EFFECTS OF OPEN CIRUIT SCUBA EXHAUST ON REEF FISH SURVEYS IN THE MAIN HAWAIIAN ISLANDS

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ABSTRACT

The predominant method to quantify reef fish populations is the Open Circuit SCUBA (OC) *in-situ* fish survey. However, there are many biases associated with these surveys including the expelled OC exhaust which can cause visual and audible disturbances. This study aims to evaluate the bias created by OC exhaust utilizing closed-circuit rebreather (CCR) surveys, along surveys were conducted in protected areas and fished areas. The three sites in the main Hawaiian Islands were Kealakekua Bay (KK), Old Kona Airport (OA), and Pūpūkea (PK) marine life conservation district. This study found that the total fish biomass and species richness from all sites pooled showed no significant differences between gear types. However, there was a significant interaction between the gear type and the protection status (Pr(>|t|) = 0.025), indicating that there are greater differences between OC and CCR in the fished areas than the protected areas. The difference between the gear types showed a greater magnitude of OC having a higher biomass in the fished areas opposed to the protected areas where that difference was smaller. When fished species (Table 4 – a, b) were examined, significant differences between gear types were shown (Pr(>|t|) = 0.010). The OC surveys showed more fished biomass than the CCR surveys which could mean that the attraction to the exhaust within the protected areas were greater than the repulsion of the exhaust in the fished areas. Differences in the fished species biomass while having no difference in the all fish biomass supports the previous studies findings that fishing pressure is very influential on the magnitude of difference between the gear types. For researchers, estimating fishing pressure is of high importance in order to assess the level of bias associated with OC exhaust on surveys. These biases need to be accounted for in population estimations for protected areas and non-protected areas in order to get more accurate biological fish data.

KEYWORDS: marine protected area, closed-circuit rebreather, near shore fisheries, Hawai‘i fish management

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INTRODUCTION

Scientific inquiry of fish communities and populations has been problematic for marine researcher's due to the challenging aquatic environment which poses unique limitations. *In-situ* fish surveys have evolved from one of the earliest proposed methods of Open Circuit SCUBA (OC) survey which utilized a 500 yard by 20 feet, strip transect (Brock 1954). Present day nearshore fishery managers typically use multiple, shorter strip transects when conducting OC surveys (Kulbicki et al. 2010). Though these methods are popular, it is important to recognize that all *in-situ* OC surveys have some bias associated with them. By understanding these biases scientists will be better able to interpret these data and more accurately estimate fish abundances.

There are many types of bias in survey methods including diver experience and the number of surveys previously conducted (Williams et al. 2006, Bernard et al. 2013). Also, learned fish behavior and diver avoidance due to fishing pressure can also affect fish surveys (Kulbicki 1998, Kulbicki et al. 2010) . If divers are perceived as threats, the threshold for flight response by fish will be lowered, resulting in the underestimation of the fish population. However, in refuge areas where fishing is not allowed the familiarity with divers and people can have a positive or negative affect on the observed fish data. Additionally, a built-in bias due to the methodology of the survey can also result in imprecise fish data. For example, the strip transect requires a diver to lay out 25 to 50 m of fiberglass tape and count fish adjacent to that tape (Goetze et al. 2014). This method is biased along the edges of the transect boundary which reduces divers' accuracy with increasing distance. Additionally, the rolling transect is very dependent on the speed of the diver. There is an inverse relationship between diver speed and the amount of fish counted (Watson & Quinn 1997). Also, the speed and the directionality of the fish will affect the data of the strip transect. Most big fish swim faster resulting in an underestimation in surveys (Ward-Paige et al. 2010). In addition to the speed of the fish, if a fish is approaching the diver it has a positive bias while fish swimming away from the diver show a negative bias, and fish that are perpendicular to the diver show little or no bias (Watson & Quinn 1997).

While researchers have been able to compensate for many of the biases associated with underwater visual surveys of reef fish, the exhaust bubbles released by OC SCUBA, specifically the noise and visual disturbance they produce, represent a uncontrolled and poorly understood bias that is inherent to the gear type. The visual and audible disturbances could be a substantial influence in fish surveys. OC bubble noise has the potential to scare fish from being observed at all by divers (Schmidt & Gassner 2006). Exhaust bubbles could potentially repel fish, attract fish, or have some combination of effects resulting in fish observations that are misrepresentations of the actual community (Radford et al. 2005). Most modern OC regulators emit audible sound at frequencies that average 90 dB (Gemba et al. 2014). These frequencies are in the hearing range of fish and are likely to be heard as far away as 200m (Radford et al. 2005). The relatively silent closed-circuit rebreather (CCR) can be heard by fish from distances of < 5m in noisy conditions and up to 79.4 m in ideal conditions (Radford et al. 2005). A study utilizing a semi-closed circuit rebreather, which emits a small and constant stream of bubbles, resulted in no difference in fish biomass between the two gear types of OC and CCR (Cole et al. 2007). Another study that used a CCR, which emits no bubbles at a constant depth, reported increases of up to 48% more species richness and 260% greater fish abundance between the OC and CCR gear types (Lindfield et al. 2014). These relatively large differences were not observed in a recent publication by Gray et al. (2016) which reported differences that had OC fish biomass between 32 and 68% of the CCR biomass. It is due to these wide-ranging results that requires further exploration into the potential effects of OC exhaust on fish surveys.

The scientific merits of *in-situ* fish surveys have been extensively studied and are widely accepted by the scientific community (Ward-Paige et al. 2010). The biases associated with these various types of survey methods have been thoroughly examined except for the effects of OC exhaust. This study aims to further explore these effects on fish surveys by eliminating exhaust bubbles by utilizing a CCR. These surveys were conducted in fished areas and protected marine life conservation districts (MLCDs). The MLCDs was used to assess differences between gear type due to fishing pressure. Two study sites were located in the West Hawaii Regional Fisheries Management Area which does not allow SCUBA spear fishing (HAR 13-60.4). This legislation eliminates threats by any SCUBA diver, OC or CCR, along this coastline, effectively eliminating the perception of threat solely from the diver and not just a person in the water (i.e. freediver spearfisher).

METHODOLOGY

SITE

OC and CCR surveys were conducted on 30 paired transects consisting of one fish survey for each gear type. Two locations were on the west coast of Hawai‘i Island, Hawai‘i, USA, and one on O‘ahu’s North Shore (Figure 1). All three locations had a total of 10 transects, five of which were located within the protected area and five transects located outside, in fished areas. Surveys of the five transects outside of the Pūpūkea MLCD (Figure 1 – a) were conducted by NOAA, Coral Reef Ecosystem Program (CREP) using the same survey methods and incorporated into this data set. The two locations on Hawaii Island were on the west coast, Old Kona Airport (OA; Figure 1 - b) and Kealakekua Bay (KK; Figure 1 - c). PK was established in 1983 as a no take zone except for a couple of mackerel species by net. OA was established in 1992 and allows for take of fish with throw net and some pole fishing from shore. The KK MLCD was established in 1969 and consists of two zones, one zone is a no take zone while the other area that this study was conducted in allows for pole and net fishing from shore. These three sites were selected to ensure that divers would not be perceived as a threat to the fish in the area. Each transect location was selected utilizing random points generated in geographic information systems, and habitat base layer maps provided by NOAA (CREP). All of the sites were between 10-20 m in depth with an aggregate coral, hard bottom substrate. These surveys were conducted from July 19 – August 12, 2016, and January 28 – 29, 2017.

DIVE EQUIPMENT

The OC surveys were conducted with a standard compressed gas cylinder, with an inflatable buoyancy control device, and an oral regulator. The CCR used in this study was the Poseidon Se7en (Se7en) (Poseidon Diving Systems AP). The Se7en is a completely closed loop breathing systems which recirculates the divers breathing gasses. The exhaled gas flows through the closed loop and the CO_2 is removed via chemical scrubber. This gas is then analyzed, and oxygen is added to the loop if necessary. This completely sealed unit renders the Se7en relatively bubble and noise free when at a constant depth (Pyle 1996). The only minute sounds emitted from this unit is the solenoids injecting gasses into the breathing loop. The extended dive time capacity of up to 3 hours allowed for up to 4 CCR surveys in one field day.

SURVEY METHOD

The survey method selected for this study is the stationary point count (SPC) as described by Bohnsack & Bannerot (1986), and modified by Ayotte et al. (2011). Prior to the beginning of this study the divers trained and calibrated with several practice surveys. The overall transect length was 22.5 m with divers stationed at 7.5 m and 15.0 m marks. The 7.5 m distance between divers was necessitated by the need to increase the safety of the divers and mitigate the added risk associated with CCR diving. The transect was made up of paracord, with flagging tape to demark 0.0 m, 7.5m, 15.0 m, and 22.5m. Each diver surveyed a 15.0 m overlapping, imaginary cylinders which extended to the ocean surface. The divers signal each other to start the timed portion of the survey. At this point a fish presence list is created during the first 5 minutes of the survey. After the first 5 minutes have passed the divers then quantify the fish species beginning at the top of the list, noting the quantity and total length (cm). This is continued until the species list is completely counted. In addition to the species list, if a new fish species enters the survey area while the quantification procedure is being done, it is counted in a separate column, with the number and size of the fish or fishes. There are two categories for these newly entered fish species, after 5 minutes or after 10 minutes.

