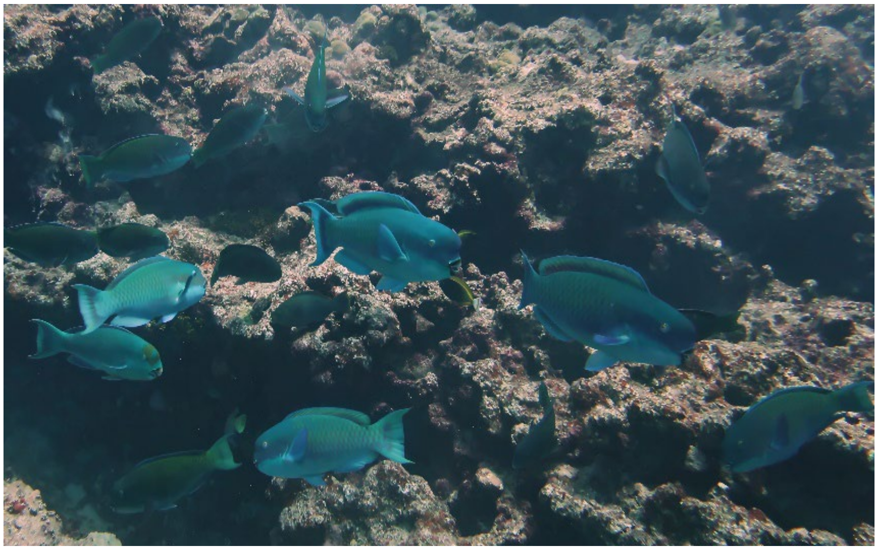
Data Report: Assessment of Coral Reef Fishes Inside and Outside of Guam's Piti Bomb Holes Marine Preserve



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Introduction

Marine preserves are useful tools for protecting fish populations from the pressures of fishing and other human activities (Bohnsack, 1990; Davis, 1989; Espectato et al., 2017; Filous et al., 2017). Marine preserves often result in higher fish biomass inside the protected area (McClure et al., 2020; Tupper, 2007; Wantiez et al., 1997), higher fish density (Russ & Alcala, 2003), and a spillover effect when areas outside of the preserves also show increased biomass (Russ et al., 2003). These areas may also support larger and older fish than fished areas (Taylor & McIlwain, 2010). Adequate enforcement of regulations within preserves often improve these benefits (Edgar et al., 2014).

In 1997, Guam established a network of no-take marine preserves, although enforcement was not fully implemented until 1999 (Tupper, 2007). A previous assessment of fish populations around Guam demonstrated that these no-take marine preserves had more and larger fish than in areas open to fishing, as well as much higher densities of both rare and highly targeted species (Williams et al., 2012). Importantly, there is a known poaching history within these no-take areas (Taylor et al., 2022), prompting the need for further analysis of the effectiveness of Guam's no-take marine preserves.

Since 2002, Pacific Islands Fisheries Science Center scientists have routinely surveyed coral reefs of the Mariana Archipelago as part of the National Oceanic and Atmospheric Administration's (NOAA) National Coral Reef Monitoring Program (NCRMP). The national monitoring program, funded by the Coral Reef Conservation Program (CRCP), is a long-term effort to monitor the status and trends of U.S. coral reefs. Scientists conducted their routine surveys around Guam in 2022, and with supplemental resources, were able to intensively sample inside and outside of one preserve, Piti Bomb Holes (hereafter, 'Piti'), which was designated as a priority marine preserve by jurisdictional representatives as a component of CRCP Fisheries Pillar objectives (NOAA Coral Program, 2021). All Guam preserves are also surveyed by the Comprehensive Long-term Monitoring at Permanent sites on Guam project, also known as the Guam Long-term Coral Reef Monitoring Program (GLTMP), since 2010, and we were able to incorporate their survey data for 2022.

In this report, we assess the effectiveness of Piti by comparing reef fish biomass and size distributions inside and outside the preserve. We assess metrics for food fish species as defined by the the Division of Aquatic and Wildlife Resources (DAWR). We focused on these species because they are targeted and prone to poaching. We compare different taxonomic groups, trophic levels, and size classes from within Piti to other Guam preserves and to larger surrounding areas that are open to fishing to investigate the possibility of poaching.

Methods

Overview

Data were collected by NCRMP and GLTMP between May and August of 2022. Both programs collected fish data using the same visual census method (Ayotte et al., 2015), and a comparison of data showed that there were no clear biases between programs (Appendix A).

Sampling methods

Site selection

Guam

NCRMP monitors conditions over very large spatial scales and the core reporting unit is at the island scale, or sub island scale for larger islands. As Guam is the largest island in the Mariana Archipelago, it is divided into smaller spatial sectors that reflect broad differences in oceanographic exposure, reef structure, and regulated protection. As part of the routine monitoring, we selected sites in five sectors—three preserves: Pati Point, Tumon, and Achang, and two areas that are open to fishing, encompassing the remaining reefs of the east and west sides of Guam.

Piti and Asan

We added additional sites inside the Piti preserve and the Asan area which is outside of the preserve. Asan was selected, using local knowledge (David Burdick, pers. com.), as a region with similar habitat to the preserve, and approximately of the same size (Figure 1). Within each area, all sites were selected using a random number generator for all possible site locations. For the area inside Piti, we incorporated sites surveyed by the GLTMP, which was a smaller portion of the larger Piti preserve. This smaller area was on either side of the Tepungan Channel, between 7 and 15 meters (m) depth. It was selected to capture reef conditions downstream from a watershed that was a site for various improvement projects.

All surveys were conducted on the forereef beyond the reef crest. There is a substantial area of habitat on the reef flat between the shore and the reef crest that was not surveyed due to logisitical complications (the turquoise area in Figure 1).

The target sampling domain was hard-bottom habitat in water shallower than 30 m, stratified by depth zone: shallow (> 0–6 m), mid (> 6–18 m), and deep (> 18–30 m). The density of sites sampled per stratum was determined by proportionally allocating effort (e.g., the number of sites to be surveyed) based on a weighting factor calculated from the area per stratum and the variance of the target output metrics (e.g., consumer group biomass and total fish biomass).

Stationary point count

We conducted visual censuses of reef fish by using the stationary point count (SPC) method. This protocol (Ault et al., 2006) consists of a pair of divers conducting simultaneous counts in adjacent, visually estimated 15-m-diameter cylindrical plots extending from the substrate to the limits of vertical visibility. Each count has two components. The first is a 5-minute species enumeration period in which the diver records the taxa of all species observed within their cylinder. At the end of the 5-minute period, divers begin the tallying portion of the count, in which they systematically work through their species list and record the number and approximate size (total length, TL, to the nearest centimeter, cm) of each individual fish. The tallying portion is a series of rapid visual sweeps of the plot, with one species-grouping counted per sweep (Ayotte et al. 2015).

Calculated response metrics

We analyzed the food fish species as defined by DAWR, comprised of 115 species from the following families: Acanthuridae, Balistidae, Caesionidae, Carangidae, Haemulidae, Holocentridae, Labridae, Lethrinidae, Lutjanidae, Malacanthidae, Mullidae, Muraenidae, Nemipteridae, Pempheridae, Scaridae, and Serranidae.

We assessed metrics for management-relevant species defined by the Government of Guam in ongoing development of a Jurisdictional Coral Reef Fisheries Management Plan (version 05/17/2023), and species identified from a Guam fisheries catch assessment (Houk et al., 2018). The complete species list is in Appendix B.

Site was the base sample unit, and the response metric per site (biomass and density) was calculated by taking the mean value from the paired SPC surveys to create site estimates. Total counts per fish species were used to calculate fish density (count m^{-2}) for size distributions. Using the fish count and size data collected per observer in each replicate survey, the body weight of each individual fish was calculated using length-to-weight (LW) conversion parameters and, where necessary, length-length (LL) parameters (for example, to convert TL to fork length [FL] for species with LW parameters based on FL). LW and LL conversion parameters were taken from FishBase (Froese & Pauly, 2010; Kulbicki et al., 2005). Herein, the term "biomass" refers to the aggregate body weight of a group of fishes per unit area in grams per meters squared (g m^{-2}).

We calculated response metrics for consumer groups, families and species of interest, and size classes. Consumer groups consisted of primary consumers (herbivores and detritivores), secondary consumers (omnivores and benthic invertivores), planktivores, and piscivores. These classifications are based on diet information taken largely from FishBase (Froese & Pauly, 2010). We also assessed size distributions in terms of density per 10-cm size bins.

Pooled estimates for Piti and Asan

Due to the complex design across depth strata and unbalanced nature of our study design, we used the 'survey' package in R, a statistical software, which allows us to generate unbiased estimates when using site-level data (Lumley, 2022). Sites were first inverse proportion weighted based on their selection probability within strata (number of possible sites in a stratum/number of sites surveyed). The nested structure was defined as sector (inside or outside) and depth bin using the 'strata' argument of the *svydesign* function. To test for statistical differences between sectors, survey-weighted generalized linear models (GLMs) were fit using the *svyglm* function with density as a Poisson response variable or biomass as a Tweedie response variable and sector as predictor variable. To visualize patterns in density and biomass, weighted means and standard errors were calculated using the *svymean* function in the 'survey' package in R. Therefore, we did not conduct statistical analyses on size distributions that were further broken down by family or species, or on data that were further subset by depth bin, due to limited data and decreased statistical power.

Pooling estimates for additional Guam sectors

We qualitatively compared metrics of Piti and Asan to five additional sectors around Guam. The surveys that were conducted outside of Piti and Asan were summarized using a slightly different method, one that is routinely used by NCRMP scientists. For these other sectors, mean and variance of each response metric were calculated by averaging values across the sampled sites within each stratum. These values were then pooled to larger reporting scales (sector) using a weighted average approach via formulas below due to the variance in size among survey strata, whereby

(1) pooled mean biomass (X) across S strata: $X = \sum^{S} (X_i * w_i)$ and;

(2) pooled variance of mean biomass (VAR) across S strata: $VAR = \sum^{S}(VAR_i * w_i)$

where X_i is the estimate of mean biomass within stratum i, VAR_i is the estimated variance of X_i, and w_i is the stratum-weighting factor. Strata weighting factors are based on the size of strata, i.e., if a stratum is 50% of the total habitat area surveyed at an island, its weighting factor will be 0.5, and the total of all weighting factors in an island sums to 1 (Smith et al., 2011). We did not conduct statistical analyses with these additional sectors as the pooling methods differed.

