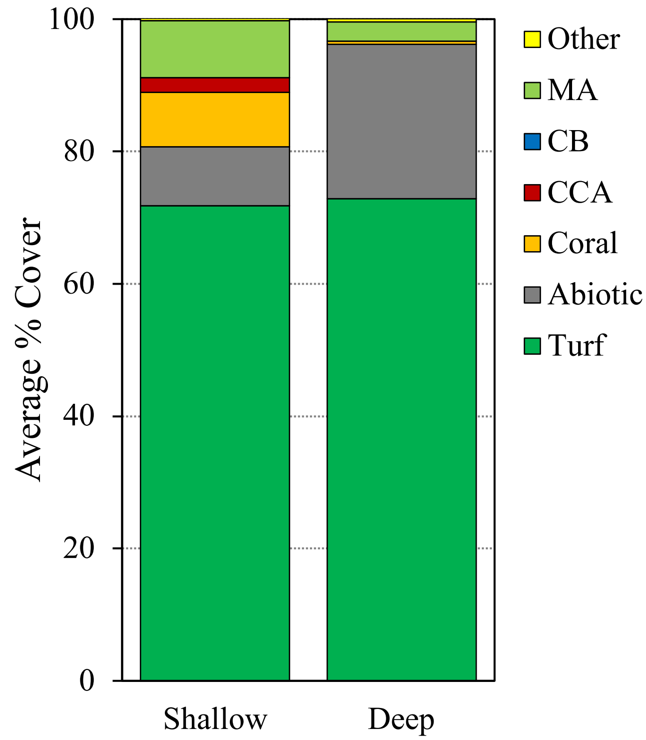

Figure 3.5. Average percent cover by benthic group in the Kahana FW. Data are from 2016-2018. MA=macroalgae, CB=cyanobacteria, CCA=crustose coralline algae

The depth-associated pattern of coral cover noted in the 2016-2018 data (Figure 3.4a) was also observed in earlier years (Figure 3.4b), suggesting low cover at depth was not a new condition for the benthic assemblage within the Kahana FW and did not arise from the 2015 bleaching event. Although variability was high, mean coral cover on both shallow and deep reefs has shown a declining trend since 2002, losing about half its cover during that period (Figure 3.6). While coral cover appears to decline in the year following the 2015 bleaching event for both shallow and deep sites, it is not clear if these declines are the result of bleaching-related mortality or a continuation of the long-term trend. Coral cover at shallow sites appears to have recovered in the years following the event to pre-bleaching levels, and it is not possible from the existing data to determine if these changes are due to bleaching mortality and subsequent recovery or a product of natural spatial and/or temporal variability of the coral assemblages. At shallow sites, at least, the 2015 bleaching event appears to have had little lasting effect on the coral. At deep sites, however, coral has not recovered to pre-bleaching levels and has continued to decline towards zero (Figure 3.6), although any conclusions should be drawn with caution because only two deep sites were surveyed in 2017, and none in 2018. Declines in coral cover appear to have been offset primarily by an increase in the cover of turf algae at all depths.

Coral Health and Reef Resilience

In 2018, a reef resilience assessment of leeward Maui was conducted by TNC and its partners. These assessments were intended to quantify the relative resilience of Maui's reefs to the effects of climate change. Resilience is the ability of a reef to resist, recover from, and adapt to a climate-related event (*e.g.*, coral bleaching) to maintain a diverse, coral-rich state that provides key ecological functions and services to people[27]. Given the integral role of reefs to the people of Hawaiʻi, reef resilience is closely linked with social resilience, which is the ability of human communities to adapt to social, political, environmental, or economic change[28].

[27] Nystrom and Folke (2001)
[28] Adger (2000)

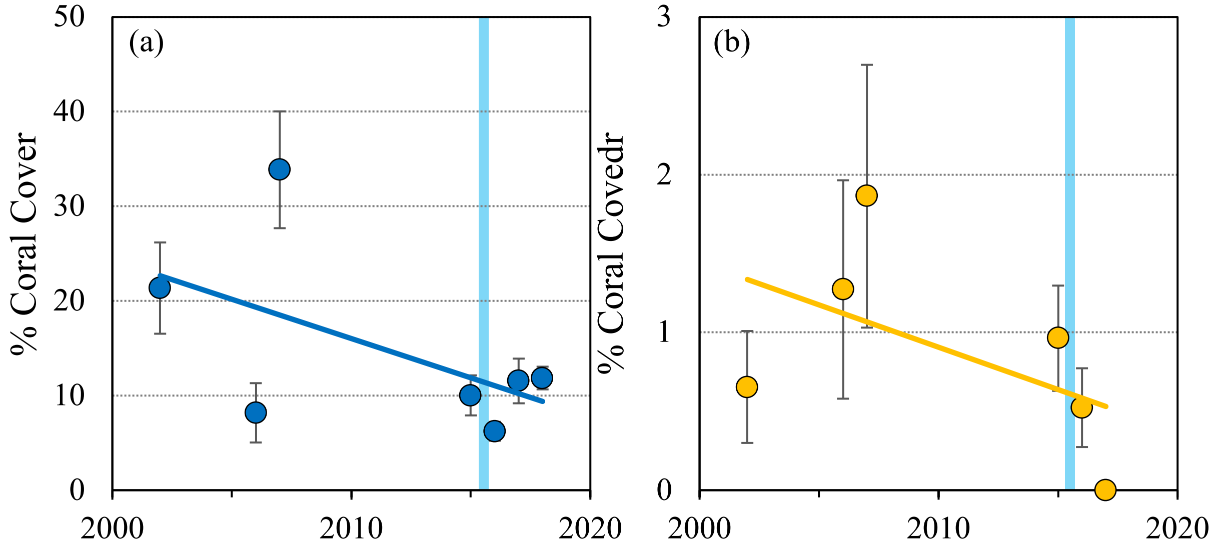

Figure 3.6. Average (±SEM) percent coral cover at (a) shallow (<6 m) and (b) deep (>6 m) sites in the Kahana FW from 2002-2018. Lines are linear trendlines intended to help visualize the downward trajectory of coral cover. The blue bar signifies the approximate months over which the 2015 mass coral bleaching event affected Maui reefs. No data were available for deep sites in 2018. Error bars for some points are smaller than the diameter of the circle. Note: scales on a) and b) are different.

One shallow-water reef resilience site (Alaeloa Point) was surveyed within the Kahana FW. The complete results of that assessment are detailed elsewhere[29], so only the coral health and resilience findings for the site in the Kahana FW are summarized here.

The benthic assemblage at the Alaeloa Point reef resilience site had similar composition and abundance to nearby sites visited in 2016 and 2017. The prevalence of coral disease (4.0% of colonies affected) and algal overgrowth (11.0%) ranked in the bottom half of the 31 shallow sites surveyed in the reef resilience assessment, suggesting the reef off Alaeloa Point is under stress. Benthic photographs showed little indication of sediment stress, but given the proximity of the site to developed coastal areas, it is likely that nutrient inputs either from condominium or resort landscaping or onsite wastewater disposal systems[30] percolating into the coastal waters via submarine discharges could be occurring. Elevated nutrient levels have been found at a nearby water quality monitoring station in Kaʻopala Bay, but no information is available from the waters directly off Alaeloa Point. In contrast to coral disease and algal overgrowth, the prevalence of coral paling/bleaching was low (4.3%) at the Alaeloa Point site, ranking it among the better locations in leeward Maui for coral bleaching.

As part of the reef resilience assessment, the 31 shallow-water and 20 deep-water sites were assigned a relative reef resilience rank, based on several indicator variables, including coral cover, coral disease prevalence, coral diversity, coral recruitment, reef builder ratio (ratio of

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[29] Maynard *et al.* (2019)
[30] Barnes *et al.* (2019)

calcifying species to non-calcifying species), rugosity, and herbivorous fish biomass. The Alaeloa Point reef resilience site ranked 27th out 31 shallow-water sites, placing it among the worst of the leeward Maui sites with low potential reef resilience.

Fish Assemblage

Current Spatial Patterns: Fish

While the benthic assemblage appears to be degraded over much of the Kahana FW, the average total fish biomass was unexpectedly high (56.1 ± 6.8 g/m^2), and similar to other reef areas in the WMR with high coral cover and benthic diversity (*e.g.*, Olowalu). Variability in fish biomass was also high, and only a few sites had very high fish biomass while 73% of the survey sites had a total fish biomass less than the mean (*i.e.*, data were right skewed).

Spatial analysis indicated several fish "hotspots" in the Kahana FW (Figure 3.7) that loosely corresponded with areas of higher coral cover (Figure 3.2)—for example, off Alaeloa Point—although this was not always the case. High fish biomass also appeared linked to prominent points of land, such as Hāwea Point, which had a site with the fourth highest total fish biomass (723.8 g/m^2) of any in the WMR, and was the only site not within a current fishery management area among the 10 sites with the highest total fish biomass.

Total fish biomass was marginally correlated with depth (Correlation, $r=-0.158$, $p=0.07$), with higher biomass in shallow waters. Like coral cover, total fish biomass showed evidence of a distinct depth threshold around 6 m (Figure 3.8). Other than the high biomass site off Hāwea Point, which appears to be an outlier to the general trend, no survey site deeper than 6 m had a total fish biomass >57 g/m^2. Even including the Hāwea Point outlier, mean total fish biomass at deep sites was 46.6 ± 27.2 g/m^2, compared to 62.5 ± 7.0 g/m^2 for sites <6 m deep (Table 3.4). Removing the Hāwea Point outlier, total fish biomass at deep sites drops to only 19.5 ± 3.1 g/m^2. The lower total fish biomass at deep sites is likely related to poor fish habitat at depth. Poor fish habitat can cause low fish biomass by supporting fewer and/or smaller fish. The 19 most common species were both larger in average size (t-test; $t_{18}=1.82$; $p=0.086$) and more abundant (t-test; $t_{71}=1.66$; $p<0.001$) at shallow than deep sites, indicating that habitat is likely the driving factor behind the observed depth differences in the fish assemblage.

Resource fish biomass, which is comprised of species important for consumption and that tend to be prized by fishers [31], showed similar spatial (Figure 3.9) and depth patterns (Figure 3.8) as total fish biomass. "Hotspots" of resource fish biomass were present off Alaeloa Point and Hāwea Point, and shallow sites tended to have higher resource fish biomass than deep ones. The effect of depth appeared more pronounced for resource fish than total fish biomass. Resource fish comprised a smaller proportion of the assemblage's biomass at deep compared to shallow sites, $29.3 \pm 6.4\%$ compared $48.3 \pm 3.0\%$, respectively. Higher fishing pressure at deep sites could produce this pattern, but this is unlikely because fishing pressure in Hawaiʻi tends to decline with distance from shore, which should produce a greater proportion of resource fish biomass at deep compared to shallow sites. Alternatively, differences in fish habitat quality across depth could be responsible, but it is also not clear why lower habitat quality would affect resource fish more

[31] See Appendix B for a list of resource and non-resource species

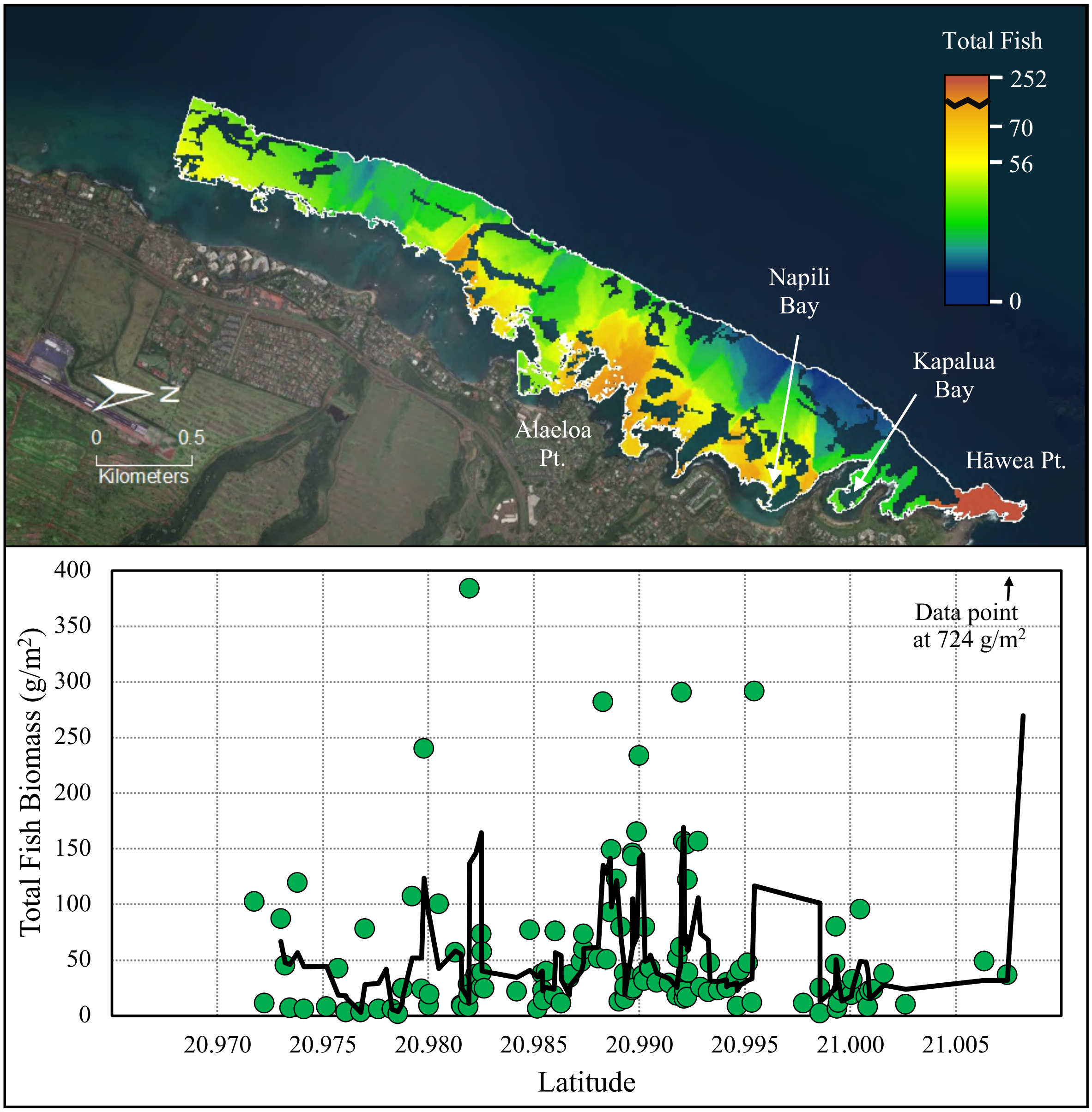

Figure 3.7. Total fish biomass across the Kahana FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average total fish biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of total fish biomass at consecutive survey sites along the north-south axis.

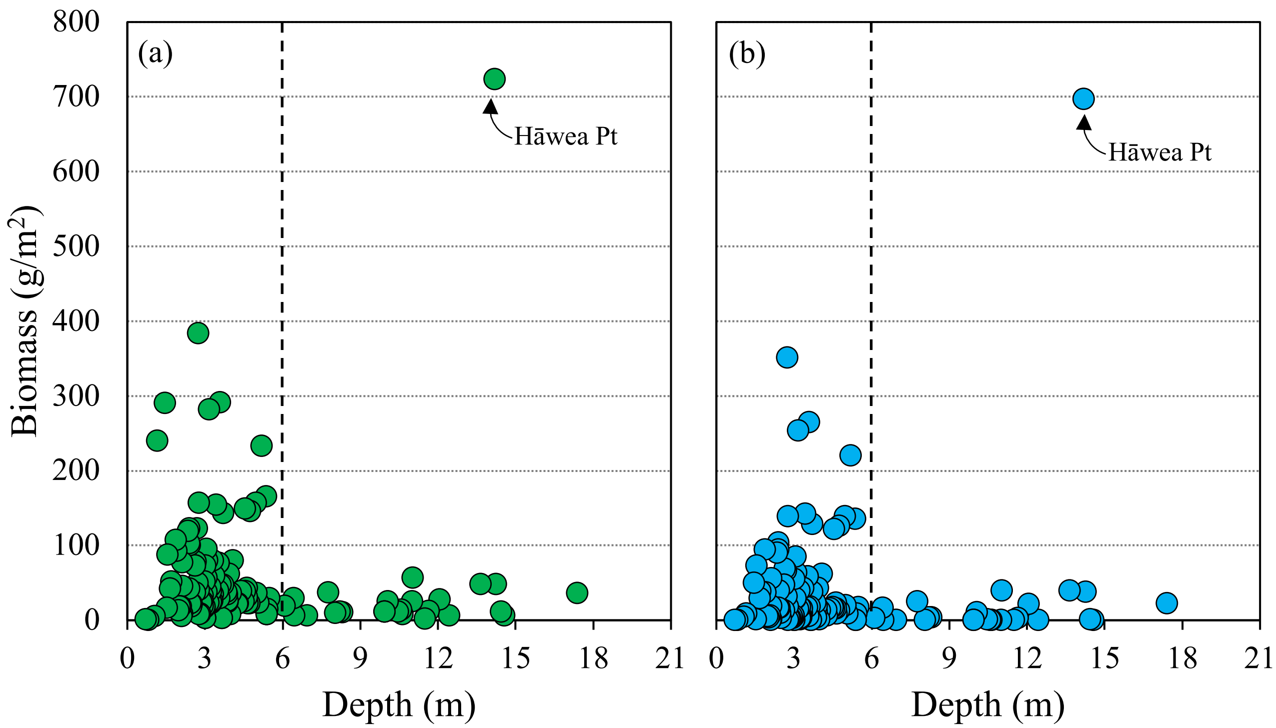

Figure 3.8. Total fish (a) and resource fish (b) biomass (g/m^2) by depth in the Kahana FW for 2016-2018. Dotted line represents the "6 m threshold" beneath which high fish biomass sites rarely occur.

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than non-resource fish. Theoretically, a change in fish habitat quality would result in a decrease in the biomass of both groups, and proportion of resource fish biomass should remain relatively constant across depths. To adequately address this question, additional research would be needed.

The structure of the fish assemblage also changed with depth. Interestingly, while biomass was lower, deep sites had greater diversity of resource fish groups than shallow sites (Figure 3.10). Resource fish at shallow sites were dominated by surgeonfish, followed by goatfish and parrotfish. These three groups comprised almost 96% of the resource fish biomass. At the deep sites, surgeonfish and apex predators comprised the largest percentage of the resource fish biomass (Figure 3.10), and several resource fish groups had more average biomass at deep sites than shallow sites, for example, wrasses, redfish, other resource fish, and apex predators.

A primary feature of the resource fish assemblage at deep sites was the high percentage of apex predator biomass compared to shallow sites. This high percentage also translated to 70% greater apex predator biomass at deep compared to shallow sites (Figure 3.10). Apex predator biomass at deep sites was exclusively one species, *Aprion virescens* (green jobfish). In contrast, apex predator biomass at shallow sites was comprised of five species: *A. virescens*, *Caranx melampygus* (bluefin trevally), *Decapterus macarellus* (mackerel scad), *Heteropriacanthus cruentatus* (glasseye), and *Scomberoides lysan* (doublespotted queenfish).

Table 3.4. Average (±SEM) fish biomass (g/m^2) by fish family in the Kahana FW (n=151), and at deep (n-=26) and shallow (n=102) sites. Some sites in the FW had no associated positional or depth information, which accounts for the discrepancy between the number of surveys in the depth categories and the FW. Data are from 2016-2018.

	Kahana FW	Shallow (<6 m)	Deep (>6 m)
Acanthuridae	34.5 ± 5.8	38.4 ± 5.3	30.7 ± 26.5
Mullidae	5.7 ± 1.8	6.2 ± 1.9	0.7 ± 0.2
Balistidae	5.1 ± 0.3	4.7 ± 0.4	8.2 ± 0.9
Scaridae	3.2 ± 1.1	4.5 ± 1.5	0.9 ± 0.6
Labridae	1.8 ± 0.1	2.1 ± 0.2	0.7 ± 0.2
Carcharhinidae	1.3 ± 1.3	2.0 ± 2.0	0
Carangidae	0.7 ± 0.4	1.0 ± 0.6	0
Lutjanidae	0.7 ± 0.4	0.4 ± 0.4	2.0 ± 1.4
Chaetodontidae	0.6 ± 0.1	0.6 ± 0.1	0.6 ± 0.4
Pomacentridae	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.2
Monacanthidae	0.5 ± 0.1	0.7 ± 0.2	0
Holocentridae	0.3 ± 0.2	<0.1	1.2 ± 1.1
Zanclidae	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1
Lethrinidae	0.3 ± 0.1	0.2 ± 0.2	0.7 ± 0.4
Diodontidae	0.3 ± 0.1	0.3 ± 0.2	0
Cirrhitidae	0.1 ± 0.1	0.1 ± 0.1	<0.1
Tetraodontidae	0.1 ± 0.1	0.1 ± 0.1	<0.1
Serranidae	0.1 ± 0.1	0.1 ± 0.1	<0.1
Aulostomidae	<0.1	0.1 ± 0.1	0
Ostraciidae	<0.1	<0.1	<0.1
Hemiramphidae	<0.1	<0.1	0
Kyphosidae	<0.1	<0.1	0
Synodontidae	<0.1	<0.1	<0.1
Fistulariidae	<0.1	<0.1	0
Blenniidae	<0.1	<0.1	<0.1
Malacanthidae	<0.1	0	<0.1
Microdesmidae	<0.1	0	<0.1
Pomacanthidae	<0.1	<0.1	0
Scorpaenidae	<0.1	<0.1	0
Apogonidae	<0.1	<0.1	<0.1
Priacanthidae	<0.1	<0.1	0
Pinguipedidae	<0.1	0	0
Caracanthidae	<0.1	<0.1	0
Gobiidae	<0.1	<0.1	0
Bothidae	*	*	*
Muraenidae	*	*	*
Total Fish Biomass	56.1 ± 6.8	62.5 ± 7.0	46.6 ± 27.2

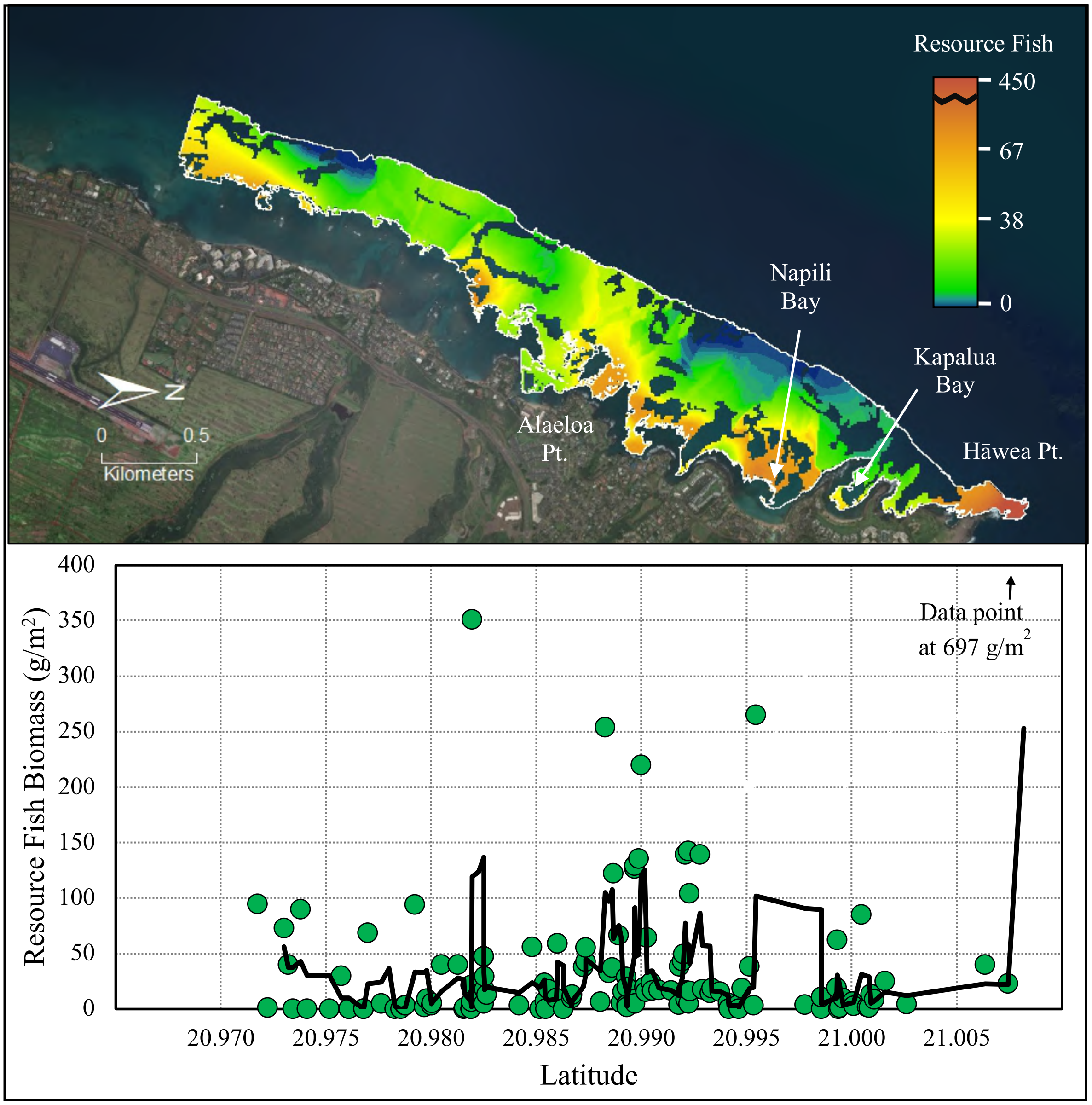
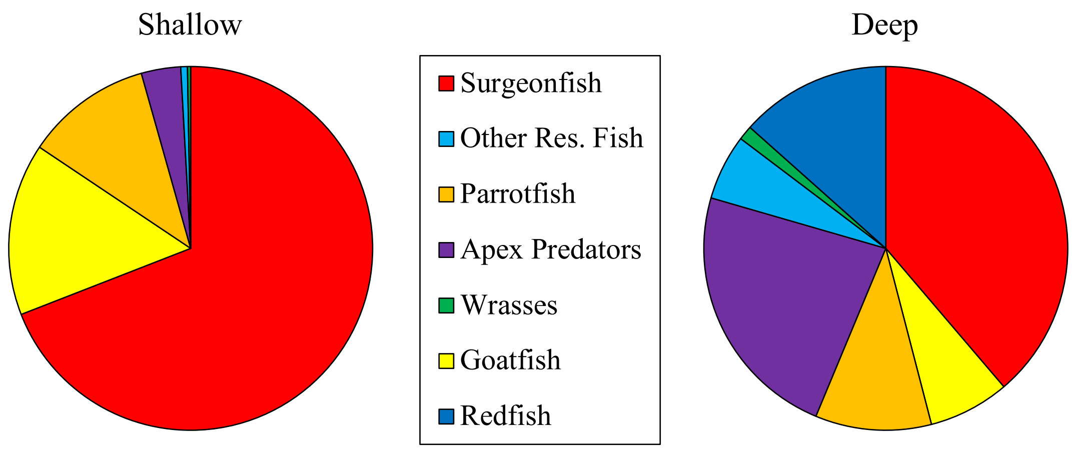


Figure 3.9. Resource fish biomass across the Kahana FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average resource fish biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of resource fish biomass at consecutive survey sites along the north-south axis.



Shallow		Deep
40.5 ± 6.0	Resource Fish	9.1 ± 2.7
28.0 ± 4.4	Surgeonfish	3.5 ± 1.6
6.2 ± 1.9	Goatfish	0.7 ± 0.3
4.5 ± 1.5	Parrotfish	0.9 ± 0.6
1.4 ± 0.7	Apex Predators	2.1 ± 1.5
0.2 ± 0.2	Other Res.	0.5 ± 0.4
0.1 ± 0.1	Wrasses	0.1 ± 0.1
0	Redfish	1.2 ± 1.2
17.8 ± 2.5	Non-resource Fish	9.5 ± 0.9

Figure 3.10. Relative composition (percent of total resource fish biomass) and table of biomass (g/m^2) of resource fish at shallow and deep sites in the Kahana FW. Data are from 2016-2018 and exclude the Hāwea Point deep site, which has unusually high resource fish biomass (see text for more information).

Prime spawners are individual resource fish >70% of the maximum length for that species. These individuals tend to exert a disproportionately large effect on population dynamics due to their considerably higher fecundity and egg quality compared to smaller individuals[32]. Conservation of prime spawners is important to maintaining sustainable fisheries and ecosystems.

Prime Spawner biomass was high for the WMR at 10.6 ± 3.0 g/m^2 within the Kahana FW, but was patchily distributed into three primary reef areas: on the shallow-water reef along the south end of the FW, on the shallow-water reef off Alaeloa Point, and in the deep waters off Hāwea Point on the northern end of the FW (Figure 3.11). As with total and resource fish biomass, prime spawner biomass varied with depth and showed a threshold around 6 m, below which only one survey location off Hāwea Point (336 g/m^2) had a prime spawner biomass exceeding 6.0 g/m^2. If the Hāwea Point site was removed from the estimate, mean prime spawner biomass at depth dropped to 0.6 ± 0.3 g/m^2, which would easily place it among the lowest values for any

[32] Birkeland and Dayton (2005) and Hixon *et al.* (2014)

reef in the WMR. Removing the Hāwea Point site would also lower the prime spawner biomass for the entire FW to 8.5 ± 2.1 g/m^2, which would drop the primer spawner biomass for the Kahana FW to medium-high at the regional level.

The high prime spawner biomass off Hāwea Point was associated with two species of surgeonfish, *Acanthurus dussumieri* (eyestripe surgeonfish) and *A. nigroris* (bluelined surgeonfish). At other deep-water sites, prime spawners were comprised of only five species, including three species of surgeonfish, a goatfish, and a parrotfish (Table 3.5). Prime spawner species richness at shallow sites was more than double that of deep sites and comprised of seven surgeonfish species, four goatfish, three parrotfish, a wrasse and a redfish.

Fish diversity was low in the southern half of the FW and increased toward the north, peaking around Kapalua and Namalu Bays, where diversity was 3-to-4 times greater than on reefs farther south (Figure 3.12). Effective species richness was also high off Alaeloa Point. Both of these reef areas were also "hotspots" for benthic diversity (Figure 3.3).

Historical Patterns: Fish

Like the benthic assemblage, a 17-year time series of fish data exists for the Kahana FW, with robust sampling efforts in 2002, 2006, 2007, 2015, 2016, and 2017. Unfortunately, this time series does not include data collected in either 2013 or 2014, which would predate a large reef

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Table 3.5. Prime spawner species at deep and shallow sites in the Kahana FW. Species arranged in decreasing order of their contribution to prime spawner biomass. Data are from 2016-2018.

Deep Sites	Shallow Sites
Acanthurus dussumieri	*Acanthurus olivaceus*
Acanthurus olivaceus	*Acanthurus blochii*
Parupeneus multifasciatus	*Mulloidichthys flavolineatus*
Naso lituratus	*Naso lituratus*
Scarus psittacus	*Acanthurus triostegus*
Acanthurus nigroris	*Mulloidichthys vanicolensis*
Acanthurus leucopareius	*Scarus rubroviolaceus*
	Naso brevirostris
	Acanthurus dussumieri
	Parupeneus multifasciatus
	Acanthurus leucopareius
	Scarus psittacus
	Cheilio inermis
	Parupeneus pleurostigma
	Chlorurus spilurus
	Myripristis spp.

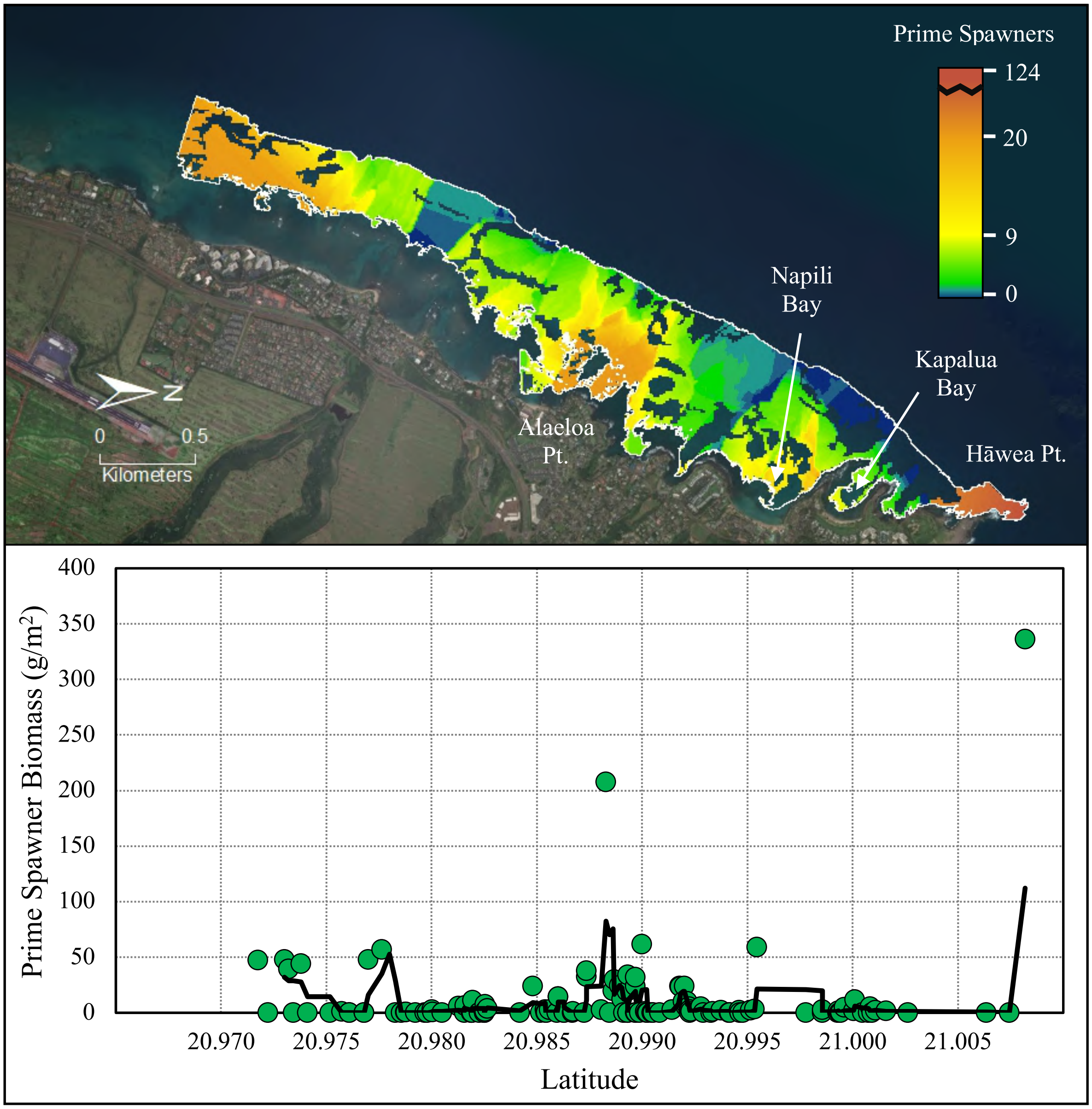


Figure 3.11. Prime spawner biomass across the Kahana FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the prime spawner biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of prime spawner biomass at consecutive survey sites along the north-south axis.

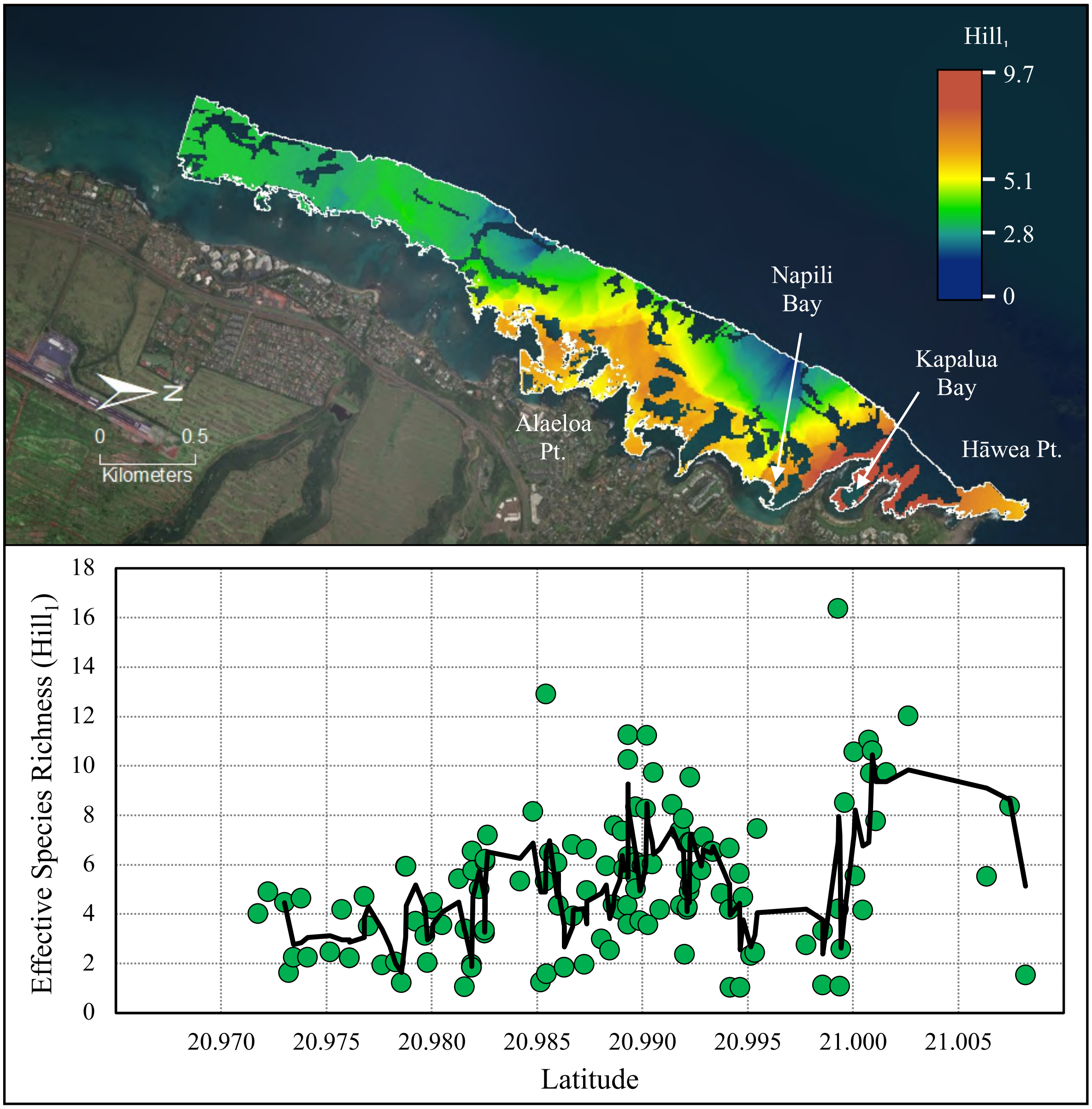


Figure 3.12. Effective species richness for fish ($Hill_1$) across the Kahana FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average effective species richness for the FW and red would be considered high richenss for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of effective species richness at consecutive survey sites along the north-south axis.

fish recruitment event that resulted in an unusually larger settlement of juveniles across a wide range of fish species[33]. This recruitment event has been documented on West Hawai'i reefs[34], and was also observed on O'ahu[35] and Maui[36]. In addition to the recruitment event, the 7-year gap (2008-2014) gap in the data makes interpretation of any patterns difficult, especially given the naturally high spatial and temporal variability of most reef fish populations, and the depth-dependent differences already identified within the FW.

Between 2002 and 2017, total fish and resource fish biomass increased in the Kahana FW (Figure 3.13). Unfortunately, the majority of the increase occurred within the 7-year gap in the time series making it difficult to pinpoint the potential reason(s) for the change. Considering there was little change in the benthic assemblage during this same time period, any change in the fish assemblage was likely associated with ecological processes and stressors that directly affect reef fish demographic processes (*e.g.*, survival, reproduction, settlement, etc.). The 2014 reef fish recruitment pulse is on one potential event that could result in a large increase in many species, including both resource and non-resource species. Another change of note that occurred during this

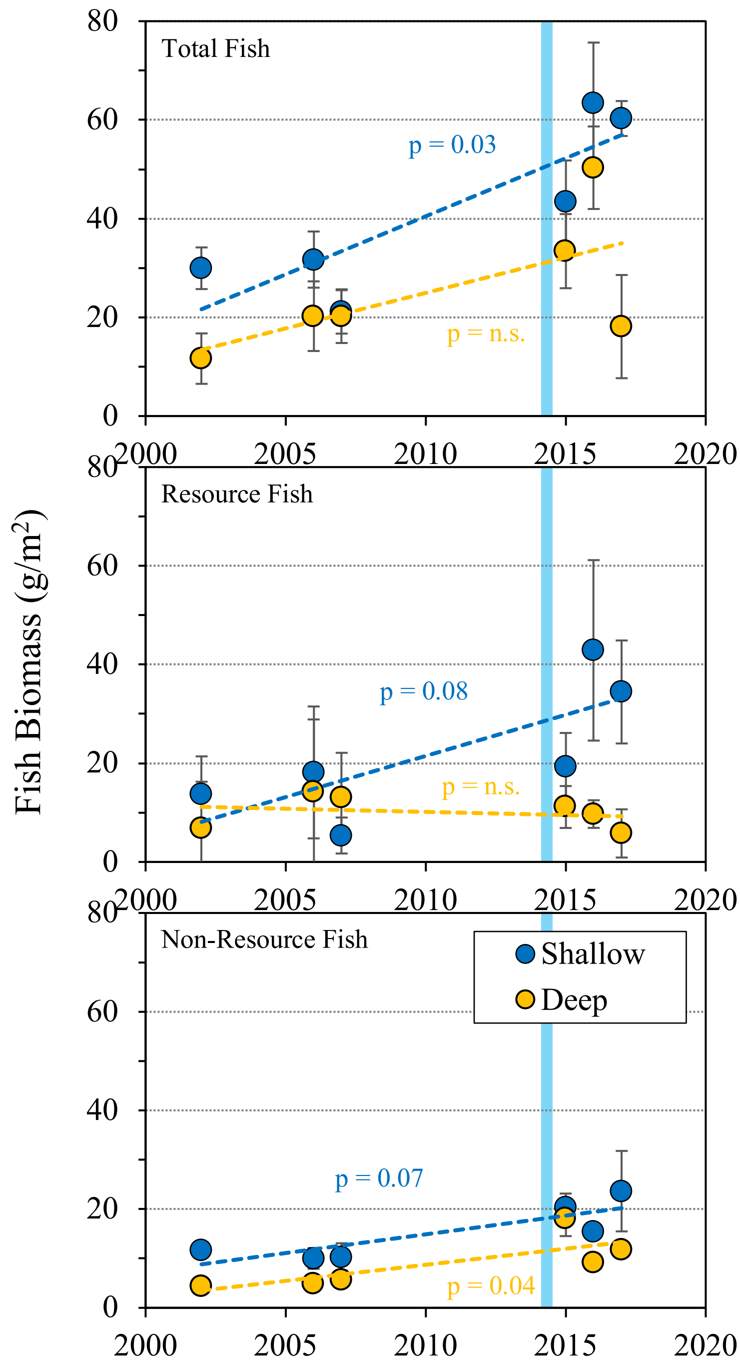


Figure 3.13. Total fish, resource fish, and non-resource fish biomass (g/m^2) at shallow (blue) and deep (orange) sites in the Kahana FW between 2002 and 2017. The blue bar marks the 2014 reef fish recruitment event.

[33] Talbot (2014)
[34] Minton *et al.* 2018a
[35] TNC, unpub. data
[36] TNC Maui and DAR-Maui, per. comm.

timeframe was the enactment of the Maui laynet rules in March 2007, which could contribute, at least in part, to increases in resource, and to a lesser extent, non-resource fish, especially in shallow water, where the new management rules would be expected to have a larger effect.

While reef fish biomass increased over time, changes observed in the fish assemblage were not the same at shallow and deep sites. The shallow fish assemblage showed significant improvement in total fish biomass since 2002, whereas the deep fish assemblage did not (Figure 3.13). This pattern of improvement in biomass at shallow- but not deep-water sites occurred for both resource and non-resource fish, although the improvement in resource fish was larger than that observed for non-resource species over the past 17 years. In addition, the size of resource fish has increased more than size of non-resource species during this time period at shallow compared to deep sites (Figure 3.14), so while both resource and non-resource species appear to have increased at shallow sites, resource species appear to have experienced greater gains than non-resource species. This pattern suggests that factors contributing to the increase of fish on the shallow water reefs within the Kahana FW are multifaceted and complex, but that fishery management has likely played a role. Unfortunately, the data are not sufficient to provide more definitive conclusions.

The Big Picture

Within the context of the WMR, reef resources within the Kahana FW are a “mixed bag.” While the fish assemblage had medium-high total fish and prime spawner biomass, resource fish biomass was average and coral cover was the lowest for any of the FWs in the WMR, raising questions about the long-term potential for the reefs at Kahana. Time series data show coral cover has been below average since at least 2002 and with poor water quality conditions, reef fish habitat may be in relatively poor condition. One positive that gives hope for potential

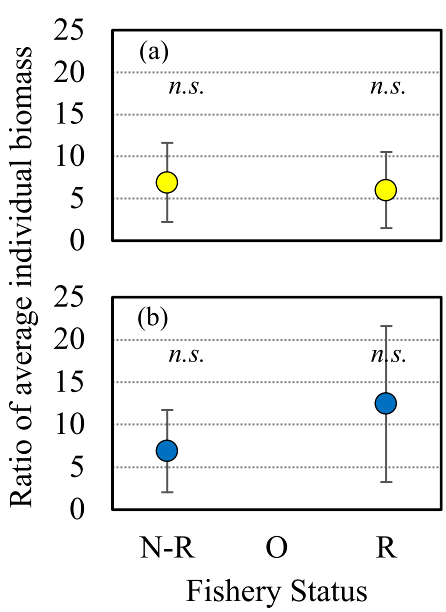


Figure 3.14. Comparison of fish size (ratio of average individual biomass) between deep and shallow sites within the Kahana FW (a) between 2002-2007 (b) and from 2015-2018. A ratio=1 means the fish at shallow sites are of approximately equal size to those at deep sites, a ratio>1 indicates fish at shallow sites are larger on average than those at deep sites, and a ratio<1 means fish at shallow sites are smaller on average than those at deep sites. N-R=non-resource fish (5 species: *Acanthurus nigrofuscus*, *Rhinecanthus rectangulus*, *Sufflamen bursa*, *S. fraenatus*, *Thalassoma duperrey*), O=other moderately-prized fish (no species), R=resource fish (6 species: *Parupeneus multifasciatus*, *Scarus psittacus*, *A. blochii*, *A. dussumieri*, *A. olivaceus*, *Naso lituratus*). Significance was tested using a 1-sample t-test.

improvement is that the reefs within the Kahana FW are also spatially heterogenous, so while deep reefs (>6 m) may have below average abundance, biomass, and diversity, shallow reefs (<6 m) had some areas of above average coral cover and fish biomass. In addition, shallow water fish have shown an increase in fish biomass since the early 2000s, suggesting that with improved fishery and habitat management this has potential to be beneficial.

Statewide Context

Averages for coral cover (14.4 ± 0.7%), total fish biomass (40.9 ± 2.5 g/m^2), resource fish biomass (22.3 ± 1.8 g/m^2), and prime spawner biomass (3.7 ± 1.0 g/m^2) were calculated for the MHI, to serve as a gauge for how the reefs of the WMR are faring relative to those from around the state. All across the MHI, reefs are affected by overfishing, sediments, land-based pollution, and invasive species. Over the past century, populations of some commercially important reef fish populations have declined by over 90%, and coral cover in some areas has declined by at least 40% in just the last 40 years. While there are many reef areas around the state that still have abundant and healthy resources, the current statewide averages used for comparison here certainly reflect substantial declines in resource condition seen broadly across the reefs of the MHI. Reefs in the WMR were consistent with the statewide averages for coral and fish assemblages (see Chapter 1). However, considerable variability in the condition of reefs exists across the WMR, and the reefs within the Kahana FW ranged from below average to above average when compared to reefs statewide (Figure 3.15). The Kahana FW had medium-low coral cover but above average total fish biomass and high prime spawner biomass compared to reefs in the MHI.

<u>Synthesis</u>

The reef within the Kahana FW is strongly delineated based on depth. Reef areas deeper than 6 m (20 ft) across the entire shoreward extent of the FW have low diversity, fish biomass and coral cover. The deep reef is dominated by turf-covered hardbottom interspersed with ample sand, suggesting that the reef may be fragmented, and likely constitutes relatively poor reef fish habitat. In contrast, the shallow-water reef areas in the Kahana FW have more coral cover than the deep reef and support a fish assemblage with an above-average biomass for the WMR, especially for prime spawners. However, the reef areas at Kahana are highly variable.

Much of the reef within the Kahana FW has low abundance, biomass, and diversity, but two reef areas of note exist. The shallow-water reef off Alaeloa Point and extending into Honokeana Bay has average coral cover (around 0-20%) and benthic diversity, but high biomass and diversity of fish, especially resource fish and prime spawners. While recent survey data are limited, the reef off Hāwea Point also appears to have high fish biomass, including resource fish and prime spawners. One of the survey sites off Hāwea Point had the fourth highest (and highest outside a protected area) fish biomass in the WMR, and other nearby sites also had high fish biomass, indicating an abundant fish assemblage is likely in the general area off the point. Current data on the benthic assemblage off Hāwea Point are not available but would warrant investigation.

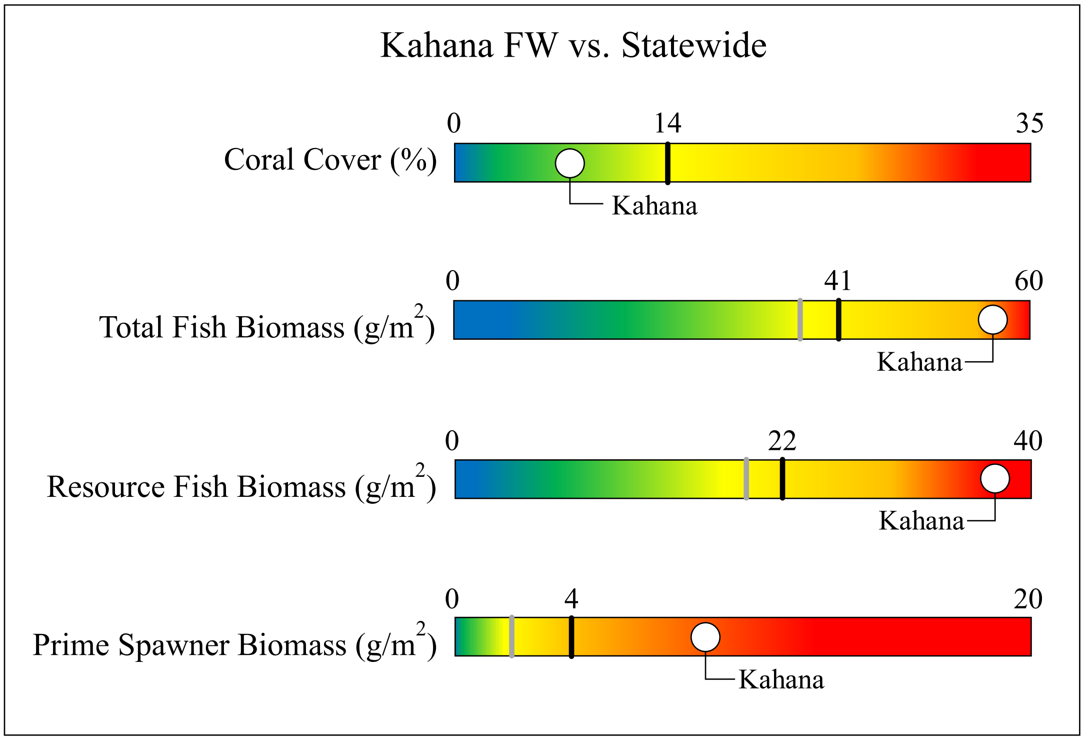
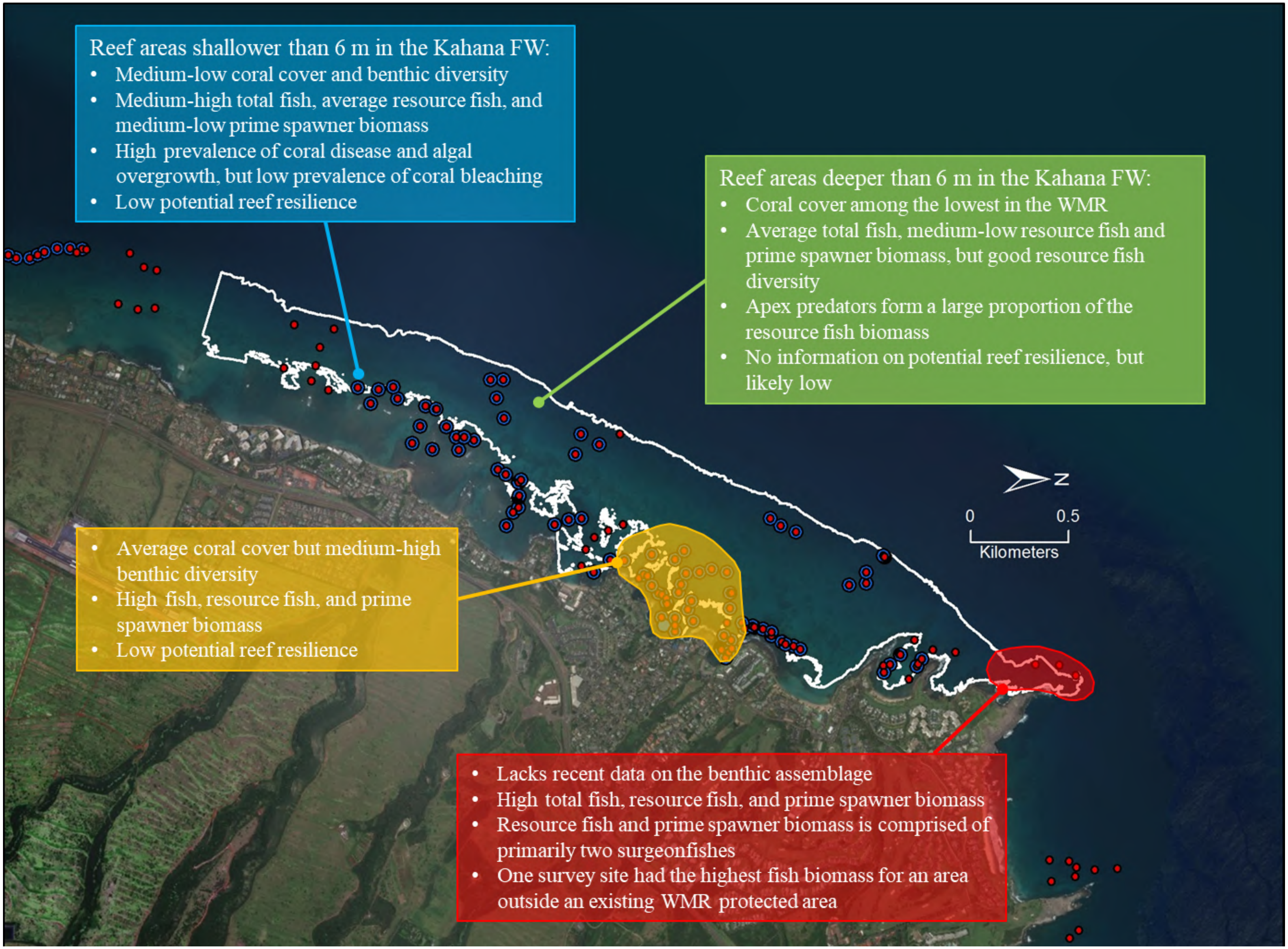


Figure 3.15. Comparison of the Kahana FW to statewide averages for coral cover (%), total fish, resource fish, and prime spawner biomass (g/m^2). Black vertical line and value denote the statewide average. For the three fish metrics, the grey vertical line is the statewide trimmed mean, which was used to develop the qualitative categories; see the methods (Appendix B) for more details on the use of the trimmed means.


Reef areas shallower than 6 m in the Kahana FW:
• Medium-low coral cover and benthic diversity
• Medium-high total fish, average resource fish, and medium-low prime spawner biomass
• High prevalence of coral disease and algal overgrowth, but low prevalence of coral bleaching
• Low potential reef resilience
Reef areas deeper than 6 m in the Kahana FW:
• Coral cover among the lowest in the WMR
• Average total fish, medium-low resource fish and prime spawner biomass, but good resource fish diversity
• Apex predators form a large proportion of the resource fish biomass
• No information on potential reef resilience, but likely low
N
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Kilometers
• Average coral cover but medium-high benthic diversity
• High fish, resource fish, and prime spawner biomass
• Low potential reef resilience
• Lacks recent data on the benthic assemblage
• High total fish, resource fish, and prime spawner biomass
• Resource fish and prime spawner biomass is comprised of primarily two surgeonfishes
• One survey site had the highest fish biomass for an area outside an existing WMR protected area

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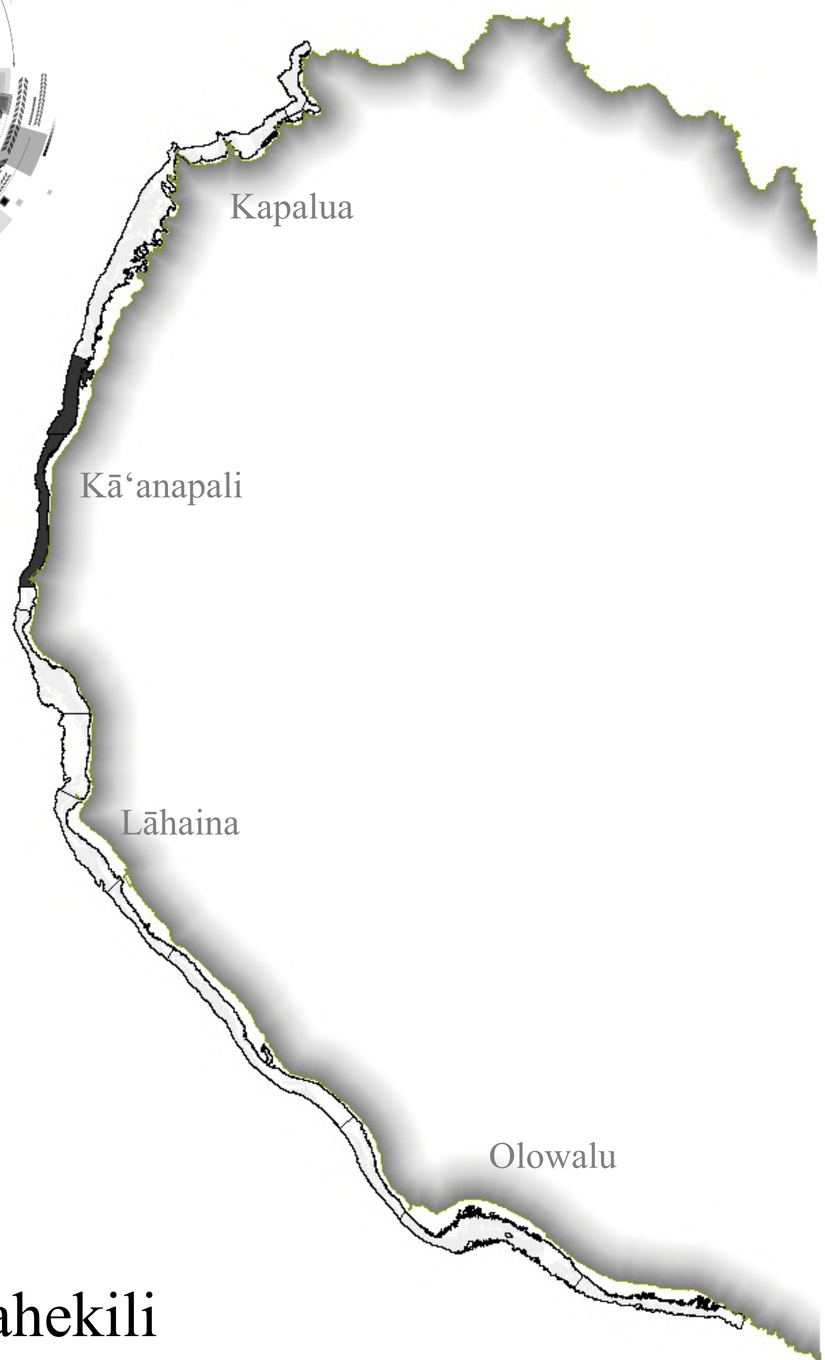

Reefs of Kahekili

Geographic Setting

The Kahekili Focus Window (FW) extends from Pōhaku Park southward to the southern boundary of, and including the entirety of, the Kahekili Herbivore Fisheries Management Area (KHFMA). The approximately 5 km stretch of coastline contains no significant bays and has an extensive white sand beach fronting primarily tourist resorts. It has only one large point of land, Keka‘a Point (Black Rock), near the southern end of the FW. Coastal development is primarily tourist-related, including large resorts, numerous condominiums, and golf courses. Upland areas are a mix of agriculture (coffee, seed corn, and fallow fields) and conservation land under the management of the West Maui Mountains Watershed Partnership. Impervious surfaces, fallow agricultural fields, and heavily manicured landscapes have promoted runoff of sediment and nutrients into coastal waters resulting in high turbidity. In addition, contamination from injection wells and the Lāhaina Wastewater Reclamation Facility (WWRF) has been detected in coastal submarine groundwater discharges, especially near Kahekili Beach Park[37]. Data collected from a network of 20 water quality monitoring stations across the West Maui Region (WMR)[38] showed the Kahekili FW exceeded state water quality standards for all parameters that were measured, including turbidity, and organic nutrients. In particular, the waters off Kahekili Beach Park had high phosphorus and nitrate.

The KHFMA was established by DAR in 2009 to conserve the coral reef by controlling the overabundance of alien and native marine algae by increasing the abundance of herbivorous fishes and sea urchins. Through 2015, data suggest the management area has promoted an increase in the biomass of herbivores, with both an increase in abundance and individual size relative to several reference areas around Maui[39]. As of 2015, it was unclear if the increased herbivore biomass had also produced the desired effect on the benthic assemblage, but increases in cover of crustose coralline algae (CCA), a decrease in cover of turf, and continuing low cover of macroalgae suggest the reserve is working as intended. The purpose of the Atlas is not to assess the effectiveness of the KHFMA, but the potential effects of this management area cannot be ignored when examining the benthic and fish assemblages within the Kahekili FW.

The Data

The Kahekili FW is comprised of two reef tracts: Mahinahina and North Kā‘anapali (Figure 4.1):

- Mahinahina reef tract extends ~1.3 km (0.8 mi) from the southern edge of Pōhaku Park on Lower Honoapi‘ilani Road to the northern boundary of the KHFMA. This reef tract was surveyed several times between 2004 and 2018, with the highest survey effort occurring in 2015 and 2016 (Table 4.1). In 2018, The Nature Conservancy (TNC) assessed one reef resilience site within the Mahinahina reef tract.
- North Kā‘anapali reef tract comprises all eligible reef area within the boundary of the KHFMA and includes approximately 3.7 km (2.3 mi) of coastal marine waters. While

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[37] Hunt and Rosa (2009) and Glenn *et al.* (2012)
[38] Hui O Ka Wai Ola and the State Department of Health collect water quality data at 20 sites in the WMR, including two locations in the Kahekili FW: Kā‘anapali Shores and Kahekili Beach Park. To learn more about Hui O Ka Wai Ola and download raw data, please visit huiokawaiola.com.
[39] Williams *et al.* (2016)

sampling effort within the reef tract was considerablyy greater than in the Mahinahina reef tract, it was primarily restricted to the northern 2/3 of the KHFMA and comprises an extensive time series of data (1999-2017), including robust annual sampling from 2008 and 2016 (Table 4.1). Two Hawai‘i Coral Reef Assessment and Monitoring Program (CRAMP) long-term monitoring sites (Kahekili Shallow and Kahekili Deep) are in this reef tract and were surveyed nearly annually from 1999-2012. In 2018, TNC assessed four reef resilience sites within the North Kā‘anapali reef tract.

