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Benefits of protection on reef fish assemblages in a human impacted region in Costa Rica

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ABSTRACT

In recent years, there has been a health decrease in marine ecosystems. Due to this accelerated degradation, there is a more pressing need to investigate the effectiveness of MPAs in these degraded zones. In this work, we evaluate the effect of MPAs over species richness, biomass and size of reef fishes. The sampling was conducted in 31 sites in the north Pacific coast of Costa Rica in 2013 and 2014. We found a positive effect of MPAs on biomass and community structure, as almost all commercially important species were more abundant in MPAs. Apex predators, carnivores and herbivores showed higher biomasses in protected areas, while planktivorous were similar among sites. As well, target species of artisanal fisheries and dive-ornamental fisheries were larger in MPAs. Areas closed to fishing can contribute to keeping biomass high, improve species richness in the region, and help to recover ecosystem services in coral reefs, even in anthropogenic impacted areas. The improving of regulations in and out of MPAs will assure the ecosystem services and life quality of coastal populations.

1. Introduction

The use of a Marine Protected Area (MPA) is a management strategy designed to maintain essential ecological processes and life support systems, preserve genetic diversity and to ensure the sustainable utilization of species and ecosystems (IUCN, 1980; Lubchenco et al., 2003; Edgar et al., 2007). To accomplish those objectives, MPAs are established in sites identified as conservation priorities, usually vulnerable, diverse and unique ecosystems (Kelleher, 1999). Protecting sites that are already deemed healthy is widely implemented and recommended because this type of site is easier to maintain, and the protection typically reduces the conflicts with other users (Edgar et al., 2008; UNEP-WCMC, 2008). However, due to the accelerated rate at which marine ecosystems are being degraded (Jackson et al., 2001; McCauley et al., 2015), there is a need to define protected sites under a wider variety of criteria.

When a MPA is established, it is expected that there will be an increase in the health of the populations and ecosystems inside its borders. If the area is protecting mobile commercially valuable species, it is likely that the fishing communities in the surrounding areas are going to benefit due to the spillover out of the MPA boundaries (Sale et al., 2005). However, this increase in benefits does not always occur, as there are many factors that can affect the marine communities besides fishing (Hilborn, 2015). For example, reef fish use chemical and acoustical signals to determine settlement sites. Environmental changes in degraded ecosystems affect those signals and prevent proper recruitment (Dixson et al., 2014; Piercy et al., 2014). The loss of coral structure due to natural (such as ENSO, bioerosion, hurricanes) and human impacts (i.e. deficient coastal management) has been related to declines in diversity and biomass of commercially important fishes (Bellwood et al., 2004). Those multiple drivers generate degraded areas and contribute to the failure of more than a half of the MPA's (Edgar et al., 2014).

Costa Rica has a network of marine protected areas that comprise more than 2% of the marine surface of the country (Alvarado et al., 2012, 2016a,b; Fargier et al., 2014). However, conservation and management efforts have not been the same for all MPAs, which has produced inequalities in terms of their effectiveness. On one side there are areas like Isla del Coco National Park, which has been considered one of the best MPA in the world (Edgar et al., 2014), and presents one of the highest biomass of top predators in coral reefs (Friedlander et al., 2012; Alvarado et al., 2016b; Fourriére, 2016). On the other hand, MPAs like

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those in the north Pacific of Costa Rica are amongst several fishing communities (Villalobos-Rojas et al., 2014) and surrounded by a strong and messy coastal development (Alvarado et al., 2018). Multiple uses of the marine resources in this region generate conflicts and difficulties to enforce MPAs (Villalobos-Rojas et al., 2014). For these reasons, the North Pacific of Costa Rica has become a conservation priority and a challenge, due to the degree of environmental deterioration.

