The Effects of Fishing and Protection through Marine Protection Areas: Three Case Studies and Implications to Reef Fish Functional Groups in Brazil

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Abstract

The vast Brazilian coast harbors unique and diverse reef fish communities. Unfortunately, relatively little is known about the impact of fishing on these fish species. Here we review the effect of different levels of protection on the composition, abundance, and size structure of reef fish species along a large portion of the Brazilian coastline. Pairwise comparisons of sites with different protection status (more versus less protected) were used to determine the potential responses of reef fishes to the establishment of marine protected areas. Highly targeted species (top predators and large herbivores) were significantly more abundant and larger in size within sites with a higher degree of protection, indicating that they benefit from protection, while lightly fished and unfished species were not. These results are consistent with past work documenting the responses of species to protection. Based on these results we suggest strategies and expectations for managing and protecting Brazilian reef fisheries.

Key Words: reef fisheries, Brazil, marine protected areas, reserves, overfishing.

Introduction

The Brazilian coastline is a vast area extending nearly 8000 km from the northern edge just north of the equator to the southern temperate edge bordering Uruguay. Reef environments occur along at least a third of this coastline, with coral reefs in the north (latitude 0o52'N to 19oS) and rocky reefs in the south (20oS to 28oS). These reefs are known to harbor a large number of endemic corals (40 % – Castro, 2003), sponges (36% – Eduardo Hajdu, pers. com.) and fish species (15-20% – Floeter & Gasparini, 2000; 2001). In the last decade there was an significant increase in the knowledge about the biogeography and macroecology of Brazilian reef fishes (e.g. Ferreira *et al*., 2004; Floeter *et al*., 2001, 2004, 2005), which is the foundation to understanding the status of Brazilian reef fish populations and design appropriate management and conservation strategies. For example, the considerable endemism shown by different faunistic groups

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in Brazil is even more impressive if analyzed in proportion to their area of distribution. The Brazilian reefs represents only 0.4% of the global reef area, and 5% of the Atlantic reef area, however, the ratio between level of endemism and reef area in Brazil is 6.5 for fish (endemism/100 km^2 of reef area) and 0.9 for corals. In the Caribbean this ratios are only 1.5 and 0.26 respectively (Moura, 2002). The high endemism pre unit area warrants that the Brazilian reefs should be considered priority areas for conservation. Because the Brazilian biogeographic province (sensu Briggs, 1974, 1995; Floeter & Gasparini, 2000) lies entirely within the jurisdiction of a single nation (Brazil), there may be unique and significant opportunities to effectively manage and conserve these fish species.

Unfortunately, relatively little is known about the fishing or conservation status of Brazilian reef fishes. How abundant are Brazilian reef fish and are many of the species currently threatened? Are different types of spatial management (e.g. no-take areas, spatial fishing regulations) affecting species positively, and are these effects different? Are the endemic species threatened or impacted, and if so, what are the implications for managing this unique biogeographic region? Limited research suggests that both commercial and aquarium fisheries are taking large numbers of fish from Brazilian reefs, leading to significant changes in community structure (Costa *et al*., 2003; Gasparini *et al*., 2005; Ferreira *et al*., 2006), and both artisanal and commercial fisheries appear to be affecting the population size and size structure of fish populations (Ferreira & Gonçalves, 1999; Ferreira, 2005; Gasparini *et al*., 2005; Frédou *et al*., 2006). Other threats deriving from urban development and agricultural runoff along the Brazilian coast were reviewed by Leão & Dominguez (2000), although little is known about the effect of these threats to reef fishes. With Brazil's large (179 million) and growing (1.3% per year) population (PRB, 2004), half of which lives along the coast, the demand for fish protein will only increase in the coming years. The need is pressing to understand the status of Brazilian reef fish populations and design appropriate management and conservation strategies.