Results

Biomass

A total of 57 sites were surveyed, 30 inside the preserve and 27 outside the preserve (Table 1, Figure 1). Of the 115 species of food and management relevant fish, total mean biomass (± SE) was higher inside the preserve (24.8 ± 3.9 g m^{-2} vs. 9.4 ± 1.0 g m^{-2}). There were several schools inside the preserve that contributed to the greater overall biomass: 4 schools of *Scarus altipinnis* totaling 24 fish, 4 schools of *Chlorurus microrhinos* totaling 25 fish, and 4 schools of *Acanthurus triostegus* totaling 310 fish. Even with those schools removed, overall biomass was still significantly higher inside ($t = 24.919$, $p < 0.0001$; 21.3 ± 2.7 g m^{-2}). Mean biomass values of all trophic groups were also higher inside the preserve (Figure 2). Of the groupings, mean biomass of primary and secondary consumers was significantly higher inside the preserve ($t = 28.02$, $p < 0.0001$; $t = 5.892$, $p = 0.020$, respectively). Primary consumer biomass was even qualitatively greater than all other sectors of Guam, including the other preserves (Figure 3). Scaridae, or parrotfish, an important primary consumer family, was the highest contributor to observed differences in total biomass (significantly higher biomass inside the preserve: $t = 23.689$, $p < 0.0001$; Figure 4). Acanthuridae biomass was similarly higher inside the preserve ($t = 4.729$, $p = 0.034$; Figure 4), also contributing to the overall differences in biomass of primary consumers (Figure 2). Scaridae biomass (Figure 5) was highest inside Piti compared to all other sectors of Guam including the other preserves, although this was a qualitative observation. Piti had higher mean Acanthuridae biomass than the entire surrounding west coast of Guam (Figure 5) and had fairly comparable biomass to the other preserves. The difference in secondary consumer biomass appears to be due to patterns in the wrasse family, Labridae (significantly higher biomass inside the preserve: $t = 15.291$, $p = 0.0003$; Figure 4). Lastly, the biomass of Serranidae was significantly higher inside the preserve ($t = 5.210$, $p = 0.027$), although the mean biomass both inside and outside the preserve was relatively low (Figure 4).

Table 1. Number of sites surveyed in each depth strata: shallow (> 0–6 m), mid (> 6–18 m), and deep (> 18–30 m).

	Outside preserve (Asan)	Inside preserve (Piti)
Deep	8	6
Mid	11	17
Shallow	8	7
Total	27	30

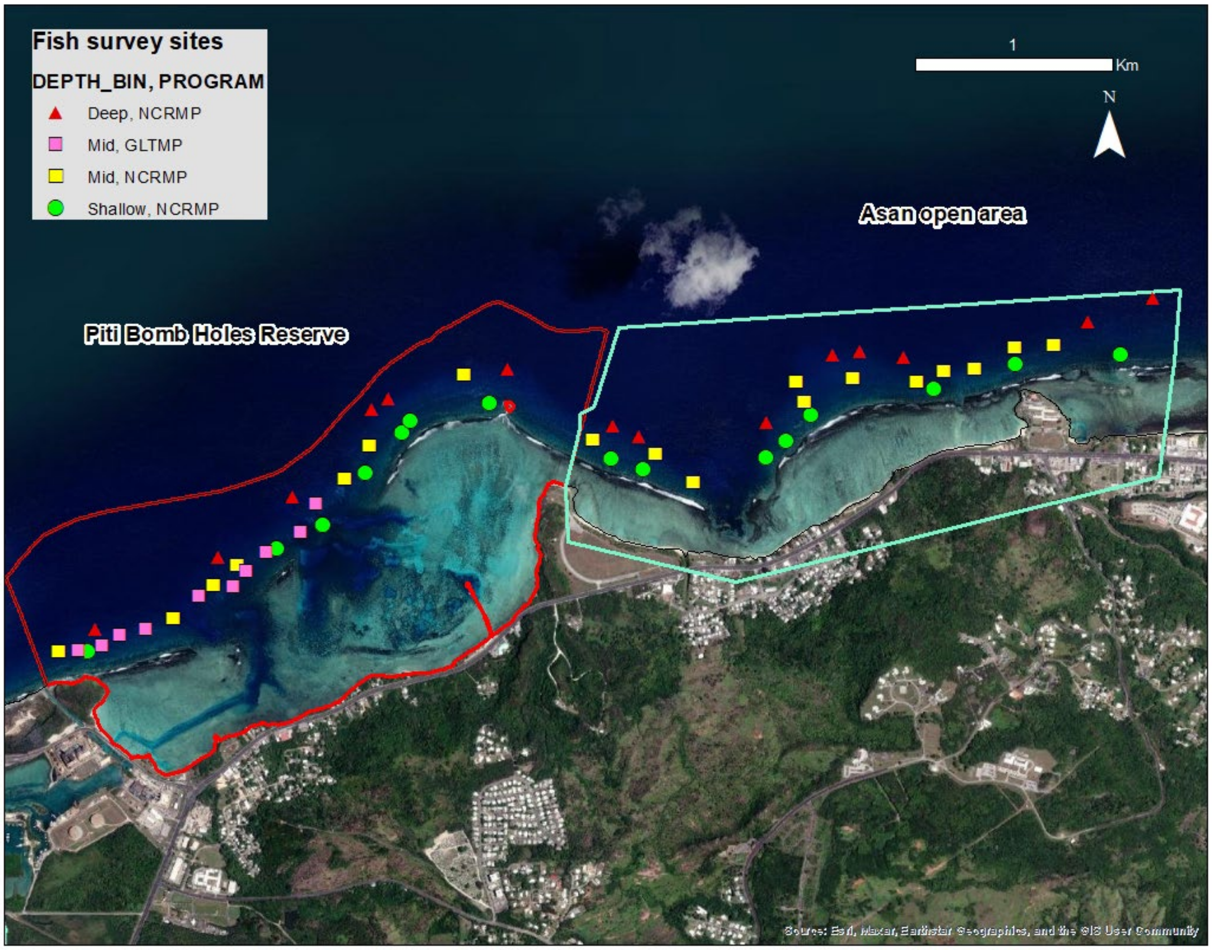

Figure 1. Map of the survey area and location of survey sites. Piti Bomb Holes Marine Preserve is outlined in red, the Asan area is outlined in blue. Different depth bins are represented by different shapes and colors; GLTMP sites are represented by pink squares.

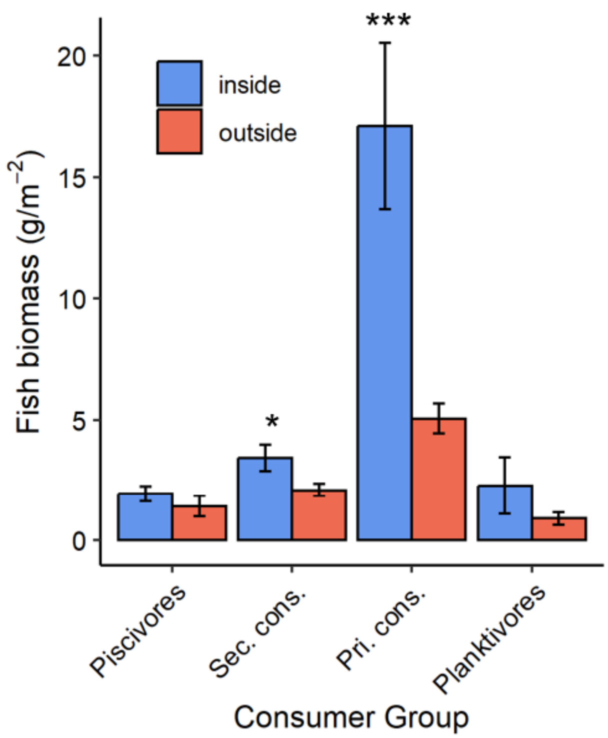

Figure 2. Mean fish biomass (g m^{-2}) ± standard error inside and outside of the Marine Preserve. Primary consumers (pri. cons.) include herbivores (which eat plants) and detritivores (which bottom-feed on detritus), and secondary consumers (sec. cons.) are largely omnivores (which eat a variety of fish and invertebrates) and invertivores (which eat invertebrates). Significance: '***' p<0.001, '**' p<0.01 '*' p<0.05.

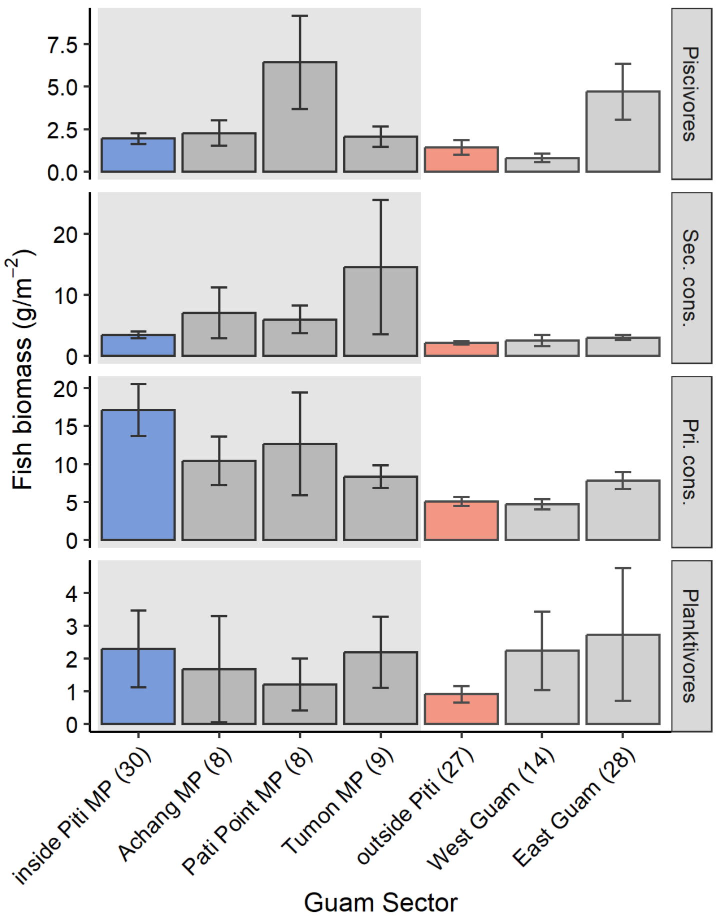

Figure 3. Mean fish biomass (g m^{-2}) ± standard error by sector and consumer group. Pri. cons. = primary consumers, Sec. cons. = secondary consumers. Sectors shaded in gray are marine preserves with restricted or no fishing. The forereef area of Piti is represented in blue, and outside Piti in pink. Note different y-axis scales for each consumer group. Large error bars for other marine preserves are due to small sample sizes, which are indicated in parentheses for each sector. As noted in the methods, these plots are supplemental visual estimates to aid our understanding of underlying patterns in differences in biomass.