Recently it has been proposed that MPAs in degraded zones should be a priority since effective protection can contribute to adequate ecosystems recovery (Abelson et al., 2016). If this is true, reef fish assemblages in the north Pacific of Costa Rica should be showing benefits of that protection even though they are in a region severely impacted by human activities. In this paper, the effect of MPAs across richness, biomass and size of the reef fishes in the north Pacific of Costa Rica is evaluated. Differential effects of protection are expected depending on the trophic group and commercial value of the species (Pauly et al., 1998).

2. Materials and methods

2.1. Study area

The North Pacific of Costa Rica is a region between Nicaragua and the external part of the Gulf of Nicoya. The northern part is influenced by a seasonal wind-driven coastal upwelling that takes place between December and April, this phenomenon brings cold and productive waters to the coast. Administratively it is divided in the provinces of Guanacaste and Puntarenas. During the last 30 years the area has been exposed to intense fishing pressure and unplanned coastal development resulting in a continuous degradation of the marine habitats. There are several Marine Protected Areas, from National Parks with a non-take marine component to Marine Areas of Responsible Fishing with some regulation to exploit the resources (Villalobos-Rojas et al., 2014). In this study we only considered a site as protected if it is non-take.

2.2. Data collection

During 2013, 2014, 31 sites in the North Pacific coast of Costa Rica were surveyed, the sites were chosen according to accessibility to divers and to capture a representative variability of the coral ecosystems of the zone both inside and outside marine protected areas (Fig. 1, Table S1). The sampling was done between March and July of both years to avoid the temporal effect and the bad diving conditions that might cause the seasonal upwelling or the intense part of the rainy season.

To remain the sampling effort uniform, three to six underwater visual censuses using belt transects (10 m long, 5 m wide, 5 m height) were performed in each site each year, all conspicuous fishes in the reef were counted and identified. The size of each fish was estimated in five-cm intervals. Those sizes were transformed to biomass using the parameters a and b (from FishBase: Froese and Pauly, 2016) in a simple potential equation (Alvarado et al., 2015). According to its trophic level and food items reported in FishBase (2016), each species was categorized in different functional groups: top predators, carnivores, planktivorous, and herbivores (*sensu* Friedlander et al., 2012).

2.3. Statistical analysis

To compare the number of species in and out of marine protected areas, a rarefaction analysis was performed using 10000 permutations with the function speccum included in the R package vegan (Oksanen et al., 2017). To determine the fish assemblage's biomass similitude between the sites a non-metric multidimensional scaling analysis (nMDS) based on a Bray-Curtis similarity matrix was performed. The data was transformed with the function $\mathrm{Log}_{10}(X+1)$. To detect differences in the reef fish assemblages in and out of marine protected areas an analysis of similarities (ANOSIM) was used. The species contribution to the differences among protection levels was calculated by a similarity percentage analysis (SIMPER). Those analyses were performed using the software PRIMER 6.0 (Clarke and Gorley, 2006).

To test if the biomass of each functional group was different depending on the presence or absence of MPAs, a Bayesian logistic regression model was fit for each group. The presence of MPA was used as a dichotomic response variable and the biomass was a continuous predictor. The resulting interval of 95% credibility was plotted-if the interval included zero, the biomass of that functional group was not considered a good predictor of the protection level. The same model was performed for 12 species to determine if the size of fishes used in different fisheries was a predictor of the presence of MPA. The three more-abundant species utilized in each type of fishery were selected based on Villalobos-Rojas et al. (2014), the groups were: target species in artisanal fisheries, occasional captures in artisanal fisheries, species captured in dive-ornamental fishery and species that don't have any commercial value. The models were executed using the MCMClogit function in R, included in the package MCMCpack. Uninformative multivariate normal priors were used for the parameters (for details on the algorithms used in the calculations see Martin et al., 2011).

3. Results

A total of 21043 specimens in 94 reef fish species were found during the sampling period, representing 37 families (to detailed list of species see supplementary materials, Table S2). Species richness in MPAs was higher compared with sites without protection after standardization by rarefaction (Fig. 2.)

