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Assessing Assemblage Composition of Reproductively Mature Resource Fishes at a Community Based Subsistence Fishing Area (CBSFA)

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Abstract: Nearshore fisheries in Hawai'i have been steadily decreasing for over a century. Marine protected areas (MPAs) have been utilized as a method to both conserve biodiversity and enhance fisheries. The composition of resource fishes within and directly outside of the recently established Hā'ena Community Based Subsistence Fishing Area (CBSFA) on the island of Kaua'i were assessed to determine temporal and spatial patterns in assemblage structure. In situ visual surveys of fishes, invertebrates, and benthos were conducted using a stratified random sampling design to evaluate the efficacy of the MPA between 2016 and 2020. L_{50} values—defined as the size at which half of the individuals in a population have reached reproductive maturity—were used as proxies for identifying reproductively mature resource fishes both inside and outside the CBSFA. Surveys between 2016 and 2020 did not indicate strong temporal or spatial changes in overall resource fish assemblage structure; however, some species-specific changes were evident. Although overall resource species diversity and richness were significantly higher by 2020 inside the MPA boundaries, there is currently no strong evidence for a reserve effect.

Keywords: resource fishes; assemblage composition; reproductive maturity; community based subsistence fishing area; marine protected area; L_{50}



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1. Introduction

Marine protected areas (MPAs) have been increasingly employed as an effective method for managing overfished nearshore coral reef ecosystems [1,2]. MPAs have been shown to increase fish biomass, diversity, and reproductive output within the protected area, as well as enhance adjacent areas via adult and larval spillover [1,3]. However, MPAs are not a panacea for overfished stocks, poor habitat quality, or ineffective management or enforcement [1,3–6]. The effectiveness of a MPA is often reliant on careful consideration of key features, such as size, shape, configuration, larval connectivity and recruitment, life-history traits, habitat types, enforcement, and community support [3,5–7].

Nearshore fisheries declines in the State of Hawai'i over the last century have paved the way for implementation of some level of protection in ~17% of state waters, yet only 3.4% of nearshore waters are considered to be highly protected [2]. It is within these few, highly protected areas where resource fish biomass is substantially greater compared to lower or non-protected areas [8]. Additionally, with such a wide variety of MPA features, restrictions, and enforcement comes varying degrees of success. Contrasting examples include the successful recovery of herbivorous species in the Kahekili Herbivore Fisheries Management Area (KHFMA) on Maui [7] and the rapid depletion of reefs upon the opening of the Waikiki-Diamond Head Shoreline Fisheries Management Area on O'ahu where restrictions to fishing are implemented on a yearly rotational basis [4]. In general, most of

the MPAs in Hawai'i follow contemporary styles of management, with the exception of a few community-based subsistence fishing areas (CBSFAs).

Communities in Hawai'i have increasingly explored the development of co-management partnerships between state resource management agencies and community groups to incorporate aspects of traditional ecological knowledge and customary marine tenure and to devolve some management authority to local scales where it was traditionally based [9,10]. Despite efforts to re-establish local marine stewardship, CBSFAs are located in only three communities: Mo'omomi on Moloka'i, Miloli'i on Hawai'i, and Hā'ena on Kaua'i. In 2015, the Hā'ena CBSFA became the first of its kind to officially institute and enforce rules and regulations, which were drafted and finalized through collaboration from the Hā'ena community. The following year, the Hawai'i Department of Land and Natural Resources (DLNR), the Division of Aquatic Resources (DAR), and the Division of Boating and Ocean Recreation (DOBOR), partnered with the University of Hawai'i, Hawai'i Institute of Marine Biology (UHHIMB), Coral Reef Ecology Lab (CREL), and the Coral Reef Assessment and Monitoring Program (CRAMP) to conduct surveys at Hā'ena CBSFA to determine the efficacy of the rule changes over time [11]. Baseline surveys were conducted by the University of Hawai'i Fisheries Ecology Research Laboratory (UH FERL) between 2013 and 2014 on the nearshore shallow reef flats before the regulations were approved [12]. These baseline surveys were not spatially representative of the areas covered in the 2016–2020 surveys and were therefore not included in this study.

This current study focuses on monitoring assemblage composition patterns of reproductively mature resource fish species throughout the full five-year monitoring period in an attempt to determine the efficacy of the CBSFA. Resource fish species were defined by the Hā'ena community and the reproductive maturity of these species was determined using L_{50} values derived from previous studies (Table A1) [13–27]. The objective of this study was to examine fish assemblage structure of reproductively mature resource fishes throughout this monitoring period, so as to examine the efficacy of the Hā'ena CBSFA rules enacted in 2015 and to provide information for adaptive management strategies relative to the existing rules and regulations.

2. Materials and Methods

Hā'ena is located on the north shore of Kaua'i Island within the Hawaiian Archipelago. Coral reef structures extend along the inner reef of the Hā'ena coast in shallow water, and along the forereef into deeper depths (~20 m). Its location on the north shore exposes Hā'ena's reefs to high wave energy and flushing year round, but particularly during winter months (November–March) when large North Pacific swells regularly generate waves in excess of 10 m. Several streams enter the ocean both within and adjacent to the CBSFA boundaries. These boundaries extend 1610 m (~1 mile) offshore and 5633 m (~3.5 miles) along the coastline [11,28] (Figure 1a). There are varying fishing restrictions within the CBSFA boundaries, including a designated area on the shallow backreef where all fishing is prohibited. This area is referred to as the Makua Pu'uhoenua, which translates to "nursery area" in Hawaiian, and was set aside to protect juvenile fishes during this critical life-history phase.

2.1. Sample Design

Surveys were conducted both within and directly east of the CBSFA (hereafter referred to as "inside" and "outside") along the coast of Hā'ena. Due to varying benthic structure, the Nā Pali State Park on the west side of the CBSFA boundaries was intentionally not surveyed. A stratified random sampling design was used to pre-determine survey stations to allow for spatial representation by depth, habitat type, and location (inside and outside). Approximately 100 random points were generated and stratified by depth (shallow < 7 m, deep \geq 7 m) using ArcGIS 10.6.1 (Figure 1b). Points were overlaid on National Oceanographic and Atmospheric Administration (NOAA) habitat base maps [28]. Surveys were conducted at the original pre-determined stations. If hazardous conditions were encoun-

tered, depth estimates were in error, or <50% of the substrate was hard bottom, then divers swam the depth contour at a pre-determined compass heading (<100 m from the original site) until safe conditions, accurate depths, and >50% hard substrate were reached.

