2019 Long-term Monitoring and Assessment of the Hāʻena, Kauaʻi Community Based Subsistence Fishing Area

Year 4 CBSFA Efficacy Study

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August 2020

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Project Period 1 August 2019 – 31 July 2020
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EXECUTIVE SUMMARY

The Hāʻena community in collaboration with State of Hawaiʻi's Department of Land and Natural Resources established a Community Based Subsistence Fishing Area (CBSFA) in 2015 in Hāʻena, Kauaʻi. 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 management practices of 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 Hawaiʻi's (UH) Hawaiʻi Institute of Marine Biology (HIMB) Coral Reef Ecology Lab/Coral Reef Assessment and Monitoring Program (CRAMP), the State of Hawaiʻi'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), and 2018 (n=110).

In the spring and summer of 2019, 98 Kauaʻi Assessment of Habitat Utilization (KAHU) surveys were conducted within and outside the established boundaries of the CBSFA. Fish communities are compared to baseline surveys conducted in 2013/14 by the Fisheries Ecology Research Laboratory (FERL) prior to the establishment of the CBSFA and annually data collected since 2016. This data allows for a sampling design that compares marine communities before the initiation of management action to any changes that may have occurred following commencement of regulations.

A stochastic freshwater event occurred on April 13-16, 2018, impacting the entire north shore of Kauaʻi. It was the worst natural disaster to occur on Kauaʻi in the 25 years since Hurricane Iniki. The record for the most rainfall in a 24-hour period for the Hawaiian Islands was broken. According to the National Weather Service in Honolulu, the rain gauge about a mile west of Hanalei Bay recorded over four feet (49.69") of rain during April 15-16. In the Hāʻena region, damage to roads resulted in a closure of the area to visitors. The freshwater increase and changes in the user population resulted in a nearshore biological shift with anecdotal reports of large increases in some species of resource fishes that were leaner than prior accounts. This prompted surveys to extend prior to and following road closure to determine any shifts in fishes, corals, or invertebrates that could no longer be attributed solely to management actions but may instead be ascribed to the freshwater that provides nutrients for plankton and macroalgae, increasing certain species of fishes and shifting biological populations. Surveys were conducted between 27 March and 6 August, 2019. Ninety-eight surveys were conducted during the Kuhio Highway road closure to visitors (n=64) and following its reopening (n=34). Road closure to visitors remained in place between the April 2018 flood event and June 2019, a 14-month period.

The drastic reduction in visitors to the nearshore waters may also contribute to the population shifts due to changes in fish behavior. The freshwater lens coupled with low tides have also resulted in a change in the benthic community and a sharp decrease in urchin populations. In June 2018, Drs. Kostantinos Stamoulis and Jade Delevaux, Kauaʻi DAR, and community volunteers surveyed fish populations, behavior, and minimum approach distance in nearshore waters. With roads opened in June of 2019, fish behavior was resurveyed to determine any changes in fish populations with the influx of visitors.

Fish Communities
Overall, fish abundance ($p \leq 0.001$) and biomass ($p = 0.032$) was greatest in 2017 as compared to all previous (2016) or subsequent (2018, 2019) years. Fish abundance ($p=0.005$) and biomass ($p=0.027$) in 2019 were greater inside the CBSFA as compared to outside the boundaries, similar to previous years. Number of species were not found to be statistically different across years from 2016-2019. However, number of species was significantly different between divisions ($p= 0.003$) with higher counts reported inside the CBSFA ($p=0.005$) and the Makua Puʻuhonua ($p=0.038$) as compared to outside the boundaries.

Resource Fishes
Of the 32 species listed by the community as important cultural and subsistence resources, 17 species were recorded in 2019. A decline in the number of food fish species in each sector has occurred since 2018. Species perceived to be in "good" condition by the community were fairly prevalent as expected. *Selar crumenophthalmus* (*akule*), Big-eyed scad schools, perceived to be in poor condition, was reported in the Makua Puʻuhonua in the past two years. While the majority of food fishes were more prevalent inside the CBSFA, two *uhu* species, *Chlorurus spilurus* and *Chlorurus perspicillatus* were found in greater abundance outside the CBSFA. In 2019, 112 fish species were recorded in Hāʻena overall. The CBSFA had more species recorded (98) than outside the CBSFA (89). The Makua Puʻuhonua had 53 species likely due to the smaller size and fewer transects conducted. There was no statistical difference found in resource fish diversity inside and outside the CBSFA among years, however, diversity inside the Makua Puʻuhonua in 2019 was higher than in 2016 ($p=0.0311$). Diversity inside the CBSFA boundaries was higher than outside ($p \leq 0.001$). Both food and non-food fishes show greater numbers and biomass inside the CBSFA as compared to outside. Higher abundance and biomass were reported in 2019 as compared to all previous years except 2017.

Reproductive Size
Overall findings show significantly higher frequencies of occurrence of resource fishes increasing across years and higher biomass, abundance, and diversity of all fish species inside the CBSFA. However, an examination of the reproductive maturity of resource fishes to determine whether there has been an increase in fish reproductive size since the initiation of the CBSFA shows no strong reserve effect. This may be due to the flood effect in 2018 and the exclusion of data for 2019. Comparison of mean abundance of 14 food fish species show only five species with the abundance of individuals above their L_{50} values (size at which half the individuals in a population reach reproductive maturity) within the CBSFA from 2016 through 2018. These included the Convict Tang, *Acanthurus triostegus* (*manini*), the Blue Goatfish, *Parupeneus cyclostomus* (moano kea), the Ember Parrotfish, *Scarus rubroviolaceus* (*palukaluka*), and the introduced species the Peacock Grouper, *Cephalopholis argus* (*roi*), and the Black-tailed Snapper *Lutjanus fulvus* (*toʻau*).

Top Fish Species

As in previous years, the Saddle Wrasse, *hīnālea lauwili* is the most common fish recorded in 2019. Two endemic species, *hīnālea lauwili* and *A. triostegus* (*manini),* were frequently observed in all sectors. Six common species are shared among sectors for abundance: *Chromis vanderbilti* (Blackfin Chromis), *Thalassoma duperrey (*Saddle wrasse, *hīnālea lauwili), Acanthurus nigrofuscus* (Brown Surgeonfish, *māʻiʻi*), *Acanthurus triostegus* (Convict Tang, *manini*), *Acanthurus leucopareius* (Whitebar Surgeonfish, *māikoiko*), and *Acanthurus olivaceus* (Orangeband surgeonfish, *naʻenaʻe*). *Lutjanus kasmira* (the Bluestripe Snapper, *taʻape*), an introduced species, appears in the top ten species both within and outside the CBSFA. There was a noticeable decrease of *taʻape* outside the CBSFA from 2018-2019 (10% to 3%).

Fish biomass of the top species varies between sectors. Only three fish species overlap within the top ten (*A. leucopareius*, *A. triostegus,* and *Kyphosus* species (the Lowfin Chub, *enenue*)). *Triaenodon obesus* (Whitetip reef shark, *mano lalakea*) not recorded previously on transects, was recorded on two separate transects in 2019. A large decline in biomass (0.8%) of *Caranx melampygus* (the Blue Trevally, *ʻomilu*) is seen inside the Makua Puʻuhonua since 2018 (8.8%).

Trophic Levels

Throughout the years surveyed (2016-2019), herbivore biomass dominates within all sectors. However, in 2019, abundance of invertebrate feeders comprised the largest percentage in the Puʻuhonua (50%). No significant differences were found in piscivores between years for abundance, however, piscivore biomass increased in 2019 due to the sighting of two sharks. A significant increase in herbivore biomass inside the Makua Puʻuhonua has been observed since 2016 (p=0.026) No statistically significant differences were detected for trophic levels between years outside the CBSFA.

Endemism

Endemic abundance and biomass of fishes were significantly greater in the Makua Puʻuhonua ($p \leq 0.001$) and the entire CBSFA ($p \leq 0.001$) as compared to outside the boundaries (p=0.006). *Thalassoma duperrey (hīnālea lauwili)* is responsible for the majority of the high endemic composition, contributing 83% to the total endemic fish abundance and 40% to the total fish abundance. Endemic biomass is mainly attributed to *Acanthurus triostegus, manini*, which comprise 67% of total biomass. Indigenous percent composition for abundance and biomass is higher inside the boundaries compared to outside (p=0.009). This is due to high biomass of *Acanthurus leucopareius (māikoiko), Melichthys niger (humuhumuʻeleʻele), Monotaxis grandoculis (mu),* and *Naso unicornis (kala)*. Non-native species are greatest outside the CBSFA mainly attributed to *taʻape*. A community invasive species removal, the Kauaʻi Invasive Xtermination (KIX) fishing tournament, was initiated in Hāʻena on 24 August, 2019. DLNR, DAR and UH were among the participants at the YMCA Camp Naue, conducting otolith collections and assisting Hui Makaʻāinana o Makana with fish counts, species identifications, weights, and measurements. Seventy-two divers removed 249 invasive fishes ranging from 17 cm to 45 cm and weighing between 90 and 1,710 grams. Select fishes were retained for a community fish fry.

Size Class

When comparing all sectors across all years surveyed (2016-2019), abundance in the largest size class was statistically greater inside the CBSFA than outside ((p=0.010). Dominant fishes in the larger size range (>15 cm) include *Acanthurus leucopareius (māikoiko,* Whitebar Surgeonfish), *Melichthys niger (humuhumuʻeleʻele,* the Black Durgon), and *Monotaxis grandoculis* (*mu*, the Bigeye Emperor) within the CBSFA. Outside the CBSFA, *Acanthurus olivaceous* (the Orangeband Surgeonfish, *naʻenaʻe), A. leucopareius,* and *Kyphosus* species (the Lowfin Chub, *enenue*) comprise the majority of the larger fishes. Inside the Makua Puʻuhonua, *Abudefduf abdominalis* (Hawaiian Sergeant, *mamo)* and *A. vaigiensis* (Indo-Pacific Sergeant) are the largest fishes found (15-17 cm), although relatively smaller than other common large fishes. Size class composition in all sectors were similar compared to 2018, with the exception of an increase in biomass of the mid-size class inside the Puʻuhonua from 11% of total biomass to 28%.

Coral Cover

The largest change in coral cover is a slight decrease (2.5%) in mean coral cover outside the CBSFA in shallow sites (<7 m). All other patterns of benthic cover are similar to the 2018 surveys. The shallow, protected Puʻuhonua continues to have higher mean coral cover than other sectors (11.9%), a slight increase from 2018. Mean coral cover inside the CBSFA is similar at shallow stations (5.9%) as compared to deep transects (4.1%) with slight increases in both sectors from the previous year. Outside the CBSFA, mean coral cover was higher at shallow stations (7.1%) than at the deeper stations (3.2%) as in the previous year. The percent of bleached corals of the total coral cover showed an extreme increase across all sectors at Hāʻena. The average percentage of bleached corals between 2018 and 2019 tripled in just one year. This sudden site-wide increase of bleaching is likely attributed to the bleaching that occurred statewide in 2019. However, follow up recovery surveys show low mortality statewide. Bleaching continued to be higher outside the CBSFA as compared to inside (17.0% and 10.8%). Deep sites showed a slightly higher percentage of bleached corals as compared to shallow sites (15.5% vs. 12.3%), contradicting previous observations and studies which suggest corals in higher irradiance environments due to depth variability are more susceptible to bleaching. The most common species recorded as bleached in all sectors was *M. capitata*, identical to the 2018 surveys. *P. meandrina* was the next most bleached coral species.

DAR/CRAMP Limahuli Long-term Monitoring Site

Total coral cover in 2019 at the 1 m station (9.71%) has increased since 2018 (7.16%). However, the 10 m station average coral cover was the lowest recorded over a 20-year period which ranged from 28.3% in 2008 to 4.74% in 2019. Coral cover has continued to decline since last year in 2018 (7.60%). While recovery since the 2015/16 statewide bleaching event is occurring at the shallow reef flat, the deeper station shows no signs of recovery and continues to decline.

Sea Urchins

There is an overall decline in shallow waters of all seven species of urchins recorded. However, *Echinometra mathaei* appears to be the species exhibiting the greatest change. This species drastically declined only at shallow stations between 2017 (7.7 urchins/transect) and 2018 (1.1 urchins/transect) before increasing slightly to 2.7 urchins/transect in 2019, evidence of partial recovery from the 2018 flood event. At deeper sectors there was no statistically significant change in abundance from 2017 (5.9 urchins/transect) to 2018 (7.0 urchins/transect) providing strong evidence of freshwater impacts, however urchins have continued to decrease in 2019 to 4.5 urchins/transect. In both the CBSFA and outside sector, urchin composition and species diversity are similar with the exception of *Heterocentrotus mammilatus*, the Slate Pencil Urchin, found inside the boundaries and absent outside. This is identical to the previous three years (2016-2018). *H. mammilatus* has continually been found in low numbers with only one individual found in 2019.

Four Year Management Efficacy Evaluation Summary of the Hāʻena CBSFA (2016-2019)
Maintaining the sustainability of the Hāʻena CBSFA fishery is a key goal of all parties involved. An initial assessment over the four-year period the CBSFA has been in effect was conducted to compare resource fishes identified by the community to non-resource fishes (food vs. non-food) to determine management success. By comparing the patterns between fished and un-fished species we attempt to isolate changes due to management strategies and/or fishing impacts.

When examining biomass of food and non-food fishes inside the reserve, a similar pattern of increase should be evident if fishing pressure has been considerably reduced. In addition, there should be greater increases inside as compared to outside the reserve for food fishes. Figure 1a shows an overall pattern of increase in biomass of food fishes inside and outside the CBSFA and a similar pattern of increase in non-food fishes. Importantly, it also depicts a steeper slope for food fishes inside the reserve as compared to outside with higher biomass values for all survey years. The increase in biomass of food fishes from 2016 to 2017 and from 2018 to 2019 is evident. The density of food fishes is consistent and similar both inside and outside the CBSFA (Fig. 1b) suggesting that the biomass increase is due to growth (larger fishes) rather than higher numbers. The density of non-food fishes shows a pattern more similar to non-food fish biomass suggesting that the increase in numbers of non-food fishes contributes more to the biomass increase. Examining the ratio of food and non-food fishes inside to outside the reserve over time, a biomass increase is apparent (Fig. 2a). In contrast, the density ratio appears to decline overall for both food and non-food fishes over time (Fig. 2b) though the trend from 2018 to 2019 is strongly positive.

The declines in 2018 for both food and non-food fishes are linked to the April 2018 freshwater flood event. The reserve impacts were more evident inside the reserve than outside likely due to the freshwater input from Limahuli and Mānoa streams. The decrease in non-food fishes can be attributed to the freshwater effects, while the decline in food fishes may also indicate an increase in fishing during the year of road closure when the community relied more heavily on local food sources. Freshwater impacts on the marine environment were documented using bioindicators of low salinity. Urchins, bleached corals (outside the temperature effect), and the octocoral *Sarcothelia edmondsoni* were heavily impacted by the freshwater at shallow stations and unimpacted at deeper stations where the effect of lowered salinity was negligible. The recovery of the fisheries in 2019 is supporting evidence of the efficacy of the management approach. This will be further tested next year once data from all five years are available.

It is reasonable to assume that the CBSFA rules would increase the fished species, however the unfished species are also increasing. This may be due to habitat protection afforded by the rules, removal of human disturbance within the Makua Puʻuhonua, 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. Continued monitoring will verify a signal outside patterns of typical variation. A fish spillover effect will be assessed in the final reporting in 2021 encompassing the five-year CBSFA evaluation, to determine any additional fisheries benefits to the community.

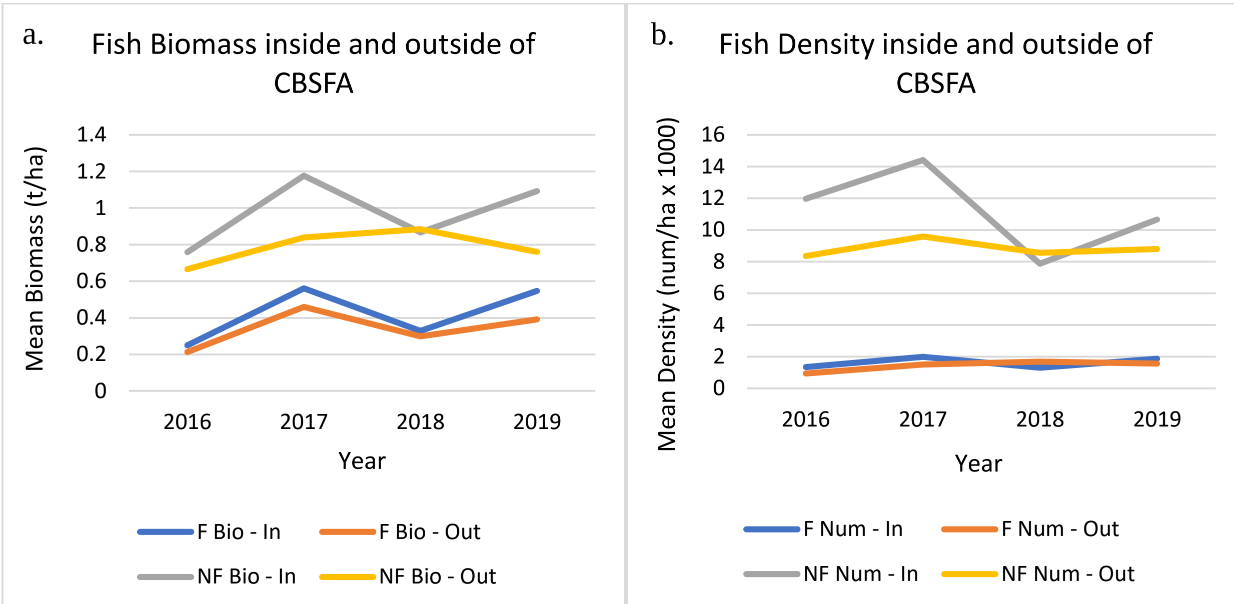


Figure 1. a) Fish Mean Biomass (tons/hectare) and b) Fish Mean Density (number/hectare x 1000) inside and outside the Hāʻena CBSFA by year from 2016 through 2019. Key: F=Food fishes, NF=Non-Food fishes.

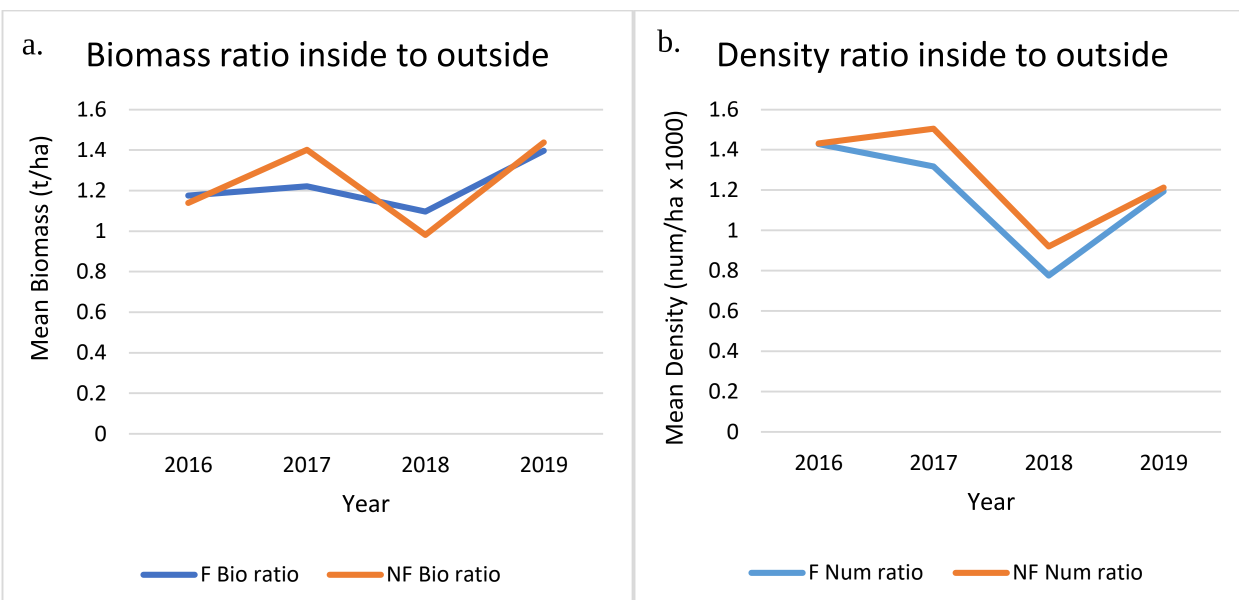


Figure 2. a) Fish Mean Biomass ratio (tons/hectare) and b) Fish Mean Density/number ratio (number/hectare x 1000) inside and outside the Hāʻena CBSFA by year from 2016 through 2019. Key: F=Food fishes (blue line), NF=Non-Food fishes (orange line). Ratio calculated by dividing the mean fish biomass or number inside the CBSFA to the mean fish biomass and number outside the CBSFA.

Conclusions (2019)

Some recovery has been observed following the effects of the freshwater flood event in April 2018.

- The octocoral *Sarcothelia edmondsoni* 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 show a slight increase from the previous year.
- Sea urchin populations increased slightly following the significant decline in 2018 following the massive flood event.
- Fish abundance and biomass were highest in 2017 but showing some recovery in 2019 since the flood.
- Across all years surveyed, herbivorous fishes dominate.
- Comparisons in fish populations during road closure beginning in April 2018 and after road reopening in June 2019 show few differences except with increases following opening in herbivorous fishes and fishes within the Makua Puʻuhonua.

Fish populations remain higher inside the CBSFA boundaries as compared to outside.

- The fish abundance and biomass remain higher inside the CBSFA than outside.
- The number of fish species was higher inside the CBSFA than outside the boundaries
- Both resource and non-resource fishes show higher abundance and biomass inside the CBSFA than outside the boundaries in 2019.
- Fishes in the largest size class are greater inside the CBSFA as compared to outside.

Coral Reef Assessment and Monitoring Program (DAR/CRAMP)

- While coral recovery since the 2015/16 statewide bleaching event is occurring at the shallow reef flat, the deeper station shows no signs of recovery and continues to decline.

Table 1. Summary of fish community composition factors by years surveyed and by division.

		Prior to CBSFA	Inside CBSFA				Prior to CBSFA	Makua Pu‘uhonua				Prior to CBSFA	Outside CBSFA			
		2013-2014	2016	2017	2018	2019	2013-2014	2016	2017	2018	2019	2013-2014	2016	2017	2018	2019
	Count of Transect	84	48	99	55	48	41	8	20	23	10	-	42	92	32	40
	Mean # of species	12.62	18.21	17.39	16.64	15.98	12.05	14.63	19.00	15.39	19.60	-	15.31	15.65	13.66	14.88
	Mean Abundance(IND/m²)	0.47	1.43	1.53	1.01	1.26	0.46	0.71	2.21	0.73	1.20	-	0.92	1.11	1.02	1.04
	Mean Biomass (g/m²)	63.03	111.66	164.94	135.84	196.89	36.76	28.39	215.47	70.53	78.36	-	89.06	129.98	118.28	115.14
	Diversity	1.93	1.91	1.96	2.08	1.91	1.82	1.99	1.84	1.91	2.01	-	1.86	1.91	1.86	1.84
	Eveness	0.80	0.69	0.72	0.76	0.70	0.73	0.75	0.64	0.71	0.68	-	0.69	0.72	0.74	0.72
	Top abundance species	*hīnālea lauwili*	*C. vanderbilti*	*C. vanderbilti*	*hīnālea lauwili*	*C. vanderbilti*	*hīnālea lauwili*	*hīnālea lauwili*	*‘opelu*	*hīnālea lauwili*	*hīnālea lauwili*	-	*C. vanderbilti*	*C. vanderbilti*	*hīnālea lauwili*	*C. vanderbilti*
	Top biomass species	*māikoiko*	*na‘ena‘e*	*nenue*	*māikoiko*	*akule*	*nenue*	*māi‘i‘i*	*‘opelu*	*na‘ena‘e*	*māi‘i‘i*	-	*na‘ena‘e*	*na‘ena‘e*	*ta‘ape*	*na‘ena‘e*
Trophic Abundance	Herbivores	45.48%	33.73%	41.86%	48.09%	44.82%	32.50%	30.01%	18.83%	32.78%	39.14%	-	33.18%	36.17%	37.70%	37.88%
	Invertebrate Feeders	47.95%	36.86%	29.47%	35.10%	32.86%	61.53%	56.80%	21.00%	54.65%	49.83%	-	37.97%	38.80%	43.98%	31.22%
	Piscivores	2.27%	1.70%	1.51%	2.52%	1.68%	2.45%	1.68%	0.58%	2.81%	0.93%	-	1.84%	1.54%	1.64%	2.95%
	Zooplanktivores	4.31%	27.71%	27.16%	14.29%	20.64%	3.51%	11.50%	59.59%	9.77%	10.10%	-	27.02%	23.49%	16.68%	27.94%
Trophic Biomass	Herbivores	77.29%	69.92%	76.48%	77.92%	59.23%	68.85%	59.35%	29.52%	60.27%	80.63%	-	61.68%	65.03%	54.44%	65.35%
	Invertebrate Feeders	17.28%	21.28%	17.55%	14.68%	19.23%	26.13%	35.77%	11.00%	23.87%	14.79%	-	32.92%	28.56%	41.11%	20.45%
	Piscivores	5.08%	5.81%	4.38%	4.98%	11.34%	4.12%	3.62%	2.04%	14.22%	1.40%	-	1.61%	3.36%	3.67%	9.46%
	Zooplanktivores	0.35%	2.99%	1.58%	2.42%	10.21%	0.91%	1.26%	57.44%	1.64%	3.18%	-	3.79%	3.05%	0.78%	4.74%
Endemism Abundance	Endemic	40.30%	28.68%	20.88%	28.21%	27.15%	53.07%	49.93%	18.71%	50.40%	48.24%	-	27.37%	26.60%	29.69%	28.04%
	Non-native	58.67%	70.53%	77.30%	70.61%	69.43%	46.80%	49.65%	80.77%	48.93%	51.30%	-	70.55%	72.22%	59.83%	68.89%
	Indigenous	1.03%	0.79%	1.82%	1.18%	3.42%	0.13%	0.42%	0.52%	0.67%	0.47%	-	2.08%	1.18%	10.48%	3.07%
Endemism Biomass	Endemic	11.53%	14.08%	9.17%	10.13%	8.91%	15.61%	21.72%	3.14%	11.65%	13.57%	-	14.33%	8.94%	7.82%	11.43%
	Non-native	85.08%	82.37%	85.96%	88.12%	86.50%	83.52%	75.62%	95.47%	85.31%	85.51%	-	73.73%	83.21%	74.50%	78.29%
	Indigenous	3.38%	3.54%	4.86%	1.74%	4.59%	0.87%	2.66%	1.39%	3.04%	0.92%	-	11.94%	7.85%	17.68%	10.28%
Size Classes Abundance	Small (<5cm)	21.08%	14.69%	20.37%	14.33%	22.77%	27.13%	10.38%	3.99%	24.25%	24.92%	-	15.05%	21.12%	12.53%	24.10%
	Medium (5-15)	41.13%	63.06%	50.16%	49.68%	39.57%	47.99%	77.00%	25.97%	51.69%	56.08%	-	57.83%	51.80%	48.50%	46.17%
	Large (>15)	37.79%	22.25%	29.47%	36.00%	37.67%	24.88%	12.62%	70.03%	24.06%	19.00%	-	27.12%	27.08%	38.97%	29.74%
Size Classes Biomass	Small (<5cm)	0.11%	0.25%	0.23%	0.11%	0.14%	0.16%	0.46%	0.04%	0.24%	0.28%	-	0.19%	0.20%	0.11%	0.21%
	Medium (5-15)	7.68%	21.00%	11.36%	11.63%	7.24%	12.50%	43.14%	6.76%	11.48%	28.31%	-	13.33%	9.74%	11.13%	10.71%
	Large (>15)	92.21%	78.74%	88.42%	88.27%	92.63%	87.34%	56.40%	93.20%	88.28%	71.41%	-	86.47%	90.07%	88.76%	89.08%

INTRODUCTION

<u>Purpose</u>

Historical Background

The Community-based Subsistence Fishing Area (CBSFA) of Hāʻena was designated in August 2015 to protect the marine resources for the sustainable support of the needs of the community through culturally based management that acknowledges the *mauka/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 Hāʻena community and the Hawaiʻi Department of Land and Natural Resources. This partnership will collectively monitor and evaluate for 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 management goals outlined in the HAR Chapter 13-60.8 are as follows:

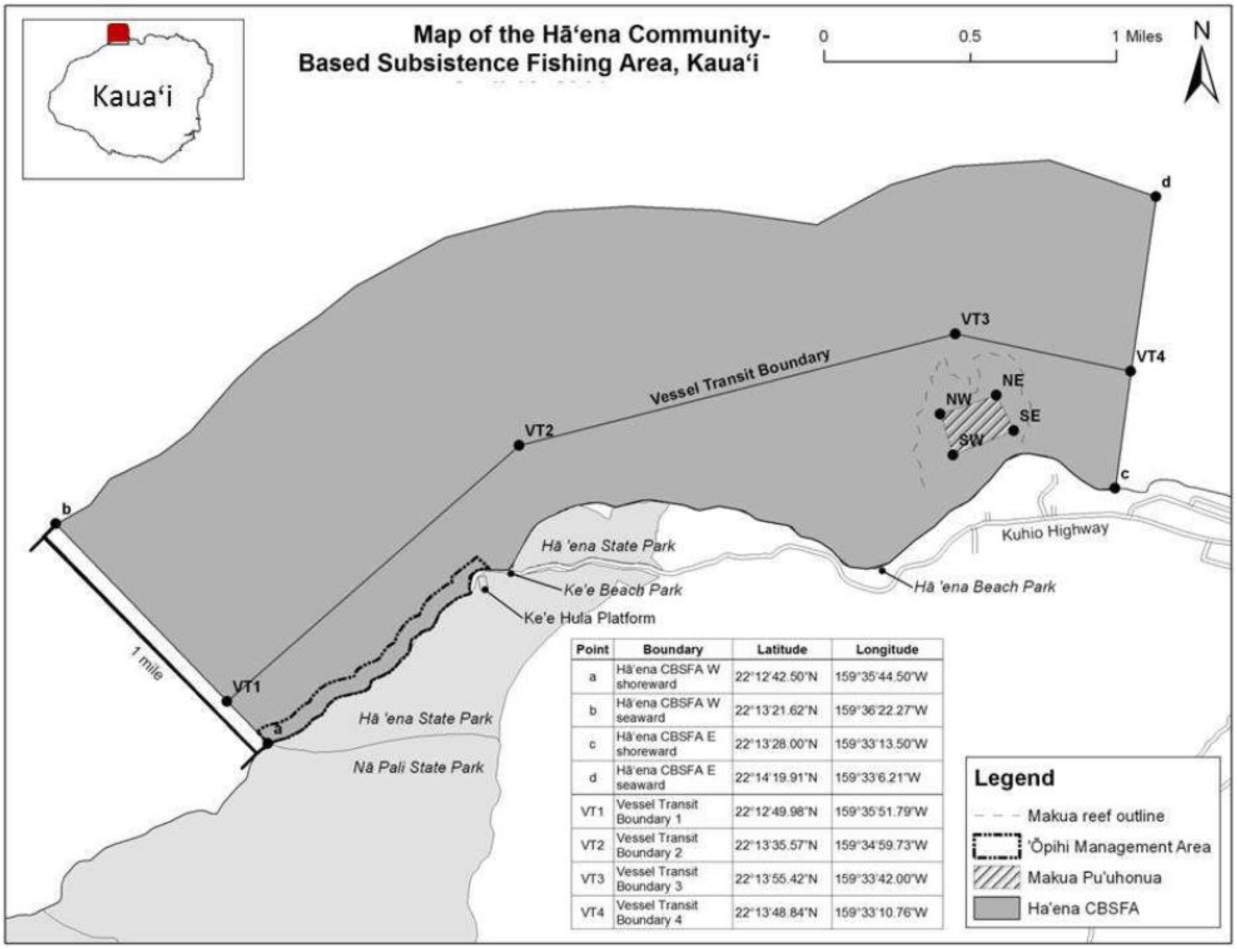
- Sustainably support the consumptive needs of the Hāʻena *ahupuaʻa* through culturally-rooted community-based management;
- Ensure the sustainability of nearshore ocean resources in the area through effective management practices;
- Preserve and protect nursery habitat for juvenile reef fishes;
- Recognize and protect customary and traditional native Hawaiian fishing practices that are exercised for subsistence, cultural, and religious purposes in the area and;
- 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*, *heʻe*, urchins, lobsters, *ʻōpihi* and other shellfish.
- Increase percent coral cover by reducing human impacts on coral reef resources.

