Shelf-edge reefs as priority areas for conservation of reef fish diversity in the tropical Atlantic

GEORGE OLAVO, PAULO A. S. COSTA, AGNALDO S. MARTINS and BEATRICE P. FERREIRA

SEDAR82-RD32

June 16, 2021

AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS

Aquatic Conserv: Mar. Freshw. Ecosyst. **21**: 199–209 (2011)

DOI: 10.1002/aqc.1174

Shelf-edge reefs as priority areas for conservation of reef fish diversity in the tropical Atlantic

GEORGE OLAVO[a,b,*], PAULO A. S. COSTA[c], AGNALDO S. MARTINS[d] and BEATRICE P. FERREIRA[b]
[a]*Laboratório de Biologia Pesqueira, Universidade Estadual de Feira de Santana, Brazil*
[b]*Programa de Pós-Graduação em Oceanografia, Universidade Federal de Pernambuco, Brazil*
[c]*Laboratório de Dinâmica de Populações Marinhas, Universidade Federal do Estado do Rio de Janeiro, Brazil*
[d]*Laboratório de Necton, Universidade Federal do Espírito Santo, Brazil*

ABSTRACT

1. Data from fishing surveys employing bottom long-lines were analysed to characterize the diversity, assemblages and distribution patterns of demersal fish along the Brazilian outer shelf and upper slope, between latitudes 13°S and 22°S.

2. Non-metric multi-dimensional scaling (MDS) and cluster analysis indicate three distinct species assemblages separated primarily by depth (the 200 m isobath) and secondarily by latitude (19°S), suggesting a continual transition along the depth and latitudinal gradients in the study area. Species richness was negatively correlated with depth, but with no clear relationship with latitude.

3. Results suggest the existence of reef formations on the shelf-edge zone (40–200 m) and slope down to 500 m depth off the eastern Brazilian coast. More than 75% of the catches recorded were reef fish species from the families Serranidae, Lutjanidae, Malacanthidae, Muraenidae, Sparidae, Balistidae, Carangidae, Haemulidae, Scorpaenidae and Priacanthidae.

4. The maximum depth of occurrence for 20 reef species was extended from limits previously recorded.

5. The findings reinforce the hypothesis of a faunal corridor for species associated with deep reef formations along the shelf-edge zone (40–200 m), in the South American continental margin, connecting the south-western Atlantic and the Caribbean provinces.

6. The shelf-edge reefs support important multi-species fisheries and harbour critical habitats for the life cycle of many reef fish species, including spawning aggregation sites that are extremely vulnerable to human pressures, such as intensive fishing, shipping and offshore oil and gas exploitation; all activities currently expanding off the Brazilian coast.

7. Results reveal the biological importance of deep shelf-edge reefs as a critical ecological area. Despite their importance, shelf edge reefs are not currently included in any marine protected area network in the tropical south-western Atlantic. There is now an urgent need to enhance knowledge, implement adequate management strategies and consider these deeper habitats as priority areas for conservation.

Received 3 August 2010; Revised 25 December 2010; Accepted 3 January 2011

KEY WORDS: deep reefs; snapper–grouper complex; assemblages; biodiversity; reef fisheries

INTRODUCTION

The continental shelf-edge zone is a marine ecotone characterized by the coexistence of different components of the demersal, benthic and benthopelagic communities of the continental shelf, upper slope and adjacent pelagic biota, in a narrow strip along the continental margin (Briggs, 1974; Spalding *et al.*, 2007). The depth limits of this zone situated between the shelf break and the beginning of the slope is not always clear. This ecotone, characterized by high population densities and species richness, provides a concentration of diverse fishing resources over a relatively narrow area,

---

*Correspondence to: George Olavo, Km-3, BR 116 Campus Universitário, s/n. Postal Code 44031–460 Feira de Santana, BA, Brazil. E-mail: georgeolavo@uol.com.br

sustaining important multispecific reef fisheries in the Tropical Atlantic (Longhurst and Pauly, 1987; Polunin and Roberts, 1996; Costa *et al.*, 2003, 2005; Frédou and Ferreira, 2005; Olavo *et al.*, 2005).

Increasing attention has been given to the presence of reef formations located on the continental shelf break and upper slope, particularly in the north-western Atlantic (Parker and Mays, 1998; Sedberry *et al.*, 2004; Olavo *et al.*, 2007; Francini-Filho and Moura, 2008). The Brazilian outer shelf reef formations have been characterized by Leão *et al.* (2003). Kikuchi and Leão (1998) includes a first reference to the marginal or shelf-edge reefs, classified as oceanic reefs and described for the northern coast of Bahia as structures that may reach 3 km in width, with a relief of up to 35 m and the top of the reefs located at depths of 50 m. These marginal reefs may have begun their growth in the Holocene period, 8000 years BP, building up during successive phases of changes in sea level (Leão *et al.*, 2003). They are currently colonized by crustose coralline algae, calcareous sponges, rhodolithes and macroalgae. These reef formations at the edge of the continental shelf sustain numerous local fleets dedicated to artisanal hook and line fisheries established on the eastern and north-eastern Brazilian coast (Fonteles-Filho and Ferreira, 1987; Paiva *et al.*, 1996; Costa *et al.*, 2003; Frédou and Ferreira, 2005; Olavo *et al.*, 2005; Martins *et al.*, 2006).

Knowledge of the shallow Brazilian reef ichthyofauna has increased significantly over the last decade (Ferreira *et al.*, 1995; Rocha *et al.*, 1998; Moura *et al.*, 1999; Floeter and Gasparini, 2000; Joyeux *et al.*, 2001; Moura and Francini-Filho, 2006). Recent studies have shown a diverse fauna, with similarities to the Caribbean fauna, but with a high level of endemism, suggesting that the Amazon's runoff represents a dynamic filter, allowing the dispersion of reef species, halopatric speciation and mixing between Brazilian and Caribbean faunas (Rocha, 2003; Robertson *et al.*, 2006; Floeter *et al.*, 2008).

Feitoza *et al.* (2005), in a pioneer study using underwater visual census (UVC) techniques in depths from 30 to 70 m, have shown the importance of the deep outer-shelf reefs of north-east Brazil, as part of a marine corridor (Collette and Rutzler, 1977) for the ichthyofauna on the South American continental margin, favouring connection between habitats of colder waters from the Brazilian south-east and south with the Caribbean region. Until now only very limited information from fishing surveys carried out by the REVIZEE Programme (Assessment of the Sustainable Yield of the Living Resources in the Exclusive Economic Zone) is available for deeper outer-shelf and the upper slope reef fish fauna in the north-east and central regions of the Brazilian EEZ (Fagundes-Netto *et al.*, 2005; Martins *et al.*, 2005, 2007; Olavo *et al.*, 2007).

The current study aims to perform the first comprehensive characterization of the structure of reef fish assemblages, as well as to describe patterns of species diversity and distribution on eastern Brazilian shelf-edge and upper slope reef formations. The need for implementation of effective conservation and management measures in the face of growing threats is discussed.

STUDY AREA

The study area covers the continental shelf and upper slope, down to a depth of 500 m, off the eastern Brazilian coast between the parallels 13°S and 22°S (Figure 1). The continental shelf in this area is shallow, the shelf-break occurring between depths of 40 and 80 m (França, 1979). The shelf width varies along the coast. The narrowest area

