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The 'ghost of past fishing': Small-scale fisheries and conservation of threatened groupers in subtropical islands

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ABSTRACT

Groupers are highly targeted and vulnerable reef fishes. The effects of fishing pressure on the density of three reef fishes were investigated in 21 islands outside (n=15) and inside (n=6) a Marine Protected Area (MPA) at the Paraty Bay, Brazilian southeastern coast. Two valued groupers (*Epinephelus marginatus* and *Mycteroperca acutirostris*) and a non-target grunt (*Haemulon aurolineatum*) were studied. The total biomass of fish caught in each island was considered as a measure of current fishing pressure, while the island distance from the villages was considered as a measure of past fishing pressure. Fish densities were recordedin number and biomass. The biomass of *M. acutirostris* was inversely related to current fishing pressure, which did not affect the other two fishes. The density of *E. marginatus* increased with the island distance from one of the fishing villages, which indicated that past fishing may have had decreased the abundance of *E. marginatus*. Densities of the three fishes and fishing pressure did not differ between islands inside and outside the MPA. Data on fishing pressure, densities of groupers and coral cover were combined here to assign conservation scores to islands. A redefinition of MPA boundaries to reconcile fish conservation, fishing activities and fishers' food security was proposed.

1. Introduction

Fishing has affected tropical reef ecosystems and the ecological services provided by reef fishes [11,38]. However, small-scale reef fisheries provide food to millions of people, especially in tropical developing countries [5,9], where the abundance of reef fishes is inversely related to fishing demand [15]. The need to protect reef fishes while also assuring sustainable fisheries resulted in multiple marine protected areas (MPAs) around the world [36]. Although MPAs that include no-take sites have increased the abundance of commercial reef fishes [23], these MPAs can also create or exacerbate conflicts with local fishers and some had failed to deliver their expected outcomes [46]. Furthermore, socioeconomic needs may be an obstacle to implement no-take areas in tropical developing countries [39].

Large fishes from the Epinephelidae family (groupers, such as *Epinephelus* spp. and *Mycteroperca* spp.) are highly valued and threatened reef predators [30,38]. Groupers are susceptible to fishing because they grow slowly, are monandric protogynous, have an extended life span, delayed sexual maturity and form spawning aggregations [43]. The Brazilian coast is one of the most important regions of the world for grouper conservation, as it has several threatened species of serranids, including the dusky grouper (*Epinephelus marginatus*), which is considered endangered by the IUCN [43]. Although MPAs have helped to protect groupers along the Brazilian coast [2,19], there is evidence of ineffective MPAs and overfishing [9,32,33]. In the Mediterranean sea, there are several MPAs that include populations of *E. marginatus* [21]. However, the connectivity through larval dispersal in these MPAs is very important, as low connectivity among MPAs could be a limitation in the conservation efforts for this species [3].

Few studies have compared fish density and fishing effort at local scale [5,41]. Stocks of more sedentary fishing resources, such as groupers [25] or benthic invertebrates [47] trend to be first depleted in nearby sites, and, subsequently, fishing effort is displaced to more distant sites. In Brazil and in other developing countries, the lack of long-term data is an obstacle to assess spatial and temporal patterns of fishing influence on reef fishes, which requires additional methods to infer past impacts.

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In the Paraty Bay, in the southeastern Brazilian coast, 29 islands are included in a MPA established more than 20 years ago, but only enforced since 2008, which caused conflicts between governmental authorities and local fishers [32]. Furthermore, this MPA does not seem to have improved local fisheries nor increased the abundance of groupers in no-take islands [33]. The potential effects of fishing pressure on densities of threatened groupers were evaluated in islands located inside and outside this MPA in the Paraty Bay, applying the results to propose changes in the current zoning of this MPA. Specifically, this study addresses two groupers of high commercial value: *E. marginatus* and *Mycteroperca acutirostris*, besides the grunt (*Haemulon aurolineatum*, Haemulidae), which has negligible commercial value and served as a control for fishing effects. Three hypotheses were investigated. First, groupers' densities (in number and biomass) would be inversely related to current fishing pressure. Second, the densities of groupers would be positively related to island distance from fishing villages, which is an inverse indicator of past fishing pressure. Third, groupers' densities will not be affected by the presence of the MPA in some of the islands.

