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A ictiofauna associada aos costões rochosos da Praia Vermelha, Rio de Janeiro: Estrutura da comunidade e respostas às variáveis físicas e químicas da água

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Dissertação apresentada ao Programa de Pós-Graduação em Ciências Biológicas (Biodiversidade Neotropical) da Universidade Federal do Estado do Rio de Janeiro como requisito parcial para obtenção de Título de Mestre

Orientador: Prof. Dr. Luciano Neves dos Santos

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"No final, conservaremos apenas o que
amamos, amaremos apenas o que
compreendemos, compreenderemos
apenas o que houver sido ensinado."
Baba Dioum

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INTRODUÇÃO GERAL

Baías costeiras são corpos de água de grandes dimensões, distribuídas em todos os continentes e desempenham um importante papel na sobrevivência de diversos organismos marinhos. Atuam como áreas propícias para reprodução, crescimento, alimentação e proteção de várias espécies de peixes (Monteleone, 1992; Araújo et al., 2002; Jablonski et al., 2006). Em tais sistemas trocas contínuas de águas entre o interior da baía, de maior influência continental, e o oceano adjacente, ocorrem com bastante frequência acarretando em intenso transporte de matéria orgânica, nutrientes e organismos (Kjerfve et al., 1997; Castro et al., 2005). Essa flutuação das variáveis físicas e químicas da água é uma das suas principais características e ocorre em decorrência de mudanças sazonais e espaciais nas condições ambientais nas quais estão inseridas (Kjerfve *et al*., 1997; Castro *et al*., 2005; Araújo & Azevedo, 2001; Araújo et al., 2002; Ferreira et al. 2001; Castro et al., 2005; Chaves, 2011). Neste sentido, a composição e estrutura da ictiofauna de baías costeiras respondem significativamente às eventuais alterações nas variáveis abióticas que possam ocorrer ao longo do gradiente continente-oceano (Araújo *et al*., 2002; Castro *et al*., 2005).

Abrangendo grande parte da região costeira do município do Rio de Janeiro, a Baía de Guanabara, se destaca não apenas por sua dimensão (segunda maior baía do Brasil; ~400 km^2) e heterogeneidade ambiental, mas também por sua inserção em uma das zonas mais urbanizadas do Brasil, cujos impactos antropogênicos resultantes têm adversamente afetado a integridade de seus habitats e organismos, e em especial, a ictiofauna (Valentin et al., 1999; Kehrig et al., 2002; Silva et al., 2003). Apesar dos níveis crescentes de degradação ambiental, a Baía de Guanabara constitui, como todo estuário e baía costeira tropical, uma importante área de reprodução, alimentação e berçário para numerosas espécies de peixes, abrigando uma intensa atividade pesqueira comercial (Jablonski et al., 2006). Embora muitos estudos tenham abordado o efeito de contaminantes sobre as populações de peixes da Baía de Guanabara (Amaral & Jablonski, 2005; Jablonski et al., 2006), ainda não existem, surpreendentemente, informações sistematizadas sobre as interações entre as principais espécies ícticas e os diferentes tipos de habitats submersos presentes na Baía.

Entre os diferentes biótopos existentes, substratos rochosos são encontrados em todas as zonas da Baía de Guanabara, constituindo ambientes estruturalmente complexos, que por abrigarem elevada diversidade e produtividade de peixes (Ferreira *et al.,* 2001; Floeter, 2007 ,Coutinho & Zalmon, 2009), são potenciais candidatos para serem usados como sensores biológicos das condições ambientais e da integridade biótica na Baía (Murray *et al.*, 2006). Em geral, as maiores riquezas de espécies foram encontradas em substratos rochosos próximos à entrada da Baía de Guanabara, onde a influência oceânica é maior e a qualidade da água se encontra dentro dos padrões mínimos, enquanto uma redução significativa da riqueza ocorre nas áreas mais internas, mais impactadas pela poluição e de circulação de água mais restrita (Paranhos *et al.*, 1993; Rodrigues *et al.*, 2007). Neste sentido, por constituírem um excelente sensor biológico das condições ambientais (Murray *et al.*, 2006), as comunidades associadas a substratos rochosos podem contribuir significativamente para uma melhor avaliação dos impactos a que Baía está submetida.

Apesar da importância aplicada para a elaboração dos programas de manejo pesqueiro e de conservação, surpreendentemente, ainda pouco se sabe sobre os efeitos das variáveis ambientais e da sazonalidade sob a composição e estrutura da ictiofauna recifal (Ferreira et al., 2001; Floeter et al., 2006). Neste sentido, o presente trabalho objetivou primeiramente descrever por meio de amostragens subaquáticas sistematizadas a composição e estrutura da comunidade de peixes associados aos costões rochosos da Praia Vermelha, Rio de Janeiro e a partir dessas informações entender a influencia, ordem de importância e efeitos das variações sazonais e de condicionantes ambientais sobre as principais espécies da comunidade íctica.

MATERIAL E MÉTODOS GERAL

A Praia Vermelha

Localizada na região da Urca, município do Rio de Janeiro, entre as coordenadas 22º 57' S e 043º 09' W, a Praia Vermelha está inserida na zona mais externa (entrada) da Baía de Guanabara, sofrendo influências diretas das águas da Baía e de águas oceânicas, mais salinas e de maior qualidade. As características hidrológicas da Baía de Guanabara obedecem a um fator temporal, regido pelo período de chuvas, a passagem de frentes e o regime de maré, e a um fator espacial ligado a dois gradientes: (a) gradiente longitudinal entre a entrada da baía e as áreas internas, (b) gradiente vertical (Mayr *et al.*, 1989). A alternância destes dois fatores imprime uma forte variabilidade às condições ambientais. A Praia Vermelha também é caracterizada por estar localizada em uma zona de livre acesso por banhistas e pescadores durante todo o ano e amplamente exposta à ação de ondas, que se formam na região oceânica adjacente à Baía.

A Praia Vermelha possui dois costões rochosos, um em cada lado, que distam aproximadamente 250m entre si e diferem quanto ao nível de complexidade estrutural. O costão esquerdo é composto por matacões de rochas basálticas de tamanhos diversos, contendo bancos esparsos de *Codium* sp. e *Ulva* sp., algas verdes muito frequentes e dominantes em ambos os costões. O costão direito, por outro lado, apresenta uma topografia inclinada (entre 45º e 60º), contendo bancos de mexilhões bem definidos e outros mesclados com manchas de *Codium* sp. e *Ulva* sp. Neste costão, a presença de pescadores é frequente, devido a maior facilidade de acesso.

Amostragens

As amostragens de peixes foram realizadas pela manhã e início da tarde, entre os meses de abril a dezembro de 2011 e janeiro e fevereiro de 2012, a partir de censos visuais realizados por meio de mergulhos livres ao longo de transectos lineares. Cada transecto consistiu de um cabo de 5m de comprimento, disposto paralelamente sobre o substrato, segundo metodologia adaptada de Brock (1954). Além de não-destrutiva, por não retirar indivíduos do ambiente, a metodologia de censos visuais constitui um dos métodos mais utilizados para amostragem de peixes em ambientes recifais (English *et al.*, 1997).

Os peixes situados até 1m de distância de cada lado do transecto foram identificados e anotados *in situ* em pranchetas de PVC, sendo também registrados a abundância e o tamanho para cada espécie. Em campo, os peixes foram identificados ao menor nível taxonômico utilizando-se da experiência dos mergulhadores e de planilhas fotográficas montadas em laboratório (contendo as espécies esperadas para a região, de acordo com levantamento bibliográfico prévio). Fotografias também foram tomadas e auxiliaram na confirmação em laboratório de algumas poucas espécies de identificação mais complicada, utilizando-se bibliografia específica, em particular Figueiredo & Menezes (1978, 1980, 2000) e Menezes & Figueiredo (1980, 1985) e bases eletrônicas de dados (Froese and Pauly, 2012). O tamanho de cada indivíduo foi estimado por meio de comparação com objetos de tamanho conhecido. Os dados obtidos durante os censos visuais foram posteriormente transferidos para planilhas eletrônicas.

Em todas as amostragens, algumas variáveis físicas e químicas da água, como temperatura, oxigênio dissolvido, pH e salinidade, também foram medidas por meio de sonda multiparâmetros, ao passo que a visibilidade horizontal e a profundidade foram estimadas em cada transecto por meio de observações do cabo graduado em posição vertical.

Chapter 1: ***The rocky reef fishes of Vermelha Beach, a marine-estuarine transitional zone at Guanabara Bay, Rio de Janeiro, Brazil.***

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Short-tittle: Rocky reef fishes of a transitional zone at Guanabara Bay, Brazil

The rocky reef fishes of Vermelha Beach, a marine-estuarine transitional zone at Guanabara Bay, Rio de Janeiro, Brazil

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Abstract

Rocky reefs are one of the most important biotopes in Guanabara Bay, because of their broad distribution and high species diversity. This study aimed to describe the composition and structure of the fish assemblages associated with rocky reefs in Vermelha Beach (RJ, Brazil), an estuarine-marine transitional zone, located at the entrance of Guanabara Bay. Fish were surveyed through underwater visual censuses, conducted by snorkeling divers along 10 m^2 linear transects (N=90). A total of 2,487 fishes were recorded, belonging to 29 species in 18 families. Excepting for *Atherinella brasiliensis*, all the fish species were intimately associated with rocky reefs or hard substrates, showing the high efficiency and selectivity of our visual censuses. The present work also stressed the importance of further studies to evaluate the role of periodic influences of estuarine and oceanic waters as structuring factors of the fish assemblages associated with rocky reefs at Vermelha Beach.

Introduction

Guanabara Bay (22°24' – 22°57' S, 42°33'– 43°19' W), the second biggest costal bay in Brazil, is an important estuary of approximately 400 km^2 in Rio de Janeiro State (Valentin *et al.* 1999). It stands out not only for its environmental heterogeneity, with sandy beaches, rocky reefs, mangroves forests and many inflowing rivers, but also for its location on one of the most urbanized areas of Brazil, with more than 11 millions of people. As a consequence, the Bay had progressively become throughout the years one of the most eutrophic ecosystems in the world (Guenther *et al.* 2008), functioning as a final receiver of high loads of both domestic and industrial non-treated effluents, that have been significantly changing its physical and chemical conditions, and thus adversely affecting habitats and organisms integrity (Jablonski *et al.* 2006; Neves *et al.* 2007; Seixas *et al.* 2013).

Rocky reefs are one of the most relevant biotopes on coastal systems, harbouring a great diversity of organisms with ecological and economic importance (Ferreira *et al.* 2001). They rank amongst the prevalent submerged habitats in Guanabara Bay, being less common in the inner region, where mangroves are dominant (Coutinho and Zalmon 2009). In general, higher species richness are found at rocky reefs located in the entrance of the Bay (largely influenced by oceanic waters), in contrast to the lower species richness recorded in the inner areas, with limited water circulation (Kjerfve *et al.* 1997; Veloso and Neves 2009). Since rocky shores are recognized as excellent sensors of environmental conditions (Murray *et al.* 2006), their associated fish assemblages can be used to assess the impacts posed on Guanabara Bay. Despite the high anthropic pressure, this Bay plays an important role of nursery and feeding grounds for many fisheries resources, also harboring an intense commercial fishing activity (Jablonski *et al.* 2006). While fish contamination by heavy metals and hydrocarbons have been documented (Kehrig *et al.* 2002; Silva *et al.* 2003), there are, surprisingly, no data about fish use patterns of the major submerged habitats in Guanabara Bay.

In this context, the present study aimed to describe, through visual censuses conducted by snorkeling divers along 10 m^2 linear transects, the composition and structure of the fish assemblages associated to the rocky reefs of Vermelha Beach, Guanabara Bay. This area is located in a transitional zone between the estuarine and marine environment, undergoing influences of both oceanic nutrient rich and more saline waters, and inner bay oligohaline waters. In addition to providing information on fish density and occurrence, trophic guilds were used to describe the functional structure of the reef fish assemblages and some interactions between the major species and micro-scale habitat features were also recorded and briefly discussed.

Materials and Methods

Study site

Vermelha Beach (22º 57' S; 043º 09' W) is located at Rio de Janeiro State, in the outer zone (entrance) of Guanabara Bay, undergoing direct influences of both transparent and more saline oceanic waters, and more eutrophicated, turbid estuarine inner bay waters (Figure 1). Guanabara Bay hydrologic characteristics show a temporal pattern, affected by the rainy season, the tidal regime and by two spatial gradients: (a) longitudinal, from the entrance of the Bay toward inner areas and (b) vertical (Mayr *et al.* 1989). The complex and often synergistic changes in these factors lead to a strong variability on environmental conditions. Vermelha beach has also no restriction for bathing and fishing through the year, being broadly exposed to waves generated in the adjacent oceanic region.

