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Effects of fishing and protection on Brazilian reef fishes

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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, and few management or conservation efforts are being made to protect them. Here we examine 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, noting in particular the relative abundance of endemics and the effect of protection on these species. 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. Here, we use our results in particular to suggest strategies and provide expectations for managing and protecting Brazilian reef fisheries. Because this biogeographic province lies entirely within the jurisdiction of a single nation, there may be unique and significant opportunities to effectively manage and conserve these fish species.

Key Words: reef fisheries; Brazil; marine protected areas; reserves; overfishing

1. 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 $0^{o}52'$N to 19^{o}S) and rocky reefs in the south (20^{o}S to 28^{o}S). 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 and Gasparini, 2000; 2001), creating an endemic-species/area ratio at least four times higher than in the Caribbean for fishes and three to four times higher for corals (Moura, 2002). Due to a high level of endemism, this region has been proposed as a distinct biogeographic province (Briggs, 1995; Floeter and Gasparini, 2000; 2001; Joyeux et al., 2001; Rocha, 2003).

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), and both artisanal and commercial fisheries appear to be affecting the population size and size structure of fish populations (Ferreira and Gonçalves, 1999; Frédou, 2004; Gasparini et al., 2005). 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 and 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., 2004*a*). 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.

In this paper we examine the abundances of reef fishes within areas of greater or less protection along a 2500 km portion of the Brazilian coastline (Fig. 1), paying particular attention to the distribution and abundance of southwestern Atlantic endemics across this stretch of the coastline. We then use pairwise comparisons of sites with different protection status within 3 different locations (Table 1) to determine the current threat to reef fishes within and among the sites. We also use the change in density and size distribution of species (endemics only and all species) to evaluate the potential responses of reef fishes to protection from fishing and to different types of protection (full no-take reserves versus partial protection from different levels of fishing). Finally, we use these results to suggest strategies and provide expectations for managing and protecting Brazilian reef fisheries. Because this biogeographic province lies entirely within the jurisdiction of a single nation, there may be unique and significant opportunities to effectively manage and conserve these fish species.

2. Methods

2.1. The sites

Three pairs of sites were chosen to be in close geographic proximity but have different levels of fishing pressure (Fig. 1). Sites were designated a priori as protected (P), partially-protected

(PP) or non-protected (NP) based on a combination of characteristics for each site (e.g. reserve status, effectiveness of enforcement, fishing gears used, accessibility – Table 1) and long-term knowledge (S.R. Floeter and C.E.L. Ferreira) of local fishing pressure. Because there are so few fully or partially protected areas in Brazil, and fewer still with nearby comparable control sites, these three paired comparisons represent a substantial portion of available data of this type.

2.2. The fish dataset

Surveys of populations of 135 different fish species were conducted from 1998 to 2002 in a variety of reef habitat types (e.g. shallow, reef wall, sand-reef interface – the depth range of these habitats varied slightly from site to site) at each site. Data from each pairwise comparison were collected in the same period. Underwater visual censuses along transects 20 or 30m long and 2m wide (40 or 60m^2) were used to count fishes in the Abrolhos and Arraial do Cabo areas (C.E.L. Ferreira) and in Guarapari islands, Laje de Santos and Arvoredo (C.E.L. Ferreira, S.R. Floeter, J.L. Gasparini, and O.J. Luiz- Júnior; Fig. 1). A pilot study was conducted in order to calibrate differences among divers regarding total number of fish per transect. No significant differences were observed among divers (ANOVA $p< 0.883$, $F= 0.124$). The number of each species was recorded for each transect, and size structure data (in four size classes: <10, 10–19, 20–30, >30cm) were collected for three abundant and conspicuous families. A 1m ruler attached to a stick was used to help estimate fish size. Two of these families are primary target fish families for spearfishing (Serranidae and Scaridae) and one is only occasionally fished in Brazilian reefs (Acanthuridae).

Fishes were grouped into fishing pressure categories based on published literature documenting the level of fishing pressure on many species (for heavily fished species) as well as the authors' (C.E.L. Ferreira and S.R. Floeter) long experience in Brazilian reef fisheries (Table 2). For example, species that are targeted by multiple gear types or fishing methods across a wide range of coastline were classified as heavily fished. Major trophic categories were assigned following Ferreira et al. (2004*a* –Table 2). Southwestern Atlantic endemic species were also analyzed separately to determine relative numbers and abundances of these species.

2.3. Data analysis

The effect of different levels of protection on the abundance of fish species was measured using the standard meta-analysis metric of the weighted response ratio (w*lnR) of each pair of more and less protected sites, with weights calculated from the standard deviation of the abundance of each fish species (Hedges et al., 1999). Weighted response ratios are used to give greater value to measurements with larger sample size and smaller variance since these measurements should be better estimates of the real value. Standard deviations were calculated from ≥ 30 transects (mean= 43.3) per site in all cases. The mean ± 95% CI of species responses within groups (fishing pressure or trophic group) was then used to determine if increased protection significantly affected groups of species. Differences in size class distributions of three families between sites were tested using the Chi-square contingency test (Zar, 1999). All analyses were done for the entire set of species and for endemic species only.

3. Results

Protection status had strong effects on the abundance of several trophic groups and heavily fished species (Figs 2 and 3). In particular, heavily targeted species were significantly more abundant in more versus less protected areas, while lightly fished and unfished species were actually more abundant in unprotected areas (Fig. 2a). At all three sites, heavily fished species were significantly more abundant in areas with greater protection, while the lightly fished and unfished species responded differently to protection at the different sites (Fig. 2b). Comparisons of responses to protection by different trophic groups showed that the piscivores, carnivores, mobile invertebrate feeders, and territorial herbivores all were significantly more abundant in protected sites, while sessile-invertebrate feeders and roving herbivores (acanthurids, small scarids and chaetodontids) were more abundant in the unprotected sites (Fig. 3). However, it is important to note that fish that are targets of spearfishing will likely be wary of divers and thus less prone to be counted in visual transects. This fact could have inflated the differences observed between protected and non or partially protected areas in terms of the main target fishes.

Results for a particular group of heavily fished, carnivorous species (Serranidae, tribe Epinephelini) showed some interesting patterns. The density and proportional abundance of this family were significantly greater in the partially protected sites at Guarapari and Arraial do Cabo compared to the less protected sites in those regions, and abundances at Pedra Vermelha (partial protection) were higher than the fully protected sites both north and south of these regions (Abrolhos, Laje de Santos, and Arvoredo; Fig. 4). These results suggest that fisheries regulations that provide partial protection to reef fishes (e.g. Pedra Vermelha) may be as effective as full no-take reserves at protecting this and similar groups of species.

