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Variações sazonais da ictiofauna residente e transiente associada aos costões rochosos da Praia Vermelha, baía de Guanabara

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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 do título de Mestre em Ciências Biológicas.

Orientador: **Prof. Dr. Luciano Neves dos Santos**

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"A tarefa não é tanto ver aquilo que ninguém viu,
mas pensar o que ninguém ainda pensou
sobre aquilo que todo mundo vê".
Arthur Schopenhauer

RESUMO

As baías costeiras são ambientes importantes no ciclo de vida de peixes tropicais e subtropicais, muitos de interesse comercial por serem áreas propícias para reprodução, crescimento, alimentação e proteção contra predadores. Muitas baías situam-se em regiões de intensa atividade antropogênica, tornando esses ambientes e sua comunidade biológica suscetíveis a impactos. A baía de Guanabara, segunda maior baía costeira do Brasil, abrange grande parte da costa do município do Rio de Janeiro se destaca não apenas por sua dimensão e heterogeneidade ambiental, mas, também, por abrigar numerosas espécies de peixes e diversificados biótopos, como manguezais, praias arenosas e costões rochosos. Os costões rochosos apresentam elevada importância por sustentarem uma fauna e flora muito ricas, as quais constituem um excelente sensor biológico das condições ambientais. Apesar disso, pouco ainda se sabe sobre os efeitos das condicionantes ambientais sobre essas comunidades. Neste contexto, o presente estudo visou caracterizar, por meio de coletas sistematizadas com redes de espera, a comunidade de peixes da Praia Vermelha e descrever como as principais espécies respondem a mudanças sazonais e anuais em algumas variáveis ambientais. Esse objetivo foi alcançado através da comparação entre os padrões de resposta a mudanças sazonais e interanuais das variáveis ambientais de temperatura, salinidade e pH pela ictiofauna transiente e residente do costão da área estudada (capítulo 1). Além disso, foi avaliado o efeito das variações sazonais e interanuais da temperatura, salinidade e pH sobre a ictiofauna recifal, e o efeito dessas variáveis sobre a comunidade como um todo e sobre as espécies mais representativas (capítulo 2). Nossos resultados indicaram a necessidade de alguns ajustes estatísticos em estudos com comunidades compostas por grupos de espécies residentes e transientes. Além disso, a influência alternada de águas estuarinas e oceânicas foi detectada na área de estudo, favorecendo as espécies de peixes residentes mais abundantes. Porém ainda são necessários estudos complementares, especialmente de longa-duração e que incluam um maior número de variáveis ambientais, para validação da abordagem analítica utilizada e verificação dos padrões encontrados.

Palavras-chave: variáveis ambientais, baía de Guanabara, ictiofauna, costão rochoso

ABSTRACT

Coastal bays are transitional areas that play a key role as breeding, nursery and feeding sites for many tropical and subtropical fish species. Many bays are located in regions of intense anthropogenic activity, resulting in several impacts the associated biological community. Guanabara Bay, the second biggest coastal bay in Brazil, is located in the metropolitan area of Rio de Janeiro city, harbouring great fish diversity and also several biotopes as, mangroves, sandy beaches and rocky shores. Rocky shores support a great diversity of fauna and flora, which can be used as sentinels for environmental changes. In this sense, the present study aimed to characterize, through gillnet samplings, the fish assemblage of Vermelha beach and describe seasonal and interannual responses of the main species to environmental variables. These aims were attained through a comparison of the seasonal and interannual responses of the resident and transient fish assemblage to temperature, salinity, and pH in the rocky shores of the study site (chapter 1). Furthermore, it was evaluated the effects of seasonal and interannual variations in temperature, salinity, and pH on reef fish assemblage, and the effects of these variables on the community structure and on the main species (chapter 2). Our findings indicated the need of statistical adjustments to evaluate fish assemblages composed by resident and transient groups of species. Besides, it was detected an alternating influence of estuarine and oceanic waters on the study site, which favored the resident species that were more abundant. However, further studies are needed, especially those performed in long-tem periods and addressing other environmental variables, to validate the analytical approach used and confirm the observed patterns.

Keywords: environmental variables, Guanabara Bay, fish assemblage, rocky shore

SUMÁRIO

INTRODUÇÃO GERAL

As baías costeiras são corpos d’água marinha de grande porte circundados por terra que podem ser mais complexos e dinâmicos que estuários costeiros, devido à maior troca de energia entre águas oriundas da drenagem continental e de origem oceânica, intensificando o transporte de matéria orgânica, nutrientes e organismos (Kjerfve et al. 1997; Castro et al. 2005). São ambientes importantes no ciclo de vida de peixes tropicais e subtropicais, muitos de interesse comercial, onde a abundância da ictiofauna está relacionada com interações bióticas e variáveis ambientais, além de serem áreas propícias para reprodução, crescimento, alimentação e proteção contra predadores (Araújo et al. 2002; Castro et al. 2005). Por estarem situadas em áreas costeiras, muitas baías situam-se em regiões de intensa atividade antropogênica, tornando esses ambientes e sua comunidade biológica suscetíveis aos seus impactos (Meniconi et al. 2012a). No Brasil destacam-se por suas dimensões e importância econômica, as baías de Todos-os-Santos (1233 km^2), de Guanabara (400 km^2) e de Camamu (384 km^2).

A costa do estado do Rio de Janeiro é geomorfologicamente complexa, possibilitando a formação de inúmeras baías e lagoas costeiras, onde diversos organismos marinhos, muitos dos quais comercialmente importantes, passam parte ou todo o seu ciclo de vida (Rodrigues et al. 2007). O estado do Rio de Janeiro apresenta três grandes sistemas de baías, Ilha Grande, Sepetiba e Guanabara, das quais as duas últimas vêm sofrendo crescentes impactos decorrentes de atividades antrópicas e a baía de Ilha Grande, ainda apresentando grande parte de seu entorno recoberto por Mata Atlântica preservada (Valentin et al. 1999; Araújo et al. 2002; Lima et al. 2002). Com poucos estudos sobre a ictiofauna da baía de Ilha Grande (Brotto & Araújo 2001; Lima et al. 2002; Teixeira et al. 2009), as baías de Sepetiba (116 espécies; Araújo 1998; Pessanha et al. 2000; Araújo & Azevedo 2001; Azevedo et al. 2007) e de Guanabara (169 espécies; Meniconi et al. 2012b) destacam-se por suas ricas ictiofaunas.

A baía de Guanabara (22°50’S-43°10’W), segunda maior baía costeira do Brasil, abrange grande parte da costa do município do Rio de Janeiro, caracterizando-se por um ecossistema costeiro semifechado de natureza estuarina (Amador 1980). Esta baía se destaca não apenas por sua dimensão e heterogeneidade ambiental, mas, também, por sua inserção em uma das zonas mais urbanizadas do Brasil, cujos impactos antropogênicos têm adversamente afetado a integridade de seus habitats e organismos, e, em especial, da ictiofauna (Valentin et al. 1999; Kehrig et al. 2002; Silva et al. 2003). Atualmente é considerada um dos sistemas estuarinos mais degradados da costa brasileira (Amador 1997; Valentin et al. 1999), devido ao intenso aporte decorrente de fontes difusas de poluição, através dos cerca de 55 rios, riachos e canais que deságuam diretamente em suas águas (Amador 1997), além das intervenções de caráter físico, como inúmeros aterros e constantes dragagens (Meniconi et al. 2012a). Apesar dos impactos crescentes a que vem sendo submetida, a baía de Guanabara ainda abriga numerosas espécies de peixes e, desta maneira, possui considerável importância econômica, com uma intensa atividade pesqueira comercial. Entre abril de 2001 e março de 2002 foram desembarcadas 19.000 toneladas de pescado, as quais corresponderam a US$ 4,8 milhões (Jablonski et al. 2006). Além disso, a baía também apresenta uma evidente importância ecológica, abrigando diversificados biótopos, como manguezais, praias arenosas e costões rochosos.

Entre os diversos biótopos aquáticos encontrados na baía de Guanabara, os costões rochosos figuram como um dos mais importantes, já que além de se distribuírem ao longo de toda a baía (desde zonas mais externas e oceânicas até zonas mais internas e de circulação restrita), abrigam um elevado número de espécies de importância ecológica e econômica (Coutinho 2002). Apesar de apresentarem menor complexidade quando comparados a recifes de corais, os costões rochosos tropicais ainda assim sustentam uma fauna e flora muito ricas (Ferreira et al. 2001). Além disso, as comunidades associadas a essas estruturas rochosas, constituem um excelente sensor biológico das condições ambientais (Murray et al. 2006) e podem contribuir significativamente para uma melhor avaliação dos impactos a que os ecossistemas estão submetidos. No Brasil, as comunidades de peixes associadas a substratos rochosos vêm sendo bem estudadas ao longo dos últimos anos (Ferreira et al. 2001; Floeter et al. 2001; Floeter et al. 2006; Floeter et al. 2007; Rangel et al. 2007; Mendonça-Neto et al. 2008; Chaves & Monteiro-Neto 2009; Gibran & Moura 2012; Monteiro-Neto et al. 2013; Nunes et al. 2013), mas pouco ainda se sabe sobre o efeito das condicionantes ambientais sobre essas comunidades.

Modificações nas condições dos habitats promovem alterações na composição das comunidades de peixes (Araújo et al. 2000). Ciclos na abundância de peixes em estuários e baías foram correlacionados com interações bióticas intrínsecas e a mudanças nas condições ambientais. A composição dessas comunidades varia em resposta a variáveis ambientais como, temperatura, oxigênio dissolvido e pH (Araújo et al. 2002; Araújo et al. 2009). Ostrand and Wilde (2002) sugeriram que a estrutura das comunidades é determinada mais por diferenças persistentes nas condições ambientais entre locais do que por variações sazonais no ambiente. A avaliação da influência das variáveis ambientais, e de seus padrões espaciais e temporais, sobre a ictiofauna é uma ferramenta crucial para programas de conservação e manejo (Araújo et al. 2009)., Apesar da relevância desses fatores, surpreendentemente ainda pouco se sabe sobre os efeitos das variáveis ambientais e da sazonalidade sobre a composição e estrutura da ictiofauna recifal (Ferreira et al. 2001; Floeter et al. 2006; Barreto 2013).