In the last decade or so marine resource management and conservation has focused on marine protected areas as a tool for managing coastal ecosystems and species (reviewed in NRC, 2001, Palumbi, 2002), based in part on the growing scientific literature demonstrating the recovery of species within the boundaries of protected areas (synthesized in Halpern, 2003). Cooperative and traditional (small-scale) fisheries management have also been shown to provide effective protection for fisheries in some cases (e.g. McClanahan *et al*., 1997; Ferreira & Maida, 2001). However, not all species respond positively to protection, with primarily heavily exploited species showing the strongest response (Micheli *et al*., 2005; Dulvy *et al*., 2004a). These differences in response of species to protection from fishing pressure can in turn be used as a surrogate measure for the fishing pressure, or threat, experienced by a species or group of species. As such, a lack of response by a species to protection indicates that either the species was not affected by fishing pressure, or that the protection provided (on paper or in reality) is not sufficient to protect the species from fishing.

Effects of different fishing pressures

Recent comparisons (Floeter *et al*., 2006) examined the effect of different levels of protection on the composition, abundance, and size structure of reef fish species along a 2500 km portion of the Brazilian coastline (from the Espírito Santo State to Santa Catarina State; Fig. 1 - see at the end of the article). Pairwise comparisons of sites with different protection status (more versus less protected – Table 1) were used to determine the potential responses of reef fishes to the establishment of marine protected areas. Highly targeted species (top predators and large herbivores) were significantly more abundant and larger in size within sites with a higher degree of protection, indicating that they benefit from protection, while lightly fished and unfished species were not (Figs. 2, 3, 4 - see at the end of the article). These results are consistent with past work documenting the responses of species to protection (e.g. Halpern, 2003 and references; Ferreira, 2005).

Reef site	distance from coast (km)	MPA area	kinds of fisheries	reserve status	year of establis h-ment	effectiveness of the reserve
Abrolhos Reefs Arquipélago (P)	50	802 km^2	None	Marine National Park	1983	Full protection. enforced since 1986
Timbebas (PP)	10	110 km^2	Spearfishing, nets, hook and line	Marine National Park	1983	Not enforced**.
Guarapari Islands						
Escalvada (PP)	11	None	Spearfishing, hook and line	None	–	Partially protected by distance
Coastal (NP)	0.5	None	Spearfishing, nets, hook and line	None	–	None
Arraial do Cabo						
Pedra Vermelha (PP)	–	500 m^2	Hook and line*	'Artisanal Fisheries Reserve'	1997	Not continuously enforced
Saco do Anequim (NP)	–	500 m^2	Hook and line, Spearfishing	None	–	None
Laje de Santos (P)	36	50 km^2	None	Marine State Park	1993	Full Protection. Not continuously enforced
Arvoredo Island (P)	11	178 km^2	None	Biological Reserve	1990	Full Protection. enforced

*= mid-water fish only. **= not enforced during the studied period. Since 2002, the Abrolhos National Park has a 45' vessel, a 12-people field staff including rangers, as well as an annual budget of more than US$150,000.00 that are also covering Timbebas.

Table 1 - Characteristic features of the studied Brazilian reef sites. Sites are classified as protected (P), partially protected (PP), or not protected (NP).

The different responses by reef fishes to the different management strategies at the three sites provide a unique opportunity to evaluate the relative consequences of these management strategies. At Abrolhos both sites are part of a National Marine Park, but one site is effectively a "paper park"; at Guarapari both sites are open to fishing, but one site is partially protected due to its distance from the coast (11 km); and at Arraial do Cabo one site is open to all types of fishing while the other contiguous site allows only hook and line fishing of mid-water fishes like the carangids. In all cases, heavily fished species were more abundant in the site with greater protection, but results varied for lightly fished and unfished species. It is encouraging that even very small, partially protected areas can provide benefits to fishes that are heavily fished (Pedra Vermelha is only 500m^2), as was found to be true for fully protected small reserves in other places around the world (Halpern, 2003).

The effect of different management strategies on fish density and size is also confounded by spatial factors. The Abrolhos reefs are much larger than the sites in the other two regions (Table 1) and are far from developed urban centers. The Guarapari islands, on the other hand, are close to the city of Vitória (with a population of one million people), and Escalvada is partially protected from fishing only due to its distance from shore. Grouper density was lowest here of any of the sites (Fig. 4 - see at the end of the article), and average size of groupers and parrotfishes was even lower than the 'paper park' Timbebas (Fig. 3 - see at the end of the article).

The general increase in abundance of non-target fishes, particularly for the small size classes, could be related to an indirect effect of the removal of the big predators at these sites, as has been documented for other locations (Dulvy *et al*., 2004b; Ashworth & Ormond, 2005).