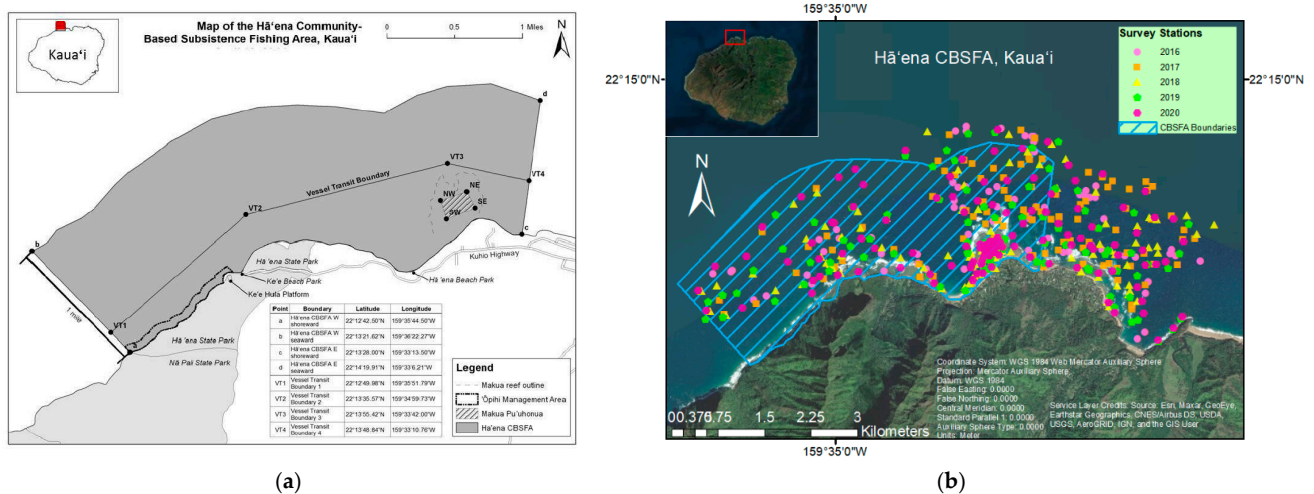


Figure 1. Hā'ena site maps of (a) community-based subsistence fishing area (CBSFA) boundaries, the restricted Makua pu'uhonua, the vessel transit boundary, and the 'opihi (limpet, *Cellana* spp.) management area with coordinates [28] and (b) survey stations from all five years within and outside the CBSFA boundaries.

2.2. Fish and Benthic Surveys

Fish counts and sizes were estimated inside and outside the CBSFA using the Kaua'i Assessments of Habitat Utilization (KAHU) rapid assessment technique over a five year period [28]. This method employed 25 × 5 m belt transects [29], designed by the UH FERL Fish Habitat Utilization Study (FHUS). The time frame of this study included surveys conducted in August 2016 ($n = 55$ inside, $n = 43$ outside), August 2017 ($n = 59$ inside, $n = 49$ outside), August 2018 ($n = 71$ inside, $n = 32$ outside), and June and August in 2019 ($n = 58$ inside, $n = 40$ outside), and June and August in 2020 ($n = 79$ inside, $n = 44$ outside). At each station, a 25 m transect was deployed in the direction of a pre-determined compass bearing (0° , 90° , 180° , or 270°). All fish species, counts, and sizes (total length [cm]) were recorded within a 5-m swath (125 m^2 total area per transect) for a minimum of 10 min [28]. Fish surveyors annually participated in calibration dives to account for observer variability.

A benthic surveyor followed the fish diver to quantify habitat types associated with each transect [28]. Photographs were taken of the substrate on a previously calibrated Cannon S100 camera at every 1 m mark at a 90° angle to the transect ($n = 26$). Invertebrate (urchins and sea cucumbers) abundances were also recorded. The surveyor also enumerated macroinvertebrates within a 2 m × 25 m swath (50 m^2) along the transect line. The twenty-six benthic photographs collected at each transect were later processed by overlaying 30 points per photograph using the benthic image analysis program CoralNet [28].

2.3. Assessing Reproductive Maturity

L_{50} values—defined as the size at which half of the individuals in a population have reached reproductive maturity—were obtained from previous studies within the main Hawaiian Islands (MHI) (Table A1). Female L_{50} values were used rather than male L_{50} values owing to the disproportionate importance of large females in population reproductive output [17,19,29–31]. Careful consideration was taken to use L_{50} values that were most appropriate for Hā'ena because L_{50} values have been shown to vary within and among islands in Hawai'i between individuals within a species [26]. *Acanthurus triostegus* (convict tang, *manini*), which is an endemic subspecies, was the only resource fish with L_{50} values derived from gonad measurement on the northshore of Kaua'i. The majority of the remaining L_{50} values were selected from similar reproductive studies conducted within

the Hawaiian Archipelago [15–20,23,25,26,32]. A select few L_{50} values were chosen from reproductive studies from the Northwestern Hawaiian Islands (NWHI) [32] or Papua New Guinea (*Kyphosus* spp., lowfin chub, *nenue*) [33]. Resource fish species with L_{50} values from outside the Hawaiian Archipelago, with the exception of the one Papua New Guinea study, were excluded from our analyses.