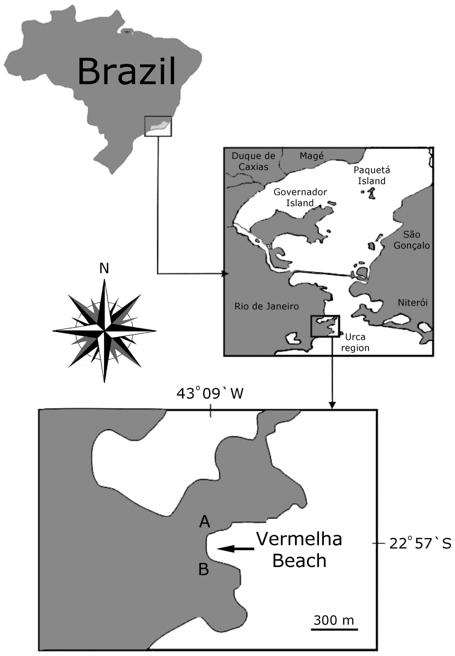

Figure 1 - Geographic location of the studied site showing Guanabara Bay at Rio de Janeiro State, Brazil and in detail Vermelha beach at the outer zone of the Bay with both rocky reefs (A = left and B = right).

The Vermelha Beach has two rock reefs (Figure 1), distant 250m from each other. The left rocky reef (A) is composed of basalt rock boulders of various sizes, covered by sparse banks of *Codium* sp. and *Ulva* sp., very common green algae that prevail on both reefs. The right rocky reef (B), on the other hand, has a steep topography (between 45º and 60º), colonized by mussel beds mixed with patches of *Codium* sp. and *Ulva* sp. Due to easier access, the presence of fishermen in the right rocky reef is constant.

Samples

Underwater visual censuses (UVC) were conducted monthly from April 2011 to February 2012, from 10:00 h to 16:00 h, through snorkeling dives along 5 m-linear transects over the rocky substrate (following Floeter *et al.* 2007). Fish located up to 1 m distance on each side of the transect (10 m^2) were identified to the lower taxonomic level and the abundance and size of each species were recorded in situ on 15 cm x 20 cm PVC boards. A total of 90 linear transects was performed, being 42 conducted on rocky shore A and 48 on B, in depths ranging from 2 to 5 m. Besides of being non destructive, by not removing individuals off the environment, visual censuses are one of the most widely used method for sampling reef associated fish (English *et al.* 1997).

Data collection

The fishes were identified using keys and guides provided by Figueiredo and Menezes (1978; 1980; 2000), Menezes and Figueiredo (1980; 1985) together with searches on electronic database (Froese and Pauly 2012). Fish species were grouped into six trophic categories (as in Ferreira *et al.* 2004; Floeter *et al.* 2004; Bertoncini *et al.* 2010; Feitosa *et al.* 2012): CAR = carnivores (eat a variety of mobile organisms, including invertebrates and fishes), MIF = mobile invertebrate feeders (feed primarily on small benthic mobile invertebrates like mollusks, crustaceans, worms, etc. associated to the hard- or nearby soft-substrate), OMN = omnivores (feed on a variety of organisms, both animal and vegetal), PLA = planktivores (feed primarily on macro- and micro-zooplankton), HER = herbivores (small to large herbivores that include in their diet a large amount of detritus, turf algae and macroalgae) and SIF = sessile invertebrate feeders (feeds on a variety of sessile benthic invertebrates, like cnidarians, ascidians and sponges, that are mostly associated with hard substrate).

Results

Out of the 90 transects, 2,487 fishes in 18 families and 29 species were recorded through visual censuses (Table 1). Except for *Atherinella brasiliensis*, all the fish species were intimately associated with rocky reefs or hard substrates, showing the efficiency and selectivity of our visual censuses. It is also noticeable that few species of commercial use, as the threatened top-predator dusky grouper *Epinephelus marginatus* (only juveniles), highly targeted as food resource, the cocoa damselfish *Stegastes variabilis*, often exploited for ornamental purposes, and the queen triggerfish *Balistes vetula*, used for aquarium and as gamefish, were recorded in our censuses. Most fish (59%) belonged to the omnivorous trophic guild, followed by mobile invertebrate feeders (25%) and carnivores (10%).

Diplodus argenteus was the most abundant species followed by *Haemulon aurolineatum*, *Stephanolepis hispidus*, *Abudefduf saxatilis*, *Holocentrus adscensiones*, *Sphoeroides testudineus*, *Labrisomus kalisherae*, *Chilomycterus spinosus*, *Parablennius pilicornis* and *Atherinella brasiliensis*, which accounted together for 90.4% of total abundance. *Stephanolepis hispidus*, *D. argenteus*, *S. testudineus*, *C. spinosus* and *H. aurolineatum* were the most frequent species, occurring individually up to 30% of all transects. The more sedentary monacanthid *Stephanolepis hispidus* also showed high total abundances and occurrences (12.6% e 71%, respectively). Other benthopelagic species, like most tetraodontids and diodontids, also displayed high occurrences. *Sphoeroides testudineus* and *Chilomycterus spinosus* were recorded in 44% of all transects but not with high abundances. Two cryptic species *Labrisomus kalisherae* and *Parablennius pilicornis* showed individual contributions of 3.3% and 2.8% respectively, ranking amongst the ten most abundant species.

Table 1 - Fish species recorded though visual censuses on both rocky reefs (A and B) of Vermelha Beach, Guanabara Bay, Rio de Janeiro. Density (fish per m^2) and trophic categories are also represented.

	Trophic Category	Total Density (fish/m²)	Occurrence (90 transects)
Atherinopsidae			
Atherinella brasiliensis (Quoy and Gaimard 1825)*	PLK	5,5	2
Holocentridae			
Holocentrus adscensiones (Osbeck 1765)	CAR	13,9	18
Fistulariidae			
Fistularia tabacaria (Linnaeus 1758)	CAR	0,1	1
Dactylopteridae			
Dactylopterus volitans (Linnaeus 1758)	MIF	1,3	11
Serranidae			
Epinephelus marginatus (Lowe 1834)	CAR	0,3	2
Haemulidae			
Anisotremus virginicus (Linnaeus 1758)	MIF	0,1	1
Haemulon aurolineatum (Cuvier 1829)	MIF	34,6	29
Haemulon steindachneri (Jordan and Gilbert 1882)	MIF	1,4	6
Sparidae			
Diplodus argenteus (Valenciennes 1830)	OMN	85,2	45
Sciaenidae			
Pareques acuminatus (Bloch and Schneider 1801)	CAR	1,3	8
Mullidae			
Mullus argentinae (Hubbs and Marini 1933)	MIF	0,1	1
Pseudupeneus maculatus (Bloch 1793)	MIF	0,2	1
Chaetodontidae			
Chaetodon striatus (Linnaeus 1758)	SIF	2,3	16
Pomacentridae			
Abudefduf saxatilis (Linnaeus 1758)	OMN	22,4	18
Stegastes fuscus (Cuvier 1830)	TERH	2,2	17
Stegastes variabilis (Castelnau 1855)	TERH	0,9	6
Labridae			
Halichoeres poeyi (Steindachener 1867)	MIF	1,5	7
Labrisomidae			
Labrisomus kalisherae (Jordan 1904)	CAR	8	19
Labrisomus nuchipinis (Quoy and Gaimard 1824)	CAR	0,7	6
*Malacoctenus delal*andii (Valenciennes 1836)	MIF	1,3	8
Blenniidae			
Parablennius pilicornis (Cuvier 1829)	OMN	6,8	16
Scartella cristata (Linnaeus 1758)	HER	3,9	23
Balistidae			
Balistes vetula (Linnaeus 1758)	MIF	0,4	3
Monacanthidae			
Monacanthus ciliatus (Mitchill 1818)	OMN	2,2	8
Stephanolepis hispidus (Linnaeus 1758)	OMN	31,2	64
Tetraodontidae			
Sphoeroides greeleyi (Gilbert 1900)	MIF	3,6	13
Sphoeroides testudineus (Linnaeus 1758)	MIF	9,8	40
Diodontidae			
Chilomycterus reticulatus (Linnaeus 1758)	MIF	0,2	3
Chilomycterus spinosus (Linnaeus 1758)	MIF	7,3	40
TOTAL: 29 Species		2487 individuals	

*** Not closely associated with rocky reefs**

Photographs taken at the Vermelha Beach provided insights on inter and intraspecific interactions of the major fish species as well as some of their different use of the rocky substrates. *Anisotremus virginicus, Abudefduf saxatilis* and *Diplodus argenteus* were commonly seen in association with big boulders (130 cm diameter) of the left rocky reef (Figure 2A). Small shoals (N < 5) of *Pareques acuminatus* (Figure 2B) was often seen in gregarious behavior, probably for protection. The aggressive territory defender damselfish *Stegastes fuscus* was photographed attacking a young grouper (*Epinephelus marginatus*), a potential egg and juvenile predator (Figure 2C). A probable couple of butterfly fish *Chaetodon striatus* were recorded foraging on the rocky bottom (Figure 2D). Different types of substrate usage were observed for *Parablennius pilicornis*, changing its behavior from a camouflage strategy on a complex turf algae substrate (Figure 2E) to interaction with sea urchin in a structure-less habitat (Figure 2F). A single *Holocentrus adscensiones* was recorded using a rock cavity and sea urchins as shelter (Figure 2G). *Fistularia tabacaria*, an occasional visitor of the reef, was also photographed (Figure 2H). Others behaviors were also observed, as *Dactylopterus volitans* displaying its pectoral fins as warning signal for potential predators (Figure 2I) and *Chilomycterus spinosus* using dense *Codium* sp. beds (Figure 2J).