Efects in the functional groups

Among the different reef fish trophic groups, three are known to have great functional importance in reef systems besides being important impact bioindicators: herbivorous fishes, top predators and cleaning fishes.

Herbivores

In shallow coral reefs worldwide, herbivory is ubiquitous and intense (Steneck 1988; Hay 1991). Herbivorous fishes have a profound impact on the distribution, abundance and evolution of tropical reef algae (reviewed by Hay, 1991; Bellwood, 2003). The overfishing of herbivorous fishes seems to be responsible for the phase-shift from coral to algae dominated reefs (Hughes, 1994). On shallow reefs, fishes can take over 100.000 bites/m^2/day (Hatcher, 1981; Bruggemann, 1994), consuming almost all benthic algal production (Hay, 1991; Ferreira *et al*., 1998b). Fish are therefore the major link for energy transfer to higher trophic levels (Polunin & Klumpp, 1992).

Such a functional importance in the reef systems have been affected by the chronic overfishing of the large herbivores, mainly the parrotfishes (Scaridae). This phenomenon has been described globally as "fishing down the food webs" (Pauly *et al*., 1998), being defined as the succession of fishing pressure from the highly prized top predators to other large species from lower trophic levels, such as the scarids, after the collapse of the formers. In the Abrolhos Region (Bahia State), differences among size classes of these important herbivorous fishes have been detected when protected areas are compared to less protected areas (Figs. 3 to 5; Ferreira & Golçalves, 1999; Ferreira, 2005 - see at the end of the article). In terms of abundance, the results also show lower numbers at less protected areas (Fig. 2 - see at the end of the article). In Arraial do Cabo (Rio de Janeiro State), the largest scarid *Scarus trispinosus* (up to 60 cm) used to be abundant, but now is a rare species (Fig. 6 - see at the end of the article).

Top Predators

The ecological stability of the communities depends heavily in the predator-prey interactions. Bascompte *et al*. (2005) showed that in complex food webs in the Caribbean, top predators (Fig. 7; the ones that are usually selectively removed by fishing – Pauly *et al*., 1998 - see at the end of the article) are disproportionably important in terms of interactions in the food web. Top predators (e.g. Fig. 7) present much more trophic links than their numerical abundance could predict, thus, indicating potential effects in all the community structure.

Floeter *et al*. (2006) found higher densities and larger sizes of groupers (Serranidae) at protected areas comparing to less or non-protected areas in Abrolhos, Guarapari and Arraial do Cabo (Figs. 3 e 4 - see at the end of the article). Reproductive aggregations of serranids are known from several locations along the Brazilian coast, but unfortunately no one has any specific conservation status (Gehrardinger, L.C., pers. com.).

Cleaner Fishes

Cleaner fishes are also known by their functional importance in reef systems. Mutualistic associations among cleaner fishes and their 'clients' could affect the community health and even influence local diversity (e.g. Bshary, 2003; Grutter *et al*., 2003; Sazima & Sazima, 2004). Intensive harvesting of the cleaners may disrupt inter-specific associations such as cleaning symbiosis (Sazima & Sazima, 2004; Gasparini *et al*., 2005). The conspicuous colors and small size of reef cleaners, instrumental in their cleaning role on the coral reef (Côté 2000), are their most sought-after features for the aquarium trade. Of the ca. 25 species of cleaner fishes and eight cleaner shrimps known from Brazil's coast, all the shrimps and at least 15 fish species are regularly harvested for the ornamental trade (Gasparini *et al*., 2005). The two best studied cleaners in Brazil are the barber goby (*Elacatinus figaro*) and juvenile French angelfish (*Pomacanthus paru*), both of which clean numerous and varied client assemblages, from small herbi-

vores to large carnivores (Sazima *et al*., 1999; Sazima & Sazima, 2004; Floeter *et al*., 2007) including several economically-important species for reef fisheries (groupers, snappers, jacks).