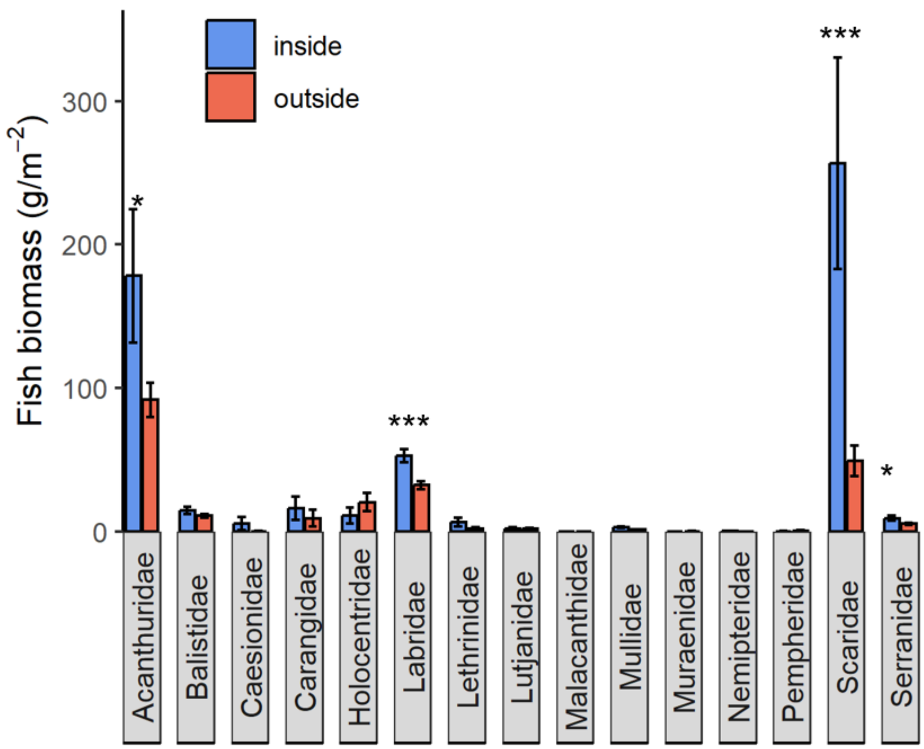

Figure 4. Mean fish biomass (g m^{-2}) ± standard error inside the forereef area of Piti (in blue) and outside (in pink) the preserve, by fish family. Significance: '***' p<0.001, '**' p<0.01, '*' p<0.05.

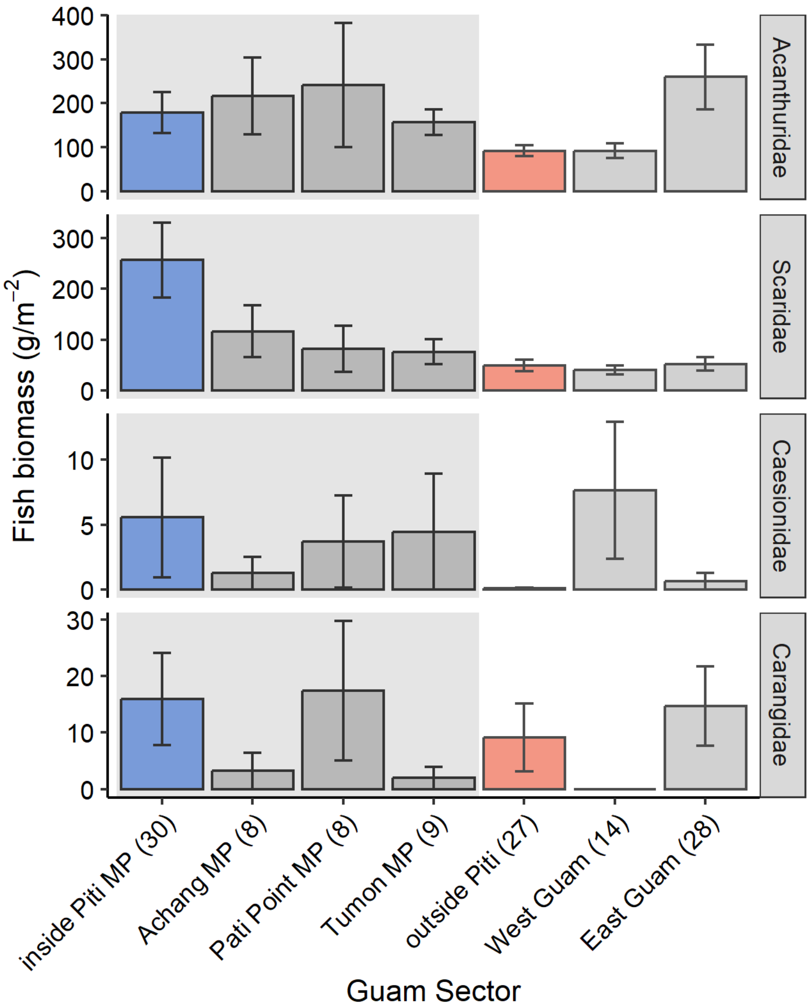

Figure 5. Mean fish biomass (g m^{-2}) ± standard error by sector (x-axis) and fish family (rows). Sectors shaded in gray are marine preserves with no or restricted fishing. The forereef area of Piti is represented in blue, and outside Piti in pink. Note different y-axis scales for each family. Large error bars for other marine preserves are due to small sample sizes, which are indicated in parentheses for each sector. As noted in the methods, these plots are supplemental visual estimates to aid our understanding of underlying patterns in differences in biomass.

Of the priority species, parrotfishes had the highest biomass inside the preserve; *Scarus psittacus* (SCPS) had the greatest mean biomass, followed in order by *Scarus schlegeli* (SCSC), *Chlorurus microrhinos* (CHMC), *Chlorurus spilurus* (CHSL), and *Scarus altipinnis* (SCAL; Figure 6). The schools of *S. altipinnis* and *C. microrhinos* observed inside the preserve account for the large error bars. Scaridae family biomass remained significantly higher inside the preserve, even with these schools removed. Four species of parrotfish (*C. frontalis, C. microrhinos, S. altipinnis,* and *S. schlegeli*) had the highest mean values of all sectors around Guam, including the other preserves (Figure 7). Mean biomass was also significantly higher inside the preserve for two Acanthurids: *Acanthurus lineatus* (ACLI; $t = 6.172$, $p = 0.016$) and *Naso lituratus* (NALI; $t = 5.983$, $p = 0.018$; Figure 6). Three species of parrotfish (*C. frontalis, C. microrhinos*, and *S. altipinnis*) were not observed outside of the preserve. Conversely, a snapper (*Lutjanus fulvus*) and grouper (*Plectropomus laevis*) were observed outside the preserve, but not inside. Although Carangidae biomass was not significantly different inside versus outside of the preserve (Figure 4), Piti had a higher Carangidae biomass than two other preserves. It also had much higher biomass than the rest of the surrounding west Guam sector (Figure 5), which is further reflected in the biomass of *Caranx melampygus* (CAME, Figure 7).

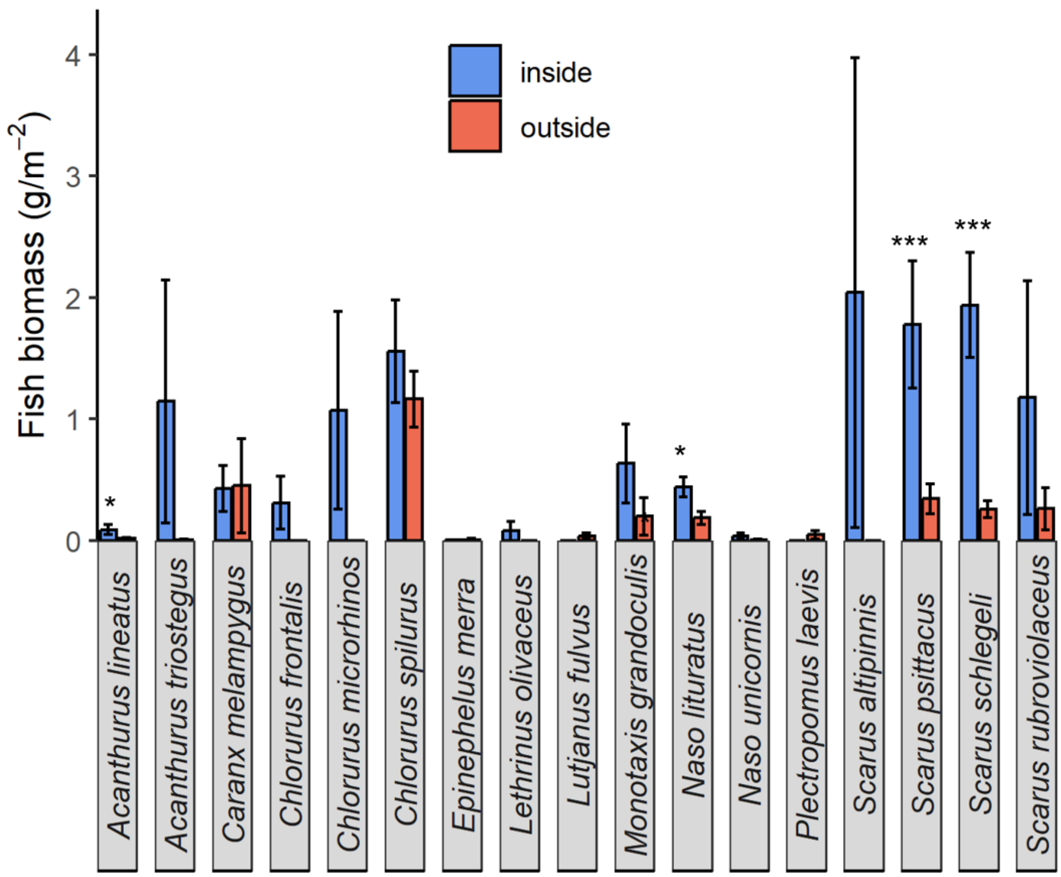

Figure 6. Mean fish biomass ± standard error inside the forereef area of Piti (in blue) and outside (in pink) the preserve, by fish species. Significance: '***' p<0.001, '**' p<0.01, '*' p<0.05.