The divers began the surveys by navigating to the transect sites using handheld GPS units secured to a dive float. After decent, the divers deployed the 22.5 m paracord on the substrate, being mindful not to damage corals or other marine life. After the initial survey was completed utilizing the protocols mentioned previously, the transect line was left behind with a surface marker buoy located within 10.0 m demarking its location from the surface. The divers then navigated to a second location and deployed and conducted a second separate transect. After the two transects were completed utilizing the first gear type, the divers returned to shore and swapped apparatus. The divers, now equipped with the second gear type, navigated back to the floats and conducted the second survey on the same transects. After these revisited transects were completed, the divers then navigated to two different sites and conducted more surveys as gas and time allowed. Those transect lines were then left behind in order for the divers to navigate back to them on OC gear and finish the comparative fish counts. There were at least 30 minutes between the surveys on the different gear types. This daily diving evolution varied in productivity ranging from 2 to 4 comparisons per day. Logistical factors, such as tank refills, distance to the dive location, and the length of surface swim to the transect site, all played a role in the amount of surveys completed per day. Additionally, the paired surveys needed to be completed on the same day, and if it was not possible, subsequent dives were postponed.

DATA ANALYSIS

The means in total fish biomass, fished species biomass, unfished, and species richness were separated by gear types, OC and CCR, and by site (Table 1). Additionally, species that are rare and live in large schools or have large biomass were removed in order to avoid erroneously masking differences between the gear types. Examples of these species include *Lutjanus kasmira* (blue lined snapper), sharks and rays, and some mid water species like *Decapterus macarellus*. The fished species consisted of highly desirable species in Hawaii that fishers are known to target (Gray et al. 2016). These fished species include scarid parrotfishes, acanthurid surgeonfishes, mullid goatfishes, carangid jacks, one species of lutjanid snapper (*Lutjanus fulva*), one serranid grouper (*Cephalopholis argus*), and several other selected species. The unfished species were further classified into midwater, and a benthic group. Only the unfished benthic group was used in this study to eliminate the variations between site abundance of the midwater unfished species. In addition to those subsets, species richness and fish abundance were also utilized in this study.

Fish biomass was calculated utilizing the length to weight ratio the as described by Kulbiki (2004, 2005), Froese (2015), and Gray et al. (2016). All the response variables of interest, including fish biomass, species richness, fish abundance, fished and unfished species biomass were pooled and not transformed. A generalized mixed model approach was used to deal with the multiple fixed and random variables, low sample size, and non-normal data distribution. The statistical analyses were conducted with R version 3.2.3 statistical software, the lme4 package, with graphical output utilizing ggplot2 (Wickham 2009, Bates et al. 2015, R Core

Team 2017). The best fit distribution of the response variables was tested utilizing a log likelihood approach. Fish biomass data fit best a gamma distribution and the discrete data of species richness was fitted to a Poisson distribution. The Aikaike Information Criterion for low sample size (AICc) model selection utilized the AICcmodave package for R for each response variable and subset (Arnold 2010) (Mazerolle, 2016). Candidate models were chosen comprising of the fixed variables of interest the apparatus used (GEAR), i.e., OC or CCR, the protection status (MGMT), fished or protected. Random variables included the transect (SITE), and location (LOCATION). The best candidate models for each response variable were selected by AICc score considering the factors of interest for this study which is GEAR and MGMT (Burnham & Anderson 2002; Burnham 2004). The model selection for the fished and unfished response variables utilized only the fixed variables of gear type and protection status in order to reduce the model complexity and increase the ability for it to detect differences. The selected generalized linear mixed model was then applied to each response variable as described by Zuur et al (2009).

To determine the most suitable generalized mixed model, each response variable was independently tested with a priory set of candidate models. These response variables were all fish species biomass, fished species biomass, unfished benthic species biomass, species richness, and fish abundance. The primary variable of interest was GEAR type (OC, CCR), while including management status (MGMT), i.e., fished or protected, to determine the effects of fishing pressure on the response variable. Some models included the interaction between the GEAR type and MGMT status. Additionally, the individual transects (SITE) were included in all the models and treated as a random variable along with location, for the response variables that were pooled across all sites. The result of the AICc model selection is contained in the supplemental materials (S1). The response variable of time resulted in errors of convergence, primarily in the individual site analysis, therefore eliminated from the AICc in the OA and PK models. The species richness models were selected with the same protocols as was done for the fish biomass data set.

RESULTS

The mean estimate of total fish biomass for OC surveys was similar to that of CCR surveys, regardless of the location of the survey or its protection status (OC: 28.17 ± 5, CCR, 27.05 ± 4.95; Table 1). However, estimates of fish biomass were lower from surveys conducted in protected areas relative to those conducted outside the boundaries of protected areas (Protected: 20.21 ± 2.59, Fished: 35.01 ± 3.91; Table 2). Furthermore, there was an interaction between the gear type used and the protection status of the survey location (Pr(>|t|) = 0.025) corresponding to a larger difference in the estimates of total fish biomass between OC and CCR surveys at protected areas than that seen between the gear types in unprotected areas (Figure 5). The Old Kona Airport site also showed a similar significant difference in MGMT type (Pr(>|t|) = 0.022), with more fish in the fished areas than in protected area.

The mean biomass of fished species was higher on the OC than on the CCR in the fished areas (Pr(>|t|) = 0.01; Table 1). The visualization of the fished biomass data in a principal co-ordinate analysis suggests that the parrotfish taxa is the driving factor for the differences in gear type (Figure 8). Differences in the estimated biomass of parrotfishes seems to be the taxa primarily driving observed differences between gear types. This effect of gear type was not seen for non-targeted species (Pr(>|t|) = 0.966). However, the estimated biomass of non-targeted species was lower from surveys conducted in protected areas compared to those conducted in fished areas, independent of the gear type used for the survey (Pr(>|t|) = 0.004; Table 2). This was also significant at Old Kona Airport having a Pr(>|t|) = 0.050 with a similar interpretation of more biomass outside of the protected area than within the protected area.

Two sites showed differences by gear type for fish abundance, OA (Pr(>|t|) = 0.023) and PK (Pr(>|t|) = 3.32^{-6}). There also was a significant difference by protection status for the OA site (Pr(>|t|) = 0.009). There was less fish abundance in the OA protected area with 2.76 fish /m^2 and 6.25 fish/m^2 in the fished areas. In addition to differences in the fish abundance, there was a significantly higher species richness outside of the protected area than within the protected area (Pr(>|t|) = 0.002). The KK site also had a significant difference between the protected and non-protected areas (Pr(>|t|) = 0.007). Generally, the fished areas exhibited greater abundance and had greater species richness than the protected areas in this study.

Surveys conducted with CCR also reported similar species richness values compared to those conducted with OC, independent of survey location or its protection status ($Pr(>|t|) = 0.107$; Table 1). There was a significant difference due to protection status. These differences in the pooled species richness and the Kealakekua site ($Pr(>|t|) = 0.002$ and $Pr(>|t|) = 0.007$) (Table 5). In contrast, fish abundance estimates were higher using CCR at Old Kona Airport and Pūpūkea compared to estimates from surveys using OC at those same sites ($Pr(>|t|) \leq 0.023$). However, no such difference was observed in the surveys conducted at Kealakekua. In addition to significant differences in gear type, the protection status was also significant for the Old Kona Airport site ($Pr(>|t|) = 0.009$). This site also showed greater fish abundance in the fished area than the protected area. The principal co-ordinate analysis (PCoA) visualized the fish community variation by the gear type and protection (Supplemental 3).

DISCUSSION

The use of CCR allowed for the complete elimination of OC exhaust during fish surveys, and allowed us to examine the effects these bubbles have on the resulting data collected. The influence of fishing pressure was examined to evaluate whether fishes associated exhaust bubbles with the presence of a potentially dangerous predator. We found that the use of CCR did not produce a strong, consistent bias on estimates of fish biomass or species richness, though it did seem to have the potential to influence estimates of abundance and the biomass of targeted species, especially parrotfishes. However, these results were not unequivocal as they were often also influenced by the protection status of the survey site and potentially other factors related to the site. In that sense, the results are consistent with previously published studies indicating that while exhaust bubbles may influence fish survey results, the bias is not necessarily consistent in direction or magnitude. For example, Cole et al. (2007) found no differences between OC and CCR while Lindfield et al. (2014) found large differences. Gray et al. (2016) found modest differences between OC and CCR in heavily fished areas, but no differences in locations with low fishing pressure.

Counterintuitively, fish biomass estimates were generally higher from the surveys conducted in the fished areas than in the protected areas. However, while protection status seemed to be the more influential factor, there was a greater difference between estimates of biomass from OC and CCR within the protected areas than those from the unprotected areas. No significant differences between gear types are consistent with the findings of Cole et al. (2007). One possible reason for the similarity that they found between the gear types may not be the same reason for the similarities in this study. They used a semi closed-circuit rebreather which emits a consistent stream of bubbles which makes the OC unit less different than if they used a CCR unit which emits no bubbles. This continuous flow of exhaust from both the OC and semi closed-circuit rebreather may be the reason for their inability to detect the effects of OC exhaust on fish surveys.