2. Material and methods

2.1. Study site

The Paraty Bay is a touristic region in the southeastern Brazilian coast (Fig. 1a and b). The local small-scale fisheries are important for food in the local and regional economy, targeting shrimps, pelagic and reef fishes (including groupers), whereas the most used fishing gears are gillnets, trawling and hand line [10]. The two studied fishing villages, Praia Grande (including the nearby Araújo Island) and Tarituba are among the largest fishing villages in the Paraty Bay: each village has approximately 40 fishers, who use mainly powered wooden boats with 6–8 m length, besides paddled or motorized canoes with 3–5 m [10]. The Brazilian government imposed a restrictive MPA (*Estação Ecológica Tamoios*) in the Paraty Bay in 1990, as an environmental compensation measure from the construction of a nuclear power plant in Angra dos Reis. This MPA includes separate scattered islands (some of which are shown in Fig. 1) with a buffer zone of 1 km around each island. A more detailed map showing all the islands included in the MPA is in Lopes et al. [32].

2.2. Fish landings: current and past fishing pressure

Fish landings were sampled monthly, on two consecutive and randomly chosen days per month in each village, avoiding weekends and public holidays from November 2009 to January 2011. On each day one researcher sampled all fish landings during regular commercial operations (from 8:00 to 17:00 h), recording the biomass of fish caught separately per species (or group of species) [10].

The total biomass of fish caught in the 21 studied islands was considered as a measure of current fishing pressure. Fishing occurs throughout the islands, even in those that are within the MPA (irregular fishing) [32].

Small-scale fisheries, such as the studied fishery in the Paraty Bay, usually include several distinct kinds of fishing gears [8,10], which makes difficult to compare and to accurately measure fishing pressure or fishing effort. Some of the studied islands had no fish landings recorded during the studied period (Table 1) and these detailed data were lacking for two islands with a small number of fish landings. Fishers used seven main kinds of fishing gear in fish landings (n=238) sampled in 12 of the studied islands (Supplementary material, Fig. S1): gillnets, trawling (to catch shrimp), line (several techniques to catch pelagic fish or squid), long line, mixed (any combination of two or more fishing gears in the same fish landing), trap (usually encircling nets) and spear (while snorkeling). The composition of gears used varied among the studied islands and gillnets and trawling were the most used gears (Fig. S1). This variety of gears makes difficult to compare fishing effort, as each gear would have a proper measure of effort. For example, number of fishers may be a relevant measure of effort for line fishing, but not so much for gillnets nor for long line, which are fixed gears usually set in the water overnight for several hours. Biomass of fish caught was thus adopted as a measure of fishing pressure because it could be readily compared among fishing gears and it should better reflects the impact on fish communities, as a large biomass of fish caught should indicate that more fish were removed from that island. Indeed, considering a subset of 12 islands for which these data were available, the biomass of fish caught by fishers was positively and strongly related to at least three alternative measures of fishing pressure: number of fishing trips to each island (Fig. S2a), total number of fishers (Fig. S2b) and diversity of fishing gear used (Fig. S2c). Although the biomass of fish caught was unrelated to average boat length, this potential measure of effort varied little among islands with a range from 6 to 8.4 m of average boat lengths (Fig. S2d). Therefore, biomass of fish caught was considered to be a suitable proxy of fishing effort that fits the aims of this survey.

The islands distances from the two studied fishing villages (Praia Grande and Tarituba) were also measured and considered as a measure of past fishing pressure. This follows the rationale that islands closer to fishing villages would be more susceptible to fishing pressure [47].

2.3. Fish density: response variable

Fish density was estimated through underwater visual census (UVC) surveys along 30 belt transects 50 m long x 4 m wide (200 m^2 each transect) in 21 islands of the Paraty Bay (Fig. 1a and b, Table 1), on non-consecutive days in summer and autumn (December to April) of 2011 and 2012. Nine of these 21 islands are partially or entirely submerged rock outcrops, locally called '*lajes*'. These islands are usually small, not accommodating two or more transects. On each transect the number of individuals of studied reef fishes were counted and their sizes were estimated at 5 cm intervals. Data from repeated transects were pooled for each island, thus considering each island as a replicate. The UVC surveys were made by a different research team and not on the same days when fish landings were recorded, due to logistic constraints (weather and sea conditions). However, UVC surveys were conducted in 2011–2012, soon after recording fish landings (2009–2011). Considering the long life span and site attachment of large groupers [43], our UVC data should reflect fishing pressure measured by fish landings. Fish biomass was estimated from the observed fish size through length-weight equations of the three studied fishes [22]. Therefore, the response variable 'fish biomass' also includes a measure of fish size in the studied islands. The depth range of UVC surveys were from 3 to 12 m with a mean depth of 6 m (± 2 m SD).

2.4. Data analyses

The distance from Tarituba and the distance from Praia Grande of each island were not significantly correlated (r =−0.4, n =21, p=0.06). The biomass of fish caught by fishers (current fishing pressure) was not correlated with the islands distance from Tarituba (r =−0.22, n =21, p=0.35), nor from Praia Grande (r =−0.3, n =21, p=0.19). The influences of these three independent variables (biomass of fish caught, distance from Tarituba, and distance from Praia Grande) on the dependent variables (densities in number and biomass of the studied reef fishes) were checked through multiple linear regressions.