2.4. Statistical Analysis

Changes in assemblage composition of resource fishes throughout the five years inside and outside the CBSFA were analyzed using both multivariate and univariate statistics in the R statistical software. Simpson's diversity, Menhinick's richness, and Pielou's evenness were also calculated using biomass metrics for the resource fish assemblage. Biomass was calculated using the following equation:

$$W = a \times (\text{standard length})^b, \quad (1)$$

where standard length in cm was converted from total length and the a and b parameters were obtained from the Hawai'i Cooperative Fishery Research Unit database. Non-metric multidimensional scaling (nMDS) is a rank-based analysis that was used to visualize trophic level patterns in resource fish assemblages. Fish taxa were categorized into trophic categories (corallivores, herbivores, mobile invertebrate feeders, sessile invertebrate feeders, piscivores, zooplanktivores, and detritivores) according to various published sources and FishBase (www.fishbase.org (accessed on 7 March 2021)). Species that occurred in <5% of stations were eliminated prior to analysis. Biomass was down-weighted to account for rare species and a Bray–Curtis dissimilarity matrix was used. Permutation-based multivariate analysis of variance (PERMANOVA) was conducted using Type II sum of squares on trophic level (herbivore, piscivore, planktivore, and mobile invertivore) matrices to assess patterns of resource fish species assemblages through time (2016, 2017, 2018, 2019, 2020) and location (inside or outside). Homogeneity of variances were assessed for reliability of the PERMANOVA results using the PERMDISP2 procedure [34]. Pairwise comparisons with a Holm's correction was applied following significant ($p < 0.05$) PERMANOVA results. SIMPER (similarity percentages) were used to analyze resource species with the highest influence on the multivariate test; however, unequal sample sizes may result in unreliable SIMPER results [35]. Therefore, further univariate analyses were conducted to determine resource species patterns.

Univariate analyses included ANOVA with Holm's correction on multiple pairwise comparisons on quarter-root or \log_{10} transformed data. However, the large number of zeros in most of the datasets meant zero-inflated models were most appropriate. Due to the inability to run biomass, a non-integer response variable, through zero-inflated models, data were manually split into two sections and generalized linear models (GLMs) were used. Non-normal data were first divided into presence/absence to account for the high number of zeros present. A binomial distribution with a complementary-log–log link function was used for presence/absence data to account for the unequal number of zeros-to-ones in each matrix. Non-zero biomass data were analyzed using a Gamma distribution with a log-link function run on quarter-root transformed biomass. Least-squares means were applied to GLM models to examine pairwise comparisons.

Finally, distance-based RDAs (redundancy analyses) (dbRDAs) were used to compare biomass matrices with depth, habitat type, and percent cover of coral, calcareous coralline algae (CCA), turf, and macroalgae and abundances of invertebrates, to examine drivers of patterns in fish biomass over time and between management regimes. Turf was excluded from the analysis, as it was found to be highly correlated with CCA. An Akaike information criterion (AIC) forward and backwards step model selection was used to determine the critical variables to run in the dbRDA model using a Bray–Curtis index.

All analyses were run in the R statistical software using the following packages: *tidyverse*, *pscl*, *MASS*, *rstatix*, *vegan*, *multcomp*, *multcompView*, *lsmeans*, *corrplot*, *GGally*, *ggplot2*, *gridExtra*, *ggpubr*, *plyr*, and *dplyr* [36].

3. Results

A total of 156 fish species were surveyed over the 5 year period across all locations. Mobile invertivores and herbivores occurred at over 90% of the total stations, while planktivores, corallivores, and piscivores occurred at >50% of the stations surveyed. Of the 156 species, 32 (20.5%) were classified as resource fishes by the Hā’ena community, and were composed mainly of herbivores (82.8%) and piscivores (48.5%). After eliminating species that occurred in <5% of the stations, 65 fish species overall and 19 resource fish species remained for analyses.

3.1. Overall Fish Assemblage

Fish assemblage structure showed a high degree of overlap among years (Figure 2a). Assemblage structure outside the CBSFA was more concordant and was a subset of the assemblage inside the CBSFA (Figure 2b). Clear spatial patterns in overall fish assemblages were evident among sub-locations in the nMDS plot (Figure 2c). Fish assemblages inside and outside shallow (<7 m) and inside and outside deep (≥7 m) strata had similar assemblage structures, while the Makua pu’uhonua had a distinct assemblage (Figure 2c).