Geographic Location

The Hāʻena CBSFA is located within the *ahupuaʻa* of Hāʻena in the larger *moku* of Haleleʻa on the north shore of the island of Kauaʻi. 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 Hāʻena Beach Park, Hāʻena State Park, and Keʻe Beach Park. The CBSFA begins at the boundary between Hāʻena State Park and Nā Pali State Park (22^{o}12’42.50”N, 159^{o}35’44.50”W) and terminates between Hāʻena and Wainiha (22^{o}13’28.00”N, 159^{o}36’22.27”W). Within the boundaries of the CBSFA lie three subzones, the *ʻōpihi* (*Cellana* genus) restoration area, the Makua Puʻuhonua, and the vessel transit boundary (Fig. 3).



Point	Boundary	Latitude	Longitude
a	Hā'ena CBSFA W shoreward	22°12'42.50"N	159°35'44.50"W
b	Hā'ena CBSFA W seaward	22°13'21.62"N	159°36'22.27"W
c	Hā'ena CBSFA E shoreward	22°13'28.00"N	159°33'13.50"W
d	Hā'ena CBSFA E seaward	22°14'19.91"N	159°33'6.21"W
VT1	Vessel Transit Boundary 1	22°12'49.98"N	159°35'51.79"W
VT2	Vessel Transit Boundary 2	22°13'35.57"N	159°34'59.73"W
VT3	Vessel Transit Boundary 3	22°13'55.42"N	159°33'42.00"W
VT4	Vessel Transit Boundary 4	22°13'48.84"N	159°33'10.76"W

Figure 3. Map of Hāʻena showing the CBSFA boundaries, vessel transit limits, and the *ōpihi* management borders.

Two perennial streams intersect the Hāʻena *ahupuaʻa* originating in the valleys of Mānoa and Limahuli. 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).

2019 Surveys

From March through August 2019, a joint collaboration between the University of Hawai‘i’s (UH) Coral Reef Assessment and Monitoring Program (CRAMP), the State of Hawai‘i’s Department of Land and Natural Resources (DLNR) Division of Aquatic Resources (DAR) O‘ahu, Maui, and Kaua‘i Monitoring, and the Department of Boating and Ocean Recreation, Kaua‘i (DOBOR) conducted rapid assessments at Hā‘ena, Kaua‘i (Fig. 4).

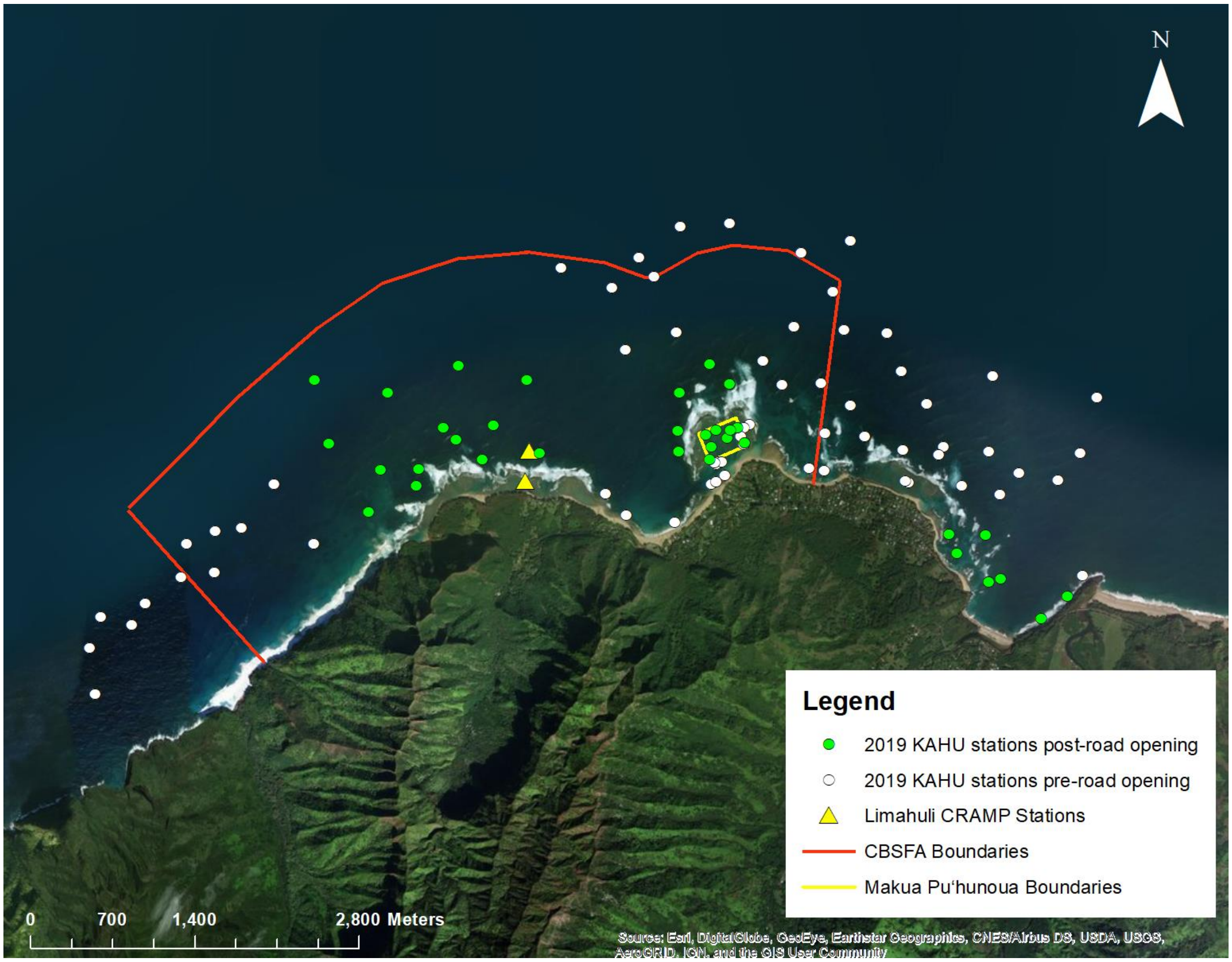


Figure 4. Map showing March-August survey locations (n=98) within and outside the CBSFA at Hā‘ena, Kaua‘i. Triangles depict locations of long-term monitoring stations. Surveys conducted during the Kuhio Highway road closure are depicted as white circles while post-road surveys are illustrated as green circles.

Surveys prior to the reopening of the Kuhio Highway that affected Hā‘ena, were conducted from 27 March 2019 (n=31) through 14 June 2019 (n=64) with support of DOBOR vessels. Post road opening surveys with the return of visitors to Hā‘ena began 24 June, 2019 and continued through 6 August, 2019 (n=34). All surveys were noninvasive and did not impact the biological communities (Fig. 5). Five teams consisting of a fish and a benthic surveyor completed 98 Kaua‘i Assessments of Habitat Utilization (KAHU) within the boundaries of the Community-based Subsistence Fishing Area (CBSFA), 64 surveys were conducted while the road was closed to the public in all sectors, and 34 surveys following reopening in all sectors except sites >7 m outside the CBSFA boundaries.

Figure 5. Diver conducting fish surveys within the Hāʻena CBSFA.

Surveyors quantified fish populations by recording count, species, and size to characterize fish abundance, biomass, feeding guild, diversity, size class, and endemism. Digital photos were analyzed in the lab using the annotation program CoralNet (Beijbom et al. 2012) to determine benthic composition and diversity of corals, algae, and macroinvertebrates (Fig. 6). Fish results for the Makua Puʻuhonua reserve were compared to baseline data collected by the UH Fisheries Ecology Research Lab in 2013/14 to determine any changes in biological populations since the establishment of the CBSFA. The 2016 KAHU data surveyed by CRAMP/DAR serves as the initial baseline for comparison with all subsequent annual survey data.

Additional separate surveys were conducted from 6 June, 2019 to 13 June, 2019 by Dr. Jade Delevaux of the University of Hawaiʻi at Mānoa and Dr. Kostantinos Stamoulis, previously of the UH Fisheries Ecology Research Lab, to examine any possible changes due to the road closure within and around the Makua Puʻuhonua. A total of 30 KAHUs (15 outside the Pu'uhonua and 15 inside), 10 timed swims (5 at Papaloa, 3 at Makua, and 2 at Keʻe), and 22 human use surveys (14 during weekdays and 8 during the weekend) were completed. This pre-road opening dataset is significant because it took place a year after the road was closed in the same area previously surveyed in 2018. Any effects of the road closure on fishes would therefore be maximized. In addition, flooding effects from the heavy rainfall that impacted the north shore of Kauaʻi in April of 2018 will diminish over time, allowing later surveys to attribute changes found directly to human use. These preliminary results are based on a comparison of data collected at Papaloa reef and the Makua Pu'uhonua in June of 2018 (two months following the flood and road closure). Data collected in June 2019, just prior to the road opening, were conducted at the same locations using identical methodology. Survey effort was focused on the shallow Papaloa reef which is known to experience high traffic of tourist snorkeling and wading. Surveys on the tip of Makua reef (outside the Pu'uhonua) were also conducted to encompass an area where a large number of snorkel boats moor and anchor.

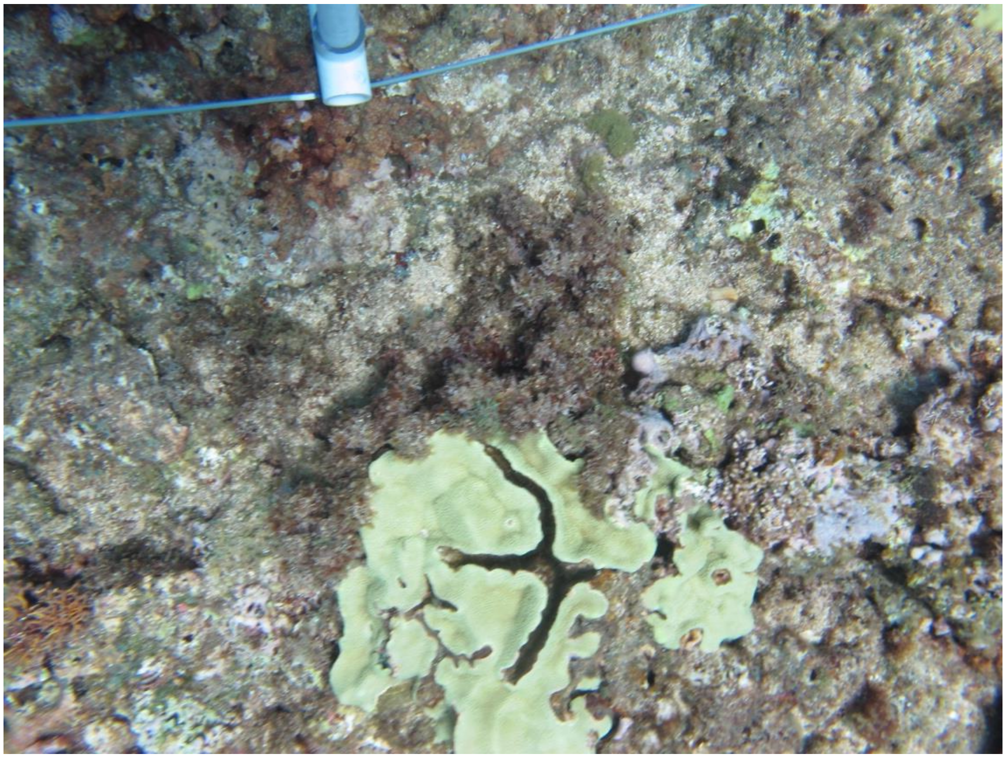


Figure 6. Example of digital photo used in analysis of habitat and organisms.

METHODOLOGY

Kauaʻi Assessments of Habitat Utilization (KAHU) Survey Assessment

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

Survey methodology is based on the UH Fisheries Ecology Research Laboratory's (FERL) Fish Habitat Utilization Surveys (FHUS) also used by Maui DAR. There are two members on a survey team consisting of a fish and benthic surveyor. The bearing is predetermined by a random number generator (0°, 90°, 180°, 270°). If the bearing does not allow divers to stay on a hard-bottom substrate, they rotate clockwise to the next appropriate bearing until they are able to stay on the hard bottom for the entire transect, providing the depth remains fairly consistent. The fish surveyor spools the 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 is required per transect. The benthic surveyor adjusts the white balance setting on the digital camera and completes the metadata on the survey identification datasheet. To avoid interference or altered fish behavior, the benthic diver waits until the fish surveyor is 5 m along the line before taking four digital pans of the seascape, with an approximate 60 (benthic habitat)/40 (water column) split, in the cardinal directions (N, W, E, S) to get an overview of the station and the habitat. A photo of the station number is taken from the slate. Benthic photos are then taken on the shoreward side of the transect at every meter along the 25 m line keeping the monopod perpendicular to the bottom to avoid parallax. The benthic diver counts all urchin species in a 1 m wide belt, on the same side photos are taken. Urchins may be counted concurrently with the benthic photos as the benthic diver follows the fish diver or may be counted on the return back to the start position. Once the fish surveyor reaches the end of the line, replicate sediment samples may be collected at two locations in close proximity to the line. The fish diver reels in the line and the survey is complete. All survey methods are non-invasive and do not disturb any of the biota.

Temperature Loggers

Pro v2 Onset Temperature loggers were placed at the Limahuli Division of Aquatic Resources/Coral Reef Assessment and Monitoring Program (DAR/CRAMP) site at 1 m and 10 m depth at the on a 3/16” stainless steel pin marking the start of the transect. A steel cable tie secures the temperature gauge set to record continuously every 30 minutes (Fig. 7). GPS coordinates and photo triangulations above and underwater are documented for all DAR/CRAMP locations statewide. Temperature loggers are retrieved, downloaded, and replaced annually by DAR Kaua‘i to relate to biological surveys and compare to statewide monitoring data.

Figure 7. Onset v2 water temperature data logger placed at two locations at the DAR/CRAMP Limahuli site at 1 m and 10 m depths.

Statistical Analyses

All statistics are run using R (3.6.2) and figures generated using the 'ggplot2' package (R Core team 2017, Wickham 2009).

Response variables: difference in means
1. Overall abundance, biomass, diversity, evenness, and number of species
2. Size classes (A=<5 cm, B=5-15 cm, C= >15cm): abundance
3. Trophic levels (H, INV, Z, P): abundance, biomass
4. Endemism (E, I, X): abundance, biomass
5. Food/non-food fish (Y, N): abundance, biomass

Predictors:
Year: 2016, 2017, 2018, 2019
Division: Puʻuhonua (PU), Hāʻena Inside (HI), and Hāʻena Outside (HO)

Total number of transects:
2016: HI =47, HO=43, PU=8
2017: HI=85, HO=82, PU=20
2018: HI=55, HO=32, PU=23
2019: HI=48, HO=40, PU=10

Overall Abundance and Biomass of Fishes, Endemism, Diversity, and Evenness:

Abundance

Transformation of non-Gaussian distributed data is not recommended for ecological count datasets (O'Hara & Kotze 2010), thus Generalized Linear Models (GLMs) were used for all abundance analyses. For overall abundance, a negative binomial distribution was applied as it established the most appropriate fit with respect to goodness-of-fit parameters and dispersion; estimated marginal means drawn from the GLM were used for comparison of abundance among divisions and years, and of interactions between these variables.

Biomass

Overall biomass data were transformed by raising original data to the fourth-root (1/4 power) in order to better resemble a Gaussian distribution. Variance was homogenous between years and a one-way ANOVA and a Tukey post-hoc test was conducted for analyses by year following transformation of data. Parametric tests were also used for division-specific analyses among years. With respect to division, variance was not homogenous thus non-parametric tests were performed (Kruskal-Wallis Rank Sum Test). This was followed by post-hoc Dunn-test for multiple pairwise comparisons.

Species Count

Overall species count (number of species observed) data were transformed by taking the square root of the original data in order to better resemble a Gaussian distribution. Variance was not homogenous among years thus non-parametric tests were selected. Non-parametric tests were also used for division-specific analyses among years. Variance was homogenous among divisions thus a one-way ANOVA test was used.

Food/Non-Food Fishes

Abundance and Biomass: Kruskal-Wallis rank sum tests were performed while transformed response values did not meet the assumptions for using parametric approaches. Negative values produced by transformations also prevented use of parametric approaches. Non-parametric tests were followed by Dunn's post-hoc multiple pair-wise comparisons if statistically significant.

Size Classes

Size class data were not normally distributed so non-parametric Kruskal-Wallace tests (and subsequent Dunn tests) were used to assess differences in fish size classes (A=<5 cm, B=5-15 cm, C= >15cm).

Trophic Levels

Abundance and biomass data were not normally distributed so non-parametric Kruskal-Wallace tests (and subsequent Dunn tests) were used to assess differences in fish trophic levels.

Endemism Status and Food/Non-Food Fishes

Abundance data were not normally distributed so non-parametric Kruskal-Wallace tests (and subsequent Dunn tests) were used to assess differences in fish abundance and biomass for endemism status and food/non-food fishes.

Diversity and Evenness

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^{th} species. Shannon Weiner diversity index (Shannon and Weaver 1963) considers both the number of species and the distribution of individuals among species. Buzas and Gibson's evenness (Harper 1999) was measured using E = eH/S to measure the evenness of fishes.

Overall diversity data did not require transformation. Variance was homogenous between divisions thus a one-way ANOVA and a Tukey post-hoc test was used. With respect to year, variance was not homogenous thus non-parametric tests were performed. Non-parametric tests were also used for division-specific analyses among years.

Overall evenness data were transformed by squaring original data in order to better resemble a Gaussian distribution. Variance was homogenous among years and a one-way ANOVA test applied. Parametric tests were also used for division-specific analyses among years. Variance was not homogenous among divisions thus non-parametric tests were employed.

Hāʻena Road Closure Comparisons

Road Closure Status

In April of 2018, heavy flooding and landslides occurred in the Hāʻena region of Kauaʻi with resultant damage and closure of several sections of Kuhio Highway. This extreme weather event precluded outside visitation to the Hāʻena region, including Hāʻena State Park, until the reopening of Kuhio Highway on 17 June, 2019. To examine any possible changes in fish distribution and populations due to a shift in human pressure, 64 transects were conducted during the road closure, and 34 transects were completed after the road re-opening. Data were grouped into two categories: transects sampled prior to road opening (PRE) and transects sampled following road opening (POST) (after 17 June, 2019).

Abundance and Biomass

Due to a non-Gaussian distribution fish abundance were conducted with the non-parametric Mann-Whitney U Tests to compare grouped abundances before and after road opening. Abundance data were not altered as log-transformation is not recommended for count data (O'hara and Kotze 2010). Biomass data was transformed to the fifth root and normality conformed using a Shapiro-Wilks test of normality. For biomass and diversity data, a homogeneity of variance was confirmed using a Levene's Test, where a corresponding two-sample t-test was used to investigate differences in mean biomass before and after opening. A two-way ANOVA and Tukey post-hoc test were used to examine differences in mean biomass between divisions (Inside, Outside, Pu'uhonua).

Days After Opening (DAO)

Data before road opening were excluded from these analyses in order to investigate trends in population dynamics after park re-opening over time.

Abundance and biomass data demonstrated non-Gaussian distributions. Abundance data was not altered as log-transformation is not recommended for count data. Data was found to best fit a negative binomial GLM, which was then used to compare fish abundance and DAO.

Biomass data was log-transformed to meet the assumption of normality, which was confirmed by a Shapiro-Wilks test. Linear regression analysis was then used to compare fish biomass and DAO. Diversity data fit a Gaussian distribution; thus, linear regression analysis was used to compared with DAO.

Depth Comparisons

A subset of fish abundance and biomass were used to categorize transects into depth groups of <3 m, <5 m, and all depths. The depths were stratified to mimic community anecdotal reports of fish population changes. These depth subsets were only used for pre and post road opening comparisons. T-tests were used to assess differences in means between road-status groups for all depth groups in abundance data. Homogeneity of variance was confirmed using Levene's Tests. For depth groups of <3 m and <5 m, biomass data were not normally distributed and were log-transformed to meet the assumption of normality. All transformed fish biomass data had normality confirmed using Shapiro-Wilks tests and homogeneity of variance confirmed using Levene's Tests.

Herbivore Comparisons

A subset of herbivore abundance and biomass were used in transect depth groups of <3 m, <5 m, and all depths. Herbivore abundance data for the all depths group used a Mann-Whitney U Test to fit normality assumptions to compare distributions before and after road opening. Herbivore biomass for the all depths group was transformed to the third power. Shapiro-Wilks and

Levene's tests were used to confirm normality and homogeneity of variance. Herbivore abundance and biomass at the <3 m and <5 m depth group were square-root transformed to the third power.

Precipitation

Rainfall data from 2019 were obtained from the Wainiha (WNHHI41) rain gauge via the National Weather Service website (https://www.weather.gov/hfo/rra_graphs). Rainfall from the two days prior to the date of transect were aggregated as a proxy for freshwater input on the day of sampling. Rainfall during the study period fluctuated between little to no rain (<1.8 cm) and high rainfall (>135 cm), prompting binning into two categories: little to no rain and high rain. Difference in abundance of fishes between these two rain categories were assessed using a Wilcoxon Rank Sum Test, as fish abundance data did not fit a Gaussian distribution.

Benthic data

The proportion of coral cover was transformed by applying arcsine to square-root values. A general linear model was used as values were normally distributed with equal variance (Leven's test, p=0.21). Non-metric Multi-Dimensional Scaling was used for benthos biological data to visualize and interpret the dissimilarity in multiple benthic communities. Benthic data were square-root transformed, and Bray-Curtis index was calculated for constructing distance matrices. Permutational multivariate analysis of variance (PerMANOVA, Anderson 2001) was performed to find how different sampling years and divisions may explain a variation in composition of benthic organisms. Post-hoc analyses included the analysis of similarity (ANOSIM, Clarke 1993) and similarity percentage analysis (SIMPER) investigating which pair-wise comparisons were likely influencing the overall effect of year and sector on a dissimilarity of species composition.

Urchins and Sea Cucumbers

The generalized linear model (GLM) was used to analyze the urchin abundance. Results of the GLM with a negative binomial distribution were used to analyze the effect of year and sector. No interaction was significant thus the additive model was selected for interpretation. A GLM was also used to analyze sea cucumber abundance. A zero-inflated GLM with a negative binomial distribution was selected to analyze effects of year and sector on variation of the abundance of sea cucumbers while accounting for the presence of zeros. In examining any effect of the road closure on urchins, the model response was total number of urchins per transect and predictors were 1) Transects conducted during closure and following reopening of the access road (pre and post), 2) Division (HI, HO, PU), and 3) Depth (deep (>7m) and shallow (<7m)). A non-parametric Kruskal-Wallis test was used to determine whether road closure impacted urchins overall or by division. A generalized linear model (GLM) was explored but did not meet the model assumptions. To determine differences by depth, a GLM with a negative binomial distribution were used to analyze the effect of road re-opening, depth, and the interaction. This GLM model was repeated without one extreme outlier observation (Transect 15, Hāʻena Inside Shallow, post re-opening of the road).

Coral Coverage

Data did not fit a Gaussian distribution and were unable to be transformed using a logit approach. Arcsine square-root transformation was not employed as it is not recommended for proportion data. Thus, non-parametric Kruskal-Wallace and subsequent Dunn tests were used to assess differences in total coral coverage between groups.

RESULTS

Overall Results

By examining the differences in resources in areas with different management regimes, the evaluation of the efficacy of management efforts can be determined and adaptive procedures implemented. Comparisons were made of three separate areas within the larger Hāʻena region because different regulations apply to the Hāʻena CBSFA management protected area, the smaller Makua Puʻuhonua 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 nearshore waters apply. A total of 98 transect surveys were conducted in the spring and summer of 2019.

Two measures of abundance: numerical (number of fishes) and biomass (weight of fishes) are important population factors that address different aspects of fish community structure. A transect may have very different numbers of fishes (a large school of small fish or one very large fish) and have equal biomass. By distinguishing between these measures, information about the population is retained. In reporting statistical significance, a significance level of 0.10 was used. An alpha of 0.10 assumes a 10% risk of concluding that a difference exists when there is no actual difference. When p-values are below 0.05 or 0.01 the risk is reduced to 5% and 1% and the probability is stronger there is an actual difference. A significance level of 0.10 was selected as a result of the high variability in the field data due to spatial and temporal differences in fish communities.

Fish abundance in 2017 was highest among years and within the majority of sectors. Overall fish abundance was greater in 2017 than in 2016 and 2018 ($p \leq 0.001$). Within divisions, overall abundance was greatest inside the Hāʻena CBSFA boundaries as compared to outside ($p=0.005$). No other significant differences were found between sectors. The GLM for overall abundance with respect to division and year was found to be interactive ($p=0.002$), suggesting some covariance of predictor variables. Abundance in 2017 was greater than in 2018 for Hāʻena inside ($p=0.026$). Abundance inside the Makua Puʻuhonua was significantly greater in 2017 than 2016 and 2018 ($p=0.011$ and $p \leq 0.001$, respectively), and was greater than outside the CBSFA boundaries ($p=0.007$) (Fig. 8). Although mean fish abundance increased in 2019, no significant differences were found since the previous year.

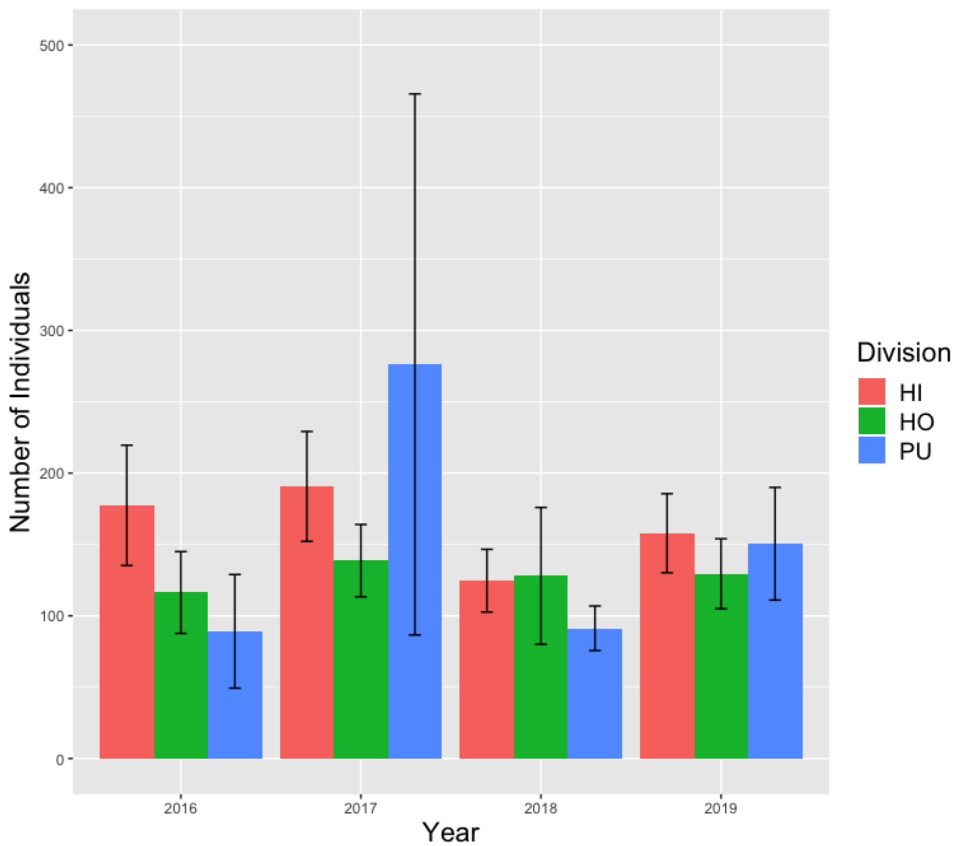


Figure 8. Differences in overall abundance (number/transect) between years and among sectors: Within CBSFA (HI), Outside CBSFA (HO), and within the Makua Pu'uhonua (PU). Error bars represent the +/- 95% confidence intervals around the mean number of individuals.

There was a statistically significant difference in overall biomass among years (p= 0.032). Biomass was higher in 2019 than in 2016 (p=0.034) (Fig. 9). There was also a significant difference in overall biomass among divisions (p=0.023), showing a statistically greater biomass inside the CBSFA as compared to outside (p=0.027). Biomass inside the Makua Pu'uhonua in 2017 was significantly greater than in 2016 and 2018 (p=0.005 and p=0.047, respectively), with no significant differences found among years for the sectors inside or outside the CBSFA boundaries. Overall species count among years was not statistically significant in the survey period from 2016-2019. Among divisions, mean number of species were significantly different (p= 0.003), with a higher count both inside the CBSFA and the Makua Pu'uhonua as compared to outside the CBSFA (p=0.005 and p=0.038, respectively). No statistical difference was found in species count between inside the CBSFA and the Pu'uhonua. No significant differences were detected among years within each division.

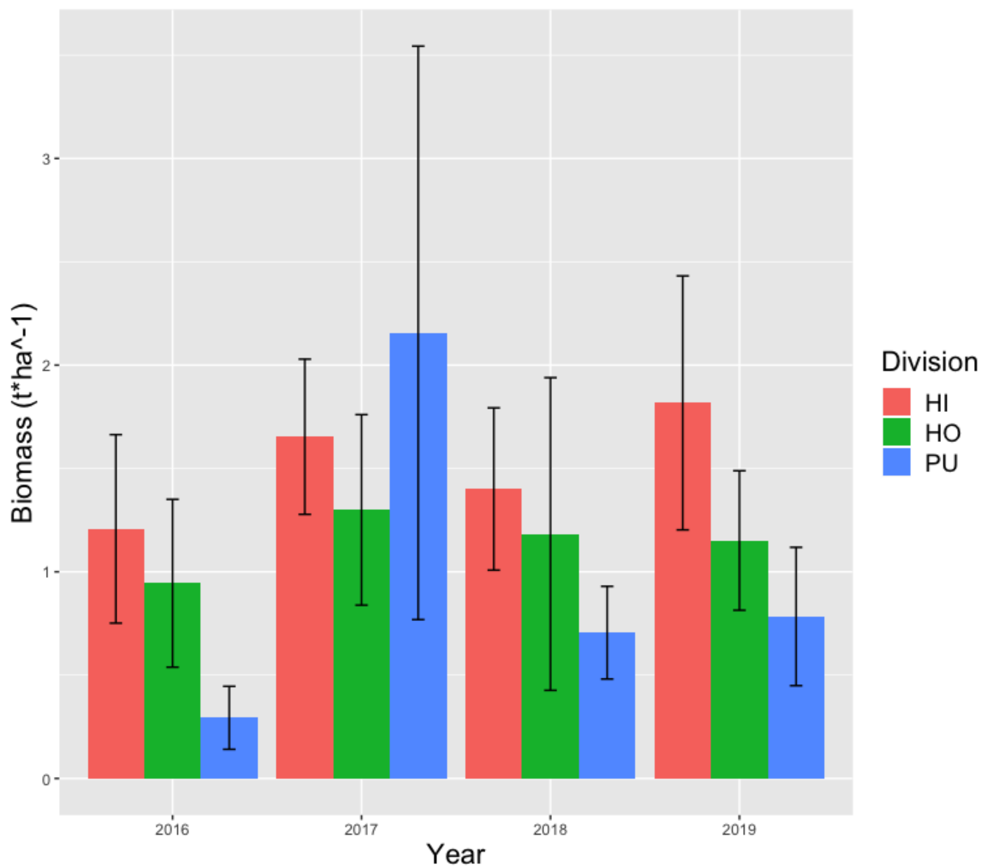


Figure 9. Differences in overall biomass (tons/hectare) between years and among sectors: Within CBSFA (HI), Outside CBSFA (HO), and within the Makua Puʻuhonua (PU). Error bars represent the +/- 95% confidence intervals around the mean biomass.