While the total biomass from surveys using OC did not differ from those using CCR, the estimates of the biomass of fished species was higher from surveys using OC. These differences in CCR biomass is calculated to have ~75% of the OC biomass for all sites combined. The largest difference in fished biomass was at KK with the CCR unit having ~ 59% of the OC biomass. The magnitude of these results is more similar to Gray et al. (2016), with the OC having 32 to 68% of the biomass of the CCR surveys. However, this study has larger biomass on the OC unit opposed to the Gray study observing more biomass on the CCR unit. These inverted results convolute the true effects of OC exhaust on fish surveys. The simplicity of exhaust bubbles attracting fish in protected areas and repelling them in fished areas as Lindfield et al. (2014) results suggest, this may not be the case. They reported a 48% increase in species richness along with a 200 – 300% increase in relative abundance and biomass when surveys were conducted on CCR. The results of this study are substantially different. Their study in Guam could have been the result of heavy fishing pressure which triggered dramatic flight response in the fish there. Another reason for the greater differences between gear types could be the fish survey method. They performed strip transects in which the constant forward motion of the diver could have induced a more severe flight response by fishes, thus exacerbating the differences between gear types. A third potential source of increased variability in that study could be the use of a diver operated video camera. The camera may have been viewed as a threatening object by fishes during the surveys which may have also lead to an increased flight response. It would be plausible to conclude that OC exhaust is more of an attractant to fish within protected areas than as a repellent in fished areas. Because the fished species biomass between the protected and fished areas are statistically similar, and there is greater biomass on OC, the difference in gear type could be driven by the stronger attraction to bubbles from the fish in the protected areas.

The recent paper by Gray et al. support some differences in fish surveys between the two gear types depending on the potential fishing pressure of the area (2016). Differences of lesser magnitude were observed in the highly-fished areas of Oahu. They also found insignificant differences with the moderately fished areas in their study. For their sites in the West Hawaii Fisheries Management Area, they classified them as "unassigned" (Gray et al. 2016). This coastline is more difficult to assess the fishing pressure and would have a high probability of arriving at the same conclusions as this project.

This study presents an additional body of work to help dissect the effects of SCUBA exhaust on *in-situ* fish surveys with considerations taken for fishing pressure. This uniquely managed coastline in Hawai'i does not allow SCUBA spearfishing, which may have had a significant effect on the results of this study. These results emphasize the importance of understanding local fishing when interpreting the results of fish surveys. If we take the estimate of the fish biomass of Hanauma Bay, Oʻahu from Friedlander et al. of 1.1 t/ha within the MLCD and a mean biomass of 0.3 t/ha outside of the MLCD which is a difference of 3.67 times (Friedlander et al. 2006). Then, utilizing the observed differences between the two apparatus as found by Gray et al. (2016), and OC having 68% less biomass (fished taxa), this will reduce the difference of biomass between the protected and non-protected areas, essentially, reducing the overall efficacy level of this particular MLCD. That study showed a larger variation in fish surveys in more heavily fished areas, therefore, if these differences are applied the true managerial value of these reserves can be assessed.

A similar approach could be taken for OC surveys conducted in less heavily fished areas. These surveys could be evaluated without prejudice due to the similarity of OC and data collected in such areas. If natural resource managers elsewhere implement a similar prohibition on spearfishing on SCUBA, the present study suggests that minimal differences would be found between gear types, and either could be effectively used for *in-situ* fish surveys. Implementation of such a regulation would provide fishes with a refugium in depth due to the depth limitations of most freedivers.

One can speculate that fishes are able to discriminate a freediving spearfisher and a SCUBA diver based on behavior. The freediver spends a majority of time on the surface punctuated by occasional short trips to the bottom for a minute or two. In comparison, a SCUBA diver remains on the bottom for extended periods, exhales conspicuous clouds of bubbles. In order to further this area of study a large scale, near pristine marine reserve needs to be considered for a study site. A location with no fishing pressure which could become the baseline for all studies exploring the effects of OC exhaust on *in-situ* fish surveys. The variation among these similar studies indicates that fishing pressure has a major influence on the effects of OC exhaust on fish surveys and a comparative study in a large-scale marine protected area may be a good baseline for studies of this type.

TABLES

Table 1: The mean and standard error of biomass (g/m^2) for all fish, fished species, unfished midwater species, and unfished bottom species separated by gear type (OC/CCR). The total number of transects were n=30, with n=10 for the individual sites of Kealakekua Bay, Old Kona Airport, and Pūpūkea MLCD. Differences between gear type on the species richness is at the bottom of this table.

Fish Group	**Location**	**OC**			**CCR**		
	Site	**Mean**		**SE**	**Mean**		**SE**
All Fish	**All**	28.17	±	5	27.05	±	4.95
	Kealakekua	18.91	±	2.9	17.12	±	2.84
	Old Kona Airport	51.13	±	5.63	47.73	±	5.75
	Pūpūkea	14.49	±	2.62	16.28	±	2.78
Fished Biomass	**All**	11.80	±	1.35	8.85	±	1.20
	Kealakekua	9.18	±	1.98	5.34	±	1.27
	Old Kona Airport	17.68	±	2.09	12.81	±	2.28
	Pūpūkea	8.54	±	1.86	8.41	±	1.98
UnFished Midwater	**All**	2.02	±	0.74	2.73	±	0.94
	Kealakekua	0.91	±	0.32	0.73	±	0.14
	Old Kona Airport	4.83	±	1.97	6.17	±	2.50
	Pūpūkea	0.30	±	0.10	1.28	±	0.51
UnFished	**All**	5.31	±	0.92	5.29	±	0.66
	Kealakekua	3.01	±	0.32	3.37	±	0.35
	Old Kona Airport	8.12	±	2.50	7.47	±	1.72
	Pūpūkea	4.80	±	0.61	5.03	±	0.48
Species Richness							
All Fish	**All**	33.80	±	2.67	35.73	±	2.75
	Kealakekua	31.70	±	2.27	33.00	±	2.14
	Old Kona Airport	40.00	±	2.59	41.20	±	2.67
	Pūpūkea	29.70	±	2.24	33.00	±	2.81

Table 2: The mean and standard error of biomass (g/m^2) for all fish, fished species, unfished midwater species, and unfished bottom species separated by protection status (Protected/Fished). The total number of transects were n=30, with n=10 for the individual sites of Kealakekua Bay, Old Kona Airport, and Pūpūkea MLCD. Differences between protections status on the species richness is at the bottom of this table.

Fish Group	**Location**	**Protected**			**Fished**		
	Site	**Mean**		**SE**	**Mean**		**SE**
All Fish	**All**	20.21	±	2.59	35.01	±	3.91
	Kealakekua	14.61	±	2.12	21.42	±	3.09
	Old Kona Airport	29.11	±	3.34	69.74	±	5.71
	Pūpūkea	16.89	±	2.30	13.88	±	2.95
Fished Biomass	**All**	10.60	±	1.06	10.05	±	1.51
	Kealakekua	6.84	±	1.20	7.67	±	2.21
	Old Kona Airport	13.50	±	2.26	16.99	±	2.26
	Pūpūkea	11.46	±	1.32	5.49	±	1.93
UnFished Midwater	**All**	1.37	±	0.33	3.38	±	1.12
	Kealakekua	0.88	±	0.30	0.76	±	0.19
	Old Kona Airport	2.90	±	0.73	8.11	±	2.87
	Pūpūkea	0.32	±	0.20	1.26	±	0.49
UnFished	**All**	3.79	±	0.32	6.81	±	1.01
	Kealakekua	2.66	±	0.25	3.72	±	0.32
	Old Kona Airport	4.70	±	0.63	10.89	±	2.59
	Pūpūkea	4.02	±	0.56	5.81	±	0.34
Species Richness							
All Fish	**All**	32.00	±	2.01	37.53	±	2.46
	Kealakekua	28.90	±	1.91	35.80	±	1.74
	Old Kona Airport	38.60	±	2.20	42.60	±	2.83
	Pūpūkea	28.50	±	1.90	34.20	±	2.81

Table 3: Generalized linear mixed model summary (GLMER) for total fish biomass, fished biomass, and unfished biomass. Fished species comprised of fish regarded as highly desirable, and unfished biomass comprised of species that are not a desirable food fish and are considered a "noisy" species in which the random high count could obscure the effects of the OC exhaust. Gear type (OC, CCR), Management Status (MGMT) (Fished and Protected). The AICc best model for total fish biomass at all sites combined and for the Old Kona Airport (OA) site included the interaction between the Gear type and the MGMT.

Fixed effects	Estimate	Standard Error	t value	Pr (>|t|)
All Fish Biomass				
All Sites				
GEAROC	0.001	0.002	0.559	0.576
MGMTProtected	0.002	0.014	0.140	0.888
GEAROC:MGMTProtected	0.012	0.005	-2.235	0.025 *
Kealakekua Bay				
GEAROC	-0.004	0.009	-0.422	0.673
MGMTProtected	0.013	0.014	0.899	0.369
Old Kona Airport				
GEAROC	0.001	0.002	0.364	0.716
MGMTProtected	0.023	0.010	2.285	0.022 *
GEAROC:MGMTProtected	-0.015	0.007	-2.178	0.029 *
Pupukea MLCD				
GEAROC	0.007	0.008	0.841	0.401
MGMTProtected	-0.034	0.030	-1.116	0.264
Fished Biomass				
All Sites				
GEAROC	2.946	1.062	2.775	0.010 **
MGMTProtected	0.549	2.022	0.271	0.788
Kealakekua Bay				
GEAROC	3.841	1.847	2.080	0.067
MGMTProtected	-0.833	2.922	-0.285	0.783
Old Kona Airport				
GEAROC	4.868	1.545	3.150	0.012 *
MGMTProtected	-3.489	4.163	-0.838	0.426
Pupukea MLCD				
GEAROC	0.129	1.928	0.067	0.948
MGMTProtected	5.968	2.839	2.103	0.069
Unfished Biomass				
All Sites				
GEAROC	-0.001	0.012	-0.042	0.966
MGMTProtected	0.089	0.031	2.863	0.004 **
Kealakekua Bay				
GEAROC	0.033	0.031	1.057	0.291
MGMTProtected	0.103	0.057	1.807	0.071
Old Kona Airport				
GEAROC	-0.007	0.020	-0.364	0.716
MGMTProtected	0.092	0.047	1.958	0.050*
Pupukea MLCD				
GEAROC	0.009	0.017	0.510	0.610
MGMTProtected	0.124	0.076	1.632	0.103

Table 4a,b: Individual fish counts for species of interest by site and the total. Kealakekua Bay (KK) and Old Kona Airport are on Table 3(a) and Pūpūkea and the accumulated totals are on Table 3(b).