There was an effect of being in or out of a MPAs on the similarity of the sites based on reef fish biomass (Fig. 3; ANOSIM, $R = 0.25$, $p = 0.001$), with eight of the species explaining most of the dissimilarity among sites, in and out MPAs, being commercially important (Table 1). All of them were more abundant in protected areas, except for the grunt *Haemulon maculicauda*. The biomass of apex predators, carnivores and herbivores was higher in MPAs compared with fished zones, while the biomass of planktivorous fishes was similar among sites with different degrees of protection (Fig. 4).

Looking at the effects of the marine protected areas on the size of fishes used in different types of fisheries, we found that the target species in artisanal fisheries and the wrasse used in dive-ornamental fishery were bigger inside MPAs (Fig. 5). Species captured occasionally in artisanal fisheries, other ornamental species and those without commercial value had similar sizes independent of the protection levels (Fig. 5).

4. Discussion

Villalobos-Rojas et al. (2014) determined that 424 fish species have been reported for the North Pacific of Costa Rica. This number suggests that there is a great richness of reef fish for the region, however this was not the case in our findings. We found 94 species, an intermediate richness compared to other closer reefs in Nicaragua (53 species) (Alvarado et al., 2011) or Panamá (129 species) (Dominici-Arosemena and Wolff, 2006). Comparisons with other regions are shown in Alvarado et al. (2018). Fish diversity has been associated with habitat complexity and water conditions like temperature or salinity (Dominici-Arosemena and Wolff, 2006; McClanahan and Jadot, 2017). However, a recent study in Madagascar found that the richness is strongly related to the biomass present in a site (McClanahan and Jadot, 2017). This implies, that even in cases like the North Pacific of Costa Rica where there has been a great habitat degradation (Alvarado et al., 2018), areas with fishing closures can contribute not only to maintaining a high biomass, but also can improve the number of species in a region, as shown in our results.

We found that the fish assemblages in MPAs differ significantly from those open to fishing. This result shows a real effect of the protection,