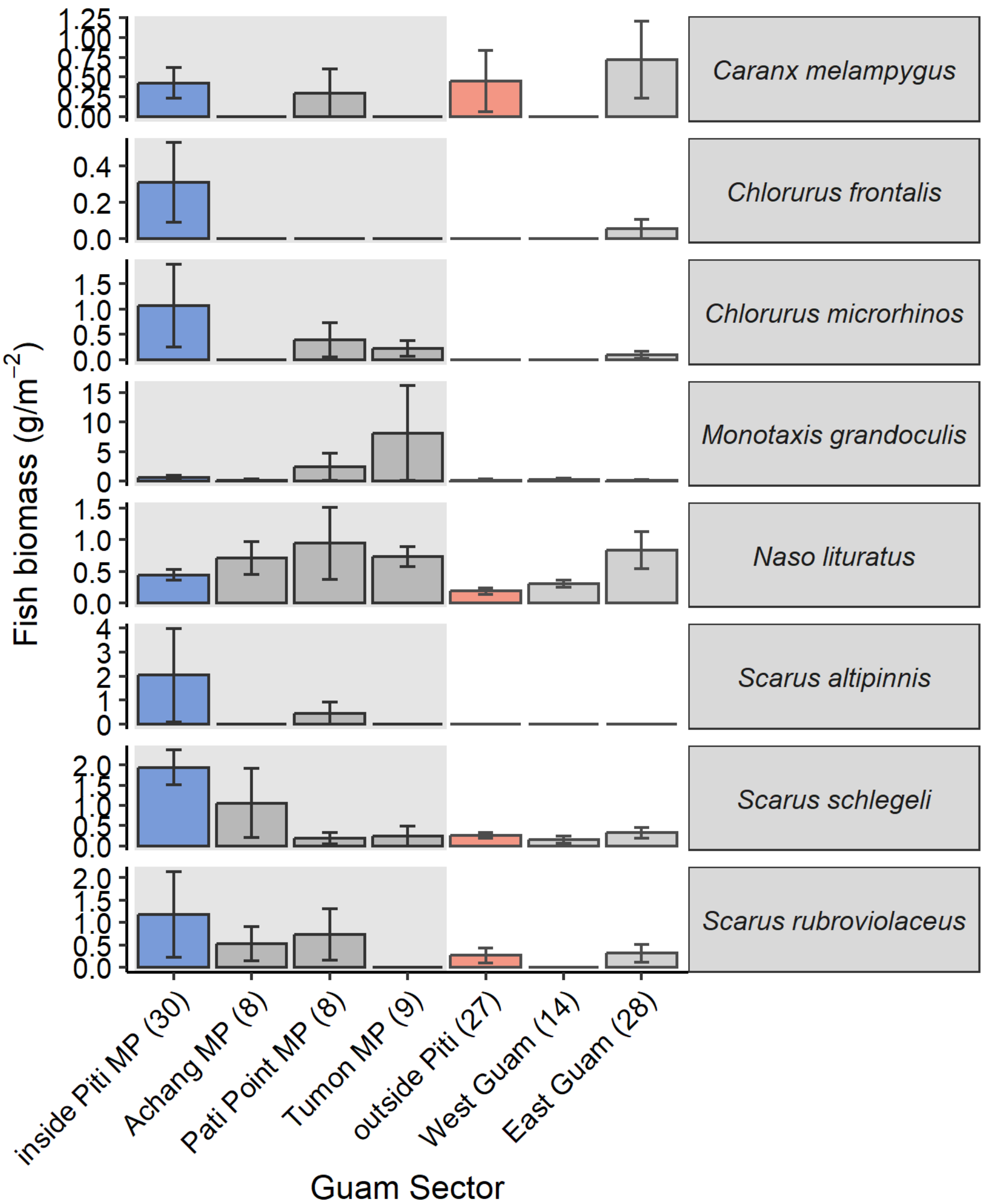

Figure 7. Mean fish biomass (g m^{-2}) ± standard error by sector (x-axis) and fish species (rows). Sectors shaded in gray are marine preserves with no or restricted fishing. The forereef area of Piti is represented in blue, and outside Piti in pink. Note different y-axis scales for each species. Large error bars for other marine preserves are due to small sample sizes, which are indicated in parentheses for each sector.

Fish size

Of the 210 target species we focused on for this analysis, we observed 115 on surveys. There was a noticeable lack of large fish, both inside and outside the preserve, with few fish greater than 40 cm (Figure 8). Inside the preserve, the largest fish of the subset we focused on was a 46 cm (TL) emperor, *Monotaxis grandoculis* (MOGR), followed by a 45 cm parrotfish, *Scarus rubroviolaceus*. The largest fish observed outside the preserve was a 45 cm eel, *Gymnothorax* *javanicus*, followed by a 40 cm emperor, *M. grandoculis*. Overall, the abundance of 2 of the 5 size classes was significantly higher inside the preserve: 10–20 cm (t=15.297, p= 0.0003), and 20–30 cm (t= 7.745, p=0.008, Figure 8). Most primary consumers were in the 10–20 cm size class (Figure 9); this pattern also persisted for parrotfishes (Figure 10, Scaridae). Four species of parrotfish (*C. frontalis, C. microrhinos, S. altipinnis,* and *S. schlegeli*) had individuals that were over 30 cm in addition to the 45 cm *S. rubroviolaceus* (Figure 12). More larger individuals were consistently seen inside the preserve across all the priority parrotfish species. Small Acanthurids (0–10 cm) were more abundant both inside and outside of the preserve, but the largest difference between locations was in medium-bodied Acanthurids (10–20 cm; Figure 10). The difference in secondary consumers biomass appears to be due to differences in smaller and medium-bodied fishes (0–10 cm and 10–20 cm; Figure 9). Notably, although *C. melampygus* (CAME) had a higher biomass outside the preserve (Figure 5), there were more larger fish inside the preserve (30–43 cm, Figure 11).

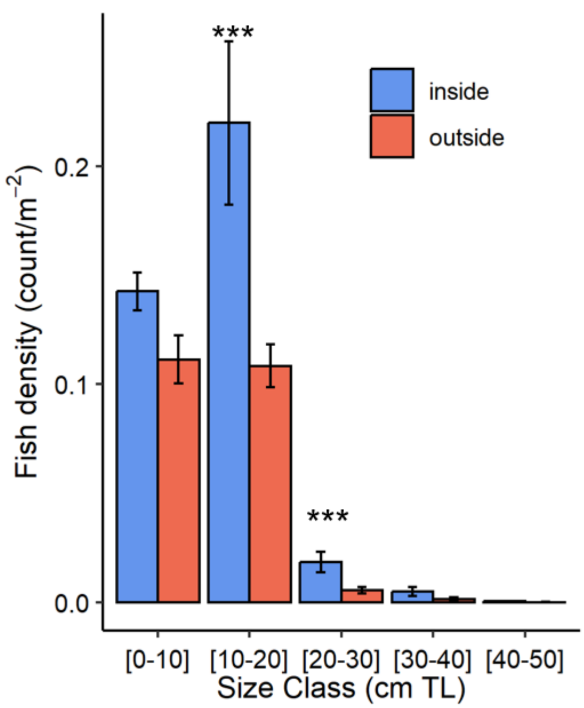

Figure 8. Mean fish density (count/ m^{-2}) ± standard error inside and outside of the Marine Preserve. Fish lengths are in 10 cm bins. Significance: '***' p<0.001, '**' p<0.01, '*' p<0.05.

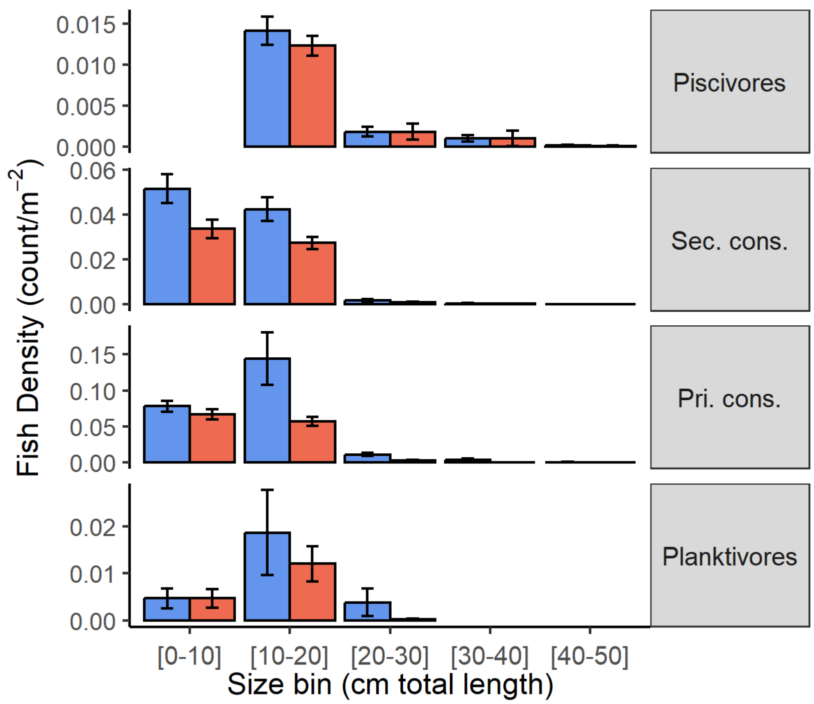

Figure 9. Mean fish density by size class and consumer group. Pri. cons. = primary consumers, Sec. cons. = secondary consumers. Note different y-axis scales for each consumer group. As noted in the methods, these plots are supplemental visual estimates to aid our understanding of underlying patterns in differences in density, and only represent the forereef area.

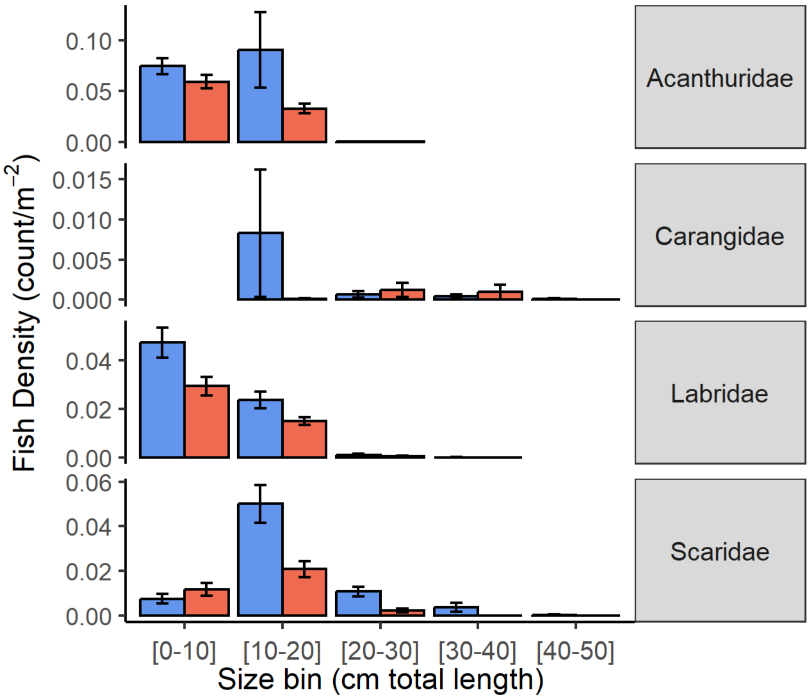

Figure 10. Mean fish density by size class (x-axis) and fish family. Note different y-axis scales for each family. As noted in the methods, these plots are supplemental visual estimates to aid our understanding of underlying patterns in differences in density and only represent the forereef area.