Gasparini *et al*. (2005) evaluated the density of angelfishes (Pomacanthidae) in a gradient of distance from the coast, which is related to a gradient of harvesting pressure at the coastal islands of the Guarapari Region, Espírito Santo State. Densities of angelfishes were censused at three sites with progressively greater distances from the coast near through visual transects (20 m long and 2 m wide = 40 m^2) using SCUBA. Densities of the smaller size classes (juveniles and sub-adults) were greater at progressively greater distances from the coast, as expected (Fig. 8 - see at the end of the article). The trend we found is consistent with our suggestion that harvesting is greater in coastal areas and that it has the potential to reduce the overall abundance of the harvested species at local scales. These results are not to be confounded with natural variation due to habitat characteristics (authors' personal observations), since we also found that the larger size classes of these fishes (adults usually not targeted by the trade) were present in approximately equal numbers at the three sites, a strong indication that these species would be found in similar numbers at all sites were not for harvesting trade. The differences in Figure 8 exemplify the greatest pressure exerted upon the small size classes (more suitable for the trade).

Specialized cleaners generally survive for a short time in aquariums due to their distinctive feeding habits (e.g. gnathid isopods), and thus experience a high turnover in the ornamental trade (Wood, 2001).

Future Perspectives

Recent comparisons with other reefs in the Atlantic Ocean are generating comparative knowledge in terms of biodiversity, biogeography and macroecology (e.g. Ferreira *et al*., 2004; Floeter *et al*., 2001, 2004, 2005, 2007 and their references). The increase in the knowledge related to the distribution and abundance of marine species and its trophic structure patterns will certainly constitute essential tool to our greatest challenge: the sustainable management of marine resources, especially through the creation of marine protected areas.

Further investigations on actual fish densities and biomass as well as abundance and biomass of food sources (i.e. macrofauna associated to hard and soft substratum, algal turfs, seaweeds, plankton, and small fishes), will certainly help to decipher the complex patterns in reef fish distribution and trophic structure along the Brazilian coast. Also, the trophic role of cryptic species and the patterns in community structure of deep reefs are barely known, if at all. Despite the rarity of fish surveys in Brazilian deep reefs (> 50m; Feitoza *et al*., 2005), these habitats are already suffering high fishing pressure (Costa *et al*., in press).
A critic review on sampling methods as well as statistical analyses is now necessary to provide a solid foundation and standardization for future stu-

dies. This would allow the integration of datasets and a better planning of regional, national or global joint projects.

Comparisons between impacted and protected areas from fishing and tourism are of relevant practical application for environmental stakeholders. Many times, stakeholders do not have scientific basis to establish their decisions. Clearly fishing pressure has an effect on reef fish communities along the Brazilian coast (Ferreira & Gonçalves, 1999; Ferreira, 2005; Floeter *et al*., 2006) as well as in many other places in the world (Halpern, 2003). Unfortunately, very little of the coastline is under any form of protection or management (see Amaral & Jablonski, 2005 for the list and sizes of MPAs in Brazil). Huge stretches of coast (500–1500Km) between these sites remain completely open to fishing and other impacts (e.g. the Espírito Santo and Ceará coasts). Given the high levels of endemism in this region and the likelihood that a growing human population will continue to create greater fishing pressure, a large-scale conservation and management plan is urgently needed. Fortunately, the entire coastline falls within the jurisdiction of a single nation. This situation provides a unique opportunity for developing and implementing a single, coordinated plan for managing the reef fisheries, although subtropical (rocky) and tropical (coral) reef fisheries may require different specific management strategies. Standard fisheries management (e.g. gear and effort limits) will be an important component of any such plan, however, effective conservation will likely require some form of a network of marine protected areas as well.

It is important to note that the studies done so far showing the effects of fishing and protection along the Brazilian coast were performed through pairwise comparisons of fished and unfished areas (Ferreira & Maida, 2006; Floeter *et al*., 2006). These are not ideal data since habitat differences could mask fishing effects. To avoid confounding future efforts to establish networks of marine protected areas in Brazil should include baseline studies (i.e. surveys to assess initial conditions), whenever possible. The results compiled in the present work show clear evidence of what to expect from marine protected areas in reef systems in Brazil. On average, the density of heavily fished species should increase in reserves by about 10%, but exact results will be site-specific and may range as high as a 5-fold increase in protected areas. Thus, data of this type could give support and basis for stakeholder decisions as well as awareness to the general public regarding conservation of the fishing stocks in Brazilian reefs.

