



**2016-2020 Five Year Efficacy Study of the Management Regulations  
within the Community Based Subsistence Fishing Area of Hā'ena,  
Kaua'i**

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## EXECUTIVE SUMMARY

The Hā'ena community, in collaboration with the State of Hawai'i's Department of Land and Natural Resources, established a Community Based Subsistence Fishing Area (CBSFA) in 2015 in Hā'ena, Kaua'i. The goal of this biologically and culturally managed area is to support fishing and gathering for subsistence, religious, and cultural purposes in a sustainable manner through effective collaborative practices of both local community and State management. This partnership includes monitoring, enforcement, education, and outreach. Part of the evaluation of the efficacy of the management plan includes annual biological surveys and strategic environmental and physical monitoring, along with ongoing community monitoring.

This 5-year monitoring collaborative is a joint effort between the University of Hawai'i's (UH) Hawai'i Institute of Marine Biology (HIMB) Coral Reef Ecology Lab, the State of Hawai'i's Department of Land and Natural Resources (DLNR) Division of Aquatic Resources (DAR), and the Division of Boating and Ocean Recreation (DOBOR). This collaboration has been conducting annual biological surveys to determine the efficacy of the management strategies since 2016. To evaluate efficacy outside natural variability, a large number of transects were surveyed in 2016 (n=98), 2017 (n=211), 2018 (n=110), 2019 (n=98), and 2020 (n=123) for a total of 640 transects over the 5-year study period.

In the summer of 2020, 123 Kaua'i Assessment of Habitat Utilization (KAHU) surveys were conducted within and outside the established boundaries of the CBSFA. Fish communities from 2016-2020 inside the CBSFA and the Pu'uho'ou were compared to baseline surveys conducted in 2014 by the Fisheries Ecology Research Laboratory (FERL) prior to the establishment of the CBSFA. These data allowed for a sampling design that compared marine communities before the initiation of management action to any changes that may have occurred following commencement of regulations. This report is structured to account for the results of the collective 5-year findings (2016-2020).

During this 5-year period, a heavy rainstorm and stochastic freshwater event occurred on April 13-16, 2018, impacting the entire north shore of Kaua'i. It was the worst natural disaster to occur on Kaua'i in the 25 years since Hurricane Iniki. The record for the most rainfall in a 24-hour period for the Hawaiian Islands was broken. The National Weather Service rain gauge a mile west of Hanalei Bay recorded over four feet (49.7") of rain during April 15-16, 2018. In the Hā'ena region, damage to roads resulted in a closure of the area to visitors. Road closure to visitors remained in place between the April 2018 flood event and June 2019, a 14-month period. This prompted the continuation of surveys following the road opening to determine any population shifts that could no longer be attributed solely to management actions but may instead also be ascribed to changes in human pressure and, specifically, freshwater input, which provides nutrients for plankton and macroalgae (Rodgers *et al.* 2020). The subsequent increases in freshwater and sediment due to the storm, in addition to changes in the user population, resulted in a nearshore biological shift in fishes, urchins, and other benthic populations (Rodgers *et al.* 2021). This anomalous event was clearly evident in the data and was thus accounted for over this 5-year study in order to determine management efficacy.



## Five Year Management Efficacy Evaluation Summary of the Hā‘ena CBSFA (2016-2020)

### Evaluation of Management Goals and Activities

The management goals and activities to achieve objectives that pertain to this efficacy study, as stated in the Hawai‘i Administrative Rules Chapter 13-60.8, were evaluated to determine whether they have been met in the five year survey period.

#### *Preserve and protect nursery habitat for juvenile reef fishes*

Within the Makua Pu‘uhonua, the fully protected juvenile fish habitat, both fish density and biomass have significantly increased overall. A substantial increase occurred from 2014 to 2017 with a decline in 2018, the year of the freshwater flood event. A significant recovery has occurred in fish density since the flood, however fish density has not yet returned to 2017 levels. Medium (5-15 cm) and large (> 15 cm) sized fishes showed a significant increase from the 2014 baseline until the 2018 flood event. Small juvenile fishes <5 cm and medium sized fishes (5-15 cm) have statistically increased following the flood from 2018 to 2020.

#### *Increase the abundance of native fish species, limu kohu, he‘e, urchins, lobsters, ‘ōpihi and other shellfish.*

Within the purview of this study, we found that the biomass and density of native fishes (endemic and indigenous) inside the CBSFA reserve showed statistically significant increases from 2014-2017 prior to the flood event, while no increases were found outside the reserve boundaries. These same patterns were found for introduced species, although the sample size was notably smaller and there were no introduced species found on 70% of the transects. Following the decline in all fish communities the year of the flood (2018), endemic fish density inside the Makua Pu‘uhonua showed a positive rebounding trend. The same was found for indigenous fish biomass outside the reserve and for indigenous fish density within the CBSFA and the Pu‘uhonua. Seasonality and low sample sizes restrict the abundance assessment of *Asparagopsis taxiformis* (limu kohu) within this study.

#### *Increase percent coral cover by reducing human impacts on coral reef resources.*

Coral cover proportion has remained fairly stable following the 2014-2015 statewide bleaching event that reduced coral cover by 34% statewide. Coral bleaching following the flood event was significant but did not result in extensive mortality. Long-term monitoring sites at Limahuli, within the reserve, showed coral cover on the shallow reef flat has remained stable across the years while a continued decline at the 10 m site has occurred. Increased ocean temperatures and freshwater intrusion are the major drivers of coral mortality. Links to human impacts are more difficult to determine in the absence of direct human contact data.

### Overall Fishes

Statistical tests were performed for pre- and post-flood periods to separate the extraneous effect of the flood and examine recovery subsequent to the flood. Baseline surveys conducted in 2014 by the Fisheries Ecology Research Laboratory (FERL) inside the reserve and within the Makua Pu‘uhonua were included in these analyses. The earliest baseline for the area outside the reserve was in 2016, thus statistical tests for outside only include years 2016 through 2020.

There were some significant increases in the number of fishes on transects between 2016 and 2020 despite significant declines following the 2018 flood event. Results show a significant increase from the 2014 baseline to 2017, prior to the flood, inside the CBSFA boundaries and within the Pu‘uhonua, while the number of fishes outside the CBSFA was not found to be different across pre-flood years (2016-2017). Regardless of the sharp decline the year of the flood in 2018, a rebound effect has occurred post-flood inside the CBSFA and in the Makua Pu‘uhonua with significant increases found. No significant increases in the number of fishes were found outside the CBSFA following the flood.

Fish biomass showed a statistical increase pre-flood inside the CBSFA and within the Pu‘uhonua, although these trends were not continued post-flood. Outside the CBSFA, there was no significant trend in fish biomass pre-flood, however there was a significant positive trend post-flood. Post-flood increases in 2020 have not yet reached 2017 levels.

### Resource and Non-resource Fishes Ratio

To more fully understand the reserve effect and how it differs for food and non-food fishes, ratios of fish biomass and density inside the reserve compared to outside were employed. If the reserve is effective at protecting fished species, then the biomass and density of food fishes should be greater inside the reserve. This would be indicated by a ratio (inside/outside)  $> 1$  and should increase over time. The ratio over the five-year period of this study showed the reserve biomass ratio for both food and non-food fishes declined overall, with the greatest decrease occurring from 2019-2020, although there was a notable increase from 2018-2019. Similarly, the reserve density ratio appears to decline overall for both food and non-food fishes over time, though the trend from 2018 to 2019 is strongly positive. For both biomass and density reserve ratios, patterns for food and non-food fishes were similar, suggesting they are a result of factors other than protection from fishing. The exception is in 2020, when the reserve density ratio for food and non-food fishes diverged, with a continued increase for non-food fishes and a decrease for food fishes. This is suggestive of increased fishing pressure in 2020.

### Resource Fishes

An assessment over the five-year period the CBSFA has been in effect was conducted to compare resource fishes identified by the community to non-resource fishes in order to determine management success. By comparing the patterns between fished and un-fished species, we isolated the changes due to management strategies and/or fishing impacts.

The results for resource fishes are similar to the results for fishes overall prior to the flood event. The biomass and density of resource fishes on transects increased significantly inside the reserve between 2014 and 2017. No statistical difference was found outside the reserve. Post-flood, the Pu‘uhonua showed a significant increase in density of resource fishes, though biomass did not change significantly. The only other post-flood increase was biomass outside the reserve.

### Reproductively Mature Resource Fishes

Results for reproductively mature resource fishes indicated no major shifts in overall fish community compositions on a temporal or spatial scale. However, finer scale species level

increases were evident. Of the 19 resource fishes analyzed, the density of four large reproductive fishes (*Acanthurus triostegus* (manini), *A. blochii* (pualu), *Mulloidichthys flavolineatus* (weke), and *Naso lituratus* (umaumalei)) were significantly higher inside the boundaries of the reserve. Resource fishes with significantly higher biomass inside the reserve include *N. lituratus* (umaumalei) and *Kyphosus* spp. (nenu). From 2016-2020, *Caranx melapygus* ('omilu) significantly increased both inside and outside the CBSFA, with larger increases outside as was found for reproductively mature *Aprion virescens* (uku) and *Lutjanus kasmira* (ta'ape). An overall increase in the number of large reproductively viable herbivorous resource fishes was statistically significant while biomass of herbivores was not significant. The diversity of reproductively mature resource fishes significantly increased over time and was higher inside the CBSFA, however evenness and species richness did not change significantly.

### Endemism

Endemic species are native to and live naturally in only one region. Indigenous species are also native but may be more widely distributed in other regions. Introduced species were either intentionally or unintentionally introduced and may become invasive, potentially displacing native species.

Inside the reserve, a statistically significant increase in the density and biomass of endemic, indigenous, and introduced fishes was found pre-flood (2014-2017), with the exception of endemic fish biomass within the Makua Pu'uhonua. Significant post-flood increases (2018-2020) in density were found in the Pu'uhonua for endemic and indigenous fishes. No significant differences were found outside the CBSFA except for the post-flood biomass of indigenous fishes.

### Freshwater Flood Event

The outcomes of Rodgers *et al.* (2021) unequivocally showed that the April 2018 historic flood event on the north shore of Kaua'i had a deleterious effect on the Hā'ena reef communities and their individual populations. Community models combining fishes, urchins, and coral bleaching factors showed significant shifts in community structure before and after the storm event. In tandem with community changes, discrete population analyses showed significant declines of overall fish populations at shallow sites in Hā'ena, suggesting flooding inputs were concentrated nearshore. There is also evidence showing coral bleaching increased following the flood event, despite temperatures consistently being recorded within the range of coral tolerance at other north shore Kaua'i sites. Species-specific bleaching following this flood event were consistent with statewide patterns from temperature-related bleaching, with corals in the genus *Montipora* and *Pocillopora* exhibiting the lowest tolerance to reduced salinity. A major population increase in the octocoral *Sarcothelia edmondsoni* after the storm event, followed by subsequent declines by 2020, suggest it is relatively resilient to low salinities and may act as a bioindicator of freshwater input. A marked decline in the abundance of the dominant urchin species, *E. mathaei*, was recorded in the inundation-prone shallow waters. Over the two years since the 2018 flood, urchins have been slowly recovering in some sectors.

## Conclusions (2014-2020)

The resource fishes of Hā'ena have a range of life history characteristics, thus recovery rates will differ. Based on their short life spans, the first species likely to show an increase are the goatfish and small parrotfish, with full recovery for these faster growing species possible within 10 years. Recovery of larger, long-lived species such as jacks, surgeons, and large parrotfish may take 20-40 years. These estimates assume complete cessation of fishing, which is not the case for the Hā'ena CBSFA, with the exception of the Makua Pu'uho'oua. The Pu'uho'oua was designed to protect juveniles and is likely too small to be effective for most adult fish species. Furthermore, biotic populations often fluctuate, taking years to determine if current shifts will be consistent over the long term because they may be cyclical, making it difficult to see the true patterns unless monitoring is continued over a longer period. This five-year efficacy review shows increasing trends for some fish species but will take further monitoring of fish populations to determine the full effect of management activities.

Fish populations remained higher inside the reserve boundaries as compared to outside despite the 2018 decline.

- A significant reserve effect was determined pre-flood. Post-flood fish population factor levels have not yet returned to pre-flood levels.
- Fish abundance and biomass remained higher inside the CBSFA than outside across all years.
- The number of fish species was higher inside the CBSFA than outside the boundaries.
- Both resource and non-resource fishes showed higher abundance and biomass inside the CBSFA than outside the boundaries.
- Fishes in the largest size class were greater inside the CBSFA as compared to outside.
- An overall increase in the number of large reproductively mature herbivorous resource fishes increased significantly inside the reserve while biomass did not change.
- While no overall community shift for reproductively mature fishes occurred, species specific increases were found.
- The diversity of reproductively mature resource fishes significantly increased over time within the reserve.

Some recovery has been observed following the effects of the freshwater flood event in April 2018. Octocoral and urchins may serve as a bioindicator or proxy of community health following input of freshwater, nutrients, and/or sediment from storms, or as an indicator of pollutants.

- The octocoral *Sarcothelia edmondsoni* has decreased substantially in all sectors since the 2018 freshwater flood.
- Although a slight drop in coral cover was found at shallow stations outside the CBSFA, when combining all depths, sectors showed a slight increase post flood.
- Sea urchin populations increased slightly, albeit statistically insignificant, post-flood following the significant decline in 2018.
- Fish abundance and biomass were highest in 2017 and have shown some post-flood recovery.
- Across all years surveyed, herbivorous fishes dominated fish trophic composition.

Coral Reef Assessment and Monitoring Program (DAR/CRAMP)

- Coral recovery since the 2014/15 statewide bleaching event is occurring at the shallow reef flat (1 m) with total coral cover remaining stable over the past five years. The deeper station (10 m) showed no signs of recovery and has continued to decline from a high of 9.2% coral cover in 2016 (following the 2015 bleaching) to an unprecedented low of 2.1% in 2020.

### **Recommendations**

- Continue DAR monitoring of the CBSFA and reassess findings periodically.
- Review management strategies that consider findings (e.g., 2020 decrease in resource fishes) and apply adaptive management approaches.
- Monitor fishing in reserve by conducting fishing effort CREEL surveys and incorporating them into the Makai Watch monitoring.
- Support community monitoring of natural and cultural resources, education, and outreach.

**Table 1.** Summary of fish community composition factors by years surveyed within the Hā'ena CBSFA.

		Prior to CBSFA	Hā'ena Inside (CBSFA)				
		2014	2016	2017	2018	2019	2020
	Count of Transect	65	47	99	55	48	64
	Mean No. of species	9.80 ± 0.69	18.10 ± 1.23	17.40 ± 0.77	16.60 ± 0.75	16.00 ± 0.78	17.20 ± 0.62
	Mean Abundance (IND/m <sup>2</sup> )	3.43 ± 0.49	1.44 ± 0.17	1.53 ± 0.16	1.00 ± 0.09	1.26 ± 0.11	1.33 ± 0.14
	Mean Biomass (g/m <sup>2</sup> )	34.8 ± 7.6	121.0 ± 23.3	165.0 ± 19.2	140.0 ± 20.0	182.0 ± 31.4	122.0 ± 18.5
	Diversity	1.70 ± 0.09	1.92 ± 0.07	1.96 ± 0.04	2.08 ± 0.04	1.91 ± 0.06	1.90 ± 0.05
	Evenness	0.77 ± 0.03	0.70 ± 0.02	0.72 ± 0.01	0.76 ± 0.01	0.70 ± 0.02	0.68 ± 0.02
	Top abundance species	<i>T. duperrey</i>	<i>C. vanderbilti</i>	<i>C. vanderbilti</i>	<i>T. duperrey</i>	<i>C. vanderbilti</i>	<i>C. vanderbilti</i>
	Top biomass species	<i>Kyphosus spp.</i>	<i>A. olivaceus</i>	<i>Kyphosus spp.</i>	<i>A. leucopareius</i>	<i>A. leucopareius</i>	<i>A. leucopareius</i>
Trophic Abundance (IND/m <sup>2</sup> )	Herbivores	0.159 ± 0.042	0.482 ± 0.116	0.641 ± 0.067	0.477 ± 0.065	0.566 ± 0.089	0.440 ± 0.062
	Invertivores	0.162 ± 0.027	0.522 ± 0.040	0.452 ± 0.025	0.348 ± 0.031	0.415 ± 0.054	0.469 ± 0.041
	Piscivores	0.009 ± 0.002	0.024 ± 0.005	0.023 ± 0.003	0.025 ± 0.005	0.021 ± 0.005	0.024 ± 0.006
	Zooplanktivores	0.013 ± 0.004	0.380 ± 0.094	0.409 ± 0.125	0.129 ± 0.035	0.261 ± 0.047	0.402 ± 0.098
Trophic Biomass (g/m <sup>2</sup> )	Herbivores	25.6 ± 6.7	77.7 ± 17.9	127.1 ± 16.9	105.9 ± 17.1	116.6 ± 19.9	85.1 ± 15.3
	Invertivores	7.1 ± 1.0	23.6 ± 2.8	24.8 ± 3.9	19.9 ± 2.4	37.9 ± 17.5	20.8 ± 3.1
	Piscivores	1.9 ± 0.7	6.3 ± 1.8	6.6 ± 1.3	6.8 ± 2.7	24.5 ± 10.9	12.9 ± 3.9
	Zooplanktivores	0.2 ± 0.1	3.3 ± 1.5	2.9 ± 0.8	7.5 ± 4.3	2.7 ± 1.5	3.5 ± 1.5
Endemism Abundance (IND/m <sup>2</sup> )	Endemic	0.132 ± 0.038	0.407 ± 0.039	0.320 ± 0.033	0.280 ± 0.028	0.343 ± 0.043	0.338 ± 0.032
	Non-native	0.003 ± 0.004	0.011 ± 0.008	0.028 ± 0.018	0.012 ± 0.012	0.043 ± 0.041	0.021 ± 0.019
	Indigenous	0.208 ± 0.032	0.989 ± 0.157	1.178 ± 0.186	0.688 ± 0.078	0.877 ± 0.088	0.975 ± 0.125
Endemism Biomass (g/m <sup>2</sup> )	Endemic	2.9 ± 0.4	16.0 ± 3.6	15.1 ± 2.0	13.8 ± 2.6	17.5 ± 5.3	11.7 ± 1.5
	Non-native	1.2 ± 0.7	4.0 ± 1.5	8.0 ± 2.9	2.4 ± 0.8	9.0 ± 4.9	4.1 ± 2.0
	Indigenous	30.7 ± 7.0	93.1 ± 18.7	142.0 ± 17.5	124.0 ± 18.6	155.0 ± 26.5	107.0 ± 17.4
Size Class Abundance (IND/m <sup>2</sup> )	Small (<5cm)	0.090 ± 0.039	0.210 ± 0.070	0.307 ± 0.046	0.132 ± 0.022	0.288 ± 0.047	0.346 ± 0.098
	Medium (5-15)	0.154 ± 0.029	0.880 ± 0.125	0.765 ± 0.154	0.489 ± 0.045	0.500 ± 0.048	0.609 ± 0.058
	Large (>15)	0.099 ± 0.017	0.317 ± 0.070	0.453 ± 0.076	0.358 ± 0.051	0.476 ± 0.094	0.379 ± 0.061

**Table 2.** Summary of fish community composition factors by years surveyed within the Makua Pu‘uhonua.

		Prior to CBSFA	Makua Pu‘uhonua				
		2014	2016	2017	2018	2019	2020
	Count of Transect	9	8	20	23	10	15
	Mean No. of species	14.70 ± 1.27	14.60 ± 1.40	19.00 ± 1.47	15.4 ± 0.85	19.60 ± 1.69	19.40 ± 1.34
	Mean Abundance(IND/m <sup>2</sup> )	3.63 ± 0.27	0.71 ± 0.16	2.21 ± 0.77	0.73 ± 0.06	1.20 ± 0.16	1.25 ± 0.11
	Mean Biomass (g/m <sup>2</sup> )	54.3 ± 15.3	29.3 ± 7.8	216.0 ± 70.8	70.5 ± 11.4	78.4 ± 17.1	74.8 ± 16.3
	Diversity	2.24 ± 0.08	1.99 ± 0.11	1.84 ± 0.15	1.91 ± 0.07	2.01 ± 0.08	1.96 ± 0.07
	Evenness	0.84 ± 0.01	0.75 ± 0.03	0.64 ± 0.05	0.71 ± 0.02	0.68 ± 0.02	0.67 ± 0.01
	Top abundance species	<i>T. duperrey</i>	<i>T. duperrey</i>	<i>D. macarellus</i>	<i>T. duperrey</i>	<i>T. duperrey</i>	<i>T. duperrey</i>
	Top biomass species	<i>A. olivaceus</i>	<i>A. nigrofuscus</i>	<i>D. macarellus</i>	<i>A. olivaceus</i>	<i>A. nigrofuscus</i>	<i>A. nigrofuscus</i>
Trophic Abundance (IND/m <sup>2</sup> )	Herbivores	0.141 ± 0.016	0.214 ± 0.076	0.417 ± 0.032	0.239 ± 0.025	0.471 ± 0.080	0.478 ± 0.074
	Invertivores	0.183 ± 0.016	0.405 ± 0.076	0.465 ± 0.042	0.399 ± 0.041	0.600 ± 0.077	0.635 ± 0.060
	Piscivores	0.005 ± 0.004	0.012 ± 0.005	0.013 ± 0.003	0.021 ± 0.007	0.011 ± 0.003	0.012 ± 0.004
	Zooplanktivores	0.033 ± 0.018	0.082 ± 0.027	1.315 ± 0.757	0.071 ± 0.024	0.122 ± 0.042	0.129 ± 0.048
Trophic Biomass (g/m <sup>2</sup> )	Herbivores	35.4 ± 10.1	16.8 ± 5.0	63.6 ± 11.7	42.5 ± 9.1	63.2 ± 15.2	45.0 ± 6.9
	Invertivores	17.2 ± 6.5	10.2 ± 2.8	23.7 ± 6.4	16.8 ± 3.8	11.6 ± 2.0	26.8 ± 12.4
	Piscivores	1.0 ± 1.0	1.0 ± 0.4	4.4 ± 1.4	10.0 ± 6.1	1.1 ± 0.6	1.5 ± 0.8
	Zooplanktivores	0.7 ± 0.6	0.4 ± 0.2	123.9 ± 70.7	1.2 ± 0.6	2.5 ± 1.5	1.5 ± 0.5
Endemism Abundance (IND/m <sup>2</sup> )	Endemic	0.172 ± 0.015	0.356 ± 0.095	0.414 ± 0.038	0.368 ± 0.073	0.581 ± 0.078	0.591 ± 0.078
	Non-native	0	0.003 ± 0.000	0.012 ± 0.005	0.005 ± 0.008	0.006 ± 0.002	0.030 ± 0.042
	Indigenous	0.191 ± 0.019	0.354 ± 0.080	1.784 ± 0.760	0.357 ± 0.075	0.618 ± 0.092	0.632 ± 0.078
Endemism Biomass (g/m <sup>2</sup> )	Endemic	6.8 ± 1.4	6.2 ± 1.6	6.8 ± 1.6	8.2 ± 1.8	10.6 ± 2.5	13.5 ± 4.1
	Non-native	0.0 ± 0.0	0.8 ± 0.4	3.0 ± 1.0	2.2 ± 1.4	0.7 ± 0.3	11.6 ± 10.8
	Indigenous	47.5 ± 14.3	21.5 ± 6.7	206.0 ± 70.2	60.2 ± 11.1	67.0 ± 15.7	49.7 ± 7.2
Size Class Abundance (IND/m <sup>2</sup> )	Small (<5cm)	0.099 ± 0.010	0.074 ± 0.018	0.088 ± 0.019	0.177 ± 0.045	0.300 ± 0.058	0.314 ± 0.058
	Medium (5-15)	0.127 ± 0.024	0.549 ± 0.145	0.571 ± 0.051	0.377 ± 0.068	0.675 ± 0.101	0.690 ± 0.070
	Large (>15)	0.137 ± 0.028	0.090 ± 0.030	1.550 ± 0.765	0.176 ± 0.034	0.229 ± 0.042	0.250 ± 0.052

**Table 3.** Summary of fish community composition factors by years surveyed outside the Hā‘ena CBSFA boundaries.

		Prior to CBSFA	Hā‘ena Outside				
		2014	2016	2017	2018	2019	2020
	Count of Transect	ND	43	92	32	40	44
	Mean No. of species	ND	15.30 ± 1.12	15.70 ± 0.69	13.70 ± 0.84	14.90 ± 0.91	16.60 ± 1.06
	Mean Abundance(IND/m <sup>2</sup> )	ND	0.93 ± 0.12	1.11 ± 0.10	1.02 ± 0.20	1.04 ± 0.10	1.05 ± 0.09
	Mean Biomass (g/m <sup>2</sup> )	ND	94.5 ± 20.7	130.0 ± 23.5	118.0 ± 38.6	115.0 ± 17.2	151.0 ± 17.6
	Diversity	ND	1.84 ± 0.10	1.91 ± 0.05	1.86 ± 0.07	1.84 ± 0.06	1.94 ± 0.06
	Evenness	ND	0.69 ± 0.03	0.72 ± 0.01	0.74 ± 0.02	0.72 ± 0.02	0.72 ± 0.02
	Top abundance species	ND	<i>C. vanderbilti</i>	<i>C. vanderbilti</i>	<i>T. duperrey</i>	<i>C. vanderbilti</i>	<i>C. vanderbilti</i>
	Top biomass species	ND	<i>A. olivaceus</i>	<i>A. olivaceus</i>	<i>L. kasmira</i>	<i>A. olivaceus</i>	<i>A. olivaceus</i>
Trophic Abundance (IND/m <sup>2</sup> )	Herbivores	ND	0.301 ± 0.057	0.401 ± 0.055	0.386 ± 0.096	0.392 ± 0.061	0.402 ± 0.043
	Invertivores	ND	0.349 ± 0.037	0.430 ± 0.055	0.450 ± 0.101	0.323 ± 0.033	0.388 ± 0.046
	Piscivores	ND	0.017 ± 0.005	0.017 ± 0.002	0.017 ± 0.004	0.031 ± 0.007	0.019 ± 0.004
	Zooplanktivores	ND	0.263 ± 0.057	0.261 ± 0.047	0.171 ± 0.054	0.289 ± 0.058	0.245 ± 0.048
Trophic Biomass (g/m <sup>2</sup> )	Herbivores	ND	54.1 ± 9.7	84.5 ± 14.9	64.4 ± 14.8	75.2 ± 12.9	90.9 ± 10.6
	Invertivores	ND	28.8 ± 9.0	37.1 ± 13.8	48.6 ± 24.8	23.5 ± 5.1	38.3 ± 9.2
	Piscivores	ND	1.6 ± 0.5	4.4 ± 1.4	4.3 ± 1.9	10.9 ± 3.3	7.8 ± 1.9
	Zooplanktivores	ND	3.4 ± 1.9	4.0 ± 1.6	0.9 ± 0.6	5.5 ± 3.0	14.4 ± 7.4
Endemism Abundance (IND/m <sup>2</sup> )	Endemic	ND	0.251 ± 0.027	0.295 ± 0.029	0.304 ± 0.061	0.290 ± 0.041	0.283 ± 0.031
	Non-native	ND	0.019 ± 0.023	0.013 ± 0.010	0.107 ± 0.197	0.032 ± 0.017	0.060 ± 0.039
	Indigenous	ND	0.660 ± 0.092	0.801 ± 0.102	0.613 ± 0.117	0.714 ± 0.080	0.711 ± 0.071
Endemism Biomass (g/m <sup>2</sup> )	Endemic	ND	12.5 ± 2.9	11.6 ± 2.1	9.3 ± 2.8	13.2 ± 2.7	17.2 ± 3.4
	Non-native	ND	10.4 ± 8.1	10.2 ± 7.9	20.9 ± 14.5	11.8 ± 4.9	13.2 ± 6.8
	Indigenous	ND	65.0 ± 10.8	108.0 ± 20.2	88.1 ± 25.9	90.1 ± 14.4	121.0 ± 13.9
Size Class Abundance (IND/m <sup>2</sup> )	Small (<5cm)	ND	0.137 ± 0.060	0.234 ± 0.035	0.128 ± 0.034	0.250 ± 0.038	0.220 ± 0.044
	Medium (5-15)	ND	0.547 ± 0.072	0.575 ± 0.065	0.497 ± 0.058	0.478 ± 0.060	0.404 ± 0.042
	Large (>15)	ND	0.246 ± 0.064	0.300 ± 0.060	0.399 ± 0.187	0.308 ± 0.043	0.430 ± 0.057



# INTRODUCTION

## Historical Background

The Community-based Subsistence Fishing Area (CBSFA) of Hā'ena was designated in August 2015 to protect and sustainably manage marine resources, while supporting the needs of the community through culturally based management practices. This framework acknowledges the *mauka to makai* (ridge to reef) linkage and endeavors to restore natural balance. As specified in HAR Chapter 13-601.8, it is managed collaboratively by the Hā'ena community and the Hawai'i Department of Land and Natural Resources. This partnership will collectively monitor and evaluate efficacy for future adaptive management purposes. The management plan addresses enforcement, education and outreach, user conflict resolution, methods for funding, monitoring, evaluation, and measures of success.