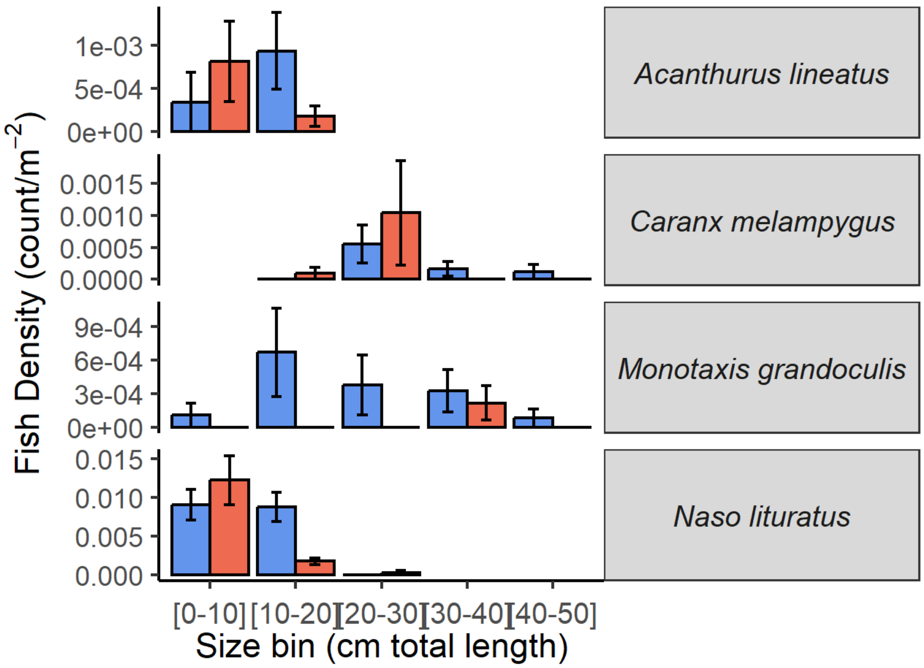

Figure 11. Mean fish density by size class and species. Note different y-axis scales for each species. As noted in the methods, these plots are supplemental visual estimates to aid our understanding of underlying patterns in differences in density and only represent the forereef area.

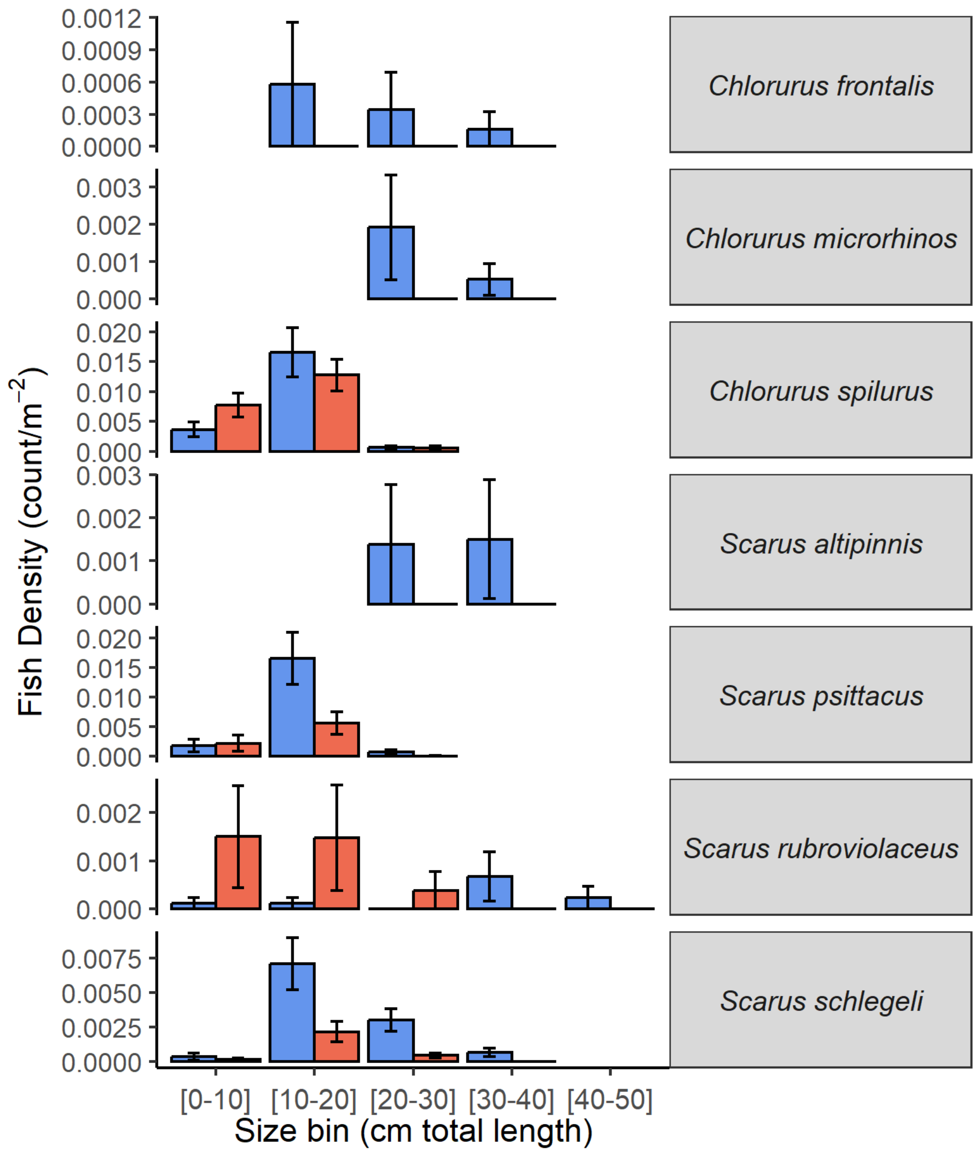

Figure 12. Mean fish density by size class and species for parrotfishes. Note different y-axis scales for each species. As noted in the methods, these plots are supplemental visual estimates to aid our understanding of underlying patterns in differences in density and only represent the forereef area.

Depth strata

The highest mean biomass of parrotfish (380.73 ± 233.95 g m^{-2}) and Acanthurids (311.42 ± 156.59g m^{-2}; Figure 14) was observed in the shallow strata, from 0 to 6 m deep. The large standard error for both families was due to the presence of schools that were observed during the surveys. Larger fish were more abundant in the shallow sector inside the preserve. Overall, there are more fish inside the preserve across all sizes and depth bins, although there is a clear lack of fish of the largest size classes in the mid and shallow depth strata (Figure 15).

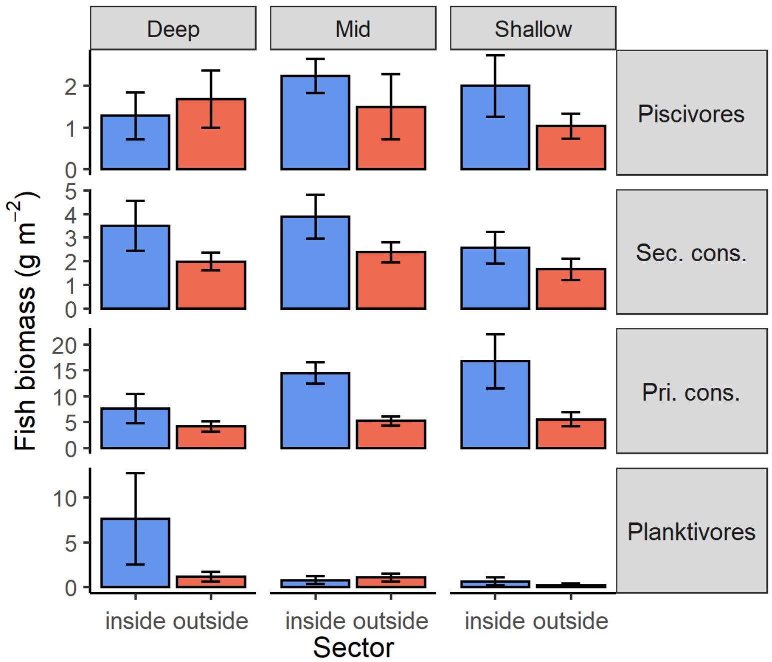

Figure 13. Mean fish biomass ± standard error inside (in blue) and outside (in pink) the preserve by consumer group and depth bin. Note different y-axis scales for each consumer group. As noted in the methods, these plots are supplemental visual estimates to aid our understanding of underlying patterns in differences in biomass and only represent the forereef area.

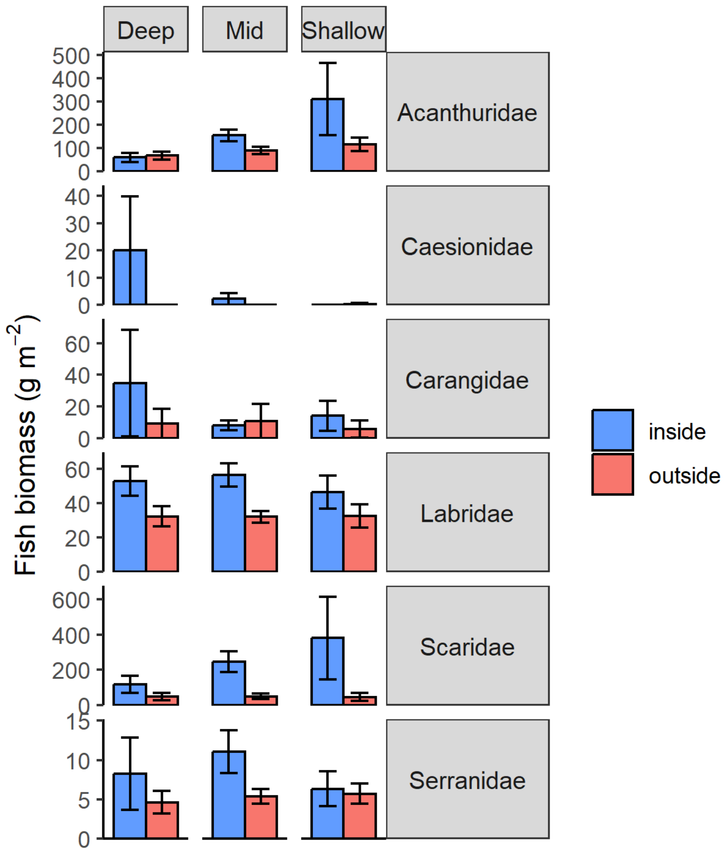

Figure 14. Mean fish biomass ± standard error inside (in blue) and outside (in pink) the preserve by fish family and depth bin. Note different y-axis scales for each family. As noted in the methods, these plots are supplemental visual estimates to aid our understanding of underlying patterns in differences in biomass and only represent the forereef area.

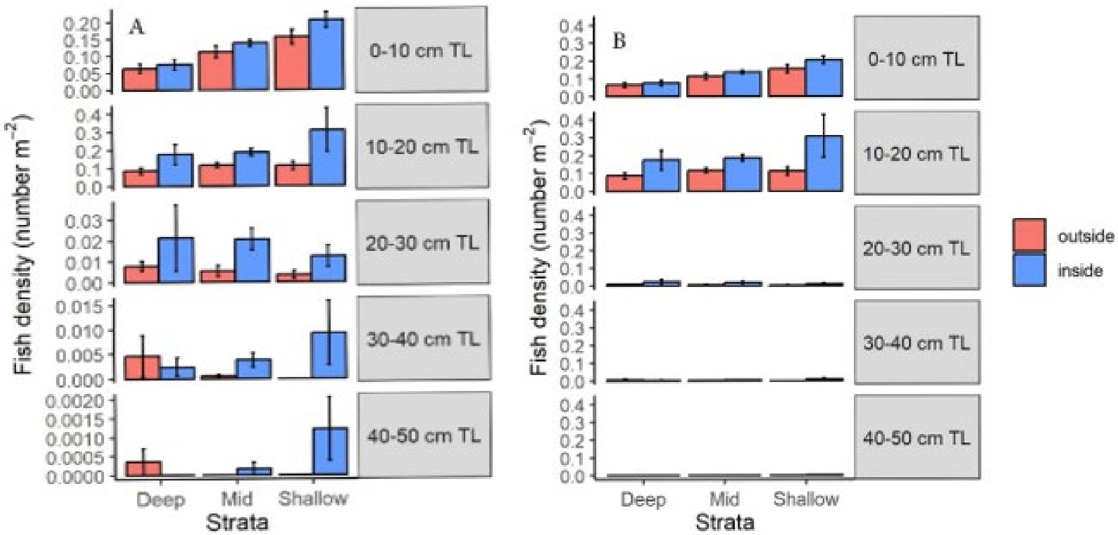

Figure 15. Mean fish density ± standard error inside and outside of the Marine Preserve. Fish lengths are in 10 cm bins. A: y-axis scales are different for each size class. B: y-axis scales are fixed for all size classes. As noted in the methods, these plots are supplemental visual estimates to aid our understanding of underlying patterns in differences in density and only represent the forereef area.