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Figure 1 - Map of the Brazilian coast showing sites where surveys were conducted (sites A, B, C, Laje de Santos, and Arvoredo) and the location of another site where a similar study were done in the 'Hump of Brazil' (Environmental Protection Area 'Costa dos Corais' –Tamandaré Reefs).

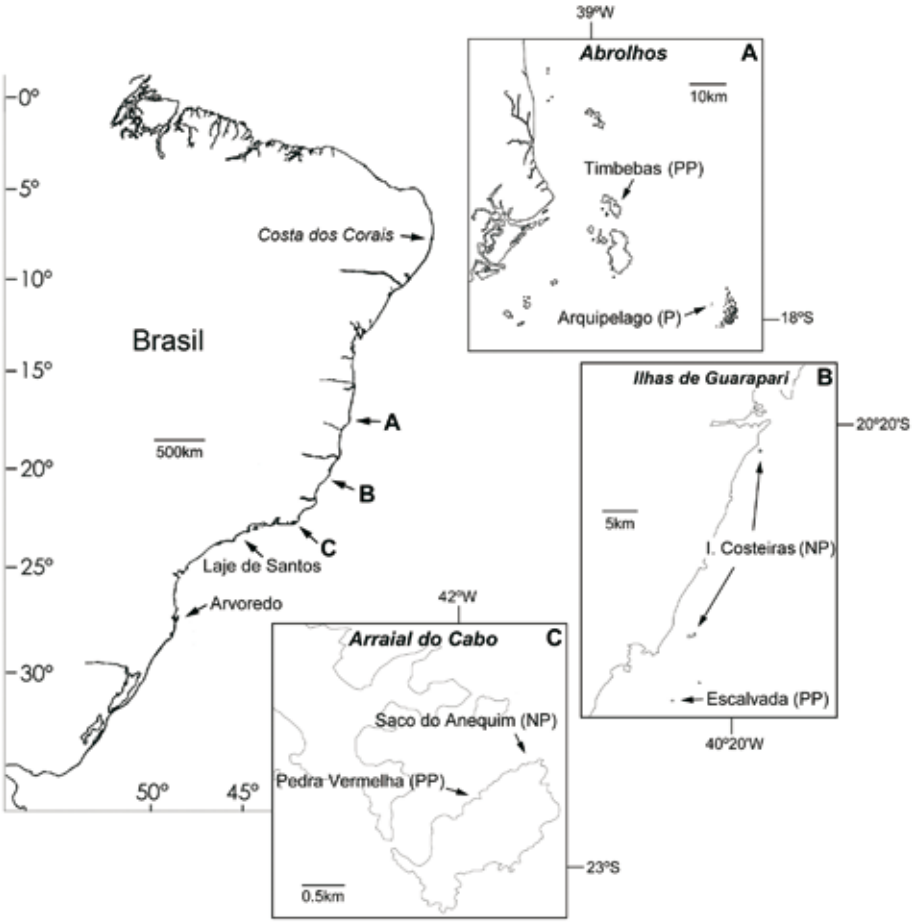


Figure 2 - Weighted response ratios for more versus less protected sites for species grouped by expected fishing pressure. Results are presented for all species across all studied sites (A, B and C of Fig. 1). The y-axis (weighted lnR) is the variance-weighted response ratio of fish density in the more protected area divided by fish density in the less protected area (reference site). A value of zero indicates no difference between protected and less protected sites. Values above zero indicate larger abundances in the more protected areas; values below zero indicate the opposite. Numbers in parenthesis are the number of species in each comparison. Details in Floeter et al. (2006).

Figure 3. Size frequency distribution of serranids and scarids in more and less protected sites, based on the percent of observations in visual censuses. P = Protected from fishing, PP = Partially protected from fishing, NP = Non protected area. Modified from Floeter et al. (2006).

