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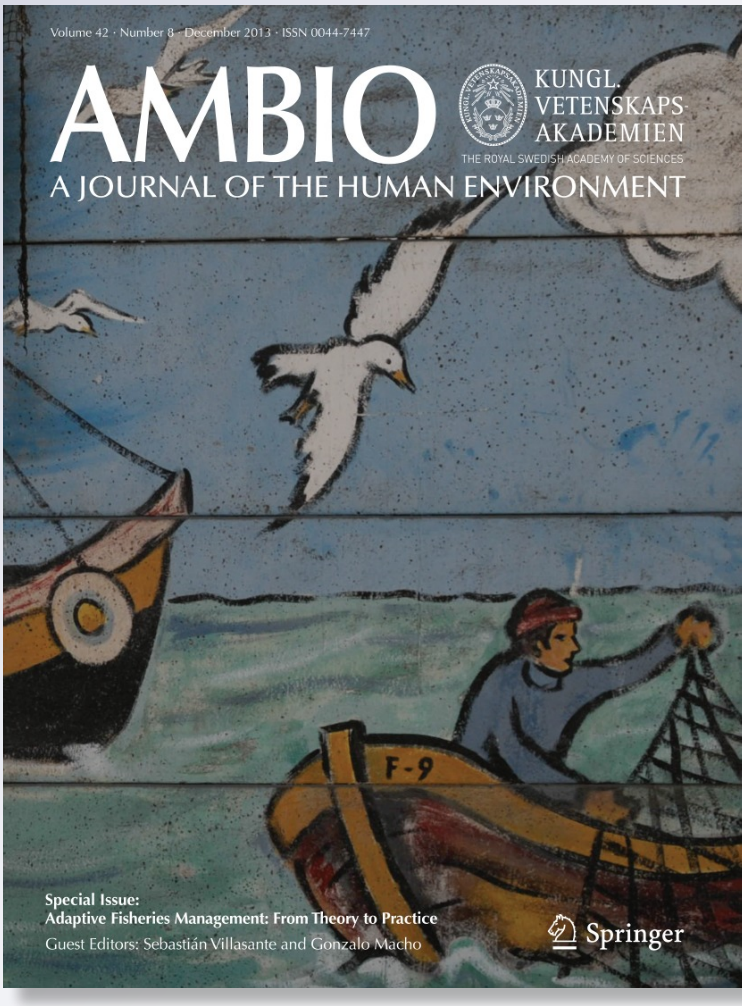

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Transboundary Socio-Ecological Effects of a Marine Protected Area in the Southwest Atlantic

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Abstract Marine Protected Areas (MPAs) have been regarded as an alternative to protect natural resources and to improve fisheries. However, MPAs may also have negative socio-economic consequences on fishing communities. We aimed to check the effectiveness of a socially conflicting MPA in Brazil by assessing target reef fish biomass in islands inside ($n = 6$) and outside ($n = 6$) the MPA, fisheries' productivity (biomass), catch per unit of effort (CPUE), and fishers' socio-economic status (mainly fishers' income) in three fishing communities subjected to different degrees of influence (close, average, and long distance) of the MPA. The CPUE was higher in the fishing community that was further away from the MPA, fish biomass was higher in the islands located inside the MPA in the southern region and in the islands located outside the MPA in the northern region, while fishers were making the most money closest to the MPA, where conflicts are the highest, probably from practicing very intensive fisheries. This integrated approach showed that the studied MPA has not delivered ecological benefits, such as higher CPUE or more fish, while higher income closer to the MPA could not be clearly attributed to its effects.

Keywords Small-scale fisheries · Fisheries conflicts · Reef fishes · Ecosystem-based management · Fish conservation · Fisheries management

INTRODUCTION

Most commercial fisheries all over the world have experienced some pressure, with an estimated 29 % of the assessed stocks considered overexploited in 2003 (Worm et al. 2006) and 63 % needing rebuilding by 2009 (35 % of these were overfished) (Worm et al. 2009, but see FAO 2012 for regional variations), a figure that may be higher for the poorly assessed small-scale fisheries (Costello et al. 2012). It is no surprise then that management initiatives such as Marine Protected Areas (MPAs) are becoming common globally to prevent overexploitation of fishing resources (Worm et al. 2009). Yet, effective implementation of MPAs takes time, delaying management actions. This delay, due to different reasons (e.g., market pressures, lack of funding, lack of environmental concern, and uncertainty in scientific advice; Rosemberg 2003), may add another constraint on the achievement of fisheries' sustainability: the adoption of incorrect or conflicting socio-economic management measures (Jentoft and McCay 1995).

As a fishing management measure and/or conservation strategy, MPAs can potentially enhance the fish production of surrounding areas through ecological processes of spill-over (export of adult fish or of fish and crustacean pelagic larvae from the reserve) (Gell and Roberts 2003; Evans and Russ 2004). However, "ill-planned" MPAs may not achieve these desirable outcomes and instead can generate conflicts with fishers (Sale et al. 2005). This happens largely due to ineffective designation of reserve boundaries established with no consideration for their legitimacy, undermining their potential from the beginning, depending on the local governance system (Lopes et al. 2013). New boundaries can result in net economic loss to local users due to their socio-economic dependency on some areas.

Local socio-economic aspects are especially relevant in small-scale fisheries, an activity that not only feeds 1×10^9 people but also employs 97.5 % of the fishers in the world, sustains rural poor people who depend on aquatic resources, and caters 50 % of the fishes that reach the market

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every year (Berkes et al. 2006; Pauly 2006; Begossi 2010). This widespread activity is hard to regulate as it usually takes places in small communities whose fishers rarely register in any database and where commercialized products enter markets through a complex intertwined chain of middlemen (Crona et al. 2010). Moreover, although small-scale fisheries can focus on specific target species (Begossi et al. 2012a), their landings are usually made of multiple species (Ali and Lee 1995), making it difficult to adopt standard management measures such as quota systems and minimum sizes for capture. As such, management initiatives could work better if they are locally devised and enforced. Successful examples, although few, include the management of mollusks in Chile through Territorial User Right Fisheries (TURFs) (Castilla et al. 2007) and the management of the snow crab in Nova Scotia, Canada (Loucks 2007).