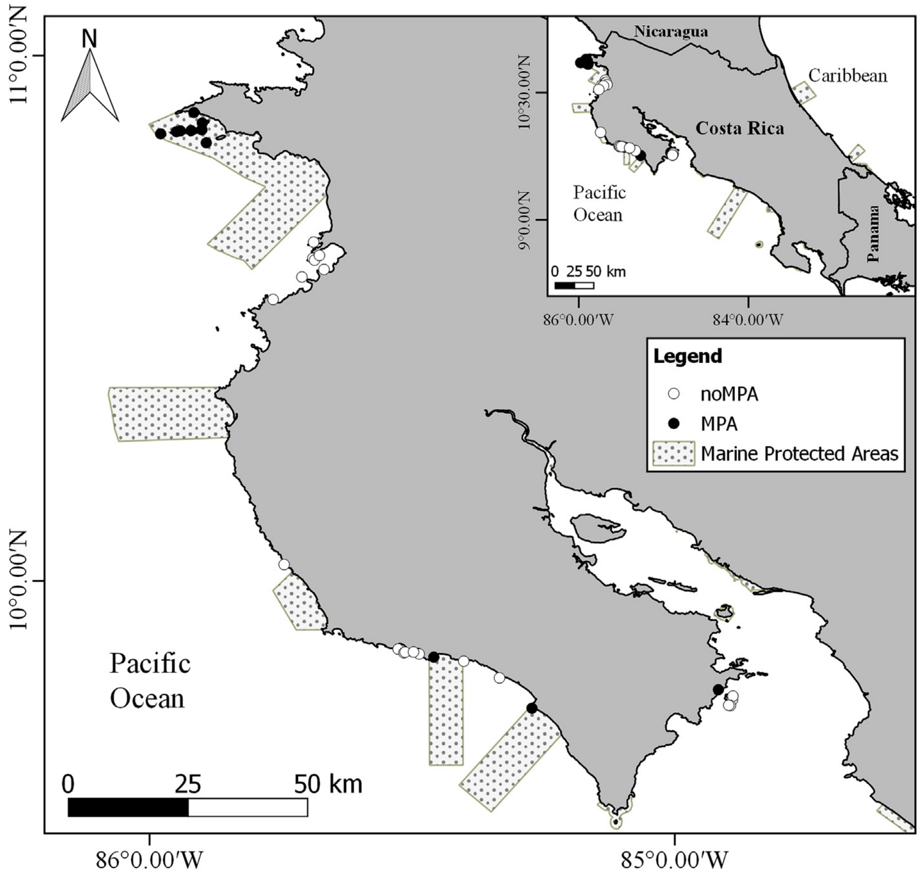

Fig. 1. Map of the North Pacific of Costa Rica with the sites inside and outside marine protected areas.

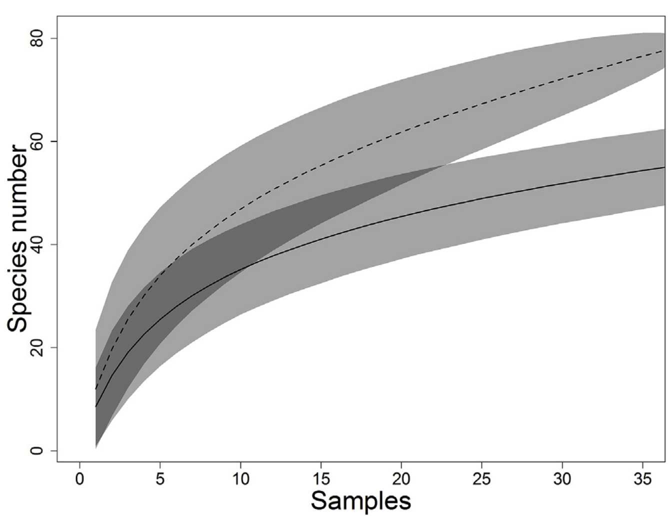

Fig. 2. Cumulative number of species in (dashed line) and out (solid line) of marine protected areas (MPA) in the north Pacific of Costa Rica. The shade represents the 95% confidence interval.

given that the majority of species causing the differences are important to the fisheries of the region (Table 1). The benefit of protection is also reflected in the biomasses by trophic group. Our analysis showed that the biomass of predators, carnivores and herbivores was greater in areas with protection. It is well known that species with higher trophic level tend to be the first affected by exploitation (Pauly et al., 1998). In coral reefs, herbivores also play an important role in artisanal fisheries (Bonaldo et al., 2017; Edwards et al., 2014), so those groups are expected to be favored in areas without fishing.

Herbivore fishes are essential to maintaining healthy and resilient reefs (Doropoulos et al., 2013; Edwards et al., 2014). In the North Pacific of Costa Rica there has been a serial degradation of the coral ecosystems produced by overfishing and changes in water quality. Coral cover has declined from 43% to 5% in the last 15 years and the ecosystems are now dominated by macroalgae (mainly *Caulerpa sertularioides*) (Alvarado et al., 2018). A reduction in herbivore biomass is an important factor that affects the changes in the structure of the systems in the region (Roth et al., 2015). The positive effect that marine protected areas have on herbivore fish may represent a benefit to the recovery potential to coral reefs in region. An example of that can be seen in Fiji, where the MPAs increased the number of herbivores resulting in a significative increment in the grazing rate and coral recruitment (Bonaldo et al., 2017.)

Fishing is often size selective, bigger organisms are more valuable and more susceptible to fishing gears. This selectivity can produce significant changes in the size structure of fish populations. A recent global study determined that between 79% and 97% of the exploited fish populations have lost their bigger and older organisms (Barnett et al., 2017). This change not only affects fishermen that are looking for bigger fish to increase profits, but also the size truncation caused by exploitation can affect the reproductive potential and the sustainability of the resources (Barnett et al., 2017). The use of MPAs has been one of the solutions proposed to avoid the effects produced by this selectivity (Barnett et al., 2017). We support this recommendation based on our results. That is, fish species targeted in artisanal fisheries are larger inside the MPAs than outside.