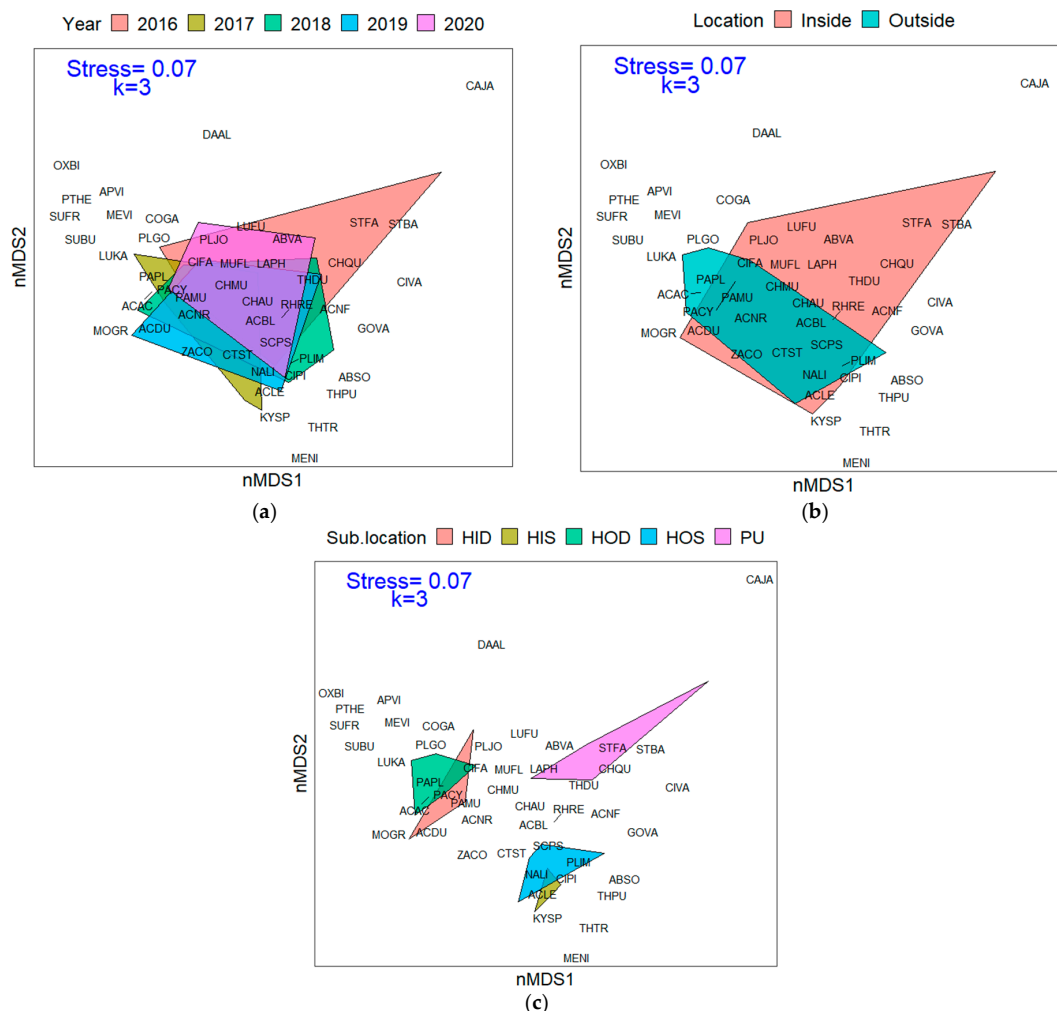


Figure 2. Non-metric multidimensional scaling (nMDS) plots of overall fish species assemblages by (a) 5 years, (b) inside or outside, and (c) sub-location divisions with depth incorporated. Clear spatial patterns in overall fish assemblages are evident in the sub-location nMDS. See Table A1 for species code identification. Sub-location codes are as follows: Hā’ena Inside Deep (HID), Hā’ena Inside Shallow (HIS), Hā’ena Outside Deep (HOD), Hā’ena Outside Shallow (HOS), and Pu’uhonua (PU; located within Hā’ena Inside Shallow).

Simpson's diversity did not significantly differ among the 5 years ($F_{4,518} = 0.95$, $p = 0.44$). Species richness was significantly lower in 2019 compared to 2016 ($F_{4,518} = 2.51$, $p = 0.04$), while evenness increased from 2017 to 2018, and declined again in 2020 ($\chi^2 = 2.82$, $p = 0.02$). While diversity and richness did not differ between locations ($F_{1,518} = 0.57$, $p = 0.45$ and $F_{1,518} = 0.61$, $p = 0.43$, respectively), evenness was significantly higher outside compared to inside the CBSFA ($\chi^2 = 12.8$, $p < 0.001$).

3.2. Resource Fish Assemblages (above L_{50})

The diversity of reproductively mature resource fishes (i.e., individuals above their respective L_{50} values) significantly increased from 2016, 2017, and 2018 to 2020 ($\chi^2 = 3.46$, $p = 0.01$), likely in part to increased species richness from 2017 and 2018 to 2020 ($F_{4,447} = 2.84$, $p = 0.02$). Evenness did not differ significantly over the 5-year period ($p = 0.06$) or between inside and outside the CBSFA boundaries ($p = 0.31$). Diversity was significantly higher inside the CBSFA compared to outside ($\chi^2 = 5.33$, $p = 0.02$), while species richness remained similar between locations ($p = 0.21$).

3.2.1. Trophic Level Assemblage

Reproductively mature trophic level resource fishes had distinct assemblages in 2016 and 2017, while no distinctions were evident between 2017, 2018, 2019, and 2020. There were small differences between the fish assemblages at deep water stations inside the CBSFA compared to deep water stations outside the boundaries. Shallow water stations inside and outside the boundaries have similar assemblages, yet were distinct from deeper water stations. Trophic level resource fish biomass revealed significant differences among years (PERMANOVA, Table 1). Specifically, pairwise comparisons detected higher biomass in 2017 and 2019 compared to 2016 (Pairwise, Table 2).

Table 1. PERMANOVA results for trophic level matrix across year and location. Bold numbers indicate significance. Df = degrees of freedom, SS = sum of squares, MS = mean squares. Significant values in bold.

	Df	SS	MS	Pseudo-F	R ²	p
Location	1	0.58	0.58	2.114	0.004	0.052
Year	4	2.52	0.63	2.292	0.019	0.001
Location:Year	4	0.97	0.24	0.879	0.007	0.613
Residuals	433	119.11	0.28		0.911	

Table 2. Pairwise comparison with holm's adjustment results for trophic level matrix across years. Significant values in bold.

Pairs	F.Model	R ²	p-Value	p-Adjusted
2016 vs.2017	3.520	0.021	0.001	0.010
2016 vs. 2018	2.151	0.012	0.046	0.276
2016 vs.2019	5.565	0.034	0.001	0.010
2016 vs. 2020	2.932	0.015	0.014	0.112
2017 vs. 2018	1.929	0.011	0.071	0.355
2017 vs. 2019	0.859	0.005	0.500	0.752
2017 vs. 2020	1.711	0.008	0.115	0.460
2018 vs. 2019	2.503	0.014	0.020	0.140
2018 vs. 2020	1.045	0.005	0.376	0.752
2019 vs. 2020	1.422	0.007	0.199	0.597

Reproductively mature herbivores and piscivores had higher abundances in 2020 compared to 2016 ($\chi^2 = 7.15$, $p = 0.041$ and $\chi^2 = 7.68$, $p = 0.025$, respectively). There was a higher number of herbivores inside the CBSFA ($\chi^2 = 18.05$, $p < 0.001$), while planktivores were more abundant outside the boundary ($\chi^2 = 4.09$, $p = 0.045$). Of the species present, mobile invertivores and planktivores had a higher biomass outside ($\chi^2 = 11.83$, $p < 0.001$).

and $\chi^2 = 4.41$, $p = 0.039$, respectively), while herbivore and piscivore biomass was not significantly different by year or location (both $p > 0.05$).

Despite similar assemblage compositions through time and locations, specific species level changes were analyzed to examine species-level differences. Ten herbivore species, six piscivore species, and four mobile invertivore species were further analyzed. Spatial ordination plots did not reveal any distinct species assemblages through time or location for piscivores or mobile invertivores; however, herbivore species may be responsible for the distinction in assemblages between 2016 and 2017. Herbivore biomass in 2016 was significantly lower compared to 2020 in pairwise comparisons (pairwise, $F_{4,438} = 1.77$, $p = 0.002$).

Specific herbivorous species patterns show that *A. triostegus*, *A. blochii* (ringtail surgeonfish, *pualu*) and *Naso lituratus* (orangespine unicornfish, *umaumalei*) presences were higher inside the CBSFA ($\chi^2 = 9.9$, $p = 0.002$; $\chi^2 = 6.6$, $p = 0.006$; $\chi^2 = 6.0$, $p = 0.013$, respectively; Figure 3). *N. lituratus* was the only species that showed a significant trend, with a decrease in presence over the 5 year period ($\chi^2 = 8.72$, $p = 0.022$; Figure 3).

