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Reef fish hotspots as surrogates for marine conservation in the Brazilian coast

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A B S T R A C T

This work presents a new spatial dataset comprising biological information with analytical potential to advance reef conservation, reef fish studies and decision making at multiple levels in Brazil. Here we use reef fish hotspots as a case study to inform mismatches in the current Marine Protected Areas (MPAs) network in Brazil. Currently, MPAs protects only 2% of the Economic Exclusive Zone in Brazil. Both quantity and protection level of MPAs is uneven: while approximately 62% are for sustainable use, numbers and area of no-take MPAs are very small. We report a clear mismatch between MPAs and reef fish hotspots in Brazil, with the northeast coast and the state of Espírito Santo being the most critical areas for conservation actions. However, MPAs can no longer be considered as a 'quick fix' conservation tool, but rather, a very complex ecological/social-political operation. Therefore, MPAs networks should be expanded in these most critical areas (including more no-take zones) within a broader spatial planning to lessen user conflicts.

1. Introduction

Marine Protected Areas (MPAs) are one of the most advertised tools for ecosystem conservation and management of marine resources, however, they currently cover only 3% of the oceans (Roberts et al., 2001; Toropova et al., 2010; IUCN/UNEP-WCMC, 2013). Recently, the process of planning and creating MPAs have been more integrated to other management needs and the challenges of considering the seascape as a whole (Douvere, 2008; Halpern et al., 2010). Connectivity (and closeness) among MPA networks is regarded as one of the main characteristics for its effectiveness, to rebuild and/or to maintain levels of species biomass (*e.g.*, McCook et al., 2009; Christie et al., 2010).

Hotspots are traditionally described as areas with high richness, endemism, and/or number of species under threats (Reid, 1998), being a valuable strategy to pinpoint priority areas for conservation and protect patterns of biodiversity (Reid, 1998; Roberts et al., 2001). In this sense, hotspots have been widely used as part of the planning process for MPAs (*e.g.*, Roberts et al., 2002; Worm et al., 2003; Fox and Beckley, 2005; Lucifora et al., 2011). Nevertheless, hotspot analyses are even best informative when combined to other attributes, such as ecosystems representativeness (Reid, 1998). When such information is unavailable, the use of surrogates may be an interesting component to help meet conservation targets in areas where more refined biological data is absent (Roberts et al., 2002). In this sense, reef fish have been tested as an important surrogate for other taxa in marine conservation planning, especially at low protection targets (*i.e.*, 10–20% of the area, Ward et al., 1999; Beger et al., 2003). Moreover, reef fish are responsible for energy flow on reefs and play an important role in influencing function, structure (Bellwood et al., 2004; Dulvy et al., 2004), as well as contributing to social, economic and cultural elements of the region (Gladstone, 2007).

In Brazil, studies on marine diversity loss (*e.g.*, Amaral and Jablonski, 2005; Freire and Pauly, 2010) show results with similar patterns of global decline (*e.g.*, Burke et al., 2011; Halpern et al., 2008). Marine conservation strategies across the country can be observed in different scales, levels of governance and effectiveness (MMA, 2010; Gerhardinger et al., 2011). At the national level, the MPAs have been established since the mid-70s; other conservation

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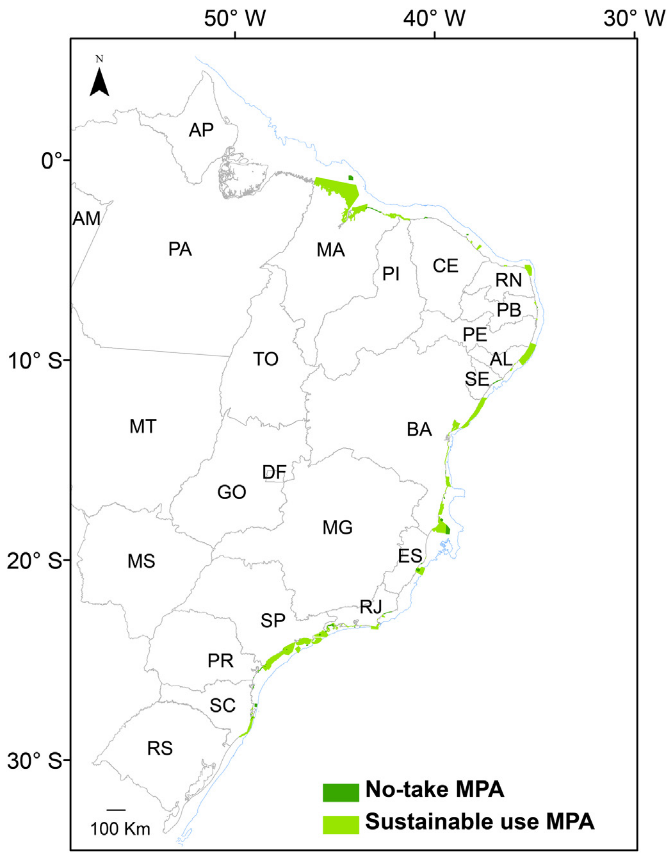