Despite the effects of protection on size structure in the reef fishes of the North Pacific of Costa Rica, the size of first maturity for the red snapper *Lutjanus guttatus* has been determined as 34 cm (Rojas, 1996) and the mean size of this species in protected areas in this study barely exceeds 22 cm (Fig. 5). This means that there are effects of fishing

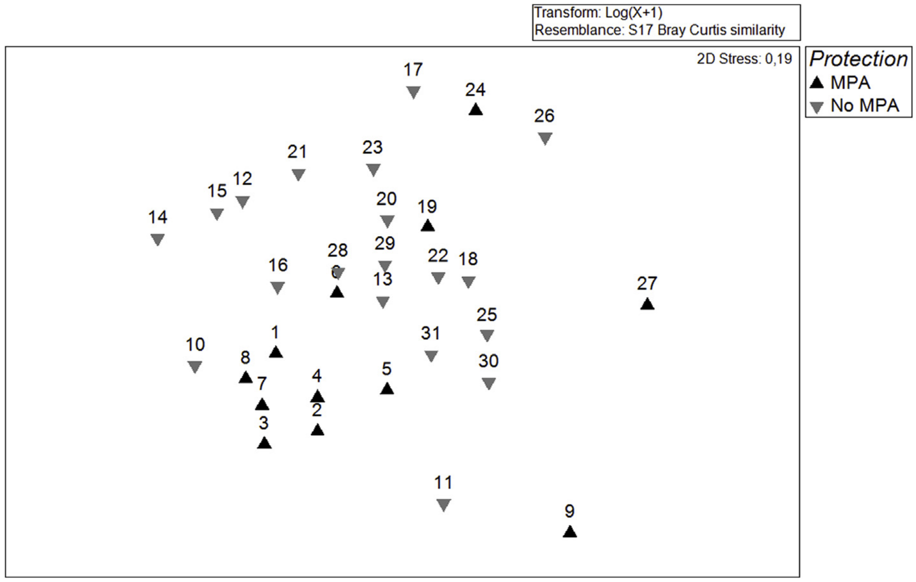

Fig. 3. Non-metric multidimensional scaling analysis (NMDS) based on a Bray-Curtis similarity matrix of fish biomass showing the aggregation of reefs by level of protection (ANOSIM, R = 0.25, p = 0.001). For the names of the sites see supplementary materials (Table S1).

mortality inside protected areas, and under the current conditions, those areas are not enough to maintain healthy and productive populations.

In the case of species harvested by the dive fishery, most of the specimens caught are small, as those are intended to live in aquariums. However, the case of *Thalassoma lucasanum* is different. The species is protogynous hermaphroditic and present color dimorphism. The bigger males (terminal face, TF) are called blue head wrasse and are more attractive to the fishery for their vibrant colors (McCauley, 2008). We found that the size of this species was bigger in protected areas. This is supported by McCauley (2008), who determined that sites with greater fishing pressure present lower sizes and abundance compared with unfished populations.

Although we only evaluated biological indicators inside MPAs (richness, biomass, and size) and we did not test if there is evidence of spillover effects, in several areas of the world such as the South Pacific of Costa Rica (Ross-Salazar, 2013), Kenia (McClanahan and Mangi, 2000) and Philippines (Abesamis & Russ GR, 2005) have been shown that benefits on reef fish assemblages as the ones here studied can be translated into opportunities for coastal communities. For instance, protection increase fish size and biomass, these benefits can potentially be reflected in the fisheries adjacent to the MPAs, which it's important due to the relevance of the fishing activities to the economy and welfare of the people in the North Pacific region of Costa Rica. Also, the effect of the protection on diversity, biomass and sizes can contribute to the scenic beauty of the sites, and increase diving tourism, which is another important economic activity in the region (Villalobos-Rojas et al., 2014).