4(a)

Taxon	Species	Kealakekua				Old Kona Airport			
		Non-Protected		Protected		Non-Protected		Protected	
		OC	CCR	OC	CCR	OC	CCR	OC	CCR
Acanthuridae	*Acanthurus blochii*	9	3	3	0	1	7	2	1
	Acanthurus dussumieri	0	0	0	0	6	2	3	0
	Acanthurus nigroris	0	0	0	1	7	5	0	3
	Acanthurus olivaceus	10	0	23	12	10	5	12	9
	Acanthurus triostegus	0	0	0	0	10	0	0	0
	Acanthurus xanthopterus	0	0	1	0	0	0	0	0
	Ctenochaetus hawaiiensis	31	30	23	21	20	30	6	6
	Ctenochaetus strigosus	226	265	479	475	254	195	233	208
	Naso hexacanthus	18	77	0	0	1	12	17	9
	Naso lituratus	23	35	7	9	10	17	18	19
	Naso unicornis	1	2	0	0	3	1	0	0
	Zebrasoma flavescens	213	230	145	163	222	247	215	161
Carangidae	*Caranx melampygus*	0	0	0	0	2	0	0	0
	Decapterus macarellus	0	0	3	8	0	22	0	0
Labridae	*Bodianus albotaeiatus*	0	0	0	2	2	1	3	0
Lethrinidae	*Monotaxis grandoculis*	0	0	8	11	0	0	0	2
Lutjanidae	*Aphareus furca*	1	2	0	0	8	8	8	3
	Aprion virescens	0	0	0	0	0	0	0	0
	Lutjanus kasmira	1	1	7	9	4	6	2	0
Malacanthidae	*Malacanthus brevirostris*	0	0	0	0	0	0	0	0
Microdesmidae	*Gunnellichthys curiosus*	0	0	0	0	0	0	0	0
Mullidae	*Parupeneus cyclostomus*	0	0	2	3	5	1	1	0
	Parupeneus insularis	1	1	6	3	2	3	5	2
	Parupeneus multifasciatus	8	7	8	10	9	13	7	6
	Parupeneus pleurostigma	0	0	0	0	1	0	2	1
Scaridae	*Calotomus carolinus*	3	2	1	2	3	6	2	1
	Chlorurus perspicillatus	1	0	0	0	0	0	0	0
	Chlorurus spilurus	53	32	11	6	17	9	12	12
	Scarus psittacus	0	0	9	4	0	3	0	2
	Scarus rubroviolaceus	0	1	2	2	8	4	2	1
Serranidae	*Cephalopholis argus*	12	6	11	20	9	9	14	9
	All species	611	694	749	761	614	606	564	455

4(b)

Taxon	Species	Pūpūkea				All Locations			
		Non-Protected		Protected		Non-Protected		Protected	
		OC	CCR	OC	CCR	OC	CCR	OC	CCR
Acanthuridae	*Acanthurus blochii*	0	0	1	0	10	10	6	1
	Acanthurus dussumieri	0	3	5	6	6	5	8	6
	Acanthurus nigroris	0	0	0	0	7	5	0	4
	Acanthurus olivaceus	9	9	14	8	29	14	49	29
	Acanthurus triostegus	0	1	7	28	10	1	7	28
	Acanthurus xanthopterus	0	0	1	1	0	0	2	1
	Ctenochaetus hawaiiensis	0	0	0	0	51	60	29	27
	Ctenochaetus strigosus	26	12	4	1	506	472	716	684
	Naso hexacanthus	1	0	0	0	20	89	17	9
	Naso lituratus	10	8	8	6	43	60	33	34
	Naso unicornis	4	6	2	7	8	9	2	7
	Zebrasoma flavescens	0	0	1	0	435	477	361	324
Carangidae	*Caranx melampygus*	0	2	6	5	2	2	6	5
	Decapterus macarellus	12	1	0	5	12	23	3	13
Labridae	*Bodianus albotaeiatus*	8	6	10	6	10	7	13	8
Lethrinidae	*Monotaxis grandoculis*	2	2	8	11	2	2	16	24
Lutjanidae	*Aphareus furca*	0	1	0	0	9	11	8	3
	Aprion virescens	1	3	0	0	1	3	0	0
	Lutjanus kasmira	0	0	3	3	5	7	12	12
Malacanthidae	*Malacanthus brevirostris*	2	1	0	0	2	1	0	0
Microdesmidae	*Gunnellichthys curiosus*	0	1	0	0	0	1	0	0
Mullidae	*Parupeneus cyclostomus*	1	2	3	3	6	3	6	6
	Parupeneus insularis	0	2	2	5	3	6	13	10
	Parupeneus multifasciatus	53	55	23	26	70	75	38	42
	Parupeneus pleurostigma	6	8	5	6	7	8	7	7
Scaridae	*Calotomus carolinus*	0	1	2	0	6	9	5	3
	Chlorurus perspicillatus	0	0	0	0	1	0	0	0
	Chlorurus spilurus	0	2	0	1	70	43	23	19
	Scarus psittacus	3	2	0	0	3	5	9	6
	Scarus rubroviolaceus	1	1	1	1	9	6	5	4
Serranidae	*Cephalopholis argus*	0	0	1	0	21	15	26	29
	All species	139	129	107	129	1364	1429	1420	1345

Table 5: Generalized linear mixed model summary of Fish Abundance and Species Richness for all sites totaled and individual sites.

Fixed effects	Estimate	Standard Error	t value	Pr (>|t|)
Fish Abundance				
All Sites				
GEAROC	0.004	0.227	0.016	0.987
MGMTProtected	1.265	0.992	1.275	0.202
Kealakekua Bay				
GEAROC	0.655	0.433	1.511	0.131
MGMTProtected	1.687	1.599	1.055	0.292
Old Kona Airport				
GEAROC	-0.317	0.139	-2.280	0.023 *
MGMTProtected	1.473	0.563	2.615	0.009 **
Pupukea MLCD				
GEAROC	3.252	0.699	4.650	3.32e-06 ***
MGMTProtected	-6.879	5.218	-1.318	0.187
Species Richness				
All Sites				
GEAROC	-0.096	0.060	-1.610	0.107
MGMTProtected	-0.202	0.078	-2.580	0.002**
Kealakekua Bay				
GEAROC	-0.040	0.079	-0.510	0.609
MGMTProtected	-0.214	0.079	-2.710	0.007 **
Old Kona Airport				
GEAROC	-0.030	0.070	-0.420	0.674
MGMTProtected	-0.097	0.091	-1.070	0.285
Pupukea MLCD				
GEAROC	-0.105	0.080	-1.320	0.188
MGMTProtected	-0.180	0.100	-1.800	0.072

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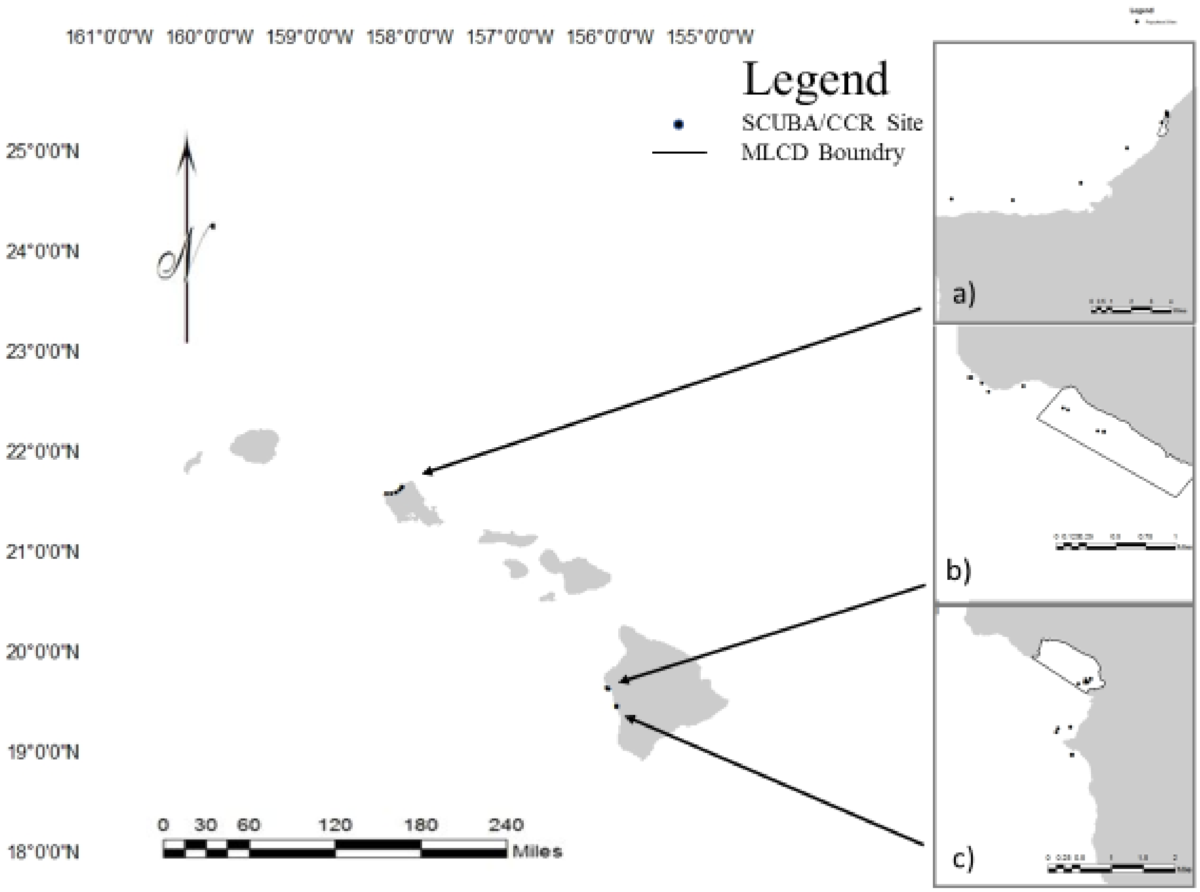