In a previous study, the influences of ten environmental variables on densities of the three studied reef fishes were evaluated, but only the proportion of coral cover and water visibility were positively related with density (number of individuals and biomass) of *E. marginatus* [49]. Coral cover, which was positively related with visibility (r =0.48, n =21, $p < 0.05$) and indicates habitat quality, was thus included as a covariate in multiple regression analyses of *E. marginatus*. The propor-

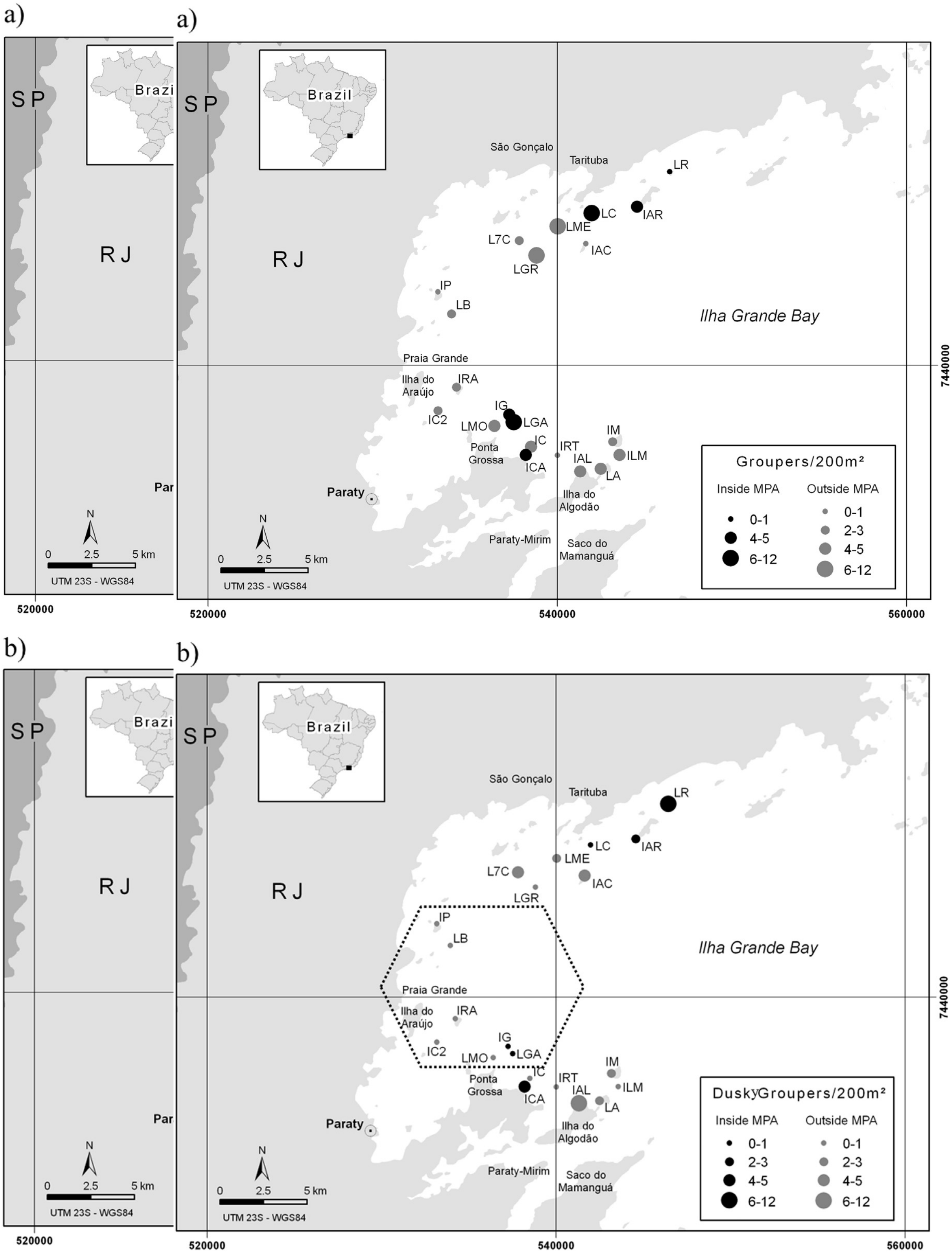

Fig. 1. The studied islands and rocks located inside (black, n=6) or outside (gray, n=15) the Marine Protected Area of ESEC Tamoios and the two studied fishing villages (Praia Grande and Tarituba) in the Paraty Bay, southeastern Brazilian coast. The sizes of the circles indicate the density of fish observed during the underwater visual census: a) *M. acutirostris* (groupers); b) *Epinephelus marginatus* (dusky grouper): the polygon indicates the islands closer to Praia Grande that have reduced densities of this fish. Codes refer to islands (I) or rocks (L for *lajes* in Portuguese). Names of islands corresponding to codes are in Table 1.