These results also showed that the benefits of the protection are not enough to keep healthy and productive fish populations. A study on Costa Rican MPAs found that the compliance of fishers with the regulations is often poor. The fishers tend to abide by the rules when there is a better enforcement by authorities and when they feel that their opinions about the areas are taken into account (Arias et al., 2015). These conditions are not necessarily met in the areas studied.

There are several factors that we did not directly evaluate in this paper that can drive reef fishes. For instance, the tridimensional complexity of the substrate and coral cover, as well as relations with other reef organisms can be related to the diversity, biomass and size structure of fish communities (Bellwood et al., 2004; Richards et al., 2012), the relation between them and fish assemblages under different levels of protection in Costa Rica is yet to be studied. The natural variability of the area such as ENSO or local upwelling can also produce temporal patters in fish communities (Bellwood et al., 2004; Roth et al., 2015), we did not consider this in our analysis.

It is important to remember that MPAs are just one management strategy, but they should not be the only one. Other alternatives such as co-management, multiple use areas, and traditional fisheries

Table 1
Species with greater contribution (50%) to the dissimilarity in the composition of the biomass in and out of protected areas using a similarity percentage analysis (SIMPER). TA: target species in artisanal fisheries, OA: occasional captures in artisanal fisheries, DI: species captured in dive-ornamental fishery and NO: any commercial value.

Species	Fishery	Standarized biomass in MPA	Standarized biomass out MPA	Cummulate contribution (%)
Scarus ghobban	OA	0.28	0.04	7.59
Caranx caballus	TA	0.25	0.06	13.63
Sufflamen verres	NO	0.28	0.08	19.66
Lutjanus guttatus	TA	0.22	0.06	24.44
Haemulon flaviguttatum	OA	0.27	0.23	29.08
Stegastes acapulcoensis	NO	0.16	0.08	33.16
Lutjanus argentiventris	TA	0.26	0.03	37.19
Haemulon maculicauda	OA	0.07	0.21	41.19
Holacanthus passer	DI	0.24	0.03	44.81
Scarus rubroviolaceus	OA	0.12	0.01	48.24
Abudefduf troschelii	NO	0.07	0.09	50.94

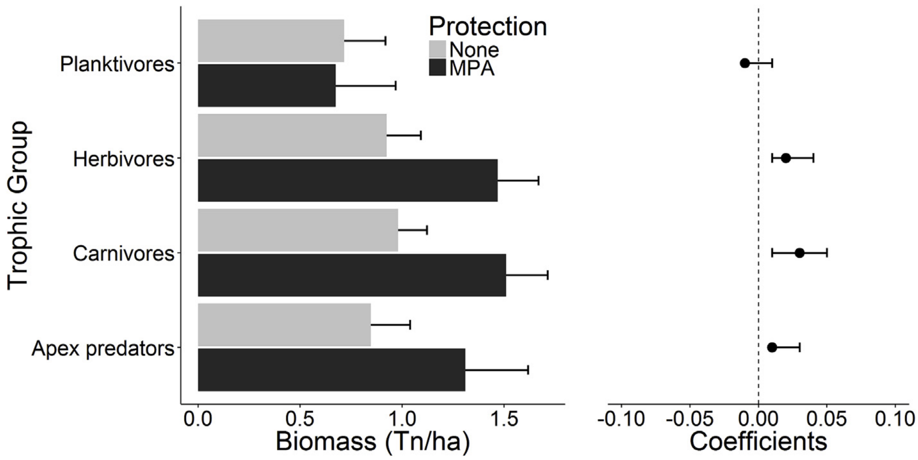

Fig. 4. Barplot (left) of the mean and standard deviation (error bars) of the biomass of functional groups in and out of marine protected areas. Resultant coefficients (right) corresponding to the biomass in the Bayesian logistic regression model. Shown are the mean (point), the 95% interval of credibility (error bars) and zero (dotted line). Intervals that do not intercept the zero line are those in which the biomass is higher in protected areas.