Discussion

We compared the fish biomass of food and management-relevant fishes (total of 115 species) and their size distributions inside and outside of Piti preserve, within different depth strata, and relative to other preserves and areas open to fishing in Guam. This assessment found trends in fish populations that align with expected patterns in relatively unfished areas, including higher overall fish biomass inside Piti preserve than in the adjacent outside area.

All trophic groups had higher mean biomass inside the preserve; primary consumers had more than twice the mean biomass inside as outside. Piti not only had high primary biomass compared to Asan, but it had the highest mean biomass for all other preserves and open areas around Guam, suggesting that this may be a refuge for primary consumers. Primary consumers, made of herbivores and detritivores, play an important role in coral reef resilience. Herbivores graze on algae, allowing new coral recruits to settle on the bare substrate (Chung et al., 2019; McClanahan et al., 2012; Williams et al., 2019). Another promising sign that the preserve has positive impacts is the high Scaridae mean biomass. These parrotfish species are targeted in Guam (Amesbury & Hunter-Anderson, 2008; Houk et al., 2011), and seven species are on the priority list of interest to the Governemnt of Guam for management. Compared to other sectors around Guam, Piti had the highest Scaridae biomass, with almost twice the amount as the next largest value from Achang preserve. It has been noted that in recent years parrotfish biomass increased inside Piti preserve and Pati Point preserve, which may be due to the fact that these are the two most protected preserves (Taylor et al., 2022).

Acanthuridae biomass was also significantly higher inside the preserve than outside, although it had lower biomass than the other preserves. These results follow similar trends to a recent report (Burdick, 2019) that found the highest biomass in Piti to be attributed to Pomacentridae (not analyzed here), followed by Scaridae, Acanthuridae, and Labridae.

Carangidae biomass was not significantly different inside versus outside, but both areas had relatively high biomass when compared to other areas on the west side of Guam, including the west preserves. This could be due to a spillover effect from Piti, meaning that areas surrounding the preserve (i.e., Asan) will also show increased biomass (Russ et al., 2003); a more in-depth assessment would be needed to test this hypothesis.

Piti's biomass of planktivores, however, was lower than that of the surrounding west Guam area. This could suggest that these species are exposed to fishing pressure or other environmental factors that may have an effect on planktivore biomass. Planktivores that are likely targeted food fish island-wide are *Naso hexacanthus*, fusiliers, such as *Pterocaesio marri* and *Pterocaesio tile,* and mackerel scad, *Decapterus macarellus*. Fishing pressure is one possibility indicated by the low biomass of planktivores in the shallower depths which are more accessible to poachers. However, the mean biomass in the deep strata inside the preserve was mainly due to schools of fusiliers and mackerel scad, as well as the triggerfish *Odonus niger*, which is not likely targeted, and is usually found at deeper depths. There are many other site-based factors aside from fishing pressure that could be contributing to this.

Of the 115 management-relevant species, 4 were only seen within the preserve, and 3 of these were Scaridae. Two of those species, *C. frontalis* and *S. altipinnis*, were rarely seen in any other sectors around Guam. Piti may be serving as a refuge for Scaridae species, or the habitat may be more suitable for them than other areas of the island. Site-based factors such as habitat complexity may be higher, or there may be more abundant food sources. This is important, as a recent study has found that Scaridae biomass across Guam has decreased by 30% over the last 10 years (Taylor et al., 2022).

Size distributions for fish species in fished areas tend to lack large individuals, as those are typically targeted for consumption (Friedlander, 2002; Pauly, 1998; Sandin, 2008; Williams, 2011). Piti had a slightly higher density of larger bodied primary consumers than Asan. The majority of the biomass inside was due to fish in the 10–20 cm size bin. This could mean that larger fish are poached within the preserve, but it could also mean that the preserve is an important refuge for fish of this size. We did observe a pattern of more larger individuals inside the preserve, indicating that the area is unfished; however, we only observed a few large fish overall.

When assessed by depth bin, the majority of the primary consumers was seen in the shallow waters (0–6 m). Piscivore biomass was higher in the mid and shallow strata inside the reserve, but was highest in the deep strata outside the preserve, suggesting that piscivores may seek refuge in deeper waters outside the preserve. Most of the Scaridae biomass was observed in the shallow strata, as opposed to the Asan area where the majority of the Scaridae biomass was in the deep strata, suggesting the same possible depth refuge trend outside the preserve.

Future directions for determining the effectiveness of the preserve would be to analyze the habitat in conjunction with the fish populations. Differences in habitat such as habitat complexity may correlate strongly to differences in fish biomass and abundance which is important to consider in conjunction with fishing pressure. However, it appears that Piti is well protected (Taylor, 2022) and, in particular, harbors more Scaridae than any other area on Guam. The data show Piti supports higher fish biomass than the surrounding area, and these patterns align with the general goals for protected areas.

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Appendix A. NCRMP and GLTMP data comparison

Both programs surveyed mid depth bin sites in Piti. The NCRMP scientists surveyed 7 sites and the GLTMP scientist surveyed 10 sites. Two different divers simultaneously surveyed a cylinder at the NCRMP sites. All GTLMP sites were surveyed by the same diver, using a slightly different method. They surveyed one cylinder then swam 15 m to survey the second cylinder.

Diver vs. diver comparisons

The GLTMP diver also surveyed with NCRMP divers, so we can compare visual estimates of that diver with her NCRMP dive buddy. Although the GLTMP diver's estimates of total fish biomass are slightly higher, the estimates are not significantly different (see Table A.1.1, "TotFish"; Figure A. 1.1).

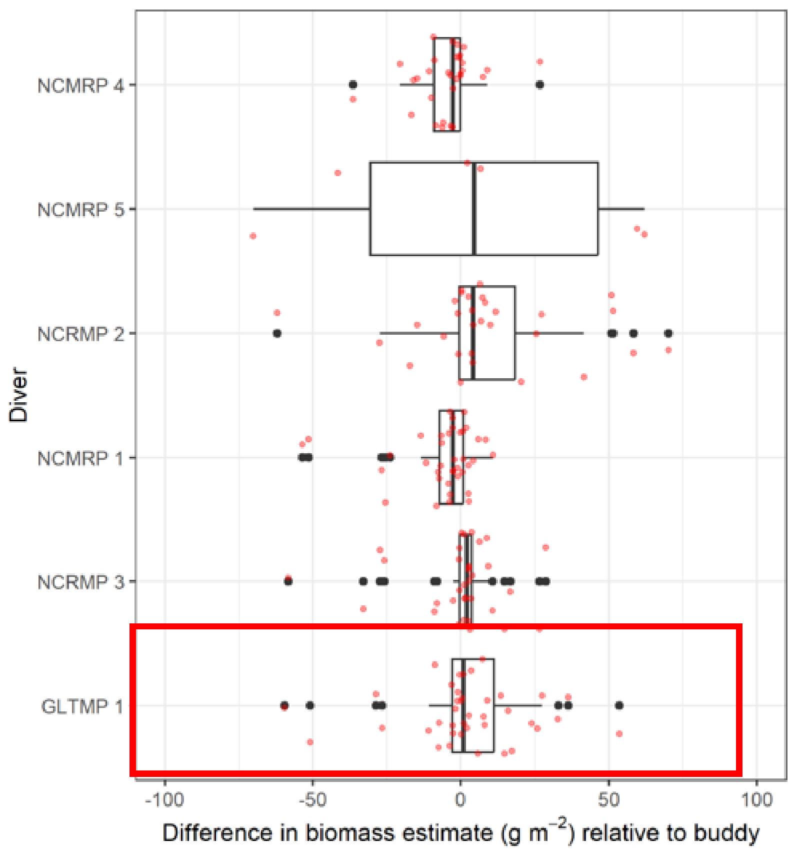

Figure A.1.1. Box plot representing mean biomass estimates for sites surveyed for each diver compared to their buddy. If estimates are the same, the median of the box will align with zero. Black dots indicate outliers, and red dots indicate values for individual sites. GLTMP diver is outlined in red.

We looked at average sizes of some of the commonly seen fish in Piti from each diver. Overall, the GLTMP diver's sizes are comparable to NCRMP divers. SCPS sizes are slightly higher than most NCRMP divers, CEUR sizes are slightly lower. CTSR and ACNF sizes are about average (Figure A.1.2).