Although the differences in size structure of the serranids between more and less protected sites indicate that partial protection can increase fish biomass, results for parrotfishes (Scaridae) suggest that partial protection provides minimal if any benefit for other heavily fished species (Fig. 5). The percent of observed fishes in the four size classes at the three pairwise comparisons showed significant differences in all but two cases (Serranidae in Guarapari, and Scaridae in Arraial do Cabo; see Fig. 5) but the differences for scarids and acanthurids were a result of more large fish in the more protected site only for scarids in the fully-protected site at Abrolhos (i.e., the size distributions at the other sites were different, but it was differences in the number of smaller size classes that was driving the pattern; Fig. 5). Interestingly, at Guarapari and Arraial do Cabo the largest size class of serranids (>30cm) was only found in the protected areas, and it was by far the most abundant size class in the fully-protected area in the Abrolhos region (Fig. 5). As expected, the differences in size class distribution for the surgeonfishes (Acanthuridae) was not related to levels of protection, but did show a clear latitudinal pattern where fishes became larger from north to south (Abrolhos region, 17^{o}20'S, to Arraial do Cabo, 23^{o}S; see Choat and Robertson, 2002).

The abundance of southwestern Atlantic endemic reef fishes was surprisingly high along the Brazilian coast (mean density = 19.8 fish/40m^2) and constituted a high proportion of total fish abundance (25.1%) and species richness (19.0%). This result is particularly striking since we excluded from calculations five species formerly considered endemics. Due to their large range in the Brazilian coast, they presumably originated in Brazil but have recently been found in the very southern tip of the Caribbean (Joyeux et al., 2001; Rocha, 2003 – Table 2). The density, relative abundance and number of endemic species were similar across different protection statuses and latitude (Fig. 6). In contrast, weighted meta-analyses showed that endemics were more abundant overall in less protected areas, regardless of fishing pressure, although they were actually significantly more abundant in more protected areas at two of the three locations (figures not shown).

4. Discussion

Our work highlights three important results regarding Brazilian reef fishes. First, and not surprisingly, fishing pressure had a significantly negative effect on the abundance and size of many species of fishes. These results are very similar to those of Micheli et al. (2005), Hawkins and Roberts (2004), and Graham et al. (2005) and suggest that Brazilian fishes are as threatened as fishes elsewhere in the world, and that it is similar groups of species that are threatened in Brazil. Second, traditional fisheries management (via fishing regulations) appears to be able to benefit some species, but full protection may be necessary to adequately protect and manage entire reef fish communities. Finally, endemic species constitute a large portion of the density and richness of species in reef fish communities. Although the high level of reef fish endemism in Brazil has been known for a long time (Floeter and Gasparini, 2000; 2001), our results show that these endemics also constitute a relatively large portion of the total fish abundance. Some of these species are also threatened by fishing pressure, although many appeared to not be adversely affected by fishing.

4.1. Trophic guilds and size structure

Many different species, largely from the piscivorous, carnivorous, and mobile invertebrate-feeding families, are clearly experiencing heavy fishing pressure along the Brazilian coast (Fig. 3). For example, not a single specimen of the goliath grouper (*Epinephelus itajara*) was observed at any of the sites, despite that these sites fall within the historic range of the species (and older fishermen report the species used to be common), indicating heavy threat to certain species. Even partial protection led to much greater numbers of these groups of species, indicating both that fishing poses a real threat to these species and that traditional fisheries management (e.g. gear restrictions, low fishing pressure) can successfully increase the abundances of these fishes. Results were similar in Northeastern Brazil at the Environmental Protection Area ‘Costa dos Corais’ – Tamandaré Reefs (see Fig. 1), where

Ferreira et al. (2001) reported a four-fold increase in the total abundance of studied species (from six families: Acanthuridae, Chaetodontidae, Holocentridae, Lutjanidae, Scaridae, and Serranidae) and up to an 11 times increase in lutjanid density alone in protected versus fished areas. Using traditional stock assessment models, Frédou (2004) also found that the most common lutjanids (5 species) in this region were fully or overexploited in fished areas. A few exceptions to these patterns exist, although they tend to have clear explanations. For example, roving herbivores showed an overall negative response to greater protection (Fig. 3), but this result is being driven by large numbers (although of small size classes) of these fish at Timbebas (partial protection). Roving herbivores were significantly more abundant in the more protected site at the other two locations.

Fishing pressure has already shifted to species at lower trophic levels in Brazil, as has been occurring with global fisheries (Pauly et al., 1998). For example, herbivorous parrotfishes have been the target of spearfishing during the last two decades at many locations in Brazil (Ferreira and Gonçalves, 1999). An extreme case is the large rainbow parrotfish, *Scarus guacamaia*, that has probably been fished to ecological extinction in Brazil (Ferreira et al., 2005), as it has in many areas of the Caribbean (Mumby et al., 2004). Since almost all large Brazilian parrotfish species are endemic (Moura et al., 2001), this fishing pressure threatens to drive species globally, not just locally, extinct.

The effect of fishing pressure on reef fishes can also be seen in the shift in size structure for many groups of species, regardless of trophic level. Although the differences in size structure of the serranids between more and less protected sites indicate that partial protection can increase fish biomass (Fig. 5), results for parrotfishes (Scaridae) suggest that partial protection provides minimal if any benefit for other heavily fished species (Fig. 5). Importantly, even though relative abundances of the species studied here were not always greater in more versus less protected areas, size differences for key families of fished species showed striking differences, with the largest fish in much greater numbers inside areas with greater protection (Fig. 5). These size differences appear to have accrued relatively quickly for the serranids; fishing regulations were only implemented at Arraial do Cabo in 1997 (see Table 1) yet large serranids are much more abundant in the partially protected versus unprotected site. The scarids, on the other hand, appear to have responded more to the size of the protected area and less to the length of protection. The lack of difference in size distribution for scarids in the very small protected area at Arraial do Cabo and the strong difference in the large reserve at Abrolhos suggest that species mobility may in part determine a species' response to protection, as others have noted (Kramer and Chapman, 1999). Large scarids perform considerable daily movement while feeding (greater than 3 km being common – CELF, pers obs) and the lack of response in size distribution to partial protection is likely due to large individuals roaming outside the boundaries of the protected area and being caught by spearfisherman. The heavily fished carangids also showed significantly different size structures between sites in the Abrolhos region (χ^2=63.97, $p<0.0001$; figure not shown) – the only location where size structure data were recorded for carangids—with larger sizes in the protected site (Arquipélago).

4.2. Responses to different management strategies

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; 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 (see Table 1). In all cases, heavily fished species were more abundant in the site with greater protection, but results varied for lightly fished and unfished species (Fig. 3B), and the relative change between less and more protected sites was clearly greatest at Arraial do Cabo, where fisheries are managed by local fishermen through an "Artisanal Fisheries Reserve." Surprisingly, the heavily fished groupers (mainly the Comb Grouper – *Mycteroperca acutirostris*) had the highest absolute abundance at Arraial do Cabo (Fig. 4).

