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Fewer but bigger fish? Examining the long-term effects of protection in a marine sanctuary in Verde Island Passage

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ABSTRACT

Monitoring marine protected areas is important in assessing their effectiveness in accumulating fish biomass, yet much of these monitoring efforts are intermittent. This study examined the long-term effects of protection on the community and size structure of commercially targeted reef fishes in Twin Rocks Marine Sanctuary (TRMS), in Mabini, Batangas. Data inside and outside the sanctuary collected by Conservation International in 2009 and the Coral Reef Visualization and Assessment (CoRVA) project in 2015 and 2018 were analyzed. Total fish abundance and biomass were found to be higher inside than outside TRMS in 2009, but decreased inside TRMS in later years. These declines appeared to be associated with the drop in the abundance of transient schooling species such as jacks, fusiliers, and barracudas that were observed in more recent years, especially inside TRMS. However, other reef-associated species such as surgeonfishes and parrotfishes also declined in their abundances or biomass since 2009. Interestingly, modal sizes of most targeted families, excluding transient species, appeared to increase inside and outside TRMS through time. In contrast, transient fish families observed inside TRMS were smaller in 2018 than in 2009. These suggest that TRMS had a positive effect on the growth of most fish populations. However, the small area (22.91 ha) of TRMS may not be effective in protecting transient fishes with larger home ranges. Further, shifts in benthic composition to algal and abiotic components could have also driven the declines of other fish populations. We suggest expanding the area of TRMS and addressing the underlying drivers of its habitat degradation.

Keywords: coral reef fish, marine protected areas, size structure, Twin Rocks Marine Sanctuary

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1. Introductions

The Philippines is at the apex of the Coral Triangle, a region containing the highest concentration of marine species in the world [1,2]. As such, the conservation of marine resources in the Philippines is critical in maintaining global marine biodiversity [3]. However, Philippine marine resources are now exposed to stressors due to various anthropogenic actions and climatic changes. In fact, the Philippines is identified as the region with the highest level of threat to coral reefs, along with any other center of marine life [4]. In order to conserve these resources, Marine Protected Areas (MPAs) were established in the Philippines as early as 1974 [5]. By 2014, more than 1,800 MPAs had been established in the Philippines [6]. However, this high abundance of MPAs can be a misleading indicator of progress on conservation if these are not well-enforced. Systematic assessments on the effectiveness of MPAs in the Philippines are still lacking [7], and existing assessments also tend to be inconsistent across studies [8,9].

Few long-term studies investigate how small-scale MPAs affect fish populations in the Philippines [10]. The marine sanctuary in Apo Island, Negros has demonstrated benefits to fisheries via the spillover effect though these benefits might manifest after several years of consistent protection [11,12]. A study wherein fish population data were compiled from discontinuous surveys showed that 71% of MPAs positively influence fish populations, but their specific effects are highly variable among MPAs [13]. Another study using fish population data from 2005 to 2009 showed a shift in larger body sizes, although this was only observed in 12 out of the 23 MPA sites across the Philippines and is family-specific [14]. Analyzing the true extent to which these MPAs meet current objectives is vital in maximizing the efficiency of protected-area networks [15]. More research on the long-term

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effects can provide insights into the improvement of MPA management.

This study focuses on Twin Rocks Marine Sanctuary (TRMS), a locally managed MPA in Mabini, Batangas. The sanctuary was established in 1991, making it one of the oldest MPAs in the Verde Island Passage marine biodiversity corridor with available recorded data [16,17]. It has an area of 22.91 ha, and its management is closely tied to diving and tourism development [17]. Monitoring data from 1997 to 2001 showed an increase in abundance for all targeted fish species [18], and by the end of 2007, TRMS was recognized as the 3rd best MPA by the MPA Support Network [19]. However, it is still vulnerable to several risks that may affect its performance. These risks include poaching inside the no-take zone, the possibility of high fishing pressure in adjacent fishing grounds, and the high volume of divers visiting nearby dive sites [20].

This study aimed to analyze the long-term effects of protection on commercially important reef fishes inside the TRMS. Specifically, this study compared fish biomass inside and outside TRMS and examined the size structure of commercially targeted reef fish families inside and outside TRMS over time. If protection has a positive effect on fish populations inside MPAs, then observed populations should have a greater biomass and the size structure should skew towards large size classes than outside over time. The study focused on the biological indicators, i.e., community assemblage and population size structure [21], and did not examine the socioeconomic and governance aspects of the MPA, which also have a significant influence on the MPA's effectiveness [13].