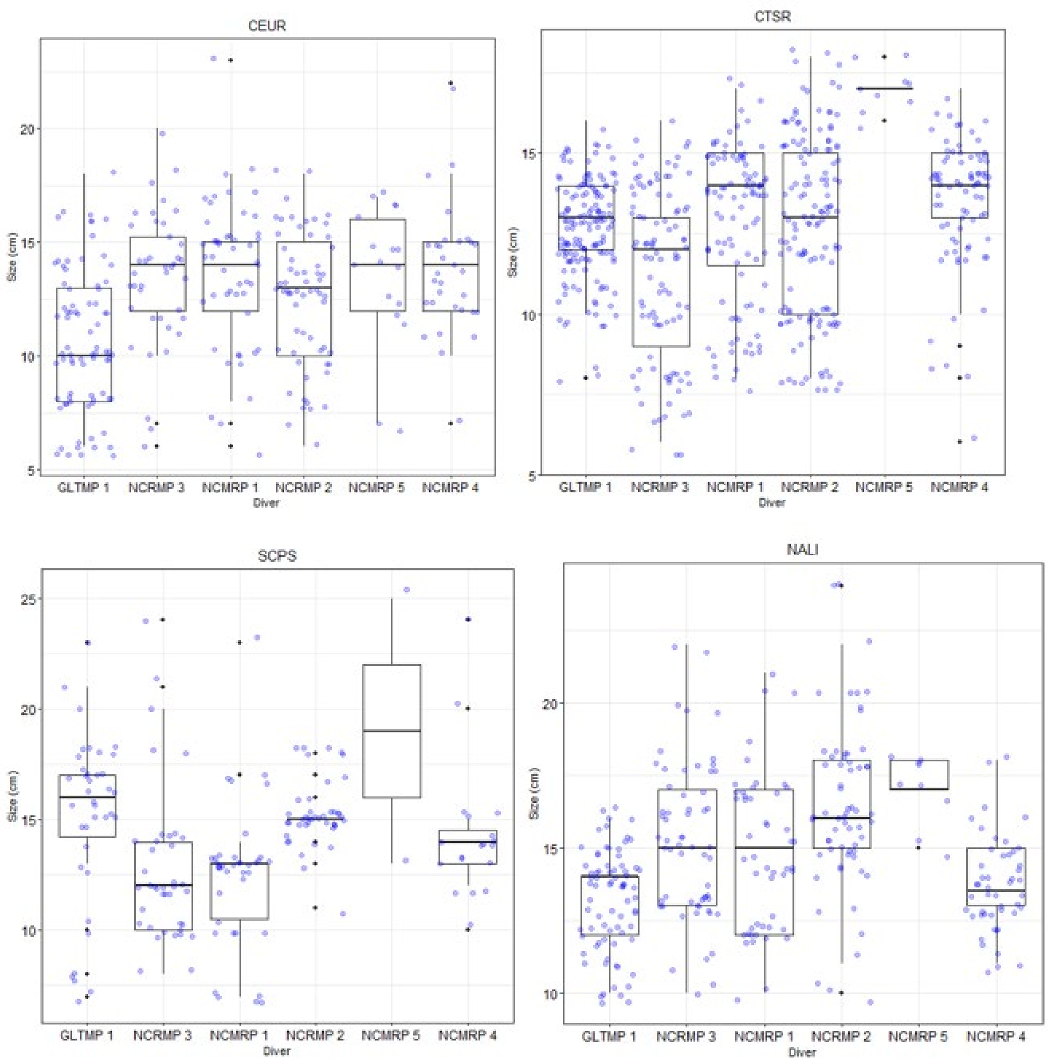

Figure A.1.2. Box plots showing mean size in cm of 4 species of fish: CEUR, CTSR, SCPS, and NALI.

We compared the GLTMP diver's mean estimates for the focal analysis groups to other NCRMP divers' pooled estimates. We calculated the mean difference and 95% confidence interval between estimates. We considered CIs that spanned zero to indicate no meaningful difference between divers. The only species that showed a significantly different estimate was for *Naso literatus* (Table A.1.1). Although the GLTMP diver's mean size estimates for NALI overall were significantly higher than NCRMP divers, her mean estimates fell within the range of our NCRMP divers while she was surveying with them.

Table A 1. 1. Estimated mean biomass ± standard deviation for reef fish trophic groups, size classes, families and species of interest for the GLTMP diver and the NCRMP divers. Mean difference and 95% confidence interval of estimates shown. Items in bold are significantly different.

Summary group	GLTMP mean (SD)	NCRMP mean (SD)	mean diff	CI
PISCIVORE	2.3 ±(1.5)	2.17 ±(2.04)	0.13	(-1.8, 2.06)
PLANKTIVORE	1.5 ±(2.38)	1.48 ±(0.88)	0.03	(-1.73, 1.78)
PRIMARY	16.22 ±(7.92)	16.34 ±(17.6)	-0.11	(-15.26, 15.03)
SECONDARY	5.86 ±(4.71)	4.78 ±(3.82)	1.08	(-3.34, 5.5)
TotFish	25.89 ±(13.12)	24.76 ±(22.93)	1.13	(-19.35, 21.61)
0_20	16.25 ±(6.49)	16.51 ±(10.56)	-0.25	(-9.82, 9.31)
20_50	9.63 ±(7.75)	8.25 ±(13.21)	1.38	(-10.47, 13.24)
Acanthurus lineatus	0.06 ±(0.18)	0 ±(0)	0.06	(-0.06, 0.18)
Caranx melampygus	0.38 ±(0.8)	0.52 ±(0.7)	-0.14	(-0.92, 0.64)
Chlorurus frontalis	0 ±(0)	0.76 ±(2)	-0.76	(-2.37, 0.85)
Monotaxis grandoculis	1.34 ±(3.29)	0.6 ±(1.59)	0.75	(-1.82, 3.31)
Naso lituratus	**0.88 ±(0.72)**	**0.26 ±(0.14)**	**0.62**	**(0.12, 1.12)**
Scarus schlegeli	2.21 ±(2.53)	2.8 ±(3.34)	-0.6	(-3.78, 2.59)
Acanthuridae	5.25 ±(3.39)	3.23 ±(1.52)	2.02	(-0.57, 4.61)
Carangidae	0.64 ±(1.06)	0.52 ±(0.7)	0.13	(-0.78, 1.03)
Chaetodontidae	0.62 ±(0.33)	0.75 ±(1.04)	-0.13	(-1, 0.73)
Holocentridae	0.27 ±(0.5)	0.41 ±(0.62)	-0.14	(-0.74, 0.47)
Labridae	2.37 ±(1.18)	1.89 ±(0.95)	0.48	(-0.62, 1.58)
Lethrinidae	1.44 ±(3.58)	0.85 ±(2.26)	0.59	(-2.44, 3.61)
Lutjanidae	0.24 ±(0.55)	0.01 ±(0.02)	0.24	(-0.13, 0.6)
Mullidae	0.75 ±(0.66)	0.33 ±(0.46)	0.42	(-0.16, 1)
Pomacanthidae	0.28 ±(0.43)	0.34 ±(0.67)	-0.06	(-0.67, 0.56)
Pomacentridae	0.76 ±(0.3)	0.78 ±(0.46)	-0.03	(-0.45, 0.4)
Scaridae	10.21 ±(6.32)	12.69 ±(16.18)	-2.48	(-16.19, 11.23)
Serranidae	0.94 ±(0.87)	0.89 ±(1.1)	0.05	(-1.01, 1.12)
Zanclidae	0.16 ±(0.12)	0.24 ±(0.33)	-0.08	(-0.36, 0.19)

We decided that the GLTMP estimates were similar enough to the NCRMP estimates overall to pool them together for the purpose of this analysis.

Appendix B. Species

Table B. 1.1. Scientific name, common name, family name, common family name, length-to-weight conversion parameters (LW_A and LW_B), length-length parameters (LL CONV.; to convert TL to fork length [FL] for species with LW parameters based on FL), and trophic group designations for each species of fish in this analysis. LW and LL conversion parameters and trophic group were taken from FishBase (Froese & Pauly, 2010; Kulbicki et al., 2005).

SCIENTIFIC NAME	COMMON NAME	FAMILY	COMMON FAMILY	LW_A	LW_B	LL CONV.	TROPHIC GROUP
Acanthurus blochii	Ringtail surgeonfish	Acanthuridae	Surgeonfish	0.02506	3.03193	0.93	PRIMARY
Acanthurus guttatus	Whitespotted surgeonfish	Acanthuridae	Surgeonfish	0.0029	3	1	PRIMARY
Acanthurus lineatus	Lined surgeonfish	Acanthuridae	Surgeonfish	0.0412	2.85	1	PRIMARY
Acanthurus nigricans	Whitecheek surgeonfish	Acanthuridae	Surgeonfish	0.067	2.669	1	PRIMARY
Acanthurus nigricauda	Epaulette surgeonfish	Acanthuridae	Surgeonfish	0.01678	3.16772	0.84	PRIMARY
Acanthurus nigrofuscus	Brown surgeonfish	Acanthuridae	Surgeonfish	0.02637	3.02837	0.91	PRIMARY
Acanthurus nigroris	Bluelined surgeonfish	Acanthuridae	Surgeonfish	0.021	2.9435	1	PRIMARY
Acanthurus olivaceus	Orangespot surgeonfish	Acanthuridae	Surgeonfish	0.03839	3.055	0.86	PRIMARY
Acanthurus pyroferus	Chocolate surgeonfish	Acanthuridae	Surgeonfish	0.018	3	1	PRIMARY
Acanthurus thompsoni	Thompson's surgeonfish	Acanthuridae	Surgeonfish	0.0153	3	1	PLANKTIVORE
Acanthurus triostegus	Convict surgeonfish	Acanthuridae	Surgeonfish	0.08306	2.56968	0.87	PRIMARY
Aphareus furca	Small toothed jobfish	Lutjanidae	Snapper	0.0105	3	1	PISCIVORE
Balistapus undulatus	Orange-lined triggerfish	Balistidae	Triggerfish	0.0058	3.554	1	SECONDARY
Bodianus axillaris	Axilspot hogfish	Labridae	Wrasse	0.0201	2.9992	1	SECONDARY
Calotomus carolinus	Carolines parrotfish	Scaridae	Parrotfish	0.0122	3.167	1	PRIMARY
Carangoides ferdau	Blue trevally	Carangidae	Jack	0.03683	2.85116	0.86	PISCIVORE
Caranx melampygus	Bluefin trevally	Carangidae	Jack	0.02866	2.974	0.89	PISCIVORE
Caranx papuensis	Brassy trevally	Carangidae	Jack	0.02354	2.923	0.8849558	PISCIVORE
Caranx sexfasciatus	Bigeye trevally	Carangidae	Jack	0.0198	2.986	0.91	PISCIVORE
Cephalopholis argus	Peacock hind	Serranidae	Grouper	0.00929	3.18074	1	PISCIVORE
Cephalopholis urodeta	Darkfin hind	Serranidae	Grouper	0.02822	2.81775	1	PISCIVORE
Cetoscarus ocellatus	Bicolour parrotfish	Scaridae	Parrotfish	0.0157	3	1	PRIMARY
Cheilinus chlorourus	Floral wrasse	Labridae	Wrasse	0.01972	2.99315	1	SECONDARY