Fig. 1. Study area encompasses the coast from the state of Maranhão to the state of Santa Catarina, to a depth of 50 m (blue line). Marine Protected Areas occurring within the study area are also shown. States abbreviation (alphabetical order): AL = Alagoas, AM = Amazonas, AP = Amapá, BA = Bahia, CE = Ceará, DF = Distrito Federal, ES = Espírito Santo, GO = Goiás, MA = Maranhão, MG = Minas Gerais, MS = Mato Grosso do Sul, MT = Mato Grosso, PA = Pará, PB = Paraíba, PE = Pernambuco, PI = Piauí, PR = Paraná, RJ = Rio de Janeiro, RN = Rio Grande do Norte, RS = Rio Grande do Sul, SC = Santa Catarina, SE = Sergipe, SP = São Paulo, TO = Tocantins. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

initiatives include the development of Priority Areas for Biodiversity Conservation (MMA, 2007) and the establishment of National Action Plans (Normative Instruction No. 25/2012). Brazil currently protects only 2% of its entire Economic Exclusive Zone (MMA, 2013; Schiavetti et al., 2013) while being signatory of the Convention on Biological Diversity – CBD's 10% target for 2020 (Aichi target #11, CBD, 2011). The distribution of MPAs in Brazil is quite uneven, both in protection categories as in proportion of protected environments (MMA, 2010; Magris et al., 2013; Schiavetti et al., 2013). Reef areas are among the systems with the highest proportion within MPAs in Brazil, particularly the shallow, near shore reefs (Prates, 2006; MMA, 2010). In this context, this present study aims to use reef fish hotspots as a case study to evaluate imbalances within the current MPA network along the Brazilian coast, thus providing a snapshot of reef conservation status.

2. Methods

2.1. Study area

The study area includes the reef patches ranging from the state of Maranhão to Santa Catarina, to a depth of 50 m (Fig. 1). In Brazil, there are two main types of reefs, which may be found associated to each other or not: biogenic reefs (formed by calcareous algae, corals and/or rodolith beds) and rocky reeks (beach rocks, granite and/or sandstone) (Castro and Pires, 2001; Amado-Filho et al., 2012). The latitudinal gradient in this area encompasses tropical and subtropical weather, with a predominance of biogenic reefs on the lower latitudes which are gradually replaced by rocky reefs on higher latitudes (Floeter et al., 2001; Castro and Pires, 2001; Amado-Filho et al., 2012).

2.2. Spatial dataset

We used spatial data of MPAs in Brazil available from the Brazilian Ministry of the Environment online database (http://mapas.mma.gov.br/i3geo/datadownload.htm). MPAs included in this study were the ones located in the shallow coastal areas (<50 m deep), from the states of Maranhão to Santa Catarina. MPAs were then classified as two main groups, according to their level of protection/management: no-take (*i.e.*, no fishing) and sustainable use (where fishing is allowed) (Fig. 1).

