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Reef fish assemblage and zoogeographic affinities of a scarcely known region of the western equatorial Atlantic

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Based on data from 151 underwater surveys (scuba) between 2002 and 2007, the present study assessed the reef fish fauna from a scarcely known region on the north-eastern Brazilian coast (Ceará State). A checklist of 179 taxa is provided and the zoogeographic patterns are analysed and discussed, including six other localities. Based only on assemblage composition, the reef fish fauna from Ceará showed a strong resemblance (73%) with the reefs of Risca do Zumbi (RN) and Paraiba (PB). The data from the visual censuses including abundance values corroborate the evaluation based only on composition and suggest ecological factors as the main drivers of the fish assemblages in the region.

Keywords: marine biogeography, fish zoogeography, marine fishes, biodiversity, north-east Brazil

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INTRODUCTION

The tropical reef ecosystems are recognized not only for their great biological diversity and complexity, but also for their susceptibility to local and global anthropic impacts (Roberts *et al.*, 2002). On the reefs, fish are among the best-studied groups, as a result of the larger number of specialists, relatively easy taxonomy and long-standing methods of assessment. Nevertheless, there are many tropical reefs worldwide from where information is scant or even absent (Costello *et al.*, 2010). In a rapidly changing world, knowledge of the composition and functioning of fish assemblages in these ecosystems is essential for conservation (Munday *et al.*, 2008, 2009).

In this context, the subtidal reef environments along the northern/north-eastern Brazilian shelf, between Parcel Manuel Luíz (Maranhão State) and Cape of São Roque (Rio Grande do Norte State), with an extension of approximately 1000 km, are still understudied. For instance, this region was described by Castro & Pires (2001) as 'unexplored' for scleractinian corals, especially along Ceará State. Thus, it becomes clear that the ecosystem is understudied as a whole. In terms of biogeography studies including reef fish from Ceará State, there are only two contributions (Araújo & Feitosa, 2003; Moura, 2003), but despite that, this scarcity was noted in the most relevant papers about the south-western Atlantic fish biogeography (e.g. Floeter & Gasparini, 2000; Feitoza *et al.*, 2005; Floeter *et al.*, 2008).

The studies on the fish fauna along the Brazilian coast went through a steep increase, both in terms of quantity and quality, but there are still many gaps to fill, especially on the northern/north-eastern Brazilian shelf (Rocha, 2003). Hence, this work presents a thorough assessment of the reef fish occurring along the Ceará State coast, presenting an evaluation of the biogeographic context of the Brazilian reef ichthyofauna.

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MATERIALS AND METHODS

Study area

The Brazilian coastline presents two directions along the north-east region, the northern portion is oriented along the east-west direction, facing north, and includes the whole coast of the Ceará State. The northern portion is limited in the east by an inflexion marked by the Cape of São Roque (Rio Grande do Norte State), then, the coastline is north-south oriented. Ceará has 573 km of shoreline (Morais *et al.*, 2009), and the associated continental shelf extends from 35 to 90 km off the coast, with the slope starting at a 40–80 m depth (Knoppers *et al.*, 1999). Sandy beaches, with occasional beach rock formations, dominate the coast. The beach rocks form the coastal reefs and are easily accessed, and their locations are well documented (Smith & Morais, 1984). The subtidal reefs, on the other hand, are poorly mapped and studied.

In order to produce a comprehensive inventory of the reef fishes of the region, we visited 16 different reefs, of which 12 were natural and four were artificial, with depths ranging between 16 and 36 m (Figure 1, Table 1). Half of the sites are located inside the Pedra da Risca do Meio Marine State Park (PRM), a conservation unit created in 1997, but still poorly managed (Soares *et al.*, 2011). There were also three sites located along Fortaleza (the state's capital and large urban area), four on the eastern side of the state and three on the western side (Figure 1).

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Table 1. Details of the sampling sites, including depth, distance from the coast, geographic coordinates and type of reef (natural or artificial).

Sites	Depth (m)	Distance from coast (km)	Geographic coordinate	Reef types
Avião*	28	19.0	3°33.858′S 38°22.454′W	Artificial
Cabeço do arrastado*	23	14.6	3°35.889′S 38°23.489′W	Natural
Cabeço do balanço*	18	14.9	3°34.747′S 38°23.235′W	Natural
Cajueiro	28	26.1	3°28.271′S 38°26.786′W	Natural
Canal das arabaianas	36	28.5	3°32.754′S 38°16.179′W	Natural
Farinhada	30	29.5	3°26.398′S 38°27.354′W	Natural
Manuel Salvador	30	22.6	3°15.826′S 38°50.200′W	Natural
Navio do Macau	19	17.6	4°14.734′S 37°43.698′W	Artificial
Navio do Pecém	32	30.3	3°17.420′S 38°43.163′W	Artificial
Pedra da botija*	26	14.8	3°34.526′S 38°25.838′W	Natural
Pedra do mar*	22	17.7	3°34.399′S 38°22.840′W	Natural
Pedra nova*	16	17.0	3°34.749′S 38°22.989′W	Natural
Pedrinha*	15	14.3	3°35.680′S 38°24.177′W	Natural
Risca do meio*	26	16.4	3°34.120′S 38°24.506′W	Natural
Risca dos Picos	27	39.7	4°20.598′S 37°14.892′W	Natural
Vapor do Paracuru	18	11.2	3°18.647′S 38°56.771′W	Artificial

*Sites are located inside the Pedra da Risca do Meio Marine State Park.