Neste contexto, o presente estudo visou caracterizar, por meio de coletas sistematizadas com redes de espera, a comunidade de peixes associadas aos costões rochosos da Praia Vermelha e descrever como as principais espécies respondem a mudanças sazonais e anuais em algumas variáveis ambientais. Apesar de abrigar uma elevada biodiversidade, dada sua proximidade à entrada da baía de Guanabara, a Praia Vermelha pode ser considerada um ambiente transicional que apresenta ampla variação nas condições ambientais, dependendo da maior ou menor influência das massas d’água oceânicas e/ou provenientes do interior da baía. Esse objetivo foi alcançado através da comparação entre os padrões de resposta a mudanças sazonais e interanuais das variáveis ambientais de temperatura, salinidade e pH pela ictiofauna transiente e residente do costão da área estudada (capítulo 1). Além disso, foi avaliado o efeito das variações sazonais e interanuais da temperatura, salinidade e pH sobre a ictiofauna recifal, e o efeito dessas variáveis sobre os atributos de comunidade e populacionais (capítulo 2).

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Chapter 1: **F*ish response to environmental variables in a tropical polluted bay: constrained versus unconstrained analyses***

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FISH RESPONSE TO ENVIRONMENTAL VARIABLES IN A TROPICAL POLLUTED BAY: CONSTRAINED VERSUS UNCONSTRAINED ANALYSES

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Running head: Fish response to environmental variables

ABSTRACT

Fish assemblage of Vermelha beach was studied between September 2011 and June 2013 through gillnets sets (60m × 1.5m) installed on two rocky shores of the study site, with water temperature, pH and salinity being measured during samples. A total of 1937 individuals were captured, splitting in 40 reef-associated species (78.38%) and 44 transient species (21.62%), confirmed by CAP analysis. PCA axis 1 revealed samples separation related positively to temperature ($r = 0.75$), and negatively to pH ($r = -0.63$) and salinity ($r = -0.74$). The environmental variables analysis confirmed the influence of both estuarine and oceanic waters on rocky shores at Vermelha beach, affecting the composition of the local fish assemblage. The most abundant families were Haemulidae, Priacanthidae, Dactylopteridae e Gerreidae. DCAs (all fish assemblages, reef-associated species, and transient species) did not display any clear pattern for samples and species separation, while CCAs revealed a pattern of species distribution in response to salinity and pH. Differential use between transient and reef-associated fish species may be related to non-mutually exclusive reasons, especially the location of the study site, a transitional zone between estuarine and oceanic areas. Our study highlights the importance of using constrained analysis, as CAP and CCA, to assess mixed fish assemblages of environmentally-complex systems, especially in cases in which the fish assemblage is composed by groups with differential habitat-use patterns, which are not easily separated by non-selective sampling gears.

Key words: tropical bay; fish assemblage; rocky shores; habitat use; environmental variables; multivariate analyses

INTRODUCTION

Coastal bays are large water bodies, broadly distributed across all continents, which play an important role in the survival of marine organisms, due to their function as breeding and nursery grounds, especially for fish species (Araújo *et al*., 2002; Azevedo *et al*., 2006; 2007). These coastal zones are transitional areas that play a key role in connecting terrestrial and marine ecosystems, affecting the distribution patterns of fish assemblages (Nero & Sealey, 2006). Many marine species use coastal habitats in different phases of their life cycle, especially because of the high availability of feeding, breeding, and refuge habitats (Blaber, 2002; Livingston, 2002). Although many studies have focused on identifying essential habitats for the maintenance of species life cycle (Araújo & Azevedo, 2001; Pessanha *et al.*, 2003; Stoner, 2006), the importance of the interconnectivity of coastal habitats, such as hard, vegetated and unconsolidated substrates, for the associated fish assemblages is barely known (Friedlander *et al.*, 2003; Monteiro-Neto *et al.*, 2008).

Guanabara Bay, the second largest coastal bay in Brazil, is located in the metropolitan area of the Rio de Janeiro city, undergoing the effects of 11 million people living in its surroundings, which comprise approximately 80% of the state population (Kjerfve *et al*., 1997). Currently, the Bay is an eutrophic ecosystem, functioning as a final receiver of high loads of domestic and industrial effluents (i.e. up to 350 m^3/s), which adversely affect habitats and organisms integrity (Jablonski *et al*., 2006; Neves *et al*., 2007; Seixas *et al*., 2013). Despite these impacts, Guanabara Bay still has high ecological and economic importance, playing a role as spawning and recruitment areas for several fish species, supporting an intense commercial fishing activity, and also harbouring several biotopes, as sandy beaches, mangroves and rocky shores (Jablonski *et al*., 2006).

Among the aquatic biotopes found in Guanabara Bay, the rocky shores have great importance, since they are distributed throughout the Bay and yield a high diversity of species with ecological and economic importance. Despite their lower structural complexity when compared to coral reefs, rocky reefs are physically complex and also support a great diversity of fauna and flora (Ferreira *et al*., 2001; Coutinho, 2002). While the availability of microhabitats and niches has overall positive effects on the diversity of species at rocky reefs (Sale, 1980), few studies have focused on whether other environmental descriptors, such as physical and chemical water characteristics and anthropogenic factors, affect the associated fish assemblages, especially in tropical rocky reefs (but see Teixeira-Neves *et al*., 2015). Therefore, it is expected that high fish richness would be found on rocky substrates near the entrance of Guanabara Bay, where the oceanic influence is greater and water quality reaches better standard quality levels, in contrast with a significant decrease on richness toward the inner areas, which are of restricted circulation and greatly impacted by pollution (Paranhos & Mayr, 1993; Rodrigues *et al*., 2007). Although rocky shore communities are recognized as excellent sensors of ecosystem conditions (Ferreira *et al*., 2001; Floeter *et al*., 2007), the potential of the associated fish assemblages to be used as sentinels for environmental changes in Guanabara Bay is virtually unknown.

The major objectives of this study was to characterize, through gillnet samplings, the composition and structure of fish assemblages associated with rocky shores in Vermelha beach, a marine-estuarine transitional zone located near the entrance of Guanabara Bay. Since transient fish species (i.e. not closely associated with submerged habitats) may respond differently to environmental variables than reef-associated assemblages, the effects of some environmental variables related to estuarine or oceanic influence on each group were addressed. Despite their applied importance for conservation and management programs, there is no study that focused on the effects of environmental variables on composition and structure of the fish assemblages associated with rocky shores in Guanabara Bay or whether sympatric reef-associated and transient fish assemblages respond differentially to environmental variables. In addition, the importance of using suitable statistical approach and perform analyses separately for each fish group according to their ecological traits was also briefly discussed.

MATERIALS AND METHODS

Study site

Guanabara Bay is a 400km^2 estuarine-marine transitional system located at Rio de Janeiro state (22°50’S-43°10’W), one of the largest metropolitan areas in Brazil, with more than 11 million inhabitants. As consequence, the water quality is poorer at the inner zone, because of the proximity to mainland and the restrict circulation, while better conditions (i.e. higher transparency and dissolved oxygen) are found toward the outer zone, more influenced by adjacent oceanic waters (Mayr *et al.*, 1989; Kjerfve *et al.*, 1997). Vermelha beach (22°57'18”S, 43°09'48”W) is an urban beach located at Rio de Janeiro city, near the outer zone of Guanabara Bay (Fig. 1), undergoing alternating influences of both transparent and more saline oceanic waters, and more eutrophic, turbid estuarine inner bay waters. The complexity and often synergistic changes in these factors lead to a strong variability of environmental conditions. Vermelha beach has two rocky reefs, apart 250m from each other; the left one is composed by basaltic rock boulders of various sizes, whereas the right rocky reef has a steep topography (between 45° and 60°). Vermelha beach has also no restriction for bathing and fishing through the year, with a high level of human presence, due to its easy access.

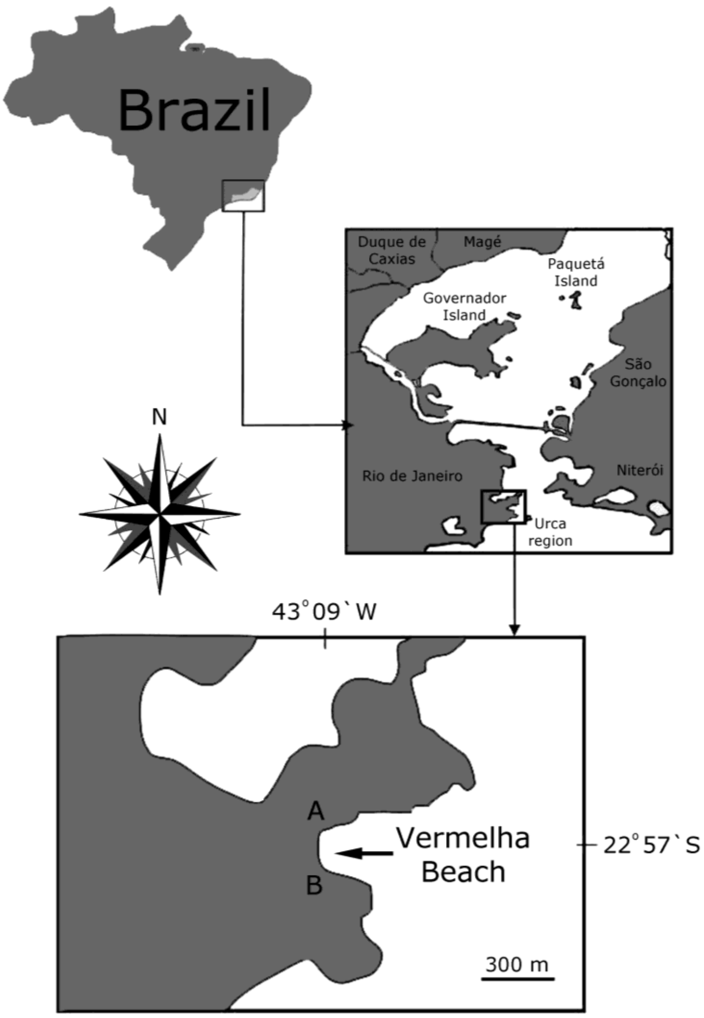

Figure 1. Geographic location of Vermelha beach with the two (A - left; B - right) rocky shores assessed in this study.

<u>Samples</u>

Samples were taken quarterly at the end of each season between September 2011 and June 2013 in the two rocky reefs of Vermelha beach, comprising two years of samples (eight seasons). Fish were collected through gillnet sets (60m × 1.5m) made by 20m of three different mesh sizes interconnected (15, 30 and 45mm) forming a set. Six gillnet sets were installed in the early afternoon of a day by a local fisherman (three sets on the left rocky reef; three sets on the right rocky reef), and retrieved on the next morning. Water temperature, pH and salinity, were measured through a multiparameter probe (Hanna HI 9828).