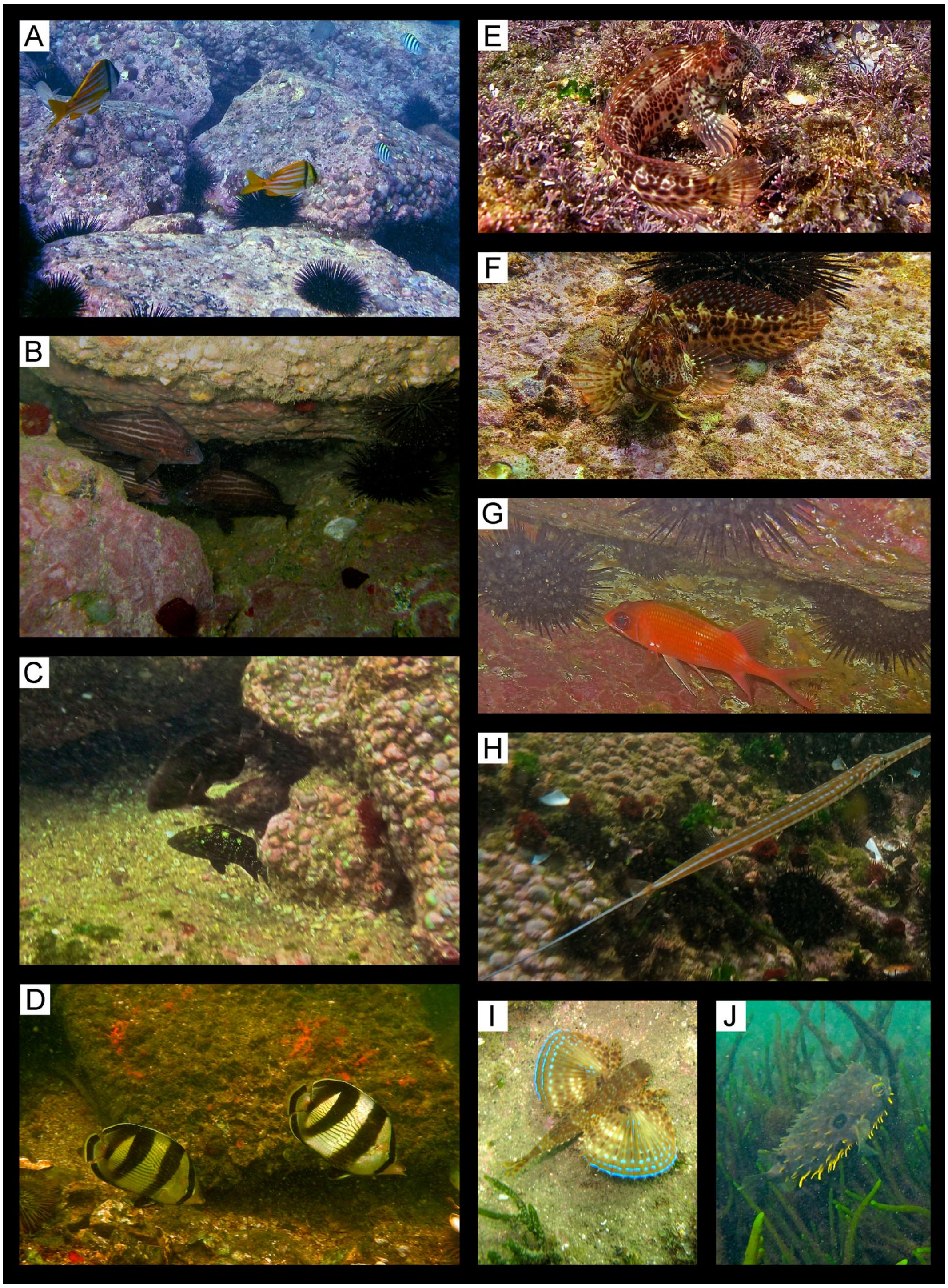

Figure 2 - Photographs taken at Vermelha beach, Guanabara Bay, Rio de Janeiro, Brazil showing some different uses and interactions between reef-associated fishes and rocky substrates. (A) *Anisotremus virginicus, Abudefduf saxatilis* and *Diplodus argenteus* on boulders of the rocky reef; (B) A small shoal (*N*=4) of *Pareques acuminatus* displaying gregarious behavior; (C) Territorial and agonistic display of *Stegastes fuscus* against a young grouper (*Epinephelus marginatus*); (D) A probable couple of butterfly fish *Chaetodon striatus* foraging on the rocky bottom; different

behavior displayed by *Parablennius pilicornis*, changing from a camouflage strategy on complex turf algae substrate (E) to interaction with sea urchin in a structure-less habitat (F); (G) a single *Holocentrus adscensiones* using rocks and sea urchins as shelter; (H) *Fistularia tabacaria*, an occasional visitor of the reef; (I) *Dactylopterus volitans* displaying its pectoral fins, and (J) *Chilomycterus spinosus* using dense *Codium* sp. beds.

Discussion

The trophic structure found in the present work for the fish associated to the rocky reefs of Vermelha Beach followed the same pattern of the reef fish assemblage recorded for the oceanic islands at the entrance of Guanabara Bay (Chaves and Monteiro-Neto 2009). The dominance of the omnivorous guild can be explained by the high abundances of the sparid *Diplodus argenteus*, which shows, as most tropical reef fish, a great plasticity on the use of food resources (Ferreira *et al.* 2004).

The high prevalence of *D. argenteus* and *H. aurolineatum*, which accounted together for 48.2% of total abundance, might be related to their gregarious behavior, in which the large roving schools probably facilitated diver detection (Kulbicki *et al.* 2010). *Stephanolepis hispidus* also showed high total abundances and occurrences (12.6% e 71%, respectively), agreeing with Ferreira *et al.* (2004), who found these three species as dominant in number and occurrence along a latitudinal gradient through the Brazilian cost.

Sphoeroides testudineus and *Chilomycterus spinosus* also displayed high occurrences, probably in response to their typical solitary behavior (Ferreira *et al.* 2001). Because of their limited swimming capacity, these species are often associated with structurally-complex habitats (*i.e.* rocky reefs) for protection to wave action.

Because of their typical eel shape, camouflage behavior, strong association with benthic community, and the high morphological and coloration similarity among labrisomids and blenniids, the abundances of these cryptic species are generally underestimated in visual censuses (*i.e.* up to 90% according to Willis 2001; Depczynski and Bellwood, 2004). Despite the probably underestimation of these cryptic species in our study, *Labrisomus kalisherae* and *Parablennius pilicornis* ranked amongst the ten most abundant species, with relative high abundances and occurrence (~20%) which could be related to the previous divers' experience acquired during previous training surveys.

In general, our results reflected the high selectivity of the visual censuses, showing better efficiency toward species closely related to hard substrates, of curious and gregarious behavior, agreeing with previous studies on reef fishes (Jennings and Polunin 1995; Kulbicki 1998; Colvocoresses and Acosta 2007; Kulbicki *et al.* 2010). Even though the Vermelha beach is under alternated influences of both inner-estuarine and outer-oceanic waters, our results recorded high fish richness with dominance of typical marine species and mostly reef associated. However, these results also shows the effects of this transitional estuarine-marine environment on fish, since other studies suggested a trend of increasing species richness for fish assemblages associated with islands toward the land-ocean gradient. This hypothesis can be confirmed by Mendonça-Neto *et al.* (2008), in which 42 species were recorded at three islands near the entrance of Guanabara Bay, and Rangel *et al.* (2007), who provided a list of 99 fish species for the Cagarras Archipelago, located ~8km outside the Bay in the open ocean. Our findings also highlighted the importance of further studies to better evaluate the role of periodic influences of estuarine and oceanic waters and other variables, such as environmental factors and rugosity, as structuring factors of the fish assemblages associated with rocky reefs at Vermelha beach.

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Chapter 2: ***The reef fish assemblage associated to the rocky reefs of Vermelha Beach, a marine-estuarine transitional zone at Guanabara Bay, Rio de Janeiro: Community structure responses to changes in water environmental variables.***

ABSTRACT

Composition and structure of fish assemblages on costal Bays respond significantly to eventual changes on water abiotic factors that may occur along an ocean-continental gradient. Rocky reefs are considered to be one of the most relevant biotopes on Guanabara Bay, for harbouring a great diversity of organisms with ecological and economic importance. the objective of the present study was to elucidate the influence, order of importance and respective effects, of seasonal variation and water environmental factors over the community structure of fishes associated to the rocky reefs of Vermelha Beach, in Rio de Janeiro, by using an underwater visual census technique. Our fish assemblage was dominated by five species accounting for 75% of total density and followed a general pattern of the reef fish assemblage inhabitant of the subtropical Brazilian waters. Cryptic species also ranked amongst the ten most abundant species, pointing out the high fishery pressure in the area and the importance of previous divers' experience. Depth variations should be viewed with caution for the restrict depth range at the Vermelha Beach. Changes on environmental variables were the main factors structuring the reef fish community distribution, nevertheless some species still respond to seasons, wich is proposed to be a cyclical change of some environmental variables. Temperature, dissolved oxygen and depth, explained the distribution of the majority of species and seems to play a greater part structuring the reef fish composition of Vermelha Beach. Densities patterns and occurrences of some species remain unclear pointing out that other unmeasured variables may also be affecting the composition of rocky-reef fish assemblage of Vermelha Beach, evidencing the importance of multiple scale continuous studies in the area.

Key words: Rocky reef fish, Community structure, environmental variables

INTRODUCTION

Many mechanisms may influence the distribution of fish within coastal marine systems. Several investigators have suggested that biotic processes may be influential in driving the spatial and temporal patterns of occurrence in fish (Ogburn-Matthews and Allen, 1993; Rueda, 2001; Rueda and Defeo, 2001). In addition, a myriad of abiotic factors have been associated with the structure of these assemblage communities, with well-defined boundaries corresponding to discontinuity in the environment, while the opposite situation corresponds to a continuum along the environmental gradient (Akin et al., 2003; Martino and Able, 2003). Variation in these environmental factors can be correlated over large areas and broad scale environmental influences are likely to drive synchrony in many animal populations (Koenig, 2002). In general, the influence of environmental factors on coral reef fish population dynamics and the spatial scale of such effects remain poorly understood. This influence partly relies on the species–energy relationship, a climatically based hypothesis that postulates that energy availability generates and maintains gradients of species richness in both terrestrial (Hawkins et al., 2003) and marine ecosystems (Allen et al., 2002).

An intensive energy exchange occurs between estuaries and coastal waters due to transport of organic matter, nutrients, and organisms (Castro et al., 2005). This interaction can influence water abiotic variables, which are known for shaping the distribution and occurrences of larval fish and adults within these environments (Bonecker et al., 2009). Therefore, composition and structure of fish assemblages on costal Bays respond significantly to eventual changes on water abiotic factors that may occur along an ocean-continental gradient (Castro *et al.*, 2005). Nevertheless, except for Patos Lagoon and Sepetiba Bay (Araújo *et al.*, 2002), surprisingly no information on the influence of environmental variables over the reef fish community structure and distribution on Tropical Coastal Bays is available.

Guanabara Bay (22^{o}24' – 22^{o}57' S, 42^{o}33'– 43^{o}19' W), according to Kjerfve *et al.* (1997) the second biggest costal bay in Brazil, stands out not only for its environmental heterogeneity, but also for its location on one of the most urbanized areas of Brazil (Guenther *et al.* 2008). As a consequence, throughout the years, it has been significantly changing its physical and chemical conditions, and adversely affecting habitats and organisms integrity (Jablonski*et al.* 2006; Neves*et al.* 2007; Seixas*et al.* 2013). Despite that fact, as an estuary, the Bay has been referred to as a fish nursery area (Franco-Gordo et al. 2003, Berasategui et al. 2004) and sustains many marine fish species (Castro et al., 2005; Bonecker, et al., 2009). It presents as main characteristic a remarked fluctuation of chemical and physical water variables, due to seasonal and spatial environmental conditions undergoing influences of both oceanic nutrient rich and more saline waters, and inner bay oligohaline waters (Castro *et al*., 2005).

Rocky reefs rank amongst the prevalent submerged habitats in Guanabara Bay, being less common in the inner region, where mangroves are dominant (Coutinho and Zalmon 2009). They are considered to be one of the most relevant biotopes on this system, for harbouring a great diversity of organisms with ecological and economic importance (Ferreira *et al.* 2001). In general, higher species richness are found at rocky reefs located in the entrance of the Bay (largely influenced by oceanic waters), in contrast to the lower species richness recorded in the inner areas, with limited water circulation (Kjerfve*et al.* 1997; Veloso and Neves 2009). On rocky reefs thermodynamic and mechanical forces with the potential to shape fish assemblages, includes water temperature, salinity, variations in depth, climatic differences, nutrients and phytoplankton production, wave exposure ocean currents and recruitment variability (Fraser & Currie, 1996; Holbrook et al., 1997; Depczynski & Bellwood, 2005; Mora & Robertson, 2005; Cowen et al., 2006; Floeter et al., 2007; Sandin et al., 2008). These factors can indirectly shape fish communities structure by influencing larval dispersal, food availability (through mixing and upwelling) and fish settlement success (Wilson and Meekan, 2002; Cowen, 2002) inducing synchrony among fish populations which may directly influence the abundance of adult reef fish assemblages (Madin & Connolly, 2006; Jones 1991, Finkl & Andrews, 2008). Most of these studies only considered variables in isolation, so any order of importance of their respective effects on the reef fishes species richness and densities remains unclear. Therefore the objective of the present study was to elucidate the influence, order of importance and respective effects, of seasonal variation and water environmental factors over the community structure of fishes associated to the rocky reefs of Vermelha Beach, in Rio de Janeiro, by using an underwater visual census technique.

METHODS

Study area - Vermelha Beach

Vermelha Beach (22º 57' S; 043º 09' W) is located at Rio de Janeiro State, in the outer zone (entrance) of Guanabara Bay, undergoing direct influences of both transparent and more saline oceanic waters, and more eutrophicated, turbid estuarine inner bay waters (**Figure 3**)Guanabara Bay hydrologic characteristics show a temporal pattern, affected by the rainy season, the tidal regime and by two spatial gradients: (a) longitudinal, from the entrance of the Bay toward inner areas and (b) vertical (Mayr *et al.*1989). The complex and often synergistic changes in these factors lead to a strong variability on environmental conditions. Vermelha beach has also no restriction for bathing and fishing through the year, being broadly exposed to waves generated in the adjacent oceanic region.

The Vermelha Beach has two rock reefs (**Figure 3**), distant 250m from each other. More details about the composition of these rocky reefs can be found in Barreto et al. (in press).