Figure 1: Study site locations in the main Hawaiian Islands, USA. Pūpūkea Marine Life Conservation District **(a)**, Oahu, Old Kona Airport **(b)** Kailua-Kona, Hawaii Island, and Kealakekua Bay **(c)**, Captain Cook, Hawaii Island. The SCUBA/CCR comparative sites are depicted by the dot and the boundary for the MLCD are represented by the line.

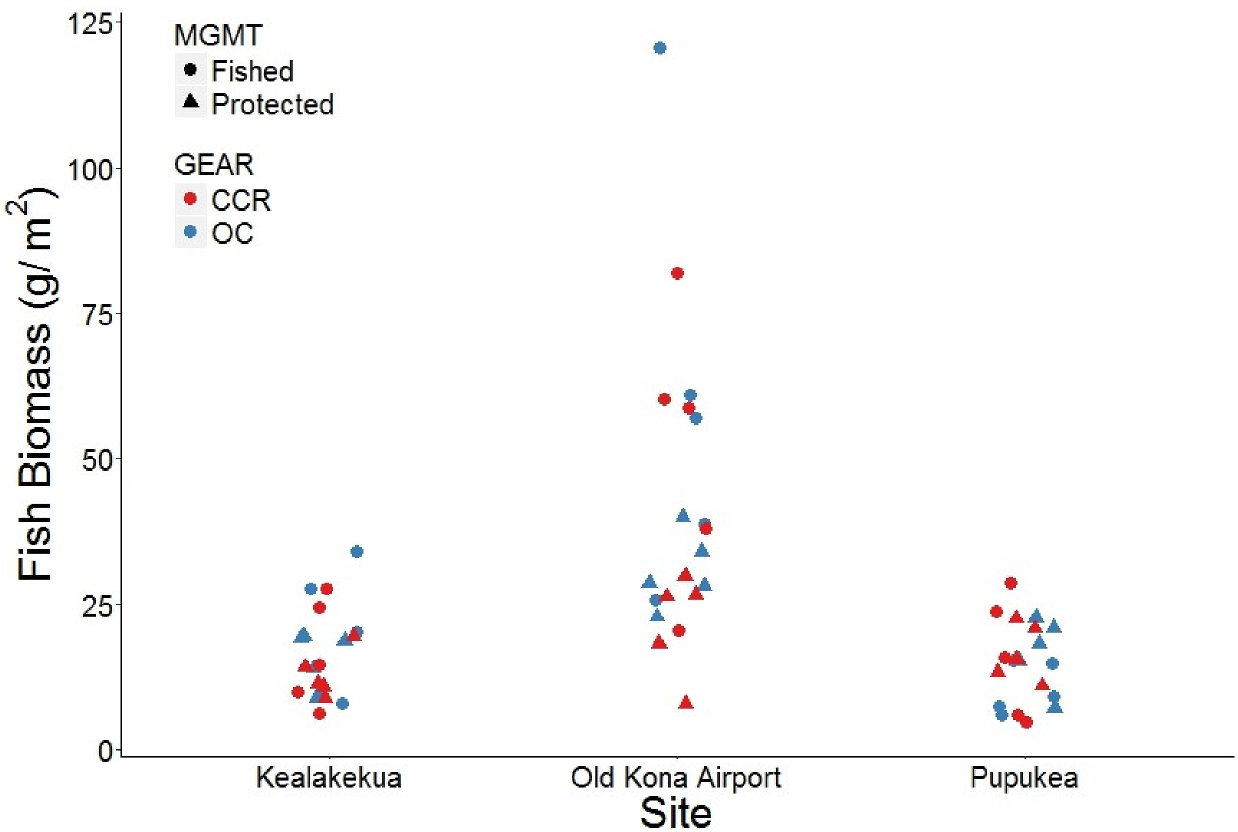

Figure 2: The strip chart show fish biomass (g/m^2) on the y-axis and the three sites on the x-axis, Kealakekua Bay (KK), Old Kona Airport (OA), and Pūpūkea MLCD (PK). Each shape represents an individual survey. The triangles represent protected areas and circles represent the non-protected areas. The color depicts the method, Closed-circuit rebreather (CCR) in red and the SCUBA in blue.

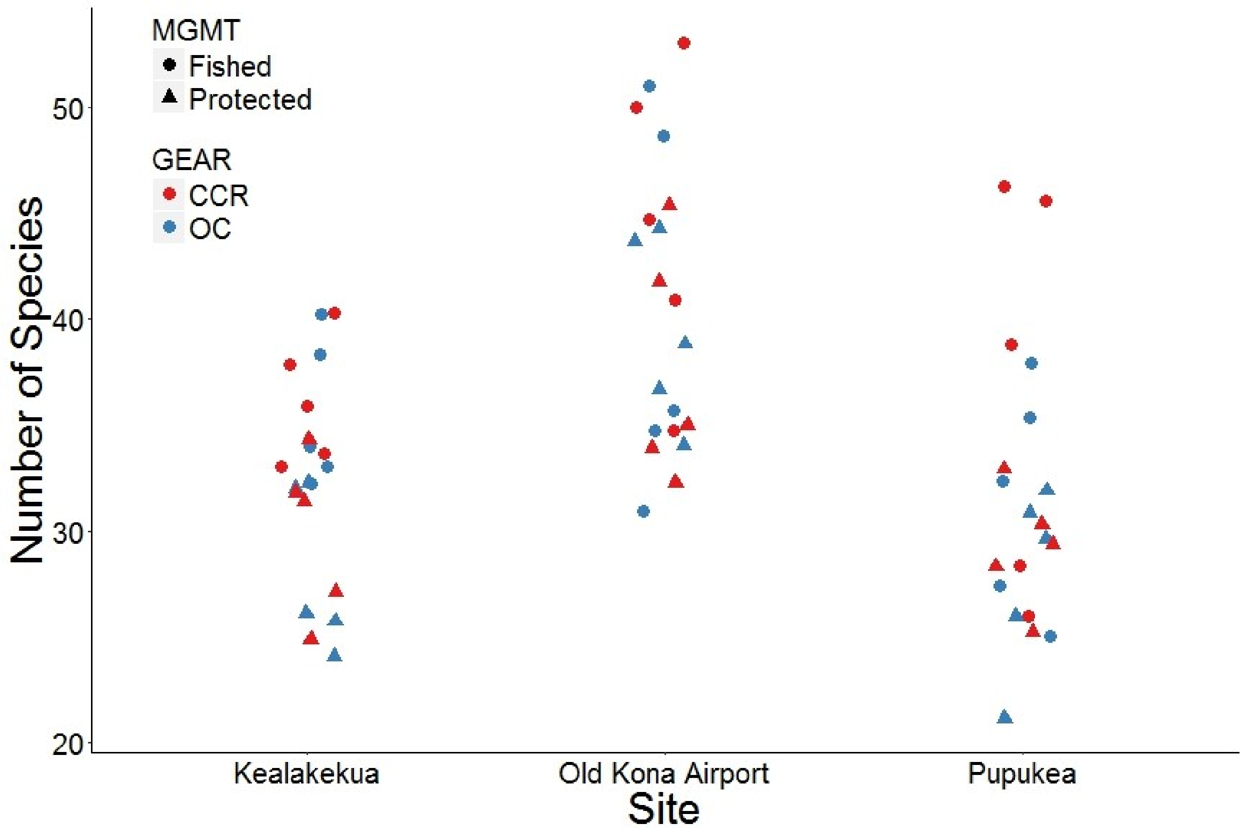

Figure 3: The strip chart show species richness on the y-axis and the three sites on the x-axis, Kealakekua Bay (KK), Old Kona Airport (OA), and Pūpūkea MLCD (PK). Each shape represents an individual survey. The triangles represent protected areas and circles represent the non-protected areas. The color depicts the method, Closed-circuit rebreather (CCR) in red and the SCUBA in blue.