Collected fish were stored in ice and then transferred to the Laboratory of Theoretical and Applied Ichthyology (LICTA) at UNIRIO, where they were identified, according to Figueiredo & Menezes (1978; 1980; 2000) and Menezes & Figueiredo (1980; 1985). All fish were dissected, weighed with a 0.01 g precision balance and the total length (TL) was measured with an icthyometer graduated by millimetres. Fish species were classified according to its association with the rocky shores into two groups, based on the specialized literature: reef-associated, for species which spend their lives associated with consolidated substratum, and transient, for species which do not intimately depend on rocky shores to survive.

Data analysis

Principal Component Analysis (PCA) was applied to the matrix of environmental variables to identify the most important water variables (temperature, salinity and pH) for sample separation among seasons and years. A two-way Permutational Analysis of Variance (PERMANOVA) was also applied on PCA scores to test for differences among year and seasons. Euclidean similarity distance was used, with data permutation of 4999 times.

Canonical Analysis of Principal Coordinates (CAP) and Principal Coordinate Analysis (PCoA) were applied in order to identify differences in the abundance (number of individuals from each fish species) of reef-associated and transient species. This technique has the advantage of allowing any distance or dissimilarity measure to be used, but also by taking into account correlation structure among variables in the multivariate sampling plot (Anderson & Willis, 2003). The Bray-Curtis dissimilarity measure was applied, and the permutation step was repeated 9999 times.

Detrended Correspondence Analysis (DCA) was first applied on log-transformed ($\log_{10}x + 1$) abundance data of all fish assemblages (i.e. reef-associated and transient) to evaluate which species contributed more for data separation. Secondly, the main matrix was divided into two, one for the abundance of reef-associated species, and the other for transient species abundance. This separation allowed the application of two partial DCAs to evaluate the response of each group, using the opposite group as covariable. Finally, Canonical Correspondence Analysis (CCA) was applied to the environmental variables and species abundance (log-transformed) matrices. As in the partial DCAs, the matrix was divided into reef-associated species and transient species, allowing the application of partial CCAs.

RESULTS

Environmental water variables (temperature, salinity and pH) measured among seasons are presented in Table I. Temperature and salinity presented wide ranges of variation, indicating the influence of both estuarine and oceanic waters in the study area. Effects of oceanic waters were mostly found in spring due to the low values of temperature and the high values of salinity. On the other hand, a prevalence of estuarine waters was detected in autumn, with high temperature and low salinity.

Table I. Mean values (range) of environmental variables measured from September 2011 to June 2013 at the rocky shores of Vermelha beach, Guanabara Bay.

Environmental variable	Seasons mean (range)			
	Winter	Spring	Summer	Autumn
Temperature (ºC)	21.0 (19.7 – 21.8)	17.3 (15.8 – 18.9)	22.1 (19.4 – 25.1)	23.1 (22.9 – 23.4)
Salinity	33.1 (27.4 – 35.4)	35.7 (33.7 – 37.1)	31.2 (28.4 – 35.3)	31.0 (22.1 – 34.4)
pH	8.3 (7.7 – 8.8)	8.5 (7.9 – 9.0)	8.5 (8.2 – 9.9)	8.5 (8.2 – 8.8)

A total of 1937 individuals distributed in 83 species were captured. Thirty-nine species were classified as reef-associated with a contribution of 78.4% for the total abundance, in contrast to 44 transient species (21.6% of total abundance; Table II). The most abundant families were Haemulidae, Priacanthidae, Dactylopteridae and Gerreidae, which accounted together for 73% of the total abundance.

Table II. Species captured through gillnet sets in the rocky shores of Vermelha beach, Guanabara Bay, RJ.

Reef-associated species (common name)	**Abundance (size range)**	**Transient species (common name)**	**Abundance (size range)**
Orthopristis ruber (1)	842	*Eucinostomus argenteus* (41)	108
Corocoro grunt	(7.3 – 28.5)	Silver mojarra	(9.8 – 21.7)
Haemulon aurolineatum (2)	178	*Scomber japonicus* (42)	55
Tomtate grunt	(6.5 – 18.2)	Chub mackerel	(21.0 – 40.7)
Priacanthus arenatus (3)	129	*Umbrina coroides* (43)	54

Atlantic bigeye	(10.4 – 27.4)	Sand drum	(10.7 – 24.0)
Dactylopterus volitans (4)	109	*Mullus argentinae* (44)	32
Flying gurnard	(8.2 – 33.3)	Argentine goatfish	(10.0 – 12.6)
Holocentrus adscensionis (5)	58	*Eucinostomus gula* (45)	22
Squirrelfish	(12.7 – 28.7)	Jenny mojarra	(10.3 – 16.6)
Stephanolepis hispidus (6)	28	*Pseudupeneus maculatus* (46)	21
Planehead filefish	(12.2 – 25.0)	Spotted goatfish	(11.9 – 28.9)
Pareques acuminatus (7)	26	*Thyrsitops lepidopoides* (47)	14
High-hat	(9.4 – 19.3)	White snake mackerel	(23.7 – 35.8)
Sphoeroides greeleyi (8)	20	*Porichthys porosissimus* (48)	13
Green puffer	(9.2 – 22.0)	Atlantic midshipman	(16.8 – 27.6)
Diplodus argenteus (9)	19	*Diplectrum formosum* (49)	7
South American silver porgy	(7.2 – 17.5)	Sand perch	(14.1 – 17.4)
Haemulon steindachneri (10)	15	*Merluccius hubbsi* (50)	7
Chere-chere grunt	(9.9 – 24.6)	Argentine hake	(29.7 – 35.7)
Halichoeres poeyi (11)	11	*Decapterus punctatus* (51)	6
Blackear wrasse	(12.5 – 15.5)	Round scad	(13.5 – 19.0)
Labrisomus nuchipinnis (12)	9	*Sardinella brasiliensis* (52)	6
Hairy blenny	(10.5 – 16.0)	Brazilian sardinella	(13.0 – 16.8)
Odontoscion dentex (13)	9	*Mugil curema* (53)	5
Reef croaker	(11.0 – 16.4)	White mullet	(10.5 – 41.7)
Anisotremus surinamensis (14)	7	*Sphyraena tome* (54)	5
Black margate	(18.2 – 23.8)	Barracuda	(24.0 – 43.0)
Abudefduf saxatilis (15)	6	*Albula vulpes* (55)	4

Sergeant-major	(12.2 – 17.9)	Bonefish	(24.6 – 33.4)
Calamus penna (16)	5	*Genidens genidens* (56)	4
Sheepshead porgy	(12.1 – 26.4)	Guri sea catfish	(24.6 – 28.5)
Pagrus pagrus (17)	5	*Menticirrhus americanus* (57)	4
Red porgy	(9.5 – 23.5)	Southern kingcroaker	(24.6 – 28.3)
Sphoeroides testudineus (18)	5	*Sphyraena guachancho* (58)	4
Checkered puffer	(9.7 – 20.5)	Guachanche barracuda	(24.5 – 37.8)
Anisotremus virginicus (19)	4	*Sphyraena sphyraena* (59)	4
Porkfish	(16.7 – 20.0)	European barracuda	(40.2 – 47.2)
Caranx crysos (20)	4	*Umbrina canosai* (60)	4
Blue runner	(19.4 – 26.5)	Argentine croaker	(13.0 – 28.0)
Mycteroperca acutirostris (21)	4	*Bothus ocellatus* (61)	3
Comb grouper	(19.7 – 32.6)	Eyed flounder	(5.7 – 10.4)
Parablennius pilicornis (22)	3	*Elops saurus* (62)	3
Ringneck blenny	(11.7 – 15.8)	Ladyfish	(22.9 – 41.0)
Chaetodon striatus (23)	2	*Harengula clupeola* (63)	3
Banded butterflyfish	(14.0 – 15.0)	False herring	(12.3 – 19.5)
Epinephelus marginatus (24)	2	*Polydactylus virginicus* (64)	3
Dusky grouper	(18.6 – 25.0)	Barbu	(28.8 – 29.0)
Fistularia tabacaria (25)	2	*Synodus intermedius* (65)	3
Cornetfish	(60.0 – 90.5)	Sand diver	(16.0 – 19.5)
Rypticus bistrispinus (26)	2	*Cynoscion leiarchus* (66)	2
Freckled soapfish	(10.2 – 11.2)	Smooth weakfish	(35.0 – 37.8)
Scorpaena isthmensis (27)	2	*Diplectrum radiale* (67)	2

Smooth-cheek scorpionfish	(8.7 – 9.9)	Pond perch	(12.7 – 14.4)
Acanthurus bahianus (28)	1	*Genidens barbus* (68)	2
Ocean surgeon	(35.4)	White sea catfish	(37.2 – 39.7)
Acanthurus chirurgus (29)	1	*Menticirrhus littoralis* (69)	2
Doctorfish	(26.2)	Gulf kingcroaker	(24.6 – 25.7)
Caranx latus (31)	1	*Syacium papillosum* (70)	2
Horse-eye jack	(19.0)	Dusky flounder	(17.8 – 19.2)
Dules auriga (32)	1	*Synodus myops* (71)	2
Mariquita	(9.2)	Snakefish	(15.7)
Hippocampus reidi (33)	1	*Achirus lineatus* (72)	1
Longsnout seahorse	(15.3)	Lined sole	(11.1)
Hyporthodus niveatus (34)	1	*Auxis rochei* (73)	1
Snowy grouper	(7.4)	Bullet tuna	(35.9)
Labrisomus kalisherae (35)	1	*Cetengraulis edentulus* (74)	1
Downy blenny	(10.5)	Atlantic anchoveta	(7.1)
Pempheris schomburgkii (36)	1	*Cynoscion striatus* (75)	1
Glassy sweeper		Striped weakfish	(46.0)
Pseudocaranx dentex (37)	1	*Etropus crossotus* (76)	1
White trevally	(37.0)	Fringed flounder	(11.9)
Selar crumenophthalmus (38)	1	*Lagocephalus laevigatus* (77)	1
Bigeye scad	(13.5)	Smooth puffer	(37.6)
Seriola dumerili (39)	1	*Micropogonias furnieri* (78)	1
Greater amberjack	(19.5)	Whitemouth croaker	(33.0)
Stegastes fuscus (40)	1	*Mugil liza* (79)	1

Brazilian damsel	(14.0)	Lebranche mullet	(40.7)
		Ophichthus gomesii (80)	1
		Shrimp eel	(56.0)
		Paralichthys orbignyanus (81)	1
		Brazilian flounder	(37.5)
		Polydactylus oligodon (82)	1
		Littlescale threadfin	(23.0)
		Pomatomus saltatrix (83)	1
		Bluefish	(12.7)
		Trichiurus lepturus (84)	1
		Largehead hairtail	(78.5)

PCA axis 1 was significant ($P \leq 0.05$) explaining 50.7% of data variance (eigenvalue = 1.52). Temperature was positively correlated with axis 1 ($r = 0.75$), whereas pH ($r = -0.63$) and salinity were negatively correlated ($r = -0.74$). Significant difference among seasons were detected for PCA axis 1 scores (PERMANOVA; F = 23.9; $P < 0.01$) and years (F = 21.1; $P < 0.01$), with a year × month interaction (F = 38.6; $P < 0.01$). The autumn and the spring of 2012 differed from all seasons, being different also from each other (PERMANOVA *post-hoc* test; $P < 0.05$). Summer 2012 and autumn 2013 did not differed from each other, being different from all other seasons. Winter and spring of 2011 presented the same pattern (PERMANOVA *post-hoc* test; $P < 0.05$). PCA diagram shows the spring of both years related with high values of pH and salinity, and low values of temperature (Fig. 2). The other seasons did not present any clear correlation with environmental variables.