2. Materials and methods

Separate datasets using underwater fish visual census (UVC) from a 2009 fish survey under Conservation International (CI) [22] and the 2015 and 2018 fish surveys by the Coral Reef Visualization and Assessment (CoRVA) project [16,23] were used in this study. Both these datasets were obtained inside Twin Rocks Marine Sanctuary (13° 41'24.20"N, 120°53'22.70"E) and Bebot's Rock (a.k.a. Dead Palm Reef) (13°41'42.20"N, 120°53'5.50"E), a fished area outside the sanctuary that served as a control site, in Mabini, Batangas. In the 2009 study, data were gathered in May, wherein 50 m x 10 m belt transects, each with an area of 500 m^2, were used and laid at a depth between 5-8 m [22]. Two replicate transect samples were obtained in each site. In the case of the datasets in 2015 and 2018, data gathered in the months of April and May were used to minimize the influence of seasonal differences among years. Three replicate 50 m x 10 m (area = 500 m^2) belt transects were deployed in TRMS and Bebot's Rock between 5 to 15 m in depth [23,24].

Fishes were identified to the lowest possible taxon, counted, while total lengths (TL) were estimated to the nearest centimeter. Most of the observers who conducted the UVC had more than 10 years of experience monitoring coral reef fishes. In addition, all observers for UVC in 2015 and 2018, regardless of experience, underwent training workshops to estimate sizes using fish models before conducting surveys. The biomass of these fish was computed using the following equation:

$$W = (aL^b)n \qquad (1)$$

wherein *L* is the total length of the fish (cm), *n* is the number of individuals of the species, and *a* and *b* are the known species-specific length-weight relationship (LWR) parameters obtained online from FishBase [25]. The resulting biomass was expressed in kg 500 m^{-2} units.

Biomass, abundance, and family composition of commercially important fishes were compared between protection levels (i.e., inside and outside TRMS) and among years (i.e., 2009, 2015, and 2018) using various statistical methods with the software R [26]. Only commercially targeted species from various families were examined, namely: surgeonfishes (*Acanthuridae*), triggerfishes (*Balistidae*), fusiliers (*Caesionidae*), jacks and pompanos (*Carangidae*), cornetfishes (*Fistulariidae*), grunts (*Haemulidae*), squirrel fishes (*Holocentridae*), wrasses (*Labridae*), emperors (*Lethrinidae*), snappers (*Lutjanidae*), goatfishes (*Mullidae*), threadfin breams (*Nemipteridae*), parrotfishes (*Scarinae*), groupers (*Serranidae*), rabbitfishes (*Siganidae*), barracudas (*Sphyraenidae*), and lizardfishes (*Synodontidae*). Excluded from this analysis were *Zebrasoma* spp. (*Acanthuridae*), fairy basslets (*Serranidae*), fairy wrasses (*Labridae*), and other species that were not identified as "commercial species" in FishBase [25].

Total fish abundance and biomass of commercially important species were compared using generalized linear models (GLMs) with time (year) and protection level as fixed factors. Negative binomial distribution was used to analyze fish abundances, while gamma distribution was used to analyze biomass for the GLMs using the package *lme4* [27]. Assumptions of normality and homogeneity of variances were examined using the package *DHARMa* [28], and no violations were found. To determine whether a significant interaction and main effects are present, likelihood ratio tests (LRT) were performed, which examine whether the removal of the term results in increased deviance of the model.

Fish assemblages were also compared between protection levels and time (years) using non-metric multidimensional scaling (NMDS) ordination that was generated from a similarity matrix derived using the Bray-Curtis similarity index. A two-way Permutational Multivariate Analysis of Variance (PERMANOVA) was then used to examine differences in family composition between years and levels of protection. Similarity of Percentage (SIMPER) analysis was done to determine which fish families contributed to the observed difference in assemblages, if any. Multivariate analyses were conducted using the package *vegan* [29].

