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 recorded in 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 m² 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 co-variate in multiple regression analyses of *E. marginatus*. The propor-