## Management Objectives

The outlined management goals are as follows:

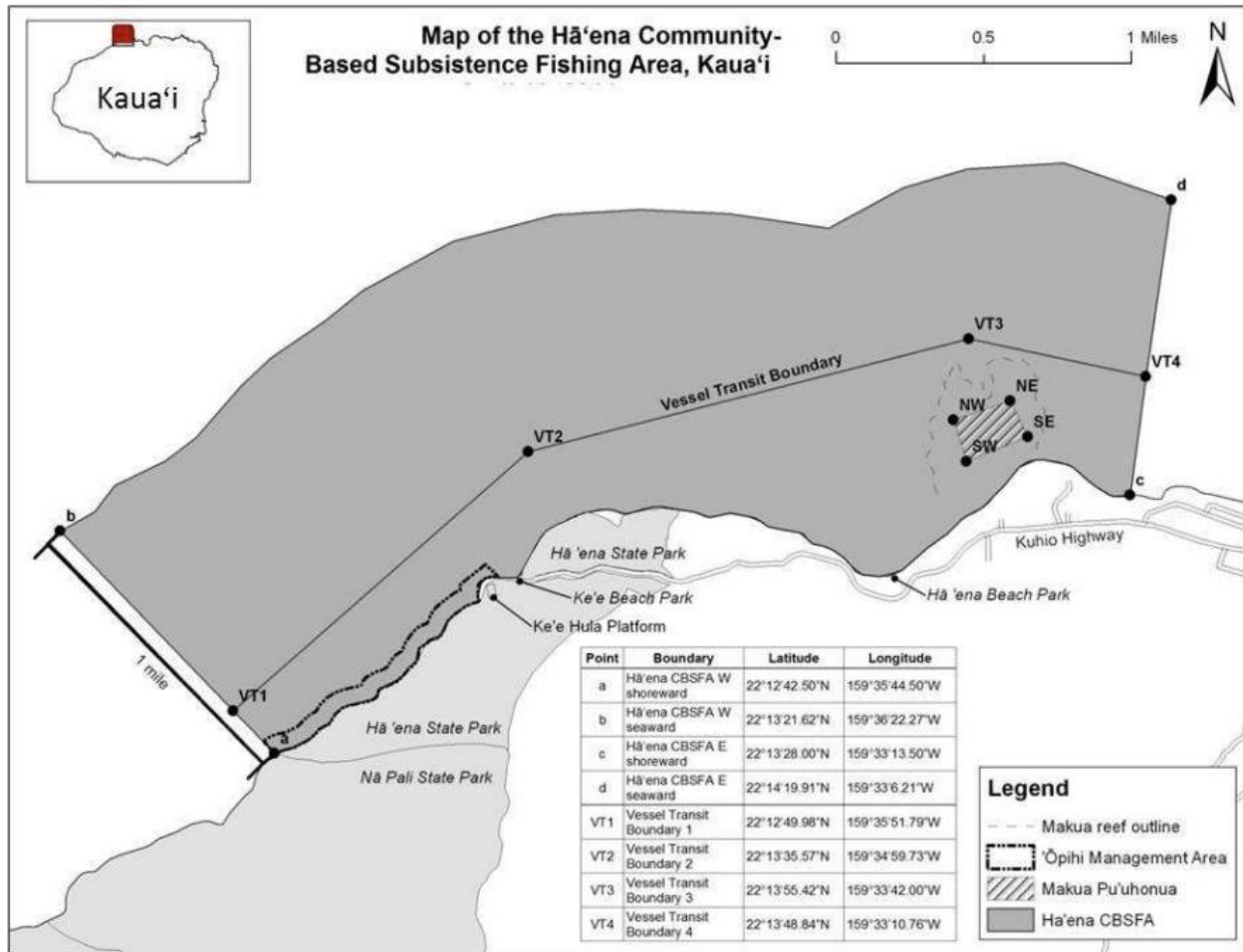
- Sustainably support the consumptive needs of the Hā'ena *ahupua'a* through culturally-rooted community-based management.
- Ensure the sustainability of nearshore ocean resources in the area through effective management practices.
- Preserve and protect nursery habitat for juvenile reef fishes.
- Recognize and protect customary and traditional native Hawaiian fishing practices that are exercised for subsistence, cultural, and religious purposes in the area.
- Facilitate the substantive involvement of the community in resource management decisions for the area.

Management activities to achieve these objectives:

- Establish rules that reflect traditional fishing and management practices.
- Establish rules to address adverse effects of tourism and ocean recreation activities on marine resources and associated subsistence practices.
- Increase the abundance of native fish species, *limu kohu*, *he'e*, urchins, lobsters, 'ōpihi and other shellfish.
- Increase percent coral cover by reducing human impacts on coral reef resources.

## Geographic Location

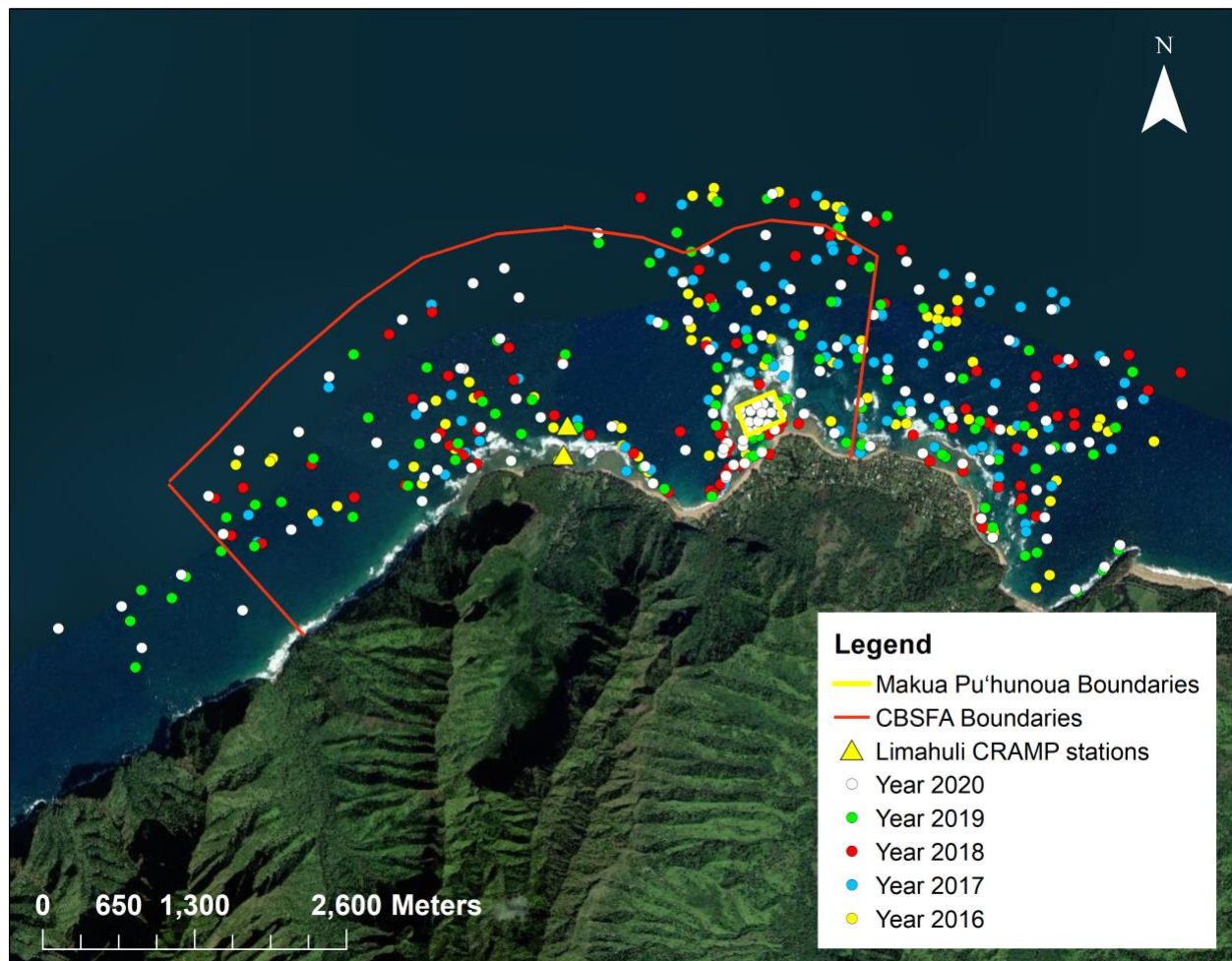
The Hā'ena CBSFA is located within the *ahupua'a* of Hā'ena in the larger *moku* of Halele'a on the north shore of the island of Kaua'i. The CBSFA covers 5.6 km (3.5 miles) of coastline extending vertically 1.6 km (1 mile) out from the high water mark, encompassing the waters adjacent to Hā'ena Beach Park, Hā'ena State Park, and Ke'e Beach Park. The CBSFA begins at the boundary between Hā'ena State Park and Nā Pali State Park (22°12'42.50"N, 159°35'44.50"W) and terminates between Hā'ena and Wainiha (22°13'28.00"N, 159°36'22.27"W). Within the boundaries of the CBSFA lie three subzones, the 'ōpihi (*Cellana* genus) restoration area, the Makua Pu'uhoonua, and the vessel transit boundary (Fig. 1).



**Figure 1.** Map of Hā'ena showing the CBSFA boundaries, vessel transit limits, and the *ōpihi* management borders.

Two perennial streams, which originate in the valleys of Mānoa and Limahuli, intersect the Hā'ena *ahupua'a*. They provide a significant freshwater contribution to the nearshore biotic composition. Most of the common species of corals and fishes occur in this area. This region includes limestone/basalt boulders with sand pockets or shallow carbonate reef flats that dominate the shallow shoreline with low to medium spatial complexity. Parts of this region (Limahuli) are protected from the north swell by a well-developed reef crest. The deeper reefs are equally diverse, characterized by low-relief spur and grooves, to areas of high relief with colonized basalt and boulder habitat with high fish standing stock. The main forcing function and dominant driver of benthic communities at this north exposed site is the North Pacific Swell. Found within this habitat are the endangered species *Chelonia mydas* (Green Sea Turtle), *Eretmochelys imbricata* (Hawksbill Turtle), *Neomonachus schauinslandi* (Hawaiian Monk Seal), and *Megaptera novaeangliae* (Humpback Whale).

The monitoring collaborative is a joint effort between the University of Hawai‘i’s (UH) Hawai‘i Institute of Marine Biology (HIMB) Coral Reef Ecology Lab, the State of Hawai‘i’s Department of Land and Natural Resources (DLNR) Division of Aquatic Resources (DAR), and the Division of Boating and Ocean Recreation (DOBOR). This collaborative has been conducting biological surveys annually to determine the efficacy of the management strategies since 2016. To evaluate efficacy outside natural variability, a large number of transects were conducted in 2016 (n=98), 2017 (n=211), 2018 (n=110), 2019 (n=98), and 2020 (n=123) for a total of 640 transects over the 5-year period of this study (Fig. 2). Statewide travel restrictions due to the COVID-19 pandemic during the 2020 Hā‘ena survey period prohibited interisland travel for O‘ahu DLNR/DAR and UH employees. In response, the DAR Kaua‘i Monitoring team conducted all 2020 rapid assessments with vessel assistance from DOBOR.



**Figure 2.** Map showing the 640 transect surveys conducted within and outside the Hā‘ena, Kaua‘i reserve from 2016 through 2020. Triangles depict locations of the Division of Aquatic Resources Coral Reef Assessment and Monitoring Program long-term monitoring stations at Limahuli. Reserve boundaries delineated.

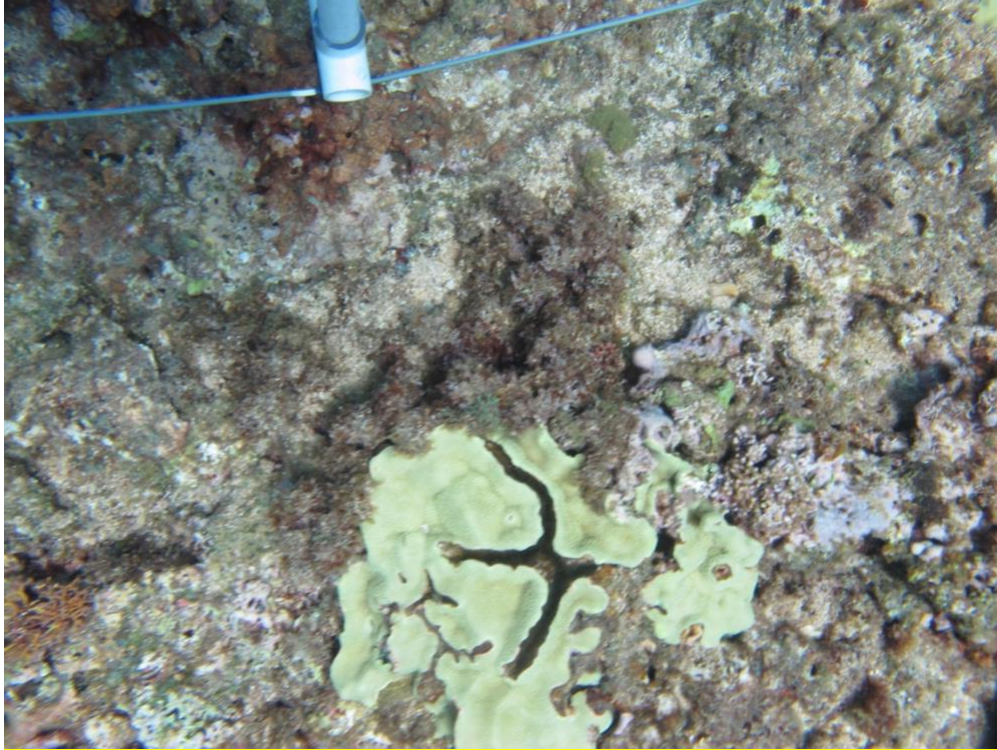
Surveyors quantified fish populations by recording count, species, and size to characterize fish abundance, biomass, feeding guild, diversity, size class, and endemism (Fig. 3). Digital photos were analyzed in the lab using the annotation program CoralNet (Beijborn *et al.* 2012) to determine

benthic composition and diversity of corals, algae, and macroinvertebrates (Fig. 4). Fish results for the CBSFA and the Makua Pu‘uhonua reserve were compared to baseline data collected by the UH Fisheries Ecology Research Lab (FERL) in 2014 to determine any changes in biological populations since the establishment of the CBSFA. The 2016 KAHU data surveyed by CRAMP/DAR served as the initial baseline for outside the reserve boundaries and used for comparisons with all subsequent annual survey data.



**Figure 3.** Diver conducting fish surveys within the Hā‘ena Community-Based Subsistence Fishing area.





**Figure 4.** Example of digital photo used in analysis of habitat and organisms.

## **METHODOLOGY**

### **Kaua'i Assessments of Habitat Utilization (KAHU) Survey Assessments**

Transects within each site were randomly selected by generating >100 random points onto habitat maps using ArcGIS10.3.1. National Oceanic and Atmospheric Administration (NOAA) habitat base maps were used to stratify the area by depth and habitat. To assure adequate coverage of different habitats and full spatial representation of each site, a stratified design was employed. Points were stratified on hard bottom habitat of the reef flat. In the field, each team navigated to a stratified random waypoint imported into a Garmin GPS map 78S or similar GPS unit. If predetermined points presented hazardous conditions or were outside the habitat or depth range, transects were haphazardly placed within a 100-meter radius of the original GPS points and new coordinates were recorded or a predetermined number of fin kicks initiated. Once the transect was located, the following methodology was employed.

Survey methodology was based on the UH Fisheries Ecology Research Laboratory's (FERL) Fish Habitat Utilization Surveys (FHUS), also used by Maui DAR. There were two members on a survey team consisting of a fish and benthic surveyor. The bearing was predetermined by a random number generator (0°, 90°, 180°, 270°). If the bearing did not allow divers to stay on a hard-bottom substrate, they rotated clockwise to the next appropriate bearing until they were able to stay on the hard bottom for the entire transect (provided that depth remained fairly consistent.) The fish surveyor spooled a 25 m transect line out, while recording species, size (TL in cm), and the number of individual fishes to 2.5 m on each side of the transect line (5 m

width). To allow for larger, fast moving fishes, a minimum observation time of 10-minute was required per transect. The benthic surveyor adjusted the white balance setting on the digital camera and recorded the metadata on the survey identification datasheet prior to starting the transect. To avoid interference or altered fish behavior, the benthic diver waited until the fish surveyor was 5 m along the line before taking four digital pans of the seascape, with an approximate 60 (benthic habitat)/40 (water column) split in cardinal directions (N, W, E, S) to get an overview of the station and habitat. A photo of the station number was taken from the slate. Benthic photos were then taken on the shoreward side of the transect at every meter along the 25 m line, keeping the monopod perpendicular to the bottom in order to avoid parallax. The benthic diver counted all urchin species in a 1 m wide belt on the same side photos were taken. Urchins may have been counted concurrently with benthic photos, as the benthic diver followed the fish diver, or alternatively may have been counted on the return to the start position. All survey methods were non-invasive and did not disturb any biota.

## Statistical Analyses

R (Version 3.6.2) and the integrated development environment, R-Studio Desktop (Version 1.1.453, RStudio PBC, Boston, MA, USA), were used for all data analyses (R Core Team 2017). Significance level was set at  $\alpha = 0.05$  for all analyses.

### Fishes – Discrete Population Analyses

#### *Response variables:*

1. Overall Fish: count, biomass, diversity, evenness, and number of species
2. Size Class: count
  - A < 5 cm; B = 5-15 cm; C > 15cm
3. Trophic Level: count and biomass
  - H = herbivore; INV = invertivore; Z = zooplanktivore; P = piscivore
4. Endemism: count and biomass
  - E = endemic; I = indigenous; X = introduced
5. Foodfish: count and biomass
  - F = food/resource fish; NF = non-food/resource fish

#### *Predictor variables:*

1. Division: Makua Pu‘uhonua (PU), Hā‘ena Inside (HI), and Hā‘ena Outside (HO)
2. Division/Depth: Shallow ( $\leq 7$  m) and Deep ( $> 7$  m)
  - Makua Pu‘uhonua (PU, all shallow)
  - Hā‘ena Inside Shallow (HIS)
  - Hā‘ena Inside Deep (HID)
  - Hā‘ena Outside Shallow (HOS)
  - Hā‘ena Outside Deep (HOD)
3. Year: 2014 (only PU and HI), 2016, 2017, 2018, 2019, and 2020
4. Flood: Pre-flood (2014, 2016-2017) and Post-flood (2018-2020)

#### *Sample Size by Division (n):*

- 2014: HI = 65, PU = 9

- 2016: HI = 47, HO = 43, PU = 8
- 2017: HI = 99, HO = 92, PU = 20
- 2018: HI = 55, HO = 32, PU = 23
- 2019: HI = 48, HO = 40, PU = 10
- 2020: HI = 64, HO = 44, PU = 15

*Sample Size by Division/Depth (n):*

- 2014: HIS = 65, HID = 0, PU = 9
- 2016: HIS = 20, HID = 27, HOS = 14, HOD = 29, PU = 8
- 2017: HIS = 49, HID = 50, HOS = 43, HOD = 49, PU = 20
- 2018: HIS = 36, HID = 19, HOS = 15, HOD = 17, PU = 23
- 2019: HIS = 28, HID = 20, HOS = 20, HOD = 20, PU = 10
- 2020: HIS = 34, HID = 30, HOS = 21, HOD = 23, PU = 15

*Overall Count*

Negative binomial generalized linear models (GLM) were applied to model the non-Gaussian distributed total fish count data using the package *MASS* (Ripley *et al.* 2013). Negative binomial distributions were selected by evaluation of Akaike information criterion (AIC) values, overdispersion indices, and residual plots. Two separate sets of analyses were run with and without consideration of transect depth. Models excluding depth were created for each division and flooding period and treated year as an explanatory factor. Models including depth were run for each division/depth combination (HID, HIS, HOD, HOS, and PU) and flooding period. Viability of individual models (i.e., goodness-of-fit, overdispersion, and outliers) were assessed using the package *DHARMA* (Hartig 2021).

*Overall Biomass*

Overall biomass data were fifth-root ( $1/5^{\text{th}}$  power) transformed in order to better resemble a Gaussian distribution. Similar to overall count data, two separate sets of analyses were run with and without depth as a subset identifier. Transformed data were modeled using linear regressions, which were run for each subset of division or division/depth and flooding period with year as the explanatory factor. The statistical significance of linear regressions with significant slope estimates were compared to and confirmed using Spearman rank sum correlation tests.

*Species Count*

Overall species count data were square-rooted transformed in order to better resemble a Gaussian distribution. Similar to transformed biomass data, data were modeled using linear regressions for each subset of division and flooding period with year as the model explanatory factor, although depth-specific trends were not considered. Homoscedasticity between years for a given division was confirmed via Levene's tests using the package *car* (Fox & Weisberg 2019). The statistical significance of linear regressions with significant slope estimates were compared to and confirmed using Spearman rank sum correlation tests.

*Diversity*

The Shannon Weiner diversity was calculated by the formula

$$H' = \sum_{i=1}^S p_i \ln p_i$$

where S is the total number of species and  $P_i$  is the relative cover of  $i^{\text{th}}$  species. Shannon Weiner diversity index (Shannon and Weaver 1963) considers both the number of species and the distribution of individuals among species. Diversity data were unable to be normalized and thus were assessed using Spearman rank sum correlation tests. Data were subsetted into division and flooding period groups then evaluated over time.

#### *Evenness*

Buzas and Gibson's evenness (Harper 1999) was measured using  $E = eH/S$  to calculate fish evenness by transect. Evenness proportional data were modeling using beta regressions with a logit link function via the package *betareg* (Cribari-Neto & Zeileis 2010). Six transects (~0.8% of all data) with proportions equal to 0 or 1 were removed from analyses as non-inflated beta regression models only apply to measurements in the (0,1) interval. Data were separated into subsets of division and flooding period with year as the explanatory factor. Significant slope trends were compared to and confirmed using Spearman rank correlation tests.

#### *Foodfish Count*

Negative binomial generalized linear models were applied to model the non-Gaussian distributed foodfish count data. Viability of individual models were confirmed through comparison of model and simulated residuals using the aforementioned *DHARMA* package. Data were separated into subsets of division and flooding period with year as the explanatory factor in corresponding GLMs. Significant slope trends were compared to and confirmed using Spearman rank correlation tests.

#### *Foodfish Biomass*

Foodfish biomass data were unable to be normalized or fit with GLMs, and thus were assessed using Spearman rank sum correlation tests. Data were subsetted into division and flooding period groups then evaluated over time.

#### *Size Class*

Count data for all size classes were fourth-root ( $1/4^{\text{th}}$  power) transformed in order to resemble a Gaussian distribution. Size class data from 2014 were not available for any division. For a given size class, linear regressions were used to model trends over time for a given division and flooding period subgroup. Homoscedasticity between years for a given division was confirmed via Levene's tests. Subsets with significant slope estimates were confirmed using Spearman rank sum correlation tests.

A three-way analysis of variance (ANOVA) was used to compare differences in mean count by size class, year, and division. Tukey-adjusted *post hoc* contrasts were compiled for pairwise comparisons using the *emmeans* package (Lenth *et al.* 2020).



### *Trophic Level*

Count and biomass data for all trophic levels were unable to be normalized or fit with GLMs, and thus were assessed using Spearman rank sum correlation tests. Data were subsetted into division and flooding period groups then evaluated over time.

### *Endemism Status*

A list of fish species along with endemism status is provided in Appendix A.

#### Endemic:

Count data of endemic species were third-root ( $1/3^{\text{rd}}$  power) transformed in order to reach a normal distribution, whereas biomass data of endemic species were fifth-root ( $1/5^{\text{th}}$  power) transformed in order to assume a Gaussian distribution. Data were separated into subsets of division and flooding period with linear regressions used to assess change over time. Subsets with significant slope estimates were confirmed using Spearman rank sum correlation tests.

#### Indigenous:

Count and biomass data of indigenous species were both fifth-root ( $1/5^{\text{th}}$  power) transformed in order to resemble a Gaussian distribution. Data were separated into subsets of division and flooding period with linear regressions used to assess change over time. Subsets with significant slope estimates were confirmed using Spearman rank sum correlation tests.

#### Introduced:

Count and biomass data for introduced species were unable to be normalized or fit with GLMs, likely because ~70% of all transects did not record any indigenous fish species. Instead, count and biomass data were assessed using Spearman rank sum correlation tests. Data were subsetted into division and flooding period groups, then evaluated over time.

### Fishes – Multivariate Community-level Analysis

Fish data at the family level were compared using nonmetric multidimensional scaling (nMDS) models. Separate nMDS models were created for each division in order to visualize and interpret any dissimilarity in the multivariate community over time. Community data from 2014, 2016, and 2020 were compared inside the CBSFA and the Makua Pu‘uhonua, while community data from only 2016 and 2020 were compared outside the CBSFA. Fish families below a specific total combined abundance across all assessed years were removed using the following cutoffs: HI – 1.00 ind/m<sup>2</sup>, HO – 1.00 ind/m<sup>2</sup>, and PU – 0.25 ind/m<sup>2</sup>. For the inside CBSFA model, there were a total of 177 observations. For the outside CBSFA model, there were a total of 87 observations. Lastly, for the Pu‘uhonua model, there were a total of 32 observations.

Data were already separated by division, thus year was used as the only grouping factor to compare community-level changes. Input data for multivariate analyses were square-root transformed and a Bray–Curtis index calculated to construct distance matrices for the creation the nMDS plots. All nMDS model were iterated a maximum of 100 times at three dimensions ( $k = 3$ ). Permutational multivariate analyses of variance (PERMANOVA, Anderson 2001) with Bray–Curtis distances were conducted to determine any effects of year on community structure, with number of permutations set at a maximum of 999. Subsequently, pairwise comparisons of communities by year were examined using the package *pairwiseAdonis* (Martinez-Arbizu 2020).

Finally, in order to evaluate the contribution of each family to the average dissimilarity between groups, similarity percentages were employed (SIMPER, Clarke 1993). All nMDS, PERMANOVA, and SIMPER analyses were performed using the R package *vegan* (Oksanen *et al.* 2017).

### Sea Urchins

#### *Sample Size by Division/Depth (n):*

- 2016: HIS = 17, HID = 23, HOS = 13, HOD = 23, PU = 7
- 2017: HIS = 24, HID = 25, HOS = 23, HOD = 26, PU = 10
- 2018: HIS = 36, HID = 19, HOS = 15, HOD = 17, PU = 23
- 2019: HIS = 28, HID = 20, HOS = 20, HOD = 20, PU = 10
- 2020: HIS = 34, HID = 29, HOS = 21, HOD = 23, PU = 15

#### *Total Urchin Count*

Negative binomial generalized linear models were applied to the non-Gaussian distributed total urchin count data. Negative binomial distributions were selected by evaluation of Akaike information criterion (AIC) values, overdispersion indices, and residual plots. Models including depth were run for each division/depth combination (HID, HIS, HOD, HOS, and PU) and flooding period. Viability of individual models (i.e., goodness-of-fit, overdispersion, and outliers) were then assessed using the aforementioned *DHARMA* package.

### Benthic Cover

#### *Sample Size by Division/Depth (n):*

- 2016: HIS = 20, HID = 27, HOS = 14, HOD = 29, PU = 8
- 2017: HIS = 25, HID = 26, HOS = 21, HOD = 25, PU = 10
- 2018: HIS = 35, HID = 20, HOS = 15, HOD = 17, PU = 23
- 2019: HIS = 27, HID = 19, HOS = 21, HOD = 20, PU = 10
- 2020: HIS = 34, HID = 30, HOS = 20, HOD = 24, PU = 15

#### *Coral Cover*

Coral cover was calculated as the proportion of total benthic cover. In order to resemble a Gaussian distribution, coral proportion data were arcsine third root transformed. Data were then subsetted by division/depth combination and flooding period, with subgroups then analyzed over time using linear regression models. Parametric assumptions of linear models were assessed via model residual plots.

#### *Coral Bleaching*

Coral bleaching was determined as the proportion of total coral that was bleached. Data were not normally distributed and were unable to be successfully transformed or modeled, thus non-parametric Spearman rank sum correlation was used to assess changes in bleaching over the study period. Data were subsetted into groups of division/depth and flooding period then assessed individually over time.