The population size structures of fishes were compared using Kolmogorov-Smirnov tests. This treatment was applied to all fish families. Only influential families or groups (according to SIMPER) that had a total of at least 10 individuals observed per year per station (i.e., *Acanthuridae*, *Labridae* [excluding *Scarinae*], *Scarinae*, *Lutjanidae*) had size structures separately examined using kernel density distributions. Data from some demersal families were combined and grouped under "other fish families" due to their low observed counts in some years, whereas transient schooling species such as *Carangidae, Caesionidae,* and *Sphyraenidae* were combined as "schooling transients". Biased-cross validation was used for bandwidth selection because it tends to over smooth distributions [30], which may be appropriate given that lengths are visually estimated and thus may not be precise to detect differences in frequencies between total lengths that differ by <2 cm.

3. Results and discussion

Total abundances of target fishes appeared to be highest inside TRMS in 2009, with a mean density of 1097 (± 318 SE) individuals 500 m^{-2} (Figure 1). Mean abundances during the other sampling years ranged between 117 to 183 individuals 500 m^{-2}. A significant interaction was found between year and protection level (LRT, $\chi 2 = 26.9$, df = 2, $p < 0.001$). Post-hoc comparisons showed that abundances in 2009 inside TRMS were higher than in Bebot's Rock in 2009 and inside TRMS in later years.

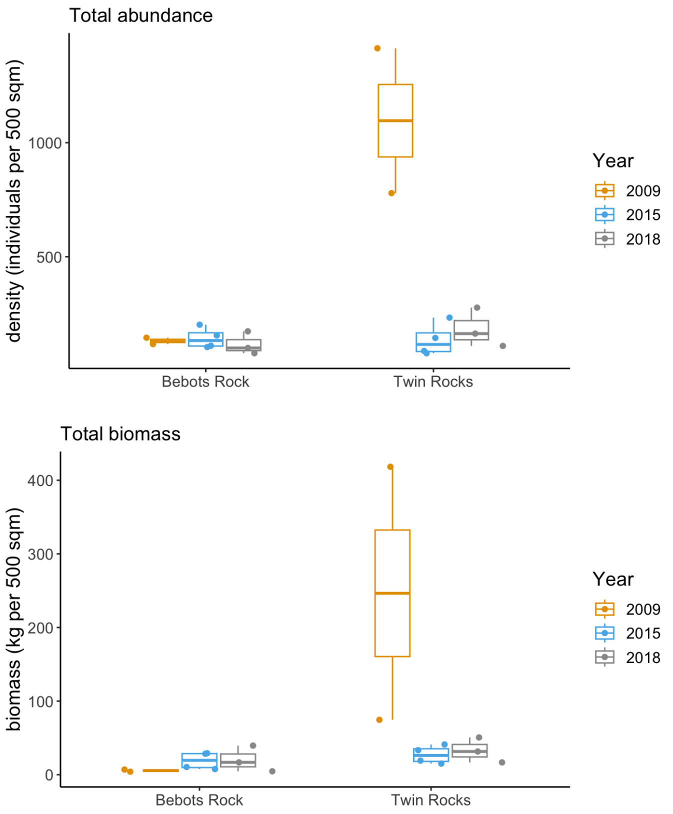


Figure 1. Boxplot of total abundances (top) and biomass (bottom) of commercially targeted fishes in Twin Rocks Marine Sanctuary (MPA) and Bebot's Rock (non-MPA) from 2009 to 2018.

Total biomass of target fishes inside TRMS in 2009 also appeared to be highest among the year-station combination groups with a mean biomass of 246.4 (± 171.9 SE) kg 500 m^{-2} (Figure 1). In contrast, mean biomass in Bebot's Rock in 2009 appeared to be the lowest at 5.6 (± 1.5 SE) kg 500 m^{-2}. Biomass inside TRMS from 2015 (27.2 ± 6.1 (SE) kg 500 m^{-2}) to 2018 (33.0 ± 9.8 (SE) kg 500 m^{-2}) did not appear to vary much. A significant interaction was also found between year and protection level (LRT, $\chi 2 = 8.5$, df = 2, p = 0.014). Comparing between years, TRMS in 2009 had higher biomass than in TRMS 2015 (Tukey contrasts, p = 0.0422).

NMDS ordinations on biomass data showed distinct fish assemblages between inside and outside TRMS and among years within each site (Figure 2). Two-way PERMANOVA tests showed significant differences among years ($F_{(2,12)}$= 2.6179, p=0.0020) and between levels of protection ($F_{(1,12)}$= 3.3993, p= 0.0026). No significant interaction between years and protection level was found ($F_{(2,12)}$=1.7056, p= 0.0504).