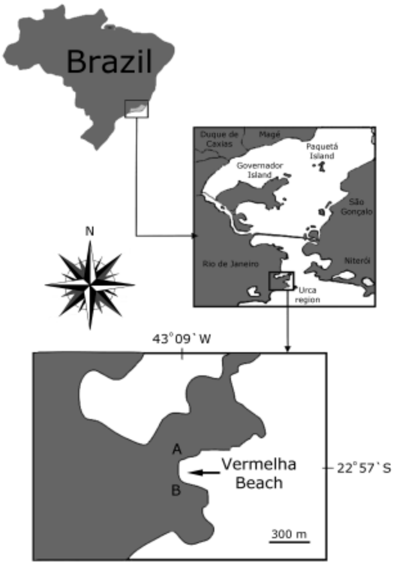

Figure 3 - Geographic location of the studied site showing Guanabara Bay at Rio de Janeiro State, Brazil and in detail Vermelha beach at the outer zone of the Bay with both rocky reefs (A = left and B = right).

Samples

Underwater visual censuses (UVC) were conducted monthly from April 2011 to March 2012, from 10:00 h to 16:00 h, through snorkelling dives along 5 m-linear transects over the rocky substrate based on that pioneered by Brock (1954). Fish located up to 1 m distance on each side of the transect (10 m^2) were identified to the lower taxonomic level and the abundance and size of each species were recorded in situ on 15 cm x 20 cm PVC boards. Keys and guides provided by Figueiredo and Menezes (1978; 1980; 2000), Menezes and Figueiredo (1980; 1985) together with searches on electronic database (Froese and Pauly 2012), were used to identify fish species. A total of 90 linear transects was performed in depths ranging from 2 to 5 m. Besides not destructive, by not removing individuals off the environment, visual censuses are one of the most widely used method for sampling reef associated fish (English *et* al.1997).

Data analyses

Fish richness, density (fish per m^2), mean size (mm) and ecological descriptors as Evenness (E), dominance of Simpson (D) and diversity of Shannon-Wiener (H'), were compared among seasons with generalized estimating equations (GEEs). These equations, calculated by the statistical package SPSS 15 (SPSS, 2006), work as an extension of generalized linear models to accommodate repeated measures designs (Diggle *et al*, 2002; Santos *et al*, 2011), as the visual censuses transects methodology. Where factors were significant, pairwise comparisons were conducted to determine which individual groups were different from each other.

The two matrices (fish density and water variables) were mostly analysed with ordination techniques. Environmental water variables were analysed with both indirect (Principal Correspondence analyses) and direct (Canonical Correspondence Analyses) gradient techniques (Carol et al., 2006). Indirect gradient techniques only uses the abiotic data versus samples matrix in the ordination, whereas in direct techniques the ordination results are constrained to optimize their linear relationship to the environmental variables. Indirect and direct gradient analyses are complementary because although direct analyses provide an ordination using the two matrices in a single analysis, indirect technics are often more robust and can show better seasonal gradients because of unmeasured environmental variables. Therefore, to identify seasonal patterns of the physical and chemical water environmental variables a Principal Components Analysis (PCA) was applied to the environmental data matrix ($\log_{10}$-transformed). By the calculus of eigenvalues and eigenvectors, this multivariate technique does a dimensional reduction of the data, analysing the main patterns of variability presents in the model (Tabachnick & Fidell, 2001).

The effects of water abiotic factors and time on species composition were evaluated by a canonical correspondence analysis (CCA), which was performed with CANOCO 4.5 (Lepš and Šmilauer, 2003). This is considered to be a powerful multivariate technique witch constrains the ordination of species composition to be a linear function of the environmental variables, therefore using the environmental and fish composition matrices simultaneously in a single analysis (Santos et al, 2011). Off the full environmental dataset only those variations selected by Monte Carlo permutation test ($p < 0,5$) were included in the biplot.

Generalized additive models (GAMs), as available in the CANOCO 4.5, were also fitted to appraise the response of fish richness, density (^{2}) and size (mm) to the water environmental variables (represented by the axis scores of the PCA analyses). These models are becoming a widely used statistical tool to analyse relationships among the distribution of the species and their environment, particularly in marine studies (Martínez-Rincón*et al*, 2012). GAM is a generalized linear model with a linear predictor involving a sum of smooth functions of covariates (Wood, 2006) that do not assume a particular functional relationship between the response variable and the predictor in this case study, the main environmental factors. The model complexity of GAMs was chosen by the stepwise procedure using the Akaike information criterion (AIC), also available in CANOCO 4.5. AIC considers not only goodness of fit but also parsimony, penalizing more complex models (Burnham and Anderson, 1998).

RESULTS

Environmental Variables

Environmental water variables (temperature, salinity, dissolved oxygen (mg L^{-1} and %), pH, horizontal visibility and depth) measured for each season are presented in **Table 2**. Salinity values showed a high variation indicating alternating estuarine and oceanic waters due to tidal influence in the study area. Temperature, dissolved oxygen (mg L-1 and %) and horizontal visibility were higher in autumn, salinity in winter and pH in spring. Lower values of dissolved oxygen and pH were observed in summer, temperature and horizontal visibility in spring and salinity in autumn.

Table 2 - Mean values and range (between parentheses) of environmental variables taken from April 2011 to March 2012 at Vermelha beach, Rio de Janeiro, Brazil.

Environmental variable	**Annual mean (range)**	**Season mean (range)**			
		Autumn	**Winter**	**Spring**	**Summer**
Temperature (^{o}C)	21.09 (15.47 - 26.47)	25.82 (21.47 - 26.47)	21.78 (21.48 - 22.39)	18.93 (15.47 - 21.32)	18.98 (18.5 - 19.35)
Salinity	33.25 (30.05 - 36.35)	30.92 (30.23 - 31.8)	35.56 (34.76 - 36.35)	34.71 (34.53 - 34.9)	32.34 (30.05 - 34.95)
Dissolved Oxygen (mg L^{-1})	5.68 (4.69 - 7.33)	6.32 (6 - 6.61)	5.98 (5.46 - 6.58)	5.54 (4.69 - 7.33)	5.15 (4.78 - 5.56)
Dissolved Oxygen (% saturation)	82.41 (58.3 - 114.6)	93.33 (89.9 - 97.1)	83.53 (76.5 - 92.2)	89.33 (58.3 - 114.6)	67.61 (63.4 - 71.2)
pH	8.13 (7.94 - 8.30)	8.15 (8.1 - 8.2)	8.18 (8.15 - 8.23)	8.19 (8.05 - 8.3)	8.02 (7.94 - 8.14)
Horizontal Visibility (m)	2.67 (1.0 - 6.0)	4.29 (3.0 - 5.0)	2.21 (1.5 - 3.0)	1.10 (1.0 - 1.5)	3.07 (1.0 - 6.0)
Depth (m)	3.15 (2.0 - 5.0)	3.24 (2.5 - 3.5)	3.94 (3.0 - 5.0)	2.64 (2.0 - 3.5)	3.04 (2.25 - 4.2)

The first two axis of the PCA (**Figure 4**) were significant (Monte Carlo test; 999 randomizations; P << 0.01 for both), explaining cumulatively 67.7% of the data variation. The first axis (eigenvalue = 2.32) explained 38.7% and showed significant positive correlations with temperature (*r* = 0.87), dissolved oxygen (*r* = 0.80) and depth (*r* = 0.63), while the second axis (eigenvalues = 1.75) had 29.0% explanation being positively correlated to salinity (*r* = 0.81) and pH (*r* = 0.71) and negatively to horizontal visibility (*r* = -0.57).No clear pattern for sample distribution among seasons was observed in the PCA diagram.

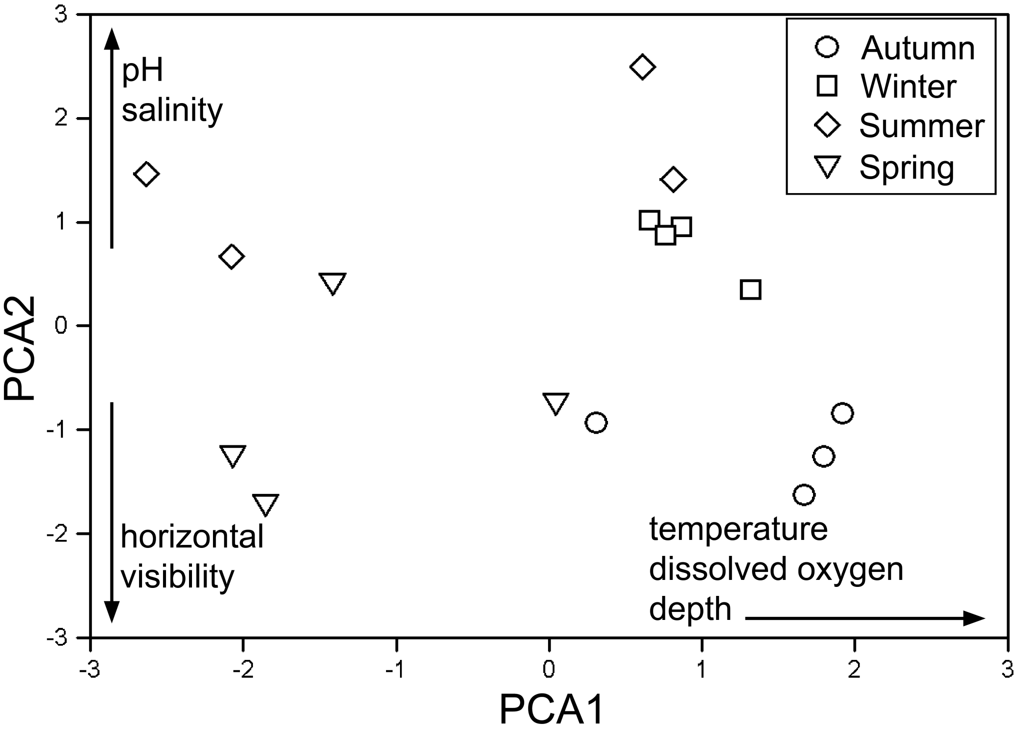

Figure 4. Ordination diagram constituted by the first two axis of the Principal Components Analysis (PCA) applied to the water environmental dataset taken at Vermelha Beach from April 2011 to March 2012. Directions of arrows indicate which variable better contributed to the distribution of samples along the axis.

Community metrics

Differences through seasons (GEEs) were observed for all community metrics excepting for Simpson's dominance and Evenness index (p≥0.1 for both), however patterns were not the same among them (**Figure 5**). Fish richness (GEE; $F_{3,86}$= 31.5; *P*

<< 0.01) and density ($F_{3,86}$ = 128.7; *P* << 0.01) presented similar patterns among seasons, with higher values in autumn, similar intermediate values in winter and summer, and lower values in spring (**Figure 5**a). Fish size (mm) ($F_{3,86}$= 96.5; *P* << 0.01) had a different pattern, with larger fish in spring in relation to all other seasons (**Figure 5**c). Shannon diversity index ($F_{3,86}$=8.9; *P* = 0.03), showed a smooth decreasing pattern from autumn to summer, nonetheless, only autumn differed significantly from spring and summer (**Figure 5**b).