<u>Food Fish Species</u>

Hāʻena community interviews conducted in 2003, 2007, and 2008 identified important food fish species. Traditional families from Hāʻena 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 2. 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 2. 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	*Selar crumenophthalmus*	*akule*	Big-Eyed Scad	Carangidae	Poor
moi	*Polydactylus sexfilis*	*moi*	Threadfin	Polynemidae	Poor
ama'ama	*Mugil cephalus*	*‘ama‘ama*	Striped Mullet	Mugilidae	Poor
kala	*Naso unicornis*	*kala*	Bluespine Unicornfish	Acanthuridae	Poor
nenue, Enenue	*Kyphosus species*	*nenue*	Chub	Kyphosidae	Excellent
	Kyphosus bigibbus	*nenue*	Brown Chub	Kyphosidae	Excellent
	Kyphosus cinerascens	*nenue*	Highfin Chub	Kyphosidae	Excellent
	Kyphosus vaigiensis	*nenue*	Lowfin Chub	Kyphosidae	Excellent
manini	*Acanthurus triostegus*	*manini*	Convict Tang	Acanthuridae	Good
oama	*Mulloidichthys flavolineatus*	*weke*	Yellowstripe Goatfish	Mullidae	Good
	Mulloidichthys vanicolensis	*weke ‘ula*	Yellowfin Goatfish	Mullidae	Good
āholehole	*Kuhlia sandvicensis*	*āholehole*	Hawaiian Flagtail	Kuhliidae	Fair
‘āweoweo	*Priacanthus meeki*	*‘āweoweo*	Hawaiian Bigeye	Priacanthidae	Fair
kahala	*Seriola dumerili*	*kahala*	Amberjack	Carangidae	Fair
ulua	*Carangoides ferdau*	*ulua*	Barred Jack	Carangidae	Fair
	Carangoides orthogrammus	*ulua*	Island Jack	Carangidae	Fair
	Caranx ignobilis	*ulua aukea*	Giant Trevally	Carangidae	Fair
	Caranx melampygus	*‘omilu*	Bluefin Trevally	Carangidae	Poor
	Caranx sexfasciatus	*ulua*	Bigeye Jack	Carangidae	Fair
	Gnathanodon speciosus	*ulua pa‘opa‘o*	Golden Trevally	Carangidae	Fair
	Pseudocaranx dentex	*ulua*	Thicklipped Jack	Carangidae	Fair
uhu	*Chlorurus spilurus*	*uhu*	Bullethead Parrotfish	Scaridae	Good
	Scarus psittacus	*uhu*	Palenose Parrotfish	Scaridae	Good
	Chlorurus perspicillatus	*uhu*	Spectacled Parrotfish	Scaridae	Good
	Calotomus carolinus	*uhu*	Star-eye Parrotfish	Scaridae	Good
	Calotomus zonarchus	*uhu*	Yellowbar Parrotfish	Scaridae	Good
	Scarus dubius	*lauia*	Regal Parrotfish	Scaridae	Good
	Scarus rubroviolaceus	*uhu*	Redlip parrotfish	Scaridae	Good
kūmū	*Parupeneus porphyreus*	*kūmū*	Whitesaddle Goatfish	Mullidae	
kawakawa	*Euthynnus affinis*	*kawakawa*	Wavy-back Tuna	Scombridae	Fair
palani	*Acanthurus dussumieri*	*palani*	Eye-stripe Surgeonfish	Acanthuridae	Good
maiko	*Acanthurus nigroris*	*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. For example, the Hawaiian name *uhu* refers to all parrotfishes in the family Scaridae, of which seven species are listed (Table 2). Of these 32 fish species listed as important cultural and subsistence resources, 15 species were found within the CBSFA boundaries, 9 within Makua Pu‘uhonua, and 12 outside the boundaries in 2019. This is a decline in all three sites from 2018 where 17 species were recorded inside boundaries, 15 within the Pu‘uhonua, and 14 outside. A total of 18 food fish species were found during the 2018 surveys compared to 17 species of food fishes in 2019. The genus *Kyphosus* (*nenue*) perceived to be in "excellent condition" was found in all sectors, with the highest frequency of occurrence inside the Makua Pu‘uhonua (70.0% of transects, Table 3). While frequency of *Kyphosus* species increased within the CBSFA from 2016 to 2019 (9% to 31%), biomass decreased from a mean of

22 to 8 g/m² between 2017 to 2018 due to a lower abundance of *Kyphosus* occurring in 2018, and increased slightly in 2019 to 11 g/m^2. The larger schools were more apparent in 2017 and account for the lower frequency of occurrence. When many large schools of fish are found on only a few transects the frequency at which they are seen declines. *Manini* and *kala* also had high frequencies of occurrence (53-80% and 25-90%, respectively, Table 3), and were more frequent on transects within the CBSFA and Puʻuhonua as compared to outside the CBSFA. *Manini* were rated as good which agrees with our surveys. While other species frequencies were fairly comparable to 2018 frequencies, *maiko (Acanthurus nigroris*, Bluelined Surgeonfish) showed a notable decrease in 2019 inside the CBSFA (16.4 to 8.3%) and the Makua Puʻuhonua (8.7 to 0%).

Across all years, species perceived to be in "good" condition were fairly prevalent as expected. The only two species not in concert with perceived "poor" conditions were *Caranx melampygus,* the Bluefin trevally *(ʻomilu),* and *Naso unicornis,* the Bluespine unicornfish (*kala).* This trend is similar to the previous year's data, showing high frequency on transects. *N. unicornis* was similarly abundant inside the CBSFA and Puʻuhonua (mean frequency of 69%), but outside the CBSFA showed a lower frequency of 25% (Table 3).

Table 3. The frequency of occurrence in 2019 (% of transects on which species were recorded) and perceived condition of food fishes found on transects within the Hāʻena CBSFA, outside the CBSFA boundaries, and within the Makua Puʻuhonua reserve.

			% Frequency		
Taxonomic Name	**Hawaiian Name**	**Perceived Condition**	**CBSFA (%)**	**Outside CBSFA (%)**	**Makua Puʻuhonua (%)**
Naso unicornis	*kala*	Poor	47.9	25.0	90.0
Kyphosus species	*nenue, Enenue*	Excellent	31.3	30.0	70.0
Acanthurus triostegus	*manini*	Good	56.3	52.5	80.0
Mulloidichthys flavolineatus	*oama*	Good	14.6	0.0	30.0
Mulloidichthys vanicolensis		Good	2.1	2.5	0.0
Seriola dumerili	*kahala*	Fair	2.1	0.0	0.0
Caranx ignobilis	*ulua*	Fair	2.1	5.0	0.0
Caranx melampygus		Poor	27.1	25.0	10.0
Chlorurus spilurus	*uhu*	Good	14.6	17.5	0.0
Scarus psittacus		Good	0.0	5.0	20.0
Chlorurus perspicillatus		Good	0.0	2.5	0.0
Calotomus carolinus		Good	4.2	0.0	20.0
Scarus dubius		Good	2.1	0.0	0.0
Scarus rubroviolaceus		Good	39.6	40.0	70.0
Parupeneus porphyreus	*kūmū*		2.1	0.0	20.0
Acanthurus dussumieri	*palani*	Good	22.9	17.5	0.0
Acanthurus nigroris	*maiko*	Good	8.3	7.5	0.0

Differences in Resource Fishes Among Years

Mean biomass of food fishes increased from 2018 to 2019 inside and outside the CBSFA, but slightly decreased inside the Makua Puʻuhonua (Fig. 10). Mean biomass of food fishes consistently remains higher inside as compared to outside the CBSFA, suggesting that the regulations within the CBSFA have resulted in an increased fitness of resource fishes. Mean biomass for food fishes and non-food fishes show a similar pattern of greater biomass inside the CBSFA as compared to outside (Fig. 11). Significant differences in the biomass of food fishes was observed among years. Biomass in 2019 was greater than biomass in 2016 (p=0.0017). Biomass inside the CBSFA was greater than biomass outside (p=0.0043), with no other differences between divisions. There were no differences in biomass between years for stations outside the boundaries.

Abundance was statistically greater in 2019 than in 2016 (p=0.0181), and abundance in 2019, although not statistically significant, was greater than abundance in 2017 (p=0.0845). There was a significant difference among divisions for the abundance of food fishes with greater abundance inside than outside the CBSFA (p=0.0002) (Fig. 12). There were no differences in abundance between years for both outside or inside the CBSFA. Within the Makua Puʻuhonua, abundance in 2019 was significantly greater than abundance in 2016 (p=0.0511) (Fig. 13). As found with biomass, abundance levels were greater inside the CBSFA as compared to outside the boundaries.

Fish diversity is comprised of species richness (number of species in a defined area) and species abundance (relative number of species) (Gorman and Karr 1978). Diversity of resource fishes inside the Makua Puʻuhonua was greater than outside the CBSFA ($p \leq 0.001$). Diversity inside the CBSFA was also greater than outside ($p \leq 0.001$). Puʻuhonua diversity in 2019 was greater than diversity in 2016 (p=0.0311), and no significant differences were found inside or outside the CBSFA among years. Evenness is a component of diversity, where diversity is divided by the total number of species present, for an expression of the abundance of different species (Brower and Zar 1984). Evenness in 2018 was greater than evenness in 2016 and 2017 (p=0.0865). Evenness inside the Makua Puʻuhonua was greater than inside or outside the CBSFA (p=0.0234 and $p \leq 0.001$, respectively), and evenness inside was greater than outside (p=0.030). There were no significant differences in evenness between years for any divisions.

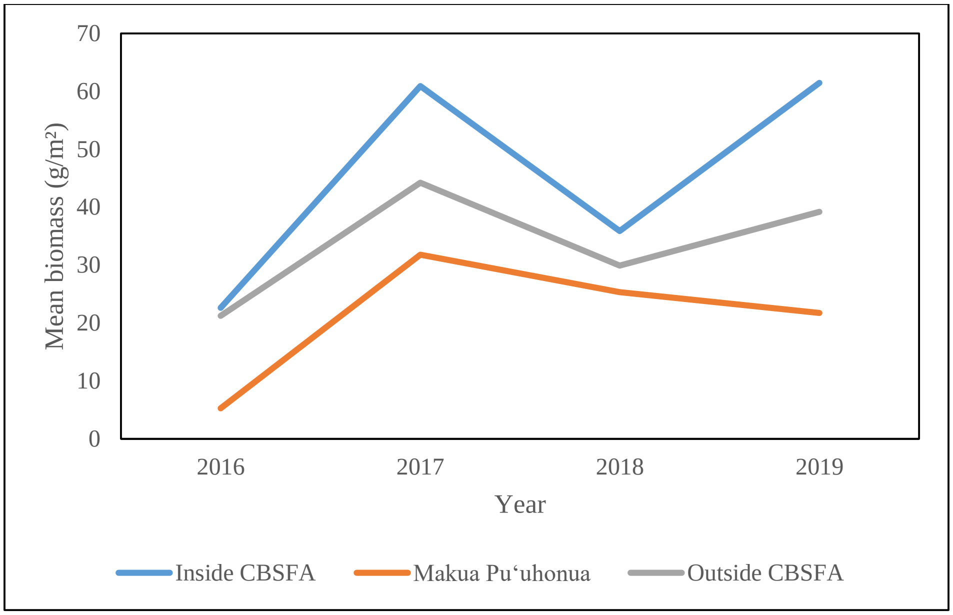


Figure 10. Mean biomass (g/m²) of food fishes within Hā‘ena sectors from 2016-2019.

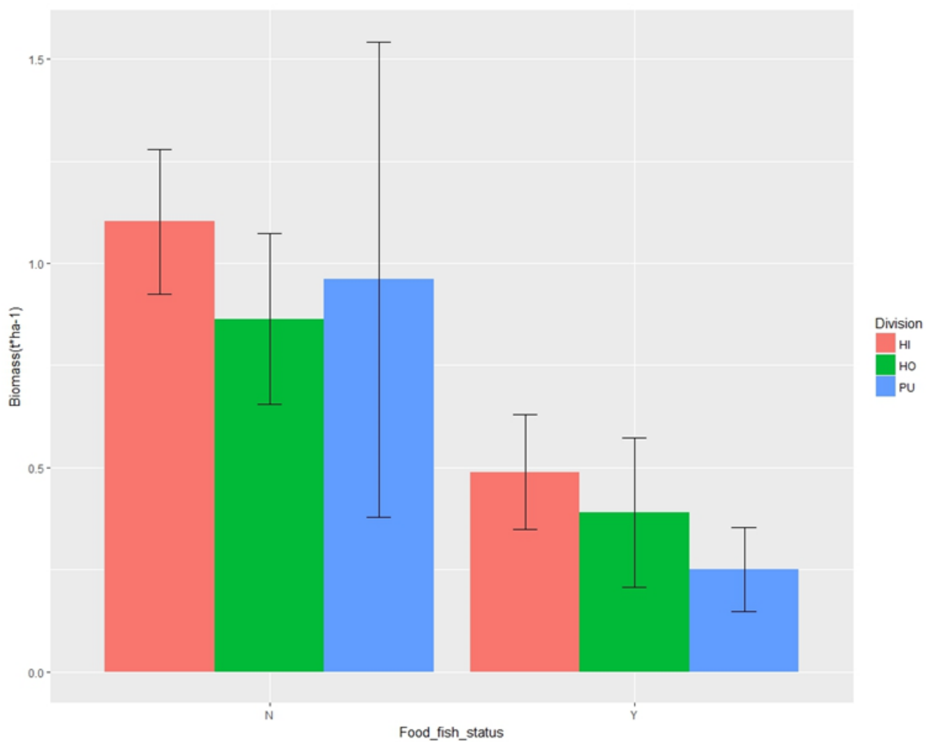


Figure 11. Variation in the mean biomass of food fishes (Y) and non-food fishes (N) Within (HI), Outside (HO) and within the Makua Pu‘uhonua (PU) pooled by year. Error bars represent -/+95% confidence intervals around the average biomass of food fishes.

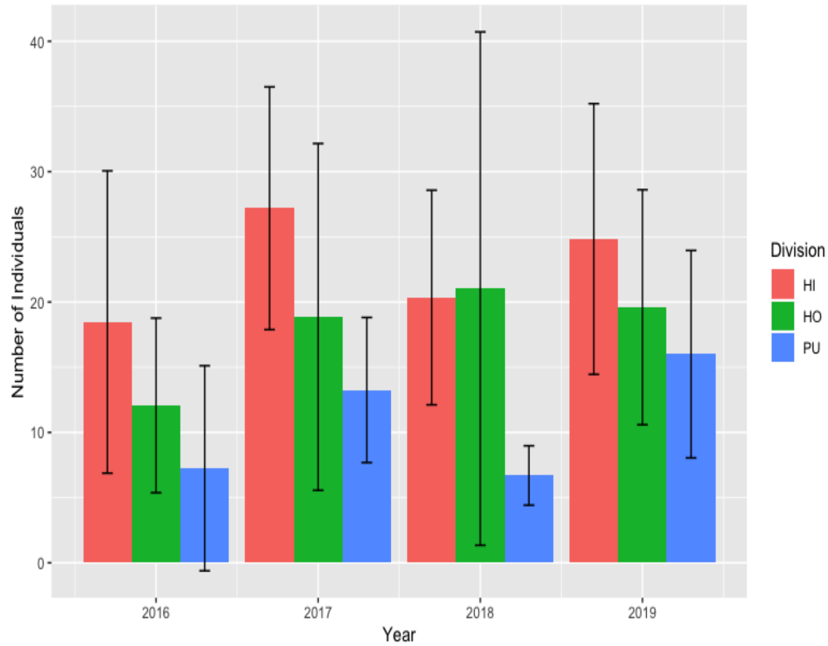


Figure 12. Variation in the mean number of food fishes (number/transect) Within (HI) and Outside (HO) the CBSFA, and within the Makua Pu'uhonua (PU) pooled by year. Error bars represent -/+95% confidence intervals around the average number of food fishes.

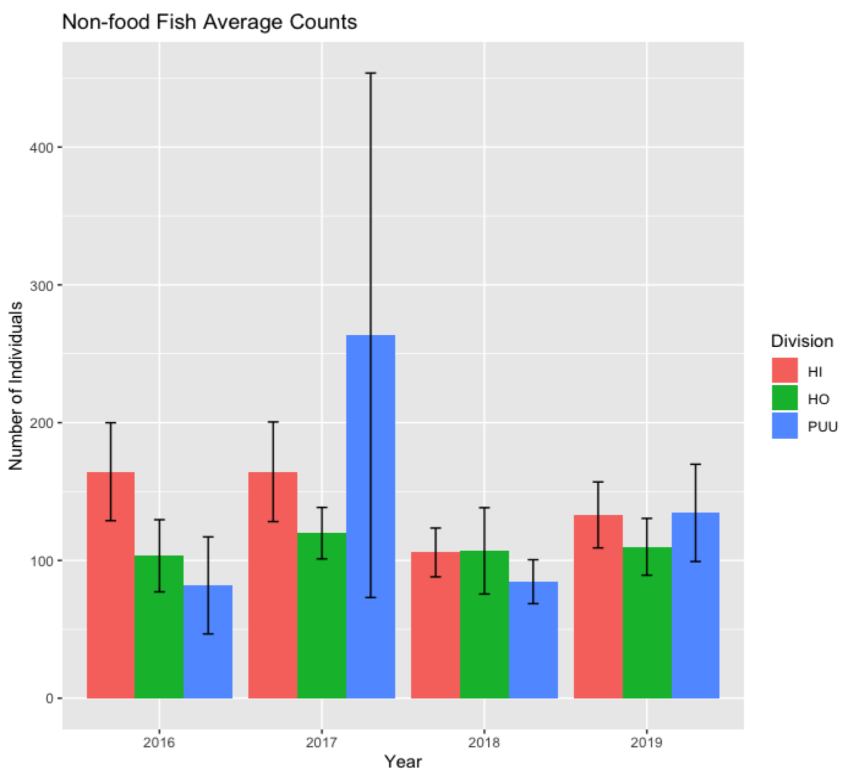


Figure 13. Variation in the mean number of non-food fishes (number/transect) Within (HI) and Outside (HO) the CBSFA, and within the Makua Pu'uhonua (PU) pooled by year. Error bars represent -/+95% confidence intervals around the average number of fishes.

C. melampygus had a fairly high frequency of occurrence in 2019 as compared to other species of Jacks, which were either completely or nearly absent outside the CBSFA and inside the Makua Puʻuhonua in 2016 (Fig. 14a). Other jack species are typically found in different habitats and depths, and have different feeding preferences than *C. melampygus*, an omnivore more commonly associated with reef habitat. The high number of *C. melampygus* in the CBSFA may be related to the large numbers of small prey in this nursery habitat. *C. melampygus* were found in much higher frequencies inside the Makua Puʻuhonua in 2019 (10%) as compared to 2016 (0%). Frequency of occurrence outside the CBSFA also increased from 2016 to 2019 (7% to 25%), while percent frequency of *ʻomilu* inside the CBSFA boundaries remained relatively consistent (30% to 27%) (Fig. 14b).

A possible explanation for the increase of *ʻomilu* outside of Hāʻena may be due to the "spillover" effect. Stamoulis and Friedlander (2013) have determined a significant spillover effect at a north shore Oʻahu MPA into adjacent areas. This increase of resource fishes outside the management protection boundaries did not apply to non-targeted fishes in the baseline surveys conducted in 2013/14 (Friedlander et al. 2015). In addition to *C. melampygus*, an increase in frequencies within the Makua Puʻuhonua for *Scarus psittacus* (the Palenose Parrotfish) was reported from 2016 to 2019 (0% to 20%).

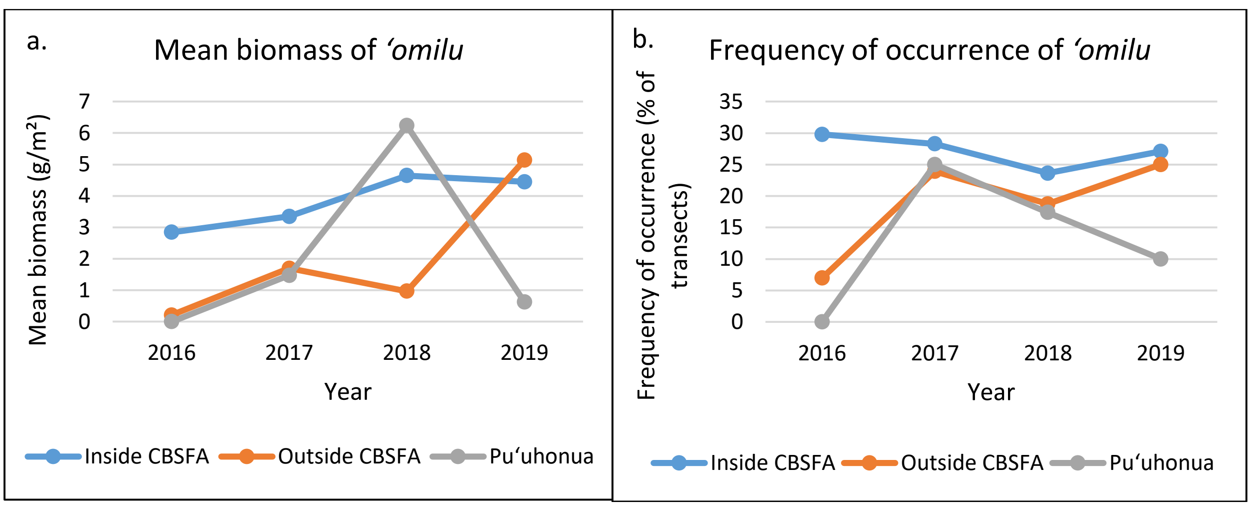


Figure 14. a) *Caranx melampygus* (*ʻomilu*) mean biomass (g/m^2) and b) frequency of occurrence (%) from 2016 through 2019 in all Hāʻena sectors.

Four species of food fishes are included in the top ten species of fishes with the highest percent biomass inside the CBSFA. *N. unicornis* has the highest mean biomass inside the CBSFA with a mean biomass of 13.4 g/m^2, followed by *A. triostegus* ranked 6^{th} (11.7 g/m^2), *Kyphosus* sp. ranked 7^{th} (10.7 g/m^2), and A*canthurus dussumieri* ranked 8^{th} (8.9 g/m^2) (Table 4). *Kala* has remained in the top ten inside the CBSFA from 2017-2019 however mean biomass did drop for the species from 9.9 g/m^2 in 2017 to 4.5 g/m^2 in 2018, before increasing again in 2019 to 13.4 g/m^2.

Inside the Makua Puʻuhonua, four food fish species (*Kyphosus* sp., *N. unicornis*, *Scarus rubroviolaceus*, and *A. triostegus)* appear in the top ten species with highest percent biomass.

Four food fish species were also found in the top 10 list in 2018, however *S. rubroviolaceus* and *A. triostegus* replaced *C. melampygus* and *Chlorurus spilurus*. *Kyphosus* species increased from 6^{th} to ranking 5^{th} from 2018 to 2019, and mean biomass also increased from 3.8 g/m^2 to 6.3 g/m^2. Similarly, *N. unicornis* which was ranked 10^{th} in 2018 with a mean biomass of 2.9 g/m^2 has increased to a 7^{th} place ranking (4.7 g/m^2) in 2019. This may be an indication of an increase of herbivores inside the Makua Puʻuhonua.

Outside the CBSFA there are also four food fish species appearing in the top ten species with the highest percent biomass. *Kyphosus* sp. is ranked 3^{rd} in the top ten species with highest percent biomass at 11.0 g/m^2, followed by *C. spilurus* in 5^{th} (7.7 g/m^2). *Manini* is ranked 6^{th} with a mean biomass of 5.2 g/m^2 (much lower compared to inside the CBSFA (11.7 g/m^2)), and lastly *C. melampygus* is ranked 7^{th} with a mean biomass of 5.1 g/m^2 (Table 4).

Table 4. Food fish species ranking in the top 10 species overall with the greatest mean biomass for Hāʻena sectors.

Location	**Taxonomic Name**	**Common Name**	**Hawaiian Name**	**Mean Biomass (g/m^2)**	**Rank**
Inside CBSFA	*Naso unicornis*	Bluespine Unicornfish	*kala*	13.41	4
	Acanthurus triostegus	Convict Tang	*manini*	11.67	6
	Kyphosus species	Chub	*nenue*	10.74	7
	Acanthurus dussumieri	Eye-stripe Surgeonfish	*palani*	8.90	8
Makua Puʻuhonua	*Kyphosus species*	Chub	*nenue*	6.28	5
	Naso unicornis	Bluespine Unicornfish	*kala*	4.70	7
	Scarus rubroviolaceus	Redlip parrotfish	*uhu*	4.36	8
	Acanthurus triostegus	Convict Tang	*manini*	4.22	9
Outside CBSFA	*Kyphosus species*	Chub	*nenue*	11.02	3
	Chlorurus spilurus	Bullethead Parrotfish	*uhu*	7.66	5
	Acanthurus triostegus	Convict Tang	*manini*	5.16	6
	Caranx melampygus	Bluefin Trevally	*ʻomilu*	5.13	7

Examination of Reproductive Maturity in Resource Fishes

Resource fish data from 2016 through 2018 was explored by Rebecca Weible as a Master of Science in Zoology thesis completed in December 2019. This detailed study examined the reproductive maturity within and outside the CBSFA boundaries to determine whether there has been an increase in fish reproductive size since 2015, when fishing restrictions were initiated. 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 differences in mature food fishes inside and outside the CBSFA. The thesis entitled, “An In-Depth Investigation of Resource Fishes within and Surrounding a Community-Based Subsistence Fishing Area at Hāʻena, Kauaʻi” found no strong evidence for an overall reserve effect based on reproductive size of food fishes (Weible 2019).

Resources fish species were selected based on a list from the FERL lab and included species not on the Hāʻena community list such as *taʻape*, *toʻau*, *roi*, *pualu*, *mu* and *umaumalei*. Resource fish species were recorded on a total of 261 of the 314 transects (83%) surveyed between August 2016 and August 2018. Resource fishes were observed on 64% of transects inside the CBSFA and 36% outside the CBSFA boundaries (Table 5). Since 2016, the number of transects where resource fish species are found has been increasing inside the CBSFA but has varied outside the boundaries.

Table 5. Total number of transects with resource fish species by year and location. Transect percentages of the total number of sites (261) are recorded in parentheses.

Year	**Inside**	**Outside**	**TOTAL**
2016	48 (18%)	30 (11%)	78 (30%)
2017	53 (20%)	37 (14%)	90 (34%)
2018	66 (25%)	27 (10%)	93 (36%)
TOTAL	167 (64%)	94 (36%)	**261**

A total of 29 of the 32 species of resource fishes from the Hāʻena community list (Table 2) were observed at least once during the three years of surveys. These 29 species comprised 9 families with 9,431 individuals. Statistical analyses exclude species of fishes found in <5% of the 261 transects, resulting in a total of 19 resource fish species (Table 6). Species excluded tend to be either the more mobile, cryptic, and/or rare species of fishes. Species that occur in >5% of the total transects comprise 98.0% of the total abundance and 96.4% of the total biomass. The most abundant species surveyed during the 3-yr span include the Convict Tang, *Acanthurus triostegus* (*manini*), Chubs, *Kyphosus* spp. (*nenue*), Bluestripe Snapper, *Lutjanus kasmira* (*taʻape*), Ember Parrotfish, *Scarus rubroviolaceus* (*palukaluka*), and Yellowfin Goatfish, *Mulloidichthys vanicolensis* (*weke ʻula*). These top five species comprise 62.7% of the total abundance and 71.6% of the total biomass of the all resource fish assemblages for the 19 species (Table 6). The most frequently observed fishes by percent frequency of occurrence on transects were *A. triostegus* (53%), *S. rubroviolaceus* (45%), Orangespine Unicornfish, *Naso lituratus* (*umaumalei*) (40%), Bluespine Unicornfish, *N. unicornis* (40%), and *Kyphosus* spp. (28%).

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

* = Hā'ena species list

Results indicate statistically higher biomass outside CBSFA boundaries for most resource fishes. This is in opposition to the results using the Hā'ena community list of culturally important species. Results show a higher biomass of resource fishes inside the CBSFA. This discrepancy may be a result of the invasive species *L. kasmira* (*ta'ape*) which are more prevalent outside the boundaries. Biomass at deep survey sites (>7m) was significantly higher than at shallower sites (<7m). Significantly higher fish biomass was found in pavement habitat than in aggregate reef (p=0.001) (Fig. 15).

Scarus rubroviolaceus (*palukaluka*), has a higher biomass outside of the CBSFA boundaries, but higher abundances (counts of individuals) inside the boundaries. This suggests that larval recruitment for *S. rubroviolaceus* may be generated from outside the boundaries, and habitat may play an important role in the location where individuals of different size may be found. Comparison of mean abundance of 14 food fish species show five species with the abundance of individuals above their L50 values within the CBSFA. These included *A. triostegus* (p=0.03), the Peacock Grouper, *Cephalopholis argus (roi)* (p=0.03), the Blue Goatfish, *Parupeneus cyclostomus (moano kea)* (p=0.03), *Lutjanus fulvus (to'au*) and *S. rubroviolaceus* (*palukaluka*) (p=0.05) (Fig. 16).

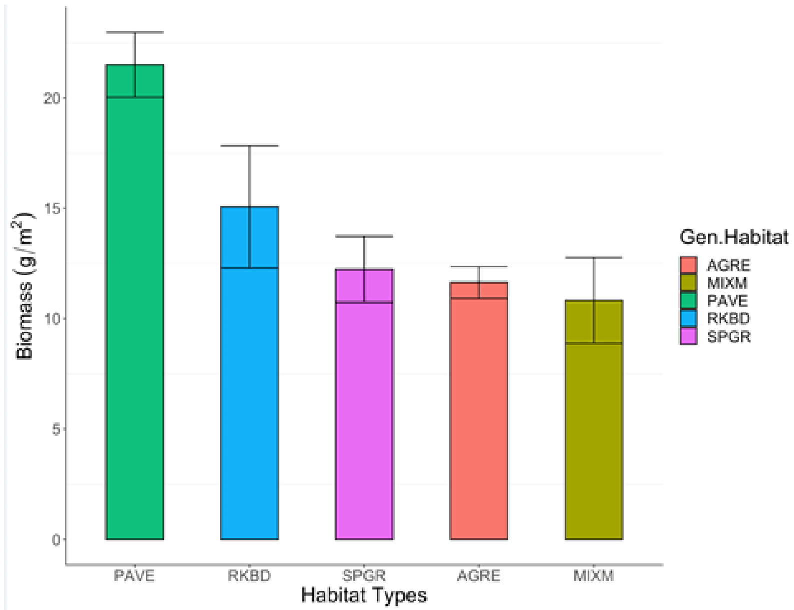


Figure 15. Generalized linear model results showing larger biomass values among pavement (PAVE) habitats in relation to rock-boulder (RKBD), spur and groove (SPGR), aggregate reef (AGRE), and mixed (MIXM) habitat types (from Weible 2019).