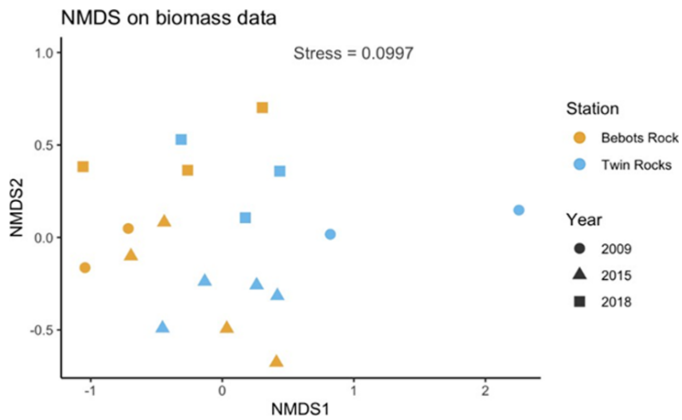


Figure 2. Non-metric multidimensional scaling of targeted fishes using biomass data among years between inside and outside Twin Rocks Marine Sanctuary.

The most predominant families contributing to around a cumulative 80% of dissimilarities among years were *Carangidae* (jacks), *Caesionidae* (fusiliers), *Acanthuridae* (surgeonfish), *Scarinae* (parrotfish), *Sphyraenidae* (barracudas), and *Lutjanidae* (snappers) (Table 1). Jacks, fusiliers, surgeonfish, and barracudas had the highest biomass and abundances in 2009, especially inside TRMS, while parrotfish had the highest biomass in 2015 (Figure 3). Jacks had disproportionately large mean biomass (181 kg 500 m^{-2}) inside TRMS in 2009 and also the highest but variable mean abundance (406 individuals 500 m^{-2}). Caesionids were also numerous inside TRMS in 2009 (465 individuals 500 m^{-2}), although their mean biomass (25 kg 500 m^{-2}) is comparable with that of acanthurids (22 kg 500 m^{-2}). Parrotfishes appeared to have higher biomass inside TRMS than outside, although their highest biomass (9 kg 500 m^{-2}) was observed in 2015. Meanwhile, snappers had the highest biomass (5 kg 500 m^{-2}) and abundance (31 individuals 500 m^{-2}) in 2018, particularly inside TRMS. The same families also contributed the most to the dissimilarities in biomass assemblages between inside and outside TRMS (Table 2). These families were on average more abundant in TRMS than in Bebot's Rock (Table 2), although most showed declining abundances since 2009 (Figure 3).

Table 1. Summary of SIMPER results showing the cumulative contributions of the most influential families over the years according to biomass

Taxon	Av. dissim	Contrib. %	Cumul. %	Mean 2009	Mean 2015	Mean 2018
Carangidae	17.19	24.81	24.81	90.60	0.03	5.00
Caesionidae	11.71	16.90	41.70	12.60	5.67	1.45
Acanthuridae	9.20	13.27	54.98	11.80	3.22	5.79
Scarinae	7.70	11.12	66.10	3.00	5.62	2.07
Sphyraenidae	4.60	6.64	72.74	1.91	3.22	0.00
Lutjanidae	4.42	6.38	79.11	0.88	1.16	3.03
Lethrinidae	3.35	4.84	83.96	0.33	0.06	2.85
Labridae	2.68	3.87	87.82	1.97	1.61	1.41
Nemipteridae	2.53	3.64	91.47	0.42	0.25	1.74
Balistidae	1.94	2.79	94.26	0.29	1.19	1.17
Serranidae	1.11	1.60	95.86	0.65	0.33	0.83
Holocentridae	1.04	1.50	97.36	0.62	0.15	0.58
Mullidae	0.59	0.85	98.22	0.27	0.20	0.40
Siganidae	0.59	0.85	99.07	0.60	0.18	0.21