These results do not necessarily indicate that fisheries management strategies based on gear or catch limits will increase fish abundances to as high a level as can be achieved with no-take zones. For example, the patterns for groupers described above may be a result of local biotic (productivity) or abiotic (temperature) factors, or strong responses by particular species within the family (e.g., *Mycteroperca acutirostris*), rather than the type of protection. In fact, the relative abundance of groupers has been shown to increase with increasing latitude along the Brazilian coast (Ferreira et al. 2004), and two Epinephelini species *Mycteroperca acutirostris* and *Epinephelus marginatus* are more associated with sub-tropical areas while in the tropical Abrolhos *M. bonaci* is the most valuable grouper. Furthermore, average response to protection from no-take reserves relative to fished sites from locations around the world (Halpern, 2003) was much higher than the average results seen here. However, our results do demonstrate that fisheries management closures can be an effective means to achieve higher abundances and larger sizes of many different 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. Consequently, even though Timbebas is a 'paper park,' differences in fish abundances between it and the Abrolhos Arquipélago (protected and enforced site) are not as large as differences between more and less protected sites in the other locations (Fig. 2b and Fig. 4). 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 (Table 1). Grouper density was lowest here of any of the sites, and average size of groupers and parrotfishes was even lower than the 'paper park' Timbebas. Some form of actual management (fishing regulations or marine reserves) is clearly needed in this region to help recover fish populations.

The variation in response of unfished species to different management strategies (Fig. 2b) is due primarily to the greater abundances of roving herbivores (acanthurids and small scarids) and the mobile invertebrate feeder *Chaetodon striatus* at Timbebas (as mentioned above) and the extreme abundance of 4 species (*Halichoeres poeyi*, *Chaetodon striatus*, *Labrisomus nuchipinnis*, and *Pseudupeneus maculatus*) at the unprotected site at Guarapari. This increase in abundance of non-target fishes, particularly for the small size classes (Fig. 5), 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., 2004*b*; Ashworth and Ormond, 2005).

4.3. Endemic reef fishes

A large proportion of the total abundance (25.1%) and species diversity (19.0%) of reef fishes are from southwestern Atlantic endemic species (Fig. 6; see also Floeter and Gasparini, 2000; 2001; Moura, 2002). Although other locations around the world are known to have relatively high numbers of endemic species (e.g., the Gulf of Guinea, isolated islands), only one other published work has found similarly high relative abundances of endemic species (the Hawaiian Islands have 31% and 21% mean relative abundance and richness of endemics, respectively; DeMartini and Friedlander, 2004). Past reports for overall proportions of endemics in Brazil (Floeter and Gasparini, 2000; 2001) were lower than results here because the visual census techniques used here focus on non-cryptic species and are not as comprehensive as methods used to assess total species richness. However, measured either way, the reef fish communities of Brazil may represent a globally unique assemblage of species.

Our results show that (in terms numerical abundance) although endemic species are on average not threatened by commercial and recreational fishing, many of these endemics are highly threatened. For example, as we noted above, many of the large parrotfish in Brazil are endemic, and these species showed clear evidence of heavy fishing pressure. Furthermore, aquarium fisheries have a notable impact on reef fisheries in other parts of the world (Wood, 2001; Sadovy and Vincent, 2002), and are fairly active along the Brazilian coast (Gasparini et al., 2005). Among the 75 species harvested for the aquarium trade in Brazil, 26 (~35%) are endemic (Gasparini et al., 2005). We were not able to evaluate the potential impact of aquarium fisheries on Brazilian reef fishes since little is known about the distribution of this type of fishing effort in Brazil. Indeed, many of the species we classified as unfished are these small, endemic species that are likely to be targets of the aquarium fisheries trade (Table 1), and so our results probably do not capture the full level of threat to Brazilian reef fishes.

4.4. Expectations and guidelines for the management of Brazilian reef fisheries

Clearly fishing pressure has an effect on reef fish communities along the Brazilian coast. Unfortunately, very little of the coastline is under any form of protection or management (see Amaral and 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 (e.g. the Espírito Santo coast). 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 (Ferreira and Maida, 2001; Ferreira et al., 2004*b*; Gerhardinger et al., 2004), and so it is encouraging that such strategies appear to provide some benefits to reef fishes. However, effective conservation will likely require some form of a network of marine protected areas as well.

It is important to note that many of the confounding factors we identified here for our results could have been avoided or quantified with the collection of fish abundance and habitat data before the creation of the marine reserves. Future efforts to establish networks of marine protected areas in Brazil should include baseline studies (i.e. surveys to assess initial conditions), whenever possible. Regardless, our results provide some important guidelines for what one can expect from Brazilian MPAs. On average, the density of heavily fished species should increase in reserves by about 10% (Fig. 2A), but exact results will be site-specific and may range as high as a 5-fold increase (Fig. 2B). In contrast, unfished and lightly fished species may decrease in abundance within reserves by as much as 10-12%, although these species can also increase in numbers in response to reserve protection. Furthermore, certain trophic groups are more likely to increase in abundance within reserves, including piscivores, carnivores, mobile invertebrate feeders, and territorial herbivores (Fig. 3). Ultimately, reserve effects on fish populations can never be fully predictable, but such guidelines can be used to establish reasonable expectations for stakeholders and governmental agencies for what the likely results from protection will be.

At the most recent Convention on Biological Diversity (CBD), 188 countries, including Brazil, signed an agreement to implement a representative network of marine protected areas by the year 2012. Although the exact amount of area that needs to be included in the network in order to protect and sustain fish populations remains debated, most agree that reserve networks should encompass at least 20–30% of a total area (e.g. NRC, 2001; Sale et al., 2005). Many countries are actively pursuing or have achieved large reserve networks – Cuba currently protects 22% of its waters (Estrada et al., 2004), and the Great Barrier Reef Marine Park in Australia was zoned to increase no-take reserves from less than 5% to 33.4% of its total area (Kemp, 2004). With less than 1% of its waters protected, Brazil is a long way off from meeting this CBD goal, although Santa Catarina, in southern Brazil, has begun working towards building a network of reserves along its coastline (Ferreira et al., 2004*c*). Our results suggest that such action is likely needed and should be effective.

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

Reef site	distance from coast (km)	MPA area	kinds of fisheries	reserve status	year of establish -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

Table 2. List of species by family with fishing pressure status and trophic group classification. *= Endemic to the southwestern Atlantic. †= present only in Brazil and the southern tip of the Caribbean (Joyeux et al., 2001; Rocha, 2003) – not included in calculations. ‡= Groupers (Epinephelini). Fishing Pressure: No = fishes not targeted by fisheries, but with some collected by the aquarium trade or by-catch only; Light = some fishing (commercial and aquarium) but not primary target species due to small sizes, low natural abundances, low commercial value; Heavy = primary targets for spearfisherman, and/or fished with multiple gears (e.g. hook and line, various kinds of nets, juveniles for the aquarium trade). Trophic Category (as defined by Ferreira et al., 2004): Pisc = piscivore; Carn = carnivore; Omni = omnivore; MIF = mobile-invertebrate feeder; SIF = sessile-invertebrate feeder; Plankt = planktivore; TH = territorial herbivore; RH = roving herbivore.