Data acquisition

A total of 151 scuba dives were carried out, at approximately 30 min each, between 2002 and 2007. During the dives, the method to assess the fish fauna composition was the visual record, through an intensive search and the analysis of photographic material. Of the six night dives, three were conducted at the Risca do Meio site, two at Pedrinha and one at the Macau shipwreck. The identification of species was based on external morphological characteristics using the available guides (Rocha, 1999, 2002; Feitoza, 2001; Humann & DeLoach, 2002; Hostim-Silva *et al.*, 2005).

Some species whose visual identification was difficult or impossible, and those that were relevant for the institutional collection, were captured with nets, spearfishing or line and hook (licence – SEMACE 543/200). The identification was based on the keys available for tropical Atlantic fishes (Figueiredo, 1977; Figueiredo & Menezes, 1978, 2000; Menezes & Figueiredo, 1980, 1985; Cervigón, 1991, 1993, 1994, 1996). The collected specimens were deposited at the Dias da Rocha Ichthyological Collection (CIDRO) of the Instituto de Ciências do Mar (LABOMAR-UFC).

The final checklist of reef fish from Ceará, including the intertidal and subtidal zones, comprises both the species observed during the dives and those from the previous records available (Araújo *et al.*, 2000; Cunha *et al.*, 2007, 2008; Jucá-Queiroz *et al.*, 2008; Freitas *et al.*, 2009;

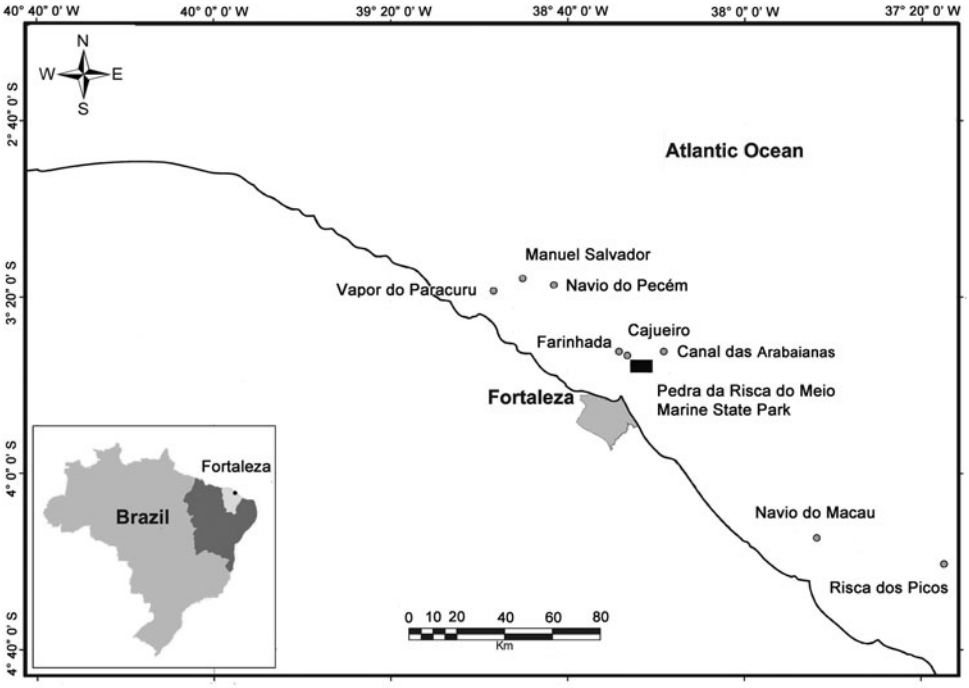

Fig. 1. Sampling points off Ceará State, north-eastern Brazil. Geometric symbols indicate specific samplings sites. Black rectangle = Pedra da Risca do Meio Marine State Park (PRM); grey circles = reef sites outside the PRM.

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Godinho & Lotufo, 2010). The species list is organized by evolutionary criteria, according to Compagno (1999), Nelson (2006) and specific literature for Epinephelidae (Craig & Hastings, 2007; Smith & Craig, 2007). The valid species names and geographic distribution data were obtained from the online version of the 'Catalog of Fishes' (Eschmeyer, 2014).

In one of the sites, a patch reef named 'Risca do Meio' located inside the PRM, we performed 21 stationary visual censuses (Bohnsack & Bannerot, 1986), between October 2002 and September 2003. These censuses were conducted with the purpose of gathering data about the assemblage structure, for back comparison with other locations where the same method was applied.

Data analysis

With the exception of the checklist, all other analyses performed for the present study comprised only the data from bony fish (Actinopterygii). The zoogeographic patterns were assessed through cluster analysis using two different approaches. The first one was qualitative, based on a binary matrix (presence/absence) of the 320 taxa of bony fish recorded for seven reef areas along the Brazilian north-east region, including intertidal and subtidal zones (Supplementary material). The similarity matrix was calculated using the Sørensen index, and the clusters generated by the hierarchical agglomerative method using the UPGMA amalgamation strategy. The seven areas included in this study were: (1) Ceará – CE (present study; Araújo *et al.*, 2000; Cunha *et al.*, 2007, 2008; Freitas *et al.*, 2009); (2) Maranhão – MA (Rocha & Rosa, 2001; Nunes *et al.*, 2011a, b); (3) Risca do Zumbi RN – ZU (Feitoza, 2001); (4) Paraíba – PB (Rocha *et al.*, 1998; Souza *et al.*, 2007; Honório *et al.*, 2010); (5) Abrolhos – AB (Moura *et al.*, 2006); (6) Atol das Rocas (Rocas Atoll) – AR (Rosa & Moura, 1997; Floeter *et al.*, 2008); and (7) Arquipélago de São Pedro e São Paulo (St Paul's Rocks) – SPSP (Lubbock & Edwards, 1981; Feitoza *et al.*, 2003).