## RESULTS

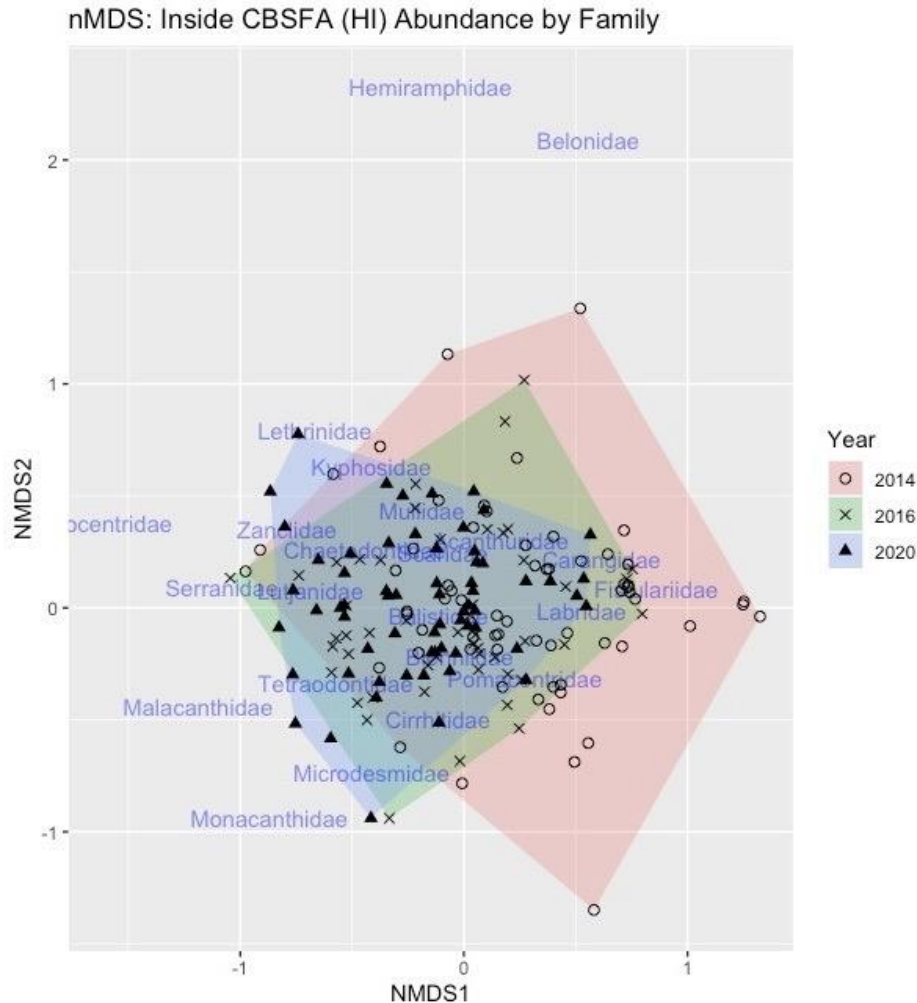
By examining resource differences in areas with varying management regimes, the evaluation of a management effort's efficacy can be determined and adaptive procedures implemented where needed. Comparisons were made of three separate areas within the larger Hā'ena region because different regulations apply to the Hā'ena CBSFA management protected area. In addition to the CBSFA zone, sectors are divided into the smaller Makua Pu'uhonua juvenile fish habitat area within the CBSFA, where no fishing is allowed, and the open access area outside the CBSFA, where only regulations that pertain to the rest of State's nearshore waters apply. These sectors, as well as pre-flood (2016-2017) and post-flood (2018-2020) periods, were used in statistical analyses. For the statistics inside the CBSFA and in the Pu'uhonua, additional baseline data were included (2014), which were acquired from surveys by the Fisheries Ecology Research Laboratory (FERL) prior to the establishment of the CBSFA. No data were collected prior to 2016 outside the CBSFA boundaries, thus its baseline began in 2016. Separation of analyses before and after the 2018 flood event were selected due to significant declines in fish and urchin populations following the flood (Rodgers *et al.* 2021). Surveys conducted the year of the flood found a notable decline in both fish abundance and biomass at shallow depths, with no change at deeper stations when combining data from all sectors. This separation (pre- and post-flood) allows for a clearer understanding of the changes due to management regulations as opposed to those generated by the flood.

### Community Level Analyses

#### Hā'ena Inside Fish Assemblages (2014, 2016, and 2020)

The nMDS model for fish family-level abundance data inside the CBSFA successfully converged and well represented fish assemblages by year (stress = 0.16, nonmetric fit  $R^2 = 0.98$ ). Figure 5 depicts shifts in community structure between 2014, 2016, and 2020, which were selected to represent assemblages before fishing restriction implementation, immediately after regulation application, and at the end of the study period. PERMANOVA results suggest dissimilarity in multivariate space of fish transect results when compared by year ( $df = 2$ ,  $p < 0.001$ ). Subsequent pairwise comparisons found significant shifts in community structure between 2014 and 2016 ( $df = 2$ ,  $F = 21.76$ ,  $R^2 = 16.39$ ,  $p = 0.003$ ) and between 2014 and 2020 ( $df = 1$ ,  $F = 30.55$ ,  $R^2 = 19.39$ ,  $p = 0.003$ ); shifts between 2014 and 2020 appear to be more intensive than between 2014 and 2016 when considering the higher  $F$  test statistic. The pairwise comparison between 2016 and 2020, however, did not find a significant shift in community structure ( $p = 0.150$ ).

SIMPER results, which identify fish families that contribute most to dissimilarity in community structure, found Pomacentridae, Labridae, Acanthuridae, Scaridae, Microdesmidae, Blenniidae, Belonidae, Lethrinidae, and Holocentridae to be significant drivers of community shifts between 2014 and 2016. These families comprised 39% (9 out of 23) of families included in the model. SIMPER results for the 2014 and 2020 comparison determined Pomacentridae, Acanthuridae, Labridae, Balistidae, Carangidae, Kyphosidae, Cirrhitidae, Chaetodontidae, Tetraodontidae, Fistulariidae, Malacanthidae, and Monacanthidae to have significantly affected community dissimilarity. These families accounted for 52% (12 out of 23) of families included in the model.

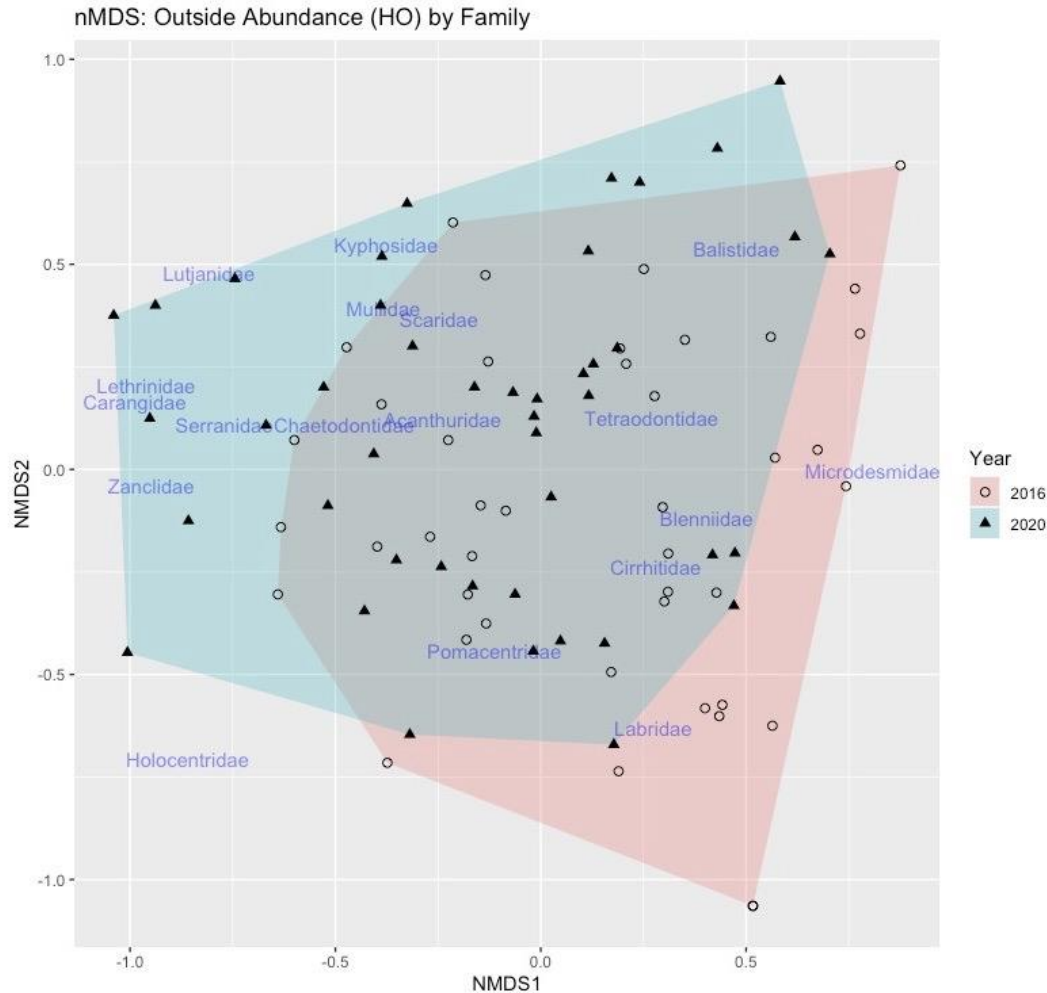


**Figure 5.** Non-metric multidimensional scaling plot of the fish assemblages inside the reserve boundaries comparing communities in 2014, 2016 and 2020.

#### Hā'ena Outside Fish Assemblages (2016 and 2020)

The nMDS model of fish family-level abundance outside the CBSFA successfully converged with stress estimates and model fit within acceptable limits (stress = 0.16, nonmetric fit  $R^2 = 0.97$ , Fig. 6). Year was found to be a significant driver of dissimilarity between 2016 and 2020 fish assemblages ( $df = 1$ ,  $F = 2.87$ ,  $R^2 = 3.26$ ,  $p = 0.012$ ). The degree of statistical power ( $F$  statistic) was an order of magnitude lower outside the CBSFA, however, compared to structural dissimilarity inside the CBSFA, suggesting changes to community structure outside the CBSFA were weaker.

Acanthuridae, Mullidae, Scaridae, Microdesmidae, Carangidae, and Serranidae were significant contributors to dissimilarity in community structure between years, with Balistidae and Lutjanidae trending towards significance ( $p = 0.061$  and  $p = 0.053$ , respectively). These families represented 33% (6 out of 18) of taxa groups included in this model.

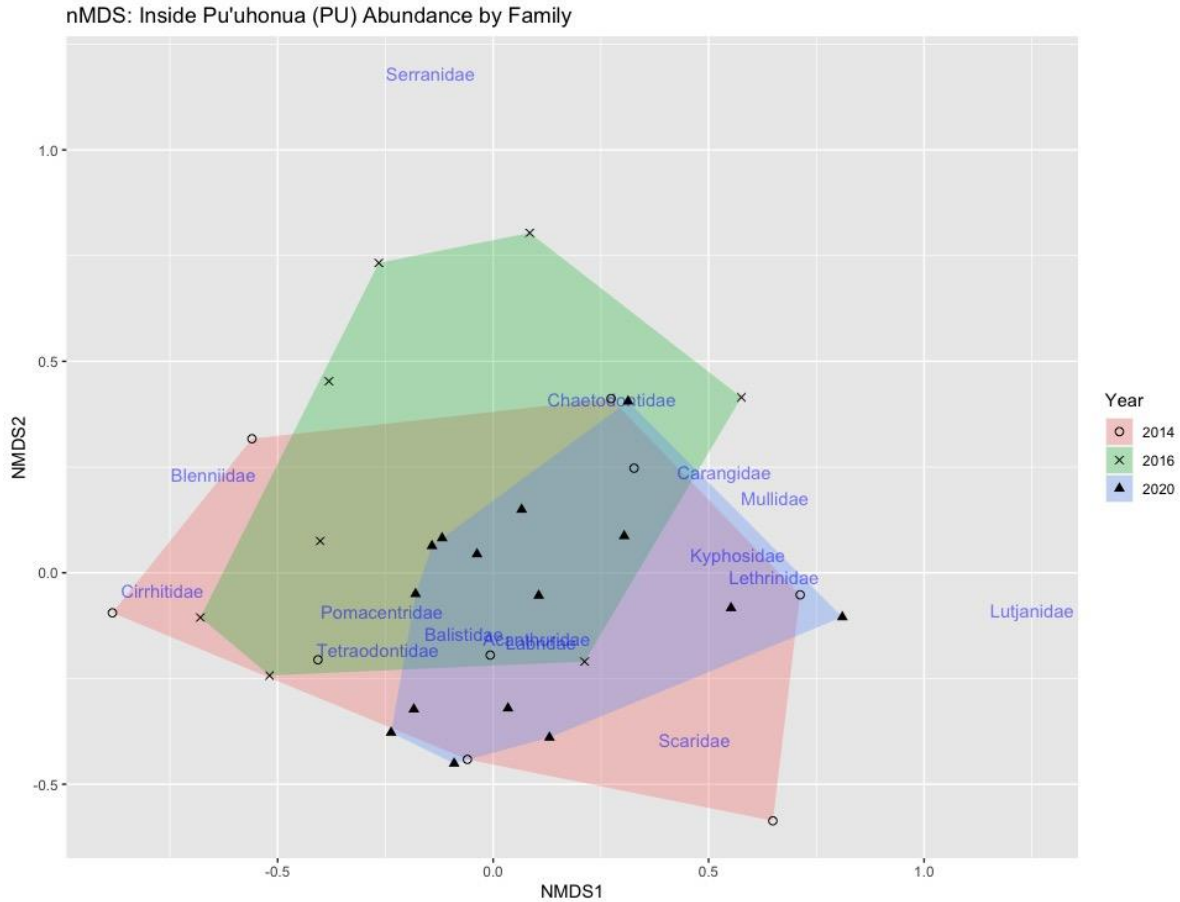


**Figure 6.** Non-metric multidimensional scaling plot of the fish assemblages outside the CBSFA comparing communities in 2016 and 2020.

#### Makua Pu‘uhonua Fish Assemblages (2014, 2016, and 2020)

The nMDS model of fish family-level abundance inside the Pu‘uhonua successfully converged and well represented community data (stress = 0.14, nonmetric fit  $R^2 = 0.98$ , Fig. 7). Year was found to be a significant predictor of dissimilarity in community structure ( $df = 2$ ,  $F = 9.98$ ,  $R^2 = 40.77$ ,  $p = 0.001$ ). Pairwise comparisons showed differences between all years; the strongest shift was observed from 2014 to 2020 ( $df = 1$ ,  $F = 20.19$ ,  $R^2 = 47.86$ ,  $p = 0.003$ ), with 2014 to 2016 ( $df = 1$ ,  $F = 4.34$ ,  $R^2 = 22.45$ ,  $p = 0.012$ ) and 2016 to 2020 ( $df = 1$ ,  $F = 4.86$ ,  $R^2 = 18.79$ ,  $p = 0.018$ ) also showing significant dissimilarity.

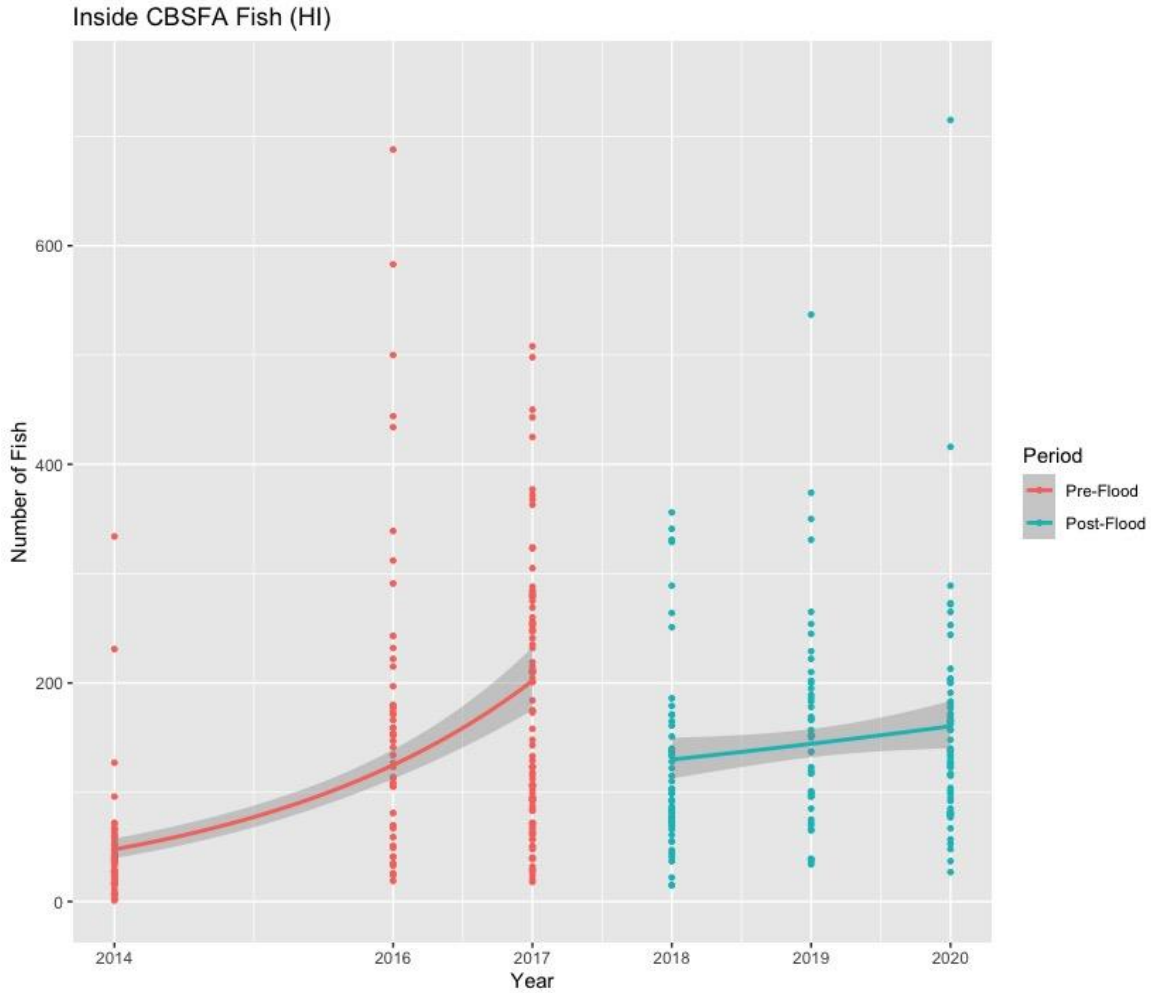
Families with significant contributions to dissimilarity between 2014 and 2020 were Labridae, Acanthuridae, and Balistidae, representing 20% (3 out of 15) of fish taxa in the model. Regarding 2014 and 2016, Mullidae, Chaetodontidae, Tetraodontidae, Cirrhitidae, and Serranidae were significantly dissimilar, comprising 33% (5 out of 15) of families. Balistidae was the only family found to have contributed significantly to dissimilarity between 2016 and 2020.



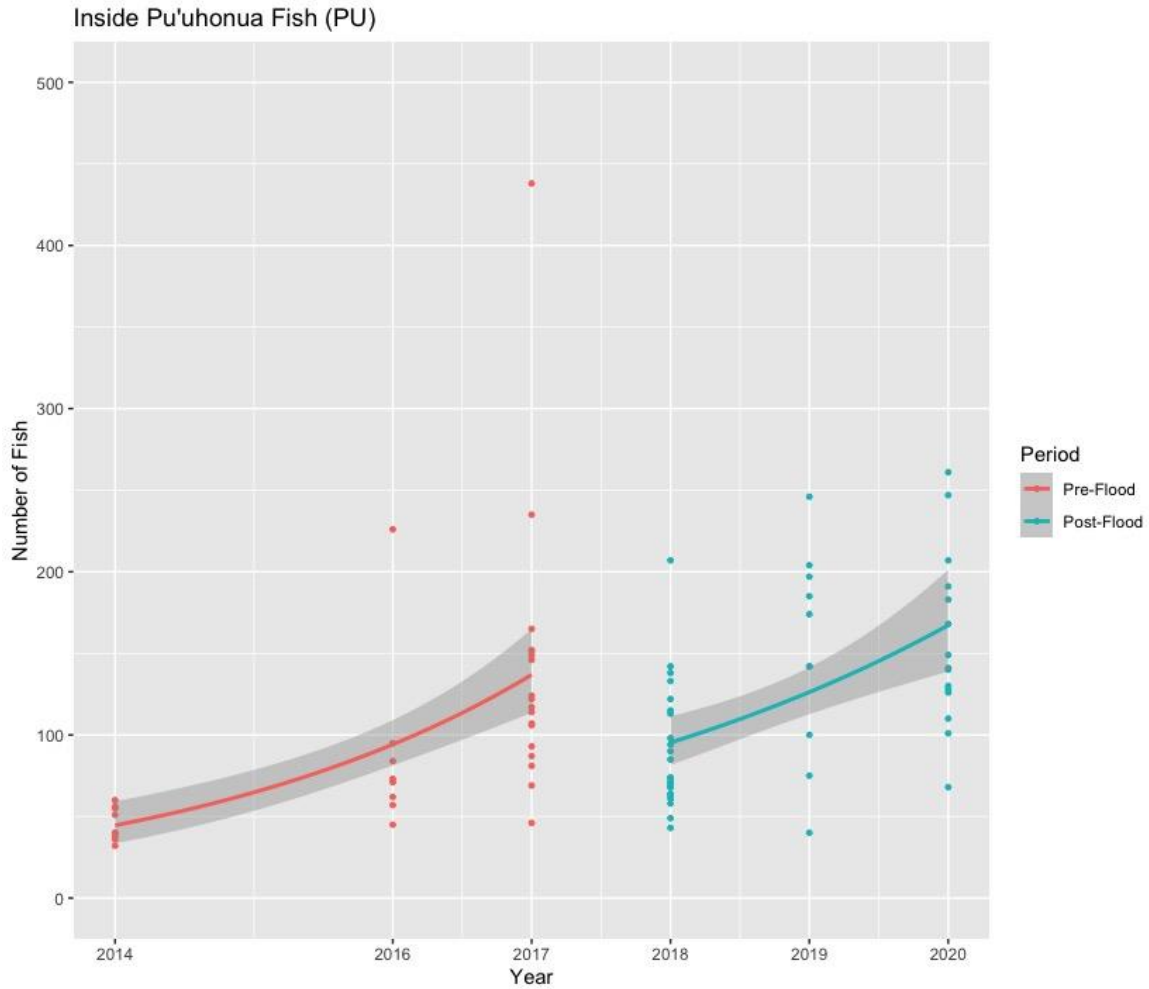
**Figure 7.** Non-metric multidimensional scaling plot of the fish assemblages inside the Makua Pu'uhonua comparing communities in 2014, 2016 and 2020.

## Fish Abundance

Statistical analyses of fish counts showed a significant positive trend from 2014-2017 inside the CBSFA prior to the flood ( $p \leq 0.001$ ) and from 2018-2020 following the flood ( $p = 0.011$ , Fig. 8). A similar pattern was also found in the Makua Pu'uhonua prior to the flood ( $p \leq 0.001$ ) and following the flood ( $p \leq 0.011$ , Fig. 9). No significant trends in fish counts were found outside the CBSFA boundaries either before the flood event from 2016-2018 or after the flood from 2018-2020 (Fig. 10).

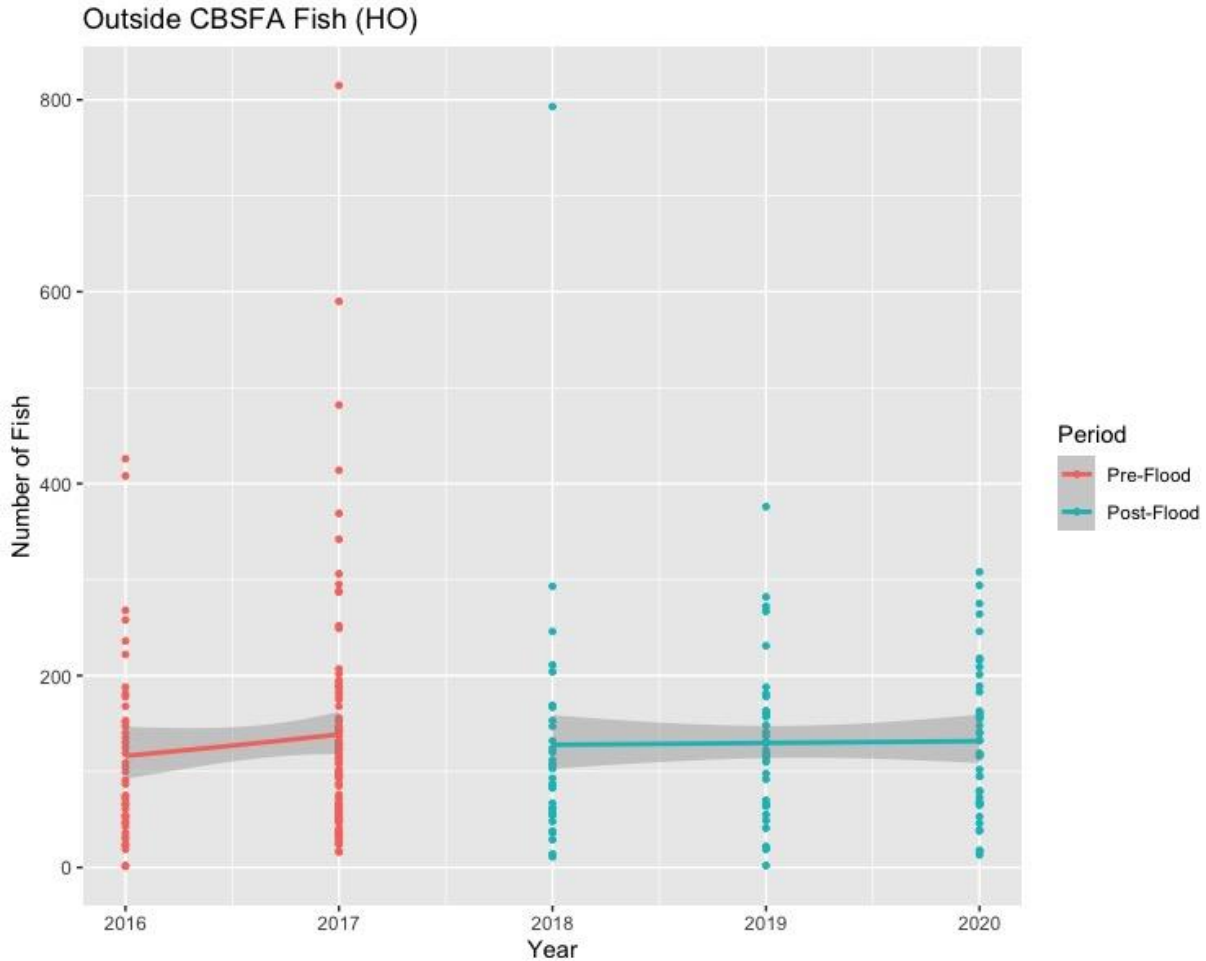


**Figure 8.** Overall fish counts per transect from inside the CBSFA with smoothed lines showing modeled fit. Shaded areas represent 95% confidence intervals for the model. Data were separated into periods before (2014-2017, no 2015 data) and after (2018-2020) the historic flooding event. Separate models were used for each period.



**Figure 9.** Overall fish counts per transect from Pu'uhonua with smoothed lines showing modeled fit. Shaded areas represent 95% confidence intervals for the model. Data were separated into periods before (2014-2017, no 2015 data) and after (2018-2020) the historic flooding event. Separate models were used for each period.