Maps within the Atlas were generated using a spatial technique called interpolation. This technique uses available survey data to generate a complete spatial model of the data by estimating values between the surveys' data using a mathematical algorithm that considers the values of nearby data weighed by their distance away. Areas with a higher density of surveys will produce more "accurate" interpolations than areas with lower survey density. Averages derived from interpolation maps are calculated across all reef areas and typically vary from averages derived from the survey data. Interpolation maps were generated for the Atlas primarily to display general spatial patterns and should not be used to predict exact values at any given location. For example, an interpolation map can, with a high degree of reliability, indicate that one reef tract has more coral than another reef tract, but it should not be used estimate the "exact" coral cover at a specific location within the reef tract. To estimate coral cover, amount of fish, etc., current survey data from the specific location should always be used over the interpolation maps when these data are available.

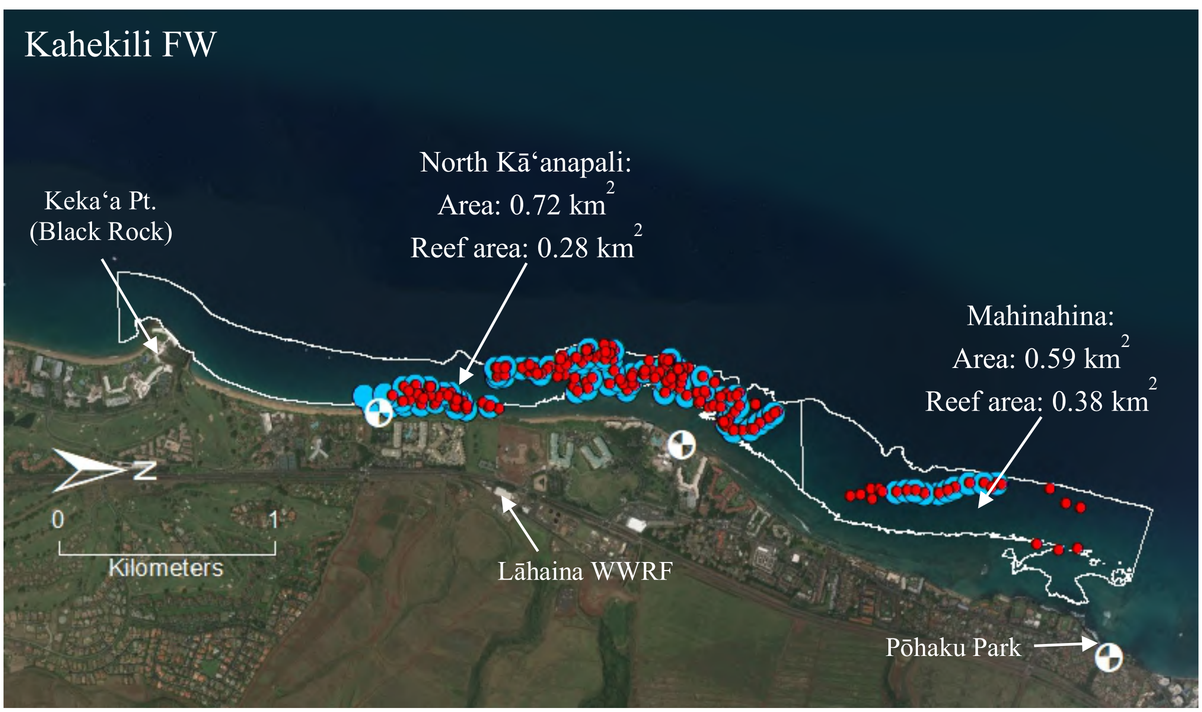

Figure 4.1. Reef tracts within the Kahekili FW. Dots indicate 2016-2018 survey efforts for the benthic (blue) and fish (red) assemblages within the FW. White quadrant circles along the shore are (north to south) Pōhaku Park (part of the Kahana FW), Kā‘anapali Shores, and Kahekili Park long-term water quality monitoring sites.

Table 4.1. Benthic and fish assemblage survey effort (number of survey sites) in the Kahekili FW between 1999 and 2018. The FW has two ref tracts: Mahinahina and North Kāʻanapali.

Reef Tract	Survey Year	Benthic	Fish
Mahinahina		58	49
	2004	2	
	2007-2014	16 (2/year)	
	2015	27	25
	2016	12	23
	2018	1	1
North Kāʻanapali		1,302	1,455
	1999	2	
	2000	2	2
	2001-2007	14 (2/year)	
	2008	155	151
	2009	82	97
	2010	87	91
	2011	208	289
	2012	183	149
	2013	200	188
	2014	152	141
	2015	138	127
	2016	77	138
	2017		78
	2018	4	4
TOTAL		1,360	1,504

Benthic Assemblage

Current Spatial Patterns: Benthic

Current benthic information (2016-2018) was limited for the Kahekili FW (Table 4.1), with most of the data collected in 2016, the year following the 2015 mass bleaching event. In 2017, DAR conducted resource surveys within the Kahekili FW, and while fish data from these surveys have been incorporated into the Atlas, benthic data were not available in time for analysis. While likely still accurate, given the relatively scarcity of data for years after 2016, descriptions of the benthic assemblage should be considered preliminary until more current data are incorporated into the analysis.

In both the Mahinahina and North Kāʻanapali reef tracts, turf cover was only slightly higher than coral cover (Table 4.2) and did not significantly differ between the two reef tracts. Overall variability in the cover of the benthic groups was low across the FW, suggesting a uniformity in

Table 4.2. Average (±SEM) percent cover of benthic groups and taxa in the Mahinahina (n=13) and North Kāʻanapali (n=81) reef tracts. Data are from 2016-2018.

	Mahinahina	**North Kāʻanapali**
Turf	39.6 ± 2.7	46.3 ± 1.9
Coral	35.2 ± 3.2	31.9 ± 1.5
Porites lobata	15.6 ± 1.3	16.7 ± 1.0
Porites compressa	14.7 ± 2.0	8.6 ± 0.8
Montipora capitata	5.3 ± 1.5	4.4 ± 0.4
Montipora patula	0.5 ± 0.2	1.6 ± 0.2
Pocillopora meandrina	0.3 ± 0.1	0.5 ± 0.1
Pavona varians	0.1 ± 0.1	0.1 ± 0.1
Montipora flabellata	0	<0.1
Leptastrea purpurea	0	<0.1
Pavona duerdeni	0	<0.1
Psammocora nierstraszi	0	<0.1
Porites rus	<0.1	0
Crustose Coralline Algae	8.8 ± 1.9	12.6 ± 1.2
Macroalgae	5.6 ± 1.5	3.8 ± 0.5
Cyanobacteria	0.3 ± 0.1	<0.1
Other	0.1 ± 0.1	0.1 ± 0.1
Abiotic	13.4 ± 3.4	7.6 ± 0.6
Sand	8.3 ± 2.0	4.6 ± 0.5
Other	4.4 ± 0.5	2.7 ± 0.2

the benthic assemblage. Coral cover seldom dropped below 20% cover at any survey site, but also never exceeded 56% cover (Figure 4.2). However, while coral cover was high compared to other reefs in the WMR (Chapter 1), coral species richness was the second lowest among the FWs in the WMR[40]. Only 11 species were observed in the Kahekili FW, and other than *Porites lobata* (lobe coral), *P. compressa* (finger coral), and *Montipora capitata* (rice coral), most were rare. While this does not appear to have resulted in a difference in coral cover, coral species richness within the North Kāʻanapali reef tract was 50% greater than that within the Mahinahina reef tract (Table 4.2). This difference could, however, be due to the much larger number of sites surveyed within the North Kāʻanapali reef tract. The Mahinahina reef tract had slightly higher benthic diversity than the North Kāʻanapali reef tract (t-test; t_{14}=2.14; p=0.036), but it appears that evenness[41] may be driving the difference in benthic diversity and not higher taxa richness (Figure 4.3), which was slightly lower than within the North Kāʻanapali reef tract.

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[40] Only the Hanakaʻōʻō Beach FW, the next reef area to the south of the Kahekili FW, had fewer species.

[41] Species richness and evenness are important facets of diversity. Richness is the number of different species present in an area, whereas evenness considers the similarity of the population size of each of the species present.

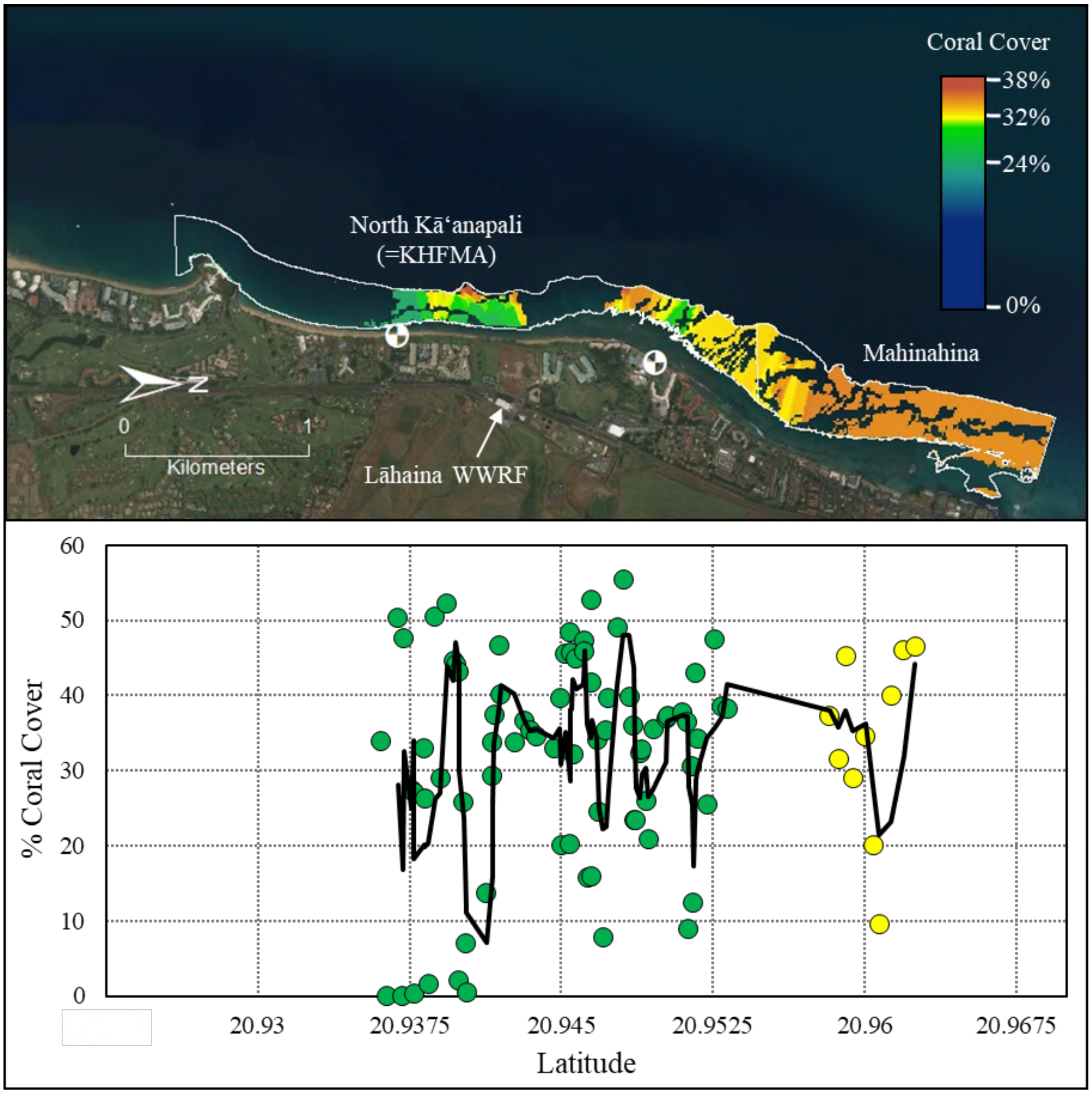

Figure 4.2. Coral cover across the Kahekili FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the two reef tracts. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of coral cover at consecutive survey sites along the east-west axis. Colored points in the graph correspond with the North Kāʻanapali (green) and Mahinahina (yellow) reef tracts. White quadrant circles along the shore are (north to south) Kāʻanapali Shores and Kahekili Park long-term water quality monitoring sites.

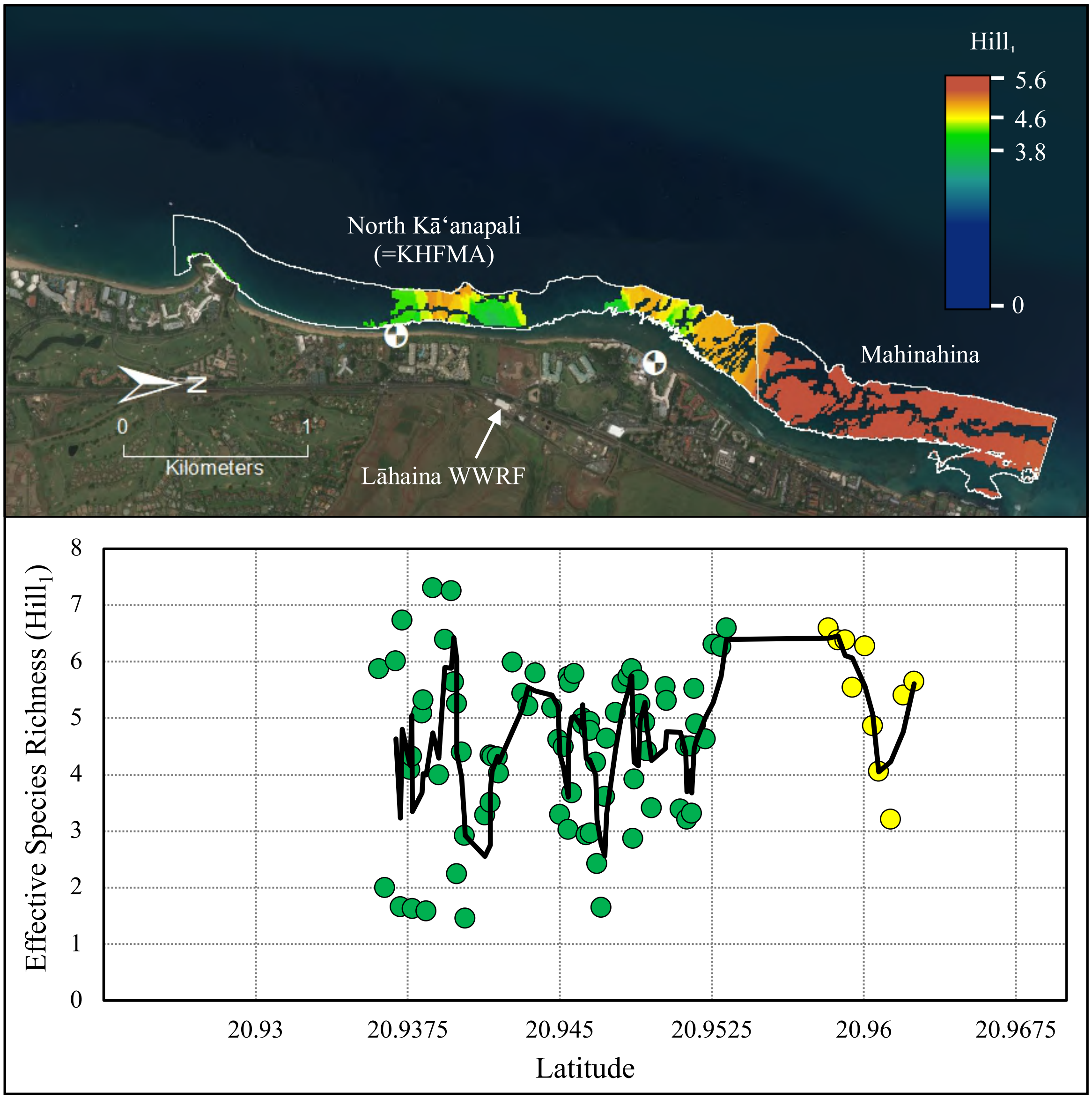

Figure 4.3. Effective species richness ($Hill_1$) of coral across the Kahekili FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the two reef tracts. Map colors are derived from the data of the FW, such that yellow is the average effective species richness for the FW and red would be considered high richness for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of effective species richness at consecutive survey sites along the east-west axis. Colored points in the graph correspond with the North Kāʻanapali (green) and Mahinahina (yellow) reef tracts. White quadrant circles along the shore are (north to south) Kāʻanapali Shores and Kahekili Park long-term water quality monitoring sites.

Interestingly, coral cover was low directly off and extending south of the Lāhaina WWRF, one of the locations in the WMR where wastewater is placed into injection wells (Figure 4.2). Several submarine groundwater discharges with elevated nutrients have been identified in this area of the North Kāʻanapali reef tract, with the resulting high-nutrient plume being carried to the south[42]. Only 10 sites in the reef tract had <10% coral cover, and eight of them occurred is this area, including all six that had ≤2% coral cover.

Since 2016, the benthic assemblages of the Mahinahina and North Kāʻanapali reef tracts showed no difference in structure (PERMANOVA; $F_{1,83}=1.26$; $p=0.259$). Recent studies[43] have documented a significant increase in CCA inside the KHFMA (=North Kāʻanapali reef tract) compared to several reference sites around Maui, but that difference has either disappeared in recent years or was not of a large enough magnitude to result in a difference in the assemblage structure between the two reef tracts. Given that the two reef tracts are part of the same contiguous reef and presumably exposed to a similar suite of environmental stressors, it is not surprising they show considerable similarity.

Historical Patterns: Benthic

A 14-year time series of data (1999-2012) is available for two permanent coral reef monitoring sites in the Kahekili FW. As with most CRAMP monitoring locations, a shallow-water (3 m) and deep-water site (10 m) site were paired and surveyed within the North Kāʻanapali reef tract. These sites were designated as "Kahekili Shallow" and "Kahekili Deep." In addition to the CRAMP sites, a robust dataset was collected by DAR-Maui for most years between 2008 and 2016 within the North Kāʻanapali reef tract. For the Mahinahina reef tract, two CRAMP monitoring sites ("Mahinahina Shallow" and "Mahinahina Deep") have limited data (coral cover only) collected sporadically between 2004 and 2016. In addition, robust data sets were collected by DAR-Maui in 2015 and 2016.

In the North Kāʻanapali reef tract, both CRAMP sites show an initial decline in coral cover between 1999 and 2001, followed by an increase in cover until 2009 (Figure 4.4). Between 2009 and 2012, coral cover was stable at both the shallow and deep CRAMP sites. Data collected across the FW also shows relatively stable coral cover from 2008 to 2015, before experiencing a marginally significant decline between 2015 and 2016 (ANOVA, F=1,209=3.03; $p=0.083$), when coral cover dropped from 36.7 ± 2.0 % to 31.7 ± 1.7% (~14% loss of coral). This decline corresponds with the mass coral bleaching event that affected Maui reefs late in the calendar year of 2015. In the Mahinahina reef tract, coral cover at both CRAMP sites declined ~15% between 2004 and 2016 (Figure 4.4). Unlike the Kahekili CRAMP sites, most of the decline occurred after 2010 at the Mahinahina CRAMP sites and did not show strong evidence of an effect from the 2015 mass coral bleaching event. This seven-year decline suggests the reef within the Mahinahina reef tract may be experiencing a different stress regime than those within the North Kāʻanapali reef tract, which did not show a similar downward trend over the same seven-year time period.

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[42] Prouty *et al.* (2017) and Hunt and (Rosa 2009). Water quality sampling by Hui O Ka Wai Ola has found elevated organic nutrients in this area.

[43] Williams *et al.* (2016)

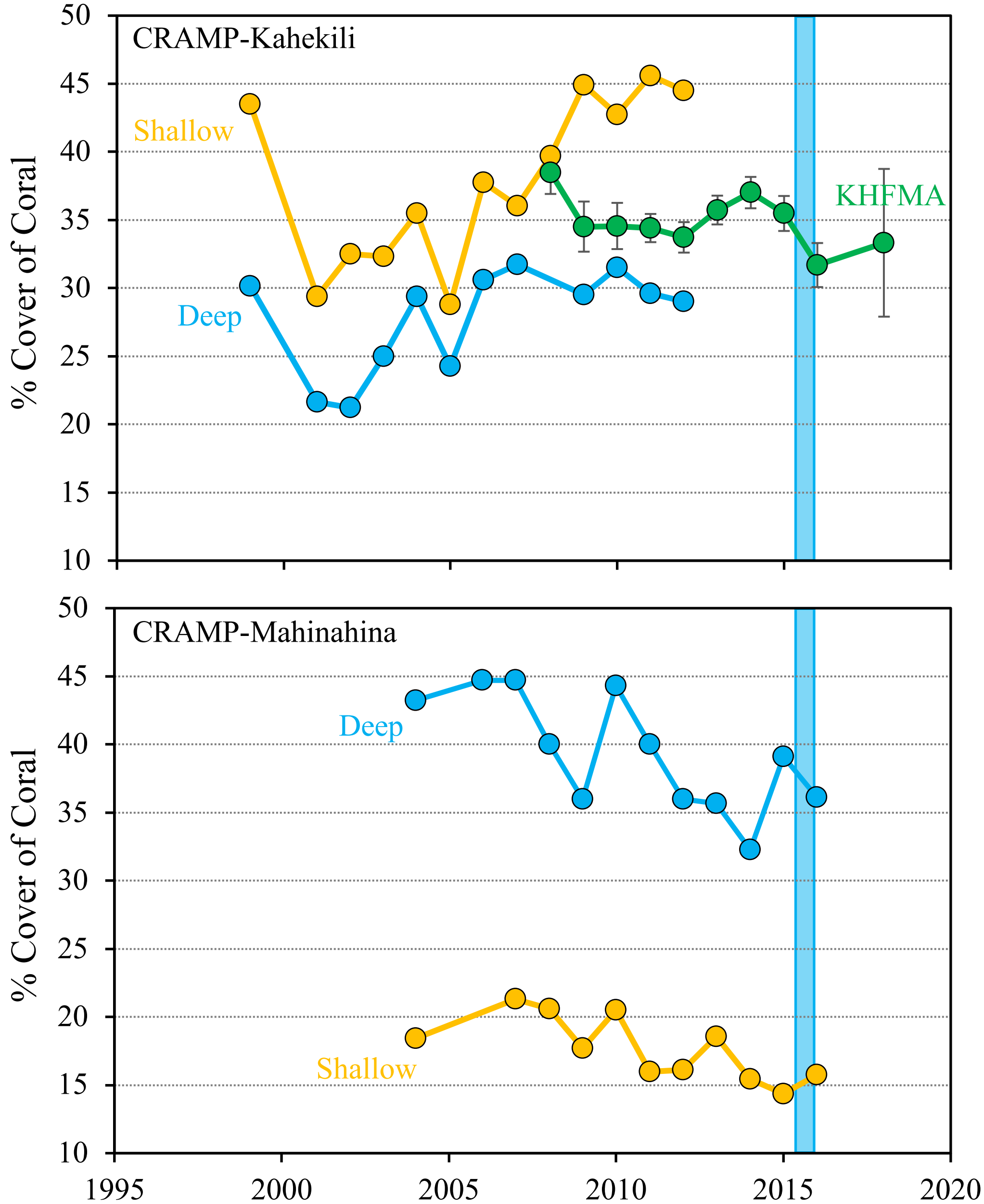

Figure 4.4. Average (±SEM) coral cover at deep (blue) and shallow (orange) CRAMP monitoring sites and in the North Kāʻanapali reef tract from 1999-2012 (top) and the Mahinahina reef tract from 2004-2016 (bottom). Starting in 2008, intensive monitoring within the North Kāʻanapali reef tract was conducted as part of a study to assess the effectiveness of the KHFMA (green). The blue bar signifies the approximate months over which the 2015 mass coral bleaching event affected Maui reefs.

From 2011 until 2015, DAR-Maui conducted biannual (March and September) surveys of the benthic assemblage within the North Kāʻanapali reef tract, with reduced levels of sampling extending into 2018. In 2015, the September round would have occurred during the height of the

2015 mass coral bleaching event, likely before significant bleaching-related mortality had occurred, but late enough that some mortality might be expected (Figure 4.5). The North Kāʻanapali reef tract lost about 14% of its cover between 2015 and 2016, and the cover of turf rose sharply, from a low of 35.4 ± 2.2% in March 2015 to 45.1 ± 2.1% in October 2016 and 54.3 ± 4.6% in March 2018, although the sampling effort was low in 2018 (four sites). The increase in turf appears to have come at the expense of coral and CCA (Figure 4.5).

It is difficult to say how severely the 2015 bleaching event affected the reefs within the Kahekili FW. Coral decline was relatively modest compared to other reef areas around Maui, which experienced 20-40% loss of coral[44]. The proliferation of turf within the North Kāʻanapali reef tract, especially into 2018, suggests a shift in benthic dominance could be underway, but firm conclusions would be premature given the low sampling effort in 2018. Of concern are the low coral recruitment rates observed during the reef resilience surveys conducted by TNC in 2018 (discussed in more detail below). Five sites surveyed within the Kahekili FW had below average recruitment rates for the greater leeward Maui region[45], which could compromise the ability of these reefs to recover following a large mortality episode, such as what would be expected following a severe mass bleaching event. Further monitoring of the North Kāʻanapali reef tract would be necessary understand the recovery trajectory of these reefs.

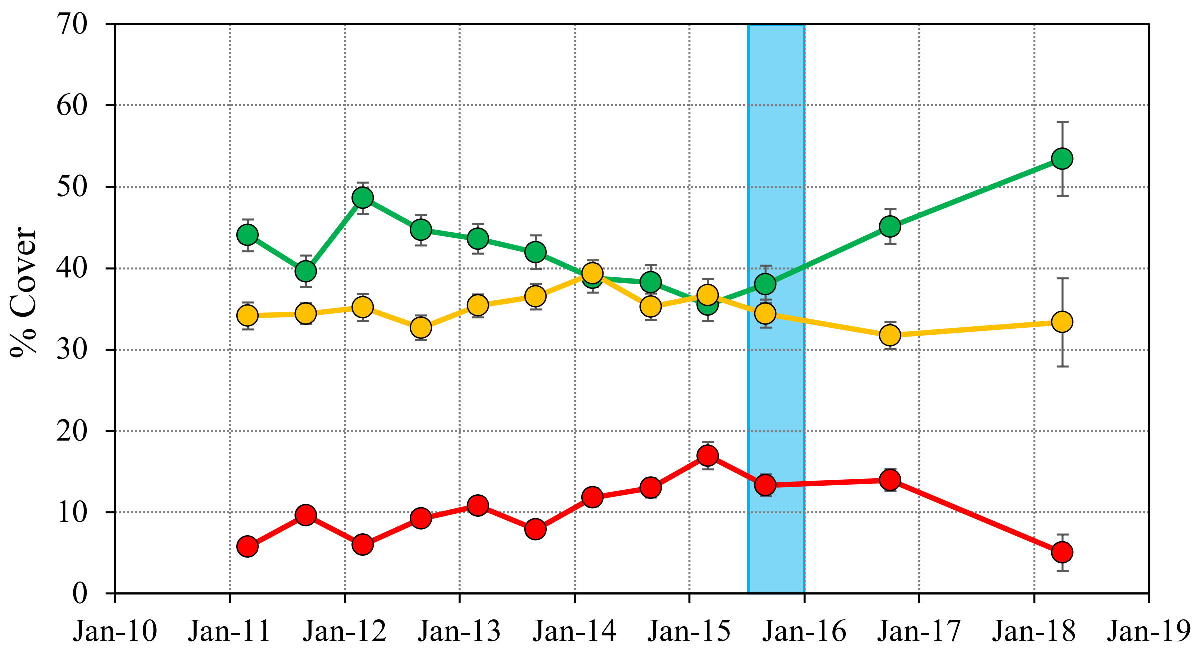

Figure 4.5. Average (±SEM) cover of coral (orange), turf (green), and CCA (red) between 2011 and 2017 within the North Kāʻanapali reef tract. The blue bar signifies the approximate months over which the 2015 mass coral bleaching event affected Maui reefs.

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[44] SSRI (2017)
[45] Maynard *et al.* (2019)

Coral Health and Reef Resilience

In March 2018, a reef resilience assessment of leeward Maui was conducted by TNC and its partners. These assessments were intended to quantify the relative resilience of Maui's reefs to the effects of climate change. Resilience is the ability of a reef to resist, recover from, and adapt to a climate-related event (*e.g.*, coral bleaching) to maintain a diverse, coral-rich state that provides key ecological functions and services to people[46]. Given the integral role of reefs to the people of Hawaiʻi, reef resilience is closely linked with social resilience, which is the ability of human communities to adapt to social, political, environmental, or economic change[47].

Two shallow-water and three deep-water (Table 4.3) reef resilience sites were surveyed within the Kahekili FW. The complete results of TNC's Maui Reef Resilience assessment are detailed elsewhere[48], so only the coral health and resilience findings for the sites in the Kahekili FW are summarized here.

The prevalence of coral disease, algal overgrowth and bleaching (Table 4.3) was relatively high at the reef resilience sites within the Kahekili FW compared to other sites in leeward Maui. Of the 31 shallow and 20 deep sites included in the resilience assessment, all five reef resilience sites within the Kahekili FW ranked in the lower half for coral disease prevalence (*i.e.*, disease was more prevalent in the FW than average). In particular, bleaching was high at the two shallow-water sites, where over 30% of corals at the North Kāʻanapali site and 43% of corals at the Honokowai site were paling/bleaching in March of 2018. Even at the three deep sites, from 7-13% of the coral colonies were bleached. The high number of colonies with compromised health suggests reefs within the FW are under stress, likely from pollutants, such as nutrients, from landscaping/agriculture and sewage, entering the coastal waters from runoff or submarine groundwater discharges. The adverse effects of nutrient-rich discharges on coral reefs, including decreased coral cover and calcification rates and increased algae, have been documented within the North Kāʻanapali reef tract[49] and elsewhere in the WMR[50].

As part of the reef resilience assessment, the 31 shallow-water and 20 deep-water sites were assigned a relative reef resilience rank, based on several indicator variables, including coral cover, coral disease prevalence, coral diversity, coral recruitment, reef builder ratio (ratio of calcifying species to non-calcifying species), rugosity, and herbivorous fish biomass. The sites within the Kahekili FW generally fell toward the middle or lower half of the rankings, with few indicator variables being exceptionally good or bad. The North Kāʻanapali shallow and deep sites (Table 4.3) were categorized as having medium-high resilience, ranking 16th and 10th, respectively. However, both sites were towards the lower end of the medium-high category. The remaining three sites were characterized as having medium-low potential resilience, with both Honokowai sites (ranked 21st and 16th for shallow and deep, respectively) falling into the lowest third of the rankings for their depth.

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[46] Nystrom and Folke (2001)
[47] Adger (2000)
[48] Maynard *et al.* (2019)
[49] Prouty *et al.* (2017)
[50] Amato *et al.* (2016)

Table 4.3. The five reef resilience (RR) sites within the Kahekili FW. "RR Rank" is the relative reef resilience rank among 31 shallow and 20 deep sites along leeward Maui, with 1 being the most resilient and higher numbers indicating less resilience. "Dis. Prev." is the percent of colonies presenting at least one disease. "ALOG" is the percentage of colonies being overgrown by benthic algae. "Paling/Bleaching" is the percent of colonies showing signs of tissue paling or bleaching. Average values for the WMR (italics) are presented for comparison.

	Reef Tract	RR Rank	Dis. Prev.	ALOG	Paling/ Bleaching
Shallow	*WMR Average*		*2.4 ± 0.5*	*9.6 ± 1.5*	*18.2 ± 4.8*
Honokowai	North Kāʻanapali	S21	2.4	27.1	43.4
N. Kāʻanapali	North Kāʻanapali	S12	5.7	19.2	31.1
Deep	*WMR Average*		*1.4 ± 0.3*	*7.2 ± 1.5*	*19.9 ± 6.4*
Mahinahina CRAMP	Mahinahina	D13	2.3	6.9	6.9
Honokowai	North Kāʻanapali	D16	1.9	4.7	8.3
N. Kāʻanapali	North Kāʻanapali	D10	1.0	9.1	12.7

Fish Assemblage

Current Spatial Patterns: Fish

While the benthic assemblage showed only minor differences between North Kāʻanapali, which lies entirely within the KHFMA, and Mahinahina reef tracts, differences between the fish assemblages were more substantial. Total fish biomass within the North Kāʻanapali reef tract (41.0 ± 7.9 g/m^2) was nearly twice that of the adjacent Mahinahina reef tract (22.2 ± 4.6 g/m^2). Goatfish (Mullidae) and parrotfish (Scaridae) accounted for most of the difference in biomass between the two reef tracts, but nearly all fish families had higher biomass inside the KHFMA than outside (Table 4.4). Notably, small, predominately non-resource fish, including wrasses (Labridae), butterflyfish (Chaetodontidae), and Moorish idols (Zanclidae), were more common within the Mahinahina reef tract than the North Kāʻanapali reef tract.

Much of the Kahekili FW had a total fish biomass (Figure 4.6) below the average for the WMR (42.2 ± 3.9 g/m^2). A hotspot of biomass was offshore of the Aston Kāʻanapali Shores Resort in the North Kāʻanapali reef tract, and slightly above average fish biomass extended north to the boundary of the KHFMA, even appearing to spill over in deeper water. Variability in total fish biomass was higher inside the KHFMA than outside. Within the Mahinahina reef tract, biomass was generally low, with only a few sites having total fish biomass above 25 g/m^2 and only a single site with biomass >50 g/m^2. Similarly, most sites within the North Kāʻanapali reef tract had total fish biomass <50 g/m^2, but unlike the Mahinahina reef tract, it also had several sites with >75 g/m^2, and one site with a total fish biomass of 1,680 g/m^2, by far the highest among the sites surveyed in the WMR since 2016. Removing this single site, lowered the estimate of the average total fish biomass within the North Kāʻanapali reef tract to 33.5 ± 2.5 g/m^2.

Table 4.4. Fish biomass (g/m^2) by fish family within the North Kā‘anapali (n=220) and Mahinahina (24) reef tracts for 2016-2018.

	North Kā‘anapali	**Mahinahina**
Mullidae	11.5 ± 7.7	0.6 ± 0.2
Acanthuridae	8.6 ± 1.2	7.3 ± 2.4
Scaridae	6.9 ± 0.5	2.1 ± 0.9
Balistidae	3.7 ± 0.4	3.5 ± 0.9
Labridae	2.9 ± 0.4	4.1 ± 1.5
Pomacentridae	1.6 ± 0.6	1.6 ± 0.9
Lethrinidae	1.3 ± 0.4	0.2 ± 0.1
Monacanthidae	1.0 ± 0.2	<0.1
Chaetodontidae	0.7 ± 0.1	1.2 ± 0.3
Serranidae	0.7 ± 0.2	0.6 ± 0.3
Lutjanidae	0.6 ± 0.3	0
Holocentridae	0.4 ± 0.2	<0.1
Carangidae	0.3 ± 0.1	0.2 ± 0.2
Muraenidae	0.2 ± 0.1	<0.1
Diodontidae	0.2 ± 0.1	0.1 ± 0.1
Cirrhitidae	0.1 ± 0.1	0.1 ± 0.1
Aulostomidae	0.1 ± 0.1	0
Zanclidae	0.1 ± 0.1	0.3 ± 0.1
Tetraodontidae	0.1 ± 0.1	0.1 ± 0.1
Fistulariidae	0.1 ± 0.1	0
Priacanthidae	<0.1	0
Pomacanthidae	<0.1	<0.1
Blenniidae	<0.1	0
Synodontidae	<0.1	0
Ostraciidae	<0.1	0
Antennaridae	<0.1	0
Apogonidae	<0.1	<0.1
Carcharhinidae	<0.1	0
Caracanthidae	<0.1	0
Total Fish Biomass	**41.0 ± 7.9**	**22.2 ± 4.6**

Resource fish biomass, which is comprised of species important for consumption[51] and that tend to be prized by fishers, showed a similar spatial pattern to total fish biomass (Figure 4.7). The North Kā‘anapali reef tract (29.5 ± 7.8 g/m^2) had nearly 3-times the resource fish biomass as the Mahinahina reef tract (12.6 ± 3.9 g/m^2). As with total fish biomass, resource fish biomass was highest on the north end of the North Kā‘anapali reef tract, especially on the reef area fronting the Aston Kā‘anapali Shores Resort. Variability was again high within the North Kā‘anapali reef

[51] See Appendix B for a list of resource and non-resource species

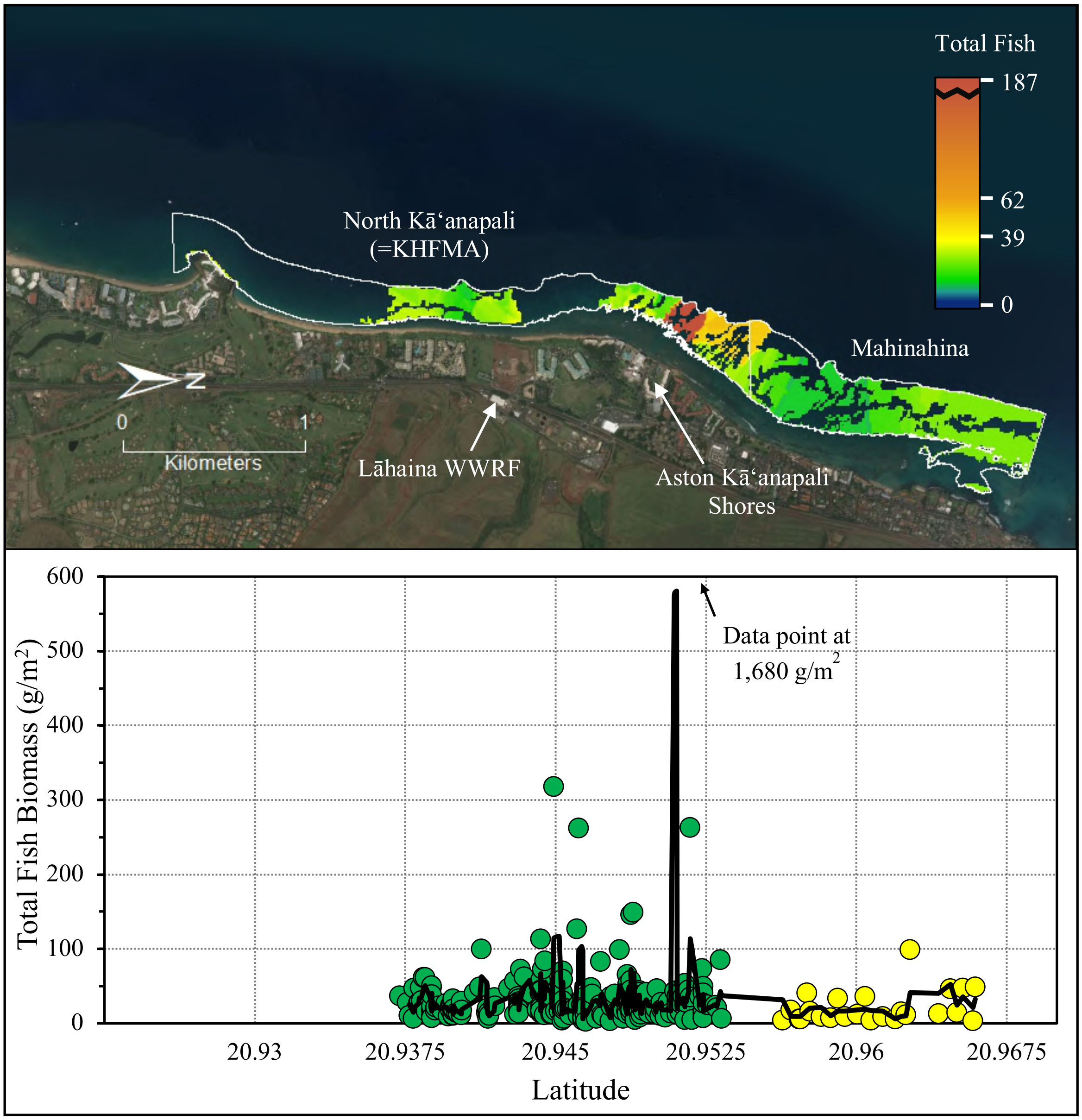

Figure 4.6. Total fish biomass across the Kahekili FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the two reef tracts. Map colors are derived from the data of the FW, such that yellow is the average total fish biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of total fish biomass at consecutive survey sites along the east-west axis. Colored points in the graph correspond with the North Kāʻanapali (green) and Mahinahina (yellow) reef tracts.

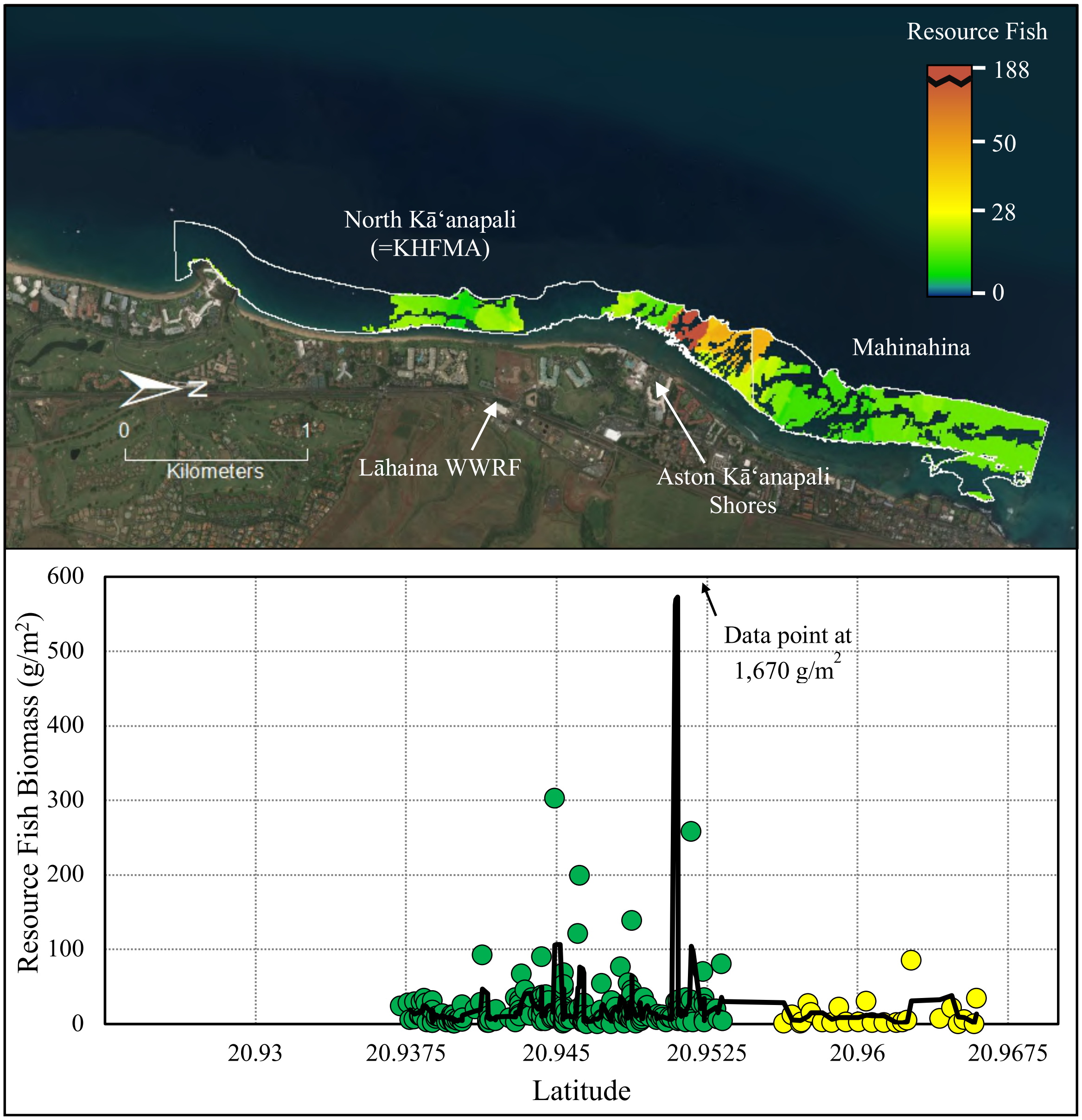

Figure 4.7. Resource fish biomass across the Kahekili FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the two reef tracts. Map colors are derived from the data of the FW, such that yellow is the average total fish biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of resource fish biomass at consecutive survey sites along the east-west axis. Colored points in the graph correspond with the North Kāʻanapali (green) and Mahinahina (yellow) reef tracts.

tract, where numerous survey sites had resource fish biomass >100 g/m^2 and one site had 1670 g/m^2, easily the highest resource fish biomass of any recent site in the WMR. The resource fish biomass at this high-biomass site was almost exclusively the goatfish *Mulloidichthys flavolineatus* (yellowstriped goatfish); surveyors identified a school of over 650 large individuals. While this was the largest school observed by an order of magnitude, schools in excess of 50 *M. flavolineatus* individuals were observed at other sites, indicating this species was common within the North Kāʻanapali reef tract. Removing the site with the unusually high biomass of *M. flavolineatus* lowered the estimate of the average resource fish biomass to 22.0 ± 2.3 g/m^2, and shifted the structure of the resource fish assemblage from one weighted toward goatfish to one with even contributions from parrotfish and surgeonfish (Figure 4.8).

Prime spawners are individual resource fish >70% of the maximum length for that species. These individuals tend to exert a disproportionately large effect on population dynamics due to their considerably higher fecundity and egg quality compared to smaller individuals[52]. Conservation of prime spawners is important to maintaining sustainable fisheries and ecosystems.

The North Kāʻanapali reef tract had higher average prime spawner biomass (16.6 ± 7.7 g/m^2) than the Mahinahina reef tract (2.1 ± 1.3 g/m^2). Compared to other areas in the WMR (*e.g.*, Olowalu, Lāhaina), prime spawner biomass within the North Kāʻanapali reef tract was high, second only to Honolua-Mokulēʻia MLCD reef tract (Chapter 2). Variability was high across the FW (Figure 4.9), with prime spawner biomass within the North Kāʻanapali reef tract ranging between 0 and 1,667 g/m^2, the highest biomass observed in the WMR. Within the North Kāʻanapali reef tract, 39% of the survey sites had no prime spawners. In contrast, within the Mahinahina reef tract, prime spawner biomass ranged between 0 and 29 g/m^2, and 75% of the survey sites had no prime spawners.

Prime spawner species richness was also high, totaling 23 species within the North Kāʻanapali compared to five within the Mahinahina reef tract. Over half (51.8%) of the prime spawner biomass within the North Kāʻanapali reef tract was *M. flavolineatus*, and nearly a quarter was the parrotfish *Chlorurus spilurus* (bullethead parrotfish). Also common were *M. vanicolensis* (yellowfin goatfish), *Acanthurus blochii* (ringtail surgeonfish), *Oxycheilinus unifasciatus* (ringtail wrasse), *Scarus psittacus* (palenose parrotfish), and *Monotaxis grandoculis* (bigeye emperor). Prime spawners in all seven of the resource fish groups were present within the North Kāʻanapali reef tract. In contrast, *O. unifasciatus* and *A. olivaceus* (orangeband surgeonfish) were the most abundant prime spawners within the Mahinahina reef tract, yet both had only a third of the biomass found inside the North Kāʻanapali reef tract.

Effective species richness showed no clear spatial pattern across the Kahekili FW (Figure 4.10). Effective species richness within the Mahinahina reef tract (7.2 ± 0.5) was higher than within the North Kāʻanapali reef tract (5.4 ± 0.1), a surprising result given the lower number of fish families represented in the Mahinahina (19 families) compared to the North Kāʻanapali (29 families) assemblage. Reasons for this pattern are not clear but could be an artifact of the low sampling effort within the Mahinahina compared to the North Kāʻanapali reef tract.

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[52] Birkeland and Dayton (2005) and Hixon *et al.* (2014)

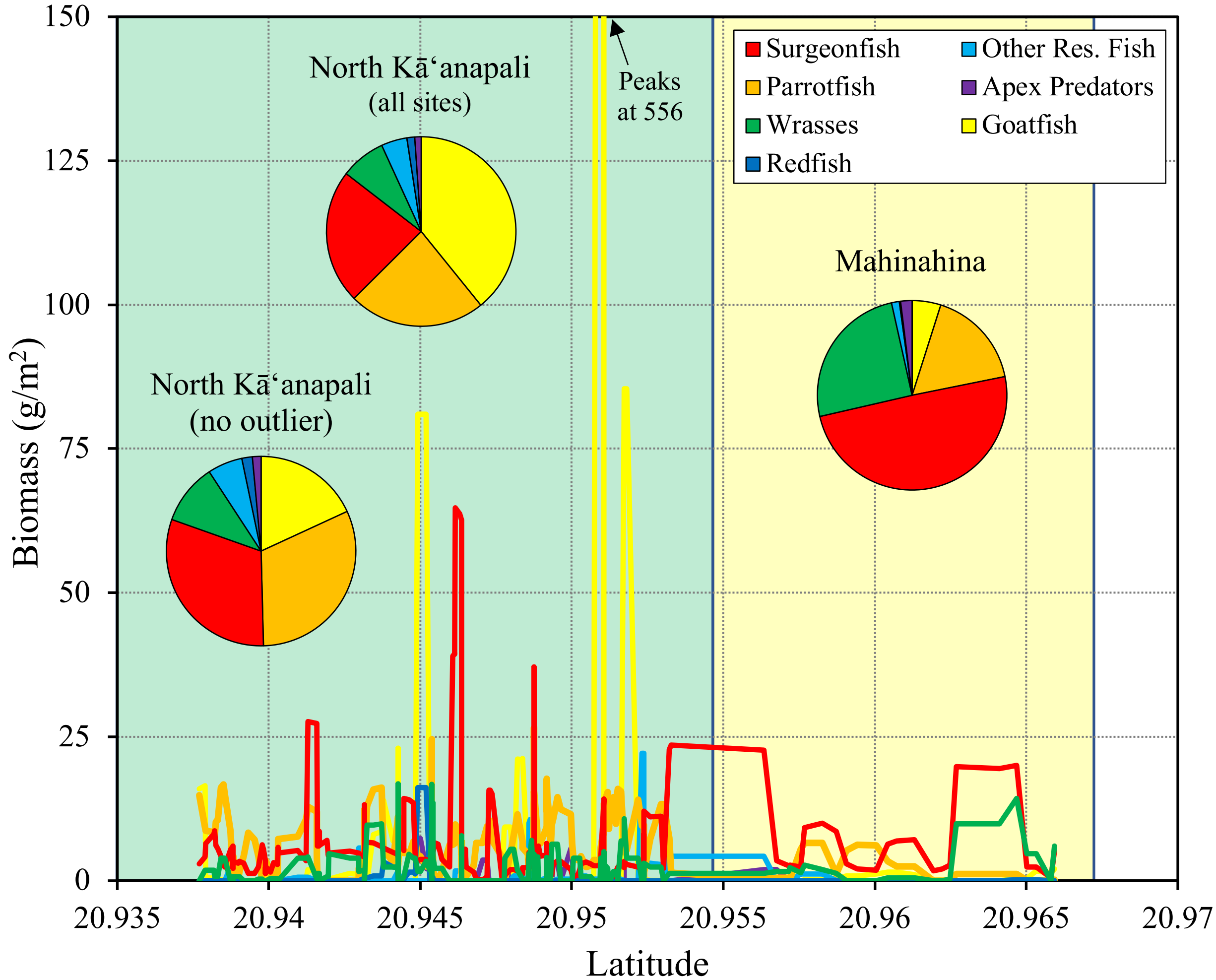

Figure 4.8. Biomass of seven resource groups across the Kahekili FW. Color boxes correspond with the North Kāʻanapali (green) and Mahinahina (yellow) reef tracts. Pie charts are the relative biomass of the seven resource groups in each reef tract. The lower pie chart for North Kāʻanapali reef tract excludes one survey site that had unusually large resource fish biomass composed primarily of the goatfish *Mulloidichthys flavolineatus* (see text for more discussion).

Historical Patterns: Fish

The North Kāʻanapali reef tract has an impressive 10-year time series of data collected annually from 2008 to 2017. Data through 2015 have been previously analyzed[53] and showed positive benefits of the KHFMA on parrotfish and surgeonfish and encouraging signs of improvement of the benthic assemblage (*e.g.*, an increase in CCA cover). In contrast, the Mahinahina reef tract has a limited times series, covering only 2015 and 2016, and therefore, is not analyzed here.

Any analysis of the North Kāʻanapali reef tract cannot ignore the management actions implemented with the establishment of the KHFMA in 2009, but the data analyzed in the Atlas

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[53] Williams *et al.* (2016)

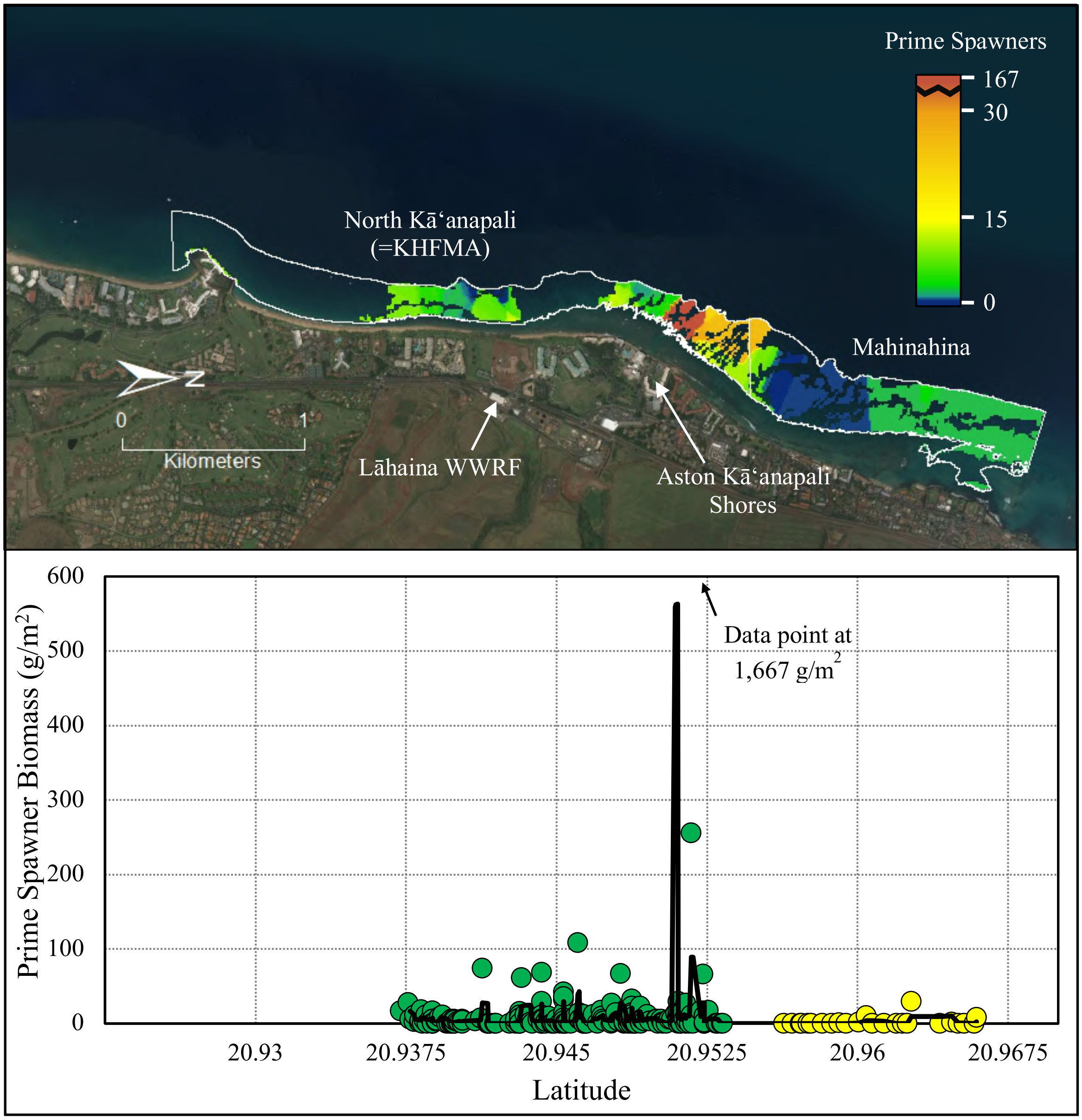


Figure 4.9. Prime spawner biomass across the Kahekili FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the two reef tracts. Map colors are derived from the data of the FW, such that yellow is the average total fish biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of prime spawner biomass at consecutive survey sites along the east-west axis. Colored points in the graph correspond with the North Kāʻanapali (green) and Mahinahina (yellow) reef tracts.

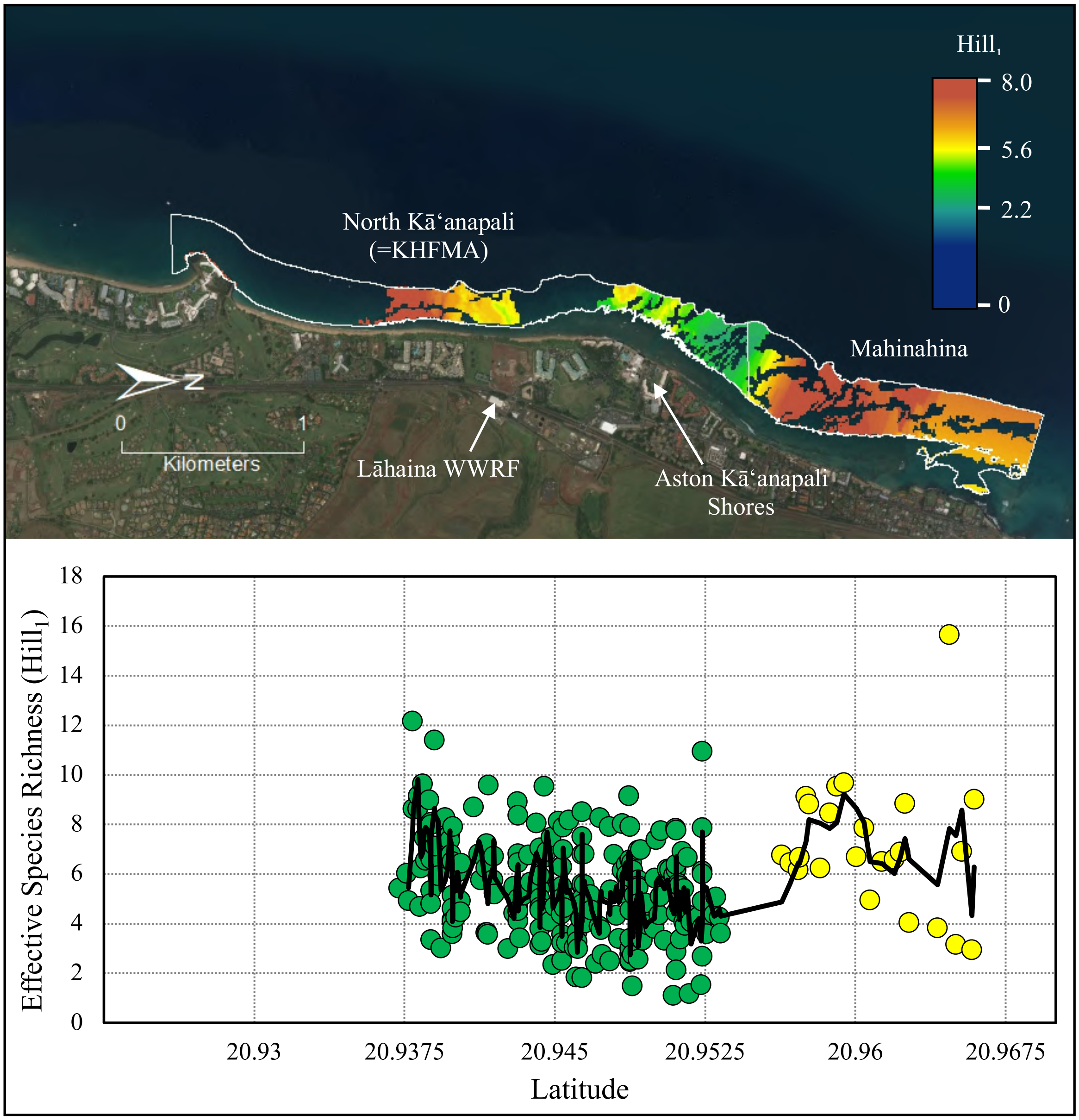


Figure 4.10. Effective species richness ($Hill_1$) across the Kahekili FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the two reef tracts. Map colors are derived from the data of the FW, such that yellow is the average total fish biomass for the FW and red would be considered high richness for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of effective species richness at consecutive survey sites along the east-west axis. Colored points in the graph correspond with the North Kāʻanapali (green) and Mahinahina (yellow) reef tracts.

are insufficient to draw rigorous conclusions about the effectiveness of the HFMA. Without comparison to appropriate reference areas, which is beyond the scope of the Atlas, it is not possible to establish a causal link between the fishery management actions and changes in fish abundance, biomass, or diversity through time. Studies examining the short-term effectiveness of the KHFMA have been completed[54], with long-term assessments still underway.

In addition to the establishment of the KHFMA, reef fish in the Kahekili FW have experienced two significant state-wide events since 2014 that could have affected their abundance and biomass. In the latter half of 2014, many reef fish species experienced an unusually larger settlement of juveniles across a wide range of fish species [55]. This recruitment event has been documented on West Hawaiʻi reefs[56], and was also observed on Oʻahu[57] and Maui[58]. Then in 2015, reefs across the state, but primarily those on Maui and Hawaiʻi Island[59] experienced a mass coral bleaching event, during which the majority of corals within the KHFMA bleached, including nearly all colonies of some genera, and by September 2015, signs of mortality were present[60]. While coral bleaching does not directly affect reef fish, it can degrade their habitat, disrupting their behavior and foraging, potentially leading to higher mortality and lower reproductive success. In the two years following the bleaching event, coral declined about 14% inside the KHFMA, but in recent years appears to have stabilized. However, cover of algal turf has increased, seemingly at the expense of CCA, and the recovery trajectory of the North Kāʻanapali reef tract is uncertain at this time.

Not surprisingly, annual variability in fish biomass was high. While fish generally showed a trend of increasing biomass, increases for many fish groups were not statistically significant (Figure 4.11). The 2014 reef fish recruitment event and the 2015 mass coral bleaching event appeared to have had little lasting, measurable effect on fish biomass. No group showed a large increase in the year following the recruitment event (2015), and the biomass trends in later years did not appear to be much different from the years immediately prior to 2014. This would suggest that any influx of juvenile fish in 2014 did not survive, although it is possible for some slow growing species that insufficient time has passed for potential gains to be detectable using the survey methods and designs employed in the Atlas. Any bleaching effect would need to occur through indirect pathways, such as trophic cascades. Indirect effects are often slower to manifest and may explain the apparent lack of response from the fish assemblage to the 2015 mass bleaching event. It is also likely that the magnitude of any fish habitat degradation from the bleaching event was too small to cause a concurrent loss of fish biomass, especially if the fish populations within the North Kāʻanapali reef tract are already depressed by other stressors, and therefore, not necessarily habitat limited.