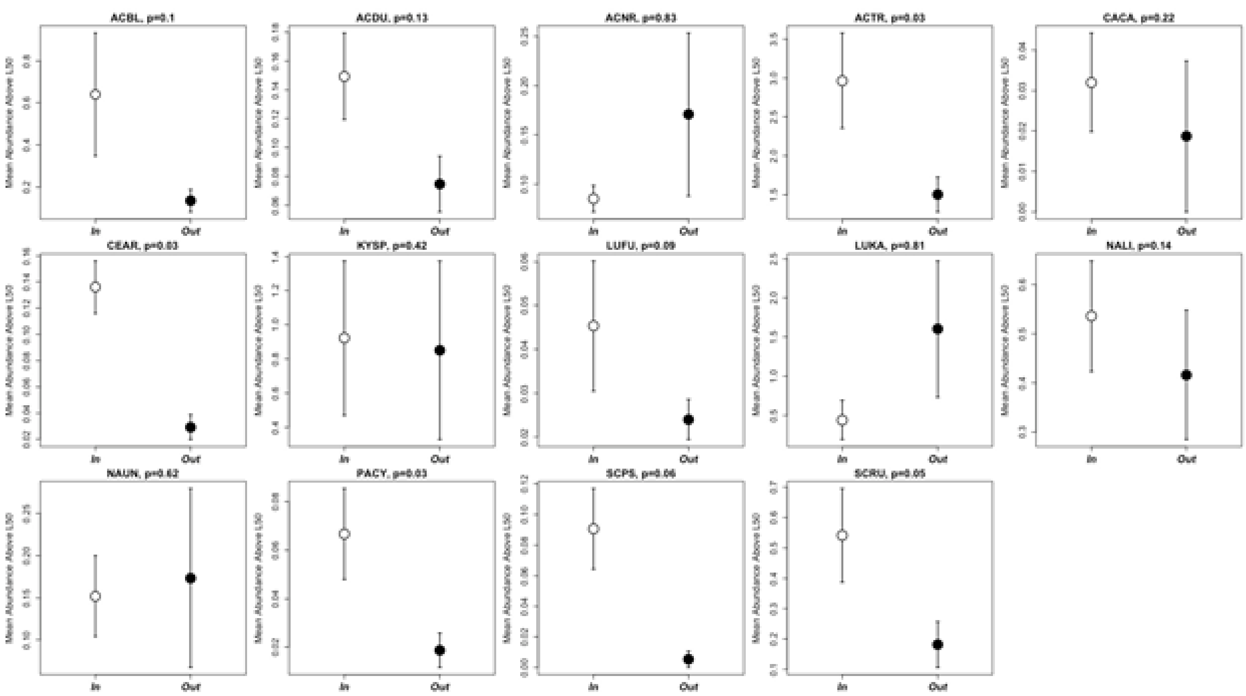


Figure 16. One-way t-tests of mean abundance of resource fish species individuals above their respective L_{50} values inside and outside the CBSFA boundaries. Asterisks (*) represent species with significant differences. ACBL = *Acanthurus blochii*, ACDU = *A. dussumieri*, ACNR = *A. nigroris*, *ACTR = *A. triostegus*, CACA = *Calotomus carolinus*, *CEAR = *Cephalopholis argus*, KYSP = *Kyphosus* spp., *LUFU = *Lutjanus fulvus*, LUKA = *L. kasmira*, NALI = *Naso lituratus*, NAUN = *N. unicornis*, *PACY = *Parupeneus cyclostomus*, SCPS = *Scarus psittacus*, and *SCRU = *S. rubroviolaceus*. (from Weible 2019).

nMDS ordination results show sites within the CBSFA with higher concordance than outside the CBSFA (Fig. 17). *Scarus psittacus* biomass was significantly correlated with sites inside the CBSFA, while *S. rubroviolaceus* biomass was significantly correlated with sites outside the CBSFA. There was a weak correlation for *Cephalopholis argus, Naso unicornis (kala),* and *Lutjanus kasmira* (*ta'ape*) with higher biomass values found outside the boundaries between 2017 and 2018. All other biomass of resource fishes was evenly distributed by location.

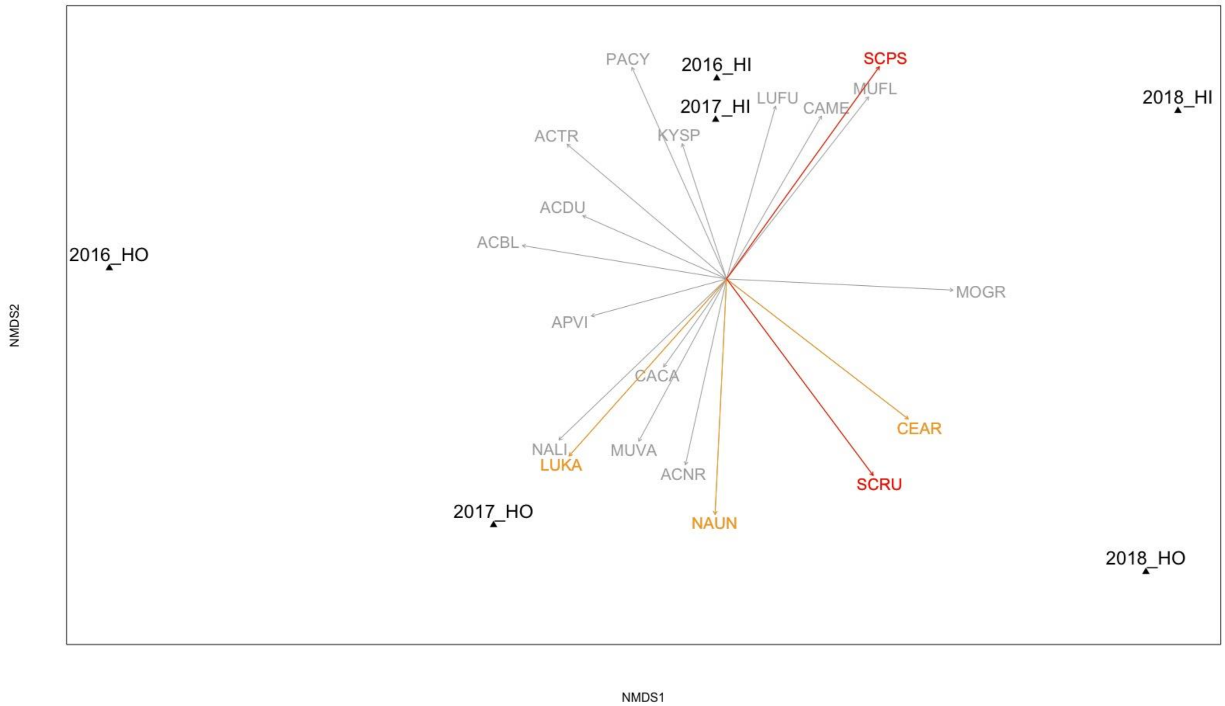


Figure 17. nMDS ordination plot of the distribution of resource fish biomass among year and location. Resource fish species are represented by vectors; red* indicates strong correlation (p<0.05) and orange indicates weaker correlations (0.05 <p< 0.1) to year and location. *SCPS = *Scarus psittacus*, *SCRU = *Scarus rubroviolaceus*, CEAR = *Cephalopholis argus*, NAUN = *Naso unicornis*, LUKA = *Lutjanus kasmira* (from Weible 2019).

Possibilities for the lack of greater biomass within the CBSFA include: 1) rules and regulations are 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) low sample sizes may limit statistical power, 6) resource species selected include invasive species, and 7) uneven selection of habitat types.

UH/DAR data show a statistically significant reserve effect eliminating the first three possibilities. Poaching has been reported within the CBSFA and may account for a less strong pattern of greater resource fishes within the CBSFA. Low sample size for specific species may be less of an issue as more surveys are added annually. 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 annual surveys to allow for long-term trends to emerge that may better predict how resource fishes are changing in reference to management changes. Selecting survey stations that equally represent habitat types within and outside of the CBSFA are critical in assessing habitat preferences and emerging patterns of resource fish biomass and abundance.

Non-Resource Fishes

The abundance of non-food fishes was significantly greater in 2017 than in 2018 (p=0.0094). Similar to food fishes, abundance was higher inside than outside the CBSFA (p=0.0030). For abundance between years with respect to division, Puʻuhonua had the greatest abundance in 2017 followed by 2019. Abundance in 2017 was significantly greater than abundance in 2018 at a=0.10 (p=0.0516). Abundance in 2019 was also greater than abundance in 2016 and 2018, and significant at a=0.10 (p=0.0859 and p=0.0854, respectively). An alpha of 0.10 assumes a 10% risk of concluding that a difference exists when there is no actual difference.

Inside the CBSFA, abundance in 2017 was statistically greater than abundance in 2018 (p=0.0424). Abundance in 2016 was greater than abundance in 2018 (p=0.0741). Outside the CBSFA boundaries showed no differences in abundance between years.

Between divisions, overall biomass was significantly greater inside the CBSFA than outside at a=0.10 (p=0.0599). There were no other differences found between divisions. Puʻuhonua was the only division to show differences in non-food fish biomass between years. Biomass in 2017 was statistically greater than biomass in 2016 and 2018 (p=0.0031 and p=0.0429, respectively). Inside and outside the CBSFA showed no differences in biomass between years.

Road Closure (April 2018-June 2019)

In April of 2018, heavy flooding and landslides occurred in the Hāʻena region of Kauaʻi with resultant damage and closure of several sections of Kuhio Highway. Rainfall was uncharacteristically concentrated on the lower elevations of the northern coast and was so extensive it set the 24hr rainfall record in the Hawaiian Islands and the United States at 1,262 mm (49.69 in). This extreme weather event precluded outside visitation to the Hāʻena region, including Hāʻena State Park, until the reopening of Kuhio Highway on 17 June, 2019. With the opening of Kuhio Highway, island-wide access to Hāʻena State Park resumed. The reopening coincided with June and July, the two heaviest tourist traffic months in Kauaʻi during 2019 (Hawaiʻi Tourism Authority 2019). With reopening came new regulations from the DLNR limiting visitation to 900 people per day.

Changes in human pressure may impact fish distribution and population structure (Albuquerque et al. 2014), potentially influencing measurable community parameters like fish abundance, biomass, and/or diversity. It is known that human disturbance can enhance avoidance behavior in fishes, particularly herbivores (Gil et al. 2015), which decreases time behaviors such as foraging, parental care, and reproduction (Frid and Dill 2002). Trampling and other reef damage from human activity can also affect coral health and survivorship (Gil et al. 2015, Rodgers and Cox 2003), which can reduce availability of fish habitat. Other factors associated with increased tourism are roadway runoff, which can contribute a substantial percentage of non-point source inputs in the form of sediment and chemical runoff (Carlson et al. 2019).

Any compositional shifts in fish population during the 2019 transect survey period after road opening, may result in reduced efficacy of the evaluation of community management practices. The following analyses examine changes in fish abundance, biomass, or diversity, inside and outside the CBSFA, following the return of visitors. Data was assessed overall and by CBSFA sector (Makua Puʻuhonua, Inside CBSFA, Outside CBSFA) and placed into depth groups to investigate observations of nearshore population changes. Shifts in herbivorous fishes are also explored. To account for any lag in population transitions, data was examined continuously over the period following road opening as opposed to categorically before and after. Rainfall was also included as a confounding effect on fish populations.

Few shifts are found in overall fish population dynamics following the opening of Kuhio Hwy. Reports of significance are based on an alpha of 0.10. An alpha of 0.10 shows a 10% risk of concluding that a difference exists when there is no actual difference, or a 90% chance that the correct conclusion was drawn. The statistical differences found are an increase in fish abundance overall, in the Puʻuhonua, in herbivorous fishes, and inside the CBSFA at stations >5 m following the opening of the road. A small sample size in the Puʻuhonua before (n=2) and after (n=8) the road opening reduces the confidence in the results for this sector. No statistical differences are found in fish biomass or diversity across sectors or depth by road status.

When examining data over a continuous time scale to help account for any lag effects of potential impact, there are few shifts in population dynamics after road opening. The post-road survey period was limited to <50 days of acclimation which may not be adequate temporal resolution to allow for fish population shifts. Pre road dates are based on four survey dates while Post road data is based on three survey dates. This may not allow for a sufficient sample size to conclude beyond the naturally high fish variability. The few significant changes suggest increases in herbivore fishes and abundance of fish populations after road opening, not prior to opening as expected. The greater abundance of fishes is a factor of increases within the Makua Puʻuhonua. These changes are likely due to a continuing increase over time in fish populations or too small a sample size. Number of transects conducted in each division before and after road opening are shown in Table 7.

Table 7. Number of transects run at each division by road status.

Division	PRE-Road opening	POST-Road opening
Outside CBSFA	33	7
Inside CBSFA	29	19
Makua Puʻuhonua	2	8

Overall fish abundance after road opening is statistically greater at *a*=0.1 as compared to before the road opening (*p*=0.051), driven by changes in the Puʻuhonua. No significant differences are found inside or outside the CBSFA. Within the Makua Puʻuhonua, fish abundance is statistically greater once the road reopened (*p*=0.049) (Fig. 18). This fish nursery is closed to all activities at all times. One suggestion for the higher abundance following the road opening may be the resumption of visitor activity in other sectors instigating fishes to frequent the Puʻuhonua, but it is more likely a factor of low sample size.

There is no statistically significant difference in fish biomass (Fig. 19) or diversity before and after road opening overall or by division.

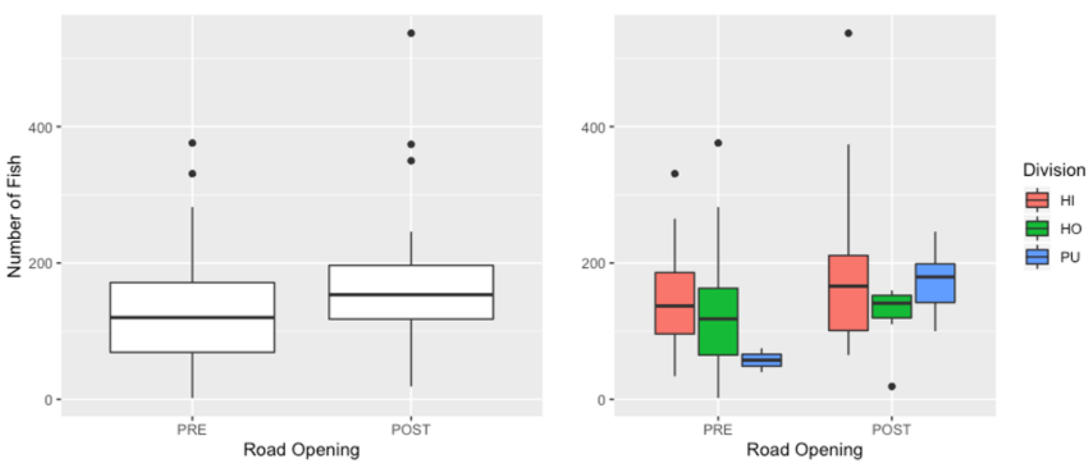


Figure 18. Boxplot distribution of number of fish (number/transect) for all divisions by road status (left) and distribution of number of fish by division by road status (right). Bold lines within boxes represent medians, box borders represent 25th (Q1) and 75th (Q3) percentiles (defining the interquartile range, IQR), vertical lines outside IQR represent predicted minimum and maximum values (e.g. Q1-1.5*IQR minimum), and dots represent outliers that significantly differ from the dataset.

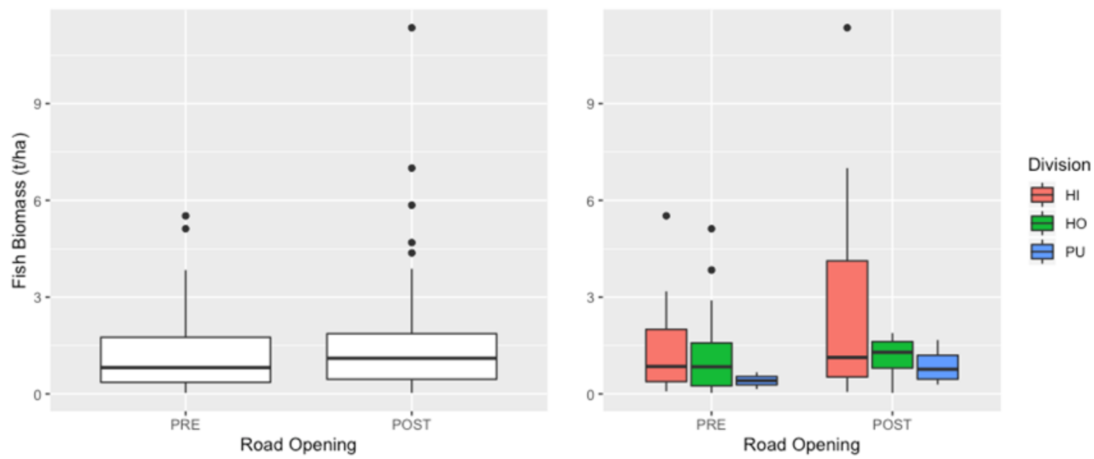


Figure 19. Boxplot distribution of fish biomass (tons/hectare) for all divisions by road status (left) and distribution of fish biomass for specific divisions by road status (right).

Fish abundance (*p*=0.791), biomass (*p*=0.778), or diversity (*p*=0.820) are not significantly correlated with the number of days following road opening (Fig. 20).

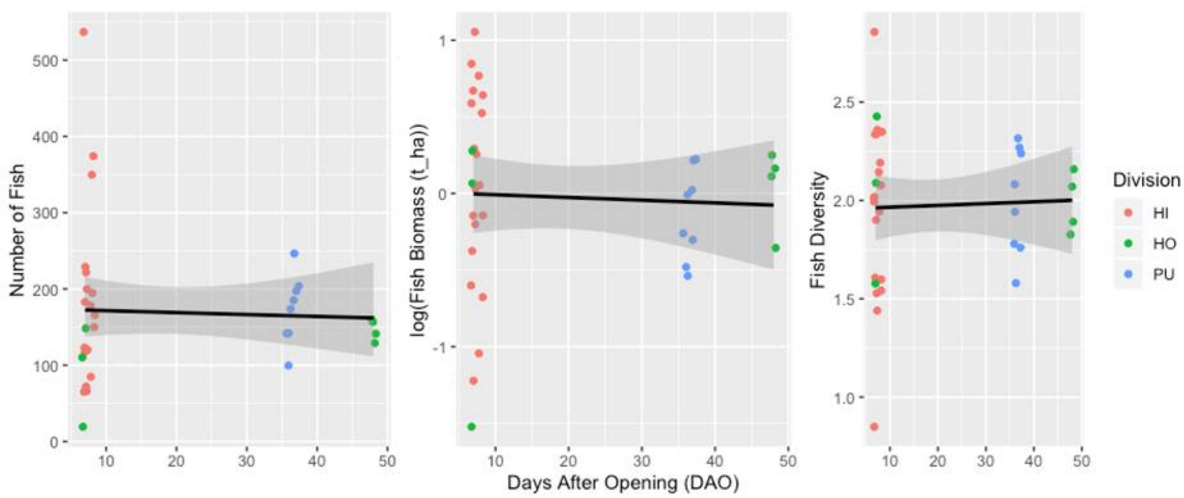


Figure 20. Overall number of fishes (number/transect) (left), fish biomass (tons/hectare) (center), and fish diversity (right) over the course of the sampling period (days after opening). Points represent data from individual transects conducted on three sampling periods and colored by division.

The subset of depth used in analyses encompasses only shallow stations (<3 m and <5 m) that may be affected by visitor presence. Fish abundance at <5 m depth inside the CBSFA is statistically greater after road opening than before at *a*=0.1 (*p*=0.051) (Fig. 21). No other abundance or biomass differences are found between road status and depth or sector.

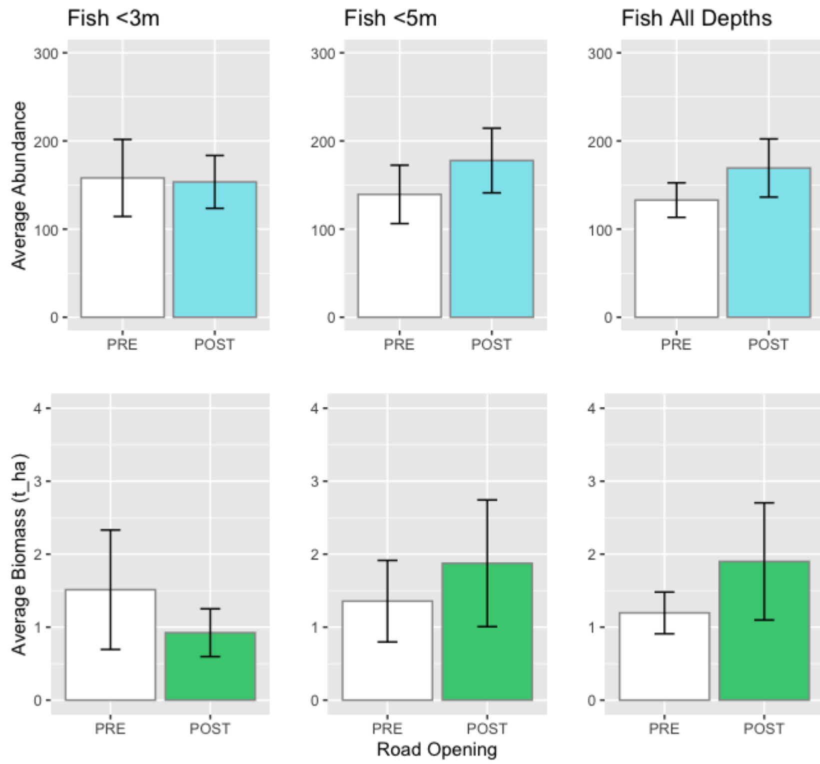


Figure 21. Overall average abundance (num/transect) and biomass (ton/ha) by road status and depth group. Error bars represent ±95% CI.

Herbivore biomass for all depths analyzed are statistically greater after road opening at a=0.1 (p=0.051, Fig. 22). No other significant differences are found. There are also no differences found in herbivore abundance or biomass following road opening by sector or rainfall.

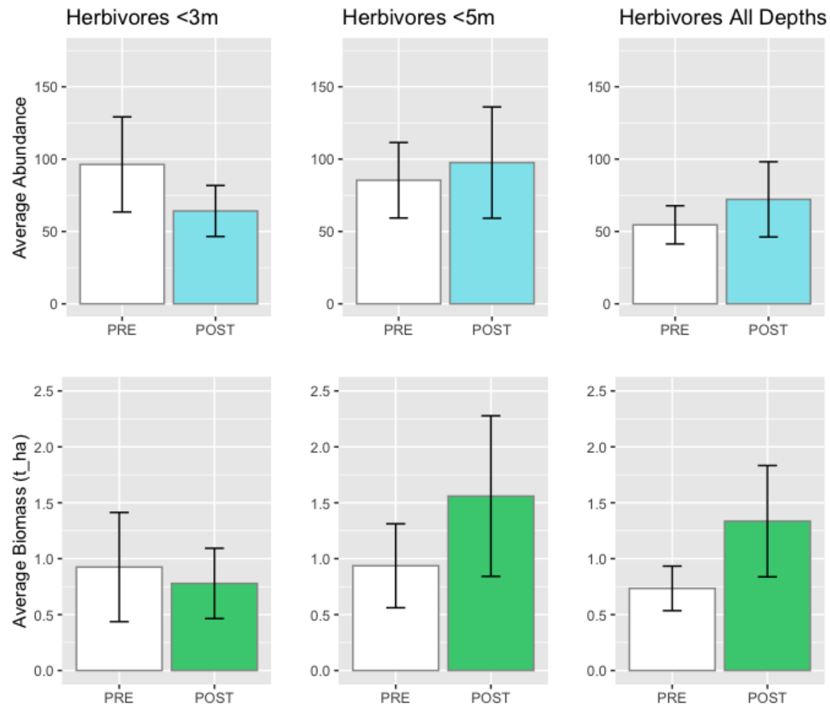


Figure 22. Mean herbivore abundance (num/transect) and biomass (ton/ha) by road status and depth group. Error bars represent ±95% CI.

Papaloa and Makua Puʻuhonua Surveys

Prior to the road closure, Papaloa experienced high human traffic with many visitors wading and snorkeling on the shallow reef. Parallel surveys were conducted in the Makua Puʻuhonua to provide a control for human interaction and compare differences between 2018 and 2019 prior to the road opening (Fig. 23). Video surveys of fish minimum approach distance (MAD) were also conducted in this area in 2018 and 2019 by Kosta Stamoulis and DAR Kauaʻi. MAD surveys conducted following the road re-opening in June 2019 are pending. Due to the Covid 19 outbreak, a visitor quarantine has been in effect since early March 2020. This restriction, park closures, and other island wide limits have severely reduced tourism leading to another major reduction in visitor use in Hāʻena since the road closure.

Overall fish abundance was lower at Papaloa reef in 2019 compared to 2018 though this difference was not significant (Fig. 24). Fish abundance did not differ in the Makua Pu'uhonua between years (Fig. 24). When considering resource (fished) species only, there was also no difference in abundance between years. Biomass of all fishes and resource species only did not differ between years at either area.

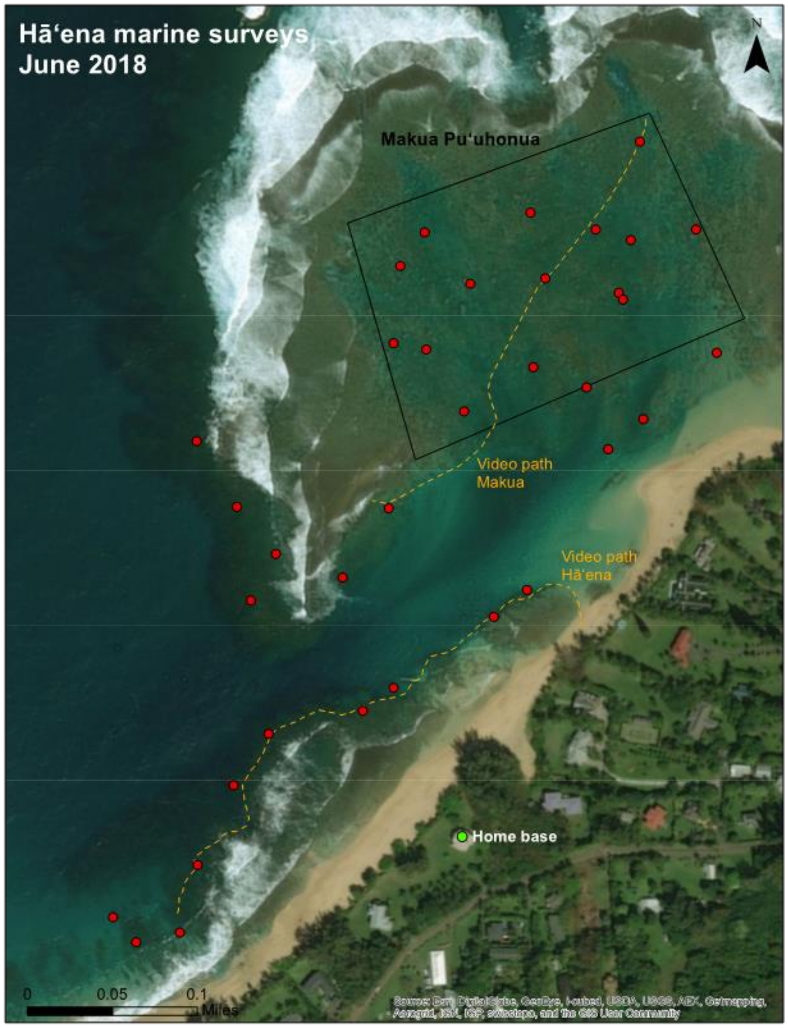


Figure 23. Location of KAHU surveys and fish behavior video surveys conducted in June 2018 and 2019.

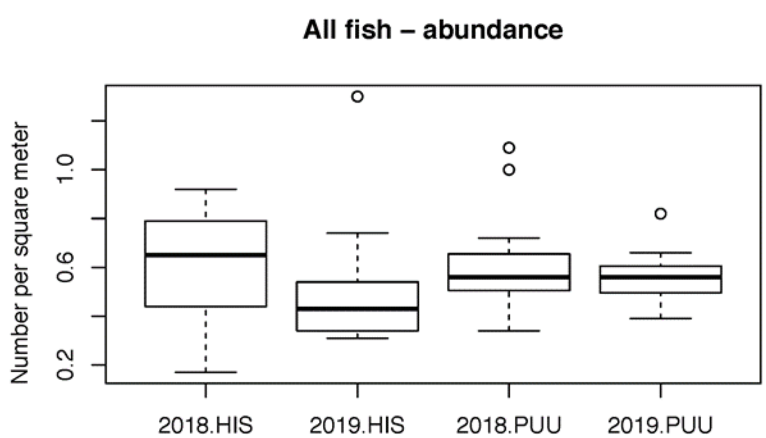


Figure 24. Abundance (number per square meter) of fishes at Papaloa reef (HIS) and Makua Pu'uhonua (PUU) in June 2018 and June 2019.

When results for all fishes were analyzed by trophic level, piscivores are significantly more abundant at Papaloa in 2019 compared to 2018 (F=5.5, $p<0.05$). Comparisons for other groups did not show any differences. When resource species alone were considered, piscivores were also more abundant at Papaloa (F=10.9, $p<0.01$) and herbivores were less abundant (F=4.4, $p<0.05$) (Fig. 25). No such differences were found in the Makua Pu'uhonua. This result for piscivores was driven by *ʻōmilu* (the Bluefin trevally, *Caranx melampygus*), while the result for herbivores was a combination of fished species.

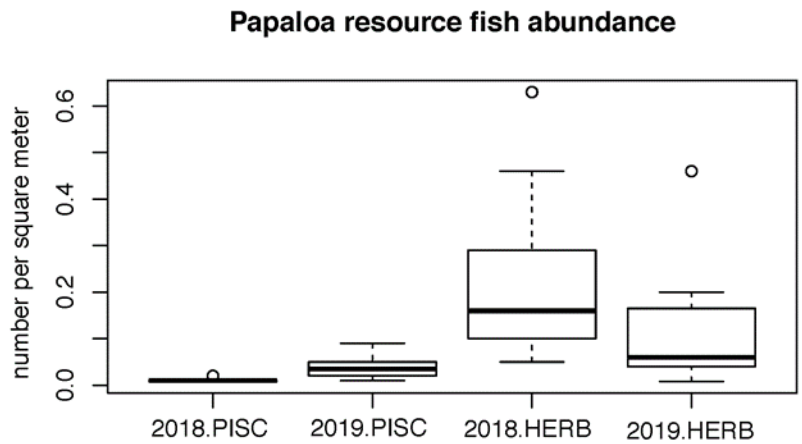


Figure 25. Resource fish abundance of piscivores (PISC) and herbivores (HERB) at Papaloa reef in June 2018 and June 2019.

Generally, higher abundance of piscivores such as was found at Papaloa reef in 2019 compared to 2018 indicates a healthier ecosystem. The fact that this difference was not reflected in terms of piscivore biomass means that it was driven by smaller individuals and accordingly we observed a number of schools of juvenile *ʻōmilu*. Because the Puʻuhonua did not show a change in piscivore biomass between 2018 and 2019, the difference at Papaloa may be due to the long term (~1 year) effects of greatly reduced human presence. In addition, in a recent tagging study at Molokini, Maui, Filous et al. (2017) found a negative relationship between snorkel vessels and *ʻōmilu*, indicating that these species may be sensitive to human presence.

Lower abundance of fished herbivores in contrast to all herbivores at Papaloa in 2019 compared to 2018 suggests an influence of fishing. The absence of this pattern in the Makua Puʻuhonua - where fishing is not allowed - also supports this possibility. The shallow reef at Papaloa is highly accessible to fishers using thrownet and is ideal for this practice. Since the road closure, community members have observed increased abundance of fishes on this shallow reef flat which is typically overrun by tourists. The absence of tourists and other visitors during the past year provided the opportunity for local fishers to access this resource and results show evidence of the increased harvest efficiency.

Summary of Top Species

In 2019 a total of 112 fish species are found in Hāʻena overall, with the most species within the CBSFA (98). Outside the CBSFA boundaries, 89 fish species are recorded, followed by the Makua Puʻuhonua with 53 species. There is partial overlap between all three sectors for the top 10 species for fish abundance inside the CBSFA, outside the boundaries, and within Makua Puʻuhonua. Six common species are shared among sectors, with *Chromis vanderbilti* (Blackfin Chromis), *Thalassoma duperrey* (the Saddle Wrasse, *hīnālea lauwili*), *Acanthurus nigrofuscus* (Brown Surgeonfish, *māʻiʻi*), *Acanthurus triostegus* (Convict Tang, *manini*), *Acanthurus leucopareius* (Whitebar Surgeonfish, *māikoiko*), and *Acanthurus olivaceus* (Orangeband surgeonfish, *naʻenaʻe*) appearing in the list of top ten species in varying order (Fig. 26). *Lutjanus kasmira* (the Bluestripe Snapper, *taʻape*), an introduced species, appears in the top ten both within and outside the CBSFA, while only one individual was recorded in Makua Puʻuhonua. There is a noticeable decrease of *taʻape* outside the CBSFA from 2018-2019 (10% to 3%), which was ranked as the third most abundant species in 2018 and is currently ranked ninth.

In contrast to abundance, biomass of the top ten species varies more between sectors. Only three fish species overlap within the top ten (*A. leucopareius*, *A. triostegus*, and *Kyphosus* species (the Lowfin Chub, *enenue*)) (Fig. 27). Two new species not seen in 2018, are included in the top ten biomass rankings inside the CBSFA: *Monotaxis grandoculis* (Bigeye Emperor, *mu*) and *Triaenodon obesus* (Whitetip reef shark, *mano lalakea*). The appearance of the whitetip reef shark in the top ten biomass rankings is attributed to two individuals recorded on two separate transects, and a large school of *mu* that appeared to be a spawning aggregation brought the species to third in ranking for top biomass. A large decline in biomass of *Caranx melampygus* (the Blue Trevally, *ʻomilu*) is seen inside the Makua Puʻuhonua, which was previously ranked third in 2018 (8.8%) but has since dropped to 0.8% of total fish biomass.