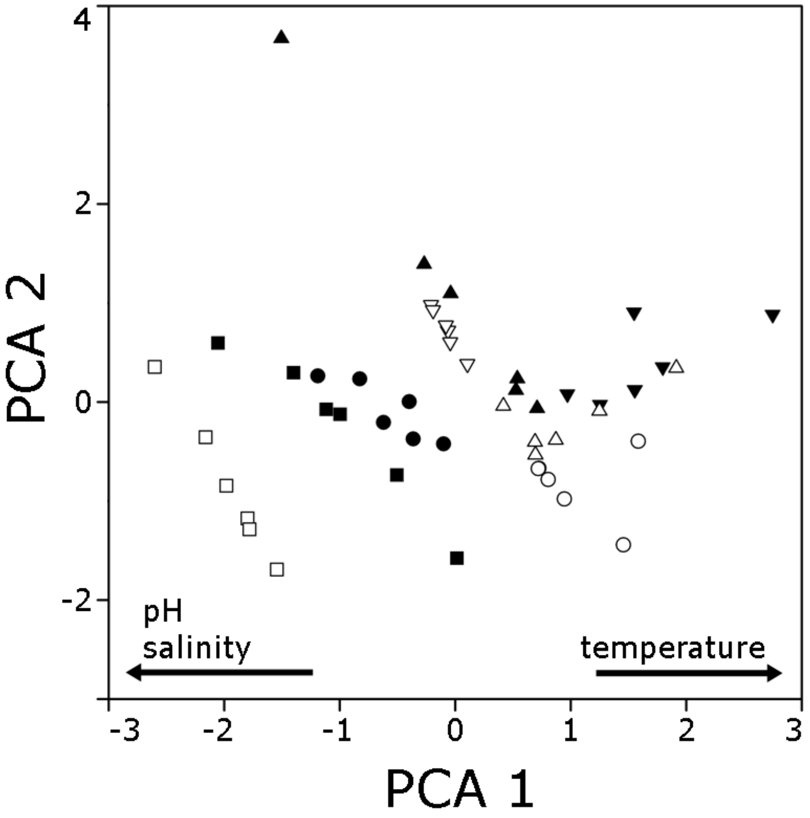

Figure 2. Ordination diagram of the first two principal component analyses (PCA) with samples coded by seasons in Vermelha beach (● - Winter 2011; ■ - Spring 2011; ▲ - Summer 2012; ▼ - Autumn 2012; ○ - Winter 2012; □ - Spring 2012; △ - Summer 2013; ▽ - Autumn 2013).

CAP analysis showed samples separation in, apparently, three groups (Fig. 3). One of these was located at the right side of the diagram, being mainly composed by transient species. The second group, located in the left-side of the diagram, was composed mostly by reef-associated species. A third group, situated mostly in the central part of the diagram, was composed by a mix of reef-associated and transient species.

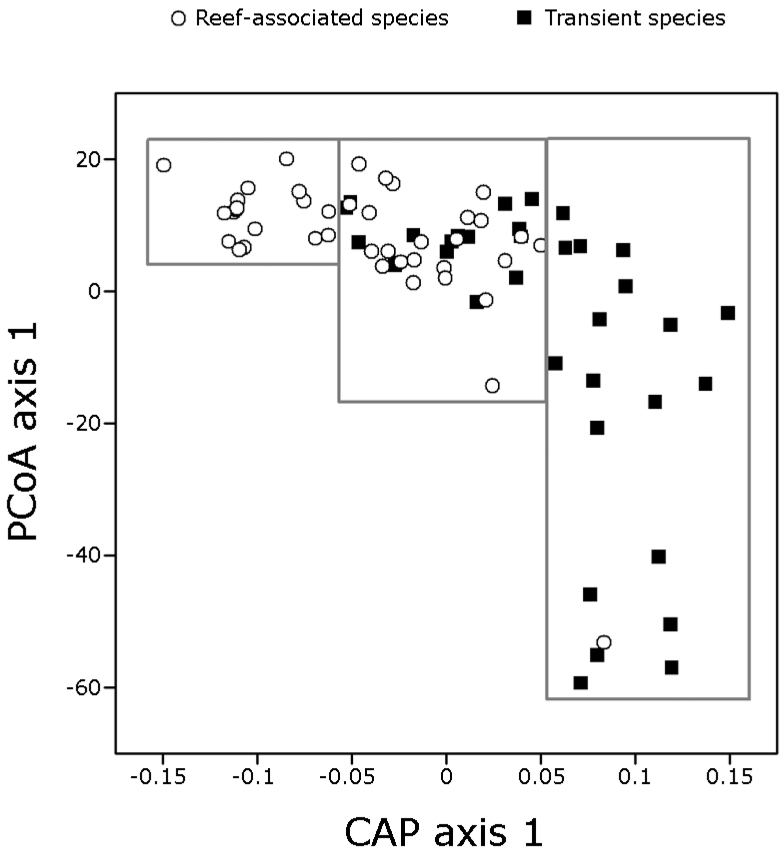

Figure 3. Ordination diagram built with the first axis of the canonical analysis of principal coordinates (CAP) and the first axis of principal coordinates analysis (PCoA), showing the species separation between reef-associated and transient.

The DCA applied on the matrix of all species together displayed a scattered distribution of samples (Fig. 4). Only an interannual pattern could be identified, with samples of the first year being mostly located at the left side of the diagram. The partial DCA of reef-associated and transient species did not show any clear seasonal pattern.

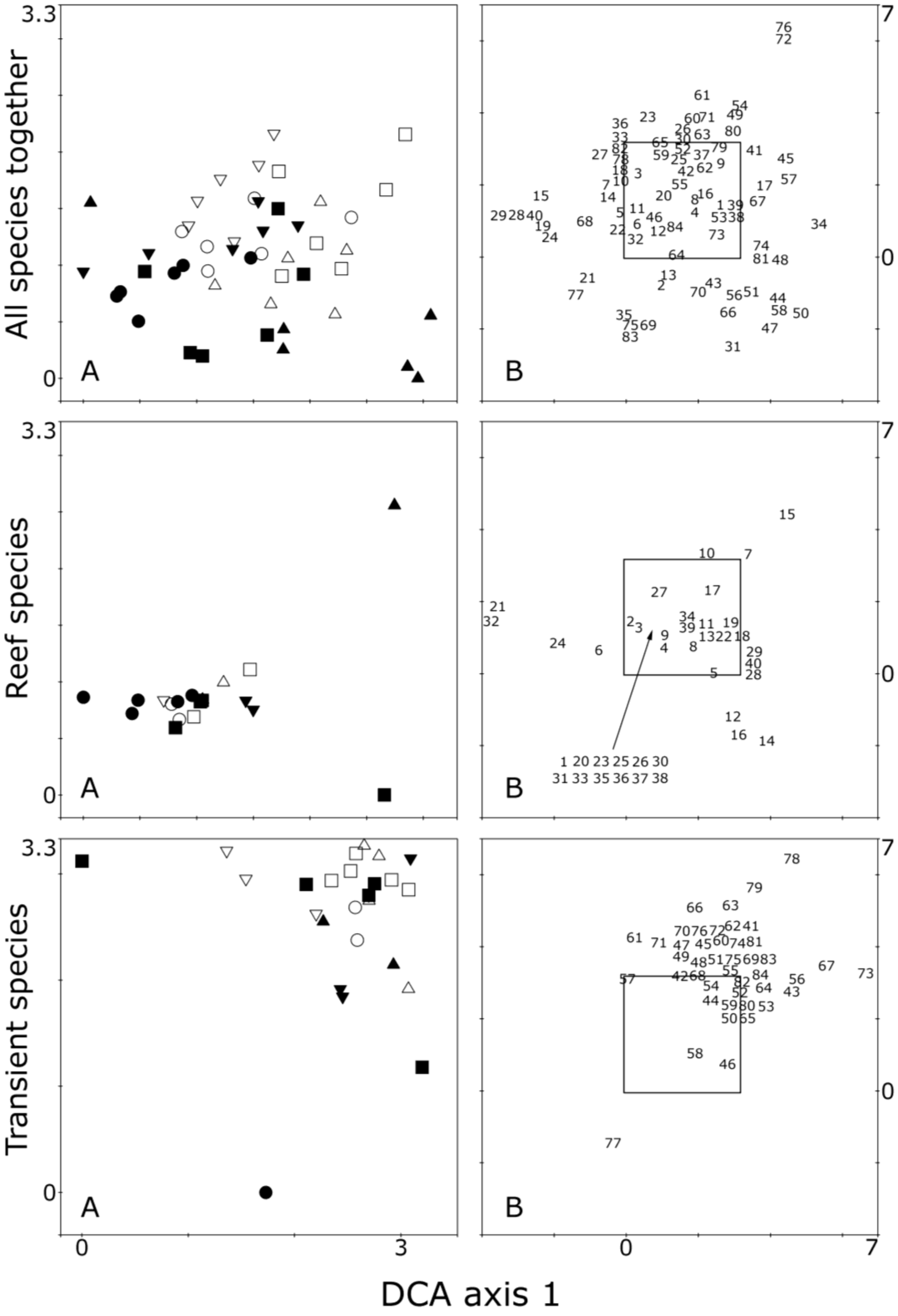

Figure 4. Ordination diagram of the detrended correspondence analysis (DCA) with A – samples and B - species. Samples are coded by seasons in Vermelha beach (● - Winter 2011; ■ - Spring 2011; ▲ - Summer 2012; ▼ - Autumn 2012;

○ - Winter 2012; □ - Spring 2012; △ - Summer 2013; ▽ - Autumn 2013). The square delimits samples distribution, and the numbers represent each species as listed Table II.