Data predating the establishment of the KHFMA are limited, making an assessment of its effectiveness without comparable reference sites difficult. Any assessment is confounded by a drop of the fish biomass immediately after the KHFMA establishment, especially among

[54] Williams *et al.* (2016)
[55] Talbot (2014)
[56] Minton *et al.* (2018a)
[57] TNC, unpub. data
[58] TNC Maui and DAR-Maui, per. comm.
[59] SSRI (2017) and Kramer *et al.* (2016)
[60] Williams *et al.* (2016)

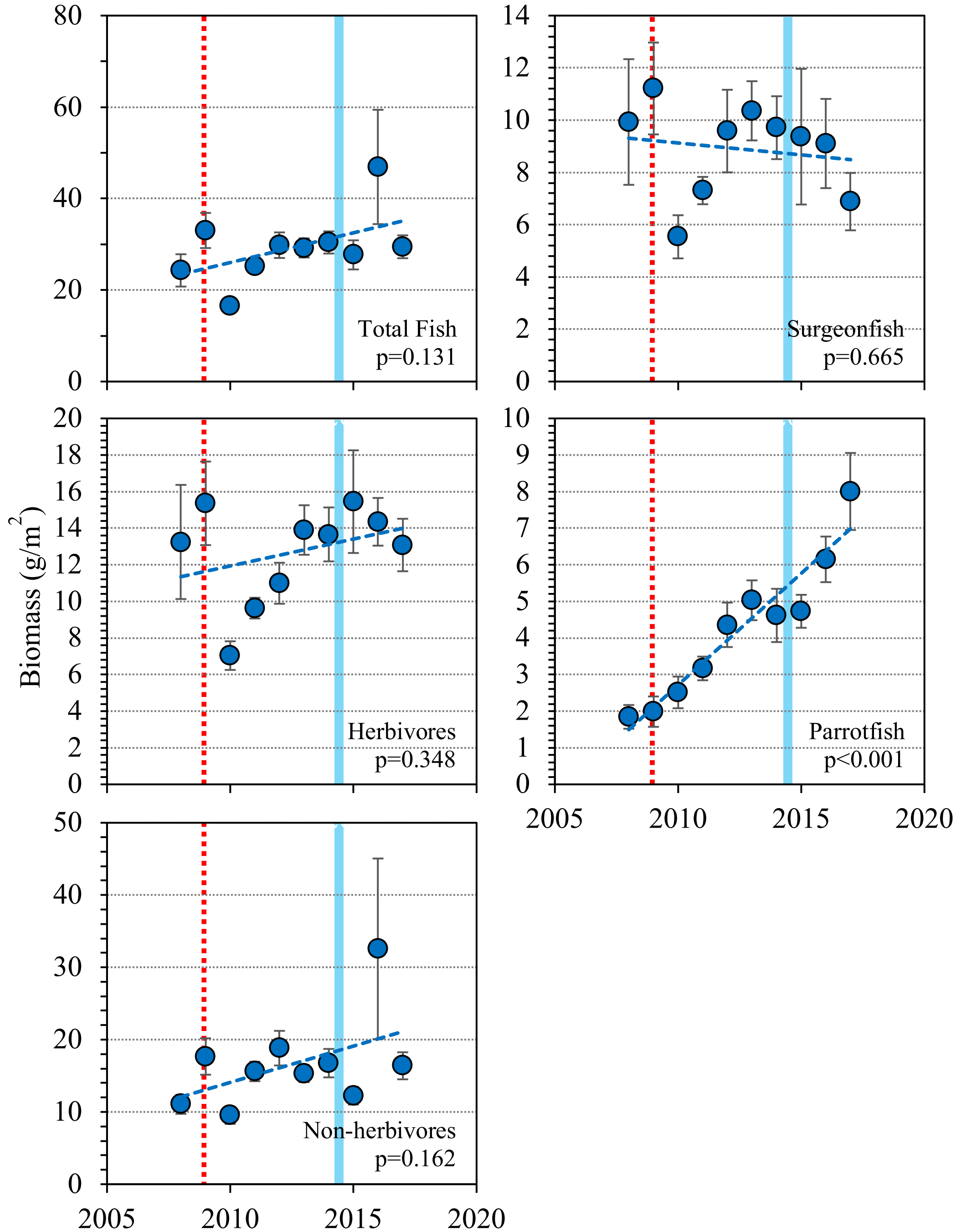


Figure 4.11. Total fish, herbivore, non-herbivore, surgeonfish (Acanthuridae), and parrotfish (Scaridae) biomass within the KHFMA reef tract between 2008 and 2017. The red dotted line marks the establishment of the KHFMA, and the solid blue line marks the 2014 reef fish recruitment event. P-values are for linear regression of biomass versus survey year. Trendlines were added to better illustrate general patterns.

herbivorous fish. Studies examining the effectiveness of the KHFMA[61] showed that even with this drop, the HFMA had beneficial effects on the target fish groups: primarily surgeonfish and parrotfish. While surgeonfish have shown no significant increase in their biomass since 2008 (and may actually be showing a downward trend), parrotfish have significantly increased, quadrupling their biomass since 2008 (Figure 4.11). Most of this increase is associated with species classified as scrapers/excavators, which feed preferentially on algal turfs, the benthic group that has increased the most in the North Kāʻanapali reef tract since the 2015 bleaching event (Figure 4.5). This increase in turf, however, is not a satisfactory explanation because prior to the bleaching event, these scrapers/excavators were still increasing even as turf declined (Figure 4.5), suggesting protection from harvest was the primary factor for the increase in parrotfish biomass within the North Kāʻanapali reef tract since 2008.

Effect of the KHFMA

The purpose of this report is not to assess the effectiveness of the KHFMA, but the potential effects of this fisheries management area cannot be ignored when examining the fish assemblage within the Kahekili FW. The KHFMA was established by DAR in 2009 to control the overabundance of alien and native marine algae by increasing the abundance of herbivorous fishes and sea urchins. It extended protections specifically to all species of parrotfish, surgeonfish, and chub (Kyphosidae).

Even with protections limited to specific fish species, the KHFMA appears to be having positive effects on the reef fish assemblage. Total fish (t-test; t_{31}=2.1, p=0.044), resource fish (t-test; t_{27}=3.0, p=0.006), and prime spawner (t-test; t_{30}=1.78, p=0.0.085) biomass were all significantly higher inside the KHFMA compared to the adjacent Mahinahina reef tract.

While no chubs were observed within the Kahekili FW and surgeonfish biomass was nearly identical inside and outside the KHFMA, parrotfish biomass was over 3-times greater within the KHFMA than within the adjacent Mahinahina reef tract (Table 4.4), and has been steadily increasing since the KHFMA was established (Figure 4.11). Parrotfish biomass also comprised a larger proportion of the fish biomass inside (16.8% of total biomass) compared to outside (9.5%) the KHFMA, suggesting the protected area has benefited these species.

Fishing effects can often be detected by examining the relative size of species by their importance in the fishery. If fishing is having an adverse effect, the average size of more heavily-fished species should be smaller than those of less-heavily fished species, whereas the average size of species not in the fishery should be unaffected, except by environmental stressors, which should affect all species somewhat similarly. A ratio of average individual size can be used to compare fish populations between two reef areas and infer the relative effects of fishing versus non-fishing effects on those fish assemblages. The size of 22 common species was compared between the two reef tracts. No significant differences were found for non-resource or moderately-prized species (Figure 4.12), which comprised mostly species that would not receive special protections within the KHFMA. Resource fish were larger on average inside than outside the KHFMA (t-test; t_8=1.8; p=0.1). Nearly all 22 species included as resource fish were 50-100% larger inside the KHFMA than outside the protected area, especially small-bodied

[61] Williams *et al.* (2016)

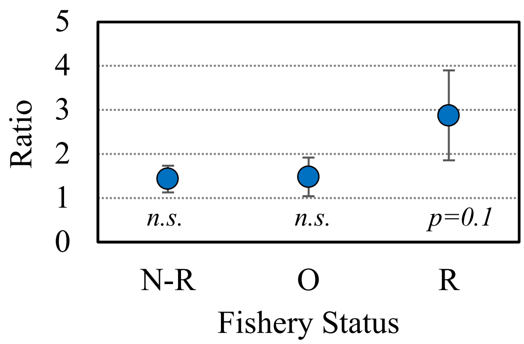


Figure 4.12. Comparison of fish size (ratio of average individual biomass) between North Kāʻanapali (inside the KHFMA) and Mahinahina (outside the KHFMA) reef tracts. A ratio=1 means the fish within the North Kāʻanapali reef tract were of equal size to those within the Mahinahina reef tract, a ratio>1 indicates fish within the North Kāʻanapali reef tract were larger on average than within the Mahinahina reef tract, and a ratio<1 means fish within the North Kāʻanapali reef tract were smaller on average than within the Mahinahina reef tract. N-R=non-resource fish (5 species), O=other, moderately-prized fish (3 species), R=resource fish (9 species). Significance was tested using a 1-sample t-test.

parrotfish such as *Chlorurus spilurus* (bullethead parrotfish). This species is relatively fast growing, and short lived (6-9 years), making it a species that should show a quick response to the management actions. In contrast, most surgeonfish are slow growing and can live multiple decades, so responses to the KHFMA would be expected to be considerably slower to manifest for surgeonfish than parrotfish.

Considering that only minor differences in fish habitat were observed between the North Kāʻanapali and Mahinahina reef tracts, the differences in the fish assemblage, including higher total fish, resource fish and prime biomass, greater individual fish size, and the increasing trend in parrotfish biomass, are likely associated with the management actions implemented within the KHFMA.

The Big Picture

In the context of the WMR, reef resources in the Kahekili FW run the range of condition from poor to good. The North Kāʻanapali and Mahinahina reef tracts present contrasting views of reef condition. The North Kāʻanapali reef tract, which lies entirely within the boundary of the KHFMA, had average to high abundance, biomass, and diversity of both the benthic and fish assemblages compared to other reefs in the WMR. While the Mahinahina reef tract's benthic assemblage had high abundance and diversity, its reef fish assemblage had the lowest total fish, resource, and prime spawner biomass of any reef tract in the WMR. The disparity in the fish assemblage between the two reef tracts appears related to the beneficial effects of the KHFMA, and as more benefits of the KHFMA accrue, the difference between the two reef tracts might be expected to widen over time.

Statewide Context

Averages for coral cover (14.4 ± 0.7%), total fish biomass (40.9 ± 2.5 g/m^2), resource fish biomass (22.3 ± 1.8 g/m^2), and prime spawner biomass (3.7 ± 1.0 g/m^2) were calculated for the MHI, to serve as a gauge for how the reefs of the WMR are faring relative to those from around the state. All across the MHI, reefs are affected by overfishing, sediments, land-based pollution, and invasive species. Over the past century, populations of some commercially important reef fish populations have declined by over 90%, and coral cover in some areas has declined by at least 40% in just the last 40 years. While there are many reef areas around the state that still have abundant and healthy resources, the current statewide averages used for comparison here certainly reflect substantial declines in resource condition seen broadly across the reefs of the MHI. Reefs in the WMR were consistent with the statewide averages for coral and fish assemblages (see Chapter 1). However, considerable variability in the condition of reefs exists across the WMR, and the reefs within the Kahekili FW had high coral cover relative to the statewide average (Figure 4.13) but were a "mixed bag" with respect to reef fish. The North Kāʻanapali reef tract had above average resource and high prime spawner biomass compared to other reefs in the MHI, likely due to the management actions associated with the KHFMA. However, the Mahinahina reef tract was below average for total fish and resource fish biomass and had average prime spawner biomass when compared to other reefs statewide.

Synthesis

The reef tracts within the Kahekili FW showed little difference in the benthic assemblage, but large differences in the fish assemblage. The benthic assemblage of both reef tracts had high coral cover and benthic diversity compared to other reef tracts in the WMR. While the North Kāʻanapali reef tract had average total fish and resource biomass, it had the second highest

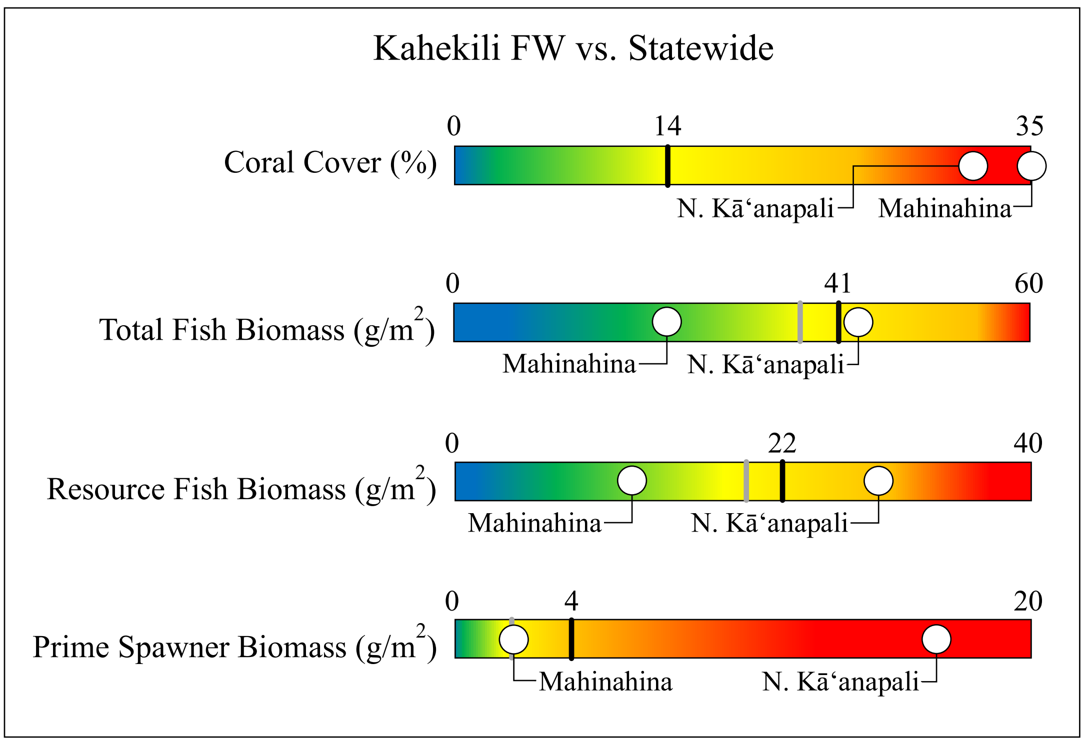
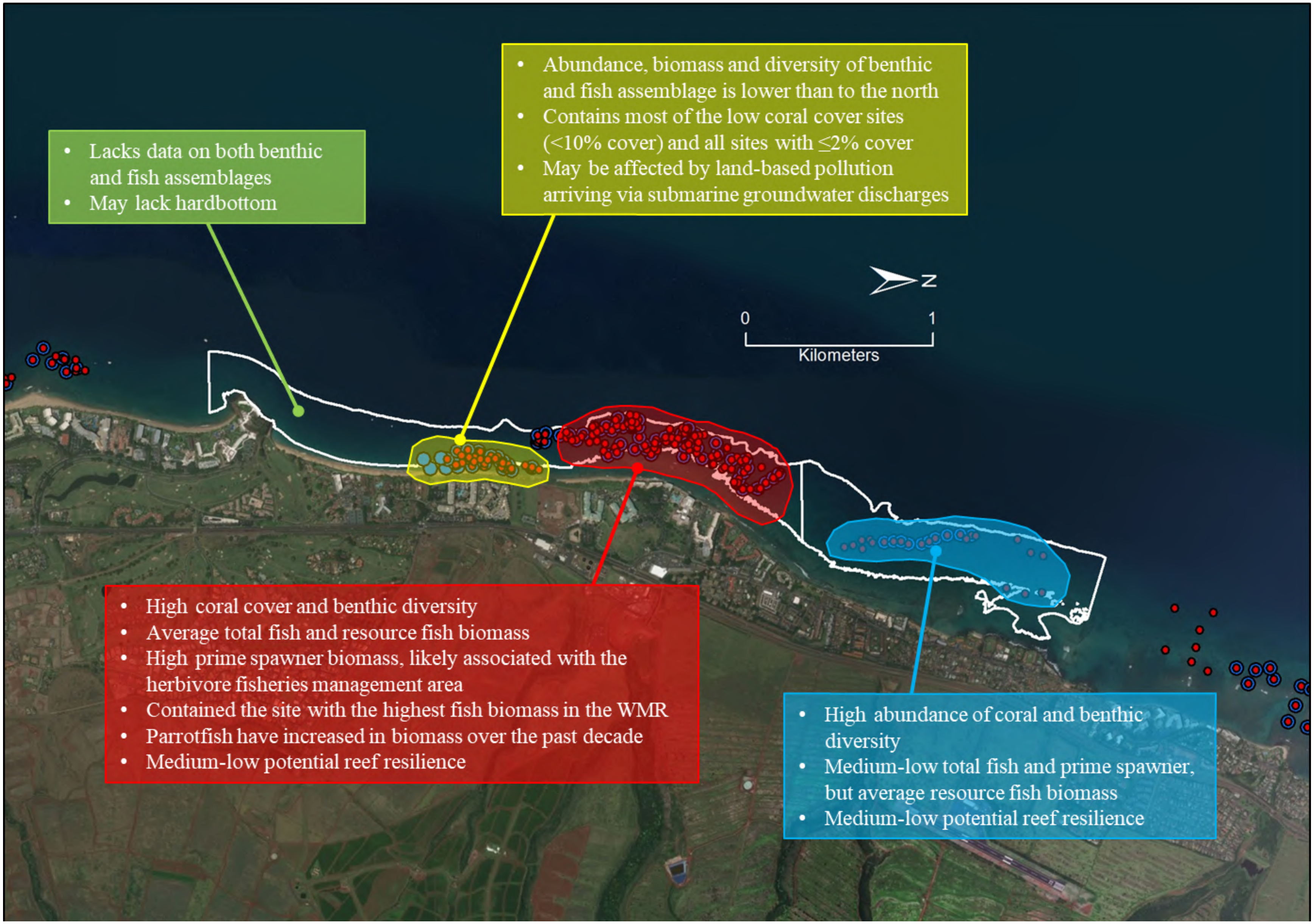


Figure 4.13. Comparison of reef tracts in the Kahekili FW to statewide averages for coral cover (%), total fish, resource fish, and prime spawner biomass (g/m^2). Black vertical line and value denote the statewide average. For the three fish metrics, the grey vertical line is the statewide trimmed mean, which was used to develop the qualitative categories; see the methods (Appendix B) for more details on the use of the trimmed means.

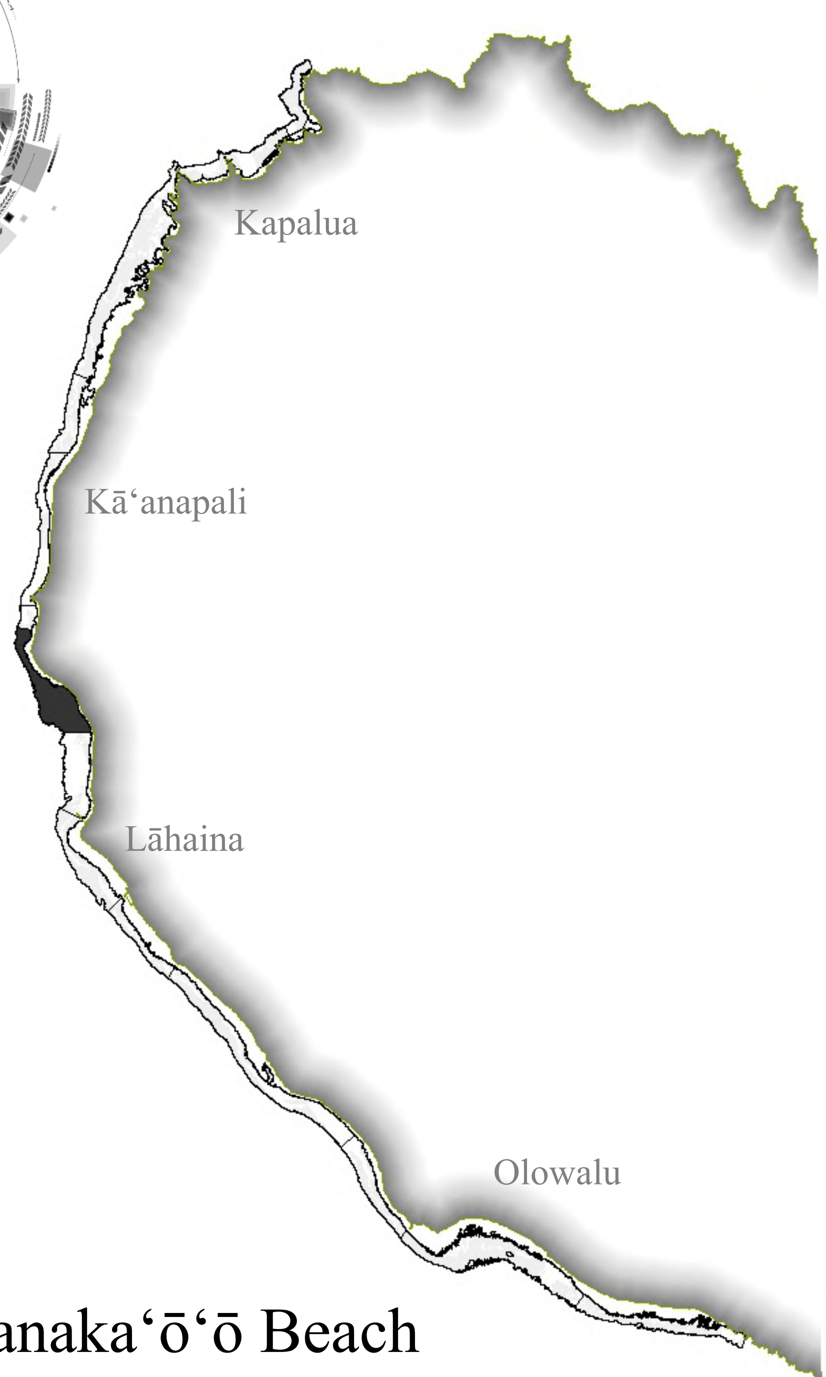
average prime spawner biomass, including one survey site with 1,670 g/m^2, by far the highest single site prime spawner biomass in the WMR. The North Kāʻanapali reef tract was not without potential issues, however. The southern half of the reef tract, especially the reef off the Lāhaina WWRF appeared to be in poorer condition than the northern half of the reef tract, possibly due to submarine groundwater discharges contaminated by nutrient-rich water from coastal injection wells. The north end of the North Kāʻanapali reef tract had a "hotspot" of total fish, resource fish and prime spawner biomass seaward of the Aston Kāʻanapali Shores Resort, which extends to the boundary and may be spilling over into the Mahinahina reef tract. Over time, the benefits of the KHFMA have increased, and this reef tract could be improved by reducing nutrient and other contaminant loads running off from shore or arriving in coastal waters via groundwater discharges.

Fish populations across the Mahinahina reef tract had uniformly low biomass, which ranked it as the worst reef tract in the WMR for total fish, resource fish, and prime spawner biomass (Chapter 1). No hotspots for the fish assemblage were identified within the reef tract, and the lack of sites with high fish biomass (which might indicate a potential to support more fish) suggests that at present, the fish assemblage within the Mahinahina reef tract appears to have little potential to improve without significant management intervention, both to lower fishing pressure and reduce land-based stressors.



• Lacks data on both benthic and fish assemblages
• May lack hardbottom
• Abundance, biomass and diversity of benthic and fish assemblage is lower than to the north
• Contains most of the low coral cover sites (<10% cover) and all sites with ≤2% cover
• May be affected by land-based pollution arriving via submarine groundwater discharges
N
0
1
Kilometers
• High coral cover and benthic diversity
• Average total fish and resource fish biomass
• High prime spawner biomass, likely associated with the herbivore fisheries management area
• Contained the site with the highest fish biomass in the WMR
• Parrotfish have increased in biomass over the past decade
• Medium-low potential reef resilience
• High abundance of coral and benthic diversity
• Medium-low total fish and prime spawner, but average resource fish biomass
• Medium-low potential reef resilience

5



Reefs of Hanaka‘ō‘ō Beach

Geographic Setting

The Hanakaʻōʻō Beach Focus Window (FW) extends from the Westin Hawaiʻi Resort and Spa in Kāʻanapali southward to Wahikuli Wayside Park and includes long stretches of sandy beaches with few embayments. This FW is within the Wahikuli watershed, which has a mixture of urban, agricultural and conservation land[62], and is a center for tourist activity in the WMR. Many resort hotels, condominiums, and golf courses with manicured landscaping lie along the coast, growing especially dense around Hanakaʻōʻō Point and coming into Kāʻanapali[63]. Upland agricultural areas contain fallow sugar cane fields and active and fallow coffee farming[64]. Given the diversity of land uses, waters in the Hanakaʻōʻō Beach FW are subject to sedimentation from agricultural fields, and nutrient and pollutant runoff from impervious surfaces, heavily manicured landscapes, and historical agricultural land. Data collected from a network of 20 water quality monitoring stations across the West Maui Region (WMR)[65] have identified higher than average organic nutrient loads off Hanakaʻōʻō Park and Wahikuli Wayside Park, including some of the highest phosphorous levels for the WMR. While typically low, turbidity in the FW can rapidly increase during and following storm events.

The Data

The Hanakaʻōʻō Beach FW is comprised of a single contiguous reef tract extending ~2.0 km (1.3 mi) from the Westin Hawaiʻi Resort and Spa in Kāʻanapali to Wahikuli Wayside Park (Figure 5.1). The Hanakaʻōʻō Beach FW was surveyed multiple times between 2008 and 2018, but robust data exist for only 2015 and 2016 (Table 5.1). In 2018, TNC assessed three reef resilience sites within the Hanakaʻōʻō Beach FW.

Maps within the Atlas were generated using a spatial technique called interpolation. This technique uses available survey data to generate a complete spatial model of the data by estimating values between the surveys data using a mathematical algorithm that considers the values of nearby data weighed by their distance away. Areas with a higher density of surveys will produce more "accurate" interpolations than areas with lower survey density. Averages derived from interpolation maps are calculated across all reef areas and typically vary from averages derived from the survey data. Interpolation maps were generated for the Atlas primarily to display general spatial patterns and should not be used to predict exact values at any given location. For example, an interpolation map can, with a high degree of reliability, indicate that one reef tract has more coral than another reef tract, but it should not be used estimate the "exact" coral cover at a specific location within the reef tract. To estimate coral cover, amount of fish, etc., current survey data from the specific location should always be used over the interpolation maps when these data are available.

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[62] SRGII (2012)
[63] Pickett and Grossman (2014)
[64] SRGII (2012)
[65] Hui O Ka Wai Ola and the State Department of Health collect water quality data at 20 sites in the WMR, including two locations in the Hanakaʻōʻō Beach FW: Hanakaʻōʻō Park and Wahikuli Park. To learn more about Hui O Ka Wai Ola and download raw data, please visit huiokawaiola.com.

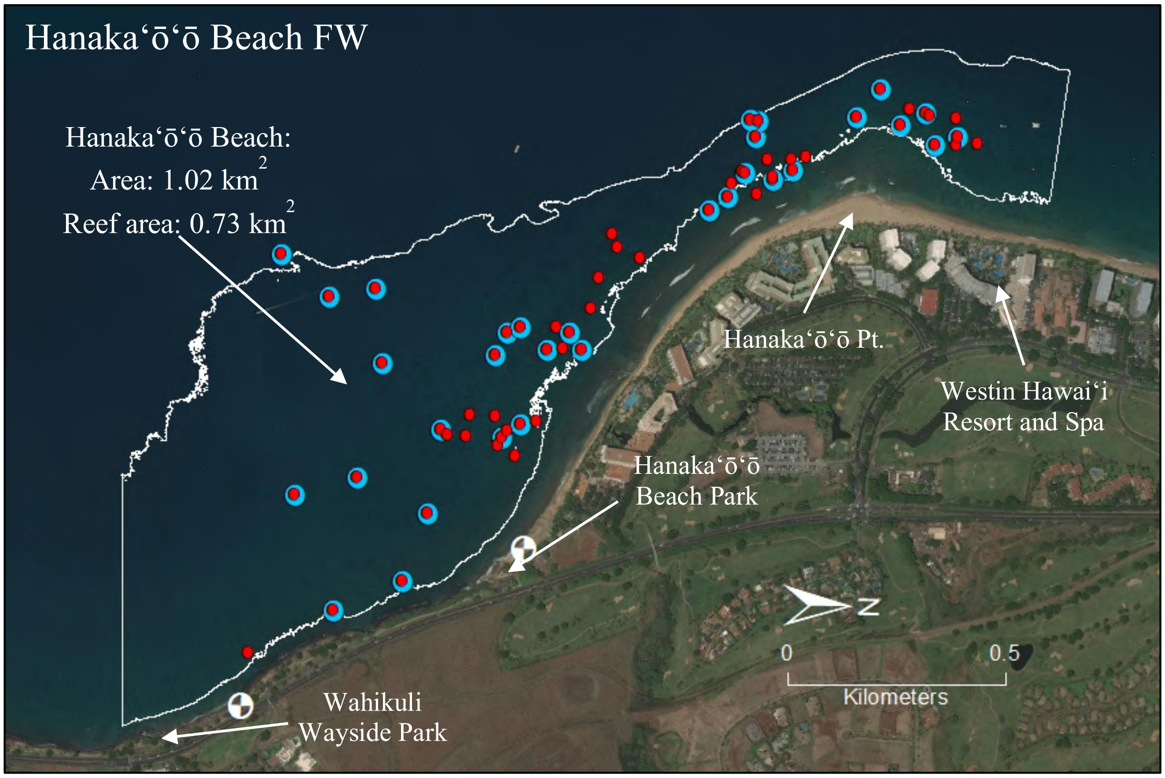

Figure 5.1. Survey effort for the benthic (light blue) and fish (red) assemblages within the Hanakaʻōʻō Beach FW from 2016-2018. White quadrant circles along the shore are (north to south) the Hanakaʻōʻō Park and Wahikuli Park long-term water quality monitoring sites.

Table 5.1. Benthic and fish assemblage survey effort (number of survey sites) in the Hanakaʻōʻō Beach FW surveyed between 2008 and 2018.

Reef Tract	Survey Year	Benthic	Fish
Hanakaʻōʻō Beach		110	124
	2008	1	1
	2009	8	
	2010	2	8
	2012	1	
	2013	2	
	2015	57	55
	2016	27	49
	2017	9	8
	2018	3	3

Benthic Assemblage

Current Spatial Patterns: Benthic

Current benthic information (2016-2018) was limited for the Hanakaʻōʻō Beach FW (Table 5.1), with most of the data collected in 2016, the year following the 2015 mass bleaching event. While likely still accurate, given the relatively scarcity of data for years after 2016, descriptions of the benthic assemblage should be considered preliminary until more current data are incorporated into the analysis.

While turf covered the largest percentage of the bottom (41.9 ± 1.3%), it did not comprise the majority of the benthic cover in the Hanakaʻōʻō Beach FW (Table 5.2). Coral (28.4 ± 1.6%) and abiotic substratum (25.3 ± 2.2%) also comprised large percentages of the benthic assemblage, and together, these three benthic groups covered over 95% of the bottom. Coral cover increased moving north within the FW (Figure 5.2), with the highest coral cover occurring off Hanakaʻōʻō Point. Coral cover was lowest off Wahikuli Wayside Park at the most southerly end of the FW. The reef at the southern end of the FW was fragmented, as evidenced by the high cover of sand and low cover of coral and other hardbottom organisms. Starting near Hanakaʻōʻō Beach Park, the reef becomes less fragmented as it rounds the point and transitions into the Kāʻanapali area (Figure 5.3), where average coral cover increases to 35-40%, which is high coral cover for the WMR. Simultaneously, the percentage of abiotic substratum declined to nearly zero, indicating the reef had become contiguous. Over this same spatial extent, turf increased slightly, but remained relatively unchanged across the FW.

Not unexpectedly, effective species richness ($Hill_1$) shows a similar pattern (Figure 5.4), increasing from south to north across the FW. Compared to other reef areas within the WMR, the Hanakaʻōʻō Beach FW had high benthic diversity, but diversity on the southern end of the FW was approximately average for the WMR. While benthic diversity was relatively robust, the Hanakaʻōʻō Beach FW had only ten species of coral, with *Porites lobata* (lobe coral), *P. compressa* (finger coral), *Montipora capitata* (rice coral), and *M. patula* (sandpaper coral) being most abundant (Table 5.2).

Historical Patterns: Benthic

An 11-year time series of benthic data (2008-2018) is available for the Hanakaʻōʻō Beach FW (Table 5.1), but robust datasets exist only for 2015 and 2016, making it difficult to elucidate long-term trends. Two survey rounds were conducted in 2015, one each in April and September, while all sampling in 2016 was done in one round in October. The September 2015 round occurred during the height of the 2015 mass coral bleaching event, likely before significant bleaching-related mortality would have occurred, but late enough that some mortality might be expected. While the 2015 and 2016 surveys were conducted over approximately the same area, the April 2015 survey effort under-sampled the southern end of the FW relative to the other two survey efforts (Figure 5.5). Given the spatial variability in coral cover (Figure 5.2), this under-sampling of the southern end of the FW in April 2005 could result in an overestimation of coral cover and an underestimation of the cover of abiotic substratum within

Table 5.2. Average (±SEM) percent cover of benthic groups and taxa in the Hanaka‘ō‘ō Beach FW (n=39). Data are from 2016-2018. Note: Summations of the cover by coral species or benthic substratum type may not add to the total for the group due to some sites having group-level, but no species-level, information.

	Hanaka‘ō‘ō Beach
Turf	41.9 ± 1.3
Coral	28.4 ± 1.6
Porites lobata	11.8 ± 0.6
Montipora capitata	6.6 ± 0.5
Montipora patula	5.8 ± 0.6
Porites compressa	5.4 ± 0.6
Pocillopora meandrina	0.2 ± 0.1
Leptastrea purpurea	<0.1
Montipora flabellata	<0.1
Pavona varians	<0.1
Porites lutea	<0.1
Leptastrea bewickensis	<0.1
Crustose Coralline Algae	3.5 ± 0.4
Macroalgae	1.5 ± 0.2
Cyanobacteria	0.1 ± 0.1
Other	0.2 ± 0.1
Abiotic	25.3 ± 2.2
Sand	26.8 ± 2.4
Other	1.2 ± 0.1
Bare Rubble	0.7 ± 0.1
Pavement	<0.1

the FW for that sampling event. To eliminate the potential sampling bias, any sites in the September 2015 and October 2016 datasets that were not in the same area as the April 2015 survey effort were removed from the analysis.

Coral cover significantly declined between the April 2015 and October 2016 surveys (ANOVA; $F_{2,68}$=3.00; p=0.057) with the September 2015 survey, conducted at the height of the mass coral bleaching event, not being significantly different from the other two (Figure 5.6). As would be expected if coral cover declined due to bleaching-related mortality, the loss of coral was countered by a significant increase in turf cover (ANOVA; $F_{2,68}$=2.78; p=0.069). Abiotic substratum did not change. While the sampling design was not sufficient to establish a clear causal relationship between the decrease in coral cover and the 2015 mass coral bleaching event, the bleaching was likely the primary factor responsible for the loss of coral. Between 2015 and

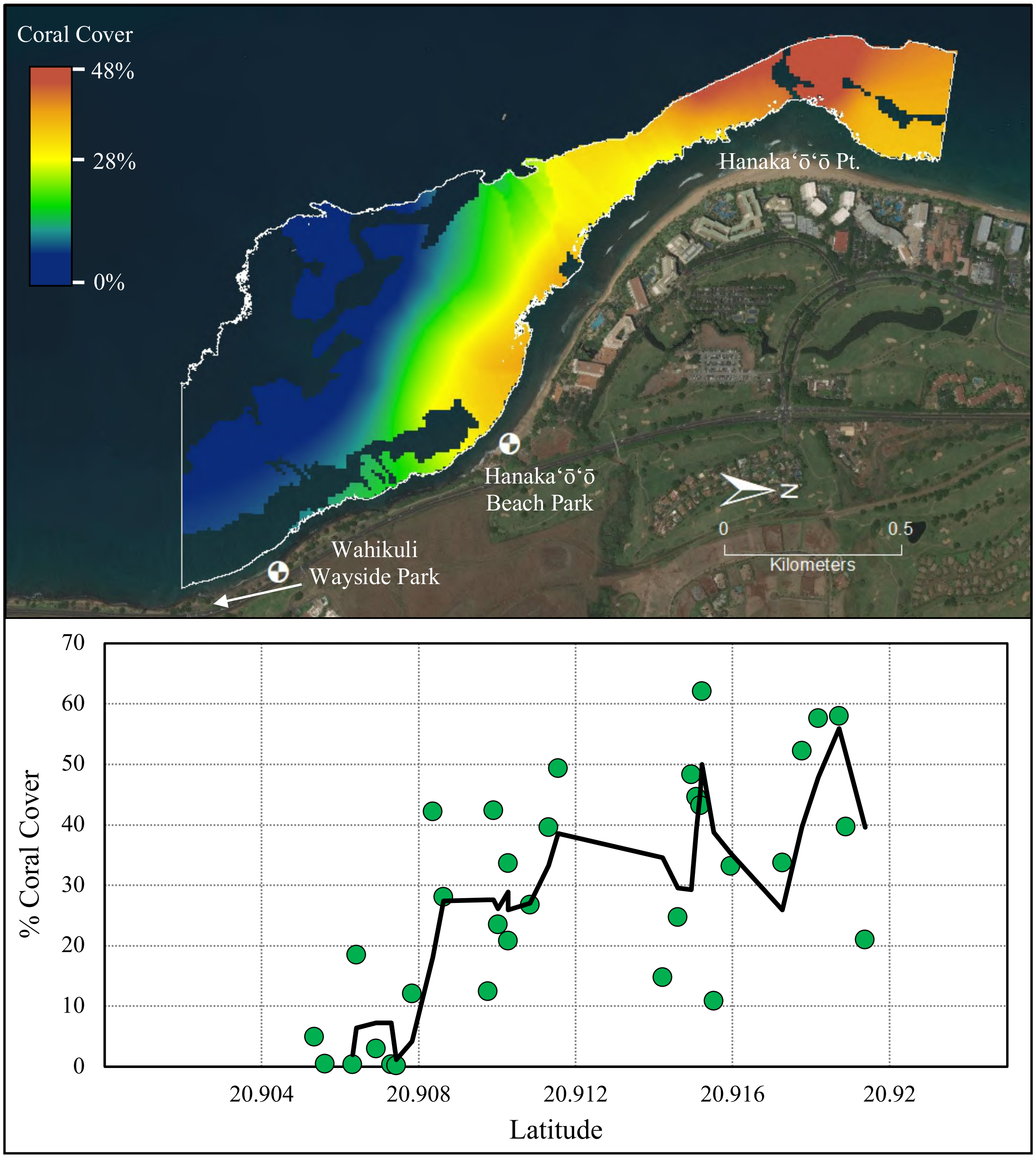

Figure 5.2. Coral cover across the Hanakaʻōʻō Beach FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of coral cover at consecutive survey sites along the north-south axis. White quadrant circles along the shore are (north to south) the Hanakaʻōʻō Park and Wahikuli Park long-term water quality monitoring sites.

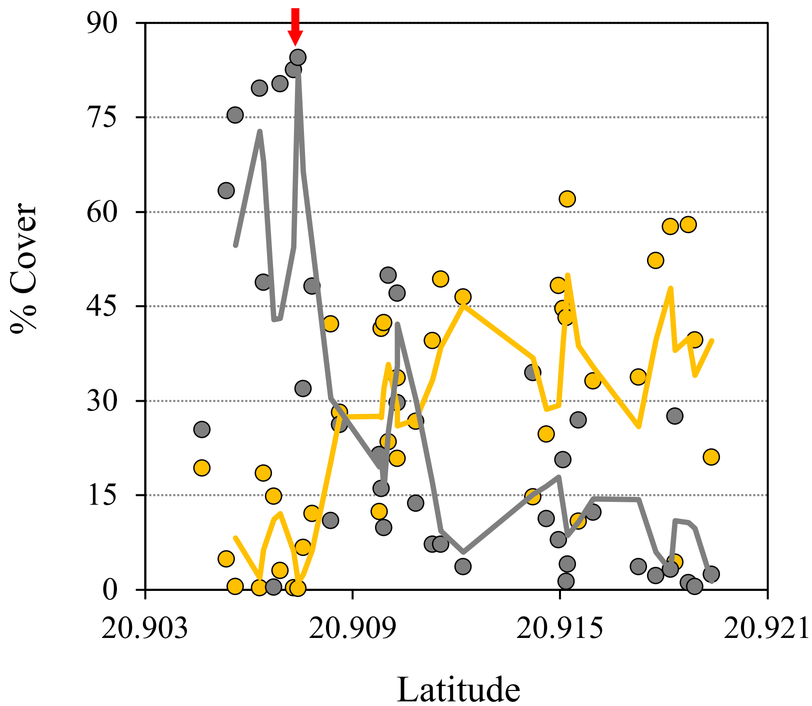

Figure 5.3. Percent cover of coral (gold) and abiotic substratum (grey) across the Hanakaʻōʻō Beach FW. The left side of the figure is the southern end of the FW. Red arrow marks the approxiate location of the southern end of Hanakaʻōʻō Beach Park. Lines are moving averages (window size 3) of consecutive north-south survey points.

2016, coral cover declined from 45.8 ± 3.3% to 35.6 ± 3.1%. This 22% relative loss[66] in coral was consistent with losses observed on other Maui reefs following the bleaching event[67].

Two common species, *P. lobata* and *P compressa*, appeared to have been the most affected corals, experiencing approximately 30% and 45% loss, respectively. Species in this genus are generally considered to be bleaching tolerant, especially compared to Hawaiian montiporids (*e.g., Montipora capitata* and *M. patula*). These montiporids, however, experienced <10% loss within the Hanakaʻōʻō Beach FW.

Coral Health and Reef Resilience

In March 2018, a reef resilience assessment of leeward Maui was conducted by TNC and its partners. These assessments were intended to quantify the relative resilience of Maui's reefs to the effects of climate change. Resilience is the ability of a reef to resist, recover from, and adapt to a climate-related event (*e.g.*, coral bleaching) to maintain a diverse, coral-rich state that provides key ecological functions and services to people[68]. Given the integral role of reefs to the

[66] Describing change in a percent value (*e.g.*, percent cover) can present challenges and cause confusion because often changes are expressed as "percent change" in the original value. This approach is often called a "relative" change, but confusion often arises when the base values are also percentages. For example, a decline from 12% to 6% cover is a 50% "relative" decrease in cover, but an "absolute" decrease of 6%. The use of the "relative" and "absolute" approaches to describe a change depends on the specific situation. In ecology, the "relative" change is used when comparing things (*e.g.*, reef areas) that may have very different underlying values.
[67] SSRI (2017)
[68] Nystrom and Folke (2001)

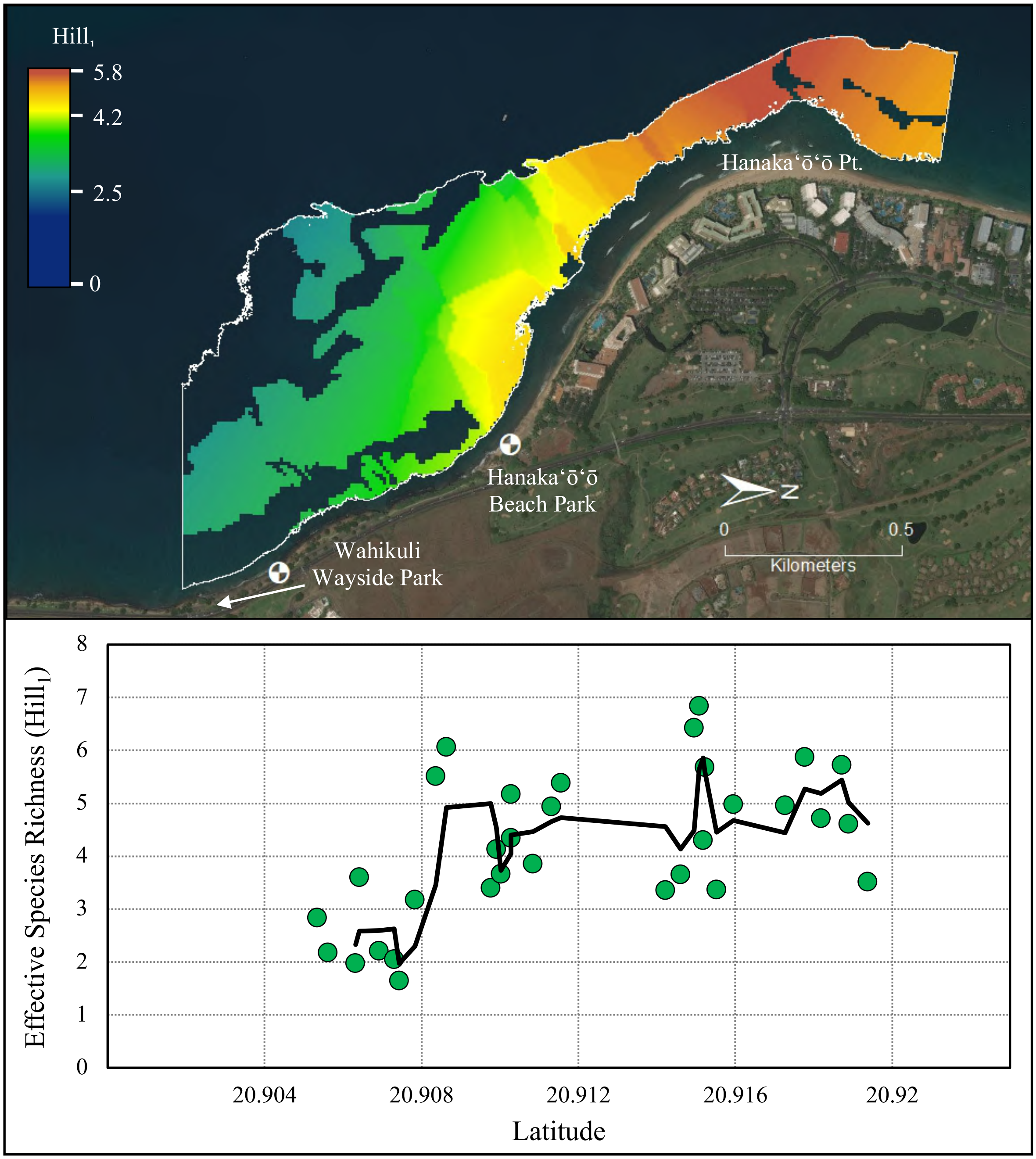

Figure 5.4. Effective species richness ($Hill_1$) across the Hanakaʻōʻō Beach FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average effective species richness for the FW and red would be considered high richness for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of effective species richness at consecutive survey sites along the north-south axis. White quadrant circles along the shore are (north to south) the Hanakaʻōʻō Park and Wahikuli Park long-term water quality monitoring sites.

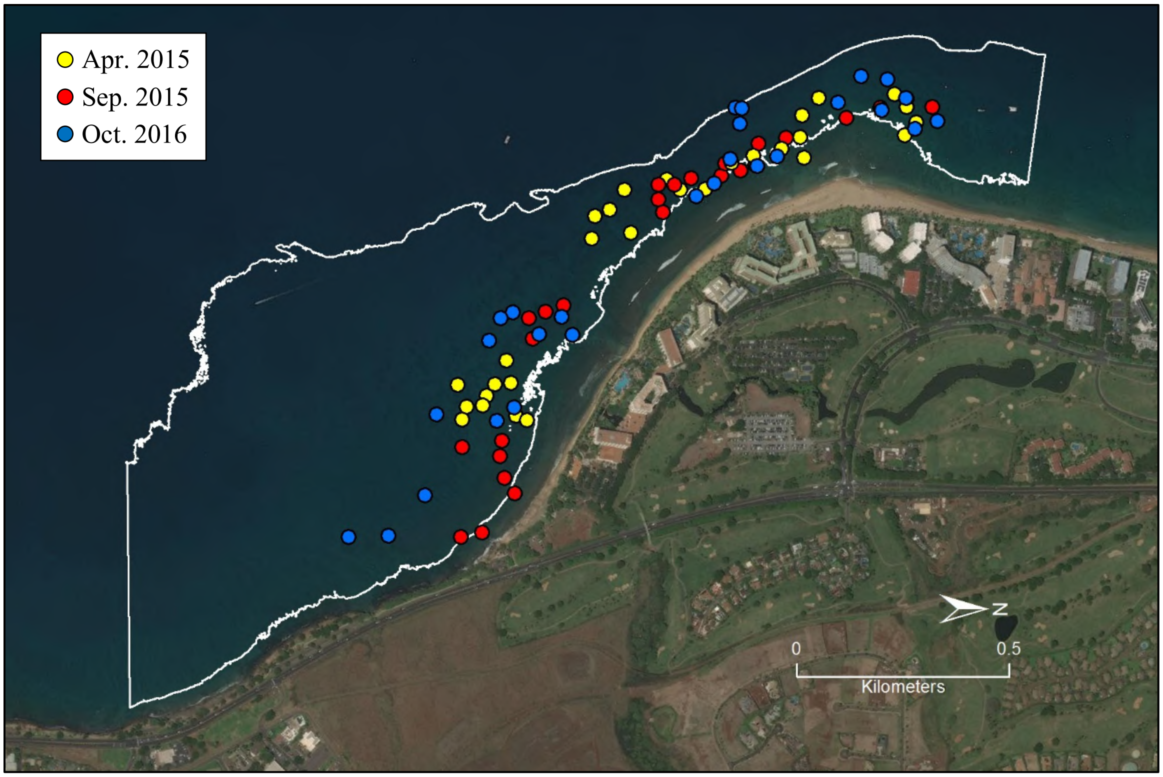

Figure 5.5. Sites surveyed in the Hanakaʻōʻō Beach FW in April 2015, September 2015 and October 2016.

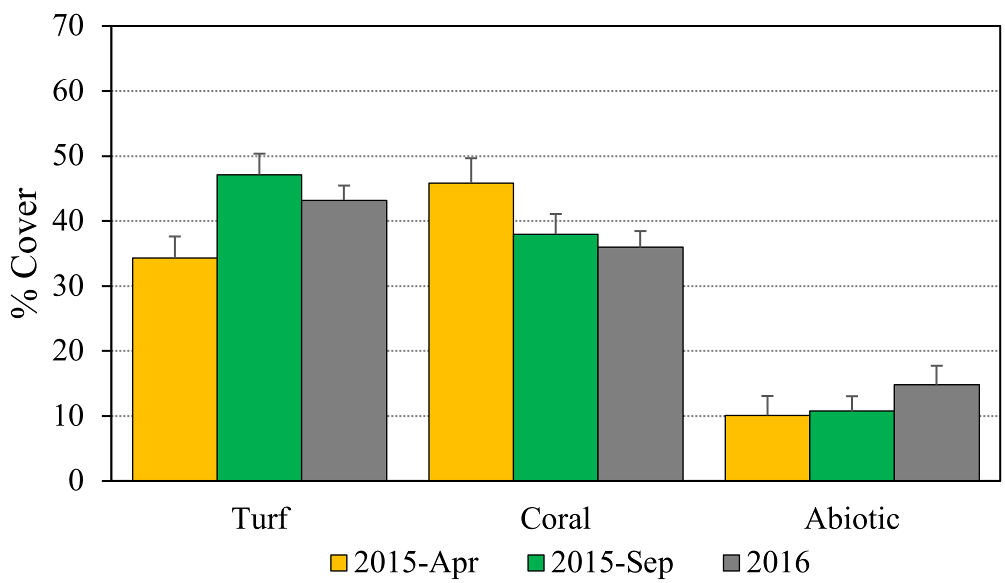

Figure 5.6. Average (±SEM) cover of turf, coral and abiotic substratum between 2015 and 2016 within the Hanakaʻōʻō Beach FW. Survey sites from September 2015 and October 2016 that did not overlap with April 2015 survey area were removed from the analysis (see text for discussion).

people of Hawaiʻi, reef resilience is closely linked with social resilience, which is the ability of human communities to adapt to social, political, environmental, or economic change[69].

Two shallow-water (Hanakaʻōʻō and Wahikuli) and one deep-water (Hanakaʻōʻō) reef resilience sites were surveyed within the Hanakaʻōʻō Beach FW. The complete results of that assessment are detailed elsewhere[70], so only the coral health and resilience findings for the sites in the Hanakaʻōʻō Beach FW are summarized here.

Both the shallow and deep Hanakaʻōʻō reef resilience sites were consistent in assemblage structure with nearby sites visited in 2016 and 2017, but the Wahikuli site had higher coral cover than nearby sites. All three were close the WMR average for their depth category for prevalence of overall coral disease, and algal overgrowth (Table 5.3). Bleaching prevalence at the Hanakaʻōʻō Shallow sites was lower than the regional average (18.2 ± 4.8%), but otherwise the sites appear unremarkable regarding their health.

As part of the reef resilience assessment, the 31 shallow-water and 20 deep-water sites surveyed were assigned a relative reef resilience rank based on a several indicator variables, including coral cover, coral disease prevalence, coral diversity, coral recruitment, reef builder ratio (ratio of calcifying species to non-calcifying species), rugosity, and herbivorous fish biomass. The Wahikuli Shallow and Hanakaʻōʻō Deep sites ranked in the lower half of sites included in the assessment, and were categorized as having medium-low potential reef resilience. However, the Hanakaʻōʻō Shallow site was ranked 8th in reef resilience, representing medium-high potential reef resilience.

Table 5.3. The three reef resilience (RR) sites within the Hanakaʻōʻō Beach FW. "RR Rank" is the relative reef resilience rank among 31 shallow and 20 deep sites along leeward Maui, with 1 being the most resilient and higher numbers indicating less resilience. "Dis. Prev." is the percent of colonies presenting at least one disease. "ALOG" is the percentage of colonies being overgrown by benthic algae. "Paling/Bleaching" is the percent of colonies showing signs of tissue paling or bleaching. Average values for the WMR (italics) are presented for comparison.

	Reef tract	RR Rank	Dis. Prev.	ALOG	Paling/ Bleaching
Shallow	*WMR Average*		*2.4 ± 0.5*	*9.6 ± 1.5*	*18.2 ± 4.8*
Hanakaʻōʻō		S8	3.2	7.6	4.6
Wahikuli		S23	1.3	6.9	20.2
Deep	*WMR Average*		*1.4 ± 0.3*	*7.2 ± 1.5*	*19.9 ± 6.4*
Hanakaʻōʻō		D14	2.3	5.3	14.3

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[69] Adger (2000)
[70] Maynard *et al.* (2019)

Fish Assemblage

Current Spatial Patterns: Fish

Current fish assemblage information (2016-2018) was limited for the Hanakaʻōʻō Beach FW (Table 5.1), with most of the data collected in 2016, the year following the 2015 mass bleaching event. While likely still accurate, given the relatively scarcity of data for years after 2016, descriptions of the fish assemblage should be considered preliminary until more current data are incorporated into the analysis.

From 2016 to 2018, 99 species of fish in 27 families were observed in the Hanakaʻōʻō Beach FW (Table 5.4), with nearly 80% of the biomass attributable to four families: surgeonfish (Acanthuridae), triggerfish (Balistidae), parrotfish (Scaridae), and goatfish (Mullidae). Total fish biomass was only 32.9 ± 4.7 g/m^2 across the Hanakaʻōʻō Beach FW, below average for the WMR, and well below other FWs with comparable and even lower coral cover (*e.g.*, Lāhaina, Olowalu, and Kahana). Also, unlike other reef areas in the WMR, total fish biomass was not correlated with coral cover (Correlation, r=-0.031, p=0.757). Total fish biomass was greatest off Hanakaʻōʻō Point (Figure 5.7), specifically on the reef area fronting the Marriott's Maui Ocean Club Resort. However, even the highest areas of fish biomass in the Hanakaʻōʻō Beach FW were under the average for the WMR, raising concerns that the reef fish assemblage with the Hanakaʻōʻō Beach FW may be in poor condition.

Table 5.4. Average (±SEM) fish biomass (g/m^2) by family in the Hanakaʻōʻō Beach FW (n = 121). Data are from 2016-2018.

	Hanakaʻōʻō Beach
Acanthuridae	8.5 ± 1.2
Balistidae	6.9 ± 1.1
Scaridae	5.2 ± 1.1
Mullidae	5.1 ± 3.5
Labridae	1.8 ± 0.3
Pomacentridae	1.3 ± 0.4
Monacanthidae	1.3 ± 0.7
Chaetodontidae	0.9 ± 0.2
Serranidae	0.7 ± 0.5
Lethrinidae	0.3 ± 0.1
Tetraodontidae	0.2 ± 0.1
Carangidae	0.2 ± 0.1
Cirrhitidae	0.2 ± 0.1
Zanclidae	0.1 ± 0.1
Lutjanidae	0.1 ± 0.1
Holocentridae	0.1 ± 0.1
Diodontidae	<0.1
Aulostomidae	<0.1
Pomacanthidae	<0.1
Synodontidae	<0.1
Microdesmidae	<0.1
Blenniidae	<0.1
Ostraciidae	<0.1
Apogonidae	<0.1
Gobiidae	<0.1
Muraenidae	*
Priacanthidae	*
Total Fish Biomass	32.9 ± 4.7

Fish biomass was unexpectedly high off Wahikuli Wayside Park (Figure 5.7), especially given the area's poor coral cover (Figure 5.2) and low benthic diversity (Figure 5.4). This area appears to be heavily fragmented reef, which ordinarily would not

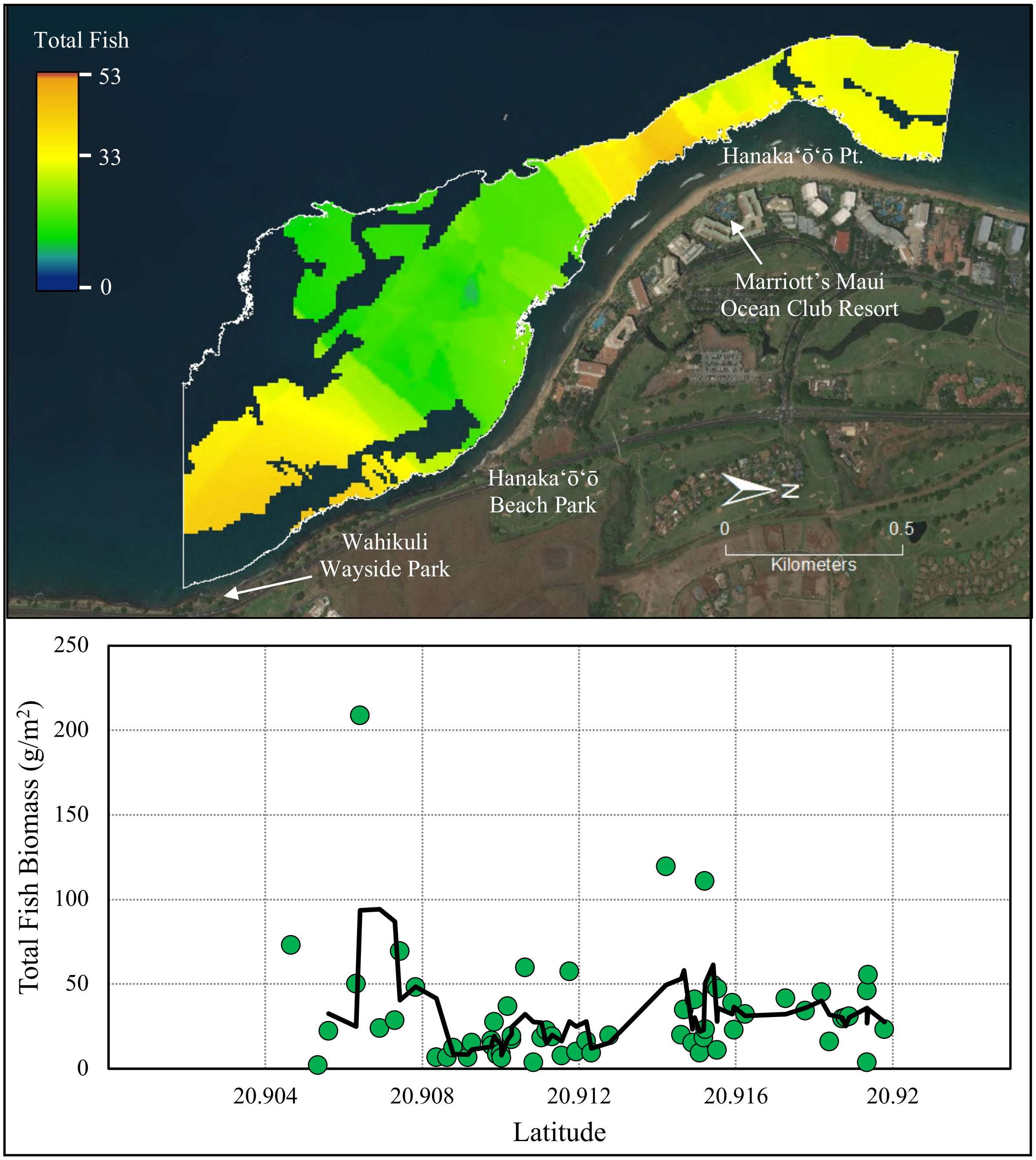

Figure 5.7. Total fish biomass across the Hanakaʻōʻō Beach FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average total fish biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of total fish biomass at consecutive survey sites along the north-south axis.

support large reef fish populations. However, much of the fish biomass in this area was comprised of the goatfish *Mulloidichthys vanicolensis* (yellowfin goatfish), a species usually found in association with sand patches over which it feeds. At two sites in this area, large schools of *M. vanicolensis* contributed greatly to the total fish biomass, accounting for as much as 88% of the fish biomass. *M. vanicolensis* was never recorded in surveys from other areas of the FW.

Resource fish biomass, which is comprised of species important for consumption[71] and that tend to be prized by fishers, showed slightly different spatial patterns (Figure 5.8) than total fish biomass. While the same two hotspots were identified for resource fish, the area of Wahikuli Wayside Park had higher resource fish biomass than the reef fronting the Marriott's Maui Ocean Club Resort. As discussed above, large schools of *M. vanicolensis* at two sites contributed to the high fish biomass in this area. While *M. vanicolensis* should not be ignored, its presence in this area radically alters the interpretation of the available data. Without *M. vanicolensis*, the hotspot along the southern edge of the Hanakaʻōʻō Beach FW disappears, which is likely a more accurate picture of the overall condition of the reef fish assemblage for this area. Without *M. vanicolensis*, the resource fish biomass for the Hanakaʻōʻō Beach FW drops from 16.3 ± 3.7 g/m^2 to 12.7 ± 2.0 g/m^2, which would make it the FW with the lowest resource fish biomass in the WMR (Chapter 1).

Considering the entire FW, the resource fish assemblage was comprised of almost equal biomass of surgeonfish, parrotfish, and goatfish (Figure 5.9), with all remaining groups comprising <8% of the resource fish biomass. Despite the low resource fish biomass, resource fish richness was robust with 38 species. While none were particularly abundant in absolute biomass, several prized species of parrotfish (*Scarus rubroviolaceus* [redlip parrotfish] and *Chlorurus spilurus* [bullethead parrotfish]) and surgeonfish (*Acanthurus dussumieri* [eyestripe surgeonfish], *A. olivaceus* [orangeband surgeonfish], *Naso brevirostris* [paletail unicornfish], and *Ctenochaetus strigosus* [goldring bristletooth]) comprised the bulk of the resource fish biomass that was not *M. vanicolensis*.

Prime spawners are individual resource fish >70% of the maximum length for that species. These individuals tend to exert a disproportionately large effect on population dynamics due to their considerably higher fecundity and egg quality compared to smaller individuals[72]. Conservation of prime spawners is important to maintaining sustainable fisheries and ecosystems.