Governmentally supported and locally devised management measures are relatively new in many countries including Brazil, where management is usually implemented in a top-down fashion (Lopes et al. 2011). Until recently, the Brazilian government created parks and reserves without consulting the local population. The coastal parks, which are supposed to work as MPAs, may have affected (positively or negatively) important fishing communities (Diegues 1999, 2008). Furthermore, the ecological effectiveness of these MPAs is hard to validate because the criteria and indicators used to establish them were unclear (Lopes et al. 2013).

Here, we evaluated the socio-economic and ecological effectiveness of a conflicting MPA established in the southeastern Brazilian coast (Begossi et al. 2010), using multiple criteria such as biomass of target reef fishes, biomass and catch per unit of effort (CPUE) of fish landings, and income of fishers from communities that could potentially harvest the benefits of a fish spillover effect from the MPA. Integrated approaches are a relative novelty in the evaluation of MPA (Camargo et al. 2009), showing potential in the assessment of successes and shortcomings of MPAs from an ecological, social, and economic perspective.

MATERIALS AND METHODS

Study Areas

The Paraty municipality lies in Rio de Janeiro State, on the Brazilian southeastern coast (Fig. 1), a region that belongs to the Atlantic Forest biome. In 1990, the Brazilian Environmental Agency (IBAMA) selected in the region 29 islands to be an MPA in the Ecological Station category (*Estação Ecológica Tamoios*, hereafter MPA Tamoios) (Federal Decree 98.864/1990). This choice of islands was undisclosed and decided without any discussion with the population who lived or depended on these islands for fisheries resources. Ecological Stations are among the most restrictive park category in the Brazilian legislation, for example, forbidding fishing and anchoring in any of the protected islands. However, this Ecological Station remained a "paper park" until about 2008, when the environmental agencies decided to enforce it. From 2008 until today, there are ongoing conflicts with the local fishers (Begossi et al. 2011). Despite the enforcement, poaching is still likely to happen, although to a smaller extent.

Data Sampling

Fish Biomass

Twelve islands were sampled: six within and six outside the MPA Tamoios. A regional division of these islands was also made; six islands (three within and three outside the MPA) were close to the region of Tarituba (northern side of the MPA, sampled in 2012) and six were in the Paraty bay (southern side of the MPA, sampled in 2011) (Fig. 1). Some of the islands sampled are partially or entirely submerged rock outcrops, but similar kinds of islands (e.g., outcrops or islands with more developed terrestrial area) were compared inside and outside the MPA. The six sampled islands inside the MPA were the ones logistically feasible to reach and to dive (depth, sea conditions, and distance) and that were also important to the studied fishing communities (Begossi et al. 2010). The six islands sampled outside the MPA were the closest and most geographically similar ones (islands or rock outcrops) to the islands sampled inside the MPA (Fig. 1). Both the time when the transects were made and the environmental variables (depth and water visibility during dives, island's area, distance from the mainland, proportion of hard substrata and coral cover) did not differ in average values between islands sampled inside and outside the MPA (Table 1). Islands being compared inside and outside the MPA were thus considered to be overall similar in relation to their environmental conditions.

Three fish species from the Serranidae family (*Epinephelus marginatus*, *Mycteroperca acutirostris* and *M. bonaci*) were sampled: These are commercially important reef species that have become less abundant in the last decades (Begossi et al. 2010, 2012a). Currently, these three species are considered as endangered (*E. marginatus*), of least concern (*M. acutirostris*), and near threatened (*M. bonaci*) (IUCN 2013).

On each island, the abundance (number of individuals) and sizes (at 5 cm size-class intervals) of the three grouper