tion of coral cover was measured during each transect as point counts on the substrate each 2 m along the 50 m tape. Coral cover was neither related with the biomass of fish caught (r =−0.02, n =21, p=0.95), nor with distance from Tarituba (r =−0.13, n =21, p=0.57), but it was positively correlated with islands' distance from Praia Grande (r =0.53, n =21, $p < 0.01$). Therefore, coral cover and distance from Praia Grande were analyzed in distinct regression models, to avoid multi-collinearity effects. Densities of reef fishes, coral cover and fishing pressure were

Table 1
Scores assigned to variables related to fishing pressure (area, total fish and reef fish caught) and conservation priority (coral cover, and density of the two studied grouper species (*Epinephelus marginatus* and *Mycteroperca acutirostris*) in 21 islands of the Paraty Bay, southeastern Brazilian coast. The islands with scores of −1 or lower for the variable 'total fish biomass caught by fishers' are traditional fishing grounds that have been regularly exploited by fishers. Mean values of these four variables and how they were applied to calculate scores are in Table 2. MPA proposed refers to a new configuration of the current MPA design.

Sites	UVC surveys	Codes[a]	Biomass of total fish (kg)	Biomass of reef fish caught (kg)	Coral cover	Density of groupers in biomass (kg/200 m^2)	Total score[b]	MPA present	MPA proposed
Ilha Araçatiba	2	IAC	−2	−2	2	1	−1	Open[c]	Open
Ilha Araraquara	2	IAR	−2	−2	2	1	−1	No-take	Open
Ilha Comprida	2	IC	0	0	2	1	3	Open	No-take
Ilha Comprida 2	2	IC2	−1	0	0	1	0	Open	Open
Ilha da Rapada	1	IRA	−2	−1	1	1	−1	Open	Open
Ilha do Algodão	3	IAL	−2	−2	2	2	0	Open	Partial[d]
Ilha do Catimbau	1	ICA	0	0	2	2	4	No-take	No-take
Ilha do Pico	2	IP	−1	−1	0	1	−1	Open	Open
Ilha dos Ganchos	1	IG	−2	−1	1	1	−1	No-take	Open
Ilha dos Meros	2	IM	−1	−1	1	1	0	Open	Partial[d]
Ilha dos Ratos	2	IRT	−1	−1	2	1	1	Open	No-take
Ilhote dos Meros	1	ILM	0	0	1	2	3	Open	No-take
Laje 7 cabeças	1	L7C	−2	−2	0	1	−3	Open	Open
Laje Branca	1	LB	−1	−1	0	1	−1	Open	Open
Laje do Algodão	1	LA	0	0	0	2	2	Open	No-take
Laje do Cesto	1	LC	0	0	2	2	4	No-take	No-take
Laje dos Meros	1	LME	−1	−1	2	2	2	Open	No-take
Laje dos Moleques	1	LMO	0	0	0	1	1	Open	No-take
Laje grande	1	LGR	−1	0	0	2	1	Open	No-take
Laje Rochedo de São Pedro	1	LR	0	0	2	1	3	No-take	No-take
Lajinha dos Ganchos	1	LGA	−1	0	1	2	2	No-take	No-take

[a] Codes for sites (islands) shown in the maps (Fig. 1a and b).
[b] Positive scores indicate higher conservation value, negative scores indicate value for fisheries.
[c] The Araçatiba Island is actually inside the MPA according to its original configuration, but fishers regularly exploit this island and the MPA managers are currently developing changes in the MPA to allow its use by fishers (V.N. Nora, personal observation); we therefore considered it as being outside the MPA for the purposes of this study.
[d] We considered that islands with 0 values could be partially open to fishing, while part of its area could be assigned no-take.

Table 2
Variables (mean ± standard deviation, SD) used to calculate scores for each studied island in the Paraty Bay, southeastern Brazilian coast. If a variable was absent for an island, its score was set at 0.

Variable	Mean ± SD	Purpose	Criteria	Score
Density of groupers in biomass (kg/ 200 m^2)[a]	2.1 (± 1.9)	Conservation	> or equal to mean	2
Coral cover (%)[b]	15.5 (± 16.2)		< mean	1
Biomass of fish caught in fishing landings (kg)	416.4 (± 756.3)	Fisheries	> or equal to mean	−2
Biomass of reef fish caught in fishing landings (kg)	15.5 (± 31)		< mean	−1

[a] Considering combined densities of *Epinephelus marginatus* and *Mycteroperca* spp., which we estimated through UVC surveys.
[b] Measured as point counts at each 2 m of a 50 m tape during dives for UVC fish surveys.

compared between islands inside and outside the MPA (Fig. 1a and b) through *t*-test (t). The normality of data was checked through the Kolmogorov-Smirnov test for normal distribution and log-transformed data to achieve normality when needed. The residuals of regression models were also visually inspected.