Range distribution maps of 405 species of reef fish were generated from information on occurrence and distribution areas obtained from various sources (Carvalho-Filho, 1999; Floeter et al., 2008; Halpern and Floeter, 2008 and updates by the authors). Each map was built following a given species areas of occurrence and the maximum depth recorded for the species. Maps were built considering only the study area: in the Brazilian continental shelf, from the state of Maranhão to Santa Catarina, to the maximum depth of 50 m for better data accuracy, even if the species is known in other regions (*i.e.*, oceanic islands) and depths (>50 m). We considered reef fish as "any shallow, tropical/subtropical, benthic or benthopelagic fish that constantly associate with hard substrates of coral, calcareous algal (*i.e.*, rodolith beds), or rocky reefs or that occupy adjacent sand substrate (*i.e.*, using reef structures or the surrounding area for feeding, reproduction, and/or refuge)" (*sensu* Floeter et al., 2008). The extent of occurrence approach was used for all species (Gaston, 1994), however, for species with known disjunctive distribution, areas with no occurrences were excluded (Gaston, 1994). This approach was particularly important for small range, sedentary, very shallow water dweller species, because of their patchy distribution throughout the coast. Each range distribution map (one polygon shapefile *per* species) was also reviewed by reef fish experts (A. Carvalho-Filho, L.A. Rocha, H.T. Pinheiro) and adjustments were made if necessary.

We listed reef fish species as endemic and/or threatened following Vila-Nova et al. (2011) and Bender et al. (2012, 2013): we considered a species as threatened if it was included within the Critically Endangered, Endangered or Vulnerable categories in local, national and global Red List Inventories (see Bender et al., 2013 for more details on the Red Lists included in this study). Targeted reef fish were assigned based on searches in peer reviewed reports (Haimovici and Klippel, 1999; Gasparini et al., 2005; Floeter et al., 2006; Bender et al., 2013). For the purposes of this study, we only classified the species as targeted or not, despite the fishing activity involved (artisanal, industrial, etc.). Functional groups classification followed that used by Halpern and Floeter (2008), combining biological attributes of maximum depth (very shallow: <10 m; shallow: 10–20 m; medium: 20–50 m; deep: 50–100 m; very deep: >100 m), maximum body size (small: <10 cm; medium-small: 10–25 cm; medium: 25–50 cm; large: >50 cm) and trophic group (herbivore, macro-carnivore, mobile invertivore, sessile invertivore, omnivore, planktivore).

2.3. Dataset caveats

2.3.1. Reef fish as surrogates

Ideally, habitat protection should also be evaluated to provide estimates of MPAs coverage over critical habitats. However, the total distribution and extent of both biogenic and rocky reefs in Brazil, especially in mesophotic and deeper waters, are still unknown (Prates, 2006; MMA, 2010; Magris et al., 2013). Reef fish, on the other hand, is a group with high richness and such diversity is correlated to other marine groups (*i.e.*, corals, mollusks, crustaceans, Tittensor et al., 2010) with relevant functional roles on reefs (Bellwood et al., 2004; Dulvy et al., 2004). In Brazil, reef fish are amongst the most studied marine groups, providing robust information for the type of study this present work is performing.

2.3.2. Data poor areas

The spatial dataset created for this study encompasses the area with the highest data quality available for reef fish in Brazil. However, we acknowledge that some areas are more sampled than others. To minimize areas where data quality were not uniform, we considered for most species a continuous distribution (especially larger species with pelagic habits), unless a species is known for sedentary, territorial habits which results in a patchy distribution. The northern part of Brazil (from the state of Maranhão towards the Amazon river mouth) is one of the least studied area in the country for reef fish, although there are few reports confirming the presence of reef structures in the region (*e.g.*, Moura and Martin Rodrigues, 1999). That region receives strong currents from the Amazon River, which makes *in situ* surveys a very difficult task. It is a common claim among research groups that this area should be considered as priority for basic research on biodiversity and habitat mapping. Another important region for reef fish not included in our study are oceanic islands. Although they present much lower richness when compared to the coastal areas, oceanic islands in Brazil are remarkably responsible for hosting several endemic species, being an important component in priority policies for marine conservation.

2.4. Analysis

Both MPAs and fish data were converted to raster format within a Geographic Information System. The resolution (cell size) of rasters was set to 6.25 km^2 (2.5 × 2.5 km), and a grid containing 39 913 cells was used. This resolution was chosen after experimenting with different cell sizes that would keep a fine spatial resolution at the smallest number of cells in total. The distance between MPAs was measured to identify large regions without any protection. We considered hotspots of reef fish corresponding to the cells with the highest 10% values (Mouillot et al., 2011). Sum analyses of reef fish species were performed using the Spatial Analyst toolset (local cell statistics) in ArcGIS 10 to identify areas with higher spatial congruence. This type of analysis is performed to evaluate two or more raster themes with similar spatial resolution: for each cell on the grid, the number of species that overlay a given cell is summed. Hence, the final value assigned to a cell will be the sum of the values of the cell in each old layer (*i.e.*, one raster layer for each species) that corresponds to the location of the cell in the new layer (*i.e.*, the hotspot raster layer) (Figure S1). The sum analysis was performed using five different combination of species: total richness (using all 405 species), endemic species (using only endemic species), threatened species (using only species found in red list inventories), targeted species (using only species with economic value) and functional groups (using all groups after combining biological attributes), creating five distinct hotspot layers. Each hotspot layer was then compared with the current MPA system; cells were evaluated if they fell within an MPA and if so, at what protection level.