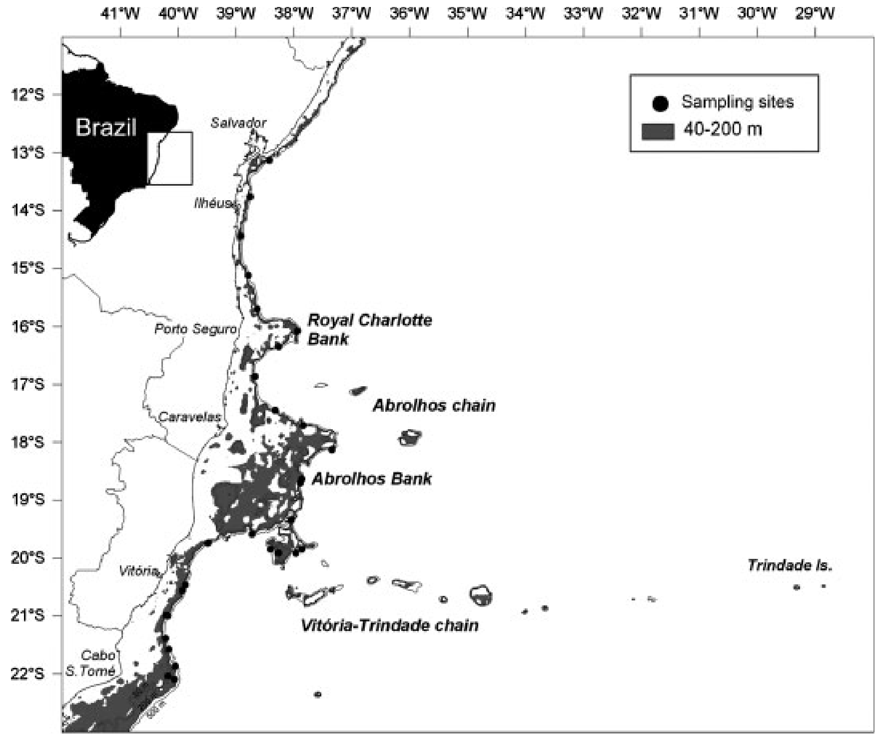

Figure 1. Study area on the eastern Brazilian coast showing the shelf edge zone (depth range 40–200 m), upper slope limit (500 m) and major submarine features (banks and seamounts). Dots represents sampling sites of experimental fishing surveys realized by REVIZEE Programme and analysed in the present study (bathymetric data: Smith and Sandwell, 1997).

(8–30 km) is located north of latitude 16°S, with a steep depth gradient and isobaths parallel to the coastline. The shelf broadens significantly to the south at Royal Charlotte and Abrolhos Banks, with a maximum width of 246 km and a gentle depth gradient (Bittencourt *et al.*, 2000). South of the 20°S parallel, the shelf is once again relatively narrow, gradually widening until the Cape São Tomé (22°S) (França, 1979). There are two chains of oceanic submarine mounts in the region: the Vitória-Trindade Chain (20–21°S) and the Abrolhos Chain (16–18°S) (Figure 1) (Martins and Coutinho, 1981).

This region represents the southernmost occurrence of the western Atlantic coral reefs, harbouring the richest coral fauna of the south Atlantic, in the region of Abrolhos Bank (Leão *et al.*, 2003). The marine biota is under the influence of three distinct water masses. The tropical water mass (TW), warm and saline, dominates the region, being transported southwards by the Brazilian Current. The south Atlantic central water (SACW), cold and less saline, is found under the TW on the continental slope. The coastal water mass (CW), warm and of low salinity, predominates on the shallow continental shelf, while the shelf-edge is characterized by the TW and by events of vertical mixing between TW and SACW (Castro and Miranda, 1998).

METHODS

Between February/March and October/November 1997 two fishing survey cruises using bottom longlines were conducted in the study area (Figure 1). These surveys were performed as part of REVIZEE research programme activities, using the chartered commercial fishing vessel *Margus II*. The longline was 10 000 m long, equipped with circular hooks (Mustad Tuna Circle Hook N°13/0 39960 D), with a 32 mm gap. It was divided into groups of 150 hooks, totalling between 24 and 35 hook-groups per sampling site. Each hook-group was considered a sampling unit. The longline was deployed twice a day at each sampling site at depths between 40 and 500 m, during sunrise and afternoon, when the number of hooks, the initial and final latitude, longitude, and depth of each hook-group were recorded with a commercial fishing sonar and GPS. The soak time for each deployment varied between 3 and 3.5 h. At the time of retrieval, the capture of each hook-group was recorded in addition to position, depth and immersion time for the hook-groups. Such a strategy permitted the re-aggregation of hook-groups per depth intervals during data analyses, covering the entire depth range.

Data from 41 sampling sites on the continental margin between 13°S and 22°S were analysed, totalling 1555 hook-groups (samples) and over 200 000 hooks. The catches in number of individual specimens (ind) and in weight (kg) were standardized for catch per unit of effort (CPUE). The fishing effort, measured by the number of hooks deployed, was expressed in units of 1000 hooks. The CPUE in number, defined as the number of specimens captured per 1000 hooks (ind/1000hooks), was adopted as relative abundance index.

The depths distribution patterns were analysed for reef fish families from the groups of hooks with captures recorded. The hook-group samples were analysed individually. The maximum depth of occurrence for each species was considered to be equal to the lower depth (shallowest hook) of the deepest sample (hook-group) in which the species was captured. The presentation of these results maintained the depth average of the selected sample, calculated as the arithmetic average between initial and final hooks of the hook-group selected, expressing depth range of the sample as error notation. The same approach was considered to establish the minimum depth of species occurrence, selecting the hook-group with the lowest depth among deepest hooks of each group. This was a conservative approach adopted to later perform comparisons with depth records previously published for the species.

In the analysis of the diversity and association of species, the samples were grouped per degree of latitude and per depth intervals of 40 m (40–79 m, 80–119 m, 120–159 m, 160–199 m, 200–239 m, 240–279 m, 280–319 m, 320–359 m, 360–399 m, 400–439 m, 440–479 m, 480–519 m, 520–559 m), recalculating the average CPUE per species per latitude and depth intervals. Species diversity was analysed in relation to depth and latitude using Margalef's index (Magurran, 1988).

To determine the patterns of association between the regrouped samples and analyse the spatial distribution of the species, hierarchical agglomerative clustering was performed and samples ordinated by multi-dimensional scaling (MDS), using the routines available in the PRIMER program (Clarke and Gorley, 2001). Samples with up to five species were excluded from the regrouped matrix. The data of numeric abundance (CPUE in ind/1000 hooks) were converted to logarithms (log CPUE+1). In all the analyses no species was deliberately excluded, even those of predominantly pelagic or characteristic of soft bottom demersal habitats, which may occasionally explore reef habitats, in order to maintain the integrity of the associations and their co-occurrence in the study area.

The Bray–Curtis' dissimilarity coefficient (Krebs, 1999) was adopted to produce a dissimilarity matrix considering the relative abundance of the species. The weighted average linkage method (WPGMA) was used in the cluster analysis, complemented by non-metric MDS. The unidirectional analysis of similarity ANOSIM (Clarke and Warwick, 1994) was applied in order to test the hypothesis of differences among the associations of species identified at different regions, in the study area. This sub-routine compares average values of similarity within groups of predefined samples, with average similarity among the groups.

Published information available on the occurrence of reef fish species in shallower areas (<40 m), not covered by the fishing surveys, was analysed to evaluate the relative importance of the shelf-edge zone (defined as the strip between 40–200 m) for species distribution and connectivity between coastal habitats. Data recorded by underwater visual census (UVC) and published by the Brazilian Coral Reef Monitoring Program (Ferreira and Maida, 2006) and by the International Conservation's Rapid Assessment Program for the coastal region of the Abrolhos bank (Moura and Francini-Filho, 2006) were compiled, as well as other records from reef fisheries monitoring conducted under the REVIZEE Programme in the study area (Costa *et al.*, 2003, 2005) and along the north-eastern Brazilian coast (Frédou and Ferreira, 2005).

The degree of dependence upon, or use of, shelf-edge zone habitats was analysed for each species from the depth range of distribution of the species, throughout the continental shelf and upper slope. To this effect, a tentative 'dependence index' was determined as a first approximation of a numerical indicator of the dependence or restricted use of the edge zone, defined thus:

1 = distribution across the continental shelf and upper slope, depths 0–500 m;

2 = distribution across the continental shelf, depths 0–200 m;

3 = distribution restricted to the shelf-edge and upper slope, depths 40–500 m;

4 = distribution restricted to the shelf-edge zone, depths 40–200 m.

Complementary information was also compiled on ecological and behavioural characteristics of these species, including preferential adult habitats (bottom type), according to Froese and Pauly (2008), as well as occurrence and type of spawning aggregation behaviour, according to Domeier and Colin (1997). Lastly, the conservation status of the snapper–grouper complex species was considered (Coleman *et al.*, 2000). Special attention was given to the species for which stock assessment was performed under the REVIZEE Programme (Klippel *et al.*, 2005; Brasil, 2006) in the study area – central region of the Brazilian EEZ. Results for the Serranidae family, Epinephelinae subfamily, were also compiled from the last evaluation of the IUCN, carried out during the Workshop for Global Red List Assessment of Groupers, in February 2007 (Sadovy, 2007).