Family	**Species**	**Fishing Pressure**	**Trophic Category**
ACANTHURIDAE	*Acanthurus bahianus* Castelnau, 1855	No[1]	RH
	Acanthurus chirurgus (Bloch, 1787)	No[1]	RH
	Acanthurus coeruleus Bloch & Schneider, 1801	No[1]	RH
AULOSTOMIDAE	*Aulostomus strigosus* Wheeler, 1955	Light	Pisc
BALISTIDAE	*Balistes vetula* Linnaeus, 1758	Heavy[2,6]	MIF
BLENNIIDAE	*Hypleurochilus fissicornis* (Quoy & Gaimard, 1824)	No	Omni
	Parablennius marmoreus (Poey, 1875)	No	Omni
BOTHIDAE	*Bothus lunatus* (Linnaeus, 1758)	Light	Carn
	Bothus ocellatus (Agassiz, 1831)	Light	Carn
CARANGIDAE	*Carangoides crysos* (Mitchill, 1815)	Heavy[2,3,4,6]	Pisc
	Caranx latus Agassiz, 1831	Heavy[4,6]	Pisc
	Caranx lugubris Poey, 1860	Heavy[4,6]	Pisc
	Pseudocaranx dentex (Bloch & Schneider, 1801)	Heavy[6]	Plankt
	Selar crumenophthalmus (Bloch, 1793)	Heavy[6]	Plankt
	Seriola spp	Heavy[2,3,4,6]	Pisc
CHAENOPSIDAE	*Emblemariopsis signifera* (Ginsburg, 1942)	No	MIF
CHAETODONTIDAE	*Chaetodon sedentarius* Poey, 1860	No	SIF
	Chaetodon striatus Linnaeus, 1758	No	SIF
	Prognathodes brasiliensis (Burgess, 2001)*	No	MIF
CIRRHITIDAE	*Amblycirrhitus pinos* (Mowbray, 1927)	No	MIF
DACTYLOPTERIDAE	*Dactylopterus volitans* Linnaeus, 1758	Light	MIF
DIODONTIDAE	*Diodon hystrix* Linnaeus, 1758	No	MIF
FISTULARIIDAE	*Fistularia tabacaria* Linnaeus, 1758	Light	Pisc
GOBIIDAE	*Coryphopterus* spp	No	Plankt
	Elacatinus figaro Sazima, Moura & Rosa, 1996*	No	MIF
	Gnatholepis thompsoni Jordan, 1902	No	Omni
GRAMMATIDAE	*Gramma brasiliensis* Sazima, Gasparini & Moura, 1998*	No	MIF
HAEMULIDAE	*Anisotremus moricandi* (Castelnau, 1855)†	Heavy[6]	MIF
	Anisotremus surinamensis (Bloch, 1791)	Heavy[2,6]	MIF
	Anisotremus virginicus (Linnaeus, 1758)	Heavy[6]	MIF
	Haemulon aurolineatum Cuvier, 1830	Light	Plankt
	Haemulon plumieri (Lacepède, 1801)	Light	MIF

	Haemulon steindachneri (Jordan & Gilbert, 1882)	Light	MIF
	Orthopristis ruber (Cuvier, 1830)	Light	MIF
HOLOCENTRIDAE	*Holocentrus ascensionis* (Osbeck, 1771)	Light	MIF
	Myripristis jacobus Cuvier, 1829	Light	Plankt
KYPHOSIDAE	*Kyphosus* spp	Light	RH
LABRIDAE	*Bodianus pulchellus* (Poey, 1860)	Light	MIF
	Bodianus rufus (Linnaeus, 1758)	Light	MIF
	Clepticus brasiliensis (Heiser, Moura & Robertson, 2001)*	Light	Plankt
	Doratonotus megalepis Günther, 1862	No	MIF
	Halichoeres brasiliensis (Bloch, 1791)*	Light	MIF
	Halichoeres dimidiatus (Agassiz, 1831)*	No	MIF
	Halichoeres penrosei (Starks, 1913)*	No	MIF
	Halichoeres poeyi (Steindachner, 1867)	No	MIF
	Thalassoma noronhanum (Boulenger, 1890)*	No	Plankt
LABRISOMIDAE	*Labrisomus kalisherae* (Jordan, 1904)	No	Carn
	Labrisomus nuchipinnis (Quoy & Gaimard, 1824)	No	Carn
	Malacoctenus delalandei (Valenciennes, 1836)	No	MIF
	Malacoctenus sp.n.*	No	MIF
LUTJANIDAE	*Lutjanus jocu* (Bloch & Schneider, 1801)	Heavy[2,3,4,6]	Carn
	Lutjanus synagris (Linnaeus, 1758)	Heavy[2,3,4,6]	Carn
	Ocyurus chrysurus (Bloch, 1791)	Heavy[3,4,6]	Carn
MONACANTHIDAE	*Aluterus scriptus* (Osbeck, 1765)	Light	Omni
	Cantherhines pullus (Ranzani, 1842)	Light	Omni
	Stephanolepis hispidus (Linnaeus, 1766)	Light	Omni
MUGILIDAE	*Mugil curema* (Valenciennes, 1836)	Light	Pisc
MULLIDAE	*Mulloidichthys martinicus* (Cuvier, 1829)	Light	MIF
	Pseudupeneus maculatus (Bloch, 1793)	Light	MIF
MURAENIDAE	*Gymnothorax moringa* (Cuvier,1829)	Light	Carn
	Gymnothorax vicinus (Castelnau, 1855)	Light	Carn
OGCOCEPHALIDAE	*Ogcocephalus vespertilio* (Linnaeus, 1758)	No	Carn
OPHICHTHIDAE	*Myrichthys ocellatus* (Lesueur, 1825)	No	MIF
OSTRACIIDAE	*Acanthostracion polygonia* Poey, 1876	No	Omni
	Acanthostracion quadricornis (Linnaeus, 1758)	No	Omni
POMACANTHIDAE	*Centropyge aurantanotus* Burgess, 1974†	No	Omni
	Holacanthus ciliaris (Linnaeus, 1758)	No	SIF
	Holacanthus tricolor (Bloch, 1795)	No	SIF
	Pomacanthus arcuatus (Linnaeus, 1758)	No	Omni
	Pomacanthus paru (Bloch, 1787)	No	Omni
POMACENTRIDAE	*Abudefduf saxatilis* (Linnaeus, 1758)	No	Omni
	Chromis flavicauda (Günther, 1880)	No	Plankt
	Chromis jubauna Moura, 1995†	No	Plankt
	Chromis multilineata (Guichenot, 1853)	No	Plankt
	Microspathodon chrysurus (Cuvier, 1830)	No	TH
	Stegastes fuscus (Cuvier, 1830)*	No	TH
	Stegastes pictus (Castelnau, 1855)†	No	TH
	Stegastes variabilis (Castelnau, 1855)	No	TH
PRIACANTHIDAE	*Priacanthus arenatus* Cuvier, 1829	Light	Carn
SCARIDAE	*Cryptotomus roseus* Cope, 1871	No	RH