3. Results

The MPAs in our study area correspond to a total of 8 189 cells (20.5% of cells; ~51 181.2 km^2; $N = 66$ MPAs; Table S1), with only 0.8% being no-take MPAs (Fig. 1). The distribution of MPAs regarding its type and use is also uneven: there is a very small fraction of no-take MPAs whereas approximately 62% of MPAs are from "sustainable use" categories ($N = 41$; Fig. 1; Table S1), mainly Areas of Environmental Protection ($N = 27$). The highest concentration of MPAs (in number) is located in the state of São Paulo, and the largest area of MPAs lies on the coast of Maranhão (Fig. 1). Some large spacing among MPAs is also evident, notably with no-take MPAs: the northeast region has two no-take MPAs protecting reefs in south Bahia (Abrolhos and Recife de Fora Marine Parks), and the next no-take MPA protecting reefs further north is about 2 000 km away, in the state of Ceará (Risca do Meio Marine Park; Fig. 1). There is also a large spacing (~200 km) among MPAs from the southern part of Espírito Santo coast towards Rio de Janeiro (Fig. 1). The states of Ceará, Espírito Santo and Rio Grande do Norte have the least amount of MPAs and/or those with larger spacing between MPAs (Fig. 1).

Analyses of reef fish hotspots (10% of the highest scores) showed that, for all species combined ($N = 405$), shallow areas (up to ~10 m depth) in the northeast coast (from the state of Paraíba to central-northern Bahia) had the highest scores of richness (Fig. 2a; Figure S2). Forty-two percent of these hotspots are under some degree of protection, with the noticeable absence of no-take MPAs (Table S1). Hotspots for endemic species ($N = 54$) corresponded to regions of shallow depth (~10 m) between the states of Paraíba, Pernambuco, Alagoas, central-northern area of Bahia and south of Espírito Santo (Fig. 2b; Figure S3). In this region, 37.8% of hotspots fall within protected areas, however, no-take MPAs are again absent (Table S1). Twenty-six species of reef fish are found under IUCN threat categories. Areas of hotspots for threatened reef fish are found along the state of Espírito Santo coast (Fig. 2c; Figure S4); for that region, only 5.3% is under some level of protection, with 1% of no-takes (Table S1). Hotspots for targeted species ($N = 167$) were found in the northeast coast, from the state of Paraíba to the central area of Bahia, also from the southern part of the state of Espírito Santo to the coastline in São Paulo (Fig. 2d; Figure S5). There is a larger concentration of MPAs overlapping hotspots for targeted species in the Southern region, mainly in the state of São Paulo (Table S1). Hotspots for functional groups ($N = 77$) showed a spatial pattern very similar to total richness (Fig. 2e; Figure S6; Table S2), with 37.2% of hotspots within MPAs (>1% being no-take MPAs) (Table S1). The central-northern coast of the state of Bahia had the largest area for hotspots of total richness, endemics, targeted species and functional groups, whereas the state of Espírito Santo presented the largest area for hotspot of threatened species (Table S3).

4. Discussion

This work presents a new spatial dataset comprising biological information with analytical potential to advance reef conservation, reef fish studies and decision making at multiple levels in Brazil (*i.e.*, national, regional and/or local). By using a fast assessment/biological approach, which identified where large spacing among MPAs is evident and hotpots for reef fish are more noteworthy, this work highlights areas that are most essential for further evaluations and mitigating actions to foster reef fish conservation in Brazil.