The significant environmental variables in total CCA were salinity and pH. Salinity was correlated to sample separation among seasons, whereas pH was more correlated to species distribution, with no-clear separation of samples among seasons (Fig. 5A). Winter 2011, spring 2011, spring 2012, summer 2013 and autumn 2013 were associated with higher values of salinity. On the other hand, summer 2012, autumn 2012 and winter 2012 were related to low values of salinity. Species followed the same pattern, with the sand drum *Umbrina coroides* Cuvier 1830, the fringed flounder *Etropus crossotus* Jordan & Gilbert 1882, the lined sole *Achirus lineatus* (L. 1758), the sand perch *Diplectrum formosum* (L. 1766), the Brazilian flounder *Paralichthys orbignyanus* (Valenciennes 1839), the pond perch *Diplectrum radiale* (Quoy & Gaimard 1824), the atlantic anchoveta *Cetengraulis edentulus* (Cuvier 1829) and the bullet tuna *Auxis rochei* (Risso 1810) being associated with high salinity. Otherwise, the whitemouth croaker *Micropogonias furnieri* (Desmarest 1823), the ocean surgeon *Acanthurus bahianus* Castelnau 1855, the doctorfish *Acanthurus chirurgus* (Bloch 1787), the Brazilian damsel *Stegastes fuscus* (Cuvier 1830), the guachanche barracuda *Sphyraena guachancho* Cuvier 1829, and the largehead hairtail *Trichiurus lepturus* L. 1758 were related to low salinity. Higher values of pH were associated with the snowy grouper *Hyporthodus niveatus* (Valenciennes 1828), the southern kingcroaker *Menticirrhus americanus* (L. 1758) and *A. rochei*, while the white trevally *Pseudocaranx dentex* (Bloch & Schneider 1801), the Brazilian sardinella *Sardinella* *brasiliensis* (Steindachner 1879), and the freckled soapfish *Rypticus bistrispinus* (Mitchill 1818) were associated with low pH values.

Salinity and pH were also significant for the partial CCAs, however with weaker trends. CCA for reef-associated species did not provide any clear pattern among years and seasons, except for the association of winter 2011 with high salinity (Fig. 5B). The other seasons and most species were located in the central portion of the diagram. The corocoro grunt *Orthopristis ruber* (Cuvier 1830), the tomtate grunt *Haemulon aurolineatum* Cuvier 1830, the atlantic bigeye *Priacanthus arenatus* Cuvier 1829, the flying gurnard *Dactylopterus volitans* (L. 1758), the planehead filefish *Stephanolepis hispidus* (L. 1766), the South American silver porgy *Diplodus argenteus* (Valenciennes 1830), and the smooth-cheek scorpionfish *Scorpaena isthmensis* Meek & Hildebrand 1928 were related to high salinity. On the other hand, *S. fuscus*, *A. bahianus* and *A. chirurgus* were related with low salinity. The black margate *Anisotremus surinamensis* (Bloch 1791), the sheepshead porgy *Calamus penna* (Valenciennes 1830), *S. hispidus* and *S. isthmensis* were positively related to pH, in contrast to the mariquita *Dules auriga* Cuvier 1829 which was associated with low pH values

CCA diagram for transient species showed a great sample distribution among seasons and no clear pattern among years (Fig. 5C). *Etropus crossotus* and *A. lineatus* were related to high salinity, contrasting to *S. guachancho*, more associated with low salinity. Moreover, *A. rochei* was related to high pH, whereas *M. furnieri* was related to low pH.

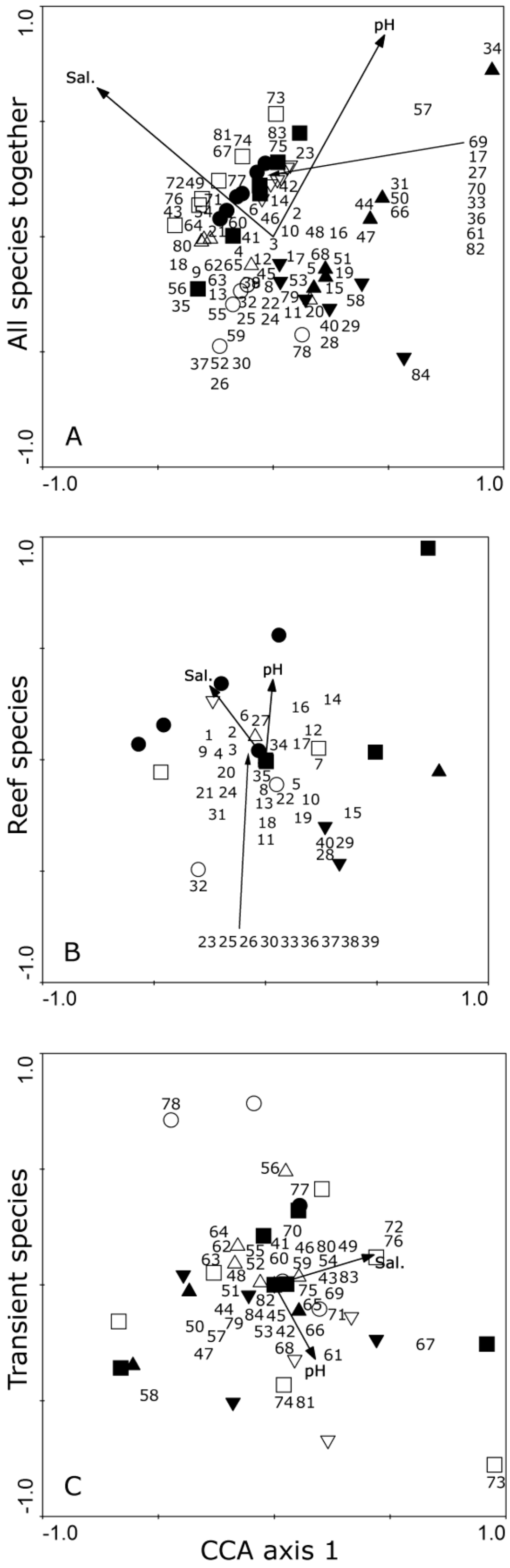

Figure 5. Ordination diagram from the canonical correspondence analysis (CCA) in Vermelha beach for: A - all species together, B - reef-associated species,

and C – transient species. Samples are coded by seasons (● - Winter 2011; ■ - Spring 2011; ▲ - Summer 2012; ▼ - Autumn 2012; ○ - Winter 2012; □ - Spring 2012; △ - Summer 2013; ▽ - Autumn 2013). Numbers represent each species as listed in Table II.

DISCUSSION

Our findings revealed that the fish assemblage associated with rocky reefs in Vermelha beach can be divided into two groups, according to its characteristics of habitat dependence, a group of reef-associated species and a group of transient species. Acosta (1997) also split the fish assemblage of Puerto Rico into a group of species that develops the most part or its life cycle in consolidated substrates, and a group of species which did not depend strongly on rocky shores. These differences in species composition are probably related to Vermelha beach location, which could function as a connection channel for fish migrating between the oceanic adjacent area and the inner areas of Guanabara Bay that function as feeding or spawning grounds. Monteiro-Neto *et al.* (2008) also found fish species in three islands in the coastal region of Itaipu, an outer zone of Guanabara Bay, with differential patterns of habitat-use, including a group of transient species.

The sampling gear (gillnets) used in our study it is not a species-specific selective gear, which is broadly used in community studies (Menezes *et al*., 2013) and allows the capture of both reef-associated and transient fishes. The use of multiple fishing gears can amplify the capture spectrum, but in reef areas the use fishing gears is limited due to the complex architecture of the substrate (Hubert, 1983). In most cases, the only suitable methods are passive gears, such as nets (as gillnets in the present study), traps, and hook and line (Acosta, 1997). The advantages of nets as sampling gears are noticeable when compared with other passive gears, as fish traps and lines. Nets catch more fish in less time, are more efficient in catching large mobile fish, and are less selective in terms of number of species than the other methods (Gobert, 1992; Acosta, 1997). We used a multi-mesh gillnet set (15, 30 and 45mm of mesh size) to widen our sampling spectrum and to minimize size selectivity, as used by Gray *et al*. (2005) and Rotherham *et al*. (2006). Still, some fish species are less vulnerable to capture with nets, as some Gobiidae and Bleniidae, which can be better studied through visual census (Acosta, 1997; Olin & Malinen, 2003). Barreto (2013) identified through visual census in Vermelha beach rocky shores eight species that were not captured in the present study, mostly cryptic species and other species with poor swimming abilities, that are less vulnerable to gillnets. Despite its limitations, gillnets are good sampling gears to study fish assemblages on rocky shores, especially multi-mesh gillnet sets, which allowed the capture of a greater fish richness than Barreto (2013) at Vermelha beach.

The present study captured a total of 83 species, with 39 species being intimately associated with rocky substrates. When compared to Mendonça-Neto *et al.* (2008), in which they accessed rocky reef fishes of three coastal islands on the outer zone of Guanabara Bay by visual census, our results recorded more species (70 species in three islands), but the same number of reef-associated species (40 species in three islands). The sampling sites of Mendonça-Neto *et al.* (2008) receive influence of both estuarine and oceanic waters, as Vermelha beach, what can explain the similarities in richness. Acosta (1997) captured 60 coral reef species in Puerto Rico through gillnets. Coral reefs support more diverse fish assemblages, since they are more complex than rocky reefs (Sale, 1980; Öhman & Rajasuriya, 1998), and sustain a high primary productivity (Ferreira *et al.*, 1998). Otherwise, Barreto (2013) recorded only 29 species on Vermelha beach rocky shores through visual census, these differences are probably related to the use of snorkelling dives, which limit the underwater time. Our findings also differed from other studies, as Ferreira *et al.* (2001) at Arraial do Cabo (91 reef-associated species), a region characterized by coastal upwelling during summer and spring (Valentin, 1984), increasing the total diversity and productivity. Floeter *et al.* (2007) and Rangel *et al.* (2007) found 99 reef-associated species at, respectively, Guarapari Islands and Cagarras Archipelago, both oceanic areas, of different environmental conditions.