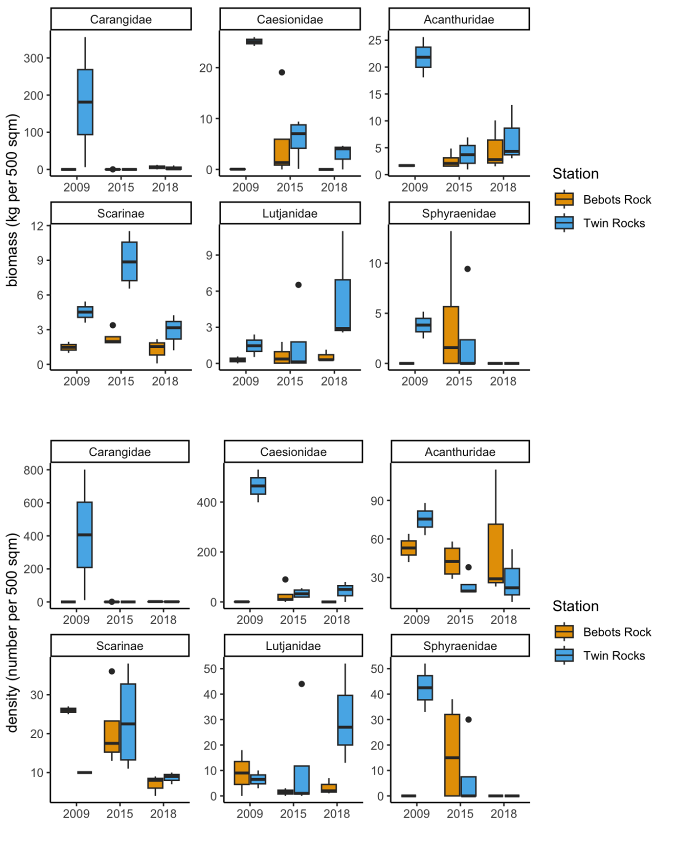
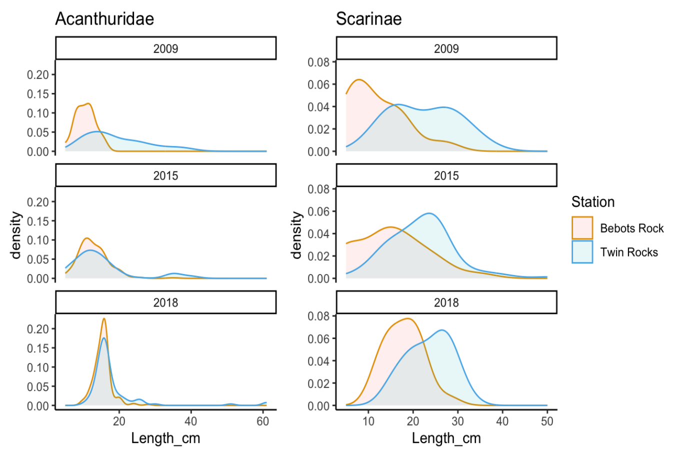


Figure 3. Boxplots of biomass and abundance of the most influential families contributing to dissimilarities between years and stations. Note the differences in the y-axes among the graphs.

Table 2. Summary of SIMPER results showing the cumulative contributions of the most influential families between sites according to biomass

Taxon	Av. dissim	Contrib. %	Cumul. %	Mean Be-bots Rock	Mean Twin Rocks
Carangidae	14.160	20.480	20.480	2.000	41.600
Caesionidae	12.700	18.370	38.850	2.430	9.170
Scarinae	10.130	14.660	53.510	1.770	5.940
Acanthuridae	9.483	13.720	67.220	3.140	8.810
Lutjanidae	5.112	7.394	74.620	0.536	2.910
Sphyraenidae	4.500	6.508	81.120	1.820	1.900
Lethrinidae	3.083	4.460	85.580	1.120	0.982
Labridae	2.331	3.371	88.950	1.480	1.770
Nemipteridae	2.134	3.087	92.040	0.463	1.100
Balistidae	1.666	2.410	94.450	0.781	1.180
Serranidae	1.234	1.785	96.240	0.203	0.929
Holocentridae	0.999	1.445	97.680	0.154	0.642
Siganidae	0.568	0.822	98.500	0.107	0.453
Mullidae	0.502	0.726	99.230	0.257	0.306

The apparent decline in biomass of commercially important fishes inside TRMS after 2009 could indicate that fishes either decreased in abundance, were smaller, or both. However, examining the size structure of these fish showed increased modal sizes, even outside the sanctuary, which suggests that the lower abundances may have driven the lowered biomass inside TRMS in 2015. The size structure of *Acanthuridae, Labridae, Scarinae,* and *Lutjanidae* generally showed increasing modal sizes not only in TRMS but also in Bebot's Rock from 2009 to 2018 (Figure 4, Table 3). Most surgeonfishes in TRMS were around 10-15 cm in 2009, which shifted to nearly 15-20 cm in 2018. Many parrotfish in TRMS were between 15-30 cm in 2009, which shifted to 25-30 cm in 2018. Likewise, other wrasses in TRMS had a modal size that increased from ~15 cm in 2009 to ~30 cm in 2018. Modal sizes of snappers did not appear to differ in TRMS between 2009 and 2018, although more prominent peaks can be seen in 2015 and 2018.