2.5. Conservation scores

Following the approach by Lopes et al. [32], scores were assigned to each studied island, which reflect its importance to either fishery or conservation. The islands value for fisheries was estimated using two variables (total biomass of fish and of reef fish caught), while the islands value for conservation considered other two variables (density of groupers and coral cover). Positive scores were assigned to islands ranging from 1 (if value of the variable was lower than the mean) to 2 (if value was higher than the mean) for the conservation related variables. Conversely, negative scores were assigned to islands ranging from −1 (if value was lower than the mean) to −2 (if value was higher than the mean) for the fisheries related variables. A 0 score was assigned if a variable was absent in a given island (for example, no fish caught or no coral cover) (Table 2). The total scores for each island were the sum of the scores for the four variables: positive values indicated its relevance for conservation (no-take), while negative values indicated its importance for fisheries (open); 0 indicated partial

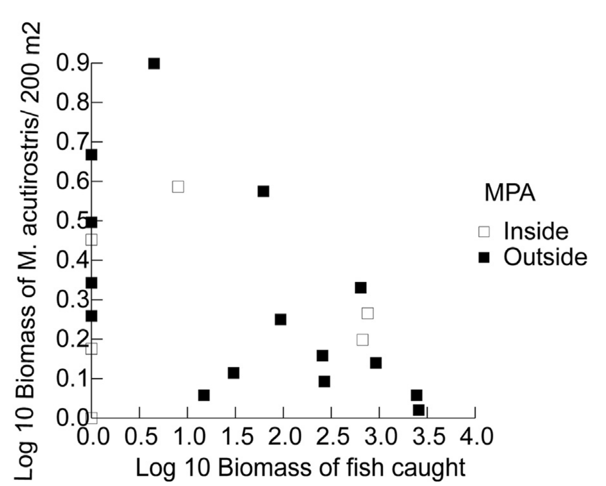

Fig. 2. Relationship between current fishing pressure (biomass of fish caught) measured through sampling of fish landings and the density of *M. acutirostris* observed during underwater visual census in 21 islands of the Paraty Bay, southeastern Brazilian coast. Islands inside the Marine Protected Area of ESEC Tamoios (n =6) are in black and those outside it (n =15) are in white.

Table 3
Regression analyses of the influence of variables related to fishing pressure on density of the studied reef fishes (*Epinephelus marginatus*, *M. acutirostris*, and *Haemulon aurolineatum*) in 21 islands of the Paraty Bay, southeastern Brazilian coast. Number and biomass (kg) of fish species observed during UVC survey of 200 m^2 transects. The variable 'biomass of fish caught' is related with current fishing pressure. The variables 'distance from Tarituba' and 'distance from Praia Grande' are related with past fishing pressure.

Model	Dependent variable	Independent variable (s)	r^2 (model)	df[a]	Coefficient[b]	*p*
1	Log (Number of *E. marginatus*)	Log (Biomass of fish caught) + Proportion of coral cover +Distance from Tarituba	0.28	17		0.122
		Log (Biomass of fish caught)			0.021	0.63
		Proportion of coral cover			0.008	0.03
		Distance from Tarituba			−0.004	0.679
2	Log (Number of *E. marginatus*)	Log (Biomass of fish caught) +Distance from Tarituba +Distance from Praia Grande	0.54	17		0.004
		Log (Biomass of fish caught)			0.088	0.035
		Distance from Tarituba			0.012	0.183
		Distance from Praia Grande			0.05	0.001
3	Log (Number of *E. marginatus*)	Log (Biomass of fish caught) +Distance from Praia Grande	0.48	18		0.003
		Log (Biomass of fish caught)			0.068	0.08
		Distance from Praia Grande			0.042	0.001
4	Log (Number of *M. acutirostris*)	Log (Biomass of fish caught) +Distance from Tarituba +Distance from Praia Grande	0.09		17	0.63
		Log (Biomass of fish caught)			−0.07	0.21
		Distance from Tarituba			−0.004	0.74
		Distance from Praia Grande			−0.011	0.517
5	Log (Number of *H. aurolineatum*)	Log (Biomass of fish caught) + Distance from Tarituba + Distance from Praia Grande	0.158	17		0.389
		Log (Biomass of fish caught)			0.028	0.660
		Distance from Tarituba			0.023	0.127
		Distance from Praia Grande			0.027	0.178
6	Log (Biomass of *E. marginatus*)	Log (Biomass of fish caught) + Proportion of coral cover + Distance from Tarituba	0.108	17		0.572
		Log (Biomass of fish caught)			−0.005	0.857
		Proportion of coral cover			0.002	0.312
		Distance from Tarituba			−0.005	0.415
7	Log (Biomass of *E. marginatus*)	Log (Biomass of fish caught) + Distance from Tarituba + Distance from Praia Grande	0.3	17		0.102
		Log (Biomass of fish caught)			0.023	0.415
		Distance from Tarituba			0.002	0.765
		Distance from Praia Grande			0.021	0.03
8	Log (Biomass of *E. marginatus*)	Distance from Praia Grande	0.27	19	0.018	0.016
9	Log (Biomass of *M. acutirostris*)	Log (Biomass of fish caught) + Distance from Tarituba + Distance from Praia Grande	0.22	17		0.24
		Log (Biomass of fish caught)			−0.08	0.08
		Distance from Tarituba			−0.006	0.54
		Distance from Praia Grande			0.002	0.89
10	Log (Biomass of *M. acutirostris*)	Log (Biomass of fish caught)	0.18	19	−0.08	0.05
11	Log (Biomass of *H. aurolineatum*)	Log (Biomass of fish caught) + Distance from Tarituba + Distance from Praia Grande	0.147	17		0.426
		Log (Biomass of fish caught)			−0.029	0.47
		Distance from Tarituba			0.005	0.57
		Distance from Praia Grande			0.012	0.316