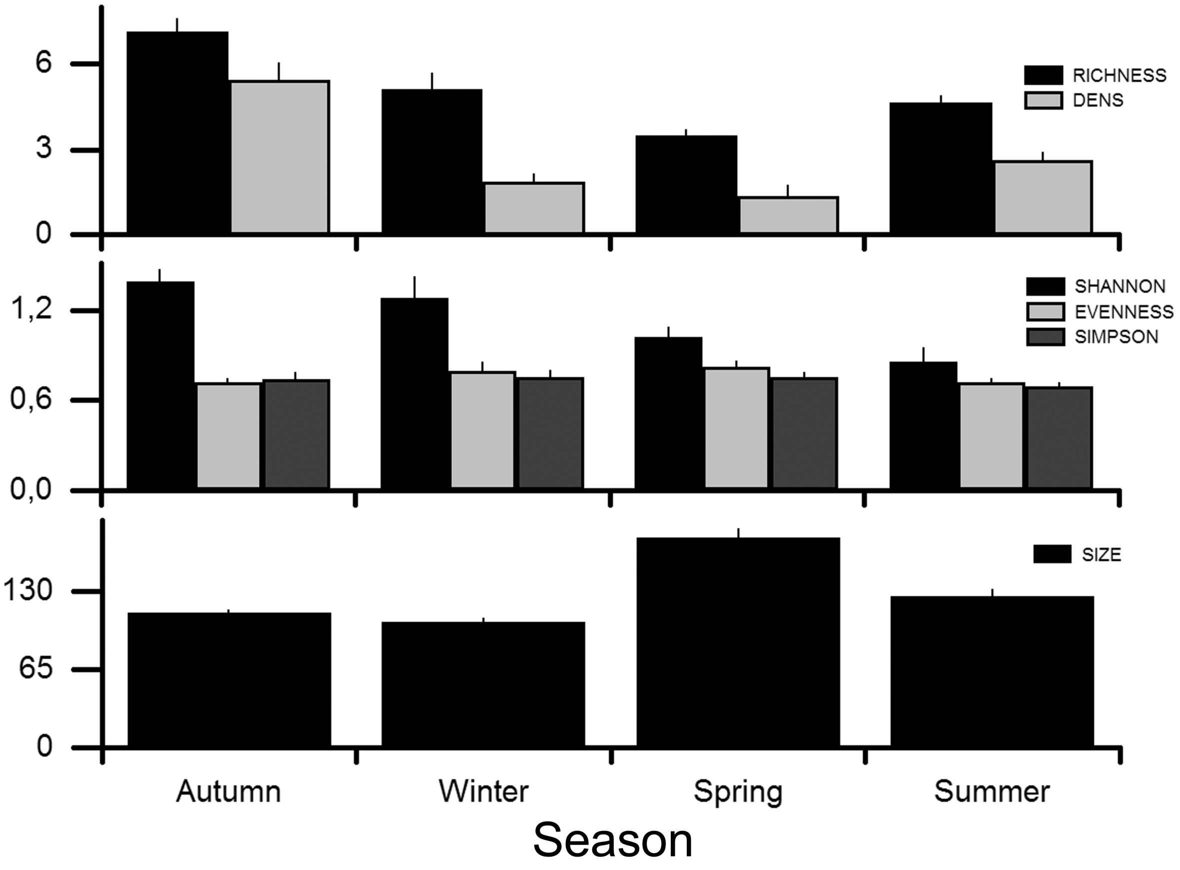

Figure 5 - Seasonal variation of mean richness, density (fish per m2) (5a), and size (mm) (5b), and diversity indexes (5c) recorded for the reef fish assemblage by visual censuses through an annual cycle at Vermelha beach. Legend of 5c:b Black = Shannon-Wiener diversity; light grey = Pielou's Evenness; and dark grey = Simpson's dominance. Vertical lines indicate standard error.

Seasonal variations of fish assemblages attributes

Off the 90 transects, 2,487 individuals were recorded through visual censes belonging to 18 families totalizing 29 species (**Table 3**). *Diplodus argenteus* was the most abundant species, followed by *Haemulon aurolineatum*, *Stephanolepis hispidus*, *Abudefduf saxatilis*, *Holocentrus adscensiones, Sphoeroides testudineus, Labrisomus kalisherae, Chilomycterus spinosus, Parablennius pilicornis* and *Atherinella brasiliensis,* which accounted together for 90.4% of total abundance. However, the last species was excluded from further analysis for being the only specie that does not present a close association to rocky reefs. In relation to the most frequent species, *S. hispidus*, *D. argenteus, S. testudineus, C. spinosus* and *H. aurolineatum* had 30% of presence summarizing their individual occurrences.

Table 3 - Fish species recorded through visual censuses at Vermelha beach, Guanabara Bay, Rio de Janeiro, Brazil. Density, specie symbol and total occurrence and are also represented.

	Symbol	Total Density (fish per m²)	Occurrence (90 transects)
Atherinopsidae			
Atherinella brasiliensis (Quoy and Gaimard 1825)*	Abra	5.5	2
Holocentridae			
Holocentrus adscensiones (Osbeck 1765)	Hads	13.9	18
Fistulariidae			
Fistularia tabacaria (Linnaeus 1758)	Ftab	0.1	1
Dactylopteridae			
Dactylopterus volitans (Linnaeus 1758)	Dvol	1.3	11
Serranidae			
Epinephelus marginatus (Lowe 1834)	Emar	0.3	2
Haemulidae			
Anisotremus virginicus (Linnaeus 1758)	Avir	0.1	1
Haemulon aurolineatum (Cuvier 1829)	Haur	34.6	29
Haemulon steindachneri (Jordan and Gilbert 1882)	Hste	1.4	6
Sparidae			
Diplodus argenteus (Valenciennes 1830)	Darg	85.2	45
Sciaenidae			
Pareques acuminatus (Bloch and Schneider 1801)	Pacu	1.3	8
Mullidae			
Mullus argentinae (Hubbs and Marini 1933)	Marg	0.1	1
Pseudupeneus maculatus (Bloch 1793)	Pmac	0.2	1
Chaetodontidae			
Chaetodon striatus (Linnaeus 1758)	Cstr	2.3	16
Pomacentridae			
Abudefduf saxatilis (Linnaeus 1758)	Asax	22.4	18
Stegastes fuscus (Cuvier 1830)	Sfus	2.2	17
Stegastes variabilis (Castelnau 1855)	Svar	0.9	6
Labridae			
Halichoeres poeyi (Steindachener 1867)	Hpoe	1.5	7
Labrisomidae			
Labrisomus kalisherae (Jordan 1904)	Lkal	8	19
Labrisomus nuchipinis (Quoy and Gaimard 1824)	Lnuc	0.7	6
*Malacoctenus delal*and*ii* (Valenciennes 1836)	Mdel	1.3	8
Blenniidae			
Parablennius pilicornis (Cuvier 1829)	Ppil	6.8	16
Scartella cristata (Linnaeus 1758)	Scri	3.9	23
Balistidae			
Balistes vetula (Linnaeus 1758)	Bvet	0.4	3
Monacanthidae			
Monacanthus ciliatus (Mitchill 1818)	Mcil	2.2	8
Stephanolepis hispidus (Linnaeus 1758)	Shis	31.2	64
Tetraodontidae			
Sphoeroides greeleyi (Gilbert 1900)	Sgre	3.6	13
Sphoeroides testudineus (Linnaeus 1758)	Stes	9.8	40
Diodontidae			
Chilomycterus reticulatus (Linnaeus 1758)	Cret	0.2	3
Chilomycterus spinosus (Linnaeus 1758)	Cspi	7.3	40
TOTAL: 29 Species		2487 individuals	

*** Not closely associated with rocky reefs**

Significant seasonal differences (GEEs; $P < 0.05$) were found for fish density (fish per m^2) often species (**Figure 6**), with marginal differences recorded for another four species ($P \leq 0.07$), most of them presenting higher densities in autumn. *Diplodus argenteus* ($F_{3,86}$= 74.0; $P << 0.01$), *Labrisomus kalisherae* ($F_{3,86}$=16.2; $P << 0.01$), *Pareques acuminatus* ($F_{3,86}$ = 16.5; $P < 0.001$) and *Scartella cristata* ($F_{3,86}$ = 11.5; $P << 0.01$) showed similar seasonal variations in density, with higher values in autumn, followed by intermediate values in summer and winter, and minimum values in spring. *Parablennius pilicornis* ($F_{3,86}$= 14.2; $P << 0.01$) and *Balistes vetula* ($F_{3,86}$ = 6.4; $P < 0.04$) also showed higher density values in autumn but with minimum densities in winter and spring. Higher densities of *Chaetodon striatus* ($F_{3,86}$= 20.2; $P << 0.01$), *Halichoeres poeyi* ($F_{3,86}$ = 11.4; $P< 0.01$) and *Sphoeroides testudineus* ($F_{3,86}$=7.4; $P = 0.06$) were recorded during autumn, whereas minimum values were found in summer and spring. *Holocentrus adscensiones* ($F_{3,86}$= 30.7; $P << 0.01$) had higher densities in autumn, with low values during winter and spring and no individuals in summer. *Dactylopterus volitans* ($F_{3,86}$= 13.0; $P << 0.01$) was not found in autumn, but showed higher densities in winter and intermediary values during summer and spring. *Labrisomus nuchipinis* ($F_{3,86}$=7.4; $P = 0.06$) were abundant in spring, occurring in low densities in autumn and summer, with no record in winter. *Stegastes variabilis* ($F_{3,86}$=5.2; $P = 0.07$) did not occur in spring and summer, showing higher densities during winter followed by autumn, whereas *Malacoctenus delalandii* ($F_{3,86}$=3.2; $P = 0.07$) were recorded only in summer.

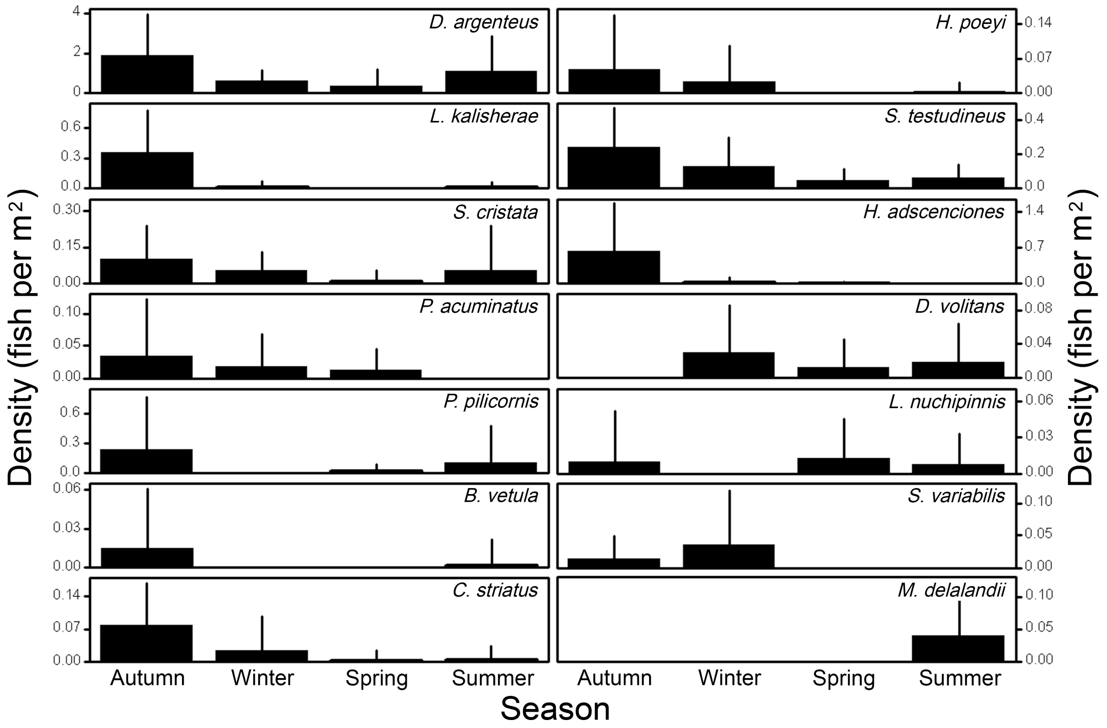

Figure 6 - Seasonal variations for density (mean fish per m2) of the major fish species associated with rocky reefs at Vermelha Beach. Vertical lines represent standard error.

The size (mm) of these fourteen species, excepting for *Labrisomus nuchipinis* ($F_{3,86}$= 0.2; *P* = 0.72) and *Stegastes variabilis* ($F_{3,86}$=0.8; *P* = 0.366), also differed between annual seasons(GEEs; *P* < 0.05; **Figure 7**). Individuals of *Scartella cristata* ($F_{3,86}$= 89.4; *P* << 0.01) were bigger in autumn and smaller in winter, with medium sizes in spring and summer. *Chaetodon striatus* ($F_{3,86}$= 50.5; *P* << 0.01), *Holocentrus adscensiones* ($F_{3,86}$ = 14248.8; *P* << 0.01) and *Pareques acuminatus* ($F_{3,86}$ = 50.5; *P* << 0.01) presented a similar size pattern among seasons, where a smaller size were observed in autumn, intermediary in autumn and winter and bigger in spring. *Diplodus argenteus* ($F_{3,86}$= 709.7; *P* << 0.01), *Parablennius pilicornis* ($F_{3,86}$ = 83.4; *P* << 0.01) and *Dactylopterus volitans* ($F_{3,86}$ = 10.7; *P* << 0.01) also presented higher size in spring but with different patterns for other seasons. For the first, medium sizes were recorded for autumn and winter, while smaller in summer. For *P. pilicornis* autumn also had intermediary values but smaller individuals were recorded at summer. *Dactylopterus volitans* had minimum size in winter and intermediary in summer. *Labrisomus kalisherae* ($F_{3,86}$=241.7; *P* << 0.01), *Halichoeres poeyi* ($F_{3,86}$ = 125.0; *P* <<0.01), *Sphoeroides testudineus* ($F_{3,86}$= 45.6; *P* << 0.01) presented bigger sizes in summer and smaller in winter. For *Balistes vetula* ($F_{3,86}$= 693.4; *P* << 0.01) higher sizes were also recorded in summer but smaller in autumn. *Malacoctenus delalandii* was recorded only in summer.