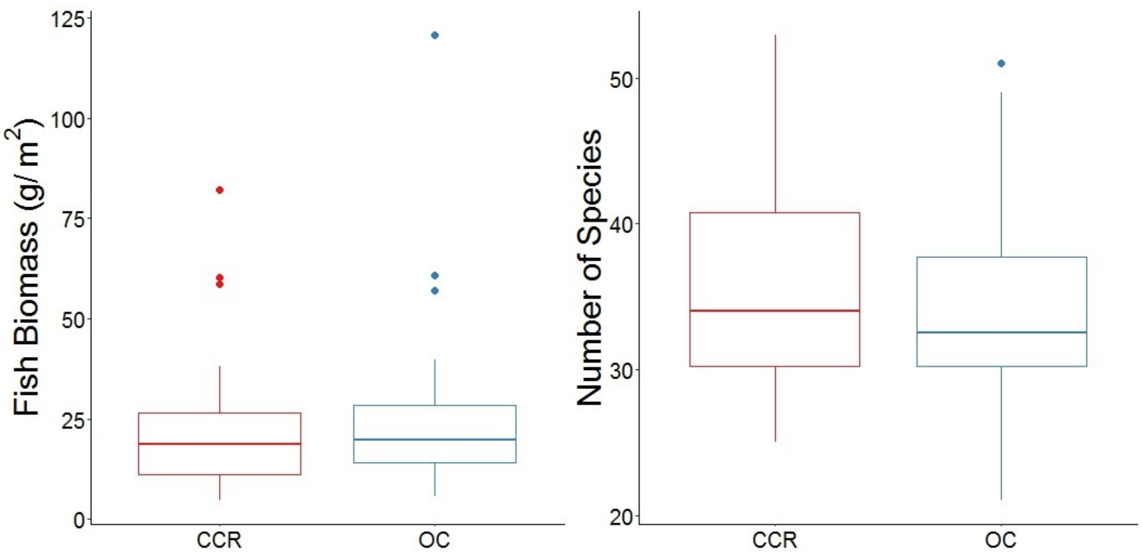

Figure 4: Boxplots with the whiskers representing the upper and lower quartiles and the bar representing the means of the pooled fish biomass (g/m^2) (left) and the species richness (right) categorized by apparatus type, CCR and SCUBA. The fish biomass shows no difference (Pr(>|t|)=0.576). Additionally there is no difference in species richness between the two gear types (Pr(>|t|)=0.107).

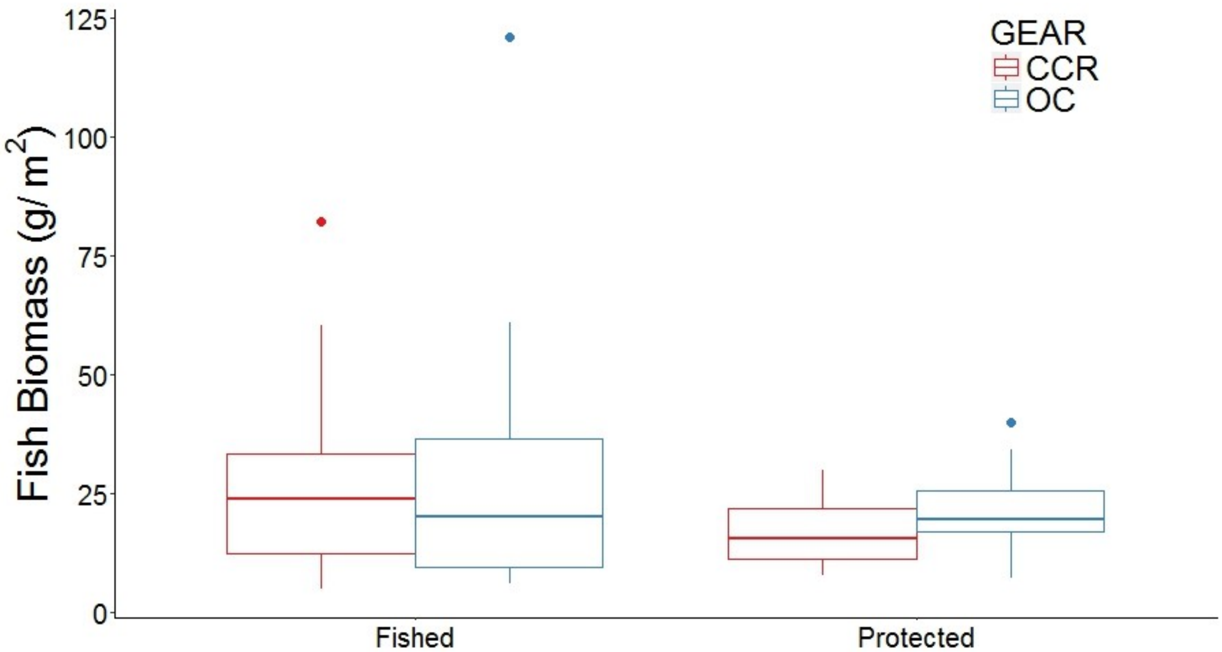

Figure 5: Boxplot for all fish biomass with whiskers representing the upper and lower quartiles and the lines represent the means for the different gear types (CCR, red, and OC, blue) separated by management status (MGMT) of fished and protected. The significant interaction between the MGMT and GEAR (Pr(>|t|)=0.025) are visually represented with the increasing difference in the means between the gear types from the fished area to the protected area.

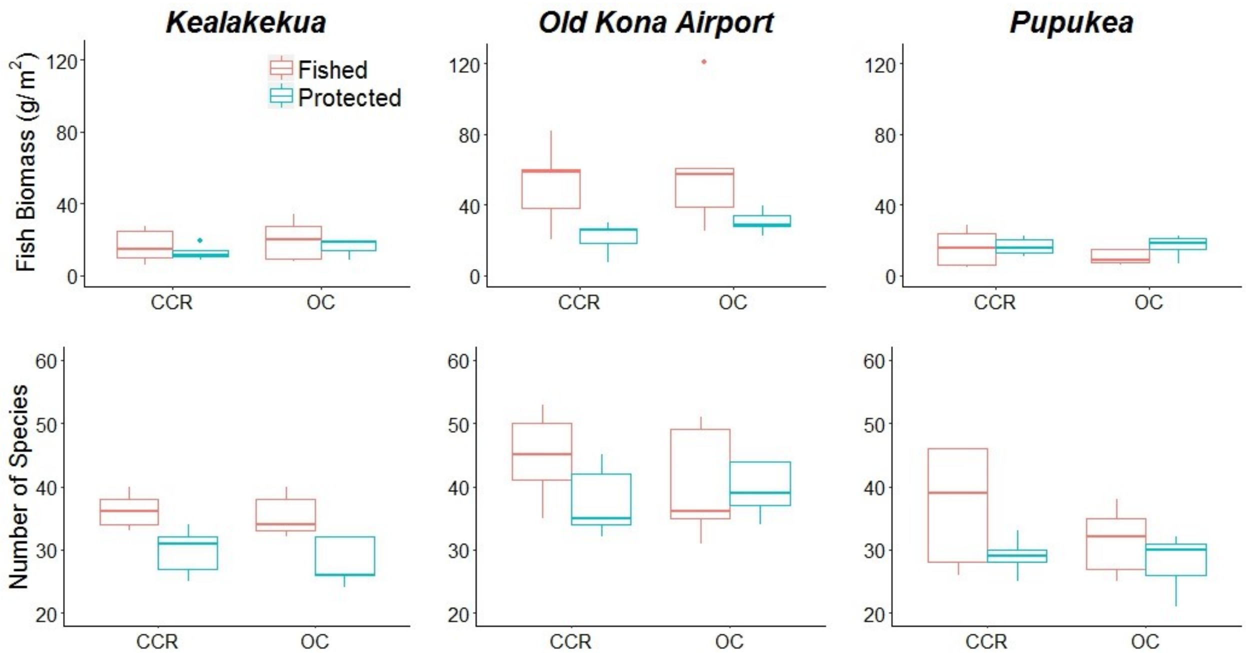

Figure 6: Boxplot for all fish biomass separated by sites, with whiskers representing the upper and lower quartiles and the lines represent the means. The top row depicts fish biomass (g/m^2) and the bottom row, species richness for Kealakekua bay (KK), Old Kona Airport (OA), and Pūpūkea (PK). The red boxes represent the fished areas while the blue represents the protected areas and the gear types are separated on the x-axis. There is a significant difference in the biomass means for protection status (Pr(>|t|)=0.022) and the interaction between protection and gear type (Pr(>|t|)=0.029) for OA. The species richness shows a significant difference in gear type for OA (Pr(>|t|)=0.012) having a higher mean with on the CCR then on the OC.