RESULTS

Species diversity and structure of fish assemblages

In total, 101 demersal fish species of 34 families and 15 orders were recorded during the experimental fishing surveys, including 84 teleost fishes distributed over 27 families and 11 orders. An additional 17 elasmobranch species were distributed over seven families and four orders. The families with the greatest number of species were: Serranidae (16), Lutjanidae (9), Muraenidae (8), Carangidae (7), Carcharhinidae (5), Haemulidae (4) and Squalidae (4). Species diversity dropped exponentially ($r^2 = 0.91$) with depth, with the most acute drop recorded in the shallow shelf edge zone between 40 and 80 m (Figure 2). No relationship between fish species diversity and latitude was found. The number of species per sample varied between 1 and 25.

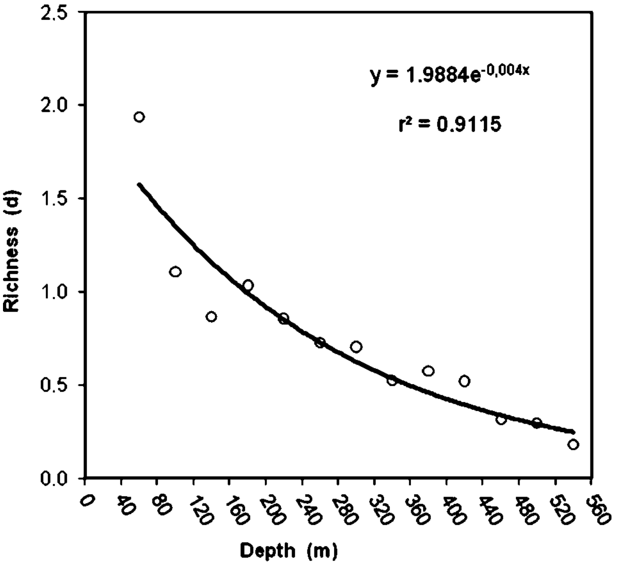

Figure 2. Depth trends of demersal fish diversity observed on the shelf edge and upper slope off eastern Brazilian coast. Average values of the Margalef's species richness index (d) were obtained per 40 m depth strata.

Three species assemblages were identified through MDS ordination (Figure 3) and cluster analysis with a cutting criteria of 80% dissimilarity (Bray–Curtis coefficient) between groups. These assemblages were distributed over the shelf-edge and upper slope, organized according to depth and latitudinal gradients. The analysis of similarity ANOSIM confirmed ($R = 0.637$) the classification results, proving the existence of significant differences ($P < 0.001$) in the composition of the three identified assemblages. The structural species obtained in the analysis of similarity percentages (SIMPER) (Clarke and Warwick, 1994) defined these three groups as characterized in Table 1 and Table 2, described as follows:

Northern shelf-edge assemblage: in the region to the north of latitude 19°S, between the shelf-break (40–80 m) and the 200 m isobath (Table 1). It was characterized by the abundance of reef species, with the coney (*Cephalopholis fulva*) and the mutton snapper (*Lutjanus analis*) explaining 52.9% of the similarity in the group. The remaining nine species comprise 90% of the group's average similarity (Table 2).

Southern shelf-edge assemblage: in the region to the south of latitude 19°S, between 40 and 200 m (Table 1). It presents high relative abundance of both reef fish and demersal species

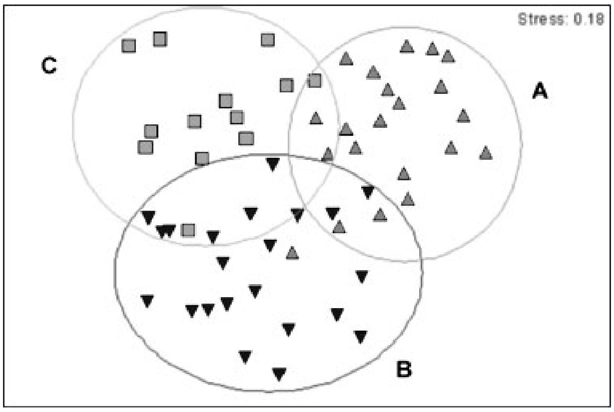

Figure 3. Ordination by non-metric multi-dimensional scaling (MDS) of samples from the bottom longline surveys realized along the eastern Brazilian continental margin. The three groups correspond to the fish assemblages identified in the northern shelf edge (A), upper slope (B) and southern shelf edge (C).

Table 1. Characteristics of the three fish assemblages identified by multivariate analysis, with percentages of average similarity (Bray–Curtis index) and number of exclusive species inside each group

Zone	Northern shelf-edge assemblage	Southern shelf-edge assemblage	Upper slope assemblage
Number of samples	21	13	22
Latitudinal range (°S)	13–18	19–22	13–22
Depth range (min-max)	40–200	40–200	200–500
Average similarity (%)	34.6	30.1	29.5
Total number of species	56	59	55
Exclusive species	21	20	18

Table 2. Species assemblages identified through cluster analysis and ordination, showing the contribution of the most abundant species (90% of total catches per group), with the average abundance per species (ind/1000 hooks) and the contribution (%) of the species inside each group

Northern shelf-edge assemblage			Southern shelf-edge assemblage			Upper slope assemblage		
Species name	Average abundance	%	Species name	Average abundance	%	Species name	Average abundance	%
Cephalopholis fulva	13.4	26.5	*Pagrus pagrus*	11.4	19.9	*Lopholatilus villarii*	11.1	32.6
Lutjanus analis	12.7	26.4	*Epinephelus niveatus*	9.4	14.4	*Epinephelus niveatus*	8.6	18.7
Balistes vetula	8.0	8.9	*Gymnothorax ocellatus*	8.3	11.6	*Etelis oculatus*	6.6	10.9
Lutjanus vivanus	6.5	7.2	*Mustelus* sp.	8.3	10.9	*Squalus megalops*	5.5	7.5
Ocyurus chrysurus	6.4	4.6	*Pseudopercis numida*	6.3	6.1	*Pseudopercis numida*	4.3	4.2
Gymnothorax sp.	4.9	3.9	*Gymnothorax vicinus*	11.1	5.2	*Urophicys cirrata*	4.4	4.2
Epinephelus niveatus	7.2	3.4	*Gymnothorax moringa*	6.3	4.1	*Lutjanus vivanus*	3.7	3.1
Mycteroperca bonaci	4.7	3.2	*Seriola dumerilli*	7.2	3.7	*Gymnothorax* sp.	3.7	2.9
Lutjanus jocu	4.8	2.9	*Mustelus canis*	5.1	3.3	*Seriola rivoliana*	3.0	2.2
Mycteroperca intertitialis	4.9	2.4	*Lutjanus vivanus*	5.2	3.2	*Pontinus rathbuni*	3.1	2.2
Gymnothorax moringa	4.1	2.3	*Caulolatilus chrysops*	4.1	3.0	*Squalus mitsukurii*	3.0	2.2
			Rhomboplites aurorubens	5.2	2.9			
			Dactylopterus volitans	4.2	1.9			

characteristic of non-consolidated substrata, in particular the occurrence of the red porgy (*Pagrus pagrus*), the snowy grouper (*Epinephelus niveatus*), the ocellated moray (*Gymnothorax ocellatus*) and the shark (*Mustelus* sp.), jointly responsible for 56.8% of the average similarity found in the group. A further nine species constitute the 13 species responsible for 90% of the group's average similarity (Table 2).

Upper slope assemblage: along the entire study area, between 200 and 500 m (Table 1). It includes demersal species characteristic of non-consolidated substrata, such as the tilefish (*Lopholatilus villarii*), the namorado sandperch (*Pseudopercis numida*) and the gulf hake (*Urophicys cirrata*), that together with the most abundant reef species, the snowy grouper, were responsible for 59.7% of the average similarity observed in the group. A further seven fish species complete the 11 species that comprise 90% of the group's average similarity (Table 2).

Some species occurred along the entire area, and were recorded in all three assemblages, such as the snowy grouper, the silk snapper (*Lutjanus vivanus*) and the ocellated moray (Table 2). Others were characteristic (exclusive) of individual assemblages. Besides the red porgy, 19 other species occurred exclusively south of Abrolhos bank. Among them are the dusky grouper (*Epinephelus marginatus*) and the sea bass (*Acanthistius brasilianus*), and sharks of the genus *Scyliorhinus*. Of a total 21 species found only in the north of the studied area, two were most abundant: the dog snapper (*Lutjanus jocu*) and the black grouper (*Mycteroperca bonaci*). In the upper slope assemblage, 18 exclusive species were recorded. The most abundant were the gulf hake, the Triakidae shark (*Squalus mitsukuri)* and the highfin scorpionfish (*Pontinus rathbuni*) (Table 2).