The second approach was quali-quantitative, using data from stationary visual censuses at the subtidal zones (12–26 m) (Supplementary material). For this analysis, the data from the Risca do Meio site was used along with data from three different studies that used the same method, comprising: Parcel do Manuel Luís – MA (Rocha & Rosa, 2001), Rocas Atoll (Rosa & Moura, 1997) and Risca do Zumbi – RN (Feitoza, 2001). The abundance data were transformed by square root analysis and the distance matrix was calculated using the Bray–Curtis index. The cluster analysis was performed as previously described for the qualitative data.

The abundance data were used for producing rarefaction curves, and also for a more direct comparison by means of trophic categories. The trophic categories followed Ferreira *et al.* (2004), including a modification of the category 'carnivores' (CAR) to 'generalist carnivore' (GEC) as proposed by Honório *et al.* (2010). The trophic categories were assigned to each species after consulting the literature (Randall, 1967; Menezes & Figueiredo, 1980; Ferreira *et al.*, 2004; Honório *et al.*, 2010) and FishBase (Froese & Pauly, 2014). The same categories were applied for the data from the different studies in order to allow direct comparisons. All multivariate analyses were performed using the software Biodiversity-Pro (McAleece *et al.*, 1997).

RESULTS

A total of 179 taxa from 66 families were recorded for the reefs of Ceará (Table 2). The most representative families in terms of species numbers were Carangidae (16 species), Haemulidae (12), Labridae (9), Epinephelidae (8) and Pomacentridae (7). Most taxa (154; 86%) are found throughout the western tropical Atlantic, including the Caribbean, while 36 species (20%) are present in both the east and west Atlantic and 18 species (10%) have circumtropical distributions. Also noteworthy is the occurrence of the 16 species (9%) considered to be endemic to the Brazilian province. The species were distributed by trophic guilds as follows: territorial herbivore (2%), roving herbivore (5%), planktivore (10%), omnivore (13%), sessile invertebrate feeder (3%), mobile invertebrate feeder (25%), generalist carnivore (30%) and piscivore (10%) (Table 2).

As for species composition, the fish fauna from Ceará were grouped with the other localities along the continental margin (Figure 2), with greater similarity (73%) to the reefs from Risca do Zumbi – RN and Paraiba – PB. The similarity level among the continental areas was 67%, and the oceanic islands formed a distinct group. When abundances are taken into account (Figure 3) a similar pattern was observed; however, the overall similarity level among the continental areas is reduced to 52%.

There is no clear pattern for the reefs when they are analysed in terms of trophic categories (Figure 4). For instance, the dominant guild for the Ceará reefs was the mobile invertebrate feeder (MIF), comprising 28% of the recorded fishes. For the Risca do Zumbi reefs, which according to the quali-quantitative cluster analysis were more similar to Ceará, the dominant guild was planktivores (PL), with 32% of the fish. Manuel Luís and Risca do Meio, on the other hand, shared a lesser proportion of planktivores. Additionally, Risca do Meio had a larger proportion of piscivores and a smaller proportion of roving herbivores when compared with all other localities analysed.

The rarefaction curves (Figure 5) indicated similar numbers in terms of species richness for the continental shelf locations, despite the differences in composition, abundance and trophic structure. The Rocas Atoll, however, showed a smaller richness in comparison to the other three locations.

DISCUSSION

The list presented here (Table 2) is, at the moment, the most comprehensive assessment for the reef fish from Ceará State, one of the least known regions of the Brazilian coast regarding reef organisms, and we believe that it represents the great majority of local reef species. Nevertheless, this list would include more species if anaesthetics or ichthyotoxics were used to capture the more cryptic species, as done in other regions (Rosa & Moura, 1997; Feitoza, 2001; Rocha & Rosa, 2001). Within a regional perspective, the reef fish from Ceará stand out with 167 species of bony fishes, representing 51% of the north-eastern region species (Rocha, 2003). It is also worth mentioning that 16 out of 46 Brazilian endemic species (Floeter *et al.*, 2008) were registered in the present account, which highlights the biological importance of this area.

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Table 2. Checklist of reef fish from the State of Ceará, including geographic range and trophic categories. WA, western Atlantic; EA, eastern Atlantic; SA, south-western Atlantic; EP, aastern Pacific; CIRC, circumtropical; BP, Brazilian Province and blank spaces – absence of information. Abbreviations adopted for trophic category: TH, territorial herbivore; RH, roving herbivore; PLA, planktivore; OMN, omnivore; SIF, sessile invertebrate feeder; MIF, mobile invertebrate feeder; GC, generalist carnivore; PI, piscivore.