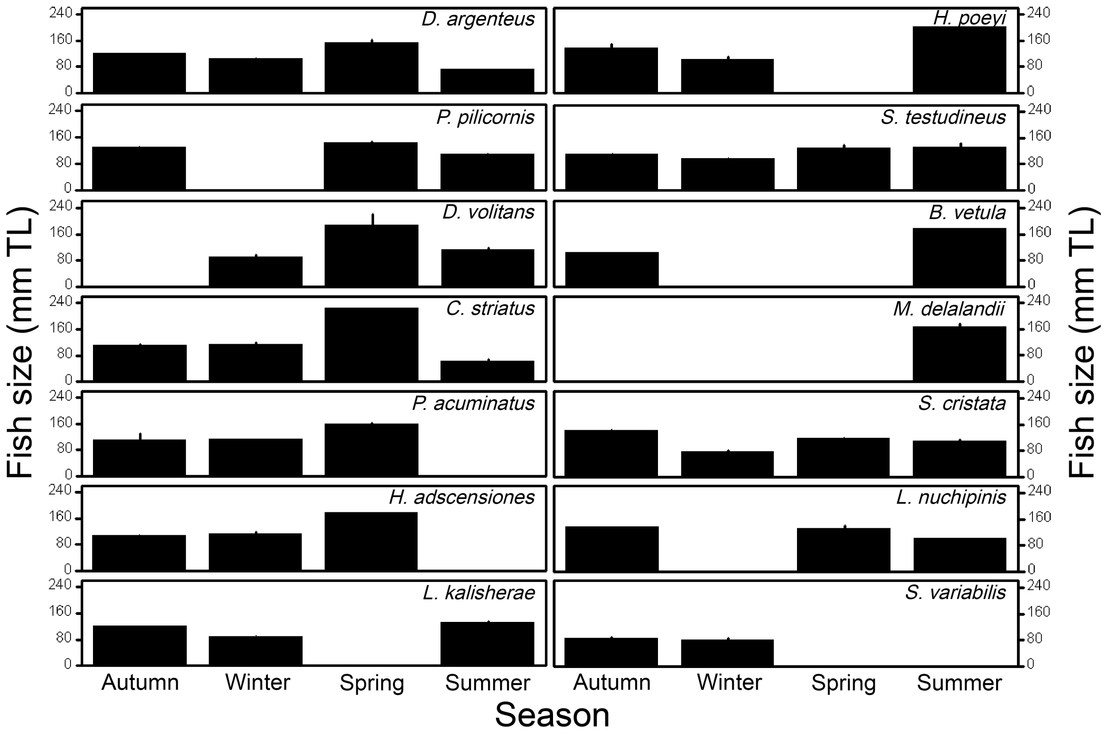

Figure 7 - Seasonal variations for mean size (mean fish per m2) of the major fish species associated with rocky reefs at Vermelha Beach. Vertical lines represent standard deviation.

Fish assemblage variation and time

The summarized first three axis of the CCA analyses explained 83.9% of the relation of species composition, season and time (Monte Carlo *test*, $P << 0.01$), which respectively explained 37.8% (eigenvalue = 0.18), 36.5% (eigenvalue = 0.18) and 9.6% (eigenvalue = 0.05) of the variation (total inertia = 3.20) but due to the low values of explanation, the third axe were not retrieved. Salinity and pH did not contribute significantly to the model ($p > 0.05$ for both) consequently were excluded from further analyses. The biplot diagram did not clearly separate the samples by seasons, as a possible effect of the sample autocorrelation with time (**Figure 8**a). Therefore, a partial CCA analysis was performed using time (i.e. days after the first transect) as covariable in order to control for the influence of repeated counting through time (**Figure 8**b).

This new CCA using time as a covariable, had the first three axis explaining 90.2% of the relation of species composition (Monte Carlo test, P= 0.002). The first axis explained 54.5% (eigenvalue = 0.18), the second 21.8% (eigenvalue = 0.07) and the third 13.9% (eigenvalue = 0.04) of the variation, evidencing a better fitting of the relation between species and variables. Temperature was the variable that better explained the distribution of the species (F_{radio}= 4.74; $P \ll 0.01$), explaining 16% of this distribution, followed by depth (F_{radio}= 3.25; $P \ll 0.01$) with 11%, dissolved oxygen (F_{radio}= 1.94; $P < 0.01$) with 7%, and horizontal visibility (F_{radio}= 1.79; $P < 0.05$) with 6%.

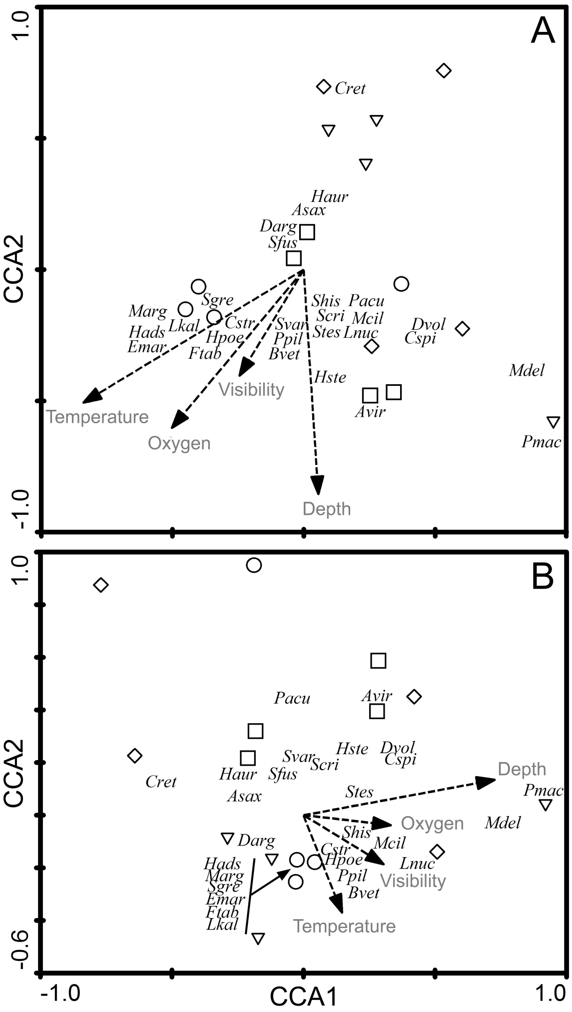

Figure 8 - a. Canonical correspondence analysis of fish composition (density) with time and environmental variables (temperature, depth, horizontal visibility and dissolved oxygen) and **b.** the same anlysis but using time as a covariant variable.

The majority of the responses to richness, density and size (mm) exhibited a non-linear tendency when correlated to the axis scores of the PCA (**Figure 9**). A non linear response was found for the relationship of fish richness and the first axis of the PCA ($F_{1,87}$= 5.36; $p < 0.01$), suggesting a raise in richness with increased water temperature and dissolved oxygen. For the second PCA axis, this relation was also nonlinear ($F_{1,87}$= 4.86; $p = 0.03$) but showed a different trend overall decreasing towards lower salinity and pH.

A relation was found between density and PCA1 (nonlinear $F_{1,87}$= 24.42; $p \ll 0.001$), in which an initial slight growth is observed related to higher values of temperature and dissolved oxygen, until reaching a certain point, then showing a sharp positive relation with these variables. Nonetheless, a linear trend was recorded for density in relation to PCA2 ($F_{1,89}$= 17.57; $p \ll 0.001$), indicating a negative relation of density with the decrease in salinity and pH, together with an increase of horizontal visibility. A positive non linear relationship of fish size with the second axis of the PCA ($F_{1,87}$= 6.64; $p = 0.01$) was observed, showing a trend of larger fish with increasing salinity and pH, and lower horizontal visibilities. The correlation with the first axis of the PCA (nonlinear $F_{1,87}$= 9.21; $p \ll 0.01$) suggested a smooth growth until a certain point where it became negative decreasing together with temperature and dissolved oxygen.

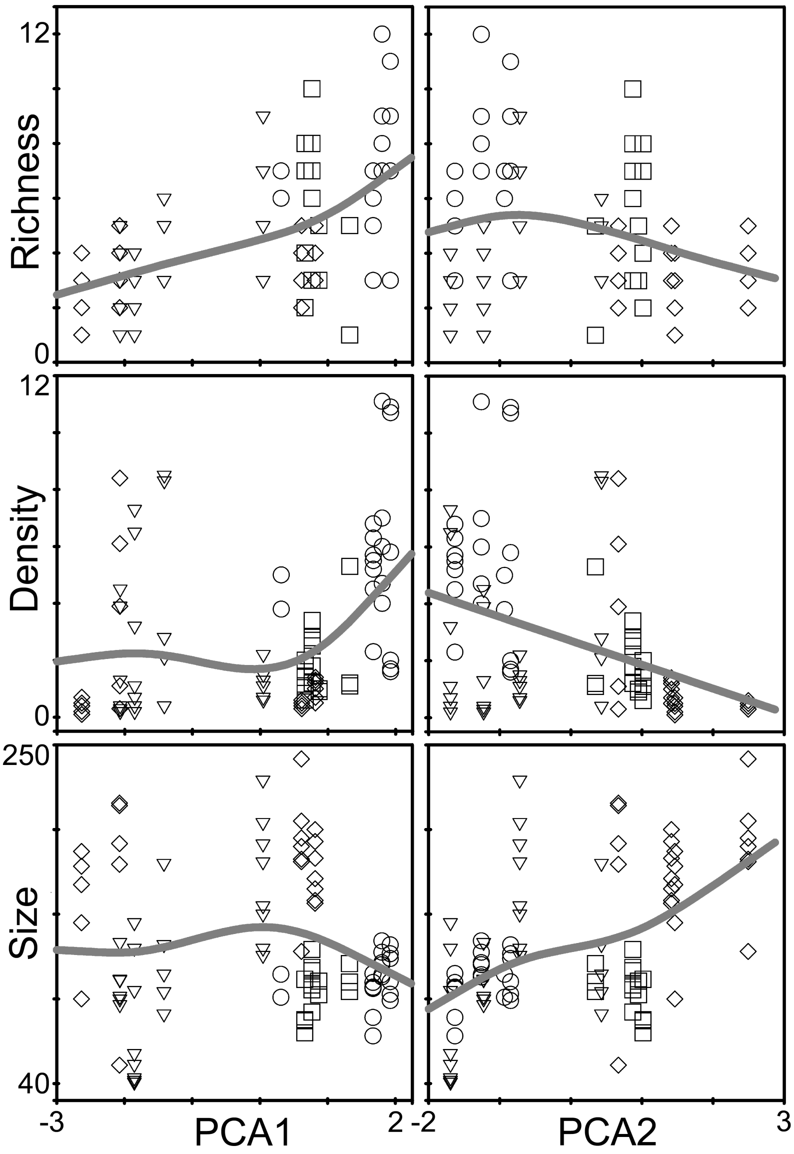

Figure 9 - Response of fish richness, density (fish/m2) and size (mm) to the scores of both axis of the PCA analyses. Lines represent the tendencies generated by the generalized additive models selected by the Akaike information criterion.