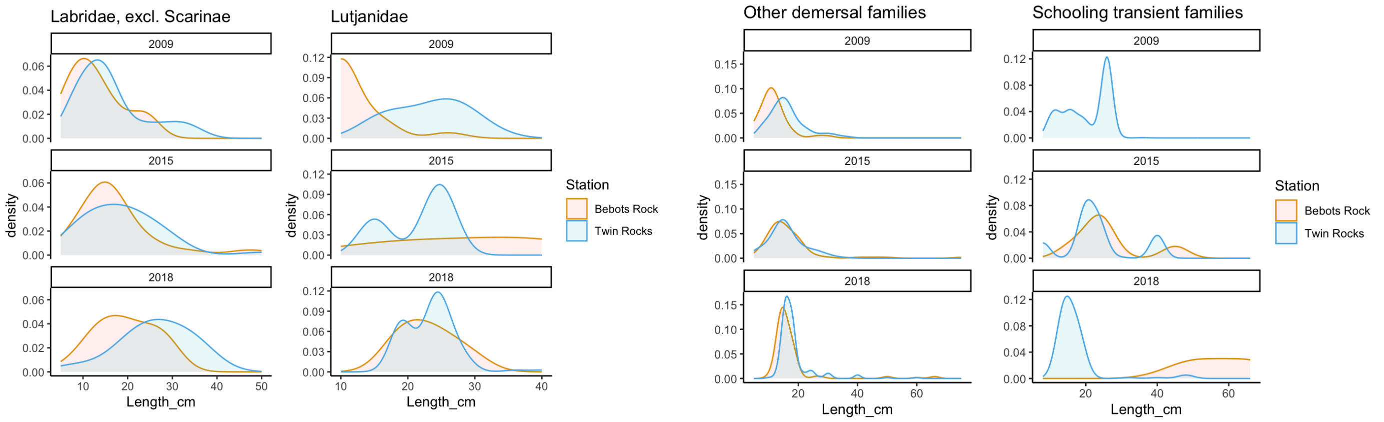


Figure 4. Kernel density distributions of the total lengths of commercially targeted reef fish families in Bebot's Rock and Twin Rocks Marine Sanctuary over the years.

Table 3. Two-sample Kolmogorov-Smirnov results comparing the size distribution of commercially targeted reef fishes between years and between Twin Rocks Marine Sanctuary (TRMS) and Bebot's Rock (BR). D statistics are shown with p-values in parentheses. Significant results are highlighted in bold. KS-tests were not performed for schooling species between BR 2009 and other treatments because of very low sample sizes observed.

Family	**2009 (TRMS vs. BR)**	**2015 (TRMS vs. BR)**	**2018 (TRMS vs. BR)**	**TRMS (2009 vs. 2015)**	**TRMS (2009 vs. 2018)**	**TRMS (2015 vs. 2018)**	**BR (2009 vs 2015)**	**BR (2009 vs. 2018)**	**BR (2015 vs. 2018)**
Acanthuridae	0.582 (<0.001)	0.110 (0.440)	0.185 (0.0419)	0.379 (<0.001)	0.2481 (0.002)	0.493 (<0.001)	0.295 (<0.001)	0.712 (<0.001)	0.490 (<0.001)
Scarinae	0.596 (<0.001)	0.391 (<0.001)	0.529 (0.003)	0.362 (0.027)	0.296 (0.275)	0.257 (0.136)	0.334 (0.002)	0.596 (<0.001)	0.286 (0.129)
Labridae	0.280 (0.078)	0.222 (0.312)	0.418 (0.080)	0.293 (0.071)	0.679 (0.0001)	0.5 (0.014)	0.374 (0.007)	0.481 (0.001)	0.313 (0.082)
Lutjanidae	0.778 (0.0002)	0.5 (0.141)	0.252 (0.615)	0.462 (0.027)	0.297 (0.268)	0.326 (0.003)	0.778 (0.009)	0.944 (<0.001)	0.5 (0.306)
Other demersal reef fishes	0.444 (<0.001)	0.109 (0.625)	0.341 (<0.001)	0.144 (0.174)	0.323 (<0.001)	0.452 (<0.001)	0.455 (<0.001)	0.712 (<0.001)	0.344 (<0.001)
Schooling transients	NA	0.312 (<0.001)	1 (0.001)	0.268 (<0.001)	0.543 (<0.001)	0.777 (<0.001)	NA	NA	1 (0.001)