Prime spawner biomass was 6.5 ± 2.8 g/m^2 within the Hanakaʻōʻō Beach FW, but was patchily distributed (Figure 5.10): 61% of the survey sites within the FW had no prime spawners. Not surprisingly, the spatial pattern of prime spawner biomass was similar to that of the resource fish biomass. The high prime spawner biomass off Wahikuli Wayside Park at the southern end of the FW was driven by numerous large *M. vanicolensis* at two sites. Average prime spawner biomass for the entire Hanakaʻōʻō Beach FW was heavily influenced by these large *M. vanicolensis*, and removing them nearly halved the estimate of prime spawner biomass for the FW to 3.5 ± 1.0 g/m^2, the lowest of any reef area in the WMR. Prime spawner richness was low, only 13 species,

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[71] See Appendix B for a list of resource and non-resource species

[72] Birkeland and Dayton (2005) and Hixon *et al.* (2014)

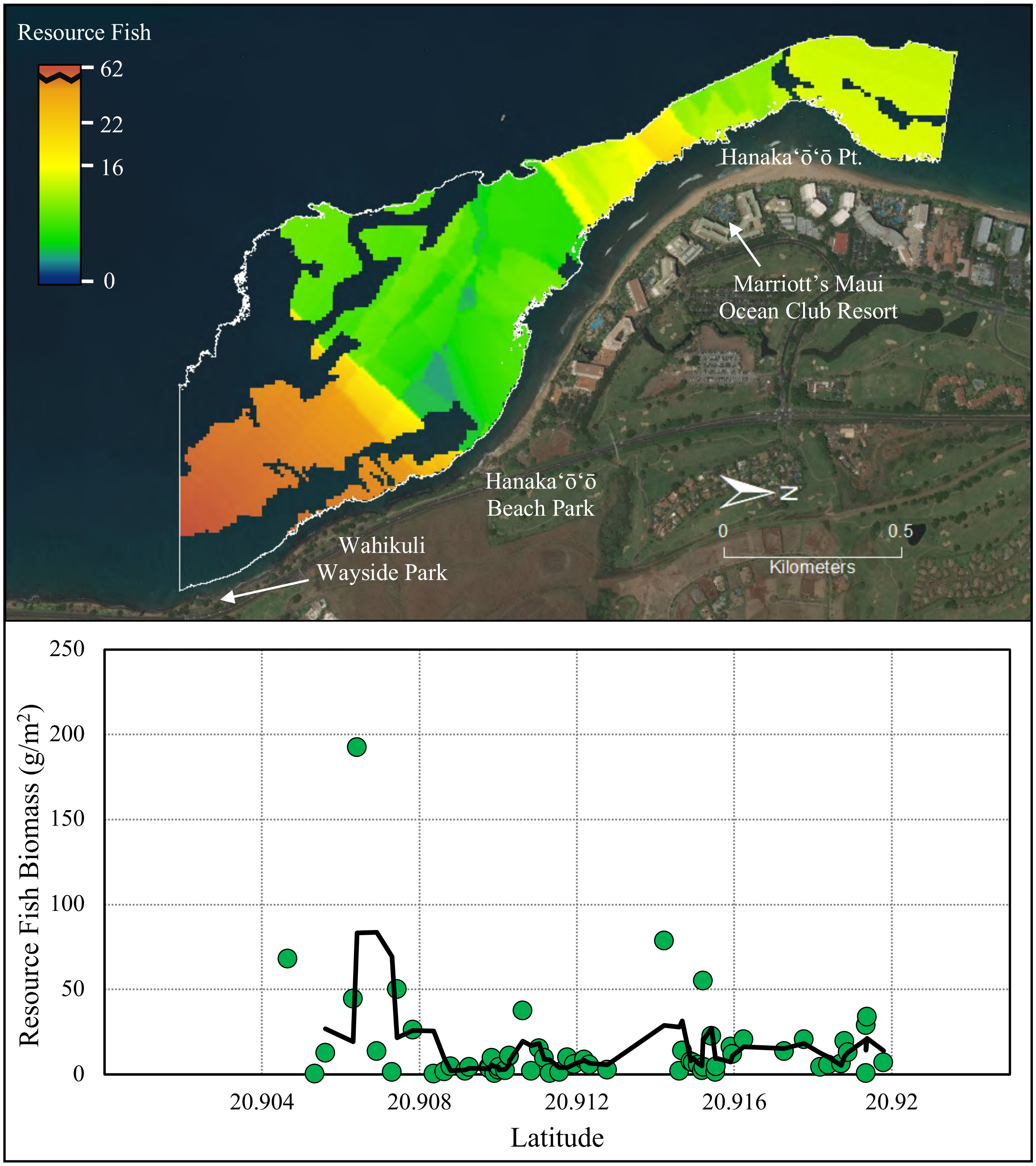


Figure 5.8. Resource fish biomass across the Hanaka‘ō‘ō Beach FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average resource fish biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of resource fish biomass at consecutive survey sites along the north-south axis.

of which just three species accounted for 78% of the prime spawner biomass: *M. vanicolensis* (48%), *A. olivaceus* (18%), and *A. leucopareius* (12%).

In general, effective species richness (measured as $Hill_1$ number) for fish was higher on the south side of the FW and decreased moving toward northward (Figure 5.11), a pattern that was opposite of that for the benthic assemblage (Figure 5.4). The high fish diversity toward the south end of the FW was likely due to the fragmented hardbottom, which would create variability in the fish habitat. Species such as goatfish were more common in this area of the FW.

Overall, the fish assemblage within the Hanakaʻōʻō Beach FW appears to be in relatively poor condition and under considerable stress. Given what appears to be a benthic assemblage in average to good condition (especially on the north end of the FW), the fish assemblage has surprisingly low abundance, biomass, and diversity, especially compared to other reef areas in the WMR. While DAR-Maui estimated fishing pressure in this area to be "medium-low" compared to other FWs in the WMR (see Figure 1.8 in Chapter 1), fishing appears to play a role in the condition of the fish assemblage, as evidenced by the low resource fish biomass and the patchy distribution of prime spawners. It is also possible that other stressors are having adverse effects on the reef fish assemblage, especially give the degraded water quality within the FW. Given this lack of clarity, further investigation would be warranted.

Historical Patterns: Fish

While an 11-year time series of fish data exists for the Hanakaʻōʻō Beach FW, sampling effort in most years was low (Table 5.1), and robust datasets exist for only 2015 and 2016. These survey years follow the 2014 reef fish recruitment event that resulted in an unusually larger settlement of juveniles across a wide range of fish species[73]. This recruitment event has been documented on West Hawaiʻi reefs[74], and was also observed on Oʻahu[75] and Maui[76]. Considering the high natural variability of reef fish populations, data from these two years alone would be insufficient to provide meaningful insight into temporal patterns within the Hanakaʻōʻō Beach FW. Therefore, no such analysis was conducted for the Atlas.

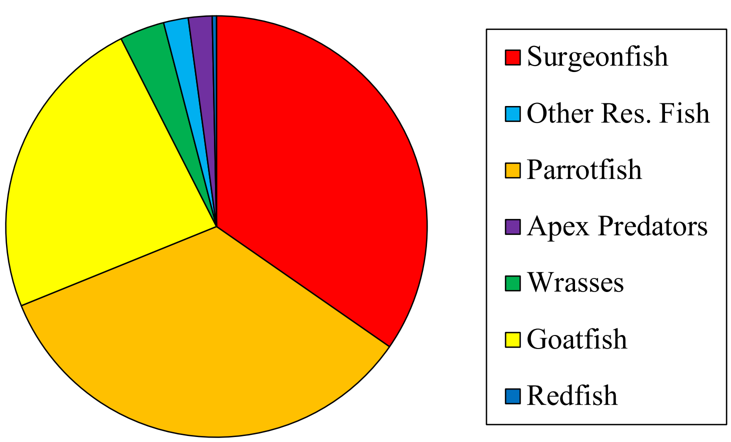


Figure 5.9. The relative composition (percent of total resource fish biomass) of the resource fish by group for the Hanakaʻōʻō Beach FW. Data are from 2016-2018.

[73] Talbot (2014)
[74] Minton *et al.* 2018a
[75] TNC, unpub. data
[76] TNC Maui and DAR-Maui, per. comm.

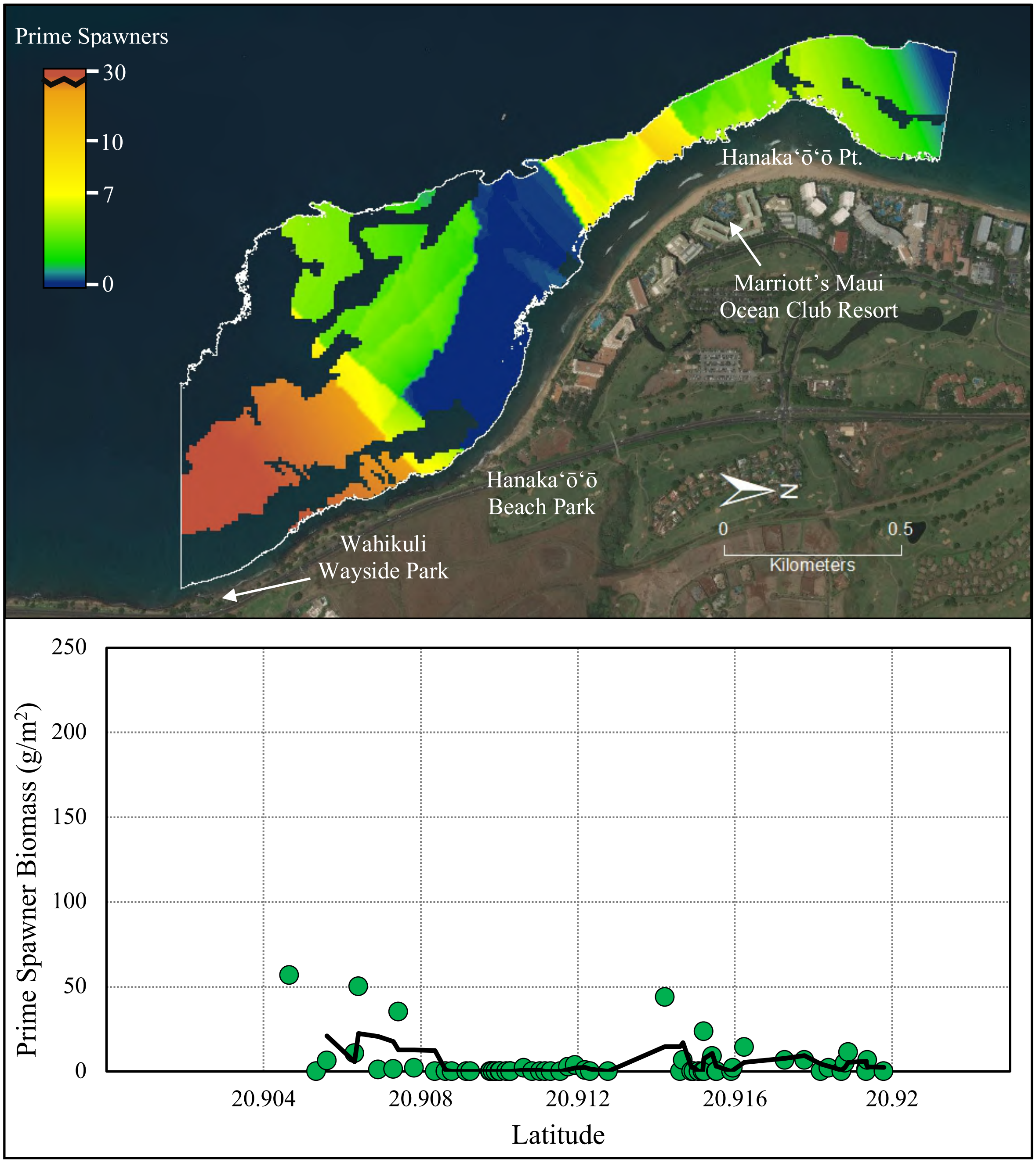


Figure 5.10. Prime spawner biomass across the Hanakaʻōʻō Beach FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average prime spawner biomas for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of prime spawner biomass at consecutive survey sites along the north-south axis.

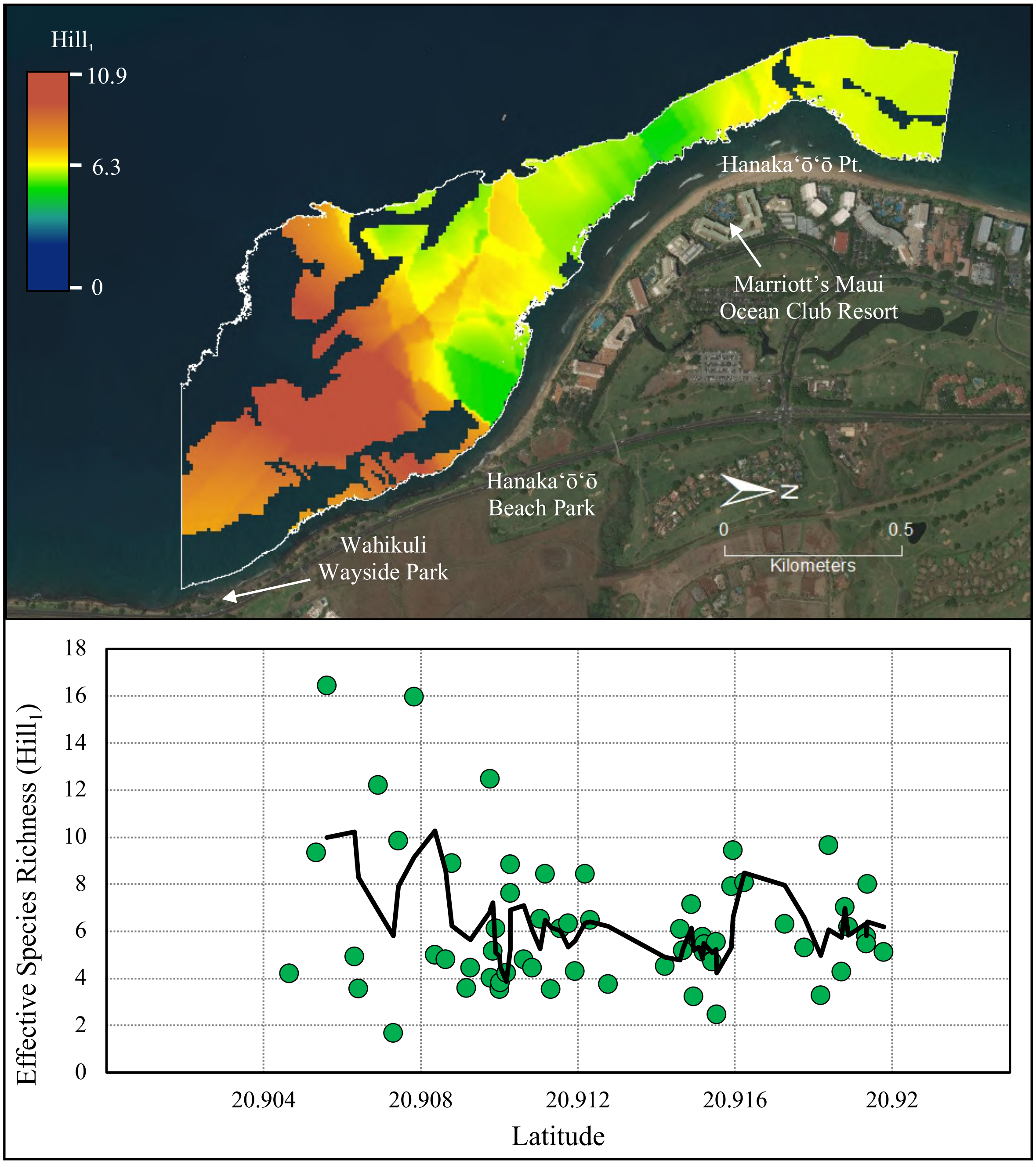


Figure 5.11. Effective species richness ($Hill_1$) for fish across the Hanaka‘ō‘ō Beach FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. Map colors are derived from the data of the FW, such that yellow is the average effective species richness for the FW and red would be considered high richness for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of the effective species richness at consecutive survey sites along the north-south axis.

The Big Picture

In the context of the WMR, reef resources in the Hanaka‘ō‘ō Beach FW are a tale of two assemblages and depend upon where one looks within the FW. The benthic assemblage had medium high average coral cover and high benthic diversity, but showed a strong north-south gradient. Reefs along the southern end of the FW were fragmented, with low coral cover and species richness when compared to the averages for the WMR. Rounding Hanaka‘ō‘ō Point, coral cover increased and at the northern end of the FW was high compared to the regional average. The fish assemblage within the Hanaka‘ō‘ō Beach FW had average abundance, biomass, and diversity when compared to regional averages, but tended to be on the lower end of average range, except for prime spawners. Fish biomass and spatial patterns were heavily influenced by one or more large schools of the goatfish *M. vanicolensis* at two survey sites, and removing these from the biomass estimates lowered the average resource fish and prime spawner biomass to among the lowest of any FW in the WMR.

Statewide Context

Averages for coral cover (14.4 ± 0.7%), total fish biomass (40.9 ± 2.5 g/m^2), resource fish biomass (22.3 ± 1.8 g/m^2), and prime spawner biomass (3.7 ± 1.0 g/m^2) were calculated for the MHI, to serve as a gauge for how the reefs of the WMR are faring relative to those from around the state. All across the MHI, reefs are affected by overfishing, sediments, land-based pollution, and invasive species. Over the past century, populations of some commercially important reef fish populations have declined by over 90%, and coral cover in some areas has declined by at least 40% in just the last 40 years. While there are many reef areas around the state that still have abundant and healthy resources, the current statewide averages used for comparison here certainly reflect substantial declines in resource condition seen broadly across the reefs of the MHI. Reefs in the WMR were consistent with the statewide averages for coral and fish assemblages (see Chapter 1). However, considerable variability in the condition of reefs exists across the WMR, and the reef tracts within the Hanaka‘ō‘ō Beach FW ranged from slightly below average to above average when compared to reefs statewide (Figure 5.12). The Hanaka‘ō‘ō Beach FW had high coral cover compared to reefs across the MHI, but had slightly below average total and resource fish biomass. Prime spawner biomass was above average when compared to reefs in the MHI, but this was driven primarily by large schools of *M vanicolensis* observed at two survey sites, and if these two sites were removed, average biomass dropped below the statewide average.

Synthesis

The marine resources within the Hanaka‘ō‘ō Beach FW were highly variable and of mixed quality, especially compared to the rest of the WMR. Coral cover and benthic diversity ranged from low (at the southern end of the FW) to high (at the northern end) while fish abundance, biomass, and diversity tended to be slightly below average for the WMR. Potential reef resilience ranged from medium-low to medium-high. The reef area between Wahikuli Wayside Park and Hanaka‘ō‘ō Beach Park and the reefs off the Marriott's Maui Ocean Club Resort were identified as “hotspots” within the FW.

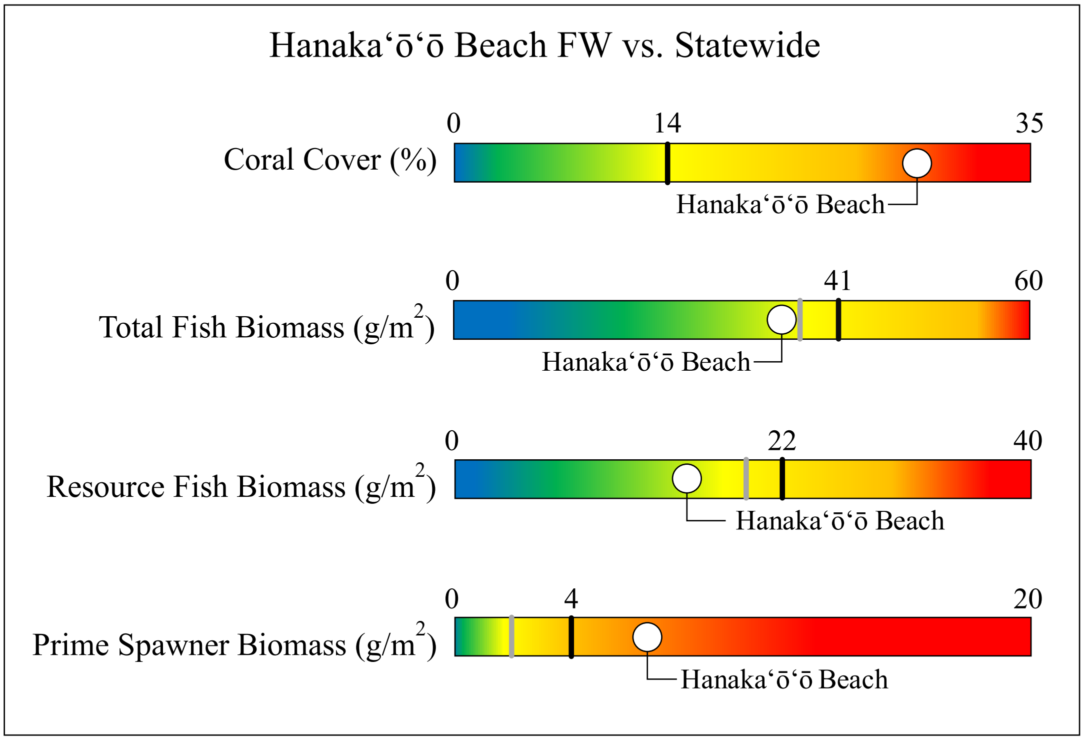
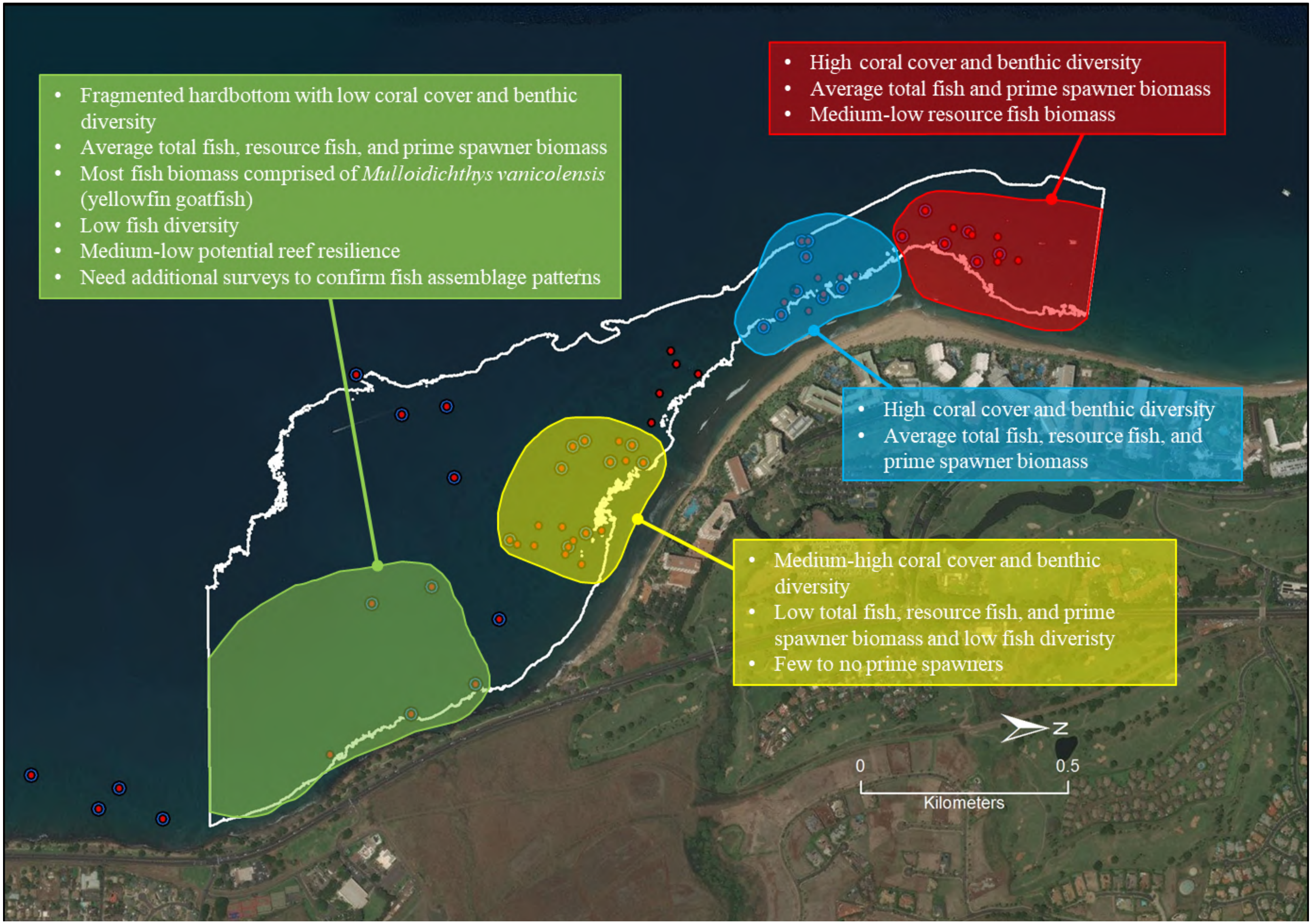


Figure 5.12. Comparison of the Hanaka‘ō‘ō Beach FW to statewide averages for coral cover (%), total fish, resource fish, and prime spawner biomass (g/m^2). Black vertical line and value denote the statewide average. For the three fish metrics, the grey vertical line is the statewide trimmed mean, which was used to develop the qualitative categories; see the methods (Appendix B) for more details on the use of the trimmed means.

The benthic assemblage at the southern end of the FW, between Wahikuli Wayside Park and Hanaka‘ō‘ō Beach Park, was characterized by low coral cover and heavily fragmented hardbottom. In contrast, this reef area had the highest resource and prime spawner fish biomass within the Hanaka‘ō‘ō Beach FW. Fish biomass was comprised mainly of the goatfish *M. vanicolensis*, a species that shelters, often in large schools, on the reef during the day before dispersing onto sand flats to feed on small invertebrates at night. Due to its reliance on sand flats for foraging, this species tends to be rare on extensive, contiguous reef tracts and was not observed elsewhere in the FW. However, *M. vanicolensis* is a prized resource species in Hawai‘i, and its high abundance and biomass in this area are notable.

The reef off the Marriott’s Maui Ocean Club Resort had high coral cover and benthic diversity, both within the FW and compared to the regional average, and above average fish biomass. While coral cover appears to increase farther north, the fish assemblage offshore of the Marriott’s Maui Ocean Club Resort had higher resource and prime spawner biomass than the northern areas of the Hanaka‘ō‘ō Beach FW. This reef area has been identified here as one of the best sections of reef within the Hanaka‘ō‘ō Beach FW, even though its reef fish assemblage would rank as average or below average compared to the WMR.



• Fragmented hardbottom with low coral cover and benthic diversity
• Average total fish, resource fish, and prime spawner biomass
• Most fish biomass comprised of *Mulloidichthys vanicolensis* (yellowfin goatfish)
• Low fish diversity
• Medium-low potential reef resilience
• Need additional surveys to confirm fish assemblage patterns
• High coral cover and benthic diversity
• Average total fish and prime spawner biomass
• Medium-low resource fish biomass
• High coral cover and benthic diversity
• Average total fish, resource fish, and prime spawner biomass
• Medium-high coral cover and benthic diversity
• Low total fish, resource fish, and prime spawner biomass and low fish diveristy
• Few to no prime spawners
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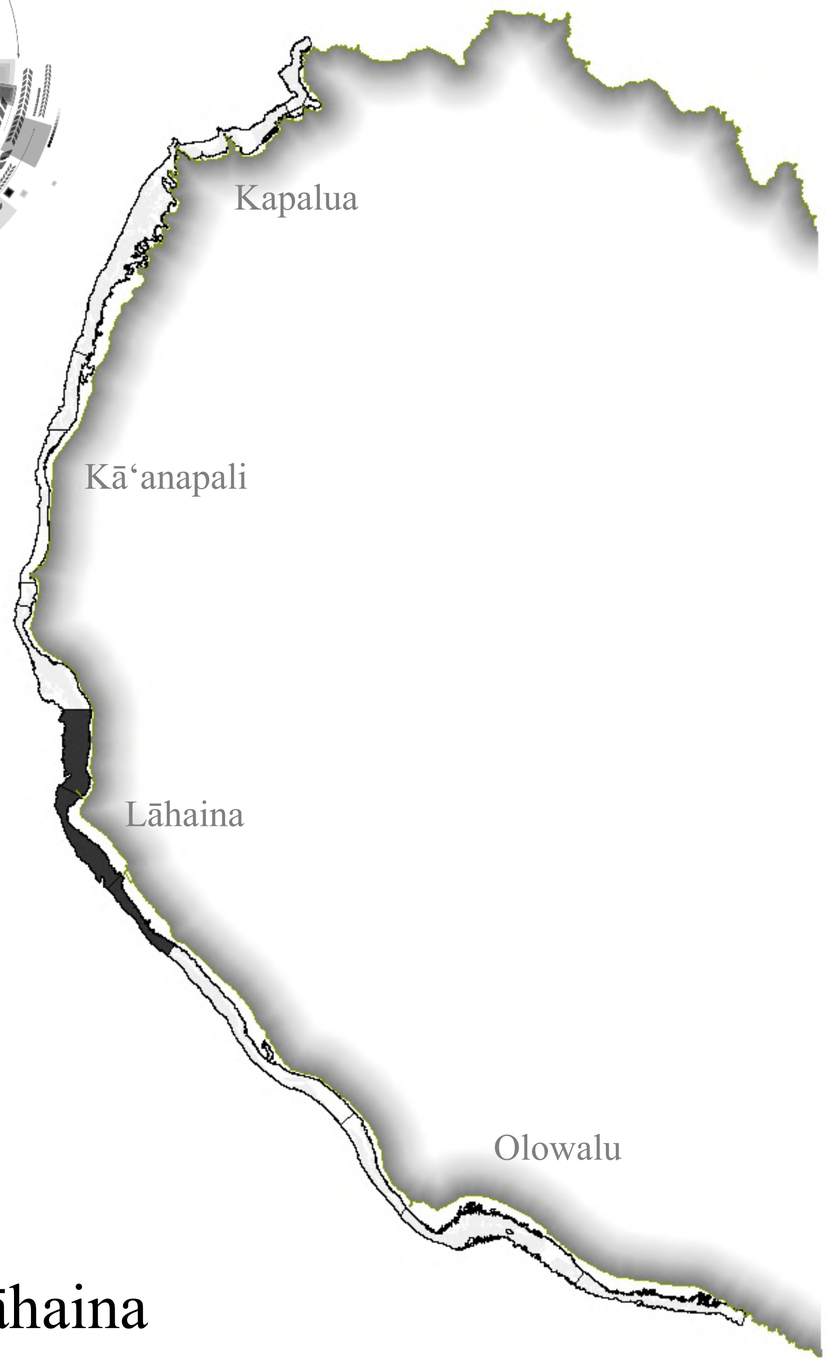

Reefs of Lāhaina

Geographic Setting

The Lāhaina Focus Window (FW) extends from Wahikuli Wayside Park to the mouth of Kaua'ula Stream at Makila Point and is fronted by considerable coastal development, piers (Mala), and channels (Lāhaina Small Boat Harbor) that cut across the fringing reef. These fringing reefs protect the coastline from seasonal south swells and Kona storms when high wave exposure is present. The coast alternates between rocky shoreline, basalt pebble beaches, calcareous sand pockets and beaches, and seawalls and revetments built to prevent damage to commercial development and tourist facilities from shoreline erosion[77]. Lāhaina Town is the commercial center of the West Maui Region (WMR), and development includes several tourist resorts, shops and restaurants, commercial properties, and residential homes[78]. Freshwater inputs to nearshore waters come from streams, storm drains, and groundwater seeps[79]. Land uses in upland areas include residential development, fallow agricultural fields, rangeland, diversified agriculture, ecotourism, and lands actively managed for conservation[80].

Lāhaina has a rich history. It was the capital of the Kingdom of Hawai'i from 1820 to 1845, and was also once revered as a resource rich place, providing abundant freshwater from Kaua'ula Valley and thriving marine life from healthy coral reefs such as Nā Papalimu O Pi'ilani, which is known for its rich abundance of *limu* (seaweed) and fish[81]. After western contact, the economy shifted from a self-sufficient Hawaiian society to one of land ownership and commercial interests[82]. Lāhaina's economy was primarily driven by the whaling, sugar, and pineapple industries. Today, tourism is the primary driver of Lāhaina's economy, and the former cane and pineapple fields are largely fallow.

Growing tourist and resident populations and development as well as past and present land management practices have increased local pressures on Lāhaina's nearshore waters and coral reefs through sediment and nutrient runoff, increased commercial and recreational use, and overharvesting. This suite of stressors has reduced water quality and marine resource abundance, degrading overall coral reef ecosystem health. Data collected from a network of 20 water quality monitoring stations across the WMR[83] showed the Lāhaina FW had several water quality issues, especially in the vicinity of Polanui, where coastal waters had elevated phosphate, nitrate, and turbidity, likely from runoff associated with the developed coastline and historical upland land management.

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[77] SOEST (2013)
[78] NRCS (2003) and Pickett and Grossman (2014)
[79] Glenn *et al.* (2013)
[80] Pickett and Grossman (2014)
[81] Lāhaina Restoration Foundation
[82] County of Maui Planning Department Long Range Division (2012)
[83] Hui O Ka Wai Ola and the State Department of Health collect water quality data at 20 sites in the WMR, including four locations in the Lāhaina FW: 505 Front Street, Kauaula Road, Lāhaina Town, and Makila Point. To learn more about Hui O Ka Wai Ola and download raw data, please visit huiokawaiola.com.

The Data

The Lāhaina FW is comprised of three reef tracts: Mala, Lāhaina Town, and Polanui (Figure 6.1):

- **Mala** reef tract extends ~1.8 km (1.1 mi) from Wahikuli Wayside Park to the Mala Pier. This reef tract was surveyed in 2017 (Table 6.1).
- **Lāhaina Town** reef tract extends ~1.7 km (1.1 mi) from the Mala Pier to the channel for the Lāhaina Small Boat Harbor. The Lāhaina Town reef tract was surveyed multiple times between 2010 and 2018 (Table 6.1), with the majority of the survey effort occurring in 2017. In 2018, The Nature Conservancy (TNC) assessed one reef resilience site (Mala Reef) within the Lāhaina Town reef tract.
- **Polanui** reef tract extends ~1.8 km (1.1 mi) from the channel for the Lāhaina Small Boat Harbor to the mouth of Kaua‘ula Stream on Makila Point. This otherwise contiguous reef is cut by a natural channel (Kauha‘ilio Channel) near the mid-point of the reef tract. Of the three reef tracts within the Lāhaina FW, the Polanui reef tract was the most intensively surveyed (2010-2018), with multiple years having robust survey efforts (Table 6.1). In 2018, TNC assessed one reef resilience site (Polanui) within the Polanui reef tract.

Table 6.1. Benthic and fish assemblage survey effort (number of survey sites) in the Lāhaina FW between 2010 and 2018. The FW has three reef tracts: Mala, Lāhaina Town, and Polanui.

Reef Tract	Survey Year	Benthic	Fish
Mala		16	16
	2017	16	16
Lāhaina		28	22
	2010	2	
	2012	2	
	2013	1	
	2016	1	
	2017	21	21
	2018	1	1
Polanui		101	98
	2010	1	
	2012	27	27
	2013	19	18
	2014	28	27
	2017	25	25
	2018	1	1
TOTAL		145	136

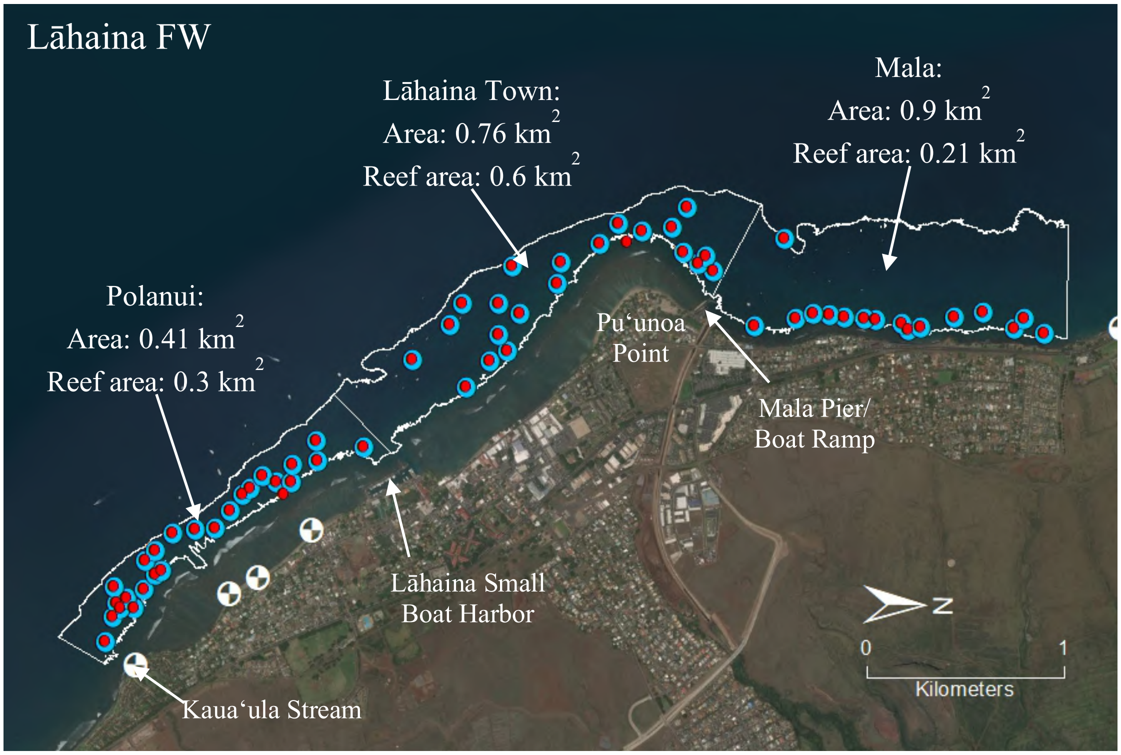

Figure 6.1. Reef tracts within the Lāhaina FW. Dots indicate 2016-2018 survey efforts for the benthic (blue) and fish (red) assemblages within the FW. White quadrant circles along the shore are (north to south) the 505 Front Street, Kaua‘ula Road, Lāhaina Town, and Makila Point long-term water quality monitoring sites.

Maps within the Atlas were generated using a spatial technique called interpolation. This technique uses available survey data to generate a complete spatial model of the data by estimating values between the surveys' data using a mathematical algorithm that considers the values of nearby data weighed by their distance away. Areas with a higher density of surveys will produce more "accurate" interpolations than areas with lower survey density. Averages derived from interpolation maps are calculated across all reef areas and typically vary from averages derived from the survey data. Interpolation maps were generated for the Atlas primarily to display general spatial patterns and should not be used to predict exact values at any given location. For example, an interpolation map can, with a high degree of reliability, indicate that one reef tract has more coral than another reef tract, but it should not be used estimate the "exact" coral cover at a specific location within the reef tract. To estimate coral cover, amount of fish, etc., current survey data from the specific location should always be used over the interpolation maps when these data are available.

Benthic

Current Spatial Patterns: Benthic

The reefs within the Lāhaina FW show considerable spatial variability in their benthic assemblage. Turf was the most common benthic group averaging 49.4 ± 1.9% cover across the FW, but ranging from 42-56% in the three reef tracts (Table 6.2).

Average coral cover in the Lāhaina FW was 19.6 ± 2.2%, but coral cover within the Polanui reef tract (10.8 ± 1.9%) was ~60% lower[84] than in both the Lāhaina Town (25.2 ± 4.2%) and Mala (24.6 ± 4.7%) reef tracts (Figure 6.2). Benthic diversity ($Hill_1$) was also lower within the Polanui reef tract (Figure 6.3). The difference between the Polanui and the other two reef tracts was driven primarily by areas of high coral cover and diversity around Puʻunoa Point and to the north of Mala Pier and boat ramp. However, in the immediate vicinity of the Mala Pier and boat ramp, coral cover and benthic richness declined (Figure 6.2, graph). This decline near the pier may be associated with the structure, but Kahoma Stream also enters the coastal waters in this area, making it difficult to clearly establish a causal relationship between the pier and the condition of the reef. Data also suggest that the Lāhaina Small Boat Harbor may be having an effect on the benthic assemblage, although any decrease in coral cover and benthic diversity may be due to the natural variability of the reef in the southern half of the FW. The lower coral cover within the Polanui reef tract appeared to be offset with an increase in turf (Figure 6.4), which would be consistent with the water quality issues (*i.e.*, elevated organic nutrients and turbidity) identified in the area by the long-term monitoring conducted by Hui O Ka Wai Ola and the State Department of Health.

During the 2017 surveys, 11 coral species were identified within the Lāhaina FW (Table 6.2). *Porites lobata* (lobe coral) was the most abundant coral species in the FW, covering 8.0 ± 0.7% and comprising over 41% of all the observed coral. Within the Polanui reef tract, *P. lobata* was by far the dominant species, accounting for 70% of all observed coral, with *P. compressa* (finger coral) being the next most common (Table 6.2). Together, these two *Porites* species accounted for >92% of the coral in the Polanui reef tract. In contrast, both the Lāhaina Town and Mala reef tracts had more encrusting corals, specifically *Montipora capitata* (rice coral) and *M. patula* (sandpaper coral), than the Polanui reef tract. While *P. lobata* was still an important component in the coral assemblage, the two encrusting *Montipora* species comprised 45% and 57% of the coral in the Lāhaina Town and Mala reef tracts, respectively.

Historical Patterns: Benthic

For years other than 2017, survey data in the Lāhaina Town and Mala reef tracts were sparse (Table 6.1); thus, a time series analysis for those reef tracts could not be conducted. Change

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[84] Describing change in a percent value (*e.g.*, percent cover) can present challenges and cause confusion because often changes are expressed as "percent change" in the original value. This approach is often called a "relative" change, but confusion often arises when the base values are also percentages. For example, a decline from 12% to 6% cover is a 50% "relative" decrease in cover, but an "absolute" decrease of 6%. The use of the "relative" and "absolute" approaches to describe a change depends on the specific situation. In ecology, the "relative" change is used when comparing things (*e.g.*, reef areas) that may have very different underlying values.

through time was examined only within the Polanui reef tract, for which sufficient data were available for 2012, 2013, 2014, and 2017. Unfortunately, this dataset lacks information in the years immediately following the 2015 mass coral bleaching event that affected many of the reefs within the Main Hawaiian Islands (MHI), including on Maui where it caused an estimated 20-40% loss of coral[85]. This lack of data makes it difficult to examine the effects of the bleaching event on Polanui's benthic assemblage.

Reefs within the Polanui reef tract have changed considerably since 2012 (Figure 6.5), most notably between the 2014 and 2017 surveys when the reefs lost approximately half their coral cover, likely as a result of the 2015 mass coral bleaching event. Declines within the Polanui reef tract were noticeable in nearly all species, with *M. patula* and *Pocillopora meandrina* (cauliflower coral) particularly affected (Table 6.3), which is consistent with other areas affected by the bleaching event[86]. Both species have shown susceptibility to bleaching-related mortality.

Table 6.2. Average (±SEM) percent cover of benthic groups and taxa in the Mala (n=16), Lāhaina Town (n=23), and Polanui (n=26) reef tracts. Data are from 2016-2018.

	Mala	**Lāhaina Town**	**Polanui**
Turf	42.3 ± 2.6	45.7 ± 2.5	56.1 ± 3.6
Coral	24.6 ± 4.7	25.2 ± 4.2	10.8 ± 1.9
Porites lobata	8.3 ± 1.5	8.2 ± 1.5	7.6 ± 1.1
Montipora capitata	9.9 ± 2.7	6.4 ± 2.0	0.2 ± 0.1
Montipora patula	4.2 ± 1.2	5.0 ± 1.7	0.6 ± 0.2
Porites compressa	2.0 ± 0.6	5.5 ± 1.3	2.2 ± 0.8
Leptastrea purpurea	0.1 ± 0.1	<0.1	0.1 ± 0.1
Pavona varians	<0.1	<0.1	0.1 ± 0.1
Pavona duerdeni	<0.1	<0.1	<0.1
Pocillopora meandrina	<0.1	<0.1	<0.1
Pavona maldivensis	<0.1	<0.1	0
Cyphastrea ocellina	0	<0.1	0
Porites lutea	0	<0.1	0
Crustose Coralline Algae	0.9 ± 0.2	2.0 ± 0.6	1.1 ± 0.3
Macroalgae	<0.1	0.1 ± 0	<0.1
Cyanobacteria	<0.1	<0.1	<0.1
Other	0.1 ± 0.1	0	<0.1
Abiotic	32.1 ± 5.0	27.1 ± 4.4	32 ± 4.9
Sand	31.5 ± 4.8	24.5 ± 3.8	31.3 ± 4.8
Rubble	0.6 ± 0.3	2.6 ± 0.9	0.7 ± 0.3
Pavement	0	<0.1	0
Recently Dead Coral	<0.1	0	0

[85] SSRI (2017)
[86] Kramer *et al.* (2016) and Minton *et al.* (2018b)

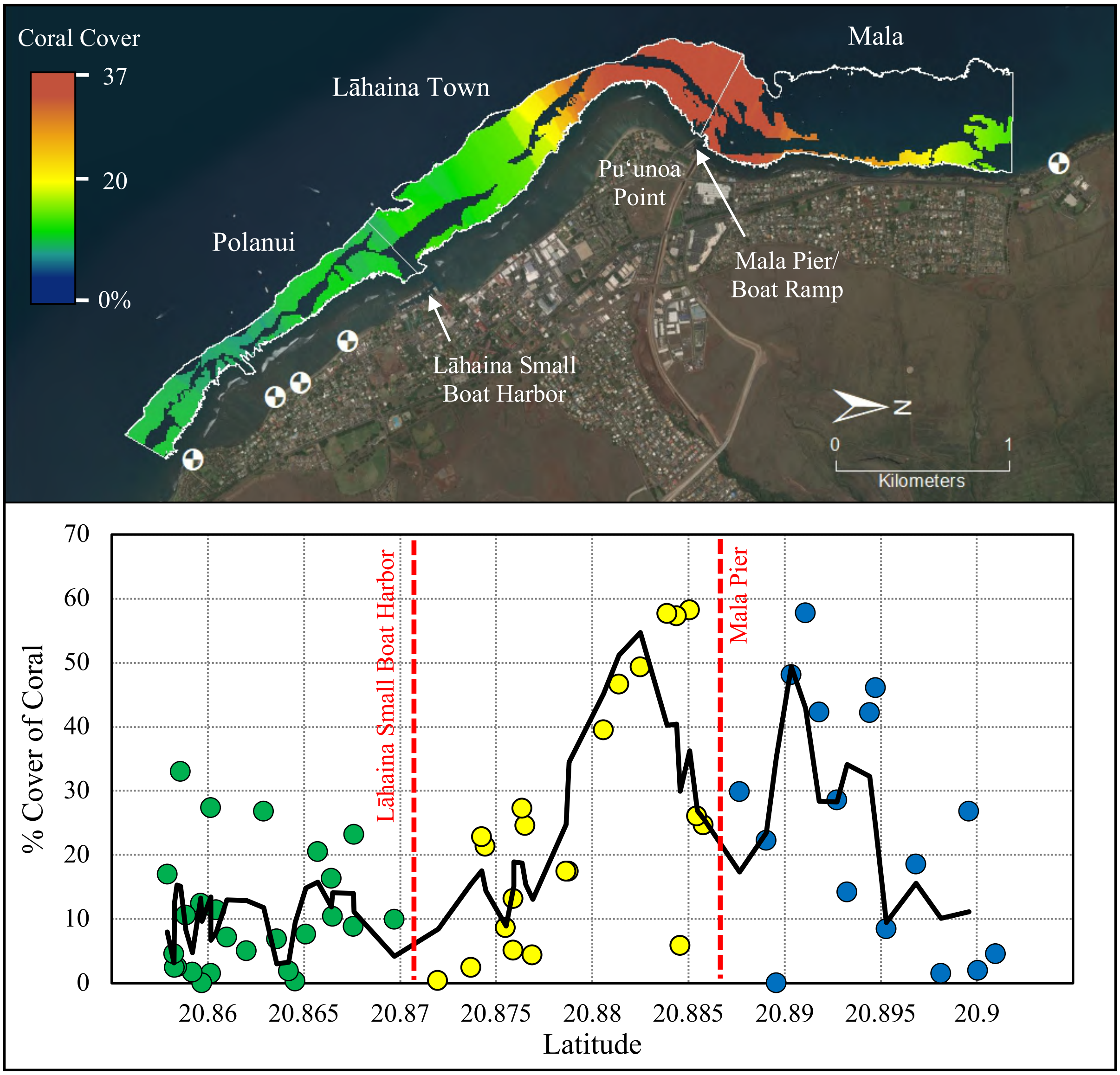

Figure 6.2. Coral cover across the Lāhaina FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of coral cover at consecutive survey sites along the north-south axis. Colored points in the graph correspond with the Polanui (green), Lāhaina Town (yellow), and Mala (blue) reef tracts. White quadrant circles along the shore are (north to south) the long-term water quality monitoring sites 505 Front Street, Kaua'ula Road, Lāhaina Town, and Makila Point.

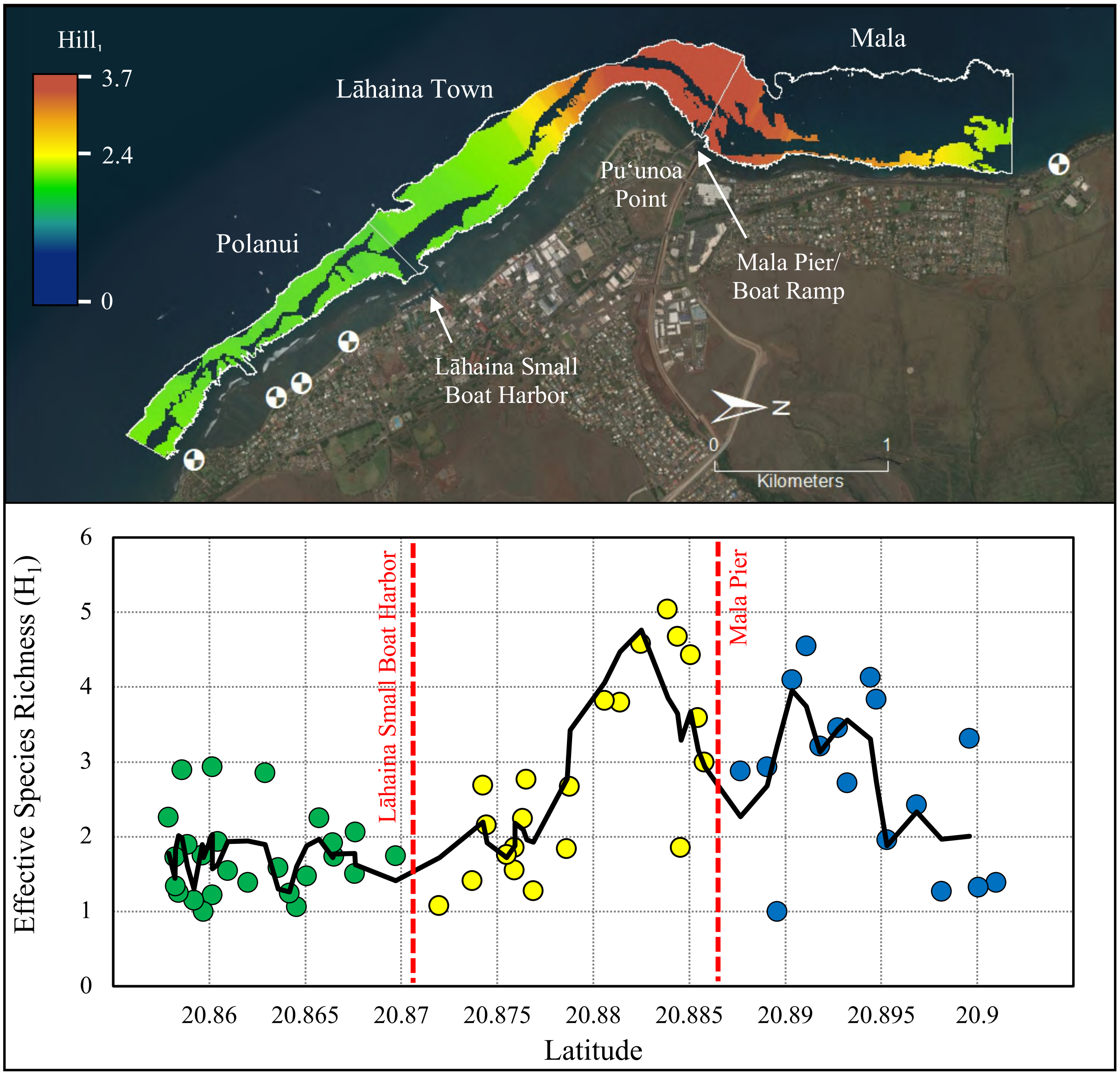

Figure 6.3. Effective species richness (Hill$_1$) across the Lāhaina FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average effective species richness for the FW and red would be considered high richness for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of effective species richness at consecutive survey sites along the north-south axis. Colored points in the graph correspond with the Polanui (green), Lāhaina Town (yellow), and Mala (blue) reef tracts. White quadrant circles along the shore are (north to south) the long-term water quality monitoring sites 505 Front Street, Kauaula Road, Lāhaina Town, and Makila Point.

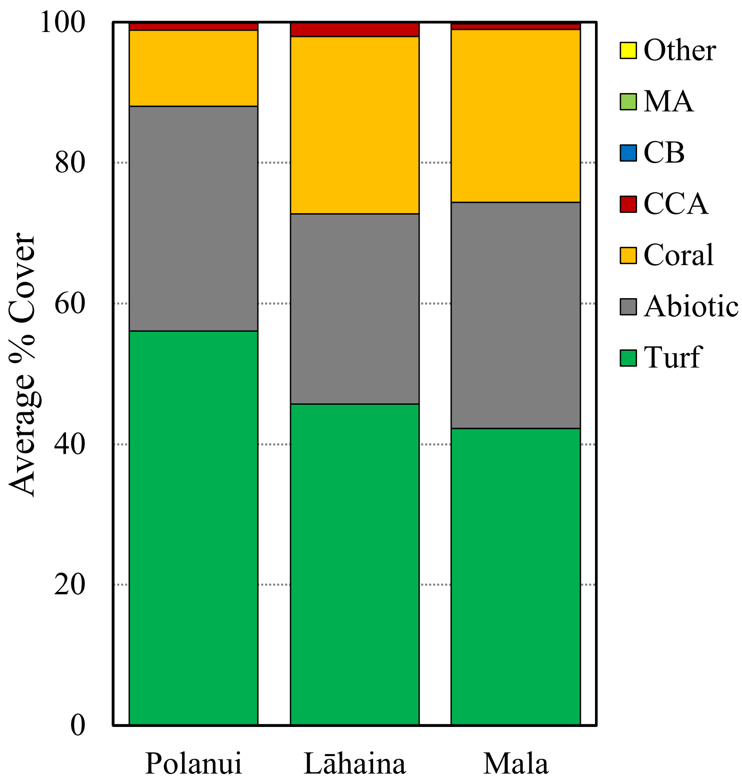

Figure 6.4. Average percent cover by benthic group in the Lāhaina FW. Data are from 2016-2018. MA=macroalgae, CB=cyanobacteria, CCA=crustose coralline algae.

Losses in coral cover were generally offset by increases in competitors for space, especially turf and crustose coralline algae (CCA), or rubble resulting from the breakage of dead coral colonies. While abiotic substratum, primarily sand, also increased between 2014 and 2017, coral cover varied independently of the abiotic substratum, suggesting the increase in sand was most likely due to the random draw of survey sites including more sandy locations in 2017 and not an indication that abiotic substratum replaced lost coral.

The Polanui reef tract also has experienced a change in benthic diversity, especially between the years of 2012-2014 and in 2017. The Polanui reef tract appears to have lost rare species and did not undergo a shift in the dominant taxa. The cover of turf, which was dominant on Polanui's reef, changed little between 2013 and 2017 (Figure 6.5), while over that same time period, the average benthic taxa richness (excluding abiotic groups) at survey sites dropped from 8.6 ± 2.6 to 5.0 ± 1.9, and the Polanui-wide taxa richness dropped from 23 to 14. All 10 taxa lost between 2014 and 2017 (including three species of coral, three species of macroalgae, and four other taxa) had <1% cover in 2014 (*i.e.*, were rare). During this same time, only one new taxon (cyanobacteria) was observed in 2017.

Between 2012 and 2013, the Polanui reef tract also appears to have undergone a change in benthic structure, but this is likely an artifact of the random selection of the survey sites. The change in benthic structure between 2012 and 2013 appears to be associated with a shift in dominance from abiotic substratum to turf. In 2012, turf covered only 19% of the bottom, but in 2013 had increased to >57% cover (Figure 6.5); yet the cover of turf and abiotic groups together was nearly identical. In addition, the average benthic taxa richness (excluding abiotic groups) at survey sites was similar: 7.2 ± 2.6 and 7.4 ± 2.8 in 2012 and 2013, respectively, and Polanui-wide taxa richness was also similar, 19 compared to 21 taxa. Taken together, these findings indicate that the benthic assemblage on the available hardbottom was very similar between the two years, and that the primary difference between years was that more sites with high cover of sand were surveyed in 2012 compared to 2013.

Table 6.3. Average (±SEM) percent cover of benthic groups and taxa within the Polanui reef tract in 2012 (n=27), 2013 (n=19), 2014 (n=28), and 2017 (n=25).

	2012	**2013**	**2014**	**2017**
Turf	19.1 ± 3.8	57.1 ± 4.1	61.4 ± 3.2	56.1 ± 3.6
Coral	21.4 ± 2.7	18.8 ± 3.4	20.7 ± 2.7	10.8 ± 1.9
Porites lobata	12.2 ± 1.4	9.8 ± 1.7	11.4 ± 1.4	7.6 ± 1.1
Montipora capitata	0.5 ± 0.2	1.0 ± 0.5	0.9 ± 0.2	0.2 ± 0.1
Montipora patula	2.6 ± 0.9	2 ± 0.8	2.1 ± 0.6	0.6 ± 0.2
Porites compressa	3.0 ± 1.0	2.9 ± 1.1	3.5 ± 1.1	2.2 ± 0.8
Leptastrea purpurea	0.1 ± 0.1	<0.1	0.1 ± 0.1	0.1 ± 0.1
Pavona varians	0.1 ± 0	0.1 ± 0.1	0.3 ± 0.1	0.1 ± 0
Pavona duerdeni	0	0	<0.1	<0.1
Pocillopora meandrina	2.7 ± 0.3	2.2 ± 0.4	2.3 ± 0.3	<0.1
Pavona maldivensis	0	0	0	0
Cyphastrea ocellina	0	0	<0.1	0
Porites lutea	0.1 ± 0.1	0.2 ± 0.2	0	0
Pocillopora eyedouxi	0	0.1 ± 0.1	<0.1	0
Porites c.f. *bernardi*	0	<0.1	0	0
Porites species	0	0.1 ± 0	0	0
Psammocora stellata	0	0	<0.1	0
Crustose Coralline Algae	1.7 ± 0.4	1.1 ± 0.3	2.3 ± 0.6	1.1 ± 0.3
Macroalgae	1.0 ± 0.3	0.9 ± 0.5	0.6 ± 0.2	<0.1
Cyanobacteria	0	0	0	<0.1
Other	<0.1	<0.1	0.2 ± 0.1	<0.1
Abiotic	56.8 ± 5.9	21.9 ± 5.8	14.7 ± 3.4	32.0 ± 4.9
Sand	56.1 ± 5.9	24.2 ± 5.9	14.6 ± 3.4	31.3 ± 4.8
Rubble	0.6 ± 0.5	0.2 ± 0.1	0.1 ± 0	0.7 ± 0.3
Pavement	<0.1	0	<0.1	0
Recently Dead Coral	<0.1	<0.1	0	0

Coral Health and Reef Resilience

In March 2018, a reef resilience assessment of leeward Maui was conducted by TNC and its partners. These assessments were intended to quantify the relative resilience of Maui's reefs to the effects of climate change. Resilience is the ability of a reef to resist, recover from, and adapt to a climate-related event (*e.g.*, coral bleaching) to maintain a diverse, coral-rich state that provides key ecological functions and services to people[87]. Given the integral role of reefs to the

[87] Nystrom and Folke (2001)

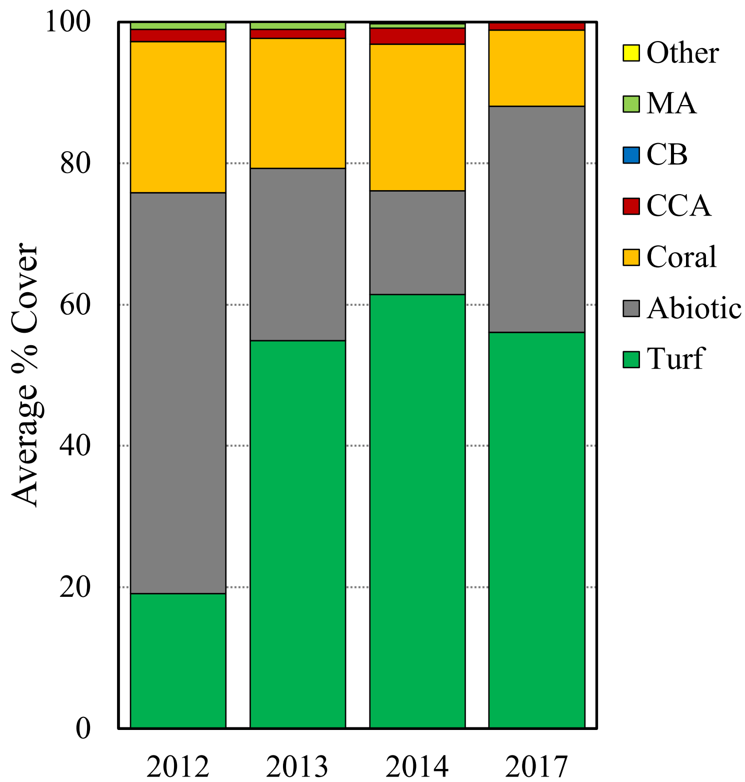

Figure 6.5. Average percent cover by benthic group in the Polanui reef tract for the years 2012-2014 and 2017. MA=macroalgae, CB=cyanobacteria, CCA=crustose coralline algae.

people of Hawai'i, reef resilience is closely linked with social resilience, which is the ability of human communities to adapt to social, political, environmental, or economic change[88].

Two shallow-water reef resilience sites (Mala Reef and Polanui) were surveyed within the Lāhaina FW. The complete results of TNC's Maui Reef Resilience assessment are detailed elsewhere[89], so only the coral health and resilience findings for the sites in the Lāhaina FW are summarized here.

Both reef resilience sites had benthic assemblages that were consistent in structure with nearby sites visited in 2017. The Mala Reef site had the second highest coral cover (57%) among the 31 shallow-water sites included in the reef resilience assessment. Disease prevalence was low (1.5%), but almost a third of all colonies showed signs of paling/bleaching (Table 6.4), which was nearly double the average for shallow-water reef resilience sites in the WMR. This suggests that Mala Reef site may be under some stress. The Polanui reef resilience site had among the worst coral cover and disease prevalence among the shallow-water reef resilience sites (Table 6.4); disease prevalence was 3-times higher than the average for the WMR (2.4 ± 0.5%).

As part of the reef resilience assessment, the 31 shallow-water and 20 deep-water sites surveyed were assigned a relative reef resilience rank, based on several indicator variables, including coral cover, coral disease prevalence, coral diversity, coral recruitment, reef builder ratio (ratio of calcifying species to non-calcifying species), rugosity, and herbivorous fish biomass. The Mala reef resilience site ranked 6th out 31 shallow-water sites, placing it among the most resilient of the leeward Maui sites with medium-high potential reef resilience. The Polanui reef resilience site was ranked 25th out 31 sites, placing it near the bottom and in the category medium-low.

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[88] Adger (2000)
[89] Maynard *et al.* (2019)

Table 6.4. The two reef resilience (RR) sites within the Lāhaina FW. "RR Rank" is the relative reef resilience rank among 31 shallow-water sites along leeward Maui. "Dis. Prev." is the percent of colonies presenting at least one disease. "ALOG" is the percentage of colonies being overgrown by benthic algae. "Paling/Bleaching" is the percent of colonies showing signs of tissue paling or bleaching. Average values for the WMR (italics) are presented for comparison.