Reef fish depth distribution and shelf-edge importance

Table 3 shows the depth limits of occurrence of the reef species identified in the experimental fishing surveys and the preferred habitats of the adult fishes. The maximum depth limit was deeper than previously recorded for 20 species (see Table 3).

Table 4 lists the conservation status of the main species of the snapper–grouper complex, as concluded by the REVIZEE programme stock assessments, as well as by recent results of the IUCN evaluation for Epinephelinae groupers. Most of these are targets of the reef fisheries in the area and include the commercial categories responsible for the greater part of the production of the Brazilian reef fisheries (Brasil, 2006).

All 25 species in Table 4 showed some dependence or use of habitats at the shelf-edge zone. Eight grouper species were restricted to the shelf-edge zone (depth range 40–200 m). Six other species observed on the upper slope were not recorded in areas shallower than 40 m, but also occurred in the shelf-edge zone (distribution between 40 and 500 m). Six species observed in commercial fishing landings (Costa *et al*., 2005; Frédou and Ferreira, 2005) or by means of UVC (Ferreira and Maida, 2006; Moura and Francini-Filho, 2006) presented cross-shelf distribution (0–200 m). Five species presented broad distribution throughout the continental shelf and upper slope (0–500 m).

DISCUSSION

Diversity and species assemblages

The results presented provide evidence for the existence of reef formations on the shelf-edge zone (40–200 m) and also at greater depths off the eastern Brazilian coast. More than 75% of the catches recorded from the fishing surveys were reef fish species. These species were from the families Serranidae, Lutjanidae, Malacanthidae, Muraenidae, Sparidae, Balistidae, Carangidae, Haemulidae, Scorpaenidae and Priacanthidae, characteristically associated with environments formed by consolidated substrata, rocky outcrops or biogenic reef formations (Longhurst and Pauly, 1987; Bellwood and Wainwright, 2001).

Multivariate analyses are consistent in differentiating three distinct species assemblages, suggesting a gradual transition (Clarke and Warwick, 1994) between the three groups along the depth and latitudinal gradients in the study area. These assemblages can be separated primarily by the 200 m isobath.

Table 3. Depth limits of occurrence of the reef species identified during the experimental fishing surveys, with mean minimum and maximum depth ± standard error and the number (N) of samples (group of hooks) where the species was observed. The asterisk (*) indicates when the maximum depth distribution was extended from limits previously recorded for the species. It also includes the preferential adult habitats (from Froese and Pauly, 2008)

Family / Species	Common name	Depth of occurrence (surveys data)			Adult habitats (bottom type)
		Min.	Max.	N	
Serranidae					
*_Acanthistius brasilianus_	Sea bass	66±1	82±2	6	Rr, Co
*_Cephalopholis fulva_	Coney	43±2	160±30	113	Co, Rr
Dermatolepis inermis	Marbled grouper	74±3	101±1	2	Co, Rr
Diplectrum radiale	Pond perch	105±18	105±18	1	Sf, Rr, Co
Epinephelus adscensionis	Rock hind	43±2	44±3	2	Rr, Co
Epinephelus flavolimbatus	Yellowedge grouper	163±47	163±47	3	Rr, Sd, Md
Epinephelus marginatus	Dusky grouper	66±1	84±14	11	Rr
Epinephelus morio	Red grouper	52±2	295±23	37	Co, Rr, Sf
Epinephelus mystacinus	Misty grouper	205±65	205±65	1	Bd
Epinephelus nigritus	Warsaw grouper	72±1	72±1	1	Co, Rr
Epinephelus niveatus	Snowy grouper	68±1	474±24	82	Sf, Rr
*_Mycteroperca bonaci_	Black grouper	50±1	188±92	2	Co, Rr
Mycteroperca interstitialis	Yellowmouth grouper	49±1	104±6	13	Co, Rr
Mycteroperca rubra	Mottled grouper	82±2	82±2	1	Co, Rr, Sd
*_Mycteroperca tigris_	Tiger grouper	59±1	112±23	3	Co, Rr
Paranthias furcifer	Creole-fish	92±14	92±14	1	Co, Rr
Lutjanidae					
Etelis oculatus	Queen snapper	91±12	418±18	26	Rr
*_Lutjanus analis_	Mutton snapper	43±1	418±250	115	Sd, Ru, Rr, Co
Lutjanus bucanella	Blackfin snapper	161±89	161±89	1	Sd, Rr, Co
Lutjanus jocu	Dog snapper	49±1	90±16	10	Co, Rr
Lutjanus purpureus	Southern red snapper	90±8	255±33	18	Rr
Lutjanus synagris	Lane snapper	68±4	69±5	5	Sd, Ru, Rr, Co
*_Lutjanus vivanus_	Silk snapper	64±1	290±10	43	Sd, Ru, Rr, Co
Ocyurus chrysurus	Yellowtail snapper	48±2	188±92	17	Co, Rr
Rhomboplites aurorubens	Vermilion snapper	56±2	230±42	23	Rr, Co
Carangidae					
*_Caranx crysos_	Blue runner	56±1	160±30	13	Rr, Co
Caranx ruber	Bar jack	79±1	79±1	1	Rr, Co
Caranx latus	Horse-eye jack	58±1	58±1	1	Rr, Co
Seriola dumerili	Greater amberjack	67±1	185±6	13	Rr, Co
Seriola fasciata	Lesser amberjack	84±17	84±17	1	Sf, Rr
Seriola lalandi	Yellowtail amberjack	130±3	381±22	3	Rr, Co
*_Seriola rivoliana_	Almaco jack	62±1	320±36	12	Rr, Co
Muraenidae					
*_Gymnothorax conspersus_	Saddled moray	77±2	380±55	6	Sf
*_Gymnothorax funebris_	Green moray	215±39	383±97	10	Rr, Co
*_Gymnothorax madeirensis_	Sharktooth moray	185±100	357±72	2	Rr, Co
Gymnothorax moringa	Spotted moray	53±1	123±6	61	Co, Rr
Gymnothorax ocellatus	Caribbean ocellated moray	65±1	399±34	44	Sf, Rr
Gymnothorax polygonius	Polygon moray	74±3	258±21	6	Rr
*_Gymnothorax vicinus_	Purplemouth moray	69±1	375±95	22	Co, Rr
Muraena retifera	Reticulate moray	65±1	69±1	2	Sf
Haemulidae					
*_Anisotremus surinamensis_	Black margate	70±6	70±6	1	Co, Rr
*_Anisotremus virginicus_	Porkfish	66±12	66±12	1	Co, Rr
*_Haemulon aurolineatum_	Tomtate grunt	59±3	59±3	1	Sf, Co, Rr
*_Haemulon plumieri_	White grunt	43±2	68±1	13	Sf, Co, Rr
Malacanthidae					
Caulolatilus chrysops	Atlantic goldeye tilefish	59±1	204±9	13	Ru, Ra
Lopholatilus vilarii	Tile fish	74±12	490±10	194	Ru, Md, Ra
Malacanthus plumieri	Sand tilefish	56±1	91±9	5	Ru, Ra
Sparidae					
*_Calamus pennatula_	Pluma porgy	59±1	147±42	5	Sd, Ru
Pagrus pagrus	Red porgy	57±1	185±1	61	Sf, Rr
Priacanthidae					
Pontinus rathbuni	Highfin scorpionfish	285±3	540±60	25	Sf, Rr
*_Scorpaena dispar_	Hunchback scorpionfish	98±17	172±6	2	Rr
Holocentridae					
*_Holocentrus ascensionis_	Squirrelfish	60±2	274±5	10	Co, Sd, Rr
Balistidae					
Balistes vetula	Queen triggerfish	59±1	147±42	5	Sd, Ru, Rr, Co
Priacanthidae					
*_Priacanthus arenatus_	Atlantic bigeye	453±43	453±43	1	Rr, Co

Co = coral reefs, Rr = rocky reefs, Sf = soft bottoms, Ru = rubble, Sd = sand, Md = muddy bottoms.