Differences in size distributions were significant in TRMS between 2009 and 2018 for surgeonfish, wrasses, and other demersal reef fish families, and between 2009 and 2015 for parrotfish and snappers (Table 3). These families, except labrids, were also larger in TRMS than in Bebot's Rock, particularly in 2009 (Figure 4, Table 3). Other demersal reef fishes combined also appeared to show larger modal sizes in Bebot's Rock in 2018 (15 cm) than in 2009 (10 cm). However, for lutjanids, their increased biomass in 2018 may be due to increased abundances since no difference in size structure was seen among years.

In contrast, the modal size of schooling transient species combined (i.e., carangids, caesionids, and sphyraenids) was smaller in 2018 (modal size ~15 cm) than in 2009 (modal size ~25 cm) in TRMS (Figure 4). Few individuals of these schooling species were observed in Bebot's Rock in 2009, but their modal size increased from 2015 (mode ~15 cm) to 2018 (mode ~20 cm) (Figure 4). These changes in size distributions were significant (Table 3).

Alternatively, the apparent declines in biomass and abundances inside TRMS may be due to a lack of replication when the surveys were conducted in 2009. Only two replicate transects were deployed in both inside and outside TRMS [22], which may not entirely represent the fish communities in those sites. In addition, densities of highly mobile species can be overestimated if counts are made after the start of the census [31]. However, in this study, observers were trained not to count fish that entered the survey area after the survey had started.

When compared to previous monitoring surveys conducted from 1991 to 2005, mean densities of target species ranged between ~67 to 130 individuals 500 m^{-2}, except in 1992, which had a mean density of 540 individuals 500 m^{-2} [17]. The observed increase from 1991 to 1992 could be attributed to the high abundances of caesionids during that year [17]. Likewise, 431.6 (± 287.8 SE) individuals 500 m^{-2} of target fishes were recorded in 2011 due to schools of jacks [20]. The transient nature of these schooling fishes, which are highly mobile, can lead to density estimates ranging from zero to large numbers in a transect during a census. This raises the importance of having enough replicates to account for the variability of fish density estimates that are inherent in fish visual census [32].

Despite being a marine sanctuary for more than 30 years, biomass obtained in 2015 and 2018 was approximately similar to that obtained for all target species in 2005, which had a total mean biomass of 30.9 kg (11.7 ± SE) 500 m^{-2} [17]. No biomass values from years before 2005 were reported; thus, it is difficult to conclude whether the decline in biomass observed from 2009 to 2018 inside TRMS indicates possible poaching or an artifact of the low replication conducted in 2009. However, surveys in 2011 [20] showed a mean biomass of target fishes at 363.5 (±336.6 SE) kg 500 m^{-2} with 5 replicate transects. This seems to suggest that the decline in target fish biomass may be significant.

It is possible that illegal fishing may have occurred since there are anecdotal reports from Mabini of lax enforcement of MPAs due to political reasons. While these have yet to be confirmed, the decline of fish biomass reported in this study suggests that implementation and enforcement of MPAs, both as a conservation and fisheries management tool in Mabini, Batangas, need to be strengthened and improved urgently.

Another factor that might explain the apparent decline of fish biomass inside TRMS is the change in benthic habitat quality. Hard coral cover was reported to have increased from 13% to 29% at depths 7-8 m and from 39% to 66% at 2-4 m depth between 1993 and 2005 [17], and then declined to 15% in 2009 [22], 14-18% in Apr-May 2015, and ~10% in 2018 [16]. Meanwhile, algal cover appeared to have increased over time. Algal cover (including dead coral with algae) was under 10% in 2001 and 2005 [17] and nearly doubled to ~20% in 2009 [22]. In 2015, algal cover further increased to about ~44 -57% in April and May [23]. Algal cover was ~13% in April 2018, but abiotic cover was around 42% [23].