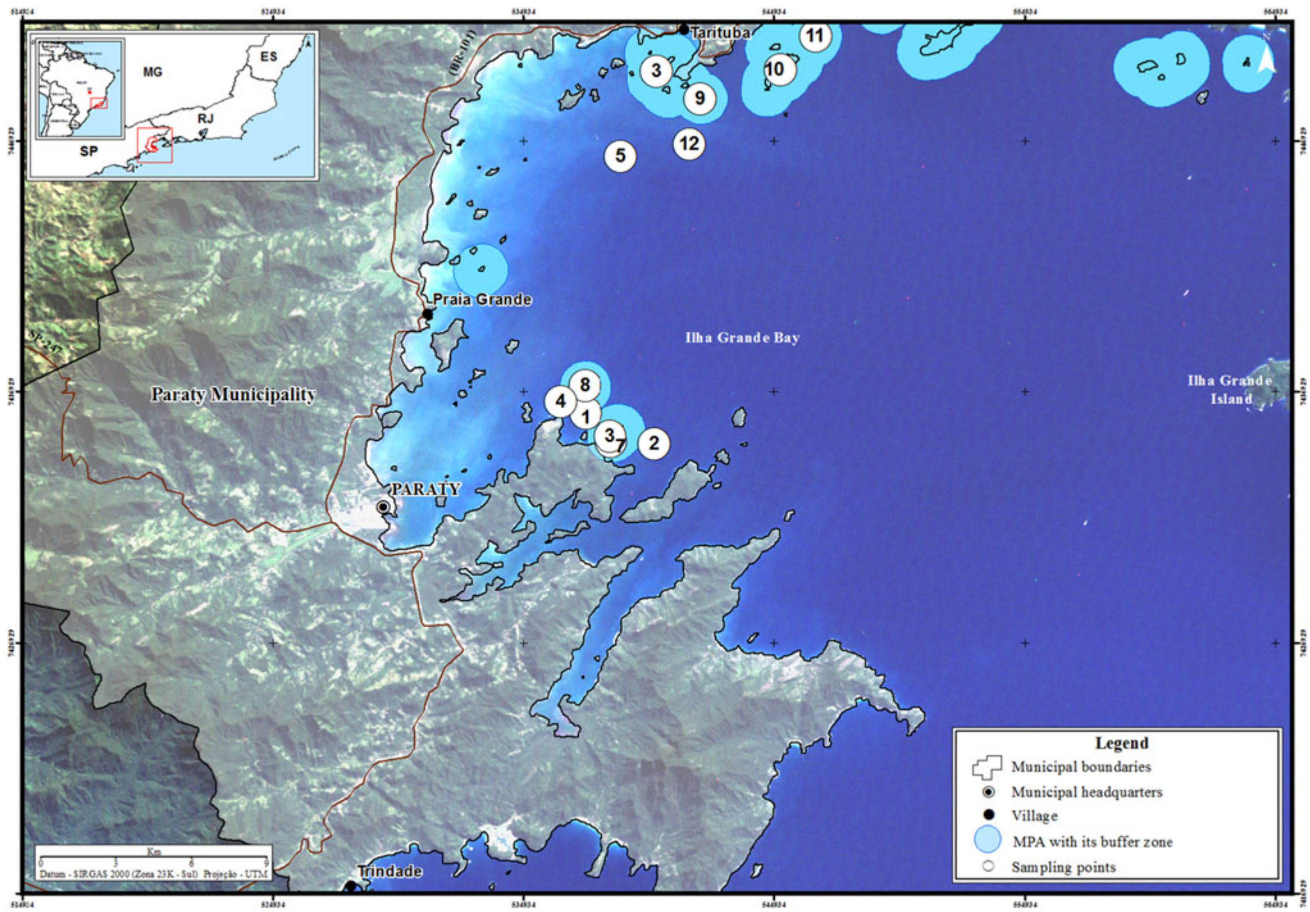

Fig. 1 *Map* of the studied area *highlighting* the three communities where interviews were done with fishers and where fish landings were sampled (Tarituba in the north, P. Grande in the central area, and Trindade in the south) in Paraty, SE Brazil. The *numbers* identify the spots where groupers (*Epinephelus marginatus* and *Mycteroperca* spp.) were sampled. The MPA with its buffer zone is identified as the *circles* around the protected islands

species were estimated through underwater visual census along a 50-m-long × 4-m-wide transect. A total of 17 transects were made (average duration of 23 ± 4 min), with one to two transects per island. Repeated transects from each island were pooled to compare fish biomass.

Fish biomass was estimated from the observed fish size classes and the length–weight equations of the three studied fishes from the literature (Froese and Pauly 2011). Each size class was converted to its mid-point range (for example, 10–14 to 12 cm); the biomass for the fish species at that size was estimated and then multiplied for the number of individuals observed of that size.

The fish biomass between inside and outside the MPA (factor 1) and between regions (Paraty bay and Tarituba bay, factor 2) was compared through a two-way ANOVA, after checking for the homogeneity of variances through a Fligner-Killeen test (MPA × Non-MPA: $\chi^2 = 1.63$, df = 1, $P = 0.20$; Tarituba × Paraty bay: $\chi^2 = 2^{e-04}$, df = 1, $P = 0.9879$) and for the normality of the data through a Bartlett test (MPA × Non-MPA: $K^2 = 3.48$, df = 1, $P = 0.06$; Tarituba × Paraty bay: $K^2 = 2.54$, df = 1, $P = 0.11$) (Crawley 2007). This ANOVA analysis was followed by a bootstrap procedure with 5000 resamplings, with unrestricted permutation of observations, due to the low sample size (Manly 1997). The frequency distributions of observed fishes among size classes between the islands located inside and outside the MPA were compared through a Kolmogorov–Smirnov test for two distributions. These analyses were performed in R (R Development Core Team 2008).

Fishers' Socio-Economic Profile

In 2009 and 2010, fishers from three communities were interviewed: Trindade, Praia Grande (including Araujo Island, hereafter P. Grande), and Tarituba. Praia Grande and Araújo Island were joined due to their proximity and because they share the same main fish landing port. Only commercial artisanal fishers were interviewed, as they are the ones most likely to be affected by a coastal MPA, due to their low boat autonomy and smaller scale of fishing operations.

Table 1 Average values and results of t tests comparing environmental variables and sampling periods of transects to sample Serranid fishes in islands inside ($n = 6$) and outside ($n = 6$) an MPA on the southeastern Brazilian coast

Variables	Inside MPA (±SD)	Outside MPA (±SD)	t^b	P
Area (km^2 [a])	0.125 (±0.246)	0.053 (±0.021)	−0.58	0.59
Distance from the mainland (km)	1.2 (±0.8)	1.7 (±1)	−0.93	0.38
Depth (m)	7.3 (±2.5)	6.8 (±1.8)	0.33	0.75
Water visibility (m)	9.1 (±2.5)	6.5 (±3.3)	1.53	0.16
Hours past 6:00 h[c]	8 (±0.9)	8.3 (±1.9)	−0.38	0.71
Proportion of hard substrate coverage[d]	0.6 (±0.2)	0.7 (±0.2)	−1	0.34
Coral coverage[e]	0.2 (±0.16)	0.19 (±0.17)	$U = 21.5$	0.57

[a] For this analysis, 4 rock outcrops were excluded (their area could not be measured, see text), thus $n = 8$ (5 inside and 3 outside the MPA) and df = 6. The data were log10 transformed

[b] For all analyses except for area, $n = 12$ and df = 10

[c] Converted in continuous variable for the analysis, considering the moment when transects started. The average of 8 h considers 2 pm as the average starting sampling time

[d] Estimated at the point counts on the substrate done on each transect, every 2 m of the 50-m tape, resulting in a total of 25 counts per transect

[e] Proportion of coral cover (from 0 to 1), which was estimated from the point counts of substrate made at each transect, at every 2 m of the 50-m tape, thus a total of 25 counts per transect. This variable was analyzed through the non-parametric Mann–Whitney U test because data were not normally distributed

These interviews addressed fishers' socio-economic status (mean monthly income, age, experience, and other economic activities performed) as these factors (age, experience, and second jobs) can affect fisheries' productivity or can be affected by the MPA. Fishers were asked to estimate their average monthly income considering seasonal variations in fish catches. When fishers could not provide a mean monthly value that considers the intrinsic annual variation, they provided seasonal mean values, which were then averaged to calculate the general monthly income.

These three studied communities were chosen to represent a gradient, based on the distance of a community from the MPA and based on their historical fishing grounds: Trindade—southernmost, most distant, and possibly not affected by the MPA; P. Grande—central and possibly moderately affected by the MPA; and Tarituba—northernmost, closer, and expected to be more affected by the MPA (Fig. 1). Interviews with expert fishers (more than 20 years of fishing in the area) in this region in a previous survey show that Trindade never uses islands that are part of the MPA, P. Grande uses a few islands inside the MPA, and Tarituba uses islands inside the MPA more often (Lopes et al. 2013).