management have been applied around the world with successes and failures depending on the specific conditions of the area and the resource (Gutiérrez et al., 2011; McClanahan et al., 2006). In Costa Rica, Marine Areas of Responsible Fishing and Marine Management Areas are two types of spatial regulations that have been applied in the last years, those strategies allow fishing and are intended to be a more participative approach (Fargier et al., 2014). In the other hand traditional fisheries assessment and management have barely been applied due to the complexity of the small-scale multispecies fisheries, the lack of information and enforcement capacities. Here we present an assessment of the effectiveness of MPAs in the North Pacific of the country, but only 2% of Costa Rican waters are protected, and we cannot expect that this small percentage is going to solve the lack of regulations in the remaining 98%. Marine resource management is more likely to be successful when there are several regulations and tools applied at the same time (Gutiérrez et al., 2011).

5. Conclusion

We found that MPAs produce a greater diversity, bigger biomass and greater size of reef fishes in the North Pacific of Costa Rica and that those effects are attributable to protection from fishing. These results show that even in human impacted regions, the marine protected areas are important and can contribute to the recovery of the ecosystem services in coral reefs. An increase in state investment in the enforcement of protected areas could translate into improvements in the quantity and quality of fishery products caught near MPAs, as well as in better tourist dive sites. Those positive effects and their limitations reinforce the importance of improving the regulations in and out of protected areas to assure the health of the ecosystems and the wellbeing of coastal communities.

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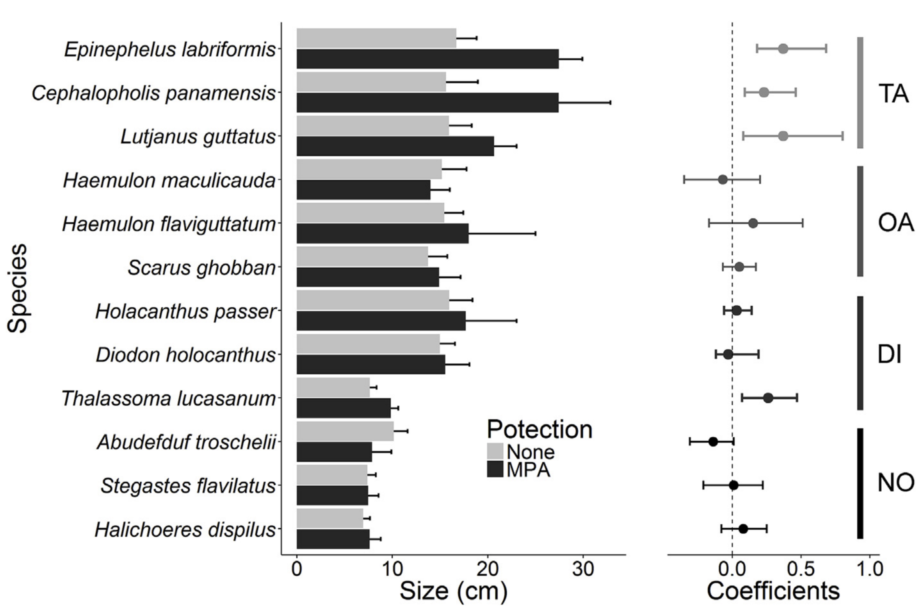

Fig. 5. Barplot (left) of the mean and standard deviation (error bars) of the size of species in and out of marine protected areas. Resultant coefficients (right) corresponding to the biomass in the Bayesian logistic regression model. Shown are the mean (point), the 95% interval of credibility (error bars) and zero (dotted line). Intervals that do not intercept the zero line are those in which the biomass is higher in protected areas. TA: target species in artisanal fisheries, OA: occasional captures in artisanal fisheries, DI: species captured in dive-ornamental fishery and NO: any commercial value.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2018.12.023.

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