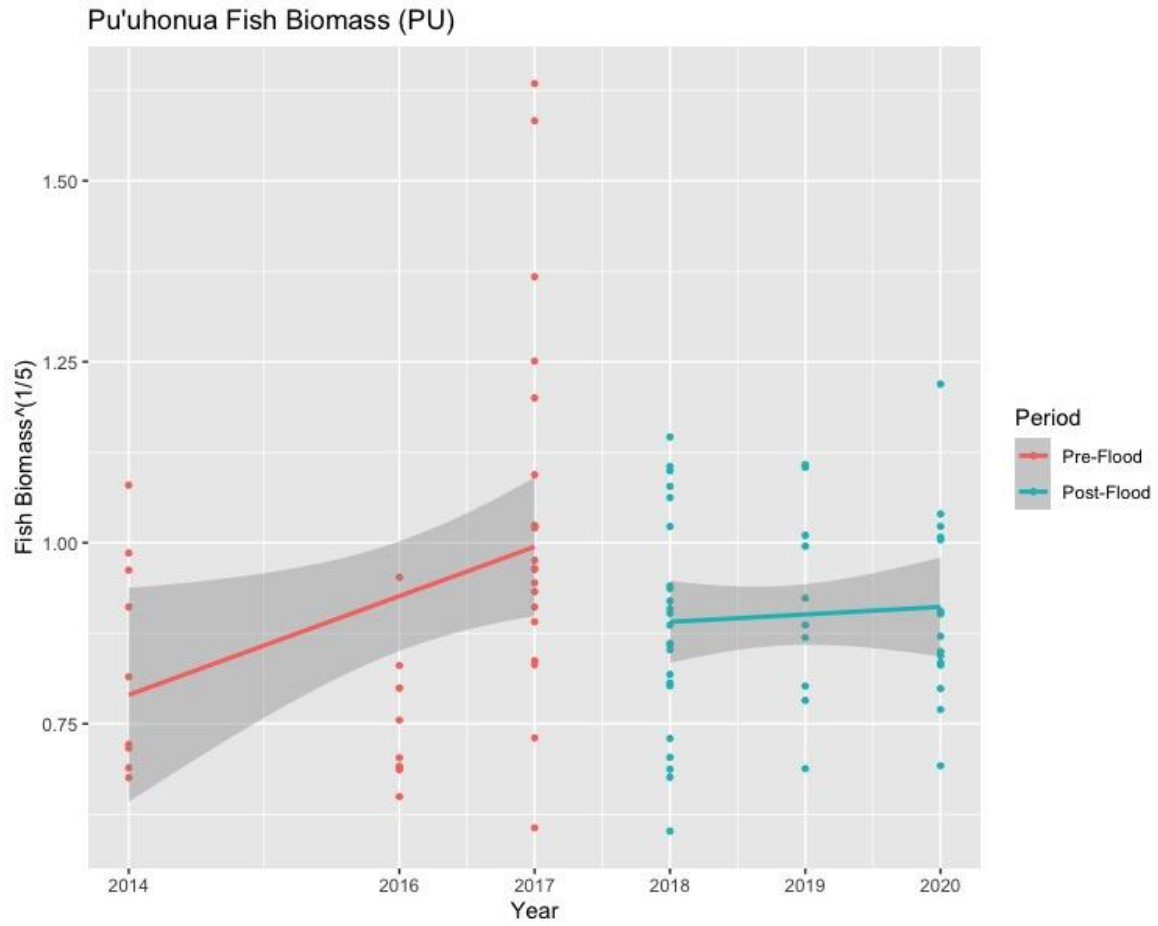




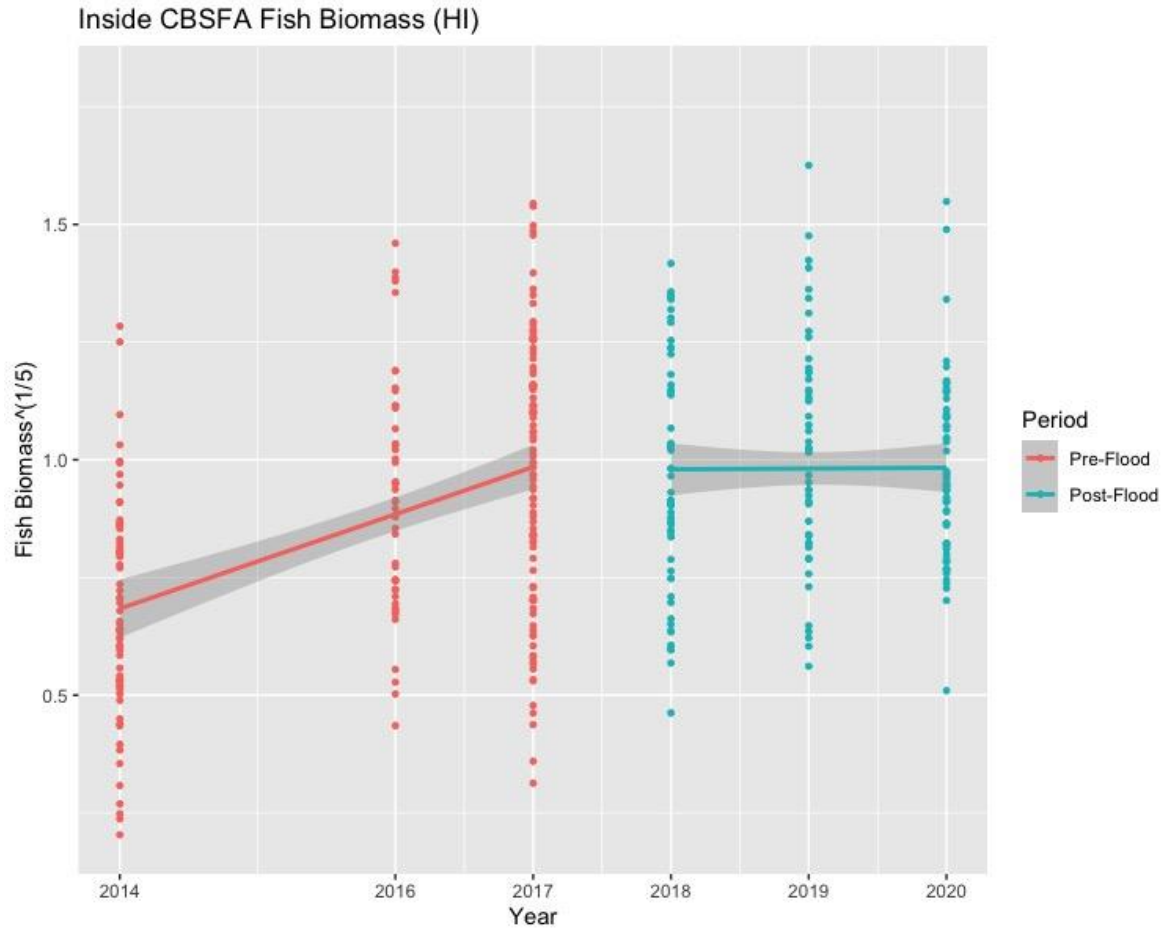
**Figure 10.** Overall fish counts per transect from outside the CBSFA with smoothed lines showing modeled fit. Shaded areas represent 95% confidence intervals for the model. Data were separated into periods before (2016-2017, no data from before 2016) and after (2018-2020) the historic flooding event. Separate models were used for each period.

## Fish Biomass

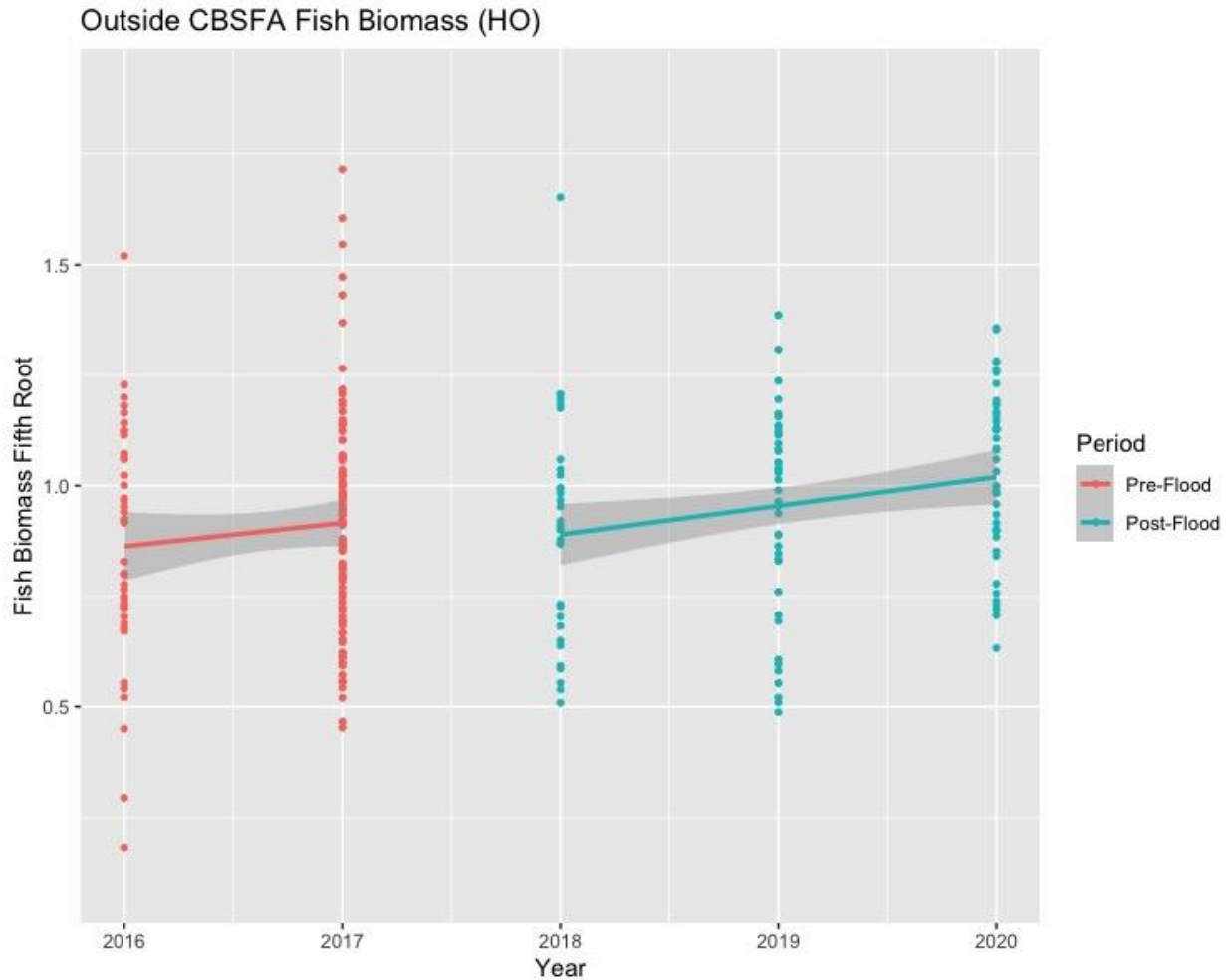
Fish biomass in the Makua Pu‘uhonua showed a statistically significant positive trend ( $p = 0.031$ ) prior to the flood (Fig. 11), however no significant changes were found in the Pu‘uhonua following the flood. Fish biomass inside the CBSFA also showed a significantly positive trend prior the flood ( $p \leq 0.001$ ), although this also did not perpetuate post-flood (Fig. 12). Surveys conducted outside the CBSFA showed no changes in biomass prior to the flood (2016-2017), however there was a significantly positive trend following the flood event ( $p = 0.013$ , Fig. 13).



**Figure 11.** Overall fish biomass (transformed) by year inside the Makua Pu'uhonua separated by period (pre/post flood). Lines represent linear regression models and shaded areas the 95% confidence intervals.



**Figure 12.** Overall fish biomass (transformed) by year inside the CBSFA separated by period (pre/post flood). Lines represent linear regression models and shaded areas the 95% confidence intervals.



**Figure 13.** Overall fish biomass (transformed) by year outside the CBSFA separated by period (pre/post flood). Lines represent linear regression models and shaded areas the 95% confidence intervals.

## Resource Fishes

Hā'ena community interviews conducted in 2003, 2007, and 2008 identified important food fish species. Traditional families from Hā'ena documented near-shore marine resources central to their subsistence and cultural practices (DAR 2016). These species, along with the perceived condition of each resource, are listed along a gradient from excellent to poor in Table 4. This perceived condition reflects the community perception of fish abundance. The following fish population condition levels include: Excellent (similar to the 1940s and 1950s), Good, Fair (stressed and in decline), Poor (degraded), Bad (severe decline), and Pau (no/very limited production) (DAR 2016).

**Table 4.** Food fishes important to the Hā‘ena community. The “Listed Name” reflects the resources cited in the Management Plan for the Hā‘ena Community-Based Subsistence Fishing Area, Kaua‘i. Additional names and families were added in adjacent columns. Species were derived from family names. “Perceived condition” depicts community perception of fish condition: Excellent (like the 1940s and 1950s), Good, Fair (stressed and in decline), Poor (degraded), Bad (severe decline), Pau (no/very limited production). Missing condition assessments are due to omissions in the management plan.

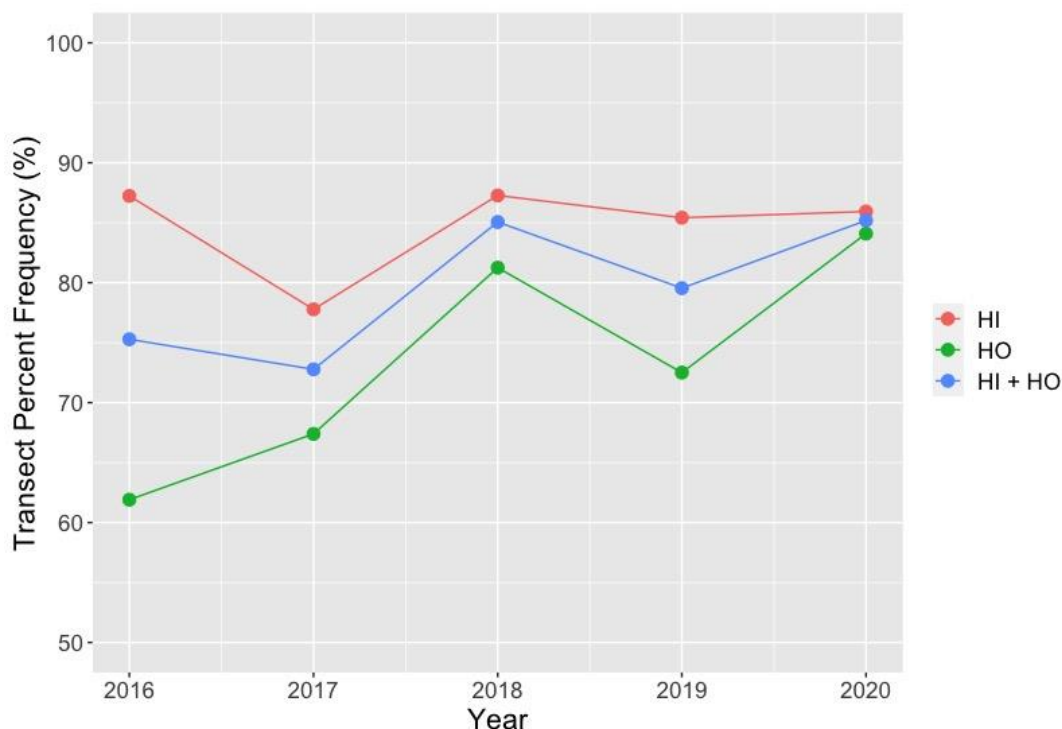
Listed Name	TaxonName	Hawaiian Name	Common Name	Family	Perceived condition
akule	<i>Selar crumenophthalmus</i>	akule	Big-Eyed Scad	Carangidae	Poor
moi	<i>Polydactylus sexfilis</i>	moi	Threadfin	Polynemidae	Poor
ama'ama	<i>Mugil cephalus</i>	'ama 'ama	Striped Mullet	Mugilidae	Poor
kala	<i>Naso unicornis</i>	kala	Bluespine Unicornfish	Acanthuridae	Poor
nenue, Enenue	<i>Kyphosus species</i>	nenue	Chub	Kyphosidae	Excellent
	<i>Kyphosus bigibbus</i>	nenue	Brown Chub	Kyphosidae	Excellent
	<i>Kyphosus cinerascens</i>	nenue	Highfin Chub	Kyphosidae	Excellent
	<i>Kyphosus vaigiensis</i>	nenue	Lowfin Chub	Kyphosidae	Excellent
manini	<i>Acanthurus triostegus</i>	manini	Convict Tang	Acanthuridae	Good
oama	<i>Mulloidichthys flavolineatus</i>	weke	Yellowstripe Goatfish	Mullidae	Good
	<i>Mulloidichthys vanicolensis</i>	weke 'ula	Yellowfin Goatfish	Mullidae	Good
āholehole	<i>Kuhlia sandvicensis</i>	āholehole	Hawaiian Flagtail	Kuhliidae	Fair
'āweoweo	<i>Priacanthus meeki</i>	'āweoweo	Hawaiian Bigeye	Priacanthidae	Fair
kahala	<i>Seriola dumerili</i>	kahala	Amberjack	Carangidae	Fair
ulua	<i>Carangoides ferdau</i>	ulua	Barred Jack	Carangidae	Fair
	<i>Carangoides orthogrammus</i>	ulua	Island Jack	Carangidae	Fair
	<i>Caranx ignobilis</i>	ulua aukea	Giant Trevally	Carangidae	Fair
	<i>Caranx melampygus</i>	'omihu	Bluefin Trevally	Carangidae	Poor
	<i>Caranx sexfasciatus</i>	ulua	Bigeye Jack	Carangidae	Fair
	<i>Gnathanodon speciosus</i>	ulua pa'opa'o	Golden Trevally	Carangidae	Fair
	<i>Pseudocaranx dentex</i>	ulua	Thicklip Jack	Carangidae	Fair
uhu	<i>Chlorurus spilurus</i>	uhu	Bullethead Parrotfish	Scaridae	Good
	<i>Scarus psittacus</i>	uhu	Palenose Parrotfish	Scaridae	Good
	<i>Chlorurus perspicillatus</i>	uhu	Spectacled Parrotfish	Scaridae	Good
	<i>Calotomus carolinus</i>	uhu	Star-eye Parrotfish	Scaridae	Good
	<i>Calotomus zonarchus</i>	uhu	Yellowbar Parrotfish	Scaridae	Good
	<i>Scarus dubius</i>	lauia	Regal Parrotfish	Scaridae	Good
	<i>Scarus rubroviolaceus</i>	uhu	Redlip parrotfish	Scaridae	Good
kūmū	<i>Parupeneus porphyreus</i>	kūmū	Whitesaddle Goatfish	Mullidae	
kawakawa	<i>Euthynnus affinis</i>	kawakawa	Wavy-back Tuna	Scombridae	Fair
palani	<i>Acanthurus dussumieri</i>	palani	Eye-stripe Surgeonfish	Acanthuridae	Good
maiko	<i>Acanthurus nigroris</i>	maiko	Bluelined Surgeonfish	Acanthuridae	Good

The Hā‘ena community listed 16 fishes of importance. The translation of Hawaiian names to species names expanded the list to 32 fishes. The Hawaiian name *uhu*, for example, refers to all parrotfishes in the family Scaridae, of which seven species are listed.

Maintaining the sustainability of the Hā‘ena CBSFA fishery is a key goal of all parties involved. An initial assessment over the five-year existence of the CBSFA was conducted to compare resource fishes identified by the community to non-resource fishes (food vs. non-food) in order to determine management success. By comparing the patterns between fished and unfished species, we attempted to isolate changes due to management strategies and/or fishing impacts.

Of the 32 food fish species indicated by the community, 21 were recorded across the five-year study. When comparing across all five years, nine species of resource fishes within the CBSFA identified by the community have increased in frequency since 2016. At least eleven species are present for the majority of years, more often inside the reserve as compared to outside.

Resource fishes consistently appeared more frequently on transects within the CBSFA as compared to outside from 2016-2019 (Fig. 14). There was an increase in the frequency of food fishes appearing on transects in all sectors from 2017 to 2018, suggesting a potential spill-over effect may be occurring (Fig. 14).



**Figure 14.** Frequency of resource fishes appearing on transects (transect % frequency) within each sector from 2016-2020. HI = Hā'ena Inside CBSFA, HO = Hā'ena Outside CBSFA, HI + HO = combined Hā'ena sectors.

The frequency of *Kyphosus* spp. increased from 8.5% in 2016 to 26.6% in 2020 within the CBSFA while also showing an increasing trend outside. The trends of *Calotomus carolinus* and *Acanthurus nigroris* also showed increases within the reserve from 2016 to 2020. Alternatively, resource fishes that have increased outside the reserve include *Scarus rubroviolaceus* and *Chlorurus spilurus*. Eight species increased in frequencies both inside and outside the CBSFA, indicating a possible spillover effect from the reserve (Table 5). The Makua Pu'uhoŋua had very high variability between years for species frequencies of occurrence. The biomass of eight resource fishes (Table 6) have increased since 2016, with the largest change detected in *Kyphosus* spp. (*nenuē*), which increased from 1.6 to 16.3 g/m<sup>2</sup> over the study period.

**Table 5.** The frequency of occurrence from 2016 through 2020 (% of transects on which species were recorded) and perceived condition of food fishes found on transects within the Hā‘ena CBSFA, outside the CBSFA boundaries, and within the Makua Pu‘uhonua reserve. Hawaiian names may differ by island.

% Frequency								
Taxonomic Name	Hawaiian Name	Perceived Condition	Location	2016	2017	2018	2019	2020
<i>Naso unicornis</i>	<i>kala</i>	Poor	Inside	36.2	30.3	30.9	47.9	42.2
			Outside	39.5	28.3	18.8	25.0	45.5
			Pu‘uhonua	12.5	55.0	30.4	90.0	40.0
<i>Kyphosus species</i>	<i>nenue, Enenue</i>	Excellent	Inside	8.5	19.2	30.9	31.3	26.6
			Outside	14.0	18.5	25.0	30.0	27.3
			Pu‘uhonua	0.0	40.0	34.8	70.0	53.3
<i>Acanthurus triostegus</i>	<i>manini</i>	Good	Inside	61.7	48.5	52.7	56.3	42.2
			Outside	34.9	35.9	34.4	52.5	50.0
			Pu‘uhonua	62.5	50.0	65.2	80.0	66.7
<i>Mulloidichthys flavolineatus</i>	<i>oama</i>	Good	Inside	2.1	4.0	7.3	14.6	4.7
			Outside	0.0	1.1	3.1	0.0	6.8
			Pu‘uhonua	12.5	5.0	4.3	30.0	6.7
<i>Mulloidichthys vanicolensis</i>		Good	Inside	0.0	7.1	9.1	2.1	4.7
			Outside	4.7	1.1	6.3	2.5	9.1
			Pu‘uhonua	12.5	5.0	0.0	0.0	6.7
<i>Seriola dumerili</i>	<i>kahala</i>	Fair	Inside	0.0	0.0	1.8	2.1	3.1
			Outside	0.0	1.1	6.3	0.0	2.3
			Pu‘uhonua	0.0	5.0	0.0	0.0	0.0
<i>Caranx ignobilis</i>	<i>ulua</i>	Fair	Inside	0.0	0.0	0.0	2.1	1.6
			Outside	0.0	0.0	0.0	5.0	0.0
			Pu‘uhonua	0.0	0.0	0.0	0.0	0.0
<i>Caranx melampygus</i>		Poor	Inside	29.8	28.3	23.6	27.1	31.3
			Outside	7.0	23.9	18.8	25.0	34.1
			Pu‘uhonua	0.0	25.0	17.4	10.0	20.0
<i>Carangoides ferdau</i>		Fair	Inside	0.0	1.0	0.0	0.0	0.0
			Outside	0.0	0.0	0.0	0.0	2.3
			Pu‘uhonua	0.0	0.0	0.0	0.0	0.0
<i>Carangoides orthogrammus</i>		Fair	Inside	0.0	1.0	1.8	0.0	0.0
			Outside	0.0	1.1	0.0	0.0	0.0
			Pu‘uhonua	0.0	0.0	4.3	0.0	0.0
<i>Chlorurus spilurus</i>	<i>uhu</i>	Good	Inside	8.5	13.1	7.3	14.6	9.4
			Outside	0.0	7.6	6.3	17.5	9.1
			Pu‘uhonua	25.0	10.0	8.7	0.0	40.0

<i>Scarus psittacus</i>		Good	Inside	6.4	9.1	3.6	0.0	9.4
			Outside	0.0	4.3	3.1	5.0	11.4
			Pu'uhonua	0.0	10.0	13.0	20.0	33.3
<i>Chlorurus perspicillatus</i>		Good	Inside	2.1	3.0	0.0	0.0	1.6
			Outside	2.3	4.3	0.0	2.5	0.0
			Pu'uhonua	0.0	0.0	0.0	0.0	0.0
<i>Calotomus carolinus</i>		Good	Inside	4.3	9.1	14.5	4.2	9.4
			Outside	4.7	10.9	3.1	0.0	2.3
			Pu'uhonua	0.0	5.0	4.3	20.0	6.7
<i>Calotomus zonarchus</i>		Good	Inside	0.0	0.0	0.0	0.0	0.0
			Outside	0.0	1.1	0.0	0.0	0.0
			Pu'uhonua	0.0	0.0	0.0	0.0	0.0
<i>Scarus dubius</i>		Good	Inside	0.0	1.0	0.0	2.1	0.0
			Outside	0.0	0.0	0.0	0.0	0.0
			Pu'uhonua	0.0	0.0	0.0	0.0	0.0
<i>Scarus rubroviolaceus</i>		Good	Inside	40.4	46.5	43.6	39.6	34.4
			Outside	23.3	32.6	15.6	40.0	45.5
			Pu'uhonua	0.0	60.0	39.1	70.0	26.7
<i>Parupeneus porphyreus</i>	<i>kūmū</i>		Inside	0.0	2.0	1.8	2.1	0.0
			Outside	2.3	1.1	0.0	0.0	6.8
			Pu'uhonua	0.0	10.0	4.3	20.0	0.0
<i>Acanthurus dussumieri</i>	<i>palani</i>	Good	Inside	19.1	18.2	23.6	22.9	17.2
			Outside	11.6	14.1	15.6	17.5	25.0
			Pu'uhonua	12.5	25.0	8.7	0.0	26.7
<i>Acanthurus nigroris</i>	<i>maiko</i>	Good	Inside	8.5	7.1	16.4	10.4	17.2
			Outside	18.6	8.7	9.4	7.5	18.2
			Pu'uhonua	12.5	0.0	8.7	0.0	0.0
<i>Selar crumenophthalmus</i>	<i>akule</i>	Poor	Inside	0.0	0.0	0.0	0.0	0.0
			Outside	0.0	0.0	0.0	0.0	0.0
			Pu'uhonua	0.0	0.0	4.3	0.0	0.0



**Table 6.** Mean resource fish biomass (g/m<sup>2</sup>) between 2016 and 2020 found on transects within the Hā‘ena CBSFA, outside the CBSFA boundaries, and within the Makua Pu‘uhonua listed with perceived conditions.

Mean Biomass (g/m²)								
Taxonomic Name	Hawaiian Name	Perceived Condition	Location	2016	2017	2018	2019	2020
<i>Naso unicornis</i>	<i>kala</i>	Poor	Inside	6.4	9.9	4.5	13.4	5.8
			Outside	4.7	9.9	2.9	3.6	6.7
			Pu‘uhonua	1.5	13.2	2.9	4.7	4.1
<i>Kyphosus species</i>	<i>nenue, Enenue</i>	Excellent	Inside	1.6	22.1	8.4	10.7	16.3
			Outside	6.5	11.9	13.6	11.0	13.4
			Pu‘uhonua	0.0	7.9	3.8	6.3	2.5
<i>Acanthurus triostegus</i>	<i>manini</i>	Good	Inside	6.4	8.4	7.5	11.7	4.2
			Outside	4.5	4.2	5.2	5.2	9.2
			Pu‘uhonua	1.3	1.3	1.0	4.2	6.3
<i>Mulloidichthys flavolineatus</i>	<i>oama</i>	Good	Inside	0.1	1.4	0.7	0.5	0.9
			Outside	0.0	0.6	0.0	0.0	1.1
			Pu‘uhonua	1.7	0.1	0.2	0.4	0.1
<i>Mulloidichthys vanicolensis</i>		Good	Inside	0.0	4.2	1.3	1.0	1.0
			Outside	2.1	9.4	2.2	0.2	3.8
			Pu‘uhonua	0.6	3.0	0.0	0.0	1.7
<i>Seriola dumerili</i>	<i>kahala</i>	Fair	Inside	0.0	0.0	0.3	2.2	2.3
			Outside	0.0	0.1	1.5	0.0	0.3
			Pu‘uhonua	0.0	1.0	0.0	0.0	0.0
<i>Caranx ignobilis</i>	<i>ulua</i>	Fair	Inside	0.0	0.0	0.0	2.6	2.3
			Outside	0.0	0.0	0.0	1.9	0.0
			Pu‘uhonua	0.0	0.0	0.0	0.0	0.0
<i>Caranx melampygus</i>		Poor	Inside	2.8	3.3	4.6	4.4	4.7
			Outside	0.2	1.7	1.0	5.1	4.0
			Pu‘uhonua	0.0	1.5	6.2	0.6	1.1
<i>Carangoides ferdau</i>		Fair	Inside	0.0	0.1	0.0	0.0	0.0
			Outside	0.0	0.0	0.0	0.0	0.1
			Pu‘uhonua	0.0	0.0	0.0	0.0	0.0
<i>Carangoides orthogrammus</i>		Fair	Inside	0.0	0.0	0.1	0.0	0.0
			Outside	0.0	0.4	0.0	0.0	0.0
			Pu‘uhonua	0.0	0.0	2.2	0.0	0.0
<i>Chlorurus spilurus</i>	<i>uhu</i>	Good	Inside	5.4	3.7	0.8	1.2	0.1
			Outside	0.0	0.3	0.6	7.7	0.3
			Pu‘uhonua	2.1	1.2	3.5	0.0	1.1

<i>Scarus psittacus</i>		Good	Inside	0.5	0.7	0.1	0.0	0.2
			Outside	0.0	0.2	0.1	0.4	1.0
			Pu'uhonua	0.0	0.2	0.4	0.6	0.4
<i>Chlorurus perspicillatus</i>		Good	Inside	0.1	0.6	0.0	0.0	0.4
			Outside	0.7	1.6	0.0	0.4	0.0
			Pu'uhonua	0.0	0.0	0.0	0.0	0.0
<i>Calotomus carolinus</i>		Good	Inside	0.1	0.5	0.4	0.5	0.2
			Outside	0.1	0.6	0.0	0.0	0.0
			Pu'uhonua	0.0	0.3	0.0	0.4	0.1
<i>Calotomus zonarchus</i>		Good	Inside	0.0	0.0	0.0	0.0	0.0
			Outside	0.0	0.0	0.0	0.0	0.0
			Pu'uhonua	0.0	0.0	0.0	0.0	0.0
<i>Scarus dubius</i>		Good	Inside	0.0	0.1	0.0	0.8	0.0
			Outside	0.0	0.0	0.0	0.0	0.0
			Pu'uhonua	0.0	0.0	0.0	0.0	0.0
<i>Scarus rubroviolaceus</i>		Good	Inside	2.2	3.7	3.0	2.9	1.7
			Outside	1.0	2.9	1.5	1.5	1.8
			Pu'uhonua	0.0	1.7	2.8	4.4	0.7
<i>Parupeneus porphyreus</i>	<i>kūmū</i>		Inside	0.0	0.1	0.1	0.1	0.0
			Outside	0.1	0.0	0.0	0.0	0.5
			Pu'uhonua	0.0	0.4	0.1	0.1	0.0
<i>Acanthurus dussumieri</i>	<i>palani</i>	Good	Inside	2.1	1.6	1.4	8.9	1.1
			Outside	0.9	1.5	0.7	1.9	2.9
			Pu'uhonua	0.2	0.8	1.3	0.0	1.3
<i>Acanthurus nigroris</i>	<i>maiko</i>	Good	Inside	0.3	0.2	0.3	0.5	0.3
			Outside	0.5	0.8	0.3	0.3	0.2
			Pu'uhonua	0.0	0.0	0.1	0.0	0.0
<i>Selar crumenophthalmus</i>	<i>akule</i>	Poor	Inside	0.0	0.0	0.0	0.0	0.0
			Outside	0.0	0.0	0.0	0.0	0.0
			Pu'uhonua	0.0	0.0	0.4	0.0	0.0

Resource fish species that were among the top ten species for biomass in 2020 are shown in Table 7. Four species of food fishes are included in the top ten with the highest percent biomass inside the reserve in 2020. *Kyphosus* spp. ranked second, with a mean biomass of 16.3 g/m<sup>2</sup>, followed by *N. unicornis* ranked 5th (5.8 g/m<sup>2</sup>), *C. melampygus* ranked 7th (4.65 g/m<sup>2</sup>), and *A. triostegus* ranked 8th (4.2 g/m<sup>2</sup>). *N. unicornis* has remained in the top ten inside the CBSFA throughout all years, however mean biomass dropped from 9.9 g/m<sup>2</sup> in 2017 to 4.5 g/m<sup>2</sup> in 2018, the year of the flood, before rebounding in 2019 to 13.4 g/m<sup>2</sup> but decreasing again to 5.8 g/m<sup>2</sup> in 2020.