Table 4. Status of conservation, depth distribution and shelf-edge dependence of the commercial snapper and grouper species with occurrence registered during REVIZEE's fishing surveys along the eastern Brazilian continental margin. Also summarized are the published references (see legend below) that indicate the occurrence of this species in shallower depth strata (< 40 m), across the continental shelf. The species are ordered by family and by increasing dependence on (or restricted distribution upon) the shelf-edge zone

Family/Species	Common name	IUCN Red List	REVIZEE Assessment	Cross-shelf distribution				Shelf-edge dependence
				< 20 m	20–40 m	40–200 m	> 200 m	
Serranidae								
Epinephelus morio	Red grouper	NT	—	p,m	p,m	o,p	o	1
Mycteroperca bonaci	Black grouper	NT	—	p,m,r	p,m	o,p	?o	1
Cephalopholis fulva	Coney	LC	—	p,m	p,m	o,p	—	2
Diplectrum radiale	Pond perch	—	—	m	m	o	—	2
Epinephelus adscensionis	Rock hind	LC	—	r	?o	o	—	2
Epinephelus flavolimbatus	Yellowedge grouper	VU	—	—	—	o	?o	3
Epinephelus mystacinus	Misty grouper	LC	—	—	—	?o	o	3
Epinephelus niveatus	Snowy grouper	VU	—	—	—	o	o	3
Acanthistius brasilianus	Sea bass	—	—	—	—	o	—	4
Dermatolepis inermis	Marbled grouper	LC	—	—	—	o	—	4
Epinephelus marginatus	Dusky grouper	EN	—	—	—	o	—	4
Epinephelus nigritus	Warsaw grouper	CR	—	—	—	o	—	4
Mycteroperca interstitialis	Yellowmouth grouper	VU	—	—	—	o	—	4
Mycteroperca rubra	Mottled grouper	LC	—	—	—	o	—	4
Mycteroperca tigris	Tiger grouper	NT	—	—	—	o	—	4
Paranthias furcifer	Creole-fish	LC	—	—	—	o	—	4
Lutjanidae								
Lutjanus analis	Mutton snapper	VU	Overexploited	p,t,m	p,t	o,p,t	?o	1
Lutjanus vivanus	Silk snapper	—	Threatened	—	p	o,p,t	o	1
Rhomboplites aurorubens	Vermilion snapper	—	Overexploited	p	p	o,p	?o	1
Lutjanus jocu	Dog snapper	—	Threatened	p,m,r	p,m	o,p	—	2
Lutjanus synagris	Lane snapper	—	Overexploited	p,m,r,t	p,t	o,p,t	—	2
Ocyurus chrysurus	Yellowtail snapper	—	Overexploited	m,t,r	p,m,t	o,p,t	—	2
Etelis oculatus	Queen snapper	—	—	—	—	o	o	3
Lutjanus bucanella	Blackfin snapper	—	—	—	—	o	?o	3
Lutjanus purpureus	Southern red snapper	—	Overexploited	—	—	o	o	3

Shelf-edge dependence index and depth range: 1 = distribution across the continental shelf and upper slope (0–500 m); 2 = distribution across the continental shelf (0–200 m); 3 = distribution restricted to the edge zone and upper slope (40–500 m); 4 = distribution restricted to the shelf-edge zone (40–200 m). **CR** = critically at risk, **EN** = endangered, **NT** = near threatened, **LC** = least concern, **VU** = vulnerable. **o-** observed data during the fishing surveys, **m-** Moura and Francini-Filho 2006, **p-** Costa *et al.* 2005, **r-** Ferreira and Maida 2006, **t-** Frédou and Ferreira 2005. Uncertain occurrences are indicated with question marks (?).

The importance and structuring effect of depth on demersal fish communities is well known and interrelated with other environmental factors, such as water masses, temperature and the substrata (Longhurst and Pauly, 1987; Bianchi, 1991, 1992; Haimovici *et al.*, 1994; Costa *et al.*, 2007), as well as depth-specific distribution of fishing effort (Jennings and Lock, 1996; Frédou and Ferreira, 2005; Olavo *et al.*, 2005; Morato *et al.*, 2006). The results indicate highly diverse reef fish fauna on the continental shelf-break (40–80 m), declining as depth increases to over 500 m.

Along the shelf-edge zone (40–200 m), latitude also acts as a secondary structuring factor over the reef fish communities.The results presented confirm the division of the reef ichthyofauna of the Brazilian outer shelf into a tropical component, to the north of 19°S, and another subtropical component to the south of this latitude, as observed by Martins *et al.* (2007). Costa *et al.* (2007) found that composition of assemblages of soft-bottom demersal fishes, sampled with otter trawl in the upper-slope, also change latitudinally, with a marked difference between regions north and south of the Abrolhos Bank. These two regions are under the influence of more tropical/subtropical regimes (water masses). However, the bottom longline data from the present study do not distinguish these two regions in the upper-slope zone.

The similarity observed between the southern shelf edge group and the upper slope group, may be related with the seasonal advance of SACW over the southern Brazilian shelf (Castro and Miranda, 1998), bringing to these shallower areas, the subtropical species more characteristic of the upper slope, permanently covered by SACW colder waters (< 18°C), as observed by Ávila-da-Silva (2002), such as the gulf hake, the yellowtail amberjack (*Seriola lalandi*), the saddled moray (*Gymnothorax conspersus*), Triakidae (*Mustelus* spp.) and Scyliorhinidae (*Scyliorhinus* spp.) sharks. The extreme south of the study area is a region of zoogeographic transition, influenced by both tropical and subtropical oceanographic regimes. The relatively broad outer shelf, comprises significant extensions of sandy and muddy bottoms with patchy rocky formations, and contributes to the diversity of the southern shelf edge assemblage, harbouring both reef species and species of non-consolidated substrata (Ávila-da-Silva, 2002; Martins *et al.*, 2005). From 59 species recorded on South Abrolhos Bank, there are nine different families contributing to the 13 main species in this assemblage.

The shelf edge assemblage of reef fish identified to the north of 19°S consisted of only 11 main species from four families. At least 15 of the 56 species recorded in this group are tropical, being shared with the Caribbean region, but not found or found rarely in south-eastern and southern regions of Brazil, examples are the rock hind (*Epinephelus adscencionis*), the southern red snapper (*Lutjanus purpureus*), the blackfin snapper (*L. buccanela*) and the pluma porgy (*Calamus pennatula*). This similarity with the Caribbean fauna is typical of the shallow reef fish communities of north-east Brazil, dominated by tropical species characteristic of the Caribbean (Floeter *et al.*, 2001), but limited probably by thermal restrictions that impede the spread of several species to subtropical regions in south-east Brazil.

Deep faunal corridor and connectivity

The survey data showed that for at least 20 reef species, the maximum depth limits were deeper than previously recorded (Froese and Pauly, 2008). Seven species previously considered of disjunctive (or anti-equatorial) distribution in the western Atlantic have been recorded from the north-eastern Brazilian outer shelf reefs (35–70 m) (Feitoza *et al.*, 2005). These authors, supported by Gilbert (1972) and Uyeno *et al.* (1983), presented evidence that the faunal corridor of South America (Collette and Rutzler, 1977) extends beyond the Amazon mouth area, includes the hump of Brazil and serves as a connection between cold habitats in southern Brazil and the Caribbean. The occurrence of reef species such as the snowy grouper, the tiger grouper (*Mycteroperca tigris*), the yellowedge grouper (*Epinephelus flavolimbatus*), the dusky grouper and the sea bass recorded in the northern shelf-edge region or even on the upper slope of the current study area reinforces the hypothesis of a dispersion corridor for deep reef fishes along the South American continental margin, connecting the south-western Atlantic with the Caribbean zoogeographical provinces. These species were previously considered rare in the north of Brazil (e.g. the snowy and tiger groupers) or reported only for the south-east and south of Brazil or for the Caribbean (*e.g.* the yellowedge and dusky groupers).

The apparent disjunctive distribution of these species was attributed to ecological factors such as temperature, salinity or turbidity of the water. Rocha (2003) and Moura and Sazima (2003) presented evidence of bidirectional flux of tropical species between the Caribbean and the south-western Atlantic. The barrier of the Amazon–Orinoco would merely act to interrupt or reduce the flux of species restricted to depths of up to 50 m and whose survival depends on shallow reef habitats, a characteristic of a large part of the endemic Brazilian reef fishes (Joyeux *et al.*, 2001; Rocha, 2003; Robertson *et al.*, 2006; Floeter *et al.*, 2008). The depth distribution of reef fish species observed in the current study suggest the existence of reef formations at depths that extend along the outer shelf and upper slope, broadening the potential zone of the previously mentioned corridor of marine biodiversity, in a depth strip between 40 and 500 m.