Response curves of *Haemulon steindachneri* ($F_{1,\,89}$ = 2.15;*P*= 0.15), *B. vetula* ($F_{1,\,89}$ = 2.11; *P* = 0.15), *S. cristata* ($F_{1,\,89}$ = 8.28; *P* << 0.01) and *S. variabilis* ($F_{1,\,89}$ = 3.14; *P* = 0.08) suggested a positive linear tendency of densities according to the increment on water temperature and dissolved oxygen (**Figure 10**). Positive but non linear trends were observed for densities of *Parablennius pilicornis* ($F_{1,\,87}$ = 4.51;*P = 0.03*), *H. Poeyi* ($F_{1,\,87}$ = 1.98; *P = 0.16*), *S. hispidus* ($F_{1,\,87}$ = 5.07; *P = 0.02*), *S. testudineus* ($F_{1,\,87}$ = 4.66; *P = 0.03*), *L. kalisherae* ($F_{1,\,87}$ = 22.19; *P << 0.01*), *S. greeleyi* ($F_{1,\,87}$ = 3.61 ; *P* =

0.06), *C. striatus* ($F_{1, 87} = 6.64$; *P = 0.01*) and *M. argenteus* ($F_{1, 87} = 2.87$; *P = 0.09*), with water temperature and dissolved oxygen. Similar and non linear trends were also seen for *H. Adscensiones* ($F_{1, 87} = 14.24$; *P<< 0.01*), *E. marginatus* ($F_{1, 87} = 3.98$; *P = 0.07*), *D. argenteus* ($F_{1, 87} = 11.99$; *P << 0.01*) and *M. ciliatus* ($F_{1, 87} = 3.0$; *P = 0.08*), but suggesting a sharp increase in densities after a certain point. Conversely, for *H. aurolineatum* ($F_{1, 89} = 3.41$; *P* =0.06) and *C. reticulatus* ($F_{1, 89} = 3.41$; *P* = 0.10) a negative linear trend is observed, suggesting a tendency of lower densities, with a increase in dissolved oxygen and temperatures. A more unimodal trend is seen for *M.delalandii* (non linear $F_{1, 87} = 12.17$; *P* <<0.01), *C. spinosus* (non linear $F_{1, 87} = 10.92$; *P* <<0.01) and *D. volitans* (non linear $F_{1, 87} = 4.39$; *P* = 0.03) where initially an increasing trend is observed together with the increment of water variables, reaching a certain point where this relationship becomes negative.

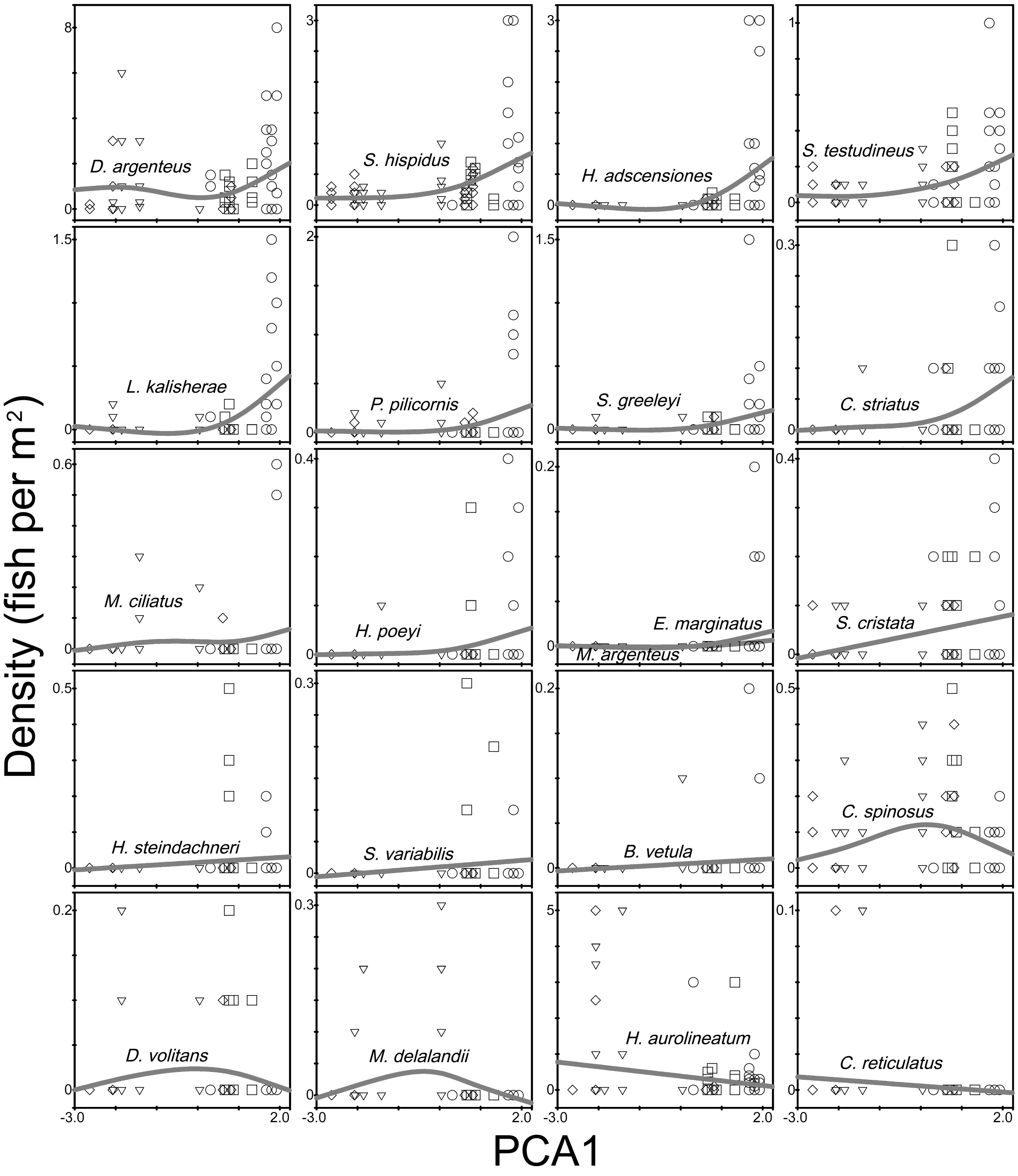

Figure 10 - Relationship of density (fish per m^2) with the environmental variables related to the first axis of the PCA. Lines are the generalized additive models selected by the Akaike criterion.

For *S. testudineus* ($F_{1, 89} = 4.29$; $P = 0.04$), *D. argenteus* ($F_{1, 89} = 10.91$; *P = 0.01*), *C. striatus* ($F_{1, 89} = 2.21$; $P = 0.14$), *B. vetula* ($F_{1, 89} = 2.33$; $P = 0.13$), *H. adscensiones* ($F_{1, 89} = 4.61$; $P = 0.03$), *P. pilicornis* ($F_{1, 89} = 2.61$; $P = 0.11$) and *S. greeleyi* ($F_{1, 89} = 3.42$; $P = 0.06$) the negative trend was linear and indicated that densities of those species were related to high horizontal visibility and low salinity and pH (**Figure 11**).

A more unimodal response was observed for densities of *H. aurolineatum* (nonlinear $F_{1, 87} = 4.09$; $P = 0.04$), *M. ciliatus* (nonlinear $F_{1, 87} = 5.33$; $P = 0.02$) *L. kalisherae* (nonlinear $F_{1, 87} = 2.51$; $P = 0.11$), *S. hispidus* (nonlinear $F_{1, 87} = 2.40$; $P = 0.12$) and *M. delalandii* (nonlinear $F_{1, 87}= 4.49$; $P = 0.03$), where higher densities were related to the increment of environmental variables of PCA2, reaching a certain point where this relationship becomes negative. Except for the relationship between density of *Chilomycterus spinosus* (linear $F_{1, 89} = 3.61$; $P = 0.06$) and the second PCA axis (**Figure 11**), in which a positive linear trend were found with increasing salinity and pH and decreasing horizontal visibility, all the response curves were negative. No relationship was selected by AIC for PCA1 and *Labrisomus nuchipinis*, *P. acuminatus*, *S. fuscus*, *F. tabacaria*, *A. saxatilis*, *P. acuminatus* and *A. virginicus*. In addition to those species, no GAM was selected by the AIC for PCA2 together with *Epinephelus marginatus*, *S. variabilis*, *M. argenteus*, *H. steindachneri*, *H. poeyi*, *S. cristata*, *D. volitans* and *C. reticulatus*.

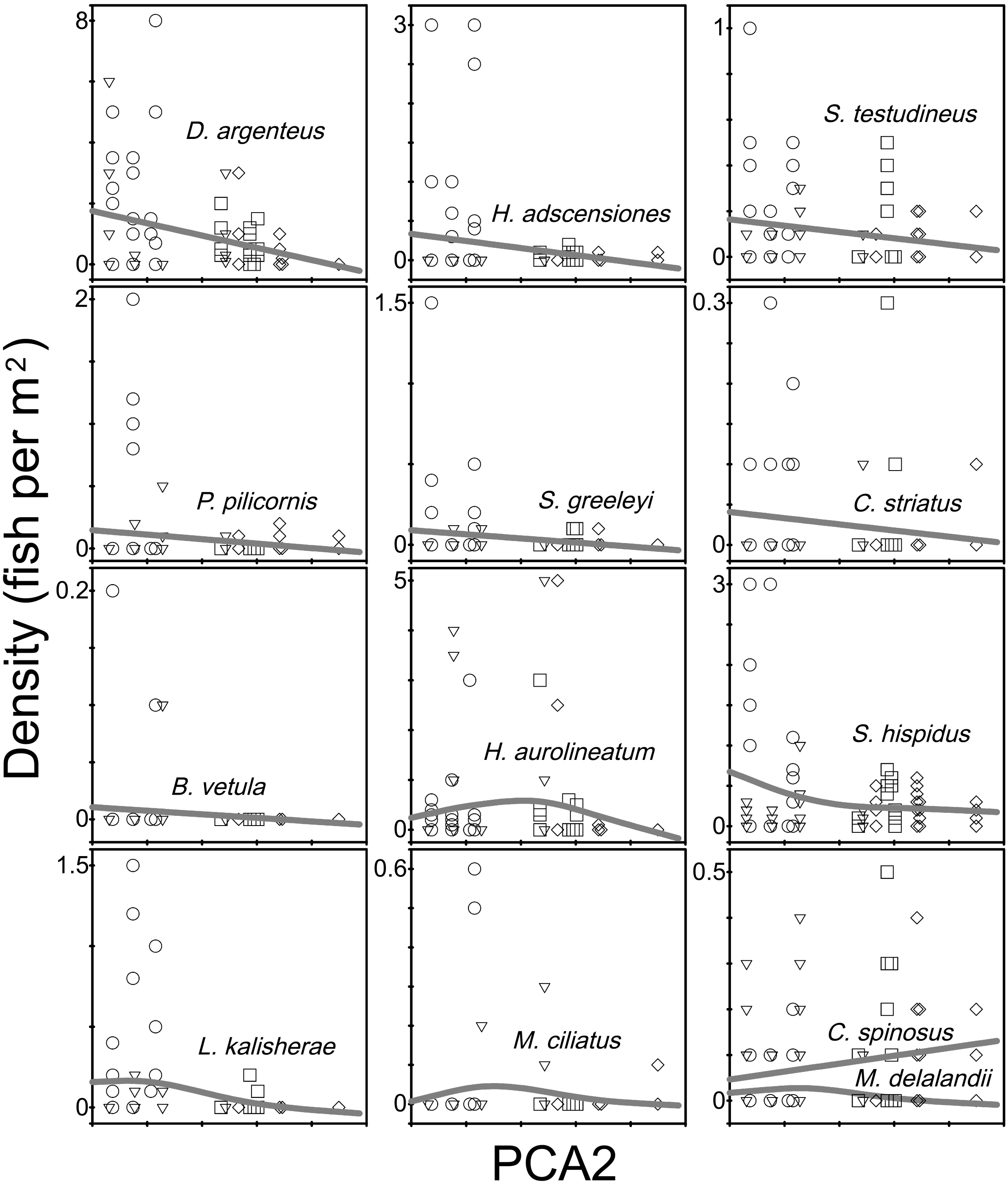

Figure 11 - Relationship of density (fish per m^2) with the environmental variables related to the second axis of the PCA. Lines are the generalized additive models selected by the Akaike criterion.

DISCUSSION

Fish community structure

Underwater censuses at the rocky reefs of Vermelha beach yielded a total of 29 species and 18 families. Comparing to Mendonça-Neto et al (2008), in which they accessed the fishes associated to the rocky reefs of three coastal islands near the entrance of Guanabara Bay, our results recorded the same richness for families but lower in species level (*i.e.* 42 species). Furthermore our fish assemblage was dominated by few species, in which five (*D. argenteus*, *H aurolineatum*, *S. hispidus*, *A. saxatilis* and *H. adscensiones*) accounted for 75% of total density. The first four species showed similar dominances of those recorded for two costal islands far from the entrance of Guanabara Bay (*i.e.* 8.2 Km and 12.3 Km; Monteiro-Neto *et al*, 2008), following a general pattern of the reef fish assemblage that is typical for the subtropical Brazilian waters (Ferreira et al., 2004).