Inside the Makua Pu‘uhonua, two food fish species (*N. unicornis* and *A. triostegus*) appeared in the top ten species with highest percent biomass in 2020. Outside the CBSFA, there were also three resource species in the top ten species with the highest percent biomass. *Kyphosus* spp. ranked 2<sup>nd</sup> at 13.4 g/m<sup>2</sup>, followed by *A. triostegus* ranked 5<sup>th</sup> (9.2 g/m<sup>2</sup>). *N. unicornis* was ranked 8<sup>th</sup> with a mean biomass of 6.7 g/m<sup>2</sup> (Table 7).

**Table 7.** Food fish species ranking in the top 10 species for greatest biomass overall in 2020 separated by Hā‘ena sectors (within the CBSFA, outside the CBSFA, and inside the Makua Pu‘uhonua).

Location	Taxonomic Name	Common Name	Hawaiian Name	Mean Biomass (g/m <sup>2</sup> )	Rank Biomass Overall
Inside CBSFA	<i>Kyphosus species</i>	Chub	<i>nenu</i>	16.26	2
	<i>Naso unicornis</i>	Bluespine Unicornfish	<i>kala</i>	5.77	5
	<i>Carnx melampygus</i>	Blue trevally	<i>‘omilu</i>	4.65	7
	<i>Acanthurus triostegus</i>	Convict Tang	<i>manini</i>	4.21	8
Outside CBSFA	<i>Kyphosus species</i>	Chub	<i>nenu</i>	13.42	2
	<i>Acanthurus triostegus</i>	Convict Tang	<i>manini</i>	9.24	5
	<i>Naso unicornis</i>	Bluespine Unicornfish	<i>kala</i>	6.70	8
Makua Pu‘uhonua	<i>Acanthurus triostegus</i>	Convict Tang	<i>manini</i>	6.31	2
	<i>Naso unicornis</i>	Bluespine Unicornfish	<i>kala</i>	4.07	5

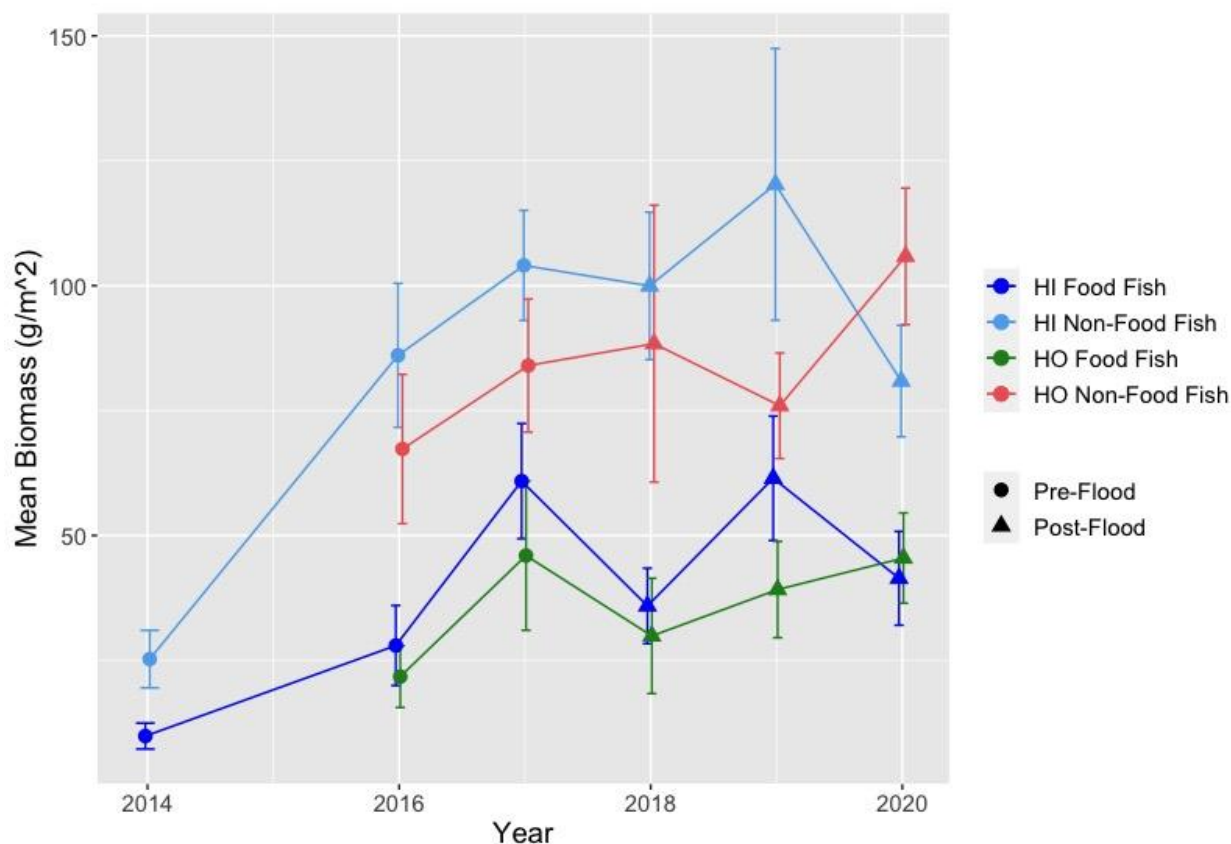
Prior to the flooding event, overall food (resource) fish abundance inside the CBSFA showed a significantly positive trend over time ( $p \leq 0.001$ ), although this trend was not consistent outside the CBSFA. Figure 15 depicts an overall pattern of increase in the biomass of food fishes inside and outside the CBSFA prior to flood, which is also observed for non-food fishes. After 2017, however, greater variation in overall biomass began to occur. Despite this variability, foodfish biomass values inside the CBSFA showed a significant increase pre-flood ( $p \leq 0.001$ ) and remained consistently higher than biomass outside the CBSFA for all survey years, with the exception of 2020. The density of food fishes was relatively unchanged and similar both inside and outside the CBSFA over the study period (Fig. 16), suggesting that observed biomass increases from 2016 to 2017 and from 2018 to 2019 were due to growth (larger fishes) rather than increases in abundance. Alternatively, the density of non-food fishes showed a pattern more similar to non-food fish biomass, suggesting that the increase in overall number of non-food fishes contributed more to biomass increases.

Resource and non-resource fish density (IND/m<sup>2</sup>) was higher inside the reserve as compared to outside in all years except 2018 (Fig. 16). Biomass of resource and non-resource fishes showed this same pattern of higher biomass inside the reserve except in 2020 (Fig. 15). The

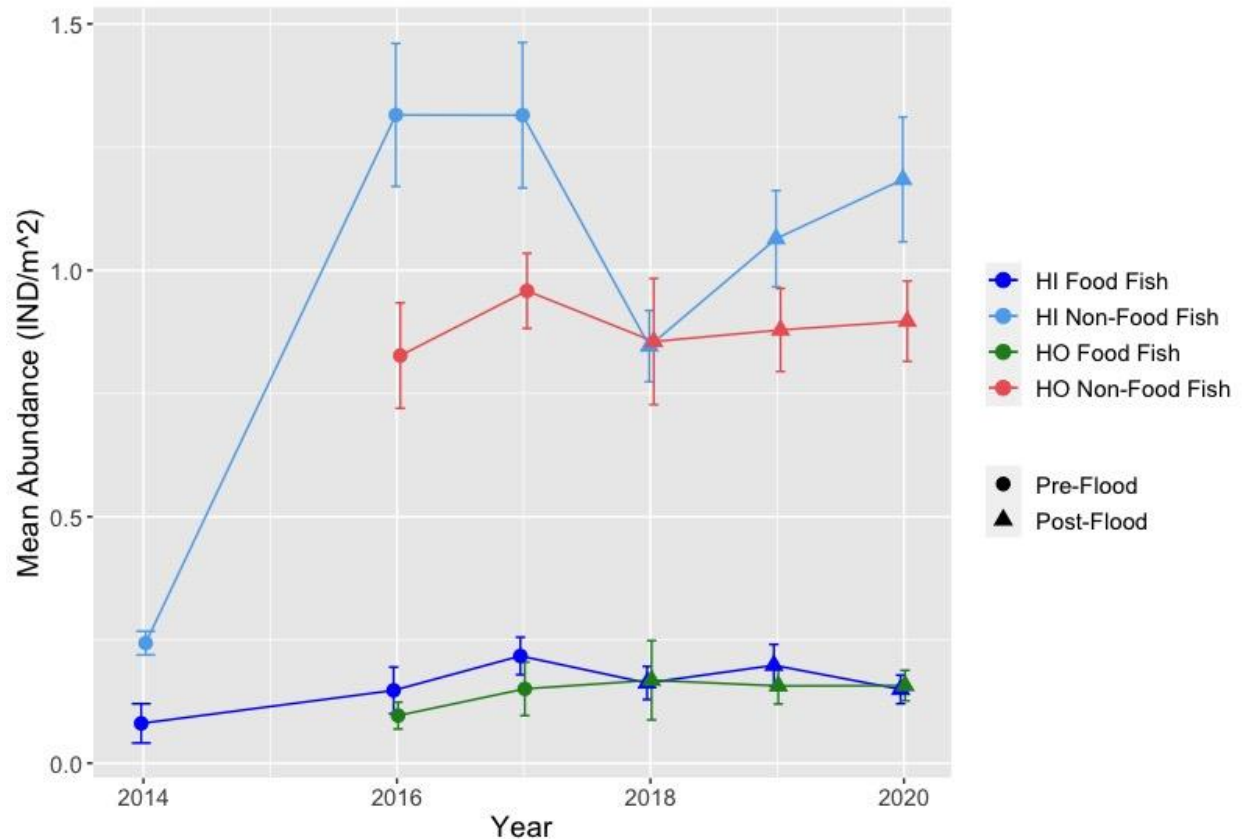
higher mean biomass and density shown in Figure 15 and 16 for non-resource fishes as compared to resource fishes is an artifact of the number of species in each group. There were 24 resource fishes recorded from the 2014-2020 surveys, and 142 non-resource fishes (Appendix B).

The overall decrease in density and biomass of resource fish inside and outside the reserve in 2018 can be linked to the effects from the April 2018 flood. Other supporting evidence includes declines in urchins, coral bleaching, proximity to streams, and freshwater effects elsewhere (Rodgers *et al.* 2021). The flood impacts were more pronounced inside the reserve than outside likely due to the freshwater input from Limahuli and Mānoa streams. The decline in biomass of food fishes in both sectors (within and outside the CBSFA) during the year of the flood may also indicate an increase in fishing during the year of road closure when the community relied more heavily on local food sources.

It is reasonable to assume that the CBSFA rules would increase populations of fished species, however unfished species have also been increasing. This may be due to habitat protection afforded by novel regulations, removal of human disturbance within the Makua Pu‘uhonua, reduced harvest of algae, or other changes since the CBSFA inception. Management success over the long-term can be tracked by continued fisheries stability or increase within the reserve in terms of biomass of food fishes. Additionally, consistent monitoring can potentially verify a signal outside patterns of typical variation.

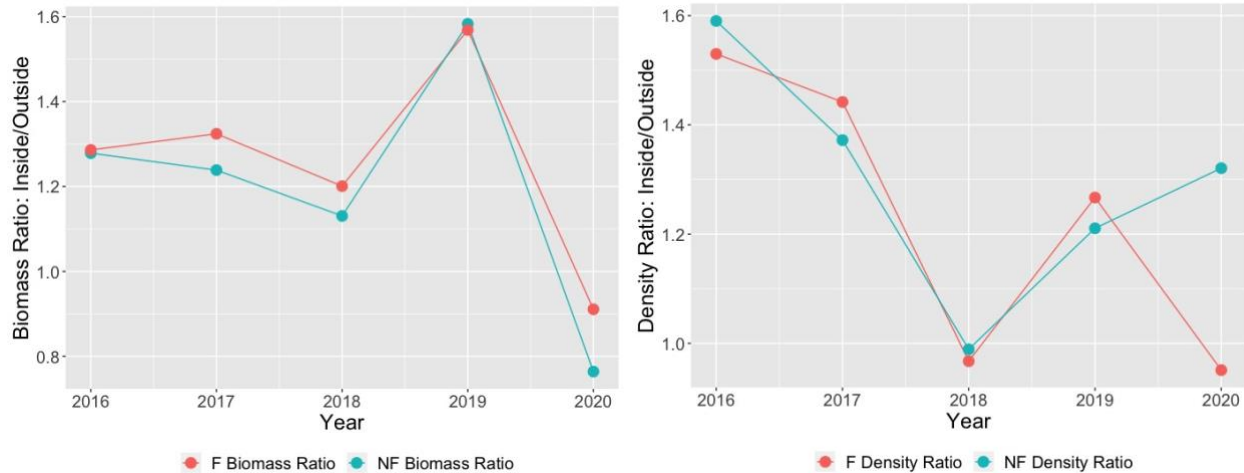


**Figure 15.** Mean biomass (g/m²) shown with standard error bars of food fishes and non-food fishes within and outside the Hā‘ena CBSFA (HI and HO, respectively) from 2016-2020.



**Figure 16.** Mean density (IND/m<sup>2</sup>) of food fishes and non-food fishes shown with standard error bars within and outside the Hā'ena CBSFA (HI and HO, respectively) from 2016-2020.

When examining the biomass and density ratios of food and non-food fishes inside and outside the reserve, a similar pattern of increase should be evident if fishing pressure has been considerably reduced. As such, a ratio of fish indicators inside the reserve, as compared to outside, can help elucidate any reserve effects and how they might differ for food and non-food fishes. If the reserve is effective at protecting fished species, then the average biomass and density of food fishes should be greater inside the reserve, so that the ratio (inside/outside) is  $> 1$  and increasing over time. In this case, the reserve biomass ratio for both food and non-food fishes showed overall declines, with the greatest decrease occurring from 2019-2020 despite a notable increase from 2018-2019 (Fig. 17). Similarly, the reserve density ratio appears to decline overall for both food and non-food fishes over time (Fig. 17), although the trend from 2018 to 2019 is strongly positive. For both biomass and density reserve ratios, patterns for food and non-food fishes are similar, suggesting they are a result of factors other than protection from fishing. The exception was in 2020, when the reserve density ratio for food and non-food fishes diverged, defined by a continued increase in non-food fishes ratio and a decrease in food fishes ratio. This is suggestive of increased fishing pressure in 2020.



**Figure 17.** Biomass and density ratios inside vs. outside the reserve for resource (food – F) and non-resource (non-food – NF) fishes from 2016-2020.

### Examination of Reproductive Maturity in Resource Fishes

Resource fish data from 2016 through 2019 were explored by Rebecca Weible as a Master of Science in Zoology thesis (completed in December 2019), and later expanded to include data from 2020 for a resulting journal publication (Weible *et al.* 2021). This detailed study examined the reproductive maturity inside and outside the CBSFA boundaries to determine whether there has been an increase in fish reproductive size since fishing restrictions were initiated in 2015.  $L_{50}$  values were used to define the size at which half the individuals in a population reach reproductive maturity. These values were used as a proxy to identify mature food fishes inside and outside the CBSFA, where individuals who had recorded sizes equal to or greater than the listed  $L_{50}$  values were considered reproductively mature.

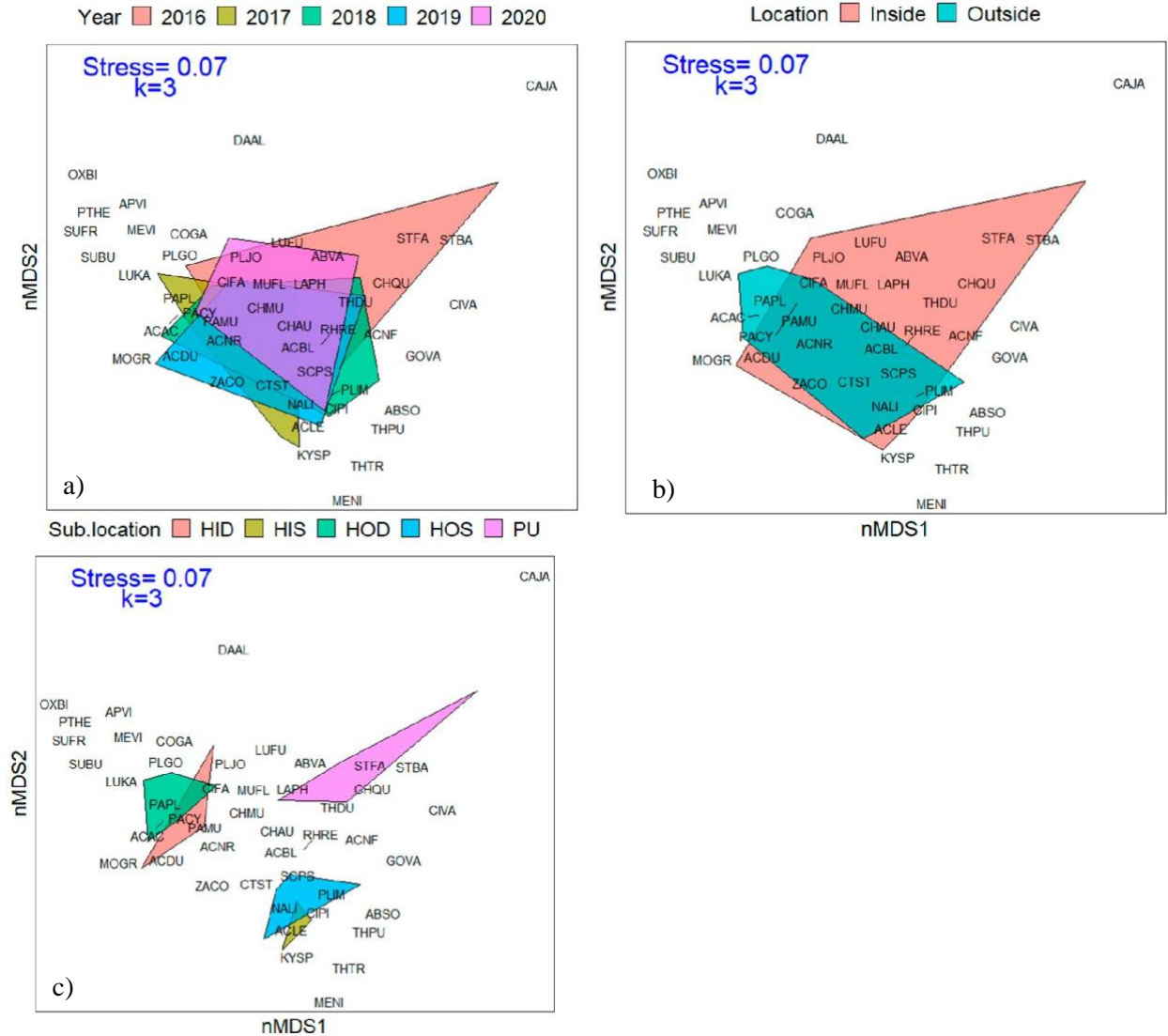
Resources fish species were selected based on a list from the FERL lab and included some species not on the Hā‘ena community list (Table 8). Of the 156 species surveyed over the 5-year period, 32 (20.5%) were classified as resource fishes by the Hā‘ena community and were composed mainly of herbivores (82.8% frequency of occurrence) and piscivores (48.5%). After eliminating species that occurred in <5% of the stations, 65 fish species overall and 19 resource fish species remained for analyses.

**Table 8.** Resource fish species that occurred in more than 5% of the total number of transects were used in statistical analysis. The percentage of total abundance, biomass, and frequency of occurrence is listed.

Scientific Name	Common Name	Hawaiian Name	% Total Abundance	% Total Biomass	% Frequency of Occurrence
<i>Acanthurus triostegus</i> *	Convict Tang	manini	24.4	5.6	53
<i>Kyphosus species</i> *	Lowfin Chub	nenue	16.1	9.9	29
<i>Lutjanus kasmira</i>	Bluestripe Snapper	ta'ape	9.7	6.8	20
<i>Scarus rubroviolaceus</i> *	Redlip Parrotfish	palukaluka	4.4	45.1	45
<i>Mulloidichthys vanicolensis</i> *	Yellowfin Goatfish	weke 'ula	8.1	4.2	6
<i>Naso lituratus</i>	Orangespine Unicornfish	umaumalei	5.5	4.7	40
<i>Naso unicornis</i> *	Bluespine Unicornfish	kala	4.9	6.0	40
<i>Acanthurus blochii</i>	Ringtail Surgeonfish	pualu	4.6	2.8	26
<i>Mulloidichthys flavolineatus</i> *	Yellowstripe Goatfish	weke	3.6	0.7	5
<i>Monotaxis grandoculis</i>	Bigeye Emperor	mu	3.0	3.3	15
<i>Caranx melampygus</i> *	Blue Trevally	'omilu	2.3	2.5	28
<i>Acanthurus nigroris</i> *	Bluelined Surgeonfish	maiko	1.7	0.4	15
<i>Acanthurus dussumieri</i> *	Eye-stripe Surgeonfish	palani	1.3	1.1	20
<i>Parupeneus cyclostomus</i>	Blue Goatfish	moano kea	0.9	0.6	17
<i>Scarus psittacus</i> *	Palenose Parrotfish	uhu	0.5	0.5	5
<i>Cephalopholis argus</i>	Blue-spotted Grouper		0.8	1.0	17
<i>Calotomus carolinus</i> *	Stareye Parrotfish		0.5	0.3	11
<i>Lutjanus fulvus</i>	Blacktail Snapper	to'au	0.5	0.2	9
<i>Aprion virescens</i>	Green Jobfish	uku	0.3	0.7	7

\* = Hā'ena species list

Results for reproductively mature resource fishes indicated no major shifts in overall fish community composition on temporal or spatial scales. Fish assemblage structure showed a high degree of overlap among years (Fig. 18a). Assemblage structure outside the CBSFA was more concordant and was a subset of the assemblage inside the CBSFA (Fig. 18b). Clear spatial patterns in overall fish assemblages were evident among sub-locations in the nMDS plot (Fig. 18c). Fish assemblages inside and outside shallow (<7 m) and inside and outside deep (>7 m) strata had similar assemblage structures, while the Makua Pu'uhonua had a distinct assemblage (Fig. 18c).



**Figure 18.** Non-metric multidimensional scaling (nMDS) plots of overall fish species assemblages by (a) year, (b) inside or outside the CBSFA, and (c) sub-location divisions with depth incorporated. Clear spatial patterns in overall fish assemblages are evident in the sub-location nMDS. Species codes follow first two letters of genus followed by first two letters of species scientific name. Sub-location codes are as follows: Hā'ena Inside Deep (HID), Hā'ena Inside Shallow (HIS), Hā'ena Outside Deep (HOD), Hā'ena Outside Shallow (HOS), and Pu'uhonua (PU; located within Hā'ena Inside Shallow).

While overall resource fish assemblages remained fairly constant, finer scale species-level increases were evident. Positive trends of specific species showed significant relationships through time and suggest continual monitoring of community composition within and outside the CBSFA could be beneficial. Of the 19 resources fishes analyzed, the presence of four large reproductive fishes (*A. triostegus* (*manini*), *A. blochii* (*pualu*), *Mulloidichthys flavolineatus* (*weke*) and *N. lituratus* (*umaumalei*)) were statistically higher inside the boundaries of the CBSFA. Resource fishes with significantly higher biomass inside the CBSFA as compared with outside the boundaries included *N. lituratus* (*umaumalei*) and *Kyphosus* spp. (*nenu*). From 2016-2020, *Caranx melapygus* (*'omilu*) significantly increased both inside and outside the CBSFA, with larger



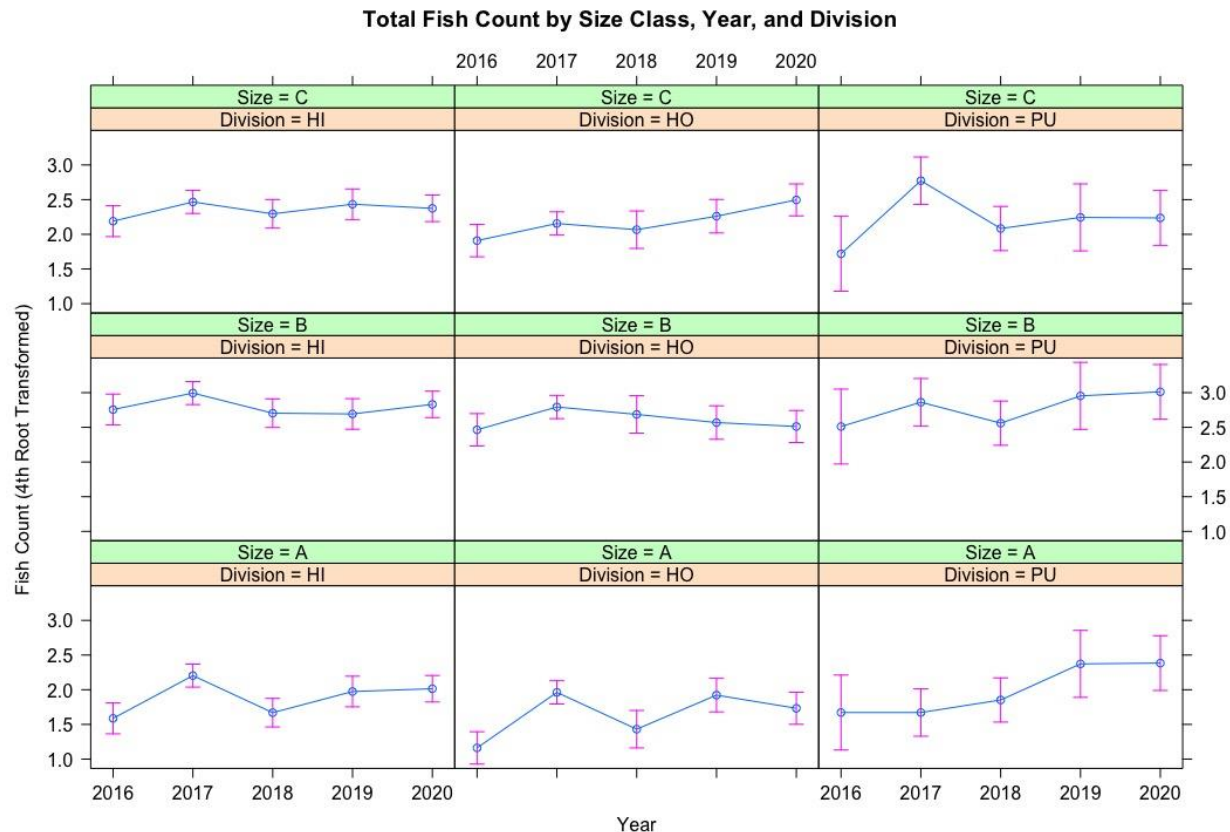
increases outside ( $p = 0.028$ ). A similar significant pattern was observed for the higher presence of *Aprion virescens* (*uku*) outside the CBSFA boundaries ( $p = 0.006$ ), and a higher biomass of *Lutjanus kasmira* (*ta'ape*) outside the boundaries throughout all years ( $p = 0.003$ ). The environmental drivers for *uku* and *'omilu* explaining the majority of variability in the data were depth, calcareous coralline algae, and macroalgae. An overall increase in the number of reproductively mature herbivorous resource fishes was statistically significant ( $p = 0.041$ ) between 2016 and 2020, although overall biomass of herbivores was not significant. The diversity of reproductively mature resource fishes significantly increased over time ( $p = 0.010$ ) and was higher inside the CBSFA ( $p = 0.020$ ). Evenness and species richness, however, did not significantly change.

Possible explanations for the lower biomass within the CBSFA include: 1) rules and regulations were not effective, 2) there has not been enough time for fishes to respond to restrictions on fishing gear, 3) the CBSFA is too small to be effective and does not incorporate substantial habitat types for resource fish species at multiple stages in their life cycles, 4) poaching for resource fish species may be occurring within the CBSFA, 5) resource species selected include invasive species, 6) despite regulations, fishing pressure may be higher inside the reserve as compared to the control area, which is more exposed to trade winds and potentially less desirable for fishing activities.

UH/DAR data showed a statistically significant reserve effect, eliminating the first three possibilities. Poaching has been reported within the CBSFA and may account for a weaker pattern of higher resource fishes within the CBSFA. Resource species should be examined individually and not as a whole due to the inclusion of invasive species, and surveys should either be stratified by habitat type or separated for analyses. Longer-term monitoring will provide additional data for more robust analyses, eliminating some of these possibilities. These monitoring data are essential if adaptive changes in rules and regulations are to be implemented in the future. The recommendation of this study is to continue periodic surveys to allow for long-term trends to emerge that may better predict how resource fishes are changing in reference to management changes.