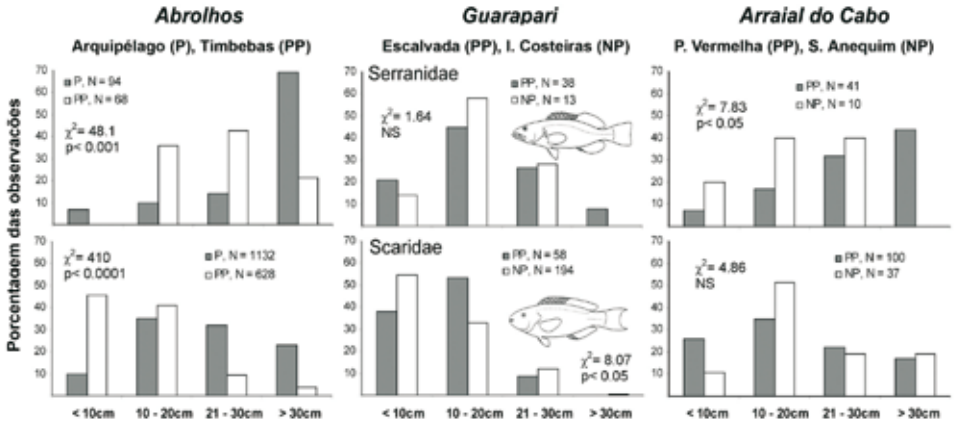


Figure 4 - Density and relative abundance of groupers (tribe Epinephelini) in more versus less protected sites. Reference sites refer to either non or partially protected sites. P = Protected from fishing, PP = Partially protected from fishing, NP = Non protected area. Laje de Santos and Arvoredo MPAs are shown for comparion. Modified from Floeter et al. (2006).

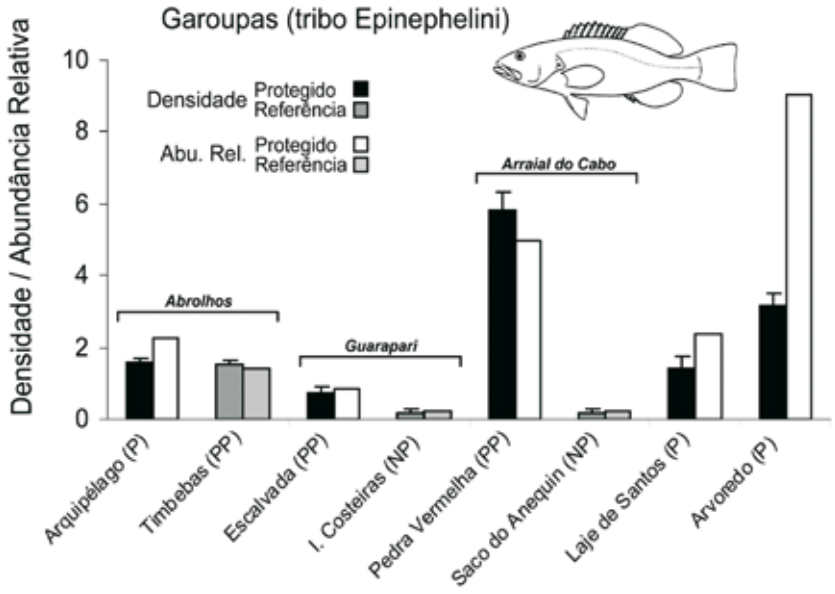


Figure 5 - School of parrotfishes (*Scarus trispinosus*) at the Arquipélago dos Abrolhos, BA in the eighties. Photo: Carlos Secchin.

Figure 6 - Mean density (SE) of Scarus trispinosus at the Ponta da Fortaleza - Arraial do Cabo, RJ. Sampling was conducted by the same observer (C.E.L.F.) through monthly visual census (n = 5) during one year in 1992 and in 2002 (see Ferreira *et al*., 2001 for methods). The decade interval between the samplings characterizes the absence of this species today exclusively due to spearfishing.