	Scarus trispinosus Valenciennes, 1840*	Heavy[1,5,6]	RH
	Scarus zelindae Moura, Figueiredo & Sazima, 2001*	Heavy[1,6]	RH
	Sparisoma amplum (Ranzani, 1842)*	Heavy[1,6]	RH
	Sparisoma axillare (Steindachner, 1878)*	Heavy[1,6]	RH
	Sparisoma frondosum (Agassiz, 1831)†	Heavy[1,6]	RH
	Sparisoma radians (Valenciennes, 1839)	No	RH
	Sparisoma spp (Juveniles)	No	RH
	Sparisoma tuiupiranga Gasparini, Joyeux & Floeter, 2003*	No	RH
SCIAENIDAE	*Odontoscion dentex* (Cuvier, 1830)	Light	Carn
	Pareques acuminatus (Bloch & Schneider, 1801)	No	MIF
SCORPAENIDAE	*Scorpaena brasiliensis* Cuvier, 1829	No	Carn
	Scorpaena plumieri Bloch, 1789	No	Carn
SERRANIDAE	*Alphestes afer* (Bloch, 1793)‡	Heavy[4,6]	Carn
	Cephalopholis fulva (Linnaeus, 1758)‡	Heavy[2,4,6]	Carn
	Dermatolepis inermis (Valenciennes, 1833)‡	Heavy[4,6]	Carn
	Diplectrum radiale (Quoy & Gaimard, 1824)	Light	Carn
	Epinephelus morio (Valenciennes, 1828)‡	Heavy[3,4,6]	Carn
	Mycteroperca acutirostris (Valenciennes, 1828)‡	Heavy[4,6]	Pisc
	Mycteroperca bonaci (Poey, 1861)‡	Heavy[3,4,6]	Pisc
	Mycteroperca interstitialis (Poey, 1861)‡	Heavy[4,6]	Pisc
	Paranthias furcifer (Valenciennes, 1828)	Light	Plankt
	Rypticus bistrispinus (Mitchill, 1818)	No	Carn
	Rypticus saponaceus (Bloch & Schneider, 1801)	Light	Carn
	Serranus baldwini (Evermann & Marsch, 1900)	No	MIF
	Serranus flaviventris (Cuvier, 1829)	No	MIF
	Serranus phoebe Poey, 1851	No	MIF
SPARIDAE	*Calamus* spp.	Heavy[1,6]	MIF
	Diplodus argenteus argenteus (Valenciennes, 1830)*	Heavy[6]	MIF
SYNODONTIDAE	*Synodus intermedius* (Spix & Agassiz, 1829)	No	Pisc
	Synodus synodus (Linnaeus, 1758)	No	Pisc
TETRAODONTIDAE	*Canthigaster figueiredoi* Moura & Castro, 2002*	No	SIF
	Sphoeroides greeleyi Gilbert, 1900	No	MIF
	Sphoeroides spengleri (Bloch, 1785)	No	SIF

References: [1] = Lessa and Nóbrega (2000); Acanthurids have recently been caught for the export market (since 2000) in the NE Hump of Brazil (i.e. not in the studied sites and after the sampling period). [2] = Netto et al. (2002). [3] = Costa et al. (2002). [4] = Rocha and Costa (1999). [5] = Ferreira & Gonçalves (1999). [6] = CELF's long experience in Arraial do Cabo, RJ and the Abrolhos Region, BA; and SRF's long experience in the Guarapari Islands, ES. These experiences were used to determine 'No' and 'Light' fishing pressure classifications.

Figure Legends

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).

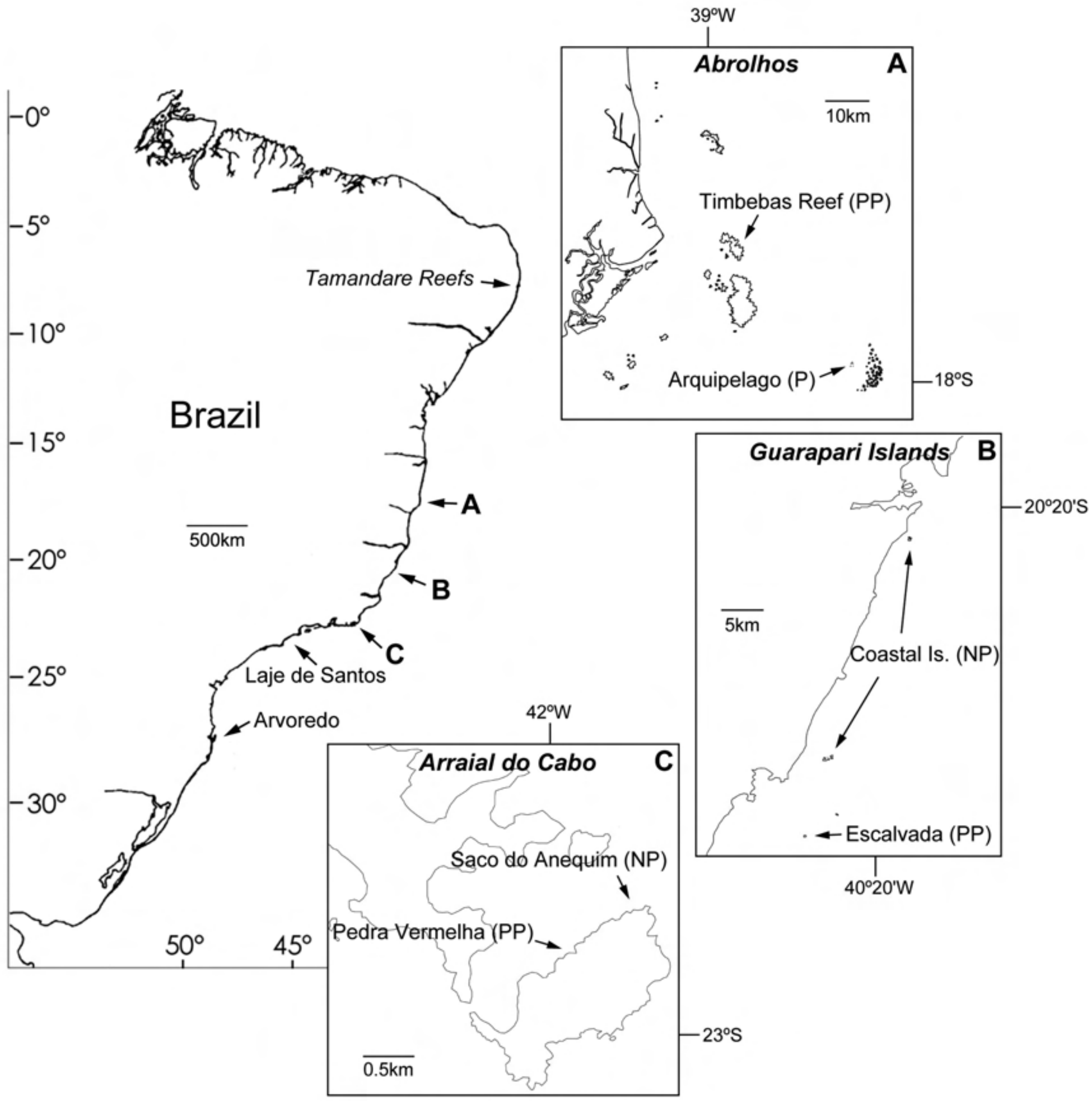
Figure 2. Weighted response ratios for more versus less protected sites for species grouped by expected fishing pressure. Results are presented for all species across all sites (A) and at each site (B). The y-axis (weighted lnR) is the variance-weighted response ratio of fish density in the more protected 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.