Species	Geographic range	Trophic category
Chondrichthtyes		
Ginglymostomatidae		
Ginglymostoma cirratum (Bonnaterre, 1788)	WA, EA, EP	GC
Carcharhinidae		
Carcharhinus perezii (Poey, 1876)	WA, EP	PI
Negaprion brevirostris (Poey, 1868)	WA, EA, EP	PI
Rhizoprionodon porosus (Poey, 1861)	WA	PI
Sphyrnidae		
Sphyrna lewini (Griffith & Smith, 1834)	CIRC	GC
Sphyrna tiburo (Linnaeus, 1758)	WA, EP	GC
Narcinidae		
Narcine brasiliensis (Olfers, 1831)	WA	MIF
Dasyatidae		
Dasyatis americana Hildebrand & Schroeder, 1928	WA	GC
Dasyatis guttata (Bloch & Schneider, 1801)	WA	MIF
Dasyatis marianae Gomes *et al.*, 2000	SA, BP	MIF
Myliobatidae		
Aetobatus narinari (Euphrasen, 1790)	WA, EA	MIF
Mobulidae		
Manta birostris (Walbaum, 1792)	CIRC	PLA
Actinopterygii		
Megalopidae		
Megalops atlanticus Valenciennes, 1847	WA, EA	PI
Muraenidae		
Gymnothorax funebris Ranzani, 1839	WA	GC
Gymnothorax miliaris (Kaup, 1856)	WA, EA	GC
Gymnothorax moringa (Cuvier, 1829)	WA	PI
Gymnothorax vicinus (Castelnau, 1855)	WA, EA	GC
Muraena pavonina Richardson, 1845	SA, EA	PI
Ophichthidae		
Myrichthys ocellatus (Lesueur, 1825)	WA, EA	MIF
Ahlia egmontis (Jordan, 1884)	WA	MIF
Congridae		
Heteroconger camelopardalis (Lubbock, 1980)°	SA	PLA
Clupeidae		
Lile piquitinga (Schreiner & Miranda Ribeiro, 1903)	WA	PLA
Opisthonema oglinum (Lesueur, 1818)°	WA	PLA
Engraulidae		
Anchoa tricolor (Spix & Agassiz, 1829)	SA	PLA
Anchoviella lepidentostole (Fowler, 1911)	WA	PLA
Lycengraulis grossidens (Spix & Agassiz, 1829)	WA	GC
Ariidae		
Cathorops spixii (Agassiz, 1829)	WA	GC
Bagre marinus (Mitchill, 1815)	WA	GC
Synodontidae		
Synodus intermedius (Spix & Agassiz, 1829)°	WA	PI
Batrachoididae		
Thalassophryne sp.*		
Ogcocephalidae		
Ogcocephalus vespertilio (Linnaeus, 1758)	WA	GC
Mugilidae		
Mugil curema Valenciennes, 1836	WA, EA, EP	OMN
Atherinopsidae		
Atherinella brasiliensis (Quoy & Gaimard, 1825)	WA	OMN
Hemiramphidae		
Hemiramphus brasiliensis (Linnaeus, 1758)°	WA, EA	OMN
Hyporhamphus unifasciatus (Ranzani, 1841)	WA, EP	OMN
Belonidae		
Ablennes hians (Valenciennes, 1846)°	CIRC	PI
Strongylura timucu (Walbaum, 1792)	WA	GC
Tylosurus crocodilus (Péron & Lesueur, 1821)	CIRC	GC

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Table 2. Continued

Species	Geographic range	Trophic category
Holocentridae		
Holocentrus adscensionis (Osbeck, 1765)	WA, EA	MIF
Myripristis jacobus Cuvier, 1829	WA, EA	PLA
Syngnathidae		
Hippocampus reidi Ginsburg, 1933	WA	PLA
Halicampus crinitus (Jenyns, 1842)	WA	PLA
Aulostomidae		
Aulostomus cf. *strigosus* Wheeler, 1955*°		GC
Fistulariidae		
Fistularia tabacaria Linnaeus, 1758°	WA, EA	PI
Scorpaenidae		
Scorpaena brasiliensis Cuvier, 1829	WA	GC
Scorpaena plumieri (Bloch, 1798)°	WA, EA	GC
Centropomidae		
Centropomus undecimalis (Bloch, 1792)	WA	GC
Epinephelidae		
Alphestes afer (Bloch, 1793)	WA, EA	GC
Cephalopholis fulva (Linnaeus, 1758)	WA	GC
Dermatolepis inermis (Valenciennes, 1833)	WA	GC
Epinephelus adscensionis (Osbeck, 1765)	WA, EA	GC
Epinephelus itajara (Lichtenstein, 1822)	WA, EA	GC
Mycteroperca bonaci (Poey, 1860)	WA	PI
Mycteroperca interstitialis (Poey, 1860)	WA	PI
Paranthias furcifer (Valenciennes, 1828)	WA, EA	PLA
Serranidae		
Rypticus saponaceus (Bloch & Schneider, 1801)	WA, EA	GC
Serranus baldwini (Evermann & Marsh, 1899)	WA	MIF
Serranus flaviventris (Cuvier, 1829)	WA	MIF
Grammatidae		
Gramma brasiliensis Sazima *et al.*, 1998	SA, BP	PLA
Opistognathidae		
Opistognathus sp.†		
Priacanthidae		
Heteropriacanthus cruentatus (Lacepède, 1801)	CIRC	GC
Priacanthus arenatus Cuvier, 1829	WA, EA	GC
Apogonidae		
Apogon americanus Castelnau, 1855°	SA, BP	PLA
Phaeoptyx pigmentaria (Poey, 1860)	WA, EA	PLA
Malacanthidae		
Malacanthus plumieri (Bloch, 1786)	WA	GC
Coryphaenidae		
Coryphaena hippurus Linnaeus, 1758	CIRC	GC
Rachycentridae		
Rachycentron canadum (Linnaeus, 1766)	CIRC	PI
Echeneidae		
Echeneis naucrates Linnaeus, 1758	CIRC	OMN
Carangidae		
Alectis ciliaris (Bloch, 1787)	CIRC	GC
Carangoides bartholomaei (Cuvier, 1833)	WA	PI
Caranx crysos (Mitchill, 1815)	WA, EA	GC
Carangoides ruber (Bloch, 1793)	WA	GC
Caranx hippos (Linnaeus, 1766)	WA, EA	GC
Caranx latus Agassiz, 1831	WA, EA	GC
Chloroscombrus chrysurus (Linnaeus, 1766)	WA, EA	PLA
Decapterus macarellus (Cuvier, 1833)°	CIRC	PLA
Decapterus tabl Berry, 1968°	CIRC	PLA
Elagatis bipinnulata (Quoy & Gaimard, 1825)	CIRC	GC
Selene setapinnis (Mitchill, 1815)	WA	GC
Selene vomer (Linnaeus, 1758)	WA	GC
Seriola dumerili (Risso, 1810)	CIRC	PI
Trachinotus carolinus (Linnaeus, 1766)	WA	GC
Trachinotus falcatus (Linnaeus, 1758)	WA	MIF
Trachinotus goodei Jordan & Evermann, 1896	WA	GC