Shelf-edge importance, vulnerability and conservation

As pointed out by Ault *et al.* (1998), Parker and Mays (1998) and Coleman *et al.* (2000) for the north-western Atlantic, deeper reefs located at the outer shelf and upper slope of the south-western Atlantic also represent strategic habitats and a last refuge for reef fishes of the snapper–grouper complex distributed across the continental shelf. All of the observed commercial species of the snapper–grouper complex showed a dependence on the deep reef habitats of the shelf-edge zone, along the study area. These species include the large groupers such as the warsaw (*Epinephelus nigritus*), misty (*E. mystacinus*), marbled (*Dermatolepis inermis*), dusky, yellowedge and tiger groupers, as well as snappers (*e.g.* the queen and blackfin snappers) and the amberjacks (*Seriola* spp.).

Observations of the depth distribution, preferential habitats and spawning behaviour of the reef species in the study area permits inference on the use of the multiple habitats of the continental margin and possible ontogenetic migrations across the shelf (Lindeman *et al.*, 2000). The species that carry out ontogenetic cross-shelf migrations are the most vulnerable to processes of degradation of coastal and marine habitats (Coleman *et al.*, 2000; Frédou and Ferreira, 2005.). On the other hand, the species whose distribution is restricted to the shelf-edge zone present greater vulnerability to intensive fishing and offshore oil and gas exploitation, currently expanding off the Brazilian coast (Marchioro *et al.*, 2005; Brasil, 2007a).

The concentration of fishing effort on reef resources in the shelf-edge zone is particularly notable in the area studied. In this zone, the main fishing activity is artisanal hand line and bottom longline fishing, with many boats (over 4000) dedicated to this activity. Around 76% of the yearly fishing effort of the hook and line local fleets (hand liners and bottom long-liners) operating in the narrowest shelf stretch of the study area (13–16°S), is concentrated at the outer shelf between 30–80 m in depth, on habitats characterized by the presence of deep reefs along the shelf break (Olavo *et al.*, 2005) (Figure 4). Illegal lobster fishing using long and non-selective gill nets ('caçoeira' nets) upon the outer shelf reef and rubble habitats is another growing regional threat for habitat integrity and reef fishes captured but retained as bait in the nets, to attract more valuable lobsters. On the inner shelf, intensive bottom-trawling, targeting shallow water shrimps is responsible for degradation of key juvenile habitats and interruption of cross-shelf migrations of species of the snapper–grouper complex.

Despite the lack of published records of spawning aggregations on the Brazilian coast, the mutton and dog snappers, the rock hind and the tiger grouper are reported to carry out regional migrations to specific spawning aggregation sites within the north-western Atlantic (Domeier and Colin, 1997). They occur predominantly in site-specific deep reef habitats on the outer shelf and edge of the continental slope (Sedberry *et al.*, 2004). Considerable evidence from commercial fishing and scientific publications suggest the same behaviour for the great amberjack, the yellowedge, the snowy and the black groupers (Domeier and Colin, 1997; Lindeman *et al.*, 2000). All of these species are targets of fisheries observed in the area, including the main commercial categories responsible for the greater part of the Brazilian reef fish production (Brasil, 2006). The negative effects of industrial activities and intensive fishing on these spawning aggregation sites may make entire populations unviable and affect traditional fisheries in more shallow areas via recruitment interruptions. It may also jeopardize the integrity of reef ecosystems, reducing the connectivity between marine and coastal ecosystems, and between zoogeographical provinces (Polunin and Roberts, 1996; Coleman *et al.*, 2000; Lindeman *et al.*, 2000; Bellwood and Wainwright, 2001). There is a clear need to enhance knowledge on, and protect spawning aggregations on the Brazilian coast.

There are two other critical gaps in knowledge shown in Table 4: the stock assessment of vulnerable/threatened groupers has not been done, and the IUCN assessments of

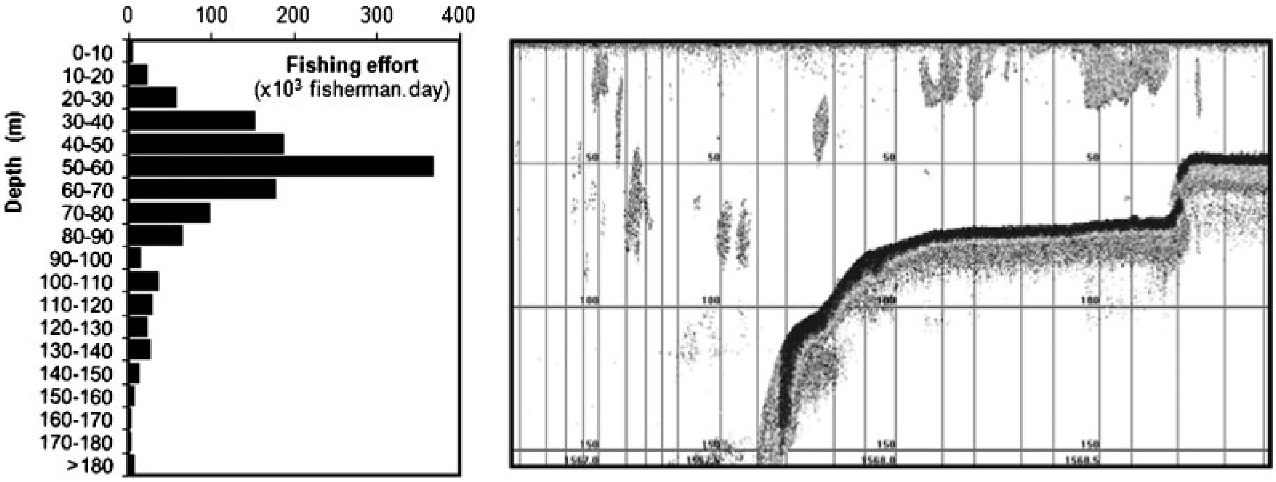

Figure 4. Depth allocation of the fishing effort estimated for the commercial hook-and-line fishing fleets based in Bahia state, operating in the study area (left). The right-hand image shows the shelf-edge bathymetric profile, between 50 and 150 m deep. Note the fishing effort concentation at the shelfbreak zone (40–80 m), characterized by the presence of marginal shelf-edge reefs (adapted from Olavo *et al*., 2005).

overfished snappers has not been done. In 2005, a Federal Act of the Ministry of Environment (MMA IN n° 5, 28/05/2005) declared the snappers *Ocyurus chrysurus*, *Romboplites aurorubens*, *Lutjanus analis* and *L. purpureus*, and the groupers *Epinephelus marginatus*, *E. morio*, *E. niveatus*, *Mycteroperca bonaci* and *M. tigris* as overexploited or threatened by overexploitation.

Owing to the ecological and behavioural peculiarities inherent to the snapper–grouper species complex and the complexity of the reef fisheries, marine protected areas (MPAs) have been proposed as an efficient alternative for the management of fishing and conservation of essential habitats for the life cycle of reef resources (Russ, 2001; Brasil, 2007b). As an area-based management tool, MPAs are considered useful in implementing both the ecosystem approach and the precautionary approach (Cooney, 2004), if effectively enforced and used concurrently with conventional management strategies including size and fishing effort limits (Coleman *et al*., 2000). In Brazil, the National Plan for Protected Areas foresees the design of a primary network of protected areas, with integral protection and no-take zones, inside auxiliary conservation areas of multiple and sustainable use, where human impacts must be minimized. This network should include several critical but still unprotected habitats such as deep reefs and mangroves, as many commercially important species undergo cross-shelf migration during their life cycle (Fredou and Ferreira, 2005). During their life cycle they are captured by different fleets at different depths and distances from the coast, depending on the gear, fishing area and width of the continental shelf in the region (Fredou and Ferreira 2005). Deeper reefs, like the ones on the shelf break, are outside the boundaries of any form of protection in Brazil (Brasil, 2007a,b). An analysis of different management regimes in the Abrolhos Bank indicate that, despite some positive signs at a local scale, the effective use of MPAs as a fishery management tool is still dependent on a larger network of MPAs including several critical but still unprotected habitats such as deep reefs (Francini-Filho and Moura, 2008).

These results reveal the biological importance of Brazil's deep shelf-edge reefs as a critical ecological area. Overexploitation of shelf edge reefs may lead to rapid loss of biodiversity, as many species are threatened with extinction. There is now an urgent need to enhance knowledge, implement adequate management strategies and include these deeper habitats as priority areas for conservation in the tropical south-western Atlantic. Despite their importance, Brazilians' shelf edge reefs are not included in any marine protected area network.