## **Fish Size Classes**

Fishes were categorized into three size classes: small (<5 cm), medium (5-15 cm), and large (>15 cm). Over the five year period, the number of small sized fishes showed significant positive trends both inside ( $p \leq 0.001$ ) and outside ( $p \leq 0.001$ ) the reserve prior to the flood event, and in the Pu'u honua post-flood ( $p = 0.016$ , Fig 19). Medium sized fishes increased over time significantly in the Pu'u honua both pre- ( $p = 0.020$ ) and post-flood ( $p \leq 0.001$ ), and outside the reserve pre-flood ( $p = 0.007$ ). The largest size fishes demonstrated significant positive trends in the Pu'u honua pre-flood ( $p = 0.044$ ) and outside the reserve post-flood ( $p = 0.014$ ).



**Figure 19.** Transformed total mean fish counts per transect separated by size class, year, and division. Size class codes: A < 5 cm, B = 5-15 cm, C > 15 cm. Sector codes: HI = Hā'ena Inside CBSFA, HO = Hā'ena Outside CBSFA, PU = Makua Pu'uhonua.

Year, division, and size class were found to interactively explain differences in mean number of fishes ( $df = 16$ ,  $F = 1.895$ ,  $p = 0.017$ ). Across all years and divisions, the mean number of medium sized fish was greater than those of small and large sized fish ( $p \leq 0.001$ ). Furthermore, mean number of large sized fish was greater than that of small sized fish ( $p \leq 0.001$ ). With all years combined, mean small sized fish count was greater inside the CBSFA and the Pu'uhonua than outside the CBSFA ( $p \leq 0.001$  and  $p = 0.005$ , respectively), while mean counts of medium and large sized fish were greater inside the CBSFA than outside ( $p = 0.018$  and  $p = 0.034$ , respectively).

When subsetting by division and size class, there were several significant differences in mean fish counts between 2016 and 2020. For small sized fish, mean count was higher in 2020 than in 2016 inside and outside the CBSFA ( $p = 0.035$  and  $p = 0.006$ , respectively). For large sized fish, mean count was higher in 2020 than in 2016 outside the CBSFA ( $p = 0.004$ ).

## Fish Endemism

### Background History

Endemic fishes are native to and live naturally in only one region. They are found nowhere else in the world. Indigenous species are also native but may be more widely distributed in other

regions of the world. Introduced or alien species are not native to the area but were either intentionally or unintentionally introduced. Invasive species have become established and may displace native species.

Both terrestrial and marine endemism in the Hawaiian Islands is high compared to the rest of the world due to geographic isolation that restricts gene flow and favors speciation. Endemism is a biologically relevant attribute in examining fish assemblages. It relates to the conservation of biodiversity, genetic connectivity, and spatial patterns of recruitment. Historically, endemic comparisons have been based solely on presence/absence data due to lack of quantitative data. Yet, endemism evaluations are more statistically meaningful when incorporating numerical and biomass densities, which allow for inclusion of spatial patterns (Friedlander & DeMartini 2004).

### Results (2014-2020)

Endemic fish density ( $p \leq 0.001$ ) and biomass ( $p \leq 0.001$ ) showed significant positive trends inside the CBSFA prior to the flood event in 2018. Increases in density were also found within the Makua Pu‘uhonua pre- and post-flood ( $p \leq 0.001$  and  $p = 0.004$ , respectively), although these trends were not evident for changes in biomass. No statistical differences were shown outside the reserve over the 5-year survey.

Indigenous fish density and biomass also demonstrated significantly positive trends prior to the flood inside the CBSFA ( $p \leq 0.001$  for both), and within the Makua Pu‘uhonua ( $p = 0.003$  and  $p = 0.030$ , respectively). No differences were found outside the reserve pre-flood. Following the flood, significant positive trends were shown for biomass outside the reserve boundaries ( $p = 0.007$ ) and for density within the CBSFA and the Makua Pu‘uhonua ( $p = 0.018$  and  $p \leq 0.001$ , respectively).

Introduced species were only found on ~30% of transects, thus the confidence in changes over time do not have the same validity as endemic and indigenous groups. The density and biomass of introduced fishes were found to have significantly increased pre-flood inside the reserve ( $p = 0.003$  and  $p = 0.005$ , respectively) and within the Pu‘uhonua ( $p \leq 0.001$  and  $p = 0.002$ , respectively), but not outside the reserve. No post-flood differences were found.

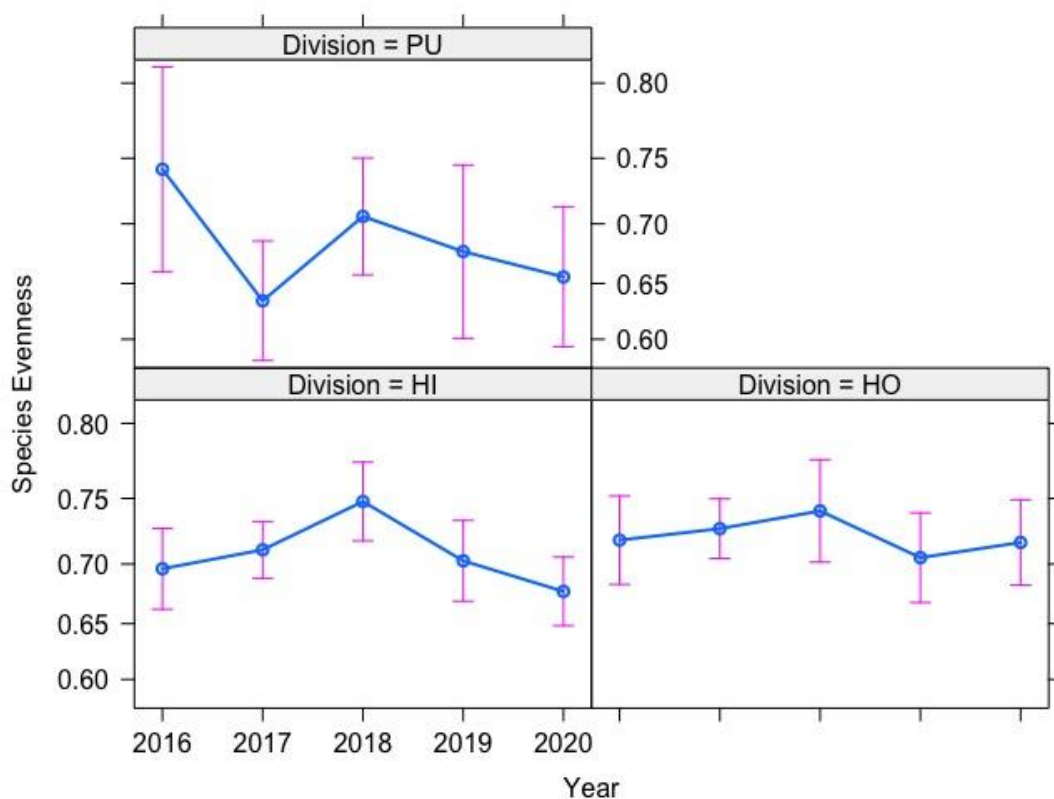
### **Fish Diversity, Evenness, and Species Richness**

Species richness in this report describes the number of species in a community while species diversity includes the number of species and a measure of the abundance of each species. Species evenness describes the distribution of abundance across the species in a community. As an example of evenness, a community is considered more even if there are 50 *manini* and 50 *pualu* than if there are 90 *manini* and 10 *pualu*.

Species richness inside the CBSFA showed a significant increase over time prior to the flood event ( $p \leq 0.001$ ). Species richness within the Makua Pu‘uhonua also showed a positive trend prior to the flood, although this was only weakly significant ( $p = 0.058$ ). Following the flood,

species richness within the Pu‘uhonua significantly increased over time ( $p = 0.010$ ), however no significant changes were detected inside or outside the CBSFA.

Diversity had a significant positive trend within the CBSFA prior to the flood ( $p = 0.042$ ) but had a significant negative trend inside the Makua Pu‘uhonua ( $p = 0.021$ ). A decreasing trend was also seen in diversity within the CBSFA following the flood event ( $p = 0.013$ ). Results show no shift in the evenness of fish composition except for a negative trend inside the CBSFA following the flood ( $p \leq 0.001$ , Fig. 20).



**Figure 20.** Beta regression model estimates of overall fish evenness by year and division. Error bars represent standard error of the beta regression model estimate for a given year/division. Division acronyms: PU = Makua Pu‘uhonua, HI = Hā‘ena Inside CBSFA, HO = Hā‘ena Outside CBSFA.

## Benthic Cover

### Coral Cover

The shallow stations both inside and outside the CBSFA have consistently shown higher coral cover across all survey years when compared to the deeper stations (Table 9). The pattern of shallow stations having higher coral cover than deeper stations is counter to prior research that has demonstrated depth stratification of coral assemblage characteristics showing higher coral cover

in deeper waters (Dollar 1982; Rodgers 2005). The significance of depth in explaining coral cover is analogous to stratification of vegetation by elevation, the most pronounced environmental gradient in terrestrial ecology. The increase in coral cover with increasing depth is partially a function of decreasing wave energy. Research conducted in the eastern Pacific (Glynn 1976) suggests that physical factors control shallow environments, while biological factors are the forcing function in deeper waters. The pattern of higher coral cover in shallower sites is consistent, however, throughout all years at Hā‘ena.

**Table 9.** Mean coral cover (% of total benthic cover) shown with SE from 2016-2020 separated by Hā‘ena sectors.

Sector	Year				
	2016	2017	2018	2019	2020
Inside CSBFA Shallow	5.3 ± 1.1	4.4 ± 0.9	4.8 ± 0.7	5.9 ± 0.9	4.9 ± 0.6
Inside CBSFA Deep	5.3 ± 0.7	4.2 ± 0.7	3.7 ± 0.6	4.1 ± 0.8	3.0 ± 0.4
Outside CBSFA Shallow	6.6 ± 1.3	5.5 ± 0.7	9.6 ± 1.0	7.1 ± 1.0	7.1 ± 1.3
Outside CBSFA Deep	4.5 ± 0.8	3.4 ± 0.4	3.9 ± 1.0	3.2 ± 0.4	4.6 ± 1.2
Makua Pu‘uhonua	13.8 ± 1.0	10.7 ± 1.1	11.7 ± 0.8	11.9 ± 2.1	12.2 ± 1.4

The number of coral species found within each sector throughout all years was relatively consistent, with the exception of a notable increase in the Makua Pu‘uhonua from 2018 to 2019 (Table 10). Coral species count was highest outside the CBSFA boundaries throughout all years except for 2020, where species count was greatest within the CBSFA. The Makua Pu‘uhonua consistently had the lowest species count for all years, most likely due to a smaller sample size from the habitat’s limited area.

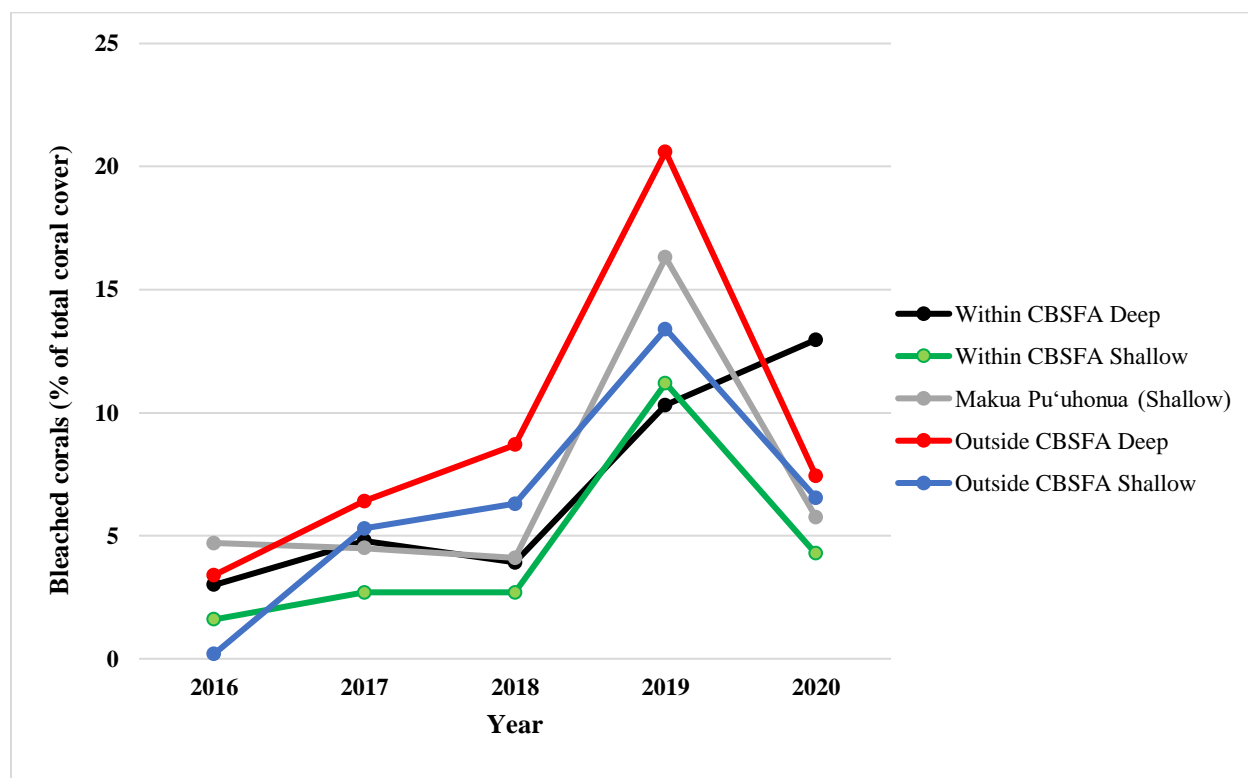
**Table 10.** Coral species richness from 2016-2020 for all Hā‘ena sectors.

Sector	Year				
	2016	2017	2018	2019	2020
Inside CBSFA	11	12	13	15	14
Outside CBSFA	12	12	16	16	13
Makua Pu‘uhonua	10	8	9	13	11

A notable decrease in the octocoral *Sarcothelia edmondsoni* was also detected in shallow transects inside and outside the CBSFA, decreasing from 14.3% of total coral cover in 2019 to 3.0% in 2020. It was nearly absent at the deep stations and at the Makua Pu‘uhonua. *S. edmondsoni* has been reported to be indicative of areas impacted by anthropogenic stress (Walsh *et al.* 2012). In West Hawai‘i, a high concentration of this species has been reported from Honokōhau Harbor and Kailua Bay, which are both heavily impacted by human populations. Octocorals have been proposed to be as a sign of pollution in studies elsewhere as well (Hernandez-Munoz *et al.* 2008; Baker *et al.* 2010).

## Coral Bleaching

The percent of bleached corals comprising total coral cover showed a decline across all sectors at Hā'ena following 2019, with the exception of the deep stations inside the CBSFA where 2020 had the highest bleaching recorded over the 5-year survey period (Fig. 21). Following the flood event, the proportion of bleached coral has shown a significant positive trend ( $p = 0.012$ ); bleached proportion has increased from 4.1% in 2018 to 10.3% in 2019 and, most recently, to 13.0% in 2020. The 2019 statewide bleaching event reached its peak several months after these surveys were conducted (March and August 2019), thus any resultant bleaching was probably more severe than was reported here. No widespread bleaching was reported in 2020. Coral bleaching was consistently higher outside the CBSFA boundaries as compared to inside when comparing only shallow or deep stations throughout all years (i.e., shallow stations inside CBSFA vs. shallow stations outside CBSFA, etc.), with the exception of 2016 where shallow stations inside the CBSFA had more bleaching than shallow stations outside the reserve boundaries, and 2020 where deep stations inside the CBSFA had higher bleaching than deep stations outside (Fig. 21). Although coral bleaching was high in 2019, the coral cover did not significantly change the following year. Unlike the high mortality experienced following the 2014/2015 statewide bleaching event, little or no mortality occurred from the 2019 bleaching event (Table 9).



**Figure 21.** The percent of bleached corals (% of total coral cover) separated by deep and shallow sectors from 2016-2020 inside and outside the CBSFA and within the Makua Pu'uhonua.

In 2020, bleaching was higher at shallow stations outside the CBSFA (6.5%) as compared to the shallow stations inside the CBSFA (4.3%, Fig. 21). Deeper stations had considerably higher bleaching inside (13.0%), however, as compared to outside the CBSFA (7.4%). Deep sites outside

the CBSFA showed a similar percentage of bleached corals as compared to shallow sites (7.4% vs. 6.5%) in 2020, while inside the CBSFA bleaching was much higher at deep stations (13.0%) as compared to shallow stations (4.3%). When examining bleaching patterns between 2016-2020 for deep and shallow sectors outside the reserve boundaries, deep stations had consistently higher coral bleaching as compared to the shallow stations throughout all years. This contradicts previous observations and studies that suggest corals in higher irradiance environments are more susceptible to bleaching due to depth variability (Bahr *et al.* 2015b; Bahr *et al.* 2016).

Consistent with statewide data, the most common species recorded as bleached in 2020 across all sectors were *M. capitata*, *M. patula*, *P. meandrina*, and *P. lobata*. This is similar to bleaching reported in other years of this survey as well. During the 2014 bleaching event in Kāneʻohe Bay, Oʻahu, *M. capitata* suffered severely from bleaching while other species in the bay appeared relatively unaffected (Cunning *et al.* 2016), suggesting that *M. capitata* may be more prone to bleaching than other species in the bay. Other factors that contribute to bleaching resistance or susceptibility include the coral host's *Symbiodinium* clade. Corals hosting clade D *Symbiodinium* are more resistant to thermal stress and bleaching, while clade C is more susceptible to bleaching but has higher fitness and resistance against diseases (Little *et al.* 2004; Berkelmans & van Oppen 2006; Cantin *et al.* 2009; Mieog *et al.* 2009; Bay *et al.* 2016; Cunning *et al.* 2016). Colony morphology can also affect bleaching vulnerability (Loya *et al.* 2001), with *M. capitata* displaying two different morphologies and two different color types, which harbor different clades of *Symbiodinium*. The two-color morphs of *M. capitata*, red and orange, have clades C and D, respectively. The red morphology exhibits a higher susceptibility to bleaching, while the orange morph shows an increased tolerance to elevated temperatures (Shore-Maggio *et al.* 2018).

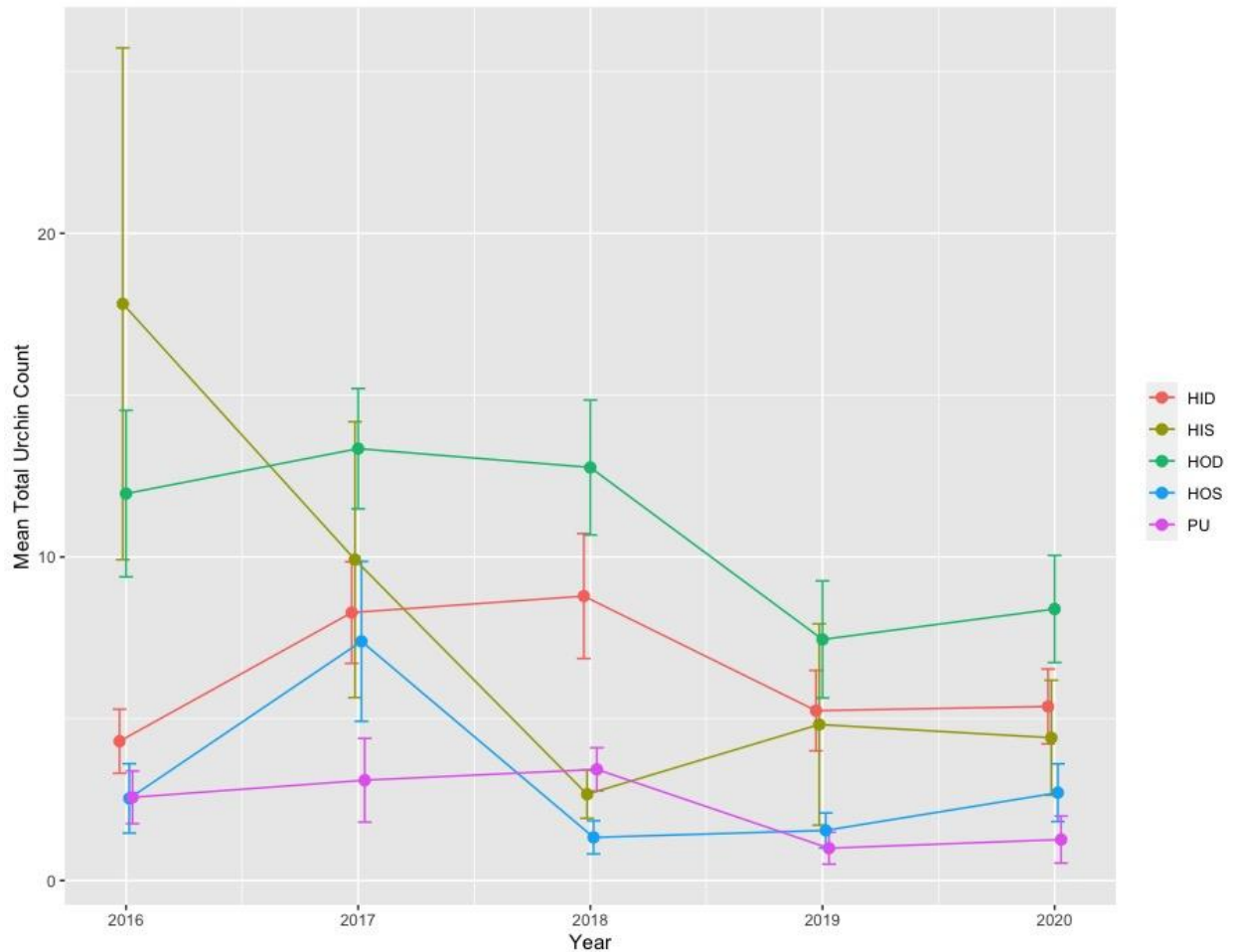
## Urchin and Sea Cucumber Surveys

### Urchins

Urchins play a critical role in the health of coral reefs. As grazers, they can maintain the balance between algae and corals. High mortality of collector urchins has been investigated by State and Federal agencies since an unusual die off was reported in the islands of Hawaiʻi and Kauaʻi in 2014 and, more recently, from Oʻahu and Maui. Urchin surveys can be used as a proxy for coral reef health and act as an early warning sign of community stress. This link between urchins and coral reef health was first demonstrated in the Caribbean in the early 1980s, when a crash in the urchin populations was followed by an 80% decline in coral cover and biodiversity within a year (Mumby *et al.* 2006). The current urchin and sea cucumber surveys at Hāʻena serve as a baseline for annual surveys conducted inside and outside the CBSFA boundaries, which aid in determining change in populations. Other factors at these stations, such as temperature, coral, macroalgae, fishes, and sediment, can be compared to any observed declines.

In 2018, a drastic decline in urchin populations was detected at shallow stations both inside and outside Hāʻena (Fig. 22). In subsequent years following 2018, urchins have remained sparse at shallow sites as compared to the deeper sites. Prior to the flood, urchins at deeper stations within the reserve showed a statistically significant increase over time ( $p = 0.020$ ). The average number

of urchins per transect at shallow sectors inside and outside boundaries declined dramatically after the flood from 2017 (8.8/transect) to 2018 (2.0/transect) ( $p = 0.050$ , Fig. 22). Little recovery was recorded in 2019 (3.2/transect) and 2020 (3.6/transect). This is in sharp contrast to mean urchin counts at deep sectors, which were identical between years in 2017 (10.8/transect) and 2018 (10.8/transect), although deep sectors showed a minor decline in 2019 (6.4/transect) and 2020 (6.9/transect).



**Figure 22.** Mean urchin counts per transect separated by sector and depth from 2016-2020 shown with SE. HID = Hā‘ena Inside CBSFA Deep, HIS = Hā‘ena Inside CBSFA Shallow, HOD = Hā‘ena Outside CBSFA Deep, HOS = Hā‘ena Outside CBSFA Shallow, PU = Makua Pu‘uhonua (shallow).

The significant decline in 2018 urchins at shallow stations can be attributed to an unprecedented freshwater event that occurred in April 2018. This broke the long-standing record for rainfall in a 24-hour period in the Hawaiian Islands. The National Weather Service in Honolulu recorded nearly four feet (49.69 in) of precipitation from a rain gauge about a mile west of Hanalei Bay during April 15-16.

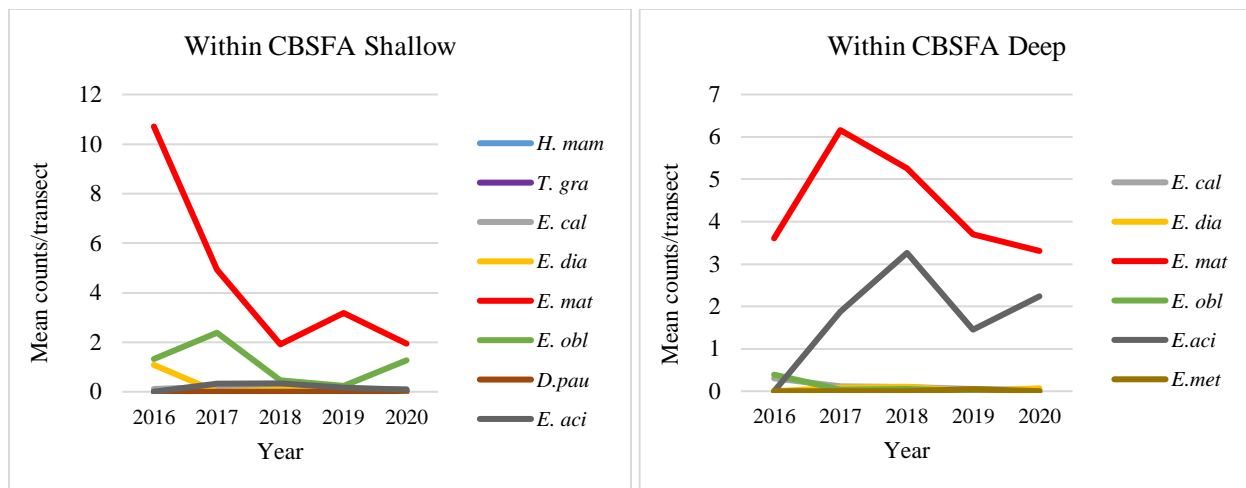
Coral reefs are highly vulnerable to storm flooding events that can reduce salinity in shallow waters (Banner 1968; Jokiel *et al.* 1993). Flash floods, which are common in Hawai‘i, are



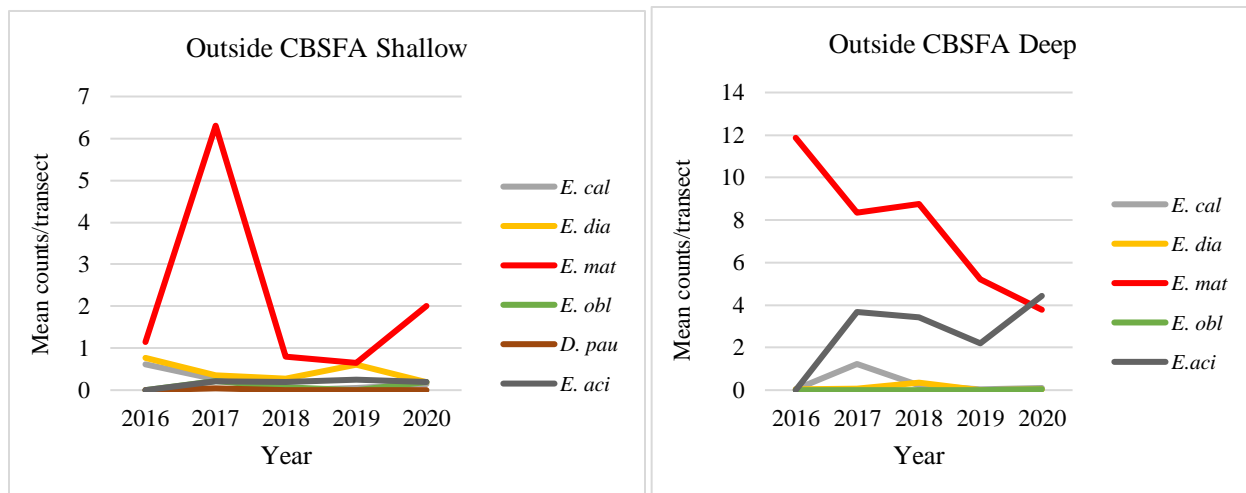
typically intense and short in duration. These flash floods are associated with upper-level forcing where convective cells develop as a result of orographic effects (Jokiel 2006). Three freshwater flood events and their impacts to coral reefs have been documented in Kāneʻohe Bay in 1965 (Banner 1968), 1988 (Jokiel *et al.* 1993), and in 2014 (Bahr *et al.* 2015a). This is a frequency of occurrence of approximately 25 years. However, as a result of climate change, the frequency and intensity of storms is increasing (USGCRP 2009, Mora *et al.* 2013). In 2014 at Kāneʻohe Bay, 24 cm (9.5 in) of rainfall caused mortality of reef organisms to 2 m (3.3 ft). Post-event salinity depth readings were calculated to estimate the freshwater layer at 27 cm (10.6 in) in depth (Bahr *et al.* 2015a; Bahr *et al.* 2015b). After extrapolating the 2014 Kāneʻohe Bay rainfall, freshwater depth, and zone of impact data, estimates of the freshwater lens depth (141 cm or 4.6 ft) and the depth of possible impact (34.4 ft or 10.5 m) were calculated for application to assessment of the 2018 Hāʻena flooding. The estimated depth of possible impact is supported by the recorded number of urchins in shallow and deep sites both inside and outside the CBSFA, where urchins at shallow sites (<7 m) suffered extensive declines, whereas populations at deeper sites (>7 m) remained stable.