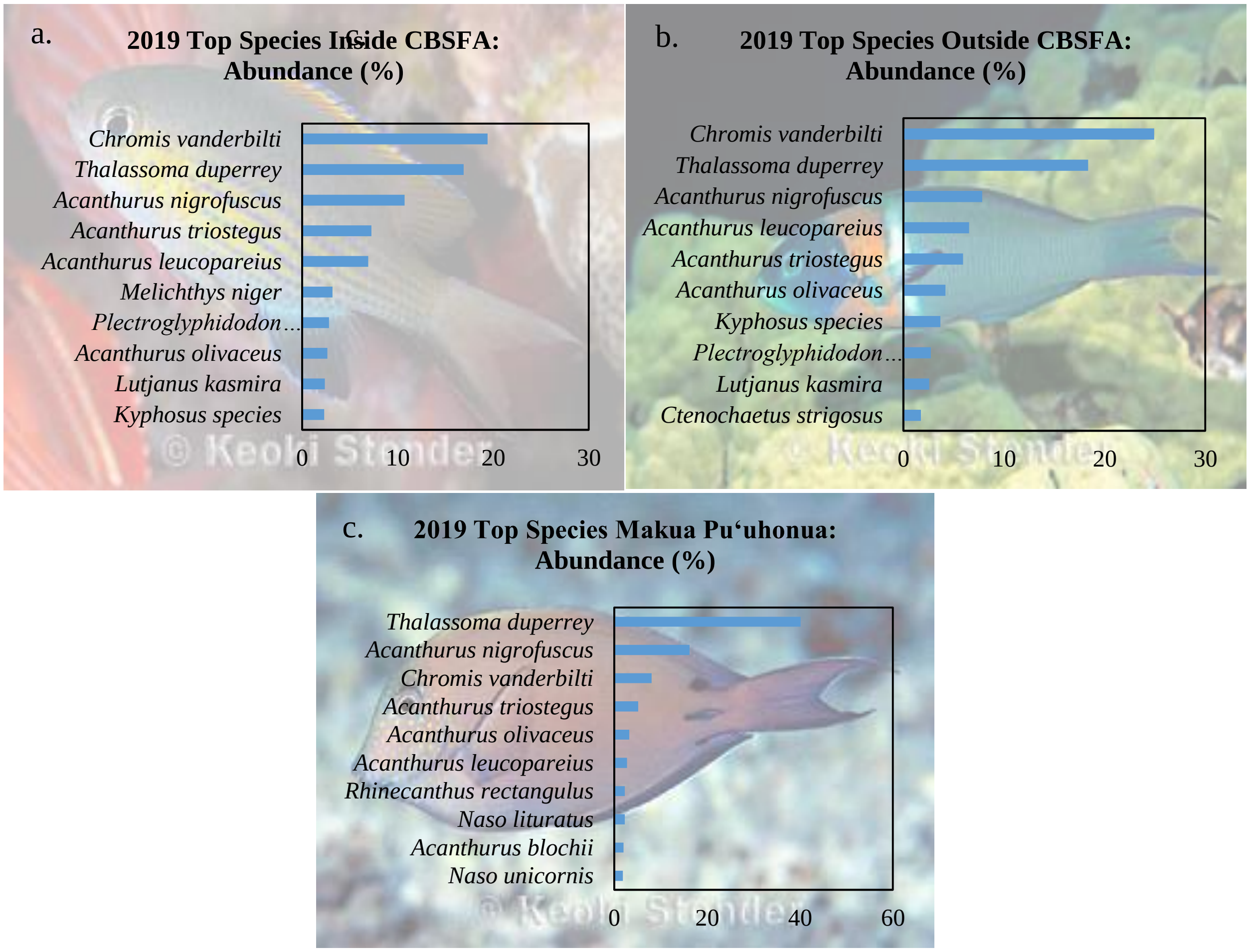


Figure 26. Top ten fish species in abundance (% of total) found a) inside the CBSFA (n=48), b) outside the CBSFA (n=40), and c) within the Makua Pu‘uhonua (n=10).

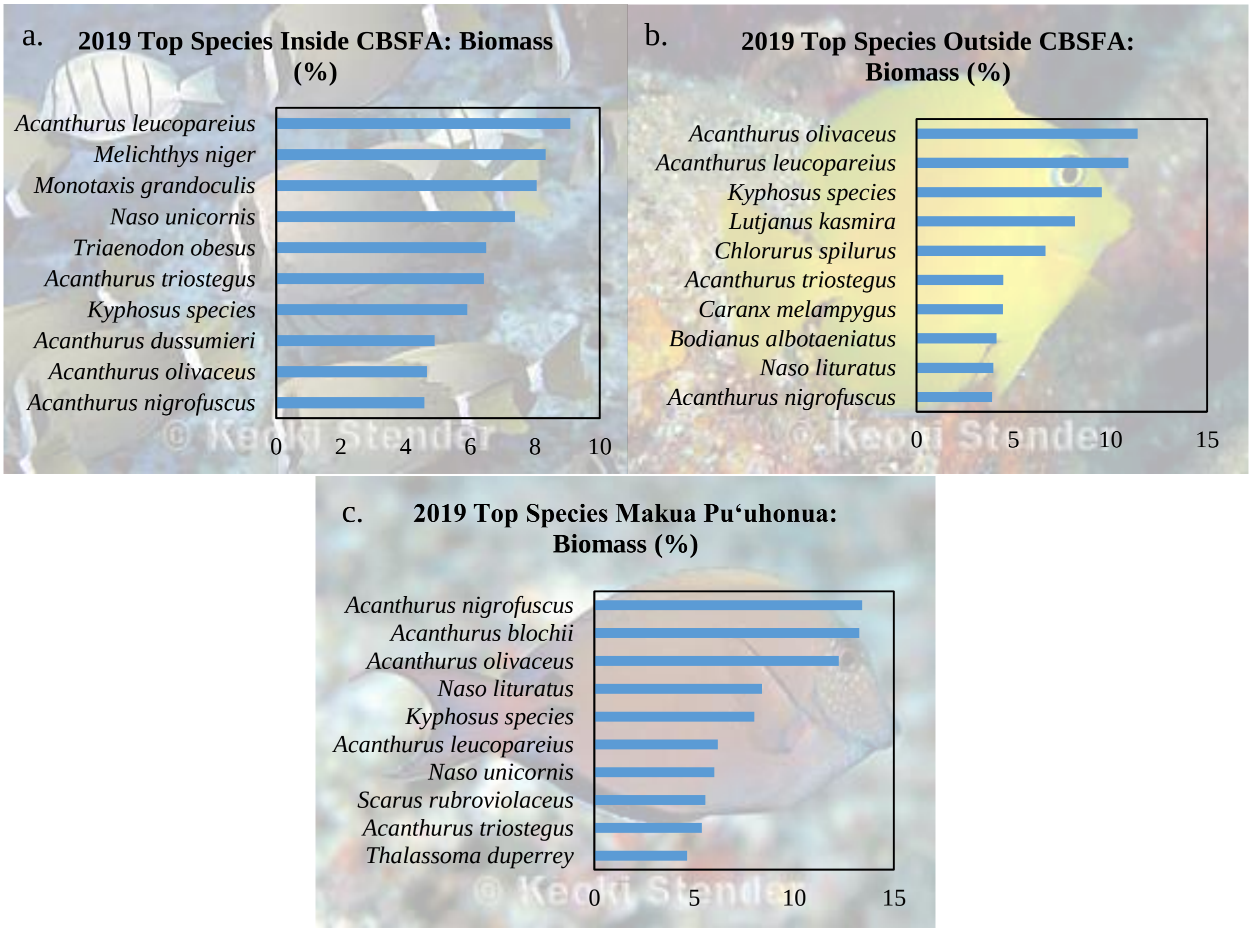


Figure 27. Top ten fish species in biomass (% of total) found a) inside the CBSFA (n=48), b) outside the CBSFA (n=40), and c) within the Makua Pu‘uhonua (n=10).

Top Families

All three sectors share the same top three families (Acanthuridae, Pomacentridae, and Labridae), with identical rankings inside and outside the boundaries, while the Makua Pu‘uhonua differs in order (Tables 8, 9, & 10). Acanthuridae (surgeonfishes) is the most abundant family within and outside the CBSFA, identical to the previous year. Mean abundance for this family remains higher inside the CBSFA (0.45 IND/m^2) as compared to outside (0.32 IND/m^2), similar to previous years. Labridae (wrasses) has the greatest abundance inside the Makua Pu‘uhonua, with a mean abundance of 0.50 IND/m^2. This is an increase from the previous year (0.34 IND/m^2). A comparable trend within the Pu‘uhonua shows Acanthuridae increasing from 0.18 to 0.40 IND/m^2.

In biomass, the Acanthuridae family ranks at the top for all three sectors inside the CBSFA, outside, and within the Pu‘uhonua. Two new families appear in the top five that were not evident last year: Lethrinidae (emperors) and Carcharhinidae (sharks). The large school of *mu* on one transect (Lethrinidae), and two whitetip reef sharks (Carcharinidae) are responsible for the high biomass. Outside the CBSFA boundaries, a noticeable increase in biomass is found for Scaridae (parrotfishes) and Carangidae (jacks) families as compared to the previous year. Parrotfish biomass increases substantially from 2.2 g/m² to 9.9 g/m². The Carangidae family shows a 220% increase (from 2.5 to 8.1 g/m²) due to the large numbers of *ʻomilu*, which comprise 63% of the total biomass for this family. Inside the Makua Puʻuhonua, contrary to trends inside and outside the CBSFA boundaries, biomass for Carangidae decreases from 8.8 to 0.7 g/m², and is not included in the top five rankings. A small sample size for the Puʻuhonua (10), compared to within the CBSFA (48) and outside the CBSFA (40), due to area limits, may increase the likelihood of missing transient species such as jacks (Carangidae). The Pomacentridae family (damselfishes) replaces Carangidae in the top families this year within the Puʻuhonua, increasing in biomass from 1.0 g/m² to 3.1 g/m² (Table 10).

Table 8. Top five families for mean abundance (IND/m²) and mean biomass (g/m²) shown in descending order within the CBSFA (n=48).

Family Name	Mean Abundance (IND/m²)	Family Name	Mean Biomass (g/m²)
Acanthuridae	0.45 ± 0.47	Acanthuridae	84.41 ± 98.13
Pomacentridae	0.29 ± 0.34	Balistidae	21.04 ± 54.42
Labridae	0.24 ± 0.17	Lethrinidae	14.64 ± 84.09
Balistidae	0.06 ± 0.15	Carcharhinidae	11.8 ± 72.77
Lutjanidae	0.04 ± 0.19	Kyphosidae	10.73 ± 27.37

Table 9. Top five families for mean abundance (IND/m²) and mean biomass (g/m²) outside the CBSFA (n=40).

Family Name	Mean Abundance (IND/m²)	Family Name	Mean Biomass (g/m²)
Acanthuridae	0.32 ± 0.31	Acanthuridae	55.90 ± 52.51
Pomacentridae	0.31 ± 0.33	Kyphosidae	11.01 ± 29.32
Labridae	0.21 ± 0.16	Lutjanidae	10.69 ± 30.02
Kyphosidae	0.03 ± 0.10	Scaridae	9.92 ± 43.00
Lutjanidae	0.03 ± 0.07	Carangidae	8.09 ± 19.84

Table 10. Top five families for mean abundance (IND/m²) and mean biomass (g/m²) inside the Makua Puʻuhonua (n=10).

Family Name	Mean Abundance (IND/m²)	Family Name	Mean Biomass (g/m²)
Labridae	0.50 ± 0.21	Acanthuridae	50.96 ± 40.00
Acanthuridae	0.40 ± 0.23	Labridae	6.417 ± 6.180
Pomacentridae	0.16 ± 0.14	Kyphosidae	6.276 ± 7.664
Balistidae	0.02 ± 0.01	Scaridae	5.38 ± 4.751
Kyphosidae	0.02 ± 0.02	Pomacentridae	3.05 ± 4.576

Fish Trophic Levels

Fish assemblage organization including trophic structure is dependent more on local than regional conditions. Thus, these assemblages are more susceptible to local disturbances of fishing pressure, pollution, eutrophication, or sedimentation, which can cause major shifts in trophic levels. Declines in apex predators are the most highly evident when comparing feeding guilds in the main Hawaiian Islands (MHI) as compared with the Papahānaumokuākea in the Northwestern Hawaiian Islands (NWHI). Large apex predators, primarily jacks and sharks, comprise over half of the total biomass in the NWHI (54%), while contributing only a small percentage (3%) in the MHI (Friedlander & DeMartini 2002).

Abundance

Trophic level composition within the CBSFA and the Makua Puʻuhonua remain similar to the previous year, with herbivores the most dominant within the CBSFA (45% of total) and invertebrate feeders dominating within the Puʻuhonua (50%, Fig. 28). Outside CBSFA boundaries, herbivores also dominate trophic composition, however, there is an increase in zooplanktivore abundance as compared to the previous year (17% to 28% of total). Mean abundance for zooplanktivores outside the CBSFA shifts from 0.17 IND/m^2 to 0.28 IND/m^2. This may be due to the large numbers of *Chromis vanderbilti* (Blackfin Chromis), which ranks as the top most abundant species outside the CBSFA, and comprises 89% of total zooplanktivore abundance. This small species often found in large schools, has little impact on biomass within categories but can heavily affect abundance based on counts.

Zooplanktivores had a higher abundance in 2016 and 2017 than in 2018 (p=0.047 and p=0.007, respectively). In 2019, abundance of zooplanktivores is greater inside and outside the CBSFA as compared to the Puʻuhonua (p=0.017 and p=0.022, respectively).

When combining all sectors, invertebrate feeders had a greater statistical abundance in 2017 than in 2018 (p=0.014). Comparing among sectors for 2019, invertebrate feeder abundance inside the CBSFA and the Makua Puʻuhonua is greater than abundance outside the CBSFA (p=0.006 and p=0.012, respectively). Within each sector between years, invertebrate feeder abundance inside the boundaries in 2016 and 2017 was greater than more recent years.

Overall herbivore abundance in 2017 (p=0.002) was significantly greater than in 2016. Herbivore abundance within the CBSFA in 2019 was also greater than outside and the Puʻuhonua ($p \leq 0.001$ for both). Inside the Puʻuhonua, herbivore abundance in 2019 was greater than in 2016 and 2018 (p=0.010 for both).

No significant differences were found in piscivores between years. No statistically significant differences were detected for trophic levels between years outside the CBSFA.

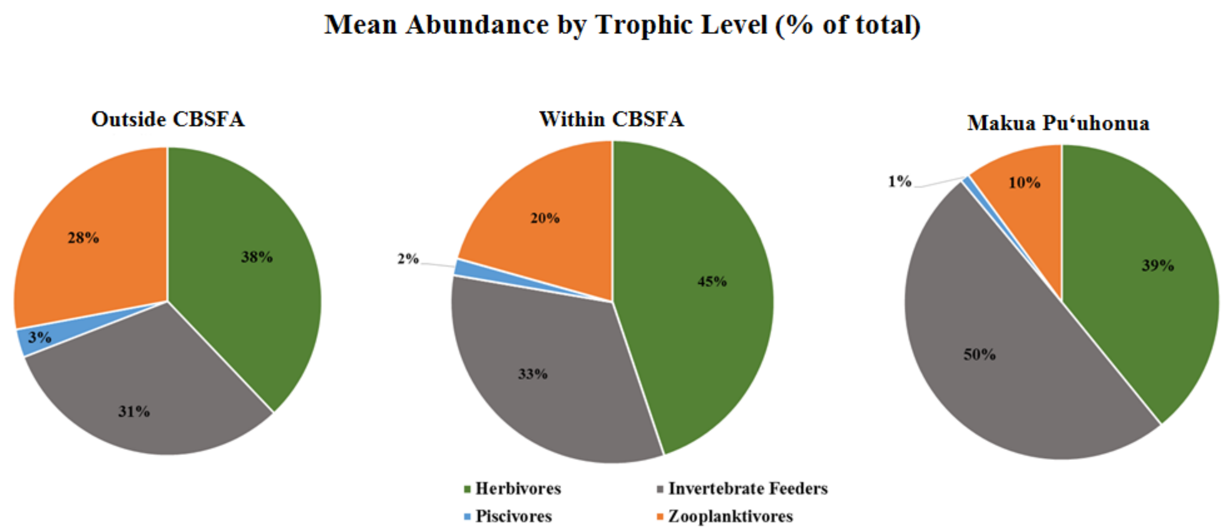


Figure 28. Mean abundance by trophic level outside the CBSFA, within the CBSFA, and inside the Makua Pu‘uhonua shown as percent of total.

Biomass

Examining overall Hā‘ena combined throughout the years, there are significant differences in trophic levels ($p<0.001$), with herbivore biomass dominating all other categories ($p<0.001$). When combining divisions and examining trends throughout the years, herbivore and piscivore biomass is significantly greater in 2019 than in 2016 ($p=0.018$ and $p=0.001$, respectively). Among sectors when combining all years, herbivores ($p=0.019$) and piscivores ($p=0.001$) have the greatest statistical biomass inside the CBSFA as compared to outside. Within sectors, no significant differences in trophic levels are observed in 2019, except for an increase in herbivore biomass inside the Makua Pu‘uhonua since 2016 ($p=0.026$) and an increase in piscivore biomass outside the CBSFA since 2016 ($p=0.026$).

In 2019, herbivores dominate in biomass in all three zones, identical to 2018. The Makua Pu‘uhonua and outside the CBSFA show a surge in herbivore biomass, increasing from 60 to 81% and 54 to 65% of the total biomass, respectively (Fig. 29). Invertebrate biomass composition in the two sectors decreases as a result, dropping from 41 to 20% of total biomass outside the CBSFA, and 24 to 15% inside the Pu‘uhonua. An increase in piscivores was detected within the CBSFA (5% to 12% of total biomass) and outside the boundaries (4% to 10%). The increase in piscivore biomass inside the CBSFA is due to the two whitetip reef sharks recorded on two transects, which results in 53% of the total piscivore biomass. The next largest contributor in 2019 to piscivore biomass is the *‘omilu* comprising 20%. The *‘omilu* is also responsible for the increase in biomass outside the CBSFA, accounting for 47% of the total piscivore biomass, increasing mean biomass from 0.97 g/m^2 the previous year (2018) to 5.13 g/m^2 in 2019.

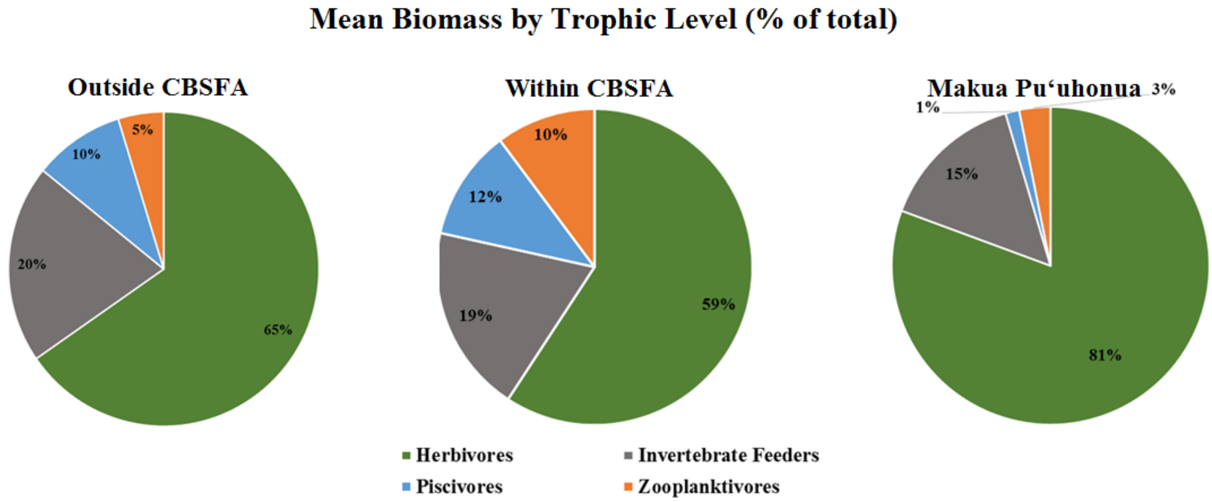


Figure 29. Mean biomass by trophic level outside the CBSFA, within the CBSFA, and inside the Makua Pu'uhonua shown as percent of total.

Endemic Status

Background History

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 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). Introduced species have become common on reefs in the MHIs. Since most snappers occurring in Hawai'i have historically been highly prized food fishes such as *Pristipomoides filamentosus* (*'opakapaka*), the Crimson jobfish, *Etelis carbunculus* (*ehu*), the Ruby snapper, and *Etelis coruscans* (*onaga*), the Long-tailed Red snapper, but inhabit depths of over 60 m, the Hawai'i Fish and Game introduced three shallow water snappers from the South Pacific and Mexico in the mid-1950s and early 1960s in hopes of stimulating the commercial fisheries. These are among the 11 demersal species introduced within a 5-year period. *L. kasmira* (*ta'ape*) the Blue-stripe snapper and *L. fulvus (to'au*) the Black-tail snapper have become widely established, while the third species, *L. gibbus*, the Humpback red snapper, is extremely rare. The more common of the non-native snappers, *L. kasmira* (*ta'ape),* was introduced from the Marquesas in 1958, while *L. fulvus* (*to'au*) was imported two years earlier in 1956. Although only 3,200 *L. kasmira* (*ta'ape*) were released on the island of O'ahu, they have increased their range to include the entire Hawaiian archipelago. The peacock grouper *Cephalopholis argus* (roi) introduced by the state for commercial purposes in 1956 from Moorea, French Polynesia, had more popularity as a food fish than the introduced snappers. Its attractiveness as a food fish rapidly declined as cases of ciguatera poisoning increased. This opportunistic feeder is perceived by many local fishermen as unsafe to consume and in direct competition with them because it preys upon native fish species. Contrary to popular belief, Dierking et al. (2005) found that the majority of roi are relatively safe to consume, with approximately 4% containing levels of toxin high enough to cause ciguatera poisoning. However, 20% of samples contained some level of ciguatoxin. Although a strong site specific correlation occurred with the highest percentage of toxic roi found on the island of Hawaiʻi, nearly all of the 28 locations tested on several islands contained fish that tested positive for ciguatoxins. Fishers on several Hawaiian Islands still participate in a culling of this species through community projects such as "Roi Roundup (Maui), Roi-a-thon, and Kill Roi Day (Kona)", and more recently Kauaʻi's "No Ka Roi." None of these introduced species has been widely accepted as a food fish among the local population or become successful in the commercial fisheries, and the ecological effects of these aliens have only recently been realized. Histological reports from Work et al. (2003) found that nearly half of the *L. kasmira* (*taʻape*) examined from Oʻahu were infected with an apicomplexan protozoan. Furthermore, 26% were infected with an epitheliocystic-like organism with potential transmission to endemic reef fishes. In addition, *L. kasmira* (*taʻape*) from Hilo were found to host the nematode *Spirocamallanus istiblenni* (Font and Rigby 2000). Species of goatfish that are popular food fishes such as *M. flavolineatus* (*weke*) and *Parupeneus porphyreus* (*kūmū*), the Whitesaddle goatfish, may be displaced by *L. kasmira* (*taʻape*) which has also expanded its range into deeper water where *P. filamentosa* (*ʻopakapaka*) reside. Friedlander and Parrish (1998) looked at patterns of habitat use to determine predation and resource competition between *L. kasmira* (*taʻape*) and several native species within Hanalei Bay, Kauaʻi, but found no strong ecological relationships.

Endemism

Endemic fishes are fishes found only in Hawaiʻi and do not occur outside the archipelago. Indigenous species can be found in Hawaiʻi and also in other areas worldwide. Introduced fishes were brought to Hawaiʻi either intentionally or inadvertently. Invasive species are species whose introduction causes or is likely to cause economic or environmental impact to ecosystem health. The term introduced and invasive are often interchangeably misused.

In 2019, when comparing among sectors with all years combined, endemic fish species within the Makua Puʻuhonua (PU) show significantly greater abundance as compared to inside the Hāʻena CBSFA (HI) and outside (HO) ($p \leq 0.001$ and $p = 0.006$, respectively) with abundance statistically greater in HI than HO ($p = 0.008$). Invasive species abundance was significantly greater within HI as compared to HO and PU with all years combined ($p = 0.002$ and $p = 0.000$, respectively). No significant differences were detected in introduced species abundance between divisions.

As with changes in endemism by abundance, biomass among sectors was also significantly greater for endemic and invasive species in HI as compared to HO ($p = 0.039$ and $p = 0.030$, respectively). No significant differences were determined in biomass of introduced species among divisions when combining all years.

A total of 20 endemic fish species were found inside the CBSFA, 22 outside the CBSFA boundaries, and 13 within the Makua Puʻuhonua in 2019. Endemic percent composition is relatively similar between sectors, with indigenous species comprising most of the biomass and abundance (Fig. 30), similar to previous years. While the Makua Puʻuhonua has the lowest number of endemic species, endemic abundance is still highest within the Puʻuhonua, comprising 48% of the total abundance as compared to inside (27%) and outside (28%) the CBSFA boundaries. *Thalassoma duperrey (hīnālea lauwili),* the Saddle wrasse, is responsible for the high endemic composition, contributing 83% to the total endemic fish abundance and 40% to the total fish abundance (Fig. 26). Mean biomass of endemic species is highest inside the CBSFA boundaries (2.23 g/m^2) as compared to outside and within the Puʻuhonua (1.63 g/m^2 and 0.94 g/m^2) (Table 11). This is attributed to *manini (Acanthurus triostegus* or the Convict tang), which comprise 67% of total biomass for endemic fishes.

Indigenous percent composition is similar between Hāʻena inside and outside the CBSFA boundaries, but mean biomass of indigenous species is 62% higher inside the CBSFA (Table 11). This is due to the high biomass of *Acanthurus leucopareius (māikoiko), Melichthys niger (humuhumuʻeleʻele), Monotaxis grandoculis (mu),* and *Naso unicornis (kala)*. Non-native species have the lowest mean biomass and abundance inside the Makua Puʻuhonua, and the highest mean biomass of non-native species are found outside the CBSFA boundaries (Table 11). *Taʻape,* or *Lutjanus kasmira* (Bluestripe snapper), is responsible for the high biomass of non-native species, comprising 80% of total non-native fish biomass outside the CBSFA. Mean biomass of *taʻape* outside the CBSFA boundaries (9.41 g/m^2) is nearly double that of inside the CBSFA (5.85 g/m^2). The Bluestripe snapper was only recorded on one transect inside the Puʻuhonua.

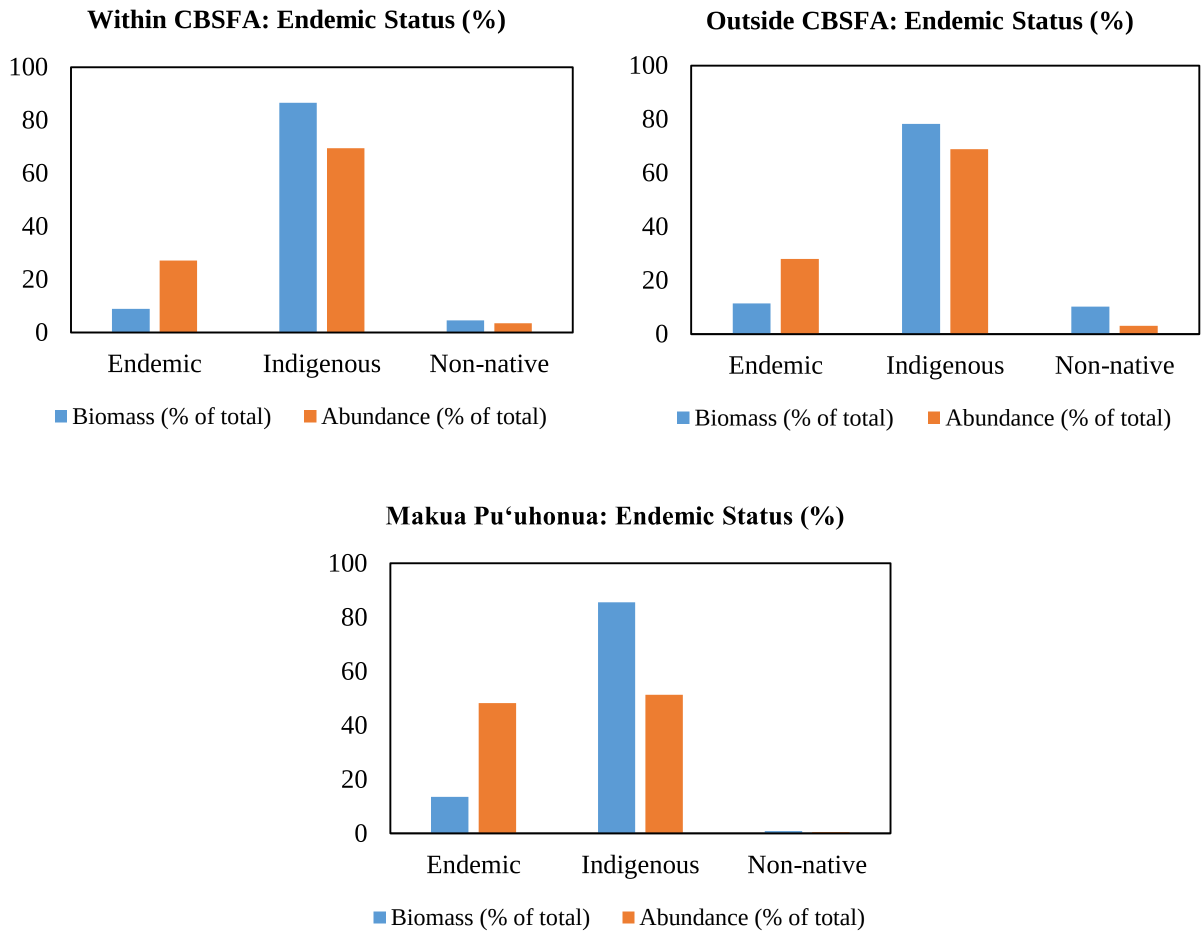


Figure 30. Endemic status within the CBSFA (n=48), outside the CBSFA (n=40), and inside the Makua Pu‘uhonua (n=10) shown as a percent of total biomass and abundance.

Table 11. Mean biomass (g/m²) and mean abundance (IND/m²) of endemic status within the CBSFA (n=48), outside the CBSFA (n=40), and inside the Makua Puʻuhonua (n=10) for 2019**.**

Sector	Status	Mean biomass (g/m²)	Mean abundance (IND/m²)
Inside CBSFA	Endemic	2.23 ± 12.44	0.04 ± 0.09
	Indigenous	7.93 ± 37.94	0.04 ± 0.09
	Non-native	9.85 ± 19.83	0.05 ± 0.09
Outside CBSFA	Endemic	1.63 ± 4.24	0.04 ± 0.05
	Indigenous	4.91 ± 10.91	0.04 ± 0.09
	Non-native	13.90 ± 28.90	0.04 ± 0.06
Makua Puʻuhonua	Endemic	0.94 ± 2.17	0.05 ± 0.05
	Indigenous	2.50 ± 4.16	0.02 ± 0.03
	Non-native	1.02 ± 0.47	0.01 ± 0.00

Invasive Species Removal Efforts

In an effort to reduce invasive species populations and promote community engagement, the first annual Kauaʻi Invasive Xtermination (KIX) fishing tournament was hosted on the 24th of August, 2019. The event was organized by Rueben Kim and his team with the support of the Department of Land and Natural Resources' Division of Aquatic Resources. Collaborators and sponsors included the non-profit Hui Makaʻāinana o Makana, Kapaʻa Beach Shop, Seasport Divers, Venture Wetsuits, Long Fins, Kauai Camper Rental, Torelli Spearfishing USA, Lopaka Customz, Slamskeez, and more. The event took place at the YMCA Camp Naue on the north shore, and competitors were allowed to fish anywhere within the Hāʻena CBSFA but were only permitted to catch the invasive species *C. argus* (*roi* or the peacock grouper), *L. kasmira* (*taʻape*), and *L. fulvus* (*toʻau*). University of Hawaiʻi researchers also participated in the event, including Dr. Tim Grabowski from UH Hilo and the Hawaiʻi Cooperative Fishery Research Unit whose team removed otoliths, the small calcareous bodies in the inner ear involved in sensing gravity and movement, which can be used to estimate the age of bony fishes (Morales-Nin 1992; Bermejo 2014). The Coral Reef Ecology Lab assisted the Hawaiʻi Cooperative Fishery Research Unit in otolith collections and Hui Makaʻāinana o Makana with fish measurements.