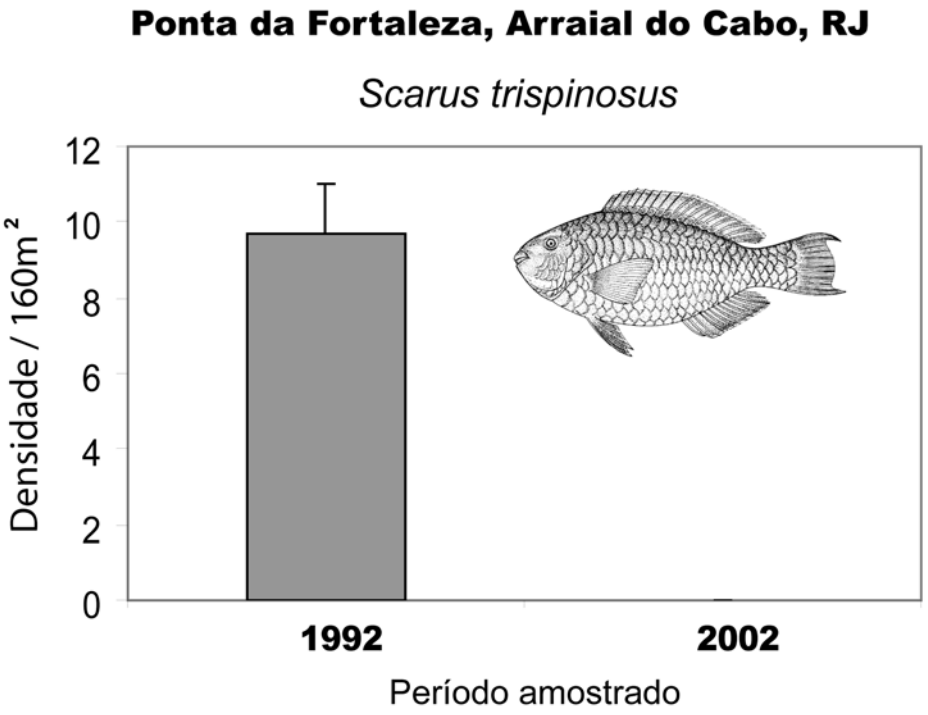
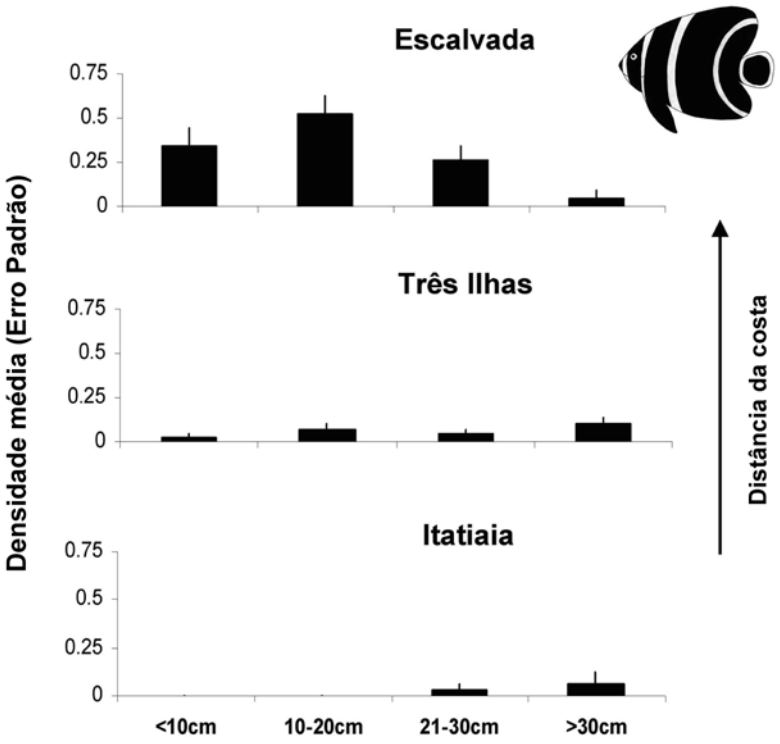


Figure 7 - The Goliath grouper (*Epinephelus itajara*) is the larger bonefish occurring on the Brazilian coast. This species is seriously threatened of extinction. Photo: Sergio Floeter.

Figure 8 - Angelfish (Pomacentridae) mean densities and standard error in four size classes at three island sites near Guarapari (Espírito Santo, SE Brazil). Fish were censused in strip transects of 20 x 2 m (Itatiaia, N = 39; Três Ilhas Archipelago, N = 72; Escalvada Is., N = 55). Distance from the coast: Itatiaia = 0.5 km, Três Ilhas = 3.5 km, Escalvada = 11 km. Modified from Gasparini et al. (2005).



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