Haemulidae, the most abundant family in the present study, accounted for 54% of the total abundance, being represented by *O. ruber*, *H. aurolineatum*, the chere-chere grunt *Haemulon steindachneri* (Jordan & Gilbert 1882), *A. surinamensis*, and the porkfish *Anisotremus virginicus* (L. 1758). The high prevalence of *O. ruber* and *H. aurolineatum*, which accounted together for 52.6% of total abundance, might be related to their gregarious behavior, and also to the preference of juvenile for living associated with algae banks (Vianna & Verani, 2002), which are common on rocky shores. The findings of the present work differed from those of Barreto (2013) at Vermelha beach, which the most abundant family was Sparidae, represented by *D. argenteus*. Barreto (2013) did not record any *O. ruber* in her visual census, even though the sampling seasons (April 2011 to March 2012) coincided with those of the present study. This could indicate that the author did not consider *O. ruber* as a species intimately associated with rocky reefs, since the visual censuses are selective, or a problem of misidentification due to the prevalent turbid waters. Differing from Barreto (2013) classification, Menezes & Figueiredo (1980) recorded for juvenile *O. ruber* behaviour of feeding on algae banks, especially abundant on rocky shores, and for adults a behaviour of alternating between rocky and sand substrates. Other authors also indicated that this species probably recruit on rocky beaches (Pessanha *et al.*, 2000; Santos *et al.*, 2007), revealing the dependence of rocky substrates. On the other hand, Acosta (1997) also recorded through gillnets Haemulidae as the most abundant family in the coral reefs of Puerto Rico.

Due to its peculiar geographic location, Vermelha beach is under direct influence of both Guanabara Bay's estuarine waters and adjacent oceanic waters. The spring of both years were characterized by high values of salinity and pH, and low values of temperature, which are typical of environments dominated by marine influence (Kjerfve *et al.*, 1997), indicating a prevalence of oceanic waters in the study area in that season. There was no other seasonal pattern distinguishable in the PCA analysis for the environmental variables, probably because of the peculiar characteristics already described for Vermelha beach. Both partials and total DCA analyses also did not displayed any seasonal pattern for fish species. In this sense, it is possible that unconstrained analyses (PCA and DCA), which do not use a priori hypotheses of groups (Ter Braak, 1995), are not the better approach to assess mixed fish assemblages with different patterns of habitat dependence on rocky reefs.

The total CCA revealed a seasonal pattern correlated to salinity, but no clear pattern association with pH. The high salinity values were correlated to the spring of both sampled years, indicating an influence of oceanic waters as recorded by PCA. During spring, salinity was higher 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 (Valentin & Monteiro-Ribas, 1993). On the other hand, low values of salinity were found at summer 2012, which indicates a prevalence of waters from inner Bay. Since summer is a rainy season, it is also expected that there was a stronger influence of freshwater from the rivers in the inner areas of Guanabara Bay.

Salinity had a great influence on species composition at Vermelha beach, corroborating the findings of Araújo *et al.* (2002) and Azevedo *et al.* (2007) for Sepetiba Bay. The transient species *U. coroides, E. crossotus, A. lineatus, D. formosum, P. orbignyanus, D. radiale*, *C. edentulus* and *A. rochei* were correlated with high values of salinity in the total CCA. These are typically marine species, and moved into Vermelha beach when the conditions were suitable to fit their ecological requirements (Santos *et al.*, 2007). The highest salinity in Vermelha beach, a transitional zone among estuarine and oceanic water, may allow a higher number of marine species to penetrate in this part of the bay (Araújo *et al.*, 2002), as salinity decreases, richness and frequency of marine species were also expected to decrease (Thiel *et al.*, 1995). Agreeing with our findings, Azevedo *et al.* (2007), described *E. crossotus, D. formosum* and *D. radiale* as more abundant at the outer zone of Sepetiba Bay and also related with high salinity. In opposition, the same authors related *A. lineatus* and *C. edentulus* to the inner zones of that Bay, which can explain the low abundances of this species in Vermelha beach. *Umbrina coroides*, and *P. orbignyanus*are are typical estuarine species (Collette, 1995; Sampaio & Bianchini, 2002), which are generally more capable of tolerating a wider range of environmental variables.

On the other hand, *M. furnieri, A. bahianus, A. chirurgus, S. fuscus, S. guachancho* and *T. lepturus* were related to low salinity values. Low salinity is an indicator of the prevalence of inner-bay waters, largely influenced by rivers discharge. Araújo *et al.* (2002) and Azevedo *et al.* (2007) also found *M. furnieri* related to low values of salinity at the inner zones of Sepetiba Bay, feeding on soft-bottom benthic macrofauna and detritus. Opposing to our findings, these same authors found *T. lepturus* related to high values of salinity, colonizing the outer zone of Sepetiba Bay. This species probably was found in Vermelha beach, even with low salinity for feeding purposes (Martins & Haimovici, 2000). *Sphyraena guachancho* is mostly related to shallow, and generally turbid waters, often situated near river mouths and estuaries (De Sylva, 1990), agreeing with our findings.

Regarding to reef-associated species, high salinity was related to *O. ruber, H. aurolineatum, P. arenatus, D. volitans, S. hispidus, D. argenteus*, and *S. isthmensis*. Corroborating with our findings, Araújo *et al.* (2002) and Azevedo *et al.* (2007) also related the haemulids to high values of salinity in the outer zone of Sepetiba Bay. Although *D. volitans* and *S. isthmensis* were not related to any environmental variable, they were caught in the outer zone of Sepetiba Bay by the same authors. Ferreira *et al.* (2001) recorded *D. volitans* at Arraial do Cabo, a region in Rio de Janeiro which upwelling events are common, suggesting a preference for low temperature and high salinity waters. Rangel *et al.* (2007) recorded all these cited species in an archipelago near Guanabara Bay, as Monteiro-Neto *et al.* (2008) in three islands of Itaipu, at the outer zone of Guanabara Bay, confirming the preference of these species for oceanic waters.

Surprisingly, the typically marine species *A. bahianus*, *A. chirurgus* and *S. fuscus* were related to low values of salinity (27.2) in the present study. Even known as intimately associated with reefs (Lawson *et al.*, 1999; Schwamborn & Ferreira, 2002), they are not common species in estuaries. This result reinforce Vermelha beach characteristic as a transitional zone among Guanabara bay, and surrounding oceanic areas, being influenced by both zones.

Fish assemblage also responded to pH, opposing the findings of other studies with the influence of environmental variables on fishes (Lara & González, 1998; Araújo *et al.,* 2002; Nero & Sealey, 2006; and Azevedo *et al.,* 2007). This is related to the fact that none of these studies measured pH in the study sites. As Kjerfve *et al.* (1997) and Barreto (2013) recorded, high values of pH were related to prevalence of marine influence. In this sense, it is possible to expect a greater contribution of marine species related to high values of pH (as occurred with *H. niveatus, M. americanus, A. surinamensis,* and *C. penna*), and greater contribution of estuarine species when pH is low (*M. furnieri*). This lack of knowledge highlights the need for further studies on environmental variables effects on composition and structure of fish assemblages.

The present study identified a differential response among ordination analysis, with constrained analysis (CAP and CCA) demonstrating a better response regarding to samples separation. Multivariate ordination methods are required in many ecological studies which involve fish assemblages and environmental variables to reduce dimensionality and to visualize patterns in multivariate data (Anderson & Willis, 2003). Unconstrained analyses (PCA and DCA) use some dispersion patterns which can cover groups' differences (Ter Braak, 1995). On the other hand, constrained analyses can be used to relate a matrix of response variables (species abundance), with some predictor variables, such as quantitative environmental variables (Anderson & Willis, 2003). Constrained analyses allow a prior determination of groups and a differential response for each group analysed, which was necessary in the present study since gillnets sampled both reef-associated and transient species. In this sense, we indicate constrained ordination methods as a protocol for analysing fish assemblages composed by mixed groups with differential pattern of habitat-use and that are not easily separated by passive sampling gears, such as gillnets.

This study also highlighted the importance of Vermelha beach as a marine-estuary transitional zone, functioning as a link among the ocean and inner-bay estuarine waters, and also harbouring great fish diversity. Nevertheless, further studies are necessary, especially those about the effects of environmental variables on composition and structure of Guanabara Bay's fish assemblage. Although gillnets are not species-specific directed sampling gears, they are effective and can also be used in studies on rocky reefs, but the proper identification of groups according to their level of habitat dependence and the selection of constrained analysis as major statistical protocol would result in more robust and clear responses.

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Chapter 2: ***Alternating influence of estuarine and oceanic waters on seasonal changes of reef fish assemblages and environmental variables in a tropical bay***

(Formatado segundo modelo da Marine and Freshwater Research)

ALTERNATING INFLUENCE OF ESTUARINE AND OCEANIC WATERS ON SEASONAL CHANGES OF REEF FISH ASSEMBLAGES AND ENVIRONMENTAL VARIABLES IN A TROPICAL BAY

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ABSTRACT

Reef fish can be used as sentinels for environmental changes but there are few correlative studies on Neotropical fish assemblages. The present study assessed tropical reef fish assemblages through gillnet sets between September 2011 and June 2013 on rocky shores in a Guanabara Bay beach. Environmental variables indicate influence of both estuarine (mostly in autumn) and oceanic waters (mainly in spring) probably due to tidal dynamic in the study area. Except for abundance, community attributes did not changed seasonally, but increased in the prevalence of estuarine waters. A total of 1518 individuals of 39 species were captured. DCA 1 scores followed a seasonal pattern, and selected six species. *O. ruber* and *D. volitans* were seasonally related to the effect of oceanic waters, whereas *D. argenteus, H. aurolineatum* and *P. acuminatus* followed an interannual distribution pattern, not related to environmental variables. Overall *O. ruber*, *P. arenatus*, and *S. greeleyi*, were more abundant under the influence of estuarine waters, suggesting that waters from the inner zones of tropical polluted bays might surprisingly favour reef fish assemblages in complex transitional systems, such as Vermelha beach, which are also periodically influenced by oceanic waters.