During the tournament, 72 divers caught 195 *roi*, 87 *taʻape,* and 67 *toʻau.* A total of 111 otoliths were collected from 44 samples of *roi*, 42 *toʻau,* and 25 *taʻape.* The size of *roi* collected for otolith samples ranged from 17.6 to 45 cm and weighed between 97 and 1,710 grams. *Toʻau* caught for sampling ranged from 17 to 35 cm and 90 to 815 grams, and *taʻape* ranged from 18.3 to 29.4 cm and 90 to 365 grams. Measurements for *toʻau* and *taʻape* were from subsamples due to the large volume collected. Results from otolith samples are pending.

Community-based collaborative efforts in invasive fish species removal have been effective in the Caribbean, and research conducted on the Big Island shows long-term eradication is effective and feasible (Peiffer et al. 2017; Giddens et al. 2014). Removal efforts of the invasive lionfish in the Caribbean have shown reefs subjected to regular removal events (approx. 2-3/mo) resulted in a 95% decrease in lionfish biomass as compared to sites subject to no removal efforts (Peiffer et al. 2017). In Puakō and Kaʻūpūlehu, Hawaiʻi, a removal experiment of *roi* by contracted fishers show that it is possible to maintain depleted populations with a sustained level of targeted fishing effort (Giddens et al. 2014). Since efforts were costly due to associated SCUBA and boat costs in the Puakō and Kaʻūpūlehu region, it is suggested that community, volunteer-based round-up events be used. These groups have the potential to impact invasive species populations with long-term, frequent eradication efforts.

Summary of Size Classes

Temporal shifts

Fishes were placed into three size classes: small (<5cm), medium (5-15 cm), and large (>15 cm). In 2019, medium sized fishes had the highest abundance overall (p<0.001), and fish abundance in the large size class was significantly greater than abundance in the small size class (p<0.001). Throughout the years when examining all divisions combined, all size classes had a significantly greater abundance in 2017 as compared to 2016, but 2017 was not significantly different from 2019 except in the largest size class. In 2019 surveys, fish in the largest size class were significantly greater in abundance than in 2016. When comparing between sectors for all years combined, abundance of the largest size class was significantly greater inside the CBSFA as compared to outside (p=0.010).

Spatial shifts

When examining trends across years within sectors, abundance for fishes in the smallest size class inside the Hāʻena CBSFA was greater in 2017 than in 2016 and 2018 (p=0.003 and p=0.004, respectively) (Fig. 31). Medium sized fishes were also greater in abundance in 2017 as compared to 2018 and 2019 (p=0.037 and p=0.042, respectively), while there were no statistical differences in abundance for the largest size class between years. Inside the Makua Puʻuhonua, small fishes have been steadily increasing in abundance since 2017, and abundance in 2019 has significantly increased since 2017 (p=0.006) (Fig. 31). A significant increase was also seen in the largest size class in 2017 as compared to 2016 (p=0.017), which is most likely due to the high frequency of *C. melampygus (ʻōmilu)* recorded on 25% of transects that year compared to a total absence in 2016. Outside the CBSFA, medium and large fish size classes remain relatively consistent with no statistical differences between years, however, fishes in the smaller size class fluctuate with significantly higher abundances in 2017 and 2019 as compared to 2016 (p=0.001 and p=0.004, respectively) (Fig. 31). These shifts in size class can be strongly related to annual fish recruitment events.

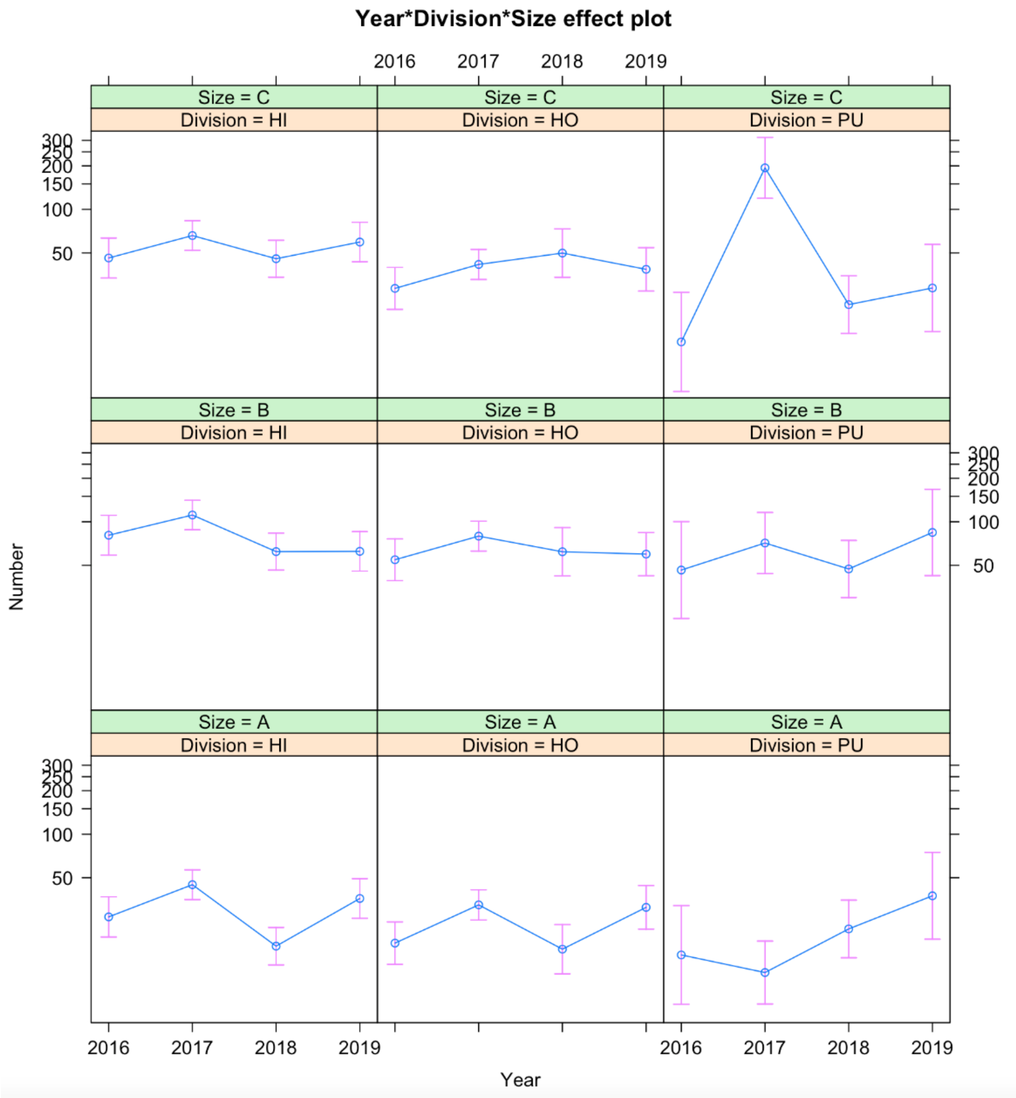


Figure 31. Differences in the mean number of fishes (number/transect) in each size class from 2016-2019 within the Hāʻena CBSFA (HI), outside (HO), and within the Makua Puʻuhonua (PU). Size classes: A (<5cm), B (5-15 cm), and C (>15 cm).

Fish size class composition is fairly similar between all three sectors, with the largest size class contributing most strongly to total biomass (HI= 93%, HO= 89%, PU= 71%) and the midsize class comprising the majority of abundance (HI= 40%, HO= 46%, PU= 56%) (Fig. 32). Size class composition for abundance is most evenly distributed within the CBSFA. Dominant fishes in the larger size range (>15 cm) include *Acanthurus leucopareius (māikoiko,* Whitebar Surgeonfish), *Melichthys niger (humuhumuʻeleʻele,* the Black Durgon), and *Monotaxis grandoculis* (*mu*, the Bigeye Emperor) within the CBSFA. Outside the CBSFA, *Acanthurus olivaceous* (the Orangeband Surgeonfish, *naʻenaʻe), A. leucopareius*, and *Kyphosus* species (the Lowfin Chub, *enenue*) comprise the majority of the larger fishes. Inside the Makua Puʻuhonua, *Abudefduf abdominalis* (Hawaiian Sergeant, *mamo)* and *A. vaigiensis* (Indo-Pacific Sergeant) are the largest fishes found (15-17 cm) although they are relatively smaller than other common large fishes. Size class composition for all sectors were similar compared to the previous year, with the exception of a notable increase in biomass of mid-size classes inside the Puʻuhonua (11% to 28% of total biomass).

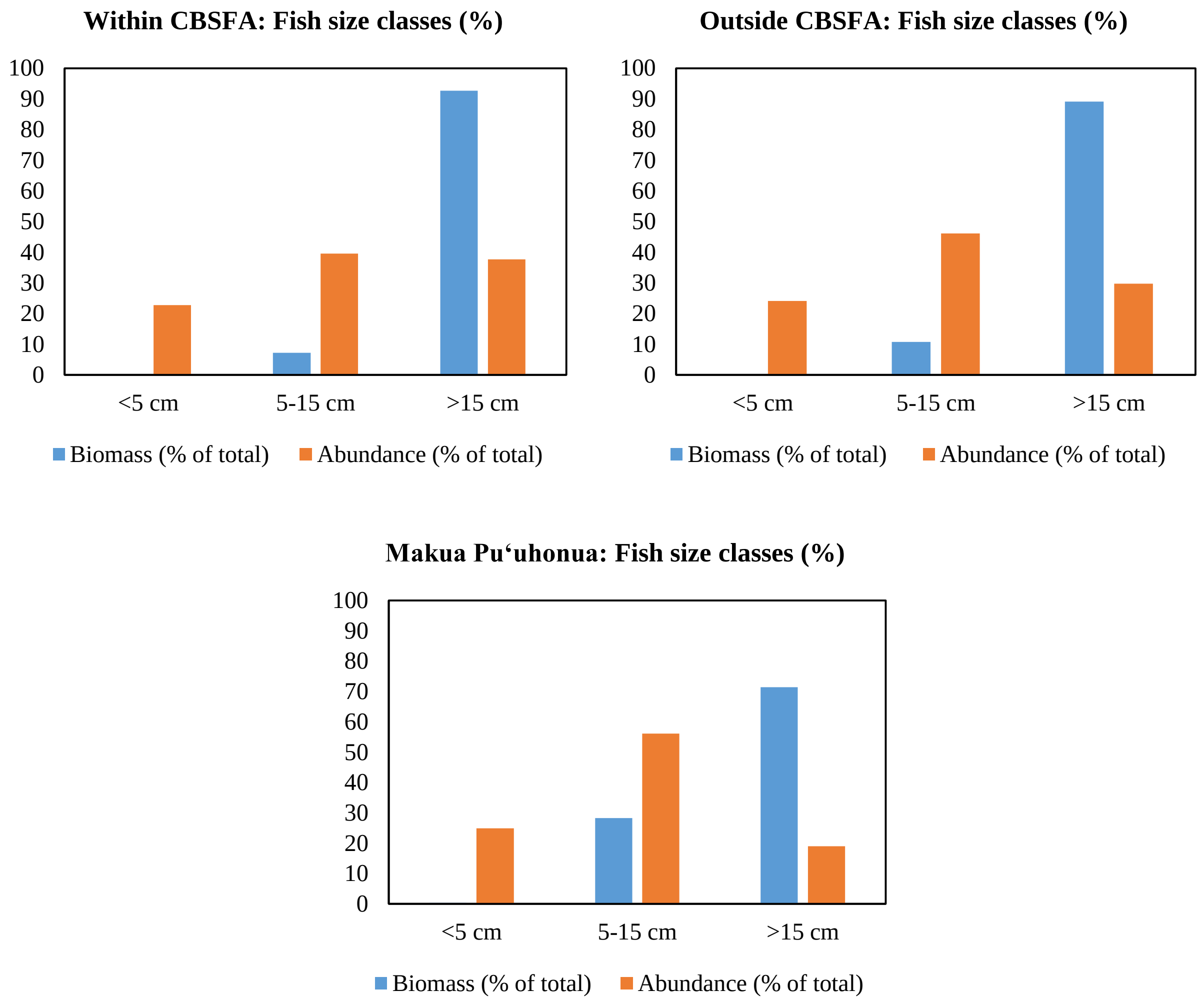


Figure 32. Size class summaries within the CBSFA (n=48), outside the CBSFA (n=40), and inside the Makua Puʻuhonua (n=10) shown as a percent of total biomass and abundance.

Diversity and Evenness

Diversity plays an important role in many ecological and conservation issues. It can be a significant factor in assessing the efficacy of management efforts. Reductions in diversity can be indicative of fishing pressure since it can selectively remove specific species. Other anthropogenic impacts, such as eutrophication and sedimentation, can also result in phase shifts that impact fish diversity. Natural conditions can also determine diversity. Areas sheltered from high wave energy have previously been reported to maintain higher fish populations and exhibit greater species diversity in the Hawaiian Islands (Friedlander & Parrish 1998; Friedlander et al. 2003). This can be attributed to reduced habitat complexity in high-energy environments. Seasonal variability in wave impacts can structure the physiography of reefs, reducing habitat and spatial complexity for fishes through a dominance of encrusting morphologies of corals. Evenness is a component of diversity, where diversity is divided by the total number of species present, for an expression of the abundance of different species (Brower and Zar 1984).

In 2019, no significant effects of year or division are found in diversity or evenness. The overall average fish diversity at Hāʻena (1.89) is similar to Kauaʻi diversity (2.11) and statewide diversity average (1.94), which ranged from 0.25 at Pelekane, Hawaiʻi to 2.99 at Molokini Island, Maui (Rodgers 2005). When comparing the diversity between sectors, diversity is highest inside the Makua Puʻuhonua (2.01), followed by within the CBSFA (1.91), and outside the CBSFA boundaries (1.84). While there are no significant differences in diversity among years with respect to division, diversity inside the CBSFA decreases from 2.08 to 1.91, and the Makua Puʻuhonua shows a slight increase from 1.91 to 2.01. Evenness at other Kauaʻi sites from 53 rapid assessment sites (0.77) and statewide from 64 CRAMP sites (0.70) was also comparable to the evenness at Hāʻena (0.71) and found to be similar (Rodgers 2005). No statistical differences in evenness for overall Hāʻena among years are found in this survey period. Evenness is fairly similar between sectors ranging from 0.68 to 0.70, with no significant differences among divisions. Evenness inside the CBSFA was greater in 2018 than in 2016 (p=0.042), but not statistically different from 2019.

Benthic Cover

A total of 98 transects were conducted in Hāʻena in March-August 2019 (48 inside the CBSFA, 10 transects in Makua Puʻuhonua, and 40 transects outside the CBSFA). As in previous years, stations are separated into shallow (<7 m) and deep (>7 m) depths. The largest change is a 2.5% decrease in mean coral cover outside the shallow CBSFA (5.46%-9.62% from 2017-2018 and 9.62%-7.14% from 2018-2019), all other patterns of benthic cover are similar to the previous years' surveys (Figs. 33, 34, 35, 36, & 37). The shallow, protected Puʻuhonua continues to have higher mean coral cover than other sectors (11.88%) with a slight increase from 2018 (11.68%). Mean coral cover inside the CBSFA is higher at shallow stations (5.87%) as compared to deep transects (4.07%) with slight increases in both sectors from the previous year (Figs. 33 & 34). Outside the CBSFA, mean coral cover is also higher at shallow stations (7.14%) than at the deeper stations (3.21%) similar to the previous year (Figs. 35 & 36), and outside sites show slight decreases in coral cover from 2018.

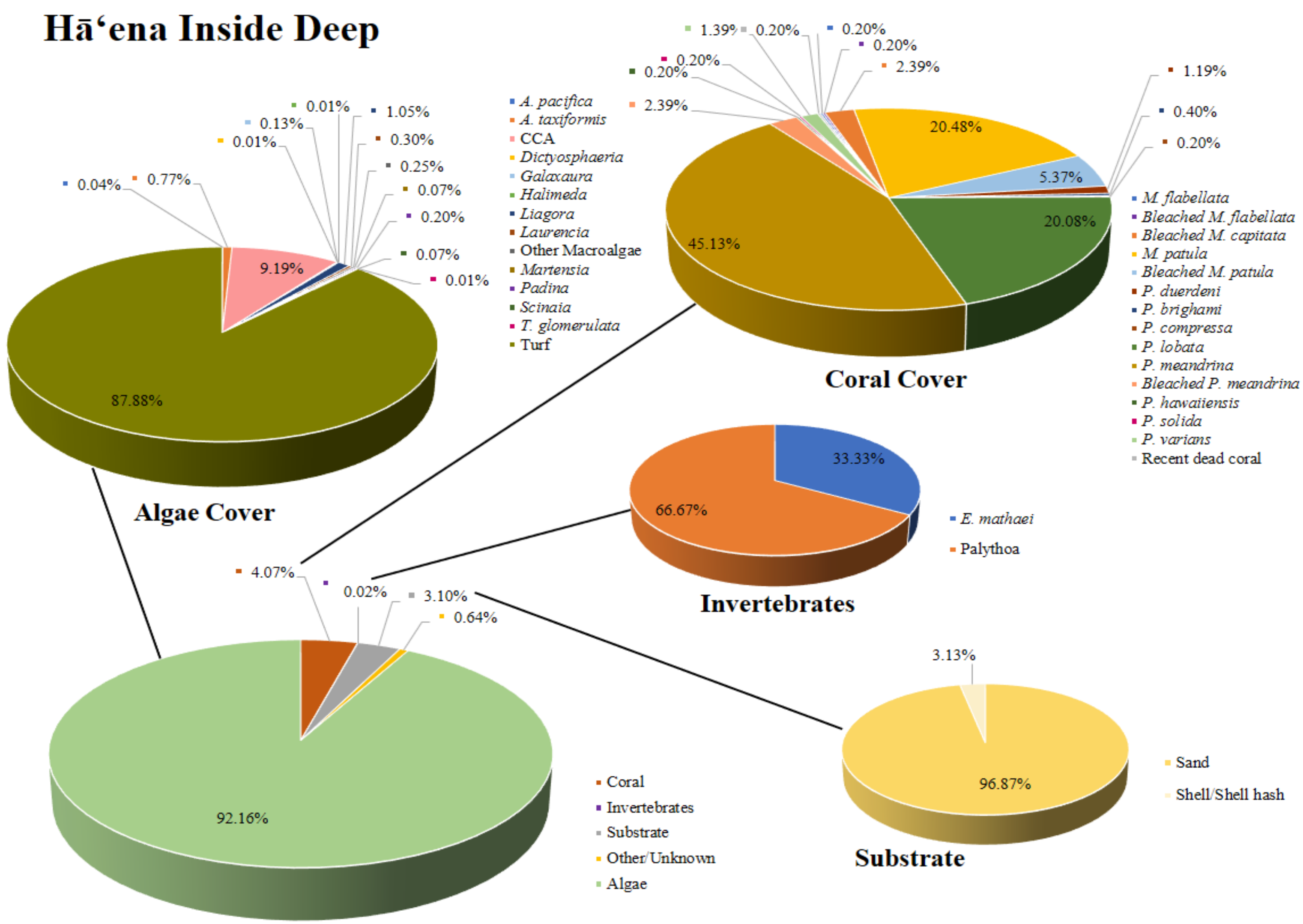


Figure 33. Overall benthic cover, coral, other invertebrates, algae and substrate at Hāʻena stations greater than 7 m depth within the CBSFA.

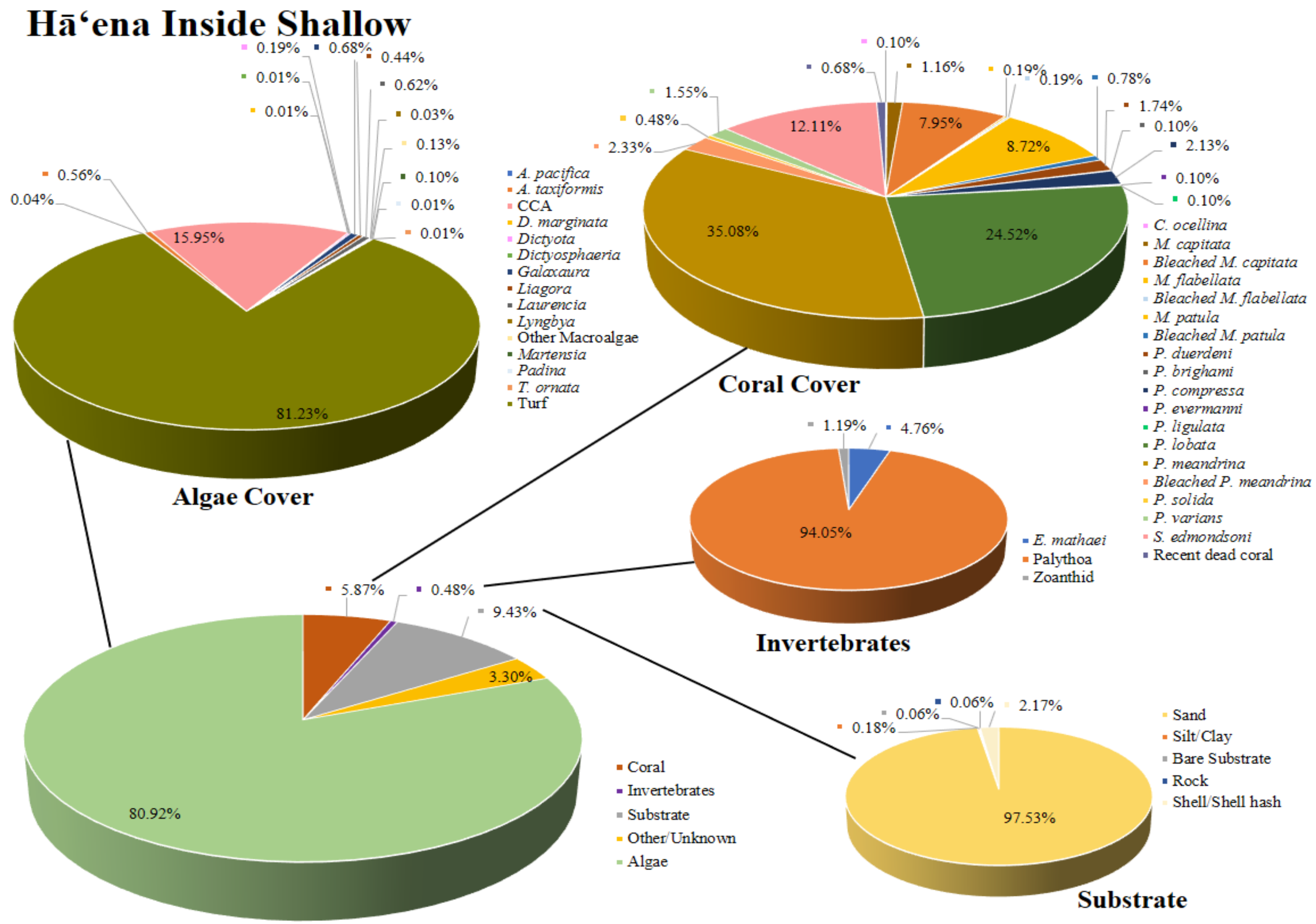


Figure 34. Overall benthic cover, coral, other invertebrates, algae and substrate at Hāʻena stations less than 7 m depth within the CBSFA.

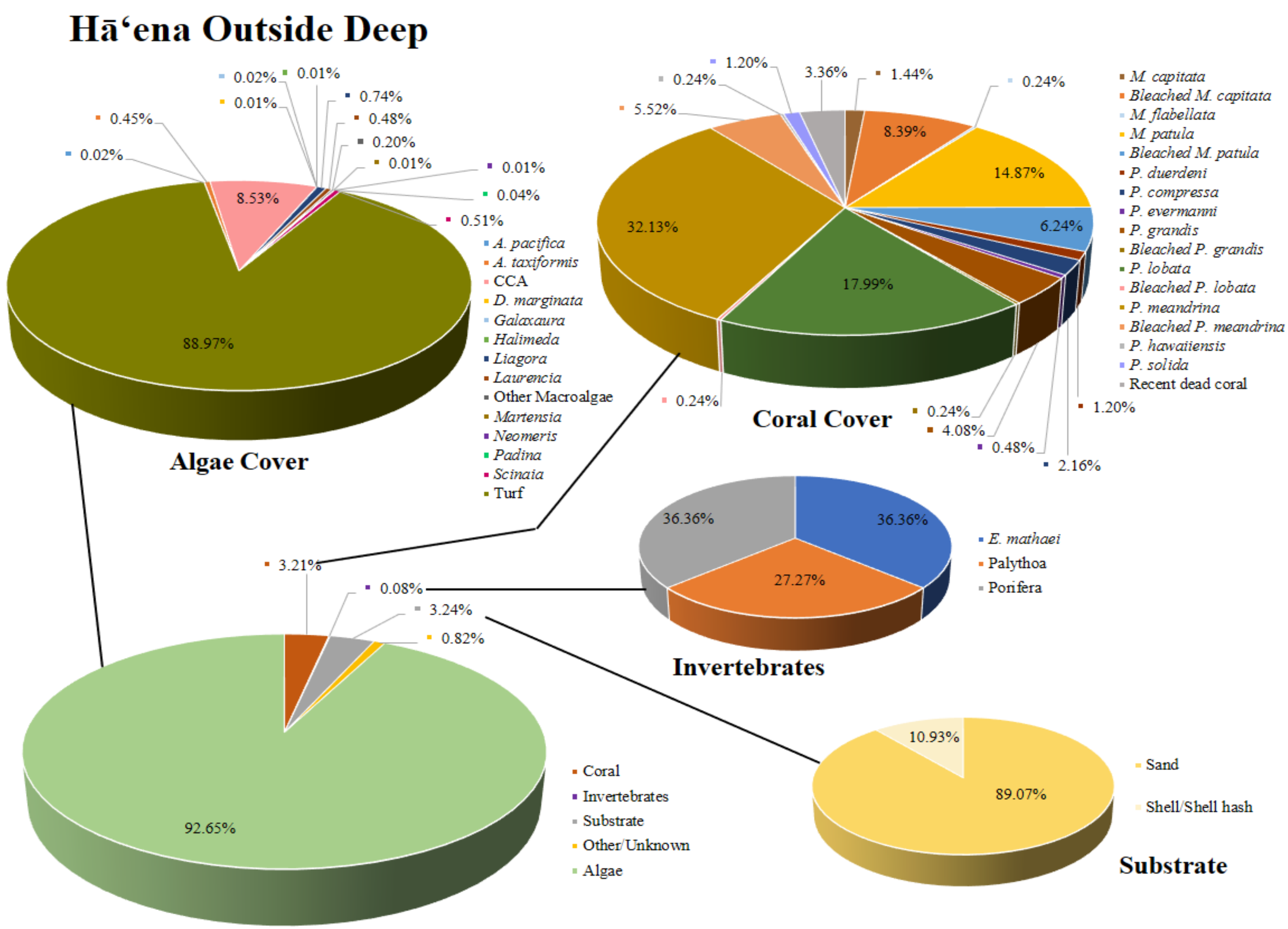


Figure 35. Benthic percent cover depicting coverage overall, coral, other invertebrates, algae and substrate at Hāʻena stations greater than 7 m depth outside the CBSFA boundaries.

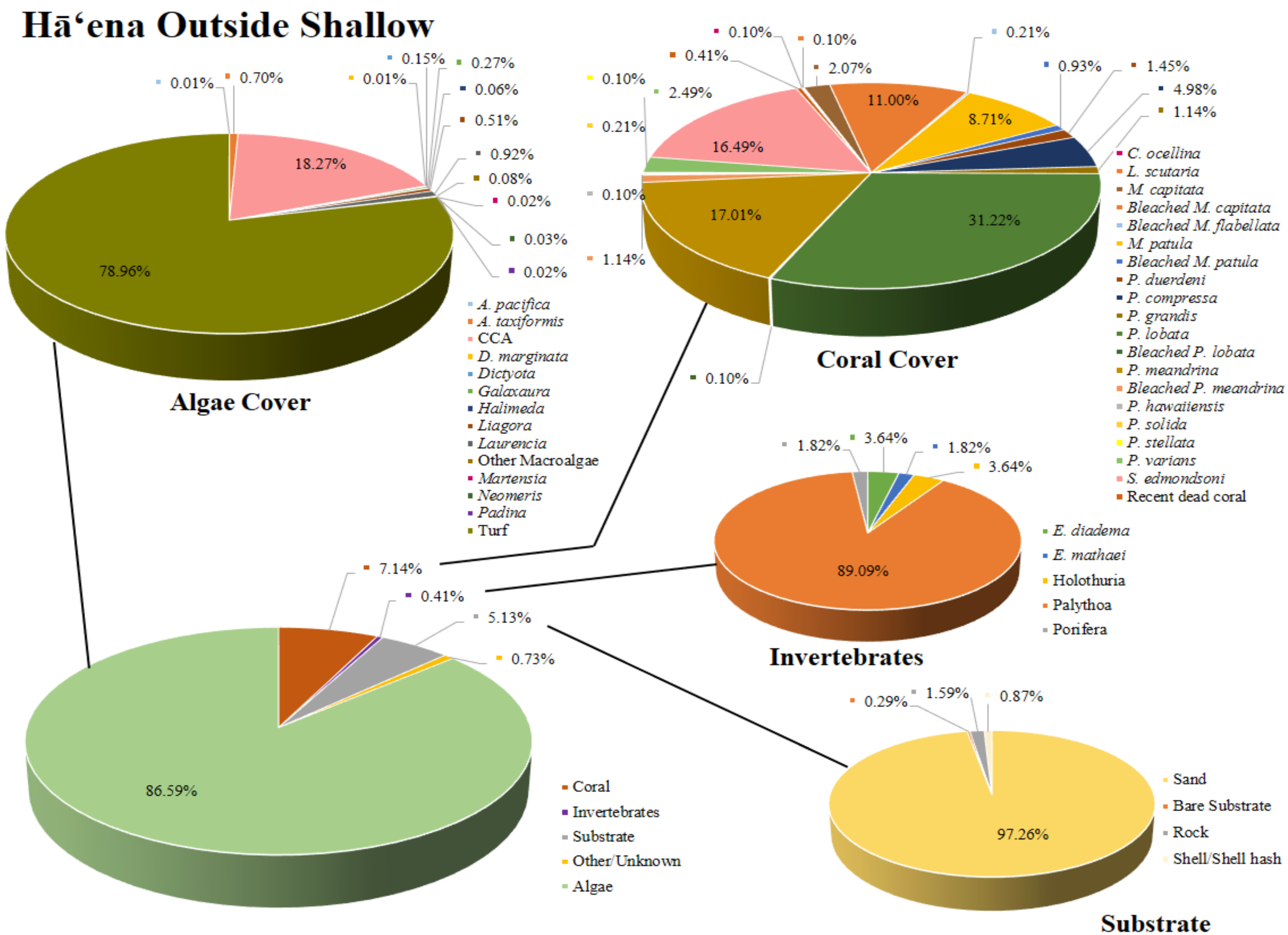


Figure 36. Benthic percent cover depicting coverage overall, coral, other invertebrates, algae and substrate at Hāʻena stations less than 7 m depth outside the CBSFA boundaries.