[a] Degrees of freedom of the residuals of the Analysis of Variance, for each regression model.
[b] Regression coefficient for the independent variables included in the model.

protection (Table 1).

3. Results

3.1. Hypothesis 1: groupers and current fishing pressure

The 268 fish landings sampled resulted in 8.7 t of fish caught in the same 21 islands where fish density was estimated (Fig. 1a and b). During the UVC surveys in the 21 islands 74 individuals of *E. marginatus*, 105 of *M. acutirostris* and 601 of *H. aurolineatum* were recorded. Our first hypothesis was partially confirmed: the biomass of *M. acutirostris* tended to be negatively related to current fishing pressure (Fig. 2), although the regression was nearly significant at p=0.05 and the regression coefficient was low (model 10, Table 3). The biomass of the low valued *H. aurolineatum* and the high valued *E. marginatus* were unrelated to current fishing pressure (Table 3).

Table 4
Mean (±SD) and results of *t* test comparing fishing pressure and density of the three studied reef fishes (*Epinephelus marginatus*, *M. acutirostris*, and *Haemulon aurolineatum*) between islands inside (n=6) and outside (n =15) a marine protected area (MPA) in the Paraty Bay, southeastern Brazilian coast. Number and biomass (kg) of fish species observed during UVC survey of 200 m^2 transects. Means (±SD) are presented for the original values, even in cases where the variable was log transformed for analysis. The variable 'biomass of fish caught' is related with current fishing pressure. The variables 'distance from Tarituba and distance from Praia Grande are related with past fishing pressure.

Variables	Inside MPA	Outside MPA	t[a]	p
Number of *E. marginatus*	2.8 (± 2.4)	2 (± 2.3)	0.7	0.49
Number of *M. acutirostris*	4.3 (± 2.7)	3.7 (± 2.8)	0.4	0.66
Log (Number of *H. aurolineatum*)	14 (±5.44)	13.9 (±17.6)	1.2	0.25
Biomass of *E. marginatus*	1.1 (±0.5)	0.6 (±0.6)	1.7	0.11
Log (Biomass of *M. acutirostris*)	1.1 (±1)	1.4 (±1.9)	−0.15	0.88
Biomass of *H. aurolineatum*	0.24 (±0.16)	0.19 (±0.19)	0.3	0.81
Biomass of fish caught (kg)	238.7 (±368.2)	487.4 (±865.9)	−0.8	0.4
Distance from Praia Grande (km)	12.7 (±5.3)	9.97 (±4.2)	1.2	0.24
Distance from Tarituba (km)	10.3 (±7)	13.5 (±5.7)	−1.1	0.29
Proportion of coral cover (%)	23.3 (±16.1)	12.3 (±15.6)	1.4	0.17

[a] Value for pooled variances, df =19.

3.2. Hypothesis 2: groupers and island distance

Our second hypothesis was also partially confirmed. The densities (in number and biomass) of *M. acutirostris* and *H. aurolineatum* were unrelated to islands distances from the two studied fishing villages (Fig. 1a, Table 3). However, the number (Fig. 1b) and biomass of *E. marginatus* were positively related with the distance from Praia Grande village (models 7 and 8, Table 3), which indicated the effect of a past fishing pressure on nearby islands. Although current fishing pressure was positively and significantly related to the number of *E. marginatus* in the model containing all variables (model 2), current fishing pressure was no longer significant when analyzed with the variable distance to Praia Grande (model 3, Table 3). This indicates that the number of *E. marginatus* in a given island was more affected by the island distance from Praia Grande than by its current fishing pressure.