In each community, the number of fishers was estimated through chats with the first fishers met, as this information is not accurately available at the fishers' associations. The goal was to interview every fisher in communities that had up to 50 families and 50 % of them in larger communities, visiting in this case every other fisher's house. A total of 71 fishers were interviewed: 21 in Trindade, 31 in P. Grande, and 19 in Tarituba. The reported fishers' mean income obtained exclusively from fisheries was compared through a Kruskal–Wallis test, followed by a Dunn test a posteriori. Fishers' age and fishing experience were compared among communities through Anova tests, followed by a Tukey test a posteriori.

Fish Landings

Fish landings were sampled monthly, during two consecutive days per month, in the same three communities (Trindade, P. Grande, and Tarituba), from November 2009 to January 2011. After fishers arrived, they were interviewed about the fishing spots visited, travel time, and crew size. The fishes caught were identified based on local names and was weighted per species. Some fishes were bought by the researchers or donated by the fishers for posterior identification in the laboratory. More details about this methodology can be found in Begossi et al. (2012b).

A General Linear Model (GLM) analysis was run to investigate the variables that affected the biomass of fish caught on fish landings ($n = 543$). Time to the fishing spot (minutes, continuous variable), number of fishers in a fishing trip (continuous), gear (factors: bottom trawling, bate–bate, hook and line, longline, gillnet, trap net fishing, mix, and others), season (factors: fall, winter, spring, and summer), and community (factors: Trindade, Praia Grande, and Tarituba) were the independent variables in this analysis, while the total catch per trip (fish biomass, continuous, $\log_n$ transformed to achieve normality) was the dependent variable. The CPUE was calculated as total catch (kg) × number of fishers^{-1}, which was then compared through a Kruskal–Wallis test (for more details, see the Appendix S1 in the Electronic Supplementary material).

The fish landings were subjected to a non-metric multidimensional scaling analysis (NMDS), using all the commercial fish species, to compare the composition of fish landings among the three fishing communities. Two NMDS analyses were made: one based on the biomass (kg) and another based on the frequency (number of fish landings) of each fish species caught. The less valuable species caught were grouped and included in the analysis as "mix" category, according to the denomination given by the fishers themselves. The metaMDS procedure was used in *R* with Bray–Curtis distance using the Vegan package (Dixon and Palmer 2003) (Appendix S1, Electronic Supplementary Material). No other formal hypothesis testing method was applied due to the low number of replicates (only three sites), which would restrain the number of possible permutations. Nevertheless, a Similarity Percentage Analysis (SIMPER) was run on Primer 6 (Clarke and Warwick 2001), considering the communities as a factor, to check which species most contributed to possible differences among the sites.

RESULTS

Fish Biomass

A total of 87 groupers were observed during all transects (total area of 16 200 m^2): 25 individuals of *E. marginatus* and 62 individuals of *M. acutirostris* and *M. bonaci*, representing an average density of 6.04 (±3.26) fish per 200 m^2.

The size frequency distribution of the observed fish did not differ between islands located inside and outside the MPA for *E. marginatus* ($\chi^2 = 1.1$, $P = 0.6$; Fig. 2a) and for *Mycteroperca* spp. ($\chi^2 = 1.9$, $P = 0.38$; Fig. 2b). Nevertheless, the largest individuals of *E. marginatus* were observed in islands inside the MPA (Fig. 2a), while the largest individuals of *Mycteroperca* spp. were found in islands outside the MPA (Fig. 2b).

The biomass of sampled fish did not differ when compared between the islands inside (2.1 ± 1.3 kg per 200 m^2) and outside (2.7 ± 3.2 kg per 200 m^2) the MPA ($F = 0.29$, $P_{Perm.} = 0.70$), and neither did biomass differ between the two regions (Tarituba = 3 ± 3 kg per 200 m^2; Paraty bay = 1.8 ± 1.4 kg per 200 m^2) ($F = 1.13$, $P_{Perm.} = 0.35$), but the interaction between the two factors was significant ($F = 5.25$, $P_{Perm.} = 0.02$; Fig. 3). Fish biomass was higher in islands inside the MPA sampled in the Paraty bay than in islands outside its limits and also in islands outside the MPA sampled in the Tarituba region in relation to islands within the MPA limits. This difference was possibly due to a larger fish biomass in the islands outside the MPA in Tarituba (Coefficient outside MPA × Tarituba region: Estimate Std = 5.31; $t = 2.29$; $P = 0.05$), in relation to all the other areas (Fig. 3).

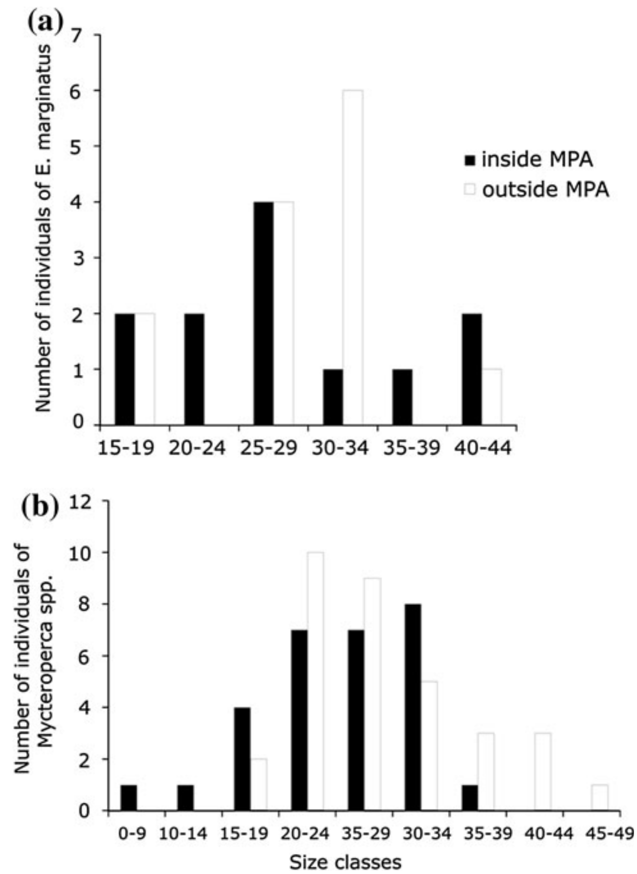

Fig. 2 Size classes of reef fishes from the Serranidae family observed during underwater visual surveys in areas inside and outside the MPA Tamoios (Paraty, Rio de Janeiro, Brazil): **a** *Epinephelus marginatus*; **b** *Mycteroperca* spp.