	Reef Tract	**RR Rank**	**Dis. Prev.**	**ALOG**	**Paling/ Bleaching**
Shallow	*WMR Average*		*2.4 ± 0.5*	*9.6 ± 1.5*	*18.2 ± 4.8*
Mala Reef	Lāhaina Town	S6	1.6	16.6	32.6
Polanui	Polanui	S25	7.7	9.6	8.5

Fish Assemblage

Current Spatial Patterns: Fish

Like the benthic assemblage, the fish assemblage in the Lāhaina FW showed considerable spatial variation, but the spatial patterns of fish were different from the benthic assemblage. The Polanui reef tract had the highest total fish biomass (57.1 ± 10.3 g/m^2), nearly double that observed within the Lāhaina Town reef tract (Table 6.5), and above average for the WMR (42.2 ± 3.9 g/m^2).

Spatial variability within all three reef tracts was high, and distinct spatial patterns emerged within the Lāhaina Town and Mala reef tracts. Total fish biomass was low between the channel for the Lāhaina Small Boat Harbor and Puʻunoa Point (Figure 6.6). Total fish biomass also dropped near the Mala Pier and boat ramp, but the spatial extent of this low-fish biomass area was restricted to within approximately 200 m of the south of the pier. This is a heavily used area, popular with divers and fishers (DAR staff, per. comm.), which may have depressed the total fish biomass. Total fish biomass was also low to the north of the Mala Pier and boat ramp, where the reef became more fragmented as it stretched toward Wahikuli Wayside Park.

Resource fish biomass, which is comprised of species important for consumption[90] and that tend to be prized by fishers, showed a different spatial pattern than total fish biomass. Resource fish biomass tended to be low across much of the Lāhaina FW, except for the reef around Puʻunoa Point and to the north and south of Mala Pier and boat ramp (Figure 6.7). Again, variability tended to be high, for example, the two sites with the greatest resource fish biomass within the FW were within the Polanui reef tract, on the reef between Kauhaʻilio Channel and Kauaʻula Stream, but they were outnumbered by many sites with low resource fish biomass. The Kauhaʻilio Channel and Kauaʻula Stream appear to be "defining" features for the Polanui reef tract and were associated with lower coral cover and reef fish biomass, likely due to the channel and stream acting as sources of sediment input[91]. Resource fish biomass in the Lāhaina Town reef tract was consistently low on the north side of the harbor channel (Figure 6.7), even though the benthic assemblage in this area was similar to that on the south side of the channel,

[90] See Appendix B for a list of resource and non-resource species
[91] Minton and Conklin (2013)

Table 6.5. Average (±SEM) fish biomass (g/m^2) by family within the Mala (n=16), Lāhaina Town (n=22), and Polanui (n=26) reef tracts. Data are from 2016-2018. *Individuals were present, but biomass was not estimated for this family.

	Mala	**Lāhaina Town**	**Polanui**
Acanthuridae	29.6 ± 10.2	10.2 ± 2.5	23.1 ± 6.4
Balistidae	1.6 ± 0.4	7.1 ± 2.1	18.1 ± 4.5
Lethrinidae	0.1 ± 0.2	4.6 ± 3.5	4.1 ± 2.5
Scaridae	2.7 ± 1.1	1.5 ± 0.5	3.4 ± 1.1
Labridae	1.7 ± 0.2	2.3 ± 0.4	2.5 ± 0.8
Pomacentridae	1.7 ± 0.5	1.4 ± 0.4	2.0 ± 0.4
Mullidae	0.3 ± 0.1	0.2 ± 0.1	1.0 ± 0.4
Chaetodontidae	0.8 ± 0.3	1.2 ± 0.3	0.8 ± 0.2
Carangidae	0.2 ± 0.2	1.4 ± 1.4	0.5 ± 0.4
Tetraodontidae	0.5 ± 0.1	0.3 ± 0.1	0.4 ± 0.1
Fistulariidae	0	<0.1	0.4 ± 0.3
Serranidae	0.1 ± 0.1	0.5 ± 0.3	0.3 ± 0.1
Cirrhitidae	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Zanclidae	0.2 ± 0.2	<0.1	0.2 ± 0.1
Holocentridae	0	<0.1	0.1 ± 0.1
Monacanthidae	<0.1	0.3 ± 0.2	0.1 ± 0.1
Pomacanthidae	0	<0.1	0.1 ± 0.1
Ostraciidae	<0.1	<0.1	<0.1
Microdesmidae	<0.1	<0.1	<0.1
Aulostomidae	<0.1	<0.1	<0.1
Blenniidae	<0.1	<0.1	<0.1
Apogonidae	0	0	<0.1
Lutjanidae	0.3 ± 0.3	0.2 ± 0.2	0
Synodontidae	<0.1	<0.1	0
Gobiidae	0	<0.1	0
Antennariidae	0	0	0
Carcharhinidae	0	0	0
Chanidae	0	0	0
Diodontidae	0	0	0
Muraenidae	*	*	*
Total Fish Biomass	**40.2 ± 11.7**	**31.6 ± 6.3**	**57.1 ± 10.3**

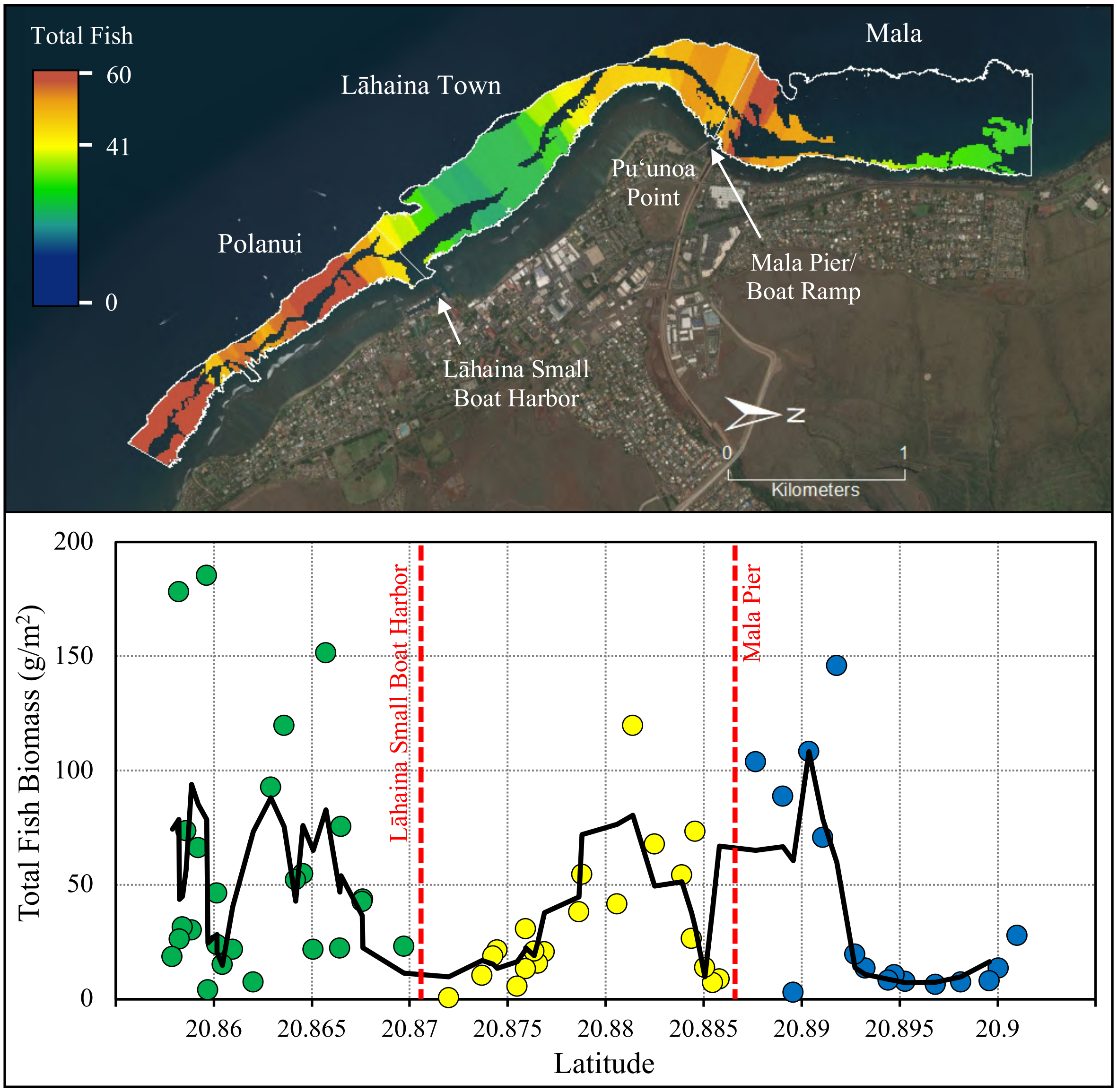

Figure 6.6. Total fish biomass across the Lāhaina FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average total fish biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of total fish biomass at consecutive survey sites along the north-south axis. Colored points in the graph correspond with the Polanui (green), Lāhaina Town (yellow), and Mala (blue) reef tracts.

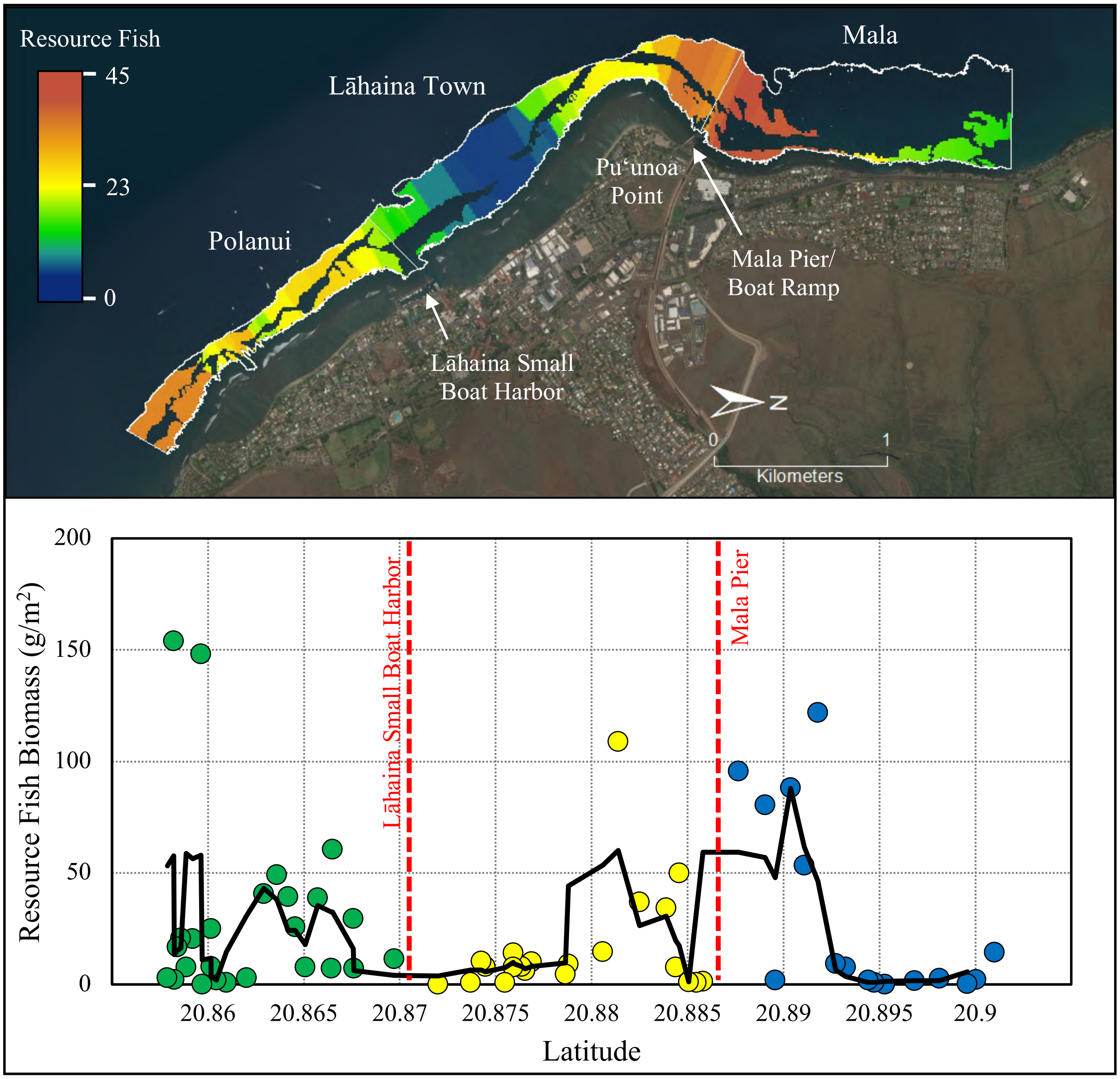

Figure 6.7. Resource fish biomass across the Lāhaina FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average resource fish biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of resource fish biomass at consecutive survey sites along the north-south axis. Colored points in the graph correspond with the Polanui (green), Lāhaina Town (yellow), and Mala (blue) reef tracts.

suggesting the low resource fish biomass was not due to poor habitat but may have been associated in some way with the harbor.

Surgeonfish were the dominant resource fish group within the Polanui and Mala reef tracts, whereas the resource fish assemblage within the Lāhaina Town reef tract was distinguished by high biomass of apex predators (including five species of jack) and *Monotaxis grandoculis* (bigeye emperor), especially on the reef off Puʻunoa Point (Figure 6.8). Resource fish were surprisingly diverse within the Polanui reef tract, with surgeonfish, parrotfish, wrasses, and *M. grandoculis* all comprising sizable components of the resource fish assemblage. In contrast, surgeonfish and parrotfish comprised nearly all the resource fish biomass within the Mala reef tract, with low contributions from other resource fish groups (Figure 6.8).

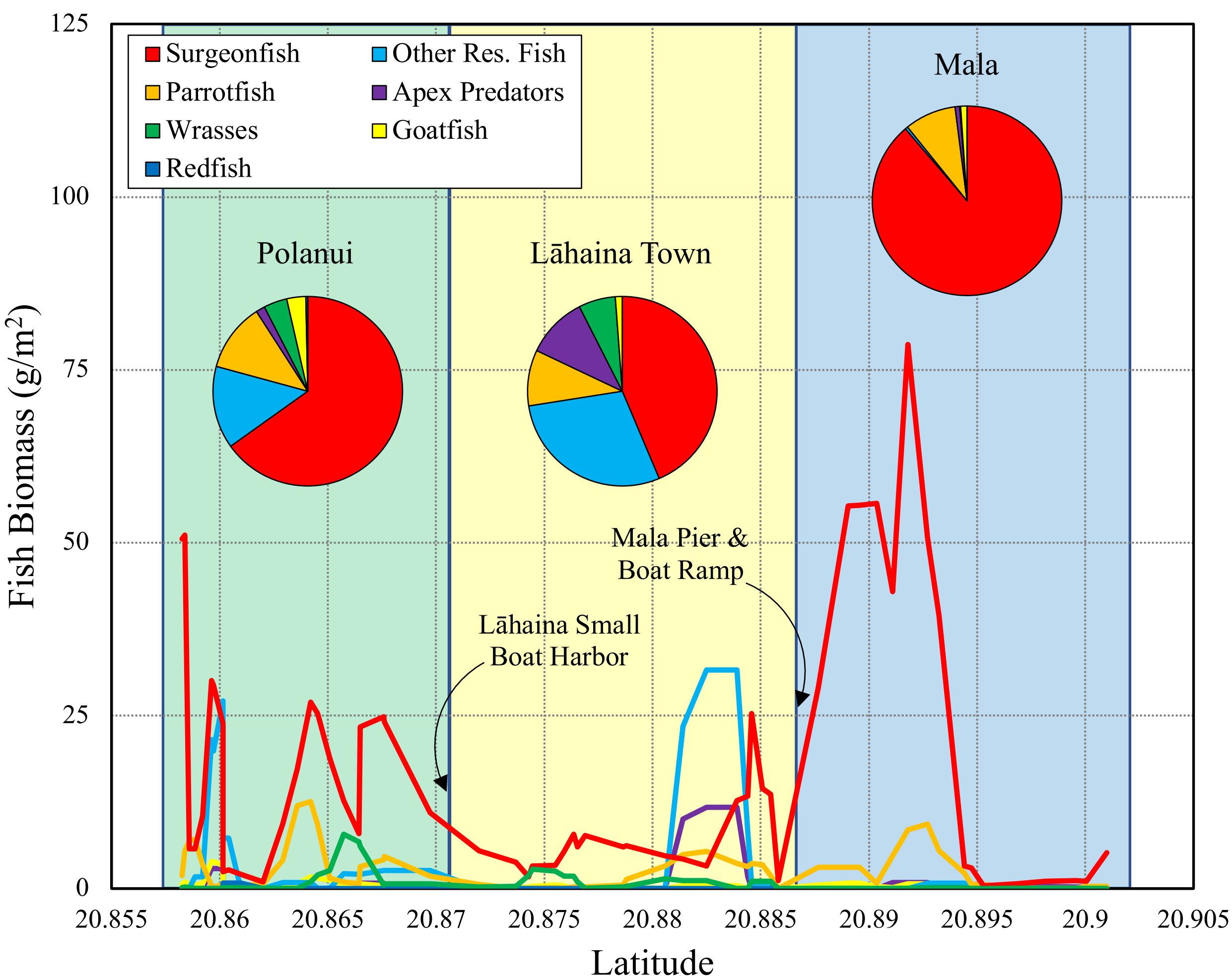

Figure 6.8. Biomass of seven resource groups across the Lāhaina FW. Color boxes correspond with the Polanui (green), Lāhaina Town (yellow), and Mala (blue) reef tracts. Pie charts are the relative biomass of the seven resource groups in each reef tract.

The most compelling spatial pattern, however, was associated with prime spawners. Prime spawners are individual resource fish >70% of the maximum length for that species. These individuals tend to exert a disproportionately large effect on population dynamics due to their considerably higher fecundity and egg quality compared to smaller individuals[92]. Conservation of prime spawners is important to maintaining sustainable fisheries and ecosystems.

Prime spawners were nearly absent from the entirety of the Lāhaina FW (Figure 6.9). Almost 42% of all sites (26 of 62 sites) had zero prime spawner biomass and 80% of the sites had prime spawner biomass below the average for the WMR (6.3 ± 1.7 g/m^2). Even sites with high resource fish biomass had low prime spawner biomass, suggesting most resource fish were small. For example, the two sites within the Polanui reef tract with the highest resource fish biomass (~150 g/m^2) had <10 g/m^2 of prime spawner biomass. Prime spawner biomass was highest north of the Mala Pier and boat ramp (Figure 6.9). In this reef area, prime spawner biomass was comprised mostly of two surgeonfish species, *Acanthurus blochii* (ringtail surgeonfish) and *A. dussumieri* (eyestripe surgeonfish). Both species were rare elsewhere in the Lāhaina FW. *Acanthurus blochii* occurred at only one other site and *A. dussumieri* was entirely absent from the rest of the FW.

Interestingly, even with the spatial heterogeneity of the fish assemblage, fish diversity varied little across the Lāhaina FW (Figure 6.10), although it did significantly decline from south to north (Correlation, $r=-0.311$, $p=0.014$). Both the Lāhaina Small Boat Harbor and Mala Pier appeared to influence fish diversity, but the effect was less than that observed for the benthic assemblage, likely due to the mobility of fish allowing them to move freely across reef areas that might be relatively poor habitat.

Fishing effects can often be detected by examining the average individual size of species by their importance in the fishery. High fishing pressure should lower the average size of more heavily-fished than less-heavily fished species, assuming other potential non-fishing stressors affect the species similarly[93]. Therefore, a ratio of average individual size can be used to compare fish populations between two reef areas and infer the relative effects of fishing versus non-fishing effects on those fish assemblages. The size of 21 common species, grouped into resource fish, non-resource fish, and moderately-prized fish, was compared across the three reef tracts in the Lāhaina FW. Most groups did not differ in size among three reef tracts, except for resource fish, which were larger in the Polanui than the Lāhaina Town reef tract (Figure 6.11). Resource species within the Polanui reef tract did not differ from the Mala reef tract, although variability was high, and did not differ between the Lāhaina Town and Mala reef tracts. Among resource fish, goatfish showed no differences in size between the Polanui and Lāhaina Town reef tracts, but parrotfish were significantly larger at Polanui and appeared responsible for the significant difference in resource fish size between the two reef tracts. Resource fish on the reef of Puʻunoa

[92] Birkeland and Dayton (2005) and Hixon *et al.* (2014)

[93] This assumption is generally true, but it is important to note that reef fish species have different habitat requirements and thus would display a differential response to environmental stressors or changes in environmental conditions. However, when averaged over many species, these species-specific differences should be reduced.

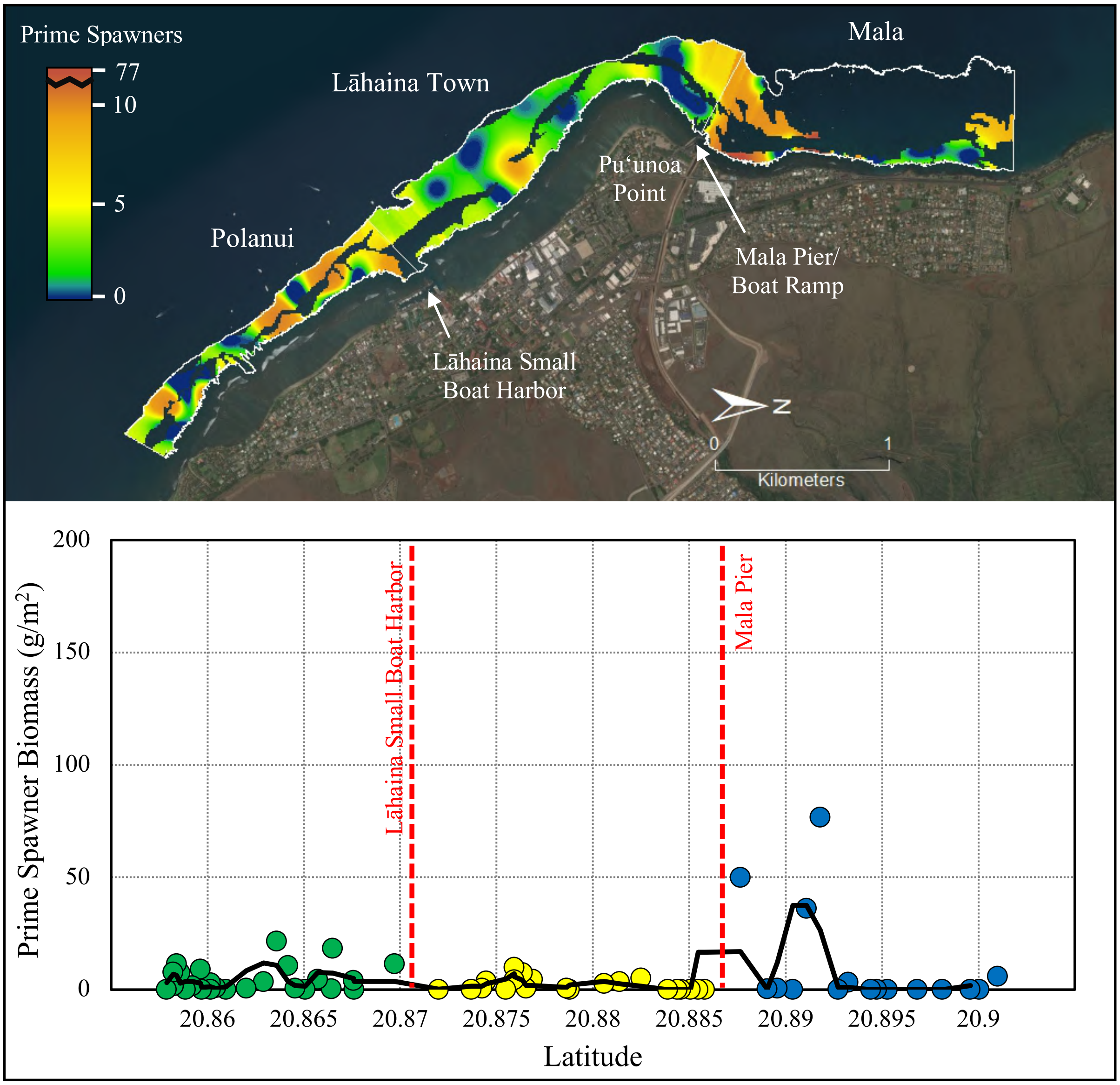

Figure 6.9. Prime spawner biomass across the Lāhaina FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average prime spawner biomass for the FW and red would be considered high biomass for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of prime spawner biomass at consecutive survey sites along the north-south axis. Colored points in the graph correspond with the Polanui (green), Lāhaina Town (yellow), and Mala (blue) reef tracts.

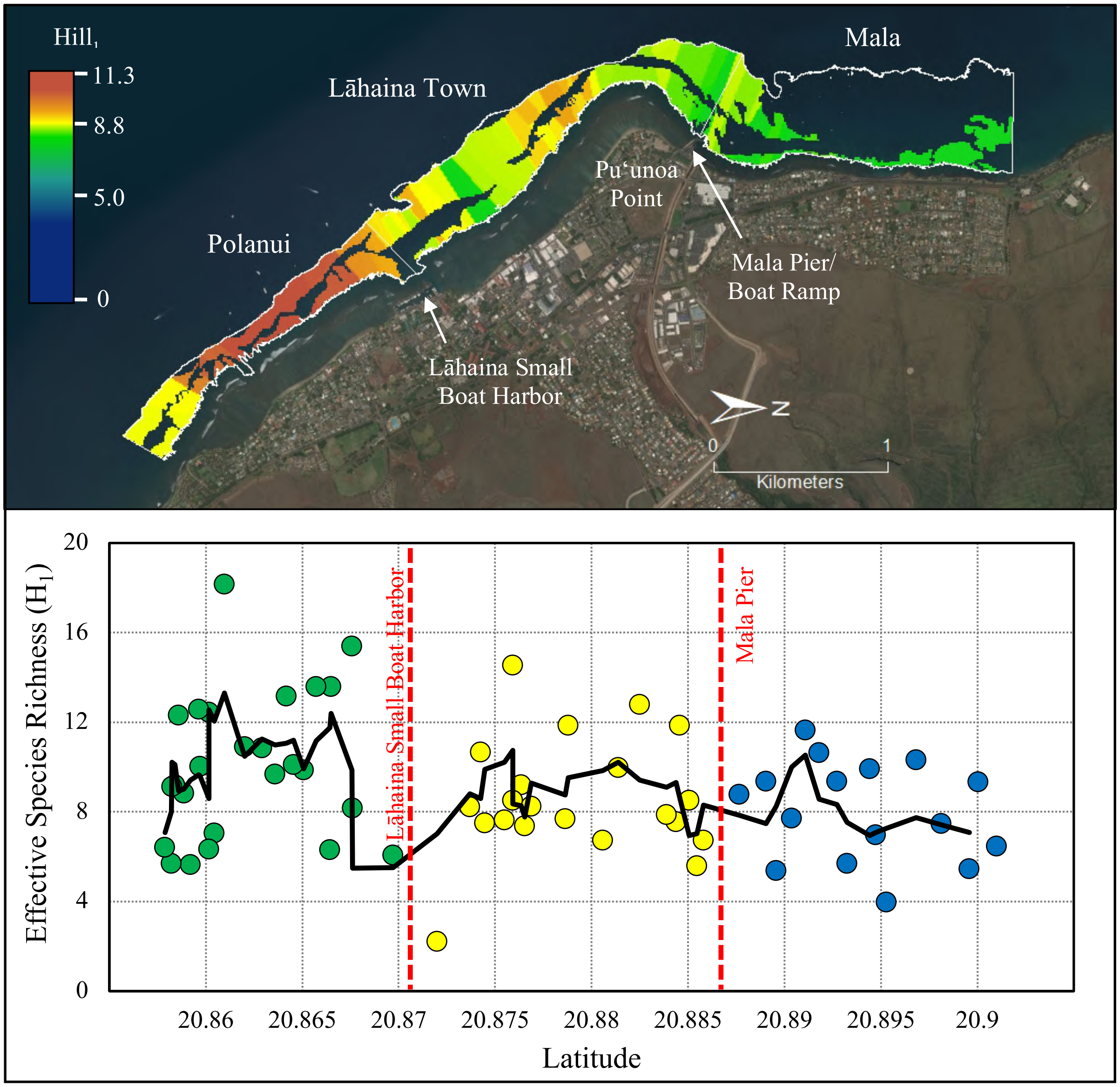

Figure 6.10. Effective species richness (Hill$_1$) across the Lāhaina FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average effective species richness for the FW and red would be considered high richness for the FW. Areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of effective species richness at consecutive survey sites along the north-south axis. Colored points in the graph correspond with the Polanui (green), Lāhaina Town (yellow), and Mala (blue) reef tracts.

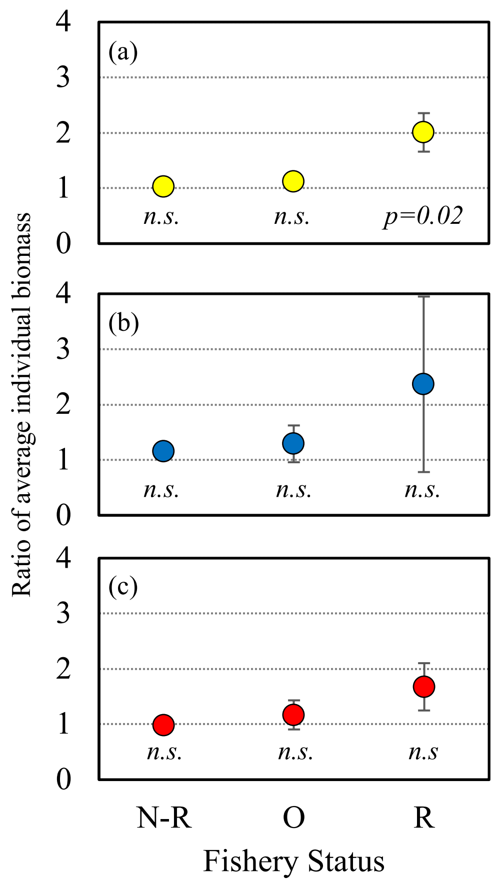

Figure 6.11. Comparison of fish size (ratio of average individual biomass) between (a) the Polanui and Lāhaina Town, (b) the Polanui and Mala, and (c) the Lāhaina and Mala reef tracts. A ratio=1 means the fish in the two reef tracts are of approximately equal size within the two reef tracts, a ratio>1 means fish within the Polanui (a and b) or Lāhaina Town (c) reef tract are larger on average than the other reef tract, and a ratio<1 indicates fish within the Polanui (a and b) or Lāhaina Town (c) are smaller on average than the other reef tract. N-R=non-resource fish (8 species), O=other moderately-prized fish (4 species), R=resource fish (10 species). Significance was tested using a 1-sample t-test.

Point also appear to be approximately twice as large as those in the rest of the Lāhaina Town reef tract, and considered alone, the Pu‘unoa Point resource fish also were not significantly different in size from those within the Polanui reef tract.

Historical Patterns: Fish

Due to limited or no data for the Lāhaina Town and Mala reef tracts prior to 2017 (Table 6.1); change through time was examined only within the Polanui reef tract, for which sufficient data were available for 2012-2014 and 2017. Unfortunately, this time series does not include data collected in 2015, the year following a large reef fish recruitment event that resulted in an unusually larger settlement of juveniles across a wide range of fish species[94]. This recruitment event has been documented on West Hawai‘i reefs[95], and was also observed on O‘ahu[96] and Maui[97]. The gap in the survey coverage during this time period makes interpreting patterns after 2014 challenging.

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[94] Talbot (2014)
[95] Minton *et al*. 2018a
[96] TNC, unpub. data
[97] TNC Maui and DAR-Maui, per. comm.

From 2012-2014, total fish biomass within the Polanui reef tract was significantly lower than in 2017 (ANOVA; $F_{1,98}$=5.04; p=0.027). Total fish biomass declined by 66% between 2013 and 2014 before rising sharply sometime between May 2014 and May 2017 (Figure 6.12). Resource fish, non-resource fish, and prime spawner biomass all appeared to show a similar temporal pattern as total fish biomass (Figure 6.12), suggesting this pattern was shared by most species and not the result of large population fluctuations of one or small group of species. Interestingly, the increase in biomass was not associated with a similar increase in total fish abundance (Figure 6.12). While greater than 2014, fish abundance in 2017 did not differ from 2012 and 2013. This suggests that the biomass increase observed in 2017 was not due to more fish being present, but larger fish. In this situation, "larger" fish could result in two ways: 1) individuals within a species are larger in 2017 compared to previous years, or 2) the fish assemblage structure has changed such that large-bodied species have increased relative to small-bodied ones.

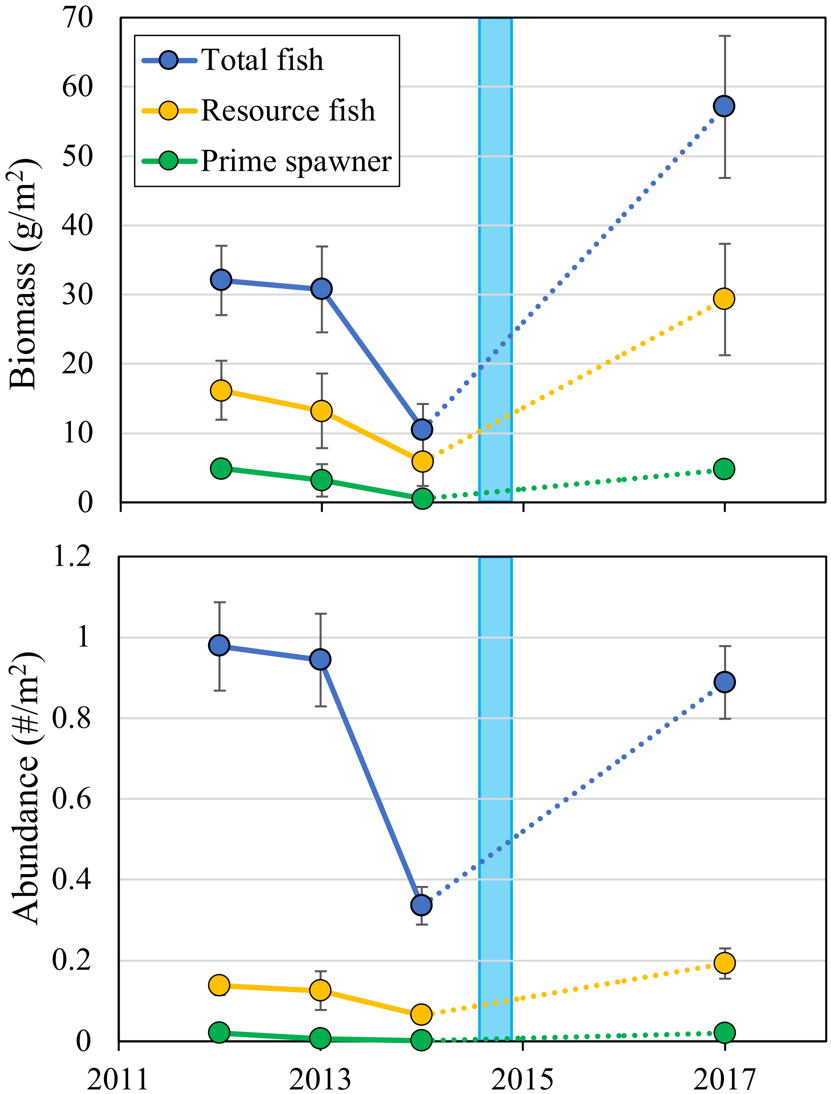


Figure 6.12. Average (±SEM) fish biomass (g/m^2) and abundance of total fish, resource fish, and prime spawners within the Polanui reef tract from 2012-2017. The blue bar marks the 2014 reef fish recruitment event. No data were available for the years 2015 and 2016. Note: some error bars are smaller than the diameter of the marker.

While differences were found in the structure of the fish assemblage among years (PERMANOVA; $F_{1,95}$=2.76; p=0.041), these differences did not show a clear pattern that suggested small-bodies species were replaced by large-bodied ones. Linking the 2014 recruitment event to the increase in biomass is difficult without data collected in 2015, but insight potentially could be obtained from examining changes in the relative size frequency distribution of the species. Unfortunately, no large-bodied species were abundant enough across the four years to generate size-frequency distributions. However, size-frequency distributions were generated for small-bodied fishes—the two most abundant species, *Acanthurus nigrofuscus* (brown surgeonfish) and *Thalassoma duperrey* (saddle wrasse) and the most abundant resource fish species, *Scarus psittacus* (palenose parrotfish). If individuals of these species that had settled in 2014 had survived for three years, they would have been 10-15 cm in length for *A. nigrofuscus*[98] and *T. duperrey*[99] and 15-20 cm in length for *S. psittacus*[100]. If large numbers had survived to 2017, we would expect this size class to be disproportionately large relative to 2014, but this is not obvious (Figure 6.13) as the proportions of individuals in the size classes are similar between years. However, average size did increase slightly for *A. nigrofuscus* and *S. psittacus* and remained unchanged for *T. duperrey*. This suggests that the increase in fish biomass likely was due to larger fish in 2017 compared to 2014, at least for some species.

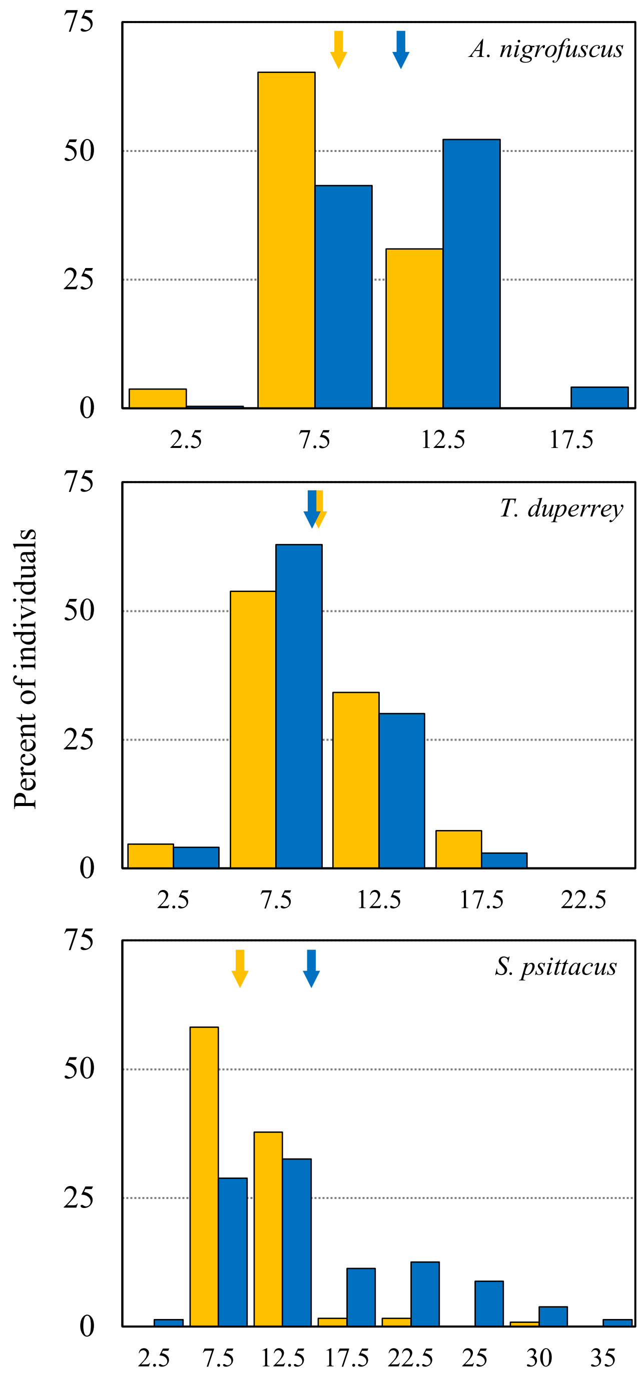


Figure 6.13. Relative size-frequency distribution for three common fish species within the Polanui reef tract in 2014 (gold) and 2017 (blue). Arrows correspond to the approximate average length of the species in 2014 or 2017.

The Big Picture

Compared to the WMR, the reef tracts within the Lāhaina FW ranged from average to above average depending upon whether the benthic or fish assemblages are considered. No reef tract had above average abundance, biomass, and diversity of both benthic and fish assemblages. The Polanui reef tract had average coral cover, although it was on the low edge of the average range for the WMR, almost slipping into the medium-low category. Total fish biomass and prime spawner biomass were also average in the Polanui

[98] Hart and Russ (1996)
[99] Ross (1984)
[100] Choat *et al.* (1996)

reef tract compared to the WMR, but it had medium-high resource fish biomass. Both the Lāhaina Town and Mala reef tracts had medium-high coral cover and benthic diversity and average total and resource fish biomass. Prime spawner biomass in the Lāhaina Town was also average, but prime spawner biomass was high in the Mala reef tract when compared to other reefs in the WMR.

Statewide Context

Averages for coral cover (14.4 ± 0.7%), total fish biomass (40.9 ± 2.5 g/m^2), resource fish biomass (22.3 ± 1.8 g/m^2), and prime spawner biomass (3.7 ± 1.0 g/m^2) were calculated for the MHI, to serve as a gauge for how the reefs of the WMR are faring relative to those from around the state. All across the MHI, reefs are affected by overfishing, sediments, land-based pollution, and invasive species. Over the past century, populations of some commercially important reef fish populations have declined by over 90%, and coral cover in some areas has declined by at least 40% in just the last 40 years. While there are many reef areas around the state that still have abundant and healthy resources, the current statewide averages used for comparison here certainly reflect substantial declines in resource condition seen broadly across the reefs of the MHI. Reefs in the WMR were consistent with the statewide averages for coral and fish assemblages (see Chapter 1). However, considerable variability in the condition of reefs exists across the WMR, and the reef tracts within the Lāhaina FW ranged from slightly below average to above average when compared to reefs statewide (Figure 6.14). While the Polanui reef tract had below average coral cover, it had medium-high total fish and resource fish biomass. In contrast, coral cover in the Lāhaina Town reef tract was high compared to other MHI reefs, but had a consistently below average fish assemblage. The Mala reef tract had high coral cover and prime spawner biomass and above average resource fish biomass when compared to reefs statewide.

Synthesis

The reef tracts within the Lāhaina FW tend to be spatially variable in the abundance, biomass, and diversity of their benthic and fish assemblages. The benthic assemblage within the Polanui reef tract appeared to be in poor condition, with low coral cover across most its reef area. However, the fish assemblage had medium-high total fish biomass compared to the regional average, but only average resource fish biomass suggesting fishing may be adversely affecting the assemblage. The Polanui reef tract appears to have potential to support abundant fish populations. The two sites with the highest total fish and resource fish biomass in the FW were located within the Polanui reef tract, and the reef area north end of the of the Kauhaʻilio Channel supported resource fish biomass greater than most other areas within the Lāhaina FW, although its resource fish biomass is about average for the WMR. The Kauhaʻilio Channel along with Kauaʻula Stream at the southern end of the Polanui reef tract appear to be defining features for this reef tract, reducing coral cover and reef fish biomass[101]. Both Kauaʻula Stream and the Kauhaʻilio Channel are likely sources for sediment input, and the waters in this area tend to have high turbidity, which could account for the poor condition of the reef. The reef resilience site within the Polanui reef tract had medium-low potential resilience.

[101] Minton and Conklin (2013)

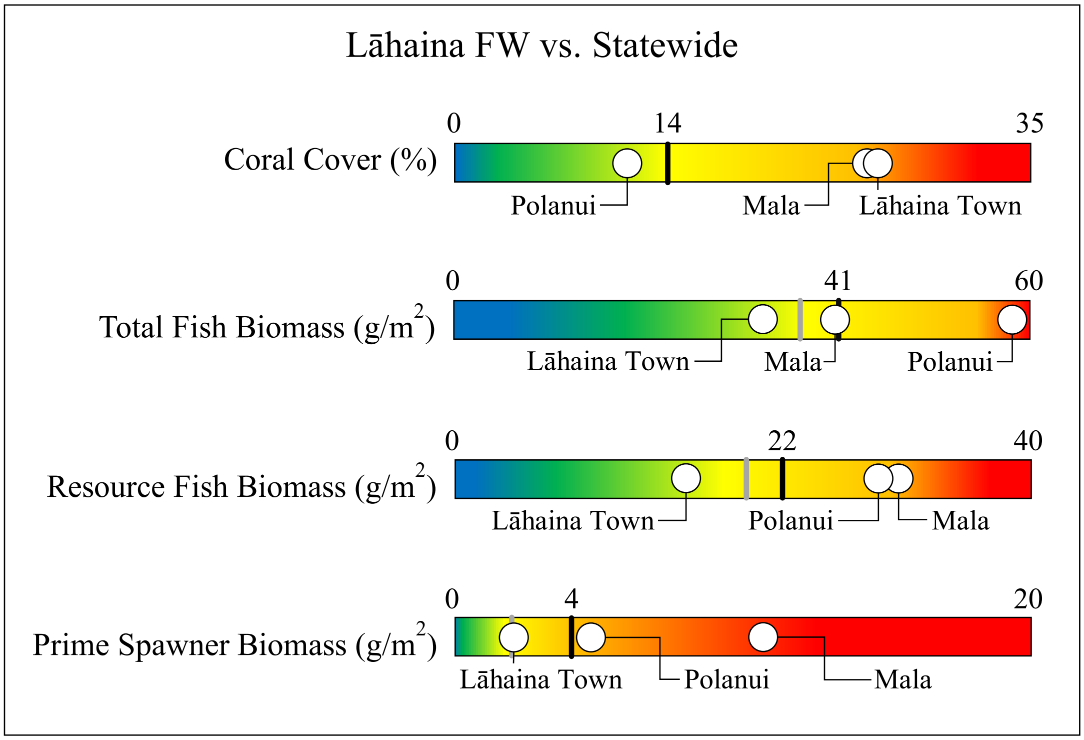
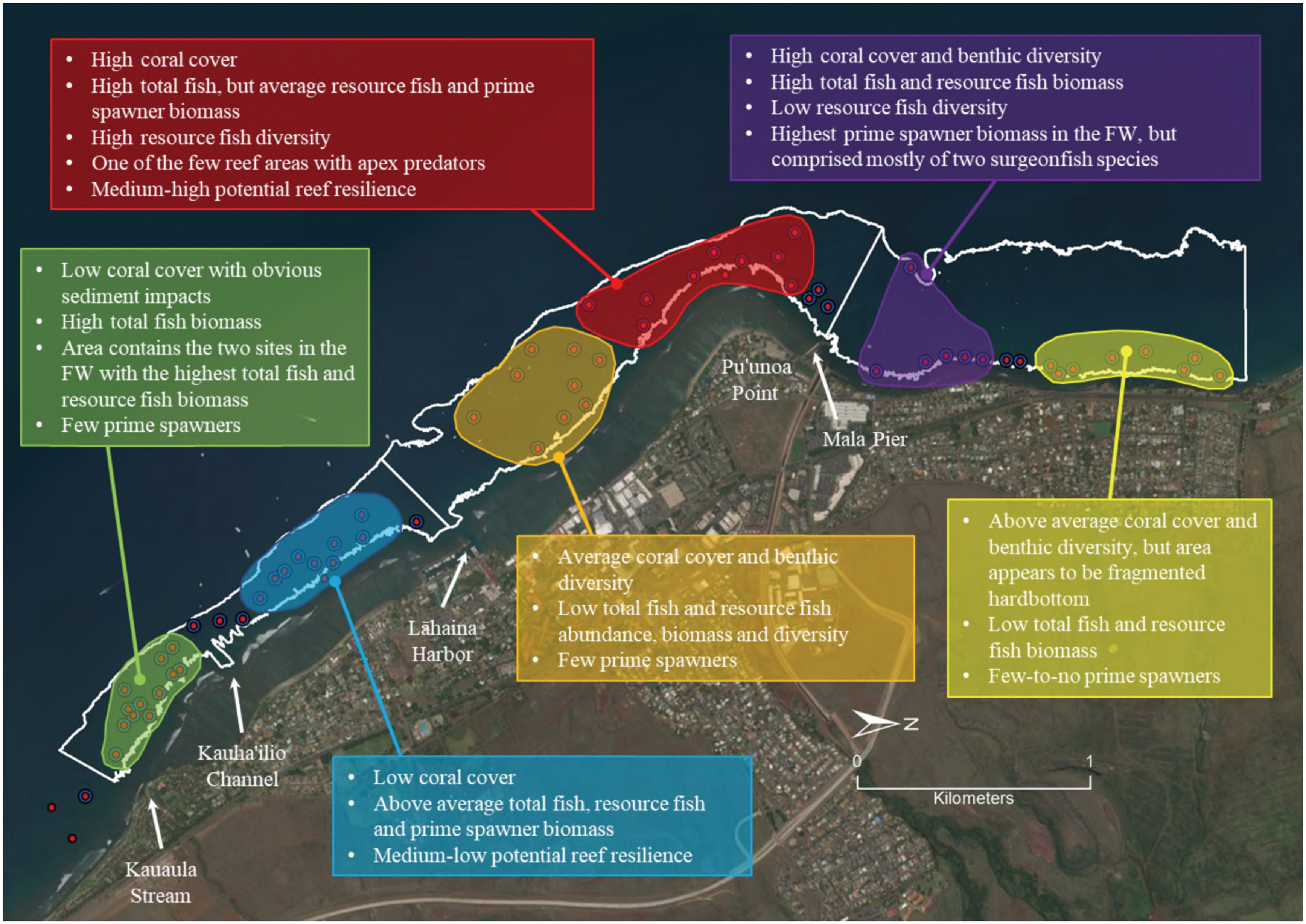


Figure 6.14. Comparison of reef tracts in the Lāhaina FW to statewide averages for coral cover (%), total fish, resource fish, and prime spawner biomass (g/m^2). Black vertical line and value denote the statewide average. For the three fish metrics, the grey vertical line is the statewide trimmed mean, which was used to develop the qualitative categories; see the methods (Appendix B) for more details on the use of the trimmed means.

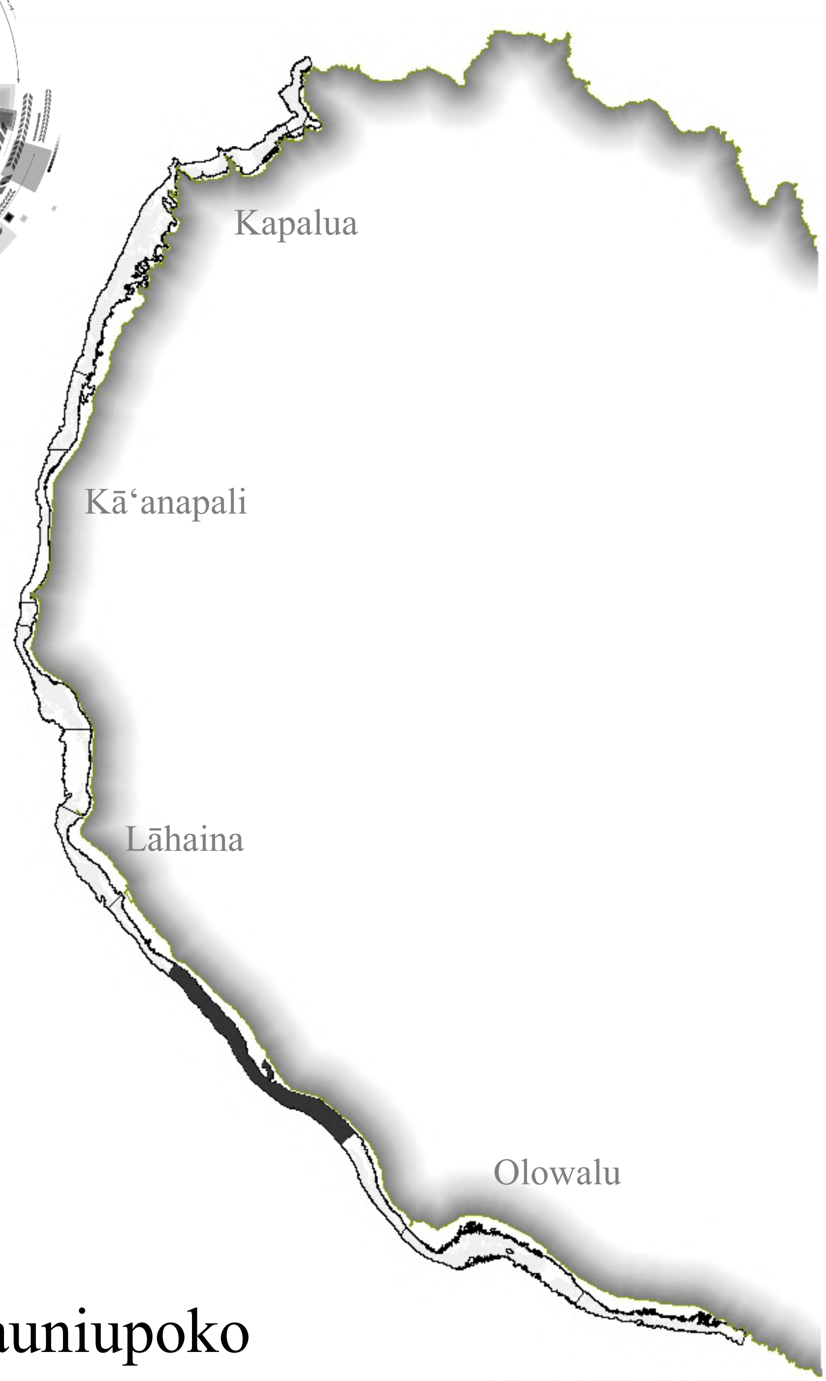
The Lāhaina Town reef tract was comprised of two different reef areas. The reef between the Lāhaina Small Boat Harbor and southern edge of Pu‘unoa Point was characterized by consistently low abundance, biomass, and diversity. Resource fish biomass was consistently low, with no-to-few prime spawners at most survey sites. The lack of survey sites with high abundance or biomass of fish suggests that this reef area demonstrates little potential to support a more abundant fish assemblage. In contrast, the reef off Pu‘unoa Point had high coral cover, among the highest in the WMR. Benthic diversity was more than twice that of most reef areas in the Lāhaina FW. The reef off Pu‘unoa Point had the highest resource fish diversity and was the only area in the Lāhaina FW where jacks were routinely observed. The reef resilience site in this reef area ranked as the fifth most resilient (medium-high) in the leeward Maui region.

Like the Lāhaina Town reef tract, the Mala reef tract also contains two distinct reef areas. North of the Mala pier and boat ramp, the reef had high abundance, biomass, and benthic diversity. Resource fish and prime spawner biomass were the highest in the FW, but they were comprised almost entirely of two species of surgeonfish, indicating low resource fish diversity. The northern half of the Mala reef tract had consistently low abundance, biomass, and diversity of both the benthic and fish assemblages. In this area of the Mala reef tract, the bottom appeared to consist of fragmented hardbottom, which serves as poor habitat for coral and reef fish.



High coral cover
High total fish, but average resource fish and prime spawner biomass
High resource fish diversity
One of the few reef areas with apex predators
Medium-high potential reef resilience
High coral cover and benthic diversity
High total fish and resource fish biomass
Low resource fish diversity
Highest prime spawner biomass in the FW, but comprised mostly of two surgeonfish species
Low coral cover with obvious sediment impacts
High total fish biomass
Area contains the two sites in the FW with the highest total fish and resource fish biomass
Few prime spawners
Pu'unoa Point
Mala Pier
Average coral cover and benthic diversity
Low total fish and resource fish abundance, biomass and diversity
Few prime spawners
Above average coral cover and benthic diversity, but area appears to be fragmented hardbottom
Low total fish and resource fish biomass
Few-to-no prime spawners
Lāhaina Harbor
Kauha'ilio Channel
Low coral cover
Above average total fish, resource fish and prime spawner biomass
Medium-low potential reef resilience
N
0
1
Kilometers
Kauaula Stream

7



Reefs of Launiupoko

Geographic Setting

The Launiupoko Survey Gap is a stretch of fragmented hardbottom lying between the Lāhaina Focus Window (FW) and the Olowalu FW (Figure 7.1). It extends ~5.3 km (3.3 mi) from the mouth of Kaua‘ula Stream on Makila Point to the intersection of Honoapi‘ilani Highway (Rte 30) and the Recycling & Refuse Center Road, which lies approximately 350 m west of mileage marker 16 on Honoapi‘ilani Highway. Insufficient data exists from the area to conduct an in-depth analysis of the benthic and fish assemblages; hence this area being considered a “gap” area for the Atlas. However, the presence of a pair of Hawai‘i Coral Reef Assessment and Monitoring Program (CRAMP) monitoring sites near the north end of the area allow for some analysis of the temporal changes of the reefs within this area. Due to the limited data in recent years (2016-2018), no spatial analysis is conducted of this reef area, but data are used to summarize general conditions. This information should be treated cautiously due to the low sampling effort in the survey gap. This reef area would benefit from additional current data.

The Data

Survey data for the Launiupoko Survey Gap are limited primarily to a robust timeseries for two CRAMP monitoring sites (Puamana Shallow and Puamana Deep) and a small number of surveys conducted sporadically since 2010 (Table 7.1). In 2018, The Nature Conservancy (TNC) assessed two reef resilience sites (Puamana and Launiupoko) within the Launiupoko Survey Gap.

Benthic Assemblage

Current Spatial Patterns: Benthic

Recent data (2016-2018) were too limited to conduct an in-depth examination of the spatial patterns of the benthic assemblage within the Launiupoko Survey Gap. Results presented here should be considered preliminary until additional information is collected for this reef area.

The bottom within the Launiupoko Survey Gap appears to be composed of primarily of fragmented hardbottom interspersed with sand. Hardbottom was covered primarily by turf, and coral cover for the area was low (Table 7.2). Coral species richness was also low (nine species), but it was unclear if this was due to the environmental conditions in the area or low survey effort. A water quality monitoring station off Launiupoko Beach Park[102] showed turbidity levels above the average for the WMR.

Historical Patterns: Benthic

A nearly-continuous, 20-year time series of data (1999-2018) is available for two permanent coral reef monitoring sites within the Launiupoko Survey Gap. As with most CRAMP

[102] Hui O Ka Wai Ola and the State Department of Health collect water quality data at 20 sites in the WMR, including one location in the Launiupoko Survey Gap: Launiupoko. To learn more about Hui O Ka Wai Ola and download raw data, please visit huiokawaiola.com.

Table 7.1. Benthic and fish assemblage survey effort (number of survey sites) in the Launiupoko Survey Gap from 1999 and 2018.

Survey Gap	Survey Year	Benthic	Fish
Launiupoko Survey Gap		59	13
	1999	2	
	2000	2 (2/year)	2
	2001-2004	8	
	2005	1	1
	2006-2007	4 (2/year)	
	2008	3	2
	2009	2	
	2010	4	
	2011	2	
	2012	6	
	2013	8	
	2014	2	
	2015	3	
	2016	4	
	2017	5	5
	2018	3	3

monitoring locations, they are a paired shallow-water (3 m) and deep-water (10 m) site, designated "Puamana Shallow" and "Puamana Deep."

Coral cover at Puamana Deep remained relatively stable between 1999-2018, fluctuating between 2.5% and 6% cover (Figure 7.2), which is below average compared to other reefs in the West Maui Region (WMR). Coral cover at the Puamana Shallow site was initially higher than the deep, but declined significantly from 15% to 1.5% cover between 1999 and 2018, the last survey year for which data were available (Correlation, r=-0.486, p=0.046). The decrease in coral cover appears to have been offset by an increase in turf, which rose from 68% to 89% cover (Correlation, r=0.431, p=0.073) over the same time period.

Given the general state of coral at Puamana, it is difficult to assess the effect of the 2015 mass coral bleaching on the benthic assemblage. The 2015 mass coral bleaching event affected many of the reefs within the Main Hawaiian Islands (MHI), including on Maui where it caused an estimated 20-40% loss of coral[103]. At both the shallow and deep Puamana sites, the 2016 coral cover was about 25% lower than that in 2015, but at the Puamana Shallow site, this was an extension of a multi-year decline that continued into 2018. At the deep site, the drop from 2015 to 2016 was within the range of temporal variability the site had shown since 1999, and coral

[103] SSRI (2017)

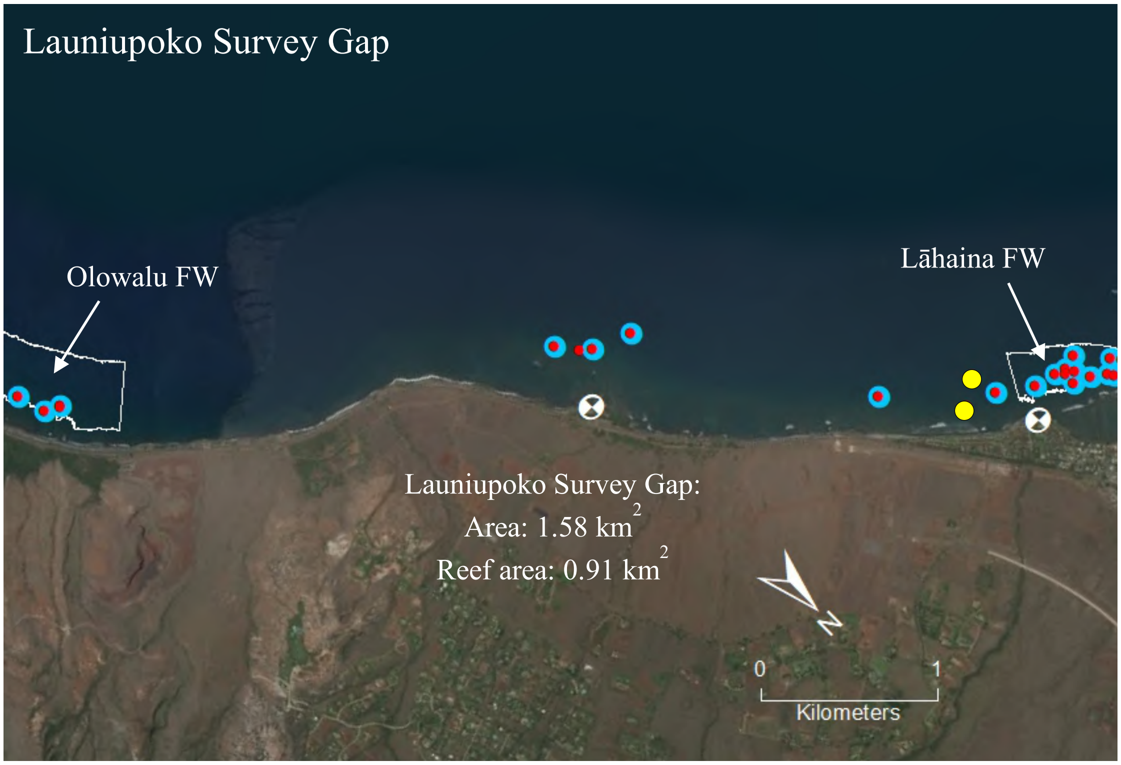


Figure 7.1. Survey effort for the benthic (blue) and fish (red) assemblages within the Launiupoko Survey Gap from 2016-2018. Yellow points are the Puamana Shallow and Deep CRAMP sites. Some survey efforts had overlapping site locations, *e.g.*, the Puamana reef resilience site surveyed in 2018 overlapped with the CRAMP Puamana Deep site. White quadrant circles along the shore are the (north to south) Makila Point (part of the Lāhaina FW) and Launiupoko Park water quality monitoring sites.

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cover remained the same in 2018. Given the available information, it is difficult to isolate a potential effect of the 2015 coral bleaching event from the trends already present at the two CRAMP sites.