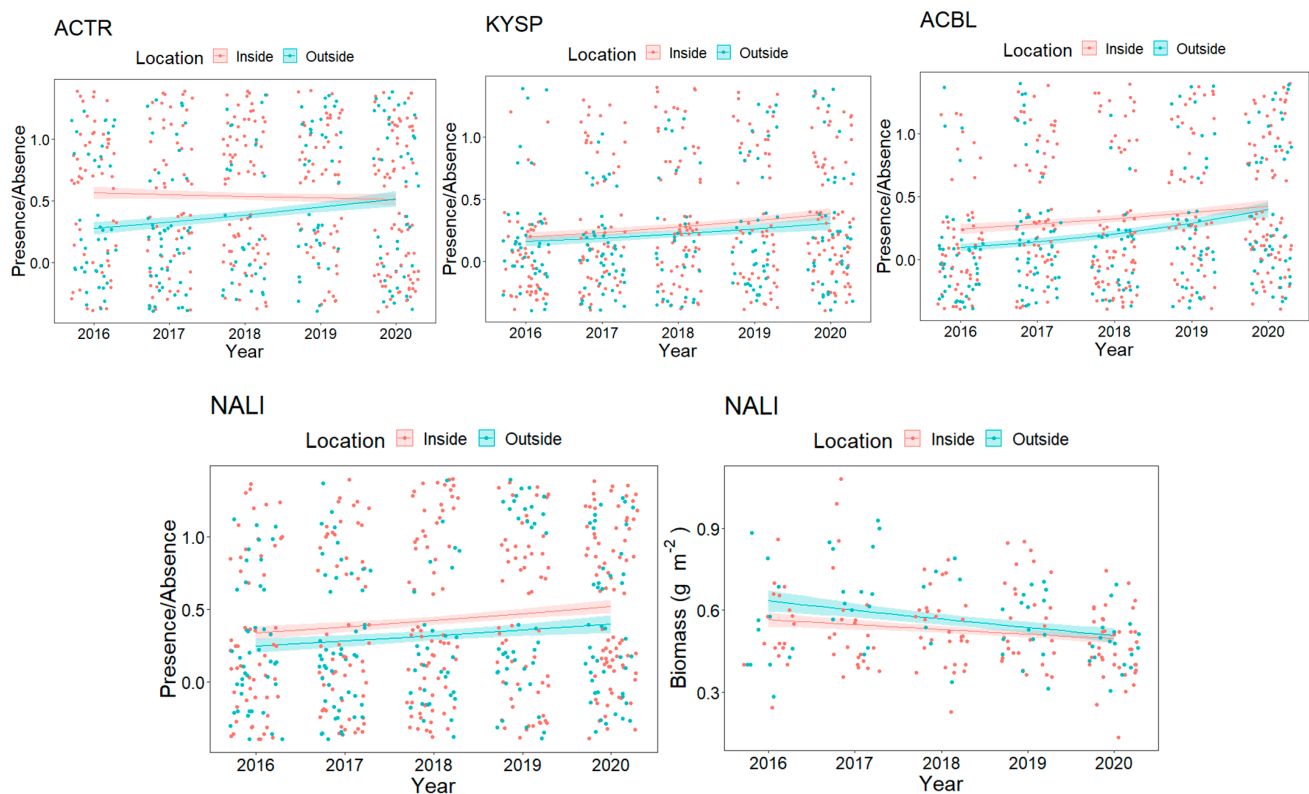


Figure 3. Generalized linear model (GLM) plots of significant trends in both presence/absence and biomass data among locations (ACTR, ACBL, and NALI-presence/absence), years (KYSP, NALI-biomass), and interaction between years and locations (ACTR). Species codes are as follows: *A. triostegus* (ACTR), *A. blochii* (ACBL), *N. lituratus* (NALI), and *Kyphosus* spp. (KYSP).

Reproductively mature piscivores showed a significant difference among years outside the CBSFA (PERMANOVA, $F_{4,85} = 1.80$, $p = 0.037$), where 2018 biomass was significantly higher compared to 2016 ($p = 0.01$). This was likely caused by the combination of *Aprion virescens* (green jobfish, *uku*) having higher presence outside the boundaries ($\chi^2 = 8.79$, $p = 0.006$; Figure 4) and *Caranx melampygus* (blue trevally, *'omilu*) biomass increasing both inside and outside the CBSFA boundaries in later years (Year: $\chi^2 = 7.11$, $p = 0.023$; Location: $\chi^2 = 5.33$, $p = 0.026$; Interaction: $\chi^2 = 5.15$, $p = 0.028$; Figure 4).