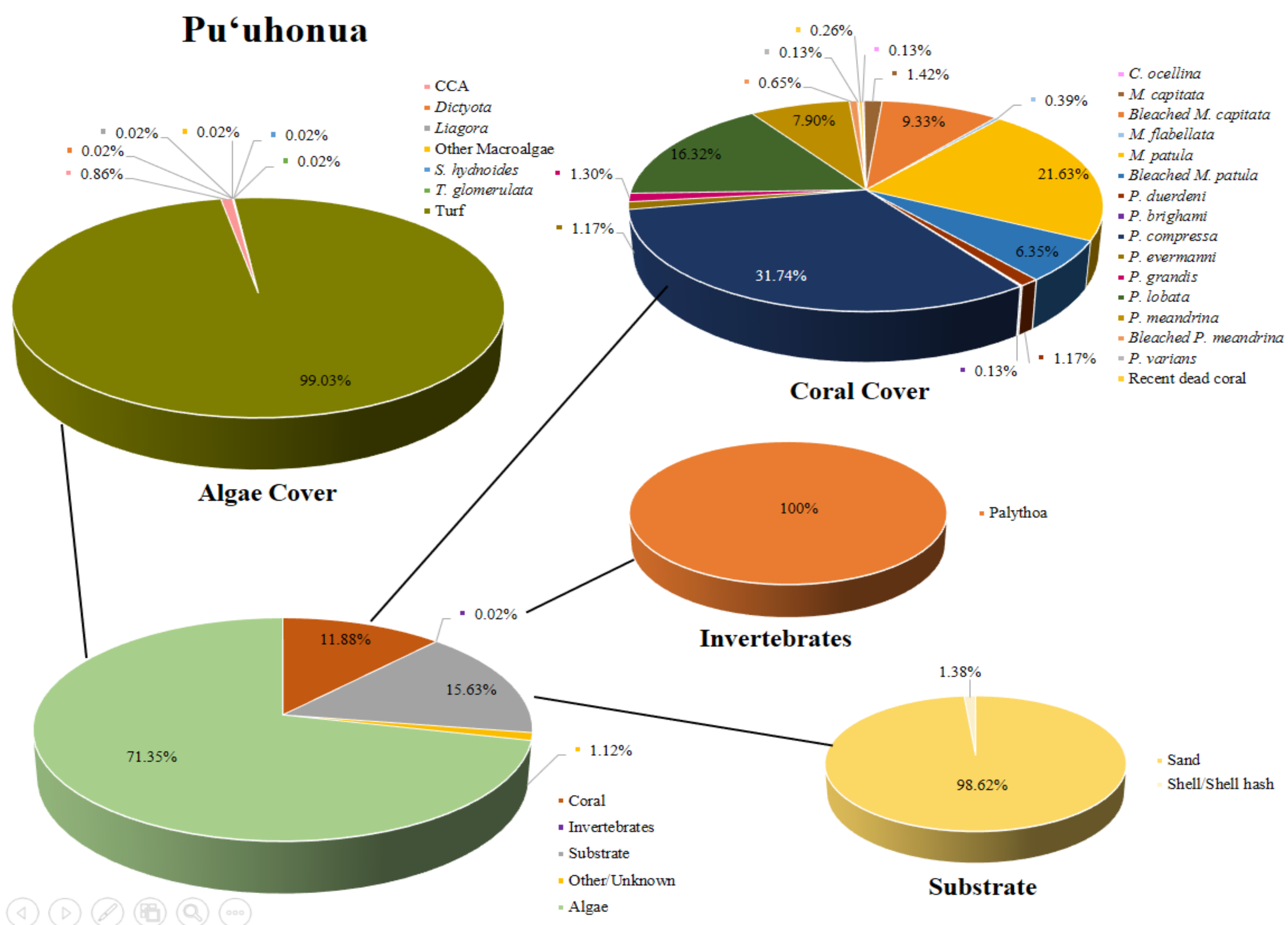


Figure 37. Benthic percent cover depicting coverage overall, coral, other invertebrates, algae and substrate at Hā‘ena stations within the Makua Pu‘uhonua.

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. However, the pattern of higher coral cover in shallower sites is consistent throughout years at Hāʻena.

Turf algae is the most dominant benthic cover both inside and outside the CBSFA. Inside the CBSFA, mean turf cover is lower on shallow (65.74% of total benthic cover) than in deep transects (81.00%). Outside the boundaries, turf cover on shallow transects (68.38% of total benthic cover) is lower than on deep transects (82.44%). As expected, mean calcareous coralline algae (CCA) is considerably higher on shallow transects (15.82% outside and 12.90% inside), where greater amounts of sunlight occur, than on deeper transects (7.91% outside and 8.47% inside).

A total of 15 coral species are reported inside the CBSFA and 16 outside. Only 12 species are reported within the Makua Puʻuhonua likely due to a smaller sample size of transects and a smaller area. This is higher than the previous year with 13 species found inside the CBSFA, nine recorded within the Puʻuhonua, and the same number of coral species reported outside the CBSFA (16). *Pocillopora meandrina* is the most common species quantified inside the CBSFA at both shallow and deep sites, comprising 35.08% and 45.13%, of the total coral cover respectively. *Porites lobata* is the most dominant coral outside the CBSFA shallow stations accounting for 31.22% of coral cover, while *P. meandrina* is the most dominant at the deep stations similar to inside the CBSFA (32.13%). Within the Makua Puʻuhonua, the most common coral was *Porites compressa,* comprising 31.74% of the total coral cover, followed by *Montipora patula* (21.63%). An increase in the octocoral *Sarcothelia edmondsoni* was detected in shallow transects inside and outside the CBSFA, rising from comprising 1.1% of total coral cover to 14.3% from 2018-2019. It was not seen at the deep stations or at the Makua Puʻuhonua. There were no significant differences between years for division and depth until 2019. Puʻuhonua in 2019 had higher coral cover than deep stations inside or deep stations outside (p=0.0028 and p=0.0004, respectively). Hāʻena outside shallow sites had statistically greater coral cover than the outside deep sites (p=0.0424).

The percent of bleached corals comprising total coral cover shows an extreme increase across all sectors at Hāʻena. The average percentage of bleached corals between 2018 and 2019 tripled in just one year. This sudden site-wide increase of bleaching is likely attributed to the bleaching that occurred statewide in 2019. This bleaching event reached its peak several months after these surveys were conducted between March and August, thus the bleaching was probably more severe than reported here. The mortality associated with this bleaching will become apparent in next year's surveys. Bleaching continues to be higher outside the CBSFA as compared to inside (Fig. 38). Stations outside the CBSFA that experienced a notable increase in bleached corals from 2016 to 2018 continue to show a sharp increase in 2019. Outside the CBSFA, deep sites show a slightly higher percentage of bleached corals as compared to shallow sites (20.6% vs.

13.4%), contradicting previous observations and studies which suggest corals in higher irradiance environments due to depth variability are more susceptible to bleaching (Bahr et al. 2015b; Bahr et al. 2016). The most common species recorded as bleached in all sectors is *M. capitata*, identical to the 2018 surveys, with the exception of deep stations inside the CBSFA where *P. meandrina* tied for the top bleached species. 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 (Berkelmans and van Oppen 2006; Bay et al. 2016; Mieog et al. 2009; Cunning et al. 2016; Little et al. 2004; Cantin et al. 2009). Colony morphology can also affect bleaching vulnerability (Loya et al. 2001), with *M. capitata* displaying two different color morphs 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). Varying morphology and *Symbiodinium* clades may account for some of the prevalence of bleached *M. capitata* in Hāʻena and Pilaʻa.

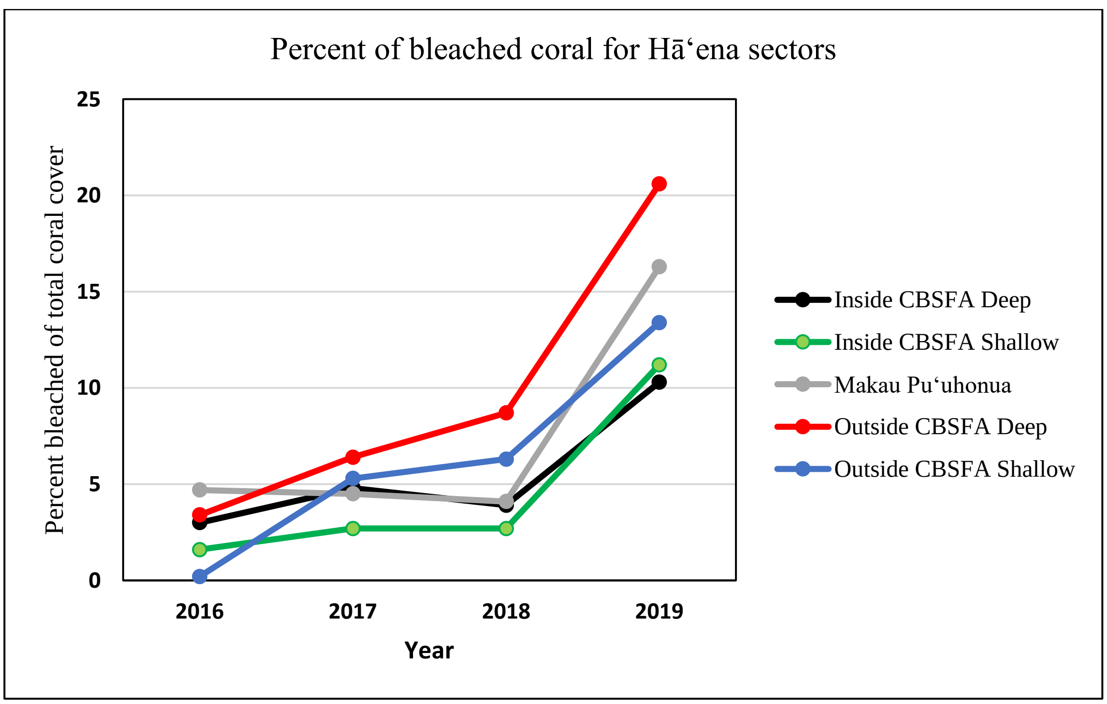


Figure 38. The percent of corals bleached of the total coral cover separated by deep and shallow sites from 2016-2019 inside the CBSFA, outside, and Makua Puʻuhonua.

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 from the islands of Hawai‘i and Kaua‘i in 2014, and more recently from O‘ahu 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 demonstrated in the Caribbean in the early 1980s when a crash in the urchin populations was followed within a year by an 80% decline in coral cover and biodiversity. The current urchin and sea cucumber surveys at Hā‘ena serve as a baseline for annual surveys conducted inside and outside the CBSFA boundaries and aid in determining change in populations. Other factors such as temperature, coral, macroalgae, fishes and sediment at these stations can be compared to any declines.

In 2018, a drastic decline in urchin populations was detected both inside and outside the CBSFA boundaries. Following previous years, a lower number of urchins were recorded at the shallow sectors (<7 m) as compared to the deeper sectors (>7 m) both inside and outside the CBSFA. The average number of urchins per transect at shallow sectors inside and outside boundaries declined dramatically from 2017 (8.8) to 2018 (2.0) before increasing slightly in 2019 (3.2). This is in sharp contrast to urchin means at deep sectors, which were identical between years 2017 (10.8) and 2018 (10.8), however, deep sectors show a decline in 2019 (6.4) (Table 12).

Table 12. Number of urchins (#) and transects (n) in each sector and year.
Number per transect (#/n). Average shown by year and depth.

2017	#	n	#/n	2018	#	n	#/n	2019	#	n	#/n
Inside Shallow	238	24	9.9		96	35	2.7		135	28	4.8
Outside Shallow	174	23	7.6		20	15	1.3		31	20	1.6
Inside Deep	207	25	8.3		167	19	8.8		105	20	5.3
Outside Deep	347	26	13.3		217	17	12.8		149	20	7.5
Shallow average 2017		8.8		Shallow average 2018			2	Shallow average 2019			3.2
Deep average 2017		10.8		Deep average 2018			10.8	Deep average 2019			6.4

The decline in 2018 urchins was 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 reduce salinity in shallow waters (Banner 1968; Jokiel et al. 1993). Flash floods that 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 Kāne‘ohe 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). Extrapolating the 2014 Kāneʻohe Bay calculations to the 2018 Hāʻena flooding, an estimate of the depth of the freshwater lens (141 cm or 4.6 ft) and the depth of possible impact (34.4 ft or 10.5 m) was made using the rainfall, freshwater depth and zone of impact data. This is supported by the frequency of occurrence of urchins from the shallow and deep sites both inside and outside the CBSFA where urchins at shallow sites <7 m suffered extensive declines while deeper sites > 7 m remained stable. Adult and larval echinoderms have been well documented to be stenohaline, 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 and Russell 2003). Freshwater floats above seawater because it is less dense, however, this low salinity lens can 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, thereby impacting the urchin populations in shallow (7 m) sites. Other possible explanations for the pronounced decline in urchin populations 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 to the shallower areas.

In 2019, there is an overall decline in shallow waters of all seven species recorded. As in 2018, *E. mathaei* appears to be the species most heavily impacted. This species may be useful as a proxy of environmental conditions or an indicator of freshwater impacts. It is found to be abundant at both depths and was the top species across all sectors in Hāʻena from 2016-2019. This species drastically declined only at shallow sectors between 2017 (7.7 urchins/transect) and 2018 (1.1 urchins/transect) before increasing slightly to 2.7 urchins/transect in 2019, possible evidence of partial recovery from the 2018 flood event. In 2019, there was a significant difference in total sea urchin abundance by depth overall ($p<0.001$) (Fig. 39). At deeper sectors there was no statistically significant change in mean abundance from 2017 (10.9 urchins/transect) to 2018 (10.7 urchins/transect) providing strong evidence of freshwater impacts, however urchins have decreased in 2019 to 6.4 urchins/transect.

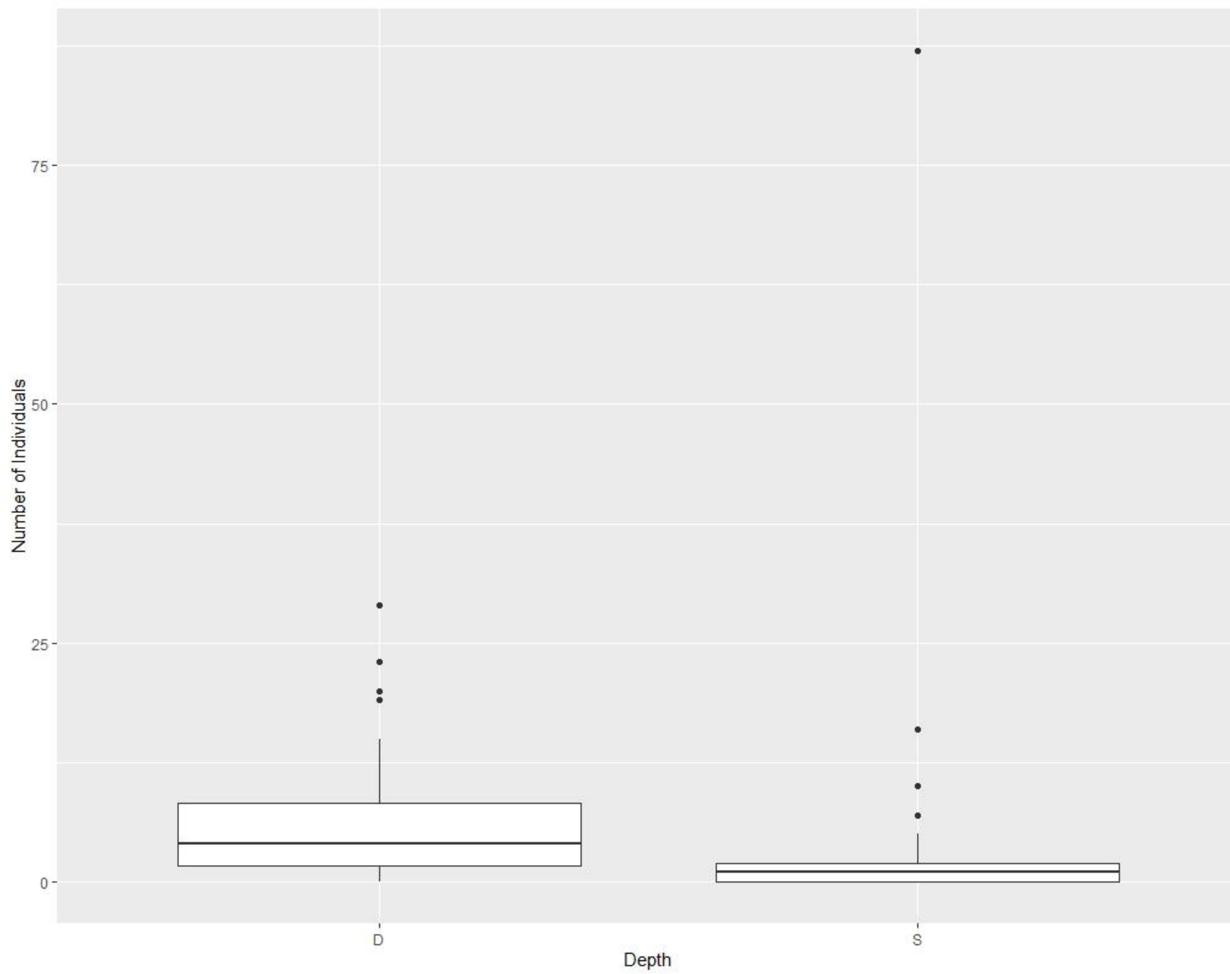


Figure 39. A box plot of the median sea urchin abundance by depth (D= deep, S= shallow) in 2019 with whiskers showing the inter-quartile range. The extreme outlier of 79 individual sea urchins seen on the upper right, was observed on the transect HIS_15_Post (Post=surveyed after re-opening of the access road).

Significantly less sea urchins were observed across all years surveyed in the Pu‘uhonua (<p=0.001) as compared to Inside or Outside the CBSFA boundaries (Fig. 40). This may be a factor of habitat rugosity. By comparing an individual sector to its 2016 baseline we can determine any shifts in urchin population. However, overall urchin abundance was also statistically different (p=0.001), showing less urchins in 2019. There was no significant interaction between year and division factors.

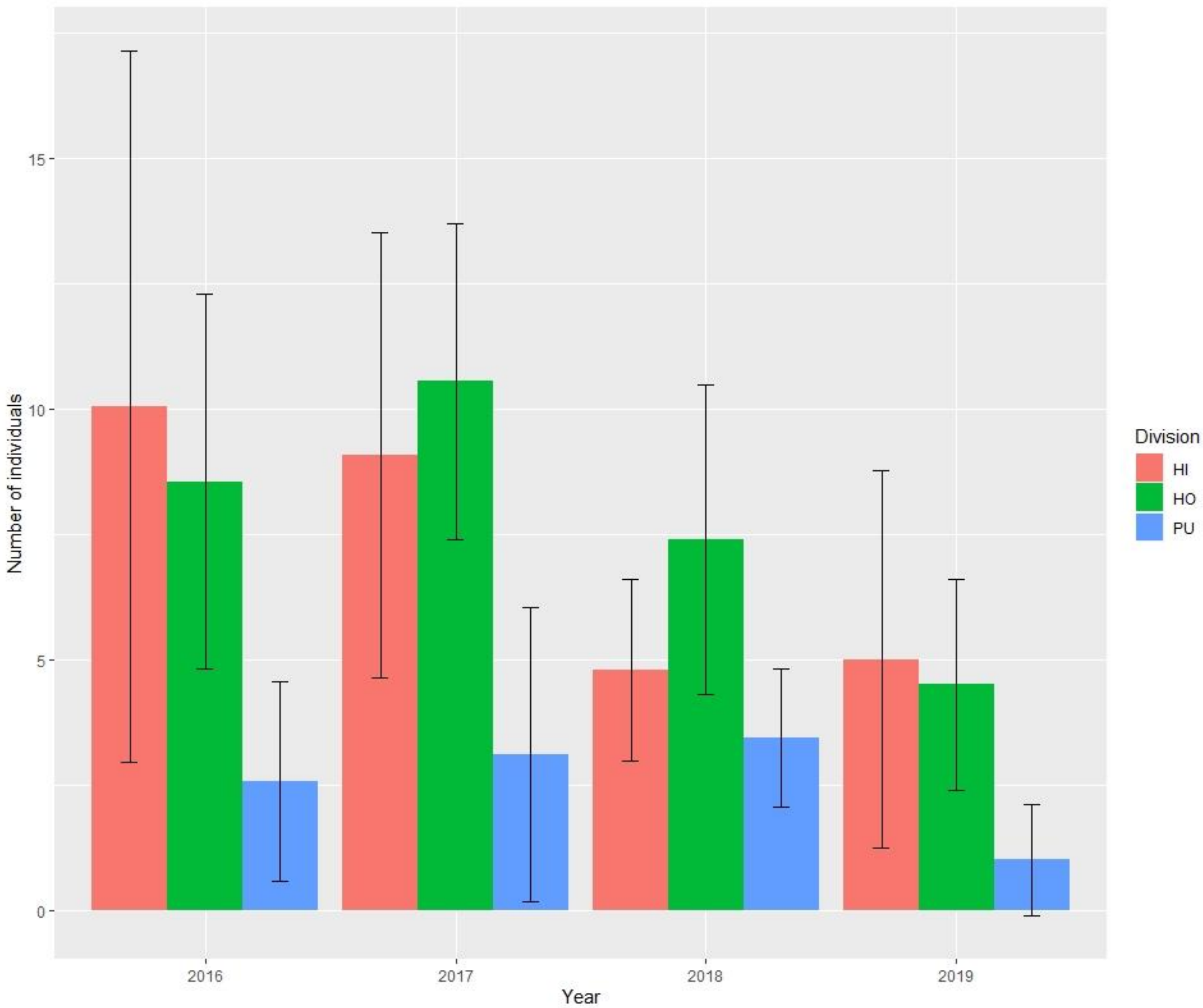


Figure 40. An interval plot of the mean number of sea urchins in Hāʻena sectors in 2016-2019. Sectors: HI= Hāʻena Inside CBSFA, HO=Hāʻena Outside the CBSFA and PU=Makua Puʻuhonua. Error bars are 95% confidence interval.

<u>Road Closure</u>

Due to severe damage to the main access road to Hāʻena (Kuhio Highway), the road was closed immediately following the April 2018 flood. Only residents were allowed access. This removed any visitor impact on reefs during this time. The road was not reopened until over a year later on 17 June 2019. Kauaʻi Assessments of Habitat Utilization (KAHU) surveys were conducted prior to the reopening of the Kuhio Highway from 27 March 2019 through 14 June 2019 (n=64) by DAR's Oʻahu and Kauaʻi teams. Post road surveys began 24 June, 2019 and continued until 6 August, 2019 (n=34). Five teams completed a total of 98 KAHU surveys.

There was no overall significant difference in total sea urchin abundance before and after the reopening of the road. There was also no statistical difference in total sea urchin abundance by division pre and post road closure (Fig. 41). There was a statistically significant difference found in total sea urchin abundance before and after the road reopening by depth (*p*=0.008) (Fig. 42). However, it appeared that one observation (Transect HIS_15_Post) with 79 individual *E. mathaei* was driving the significance. When the same model was run excluding this outlier, there was no significant effect between the interaction of road re-opening and depth (*p*=0.17).

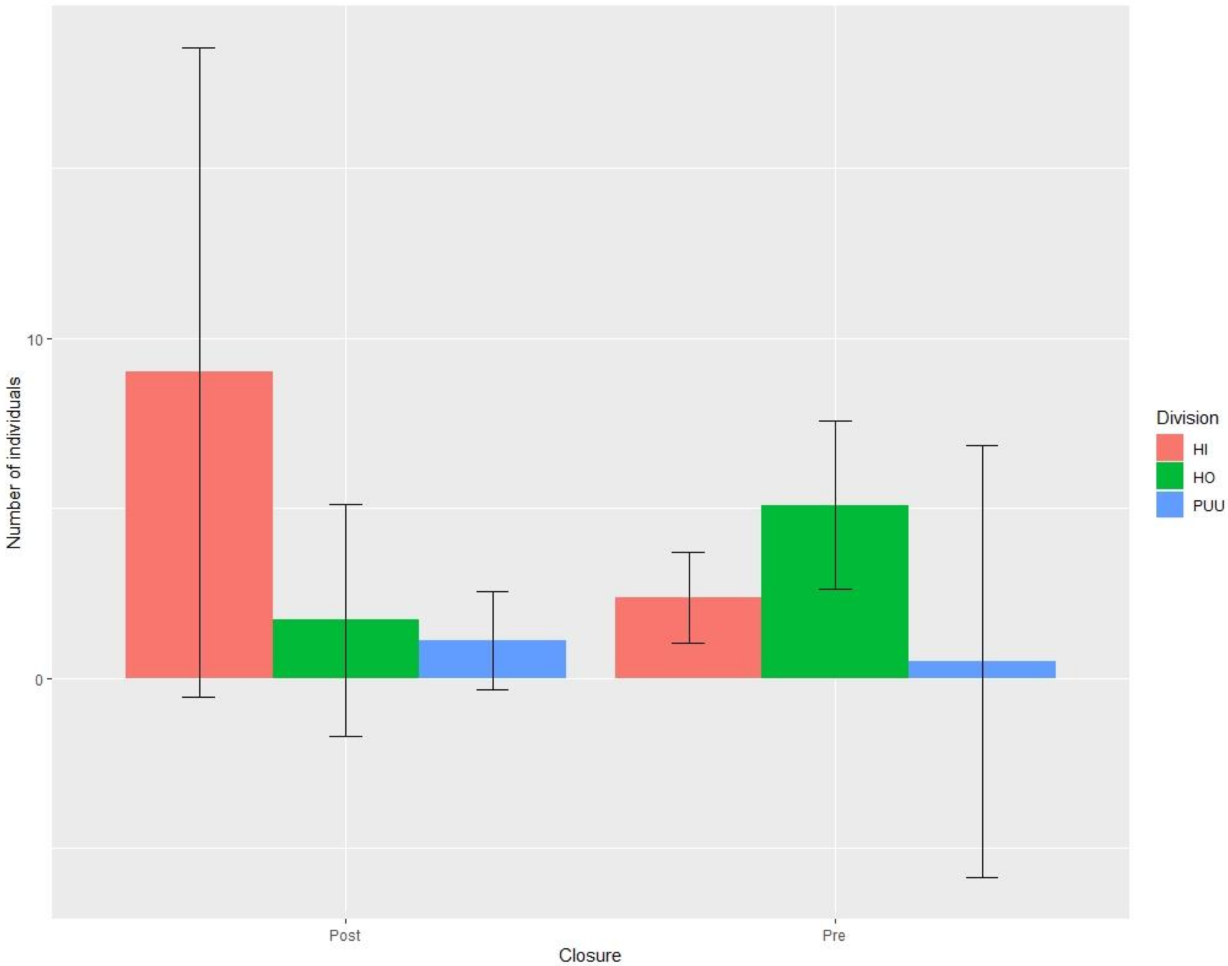


Figure 41. An interval plot of mean number of sea urchins in each sector before and after the road re-opening in Hāʻena between April 2018 and June 2019. Sectors: HI= Hāʻena Inside CBSFA, HO=Hāʻena Outside the CBSFA, and PU=Makua Puʻuhonua. Error bars are 95% confidence interval.

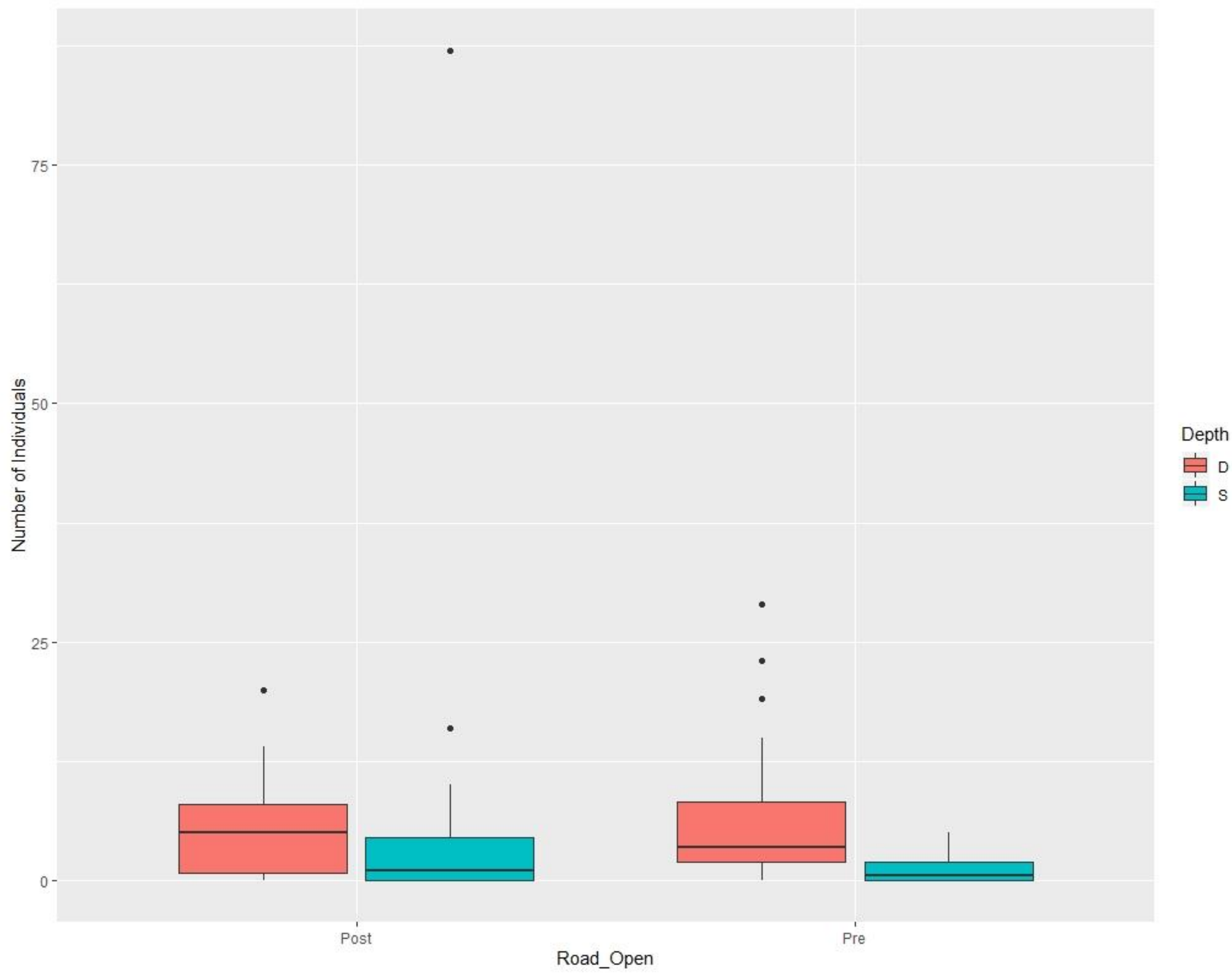


Figure 42. A box plot of median sea urchin abundance by depth (shallow=<7 m, Deep≥7 m) before and after the road re-opening with whiskers showing interquartile range. The data set used for this graph includes the anomalous shallow transect (HIS_15_Post).

Inside the Hāʻena CBSFA

E. mathaei, the Pale Rock Boring Urchin, is most abundant (191) followed in descending order by *Echinostrephus aciculatus*, the Needle-Spined Urchin (34), *E. oblonga*, the Black Rock Boring urchin (9), *Echinothrix calamaris*, the Banded Urchin (4), *H. mamillatus* the Slate Pencil Urchin (1) and *Eucidaris metularia*, the Ten-Lined Urchin (1). The top four species are identical to 2018, however, *E. diadema* is not found in 2019. Other invertebrates found on the benthic surveys include one individual of *Stenopus hispidus*, the Banded Coral Shrimp, and two *Octopus cyanea*, the Day Octopus. All three individuals were found inside the CBSFA across three separate transects. Species composition in percent of total are shown in Fig. 43.