Keywords: environmental variables; Guanabara Bay; rocky shores; fish assemblage

INTRODUCTION

Rocky shores are consolidated substrates, including steep rocky cliffs, platforms, rock pools and boulder fields. This structurally-complex habitat is characterized by erosional processes, undergoing effects of wind, sunlight, waves, and other physical factors that fluctuate daily, affecting the associated organisms, especially fish (Lewis 1964). In this sense, fish assemblages associated with rocky shores must be able to tolerate changes in temperature, salinity, and wave action to survive (Connell 1972). Although presenting lower structural complexity than coral reefs, rocky reefs and correlated environments are physically complex and support a great diversity of fauna and flora (Ferreira et al. 2001; Coutinho 2002), sustaining a high primary productivity (Ferreira 1998). In Brazil, large-scale comparisons also suggested that south-eastern rocky reefs yield great diversity than north-eastern coral reefs (Floeter et al. 2001).

Guanabara Bay, the second largest Brazilian coastal bay, is located at the metropolitan area of Rio de Janeiro city, harbouring several biotopes, as sandy beaches, mangroves and rocky shores (Jablonski et al. 2006). These habitats are distributed throughout the Bay, and high species richness is found on rocky substrates near the entrance of Guanabara Bay, where the oceanic influence is greater and water quality reaches the minimum standard quality levels (Paranhos and Mayr 1993; Rodrigues et al. 2007). Besides, rocky shore communities are recognized as excellent sensors of ecosystem conditions, so the associated fish assemblages can be used as sentinels for environmental changes (Murray et al. 2006). In Brazil, fish assemblages of rocky reef are well known (Ferreira et al. 2001; Floeter et al. 2007; Chaves and Monteiro-Neto 2009; Monteiro-Neto et al. 2013), but there is still a lack of knowledge on the effects of environmental variables on fish communities.

Changes in habitat conditions lead to alterations on fish assemblage composition, in which cycles of fish abundance in estuaries and bays appear to be related to intrinsic biotic interactions and respond to variations in environmental conditions, such as temperature, dissolved oxygen, and pH (Araújo et al. 2000, 2002, 2009). Anthropogenic degradation of coastal bay habitats could also affect the structure of fish assemblages. Degraded areas are overall less diverse and dominated by a few tolerant taxa, whereas higher-quality areas support a more balanced assemblage structure (Scott and Hall 1997; Araújo et al. 2002). In this sense, the evaluation of spatial and temporal patterns of environmental variables and its influence on fish assemblage is an important tool for management and conservation (Araújo et al. 2009). Fish communities structure seem to be more affected by environmental gradients or acute environmental changes, than to cyclic seasonal fluctuations (Ostrand and Wilde 2002; Araújo et al. 2009), but the effects of environmental variables and seasonality on composition and structure of reef communities is still poorly known, especially in the neotropic (Ferreira et al. 2001; Floeter et al. 2006; Barreto 2013). In this sense, the present study aimed to i) characterize the composition and structure of Vermelha beach reef fish assemblage; ii) evaluate the effects of alternating estuarine and oceanic waters on fish assemblage and environmental variables.

MATERIALS AND METHODS

Study site

Guanabara Bay is a 400km^2 estuarine-marine transitional system located at Rio de Janeiro state (22°50’S-43°10’W), one of the largest metropolitan areas in Brazil, with more than 11 million inhabitants. As consequence, the water quality is poorer at the inner zone, because of the proximity to mainland and the restrict circulation, while better conditions (i.e. higher transparency and dissolved oxygen) are found toward the outer zone, more influenced by adjacent oceanic waters (Mayr et al. 1989; Kjerfve et al. 1997).

Vermelha beach (22°57'18”S, 43°09'48”W) is an urban beach located at Rio de Janeiro city, near the outer zone of Guanabara Bay (Fig. 1), undergoing alternating influences of both transparent and more saline oceanic waters, and more eutrophic, turbid estuarine inner bay waters. The complexity and often synergistic changes in these factors lead to a strong variability of environmental conditions. Vermelha beach has two rocky reefs, apart 250m from each other; the left one is composed by basaltic rock boulders of various sizes, whereas the right rocky reef has a steep topography (between 45° and 60°). Vermelha beach has also no restriction for bathing and fishing through the year, with a high level of human presence, due to its easy access.

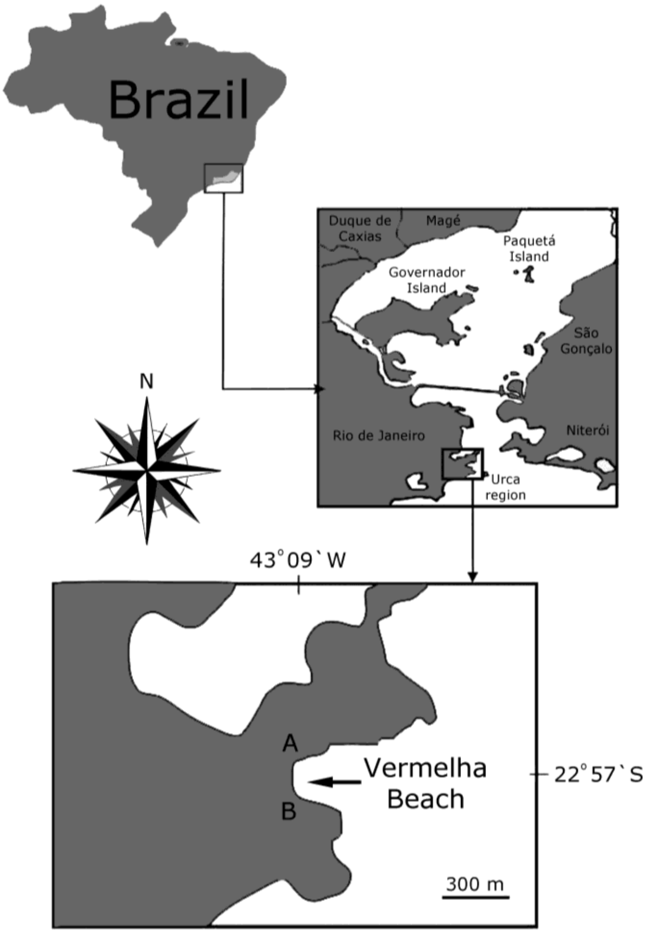

Fig. 1 Geographic location of Vermelha beach with the two (a - left; b - right) rocky shores assessed in this study.

Samples

Samples were collected between September 2011 and June 2013 in the rocky reefs of Vermelha beach, amounting two years of samples (eight seasons). Fishes were collected through gillnets (60m × 1.5m) with 20m of three different mesh sizes interconnected (15, 30 and 45mm), resulting in a set. Six sets were installed in the first day by a local fisherman: three on the left side and three on the right side. Water temperature, pH and salinity, were measured through a multiparameter probe (Hanna HI 9828).

The collected material was transferred to the Laboratory of Theoretical and Applied Ichthyology (LICTA) at UNIRIO, where they were identified, according to Figueiredo and Menezes (1978, 1980, 2000) and Menezes and Figueiredo (1980, 1985).

All fishes were dissected, weighed with a 0.01 g precision balance and the total length (LT) was measured with an icthyometer graduated in millimetres.

Data analysis

Fish species richness (n), abundance (n) and biomass (g) were calculated for each season. A Principal Component Analysis (PCA) was applied to the matrix of environmental variables to identify the most important physical and chemical water variable (temperature, salinity and pH) in samples separation by season and year. A Detrended Correspondence Analysis (DCA) was applied to the abundance matrix of the species that accounted to 95% of total abundance to evaluate which species were more relevant in samples separation by season and year. All analyses were performed with PCORD 6 for Windows.

A two-way Permutational Analysis of Variance (PERMANOVA) was also applied on PCA scores, DCA scores, community attributes (richness, abundance and biomass), and to the abundance of the species selected by the DCA to test for differences among years and seasons. Bray-Curtis dissimilarity distance was used, with data permutation of 4999 times. A PERMANOVA *post-hoc* test was applied when significant differences were found ($P < 0.05$) to verify which means differed from each other.

Generalized Additive Models (GAMs) were also applied to address relationships of community attributes (richness, abundance and biomass) and species abundance with the first axis of PCA. GAM is a non-parametric regression technique that is not limited to linear relationships, being sensitive to several types of data distribution. GAMs complexity was chosen using the stepwise selection procedure, through the Akaike Information Criterion (AIC).

RESULTS

Environmental variables

Environmental water variables (temperature, salinity and pH) measured among seasons are presented in Table 1. Temperature and salinity presented wide ranges of variation, indicating the influence of both estuarine and oceanic waters in the study area. Effects of oceanic waters were mostly found in spring due to the low values of temperature and the high values of salinity. On the other hand, a prevalence of estuarine waters was detected in autumn, with high temperature and low salinity.

Table 1 Mean values (range) of environmental variables measured from September 2011 to June 2013 at the rocky shores of Vermelha beach, Guanabara Bay.

Environmental variable	Seasons mean (range)			
	Winter	Spring	Summer	Autumn
Temperature (ºC)	21.03 (19.68 – 21.85)	17.27 (15.76 – 18.91)	22.1 (19.44 – 25.08)	23.15 (22.89 – 23.38)
Salinity	33.09 (27.44 – 35.45)	35.68 (33.71 – 37.09)	31.19 (28.38 – 35.34)	30.98 (22.11 – 34.41)
pH	8.26 (7.7 – 8.76)	8.54 (7.93 – 9.04)	8.49 (8.18 – 9.87)	8.48 (8.16 – 8.82)

PCA axis 1 was significant ($P \leq 0.05$) explaining 50.7% of data variance (eigenvalue = 1.52), while axis 2 was not significant, explaining 27.1% of data variance (eigenvalue = 0.82). Temperature was positively correlated with axis 1 ($r = 0.75$), whereas pH ($r = -0.63$) and salinity ($r = -0.74$) were negatively correlated. PCA diagram shows low values of temperature, and high values of pH and salinity related to the spring of both years and to winter 2011 (Fig. 2).

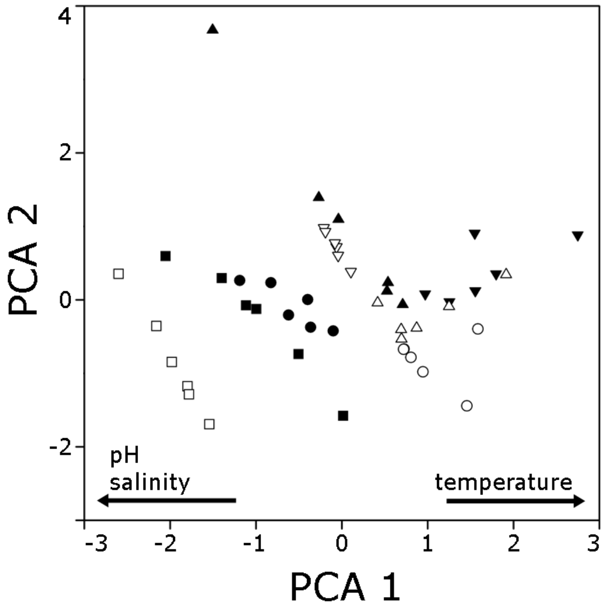

Fig. 2 Ordination diagram of the first two principal component analyses (PCA) with samples coded by seasons and years in Vermelha beach (● - Winter 2011; ■ - Spring

2011; ▲ - Summer 2012; ▼ - Autumn 2012; ○ - Winter 2012; □ - Spring 2012; △ - Summer 2013; ▽ - Autumn 2013).