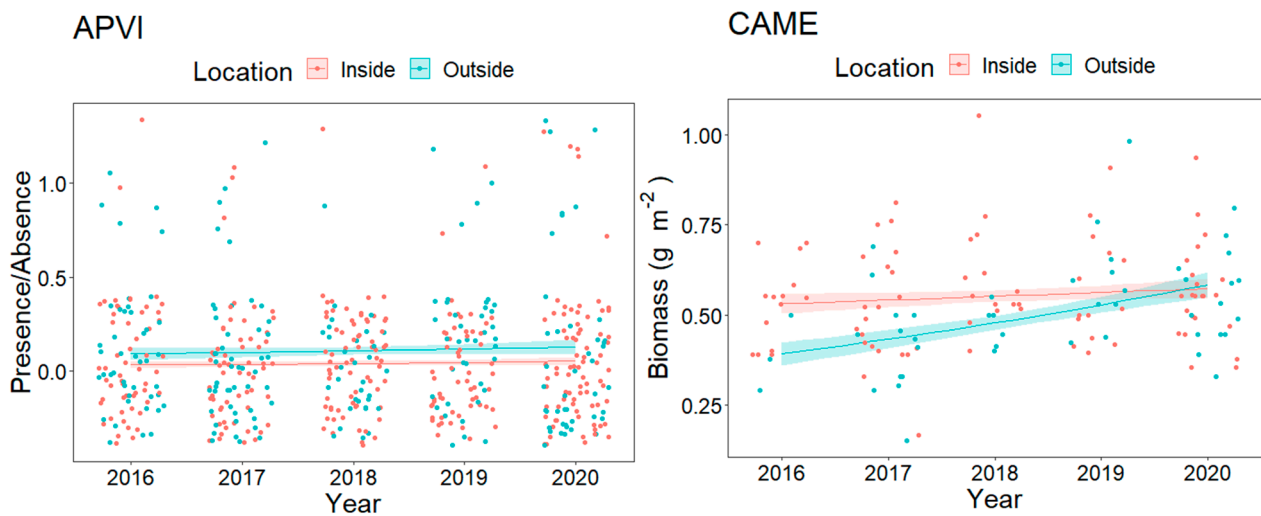


Figure 4. Generalized linear model (GLM) plots of significant trends in both presence/absence and biomass between locations (APVI-presence/absence and CAME-biomass), and among years (CAME-biomass). Species codes are as follows: *A. virescens* (APVI) and *C. melanopygus* (CAME).

Although spatial patterns were not evident in the mobile invertivore nMDS plots, the PERMANOVA identified a significant location term where reproductively mature mobile invertivore biomass was higher outside the boundaries ($p = 0.009$). This was likely driven by the higher presence of *Mulloidichthys flavolineatus* (yellowstripe goatfish, *weke*) inside the boundaries, as well as higher biomass of the introduced *Lutjanus kasmira* (bluestripe snapper, *ta'ape*) outside the boundaries ($\chi^2 = 6.47$, $p = 0.018$ and $\chi^2 = 9.41$, $p = 0.003$, respectively; Figure 5).

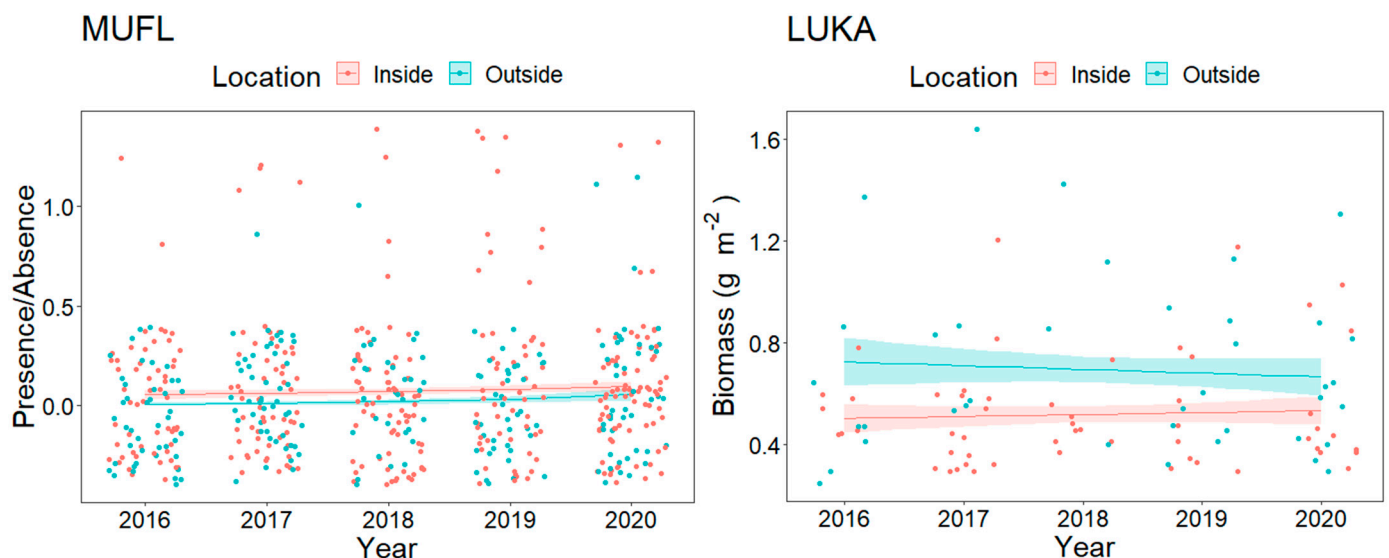


Figure 5. GLM plots of significant trends in both presence/absence and biomass data among locations (MUFL-presence/absence and LUKA-biomass). Species codes are as follows: *Mulloidichthys flavolineatus* (MUFL) and *Lutjanus kasmira* (LUKA).

3.2.2. Fish and Benthic Community Relationships

Depth and invertebrate abundance only explained ~5% (adj R^2) of the variance within reproductively mature resource fishes at the trophic assemblage level. Variations in the biomass of planktivores, piscivores, and mobile invertivores (5% adj R^2 ; Figure 6a,d) were explained by depth, while the variance in herbivore biomass was mainly explained by the abundance of invertebrates (6% adj R^2 , Figure 6a,c). Within the piscivore assemblage, CCA,

macroalgae (Mac), and depth explained $\sim 6\%$ (adj R^2) of the variability in *C. melampygyus* and *A. virescens* (Figure 6b). The majority of variance in each of the resource fish matrices remains unexplained by the variables included.