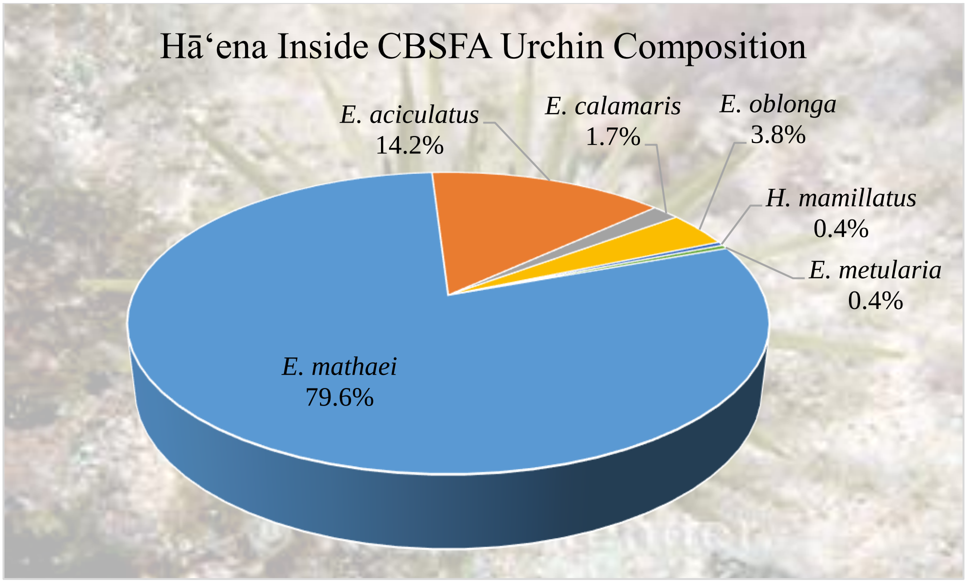


Figure 43. Sea urchin composition inside the Hāʻena CBSFA shown as a percent of total.

<u>Outside the Hāʻena CBSFA</u>

There is a total of 180 sea urchins recorded at 32 of the 40 stations surveyed. The average number of urchins per transect is 4.5. This is a decrease from 2018 where the average number of urchins per transect was 7.4. In 2019, *E. mathaei* is by far the most abundant (117) followed in descending order by *E. aciculatus* (49), *E. diadema* (12), and *E. calamaris* (2). Species composition in percent of total is shown in Fig. 44. The overall frequency of occurrence outside CBSFA boundaries (80.0%) is higher than inside the CBSFA (60.4%).

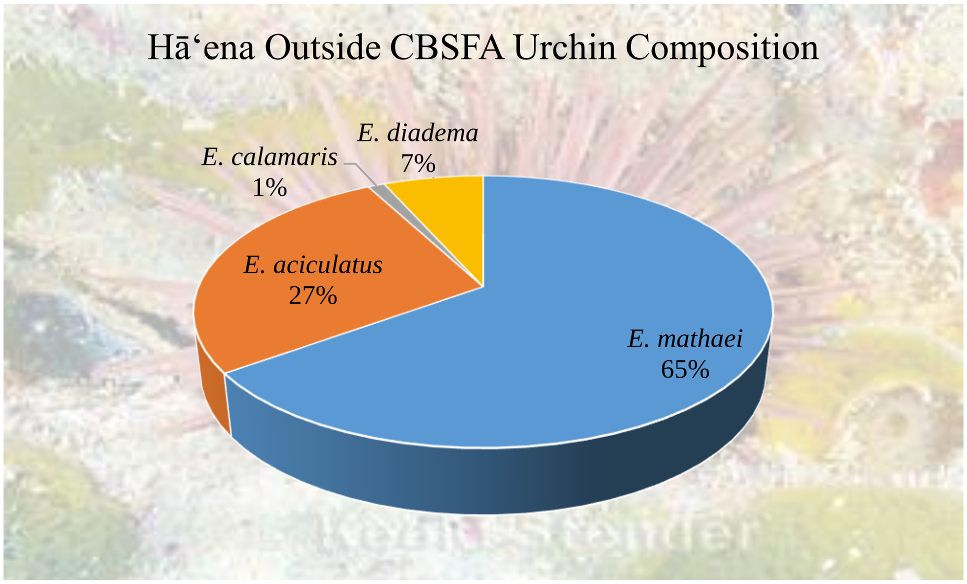


Figure 44. Sea urchin composition outside the Hāʻena CBSFA shown as a percent of total.

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 Maui and Oʻahu 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 Hawaiʻi, no rules were 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 put in place in January 2016 that bans 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 Hāʻena survey design.

In 2019, only two individuals of *Actinopyga varians*, the white spotted sea cucumber, are recorded on one transect inside the CBSFA. In 2018, there were a total of 16 sea cucumbers recorded within the CBSFA at 10 of the 55 transects surveyed. The 2019 observations are closer to the 2017 values where only one sea cucumber was found. There has been high fluctuation between years for sea cucumber abundance probably due to the small sample sizes. 2016 showed the highest numbers at 62, followed by one in 2017, 16 in 2018 and two in 2019. All of the sea cucumbers found inside the CBSFA are found on shallow transects.

Outside the CBSFA, only four individuals are recorded: two *A. varians* and two *H. atra* (Fig. 45). Sea cucumbers are recorded at three of the 40 transects for a frequency of occurrence of 7.5%. Numbers were also low in previous years outside the CBSFA boundaries (2018=3, 2017=5, 2016=12). Additionally, three of the four sea cucumbers found in 2019 outside the CBSFA were found on the shallow transects with one found in deeper waters. The small sample size restricts any conclusion of changes.

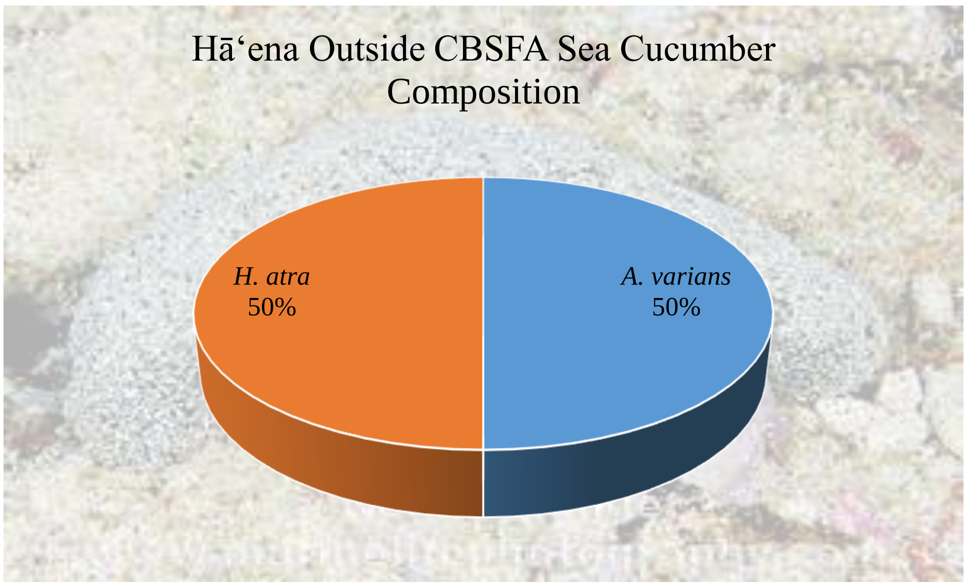


Figure 45. Sea cucumber composition outside the Hāʻena CBSFA boundaries shown as percent of total.

Sea cucumbers were statistically less abundant in 2017 and 2018 than in 2016. Across years, sea cucumbers are generally least abundant outside the CBSFA (p=0.0002). However, given the high variability and low numbers of sea cucumbers recorded (2019=2), the statistical significance is likely not valid unless a large change occurs or surveys continue across time, increasing the sample size.

Abundance of urchins and sea cucumbers by depth

In 2016, within the CBSFA, *E. mathaei* had a greater mean abundance at shallow stations, while outside the CBSFA, it was more abundant in deeper stations. 2017 showed shallow and deep stations (<7m and >7m, respectively) had similar abundance of *E. mathaei*. 2018 surveys showed that *E. mathaei* had higher abundance at deeper stations both inside and outside the Hāʻena CBSFA. 2019 shows the same pattern as 2016 where *E. mathaei* has a higher abundance at shallow stations inside the CBSFA and deeper stations have higher abundance of *E. mathaei* outside the CBSFA (Figs. 46 & 47). In both inside and outside the CBSFA, *E. aciculatus* is more abundant in deeper stations. Urchins were found on every deep transect outside the boundaries and 80% of deep transects inside, similar to 2018 values (100% outside and 95% inside). In shallow stations, 46% of the transects inside the CBSFA and 60% of transects outside the CBSFA had urchins, similar to 2018 where only half the number of transects had urchins in the shallow inside (53%) and shallow outside (53%) sectors.

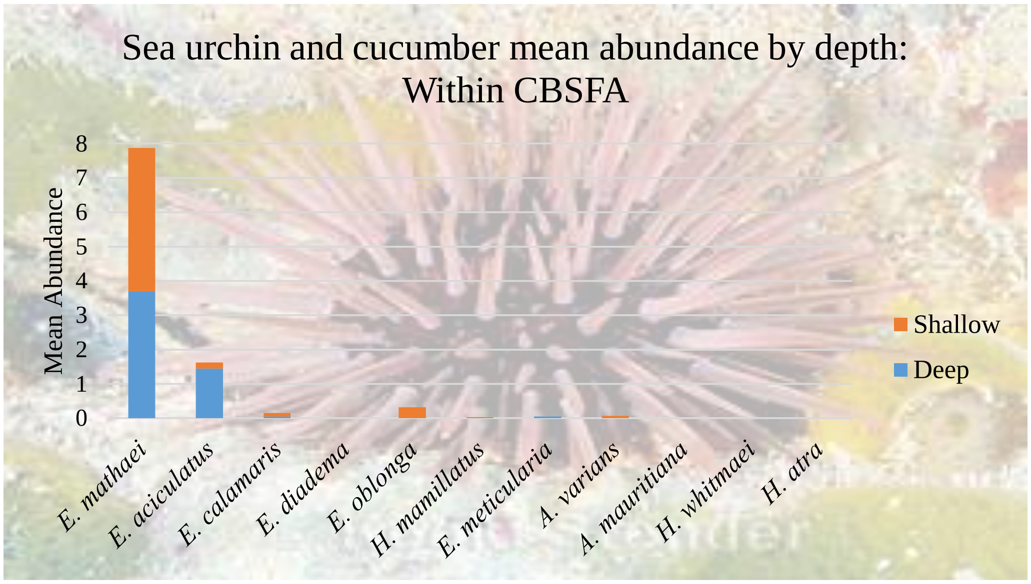


Figure 46. Sea urchin and sea cucumber composition (mean abundance per station) by depth within the Hāʻena CBSFA boundaries (n=48).

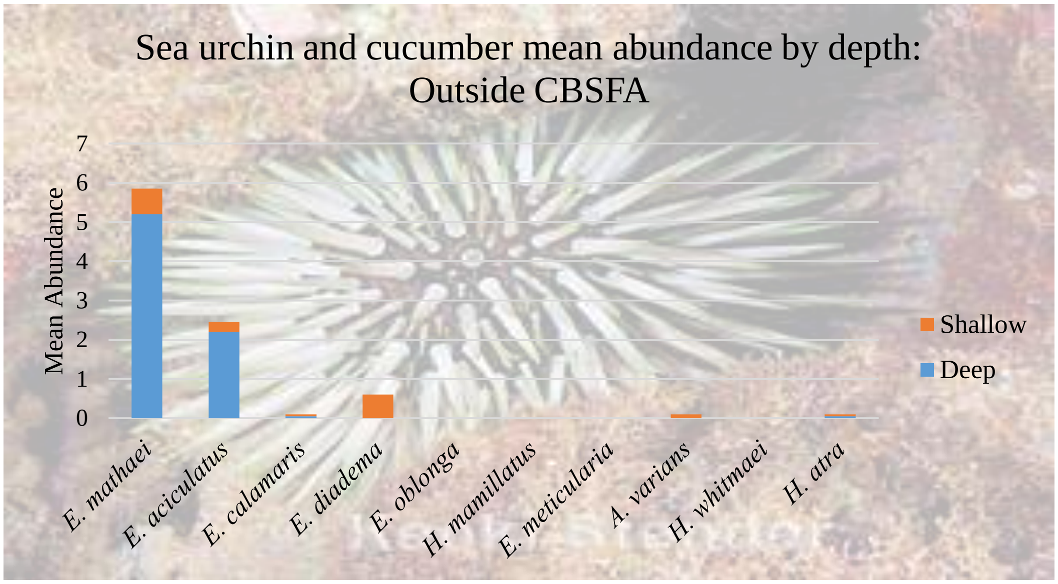


Figure 47. Sea urchin and sea cucumber composition (mean abundance per station) by depth outside the Hāʻena CBSFA boundaries (n=40).

Makua Pu‘uhonua: Urchins and Sea Cucumbers

Invertebrates within the Makua Pu‘uhonua were calculated separately since different fishing regulations apply. Only 10 urchins of four species (Fig. 44) and three sea cucumbers of two species were found on the 10 stations within the Makua Pu‘uhonua. The overall frequency of occurrence for urchins is 50.0% and 30.0% for sea cucumbers. This is the lowest value of frequency of occurrence for urchins compared to previous years (2016: 87.5%, 2017: 70.0%, 2018: 78.3%). In 2019, *E. mathaei* and *E. diadema* are the top recorded species in the Makua Pu‘uhonua (40.0% of total urchin composition each), followed by *E. aciculatus* and *E. calamaris* (10.0% each) (Fig. 48).

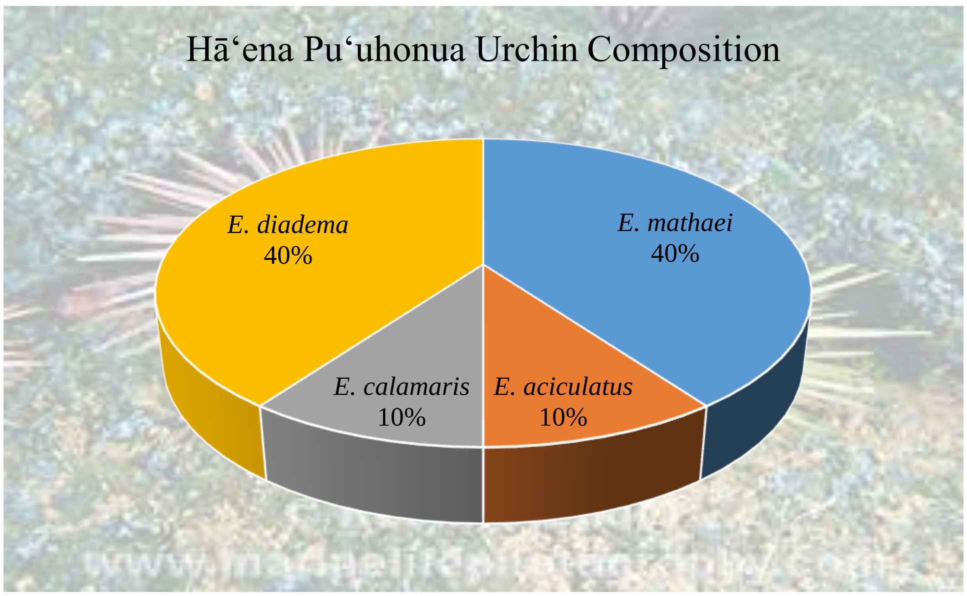


Figure 48. Sea urchin composition (percent of total) inside the Makua Pu‘uhonua..

There are three recorded sea cucumbers in the Makua Pu’uhonua found on three of the 10 transects for a frequency of occurrence of 33.3%. *H. whitmaei* was the most abundant (2) with *A. varians* (1) only being found once (Fig. 49). Sea cucumber counts were low in previous years with eight individuals (7 *H. atra* and 1 *H. whitmaei*) recorded in 2018 (n= 23) and only one individual of *H. whitmaei,* the teated sea cucumber, in 2017 (n= 10). These small sample sizes make it difficult to separate change from variability.

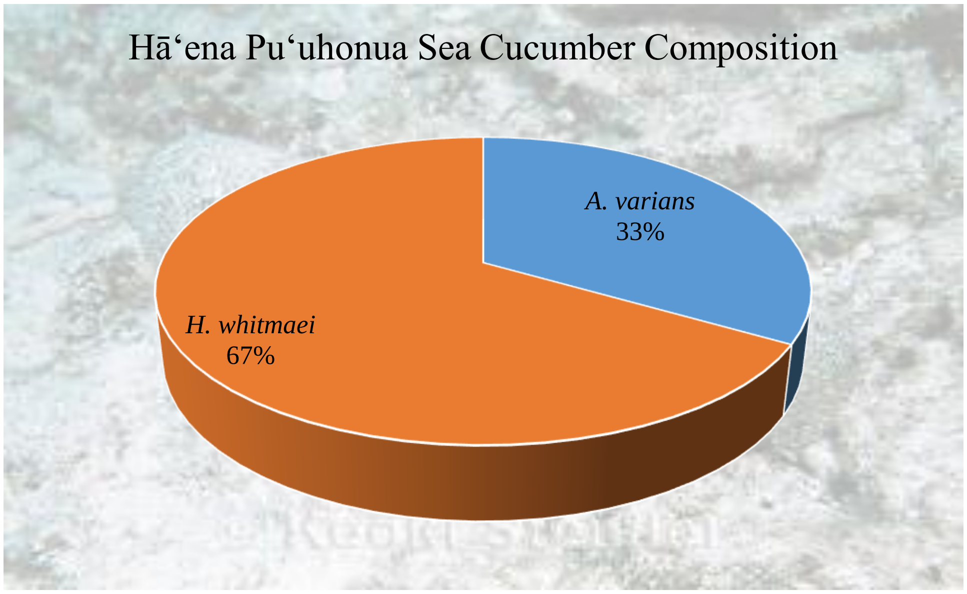


Figure 49. Sea cucumber composition (percent of total) inside the Makua Puʻuhonua.

CORAL REEF ASSESSMENT AND MONITORING PROGRAM (CRAMP) RESURVEYS

A CRAMP site in Limahuli located within the Hāʻena CBSFA was resurveyed in 2019. The 10 m depth station was surveyed in June 2019 and the 1 m station was surveyed in September 2019. This is part of a statewide integrated network of 33 sites on five islands that include 66 stations (www.cramp.wcc.hawaii.edu, Rodgers et al. 2015). At each site there are typically two stations at two depths (3m and 10m). However, at Limahuli no 3m station can be surveyed because the shallow reef flat 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 get a baseline of what our reefs around the state looked like, to recognize any changes that may occur, and to identify any impacts that are affecting these reefs. Up to that time monitoring efforts in the state were conducted on a piecemeal basis, inconsistently addressing specific problems in specific places on a project by project basis over short periods of time by different researchers and managers using different methods so they were difficult to compare. Within the first few years we established long-term monitoring sites that are tracking changes over time and rapid assessment sites to expand the spatial range of habitats and anthropogenic impacts and optimize the power to detect statistical differences.

These sites span the full spectrum of habitats. We have a geologically recent 1950's lava flow in Kaʻapuna, patch reefs in Kāneʻohe Bay, open coastlines, and almost any other reef habitat found in the Hawaiian Islands. These sites span the full latitudinal range from near Hawaiʻi's South Point to the Na Pali coast of KauaʻI, and there are both windward and leeward reefs. There is a full range of protection status including Natural Area Reserves such as at Āhihi Kīnaʻu, Marine Life Conservation Districts at Hanauma Bay and Molokini, Fisheries Management Areas and Fisheries Replenishment Areas on the Kona coast of Hawaiʻi Island, and open access sites with no other legal protection except what applies to the entire state. The sites also encompass the full range of natural and anthropogenic impacts, including sites along a gradient from nearly pristine to severely degraded.

The CRAMP network of sites was developed to have the statistical ability to detect changes in coral cover over time (Fig. 50). 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. The DAR Kaua‘i monitoring team is incorporating these six DAR/CRAMP sites (Hanalei, Limahuli, Miloli‘i, Nualolo Kai, Ho‘ai, and Pila‘a) into their annual monitoring program for statewide comparisons.

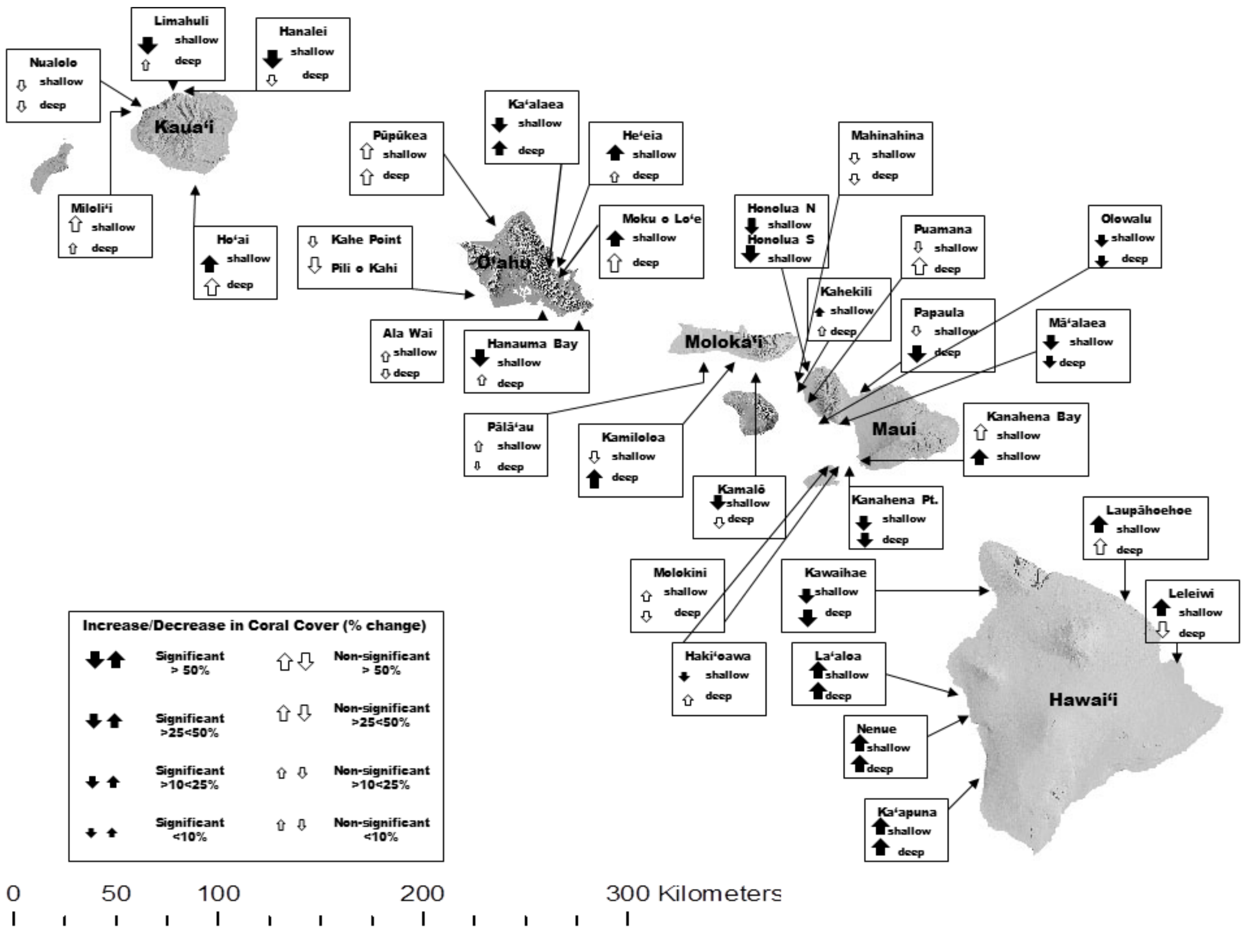


Figure 50. The Hawai‘i Coral Reef Assessment and Monitoring Program permanent network of sites throughout the main Hawaiian Islands. Direction of arrows show increase or decrease in coral cover since 1999. The size of the arrow is related to the size of the change in coral cover. The solid arrow indicates statistical significance while hollow arrows are sites that have non-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 2019 resurvey is the 9th survey at the 1 m reef flat and the 10th survey for the 10 m station (Fig. 51).

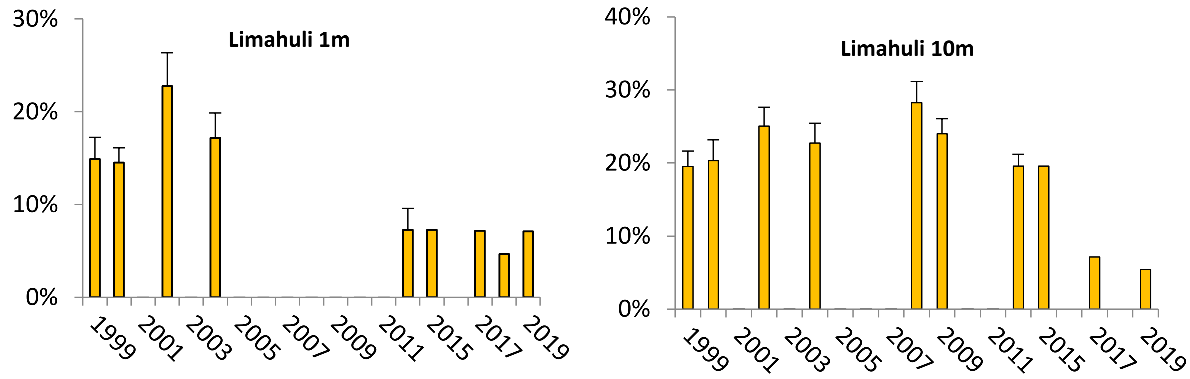


Figure 51. Change in percent coral cover for the Limahuli, Kaua'i CRAMP monitoring site (1m and 10m) initiated in 1999.

The Limahuli reef flat is characterized by a shallow limestone/basalt bolder 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 extending 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 has 10 initially randomly selected 10 m permanent transects that were established on hard substrate. These are marked for resurveys by short stainless-steel pins. Due to the shallow reef flat at Limahuli 1 m, pins are located only at the 50 m point along the transect and are 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 are collected at various times. Digital imagery is 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 are analyzed using the software program PhotoGrid (Bird 2001) to estimate benthic coverage. Twenty-five randomly selected points are generated on each image and used to calculate percentage cover.

The corals found on the shallow, wave driven reefs 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 in 2019 was 9.71% for the ten transects at the 1 m site. This is slightly higher than in 2018 (7.16%), and 2017 (5.61%) (Fig. 50). The five species of coral recorded in 2019 in order of their percent of total are *Porites lobata* (90.2%), *Pocillopora* *meandrina* (5.5%), *Montipora capitata* (3.6%), *Montipora patula* (0.04%), and *Cyphastrea ocellina* (0.04%). The dominant species has shifted back to 2017 values when *P. lobata* was clearly dominant. *M. patula* was dominant in 2018.

The average total coral cover at the ten transects at the 10 m site in 2019 was 4.93%. This is a continued reduction from the previous years' survey in 2018 (7.26%) and 2016 (9.23%). Seven species of coral were recorded, however only six could be identified from the images. Listed in descending order of percent of total: *M. patula* (61.7%), *P. lobata* (15.0%), *P. meandrina* (14.3%), *Palythoa caesia* (6.0%), *P. varians* (1.5%), and unknown coral (0.8%).

PROPOSED FUTURE ACTIVITIES

This study was enacted to determine the efficacy of the first CBSFA in the State of Hawai‘i. 2019 is year four 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. 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. Biotic populations fluctuate so it may take years to determine if shifts we are seeing today are really moving in that direction because it 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 increase in the stock market over the past ten years or in the temperature record over the last century (Fig. 52). 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 one decade, the 1940’s, it shows a different pattern. Halfway thru that decade it looks like the temperature is dropping. This is also true of environmental monitoring and why long-term monitoring is so important to understanding what is really happening. The results we currently have are preliminary and will strengthen as more surveys are conducted.

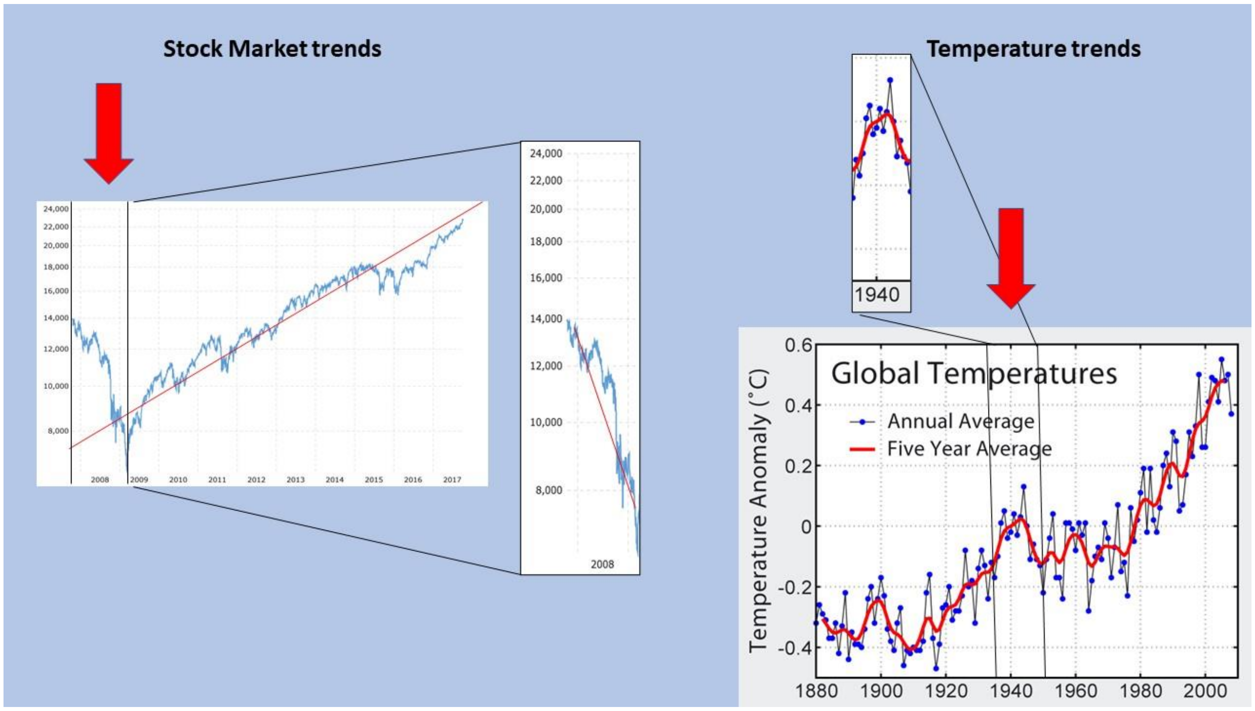


Figure 52. Graphs depicting the variability and overall trend in the US stock market (2008-2017) and global temperature record (1880-2010).

At Hāʻena, there have been several stochastic events that make separation of management effects difficult. In 2014/2015 a temperature anomaly caused a widespread bleaching event. In 2018, the flooding and associated freshwater and nutrient input occurred. In 2019, 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 return to a near pristine state or an earlier baseline, since shifting baselines will be more prevalent as effects of climate change advance in frequency and intensity. Continued monitoring will be vital. Other activities to separate management actions from extraneous factors are outlined below.

- Change in Number of Human Visitors: Surveys to determine changes in fish populations based on changes in visitor counts. Two long-term closures resulting from flooding (2018-2019) and pandemic restrictions (2020) 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 Surveys to determine harvest in recreational fisheries can examine changes in fishing pressure.

- Physiological Change: Determine changes in fish populations related to shifts in phytoplankton and macroalgae correlated with freshwater or other environmental shifts.

-Hepatosomatic Index (liver mass/somatic mass): proxy for energy reserves

-Gonadosomatic Index (gonad mass/total mass): proxy for reproductive success

-Gut Fullness Index (gut mass with contents/total body mass): proxy for foraging success

- Community and DAR Monitoring using the Koʻa (Coral) Health Assessment Card: Community and DAR education and training using quantified tool for coral monitoring.

  - Support for the Hāʻena community group, Hui Makaʻāinana o Makana and support at the annual Kauaʻi Invasive Xtermination (KIX) fishing tournament.

ACKNOWLEDGEMENTS

We are extremely grateful to the DLNR: Division of Aquatic Resources (DAR) for their extensive effort and resources provided in planning, diving, and project guidance.
DAR Acting Director: Brian Nielsen
DAR Kauaʻi Monitoring Team: Kaʻilikea Shayler, McKenna Allen, and Mia Melamed
DAR Oʻahu Monitoring team: Paul Murakawa, Kazuki Kageyama, Haruko Koike, Tiffany Cunanan, and Kimberly Fuller
DAR Maui Monitoring Team: Russell Sparks, Kristy Stone, Linda Castro, Tatiana Martinez
Additional support: Kostas Stamoulis and Jade Delevaux for additional transects and fish behavior surveys.

These surveys would not have been possible without the vessels and operators provided by the DLNR: Division of Boating and Ocean Recreation (DOBOR), Kauaʻi.

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