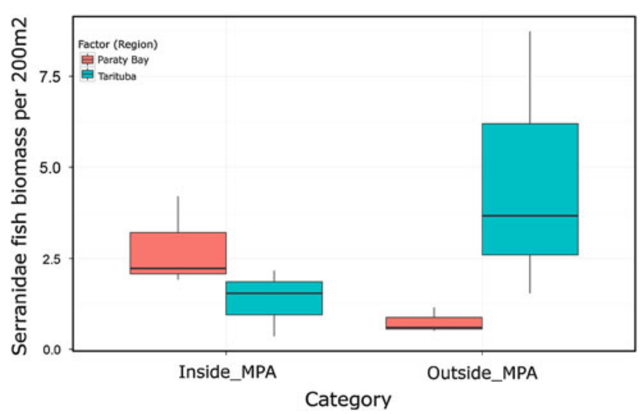

Fig. 3 Comparison of the Serranidae fish biomass (kg) estimated during underwater visual surveys in areas inside and outside the MPA Tamoios (Paraty, Rio de Janeiro, Brazil), considering two regions: Paraty bay and Tarituba

Fishers' Socio-Economic Status

Fishers from Trindade (40 ± 13.7 years old, 27 ± 13.5 years fishing, $n = 21$) were younger and, as a consequence, had been fishing for a shorter time than the ones from P. Grande (49 ± 15.1 years old, 38 ± 15.7 years fishing, $n = 31$) and Tarituba (51 ± 10.3 years old, 31 ± 12.8 years fishing, $n = 19$) (Appendix S1, Electronic Supplementary Material).

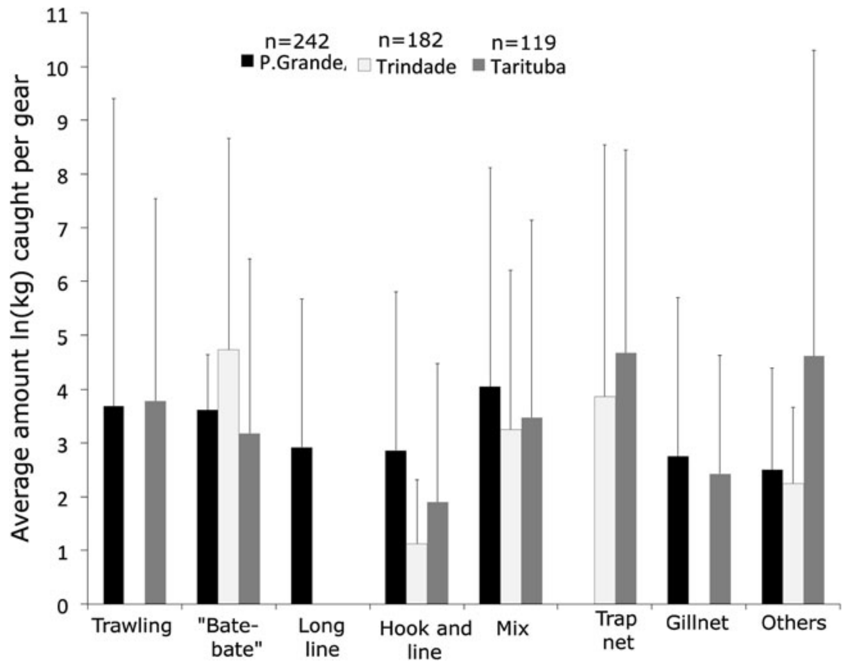

Fig. 4 Average catches per fishing gear in each of the three studied communities (Praia Grande, Trindade, and Tarituba), on the coast of Paraty, Rio de Janeiro state, Brazil. The values were transformed in natural logarithm to fit in the scale shown. *Bars* represent the positive standard deviation, and numbers on top of each bar the number of fish landing sampled for each gear in the respective community

In Trindade, only one fisher depended exclusively on fisheries, while 81 % of the interviewed fishers relied on tourism as well. In the central part of the region, in P. Grande, the percentage of interviewed fishers who depended exclusively on fisheries was 35.5 %, reaching its peak in the northern part of Paraty; in Tarituba, 63 % of the interviewed fishers ($n = 19$) depended solely on fisheries. In both P. Grande and Tarituba, fishers were not only performing secondary activities related to tourism (as property caretakers, captains of private boats, or work on the transportation of tourists to close islands; P. Grande = 29 %, Tarituba = 16 %) but also depended on working in construction, small-scale commerce, or retirement income (P. Grande = 19 %, Tarituba = 11 %).

The reported fishers' income obtained exclusively from fisheries in February 2009 was higher in Tarituba (US\$539 ± 322), compared to Trindade (US\$362 ± 444) and P. Grande (US\$311 ± 217) ($F = 2.45$, $P < 0.05$).

Fish Landings

A total of 542 fish landings (18 161 kg) were sampled between November 2009 and January 2011 in the three communities included in this study (P. Grande = 242, Tarituba = 119, and Trindade = 181 fish landings). Of these, 8.1 % ($n = 44$) of the fish landings occurred within the limits of the MPA (none by Trindade's fishers), a figure that can be underestimated due to the fear of fishers to report the use of some islands accurately. P. Grande fishers caught a total of 7222 kg of fish (29.84 ± 34.11 kg/fish landing), while Tarituba's fishers caught 4296 kg (36.10 ± 103.16 kg/fish landing) and Trindade's fishers caught 6644 kg (36.50 ± 91.32 kg/fish landing). Gillnets were the most commonly used gear in P. Grande (32 %) and Tarituba (38 %), while in Trindade, trap nets were the main gear used (68 %). However, in terms of gear efficiency, bottom trawling caught 34.2 % of the fishing resources (biomass) in P. Grande, "other" gears represented 30.7 % of the catch in Tarituba, and trap net caught 90.2 % of all the catch in Trindade (Fig. 4). The gear defined as "others" in Tarituba mostly represented a technique that consists of visually finding a fish school, encircling it with a net, and then having one or two fishers dive in the middle of the school with a spear, killing as much fish as possible and pulling the net after that.