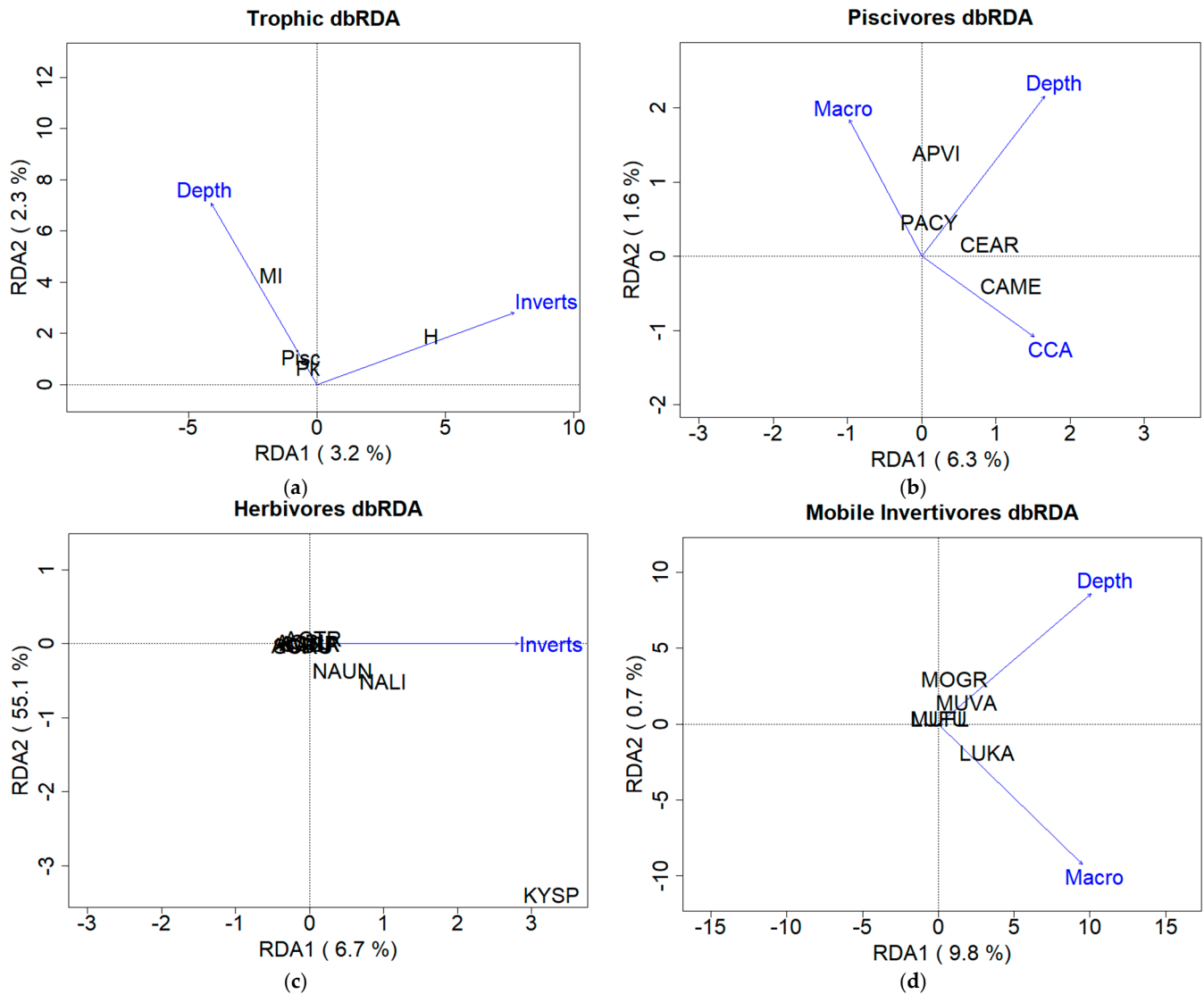


Figure 6. Distanced-based redundancy analyses (dbRDA) plots of (a) trophic level correlations, (b) piscivore correlations, (c) herbivore correlations, and (d) mobile invertivore correlations with benthic substrate components.

4. Discussion

Examining assemblage composition shifts and distributions through time is important in assessing the effectiveness of protected areas to implement adaptive management strategies [37,38]. Our overall results found no major shifts in fish assemblage composition in space or time inside or outside the Hā'ena CBSFA. Furthermore, the dbRDA models comparing resource fish biomass to depth and benthic community composition estimates explained very little of the variance in resource fish above their L_{50} values (Figure 6). While overall, reproductively mature resource fish assemblages remained fairly constant over time, species level shifts were evident. The significantly increasing biomass values of the piscivorous *C. melampygyus* outside the CBSFA boundaries in later years may suggest early signs of spillover. Positive increases in reproductively mature resource fish diversity and richness through time and between management regimes, as well as positive trends of the

species that show significant relationships through time and location suggest continual monitoring can be beneficial.

While few species level trends may be evident, the lack of major shifts in overall biomass at a temporal or spatial scale in reproductively mature resource fish assemblages may indicate several possible outcomes: (1) the CBSFA is having no effect, (2) five years is not sufficient time to see an effect, (3) habitats within and outside the CBSFA may be dissimilar, (4) the CBSFA boundaries are too small to show an effect, and/or (5) low sample sizes resulted in low statistical power. It is likely that the five year period may not have been sufficient time to begin seeing reserve effects. The Kahekili Herbivore Management Area on Maui took > 6 years before effects were witnessed [7]. It is also possible that the 2018 record breaking freshwater flood event may have delayed the effects of protection. This freshwater event caused major landslides and flooding that resulted in significantly lower total fish biomass on shallow Hā'ena reefs [39]. Furthermore, the nMDS plots of the overall assemblage, trophic level, herbivore, and piscivore matrices demonstrate overlap on a spatial scale between inside and outside assemblages at the shallow stations and overlapping inside and outside assemblages at the deep stations. These patterns are consistent with the study design in comparing similar habitats within and outside the boundaries and are consistent with a lack of influx of resource fishes moving into the CBSFA if individuals are acquiring equal resources both inside and outside the boundaries.

The size and mosaic of habitats of an MPA can greatly affect the success of that area and the Hā'ena CBSFA may be too small for the mobilities of resource fishes that we examined [40]. Within such a diverse group of organisms with varying functional roles and demands for energy [41], it is necessary for some species of fishes to travel longer distances to fulfill their energy, reproductive, and social requirements [42–44]. Although the majority of the Hā'ena CBSFA is not fully protected against fishing, it is one of the larger MPAs in the state at roughly 8 km², with is larger than the median size (1.2 km²) of MPAs in Hawai'i [2]. Yet, considering the effective size for MPAs (10 to 100 km² [2], the Hā'ena CBSFA remains below the lower threshold.

Although sample sizes were >30 for all stations by year and location, limitations in sample sizes of individuals were evident for select species. Therefore, uncommon species with low sample sizes were excluded by eliminating species that occurred in <5% of stations for the purpose of improved detection of an MPA effect. Even in unfished regions, fish population distributions are naturally skewed to smaller individuals that are more abundant in size and as they become larger, their abundance decreases.

L₅₀ values can vary not only by location and water temperature but also by season and year [45,46]. Although the L₅₀ value for *Acanthurus triostegus* came directly from gonad measurements of individuals located around the Hā'ena area, L₅₀ values of most other species were derived from measurements of individuals from the MHI, some from the NWHI, and one from Papua New Guinea (Table A1). L₅₀ values are the best estimate that can be used to assess reproductive maturity using in situ observations. Hence, conducting further research to acquire L₅₀ values for all resource fish species from the Hā'ena region could be beneficial in ensuring precise analyses of that specific location.