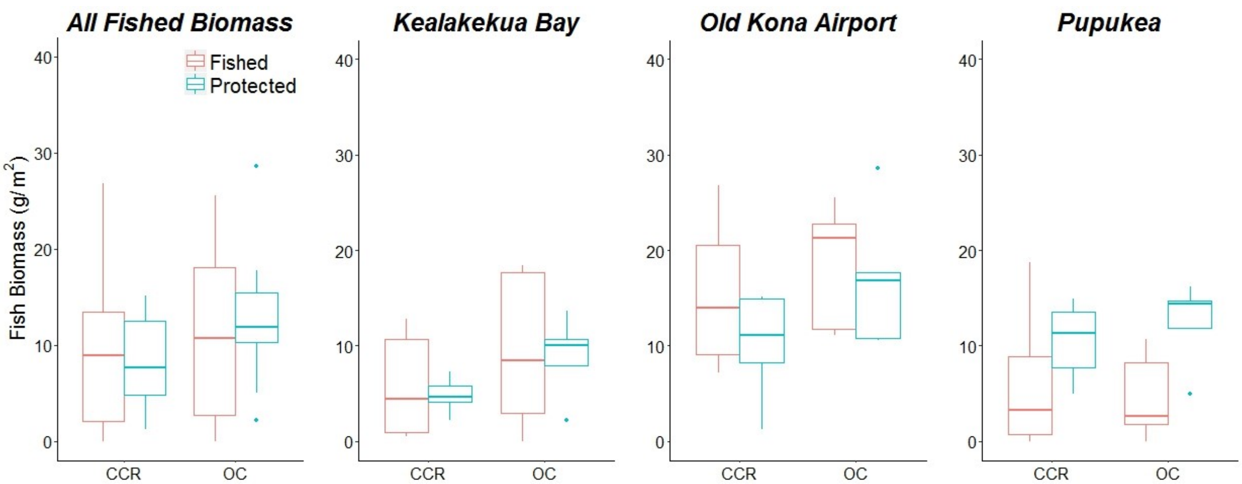

Figure 7: Box and whisker plots for the biomass of the fished species. The whiskers represent the upper and lower quartiles while the box shows the middle quartiles and the mean. From left to right the plots are the pooled biomass from the fished species from all three sites and the next plots show the individual site biomass. There is a significant difference between gear type for all sites combined (Pr(>|t|) = 0.010) and OA (Pr(>|t|) = 0.012).

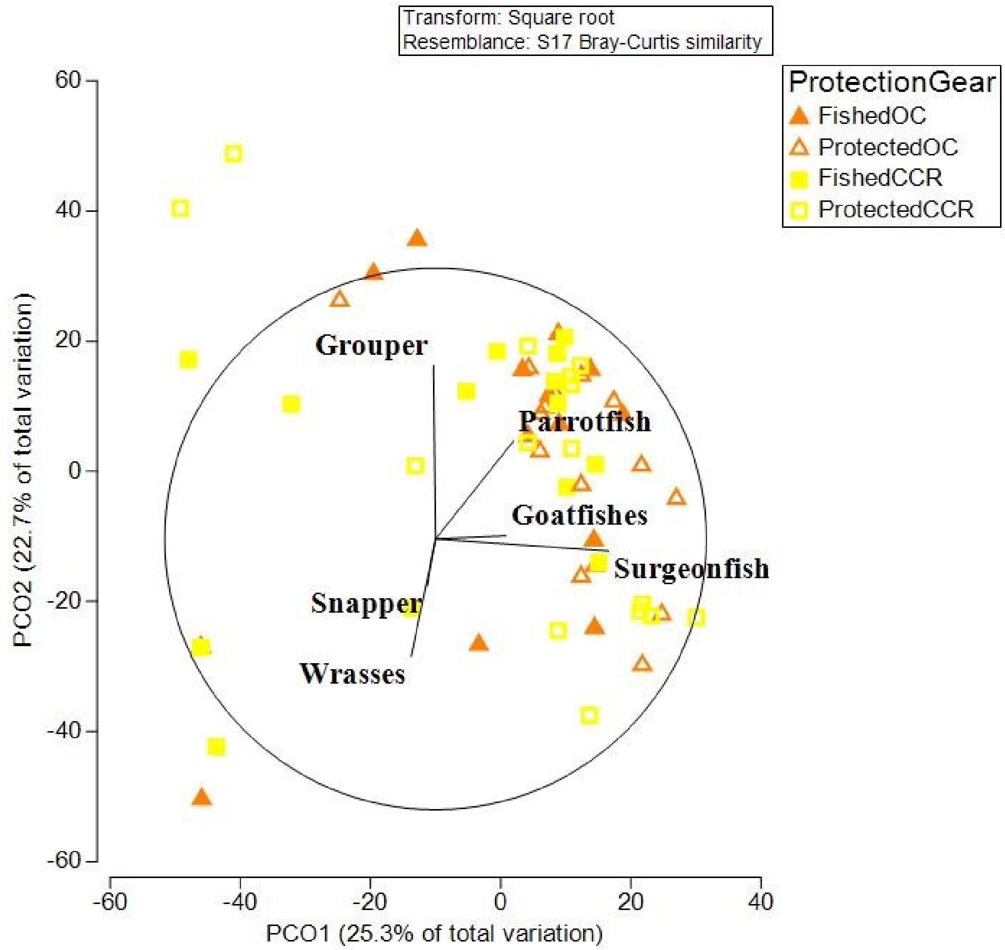

Figure 8: Principal co-ordinate analysis (PCoA) for the fished species biomass depicting 25.3% of the total variation explained on the x-axis and 22.7% variation on the y-axis. The fished species vectors suggest the parrot fish group is a strong driver toward the OC gear type (tan).

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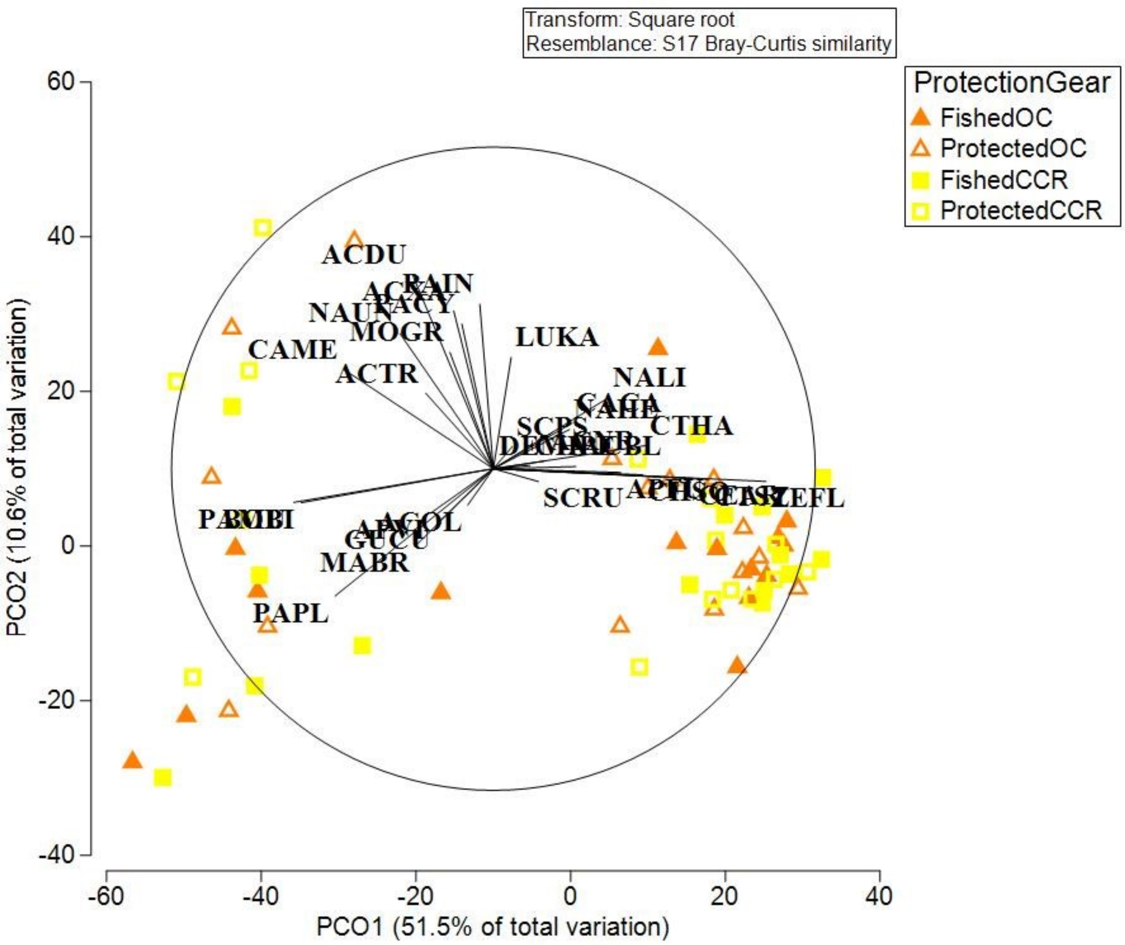
SUPPLEMENTAL 1: AICc model selection for all fish biomass and species richness.