3.3. Hypothesis 3: groupers, MPA and conservation scores

Our third hypothesis was confirmed: densities of the three reef fishes did not differ between islands inside and outside the MPA (Table 4). Current and past fishing pressure (distances from the two fishing villages) did not differ between islands outside or inside the MPA (Table 4).

Considering the conservation scores, 11 islands were recommended as no-take sites, two as partially protected, and eight as open to fishing, which would change the current status of 10 islands in the MPA (Table 1).

4. Discussion

4.1. Effects of current fishing pressure

The density of *H. aurolineatum* was unrelated to fishing pressure and to the MPA, which indicated that this non-exploited fish was an efficient control to evaluate fishing pressure and effects of the MPA [17,41]. There was an inverse relation between fish biomass of *M. acutirostris* and current fishing pressure, as expected. Nevertheless, the hypothesis of a negative influence of current fishing pressure in the density of *E. marginatus* was not confirmed, even considering that this fish has a high commercial value in the Paraty Bay [8,32]. This contradicts the observed pattern for *M. acutirostris* and the overall pattern of an inverse relationship between fishing pressure and the abundance of commercial reef fishes [11,15]. This may be partly attributable to the more refined spatial scale in this study, as fishing pressure may differ amongst fishing grounds [4,6]. Refined spatial data on fishing pressure can provide empirical support to management measures at local or regional scales [5], especially in the context of data-deficient small-scale fisheries [28]. Another reason for not detecting any effect of the current fishing pressure on *E. marginatus* could be the current reduced focus on reef fisheries in the Paraty Bay. Reef fish corresponded to 2.6% and *E. marginatus* corresponded to 0.25% of total biomass of fish caught (20 t) by fishers in the two studied fishing villages, where shrimp is currently the main fishing resource [10].

However, this study was based on a rapid assessment of fish densities through punctual UVC surveys in several islands, some of which were sampled only once. This approach was adopted because most of the studied islands were small and doing repeated UVC surveys in such a limited space would possibly lead to pseudo-replication (counting twice the same individual fish). Nevertheless, the management recommendations provided in this study could and should be reinforced by future assessments or interviews with local fishers [32,48], in an adaptive management framework. Future studies could also apply another measures of fishing pressure (hours spent fishing, amount of gear used) to check potential effects of distinct fishing gears on reef fish at several fishing grounds.

4.2. The 'ghost of past fishing'?

Fishers exploiting benthic and sedentary reef resources usually tend to overfish nearby islands first and then displace fishing pressure to more distant sites [47]. The density of *E. marginatus* was inversely related with island distance from one of the main fishing villages in the Paraty Bay, showing an "overfished" zone around this village (Fig. 1b) and partially confirming our second hypothesis. This indicated a potential negative effect of a past fishing pressure on *E. marginatus*, which may have reduced the numerical abundance and size (biomass) of groupers in nearby islands. This effect could be considered as an ecological footprint of fisheries or an effect of 'ghost of past fishing'. Although it resembles the shifting baseline syndrome [44], the 'ghost of past fishing' implies that fishing pressure has been alleviated, which makes it more difficult to detect its effects and to manage affected stocks. Indeed, such an effect could have also affected other groupers in tropical and subtropical islands, but may remain unnoticed to managers due to lack of scientific information, especially if no other data source is available. Other pieces of evidence reinforce that a past fishing pressure may have reduced the abundance of *E. marginatus* in the Paraty Bay. Most of the individuals of *E. marginatus* regularly caught by fishers in the southeastern Brazilian coast are smaller than the size at first maturity for this species [7,9]. Fishers' knowledge indicates a decrease in the abundance of groupers (including *E. marginatus*) over time in other regions of the Brazilian coast [12,48] and elsewhere [44]. In the Mediterranean, large individuals of *E. marginatus* are found nowadays only in deeper and more distant sites, but this fish were abundant in shallow reefs more than a thousand years ago, indicating historical fishing pressure in shallow islands [25]. Selective fishing of large individuals may reduce the reproductive potential and affect sex change of protogynous reef fish [30]. Besides reducing fishing stocks, overfishing of large groupers may negatively affect their ecological services and biological interactions [24,38,51].