Figure 3. Weighted response ratios for more versus less protected sites for species grouped by trophic group. 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). See Table 2 for the key to trophic group labels on the x-axis.

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.

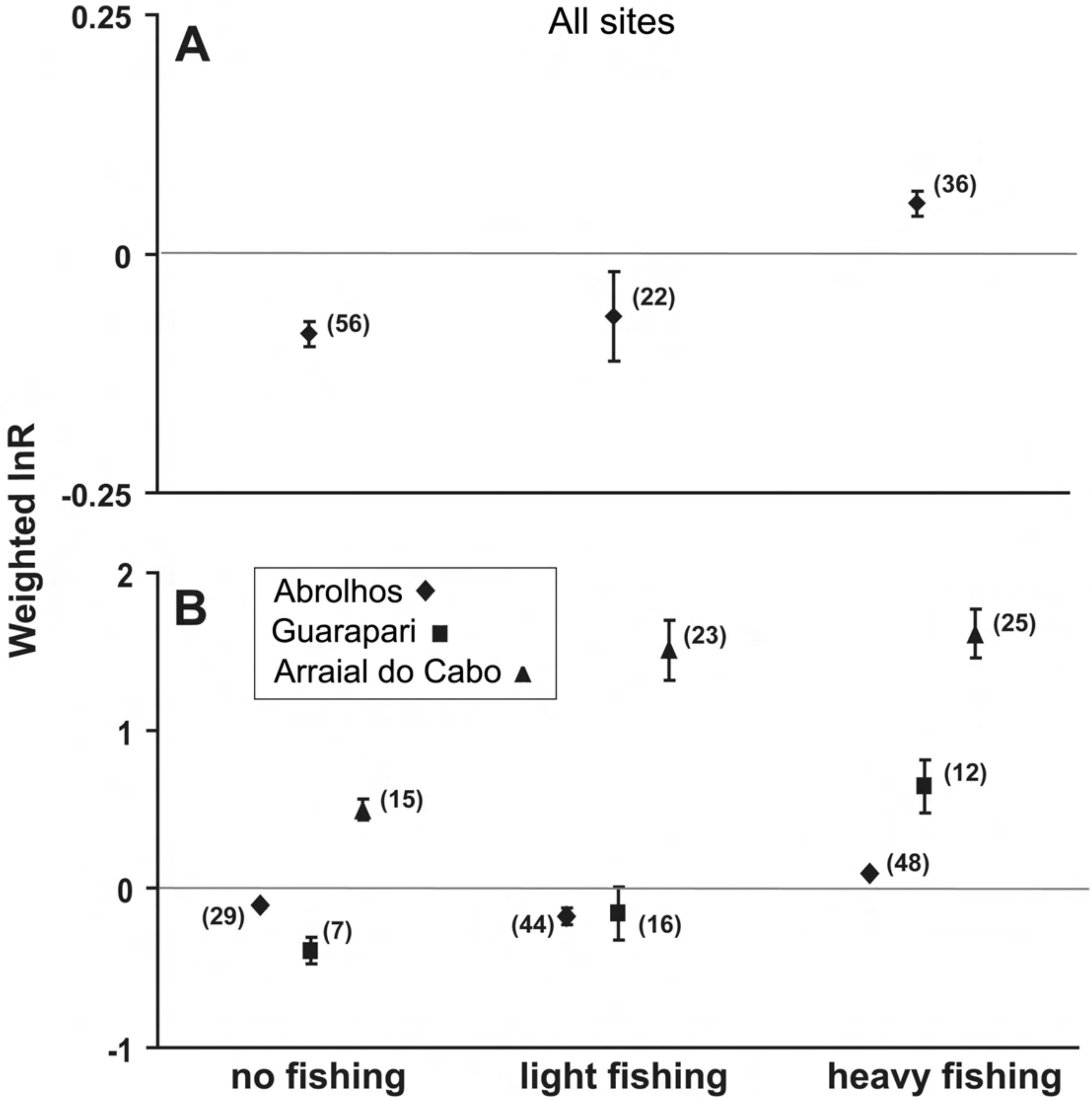
Figure 5. Size frequency distribution of serranids, scarids and acanthurids in more and less protected sites.

Figure 6. Mean density (individuals per 40 m^2), relative abundance (% of total of individuals) and relative number of endemic reef fish species (% of total species richness found in all transects in a given area) along the Brazilian coast.