All Sites	AICc	ΔAICc	K	AICcWt
AllFishBio10 ~ 1 + (1|MLCD) + (1|TIME) + (1|SITE_OLD)	446.16	0.00	5	0.48
AllFishBio10 ~ METHOD + MGMT*METHOD + (1|TIME) + (1|SITE_OLD)	449.24	3.08	7	0.10
AllFishBio10 ~ METHOD + MGMT + METHOD*MGMT + (1|TIME) + (1|SITE_OLD)	449.24	3.08	7	0.10
AllFishBio10 ~ METHOD + MGMT + (1|TIME) + (1|SITE_OLD)	449.29	3.13	6	0.10
AllFishBio10 ~ METHOD + MGMT*METHOD + (1|SITE_OLD)	449.84	3.68	6	0.08
AllFishBio10 ~ METHOD + MGMT + METHOD*MGMT + (1|SITE_OLD)	449.84	3.68	6	0.08
AllFishBio10 ~ METHOD + MGMT + METHOD*MGMT + (1|TIME) + (1|MLCD) + (1|SITE_OLD)	450.79	4.63	8	0.05
AllFishBio10 ~ METHOD + MGMT + (1|SITE_OLD)	452.20	6.04	5	0.02
Kealakekua				
AllFishBio10 ~ 1 + (1|TIME) + (1|SITE_OLD)	130.02	0.00	4	0.94
AllFishBio10 ~ METHOD + MGMT + (1|TIME) + (1|SITE_OLD)	136.95	6.93	6	0.03
AllFishBio10 ~ METHOD + MGMT + (1|SITE_OLD)	138.40	8.38	5	0.01
AllFishBio10 ~ METHOD + MGMT*METHOD + (1|TIME) + (1|SITE_OLD)	140.30	10.28	7	0.01
AllFishBio10 ~ METHOD + MGMT + METHOD*MGMT + (1|TIME) + (1|SITE_OLD)	140.30	10.28	7	0.01
AllFishBio10 ~ METHOD + MGMT*METHOD + (1|SITE_OLD)	141.65	11.63	6	0.00
AllFishBio10 ~ METHOD + MGMT + METHOD*MGMT + (1|SITE_OLD)	141.65	11.63	6	0.00
Old Kona Airport				
AllFishBio10 ~ METHOD + MGMT + (1|TIME) + (1|SITE_OLD)	-163.36	0.00	6	1.00
AllFishBio10 ~ METHOD + MGMT*METHOD + (1|TIME) + (1|SITE_OLD)	-138.58	24.78	7	0.00
AllFishBio10 ~ METHOD + MGMT + METHOD*MGMT + (1|TIME) + (1|SITE_OLD)	-138.58	24.78	7	0.00
AllFishBio10 ~ 1 + (1|TIME) + (1|SITE_OLD)	174.77	338.13	4	0.00
AllFishBio10 ~ METHOD + MGMT*METHOD + (1|SITE_OLD)	186.95	350.31	6	0.00
AllFishBio10 ~ METHOD + MGMT + METHOD*MGMT + (1|SITE_OLD)	186.95	350.31	6	0.00
AllFishBio10 ~ METHOD + MGMT + (1|SITE_OLD)	187.00	350.36	5	0.00
Pūpūkea				
AllFishBio10 ~ METHOD + MGMT + (1|TIME) + (1|SITE_OLD)	-190.39	0.00	6	1.00
AllFishBio10 ~ 1 + (1|TIME) + (1|SITE_OLD)	133.29	323.68	4	0.00
AllFishBio10 ~ METHOD + MGMT + (1|SITE_OLD)	141.88	332.27	5	0.00
AllFishBio10 ~ METHOD + MGMT*METHOD + (1|SITE_OLD)	144.91	335.30	6	0.00
AllFishBio10 ~ METHOD + MGMT + METHOD*MGMT + (1|SITE_OLD)	144.91	335.30	6	0.00

All	AICc	ΔAICc	K	AICcWt
SPECIESRICHNESS ~ 1 + (1|MLCD) + (1|TIME) + (1|SITE_OLD)	446.16	0.00	5.00	0.48
SPECIESRICHNESS ~ METHOD + MGMT*METHOD + (1|TIME) + (1|SITE_OLD)	449.24	3.08	7.00	0.10
SPECIESRICHNESS ~ METHOD + MGMT + METHOD*MGMT + (1|TIME) + (1|SITE_OLD)	449.24	3.08	7.00	0.10
SPECIESRICHNESS ~ METHOD + MGMT + (1|TIME) + (1|SITE_OLD)	449.29	3.13	6.00	0.10
SPECIESRICHNESS ~ METHOD + MGMT*METHOD + (1|SITE_OLD)	449.84	3.68	6.00	0.08
SPECIESRICHNESS ~ METHOD + MGMT + METHOD*MGMT + (1|SITE_OLD)	449.84	3.68	6.00	0.08
SPECIESRICHNESS ~ METHOD + MGMT + METHOD*MGMT + (1|TIME) + (1|MLCD) + (1|SITE_OLD)	450.79	4.63	8.00	0.05
SPECIESRICHNESS ~ METHOD + MGMT + (1|SITE_OLD)	452.20	6.04	5.00	0.02
Kealakekua				
SPECIESRICHNESS ~ METHOD + MGMT + (1|SITE_OLD)	122.98	0.00	4.00	0.60
SPECIESRICHNESS ~ METHOD + MGMT*METHOD + (1|SITE_OLD)	126.53	3.56	5.00	0.10
SPECIESRICHNESS ~ METHOD + MGMT + METHOD*MGMT + (1|SITE_OLD)	126.53	3.56	5.00	0.10
SPECIESRICHNESS ~ METHOD + MGMT + (1|TIME) + (1|SITE_OLD)	126.60	3.62	5.00	0.10
SPECIESRICHNESS ~ 1 + (1|TIME) + (1|SITE_OLD)	127.39	4.41	3.00	0.07
SPECIESRICHNESS ~ METHOD + MGMT*METHOD + (1|TIME) + (1|SITE_OLD)	130.71	7.73	6.00	0.01
SPECIESRICHNESS ~ METHOD + MGMT + METHOD*MGMT + (1|TIME) + (1|SITE_OLD)	130.71	7.73	6.00	0.01
Old Kona Airport				
SPECIESRICHNESS ~ 1 + (1|TIME) + (1|SITE_OLD)	136.79	0.00	3.00	0.59
SPECIESRICHNESS ~ METHOD + MGMT + (1|SITE_OLD)	138.71	1.91	4.00	0.22
SPECIESRICHNESS ~ METHOD + MGMT*METHOD + (1|SITE_OLD)	141.11	4.31	5.00	0.07
SPECIESRICHNESS ~ METHOD + MGMT + METHOD*MGMT + (1|SITE_OLD)	141.11	4.31	5.00	0.07
SPECIESRICHNESS ~ METHOD + MGMT + (1|TIME) + (1|SITE_OLD)	142.32	5.53	5.00	0.04
SPECIESRICHNESS ~ METHOD + MGMT*METHOD + (1|TIME) + (1|SITE_OLD)	145.28	8.49	6.00	0.01
SPECIESRICHNESS ~ METHOD + MGMT + METHOD*MGMT + (1|TIME) + (1|SITE_OLD)	145.28	8.49	6.00	0.01
Pūpūkea				
SPECIESRICHNESS ~ METHOD + MGMT + (1|SITE_OLD)	133.63	0.00	4.00	0.46
SPECIESRICHNESS ~ 1 + (1|TIME) + (1|SITE_OLD)	134.97	1.34	3.00	0.23
SPECIESRICHNESS ~ METHOD + MGMT*METHOD + (1|SITE_OLD)	136.60	2.97	5.00	0.10
SPECIESRICHNESS ~ METHOD + MGMT + METHOD*MGMT + (1|SITE_OLD)	136.60	2.97	5.00	0.10
SPECIESRICHNESS ~ METHOD + MGMT + (1|TIME) + (1|SITE_OLD)	137.25	3.62	5.00	0.07
SPECIESRICHNESS ~ METHOD + MGMT*METHOD + (1|TIME) + (1|SITE_OLD)	140.78	7.15	6.00	0.01
SPECIESRICHNESS ~ METHOD + MGMT + METHOD*MGMT + (1|TIME) + (1|SITE_OLD)	140.78	7.15	6.00	0.01

SUPPLIMENTAL 2: Principal co-ordinate analysis for the abundance of species of interest. Complete list of species in supplemental 3. This PCoA is has no obvious groupings and no observable drivers due to species which supports the statistical analysis of no overall significant difference in gear types for abundance. Most of the variation is due to the x-axis at 51.5% and a small amount of variation is due to the y-axis at 10.6%.



SUPPLIMENTAL 3: Species abbreviation list for the PCoA analysis.

SPECIES	TAXONNAME
ACBL	Acanthurus blochii
ACDU	Acanthurus dussumieri
ACNR	Acanthurus nigroris
ACOL	*Acanthurus olivaceus*
ACTR	*Acanthurus triostegus*
ACXA	*Acanthurus xanthopterus*
CTHA	*Ctenochaetus hawaiiensis*
CTST	*Ctenochaetus strigosus*
NAHE	*Naso hexacanthus*
NALI	*Naso lituratus*
NAUN	*Naso unicornis*
ZEFL	*Zebrasoma flavescens*
CAME	*Caranx melampygus*
DEMA	*Decapterus macarellus*
BOBI	*Bodianus bilunulatus*
MOGR	*Monotaxis grandoculis*
APFU	*Aphareus furca*
APVI	*Aprion virescens*
LUKA	*Lutjanus kasmira*
MABR	*Malacanthus brevirostris*
GUCU	*Gunnellichthys curiosus*
PACY	*Parupeneus cyclostomus*
PAIN	*Parupeneus insularis*
PAMU	*Parupeneus multifasciatus*
PAPL	*Parupeneus pleurostigma*
CACA	*Calotomus carolinus*
CHPE	*Chlorurus perspicillatus*
CHSP	*Chlorurus sordidus*
SCPS	*Scarus psittacus*
SCRU	*Scarus rubroviolaceus*
CEAR	*Cephalopholis argus*