Sphoeroides testudineus, *L. kalisherae*, *C. spinosus* and *P. pilicornis* accounted individually with only 3-4% for the total density, but they were frequent species, occurring at least in 18% of all censuses. Because of their typical eel shape, camouflage behaviour, strong association with benthic community, and the high morphological and coloration similarity, densities of labrisomids and blenniids are often underestimated in visual censuses (*i.e.* up to 90% according to Willis 2001; Depczynski and Bellwood 2004). Despite this fact, in our work these cryptic species ranked amongst the ten most abundant species, which could be related to the previous divers' experience acquired during training surveys. The dominance of *Labrisomus nuchipinis* within cryptic fishes is also discussed by Monteiro-Neto *et al* (2008) where its high densities were related to the absence of top predators due to fishery pressure (Tubino et al., 2007). Since the Vermelha Beach also undergo from heavy fishery pressure (Barreto et al., in press), the high occurrences of *L. kalisherae* and *P. pilicornis* in our study, could also be related to the scarcity of natural predators.

Besides, due to its peculiar geographic location, the study area is under direct influence of Guanabara Bay's water discharge (Barreto et al., in press; Castro *et al.*, 2005), providing waters with low salinity, high sediment loads and pollution runoff derived from such large body of water. These factors could be adversely affecting rocky-reef-fish richness (Silva and Araújo, 2003; Mendonça-Neto et al, 2008), especially on those site-attached species (Roberts and Ormond, 1987). Surprisingly, very few studies addressed the effects of environmental variables on rocky reef composition and structure.

Responses to seasons and the environmental variables

Castro et al., (2005), proposed that the entrance channel of Guanabara Bay function as a partially mixed estuary during dry season and a salt-wedge estuary during rainy season. Disagreeing to that, our results of water environmental variables, especially for salinity and pH, showed that the study region, as part of the same environment, functioning as a continuous transitional estuarine-marine environment, as proposed by Barreto et al., (in press). High salinity and pH values, such as those recorded in our study and also seen by Kjerfve et al. (1997) for the same region, are typical of environments dominated by marine influence, whereas the few changes among seasons were of minor importance. These factors would explain the prevalence of the marine and reef-associated fish species at Vermelha Beach, indicating thus that abiotic characteristics of the environment are key structuring factors of those fish assemblages (Araújo et al., 2002).

High dissolved oxygen values are often related to increased photosynthetic activity, which in turn could be attributable to the same ecological process in Guanabara Bay, nutrient availability, but due however to two different causes. During autumn and winter, dissolved oxygen is generally high in response to the increased occurrence and intensity of cold-front storms, which led to the homogenization of the entire water column and to a great nutrient and sediment resuspension (Gallucci & Neto, 2004). As consequence, low values for salinity and pH were commonly recorded. During spring and summer, dissolved oxygen is high due to upwelling events, both from the nearing of South Atlantic Central Waters to the coast (Kjerfve et al., 1997) as well as the intensification of beach upwelling cells by the East Winds (Godoy et al., 2002; Santos et al., 2010). As a result, low water temperature and high salinity values were recorded. Regardless to their causal mechanism, high nutrient inputs would lead to the increased food availability that probably cascade throughout the entire food chain, affecting thus positively the reef fish densities (Runge, 1988; Pauly & Christensen, 1995).

Depth variations were also correlated to changes in the community structure as seen in other works (Chaves and Monteiro-Neto, 2009; Ferreira et al., 2001). For the majority of species a tendency of increased densities toward deeper layers were observed. According to Letourneur et al. (2003) it is because of the higher availability of niches and habitats at those layers, due in part to the rocky reef-sand ecotone present in deeper layers. In constrast, for *Malacoctenus delalandii*, *C. spinosus*, *D. volitans*, *H. aurolineatum* and *C. reticulatus* the tendency was toward shallow waters, probably due to lower predator pressure for the first species and juvenile *H. aurolineatum*, and the presence of efficient anti predator mechanisms for the other species (i.e. stout spines; and poison glands). Nevertheless, this variable should be viewed with caution since transects were performed within restrict depth range (*i.e.* 2-5 m; mostly 3m), therefore part of that variation could be also related to daily tidal amplitude during the survey.

Agreeing to the results of the PCA analysis, no seasonal pattern was observed in either CCA analyses, confirming that seasonality is secondary when compared to the effects of water environmental variables over the species distribution. Those results indicate that changes on these variables are the main factors structuring the reef fish community distribution. Nevertheless a few species showed variation in response to seasons, which by considering the GAM results, are likely to be related to cyclical changes on the environmental variables.

Higher densities of *Diplodus argenteus*, *H. adscensiones*, *C. striatus*, *L. kalisherae*, *P. pilicornis, S. testudineus* and *B. vetula* in autumn were positive related to clear, warmer and more oxygenated water, together with negative relations to salinity and pH. Great horizontal visibilities in that season also indicate higher influence of oceanic inflow when comparing to the effects of estuarine waters as result of inner Bay inflow. This variable can also influence on diver perception of fish richness and densities, explaining high density recordings, specially for species with schooling behavior (Kulbicki *et al.,* 2010), such as *Diplodus argenteus*, closely associated to the substrate, such as *C. striatus* and *B. vetula,* and cryptic fishes (Willis 2001; Depczynski and Bellwood, 2004), such as *L. kalisherae* and *P. pilicornis*. Additionally, according to Vazzoler (1992) spawning season in Guanabara Bay are related to months with higher temperature values (*i. e.* autumn and summer months), since the seasonal water temperature cycle functions as controller of spawning and recruitment periods (Phonlor, 1984).

For *Diplodus argenteus*, *P. pilicornis*, *C. striatus*, *H. adscensionis*, *L. kalisherae* and *S. testudineus*, bigger individual sizes during autumn months overall coincide with gonadal maturity for these species (Rocha et al., 2002; Shinozaki-Mendes et al., 2007) which depends on lower temperatures and salinity, as also recorded in our samplings. Smaller individual sizes recorded during summer transects could therefore indicate a recruitment period, as densities of fish recruits enhance during summer months along the Brazilian coast (Bonecker, 1997; Castro and Bonecker, 1996; Castro et al., 2005).

Densities of *Dactylopterus volitans, H. poeyi*, *S. variabilis* and *S. cristata* showed variations between seasons and responded to temperature, dissolved oxygen and depth (PCA1). For *D. volitans* higher densities were recorded in spring and summer, seasons where temperature and dissolved oxygen were lower and surveys were made in shallower layers, indicating a preference of this specie for those environmental conditions. During those seasons, the nearing of the South Atlantic Central Waters to the coast would cause nutrient water enrichment, increasing food resource availability. At Arraial do Cabo, a region in Rio de Janeiro that upwelling events are widely studied, *Dactylopterus volitans* is commonly recorded (Ferreira et al., 2001) corroborating our results on the preference of this species for this kind of environment. For *Halichoeres poeyi*, *S. cristata* and *S. variabilis* higher densities were related to higher temperatures and dissolved oxygen, and deeper layers, but densities patterns between seasons were different. The first two species were more abundant in autumn while the Pomacentridae in winter, seasons where the presence of cold fronts with high influence of wave, are common. But due to Vermelha Beach geographical location, being considered to be a sheltered environment, rocky reef fish community does not experience the full effects of wave disturbance. Corroborating to our results, these species especially the labrid *Halichoeres poeyi*, are overall negatively related to wave exposure with preference of sheltered or moderately exposure habitats due to their swimming ability (Wainright et al., 2002, Floeter et al., 2007; Nunes et al., 2013).

Labrisomus nuchippinis and *Pareques acuminatus* showed only variations between seasons not being selected by any of the environmental variables tested in our work. The Labrisomid had higher densities in spring, and even though it reproduces all year round, this significant difference could be related to its preference for spawning by end of spring and beginning of summer (Carvalho-Filho, 1999; Gibran et al., 2004). *Pareques acuminatus* is highly associated to structurally complex habitats, staying hidden on the crevices (Barreto et al., in press), witch makes its visualisation during the censuses harder on months with lower horizontal visibilities, therefore in autumn probably due to higher values of that environmental variable, this specie had its higher records.

Sphoeroides greeleyi, S. hispidus, M. ciliathus, C. spinosus and H. aurolineatum showed correlations with temperature, dissolved oxygen and depth (PCA1) as well as salinity, pH, and horizontal visibility (PCA2) but did not presented significant seasonal variations. For the first three species density patterns showed similar trends increasing towards higher horizontal visibilities, temperatures, dissolved oxygen and deeper layers together with lower values of salinity and pH. Sphoeroides greeleyi has high osmoregulatory capacity not limiting its distribution by salinities variations, especially during low tide where seawater is often more diluted (Prodocimo & Freire, 2004). This salinity tolerance allows the specie to better exploit alimentary resources not being so influenced by resource variations, as its diet is composed by a large variety of items, making this specie widely spread and dominant throughout the Brazilian coast (Ferreira et al., 2004). The presence of defensive mechanisms, as the high toxicity, capacity to increase corporal volume and presence of spines through the body (Barleta & Corrêa, 1992), would also allow this specie to be found in deeper layers of Vermelha Beach, as it is rarely seen waters with more than 15m depth (Chiaverini, 2008) corroborating with our findings.

An wide feeding range and presence of defensive mechanisms are characteristics also shared with *Stephanolepis hispidus*, another typical and dominant specie for our coast (Ferreira et al., 2004). It has been observed that *Monacanthus ciliathus* overlap its distribution and feeding habitats with *S. hispidus* (Clements & Livingstone, 1983), suggesting that they would show similar responses to changes in the environment as observed in our study. Opposite relations to these environmental variables were recorded for *Chilomycterus spinosus*, with higher densities related to shallower, colder and less oxygenated waters, with lower horizontal visibilities together with higher salinities and pH. As this specie shows the same feeding range and also has defensive mechanisms like the Tetraodontids but has bigger size structure, to avoid competition within these species, density patterns observed was probably due to niche partitioning.

Higher densities of *Haemulon aurolineatum*, were related to lower values of salinity, pH, horizontal visibilities and dissolved oxygen together with colder and shallower waters. Agreeing to our findings, it has been described that this specie shows preferences to relatively shallow water (Sauskan and Olaechea, 1974; Manoocr and Barans, 1982), inhabit a vide variety of environments (Rocha et al, 1998) and are common in estuaries being more capable of tolerating lower values of salinity and pH than other marine-specific species. But opposing to the findings of Manoocr and Barans (1982) who related this specie to high temperature with migrations during colder waters, our results showed a positive relation toward lower temperatures.

Epinephelus marginatus, *Mullus argetinae*, *Haemulon steindachneri* and *Chilomycterus reticulatus* showed only relation to temperature, dissolved oxygen and depth (PCA1). Only for *C. reticulatus* a negative trend were observed in which higher densities were connected to colder and shallower waters with lower dissolved oxygen. For the other species this relation was positive toward warmer, more oxygenated and deeper waters. Temperature, dissolved oxygen and depth, explained the distribution of the majority of species and therefore seems to play a greater part structuring the reef fish composition of Vermelha Beach. These variables are known to influence changes in fish community structure but has only been studied individually (Haedrich 1983; Thorman 1986; Kneib 1997; Akin *et al.* 2003, Floeter et al., 2007; Teixeira et al., 2012). Our results demonstrate the need of further multiparametric approaches as species respond to a suite of environmental variables and that some would function as better predictors to the distribution of the fish community structure. *Fistularia tabacaria*, *Anisotremus virginicus*, *Pseudupeneus maculatus*, *Abudeffduf saxatilis* and *Stegastes fuscus* did not showed any relation to either of the environmental variables tested and neither showed seasonal significant differences. This evidenciates that not only these variables would be affecting the composition of rocky-reef fish assemblage of Vermelha Beach but also other unmeasured variables, as an example changes in habitat complexity, inter and intra specific biological interactions (*i. e.* Territorialism, competition for space and food) and human intervention, evidencing the importance of multiple scale continuous studies in the area.

CONCLUSIONS

Our fish assemblage was dominated by five species and followed a general pattern of the reef fish assemblage inhabitant of the subtropical Brazilian waters. Changes on environmental variables were the main factors structuring the reef fish community distribution, nevertheless some species still respond to seasons, which is proposed to be a cyclical change of some environmental variables. Temperature, dissolved oxygen and depth, explained the distribution of the majority of species and seems to play a greater part structuring the reef fish composition of Vermelha Beach. Densities patterns and occurrences of some species remain unclear pointing out that other unmeasured variables may also be affecting the composition of rocky-reef fish assemblage of Vermelha Beach, evidencing the importance of multiple scale continuous studies in the area.

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