ACKNOWLEDGEMENTS

We are grateful to Jean L.Valentin (UFRJ), who has been very generous with his time and support during the coordination of the REVIZEE Programme. We thank the crew and skippers of the long-liners F/V *Cricaré* (Mr Emanuel), F/V *Margus I* (Mr Bastos) and F/V *Margus II* (Mr Antonio Bianchi), for helping with development of the fishing surveys. Thanks to Gustavo W. A. Nunan (Museu Nacional/UFRJ), for helping with the identification of moreys and Otto B. F. Gadig (Universidade Estadual Paulista Júlio de Mesquita Filho) for identification of sharks. We are also grateful to all students and research collaborators from REVIZEE, especially Adriana C. Braga (UNIRIO), Cláudio Sampaio (UFBA), Paulo R. D. Lopes (UEFS), Eduardo B. F. Netto and Luiz Ricardo Gaelzer (IEAPM) for assistance during the cruises and biological sampling. We thank Bahia Pesca S.A. for logistic support and the National Research Council (CNPq) and the Brazilian Ministry of the Environment (MMA) for financial support to the REVIZEE Programme. Many thanks to Sarah Bailey for the translation and to Dr John Baxter and the anonymous reviewers of *Aquatic Conservation* for valuable comments that significantly improved the manuscript.

REFERENCES

Ault JS, Bohnsack JA, Meester GA. 1998. A retrospective (1979–1996) multispecies assessment of coral reef fish stocks in the Florida Keys. *Fisheries Bullettin* **96**: 395–414.

Ávila-da-Silva AO. 2002. *A Evolução da Pesca de Linha-de-Fundo e a Dinâmica de População de Peixe-Batata, Lopholathilus* *villari* (*Teleostei*:*Malacanthidae*), *na Margem Continental da Costa Brasileira entre os Paralelos 22 e 28°S*. Tese de Doutorado, IOUSP/ Universidade de São Paulo, São Paulo.

Bellwood DR, Wainwright PC. 2001. The history and biogeography of fishes on coral reefs. In *Coral Reef Fishes*: *Dynamics and Diversity in a Complex System*, Sale PF (ed.). Academic Press: San Diego; 5–32.

Bianchi G. 1991. Demersal assemblages of the continental shelf and slope edge between gulf of Tehuantepec (Mexico) and Gulf of Papagayo. *Marine Ecology Progress Series* **73**: 121–140.

Bianchi G. 1992. Demersal assemblages of the continental shelf and upper slope of Angola. *Marine Ecology Progress Series* **81**: 101–120.

Bittencourt ACSP, Dominguez JML, Marin L, Silva IR. 2000. Patterns of sediment dispersion coastwise the state of Bahia – Brazil. *Anais da Academia Brasileira de Ciências* **72**: 271–287.

Brasil. 2006. *Programa REVIZEE – Avaliação do Potencial Sustentável de Recursos Vivos na Zona Econômica Exclusiva do Brasil*: *Relatório Executivo*. MMA/SQA: Brasília.

Brasil. 2007a. *Áreas prioritárias para a conservação, uso sustentável e repartição dos benefícios da biodiversidade brasileira*: *atualização – Portaria MMA no. 9, de 23 de janeiro de 2007*. MMA/SBF: Brasília (Série Biodiversidade 31).

Brasil. 2007b. *Áreas aquáticas protegidas como instrumento de gestão pesqueira*. MMA/SBF: Brasília (Série Áreas Protegidas 4).

Briggs JC. 1974. *Marine Zoogeography*. McGraw-Hill Book Co.: New York.

Castro BM, Miranda LB. 1998. Physical oceanography of the Western Atlantic continental shelf located between 4°N and 34°S. In *The Sea*, Robinson A, Brink K (eds). John Wiley & Sons: New York; 209–251.

Clarke KR, Warwick RM. 1994. *Change in Marine Communities*: *an Approach to Statistical Analysis and Interpretation*. Plymouth Marine Laboratory: Plymouth.

Clarke KR, Gorely RN. 2001. *PRIMER v5*: *User Manual/Tutorial, E-Primer Ltd.* Plymouth Marine Laboratory: Plymouth.

Coleman FC, Koening CC, Huntsman JA, Musick JA, Eklund AM, McGovern JC, Chapman RW, Sedeberry GR, Grimes CB. 2000. Long-lived reef fishes: the grouper-snapper complex. *American Fishery Society Policy Statement*. *Fisheries* **25**: 14–20.

Collette BB, Rutzler K. 1977. Reef fishes over sponge bottoms off the mouth of the Amazon River. *Proceedings of the 3rd International Coral Reef Symposium* **1**: 305–310.

Cooney R. 2004. The Precautionary Principle in Biodiversity Conservation and Natural Resource Management: an Issues Paper for Policy-makers, Researchers and Practitioners. IUCN: Cambridge.

Costa PAS, Braga AC, Frota LOR. 2003. Reef fisheries in Porto Seguro, eastern Brazilian coast. *Fisheries Research* **60**: 577–583.

Costa PAS, Olavo G, Martins AS. 2005. Áreas de pesca e rendimentos da frota de linheiros na região Central da costa Brasileira entre Salvador-BA e o Cabo de São Tomé-RJ. In *Pesca e Potenciais de Exploração de Recursos Vivos na Região Central da Zona Econômica Exclusiva Brasileira*, Costa PAS, Martins AS, Olavo G (eds). Museu Nacional: Rio de Janeiro; 57–70 (Série Livros n.13).

Costa PAS, Braga AC, Melo MRS, Nunan GWA, Martins AS, Olavo G. 2007. Assembléias de teleósteos demersais no talude da costa Central brasileira. In *Biodiversidade da Fauna Marinha Profunda na Costa Central Brasileira*, Costa PAS, Olavo G, Martins AS (eds). Museu Nacional: Rio de Janeiro; 87–107 (Série Livros n.24).

Domeier ML, Colin PL. 1997. Tropical reef fish spawning aggregations: defined and reviewed. *Bulletin of Marine Science* **60**: 698–726.

Fagundes-Netto E, Gaelzer LR, Carvalho WF, Costa PAS. 2005. Prospecção de recursos demersais com armadilhas e pargueiras na região Central da Zona Econômica Exclusiva entre Salvador (13°S) e o Cabo de São Tome (22°S). In *Pesca e Potenciais de Exploração de Recursos Vivos na Região Central da Zona Econômica Exclusiva Brasileira*, Costa PAS, Martins AS, Olavo G (eds). Museu Naciona: Rio de Janeiro; 129–143 (Série Livros n. 13).

Feitoza BM, Rosa RS, Rocha LA. 2005. Ecology and zoogeography of deep-reef fishes in northeastern Brazil. *Bulletin of Marine Science* **76**: 725–742.

Ferreira BP, Maida M. 2006. *Monitoramento dos Recifes de Coral do Brasil*: *Situação Atual e Perspectivas*. MMA/SBF: Brasília (Série Biodiversidade 18).

Ferreira BP, Maida M, Souza AAET. 1995. Levantamento inicial das comunidades de peixes recifais da região de Tamandaré, PE. *Boletim Técnico Científico do CEPENE* **3**: 211–230.

Floeter SR, Gasparini JL. 2000. The southwestern Atlantic reef fish fauna: composition and zoogeographic patterns. *Journal of Fish Biology* **56**: 1099–1114.

Floeter SR, Guimarães RZP, Rocha LA, Ferreira CEL, Rangel CA, Gasparini JL. 2001. Geographic variation in reef-fish assemblages along the Brazilian coast. *Global Ecology and Biogeography* **10**: 423–431.

Floeter SR, Rocha LA, Robertson DR, Joyeux JC, Smith-Vaniz WF, Wirtz P, Edwards AJ, Barreiros JP, Ferreira CEL, Gasparini JL, *et al.* 2008. Atlantic reef fish biogeography and evolution. *Journal of Biogeography* **35**: 22–47.

Fonteles-Filho AA, Ferreira FTP. 1987. Distribuição geográfica das capturas do pargo (*Lutjanus purpureus* Poey) e sua relação com fatores oceanográficos nas regiões Norte e Nordeste do Brasil. *Boletim de Ciências do Mar* **45**: 1–23.

França JJC. 1979. Geomorfologia da margem continental leste brasileira e da bacia oceânica adjacente. *PETROBRAS Série Projeto REMAC* **7**: 89–127.

Francini-Filho RB, Moura RL. 2008. Dynamics of fish assemblages on coral reefs subjected to different management regimes in the Abrolhos Bank, eastern Brazil. *Aquatic Conservation*: *Marine and Freshwater Ecosystems* **18**: 1166–1179.