Four regions call for special attention regarding reef fish hotspots: the area from the state of Paraíba to Alagoas, and the central–north coast of Bahia were shown as hotspots for total richness,

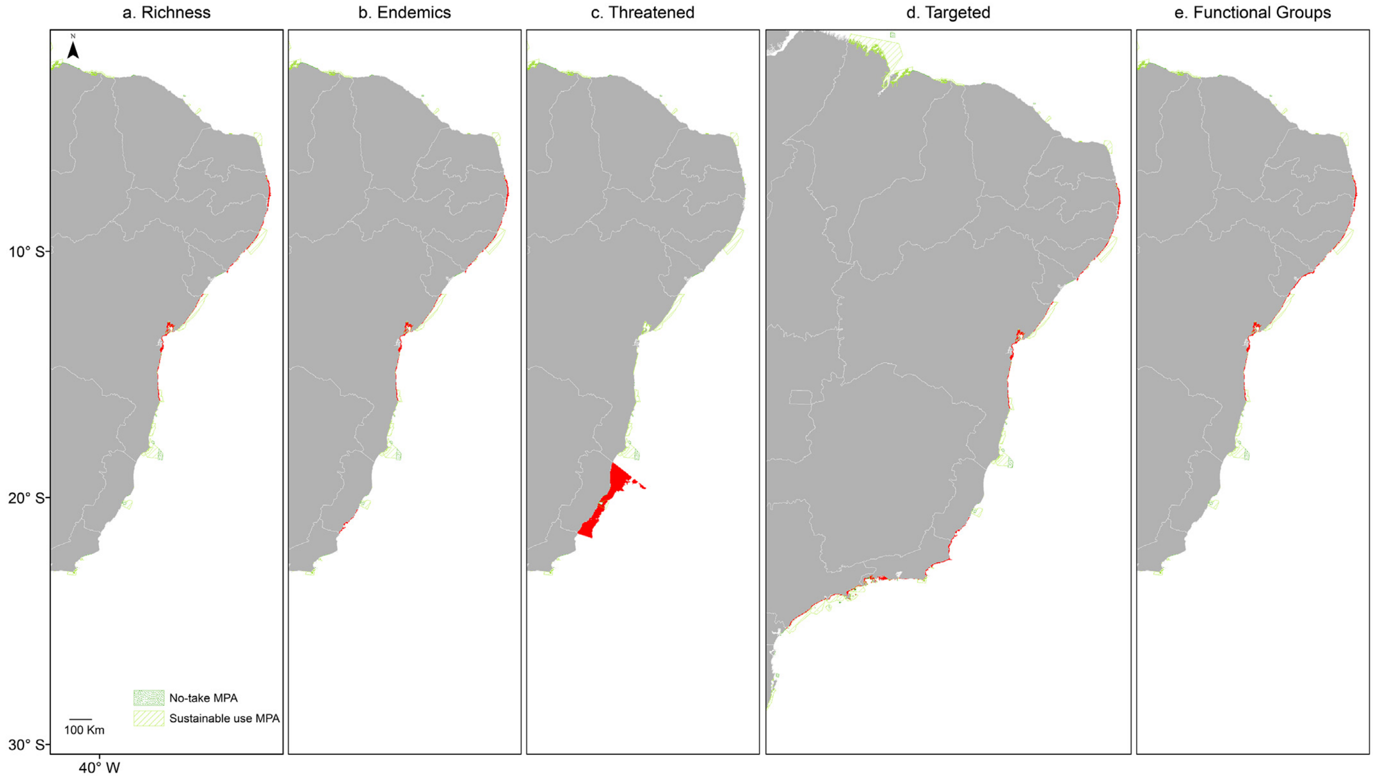

Fig. 2. Reef fish hotspots (in red), quantified as the cells with the highest 10% values: a. richness, b. endemic species, c. threatened species, d. targeted species and e. functional groups. MPAs are also shown. Refer to states abbreviation in Fig. 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

endemics, targeted species and functional groups (Fig. 2a, b, d, e; Figures S2, S3, S5, S6; Tables S1–S3). Not one no-take MPA protecting reefs (Fig. 1) can be found in the entire region, only MPAs for sustainable use with fragile evidence for reef fish recovery or ineffective management (Gerhardinger et al., 2011). Although there are some very small no-take zones within some multiple-use MPAs in the Northeast region, their total area is insufficient when compared to the reef sizes and human pressures (fishing, tourism, urbanization, etc.) existent there (Prates, 2006; Freire and Pauly, 2010; Freitas et al., 2011).