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Table 2. Continued

Species	Geographic range	Trophic category
Lutjanidae		
Lutjanus alexandrei Moura & Lindeman, 2007°	SA, BP	GC
Lutjanus analis (Cuvier, 1828)	WA	GC
Lutjanus jocu (Bloch & Schneider, 1801)	WA	GC
Lutjanus synagris (Linnaeus, 1758)	WA	MIF
Ocyurus chrysurus (Bloch, 1791)	WA	GC
Gerreidae		
Diapterus auratus Ranzani, 1842	WA	OMN
Diapterus rhombeus (Cuvier, 1829)	WA	OMN
Eucinostomus argenteus Baird & Girard, 1855	WA	GC
Eucinostomus gula (Quoy & Gaimard, 1824)	WA	MIF
Eugerres brasilianus (Cuvier, 1830)	WA	MIF
Ulaema lefroyi (Goode 1874)	WA	MIF
Haemulidae		
Anisotremus moricandi (Ranzani, 1842)	WA	MIF
Anisotremus surinamensis (Bloch, 1791)	WA	MIF
Anisotremus virginicus (Linnaeus, 1758)	WA	MIF
Genyatremus luteus (Bloch, 1790)	WA	MIF
Haemulon aurolineatum Cuvier, 1830	WA	MIF
Haemulon melanurum (Linnaeus, 1758)	WA	MIF
Haemulon parra (Desmarest, 1823)	WA	MIF
Haemulon plumierii (Lacepède, 1801)	WA	GC
Haemulon squamipinna Rocha & Rosa, 1999	SA, BP	MIF
Haemulon steindachneri (Jordan & Gilbert, 1882)	WA	MIF
Orthopristis ruber (Cuvier, 1830)	WA	MIF
Pomadasys corvinaeformis (Steindachner, 1868)	WA	GC
Sparidae		
Archosargus rhomboidalis (Linnaeus, 1758)	WA	OMN
Calamus penna (Valenciennes, 1830)°	WA	MIF
Calamus pennatula Guichenot, 1868°	WA	MIF
Sciaenidae		
Menticirrhus littoralis (Holbrook, 1847)	WA	MIF
Pareques acuminatus (Bloch & Schneider, 1801)	WA	MIF
Mullidae		
Mulloidichthys martinicus (Cuvier, 1829)	WA, EA	MIF
Pseudupeneus maculatus (Bloch, 1793)	WA	MIF
Upeneus parvus Poey, 1852	WA	GC
Pempheridae		
Pempheris schomburgkii Müller & Troschel, 1848	WA	PLA
Kyphosidae		
Kyphosus vaigiensis (Quoy & Gaimard 1825)°	CIRC	RH
Chaetodontidae		
Chaetodon ocellatus Bloch, 1787	WA	SIF
Chaetodon sedentarius Poey, 1860	WA	SIF
Chaetodon striatus Linnaeus, 1758	WA	SIF
Pomacanthidae		
Centropyge aurantonotus Burgess, 1974	WA, EA	OMN
Holacanthus ciliaris (Linnaeus, 1758)	WA	SIF
Holacanthus tricolor (Bloch, 1795)	WA	SIF
Pomacanthus arcuatus (Linnaeus, 1758)	WA	OMN
Pomacanthus paru (Bloch, 1787)	WA, EA	OMN
Cirrhitidae		
Amblycirrhitus pinos (Mowbray, 1927)	WA	MIF
Pomacentridae		
Abudefduf saxatilis (Linnaeus, 1758)	WA, EA	OMN
Chromis multilineata (Guichenot, 1853)°	WA, EA	PLA
Chromis scotti Emery, 1968	WA	PLA
Microspathodon chrysurus (Cuvier, 1830)	WA	OMN
Stegastes fuscus (Cuvier, 1830)	SA, BP	TH
Stegastes pictus (Castelnau, 1855)°	WA	TH
Stegastes variabilis (Castelnau, 1855)	WA	TH
Labridae		
Bodianus rufus (Linnaeus, 1758)	WA	MIF
Clepticus brasiliensis Heiser *et al.*, 2000	SA, BP	PLA