Information on the coral species at Paumana was not available for the years immediately preceding the bleaching event. However, from 1999 through 2006, *Porites lobata* (lobe coral) and *Pocillopora meandrina* (cauliflower coral) were the most abundant species at Puamana[104]. During the 2015 mass coral bleaching event, nearly all (>95%) *P. meandrina* colonies bleached at most locations, and mortality was high[105]. In 2018, *P. meandrina* was not observed at either site, and within the Launiupoko survey gap more broadly, it was rarely observed. Based on recent data (2016-2018) collected throughout the Launiupoko survey gap, *P. meandrina* cover was lower in 2016-2018 than the years 1999-2006, whereas *P. lobata* cover appears to have increased slightly (Figure 7.3). While comparisons between the recent data and the CRAMP sites are not ideal, they suggest that the 2015 coral bleaching did have at least some adverse effects on the reefs within this area, and that *P. meandrina* cover was likely reduced as a result.

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[104] CRAMP (2011)
[105] Kramer *et al.* (2016) and Minton *et al.* (2018b)

Coral Health and Reef Resilience

In March 2018, a reef resilience assessment of leeward Maui was conducted by TNC and its partners. These assessments were intended to quantify the relative resilience of Maui's reefs to the effects of climate change. Resilience is the ability of a reef to resist, recover from, and adapt to a climate-related event (*e.g.*, coral bleaching) to maintain a diverse, coral-rich state that provides key ecological functions and services to people[106]. Given the integral role of reefs to the people of Hawaiʻi, reef resilience is closely linked with social resilience, which is the ability of human communities to adapt to social, political, environmental, or economic change[107].

Table 7.2. Average (±SEM) percent cover of benthic groups and taxa in the Launiupoko Survey Gap (n=12). Data are from 2016-2018. Note: Summations of the cover by coral species or benthic substratum type may not add to the total for the group due to some sites having group-level, but no species-level, information.

	Launiupoko SG
Turf	67.0 ± 3.6
Coral	8.7 ± 2.3
Porites lobata	7.1 ± 1.6
Porites compressa	1.4 ± 0.8
Montipora patula	0.4 ± 0.2
Pocillopora meandrina	0.1 ± 0.1
Montipora capitata	0.1 ± 0.1
Leptastrea purpurea	0.1 ± 0.1
Pavona varians	<0.1
Coral sp.	<0.1
Psammocora stellata	<0.1
Crustose Coralline Algae	0.8 ± 0.2
Macroalgae	0.4 ± 0.1
Cyanobacteria	0
Other	<0.1
Abiotic	23.0 ± 4.9
Sand	20.9 ± 5.0
Rubble	1.4 ± 0.6

Two reef resilience sites (Puamana[108] and Launiupoko) were surveyed within the Launiupoko Survey Gap. The complete results of TNC's Maui Reef Resilience assessment are detailed elsewhere[109], so only the coral health and resilience findings for the sites in the Launiupoko Survey Gap are summarized here.

No coral disease was found at the Puamana reef resilience site, the only deep-water reef resilience site for which this was case (Table 7.3). However, prevalence of both algal overgrowth and paling/bleaching at the Puamana site were more than double the average for the WMR. In contrast, disease prevalence at the Launiupoko reef resilience site was consistent with the regional average, but algal overgrowth and bleaching at Launiupoko were less than a tenth of the regional average, suggesting the coral present at this reef resilience site was in relatively good condition.

[106] Nystrom and Folke (2001)
[107] Adger (2000)
[108] The Puamana reef resilience site partially overlapped with CRAMP Puamana Deep site, but different survey methods did not allow perfect alignment of the transects.
[109] Maynard *et al.* (2019)

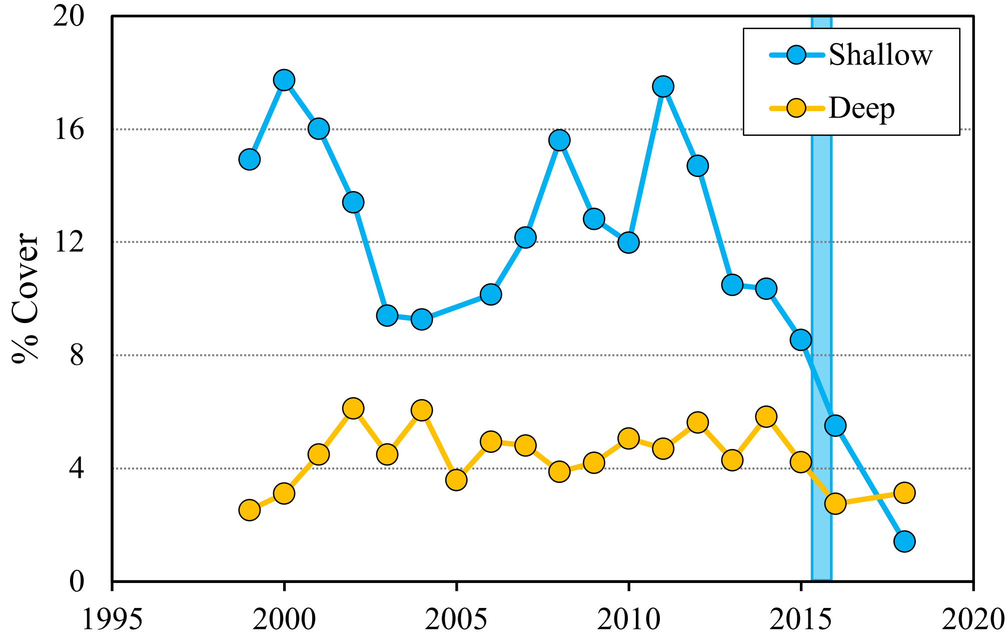

Figure 7.2. Coral cover at the Puamana Shallow and Deep long-term monitoring sites from 1999-2018. The blue bar signifies the approximate months over which the 2015 mass coral bleaching event affected Maui reefs.

Table 7.3. The two reef resilience (RR) sites within the Launiupoko Survey Gap. "RR Rank" is the relative reef resilience rank among 31 shallow-water sites along leeward Maui. "Dis. Prev." is the percent of colonies presenting at least one disease. "ALOG" is the percentage of colonies being overgrown by benthic algae. "Paling/Bleaching" is the percent of colonies showing signs of tissue paling or bleaching. Average values for the WMR (italics) are presented for comparison.

	Reef Tract	RR Rank	Dis. Prev.	ALOG	Paling/ Bleaching
Shallow	*WMR Average*		*2.4 ± 0.5*	*9.6 ± 1.5*	*18.2 ± 4.8*
Launiupoko		S9	2.3	1.6	0.3
Deep	*WMR Average*		*1.4 ± 0.3*	*7.2 ± 1.5*	*19.9 ± 6.4*
Puamana		D19	0	16.9	44.9

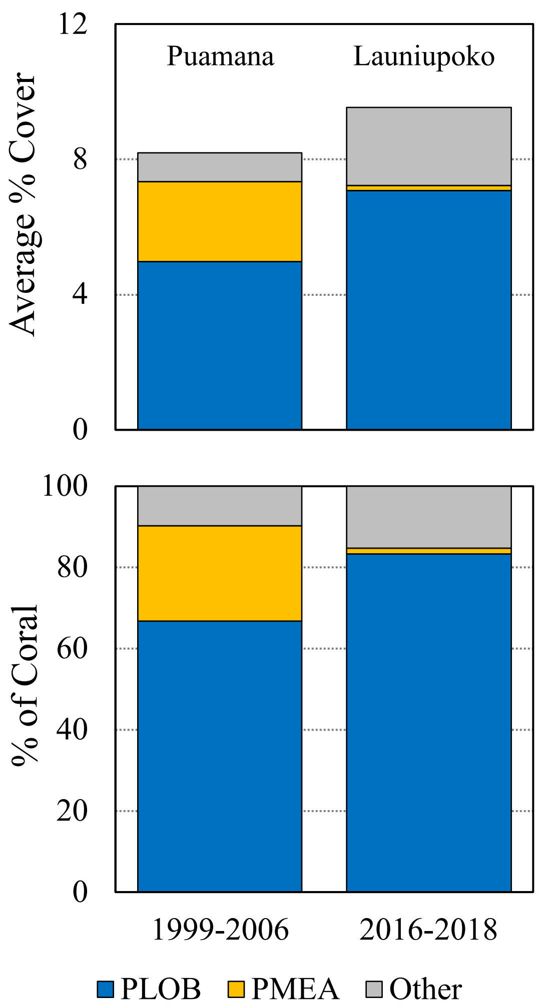

Figure 7.3. Average percent cover (top) and relative abundance of (bottom) of *P. lobata* (PLOB) and *P. meandrina* (PMEA) at the Puamana long-term monitoring size averaged across the years 1999-2006 and from within the Launiupoko survey gap in 2016-2018.

As part of the reef resilience assessment, the 31 shallow-water and 20 deep-water sites surveyed were assigned a relative reef resilience rank, based on a several indicator variables, including coral cover, coral disease prevalence, coral diversity, coral recruitment, reef builder ratio (ratio of calcifying species to non-calcifying species), rugosity, and herbivorous fish biomass. The Launiupoko reef resilience site ranked 9th out 31 shallow-water sites, which would categorize it as having medium-high potential reef resilience. The Puamana reef resilience site was ranked 19th out 20 sites, ranking it as the second worst deep-water site in the leeward Maui region. Only the Olowalu North reef resilience site, the next deep-water reef resilience site to the south of Puamana, ranked lower.

Fish Assemblage

Current Spatial Patterns: Fish

Recent data (2017-2018) were too limited to conduct an in-depth examination of the spatial patterns of the fish assemblage within the Launiupoko Survey Gap. Results presented here should be considered preliminary until additional information is collected for this reef area.

The fish assemblage had the lowest total fish (21.1 ± 10.5 g/m^2) and second lowest resource fish[110] (12.9 ± 4.7 g/m^2) biomass in the WMR. Fish diversity was also low; only 43 species in 12 families were observed, although the low survey effort certainly contributed to the low species count. Even given that sampling effort was limited to eight survey sites, however, it is likely that the estimates of low biomass and diversity are accurate. The quality of the reef fish habitat in this area is likely low due to the fragmented hardbottom and a benthic assemblage that is in relatively poor condition. While other factors such as fishing could play role, likely poor habitat quality is primary reason for the depauperate fish assemblage in the Launiupoko Survey Gap.

[110] Resource fish are comprised of species important for consumption and that tend to be prized by fishers. See Appendix B for a list of resource and non-resource species.

Prime spawners[111] were the only fish metric that was not low (4.3± 2.2 g/m^2), and the prime spawner assemblage was surprisingly diverse, including 10 species in four families (Table 7.4), and comprised of a mix of reef species and species found more commonly in or near sandy areas, such as goatfish (Mullidae).

Historical Patterns: Fish

Due to limited data for the Launiupoko Survey Gap (Table 7.1) temporal changes in the fish assemblage could not be examined for this reef area.

The Big Picture

In the context of the WMR, reef resources in the Launiupoko Survey Gap had medium-low to average abundance, biomass, and diversity for both the benthic and fish assemblages. Coral cover and total fish biomass were both medium-low, while resource fish and prime spawner biomass were average compared to other reefs in the WMR. Resource fish biomass was at the low end of the average range for the WMR. The prime spawner assemblage was surprisingly diverse, but this was likely due to the fragmented nature of the bottom, especially the presence of a mixture of hardbottom and large sandy areas.

Table 7.4. Prime spawners observed at 8 transects within the Launiupoko Survey Gap in 2017-2018. Species are arranged in descending order by their relative biomass.

Species	Family
Naso lituratus (orangespine unicornfish)	Acanthuridae
Acanthurus olivaceus (orangeband surgeonfish)	Acanthuridae
Scarus rubroviolaceus (redlip parrotfish)	Scaridae
Bodianus albotaeniatus (Hawaiian hogfish)	Labridae
Chlorurus spilurus (bullethead parrotfish)	Scaridae
Scarus psittacus (palenose parrotfish)	Scaridae
Parupeneus insularis (Island goatfish)	Mullidae
Acanthurus leucopareius (whitebar surgeonfish)	Acanthuridae
Parupeneus multifasciatus (manybar goatfish)	Mullidae

[111] Prime spawners are individual resource fish >70% of the maximum length for that species whose conservation is often important to maintaining sustainable fisheries and ecosystems.

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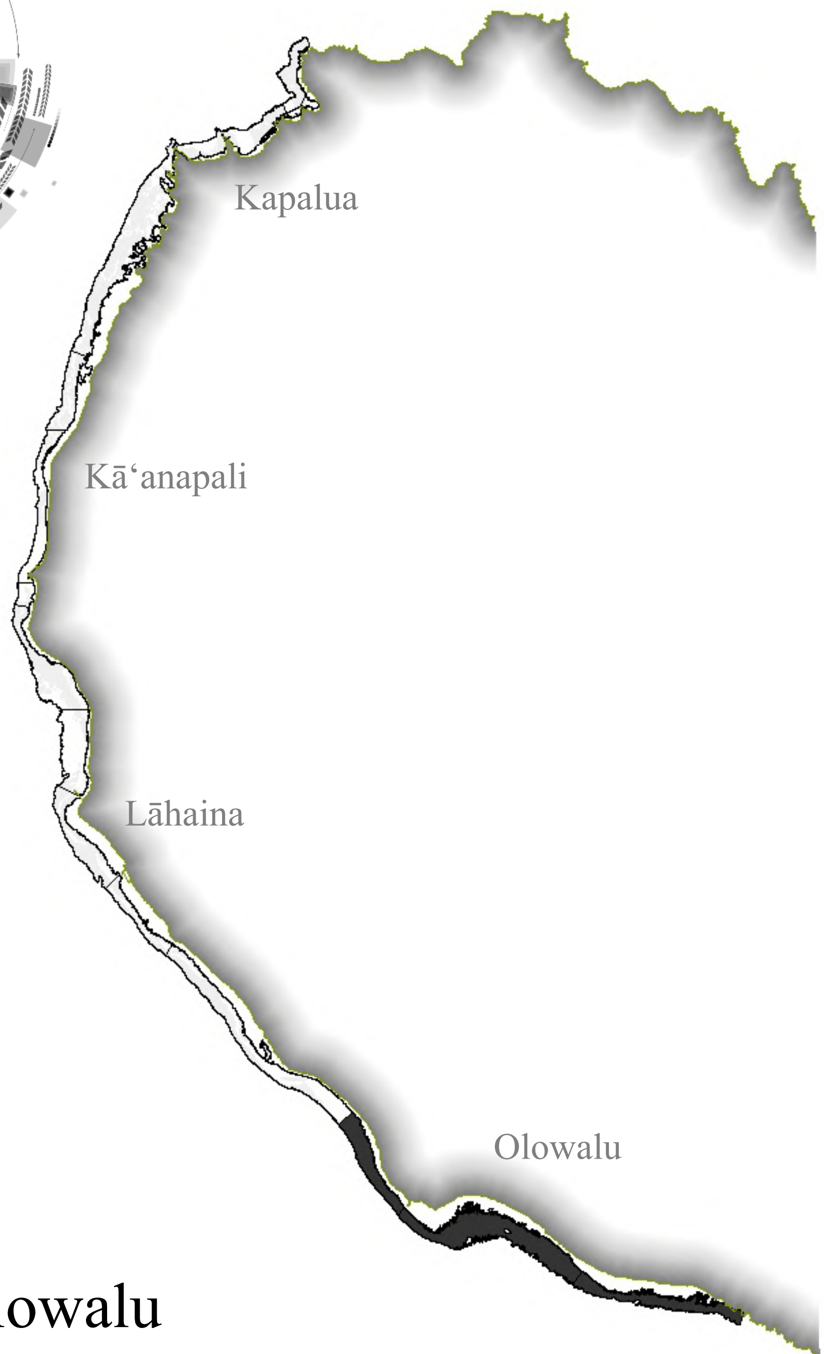

Reefs of Olowalu

Geographic Setting

The Olowalu Focus Window (FW) extends from the intersection of Honoapiʻilani Highway (Rte 30) and the Recycling & Refuse Center Road to the highway's Pali Tunnel, encompassing Olowalu Point and a small embayment known for its well-developed spur-and-groove coral reef. Coastal development is light, with a few residential homes and a small community on the north side of Honoapiʻilani Highway. Historic sugar cane operations (Pioneer Mill) have transitioned into limited-but-diversified agriculture and fallow fields. While the majority of the land upslope is under conservation management, sediment and nutrient inputs into the coastal waters are an issue. Data collected from a network of 20 water quality monitoring stations across the West Maui Region (WMR)[112] have identified higher than average turbidity across much of the Olowalu FW, especially in the east end of the FW, but organic nutrient values below the average for the WMR. This suggests water quality within the Olowalu FW is generally good, but may be compromised, especially during or following storm events.

The Data

The Olowalu FW is comprised of three reef tracts: Olowalu Point, Olowalu, and Ukumehame (Figure 8.1):

- **Olowalu Point** reef tract extends ~2.0 km (1.2 mi) from the intersection of Honoapiʻilani Highway and the Recycling & Refuse Center Road to the Olowalu Landing on Olowalu Point. This reef tract was surveyed multiple times between 2008 and 2018, with most surveys occurring in 2018 (Table 8.1). In 2018, The Nature Conservancy (TNC) assessed three reef resilience sites (Awalua, Olowalu North Shallow, and Olowalu North Deep) within the Olowalu Point reef tract.
- **Olowalu** reef tract extends ~4.2 km (2.6 mi) from Olowalu Landing on Olowalu Point to the intersection of Pohaku Aeko Street and Honoapiʻilani Highway, just north of Ukumehame Beach Park. The Olowalu reef tract was surveyed multiple times between 1999 and 2018 (Table 8.1), with most surveys occurring between 2015-2018. Two Hawaiʻi Coral Reef Assessment and Monitoring Program (CRAMP) long-term monitoring sites are in this reef tract and were surveyed annually from 1999-2016. In 2018, TNC assessed four reef resilience sites (Olowalu Point, Olowalu CRAMP Shallow, Olowalu CRAMP Deep, and Olowalu South) within the Olowalu reef tract.
- **Ukumehame** reef tract extends ~3.4 km (2.1 mi) from the intersection of Pohaku Aeko Street and Honoapiʻilani Highway to the highway's Pali Tunnel. The survey effort in the Ukumehame reef tract was low, with small numbers of sites surveyed from 2005 to 2016 and four reef resilience sites (Ukumehame Shallow, Ukumehame Deep, Pali Tunnel Shallow, and Pali Tunnel Deep) surveyed by TNC in 2018 (Table 8.1).

[112] Hui O Ka Wai Ola and the State Department of Health collect water quality data at 20 sites in the WMR, including seven locations in the Olowalu FW: Olowalu Shore Front, Olowalu Point, Camp Olowalu, Mile Marker 14, Ukumehame Park, Pāpalaua Park, and Pāpalaua Pali. To learn more about Hui O Ka Wai Ola and download raw data, please visit huiokawaiola.com.

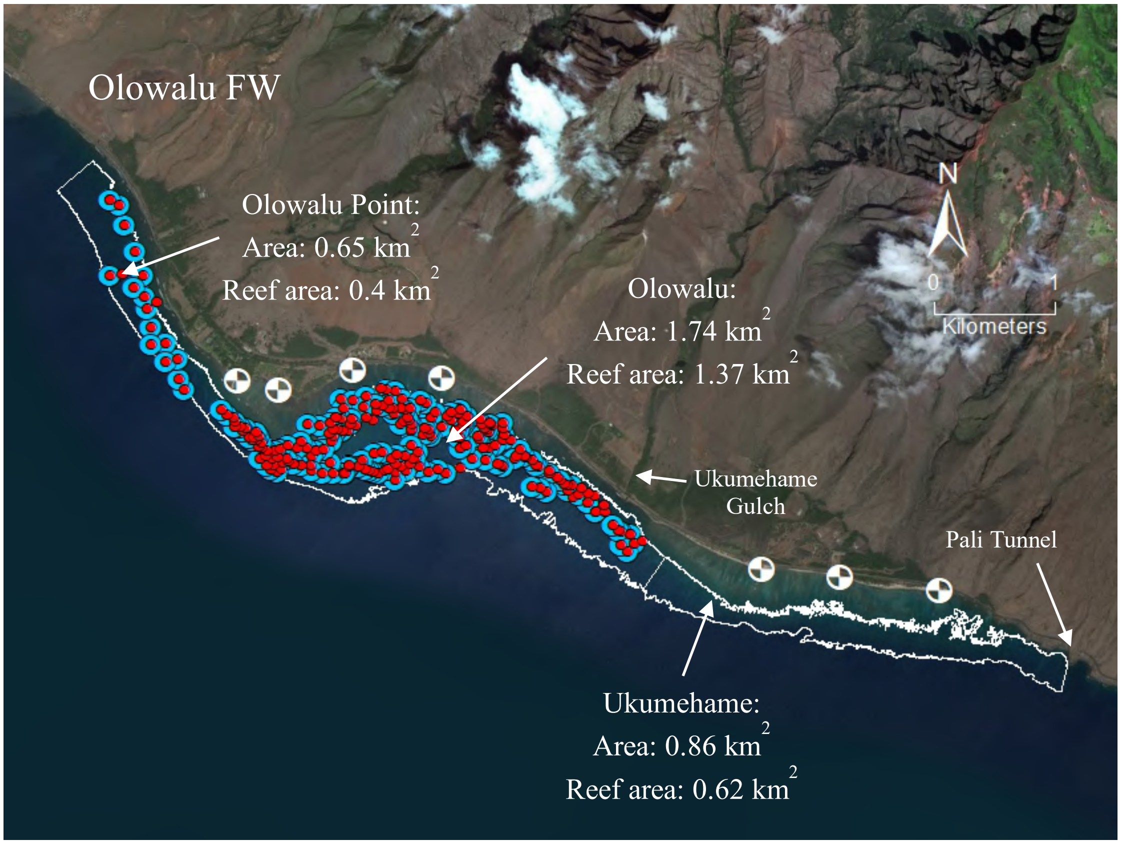

Figure 8.1. Reef tracts within the Olowalu FW. Dots indicate 2016-2018 survey efforts for the benthic (blue) and fish (red) assemblages within the FW. White quadrant circles along the shore are (west to east) the Olowalu Shore Front, Olowalu Point, Camp Olowalu, Mile Marker 14, Ukumehame Park, Pāpalaua Park, and Pāpalaua Pali long-term water quality monitoring sites.

Maps within the Atlas were generated using a spatial technique called interpolation. This technique uses available survey data to generate a complete spatial model of the data by estimating values between the surveys data using a mathematical algorithm that considers the values of nearby data weighed by their distance away. Areas with a higher density of surveys will produce more "accurate" interpolations than areas with lower survey density. Averages derived from interpolation maps are calculated across all reef areas and typically vary from averages derived from the survey data. Interpolation maps were generated for the Atlas primarily to display general spatial patterns and should not be used to predict exact values at any given location. For example, an interpolation map can, with a high degree of reliability, indicate that one reef tract has more coral than another reef tract, but it should not be used estimate the "exact" coral cover at a specific location within the reef tract. To estimate coral cover, amount of fish, etc., current survey data from the specific location should always be used over the interpolation maps when these data are available.

Table 8.1. Benthic and fish assemblage survey effort (number of survey sites) in the Olowalu FW between 1999 and 2018. The FW has three reef tracts: Olowalu Point, Olowalu, and Ukumehame.

Reef Tract	**Survey Year**	**Benthic**	**Fish**
Olowalu Point		25	22
	2008		1
	2012	2	
	2015	3	2
	2016	1	
	2017	16	16
	2018	3	3
Olowalu		349	368
	1999	2	
	2000	2	2
	2001-2002	4 (2/year)	
	2003-2007	10 (2/year)	
	2008	2	2
	2009	2	
	2010	5	
	2011	2	
	2012-2013	6 (3/year)	
	2014	2	
	2015	106	138
	2016	133	117
	2017	69	70
	2018	4	39
Ukumehame		13	6
	2005		1
	2008		1
	2010	1	
	2012	2	
	2015	2	
	2016	4	
	2018	4	4
TOTAL		387	396

Benthic Assemblage

Spatial Patterns: Benthic

The reefs within the Olowalu FW show considerable spatial variability both in composition and coverage. Algal turf was the dominant benthic type in the FW, averaging 53.4 ± 1.1% and ranging from 48-65% within the three reef tracts[113] (Table 8.2). Coral cover within the FW was only 16.8 ± 0.9%, but showed considerable spatial variability (Figure 8.2). Average coral cover within the Olowalu reef tract (30.9 ± 1.1%) was three times greater than in Olowalu Point (9.8 ± 2.6%) and over twice that of the Ukumehame (13.8 ± 6.2%) reef tracts. Eighteen coral species were identified (Table 8.2), all occurring within the Olowalu reef tract but only seven within the Olowalu Point reef tract[114]. In contrast to most reefs on Maui and Hawaiʻi Island, which are dominated by *Porites lobata* (lobe coral), the reef within the Olowalu reef tract was dominated by *Montipora capitata* (rice coral) and *M. patula* (sandpaper coral), accounting for almost 40% of all observed coral. *M. capitata* generally grows with an encrusting colony morphology, but can assume a highly complex branching form when in sheltered waters (*e.g.*, Kāneʻohe Bay on Oʻahu). The branching form was dominant within the Olowalu reef tract, which is sheltered from most swells by Olowalu Point to the west, southeast Maui and Kahoʻolawe to the east and south, and Lānaʻi to the west. *Porites lobata* was only the fourth most common coral species within the Olowalu reef tract, but accounted for over 62% of the coral within the Olowalu Point reef tract, a reef area with presumably more exposure to waves.

Coral cover declined along an east-west gradient; coral cover was highest toward the eastern end of the Olowalu reef tract and declined toward and around Olowalu Point (Figure 8.2). The reef area with the highest coral cover lays between two potential sources of runoff and sediment: the stream mouth at the bottom of Ukumehame Gulch, and a road storm drain under Honoapiʻilani Highway in front of Olowalu Village Road[115]. Likewise, sites offshore and in deeper water had significantly more coral than sites in shallow water (Correlation; $r=-0.298$, $p<0.001$). Coral cover also rose just west of Olowalu Landing within the Olowalu Point reef tract (Figure 8.2), likely due to sheltering provided by the landing, before decreasing toward the northwest. The hardbottom becomes fragmented at the northwest end of the Olowalu Point reef tract, eventually transitioning into the Launiupoko Survey Gap (Chapter 7), where coral cover was among the lowest in the WMR.

Broader differences in the benthic assemblage structure were found among the three reef tracts, but especially between the Olowalu Point reef tract and the two reef tracts to the east. While benthic diversity was similar among the reef tracts, it was slightly higher on average within the Olowalu compared to the Olowalu Point reef tract (Figure 8.3), where species richness for both corals and macroalgae was lower. This discrepancy in species numbers was likely in part an

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[113] Recent data from the Ukumehame reef tract was limited to a handful of sites with poor spatial distribution across the reef tract. This distribution made data interpolations within the Ukumehame reef tract unreliable, and they have been excluded from the figures and discussion. Summary information has been provided for completeness, but all estimates of benthic cover in the Ukumehame reef tract should be considered cautiously given the low sampling effort and limited taxonomic resolution of the data.

[114] Species-level information was not available for the Ukumehame reef tract.

[115] Only one water quality monitoring site (water quality site: Mile Mark 14) was along this stretch of coastline. While it showed elevated turbidity levels, they were about half of that measured at east end of the FW.

Table 8.2. Average (±SEM) percent cover of benthic groups and taxa for the Olowalu Point (n=20), Olowalu (n=206), and Ukumehame (n=8) reef tracts. Data are from 2016-2018. No species-level data were available for the Ukumehame reef tract.

	Olowalu Point	**Olowalu**	**Ukumehame**
Turf	47.9 ± 4.3	60.6 ± 1.1	65.2 ± 13.2
Coral	9.8 ± 2.6	30.9 ± 1.1	13.8 ± 6.2
Montipora capitata	0.1 ± 0.1	8.6 ± 0.7	
Montipora patula	0.1 ± 0.1	8.6 ± 0.5	
Porites compressa	2.6 ± 1.8	3.7 ± 0.3	
Porites lobata	6.1 ± 1.5	2.8 ± 0.3	
Porites evermanni/lutea	0	2.4 ± 0.3	
Pavona varians	<0.1	0.9 ± 0.2	
Porites rus	0	0.1 ± 0.1	
Pavona duerdeni	0	0.1 ± 0.1	
Pocillopora meandrina	0.3 ± 0.3	0.1 ± 0.1	
Montipora flabellata	0	0.1 ± 0.1	
Pavona maldivensis	<0.1	<0.1	
Pocillopora ligulata	0	<0.1	
Pocillopora eyedouxi	0	<0.1	
Cyphastrea ocellina	0	<0.1	
Leptastrea purpurea	0	<0.1	
Pocillopora damicornis	0	<0.1	
Fungia scutaria	0	<0.1	
Psammocora stellata	0	<0.1	
Crustose Coralline Algae	0.9 ± 0.3	0.6 ± 0.1	2.3 ± 0.9
Macroalgae	0.5 ± 0.3	4.1 ± 0.4	13.1 ± 5.3
Cyanobacteria	0	0	0
Other	0.1 ± 0.1	0.6 ± 0.1	0
Abiotic	40.9 ± 5.9	3.4 ± 0.4	5.3 ± 2.1
Sand	39.8 ± 6.0	2.9 ± 0.4	
Other	0	0.5 ± 0.1	
Recently dead coral	0.6 ± 0.3	0	
Bare Rubble	<0.1	0	

artifact of more sites being surveyed in the Olowalu reef tract, but this alone does not adequately explain the difference. The structure of the benthic assemblage was also different, including both in composition and dominance (Figure 8.4). Abiotic substratum (*e.g.*, sand, rubble, pavement, etc.) comprises over 40% of the benthic cover of the Olowalu Point reef tract, which was 8-10 times that of the Olowalu or Ukumehame reef tracts. Of the living component of the

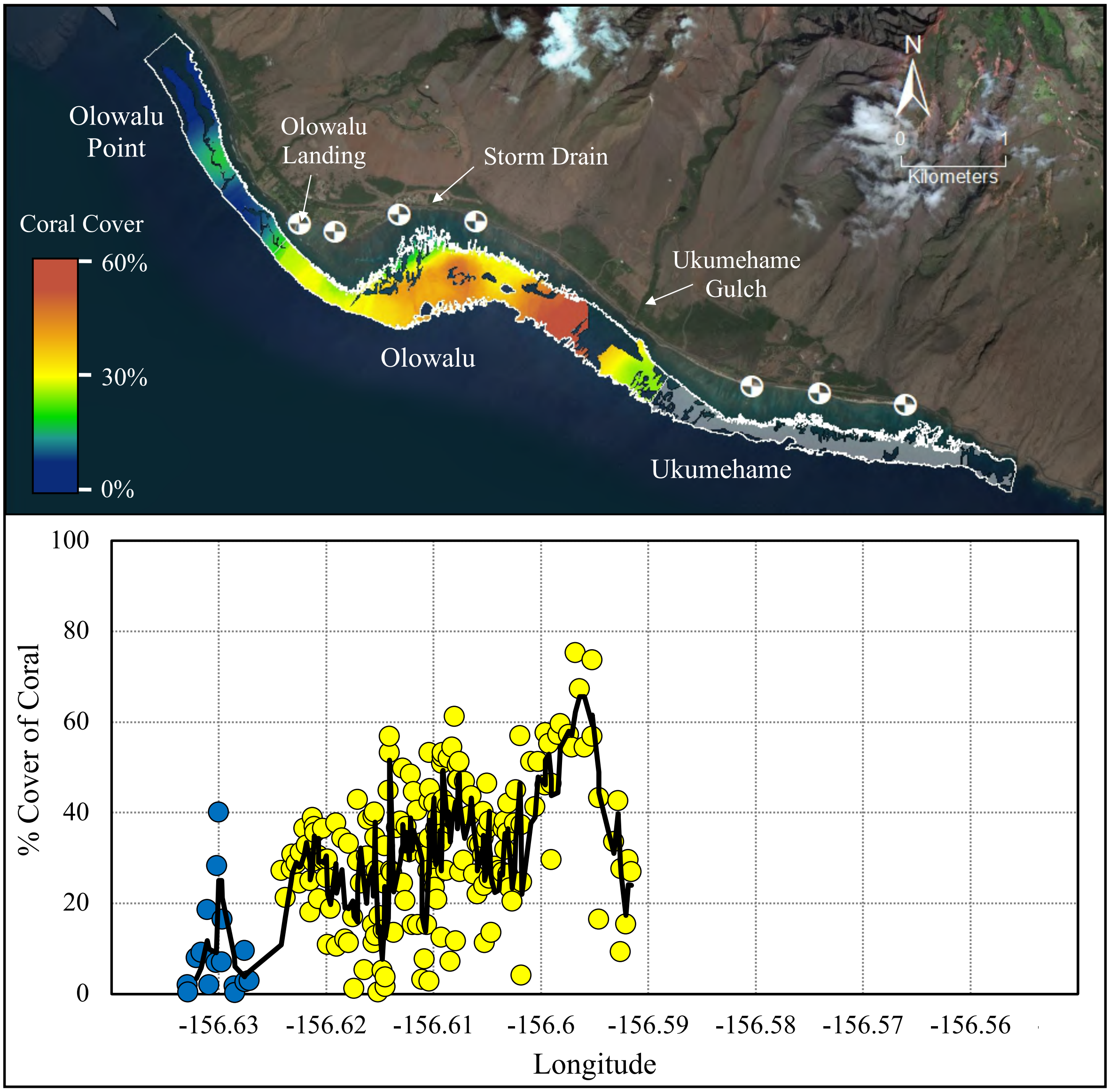

Figure 8.2. Coral cover across the Olowalu FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average coral cover for the FW and red would be considered high coral cover for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of coral cover at consecutive survey sites along the east-west axis. Colored points correspond with the Olowalu Point (blue) and Olowalu (yellow) reef tracts. White quadrant circles along the shore are (west to east) the Olowalu Shore Front, Olowalu Point, Camp Olowalu, Mile Marker 14, Ukumehame Park, Pāpalaua Park, and Pāpalaua Pali long-term water quality monitoring sites.

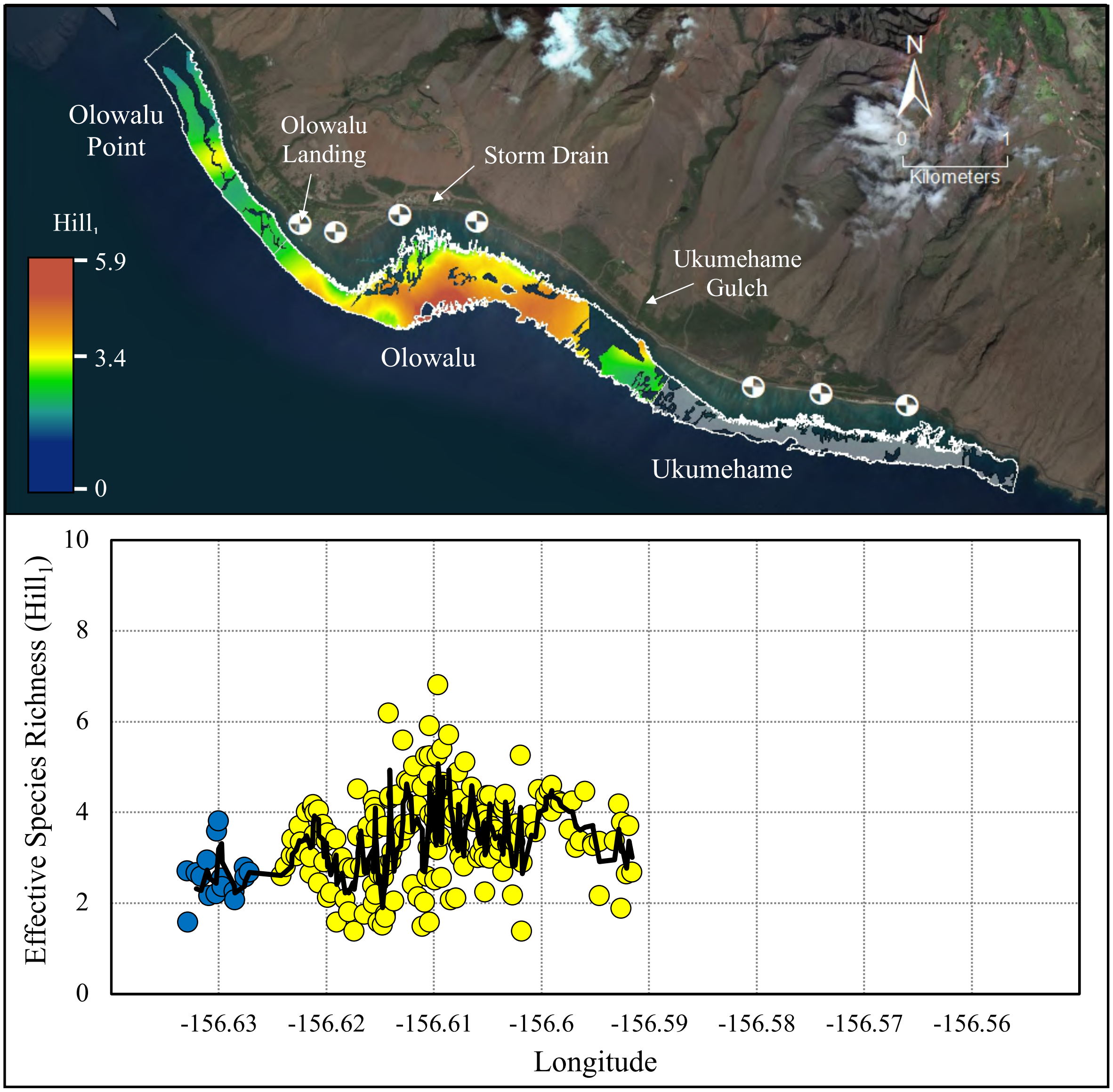

Figure 8.3. Effective species richness (Hill$_1$) of the benthic assemblage across the Olowalu FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average effective species richness for the FW and red would be considered high richness for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of effective species richness at consecutive survey sites along the east-west axis. Colored points correspond with the Olowalu Point (blue) and Olowalu (yellow) reef tracts. White quadrant circles along the shore are (west to east) the Olowalu Shore Front, Olowalu Point, Camp Olowalu, Mile Marker 14, Ukumehame Park, Pāpalaua Park, and Pāpalaua Pali long-term water quality monitoring sites.

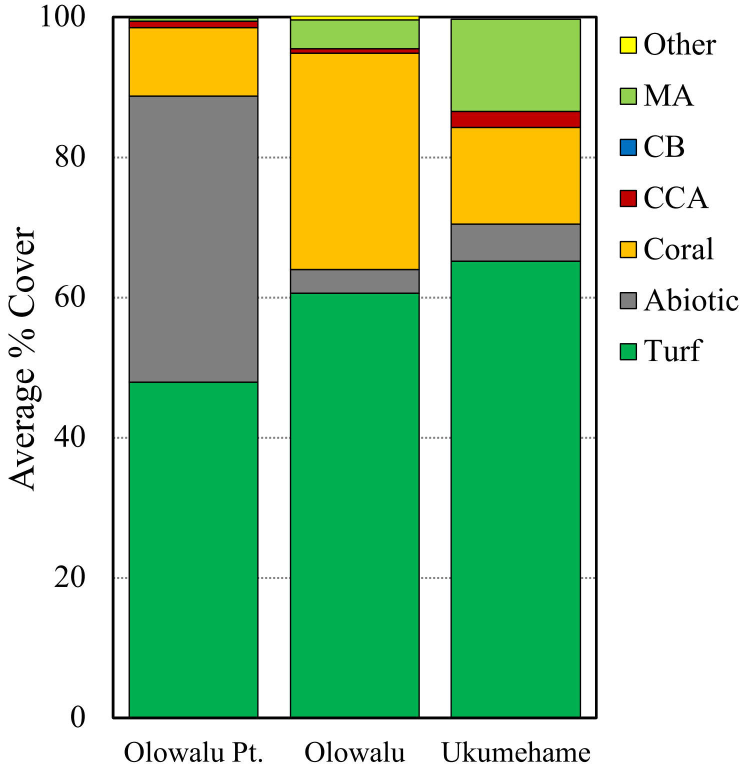

Figure 8.4. Average percent cover by benthic group in the Olowalu FW. Data are from 2016-2018. MA=macroalgae, CB=cyanobacteria, CCA=crustose coralline algae.

benthic assemblage, turf was more dominant within the Olowalu Point compared to the Olowalu reef tract, 81% to 62%, respectively. This higher dominance by turf would contribute to lowering the benthic diversity of Olowalu Point compared to the Olowalu reef tract.

Historical Patterns: Benthic

A 19-year team series of data (1999-2017) is available for the Olowalu reef tract (Table 8.1), with robust data sets existing for 2015-2017, and two permanent CRAMP monitoring sites. The Olowalu Shallow CRAMP site has data from 1999-2016, and the data for the Olowalu Deep site ranges from 1999-2012. Time series data for the Olowalu Point and Ukumehame reef tracts were not of sufficient duration or sampling effort for a meaningful analysis.

Coral bleaching affected reefs in Olowalu in both 2014 and 2015, with the latter year experiencing a more severe event. The 2015 mass coral bleaching event affected many of the reefs within the Main Hawaiian Islands (MHI), including on Maui where it caused an estimated 20-40% loss of coral[116].

The 2015 bleaching event resulted in a significant loss of coral within the Olowalu reef tract from 2015 to 2016 (Figure 8.5; ANOVA; $F_{2,305}=52.9$; $p<0.001$), with the 2015 surveys conducted in April, prior to the onset of the bleaching event. Coral cover at shallow (<9 m) sites was more severely affected than deep (>9 m) sites (Figure 8.5). Shallow reef areas lost 45% of their coral cover compared to a 23% loss for deep areas. In addition, coral loss varied across the reef, and two reef areas in particular experienced little loss of coral following the bleaching event. Coral cover did not decline in an area of reef near the center of the embayment (Figure 8.6) or in a second area along the eastern quarter of the reef tract. These two reef areas align well with the coral cover hotspots identified from the 2016-2018 (Figure 8.2), suggesting these reef areas are remnants of high coral cover that was once more widespread within the Olowalu reef tract. It is difficult to assess whether the benthic assemblages in these two reef areas are more resilient to climate change or if their specific spatial locations possessed environmental traits that made them less susceptible to increased water temperature (*e.g.*, cool water discharge, strong currents, etc.).

[116] SSRI (2017)

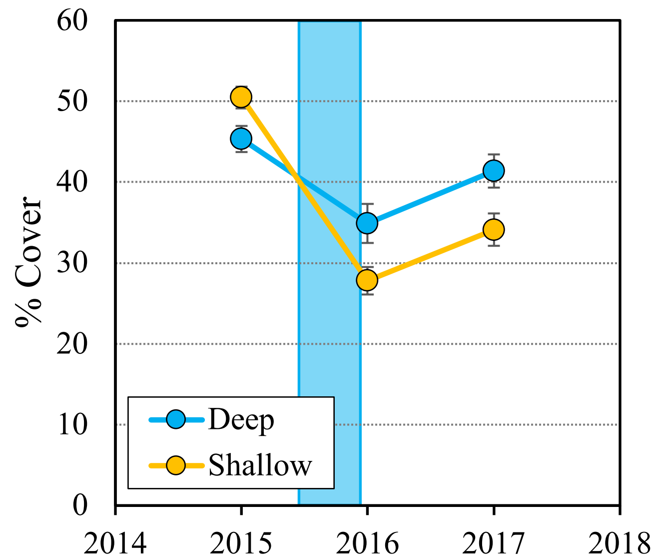

Figure 8.5. Average (±SEM) coral cover at deep (blue) and shallow (orange) sites in the Olowalu reef tract from 2015-2017. The blue bar signifies the approximate months over which the 2015 mass coral bleaching event affected Maui reefs.

While not statistically significant, coral cover did show an increasing trend between 2016 and 2017 at both shallow and deep sites (Figure 8.5). This non-significant trend may be the early stages of coral recovery from the bleaching event, with a full recovery, if it happens, likely to take years for slow-growing corals.

Similar to the survey sites across the entire reef tracts, the benthic data from the two CRAMP monitoring sites also showed a larger decrease from the 2015 bleaching event at the shallow compared to deep site (Figure 8.7). Prior to the 2015 event, the Olowalu Shallow site had experienced a steady decline in coral cover, losing 13% of its coral from the initial surveys in 1999. Between 2015 and 2016, coral cover dropped sharply from a pre-bleaching (1999-2015) average of 19.4 ± 0.6% to 5.4%, equivalent to a loss of 72% of coral cover[117]. In 2018, TNC returned to the approximate location of CRAMP's Olowalu Shallow site and conducted reef resilience assessments. While the 2018 surveys were not perfect replications of the CRAMP assessments, they should be reflective of the reef area. The 2018 survey again found low coral cover, suggesting the Olowalu Shallow CRAMP site has likely not recovered to pre-bleaching levels of coral cover as of 2018. The time series of CRAMP's deep site ended in 2012, but between 1999 and 2012, the Olowalu Deep site also experienced a 13% loss of coral (Figure 8.7), and TNC's 2018 surveys in the same location showed coral cover has continued to decline, accruing an additional 30% loss of coral over between 2012 and 2018. Whether this loss was a part of a multi-year trend starting in 2010 or primarily associated with the 2015 bleaching event (as at the Olowalu Shallow site) is unknown.

Coral species were differentially affected by the mass bleaching event (Figure 8.8). Partial and full mortality were observed in multiple coral genera, with *Montipora* spp. and *Porites* spp. particularly affected[118]. *Porites compressa* (finger coral), showed the greatest decline in cover, losing 76% and 61% of its cover at deep and shallow sites, respectively. *Montipora capitata* and

[117] Describing change in a percent value (*e.g.*, percent cover) can present challenges and cause confusion because often changes are expressed as "percent change" in the original value. This approach is often called a "relative" change. Confusion arises when the base values are also percentages. For example, a decline from 12% to 6% is a 50% "relative" decrease, but an "absolute" decrease of 6%. The use of the "relative" and "absolute" approaches to describe a change depends on the specific situation. In ecology, the "relative" change is used when comparing things (*e.g.*, reef areas) that may have very different underlying values.

[118] Sparks *et al.* (2015)

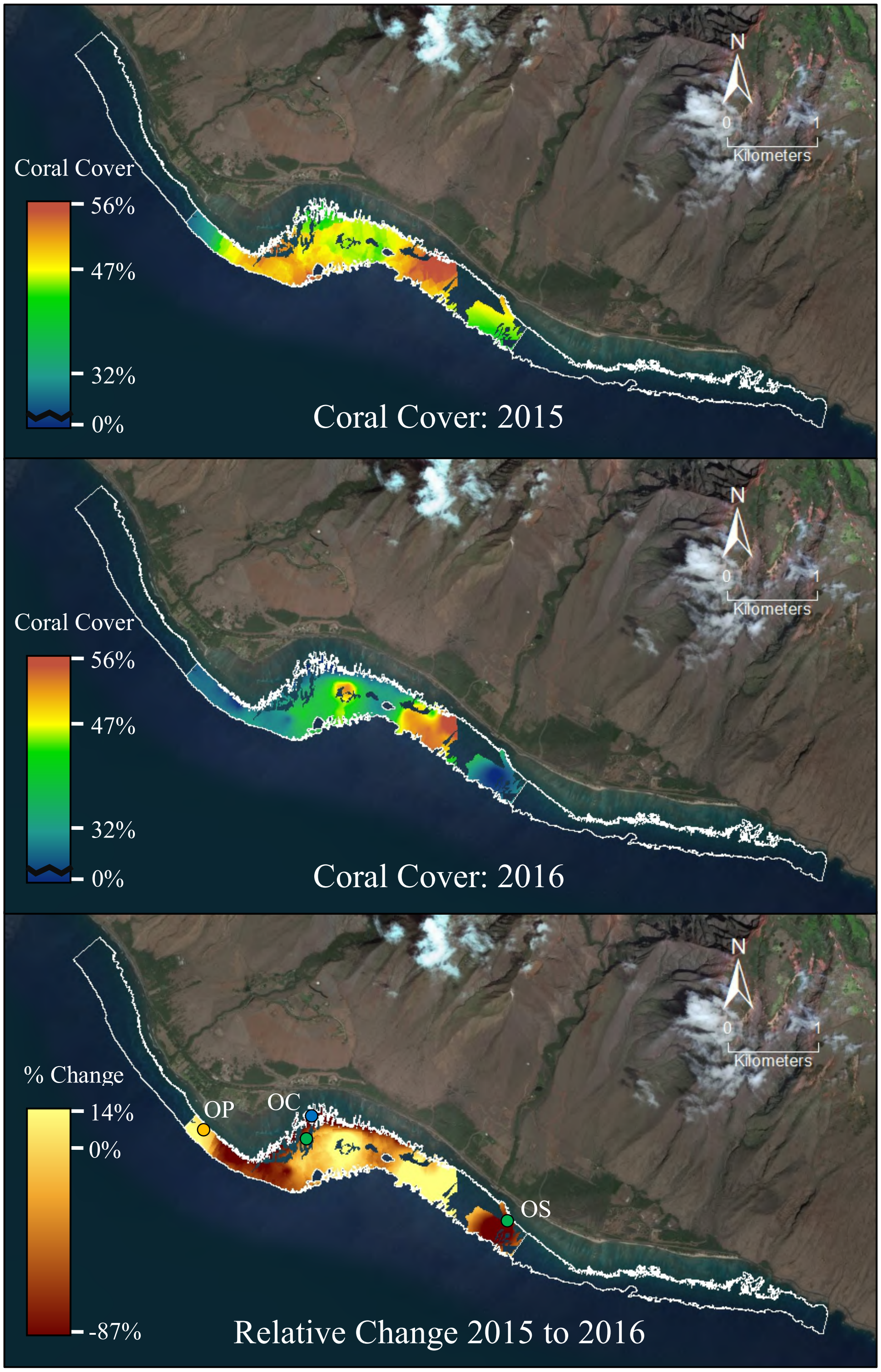

Figure 8.6. Coral cover within the Olowalu reef tract in 2015, 2016, and the relative change in cover from 2015 to 2016. Points in bottom figure are the Olowalu Point (OP), Olowalu CRAMP (OC; two sites), and Olowalu South (OS) reef resilience sites that are coded for medium-high (orange), medium-low (green), and low (blue) potential reef resilience.

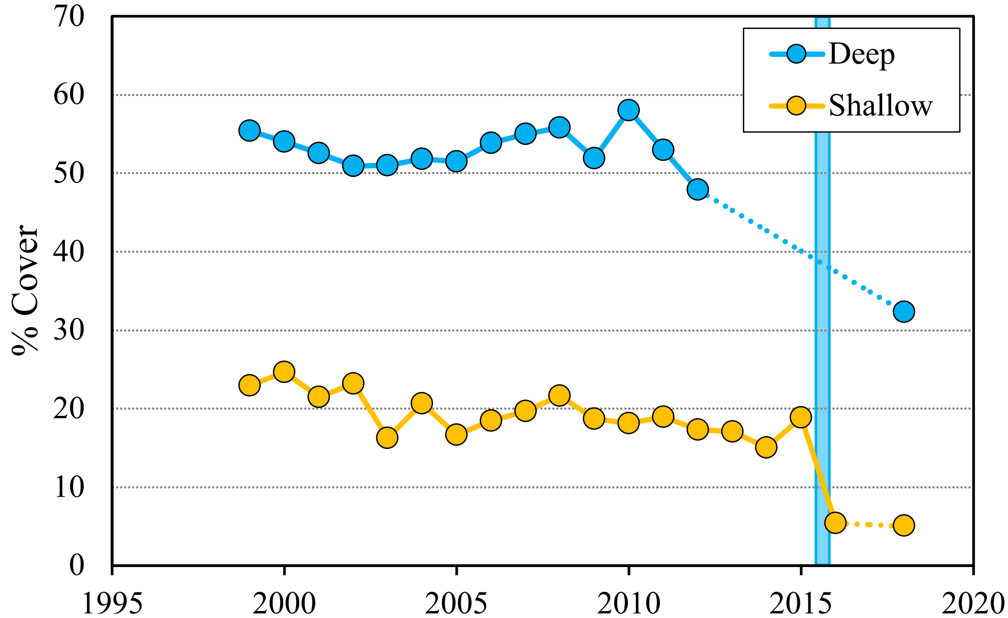

Figure 8.7. Coral cover at the Olowalu Shallow (orange) and Olowalu Deep (blue) CRAMP monitoring sites within the Olowalu reef tract. Data for the shallow site range from 1999-2016 and for the deep site from 1999-2012. In 2018, TNC returned to the approximate location of the two CRAMP sites and conducted reef resilience assessments, but these surveys were not conducted exactly on the CRAMP transects. The blue bar signifies the approximate months over which the 2015 mass coral bleaching event affected Maui reefs.

M. patula were the next most affected, experiencing a 41-51% drop in their average cover at shallow sites while doing better at deep sites (19-32% decline). The least affected species was *P. lobata* (lobe coral), which lost 21% and 10% of its cover at shallow and deep sites, respectively.

The Olowalu reef tract appears to have undergone (and may still be undergoing) a change in its benthic structure. Declines in coral following the 2015 coral bleaching event have been offset primarily by an increase in turf algae at all depths (Figure 8.9). Turf algae growing on dead coral skeletons also quickly entrained sediment[119], which would impair coral settlement and could slow or negate recovery. Coral recruits (colonies <5 cm in diameter) were assessed as part of TNC 2018 reef resilience surveys[120] and of the four sites in Olowalu, two showed among the worst recruitment in leeward Maui (Olowalu CRAMP Shallow and Olowalu CRAMP Deep), and one showed below average recruitment (Olowalu South). Only the Olowalu Point reef resilience site showed above average recruitment, likely due to its location offshore of the point, where sedimentation rates would be expected to be lower than within the embayment. While some coral recovery may be underway (Figure 8.5), macroalgae has increased in both 2016 and 2017 and now covers almost 13% of the bottom at deep sites (Figure 8.9), a value that would be considered high on reefs in Hawaiʻi, even among those under stress from herbivore overharvest or affected by nutrient inputs.

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[119] Sparks *et al.* (2015)
[120] Maynard *et al.* (2019)

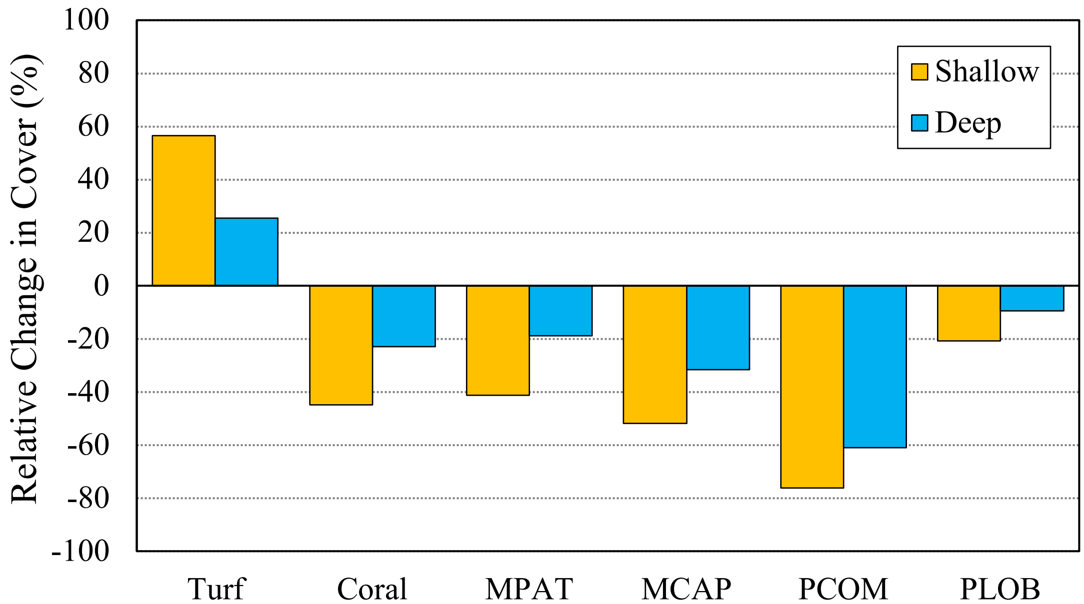

Figure 8.8. Relative change in the cover of turf, all coral, and the four most abundant coral species at shallow and deep sites in the Olowalu reef tract between 2015 and 2016. Negative values represent a decrease in cover following the 2015 mass bleaching event. MPAT= *Montipora patula*, MCAP=*M. capitata*, PCOM=*Porites compressa*, PLOB=*P. lobata*

Coral Health and Reef Resilience

In March 2018, a reef resilience assessment of leeward Maui was conducted by TNC and its partners. These assessments were intended to quantify the relative resilience of Maui's reefs to the effects of climate change. Resilience is the ability of a reef to resist, recover from, and adapt to a climate-related event (*e.g.*, coral bleaching) to maintain a diverse, coral-rich state that provides key ecological functions and services to people[121]. Given the integral role of reefs to the people of Hawaiʻi, reef resilience is closely linked with social resilience, which is the ability of human communities to adapt to social, political, environmental, or economic change[122].

Seven shallow-water and four deep-water (Table 8.3) reef resilience sites were surveyed within the Olowalu FW. The complete results of that assessment are detailed elsewhere[123], so only the coral health and resilience findings for the sites in the Olowalu FW are summarized here.

The sites were consistent in assemblage structure with nearby sites visited in 2016-2017. The shallow-water sites tended to have lower coral cover than deep-water reef resilience sites. The prevalence of coral disease (Table 8.3) was low across the FW (1.7% of colonies affected), with higher rates at the shallow sites around Olowalu Point (Olowalu North and Olowalu Point reef resilience sites). Four sites had disease prevalence <0.5%, but for these low prevalence sites,

[121] Nystrom and Folke (2001)
[122] Adger (2000)
[123] Maynard *et al.* (2019)

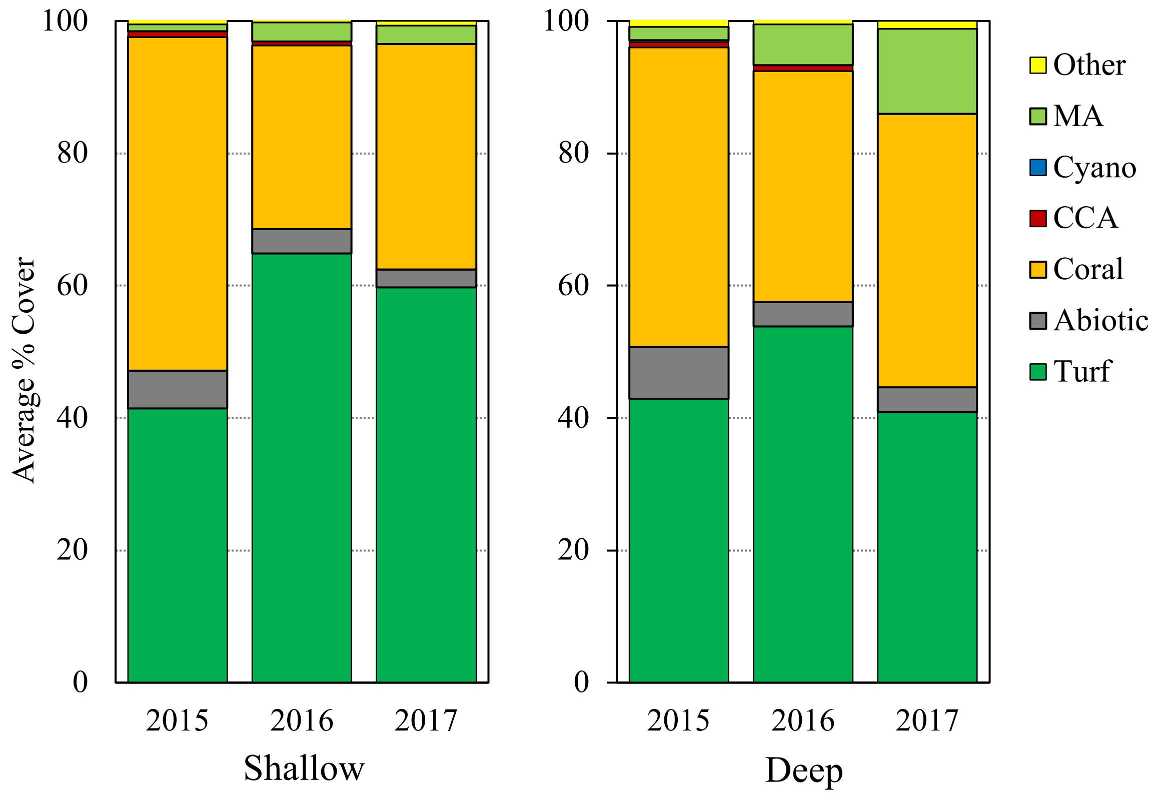

Figure 8.9. Average percent cover by benthic group at shallow and deep sites in the Olowalu reef tract in 2015, 2016, and 2017. MA=macroalgae, CB=cyanobacteria, CCA=crustose coralline algae.

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there was no clear spatial or depth pattern associated with them. A quarter of all colonies showed some signs of paling/bleaching, and unlike disease, bleaching prevalence showed a distinct spatial pattern. In the Ukumehame reef tract, an average of 49% of the colonies showed signs of paling/bleaching, and none of the four reef resilience sites within the reef tract had a paling/bleaching prevalence <33%. Paling/bleaching was particular high at both the Pali Tunnel Shallow and Pali Tunnel Deep reef resilience sites, 54% and 62% respectively. Of the remaining seven reef resilience sites, only the Olowalu CRAMP Shallow site had >5% paling/bleaching prevalence, but none of them were considered severely bleached (>50% of the tissue paled/bleached). These findings suggest several areas within the Olowalu FW are likely under stress, and that those stressors might vary depending upon the reef area. These include the reef areas from between Ukumehame Gulch to the Pali Tunnel, close to shore within the Olowalu embayment, and directly off Olowalu Point itself.

As part of the reef resilience assessment, the 31 shallow-water and 20 deep-water sites surveyed were assigned a relative reef resilience rank, based on several indicator variables, including coral cover, coral disease prevalence, coral diversity, coral recruitment, reef builder ratio (ratio of calcifying species to non-calcifying species), rugosity, and herbivorous fish biomass. Among the shallow-water reef resilience sites, Olowalu North and Ukumehame ranked medium-high for potential reef resilience, Olowalu South, Olowalu Point and Pali Tunnel ranked medium-low, and Olowalu CRAMP and Awalua ranked low (Table 8.3). Awalua was the lowest ranked shallow-water site, which was not surprising given its location at the most western edge of the FW, where the reef begins to fragment and abundance, biomass, and diversity of both the benthic and fish assemblages are low. The relatively low resilience rankings for the shallow-water sites at Olowalu appear to align well with the greater susceptibility of shallow sites to the 2015 mass coral bleaching event (Figure 8.6).

Deep-water reef resilience sites fared slightly better than shallow-water ones. Pali Tunnel ranked high for potential reef resilience, Ukumehame was medium-high, Olowalu CRAMP medium-low, and Olowalu North was the lowest ranked deep-water site on leeward Maui. In general, potential reef resilience for deep sites tended to be higher toward the eastern end of the FW. These rankings also indicate the reef resilience on the deeper reef areas within the Olowalu FW are not necessarily aligned with the shallow ones, suggesting different depth-related stressors, oceanographic processes, and ecological factors may be at play on Olowalu's reefs.

Table 8.3. The 11 reef resilience (RR) sites within the Olowalu FW. "RR Rank" is the relative reef resilience rank among 31 shallow and 20 deep sites along leeward Maui, with 1 being the most resilient and higher numbers indicating less resilience. "Dis. Prev." is the percent of colonies presenting at least one disease. "ALOG" is the percentage of colonies being overgrown by benthic algae. "Paling/Bleaching" is the percent of colonies showing signs of tissue paling or bleaching. Average values for the WMR (italics) are presented for comparison.