Adult and larval echinoderms have been well documented to be stenohaline, being able to tolerate only a narrow range of salinities (Irlandi *et al.* 1997). This is due to their permeable body wall (Drouin *et al.* 1985) and lack of separated osmoregulatory and excretory organs (Binyon 1966). Acute changes in salinity, as in a discharge or flood event, can cause up to 100% mortality in adult urchins (Campbell & Russell 2003). Freshwater floats above seawater because it is less dense, however it is possible for this low salinity lens to contact the bottom during low tides. The width of the lens is dependent on a number of factors including freshwater input, circulation patterns, and wave energy. This stochastic event, in conjunction with low tides, could have allowed the freshwater to contact the bottom at shallower sites, thereby causing depth-specific impacts to urchin populations. Other possible explanations for the pronounced decline of urchin populations at shallow sites include elevated sedimentation and nutrient levels associated with the flood runoff. As with freshwater, sediments and nutrients are diluted with distance from shore due to winds, waves, and tidal currents, with the heaviest impacts affecting shallower areas.

When examining urchins by species, *Echinometra oblonga* is the only species showing signs of recovery since the 2018 flood event (Fig. 23). The predominant species, *E. mathaei*, appears to be the most heavily impacted by the 2018 event (Figs. 23 & 24). Although this species has not recovered to pre-flood conditions, increases have occurred in outside shallow stations in 2020 (Fig. 24). *E. mathaei* may therefore be useful as a proxy of changing environmental conditions or an indicator of freshwater impacts, as it has been found to be abundant at both depths, was the top species across all sectors, and appears to show sensitivity to effects from freshwater events in Hāʻena from 2016-2020.

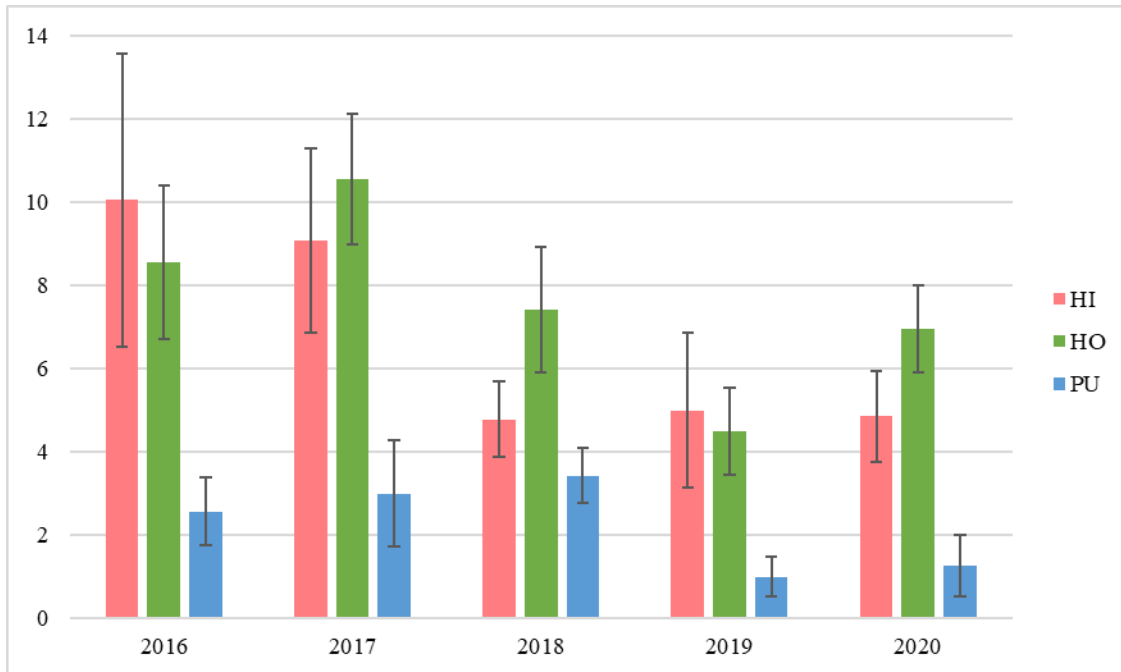


**Figure 23.** Mean urchin counts per transect across years (2016-2020) by species at shallow (<7 m) and deep stations (>7 m) inside the reserve.



**Figure 24.** Mean urchin counts per transect across years (2016-2020) by species at shallow (<7 m) and deep stations (>7 m) outside the reserve.

Significantly fewer sea urchins were observed across all years in the Pu‘uhonua as compared to inside or outside the CBSFA boundaries (Fig. 25). This may be a factor of habitat complexity. By comparing an individual sector to its 2016 baseline, we can determine any shifts in urchin populations.



**Figure 25.** Bar graph depicting the mean number of sea urchins per transect in Hā'ena sectors from 2016 through 2020. Sectors: HI = Hā'ena Inside CBSFA, HO = Hā'ena Outside CBSFA and PU = Makua Pu'uhoonua. Error bars = 95% confidence intervals.

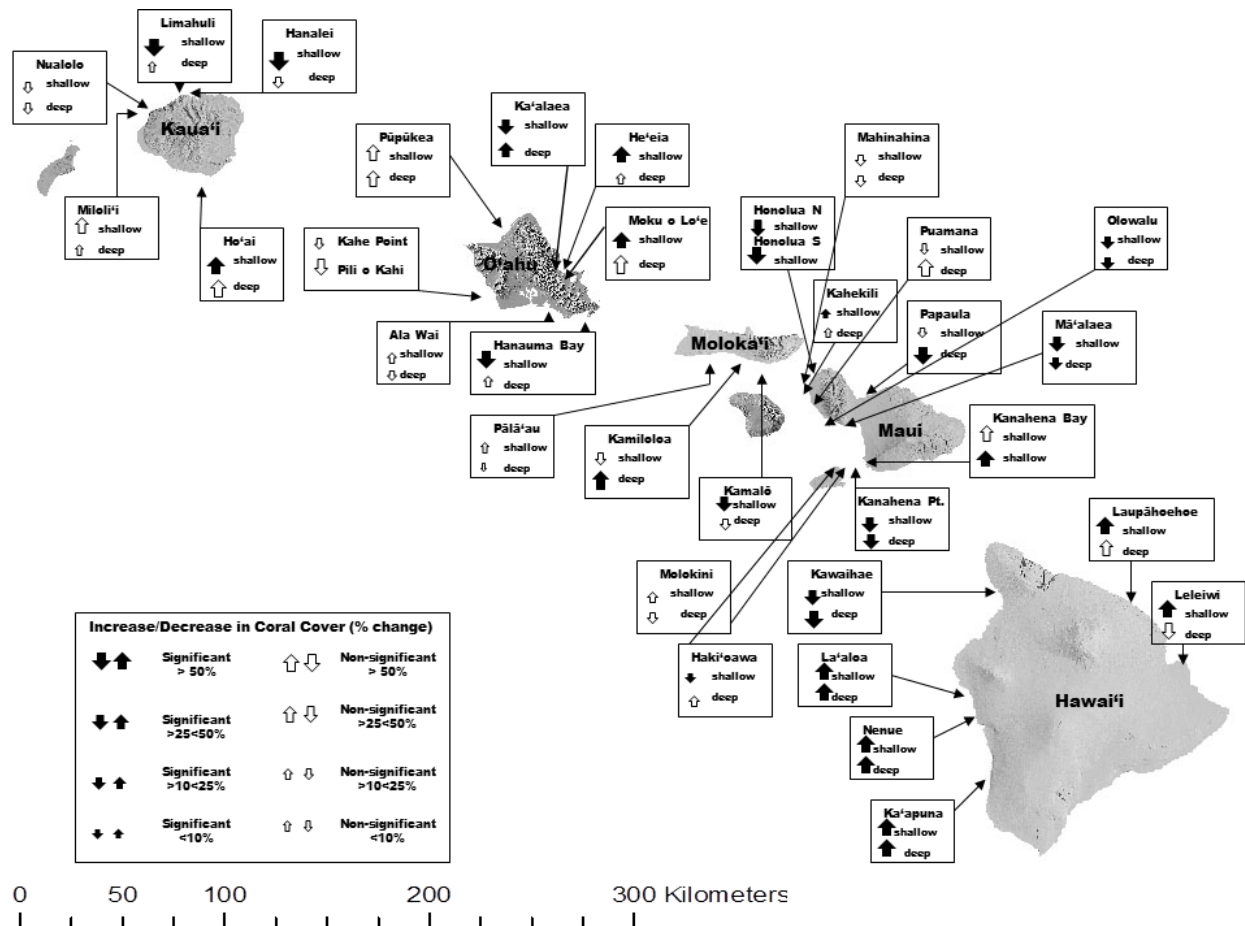
### Sea Cucumbers

The monitoring of sea cucumbers became a priority for state resource managers in 2015 following two mass commercial harvesting events that left large areas off of Maui and O'ahu clear of these critical "vacuum cleaners of the sea" (DLNR 2015). A Waimanālo fisherman reported being unable to find any sea cucumbers three months following the commercial operation cleared the area (Kubota 2015). This unprecedented exploitation resulted in public outrage and DAR enacting a 120-day emergency ban on the commercial harvesting of all sea cucumbers (DLNR 2015). Since sea cucumbers had not previously been a significant commodity in Hawai'i, no rules had been in place to limit the mass harvesting in 2015. However, sea cucumbers are in high demand for food and medicinal extracts in many Asian countries (Kubota 2015). A permanent rule was adopted in January 2016 that banned the commercial consumptive take of all but two species of sea cucumbers, *Holothuria hilla* and *H. edulis*, for which catch limits are now established (DLNR 2015). This precipitated the inclusion of sea cucumbers into the Hā'ena survey design. Due to the small sample size and high variability found throughout the years at Hā'ena, however, the statistical legitimacy of changes to sea cucumber populations is invalid. Total sea cucumber counts found throughout all sectors was highest in 2016 (78), as compared to 2017 (7), 2018 (27), 2019 (9) and 2020 (12). These low overall numbers make comparisons between sectors even more difficult.

## **Coral Reef Assessment and Monitoring Program (CRAMP) Resurveys**

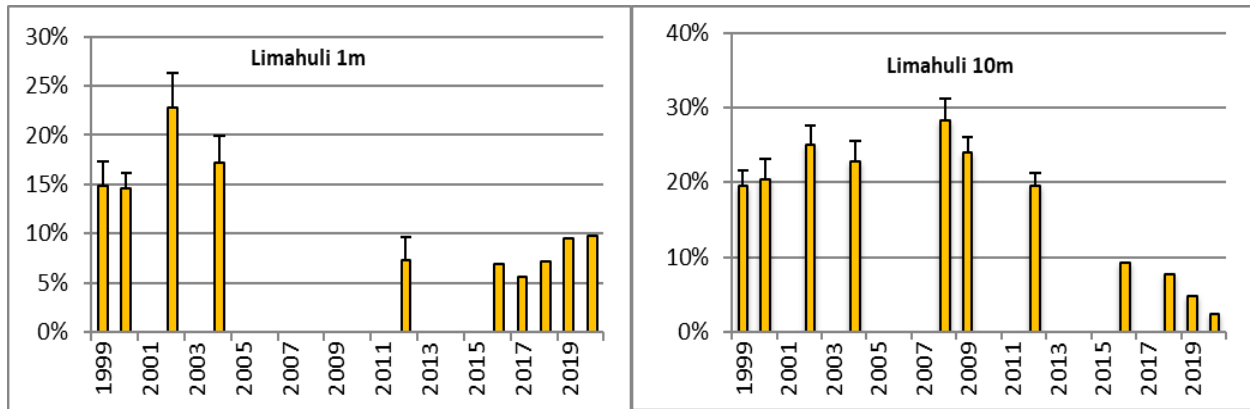
The CRAMP site in Limahuli, which is located within the Hā‘ena CBSFA, was resurveyed in 2020. The 10 m depth station was surveyed on 1 September 2020 and the 1 m station was surveyed in 15 May 2020. This is part of a statewide integrated network of 33 sites on five islands that include 66 stations ([www.cramp.wcc.hawaii.edu](http://www.cramp.wcc.hawaii.edu), Rodgers *et al.* 2015) that are monitored by the Kaua‘i Division of Aquatic Resources Monitoring Team. At each site there are typically two stations at two depths (3 m and 10 m). At Limahuli, however, no 3 m station can be surveyed because the shallow reef flat is 1 m in depth and then drops to a deeper reef. CRAMP was developed in 1998 in response to management needs. At that time, there was no long-term widespread monitoring program in this state. It was vital to establish a baseline of what our reefs around the state looked like in order to recognize any changes that might occur and to identify any impacts that are affecting these reefs. Prior to this initiative, monitoring efforts in the state were conducted on a piecemeal basis, inconsistently addressing specific problems in particular places on a project-by-project basis over short periods of time. Surveys were also being done by different researchers and managers who employed different methods, causing comparisons to become more difficult. Within the first few years, we established long-term monitoring sites that track changes over time, as well as rapid assessment sites to expand the spatial range of habitats and anthropogenic impacts and optimize the power to detect statistical differences.

The CRAMP network of sites was developed to have the statistical ability to detect changes in coral cover over time (Fig. 26). Resurveys of sites are dependent on resources, weather, and surf conditions. Abrupt changes in the trends or patterns detected at a particular site can lead to more intensive field surveys or manipulative experimentation to determine the cause of observed declines. DAR/CRAMP Maui sites have been surveyed by the DAR Maui Monitoring Team since their inception in 1999. The DAR Kaua‘i monitoring team has incorporated the six DAR/CRAMP Kaua‘i sites (Hanalei, Limahuli, Miloli‘i, Nualolo Kai, Ho‘ai, and Pila‘a) into their annual monitoring program for statewide comparisons. All other island DAR/CRAMP sites will be integrated into the DAR Monitoring Program in 2021.



**Figure 26.** The Division of Aquatic Resources Hawai'i Coral Reef Assessment and Monitoring Program permanent network of sites throughout the main Hawaiian Islands. Direction of arrows show increases or decreases in coral cover since 1999. The size of arrows is related to the size of the change in coral cover. The solid arrow indicates statistical significance, while hollow arrows represent sites without significant changes. The site at Pila'a, Kaua'i was initiated in 2017.

Limahuli CRAMP stations were initially placed at a depth of 10 meters outside the reef flat and 1-meter depth on the inner reef flat. The 2020 resurvey is the 10th survey at the 1 m reef flat and the 11th survey for the 10 m station (Fig. 27).



**Figure 27.** Change in percent coral cover for the Limahuli, Kaua‘i CRAMP monitoring sites (1m and 10m) initiated in 1999.

The Limahuli reef flat is characterized by a shallow limestone/basalt boulder shoreline with sand pockets. A shallow carbonate reef flat with low spatial complexity is protected from north swells by a well-developed reef crest. However, conditions can become rough with strong currents in the winter months. The CRAMP Limahuli 1 m site is located on the shallow reef flat directly out from Manoa Stream, which extends parallel to shore for 100 m. Selection criteria for monitoring sites were based on existing data, accessibility, degree of perceived environmental degradation, level of management protection, and extent of wave exposure. Each station had 10 initially randomly selected 10 m permanent transects that were established on hard substrate. These were marked for resurveys by short stainless-steel pins. Due to the shallow reef flat at Limahuli 1 m, pins are only located at the 50 m point along the transect and were located by GPS coordinates. Pins are rapidly overgrown with coral, coralline algae, and other marine organisms, and do not extend beyond the corals at shallow sites for safety and aesthetic reasons. Digital photos, fixed photoquadrats, belt fish transects, substrate rugosity, sediment samples, and other quantitative and qualitative data were collected at various times. Digital imagery was taken perpendicular to the substrate along each transect using a monopod to determine distance from the bottom. Twenty non-overlapping digital photos frames from each transect were analyzed using the software program PhotoGrid (Bird 2001) to estimate benthic coverage. Twenty-five randomly selected points were generated on each selected image and used to calculate percentage cover.

The average total coral cover as a proportion of total benthic cover in 2020 was 10.03% for the ten transects at the 1 m site. This is slightly higher than in 2018 (7.16%), and 2017 (5.61%) (Fig. 27). The nine species of corals recorded in 2020, in order of abundance (% of total coral cover), are *Porites lobata* (93.7%), *Montipora capitata* (1.85%), *M. patula* (1.85%), and *P. brighami* (0.74%). Other species with low prevalence include *M. flabellata*, *P. lutea*, *P. compressa*, *Pocillopora meandrina* and *Pavona duerdeni*. The dominant species, *P. lobata*, was also clearly dominant in 2019. *M. patula* was the most dominant in 2018. Corals found on the shallow, wave driven reef flat were either lobate, encrusting, or with short, thick branches. This is indicative of a high wave energy area where more delicate branching morphologies cannot survive. All species of corals reported at Limahuli are fairly common in the Hawaiian Islands (Rodgers 2005).

The average total coral cover at the ten transects at the 10 m site in 2020 was 2.13% lower than in 2019 (4.93%, Fig. 27). This is a continued reduction from previous surveys in 2018 (7.26%) and 2016 (9.23%). Only two species of corals were identified from the images, which, listed in

descending order, are *M. patula* (84.6%) and *P. meandrina* (15.4%). This low and declining coral cover is not due to lack of substrate for recruitment. High benthic cover of calcareous coralline algae (CCA) (35.5%) provides substrate for coral recruitment. High temperature and other stochastic events may be the cause of the decline at this site, however the shallow reef flat has increased or remained fairly consistent in coral cover over the last few years.

## JOURNAL PUBLICATIONS

Two manuscripts in peer reviewed journals have been published from this collaborative effort. One further article culminating the 5-year project to determine the efficacy of the Hā'ena CBSFA will be written with a projected publication date in 2022. The importance of journals provides a means of communication and a permanent record of the results. It enables others to build on the results and avoid unnecessary duplication of effort.

### 1) **Assessing Community Compositions of Reproductively Mature Resource Fishes at a Community Based Subsistence Fishing Area (CBSFA)**

Rebecca Weible, Ku'ulei Rodgers, Alan Friedlander, and Cynthia Hunter

Journal: Diversity 2021, 13, 114. <https://doi.org/10.3390/d13030114>.

**Abstract:** Nearshore fisheries in Hawai'i have been steadily decreasing for over a century. Marine Protected Areas (MPAs) have been proposed as a method to both conserve biodiversity and enhance fisheries. The community composition of resource fishes within and directly outside of the recently established Hā'ena Community Based Subsistence Fishing Area (CBSFA) were assessed to determine any temporal or spatial shifts in assemblages. In situ visual surveys of fishes, invertebrates, and benthos were conducted using a stratified random sampling design to evaluate the efficacy of the MPA between 2016 and 2020. L50 values—defined as the size at which half of the individuals in a population have reached reproductive maturity—were used as proxies for identifying reproductively mature resource fishes both inside and outside the CBSFA. Surveys between 2016 and 2020 did not indicate a strong temporal or spatial change in community composition of overall resource fish assemblages, yet some species-specific changes were evident.

**Conclusions:** Overall large reproductive resource fish community composition did not shift temporally or spatially following changes over five years in fishing regulations. Of the 19 resources fishes analyzed, the presence of large reproductive *A. triostegus* (*manini*), *A. blochii* (*pualu*) and *N. lituratus* (*umaumalei*) were higher inside the boundaries of the CBSFA. Results of this study recommend continuing yearly annual surveys to allow for long-term trends to emerge. This may better predict how resource fish assemblages are changing and advance effective management. This monitoring data is essential if future adaptive changes in rules and regulations are to be implemented. Furthermore, determining future survey sites that equally represent habitat types within and outside of the CBSFA are crucial in assessing habitat preferences and emerging patterns of community composition.

## 2) Impact to Coral Reef Populations at Hā'ena and Pila'a, Kaua'i, Following a Record 2018 Freshwater Flood Event

Ku'uilei S. Rodgers, Matthew P. Stefanak , Anita O. Tsang , Justin J. Han , Andrew T. Graham and Yuko O. Stender

Journal: Diversity: Coral Reef Ecology and Biodiversity 2021, 13, 66.

<https://doi.org/10.3390/d13020066>

**Abstract:** Many corals and reef-dwelling organisms are susceptible to the impacts of storm events, which are typically characterized by large inputs of freshwater, sediment, and nutrients. The majority of storm effects are focused on shallow, nearshore reef flats, as low salinity and sedimentation tend to dissipate with depth and distance from shore. In April 2018, record rainfall on the northern coast of Kaua'i caused extensive flooding and landslides, introducing large amounts of freshwater and sediment into nearshore reefs. Using benthic and fish transects from 2016–2019 and temperature, sediment, and rainfall data gathered pre- and post-flood, this study aimed to quantify and explicate the effects of flooding on the various biotic populations of two reef habitats at Pila'a and Hā'ena, Kaua'i. Results from the shallow Pila'a reef suggest sediment and freshwater-associated declines in mean urchin abundance (–52.0%) and increases in mean coral bleaching (+54.5%) at the flood-prone eastern sector. Additionally, decreases in mean urchin (–65.7%) and fish (–42.3%) populations were observed at shallow Hā'ena transects, but not deep sites, supporting the occurrence of depth-specific affliction. Multivariate community-level analyses affirmed much of these results, showing a significant shift in community structure before and after the flood at both Pila'a and Hā'ena. The outcomes of this study are pertinent to strategic design and solution development by local aquatic resource managers, especially as anthropogenic climate change continues to increase the frequency, duration, and intensity of storm events.

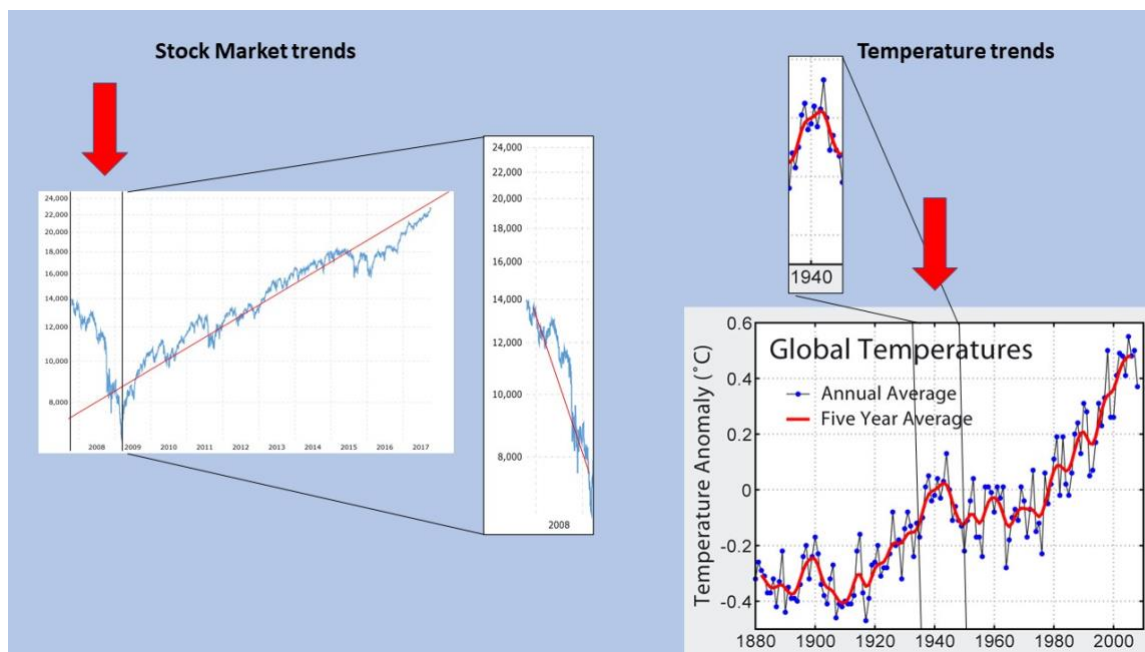
**Conclusions:** As shown in this study, other climate change-induced environmental impacts alongside temperature are major threats to reefs and the other biota they facilitate. Along with temperature increases, freshwater, sediment, and nutrient pulses can also be destructive to coral reef communities and several keystone taxa. Although many coral populations can partially recover from large flood events, the frequency and intensity of major weather events are increasing. Data on the severity and intensity of impacts to reefs from freshwater events can assist local management in strategic design and solution development for conservation, restoration, and oftentimes any accompanying legislative measures. Freshwater bioindicator taxa, such as sea urchins and octocorals, can serve as reliable early warning tools or proxies for a reef's exposure to freshwater. Bioindicators also represent a cost-effective alternative technique to the slower and relatively expensive process of continuous water quality sampling and benthic monitoring.

## PROPOSED FUTURE ACTIVITIES

This study was enacted to determine the efficacy of the first CBSFA in the State of Hawai'i. 2020 is year five of these surveys. In 2016, a year after the CBSFA went into effect, an increase in fishes was found, which continued through 2017. However, in 2018 the massive flood event affected this trend. This trend resumed in the years following the flood event. Trends such as these can be variable with a cycling of increases and declines. To determine the efficacy of the CBSFA



management regulations, we must think long-term. The intrinsic rate of population growth, size of the remaining population, as well as other factors determine population recovery after fishing pressure is removed (Jennings 2000). Without this information, rough estimates of recovery rates can be made for no-take reserves based on life-history traits (Abesamis et al. 2014). The resource fishes of Hā'ena have a range of life history characteristics, so recovery rates will differ. The first species likely to show an increase are the goatfish and small parrotfish based on their short life spans, with full recovery for these faster growing species possible within 10 years. Recovery of larger, long-lived species such as jacks, surgeons, and large parrotfish may take 20-40 years (Abesamis *et al.* 2014). These estimates assume complete cessation of fishing, which is not the case for the Hā'ena CBSFA; there is, of course, the exception of the Makua Pu'uhonua, which was designed to protect juveniles but is likely too small to be effective for most adult fish species. Furthermore, biotic populations can fluctuate stochastically, so it may take years to determine if shifts we are seeing today are really moving in that direction because they may be cyclical, making it difficult to see the real patterns until you continue to monitor over a longer period. This is similar to the stock market or the global temperature record where you find ups and downs, but the overall pattern is a clear with an increase in the stock market over the past ten years or in the temperature record over the last century (Fig. 28). If you were to only look at 2008 in the stock market, you would see the opposite pattern because of the fluctuations overall. If you look at a century of temperature data you also see a clear increase, but if we just look at just one decade, the 1940's, it shows a different pattern. Halfway through that decade it looks like the temperature is dropping. This is also true of environmental monitoring, and thus why long-term monitoring is so important to understand what is really happening. The results we currently have are preliminary and will strengthen immensely as more surveys are conducted. The DAR Kaua'i Monitoring Team will continue to collect, analyze, and interpret data in the three sectors at Hā'ena and within the reserve at the Limahuli DAR/CRAMP site at 1 m and 10 m depths.



**Figure 28.** Graphs depicting the variability and overall trend in the US stock market (2008-2017) and global temperature records (1880-2010).

At Hā'ena, there have been several stochastic events that make separation of management effects difficult. In 2018, the flooding and associated freshwater and nutrient input occurred. In 2019, a temperature anomaly caused a widespread bleaching event. In 2020, COVID-19 restrictions reduced visitor impacts and may have increased local subsistence fishing pressure. Many systems are in a constant state of flux, never reaching equilibrium, and must be managed in a manner that reflect these changes. With the rapid environmental changes, management approaches may no longer be based on returns to a near pristine state or earlier baseline, since shifting baselines will be more prevalent as effects of climate change advance in frequency and intensity. Assessment and long-term monitoring will be continued by the Kaua'i DAR Monitoring Team. Other suggested activities to separate management actions from extraneous factors and to increase community partnerships are outlined below.

- Change in Number of Human Visitors: Surveys to determine changes in fish populations based on changes in visitor counts. Three long-term closures resulting from flooding (2018-2019), pandemic restrictions (2020) and the Hanalei road closure (2021) may have an impact on fish communities through visitor reduction and/or increased fishing pressure. This difference was not apparent in the 2018-2019 closure however, a larger sample size and shifts in fishing pressure in 2020 may elucidate any effects.
- Changes in the time fish spend feeding and minimum approach distance surveys may indicate possible changes in fish behavior due to human influence. CREEL Fishing effort surveys to determine harvest in recreational fisheries can examine changes in fishing pressure.
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## APPENDICES

**Appendix A.** List of fish species along with common names, Hawaiian names, and endemism status (E= endemic, I= indigenous, X= introduced).