The GLM analysis showed that gear was the main factor affecting the fishers' catches, followed by the distance to the fishing spot and the number of fishers in the crew. Although significant, season and community had a smaller influence on the outcome of the catch (Table 2).

The CPUE varied among the three communities, with Trindade showing the highest value per trip (32.77 ± 89.85 kg fish × no. fishers^{-1}), when compared to P. Grande (23.70 ± 23.11 kg fish × no. fishers^{-1}) and Tarituba (21.33 ± 32.70 kg fish × no. fishers^{-1}) (Kruskal–Wallis

Table 2 GLM considering the total fish catch per trip (ln kg fish) ($n = 543$) in Paraty, southeastern Brazilian coast

Variable	DF	Sum sq	Sq mean	F value	Pf(>F)	% explanation
Season[a]	3	13.2	4.40	3.68	0.0121	4.6
No. of fishers	1	22.3	22.28	18.62	0.000001	7.79
Gear[b]	7	198.8	28.40	23.73	0.000001	69.18
Community[c]	2	9.8	4.90	4.10	0.0172	3.42
Time fishing	1	42.1	42.07	35.16	0.000001	14.71
Residuals	528	631.8	1.20			

[a] Factors: spring, summer, fall, and winter

[b] Factors: hook and line, gillnet, "bate–bate," longline, mix, trap net, bottom trawling, and others

[c] Factors: P. Grande, Tarituba, and Trindade

$\chi^2 = 19.75$, $P < 0.001$; Trindade differed significantly from the others at a $P < 0.01$). Therefore, the community that is the furthest away from the MPA showed the highest CPUE. It was not possible to compare the median CPUE among fishing gears because only four of them are used by all the three communities, the others being specific to each community (see Fig. 4 for gear per community).

The SIMPER analyses for biomass of fish landed per species in each community showed that P. Grande and Tarituba have 48.2 % dissimilarity, especially due to sea bob shrimp (*Xyphopenaeus kroyeri*, common in P. Grande) and round scad (*Decapterus punctatus*, common in Tarituba). P. Grande and Trindade showed a dissimilarity of 73.5 %, while the dissimilarity between Trindade and Tarituba was 55.3 %. In the first case, the main species responsible for the differences were sea bob shrimp (P. Grande), bonito (*Euthynnus alleteratus*, Trindade), and round scad (Trindade), while in the latter, the species were Spanish mackerel (*Scomberomorus brasiliensis*), bonito, mix (all Trindade), and sea bob shrimp (Tarituba) (Fig. 5a; Table 3). A visual inspection of the NMDS plot suggests a sort of a gradient of species from Trindade to P. Grande with Tarituba occupying an intermediary position (further away from Trindade) (Fig. 5a).

The same pattern was observed in terms of the gradient that approximates P. Grande and Tarituba, leaving Trindade isolated in the NMDS analysis using the frequency that each species was caught in fish landings (stress = 0.0199) (Fig. 5b). However, in this case, some of the species responsible for the dissimilarities differed from the previous analysis based on the biomass of fish caught. The dissimilarity observed between P. Grande and Tarituba (30.4 %) was due mostly to white shrimp (*Penaeus schimitti*) and sea bob shrimp, common snook (*Centropomus parallelus*), and whitemouth croaker/sand drum (*Micropogonias furnieri/ Umbrina coroides*), all more common in P. Grande. The dissimilarity between P. Grande and Trindade (62.7 %) was also due to white and sea bob shrimp and whitemouth croaker/sand drum (all in P. Grande), while the dissimilarity between Trindade and Tarituba (47.7 %) was due mostly to Spanish mackerel (more common in Trindade), although in this case many species contributed in a more equalitarian way to the dissimilarity (Table 4).

DISCUSSION

The results of this study indicated that the existing MPA has not shown clear benefits yet. For example, groupers were more abundant inside the MPA in one of the studied regions only (Paraty region), while in the other region, the opposite trend was observed (Tarituba region). Fishing yield was higher in the fishing community located furthest from the MPA (Trindade), although fishers' income specific from fisheries was higher in the fishing community that was closest to the MPA (Tarituba), but this specific result should be carefully interpreted (see below). Such elusive outcomes of the MPA may partially explain the reported conflicting and overall negative attitudes of fishing communities about this MPA, especially in Tarituba, the closest to the reserve (Begossi et al. 2011, 2012b), as fishers may not yet have reaped the benefits from this MPA in a visible way.

The higher incomes of fishers in Tarituba could at first be seen as a positive result brought about by the surrounding MPA. However, such high yields may also be the result of the more intensive fishing methods used in this community, especially the encircling net associated with spear diving and targeting high-valued fish such as snook (*Centropomus* spp.). A report done in the area showed that this method is a cause of dispute between Tarituba's fishers and the reserve managers and also between Tarituba's fishers and other fishers, who believe that this method gives no chance to the fish stocks to rebound (Begossi et al. 2010). This indicates that other proxies should be used in combination with fishers' income to evaluate MPA socioeconomic benefits and CPUE could be one of these proxies.

Despite having the highest average income, Tarituba fisheries showed the lowest CPUE values (although not statistically different from those in P. Grande), while Trindade, the community that is the most distant and possibly the least affected by the MPA, showed the highest CPUE, which did not necessarily represent the highest catches. This discrepancy between higher CPUE and higher income probably does not have a straightforward explanation. Regardless of the MPA influence, it is also important to consider social aspects, not incorporated in the analyses, which could affect the productivity of each region. Most of Trindade's fishers, for example, diversify their economic activities by practicing community tourism among others (Begossi et al. 2010). Economic diversification is also one of the multiple livelihood strategies to deal with fisheries' unpredictability (McCay 1978; Allison and Ellis 2001) and could contribute to increasing the chances of success of some specific fisheries management (Pontecorvo and Schrank 2001), by decreasing the fishing pressure. Besides, Trindade's fishers follow their own fisheries' management rules, such as establishing minimal distances among gillnets, not allowing gillnets close to river mouths, and by returning young or under-sized fish alive to the water when these are caught in the trap nets (Lopes et al. 2013). Perhaps, such local initiatives may