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Table 2. Continued

Species	Geographic range	Trophic category
Halichoeres bivittatus (Bloch, 1791)°	WA	MIF
Halichoeres brasiliensis (Bloch, 1791)	SA, BP	MIF
Halichoeres dimidiatus Agassiz, 1831	WA	MIF
Halichoeres penrosei Starks, 1913°	SA, BP	MIF
Halichoeres poeyi (Steindachner, 1867)°	WA	MIF
Halichoeres radiatus (Linnaeus, 1758)	WA	MIF
Thalassoma noronhanum (Boulenger, 1890)°	SA, BP	PLA
Scaridae		
Scarus trispinosus Valenciennes, 1840	SA, BP	RH
Scarus zelindae Moura *et al.*, 2001	SA, BP	RH
Sparisoma amplum (Ranzani, 1841)	SA, BP	RH
Sparisoma axillare (Steindachner, 1878)	SA, BP	RH
Sparisoma frondosum (Agassiz, 1831)	WA, EA	RH
Blenniidae		
Ophioblennius trinitatis Miranda Ribeiro, 1919	SA, BP	TH
Labrisomidae		
Labrisomus nuchipinnis (Quoy & Gaimard, 1824)	WA, EA	GC
Malacoctenus sp.†°		
Gobiidae		
Bathygobius aff. soporator (Valenciennes, 1837)†		
Coryphopterus glaucofraenum Gill, 1863°	WA	OMN
Elacatinus figaro Sazima *et al.*, 1997	SA, BP	MIF
Ctenogobius boleosoma (Jordan & Gilbert, 1882)	WA	MIF
Ptereleotridae		
Ptereleotris randalli Gasparini *et al.*, 2001	WA	PLA
Ephippidae		
Chaetodipterus faber (Broussonet, 1782)	WA	OMN
Acanthuridae		
Acanthurus bahianus Castelnau, 1855	WA	RH
Acanthurus chirurgus (Bloch, 1787)	WA, EA	RH
Acanthurus coeruleus Bloch & Schneider, 1801	WA	RH
Sphyraenidae		
Sphyraena barracuda (Edwards, 1771)	CIRC	GC
Sphyraena guachancho Cuvier, 1829	WA, EA	GC
Scombridae		
Euthynnus alletteratus (Rafinesque 1810)	WA, EA	GC
Scomberomorus brasiliensis Collette *et al.*, 1978	WA	GC
Scomberomorus cavalla (Cuvier, 1829)	WA	GC
Scomberomorus regalis (Bloch, 1793)	WA	GC
Paralichthyidae		
Paralichthys sp.*		
Balistidae		
Balistes vetula Linnaeus, 1758	WA, EA	OMN
Monacanthidae		
Aluterus scriptus (Osbeck, 1765)	CIRC	OMN
Cantherines macrocerus (Hollard, 1853)	WA	OMN
Cantherhines pullus (Ranzani, 1842)	WA, EA	OMN
Ostraciidae		
Acanthostracion polygonius Poey, 1876	WA	OMN
Lactophrys trigonus (Linnaeus, 1758)°	WA	OMN
Tetraodontidae		
Canthigaster figueiredoi Moura & Castro, 2002°	WA	OMN
Sphoeroides greeleyi Gilbert, 1900	WA	MIF
Sphoeroides spengleri (Bloch, 1785)	WA	OMN
Sphoeroides tyleri Shipp, 1972	WA	MIF
Diodontidae		
Chilomycterus antillarum Jordan & Rutter, 1897	WA	MIF
Diodon holocanthus Linnaeus, 1758	CIRC	MIF
Diodon hystrix Linnaeus, 1758	CIRC	MIF

°Specimens collected (CIDRO634 to CIDRO658).
*Not identified to the species level.
†Undescribed species.

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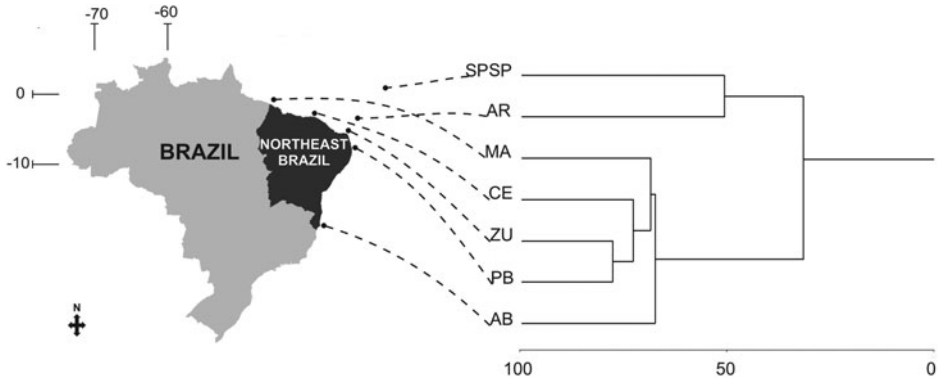

Fig. 2. Dendrogram from the cluster analysis based on presence/absence data (Sørensen index, UPGMA) of 320 reef fish species from seven reef areas of the Brazilian northeastern region: Ceará (CE), Maranhão (MA), Risca do Zumbi – RN (ZU), Paraíba (PB), Abrolhos (AB), Atol das Rocas (Rocas Atoll) (AR) and Arquipélago de São Pedro e São Paulo (St Paul's Rocks) (SPSP).