5. Conclusions

Overall resource fish assemblage composition did not change temporally or spatially over five years despite the implementation of fishing regulations. Results of this study suggest continuing annual surveys to evaluate long-term trends in order to better predict how resource fish assemblages may be changing within the current management regime. These monitoring data are essential if future adaptive changes in rules and regulations are to be implemented and effective. Furthermore, determining the habitat types and benthic structures that are beneficial to specific resource fishes at the Hā'ena CBSFA is crucial in assessing any emerging patterns of assemblage composition. Such contemporary research and management practices serve the purpose of providing data that allows local stakeholders and communities to adjust their rules and regulations as needed, thus,

allowing an adaptive management strategy to be implemented [47]. CBSFAs place local and traditional knowledge and practices at the forefront of fisheries management, allowing accountability for fisheries by local community members [37]. One of the social side effects of most MPAs in Hawai'i is the prevention of local fishers from practicing traditional fishing methods or incorporating adaptive management strategies due to temporary or permanent closures [48]. The integration of local and traditional knowledge and practices into the CBSFA design gives local people who use the protected area on a frequent basis accountability and a voice that can be beneficial in creating rules and regulations, especially as there are many communities that still depend on marine resources for subsistence.

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Appendix A

Table A1. List of resource fish species with sources from which L₅₀ values were derived. Species derived from the Hā'ena resource fish species list are noted with an asterisk (*) [13–27,32,33].

Family	Code	Taxon Name	Common	Hawaiian	Endemism	L50 (cm)	Citation
Acanthuridae	ACBL	<i>Acanthurus blochii</i>	Ringtail Surgeonfish	pualu	Native	27.6	Choat and Robertson, 2002, Kritzer, 2001
	ACDU	<i>Acanthurus dussumieri</i> *	Eye-stripe Surgeonfish	palani	Native	28.2	Choat and Robertson, 2002, Kritzer, 2001
	ACNR	<i>Acanthurus nigroris</i> *	Bluelined Surgeonfish	maiko	Native	15.7	DiBattista et al., 2010
	ACTR	<i>Acanthurus triostegus</i> *	Convict Tang	manini	Endemic	13.2	Schemmel and Friedlander, 2017
	NABR	<i>Naso brevirostris</i>	Spotted Unicornfish	kala lolo	Native	26.9	Choat and Robertson, 2002, Kritzer, 2001
	NAHE	<i>Naso hexacanthus</i>	Sleek Unicornfish	kala holo	Native	51.1	Choat and Robertson, 2002, Kritzer, 2001
	NALI	<i>Naso lituratus</i>	Orangespine Unicornfish	umaumalei	Native	25	Kritzer, 2001
	NAUN	<i>Naso unicornis</i> *	Bluespine Unicornfish	kala	Native	33	Nadon et al., 2015, Eble et al., 2009
Carangidae	CAME	<i>Caranx melampygus</i> *	Blue Trevally	'omilu	Native	47.5	Sudekum et al., 1991, Nadon et al., 2015
	CAOR	<i>Carangoides orthogrammus</i> *	Island Jack	ulua	Native	45.4	Nadon and Ault, 2016
	SECR	<i>Selar crumenophthalmus</i> *	Big-Eyed Scad	akule	Native	17	FishBase
	SEDU	<i>Seriola dumerili</i> *	Amberjack	kahala	Native	99.5	FishBase
Holocentridae	MYBE	<i>Myripristis berndti</i>	Bigscale Soldierfish	'u'u	Native	17.5	Murty, 2002, Craig and Franklin, 2008, Kritzer, 2001
Kyphosidae	KYSP	<i>Kyphosus species</i> *	Lowfin Chub	nenu	Native	25.3	Longnecker et al., 2013
Lethrinidae	MOGR	<i>Monotaxis grandoculis</i>	Bigeye Emperor	mu	Native	38.9	Nadon and Ault, 2016
Lutjanidae	APVI	<i>Aprion virescens</i>	Green Jobfish	uku	Native	50	Everson, 1989, Nadon, 2017
	LUFU	<i>Lutjanus fulvus</i>	Blacktail Snapper	to'au	Introduced	24	Nadon and Ault, 2016
	LUKA	<i>Lutjanus kasmira</i>	Bluestripe Snapper	ta'ape	Introduced	20	Allen, 1985, Kritzer, 2001
Mullidae	MUFL	<i>Mulloidichthys flavolineatus</i> *	Yellowstripe Goatfish	weke	Native	19.9	Cole, 2009, Nadon, 2017
	MUVA	<i>Mulloidichthys vanicolensis</i> *	Yellowfin Goatfish	weke 'ula	Native	20.6	Cole, 2009, Kritzer, 2001
	PACY	<i>Parupeneus cyclostomus</i>	Blue Goatfish	moano kea	Native	26.9	Nadon and Ault, 2016
	PAPO	<i>Parupeneus porphyreus</i> *	Whitesaddle Goatfish	kūmū	Endemic	26.4	Nadon et al., 2015
Scaridae	CACA	<i>Calotomus carolinus</i> *	Stareye Parrotfish		Native	24.3	DeMartini and Howard, 2016
	CHPE	<i>Chlorurus perspicillatus</i> *	Spectacled Parrotfish	uhu uliuli	Endemic	34.5	DeMartini and Howard, 2016
	CHSO	<i>Chlorurus spilurus</i>			Native	17.2	DeMartini and Howard, 2016
	SCDU	<i>Scarus dubius</i> *	Regal Parrotfish	lauia	Endemic	23.2	Nadon and Ault, 2016
	SCPS	<i>Scarus psittacus</i> *	Palenose Parrotfish	uhu	Native	13.9	DeMartini and Howard, 2016
	SCRU	<i>Scarus rubroviolaceus</i> *	Redlip Parrotfish	pālulaluka	Native	35	DeMartini and Howard, 2016
Epinephelidae	CEAR	<i>Cephalopholis argus</i>	Blue-spotted Grouper		Introduced	20	Schemmel et al., 2016

* = Hā'ena species list.

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