The third region, comprising the state of Espírito Santo, was included as a hotspot for endemic, threatened and targeted species (Fig. 2b, c, d; Figures S3, S4, S5; Tables S1, S3); however, it is the least protected region along the Brazilian coast. Southern Espírito Santo is considered a transitional zone between tropical and subtropical environments (*i.e.*, from biogenic to rocky reefs), which hosts several marine species from both systems. The fourth region is in the Southeast coast, ranging from the south part of the state of Espírito Santo to the state of São Paulo. This area was shown as an important hotspot for targeted species (Fig. 2d; Figure S5) and has big spacing among MPAs, particularly in the upper part near Rio de Janeiro and Espírito Santo (Fig. 1). When spacing among MPAs is too large, the performance of MPAs (especially no-take MPAs) can be lowered, particularly affecting harvested species and those with ontogenetic migration (Edwards et al., 2010; Olds et al., 2012). The high number of MPAs in the state of São Paulo and the fact that São Paulo was regarded as a hotspot for targeted reef fish (Fig. 2d; Figure S5; Table S1), indicate the important role that MPAs in this particular region may play in aiding population recovery for such species.

Given known movements of fish in general, we recognize that identifying areas of high biodiversity may provide only a constrained value which should be used with caution in management considerations. Nevertheless, this study could work as a baseline for follow-up investigations along the Brazilian coastline regarding connectivity, fishing regulations, and so on. While the actual status for species populations and MPA effectiveness was not evaluated in this study, we suggest that using the results presented here as a starting point may direct focal areas for more thorough assessments and policy decisions. Reef fish surrogacy in this case may also suggest important areas for other related species groups or habitats.

It is also worth noticing that distinct mitigating actions for specific groups, such as targeted and/or threatened species, call for complex initiatives. Such groups require frequent evaluations regarding biomass, population recovery, catch data and so on. Also, some key species group, such as top predators and herbivores, when absent may often lead to an imbalance or even collapse of the entire system (Lucifora et al., 2011; Hughes et al., 2010; Rupert et al., 2013). However, because many areas along the coast were regarded as hotspots for different combinations of reef fish groups (endemics, targeted, etc. See Fig. 2, Tables S1 and S3), we believe that multiple actions could be applied for distinct purposes (*i.e.*, fishery recovery, biodiversity maintenance, etc.). In this context, MPAs (especially no-takes) are frequently claimed to play an important role in providing enforced sites for such recovery (*e.g.*, Taylor et al., 2012), and we suggest that the large spacing among this MPA type along the Brazilian coast (Fig. 1) demands urgent action in itself.

Additionally, not only do we report a mismatch among MPAs and reef fish hotspots, but we call attention to the imbalance of MPA sizes and intended protection level (Fig. 1). Because MPAs can no longer be considered as a 'quick fix' conservation tool, but rather, a very complex ecological/social-political operation (Chuenpagdee et al., 2013), we urge that the MPA network in these most critical areas (Fig. 2) be expanded (including more no-take zones and no-take MPAs) within a broader spatial planning to lessen user conflicts (UNEP, 2011). On the other hand, the social/political/economic components - while not considered in the rapid assessment for this paper, are similarly relevant for the planning process and design of MPAs and should be incorporated in further, more applied evaluations. In a period of increasing use conflicts in the sea, the integration of different activities in the ocean must be managed together so that they remain sustainable over time (UNEP, 2011). If stakeholders are not involved from the very beginning of a given MPA's inception, it is most likely that the MPA will not effectively meet its goals once it is formally established.

In this study, areas that are frequently claimed to have important biological value for reef conservation (such as the Abrolhos banks, in southern Bahia) were not included in any of the hotspot outputs. We believe that such regions should not be excluded from national level conservation planning decisions, because of their broader marine value. The Abrolhos banks, for instance, possess a high value for humpback whales as a nursery area, and a high value for coral reef formation (Dutra et al., 2005). This is especially pertinent while acknowledging the literature claiming that hotspots may not provide a useful starting point for MPA evaluation and that other criteria should be used in a complementarity approach (*e.g.*, Turpie et al., 2000; Roberts et al., 2003). However, we do reinforce the relevance of this study as a baseline, especially since this is the first spatial assessment ever made using reef fish and MPAs at a national level in Brazil.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2014.09.005.

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