Taxonomic Name	Common Name	Hawaiian Name	Endemism
<i>Abudefduf abdominalis</i>	Sargent Major	mamo	E
<i>Abudefduf sordidus</i>	Blackspot Sargent	kūpīpī	I
<i>Abudefduf vaigiensis</i>	Indo-Pacific Sargent	mamo	I
<i>Acanthurus achilles</i>	Achilles Tang	pāku‘iku‘i	I
<i>Acanthurus blochii</i>	Ringtail Surgeonfish	pualu	I
<i>Acanthurus dussumieri</i>	Eye-stripe Surgeonfish	palani	I
<i>Acanthurus guttatus</i>	Whitespotted Surgeonfish	‘api	I
<i>Acanthurus leucopareius</i>	Whitebar Surgeonfish	māikoiko	I
<i>Acanthurus nigricans</i>	Whitecheck Surgeonfish		I
<i>Acanthurus nigrofuscus</i>	Brown Surgeonfish	mā‘i‘i‘i	I
<i>Acanthurus nigroris</i>	Bluelined Surgeonfish	maiko	I
<i>Acanthurus olivaceus</i>	Orangeband Surgeonfish	na‘ena‘e	I
<i>Acanthurus thompsoni</i>	Thompson's Surgeonfish		I
<i>Acanthurus triostegus</i>	Convict Tang	manini	E
<i>Acanthurus xanthopterus</i>	Yellowfin Surgeonfish	pualu	I
<i>Aetobatus narinari</i>	Spotted eagle ray	hihimanu	I
<i>Aluterus scriptus</i>	Blue Scrawled Filefish		I
<i>Amblycirrhitus bimacula</i>	Twospot Hawkfish	pili ko‘a	I
<i>Anampses chrysocephalus</i>	Psychedelic Wrasse		E
<i>Anampses cuvier</i>	Pearl Wrasse	ōpule	E
<i>Antennarius commersoni</i>	Frogfish		I
<i>Antennarius drombus</i>	Hawaiian Freckled Frogfish		E
<i>Aphareus furca</i>	Smalltooth Jobfish	wahanui	I
<i>Apogon maculiferus</i>	Spotted Cardinalfish	‘upāpalu	E
<i>Apogon species</i>	Cardinalfish	‘upāpalu	I
<i>Apogonichthys perdx</i>	Waikīkī Cardinalfish	‘upāpalu	I
<i>Apolemichthys arcuatus</i>	Bandit Angelfish		E
<i>Aprion virescens</i>	Green Jobfish	uku	I
<i>Arothron hispidus</i>	Stripebelly Puffer	keke	I
<i>Arothron meleagris</i>	Spotted Puffer	‘o‘opuhue	I
<i>Asterropteryx semipunctatus</i>	Halfspotted goby	‘o‘opu	I
<i>Atherinomorus insularum</i>	Silverside	iau	E
<i>Aulostomus chinensis</i>	Trumpetfish	nūnū	I
<i>Blenniella gibbifrons</i>	Bullethead Rickskipper		I
<i>Blenniidae</i>	Blenny sp.		I
<i>Bodianus albotaeniatus</i>	Hawaiian Hogfish	‘a‘awa	E
<i>Bothus mancus</i>	Peacock Flounder	pāki‘i	I
<i>Brotula multibarbata</i>	Large-eye Brotula	palahoana	I

<i>Calotomus carolinus</i>	Stareye Parrotfish		I
<i>Calotomus zonarchus</i>	Yellowbar Parrotfish		E
<i>Cantherhines dumerilii</i>	Barred Filefish	‘ō‘ili	I
<i>Cantherhines sandwichiensis</i>	Squartail Filefish	‘ō‘ili lepa	E
<i>Cantherhines verecundus</i>	Shy Filefish		E
<i>Canthidermis maculatus</i>	Pelagic Triggerfish	humuhumu	I
<i>Canthigaster amboinensis</i>	Ambon Toby		I
<i>Canthigaster coronata</i>	Crown Toby		I
<i>Canthigaster epilampra</i>	Lantern Toby		I
<i>Canthigaster jactator</i>	HI Whitespotted Toby		E
<i>Canthigaster rivulata</i>	Maze Toby		I
<i>Caracanthus typicus</i>	Orbicular Velvetfish		E
<i>Carangoides ferdau</i>	Barred Jack	ulua	I
<i>Carangoides orthogrammus</i>	Island Jack	ulua	I
<i>Caranx ignobilis</i>	Giant White Trevally	‘ulua aukea	I
<i>Caranx lugubris</i>	Black Trevally	ulua la‘uli	I
<i>Caranx melampygus</i>	Blue Trevally	‘ōmilu	I
<i>Caranx sexfasciatus</i>	Bigeye Trevally	pake ‘ulua	I
<i>Carcharhinus amblyrhynchos</i>	Gray Reef Shark	mano	I
<i>Carcharhinus galapagensis</i>	Galapagos Shark	mano	I
<i>Carcharhinus melanopterus</i>	Blacktip Reef Shark	mano pa‘ele	I
<i>Centropyge fisheri</i>	Fisher's Angelfish		E
<i>Centropyge flavissima</i>	Lemonpeel Angelfish		X
<i>Centropyge loriculus</i>	Flame Angelfish		I
<i>Centropyge potteri</i>	Potter's Angelfish		E
<i>Cephalopholis argus</i>	Blue-spotted Grouper		X
<i>Chaetodon auriga</i>	Threadfin Butterflyfish	kīkākapu	I
<i>Chaetodon citrinellus</i>	Speckled Butterflyfish	Lauhau	I
<i>Chaetodon ephippium</i>	Saddleback Butterflyfish	kīkākapu	I
<i>Chaetodon fremblii</i>	Bluestripe Butterflyfish	kīkākapu	E
<i>Chaetodon kleinii</i>	Blacklip Butterflyfish	kīkākapu	I
<i>Chaetodon lineolatus</i>	Lined Butterflyfish	kīkākapu	I
<i>Chaetodon lunula</i>	Raccoon Butterflyfish	kīkākapu	I
<i>Chaetodon lunulatus</i>	Oval Butterflyfish	kapuhili	I
<i>Chaetodon miliaris</i>	Milletseed Butterflyfish	lauwiliwili	E
<i>Chaetodon multicinctus</i>	Multiband Butterflyfish	kīkākapu	E
<i>Chaetodon ornatissimus</i>	Ornate Butterflyfish	kīkākapu	I
<i>Chaetodon quadrimaculatus</i>	Fourspot Butterflyfish	lau hau	I
<i>Chaetodon reticulatus</i>	Reticulated Butterflyfish		I
<i>Chaetodon tinkeri</i>	Tinkers Butterflyfish		I
<i>Chaetodon trifascialis</i>	Chevron Butterflyfish	kīkākapu	I
<i>Chaetodon unimaculatus</i>	Teardrop Butterflyfish	lau hau	I
<i>Chanos chanos</i>	Milkfish	‘awa	I



<i>Cheilio inermis</i>	Cigar Wrasse	kūpoupou	I
<i>Cheilodactylus vittatus</i>	Hawaiian Morwong		I
<i>Chlorurus perspicillatus</i>	Spectacled Parrotfish	uhu uliuli	E
<i>Chlorurus spilurus</i>	Bullethead Parrotfish	uhu	I
<i>Chromis agilis</i>	Agile Chromis		I
<i>Chromis hanui</i>	Chocolate-dip Chromis		E
<i>Chromis ovalis</i>	Oval Butterflyfish	kapuhili	E
<i>Chromis vanderbilti</i>	Blackfin Chromis		I
<i>Chromis verater</i>	Threespot Chromis		E
<i>Cirrhilabrus jordani</i>	Flame Wrasse		E
<i>Cirrhitoops fasciatus</i>	Redbar Hawkfish	pili ko‘a	I
<i>Cirrhites pinnulatus</i>	Stocky Hawkfish	po‘o pa‘a	I
<i>Cirripectes obscurus</i>	Gargantuan Blenny		E
<i>Cirripectes vanderbilti</i>	Scarface Blenny		E
<i>Conger cinereus</i>	Mustache Conger	pūhi ūhā	I
<i>Coris ballieui</i>	Lined Coris	hīnālea luahine	E
<i>Coris flavovittata</i>	Yellowstrip coris	hilu	E
<i>Coris gaimard</i>	Yellowtail Coris	hīnālea ‘akilolo	I
<i>Coris venusta</i>	Elegant Coris		E
<i>Coryphopterus sp.</i>	Goby	‘o‘opu	I
<i>Ctenochaetus hawaiiensis</i>	Black Surgeonfish		I
<i>Ctenochaetus strigosus</i>	Goldring Surgeonfish	kole	I
<i>Cymolutes lecluse</i>	Sharp-Headed Wrasse		E
<i>Dascyllus albisella</i>	Hawaiian Dascyllus	‘āloilo‘i	E
<i>Decapterus macarellus</i>	Mackerel Scad	‘opelu	I
<i>Decapterus species</i>	Mackerel Scad	‘opelu	I
<i>Dendrochirus barberi</i>	Hawaiian lionfish		E
<i>Diodon holocanthus</i>	Spiny Puffer	‘o‘opu okala	I
<i>Diodon hystrix</i>	Porcupine	kōkala	I
<i>Doryrhamphus excisus</i>	Bluestripe Pipefish		I
<i>Echidna nebulosa</i>	Snowflake Moray	pūhi kāpā	I
<i>Elagatis bipinnulata</i>	Rainbow Runner	kamanu	I
<i>Enchelynassa canina</i>	Viper Moray	puhi kauila	I
<i>Enneapterygius atriceps</i>	Hawaiian Triplefin		E
<i>Entomacrodus marmoratus</i>	Marbled Blenny	pāo‘o	E
<i>Epibulus insidiator</i>	Slingjaw Wrasse		I
<i>Epinephelus quernus</i>	Hawaiian Grouper	hapu‘u	E
<i>Euthynnus affinis</i>	Wavy-back Tuna	kawakawa	I
<i>Evistias acutirostris</i>	Whiskered Armorhead		I
<i>Exallias brevis</i>	Shortbodied Blenny	pāo‘o kauila	I
<i>Fistularia commersonii</i>	Cornetfish		I
<i>Foa brachygramma</i>	Bay Cardinalfish	‘upāpalu	I
<i>Forcipiger flavissimus</i>	Forcepsfish	lauwiliwilinukunuku‘oi‘oi	I

<i>Forcipiger longirostris</i>	Longnose Butterflyfish	lauwiliwlinukunuku‘oi‘oi	I
<i>Genicanthus personatus</i>	Masked Angelfish		E
<i>Gnathanodon speciosus</i>	Yellow-barred Jack	paopao	I
<i>Gnatholepis anjerensis</i>	Eyebar goby		I
<i>Gobiidae species</i>	Goby	‘o‘opu	I
<i>Gomphosus varius</i>	Bird Wrasse	hīnālea ‘i‘iwi, ‘akilolo	I
<i>Gunnellichthys curiosus</i>	Curious Wormfish		I
<i>Gymnomuraena zebra</i>	Zebra Moray	pūhi	I
<i>Gymnothorax eurostus</i>	Stout Moray	pūhi	I
<i>Gymnothorax flavimarginatus</i>	Yellowmargin Moray	pūhi paka	I
<i>Gymnothorax meleagris</i>	Whitemouth Moray	pūhi ōni‘o	I
<i>Gymnothorax rueppelliae</i>	Yellowhead Moray		I
<i>Gymnothorax steindachneri</i>	Steindachner's Moray	pūhi	E
<i>Gymnothorax undulatus</i>	Undulated Moray	pūhi laumilo	I
<i>Halichoeres ornatissimus</i>	Ornate Wrasse	‘ōhua	I
<i>Hazeus nephodes</i>	Cloudy goby		I
<i>Hemiramphus depauperatus</i>	Polynesian halfbeak	iheihe	I
<i>Hemiramphus species</i>	Halfbeak species	iheihe	I
<i>Hemitaurichthys polylepis</i>	Pyramid Butterflyfish		I
<i>Hemitaurichthys thompsoni</i>	Thompson's Butterflyfish		I
<i>Heniochus diphreutes</i>	Pennantfish		I
<i>Heteropriacanthus cruentatus</i>	Glasseye	‘āweoweo	I
<i>Hyporhamphus acutus</i>	Acute halfbeak	iheihe	I
<i>Iracundus signifer</i>	Decoy Scorpionfish		I
<i>Istiblennius zebra</i>	Zebra Blenny	pāo‘o	E
<i>Kuhlia sandvicensis</i>	Hawaiian Flagtail	āholehole	E
<i>Kyphosus bigibbus</i>	Brown Chub	nenu	I
<i>Kyphosus cinerascens</i>	Highfin Chub	nenu	I
<i>Kyphosus species</i>	Lowfin Chub	nenu	I
<i>Kyphosus vaigiensis</i>	Lowfin Chub	nenu	I
<i>Labroides phthirophagus</i>	Hawaiian Cleaner Wrasse		E
<i>Lactoria fornasini</i>	Thornback Trunkfish	makukana	I
<i>Lutjanus fulvus</i>	Blacktail Snapper	to‘au	X
<i>Lutjanus kasmira</i>	Bluestripe Snapper	ta‘ape	X
<i>Macropharyngodon geoffroy</i>	Shortnose Wrasse		E
<i>Malacanthus brevirostris</i>	Banded Blanquillo		I
<i>Manta alfredi</i>	Manta Ray		I
<i>Melichthys niger</i>	Black Durgon	humuhumu‘ele‘ele	I
<i>Melichthys vidua</i>	Pinktail Durgon	humuhumuhi‘ukole	I
<i>Microcanthus strigatus</i>	Stripey		I
<i>Monotaxis grandoculis</i>	Bigeye Emperor	mu	I
<i>Mugil cephalus</i>	Striped Mullet		I
<i>Mulloidichthys flavolineatus</i>	Yellowstripe Goatfish	weke	I

<i>Mulloidichthys pflugeri</i>			I
<i>Mulloidichthys vanicolensis</i>	Yellowfin Goatfish	weke 'ula	I
<i>Myrichthys magnificus</i>	Magnificent Snake Eel		E
<i>Myripristis amaena</i>	Brick Soldierfish	'ū'ū	I
<i>Myripristis berndti</i>	Bigscale Soldierfish	'ū'ū	I
<i>Myripristis chryseres</i>	Yellowfin Soldierfish	'ū'ū	I
<i>Myripristis kuntee</i>	Epaulette Soldierfish	'ū'ū	I
<i>Myripristis vittata</i>	Whitetip Soldierfish	'ū'ū	I
<i>Naso</i>	Unicornfish sp.	kala	I
<i>Naso annulatus</i>	Whitemargin Unicornfish		I
<i>Naso brevirostris</i>	Spotted Unicornfish	kala lōlō	I
<i>Naso hexacanthus</i>	Sleek Unicornfish	kala holo	I
<i>Naso lituratus</i>	Orangespine Unicornfish	umaumalei	I
<i>Naso unicornis</i>	Bluespine Unicornfish	kala	I
<i>Nemateleotris magnifica</i>	Fire Dartfish		I
<i>Neoniphon aurolineatus</i>	Goldline Squirrelfish	'ala'ihī	I
<i>Neoniphon sammara</i>	Spotfin squirrelfish	'ala'ihī	I
<i>Novaculichthys taeniourus</i>	Rockmover		I
<i>Oplegnathus fasciatus</i>	Barred knifejaw		I
<i>Oplegnathus punctatus</i>	Spotted Knifejaw		I
<i>Ostracion meleagris</i>	Spotted Boxfish	moa	I
<i>Ostracion whitleyi</i>	Whitley's Boxfish		I
<i>Oxycheilinus bimaculatus</i>	Twospot Wrasse		I
<i>Oxycheilinus unifasciatus</i>	Ringtail Wrasse	pō'ou	I
<i>Oxycirrhites typus</i>	Longnose Hawkfish		I
<i>Paracirrhites arcatus</i>	Arc-eye Hawkfish	pili ko'a	I
<i>Paracirrhites forsteri</i>	Blackside Hawkfish	hilu pili ko'a	I
<i>Parapercis schauinslandi</i>	Sand Perch		I
<i>Parupeneus cyclostomus</i>	Blue Goatfish	moano kea	I
<i>Parupeneus insularis</i>	Doublebar Goatfish	munu	I
<i>Parupeneus multifasciatus</i>	Manybar Goatfish	moano	I
<i>Parupeneus pleurostigma</i>	Sidespot Goatfish	malu	I
<i>Parupeneus porphyreus</i>	Whitesaddle Goatfish	kūmū	E
<i>Pervagor aspricaudus</i>	Lacefin Filefish		I
<i>Pervagor spilosoma</i>	Fantail Filefish	'ōili'uwi'uwi	E
<i>Plagiotremus ewaensis</i>	Ewa Blenny		E
<i>Plagiotremus goslinei</i>	Scale-eating Blenny		E
<i>Platybelone argalus</i>	Keeltail Needlefish	'aha	I
<i>Plectroglyphidodon imparipennis</i>	Brighteye Damsel		I
<i>Plectroglyphidodon johnstonianus</i>	Blue-eye Damsel		I
<i>Plectroglyphidodon sindonis</i>	Rock Damsel		E
<i>Polydactylus sexfilis</i>	Threadfin		I
<i>Priacanthus meeki</i>	Hawaiian Bigeye	'āweoweo	E

<i>Priacanthus species</i>	Bigeye species	‘āweoweo	I
<i>Priolepis eugenius</i>	Noble Goby	‘o‘opu	E
<i>Pristiapogon kallopterus</i>	Iridescent Cardinalfish	‘upāpalu	I
<i>Pristiapogon taeniopterus</i>	Bandfin Cardinalfish	‘upāpalu	E
<i>Pristilepis oligolepis</i>	Spinyface Soldierfish	‘ū‘ū	I
<i>Pseudanthias bicolor</i>	Bicolor Anthias		E
<i>Pseudanthias thompsoni</i>	Hawaiian Anthias		E
<i>Pseudocaranx dentex</i>	Thicklipped Jack	buta ulua	I
<i>Pseudocheilinus evanidus</i>	Disappearing Wrasse	mālamalama	I
<i>Pseudocheilinus octotaenia</i>	Eightline Wrasse		I
<i>Pseudocheilinus tetrataenia</i>	Fourline Wrasse		I
<i>Pseudojuloides cerasinus</i>	Smalltail Wrasse		I
<i>Psilogobius mainlandi</i>	Hawaiian Shrimp Goby	‘o‘opu	E
<i>Ptereleotris heteroptera</i>	Indigo Dartfish; Indigo hover goby		I
<i>Pterois sphex</i>	Hawaiian Turkeyfish		E
<i>Rhinecanthus aculeatus</i>	Lagoon Triggerfish	humuhumunukunukuapua‘a	I
<i>Rhinecanthus rectangulus</i>	Reef Triggerfish	humuhumunukunukuapua‘a	I
<i>Sargocentron diadema</i>	Crown Squirrelfish	‘ala‘ihi	I
<i>Sargocentron ensiferum</i>	Yellowstripe Squirrelfish	‘ala‘ihi	I
<i>Sargocentron punctatissimum</i>	Peppered Squirrelfish	‘ala‘ihi	I
<i>Sargocentron spiniferum</i>	Saber Squirrelfish	‘ala‘ihi	I
<i>Sargocentron tiere</i>	Tahitian Squirrelfish	‘ala‘ihi	I
<i>Sargocentron xantherythrum</i>	Hawaiian Squirrelfish	‘ala‘ihi	E
<i>Saurida flamma</i>	Orangemouth Lizardfish	‘ulae	I
<i>Saurida gracilis</i>	Slender Lizardfish	‘ulae	I
<i>Scarus</i>	Scarus sp.	uhu	I
<i>Scarus dubius</i>	Regal Parrotfish	lauia	E
<i>Scarus psittacus</i>	Palenose Parrotfish	uhu	I
<i>Scarus rubroviolaceus</i>	Redlip Parrotfish	pālukaluka	I
<i>Scomberoides lysan</i>	Leatherback	lai	I
<i>Scorpaenodes kelloggi</i>	Kellogg's Scorpionfish		I
<i>Scorpaenodes parvipinnis</i>	Lowfin Scorpionfish		I
<i>Scorpaenopsis cacopsis</i>	Titan Scorpionfish	nohu	E
<i>Scorpaenopsis diabolus</i>	Devil Scorpionfish	nohu‘omakaha	I
<i>Scuticaria tigrinus</i>	Tiger Moray		I
<i>Sebastapistes ballieui</i>	Spotfin Scorpionfish		E
<i>Sebastapistes coniota</i>	Speckled Scorpionfish		I
<i>Selar crumenophthalmus</i>	Big-Eyed Scad	akule	I
<i>Seriola dumerili</i>	Amberjack	kahala	I
<i>Sphyrna barracuda</i>	Barracuda		I
<i>Sphyrna lewini</i>	Scalloped Hammerhead shark	mano kihikihi	I
<i>Stegastes marginatus</i>	Hawaiian Gregory		I
<i>Stethojulis balteata</i>	Belted Wrasse	‘ōmaka	E

<i>Sufflamen bursa</i>	Lei Triggerfish	humuhumulei	I
<i>Sufflamen fraenatus</i>	Bridled Triggerfish	humuhumumimi	I
<i>Synodus binotatus</i>	Twospot Lizardfish	‘ulae	I
<i>Synodus dermatogenys</i>	Clearfin Lizardfish	‘ulae	I
<i>Synodus lobeli</i>	Lobel's Lizardfish	‘ulae	I
<i>Synodus species</i>	Lizardfish	‘ulae	I
<i>Synodus ulae</i>	Ulae Lizardfish	‘ulae	I
<i>Synodus variegatus</i>	Variegated Lizardfish	‘ulae	I
<i>Taenianotus triacanthus</i>	Leaf Scorpionfish		I
<i>Thalassoma ballieui</i>	Blacktail Wrasse		E
<i>Thalassoma duperrey</i>	Saddle Wrasse	hīnālea lauwiki	E
<i>Thalassoma lutescens</i>	Sunset Wrasse		I
<i>Thalassoma purpureum</i>	Surge Wrasse	hou	I
<i>Thalassoma quinquevittatum</i>	Fivestripe Wrasse		I
<i>Thalassoma trilobatum</i>	Christmas Wrasse	āwela	I
<i>Trachinocephalus myops</i>	Snakefish	wele‘a	I
<i>Triaenodon obesus</i>	Whitetip Reef Shark	mano lalakea	I
<i>Tylosurus crocodilus</i>	Houndfish		I
<i>Upeneus arge</i>	Nightmare Goatfish	weke pueo	E
<i>Xanthichthys auromarginatus</i>	Gilded Triggerfish		I
<i>Xanthichthys mento</i>	Crosshatch Triggerfish		I
<i>Xyrichtys niger</i>	Black Razor Wrasse		I
<i>Xyrichtys niveilatus</i>	White-side Razor Wrasse		I
<i>Xyrichtys pavo</i>	Peacock Razor Wrasse		I
<i>Xyrichtys umbrilatus</i>	Blackside Razor Wrasse		E
<i>Zanclus cornutus</i>	Moorish idol	kihikihi	I
<i>Zebrasoma flavescens</i>	Yellow Tang	lau‘īpala	I
<i>Zebrasoma veliferum</i>	Sailfin tang	māne‘one‘o	I

**Appendix B.** List of resource and non-resource fishes found in Hā‘ena during the 2014-2020 survey period.

<b>Resource Fish</b>	<b>Non-resource Fish</b>
<i>Acanthurus dussumieri</i>	<i>Abudefduf abdominalis</i>
<i>Acanthurus dussumieri</i>	<i>Abudefduf sordidus</i>
<i>Acanthurus nigroris</i>	<i>Abudefduf vaigiensis</i>
<i>Acanthurus triostegus</i>	<i>Acanthurus achilles</i>
<i>Calotomus carolinus</i>	<i>Acanthurus blochii</i>
<i>Calotomus zonarchus</i>	<i>Acanthurus guttatus</i>
<i>Carangoides ferdau</i>	<i>Acanthurus leucopareius</i>
<i>Carangoides orthogrammus</i>	<i>Acanthurus nigricans</i>
<i>Caranx ignobilis</i>	<i>Acanthurus nigrofuscus</i>
<i>Caranx melampygus</i>	<i>Acanthurus olivaceus</i>
<i>Chlorurus perspicillatus</i>	<i>Acanthurus thompsoni</i>
<i>Chlorurus spilurus</i>	<i>Acanthurus xanthopterus</i>
<i>Kyphosus bigibbus</i>	<i>Aluterus scriptus</i>
<i>Kyphosus cinerascens</i>	<i>Amblycirrhitus bimacula</i>
<i>Kyphosus species</i>	<i>Anampses chrysocephalus</i>
<i>Mulloidichthys flavolineatus</i>	<i>Anampses cuvier</i>
<i>Mulloidichthys vanicolensis</i>	<i>Aphareus furca</i>
<i>Naso unicornis</i>	<i>Apolemichthys arcuatus</i>
<i>Parupeneus porphyreus</i>	<i>Aprion virescens</i>
<i>Scarus dubius</i>	<i>Aulostomus chinensis</i>
<i>Scarus psittacus</i>	<i>Blenniidae</i>
<i>Scarus rubroviolaceus</i>	<i>Bodianus albotaeniatus</i>
<i>Selar crumenophthalmus</i>	<i>Cantherhines dumerilii</i>
<i>Seriola dumerili</i>	<i>Cantherhines sandwichiensis</i>
	<i>Canthigaster amboinensis</i>
	<i>Canthigaster coronata</i>
	<i>Canthigaster jactator</i>
	<i>Canthigaster rivulata</i>
	<i>Caracanthus typicus</i>
	<i>Centropyge potteri</i>
	<i>Cephalopholis argus</i>
	<i>Chaetodon auriga</i>
	<i>Chaetodon ephippium</i>
	<i>Chaetodon fremblii</i>
	<i>Chaetodon kleinii</i>
	<i>Chaetodon lineolatus</i>
	<i>Chaetodon lunula</i>
	<i>Chaetodon lunulatus</i>
	<i>Chaetodon miliaris</i>

	<i>Chaetodon multicinctus</i>
	<i>Chaetodon ornatissimus</i>
	<i>Chaetodon quadrimaculatus</i>
	<i>Chaetodon unimaculatus</i>
	<i>Cheilio inermis</i>
	<i>Chromis agilis</i>
	<i>Chromis hanui</i>
	<i>Chromis ovalis</i>
	<i>Chromis vanderbilti</i>
	<i>Chromis verater</i>
	<i>Cirrhitops fasciatus</i>
	<i>Cirrhitus pinnulatus</i>
	<i>Cirripectes vanderbilti</i>
	<i>Coris ballieui</i>
	<i>Coris flavovittata</i>
	<i>Coris gaimard</i>
	<i>Coris venusta</i>
	<i>Ctenochaetus strigosus</i>
	<i>Cymolutes lecluse</i>
	<i>Dascyllus albisella</i>
	<i>Decapterus macarellus</i>
	<i>Diodon holocanthus</i>
	<i>Diodon hystrix</i>
	<i>Echidna nebulosa</i>
	<i>Elagatis bipinnulata</i>
	<i>Exallias brevis</i>
	<i>Fistularia commersonii</i>
	<i>Forcipiger flavissimus</i>
	<i>Forcipiger longirostris</i>
	<i>Gomphosus varius</i>
	<i>Gunnellichthys curiosus</i>
	<i>Gymnothorax flavimarginatus</i>
	<i>Gymnothorax meleagris</i>
	<i>Halichoeres ornatissimus</i>
	<i>Hemiramphus depauperatus</i>
	<i>Labroides phthirophagus</i>
	<i>Lutjanus fulvus</i>
	<i>Lutjanus kasmira</i>
	<i>Macropharyngodon geoffroy</i>
	<i>Malacanthus brevirostris</i>
	<i>Melichthys niger</i>

	<i>Melichthys vidua</i>
	<i>Monotaxis grandoculis</i>
	<i>Myripristis berndti</i>
	<i>Myripristis kuntee</i>
	<i>Naso brevirostris</i>
	<i>Naso hexacanthus</i>
	<i>Naso lituratus</i>
	<i>Novaculichthys taeniourus</i>
	<i>Oplegnathus fasciatus</i>
	<i>Oplegnathus punctatus</i>
	<i>Ostracion meleagris</i>
	<i>Oxycheilinus bimaculatus</i>
	<i>Oxycheilinus unifasciatus</i>
	<i>Paracirrhites arcatus</i>
	<i>Paracirrhites forsteri</i>
	<i>Parapercis schauinslandi</i>
	<i>Parupeneus cyclostomus</i>
	<i>Parupeneus insularis</i>
	<i>Parupeneus multifasciatus</i>
	<i>Parupeneus pleurostigma</i>
	<i>Pervagor aspricaudus</i>
	<i>Pervagor spilosoma</i>
	<i>Plagiotremus ewaensis</i>
	<i>Plagiotremus goslinei</i>
	<i>Platybelone argalus</i>
	<i>Plectroglyphidodon imparipennis</i>
	<i>Plectroglyphidodon johnstonianus</i>
	<i>Priacanthus species</i>
	<i>Pristiapogon kallopterus</i>
	<i>Pristiapogon taeniopterus</i>
	<i>Pseudanthias bicolor</i>
	<i>Pseudocheilinus evanidus</i>
	<i>Pseudocheilinus octotaenia</i>
	<i>Pseudocheilinus tetrataenia</i>
	<i>Pseudojuloides cerasinus</i>
	<i>Psilogobius mainlandi</i>
	<i>Ptereleotris heteroptera</i>
	<i>Rhinecanthus aculeatus</i>
	<i>Rhinecanthus rectangulus</i>
	<i>Sargocentron diadema</i>
	<i>Sargocentron spiniferum</i>



	<i>Scarus spp.</i>
	<i>Scomberoides lysan</i>
	<i>Sebastapistes ballieui</i>
	<i>Sebastapistes coniota</i>
	<i>Sphyraena barracuda</i>
	<i>Stegastes marginatus</i>
	<i>Stethojulis balteata</i>
	<i>Sufflamen bursa</i>
	<i>Sufflamen fraenatus</i>
	<i>Synodus species</i>
	<i>Taenianotus triacanthus</i>
	<i>Thalassoma ballieui</i>
	<i>Thalassoma duperrey</i>
	<i>Thalassoma purpureum</i>
	<i>Thalassoma quinquevittatum</i>
	<i>Thalassoma trilobatum</i>
	<i>Triaenodon obesus</i>
	<i>Xyrichtys pavo</i>
	<i>Zanclus cornutus</i>
	<i>Zebrasoma flavescens</i>
	<i>Zebrasoma veliferum</i>