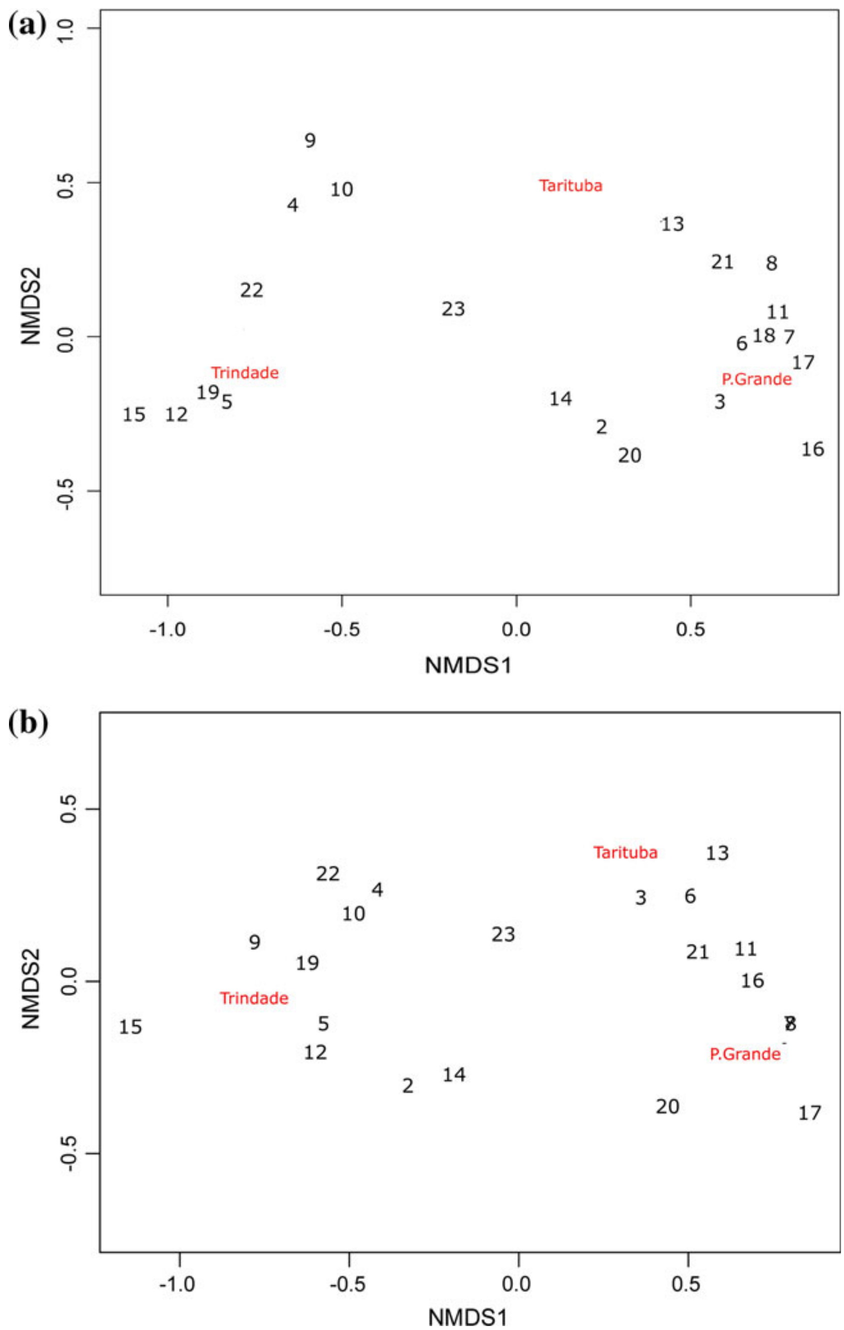

Fig. 5 NMDS ordination plot based on **a** fish composition (% of biomass) (stress = 0.023), **b** frequency of fish species in the fish landings (% of presence) (stress = 0.019) caught by small-scale fishers in three communities (P. Grande = PG, Tarituba = TT, and Trindade = TD) located in Paraty, southeastern Brazilian coast. The *numbers* correspond to the species (or group of species): 1—bluefish, 2—ray, 3—comb grouper, 4—bicuda, 5—bonito, 6—sharks, 7—sea bob shrimp, 8—white shrimp, 9—round scad, 10—king mackerel, 11—whitemouth croaker, 12—largehead hairtail, 13—dusky grouper, 14—squid, 15—yellowtail, 16—weakfish, 17—common snook, 18—fat snook, 19—Spanish mackerel, 20—mullet, 21—red snapper, 22—blue runner, and 23—mix

have increased the availability of fishing resources and were detected as higher CPUEs, which do not necessarily have to result in higher income from fisheries as fishers could be restraining their fishing effort. Controlled studies designed to separate the effects of diversified livelihood on CPUE could answer such questions.

Table 3 Fishing resources and their contribution to dissimilarity (SIMPER analysis using Bray–Curtis similarity index) among the three communities (P. Grande, Tarituba, and Trindade) in Paraty (Rio de Janeiro State, Brazil), considering the total catch (kg) of each species. The cutoff point for low contributions was set at 90 %. The main species contributing to the dissimilarities are highlighted. Total fish landings sampled = 543

Species popular name	Scientific name	Abundance (kg)			Dissimilarity contribution (%)		
		P. Grande	Tarituba	Trindade	P. Grande × Tarituba	P. Grande × Trindade	Tarituba × Trindade
Sea bob shrimp	*Xyphopenaeus kroyeri*	2409.8	844.5	0	**28.59**	**23.73**	14.07
Round scad	*Decapterus punctatus*	0	1067.5	1066.0	**19.50**	10.50	6.22
Whitemouth croaker/sand drum	*Micropogonias furnieri* and *Umbrina coroides*	928.5	381.4	8.0	9.99	9.06	3.14
Mullet	*Mugil platanus*	439.5	15.5	204.0	7.75		
Weakfish	Sciaenidae	465.5	50.7	3.1	7.58	4.55	
Mix	Small/cheap species	1164.4	830.2	1856.5	6.11	6.82	**17.09**
Common snook	*Centropomus undecimalis*	400.5	103.9	0	5.42	3.94	
White shrimp	*Penaeus schimitti*	517.2	303.4	0	3.91	5.09	5.05
Squid	*Loligo* sp.	153.0	33.2	117.2	2.19		
Bonito	*Euthynnus alleteratus*	128.5	122.0	1352.3		**12.05**	**20.49**
Spanish mackerel	*Scomberomorus brasiliensis*	62.5	92.7	999.6		9.23	**15.10**
Largehead hairtail	*Trichiurus lepturus*	25.1	24.0	644.3		6.10	10.33