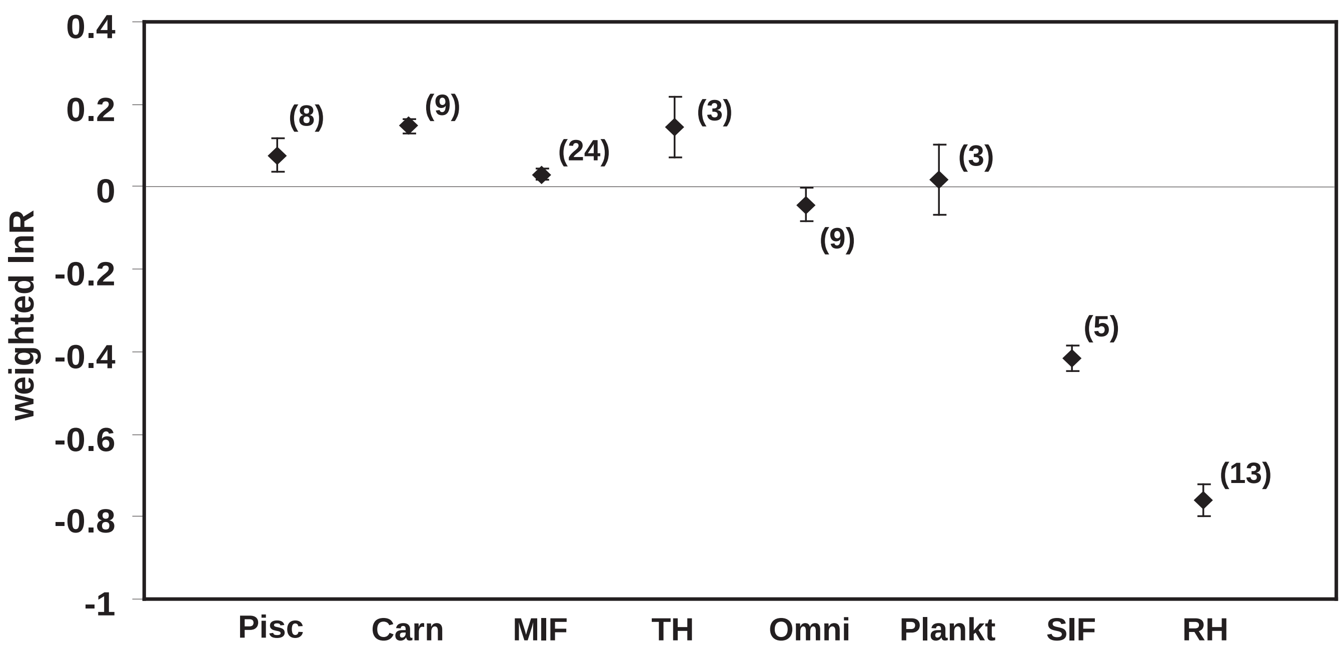


Brazil
0°
5°
10°
15°
20°
25°
30°
50°
45°
500km
Tamandare Reefs
A
B
C
Laje de Santos
Arvoredo
39ºW
Abrolhos
A
10km
Timbebas Reef (PP)
Arquipelago (P)
18ºS
Guarapari Islands
B
20º20'S
5km
Coastal Is. (NP)
Escalvada (PP)
40º20'W
42ºW
Arraial do Cabo
C
Saco do Anequim (NP)
Pedra Vermelha (PP)
23ºS
0.5km

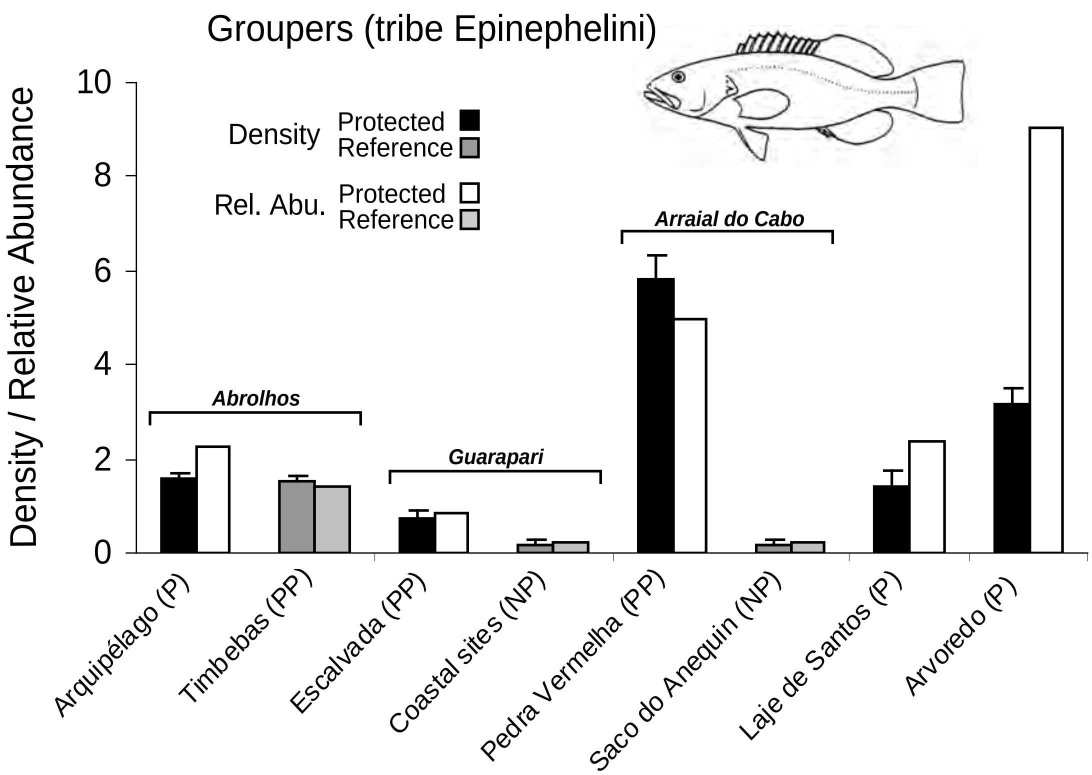
Fig 1



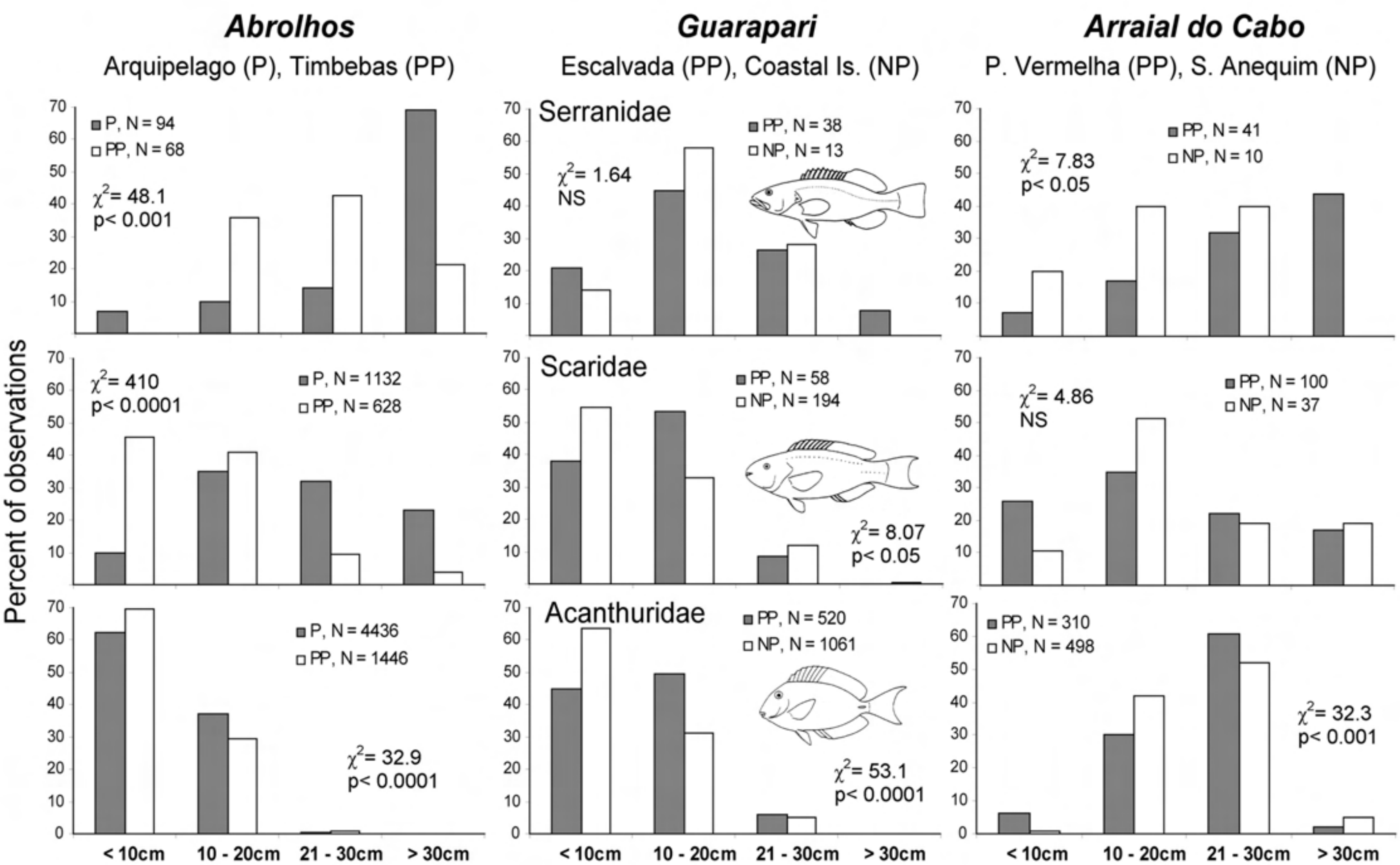
All sites
A
0.25
0
-0.25
(36)
(22)
(56)
Weighted lnR
B
2
1
0
-1
Abrolhos
Guarapari
Arraial do Cabo
(23)
(25)
(12)
(15)
(48)
(29)
(7)
(44)
(16)
no fishing
light fishing
heavy fishing