Frédou T, Ferreira B. 2005. Bathymetric trends of northeastern Brazilian snappers (Pisces, Lutjanidae): implications for the reef fishery dynamic. *Brazilian Archives of Biological Technology* **48**: 787–800.

Froese R, Pauly D (eds). 2008. *FishBase*. World Wide Web electronic publication. www.fishbase.org, version (04/2008).

Gilbert CR. 1972. Characteristics of the western Atlantic reef-fish fauna. *Quarternary Journal of Florida Academic Science* **35**: 130–144.

Haimovici M, Martins AS, Figueiredo JL, Vieira PC. 1994. Demersal bony fishes of the outer shelf and upper slope of the southern Brazil Subtropical Convergence Ecosystem. *Marine Ecology Progress Series* **108**: 59–77.

Jennings S, Lock JM. 1996. Population and ecosystem effects of reef fishing. In *Reef Fisheries*, Polunin NVC, Roberts CM (eds). Chapman & Hall: London; 193–218.

Joyeux JC, Floeter SR, Ferreira CEL, GaspariniI JL. 2001. Biogeography of tropical reef fish: the South Atlantic puzzle. *Journal of Biogeography* **28**: 831–841.

Kikuchi RKP, Leão ZMAN. 1998. The effects of Holocene sea level fluctuation on reef development and coral community structure, Northern Bahia, Brazil. *Anais da Academia Brasileira de Ciências* **70**: 159–171.

Klippel S, Olavo G, Costa PAS, Martins AS, Peres MB. 2005. Avaliação dos estoques de lutijanídeos da costa central do Brasil: análise de coortes e modelo preditivo de Thompson e Bell para comprimentos. In *Pesca e Potenciais de Exploração de Recursos Vivos na Região Central da Zona Econômica*

Exclusiva Brasileira, Costa PAS, Martins AS, Olavo G (eds). Museu Nacional: Rio de Janeiro; 83–98 (Série Livros n.13).

Krebs CJ. 1999. *Ecological Methodology*. Addison-Wesley Educational Publishers: California.

Leão ZMAN, Kikuchi RKP, Testa V. 2003. Corals and coral reefs of Brazil. In *Latin American Coastal Reefs*. Cortés J (ed.). Elsevier Science: Amsterdam; 9–52.

Lindeman KC, Pugliese R, Waugh GT, Ault J. 2000. Developmental patterns with a multispecies reef fishery: management applications for essential fish habitats and protected areas. *Bulletin of Marine Science* **66**: 929–956.

Longhurst AR, Pauly D. 1987. *Ecology of Tropical Oceans*. Academic Press: New York.

Magurran AE. 1988. *Ecological Diversity and its Measurement*. Croom Helm: London.

Marchioro GB, Nunes MA, Dutra GF, Moura RL, Pereira PGP. 2005. Avaliação dos impactos da exploração e produção de hidrocarbonetos no Banco dos Abrolhos e adjacências. *Megadiversidade* **1**: 225–310.

Martins AS, Olavo G, Costa PAS. 2005. Recursos demersais capturados com espinhel de fundo no talude superior da região entre Salvador (BA) e o Cabo de São Tomé (RJ). In *Pesca e Potenciais de Exploração de Recursos Vivos na Região Central da Zona Econômica Exclusiva Brasileira*, Costa PAS, Martins AS, Olavo G (eds). Museu Nacional: Rio de Janeiro; 109–128 (Série Livros n.13).

Martins AS, Costa PAS, Olavo G, Haimovici M. 2006. Recursos Pesqueiro da Região Central. In *Relatório Executivo do Programa REVIZEE - Avaliação do Potencial Sustentável de Recursos Vivos na Zona Econômica Exclusiva, Brasil*. MMA/SQA: Brasília; 181–206.

Martins AS, Olavo G, Costa PAS. 2007. Padrões de distribuição e estrutura de comunidades de grandes peixes recifais na costa central do Brasil. In *Biodiversidade da Fauna Marinha Profunda na Costa Central Brasileira*, Costa PAS, Olavo G, Martins AS (eds). Museu Nacional: Rio de Janeiro; 45–61 (Série Livros n.24).

Martins LR, Coutinho PN. 1981. The Brazilian continental margin. *Earth Sciences Review* **17**: 87–107.

Morato T, Watson R, Pitcher TJ, Pauly D. 2006. Fishing down the deep. *Fish and Fisheries* **7**: 24–34.

Moura RL, Francini-Filho RB. 2006. Reef and shore fishes of the Abrolhos Region, Brazil. In Rapid Marine Biodiversity Assessment of the Abrolhos Bank, Bahia, Brazil, Dutra GF, Allen GR, Werner T, McKenna AS (eds). *RAP Bulletin of Biological Assessment* **38**: 40–55.

Moura RL, Sazima, I. 2003. Species richness and endemism levels of the Southwestern Atlantic reef fish fauna. In *Proceedings of the International Coral Reef Symposium*, 9, 2000, Bali, Indonesia. Indonesia Institut of Sciences: 481–486.

Moura RL, Francini-Filho RB, Rodrigues MCM, Sazima I. 1999. Unexpected richness of reef corals near the southern Amazon River mouth. *Coral Reefs* **18**: 170.

Olavo G, Costa PAS, Martins AS. 2005. Caracterização da pesca de linha e dinâmica das frotas linheiras da Bahia, Brasil. In *Pesca e Potenciais de Exploração de Recursos Vivos na Região Central da Zona Econômica Exclusiva Brasileira*, Costa PAS, Martins AS, Olavo G (eds). Museu Nacional: Rio de Janeiro; 13–34 (Série Livros n.13).

Olavo G, Costa PAS, Martins AS. 2007. Estrutura de comunidades de peixes recifais na plataforma externa e talude superior da costa central brasileira: diversidade e distribuição batimétrica. In *Biodiversidade da Fauna Marinha Profunda na Costa Central Brasileira*, Costa PAS, Olavo G, Martins AS (eds). Museu Nacional: Rio de Janeiro; 15–43 (Série Livros n.24).

Paiva MP, Rocha CAS, Gomes AMG, Andrade MF. 1996. Fishing grounds of bottom-liners on the continental shelf of southeast Brazil. *Fisheries Management and Ecology* **3**: 25–33.

Parker RO, Mays RW. 1998. Southeastern U.S. deepwater reef fish assemblages, habitat characteristics, catch and life history summaries. *NOAA Technical Report NMFS* **138**: 1–41.

Polunin V, Roberts CM (ed.). 1996. *Reef Fisheries*. Chapman & Hall: London.

Robertson DR, Karg F, Moura RL, Victor BC, Bernardi G. 2006. Mechanisms of speciation and faunal enrichment in Atlantic parrotfishes. *Molecular Phylogenetics and Evolution* **40**: 795–807.

Rocha LA. 2003. Patterns of distribution and processes of speciation in Brazilian reef fishes. *Journal of Biogeography* **30**: 1161–1171.

Rocha LA, Rosa IL, Rosa RS. 1998. Peixes recifais da costa da Paraíba, Brasil. *Revista Brasileira de Zoologia* **15**: 553–566.

Russ GR. 2001. Yet another review of marine protected areas as fishery management tool. In *Coral Reef Fishes: Dynamics and Diversity in a Complex System*, Sale PF (ed.). Academic Press: San Diego; 421–444.

Sadovy Y (org.). 2007. *Workshop for Global Red List Assessments of Groupers Family Serranidae: Subfamily Epinephelinae*. University of Hong Kong: Hong Kong.

Sedberry GR, Cooksey CL, Crowe SF, Hyland J, Jutte PC, Ralph CM, Sautter LR. 2004. *Characterization of Deep Reef Habitat off the Southeastern U.S., with Particular Emphasis on Discovery, Exploration and Description of Reef Fish Spawning Sites*. Marine Resources Research Institute: Charleston.

Smith W, Sandwell D. 1997. Global seafloor topography from satellite altimetry and ship depth soundings. *Science* **277**: 1956–1962.

Spalding MD, Fox HE, Allen GR, Davidson N, Ferdaña ZA, Finlayson M, Halpern BS, Jorge MA, Lombana A, Lourie SA, *et al*. 2007. Marine ecorregions of the World: a biorregionalization of coastal and shelf areas. *BioScience* **57**: 573–583.

Uyeno TK, Matsuura K, Fugi E. 1983. *Fishes Trawled off Suriname and French Guiana*. Japan Marine Fishery Resource Research Center: Tokyo.