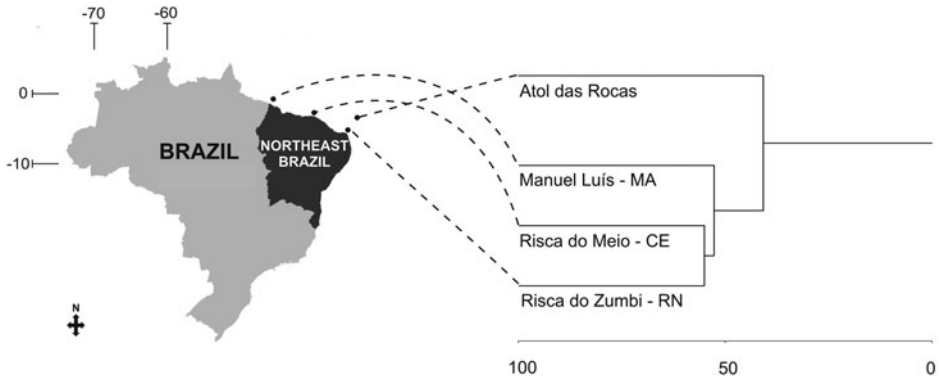

Fig. 3. Dendrogram from the cluster analysis based on quantitative data (Bray–Curtis index, UPGMA) from four localities of the Brazilian north-eastern region: Risca do Meio – CE, Manuel Luís – MA, Risca do Zumbi – RN and Atol das Rocas (Rocas Atoll).

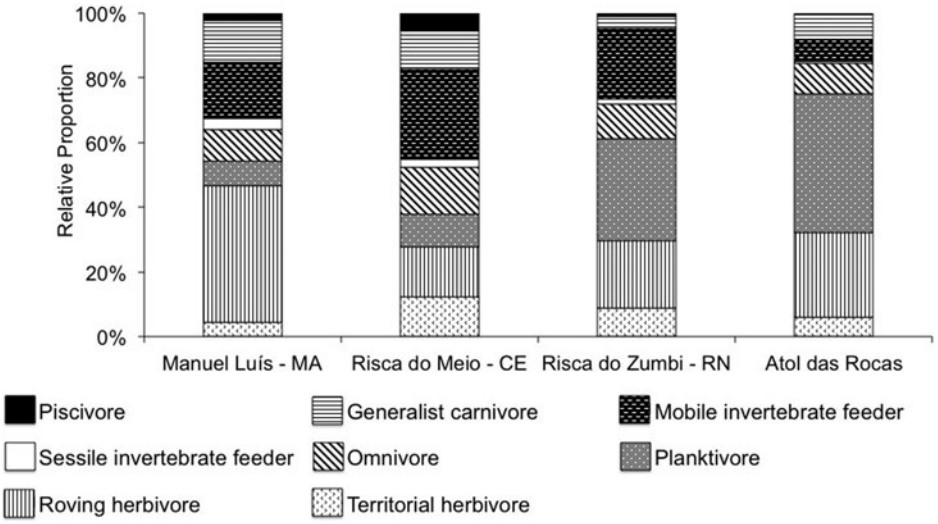

Fig. 4. Relative abundance of fish assigned to trophic categories, from four reef areas from north-east Brazil: Risca do Meio – CE, Manuel Luís – MA, Risca do Zumbi – RN and Atol das Rocas (Rocas Atoll).

As expected, most of the species with distribution limits in the Brazilian north-east (Floeter *et al.*, 2001; Feitoza *et al.*, 2005) were recorded at the reefs along Ceará State (e.g. *Haemulon melanurum* (Linnaeus, 1758), *Chaetodon ocellatus* Bloch, 1787, *Chromis scotti* Emery, 1968, *Haemulon squamipinna* Rocha & Rosa, 1999, *Halichoeres bivittatus* (Bloch, 1791)). The species *Halichoeres radiatus* (Linnaeus, 1758) is one exception; this species had only been recorded for the Caribbean, oceanic islands from the south Atlantic, and deeper reefs off the north-eastern Brazilian coast

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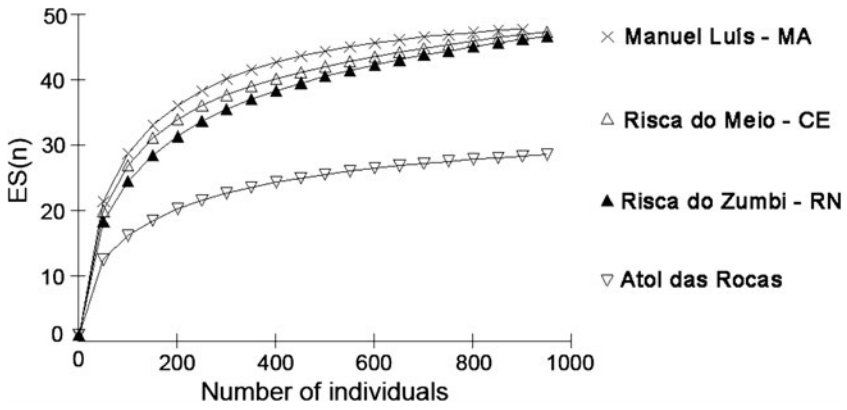

Fig. 5. Rarefaction curves for four reef areas from the Brazilian north-eastern region. ES(n) is the estimated species richness. Locations: Risca do Meio – CE, Manuel Luís – MA, Risca do Zumbi – RN and Atol das Rocas (Rocas Atoll).