	Reef Tract	**RR Rank**	**Dis. Prev.**	**ALOG**	**Paling/ Bleaching**
Shallow	*WMR Average*		*2.4 ± 0.5*	*9.6 ± 1.5*	*18.2 ± 4.8*
Awalua	Olowalu Pt.	S31	0	3.1	3.1
Olowalu North	Olowalu Pt.	S10	3.3	4.3	1.4
Olowalu Point	Olowalu	S19	5.5	3.3	0.1
Olowalu CRAMP	Olowalu	S28	0	11.5	54.3
Olowalu South	Olowalu	S18	1.1	6.3	1.1
Ukumehame	Ukumehame	S11	1.7	5.4	33.9
Pali Tunnel	Ukumehame	S26	2.1	9.2	62.2
Deep	*WMR Average*		*1.4 ± 0.3*	*7.2 ± 1.5*	*19.9 ± 6.4*
Olowalu North	Olowalu Pt.	S20	0.4	14.1	4.4
Olowalu CRAMP	Olowalu	S15	1.3	3.9	5.1
Ukumehame	Ukumehame	S8	2.9	3.8	46.6
Pali Tunnel	Ukumehame	S4	0.4	4.2	53.5

Fish Assemblage

Spatial Patterns: Fish

The fish assemblage in the Olowalu FW also showed considerable spatial variation, following spatial patterns similar to the benthic assemblage. The Olowalu reef tract had the highest total fish biomass (58.4 ± 3.2 g/m^2), nearly double that observed within the Ukumehame reef tract (Table 8.4), although data are sparse in the Ukumehame reef tract[124], making it difficult to draw rigorous conclusions. Variability tended to be high, especially within the Olowalu and Olowalu Point reef tracts[125]. If the high values were trimmed[126] from the estimate of total fish biomass, the Olowalu reef tract continued to have 60% greater total fish biomass than the Ukumehame reef tract. However, trimming high values from Olowalu Point lowered its total fish biomass to an amount that was similar to Ukumehame reef tract. The high biomass values within the Olowlu Point reef tract are not "wrong," however, but are indicative of high spatial variability. This indicates that the Olowalu Point reef tract generally had similar total fish biomass to Ukumehame, but it also had some patches of high fish biomass (Figure 8.10). Differences in fish biomass among the three reef tracts were driven primarily by two families, surgeonfish and parrotfish. Olowalu Point had <1 g/m^2 of parrotfish (Table 8.4), which was less than a tenth of that present in the Olowalu and Ukumehame reef tracts. In contrast, the Ukumehame reef tract had half the surgeonfish of either the Olowalu or Olowalu Point reef tracts. Reasons for the disparities in these two families are not clear.

Given the large size of the Olowalu reef tract (1.37 km^2 hardbottom), high spatial variability should be expected; the reef tract is the largest intact coastal fringing reef on Maui, has many large (>5 m in diameter) coral heads[127], and has a range of environmental conditions and stressors. High total fish biomass occurred in the deeper areas of the Olowalu embayment (Figure 8.10). Inshore of this area, reefs tended to have lower fish biomass. A second area of elevated total fish biomass occurred just west of Ukumehame Gulch, roughly overlapping an area of high coral cover. Both hotspots had total fish biomass considered to be high compared to the WMR average (42.2 ± 3.9 g/m^2), and the hotspot within the embayment had among the highest total fish biomass of any reef area in the region. Within the Olowalu Point reef tract, total fish biomass was high around the Olowalu Landing, but declined noticeably farther to the northwest (Figure 8.10) where the reef became more fragmented with increasing distance from the point. However, within the immediate vicinity of Olowalu Landing, total fish biomass appeared to the decline slightly. The landing is a sand and rubble berm that extends ~100 m onto the reef and, in addition to altering nearshore currents, has also affected the benthic assemblage. This decrease in fish biomass near a pier-like structure also was observed around Mala Pier (Chapter 6).

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[124] Recent data from the Ukumehame reef tract was limited to a handful of sites with poor spatial distribution across the reef tract. This distribution made data interpolations within the Ukumehame reef tract unreliable and they have been excluded from the figures and discussion. Summary information has been provided for completeness, but all estimates of biomass and diversity in the Ukumehame reef tract should be considered cautiously given the low sampling effort.

[125] Variability can be measured using the coefficient of variation (CV), in which the higher the value, the more variable the data. The CV for the Olowalu reef tract was 85% and for the Olowalu Point reef tract was 122%.

[126] See Chapter 1 or Appendix B for more information on trimmed data.

[127] Sparks *et al.* (2015)

Table 8.4. Fish biomass (g/m^2) by fish family within the Olowalu Point (n=25), Olowalu (n=234), Ukumehame (n=12) reef tracts. Data are from 2016-2018. *Individuals were present, but biomass was not estimated for this family.

	Olowalu Point	Olowalu	Ukumehame
Acanthuridae	23.7 ± 7.1	22.5 ± 1.8	11.2 ± 1.6
Scaridae	0.8 ± 0.6	13.6 ± 1.0	10.1 ± 3.9
Balistidae	6.8 ± 1.5	6.3 ± 0.5	2.9 ± 0.6
Labridae	2.1 ± 0.5	3.8 ± 0.3	1.4 ± 0.2
Chaetodontidae	0.7 ± 0.2	2.4 ± 0.2	2.0 ± 0.6
Mullidae	1.0 ± 0.7	2.3 ± 1.0	1.2 ± 0.5
Lethrinidae	0.3 ± 0.3	2.0 ± 0.6	0
Monacanthidae	<0.1	1.7 ± 0.4	0.2 ± 0.2
Serranidae	0.9 ± 0.5	1.5 ± 0.3	0.1 ± 0.1
Pomacentridae	1.2 ± 0.2	0.7 ± 0.1	2.0 ± 0.6
Lutjanidae	0	0.6 ± 0.3	0
Sphyraenidae	0	0.4 ± 0.3	0
Carangidae	0	0.1 ± 0.1	0
Kyphosidae	0	0.1 ± 0.1	0
Diodontidae	0	0.1 ± 0.1	0
Zanclidae	0.3 ± 0.2	0.1 ± 0.1	0.2 ± 0.1
Cirrhitidae	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.2
Aulostomidae	0	<0.1	0.1 ± 0.1
Fistulariidae	0	<0.1	0
Tetraodontidae	0.1 ± 0.1	<0.1	<0.1
Holocentridae	<0.1	<0.1	0
Ostraciidae	<0.1	<0.1	0.1 ± 0.1
Pomacanthidae	<0.1	<0.1	<0.1
Synodontidae	<0.1	<0.1	0
Blenniidae	<0.1	<0.1	0
Microdesmidae	0	<0.1	0
Apogonidae	<0.1	<0.1	0
Cheilodactylidae	0	<0.1	0
Chanidae	0	0	0
Priacanthidae	0	0	0
Scorpaenidae	0	0	0
Muraenidae	*	*	*
Total Fish Biomass	**38.0 ± 9.3**	**58.4 ± 3.2**	**31.8 ± 4.3**

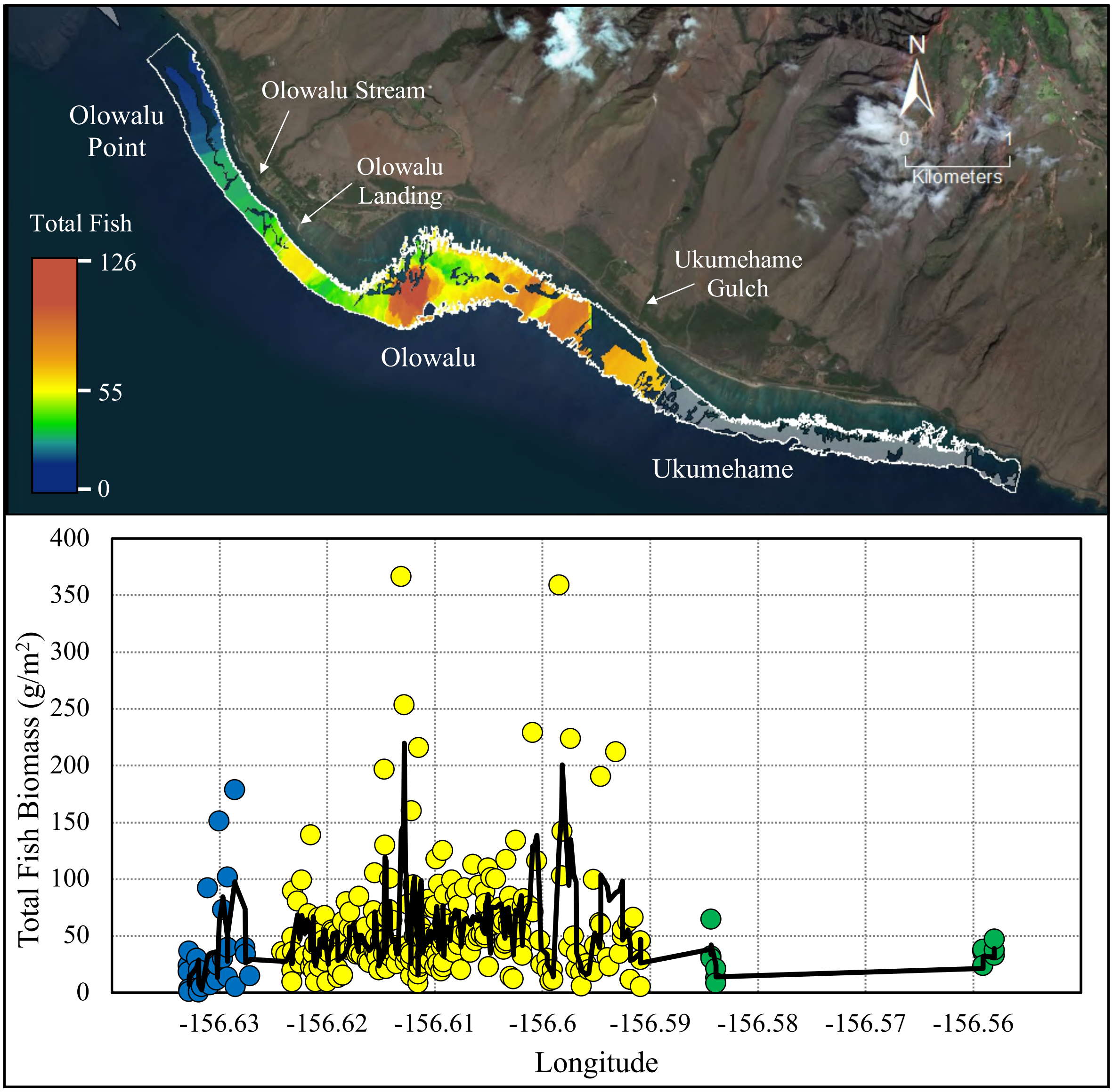

Figure 8.10. Total fish biomass across the Olowalu FW. The map (top) is interpolated from 2016-2018 survey data across hard hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average total fish biomass for the FW and red would be considered high biomass for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of total fish biomass across at consecutive survey sites along the east-west axis. Colored points correspond with the Olowalu Point (blue), Olowalu (yellow), and Ukumehame (green) reef tracts.

Resource fish biomass, which is comprised of species important for consumption[128] and that tend to be prized by fishers, showed a similar spatial pattern to total fish biomass (Figure 8.11). As with total fish biomass, resource fish biomass within the Olowalu reef tract (37.2 ± 2.7 g/m^2) was twice that within the Ukumehame reef tract (16.2 ± 3.9 g/m^2). Resource fish biomass within the Olowalu Point (25.2 ± 7.9 g/m^2) was also about 50% greater than that in the Ukumehame reef tract and also like total fish biomass, tended to be above average in the reef areas to the west of the Olowalu Landing, declining to below average levels toward the northwest (Figure 8.11).

Structure of the resource fish assemblage was different among the three reef tracts (Figure 8.12). Parrotfish was the dominant resource fish group within the Ukumehame reef tract, whereas surgeonfish comprised over 87% of the resource fish biomass within the Olowalu Point reef tract. The greatest resource fish diversity was in the Olowalu reef tract, where surgeonfish and parrotfish comprised approximately equal amounts of the resource biomass, but wrasses, goatfish, apex predators, and three “other” species comprised almost a quarter of all resource fish biomass (Figure 8.12). Apex predator diversity was high, including the jacks *Caranx melampygus* (bluefin trevally) and *Decapterus macarellus* (mackerel scad), the snappers *Aphareus furca* (smalltooth jobfish) and *Aprion virescens* (green jobfish), a bigeye *Heteropriacanthus cruentatus* (glasseye), and a barracuda *Sphyraena barracuda* (great barracuda). Notably, apex predators were present only within the Olowalu reef tract and were entirely absent from both the Olowalu Point and Ukumehame reef tracts.

Prime spawners are individual resource fish >70% of the maximum length for that species. These individuals tend to exert a disproportionately large effect on population dynamics due to their considerably higher fecundity and egg quality compared to smaller individuals[129]. Conservation of prime spawners is important to maintaining sustainable fisheries and ecosystems.

Prime Spawner biomass was similar across the Olowalu FW (Figure 8.13). The Olowalu reef tract had the lowest average biomass (5.7 ± 0.6 g/m^2), but the highest prime spawner species richness at 17 species. For seven of these 17 species, no prime spawners were observed within either the Ukumehame or Olowalu Point reef tracts (Table 8.5). Within the Olowalu reef tract, no single species dominated the prime spawner assemblage; the most common species, *Chlorurus spilurus* (bullethead parrotfish), comprised only <21% of the total prime spawner biomass. Within the Olowalu Point reef tract (9.9 ± 3.0 g/m^2), prime spawners were highest just northwest of Olowalu Stream (Figure 8.13) and declined to near zero toward the northwestern edge of the reef tract. Of survey sites northwest of the point, more than half had zero prime spawners. Prime spawners within the Olowalu Point reef tract were dominated by the surgeonfish *Acanthurus olivaceus* (orangeband surgeonfish), which accounted for 68% of the prime spawner biomass. In Ukumehame reef tract (7.8 ± 4.0 g/m^2), *C. spilurus* was the dominant prime spawner, accounting for 70% of the prime spawner biomass.

Effective species richness was similar across most of the Olowalu FW (Figure 8.14), although it may peak slightly near Olowalu Landing before declining precipitously toward the northwestern edge of the FW. This decline within the Olowalu Point reef tract is likely a real trend and not a

[128] See Appendix B for a list of resource and non-resource species
[129] Birkeland and Dayton (2005) and Hixon *et al.* (2014)

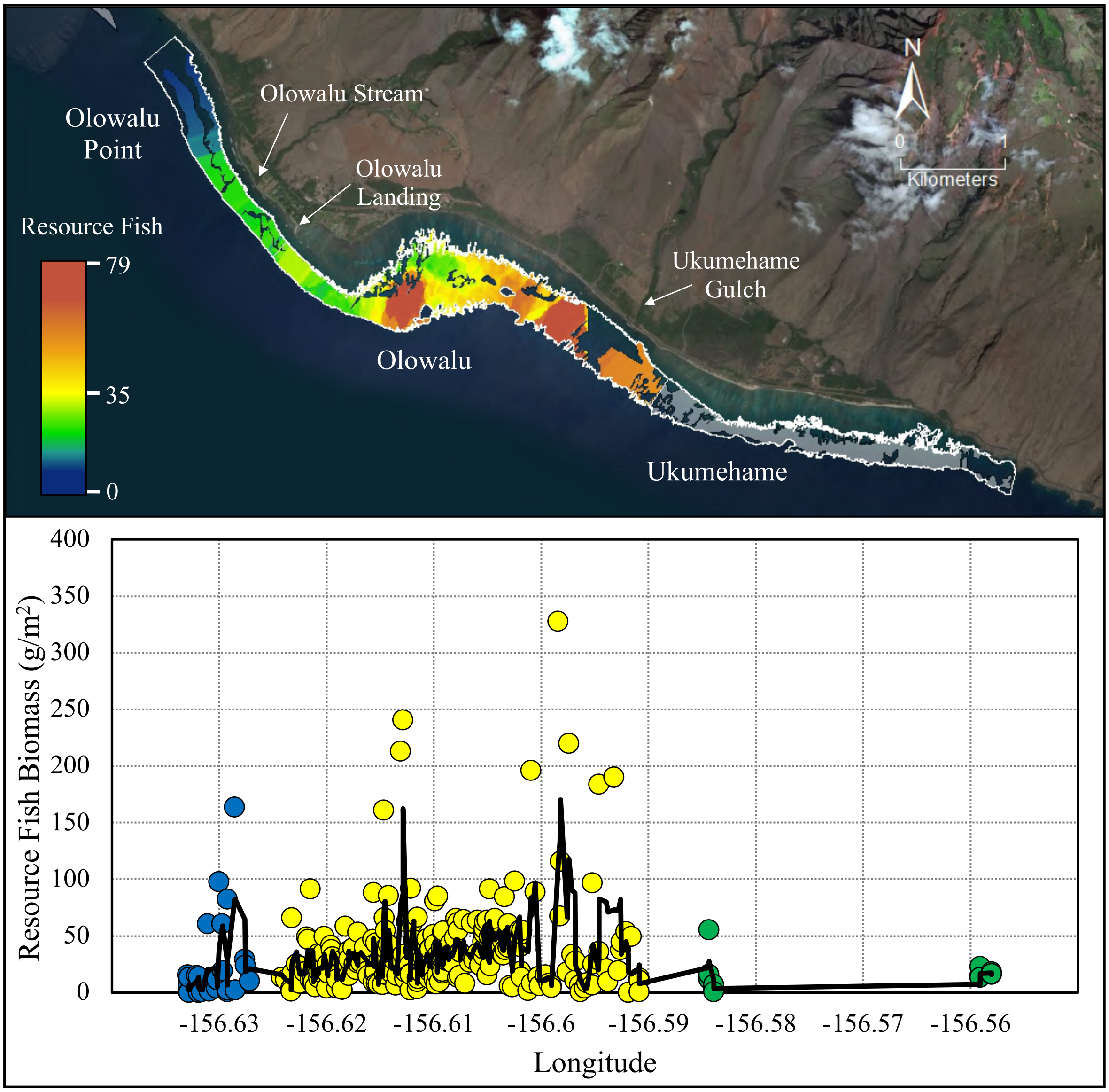

Figure 8.11. Resource fish biomass across the Olowalu FW. The map (top) is interpolated from 2016-2018 survey data across hard hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average resource fish biomass for the FW and red would be considered high biomass for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of resource fish biomass across at consecutive survey sites along the east-west axis. Colored points correspond with the Olowalu Point (blue), Olowalu (yellow), and Ukumehame (green) reef tract tracts.

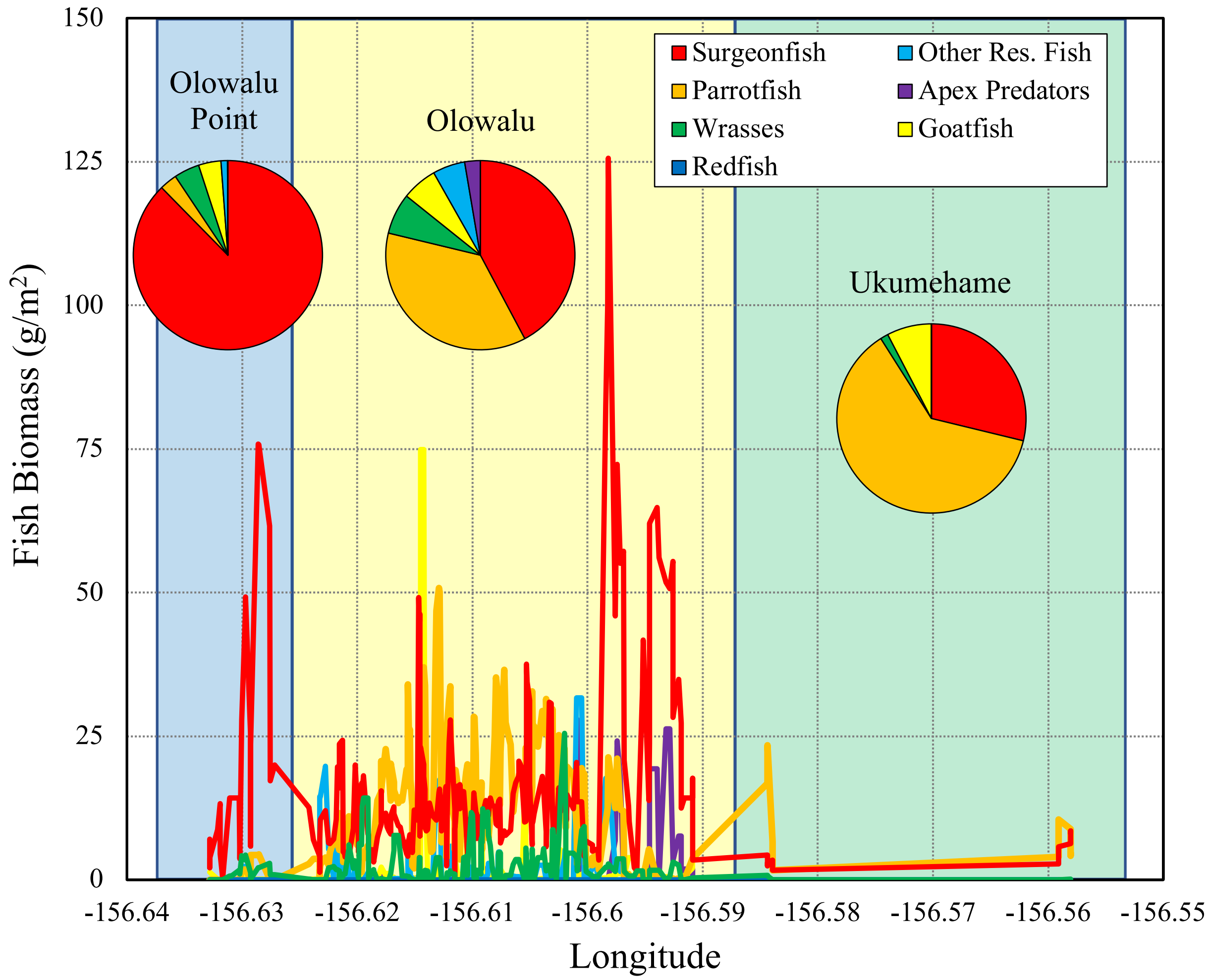

Figure 8.12. Biomass of seven resource groups across the Olowalu FW. Color boxes correspond with the Olowalu Point (blue), Olowalu (yellow), and Ukumehame (green) reef tracts. Pie charts are the relative biomass of the seven resource groups in each reef tract.

product of the variability because the reef in this direction becomes fragmented as it moves into the Launiupoko Survey Gap (see Chapter 7), where coral cover (8.7 ± 2.3%) and fish biomass (21.1 ± 10.5 g/m^2) were low.

Fishing effects often can be detected by examining the average individual size of species by their importance in the fishery. High fishing pressure should lower the average size of more heavily fished than less-heavily fished species, assuming other potential non-fishing stressors affect the species similarly[130]. Therefore, a ratio of average individual size can be used to compare fish populations between two reef areas and infer the relative effects of fishing versus non-fishing

[130] This assumption is generally true, but it is important to note that reef fish species have different habitat requirements and thus would display a differential response to environmental stressors or changes in environmental conditions. However, when averaged over many species, these species-specific differences should be reduced.

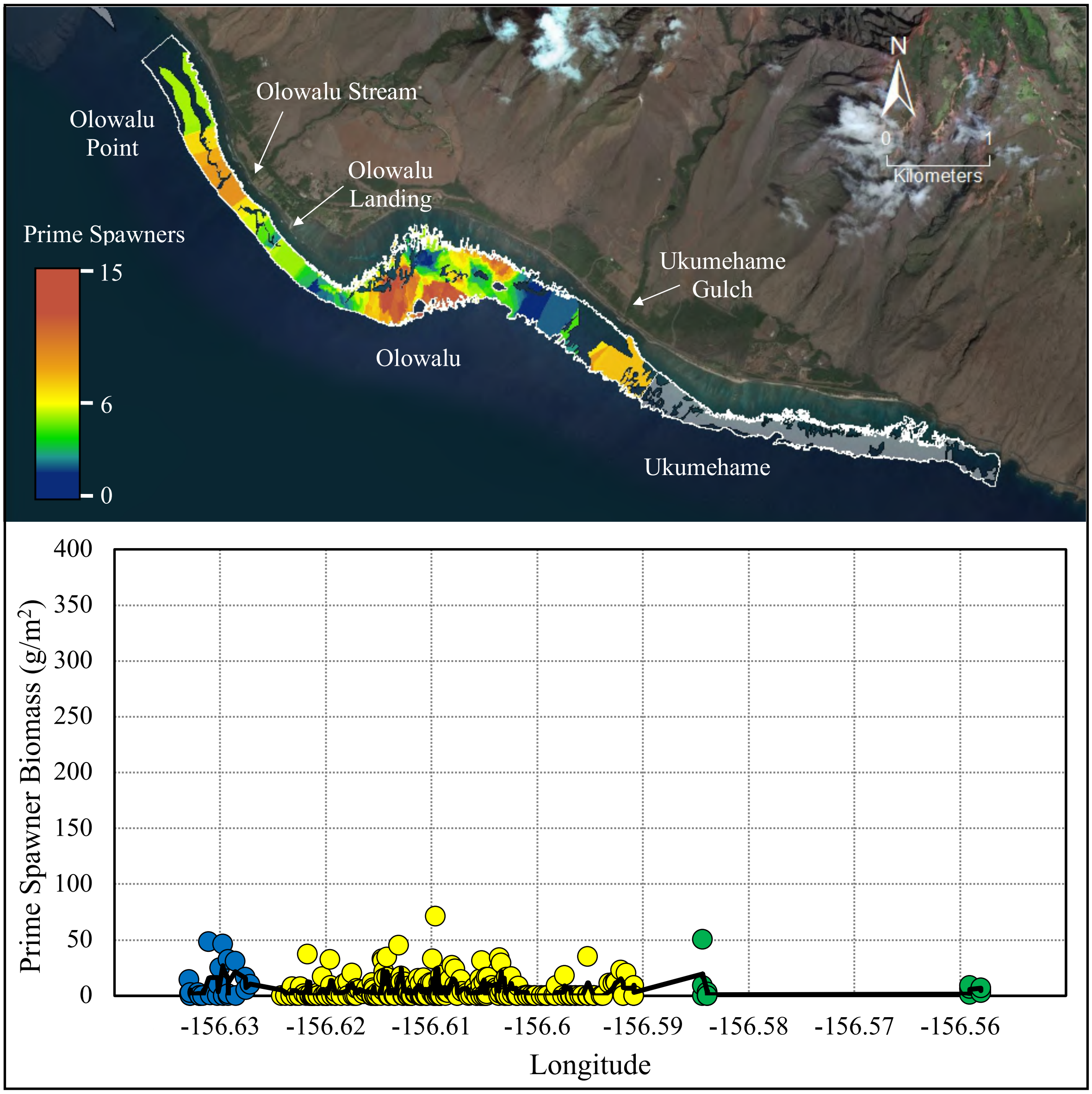

Figure 8.13. Prime spawner biomass across the Olowalu FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average prime spawner biomass for the FW and red would be considered high biomass for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of prime spawner biomass across at consecutive survey sites along the east-west axis. Colored points correspond with the Olowalu Point (blue), Olowalu (yellow), and Ukumehame (green) reef tracts.

Table 8.5. Prime spawner species richness within the Olowalu Point, Olowalu, and Ukumehame reef tracts. Species are arranged on order of dominance (% of total biomass) within each reef tract. Data are from 2016-2018.

Olowalu Point	Olowalu	Ukumehame
Acanthurus olivaceus	*Chlorurus spilurus*	*Chlorurus spilurus*
Acanthurus blochii	*Scarus psittacus*	*Scarus psittacus*
Mulloidichthys flavolineatus	*Ctenochaetus strigosus*	*Parupeneus multifasciatus*
Acanthurus dussumieri	*Acanthurus olivaceus*	*Mulloidichthys flavolineatus*
Naso brevirostris	*Acanthurus nigroris*	*Acanthurus nigroris*
Bodianus albotaeniatus	*Scarus rubroviolaceus*	
Parupeneus multifasciatus	*Acanthurus triostegus*	
Naso lituratus	*Naso lituratus*	
Acanthurus leucopareius	*Mulloidichthys vanicolensis*	
Chanos chanos	*Acanthurus blochii*	
	Naso brevirostris	
	Mulloidichthys flavolineatus	
	Parupeneus insularis	
	Parupeneus multifasciatus	
	Acanthurus leucopareius	
	Scarus dubius	
	Aphareus furca	

effects on those fish assemblages. The sizes of 22 common species were compared across the three reef tracts of the Olowalu FW. On average, the three reef tracts had similar sized resource and moderately-prized fishery species (Figure 8.15), but variability within both fish groups was high, especially between the Olowalu and Olowalu point reef tracts. For example, among the 10 resource fish species included in the analysis, most species showed little difference in size between Olowalu and Olowalu Point, except for the parrotfish *C. spilurus*, which were significantly larger within the Olowalu reef tract, driving up the average size ratio and inflating the variability. Non-resource species showed an east-west size gradient, with most species increasing in size from west to east across the Olowalu FW. Non-resource species experience low fishing pressure, and thus are affected primarily by environmental stressors that affect the condition of their habitat and/or the ecological/demographic processes that affect their growth, survival, and fitness.

This pattern is unusual and suggests that many factors are affecting the fish assemblage within the Olowalu FW. The change in size of non-resource fish suggests a gradient of fish habitat quality likely exists within the FW and is supported by the available data for the benthic assemblage. Indicators of benthic assemblage condition (*i.e.*, coral cover, disease prevalence, resilience) appear to be generally consistent with such a gradient. Environmental stressors

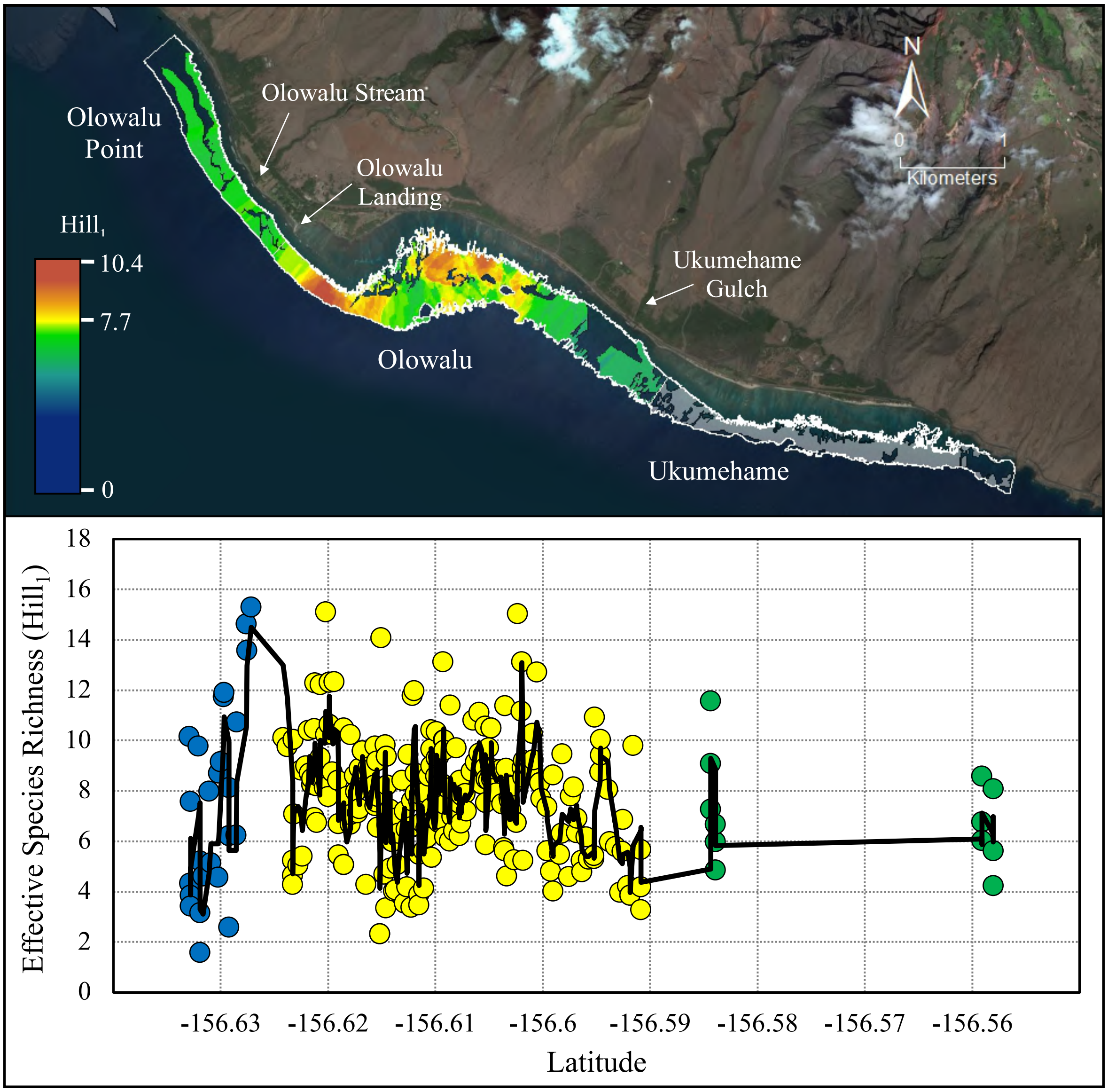

Figure 8.14. Effective species richness ($Hill_1$) of the fish assemblage across the Olowalu FW. The map (top) is interpolated from 2016-2018 survey data across hardbottom. On the map, white lines outline the three reef tracts. Map colors are derived from the data of the FW, such that yellow is the average effective species richness for the FW and red would be considered high richness for the FW. Grayed areas are hardbottom that lacked sufficient data for analysis, and areas without color do not contain hardbottom. In the graph (bottom), the line is the moving average (window size 3) of effective species richness across at consecutive survey sites along the east-west axis. Colored points correspond with the Olowalu Point (blue), Olowalu (yellow), and Ukumehame (green) reef tracts.

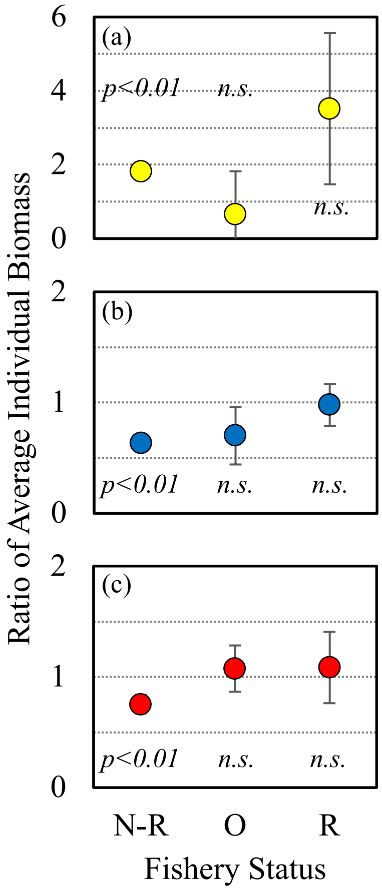

Figure 8.15. Comparison of fish size (ratio of average individual biomass) between the (a) Olowalu and Olowalu Point, (b) the Olowalu and Ukumehame, and (c) the Olowalu Point and Ukumehame reef tracts. A ratio=1 means the fish in the two reef tracts are of approximately equal size within the two reef tracts, a ratio>1 means fish within the Olowalu (a and b) or Olowalu Point (c) reef tract are larger on average than the other reef tract, and a ratio<1 indicates fish within the Olowalu (a and b) or Olowalu Point (c) are smaller on average than the other reef tract. N-R=non-resource fish (8 species), O=other fish (4 species), R=resource fish (10 species). Significance was tested using a 1-sample t-test.

also should have similar effects on resource and moderately-prized fishery species; however, no size differences were detected within these two fish groups, suggesting any gradient in fish size may have been negated by fishing effects. Most fishers tend to target and remove large individuals[131], which can create a truncated size-frequency distribution, resulting in a smaller average size of individuals. If pressure is sufficiently high, this could result in a convergence of average size across the multiple different reef tracts within the Olowalu FW, effectively masking habitat effects. An examination of the size-frequency distributions for the most common resource and non-resource species (analysis not shown) yielded no additional clarity because most of the distributions were truncated at approximately the 20-25 cm size class, with larger individuals being relatively uncommon in all three reef tracts. Currently, no formal assessments of fishing pressure have been conducted at Olowalu[132], so it is difficult to assess the validity of this hypothesis.

[131] The aquarium trade fishery is an exception, which tends to target small individuals.

[132] Maui-DAR staff have estimated fishing effort in the Olowalu FW to be average to above-average for the WMR, which was consistent with the Ocean Tipping Points project estimate for average annual catch for non-commercial fisheries from 2004-2013.

Historical Patterns: Fish

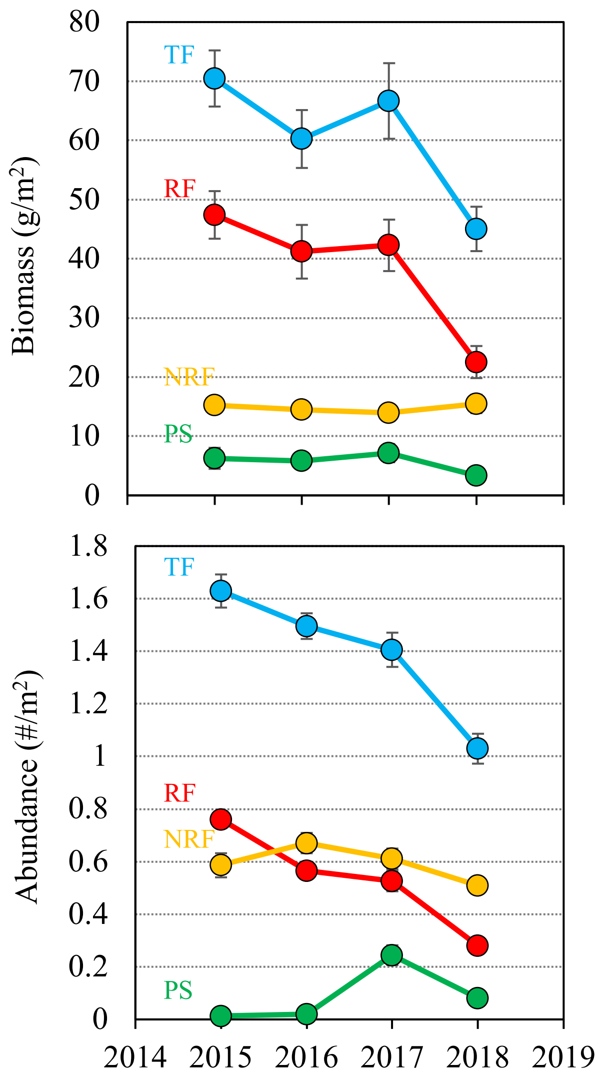

Figure 8.16. Biomass (top) and abundance (bottom) of total fish (blue), resource fish (red), non-resource fish (gold), and prime spawners (green) within the Olowalu reef tract.

Due to limited temporal data for the Olowalu Point and Ukumehame reef tracts (Table 8.1), change through time was examined only within the Olowalu reef tract, for which sufficient data were available between 2015-2018. Unfortunately, this time series does not include data collected in 2013 or 2014, the year prior to and during which a large reef fish recruitment event occurred, and many reef fish species experienced an unusually larger settlement of juveniles across a wide range of fish species [133]. This recruitment event has been documented on West Hawai'i reefs[134], and was also observed on O'ahu[135] and Maui[136]. These missing years in the Olowalu dataset make it difficult to interpret changes in the fish assemblage over this time frame, as discussed below.

Since 2015, both the biomass and abundance of coral reef fishes has declined (Figure 8.16), but not all groups have responded similarly. Biomass of both total fish (ANOVA; $F_{3,360}$ =2.98; p=0.031) and resource fish (ANOVA; $F_{3,360}$ =5.31; p=0.001) were significantly lower in 2018 compared to 2015, and both showed a generally downward trend across the time period. In contrast, neither non-resource nor prime spawner biomass has significantly declined since 2015. Total fish (ANOVA; $F_{3,360}$ =12.03; p<0.001), resource fish (ANOVA; $F_{3,360}$ =17.56; p<0.001), and non-resource fish (ANOVA; $F_{3,360}$ =3.61; p=0.013) abundance also have declined over this same period (Figure 8.16). The only positive change has been a significant increase in the number of prime spawners (ANOVA; $F_{3,360}$ =50.75; p<0.001). The decline in biomass from 2015-2018 was most associated with three common fish families, which together accounted for 83% of the lost biomass. Surgeonfish (Acanthuridae) declined by 47%, goatfish (Mullidae) declined by 87%, and parrotfish (Scaridae) declined by 51%.

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[133] Talbot (2014)
[134] Minton *et al.* (2018a)
[135] TNC, unpub. data
[136] TNC Maui and DAR-Maui, per. comm.

The observed decline in fish biomass and abundance within the Olowalu reef tract is difficult to interpret based on the temporally-limited dataset. Without biomass and abundance estimates from before 2014, it is difficult to assess the potential effect of the 2014 reef fish recruitment event. This event could have increased substantially both abundance and biomass of fishes in 2015, which in subsequent years could be declining back toward pre-event levels. This was observed at Kaʻūpūlehu on Hawaiʻi Island[137]. While maintaining the increased fish biomass from the recruitment event would be desirable, any decline in subsequent years does not represent a typical decline in fishery resources, especially if the abundance and biomass re-stabilize at pre-2014 levels. Loss of these individuals may be related to the inability of the juvenile habitat to support the large number of newly settled fish, and whose condition and abundance could have been adversely affected by the 2014 and 2015 mass coral bleaching events. Unfortunately, the data available from earlier years is too sparse and do not provide additional insight into this temporal pattern.

The Big Picture

Compared to the WMR, the reef tracts within the Olowalu FW range from below average to high when compared to regional averages. The Olowalu reef tract consistently ranks among the best reef areas in the WMR, with high coral cover and benthic diversity, and medium-high total fish and resource fish biomass. While prime spawners were not doing as well, their biomass in the Olowalu reef tract was still average compared to the WMR. Coral species richness in particular was exceptional within the Olowalu reef tract, with the greatest number of corals identified compared to other FWs in the region (Appendix E). This reef tract has long been known for its exceptional coral reef, and while it was heavily impacted by the 2015 mass coral bleaching event, it is still a "gem" of the WMR.

The other reef tracts within the Olowalu FW did not fare as well when compared to the WMR. Data within the Ukumehame reef tract was limited, but it ranked as average for most coral reef parameters compared to other reefs in the WMR, with prime spawners being above average. This may be a function of inadequate surveys, however, and given Ukumehame's proximity to a quality reef area (within the Olowalu reef tract), this reef tract should warrant additional attention. Olowalu Point tended to have below-average to average reef resources with the notable exception of prime spawner biomass, which was high compared to the WMR. This reef tract had considerable variability, however, with resource condition on the northwest half of the reef tract considerably lower than that to the southeast.

Statewide Context

Averages for coral cover (14.4 ± 0.7%), total fish biomass (40.9 ± 2.5 g/m^2), resource fish biomass (22.3 ± 1.8 g/m^2), and prime spawner biomass (3.7 ± 1.0 g/m^2) were calculated for the MHI, to serve as a gauge for how the reefs of the WMR are faring relative to those from around the state. All across the MHI, reefs are affected by overfishing, sediments, land-based pollution, and invasive species. Over the past century, populations of some commercially important reef fish populations have declined by over 90%, and coral cover in some areas has declined by at

[137] Minton *et al.* (2018a)

least 40% in just the last 40 years. While there are many reef areas around the state that still have abundant and healthy resources, the current statewide averages used for comparison here certainly reflect substantial declines in resource condition seen broadly across the reefs of the MHI. Reefs in the WMR were consistent with the statewide averages for coral and fish assemblages (see Chapter 1). However, considerably variability in the condition of reefs exists across the WMR, and the reef tracts within the Olowalu FW ranged from average to above average when compared to reefs statewide (Figure 8.17). In particular, the Olowalu reef tract generally had high quality benthic and fish resources when compared to other reefs in the MHI. Olowalu Point and Ukumehame reef tracts had consistently average to slightly above-average values for all variables.

Synthesis

The reef tracts within the Olowalu FW tend to be spatially variable in the abundance, biomass, and diversity of their benthic and fish assemblages. In general, benthic and fish distributions tended to have similar spatial patterns, and hotspots for total fish biomass overlapped hotspots for coral cover.

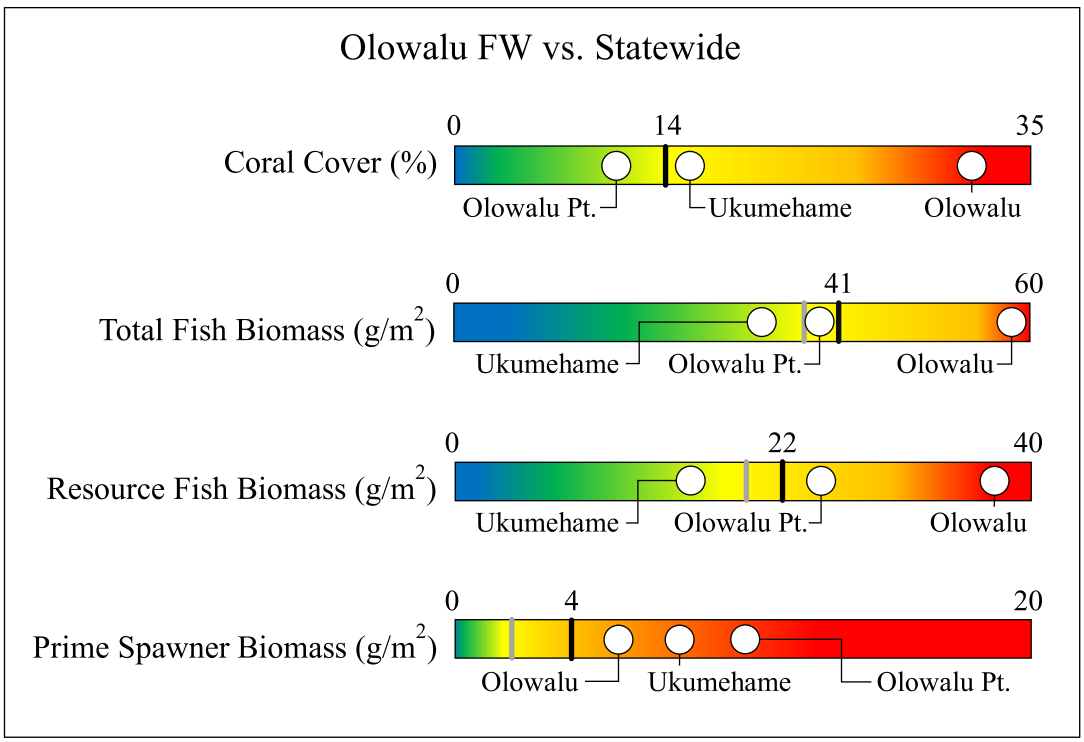
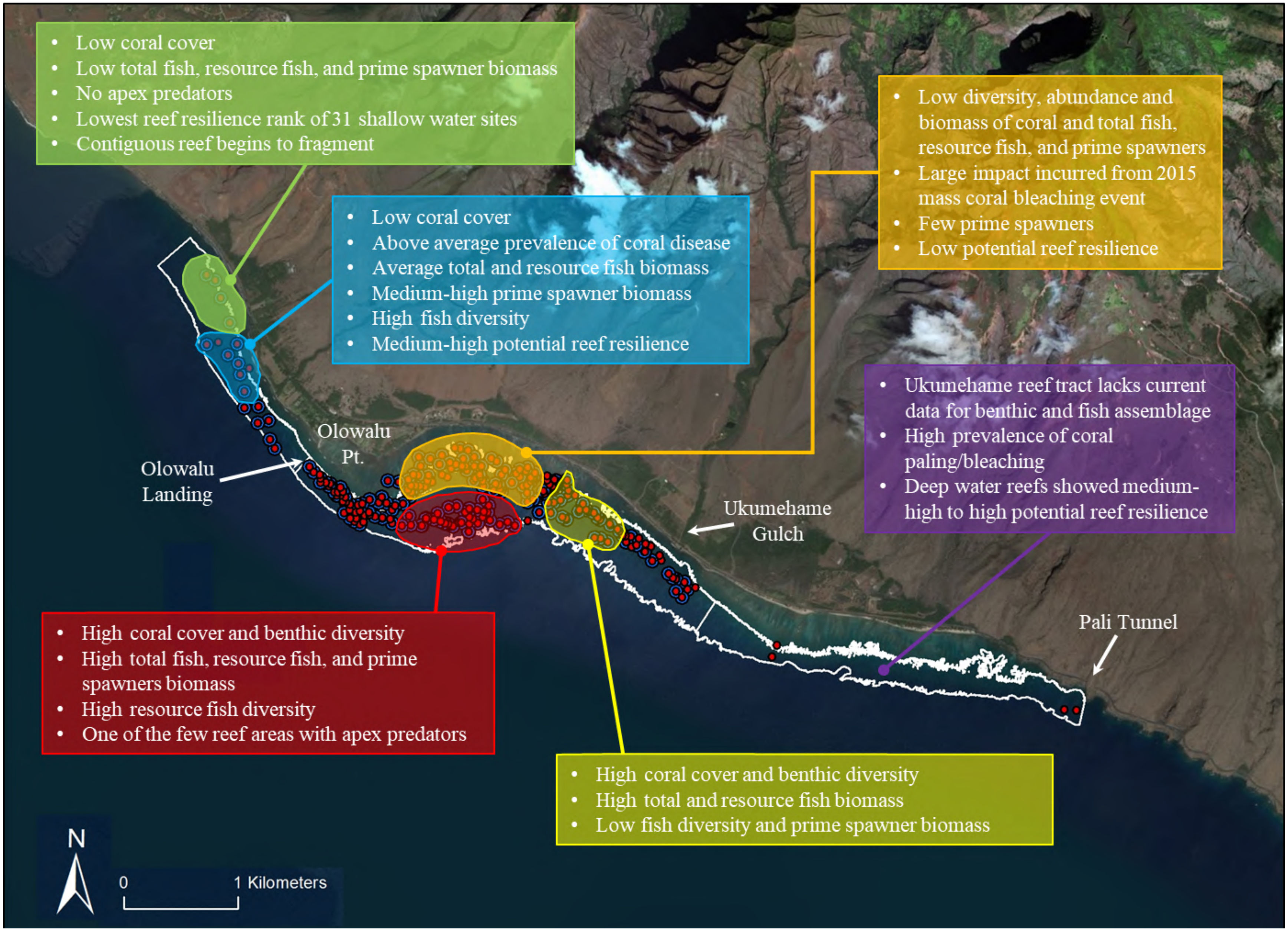


Figure 8.17. Comparison of reef tracts in the Olowalu FW to statewide averages for coral cover (%), total fish, resource fish, and prime spawner biomass (g/m^2). Black vertical line and value denote the statewide average. For the three fish metrics, the grey vertical line is the statewide trimmed mean, which was used to develop the qualitative categories; see the methods (Appendix B) for more details on the use of the trimmed means.

The Olowalu reef tract had two reef areas of particular note. The deeper waters of the embayment had high coral cover and benthic diversity and high total fish, resource fish, and prime spawner biomass, making it one of the most abundant and diverse reef areas in the WMR. Unfortunately, TNC conducted no reef resilience assessments within this part of the reef tract in 2018, but the area experienced little coral loss following the 2015 mass coral bleaching event, suggesting it was more resilient than nearby reef areas. A second reef area, laying west of the stream outlet at the bottom of Ukumehame Gulch, also had a rich benthic assemblage with high coral cover and benthic diversity and high total fish and resource fish biomass. It also showed robust resilience to the 2015 mass coral bleaching event, suffering little mortality. However, this reef area had relatively low prime spawner biomass and fish diversity.

The Olowalu Point reef tract tended to have lower quality benthic and fish assemblages than the Olowalu reef tract. Coral cover and benthic diversity tended to be slightly below the regional average and lay along a distinct gradient: highest near Olowalu Landing on the southeast edge of the reef tract and decreasing to the northwest. Prevalence of coral disease was high within the reef tract. The middle third of the reef tract (northwest of Olowalu Stream) was notable for to its medium-high biomass of prime spawners, high fish diversity, and medium-high potential reef resilience. Prime spawner biomass was dominated by *Acanthurus olivaceus*.

The Ukumehame reef tract lacked current data on both the benthic and fish assemblages, but two deep-water reef resilience sites suggest this area has above average resilience to bleaching, and this reef tract should warrant additional surveys.


• Low coral cover
• Low total fish, resource fish, and prime spawner biomass
• No apex predators
• Lowest reef resilience rank of 31 shallow water sites
• Contiguous reef begins to fragment
• Low coral cover
• Above average prevalence of coral disease
• Average total and resource fish biomass
• Medium-high prime spawner biomass
• High fish diversity
• Medium-high potential reef resilience
• Low diversity, abundance and biomass of coral and total fish, resource fish, and prime spawners
• Large impact incurred from 2015 mass coral bleaching event
• Few prime spawners
• Low potential reef resilience
• Ukumehame reef tract lacks current data for benthic and fish assemblage
• High prevalence of coral paling/bleaching
• Deep water reefs showed medium-high to high potential reef resilience
Olowalu Pt.
Olowalu Landing
Ukumehame Gulch
Pali Tunnel
• High coral cover and benthic diversity
• High total fish, resource fish, and prime spawners biomass
• High resource fish diversity
• One of the few reef areas with apex predators
• High coral cover and benthic diversity
• High total and resource fish biomass
• Low fish diversity and prime spawner biomass
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Appendices

Appendix A: References

Adger, W. N. 2000. Social and ecological resilience: are they related? *Progress in Human Geography* 24: 347-64.

Amato, D. W., J. M. Bishop, C. R. Glenn, H. Dulai, and C. M. Smith. 2016. Impact of Submarine Groundwater Discharge on Marine Water Quality and Reef Biota of Maui. *PLoS ONE* 11: e0165825. doi:10.1371/journal.pone.0165825

Barnes, M. D., W. Goodell, R. Whittier, K. A. Falinski, T. Callender, H. Htun, C. LeViol, H. Slay, and K. L.L. Oleson. 2019. Decision analysis to support wastewater management in coral reef priority area. *Mar. Poll. Bull.* 148: 16-29.

Beijbom, O., P. J. Edmunds, C. Roelfsema, J. Smith, D. I. Kline, B. Neal, M. J. Dunlap, V. Moriarty, T.-Y. Fan, C.-J. Tan, S. Chan, T. Treibitz, A. Gamst, B. G. Mitchell, and D. Kriegman. 2015. Towards automated annotation of benthic survey images: variability of human experts and operational modes of automation. *PLOS One* 10(7): e0130312.

Birkeland, C. and P. K. Dayton. 2005. The Importance in Fishery Management of Leaving the Big Ones. *Trends Ecol. Evol.* 20: 356-8.

CBD. 2018. Petition to List the Cauliflower Coral (*Pocillopora meandrina*) In Hawaiʻi as Endangered or Threatened Under the Endangered Species Act. 52 pp.

County of Maui, Planning Department Long Range Division. 2012. Maui Island Plan: General Plan 2030, pp I-6 – I-11; 8-56 – 8-61. Available online at: https://www.mauicounty.gov/1503/Maui-Island-Plan

Choat, J. H., L. M. Axe, and D. C. Lou. 1996. Growth and longevity in fishes of the family Scaridae. *Mar. Ecol. Prog Ser.* 145: 33-41.

Chu, P-S.X. Zhao, Y. Ruan and M. Grubb. 2009. Extreme Rainfall Events in the Hawaiian Islands. *J. App. Meteor. Climatology.* 48: 502-16.

CRAMP. 2011. CRAMP Study Sites: Puamana, Island of Maui. http://cramp.wcc.hawaii.edu/LT_montoring_files/lt_study_sites_Maui_Puamana.htm

Falinski, K., 2016. Predicting sediment export into tropical coastal ecosystems to support ridge to reef management, Chapter 3. Tropical Plant and Soil Science. University of Hawaiʻi at Mānoa, Honolulu, HI, p. 304.

Franklin, E. C., P. L. Jokiel, and M. J. Donahue. 2013. Predictive modeling of coral distribution and abundance in the Hawaiian Islands. *Mar. Ecol. Prog. Ser.* 481: 121-32.

Friedlander, A., G. Aeby, R. Brainard, E. Brown, A. Clark, S. Coles, E. Demartini, S. Dollar, S. Godwin, C. Hunter, P. Jokiel, J. Kenyon, R. Kosaki, J. Maragos, P. Vroom, B. Walsh, I.

Williams, and W. Wiltse. 2004. Status of Coral Reefs in the Hawaiian Archipelago, Chapter 15. Status of Coral Reefs of the World. Australian Institute of Marine Science, Cape Ferguson, Australia, pp. 411–430.

Friedlander, A. M., M. K. Donovan, K. A. Stamoulis, I. D. Williams, E. K. Brown, E. J. Conklin, E. E. DeMartini, K. S. Rodgers, R. T. Sparks, and W. J. Walsh. 2017. Human-induced gradients of reef fish declines in the Hawaiian Archipelago viewed through the lens of traditional management boundaries. *Aquatic Conserv.: Mar. Freshw. Ecosyst*. 2017; 1–12.

Friedlander, A. M., M. K. Donovan, K. A. Stamoulis, I. D. Williams, E. K. Brown, E. J. Conklin, E. E. DeMartini, K. S. Rodgers, R. T. Sparks, and W. J. Walsh. 2018. Human-induced gradients of reef fish declines in the Hawaiian Archipelago viewed through the lens of traditional management boundaries. *Aquatic Conserv.* 28(1): 146-157.

Froese, R. and D. Pauly. 2011. *FishBase*. World Wide Web electronic publication. www.fishbase.org, version (06/2011).

Glenn, C. R., R. B. Whittier, M. L. Dailer, H. Dulaiova, A. I. El-Kadi, J. Fackrell, J. L. Kelly, C. A. Waters, and J. Sevadjian. 2013. Lahaina Groundwater Tracer Study - Lahaina, Maui, Hawaiʻi. SOEST Technical Report prepared for State of Hawaiʻi Department of Health. 502 pp.

Group 70 International and SRGII. 2016. West Maui Watershed Plan: Kahana, Honokahua, and Honolua Watersheds Characterization Report. 225 pp.

Hart, A. M and G. R. Russ. 1996. Response of herbivorous fishes to crown-of-thorns starfish *Acanthaster planci* outbreaks. III. Age, growth, mortality and maturity indices of *Acanthurus nigrofuscus*. *Mar. Ecol. Prog. Ser.* 136: 25-35. 1996

Heenan, A., I. D. Williams, T. Acoba, A. DesRochers, R. K. Kosaki, T. Kanemura, M. O. Nadon, and R. E. Brainard. 2017. Long-term monitoring of coral reef fish assemblages in the Western central pacific. *Sci. Data* 4:170176 doi:10.1038/sdata.2017.176.

Hixon, M. A., D. W. Johnson, and S. M. Sogard. 2014. BOFFFFs: on the importance of conserving old-growth age structure in fishery populations. *ICES J. Mar. Sci.* 71: 2171-85.

Hui O Ka Wai Ola. 2018. Coastal Water Quality Report 2016-2018. 12 pp.

Hunt, C. D. Jr. and S. N. Rosa. 2009. A Multitracer approach to detecting wastewater plumes from municipal injection wells in nearshore marine waters at Kihei and Lahaina, Maui, Hawaii: U.S. Geological Survey Scientific Investigations Report 2009 – 5253, 166 p.

Kramer, K. L., S. P. Cotton, M. R. Lamson, and W. J. Walsh. 2016. Bleaching and catastrophic mortality of reef-building corals along West Hawaiʻi island: findings and future directions. Proc. 13th Int. Coral Reef Symp., Honolulu: 229-241.

Lahaina Restoration Foundation. n.d. Explore the Lahaina Historic Walking Trails. 4 pp. Available online at: http://lahainarestoration.org/lahaina-historic-trail/

Maynard, J., E. Conklin, D. Minton, G. J. Williams, D. Tracey, R. Amimoto, R. Carr, E. Fielding, H. Lynch, J. Rose, R. Sparks, R. Sylva, and D. White. 2019. Assessing the Resilience of Leeward Maui Reefs to Help Design a Resilient Managed Area Network. NOAA Coral Reef Conservation Program. NOAA Technical Memorandum CRCP 33, 39 pp.

McCormick, M. 1994. Comparison of field methods for measuring surface topography and their associations with a tropical reef fish assemblage. *Mar. Ecol. Prog. Ser.* 112: 87-96.

Minton, D., E. Conklin, P. Weiant, and C. Wiggins. 2012. 40 Years of Decline on Puako's Coral Reefs: A Review of Historical and Current Data (1970-2010). TNC Technical Report. 50 pp.

Minton, D., E. Conklin, K. Pollock. 2013. 2012 Baseline Surveys of Marine Resource: Polanui, Maui. TNC Technical Report. 30 pp.

Minton, D., C. Couch, R. Most, C. Wiggins, and E. Conklin. 2018a. Final Baseline Condition Assessment: 2015 and 2016 Kaʻūpūlehu, Hawaiʻi Marine Surveys. TNC Technical Report. 61 pp.

Minton, D., E. Conklin, C. Couch, R. Amimoto, R. Carr, H. Lynch, R. Most, and C. Wiggins. 2018b. Final Baseline Condition Assessment: 2016 West Hawaiʻi Reef Resilience Marine Surveys. TNC Technical Report prepared for NOAA. 37 pp.

NRCS. 2003. Lahaina Watershed Flood Control Project. Final Environmental Impact Statement. 508 pp.

Nystrom, M. and C. Folke. 2001. Spatial Resilience of Coral Reefs. *Ecosystems* 4: 406-17.

Polanui Hiu. 2012. Community Action Plan. 12 pp. Available online at: https://www.mauinui.net/polanui-hiu.html

Ocean Tipping Points. 2016. Online data layer: Fisheries Catch=Total. Last accessed February 14, 2020. https://www.pacioos.hawaii.edu/projects/oceantippingpoints/#data

Oksanen, J., F. Guillaume Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P. R. Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, E. Szoecs, and H. Wagner. 2017. Package 'vegan' (April 7, 2017).

Pickett, E. and I Grossman. 2014. Western Maui Community Wildfire Protection Plan. 137 pp.

PIFSC. 2017. Baseline assessments for coral reef community structure and demographics on west Maui. Data Report. NOAA Fisheries Pacific Science Center, PIFSC Special Publication, SP-17-001, 44p.

Prouty, N. G., A. Cohen, K. K. Yates, C. D. Storlazzi, P. W. Swarzenski, and D. White. 2017. Vulnerability of coral reefs to bioerosion from land-based sources of pollution. *Journal of Geophysical Research: Oceans* 122: 9319-31. https://doi.org/10.1002/2017JC013264

Roger, C. S. 1990. Responses of coral reefs and reef organisms to sedimentation. *Mar. Ecol. Prog. Ser.* 62(1): 185-202.

Ross, R. M. 1984. Growth and sexual strategies in the fish Thalassoma duperrey (Labridae), a protogynous hermaphrodite [abstract]. Environ. Biol. Fishes 10: 253-9.

SOEST Coastal Geology Group. 2013. Maui. Available online at: http://www.soest.hawaii.edu/coasts/publications/hawaiiCoastline/maui.html

Sparks, R., K. Stone, D. White and M. Ross. 2015. Maui and Lanai Monitoring Report. 42 pp.

SRGII (Sustainable Resources Group International, Inc.). 2012. Wahikuli-Honokōwai Watershed Management Plan, Volume 1: Watershed Characterization. 277 pp.

SSRI. 2017. Coral Bleaching Recovery Plan: Identifying Management Responses to Promote Coral Recovery in Hawai‘i. 47 pp.

Stock, J. 2019. Personal communication with Kim Falinski and Tova Callender.

Storlazzi, C. D., J. B. Logan, M. A. McManus, and B. E. McLaughlin. 2003. Coastal Circulation and Sediment Dynamics along West Maui, Hawai‘i Part II: 2003 Hydrographic Survey Cruises A-3-03-HW and A-4-03-HW Report on the spatial structure of currents, temperature, salinity and turbidity along Western Maui. U.S. Geological Survey. Open-File Report 03-430. 54 pp.

Talbot, R. 2014. Widespread reports of an unprecedented recruitment of reef fish juveniles in the Hawaiian Islands [excerpt]. *CORAL Magazine*.