Table 4 Fishing resources and their contribution to dissimilarity (SIMPER analysis using Bray–Curtis similarity index) among the three communities (P. Grande, Tarituba, and Trindade) in Paraty (southeastern Brazilian coast), considering the frequency in fish landings (number of fish landings that caught each species). The cutoff point for low contributions was set at 90 %. The main species contributing to the dissimilarities are highlighted. Total fish landings sampled = 543

Species Popular name	Scientific name	Frequency in fish landings			Dissimilarity contribution		
		P. Grande	Tarituba	Trindade	P. Grande × Tarituba	P. Grande × Trindade	Tarituba × Trindade
White shrimp	*Penaeus schimitti*	76	30	0	**16.79**	**12.79**	8.20
Sea bob shrimp	*Xyphopenaeus kroyeri*	72	29	0	**15.69**	**12.12**	7.92
Common snook	*Centropomus undecimalis*	38	8	0	10.95	6.40	
Whitemouth croaker/sand drum	*Micropogonias furnieri and Umbrina coroides*	71	43	8	10.22	10.61	9.56
Weakfish	Sciaenidae	43	22	4	7.66	6.57	4.92
Fat snook	*Centropomus parallelus*	33	17	3	5.84	5.05	3.83
Tainha	*Mugil platanus*	17	3	6	5.11		
Mix	Small/cheap species	102	115	147	4.74	7.58	8.74
Squid	*Loligo* sp.	13	3	18	3.65		4.10
Spanish mackerel	*Scomberomorus brasiliensis*	6	15	54	3.28	8.08	**10.66**
Red snapper	*Lutjanus* spp.	26	16	6	3.28	3.20	2.73
Round scad	*Decapterus punctatus*	0	8	31	2.92	5.22	6.28
Bonito	*Euthynnus alleteratus*	8	6	34		4.38	7.65
King mackerel	*Scomberomorus cavalla*	2	10	21		3.20	3.01
Bluefish	*Pomatomus saltatrix*	0	0	18		3.03	4.92
Largehead hairtail	*Trichiurus lepturus*	6	3	24		3.03	5.74
Ray	Rajidae and Myliobatidae	5	1	9			2.19

The considered MPA as a whole had no detectable effect on the biomass or size (predominantly small individuals) of commercial groupers in the protected islands. In the Tarituba region (north), a higher fish biomass was observed in the islands outside the MPA, while the MPA islands in Paraty bay (south) showed a higher fish biomass. The environmental and habitat characteristics did not differ between islands inside and outside of the MPA, which indicated that the selected islands minimized potential environmental differences that could have affected the comparison between islands inside and outside the MPA. However, 5 years of MPA enforcement may be too short a time to determine the effects on fish stocks—especially for long-lived species such as groupers (Tuya et al. 2000; Sadovy 2001). Nevertheless, higher grouper biomass outside the protected Tarituba islands indicates two possibilities that should be investigated. For example, either these protected islands in the Tarituba region were overfished in the recent past and now need time to recover, or the protected islands are not the best conservation sites. Other studies, including some done in Brazil, have shown that the choice of no-take areas is fundamental to the success of the nearby areas, because of the limited effectiveness of spillover effects due to the sub-optimal habitat quality of protected sites (Francini-Filho and Moura 2008) or due to limited management efficiency (Camargo et al. 2009). Finally, it is not possible to rule out the chance of the islands inside the MPA in Tarituba being subjected more to poaching compared to those in the Paraty bay, as the former community not only has more full-time fishers but also shows the highest conflict level involving the MPA (Lopes et al. 2013). It is known that conflicts with fishing communities have increased after management authorities enforced the MPA (Begossi et al. 2010), as fishers disagree with the choice of some areas (Lopes et al. 2013).

However enforced an MPA might be, its success will strongly depend on the involvement of local fishers in its management (Jentoft and McCay 1995; Gutiérrez et al. 2011). First, this is because the local fishers are the only ones capable of watching over the area, as in most developing countries there will be no sufficient funding to assure such thorough enforcement (Salas et al. 2007). Second, if people are not involved, they are likely to break the rules, not only because they do not agree with them but also because they did not learn about why such rules are important and make biological sense in terms of assuring more fish for the future (Nielsen and Mathiesen 2003; Crawford et al. 2004; Jagers et al. 2012). Finally, local fishers are likely to have information on important conservation grounds, such as reproductive and nursery sites of fishing resources, which could guide the choice of no-take areas (Scholz et al. 2004).

In short, the studied MPA does not yet seem to be delivering clear expected benefits to fisheries. Although the average income was higher closer to the MPA, the reasons behind it are yet to be investigated; reef fish, namely groupers, showed varied trends in abundance inside and outside the MPA in different regions; and CPUE was higher in the fishing community further away from the reserve limits. However, even if some of these findings may be inconclusive regarding the outcomes of the studied MPA, it was only possible to reach them through an integrative approach that considered ecological, social, and economic aspects. The approach of a single aspect could have led to a misleading interpretation.

Although the results about the efficacy of the studied MPA are not clearly encouraging, there is still time to build trust among reserve managers and fishers. This is not an easy step in a region marked by animosity between the governmental environmental agencies and fishing communities, but efforts such as a temporary agreement allowing limited fishing and anchoring in some of the islands have been made toward a greater interaction among all the parts (Begossi et al. 2011). If the chosen islands are not the most relevant to increase fish abundance and to improve fisheries, the MPA could eventually change the islands to be protected, with the support of fishers on the choice of new areas (Le Fur et al. 2011; Silvano and Begossi 2012). Fixing the problems of an old coastal MPA could help turn other problematic coastal MPAs into functional ones and establish new ones based on collaborative and trustworthy interactions among managers, fishers, and other stakeholders.

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