(Rocha, 2003; Rocha *et al.*, 2005). However, in the present study, juveniles of this species were detected for the first time on near-shore reefs (18 km from the coast). Despite its rarity, with only two records during the study, its presence in both near-shore and deeper reefs (Rocha *et al.*, 2005), in sympatry with its sister species *Halichoeres brasiliensis* (Bloch, 1791), may indicate the first steps of a local enrichment promoted by biodiversity hotspots (Caribbean) and/or isolated oceanic islands (Bowen *et al.*, 2013).

Zoogeographic context

The overall pattern that emerged from the cluster analysis (Figure 2) agreed with previous studies, showing a clear distinction of the fauna from the oceanic islands (Floeter & Gasparini, 2000; Feitoza, 2001; Rocha & Rosa, 2001; Araújo & Feitosa, 2003; Moura, 2003). This is somewhat expected considering the degree of isolation and small dimension of the Rocas Atoll and St Paul's Rocks, but local ecological factors may have importance as well (Rocha, 2003). These locations are usually regarded as hosting subsets of the Brazilian Province ichthyofauna, but because of their high degree of endemism, are also potential exporters of biodiversity (see *H. radiatus* discussed previously).

The Brazilian north-eastern continental shelf is relatively homogeneous in terms of oceanographic conditions, and may be regarded as a single system, characterized by a low continental input and oligotrophic water (Knoppers *et al.*, 1999). These conditions certainly have influence on the high similarity observed in the present analysis (67%, overall). Another important element to take into consideration is the continuous presence of deep reef (from 35 to 70 m deep), acting as a biological corridor connecting different reefs from the region (Feitoza *et al.*, 2005).

In the whole north-eastern shelf, two major rivers may act as biogeographic filters and, therefore, affect the local compositions: the Parnaíba river delta (Rocha & Rosa, 2001), on the northern side, and the São Francisco river mouth, on the eastern side (Floeter *et al.*, 2001). The reefs at Ceará (CE), Risca do Zumbi (RN) and Paraíba (PB) are located between these two major rivers, and the absence of important obstacles may explain their similarities (73%). Additionally, some aspects of the life history of the species may exert, post settlement, considerable influence on the composition of reef fish assemblages (Luiz *et al.*, 2013), and may have also contributed to reorganize the assemblages, making them more similar to each other.

The American tropical Atlantic biogeographic setting obtained in the present study (Figure 2) showed differences in the agreement with the two other studies that included data from Ceará State. The first one, by Moura (2003), used a standardized sampling method throughout the Brazilian coast, with a distinct approach, and yielded a pattern very similar to the one presented here, which strengthens its consistency.

However, Araújo & Feitosa (2003) observed lower levels of similarity between the fish fauna from Ceará and the neighbouring states of Rio Grande do Norte and Paraíba, differing markedly in the aforementioned results. The numbers of species from Ceará by their account (99), and the use of Jaccard's index, are certainly the main culprits of these differences. Jaccard's index, unlike Sørensen's index used in this study, does not give greater weight to the simultaneous occurrence of species in different areas.

Despite the similarities in the taxonomic composition (Figure 2) and in the species richness estimated by rarefaction (Figure 5), there are still important singularities in terms of the assemblage structure, reflected in the abundances and trophic composition (Figures 3 & 4). The dominance of the mobile invertebrate feeder (MIF) guild in Ceará is related to the great abundance of grunts, especially *Haemulon aurolineatum* Cuvier, 1830. This species is one of the most abundant MIF on coastal reefs along the Brazilian Province (Ferreira *et al.*, 2004). Besides, the relative abundance of piscivores (PI) observed at Risca do Meio was due to the large number of jacks, with the genus *Carangoides* accounting for 88% of the PI. However, their high mobility and schooling behaviour may bias the abundance estimates though visual census (Ferreira *et al.*, 2004).

The analyses including abundance data are certainly more sensitive than the qualitative analyses to detect variations in the reef fish assemblage. As an example, the abundance data of herbivorous reef fish from the south Atlantic were more efficient than the analyses based solely on assemblage composition in the detection of a latitudinal gradient (Floeter *et al.*, 2005). There are also ecological drivers not considered in the present study that may explain the differences among the continental assemblages considered.

Floeter *et al.* (2001), based only on species richness data, found a strong correlation between reef fish species distribution

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along the Brazilian province and environmental variables, such as water temperature, coral richness, distance from mainland, primary production and shelf width. We believe that more assessments taking into account both abundance and biomass, correlating this information with environmental and ecological variables, will surely help to decode the complex distribution patterns and trophic structure of reef fish assemblages along the northern/north-eastern Brazilian coast.

The present work has shown basic information about the reef fish from Ceará and how it is positioned in a regional perspective. These data have a direct application on important matters, such as fisheries administration, conservation unit management and bioinvasion. Studies concerning other taxa and functional aspects of the whole community are essential for a thorough understanding of the reef ecosystems from the north-eastern Brazil region.

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