4.3. How to conciliate MPA and fisheries?

Successful MPAs that have increased the abundance of reef fish have been well reported in the literature in Brazil [2,19] and elsewhere [17,38,45], but problematic or conflicting MPAs may have been underreported and should be addressed as well [27]. The islands that are inside the studied MPA in Paraty Bay did not have higher densities of groupers than islands outside it, thus confirming the hypothesis that this MPA has not been effective to protect these fish. The spillover of adult fish [20] was possibly not responsible for the observed similar fish densities inside and outside the studied MPA, because some of the islands with the highest densities of groupers (e.g. potential sources of fish) were located outside the MPA. Indeed, a previous study shows that this MPA has not contributed to increase fish biomass or fishing productivity in general [33]. In this study, fishing pressure did not differ between islands inside and outside the MPA in the Paraty Bay, as some islands outside the MPA received low fishing pressure, while some islands inside the MPA were regularly exploited (Fig. 2). This poaching behavior by fishers could be related to the top-down imposition of this MPA, which exacerbated conflicts and reduced compliance [8,32]. Poaching has been reported to happen in Brazilian MPAs [2,20], but few surveys have measured fishing pressure or the incidence of poaching in MPAs worldwide [30,40]. There is an ongoing negotiation between fishers and managers to change the boundaries of the studied MPA in the Paraty Bay [34], but the zoning system of this MPA has not changed yet.

The MPAs have been most effective in two contexts. First, in developed countries that have resources to provide adequate enforcement and research and where small-scale fisheries are not the most important economic activity of local communities, such as in Australia and U.S.A. [17,23]. Second, in developing countries where the government lacks management capacity, but local fishers have territorial rights over fishing grounds and manage no-take areas in nearby reefs through co-management or common based management systems [14,18,26]. The islands in the Paraty Bay and in the southeastern Brazilian coast fit neither of the above, as the government imposed a MPA, not consulting the local fishers and with limited enforcement capacity, leading to conflicts and poaching that undermine the MPA effectiveness. A previous survey proposes changes in the current design of this MPA based on fishers' knowledge, which would turn some no-take areas in fishing grounds [32]. However, only 1.9% and 0.14% of the Brazilian marine ecosystems are inside MPAs and no-take areas, respectively [35], so biologists may not want to further reduce the small fraction of protected seascape. Empirical data from fishing effort, habitat quality (coral cover) and abundance of commercial reef fish (groupers) were used here to establish a system of scores aimed to support future efforts of reevaluation of the boundaries of the studied MPA. The conservation recommendations arising from the scores would allow fishing in those islands inside the MPA that have been regularly exploited by fishers while simultaneously increasing the no-take coverage of the MPA, by including islands that have been rarely exploited. These results could serve as empirical support for changing the conservation status of those islands regularly used by fishers. Considering the current conflicts, these islands recommended to be open to fishing could be part of a sustainable or extractive reserve, a conservation unit that allows the sustainable use of fishing resources by local people [31]. These reserves have been a promising solution to conciliate small-scale fisheries and conservation in floodplain lakes in the Brazilian Amazon [29,31,50,52]. Furthermore, some of the islands to be protected in Paraty Bay include rocky banks, which are important habitats for groupers [45,48]. An improved growth and reproduction of *E. marginatus* in no-take islands could recover depleted stocks in the Paraty Bay, through spillover of adult fish [1] or larval dispersal [16]. Other management options would be to enforce size limits or closed fishing seasons for groupers [42]. However, size limits would be difficult to enforce in the southeastern coast, where most groupers are caught at small sizes [9] and closed seasons for groupers may redirect fishing pressure to other reef fishes [13].

5. Conclusions

This study shows that a threatened reef fish (*E. marginatus*) may have been affected by a more intense fishing pressure in the past, that an MPA established following a top-down approach has not been effective and compared fishing and fish abundance data to provide empirically based advice to improve MPA effectiveness, while possibly reducing existing conflicts. Conservation planning for effective MPAs usually includes more variables than just fishing pressure, coral cover and abundance of selected reef fish [37]. Nevertheless, the approach adopted here could be a useful and reliable rapid assessment to improve conservation of reef fish in most tropical developing countries that lack baseline or systematic data collection of coastal or reef fisheries [28]. The management interventions suggested here, if properly negotiated with local fishers, have potential to conciliate the conflicting goals of conservation of reef fishes and provisioning of food security to local fishers. Indeed, fishers in the Paraty Bay are not against no-take areas, as long as they get involved in the decision process of zoning the MPA [32]. The simple metrics to assign conservation value to distinct islands adopted here could also serve as a starting point to establish cooperation and dialogue between managers and scientists, which could ultimately lead to co-management initiatives that include no-take islands, or at least help to overcome the initial resistance of small-scale fishers regarding no-take areas [39]. The 'ghost of fishing past' observed here could be more broadly applicable, or remains a plausible hypothesis to be tested, wherever fisheries data is lacking and threatened reef fish, such as groupers, have been exploited by small-scale fishers. The approach and results reported here could be widely applied throughout the distribution range of groupers (*Epinephelus* spp.), especially where these reef fish are threatened and are an important fishing resource.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2016.10.002.

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