weighted lnR
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
(8)
(9)
(24)
(3)
(9)
(3)
(5)
(13)
Pisc
Carn
MIF
TH
Omni
Plankt
SIF
RH

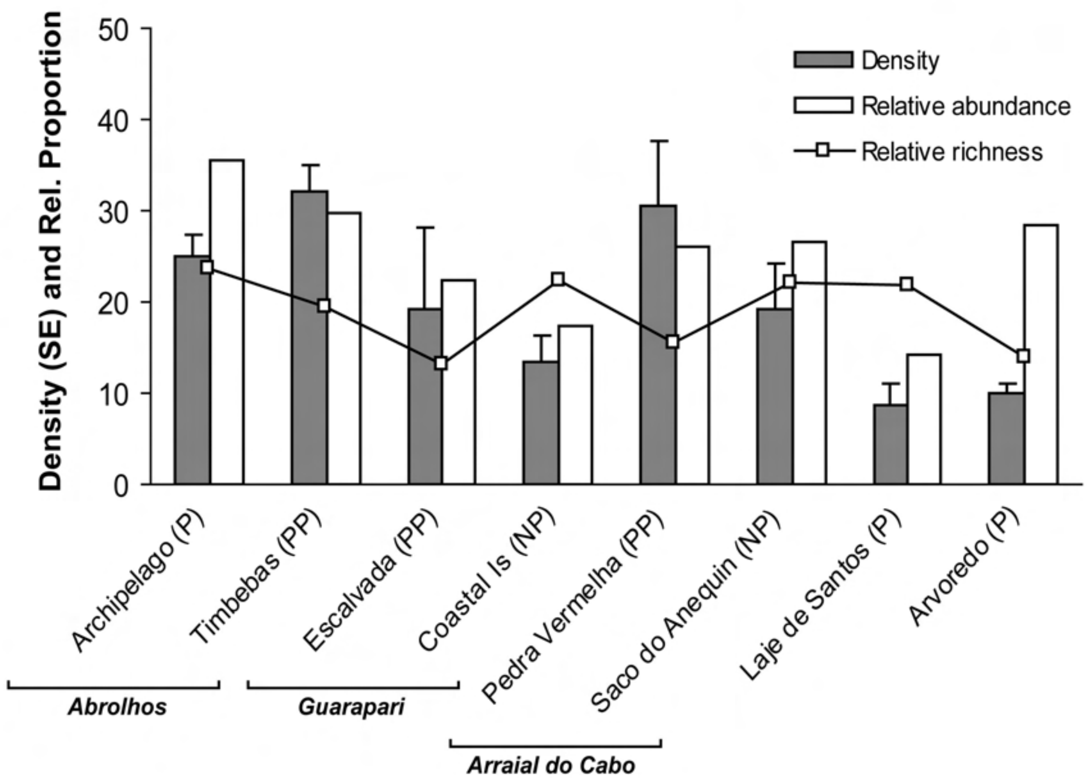


Groupers (tribe Epinephelini)
Density / Relative Abundance
10
8
6
4
2
0
Density
Protected
Reference
Rel. Abu.
Protected
Reference
Abrolhos
Guarapari
Arraial do Cabo
Arquipélago (P)
Timbebas (PP)
Escalvada (PP)
Coastal sites (NP)
Pedra Vermelha (PP)
Saco do Anequin (NP)
Laje de Santos (P)
Arvoredo (P)



Abrolhos
Arquipelago (P), Timbebas (PP)
Guarapari
Escalvada (PP), Coastal Is. (NP)
Arraial do Cabo
P. Vermelha (PP), S. Anequim (NP)
Percent of observations
P, N = 94
PP, N = 68
χ^2= 48.1
p< 0.001
Serranidae
PP, N = 38
NP, N = 13
χ^2= 1.64
NS
PP, N = 41
NP, N = 10
χ^2= 7.83
p< 0.05
χ^2= 410
p< 0.0001
P, N = 1132
PP, N = 628
Scaridae
PP, N = 58
NP, N = 194
χ^2= 8.07
p< 0.05
χ^2= 4.86
NS
PP, N = 100
NP, N = 37
P, N = 4436
PP, N = 1446
χ^2= 32.9
p< 0.0001
Acanthuridae
PP, N = 520
NP, N = 1061
χ^2= 53.1
p< 0.0001
PP, N = 310
NP, N = 498
χ^2= 32.3
p< 0.001
< 10cm
10 - 20cm
21 - 30cm
> 30cm

Fig. 5



Density (SE) and Rel. Proportion
50
40
30
20
10
0
Density
Relative abundance
Relative richness
Archipelago (P)
Timbebas (PP)
Escalvada (PP)
Coastal Is (NP)
Pedra Vermelha (PP)
Saco do Anequin (NP)
Laje de Santos (P)
Arvoredo (P)
Abrolhos
Guarapari
Arraial do Cabo

Fig. 6