SCIENTIFIC NAME	COMMON NAME	FAMILY	COMMON FAMILY	LW_A	LW_B	LL CONV.	TROPHIC GROUP
Cheilinus fasciatus	Redbreast wrasse	Labridae	Wrasse	0.0149	3	1	SECONDARY
Cheilinus oxycephalus	Snooty wrasse	Labridae	Wrasse	0.0155	3.058	1	SECONDARY
Cheilinus trilobatus	Tripletail wrasse	Labridae	Wrasse	0.01623	3.05947	1	SECONDARY
Cheilio inermis	Cigar wrasse	Labridae	Wrasse	0.00349	3.08157	1	SECONDARY
Chlorurus frontalis	Tan-faced parrotfish	Scaridae	Parrotfish	0.0224	3.0394	1	PRIMARY
Chlorurus microrhinos	Steephead parrotfish	Scaridae	Parrotfish	0.0273	2.93	0.93	PRIMARY
Chlorurus spilurus	Daisy parrotfish	Scaridae	Parrotfish	0.02431	2.96931	1	PRIMARY
Coris aygula	Clown coris	Labridae	Wrasse	0.00266	3.48857	1	SECONDARY
Coris gaimard	Yellowtail coris	Labridae	Wrasse	0.0109	3	1	SECONDARY
Ctenochaetus binotatus	Twospot surgeonfish	Acanthuridae	Surgeonfish	0.03916	2.87463	0.91	PRIMARY
Ctenochaetus cyanocheilus	Bluelip bristletooth	Acanthuridae	Surgeonfish	0.0233	3.0559	1	PRIMARY
Ctenochaetus striatus	Striated surgeonfish	Acanthuridae	Surgeonfish	0.02313	3.06347	0.91	PRIMARY
Decapterus macarellus	Mackerel scad	Carangidae	Jack	0.0078	3.14	1	PLANKTIVORE
Elagatis bipinnulata	Rainbow runner	Carangidae	Jack	0.0135	2.92	0.77	PISCIVORE
Epibulus insidiator	Slingjaw wrasse	Labridae	Wrasse	0.01614	3.08102	0.93	SECONDARY
Epinephelus fasciatus	Blacktip grouper	Serranidae	Grouper	0.01383	3.04066	1	PISCIVORE
Epinephelus hexagonatus	Starspotted grouper	Serranidae	Grouper	0.0132	3.0372	1	PISCIVORE
Epinephelus merra	Honeycomb grouper	Serranidae	Grouper	0.01584	2.96636	1	PISCIVORE
Gnathodentex aureolineatus	Striped large-eye bream	Lethrinidae	Emperor	0.02695338	3.06254326	0.91	SECONDARY
Gomphosus varius	Bird wrasse	Labridae	Wrasse	0.02437	2.70269	1	SECONDARY
Gymnothorax javanicus	Giant moray	Muraenidae	Moray	5.00E-04	3.303	1	PISCIVORE
Halichoeres hortulanus	Checkerboard wrasse	Labridae	Wrasse	0.0119	3.064	1	SECONDARY
Halichoeres trimaculatus	Threespot wrasse	Labridae	Wrasse	0.02749	2.73584	1	SECONDARY
Hemigymnus fasciatus	Barred thicklip	Labridae	Wrasse	0.0171	3	1	SECONDARY
Hemigymnus melapterus	Blackeye thicklip	Labridae	Wrasse	0.02423	2.92262	1	SECONDARY

SCIENTIFIC NAME	COMMON NAME	FAMILY	COMMON FAMILY	LW_A	LW_B	LL CONV.	TROPHIC GROUP
Hipposcarus longiceps	Pacific longnoseparrotfish	Scaridae	Parrotfish	0.0198	3	1	PRIMARY
Lethrinus harak	Thumbprint emperor	Lethrinidae	Emperor	0.01701	3.04226	0.93	SECONDARY
Lethrinus obsoletus	Orange-striped emperor	Lethrinidae	Emperor	0.01733	3.02583	0.97	SECONDARY
Lethrinus olivaceus	Longface emperor	Lethrinidae	Emperor	0.02936	2.85064	0.97	PISCIVORE
Lethrinus xanthochilus	Yellowlip emperor	Lethrinidae	Emperor	0.02007	2.9639	0.94	PISCIVORE
Lutjanus bohar	Two-spot red snapper	Lutjanidae	Snapper	0.01563	3.05865	0.96	PISCIVORE
Lutjanus fulvus	Blacktail snapper	Lutjanidae	Snapper	0.02106	2.97433	0.96	SECONDARY
Lutjanus gibbus	Humpback red snapper	Lutjanidae	Snapper	0.01309	3.13752	0.89	SECONDARY
Macolor niger	Black and white snapper	Lutjanidae	Snapper	0.0145	3	1	PLANKTIVORE
Malacanthus brevirostris	Quakerfish	Malacanthidae	Tilefish	0.0049	3	1	SECONDARY
Malacanthus latovittatus	Blue blanquillo	Malacanthidae	Tilefish	0.01	2.8763	1	SECONDARY
Melichthys niger	Black triggerfish	Balistidae	Triggerfish	0.0058	3.554	1	PLANKTIVORE
Melichthys vidua	Pinktail triggerfish	Balistidae	Triggerfish	0.0058	3.554	1	PRIMARY
Monotaxis grandoculis	Humpnose big-eye bream	Lethrinidae	Emperor	0.02296	3.02223	0.89	SECONDARY
Mulloidichthys flavolineatus	Yellowstripe goatfish	Mullidae	Goatfish	0.0089	3.0602	1	SECONDARY
Mulloidichthys vanicolensis	Yellowfin goatfish	Mullidae	Goatfish	0.0099	3.015	1	SECONDARY
Myripristis berndti	Blotcheye soldierfish	Holocentridae	Soldierfish	0.02769	3.00336	0.92	PLANKTIVORE
Myripristis kuntee	Shoulderbar soldierfish	Holocentridae	Soldierfish	0.00991	3.46765	0.88	PLANKTIVORE
Naso brevirostris	Spotted unicornfish	Acanthuridae	Surgeonfish	0.01065	3.24297	1	PLANKTIVORE
Naso hexacanthus	Sleek unicornfish	Acanthuridae	Surgeonfish	0.04244108	2.854	0.88	PLANKTIVORE
Naso lituratus	Orangespine unicornfish	Acanthuridae	Surgeonfish	0.0085	3.25	0.97	PRIMARY
Naso unicornis	Bluespine unicornfish	Acanthuridae	Surgeonfish	0.01788	3.03545	0.96	PRIMARY
Naso vlamingii	Bignose unicornfish	Acanthuridae	Surgeonfish	0.0085	3.25	1	PLANKTIVORE

SCIENTIFIC NAME	COMMON NAME	FAMILY	COMMON FAMILY	LW_A	LW_B	LL CONV.	TROPHIC GROUP
Neoniphon argenteus	Clearfin squirrelfish	Holocentridae	Soldierfish	0.031649	2.82326	0.92	SECONDARY
Neoniphon opercularis	Blackfin squirrelfish	Holocentridae	Soldierfish	0.0094	3	1	SECONDARY
Neoniphon sammara	Sammara squirrelfish	Holocentridae	Soldierfish	0.02762	2.88835	0.92	SECONDARY
Novaculichthys taeniourus	Rockmover wrasse	Labridae	Wrasse	0.013	2.91	1	SECONDARY
Odonus niger	Redtoothed triggerfish	Balistidae	Triggerfish	0.0119	3	1	PLANKTIVORE
Oxycheilinus unifasciatus	Ringtail maori wrasse	Labridae	Wrasse	0.01689	3	1	PISCIVORE
Parupeneus barberinus	Dash-and-dot goatfish	Mullidae	Goatfish	0.01307	3.12248999	0.9	SECONDARY
Parupeneus cyclostomus	Goldsaddle goatfish	Mullidae	Goatfish	0.0124	3	1	PISCIVORE
Parupeneus insularis	Twosaddle goatfish	Mullidae	Goatfish	0.0135	3.0671	1	SECONDARY
Parupeneus multifasciatus	Manybar goatfish	Mullidae	Goatfish	0.01136	3.21082	0.9	SECONDARY
Parupeneus pleurostigma	Sidespot goatfish	Mullidae	Goatfish	0.0119	3	1	SECONDARY
Pempheris oualensis	Silver sweeper	Pempheridae	Sweeper	0.0133	3	1	PLANKTIVORE
Plectorhinchus picus	Painted sweetlip	Haemulidae	Grunt	0.01151	3.08892	0.96	SECONDARY
Plectropomus laevis	Blacksaddled coralgrouper	Serranidae	Grouper	0.00591	3.23774	0.97	PISCIVORE
Pseudobalistes flavimarginatus	Yellowmargin triggerfish	Balistidae	Triggerfish	0.1297	2.6061	1	SECONDARY
Pterocaesio marri	Marr's fusilier	Caesionidae	Fusilier	0.0101	3.152	1	PLANKTIVORE
Pterocaesio tile	Dark-banded fusilier	Caesionidae	Fusilier	0.0112	3	1	PLANKTIVORE
Rhinecanthus rectangulus	Wedge-tail triggerfish	Balistidae	Triggerfish	0.0522	2.641	1	SECONDARY
Sargocentron caudimaculatum	Silverspot squirrelfish	Holocentridae	Soldierfish	0.0232	2.9554	1	SECONDARY
Sargocentron diadema	Crown squirrelfish	Holocentridae	Soldierfish	0.02505	2.95522	0.92	SECONDARY
Sargocentron microstoma	Smallmouth squirrelfish	Holocentridae	Soldierfish	0.0219	3.047	0.94	SECONDARY
Sargocentron spiniferum	Sabre squirrelfish	Holocentridae	Soldierfish	0.01541	3.11881	0.93	SECONDARY
Sargocentron tiere	Blue lined squirrelfish	Holocentridae	Soldierfish	0.0234	3	1	SECONDARY
Scarus altipinnis	Filament-finned parrotfish	Scaridae	Parrotfish	0.0184	3.02932	0.98	PRIMARY

SCIENTIFIC NAME	COMMON NAME	FAMILY	COMMON FAMILY	LW_A	LW_B	LL CONV.	TROPHIC GROUP
Scarus dimidiatus	Yellowbarred parrotfish	Scaridae	Parrotfish	0.02337	2.956	1	PRIMARY
Scarus forsteni	Forsten's parrotfish	Scaridae	Parrotfish	0.01859	3.0455	1	PRIMARY
Scarus fuscocaudalis	Darktail parrotfish	Scaridae	Parrotfish	0.0222	2.971	0.97	PRIMARY
Scarus globiceps	Globehead parrotfish	Scaridae	Parrotfish	0.0155	3	1	PRIMARY
Scarus psittacus	Common parrotfish	Scaridae	Parrotfish	0.01045	3.31871	0.97	PRIMARY
Scarus rubroviolaceus	Ember parrotfish	Scaridae	Parrotfish	0.0136	3.109	1	PRIMARY
Scarus schlegeli	Yellowband parrotfish	Scaridae	Parrotfish	0.02306	2.96919	0.98	PRIMARY
Scolopsis lineata	Striped monocle bream	Nemipteridae	Threadfin	0.0205	2.984	1	SECONDARY
Sufflamen bursa	Boomerang triggerfish	Balistidae	Triggerfish	0.0216	3	1	SECONDARY
Sufflamen chrysopterum	Halfmoon triggerfish	Balistidae	Triggerfish	0.0153	3.152	1	SECONDARY
Thalassoma hardwicke	Sixbar wrasse	Labridae	Wrasse	0.01783	2.97765	0.93	PLANKTIVORE
Thalassoma lunare	Moon wrasse	Labridae	Wrasse	0.0211	2.83173999	0.9	PLANKTIVORE
Thalassoma lutescens	Yellow-brown wrasse	Labridae	Wrasse	0.013	3.04186	0.89	SECONDARY
Thalassoma purpureum	Surge wrasse	Labridae	Wrasse	0.0259	3	1	SECONDARY
Thalassoma quinquevittatum	Fivestripe wrasse	Labridae	Wrasse	0.0139	3	1	SECONDARY
Variola louti	Yellow-edged lyretail	Serranidae	Grouper	0.01219	3.07913	0.88	PISCIVORE
Zebrasoma flavescens	Yellow tang	Acanthuridae	Surgeonfish	0.0148	3.16	1	PRIMARY
Zebrasoma scopas	Twotone tang	Acanthuridae	Surgeonfish	0.02905	2.99274	1	PRIMARY
Zebrasoma veliferum	Sailfin tang	Acanthuridae	Surgeonfish	0.03425	2.86581	1	PRIMARY