The decreasing coral cover and increasing algal cover in these sites in recent years could indicate the outcome of the chronic adverse effects of anthropogenic activities such as poor waste and sewage disposal and overfishing [19,33]. Industrial, agricultural, hazardous, and municipal solid waste management has been reported to deteriorate in 2008 due to issues in implementation and evaluation [34]. The increasing challenges in waste and sewage disposal are likely driven by the prominent diving and tourism industry in this area [20] and possibly by the multitude of currents and ships from the nearby Balayan Bay [35]. Analysis of sedimentary oxygen consumption from sewage input on small islands reveals that corals can maintain dominance on overfished reefs, but additional sewage stress drives significant benthic shifts on these ecosystems [36]. Since inappropriately managed waste leads to poorer water and habitat quality for reef fishes, this could affect their recruitment and, in turn, fish abundances. Furthermore, natural disturbances such as bleaching events from 2009 through 2016 have also been reported in Luzon [37,38], which could have also contributed to the decline in habitat quality in the two sites.

Many reef-associated species, even large-bodied fishes, depend on the structural complexity that is highly associated with live coral cover [39-41]. Loss of live corals results in reduced structural complexity that can cause declines in fisheries productivity [42]. The general shift of the benthic composition into primarily algae should benefit algal grazers such as surgeonfish and parrotfish. However, these fish also appear to have decreased since 2001 [17]. Poor habitat quality could lead to decreased recruitment of fishes, including herbivorous species because of higher predator efficiency [43]. Lowered populations of herbivorous fish could result in increasing populations of algae through a positive feedback loop. Decreased herbivory could eventually lead to further reductions in coral cover, structural complexity, and the decline of coral reef fishes [43]. Thus, improving the waste and sewer management in this area may be needed to help increase the reefs' resilience to disturbances such as mass coral bleaching events.

The small size of the sanctuary may illustrate its limitations in accumulating fish biomass, as pointed out by previous studies [9,44]. A strong fishing pressure immediately adjacent to an MPA and the failure to protect fishes with larger home ranges or dispersal distances highlight the inadequacies of small sanctuaries [7,44,45]. Larger sanctuaries may be more appropriate in protecting more species of fish and enhancing their biomass, particularly those that are more mobile and are highly exploited [46,47]. Therefore, increasing the MPA coverage size of TRMS will help in better conserving these fish in conjunction with better enforcement of fishing laws and waste management.

The significant increase in size in most of the fish species throughout the years inside TRMS shows that the marine sanctuary had a positive effect on the size structure of fish by protecting them from being harvested, thus preventing the selection for early maturation that is often associated with heavy fishing pressure [14]. In addition, increasing fish sizes leads to a critical spawning stock biomass and, in turn, ensures larval supply to other areas. White et al. [17] reported that the majority of the target species in TRMS were under size classes 11-20 cm, while this study shows that the sizes of the majority of individuals from *Labridae* and *Lutjanidae* were 20-30 cm. In addition, given the high fishing pressure adjacent to and around the MPA, the apparent increase in sizes of fish outside TRMS from 2009 to 2018 seems to suggest that possible spillover of larger individuals might be occurring [48]. However, the smaller sizes of schooling transients such as jacks (*Carangidae*), fusiliers (*Caesionidae*), and barracudas (*Sphyraenidae*) inside TRMS in 2018 suggest that the current MPA size may not be adequate to protect these fishes that have larger home ranges [47].

4. Conclusion

Total abundances and biomass of target fishes declined inside TRMS after 2009. Despite the declines in fish abundances and biomass, the modal sizes of acanthurids, lutjanids, labrids, and other demersal reef fish families increased inside and outside TRMS in 2015-2018. Interestingly, schooling species comprised of carangids, caesionids, and sphyraenids were smaller in 2018 than in 2009 inside TRMS. These results suggest that while TRMS had a positive effect on the size structure of fishes, its small area is inadequate in supporting larger populations of reef fishes, especially those that are highly mobile. Hence, it is imperative to increase the size coverage of the TRMS to include home ranges of important commercial reef fishes. In addition, improvements in the current management of Twin Rocks Marine Sanctuary must be explored, including the management of waste and sewage in the area to increase the water and reef habitat quality. Finally, there is a need to conduct monitoring and evaluation every two years and increase replication of samples to better detect the changes in the abundances and biomass of fish in the future.

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