Walsh, W. 2013. Background paper on West Hawai‘i aquarium 'white list'. 20 pp. (available online at: http://dlnr.hawaii.gov/dar/files/2014/05/WHI_Aquarium_Background.pdf)

Williams, I. D., W. J. Walsh, R. E. Schroeder, A. M. Friedlander, B. L. Richards, and K. A. Stamoulis. 2008. Assessing the importance of fishing impacts on Hawaiian coral reef fish assemblages along regional-scale human population gradients. *Environ. Conserv.* 35: 261-72.

Williams, I. D., D. J. White, R. T. Sparks, K. C. Lino, J. P. Zamzow, E. L. A. Kelly, H. L. Ramey. 2016. Responses of Herbivorous Fishes and Benthos to 6 Years of Protection at the Kahekili Herbivore Fisheries Management Area, Maui. *PLoS ONE* 11: e0159100. doi:10.1371/journal.pone.0159100.

Appendix B: Methods

Survey Area

West Maui Region (WMR)

The area of interest for the West Maui Region (WMR) was selected after consultation with Maui-based staff at Hawaiʻi Division of Aquatic Resources (DAR-Maui), The Nature Conservancy (TNC), and other Maui-based stakeholders familiar within the WMR. The survey area extends from Līpoa Point, north of Honolua Bay, to the Pali Tunnel on Honoapiʻilani Highway (Rte 30), and from approximately 3 m (10 ft) to 15 m (50 ft) depth. Surveys focused on hardbottom substratum (Figure B.1) as defined by NOAA's benthic habitat maps[138] and without regard to coral cover (*e.g.*, could be algae covered hardbottom). Within the Atlas, all hardbottom substrata are collectively referred to as "reef."

Focus Windows

The WMR was sub-divided into six Focus Windows (FW) that encompassed reef tracts with sufficient data to support detailed spatial and/or temporal analysis. Boundaries for each FW were created after consultation with DAR-Maui and TNC staff, and generally were associated with easily identified natural and artificial landmarks such as streams, points of land, public parks and marine management area boundaries, harbor channels, breakwaters, etc. (Figure B.1). The four FWs that had sufficiently dense sampling effort to support deeper spatial analysis were further subdivided into 2-3 reef tracts.

For the Atlas, the following FWs, and associated reef tracts were identified, from north to south:

- Honolua FW (Chapter 2)
  - Reef tracts: Līpoa Point, Honolua-Mokulēʻia MCLD, and Oneloa and Honokahua Bays
- Kahana FW (Chapter 3)
  - Reef tracts: None
- Kahekili FW (Chapter 4)
  - Reef tracts: Mahinahina and North Kāʻanapali
- Hanakaʻōʻō Beach FW (Chapter 5)
  - Reef tracts: None
- Lāhaina FW (Chapter 6)
  - Reef tracts: Mala, Lāhaina Town, and Polanui.
- Olowalu FW (Chapter 8)
  - Reef tracts: Olowalu Point, Olowalu, and Ukumehame

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[138] The resolution of the NOAA habitat maps for the WMR is relatively coarse compared to the spatial heterogeneity of most Hawaiian reefs and the benthic sampling unit (~10 m^2), so reef areas classified as "hardbottom" may contain patches with considerable amounts of unconsolidated bottom.

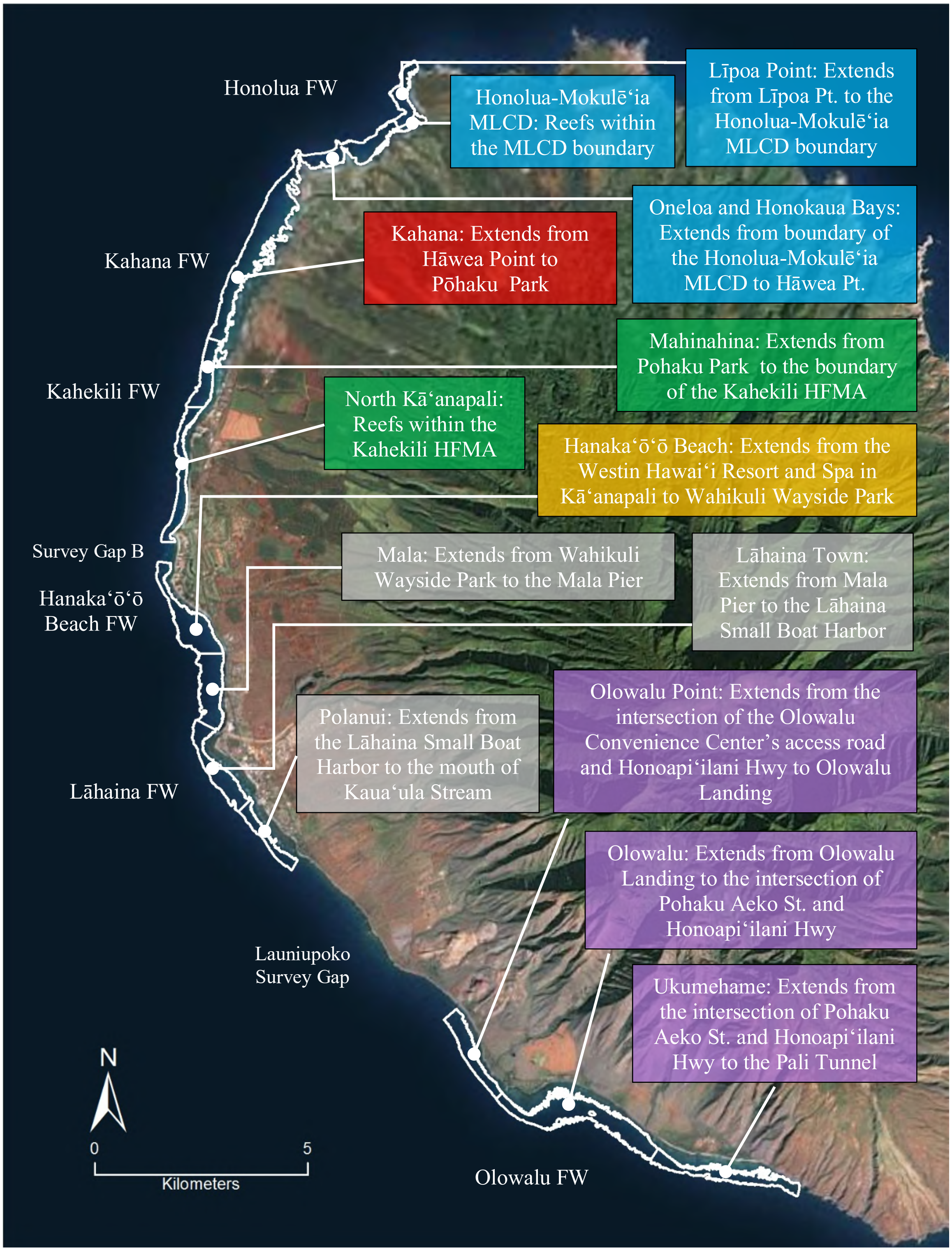

Figure B.1. The West Maui Region, including its six FWs, two survey gaps, and 13 reef tracts (white polygons and colored boxes). Reef tracts within the same FW share box colors.

The boundaries for each reef tract are briefly summarized in Figure B.1, with more detailed descriptions for each provided in their FW-specific chapters.

Survey Gaps

The six FWs covered 88.5% of the reef area for the WMR. Two survey gaps, designated Survey Gap B and Launiupoko Survey Gap (Figure B.1), were sections of reef that were poorly sampled and thus received little or no detailed analysis. Survey Gap B, which comprised 0.7% of the project area's reef, contained no surveys and was not discussed in detail in the Atlas. Launiupoko Survey Gap, comprising 10.8% of the reef area, contained few recent data (2016-2018). A pair of the Hawai‘i Coral Reef Assessment and Monitoring Program (CRAMP) long-term monitoring sites (Puamana Deep and Puamana Shallow) accounted for two-thirds of the survey gap's entire sampling effort. A limited analysis of these data is presented in Chapter 7 of the Atlas.

<u>Data Acquisition</u>

Existing Datasets

The Atlas used data collected specifically for this project (see below) and existing data that were collected within the survey area using comparable methods (Table B.1). Existing data were mined from known sources, including TNC, DAR-Maui, CRAMP, USGS Hawai‘i Cooperative Fishery Research Unit (HCFRU), University of Hawai‘i's Fisheries Ecology Research Lab (FERL), and NOAA's Ecosystems Sciences Division (ESD, but previously CRED), to whom we extend our gratitude for their assistance with acquiring and for use of these datasets.

Datasets with co-located fish and benthic data were preferred, but sites with fish- or benthic-only data were also incorporated into the analysis. While preference was given to data with geospatial information, data lacking latitude and longitude were incorporated where and when possible and appropriate, *e.g.*, the survey site was known with certainty to be within the boundary of the FW or reef tract of interest because the survey site name specified a narrowly definable location such as the Honolua-Mokulē‘ia MCLD.

Comparable data were considered of any information collected by a known organization using similar methods to those employed by TNC's marine monitoring team. These methods are described in detail below but generally involve collection of benthic cover data from photographs or video stills taken along a transect line and the sizing and identification to species of all fish along standardized belt transects, usually with an area of 100 or 125 m^2. Fish data collected by NOAA using the stationary point count method were not considered comparable with transect data and were not incorporated into the Atlas, except to estimate statewide averages (see below).

Even when methods used to collect data are similar, there exists the possibility that any differences among datasets could be an artifact of the data collection, often referred to under the general description of "observer bias." As data surveyors vary among programs and years, the training of survey personnel is critical to maintaining comparability among (and within) datasets.

Table B.1. Number of benthic and fish survey sites for each FW (by reef tract) and survey gap incorporated into the Atlas. First numbers are the surveys conducted specifically for this project (see below) followed by the number of the existing survey sites obtained from other sources. "Range" includes the range of years encompassing the earliest and latest surveys followed in parentheses by the number of years within that range that for which data exists. For example, "2002-2018 (5)" indicates there were five years for which data were available between 2002 and 2018 with the first available data occurring in 2002 and the most recent year available being 2018. The survey effort over these years may or may not have been uniform; see the specific chapters for each FW for a detailed breakdown of survey effort by year.

	Range (Years w/ data)	**Benthic**	**Fish**
Honolua FW			
Līpoa Point	2002-2019 (6)	0/10	0/33
Honolua-Mokulēʻia MCLD	1999-2019 (21)	0/124	0/109
Oneloa and Honokahua Bays	2002-2018 (6)	0/77	0/100
Kahana FW			
-	2002-2018 (12)	0/276	0/287
Kahekili FW			
Mahinahina	2004-2017 (12)	0/58	0/49
North Kāʻanapali	1999-2018 (20)	0/1,360	0/1,504
Hanakaʻōʻō Beach FW			
-	2008-2018 (9)	8/110	8/124
Lāhaina FW			
Mala	2017 (1)	16/0	16/0
Lāhaina Town	2010-2018 (6)	21/7	21/1
Polanui	2010-2018 (6)	25/76	25/73
Olowalu FW			
Olowalu Point	2008-2018 (6)	16/9	16/6
Olowalu	1999-2018 (20)	0/349	0/368
Ukumehame	2005-2018 (7)	0/13	0/6
Gap Areas†			
B		0/0	0/0
Launiupoko	1999-2018 (19)	5/54	5/8
WMR	**1999-2018 (20)**	**91/2,474**	**91/2,668**

†See the section on *Survey Gaps* for more information on these reef areas.

While "observer bias" is always a potential problem when examining datasets from different sources and times, we believe this problem is small because most survey programs in Hawaiʻi have good continuity in personnel, often work closely together, and often share team members, which has resulted in a pool of well-calibrated individuals either collecting or training new survey members within most data collection programs in the state.

New Data Collection (TNC 2017 West Maui Surveys)

Between May 8-18, 2017, TNC conducted Atlas-specific reef assessments to augment existing information and fill known data gaps in the WMR. This survey effort focused primarily on reefs between Olowalu Point and Hanakaʻōʻō Beach, approximately 14 km of coastline. Ninety-one, randomly selected[139] sites on hardbottom between 3 and 15 m depth (Figure B.2) were surveyed by trained divers to collect information on the fish and benthic assemblages. For all survey sites, locational information (latitude/longitude) and other metadata have been compiled in Appendix C.

Survey teams navigated via small, motorized boats to each predetermined site using a Garmin GPS unit. Once on site, divers on scuba were deployed and descended directly to the bottom, where they established two transect start-points approximately 10 m apart. From each start-point, divers deployed separate 25-m transect lines along a predetermined compass bearing, resulting in two transect lines running parallel to each other. If the pre-determined compass bearing resulted in a large change in depth, the bearing was altered such that the transect followed the contour at the depth of the start point. All data collection was conducted along one or both transect lines by trained divers who had been calibrated to reduce surveyor variability. The specific survey methods for each type of data collection are discussed in detail below.

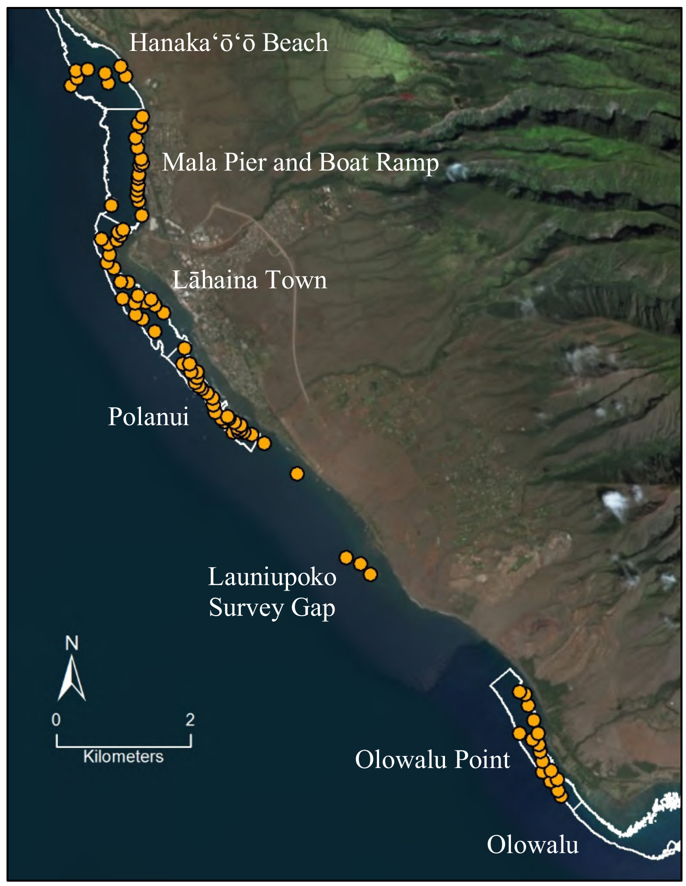

Figure B.2. Sites surveyed in 2017 by TNC's marine monitoring team.

Benthic Cover

At each survey site, photographs of the bottom were taken every meter along one of the 25-m transect lines using a Canon PowerShot camera or equivalent mounted on a PVC monopod. The white balance of the camera was adjusted prior to photographing each transect to improve color quality. This generated 25 images for each survey site, with each photo covering approximately 0.8 x 0.6 m of the bottom.

[139] Random sites were selected to get an unbiased measure of the reef community. Using a non-random site selection method, such as selecting sites known to have high fish abundance, would provide skewed or biased assessments.

Twenty randomly selected photographs from each transect were analyzed to estimate the percent cover of coral, algae, and other benthic categories. As needed, selected photographs were imported into Adobe Photoshop CS5 where their color, contrast, and tone were auto-balanced to improve photo quality prior to analysis. Photos were analyzed using CoralNet, an online repository and resource for benthic image analysis maintained by the University of California San Diego[140]. Thirty random points were overlaid on each digital photograph, and the benthic component under each point was classified into one of the following groups: coral (to species), macroalgae (to lowest possible taxonomic resolution), crustose coralline algae, turf, other biotic, and abiotic (to sand, rubble, or pavement). Once completed, the raw point data from each photograph was combined to calculate the percent cover of each benthic component for the survey site.

Benthic Topography

The topographic complexity of the bottom at each site was measured using an index of rugosity calculated along the first 10 m of the same 25-m transect used for benthic imagery by dividing the length of brass chain necessary to contour the bottom by the 10-m transect length[141]. For this index, a value of one represents a flat surface with no topographic relief, and increasing values represent more topographically complex substrata. While collected at nearly all survey sites, rugosity (Appendix C) data were not analyzed for the Atlas due to a lack of comparable data from other sources.

Coral Reef Fish Abundance and Biomass

While slowly deploying the parallel 25-m transect lines, divers identified to species and sized into 5-cm bins (*e.g.*, 0-5 cm, >5-10 cm, etc.) all fishes within and passing through a 5-m wide belt along the transect. This provided a survey area of 125 m^2. Divers took between 10 and 15 minutes to complete a single survey.

Data Management

All fish and site data were entered into a custom Access database and checked for errors. All benthic data were compiled in Excel spreadsheets prior to analysis. All databases and spreadsheets supported safeguards to ensure high data quality, and they reside on a secure, central TNC server that is backed up daily to an offsite location to protect against data loss.

Data Analysis

Data "Cleaning"

All datasets, whether collected specifically for this project or obtained from other data sources needed to be reconciled to remove duplicates, cull sites missing essential data (*e.g.*, sufficient locational information to place into a FW), standardize site names, and recombined benthic and fish data collected from the same site, but supplied to TNC in separate data files. All fish

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[140] Beijbom *et al.* (2015)
[141] McCormick (1994)

biomass values were recalculated using the length-to-biomass conversion coefficients compiled by FERL from FishBase[142] and the HCFRU. Where available, length-to-biomass coefficients specific to Hawaiʻi were used.

Benthic data were more difficult to reconcile than fish data due to differences in the taxonomic resolution among the datasets. Differences among the datasets made direct comparisons at the species-level problematic, but it was possible to combine data into higher taxonomic groups. For example, different datasets may have identified *Halimeda* algae to the species level, *e.g.*, *Halimeda opuntia*, or to the genera-level, *e.g.*, *Halimeda* spp. These were reconciled by collapsing all *Halimeda* data into *Halimeda* spp.

Data Consolidation

While both fish and benthic data were often collected with high taxonomic resolution, they were aggregated into coarser taxonomic categories (*e.g.*, fish families, invertebrate phyla, etc.), trophic groups, or other logical groupings (*e.g.*, resource fish) for analyses.

Where possible, benthic data were combined into the following benthic groups for analysis: turf, coral (subdivided by species), crustose coralline algae (CCA), macroalgae, cyanobacteria, other, and abiotic substratum (subdivided by type). In some cases, information was not available for all benthic groups at all survey sites. In these cases, the benthic group lacking complete information was removed and any existing data for that benthic group available at other survey sites were collapsed into the "other" category. In most cases, coral data at the species-level were comparable; however, macroalgae were inconsistently identified to species, so no formal analyses at this level were conducted and information was examined qualitatively.

Fish data were pooled into several groups, including total (all) fish, fish family, resource fish[143] including a selected non-resource group for comparison, and prime spawners. Resource fish refer to fishes desirable for food, commercial activity, and/or cultural practices in Hawaiʻi[144], whereas the selected non-resource fish are species not routinely targeted by fishers to a significant degree in Hawaiʻi (Table B.2). Several species included in the non-resource fish list are targeted in the aquarium fishery, but landings as part of this fishery are not high for Maui, and none of the non-resource species that are collected in this fishery comprise a large component of the catch at the state-wide level[145]. Nearly all fish species are taken by some fishers at some time in Hawaiʻi, therefore designating a fish species as either "resource" or "non-resource" is oftentimes difficult. These two groupings are intended to represent the high and low ends of the fishing pressure continuum. Most fish species fall somewhere in the middle of this continuum, and these species were considered "moderately-prized" when included in any analyses. Prime spawners are individual resource fish >70% of the maximum length for that species. These individuals tend to exert a disproportionately large effect on population dynamics

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[142] Froese and Pauly (2010)
[143] In other TNC reports, "resource fish" may be called "target fish." The species comprising these groups are identical (Table B.2).
[144] Williams *et al.* (2008)
[145] Walsh (2013)

Table B.2. Fish species comprising the seven resource species groups and the non-resource group used in this report. Groups are modified from Williams *et al.* (2008).

Resource Groups	
Surgeonfish (Acanthuridae)	Apex
Acanthurus achilles	*Aphareus furca*
Acanthurus blochii	*Aprion virescens*
Acanthurus dussumieri	All Carangidae (jacks)
Acanthurus leucopareius	All Priacanthidae (big-eyes)
Acanthurus nigroris	All Sphyraenidae (barracuda)
Acanthurus olivaceus	
Acanthurus triostegus	Goatfish (Mullidae)
Acanthurus xanthopterus	All
Ctenochaetus spp.	
Naso spp.	Parrotfish (Scaridae)
	All
Wrasses (Labridae)	
Bodianus albotaeniatus	Soldier/Squirrelfish (Holocentridae)
Cheilio inermis	*Myripristis* spp.
Coris flavovittata	*Sargocentron spiniferum*
Coris gaimard	*Sargocentron tiere*
Iniistius spp.	
Oxycheilinus unifasciatus	Others
Thalassoma ballieui	*Chanos chanos*
Thalassoma purpureum	*Cirrhitus pinnulatus*
	Monotaxis grandoculis
Non-resource	
Acanthurus nigrofuscus	*Chaetodon quadrimaculatus*
Acanthurus nigricans	*Chaetodon unimaculatus*
Chaetodon multicinctus	*Plectroglyphidodon* spp.
Chaetodon ornatissimus	*Stegastes* spp.
All wrasses, except those listed above	
All hawkfish, except *Cirrhitus pinnulatus*	
All triggerfish, except planktivorous species	

due to their considerably higher fecundity and egg quality compared to smaller individuals[146]. Conservation of prime spawners is important to maintaining sustainable fisheries and ecosystems.

Statistical Analysis

All means are presented as the average ± the standard error of the mean (SEM) unless otherwise stated. Standard univariate parametric statistical approaches, as appropriate, were used to test for

[146] Birkeland and Dayton (2005) and Hixon *et al*. (2014)

trends and differences among reef tracts and survey years. Where possible, a multifactor ANOVA including reef tract and sampling year was used to examine summary-level variables (*e.g.*, total fish biomass, total fish abundance). All factors were considered fixed. Any significant interaction term was investigated using graphical plots to assess the effect of the interaction on the interpretation of the individual factors. Model fit was assessed by examining the distribution of model residuals, Cook's distances with values greater than 4/n as the threshold for influential data points, and leverage. *A posteriori* tests were conducted using a Tukey-adjusted threshold for significance to control Type I error rates. Where a multi-factor ANOVA was not appropriate, a single factor t-test generally was employed to test for difference. As necessary, variables such as fish biomass were (log+1)-transformed to correct skewness and improve heteroscedasticity prior to analysis. Given the natural variability of coral reef ecosystems, we considered statistical significance to be $p_{adj} \leq 0.05$ and marginal significance to be $0.05 < p_{adj} \leq 0.10$. In some cases, assemblage structure was examined using PERMANOVA with reef tract and/or sampling year as factors. Multivariate data were visualized using multi-dimensional scaling (MDS).

All statistical analyses were conducted in R ver. 3.5.0 (2018-04-23). Final data were exported to Microsoft Excel for graphing and figure generation. Multi-factor ANOVAs were conducted using standard linear model functions in R. All multivariate analyses were conducting using the "vegan" package[147], with follow-up PERMANOVA pairwise comparisons made using the "pairwise.adonis()" function developed by Pedro Martinez Arbizu.

Spatial Mapping

Polygons depicting the boundaries of all reef tracts and survey gaps were delineated within ArcMap and combined to create a polygon for the WMR. Shoreward and seaward boundaries of each polygon were created using the 3 m (10 ft) and 15.2 m (50 ft) depth isoclines in the LIDAR data layer (2013 USACE NCMP Topobathy Lidar for Maui). North-south boundaries were hand digitized using visual landmarks on satellite imagery. These boundaries had been determined prior to analysis after consultation with DAR-Maui and TNC staff, and generally were associated with easily identified natural and artificial landmarks such as streams, points of land, public parks and marine management area boundaries ("Marine Managed Areas (DAR)" layer file from the State of Hawai'i Office of Planning), harbor channels, breakwaters, etc. A hardbottom layer was generated by extracting "coral and hardbottom" from the "Benthic Habitats of the Main Hawaiian Islands prepared from IKONOS and Quick Bird Satellite Imagery" layers for all but the Kahekili area. The hardbottom area inside of Kahekili was generated by manually adding the benthic categories encompassed in the "coral and hardbottom" attributes from the NOAA Benthic Habitat maps.

Survey site data were imported into ArcMap and used to generate interpolation models across the WMR to help visualize spatial patterns within the data. Models were interpolated from the most current (2016-2018) data using ArcMap's kriging spatial tool with a Gaussian semivariogram model using a variable search radius that encompassed the 12 nearest data points. Lag size was set as the observed mean distance of the nearest neighbor (as determined using the ArcMap's average nearest neighbor tool) and an output cell size of 10 was used. A cell size of 10 was

[147] Oksanen *et al*. (2017)

selected because it approximated the spatial resolution of the input data. Models were generated for the entire WMR for coral cover, benthic diversity ($Hill_1$), total fish biomass, resource fish biomass, prime spawner biomass, and fish diversity ($Hill_1$).

Models were masked using the hardbottom and FW window polygons to isolate them to appropriate survey area. Colors were ramped such that yellow was average value based on the survey data and other colors were delineated based on the variability derived from the interpolation. Color ramps for regional figures (Chapter 1) were based on the regional data, whereas color ramps for the FWs (Chapter 2-8) were developed using only the data from within the FW. This allowed for more detailed spatial patterns to be illustrated within each FW. In a few cases, color ramps were forced to be identical across multiple figures to facilitate better comparisons for the reader (*e.g.*, when comparing coral cover across two years).

For the Olowalu FW, change of coral cover from 2015 to 2016 was examined by generating separate models of coral cover for each year. These models were used to generate a new raster showing the relative change in coral cover (Δ_{cc}) using the following formula (eq.1):

$$\Delta_{CC} = \frac{(CC_{2016} - CC_{2015})}{CC_{2015}} \qquad \text{(eq.1)}$$

Standardizing Qualitative Terms

Regionally-scaled qualitative language was used to contextualize the marine resources within the FWs at a broader, WMR-scale. Table B.3 provides the mathematical definitions and a quick reference color scheme that was employed throughout the Atlas for the qualitative terms high, medium-high, average, medium-low, and low. These mathematical definitions rely on a normal probability distribution. Many of the metrics used to describe abundance, biomass, and diversity of corals reefs (*e.g.*, fish biomass, percent cover, etc.) often do not follow a normal distribution and instead tend to be right skewed. This results in an “inflated” average, which will have the practical result of causing more reef areas to be classified as average or below average. In the context of conservation planning, using a normal distribution for data that are right skewed would highlight the relatively few reef areas that have high resource abundance, biomass, or diversity, information critical for developing priorities for conservation and/or management action. In particular, fish data tend to be heavily right skewed due to a few, often very extreme outliers, so to reduce the effects of these outliers, trimmed averages were calculated after removing 5% of the data points from the upper and lower ends of the distribution. The trimmed averages were used in place of normal arithmetic averages for defining the qualitative terms, but normal arithmetic averages were used elsewhere in the Atlas.

Statewide averages

To place the condition of WMR reefs into a broader, statewide context, comparisons were made with the statewide averages for coral cover, total fish biomass, resource fish biomass, and prime spawner biomass. Average values for the four parameters were estimated for the MHI from existing data.

Table B.3. Mathematical definitions and narrative description for the five qualitative categories used in the Atlas to describe abundance, biomass, and diversity of the benthic and fish assemblages of the WMR. The color assigned to each category, with warmer colors representing higher values, is used throughout the Atlas. For all fish metrics, a trimmed mean (described in the text) was used instead of the arithmetic mean.

Term	Definition	"Real World" Description
High	$y > \bar{x} + 1\ s$	A high value is greater than the mean plus one standard deviation. Only reefs with the highest abundance, biomass, or diversity should qualify for this category. Few reefs should fall into this category.
Medium-high	$\bar{x} - ½\ s < y < \bar{x} + 1\ s$	A medium high value falls between the mean plus half the standard deviation and the mean† plus one standard deviation.
Average	$\bar{x} - ½\ s < y < \bar{x} + ½\ s$	An average value falls between the mean plus and minus half of the standard deviation. Most coral metrics are not normally distributed, which should result in most coral reef areas falling to this category or below†.
Medium-low	$\bar{x} - ½\ s < y < \bar{x} + 1\ s$	A medium-low value falls between the mean minus half the standard deviation and the mean minus one standard deviation†.
Low	$y < \bar{x} - 1\ s$	A low value is less than the mean minus one standard deviation. Only reefs with the lowest abundance, biomass, or diversity should qualify for this category†.

† For prime spawners, variability exceeded the mean even after trimming the data. Therefore, for prime spawners, low was defined as $y < 0.1$, medium-low as $0.1 < y < ½\ \bar{x}$, and average as $½\ \bar{x} < y < \bar{x} + ½\ s$.

In 2008, CRAMP estimated statewide coral cover at 20.8 ± 1.7%. This estimate was derived from their network of long-term locations (augmented with some additional data). However, due to the way CRAMP monitoring sites were selected, this is likely an overestimate of coral cover across the state (relative to the Atlas) because hardbottom areas with no coral were not included as part of the monitoring design and site selection. More recently[148], an average statewide coral cover of 10.5% (no variance estimate was provided) was estimated from an interpolation model developed from statewide data collected from 2000-2009. This estimate is more comparable to the data included in the Atlas. Unfortunately, this estimate is generated from data over a decade old, and given the 2014 and 2015 bleaching events, may no longer provide an accurate portrait of Hawai‘i's reefs. The ESD has conducted periodic surveys of benthic and fish resources across the MHI. These surveys sample randomly selected hardbottom locations and collect coral cover data directly comparable to that used in the Atlas. While these surveys were limited by logistics (*i.e.*, some large windward reef tracts could not be surveyed), these data are relatively current

[148] Franklin *et al.* (2013)

and likely provide the best estimate of the state of coral on Hawaiian Reefs. Using ESD data from 2015-2016 (the most recent post-bleaching data available), average coral cover for the state was 14.4 ± 0.7% (n=516), which likely is slightly greater than the true average given the exclusion of some windward reefs, which tend to have lower coral cover than more accessible leeward reefs. Estimates for statewide and islandwide average coral cover appear in Table B.4.

Table B.4. Statewide and islandwide averages for coral cover derived from ESD data from 2015-2016.

Island	n	% Coral
Ni‘ihau	52	2.2 ± 0.4
Kaua‘i	49	4.3 ± 0.8
O‘ahu	81	8.1 ± 1.3
Moloka‘i	68	19.2 ± 2.7
Maui	52	20.8 ± 2.4
Lāna‘i	40	25.3 ± 3.3
Kaho‘olawe	24	17.9 ± 4.3
Hawai‘i Is.	150	17.5 ± 1.2
Hawai‘i	**516**	**14.4 ± 0.7**

In 2017, a study[149] estimated average resource fish biomass for the MHI to be between 47 and 50 g/m^2, but this value is not comparable because definition of resource fish used in the study differed from that used in the Atlas. No comparable average total fish or prime spawner biomass has been located for the MHI. For the Atlas statewide average biomass values for total fish, resource fish, and prime spawners were estimated from 2016 ESD fish surveys conducted across the MHI. The ESD surveys used a different data collection method (Stationary Point Count or SPC) than the data sets used in the Atlas (Belt Transects), which complicates comparability. SPC surveys tend produce lower fish biomass estimates compared to belt transects due to their use of "instantaneous" count data, *i.e.*, divers systematically record one group of fishes at a time and do not count more of that group once moving on to the next group of fish[150]. In contrast, belt transects typically record all fishes regardless of group present in, moving into, or across a survey area ahead of the diver during some loosely defined time period ("non-instantaneous" count data). As part of their survey protocol, ESD also collected "non-instantaneous" count data, so while not a perfect solution, both instantaneous and non-instantaneous observations were pooled to generate average statewide and islandwide biomass estimates. Using the 2016 ESD fish data, average total fish biomass was 40.9 ± 2.5 g/m^2 (n=256), average resource fish biomass was 22.3 ± 1.8 g/m^2 (n=256), and average prime spawner biomass was 3.7 ± 1.0 g/m^2 (n=256). TNC also has collected fish biomass data at numerous sites in the MHI using methods directly comparable to the Atlas, but the spatial distribution of these locations is limited. However, statewide averages calculated from these data are consistent with those derived from the ESD data.

[149] Friedlander *et al.* (2017)
[150] Heenan *et al.* (2017)

Appendix C: 2017 West Maui Survey Site Metadata

Site metadata for TNC surveys conducted in 2017. Surveys were conducted specifically to augment existing information and fill known gaps in the data for the West Maui Region.

Site Code	Date	Latitude	Longitude	Rugosity	Depth (m)
2017-POL-WMAU-229	5/17/2017	20.85921	-156.67225	1.13	3.66
2017-POL-WMAU-233	5/17/2017	20.86419	-156.67785	1.02	10.06
2017-POL-WMAU-234	5/15/2017	20.86043	-156.67413	1.58	5.34
2017-POL-WMAU-238	5/15/2017	20.85789	-156.67066	1.45	4.88
2017-POL-WMAU-239	5/17/2017	20.86016	-156.67506	1.03	11.43
2017-POL-WMAU-241	5/17/2017	20.86572	-156.67844	1.3	5.79
2017-POL-WMAU-246	5/17/2017	20.86360	-156.67703	1.15	8.23
2017-POL-WMAU-248	5/17/2017	20.85840	-156.67253	1.1	9.76
2017-POL-WMAU-249	5/15/2017	20.86509	-156.67873	1.075	9.76
2017-POL-WMAU-252	5/17/2017	20.86201	-156.67614	1.31	9.91
2017-POL-WMAU-254	5/13/2017	20.85826	-156.67333	1.08	12.2
2017-POL-WMAU-255	5/15/2017	20.85970	-156.67461	1.06	10.82
2017-POL-WMAU-257	5/17/2017	20.85963	-156.67318	1.22	3.96
2017-POL-WMAU-259	5/15/2017	20.86015	-156.67395	1.4	5.03
2017-POL-WMAU-260	5/17/2017	20.86454	-156.67814	0	10.67
2017-POL-WMAU-261	5/17/2017	20.85859	-156.67227	1.49	5.18
2017-POL-WMAU-262	5/17/2017	20.86290	-156.67620	1.6	4.57
2017-POL-WMAU-270	5/17/2017	20.85823	-156.67188	1.4	7.77
2017-POL-WMAU-271	5/15/2017	20.86098	-156.67593	1.21	12.65
2017-POL-WMAU-272	5/17/2017	20.85887	-156.67274	1.5	6.71
2017-WMAU-001	5/8/2017	20.87591	-156.68565	1.42	7.47
2017-WMAU-105	5/10/2017	20.89473	-156.68584	1.43	3.51
2017-WMAU-106	5/10/2017	20.89442	-156.68618	1.56	4.42
2017-WMAU-109	5/8/2017	20.87635	-156.68485	1.52	5.34
2017-WMAU-11	5/18/2017	20.80933	-156.62758	1.04	14.33
2017-WMAU-117	5/11/2017	20.87550	-156.68433	1.33	6.25
2017-WMAU-119	5/8/2017	20.87446	-156.68307	1.35	5.79
2017-WMAU-121	5/11/2017	20.87689	-156.68668	1.325	6.25
2017-WMAU-122	5/8/2017	20.88059	-156.69009	1.475	4.57
2017-WMAU-123	5/16/2017	20.88546	-156.68947	1.42	7.77
2017-WMAU-125	5/10/2017	20.88957	-156.68641	1.1	4.73
2017-WMAU-126	5/10/2017	20.89036	-156.68665	1.2	4.73
2017-WMAU-128	5/8/2017	20.87864	-156.68810	1.275	4.88
2017-WMAU-131	5/10/2017	20.88766	-156.68605	1.5	2.74
2017-WMAU-133	5/11/2017	20.88140	-156.69106	1.515	7.16

Site Code	Date	Latitude	Longitude	Rugosity	Depth (m)
2017-WMAU-138	5/10/2017	20.89109	-156.68660	1.51	3.2
2017-WMAU-139	5/18/2017	20.88580	-156.68875	1.29	6.55
2017-WMAU-143	5/11/2017	20.88250	-156.69070	1.34	5.03
2017-WMAU-146	5/8/2017	20.88507	-156.68910	1.31	5.49
2017-WMAU-149	5/10/2017	20.89180	-156.68649	1.49	3.2
2017-WMAU-15	5/18/2017	20.82239	-156.63210	1.18	4.57
2017-WMAU-153	5/11/2017	20.88439	-156.68965	1.42	4.73
2017-WMAU-155	5/8/2017	20.88389	-156.69086	1.52	7.47
2017-WMAU-16	5/9/2017	20.80858	-156.62716	1.13	15.55
2017-WMAU-162	5/16/2017	20.87653	-156.68897	1.45	13.11
2017-WMAU-165A	5/11/2017	20.87426	-156.68715	1.45	12.65
2017-WMAU-168	5/16/2017	20.88457	-156.69184	1.32	12.65
2017-WMAU-17	5/9/2017	20.81713	-156.63026	1.28	3.81
2017-WMAU-179	5/16/2017	20.88904	-156.69034	1.53	13.11
2017-WMAU-18	5/18/2017	20.81464	-156.63004	1.53	7.47
2017-WMAU-183	5/18/2017	20.90004	-156.68640	1.21	5.64
2017-WMAU-185	5/18/2017	20.89813	-156.68673	0	7.01
2017-WMAU-186A	5/18/2017	20.89529	-156.68601	1.11	2.9
2017-WMAU-187	5/10/2017	20.89683	-156.68647	1.26	6.71
2017-WMAU-19	5/9/2017	20.81086	-156.62762	1.3	8.23
2017-WMAU-190	5/16/2017	20.87199	-156.68440	1.02	12.35
2017-WMAU-192	5/11/2017	20.87591	-156.68714	1.43	10.82
2017-WMAU-198	5/10/2017	20.90099	-156.68568	1.31	3.51
2017-WMAU-199	5/16/2017	20.89959	-156.68593	1.19	3.2
2017-WMAU-20	5/15/2017	20.82278	-156.63287	1.18	5.49
2017-WMAU-200	5/10/2017	20.89272	-156.68643	1.3	3.66
2017-WMAU-207	5/18/2017	20.90743	-156.69349	1.01	12.65
2017-WMAU-208	5/10/2017	20.90561	-156.69059	0	6.83
2017-WMAU-212	5/16/2017	20.90534	-156.69591	1.2	15.55
2017-WMAU-214	5/16/2017	20.90632	-156.69497	1.04	13.72
2017-WMAU-216	5/10/2017	20.90730	-156.69514	1.11	13.41
2017-WMAU-218	5/16/2017	20.90691	-156.69097	1.2	9.91
2017-WMAU-220A	5/18/2017	20.90783	-156.68869	1.32	3.35
2017-WMAU-221	5/16/2017	20.90642	-156.68803	1.4	3.2
2017-WMAU-227	5/18/2017	20.84114	-156.65741	1.11	12.35
2017-WMAU-24	5/9/2017	20.81204	-156.62852	1.325	7.32
2017-WMAU-25	5/9/2017	20.81329	-156.62970	1.25	9.45
2017-WMAU-28	5/18/2017	20.81066	-156.62858	1.1	13.87
2017-WMAU-29	5/9/2017	20.81625	-156.63108	1.4	7.32

Site Code	Date	Latitude	Longitude	Rugosity	Depth (m)
2017-WMAU-3	5/9/2017	20.81556	-156.63019	1.275	5.03
2017-WMAU-30	5/15/2017	20.82090	-156.63167	1.36	3.35
2017-WMAU-303	5/8/2017	20.87370	-156.68611	1.175	12.96
2017-WMAU-33	5/9/2017	20.81193	-156.62972	1.12	13.41
2017-WMAU-34	5/15/2017	20.81888	-156.63090	1.21	3.96
2017-WMAU-52	5/15/2017	20.81712	-156.63292	1.15	13.41
2017-WMAU-56	5/9/2017	20.84031	-156.65535	1.425	5.34
2017-WMAU-57	5/9/2017	20.83883	-156.65398	1.42	3.51
2017-WMAU-61	5/9/2017	20.85668	-156.66895	1.195	6.25
2017-WMAU-62A	5/9/2017	20.85255	-156.66432	1.31	5.03
2017-WMAU-66	5/11/2017	20.86644	-156.67845	1.15	3.66
2017-WMAU-67	5/11/2017	20.87878	-156.68917	1.39	7.47
2017-WMAU-71	5/11/2017	20.86649	-156.67926	1.37	7.93
2017-WMAU-78	5/8/2017	20.86971	-156.68011	1.43	7.01
2017-WMAU-79	5/11/2017	20.86757	-156.68043	1.4	8.84
2017-WMAU-87	5/11/2017	20.86761	-156.67949	1.48	4.73
2017-WMAU-93	5/18/2017	20.89324	-156.68638	1.25	3.66

Appendix D: Fish Species by Reef Tract

Fish species observed in each reef tract within the West Maui Region. Species list was obtained from surveys conducted between 2016 and 2018 (see Appendix B for number of survey sites). Reef tracts are arranged from most northerly (left) to most southerly (right), with color groups representing reef tracts within the same FW. LP = Līpoa Point, H = Honolua-Mokulēʻia MLCD, OH = Oneloa and Honokahua Bays, K = Kahana, MH = Mahinahina, NK = North Kāʻanapali, HB = Hanakaʻōʻō Beach, ML = Mala, L = Lāhaina, P = Polanui, OP = Olowalu Point, O = Olowalu, and U = Ukumehame.

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Acanthuridae													
Acanthurus achilles						X				X		X	X
Acanthurus blochii	X	X	X	X	X	X	X	X	X	X	X	X	
Acanthurus dussumieri	X	X	X	X		X	X	X		X	X	X	
Acanthurus guttatus				X									
Acanthurus leucopareius	X	X	X	X		X	X			X	X	X	X
Acanthurus nigricans	X			X		X						X	
Acanthurus nigrofuscus	X	X	X	X	X	X	X	X	X	X	X	X	X
Acanthurus nigroris			X	X		X		X		X		X	X
Acanthurus olivaceus	X	X	X	X	X	X	X	X	X	X	X	X	X
Acanthurus thompsoni					X	X							
Acanthurus triostegus	X	X	X	X		X	X		X	X	X	X	X
Acanthurus xanthopterus							X	X					
Ctenochaetus hawaiiensis						X				X		X	X
Ctenochaetus strigosus	X	X	X	X	X	X	X	X	X	X	X	X	X
Naso brevirostris	X	X	X	X	X	X	X	X	X	X	X	X	
Naso hexacanthus	X		X	X	X	X	X	X	X	X	X	X	X
Naso lituratus	X	X	X	X	X	X	X	X	X	X	X	X	X
Naso unicornis	X	X	X	X	X	X	X	X	X	X	X	X	X
Zebrasoma flavescens	X	X	X	X	X	X	X	X	X	X	X	X	X
Zebrasoma veliferum	X	X		X		X	X	X				X	

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Antennaridae													
Antennarius sp.						X							
Apogonidae													
Apogon kallopterus		X	X	X	X	X						X	
Apogon sp.				X						X	X		
Pristiapogon kallopterus											X		
Aulostomidae													
Aulostomus chinensis	X	X	X	X		X	X	X	X	X		X	X
Balistidae													
Melichthys niger	X	X	X	X	X	X	X	X	X	X	X	X	X
Melichthys vidua	X	X	X	X	X	X	X	X	X	X	X	X	X
Rhinecanthus aculeatus				X	X	X		X				X	
Rhinecanthus rectangulus	X	X	X	X	X	X	X	X	X	X	X	X	X
Sufflamen bursa	X	X	X	X	X	X	X	X	X	X	X	X	X
Sufflamen fraenatus	X	X	X	X	X	X	X		X	X	X	X	
Xanthichthys auromarginatus											X		
Blenniella gibbifrons			X										
Cirripectes vanderbilti	X	X		X		X	X	X	X			X	
Exallias brevis				X		X	X		X	X		X	
Plagiotremus ewaensis	X							X			X	X	
Plagiotremus goslinei	X	X	X	X		X				X	X	X	
Caracanthidae													
Caracanthus typicus	X		X	X		X							
Carangidae													
Carangidae												X	
Carangoides ferdau						X			X				
Carangoides orthogrammus		X				X	X						
Caranx melampygus	X	X	X	X	X	X	X	X		X		X	

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Decapterus macarellus						X							
Scomberoides lysan	X	X	X	X		X	X	X		X			
Carcharhinidae													
Carcharhinus galapagensis						X							
Triaenodon obesus				X									
Chaetodontidae													
Chaetodon auriga	X	X		X	X	X	X	X	X	X	X	X	X
Chaetodon citrinellus				X									
Chaetodon fremblii	X		X	X		X				X			
Chaetodon kleinii	X		X	X	X	X	X	X	X	X	X	X	
Chaetodon lineolatus			X									X	
Chaetodon lunula	X	X	X	X	X	X	X	X	X	X	X	X	X
Chaetodon lunulatus		X		X		X		X				X	
Chaetodon miliaris	X		X	X		X	X	X	X	X	X		
Chaetodon multicinctus	X	X	X	X	X	X	X	X	X	X	X	X	X
Chaetodon ornatissimus	X	X	X	X	X	X	X	X	X	X	X	X	X
Chaetodon quadrimaculatus	X	X	X	X		X	X	X	X			X	X
Chaetodon reticulatus												X	
Chaetodon unimaculatus		X		X	X	X	X	X	X	X		X	X
Forcipiger flavissimus	X		X	X	X	X	X		X	X	X	X	X
Forcipiger longirostris	X		X			X	X		X	X	X	X	
Hemitaurichthys thompsoni	X												
Heniochus diphreutes				X									
Chanidae													
Chanos chanos													
Cheilodactylidae													
Cheilodactylus vittatus												X	
Cirrhitidae													

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Amblycirrhitus bimacula			X										
Cirrhitops fasciatus	X	X	X	X				X		X	X	X	
Cirrhitus pinnulatus	X	X	X	X		X	X					X	
Paracirrhites arcatus	X	X	X	X	X	X	X	X	X	X	X	X	X
Paracirrhites forsteri	X	X	X	X	X	X	X	X	X	X	X	X	X
Diodontidae													
Diodon holocanthus				X								X	
Diodon hystrix		X		X	X	X	X					X	
Fistulariidae													
Fistularia commersonii	X	X		X		X			X	X		X	
Gobiidae													
Gobiidae sp.			X	X			X		X				
Hemiramphidae													
Hyporhamphus acutus pacificus				X									
Myripristis amaena							X						
Myripristis berndti		X		X		X					X		
Myripristis kuntee						X	X			X	X		
Myripristis sp.					X								
Neoniphon sammara				X		X						X	
Neoniphon sp.							X						
Sargocentron diadema						X							
Sargocentron punctatissimum												X	
Sargocentron spiniferum										X			
Sargocentron xantherythrum							X		X	X	X	X	
Kuhliidae													
Kuhlia sandvicensis		X											
Kyphosidae													
Kyphosus sp.	X	X		X								X	

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Labridae													
Anampses chrysocephalus									X	X	X		
Anampses cuvier	X		X	X					X				
Bodianus albotaeniatus	X		X	X	X	X	X	X	X	X	X	X	
Cheilio inermis	X			X		X		X				X	
Coris ballieui										X			
Coris flavovittata	X											X	
Coris gaimard	X	X	X	X	X	X	X	X	X	X	X	X	X
Coris venusta	X	X	X	X	X	X	X		X	X	X	X	
Cymolutes lecluse				X									
Gomphosus varius	X	X	X	X	X	X	X	X	X	X	X	X	X
Halichoeres ornatissimus	X	X	X	X	X	X	X	X	X	X	X	X	X
Iniistius sp.							X			X			
Labridae sp.			X										
Labroides phthirophagus	X	X	X	X		X		X	X	X	X	X	X
Macropharyngodon geoffroy	X	X	X	X		X		X	X	X	X	X	
Novaculichthys taeniourus			X	X		X			X				
Oxycheilinus bimaculatus				X						X	X	X	
Oxycheilinus unifasciatus		X			X	X	X	X	X	X	X	X	X
Pseudocheilinus evanidus	X			X	X	X	X	X	X	X	X	X	
Pseudocheilinus octotaenia	X				X	X	X	X	X	X	X	X	X
Pseudocheilinus tetrataenia	X	X	X	X	X	X	X	X	X	X	X	X	X
Pseudojuloides cerasinus				X			X		X	X	X		
Stethojulis balteata	X	X	X	X	X	X	X	X	X	X	X	X	X
Thalassoma ballieui						X						X	
Thalassoma duperrey	X	X	X	X	X	X	X	X	X	X	X	X	X
Thalassoma purpureum							X						
Thalassoma quinquevittatum		X											

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Thalassoma trilobatum	X	X	X	X									
Xyrichtys pavo				X									
Lethrinidae													
Monotaxis grandoculis	X	X	X	X	X	X	X	X	X	X	X	X	
Lutjanidae													
Aphareus furca						X						X	
Aprion virescens		X		X			X		X			X	
Lutjanus fulvus	X	X										X	
Lutjanus kasmira		X		X		X		X					
Malacanthidae													
Malacanthus brevirostris			X	X									
Microdesmidae													
Gunnellichthys curiosus	X								X	X			
Ptereleotris heteroptera	X		X	X			X	X	X	X		X	
Monacanthidae													
Cantherhines dumerilii	X	X	X	X		X	X	X	X	X		X	X
Cantherhines sandwichiensis	X	X	X	X	X	X	X		X	X	X	X	X
Pervagor aspricaudus				X		X	X	X	X			X	
Pervagor spilosoma				X	X	X	X						
Mugilidae													
Mugil cephalus		X											
Mullidae													
Mulloidichthys flavolineatus	X	X		X		X	X			X	X	X	X
Mulloidichthys pflugeri				X									
Mulloidichthys vanicolensis		X		X		X	X					X	
Parupeneus cyclostomus	X	X	X	X	X	X	X	X	X	X	X	X	X
Parupeneus insularis	X	X		X		X	X	X	X	X	X	X	
Parupeneus multifasciatus	X	X	X	X	X	X	X	X	X	X	X	X	X

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Parupeneus pleurostigma		X	X	X	X	X	X	X	X	X		X	
Parupeneus porphyreus		X	X	X				X					
Muraenidae													
Echidna nebulosa													
Gymnomuraena zebra													
Gymnothorax eurostus													
Gymnothorax flavimarginatus													
Gymnothorax meleagris						X							
Gymnothorax sp.					X								
Gymnothorax steindachneri													
Gymnothorax undulatus													
Ostraciidae													
Ostracion meleagris		X	X	X		X	X	X	X	X	X	X	X
Ostracion whitleyi								X					
Pomacanthidae													
Centropyge fisheri							X						
Centropyge potteri	X			X	X	X	X		X	X	X	X	X
Pomacentridae													
Abudefduf abdominalis				X		X	X					X	X
Abudefduf sordidus		X		X				X					
Abudefduf vaigiensis	X			X		X	X					X	X
Chromis agilis	X	X			X	X	X	X	X	X	X	X	X
Chromis hanui	X	X		X	X	X	X	X	X	X	X	X	X
Chromis ovalis	X	X	X	X	X	X	X		X		X	X	
Chromis vanderbilti	X	X	X	X	X	X	X	X	X	X	X	X	X
Chromis verater				X		X							X
Dascyllus albisella			X	X	X	X	X	X	X	X	X	X	X
Plectroglyphidodon imparipennis	X	X	X	X		X		X	X	X	X	X	X

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Plectroglyphidodon johnstonianus	X	X	X	X	X	X	X	X	X	X	X	X	X
Plectroglyphidodon sindonis				X									
Stegastes marginatus	X	X	X	X	X	X	X	X	X	X	X	X	X
Priacanthidae													
Heteropriacanthus cruentatus				X		X							
Scaridae													
Calotomus carolinus	X	X	X	X	X	X	X	X	X	X	X	X	
Chlorurus perspicillatus				X		X	X	X	X			X	X
Chlorurus spilurus	X	X	X	X	X	X	X	X	X	X	X	X	X
Scarus dubius	X			X	X	X	X					X	X
Scarus psittacus	X	X	X	X	X	X	X	X	X	X	X	X	X
Scarus rubroviolaceus	X	X	X	X	X	X	X	X	X	X	X	X	
Scarus sp.						X	X			X			
Scorpaenidae													
Scorpaenopsis diabolus				X									
Serranidae													
Pseudanthias bicolor								X					
Cephalopholis argus	X	X		X	X	X	X	X	X	X	X	X	X
Sphyraenidae													
Sphyraena barracuda												X	
Synodontidae sp.				X									
Synodus binotatus	X											X	
Synodus sp.	X			X		X	X	X	X		X	X	
Synodus ulae				X									
Tetraodontidae													
Arothron hispidus						X							
Arothron meleagris		X	X	X	X								
Canthigaster amboinensis		X	X	X		X	X	X		X	X	X	

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Canthigaster coronata			X				X						
Canthigaster jactator	X	X	X	X	X	X	X	X	X	X	X	X	X
Zanclidae													
Zanclus cornutus	X	X	X	X	X	X	X	X	X	X	X	X	X

Appendix E: Benthic Taxa by Reef Tract

Benthic taxa observed in each reef tract within the West Maui Region. Taxon list was obtained from surveys conducted between 2016 and 2018 (see Appendix B for number of sure sites). Numbers for coral species indicate the ranked relative abundance for the six most common species by percent cover of the bottom, with 1 being most common. Insufficient data were available for Līpoa Point, Oneloa and Honokahua Bays, and Ukumehame reef tracts. Reef tracts are arranged from most northerly (left) to most southerly (right), with color groups representing reef tracts within the same FW. LP = Līpoa Point, H = Honolua-Mokulēʻia MLCD, OH = Oneloa and Honokahua Bays, K = Kahana, MH = Mahinahina, NK = North Kāʻanapali, HB = Hanakaʻōʻō Beach, ML = Mala, L = Lāhaina, P = Polanui, OP = Olowalu Point, O = Olowalu, and U = Ukumehame.

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Abiotic													
Bare Rock/Pavement							X						
Other		X			X	X	X	X			X	X	
Rubble							X	X	X	X	X	X	
Sand		X		X	X	X	X	X	X	X	X	X	
Crustose Coralline Algae													
CCA		X			X	X	X	X	X	X	X	X	
Coral													
Cyphastrea ocellina				X					6			X	
Fungia scutaria										X		X	
Leptastrea bewickensis		X											
Leptastrea purpurea		X		X		X	X	5	X	5		X	
Montipora capitata		4		2	3	3	2	1	2	4	5	1	
Montipora flabellata				X		X	X					X	
Montipora patula		3		4	4	4	3	3	4	3	4	2	
Pavona duerdeni				X		X	X	X	X	X		X	
Pavona maldivensis								X	X		X	X	
Pavona varians		X		X	6	6	6	X	5	6	6	6	
Pocillopora damicornis												X	
Pocillopora eyedouxi						X	X					X	

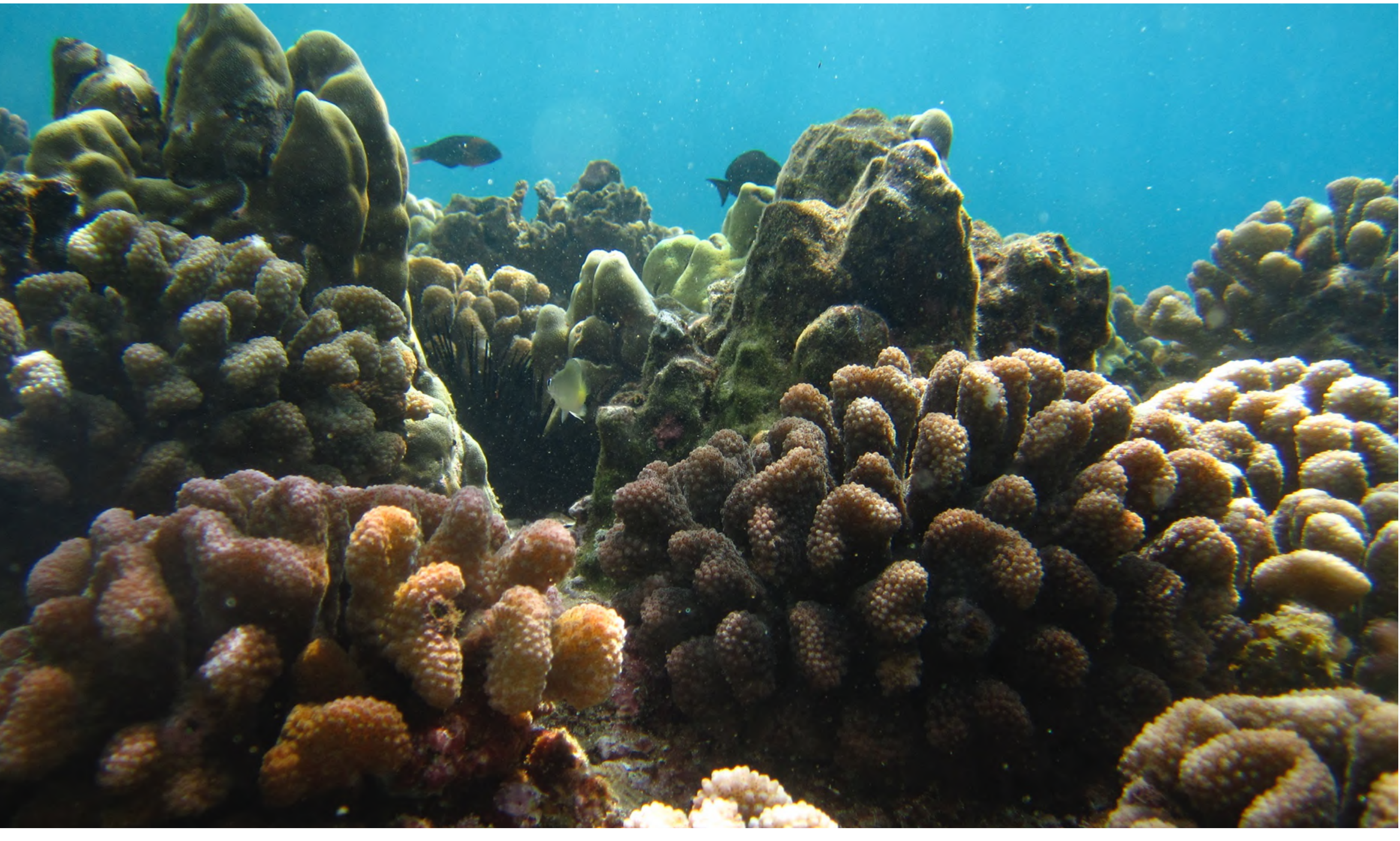
	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Pocillopora ligulata				X								X	
Pocillopora meandrina		2		6	5	5	5	6	X	X	3	X	
Porites brighami				X									
Porites compressa		4		X	2	2	4	4	3	2	2	3	
Porites evermanni/lutea				1	X	X	X					5	
Porites lobata		1		3	1	1	1	2	1	1	1	4	
Porites lutea				X					X			X	
Porites monticulosa												X	
Porites rus				5	X	X	X					X	
Psammocora nierstraszi												X	
Psammocora stellata												X	
Tubastrea coccinia					X	X	X						
Unidentified coral												X	
Cyanobacteria													
Blue-green algae					X	X	X	X	X	X		X	
Lyngbya spp.					X	X	X						
Macroalgae													
Amansia glomerata					X	X	X						
Asparagopsis taxiformis				X		X	X					X	
Caulerpa spp.							X						
Chlorophyta				X									
Coralline Algae				X								X	
Dasya irridescens						X							
Dictyosphareia cavernosa					X	X	X						
Dictyota spp.				X		X			X				
Dotyella spp.					X	X							
Galaxaura spp.						X							
Halimeda spp.				X	X	X			X	X	X	X	

	LP	H	OH	K	MH	NK	HB	ML	L	P	OP	O	U
Liagora spp.				X		X							
Lobophora spp.					X	X	X					X	
Macroalgae		X		X								X	
Microdictyon spp.							X						
Neomeris spp.							X						
Peyssonnelia spp.					X	X	X						
Phaeophyta				X				X	X			X	
Rhodophyta				X				X				X	
Tolypiocladia spp.					X	X	X						
Turbinaria sp.							X					X	
Turbinaria ornata						X	X						
Ventricaria spp.						X							
Other													
Sponge				X		X	X					X	
Unknown		X		X			X	X		X	X	X	
Zooanthid				X	X	X	X					X	
Turf													
Turf		X		X	X	X	X	X	X	X	X	X	

Appendix F: Glossary

Abundance	The number of individuals.
Assemblage	A subset of the species within a biological community that share a common feature. For example, the benthic assemblage comprises all species that live on the bottom and does not include other members of the biological community that reside elsewhere, such as in the water column.
Benthic	Residing on the bottom. Can be attached or unmoving (sessile) or moving (mobile).
Biomass	The mass or weight.
Diversity	For the Atlas, diversity refers to the composition and amount of species present in a community or assemblage. It comprises both the number of species (species richness) and their relative abundance (sometimes referred to as evenness).
Focus Window	A spatial unit within the Atlas in which greater data availability allowed for more detailed descriptions of a reef area. The Atlas has six Focus Windows: Honolua, Kahana, Kahekili, Hanakaʻōʻō Beach, Lāhaina, and Olowalu.
Functions	Functions are natural process that affect the composition and persistence of an ecosystem or assemblage. These tend to be large-scale, and can include chemical, physical, and biological process. Examples of functions are recruitment, nutrient cycling, carbon absorption, and wave attenuation. Functions do not necessarily have direct benefits to people.
Interpolation	Interpolation is a statistical method by which related known values are used to estimate an unknown value or values. In the Atlas, benthic and fish data collected at spatially explicit survey sites were used to estimate the benthic and fish values for nearby reef areas where surveys had not been conducted.
Macroalgae	Large, aquatic photosynthetic organisms. Macroalgae are most easily distinguished from seagrasses by their lack of flowers.
Normal Probability Distribution	A probability function that describes how the values of a variable are distributed. It is a symmetrical distribution where most of the observations cluster around the central peak (equal to the average or mean) and the probabilities for values further away from the mean taper off equally in both directions. In graphical form, a normal probability distribution will appear as a “bell curve.” Contrast with a “right skewed” distribution.
Ordination	As used in the Atlas, an ordination is a specialized analysis that looks at the similarity of two or more locations using multi-species data. The most common way to display ordination results is through an “ordination plot,” in which the sites appear as points on a two-

	dimensional graph. The proximity of points in the graph is related to their degree of similarity, with points closer together being more similar to each other in their species composition than points farther apart.
Reef Tract	A spatial unit within the Atlas smaller than a Focus Window that captured the geographic extent of specific datasets while remaining conscious of anthropogenic boundaries, such as marine protected areas, and the locations of neighborhoods, towns, and prominent natural (*e.g.*, headlands, streams, breaks in the reef structure, etc.) and artificial features (*e.g.,* piers, harbor channels, boat ramps, etc.).
Right Skew	A distribution is skewed when the data points cluster more toward one side of the scale than the other, creating a distribution that is not symmetrical. In graphical form, a right skewed probability distribution will have a long tail extending toward higher values (the right side of the figure). This will cause the average or mean to be greater than the peak. Contrast with a normal probability distribution.
Services	Services are values provided to humans by an ecosystem, and which generally have little effect on the persistence or function of that ecosystem. Examples of services can include shoreline protection, fishery catch, recreational use, and cultural value.
Sessile	Attached or unmoving.
Spatial Heterogeneity	Refers to the uneven distribution of various concentrations of an entity (*e.g.*, species, habitat, etc.) within an area. It is sometimes referred to as "variability in the distribution" of an entity.
Species Richness	The number of species present regardless of their abundance. This is more often presented in the form of a list of species.
Turf Algae	Algae that are diminutive and tend to grow in "turf-like" mats on the bottom. Most turfs are comprised of multiple species.



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