PERMANOVA revealed a significant difference among seasons ($F_{3,\,47} = 23.96$; $P < 0.01$) and years ($F_{1,\,47} = 21.08$; $P < 0.01$) for the scores of PCA axis 1, with a year × month interaction ($F_{3,\,47} = 38.58$; $P < 0.01$; Fig. 3). In the first year, summer and autumn of 2012 differed from the other seasons (PERMANOVA *post-hoc* test; $P < 0.05$). On the other hand, in the second year, all seasons differed from each other, except for winter and summer. It is also possible to detect similarities among winter and spring 2011, summer 2012 and autumn 2013, and winter 2012 and summer 2013 (PERMANOVA *post-hoc* test; $P < 0.05$).

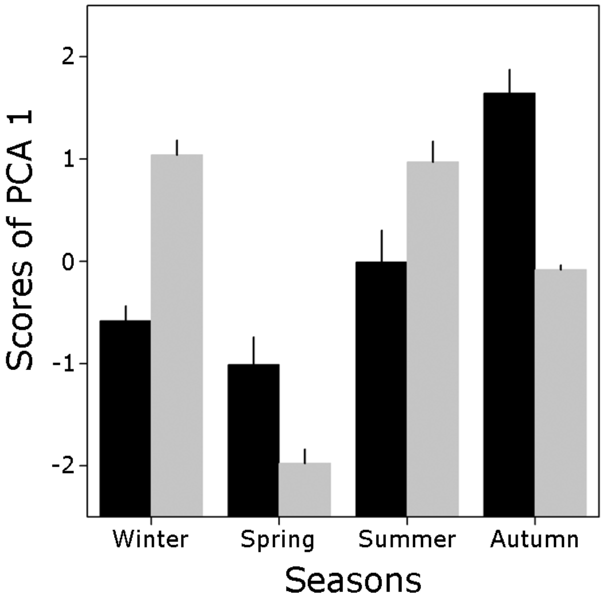

Fig. 3 Mean scores of PCA 1 by seasons (■ - first sampling year – 2011/2012; ■ - second sampling year – 2012/2013). Vertical lines are standard errors.

Fish assemblage

Fish richness differed significantly among seasons (PERMANOVA; year × season interaction $F_{3,\,47} = 3.13$; $P < 0.05$; Fig. 4a), with the first year (2011/2012) presenting a higher number of species. Species abundance differed among season ($F_{3,\,47} = 3.16$; $P < 0.05$; Fig. 4b), with a year × season interaction ($F_{3,\,47} = 3.28$; $P < 0.05$). Winter 2011 differed from summer and autumn 2012. On the second year, spring 2012 differed from all seasons, which did not differ from each other (PERMANOVA *post-*

hoc test; $P < 0.05$). Species biomass presented significant year × season interaction ($F_{3, 47} = 10.0$; $P < 0.05$; Fig. 4c). Summer 2012 differed from winter and spring 2011, while autumn 2012 differed from the spring of the first year. On the other hand, in the second year, summer differed from all seasons (PERMANOVA *post-hoc* test; $P < 0.05$).

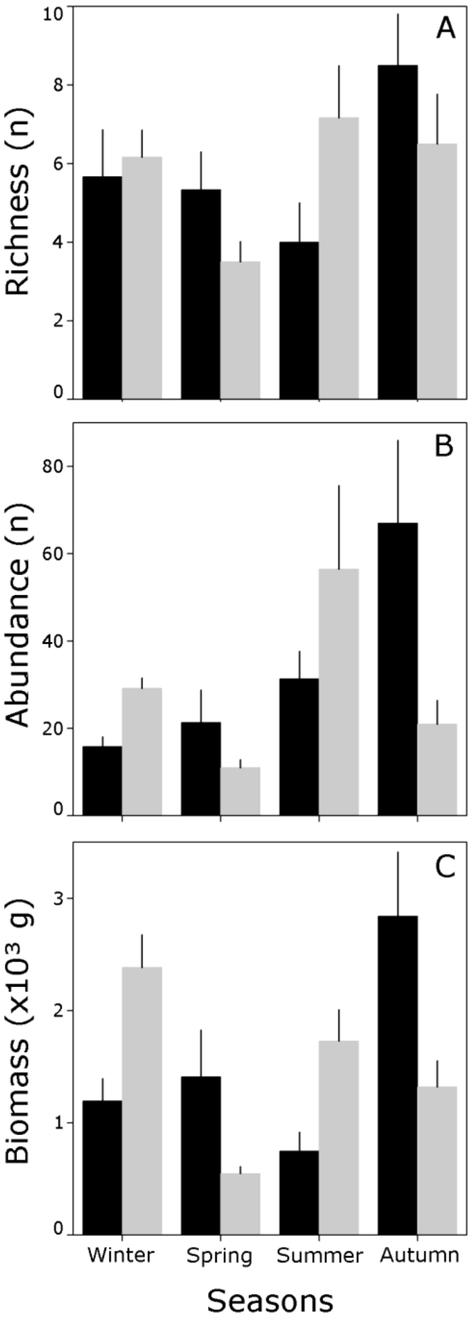

Fig. 4 Mean values of the community attributes by seasons (■ - first sampling year – 2011/2012; ▨ - second sampling year – 2012/2013). Vertical lines are standard errors.

A total of 1938 individuals distributed in 83 species were captured during samples, of which 1518 individuals of 39 species were classified into reef-associated

(Table 2). *Orthopristis ruber* was the most abundant species (55.4% of total abundance), followed by *Haemulon aurolineatum*, *Priacanthus arenatus*, *Dactylopterus volitans*, *Holocentrus adscensionis*, *Stephanolepis hispidus*, *Pareques acuminatus*, *Sphoeroides greeleyi*, *Diplodus argenteus*, *Haemulon steindachneri*, *Halichoeres poeyi*, and *Labrisomus nuchipinnis*, which accounted for 95% of total abundance.

Table 2 Species captured through gillnets in the rocky shores of Vermelha beach, with abundance (n), frequency of occurrence (%), and mean size (range).

Reef species	**Abundance (n)**	**% Frequency of occurrence (48 samples)**	**Mean size (range)**
Holocentridae			
Holocentrus adscensionis	58	35.4	21.6 (12.7 – 28.7)
Syngnathidae			
Hippocampus reidi	1	2.1	15.3
Fistulariidae			
Fistularia tabacaria	2	4.2	75.2 (60.0 – 90.5)
Dactylopteridae			
Dactylopterus volitans	109	60.4	20.6 (8.2 – 33.3)
Scorpaenidae			
Scorpaena isthmensis	2	4.2	9.3 (8.7 – 9.9)
Serranidae			
Dules auriga	1	2.1	9.2
Epinephelus marginatus	2	4.2	21.8 (18.6 – 25.0)
Hyporthodus niveatus	1	2.1	7.4
Mycteroperca acutirostris	4	8.3	25.4 (19.7 – 32.6)

Rypticus bistrispinus	2	2.1	10.7 (10.2 – 11.2)
Priacanthidae			
Priacanthus arenatus	129	58.3	16.6 (10.4 – 27.4)
Carangidae			
Caranx crysos	4	6.2	24.0 (19.4 – 26.5)
Caranx latus	1	2.1	19.0
Pseudocaranx dentex	1	2.1	37.0
Selar crumenophthalmus	1	2.1	13.5
Seriola dumerili	1	2.1	19.5
Haemulidae			
Anisotremus surinamensis	7	10.4	20.3 (18.2 – 23.8)
Anisotremus virginicus	4	4.2	18.3 (16.7 – 20.0)
Haemulon aurolineatum	178	47.9	12.5 (6.5 – 18.2)
Haemulon steindachneri	15	18.7	15.0 (9.9 – 24.6)
Orthopristis ruber	842	93.7	11.2 (7.3 – 28.5)
Sparidae			
Calamus penna	5	10.4	17.3 (12.1 – 26.4)
Diplodus argenteus	19	20.8	11.3 (7.2 – 17.5)
Pagrus pagrus	5	10.4	18.1 (9.5 – 23.5)
Sciaenidae			
Odontoscion dentex	9	14.6	12.7 (11.0 – 16.4)

Pareques acuminatus	26	31.25	13.4 (9.4 – 19.3)
Pempheridae			
Pempheris schomburgkii	1	2.1	-
Chaetodontidae			
Chaetodon striatus	2	2.1	14.5 (14.0 – 15.0)
Pomacentridae			
Abudefduf saxatilis	6	6.2	14.7 (12.2 – 17.9)
Stegastes fuscus	1	2.1	14.0
Labridae			
Halichoeres poeyi	11	12.5	13.8 (12.5 – 15.5)
Blenniidae			
Parablennius pilicornis	3	6.2	13.4 (11.7 – 15.8)
Labrisomidae			
Labrisomus kalisherae	1	2.1	10.5
Labrisomus nuchipinnis	9	16.7	12.7 (10.5 – 16.0)
Acanthuridae			
Acanthurus bahianus	1	2.1	35.4
Acanthurus chirurgus	1	2.1	26.2
Monacanthidae			
Stephanolepis hispidus	28	33.3	18.6 (12.2 – 25.0)
Tetraodontidae			
Sphoeroides greeleyi	20	27.1	12.0 (9.2 – 22.0)
Sphoeroides testudineus	5	8.3	17.2 (9.7 – 20.5)

DCA axis 1 was significant ($P < 0.05$) explaining 32.4% of data variance (eigenvalue = 0.64), while DCA axis 2 was not significant ($P = 0.95$) and explained 10.2% of data variance (eigenvalue = 0.2). *H. aurolineatum* ($r = 0.65$), *H. adscensionis* ($r = 0.41$), and *P. acuminatus* ($r = 0.38$) were positively related with axis 1. On the other hand, *O. ruber* ($r = -0.47$), *D. argenteus* ($r = -0.31$), and *D. volitans* ($r = -0.30$) were negatively correlated with axis 1 (Fig. 5).

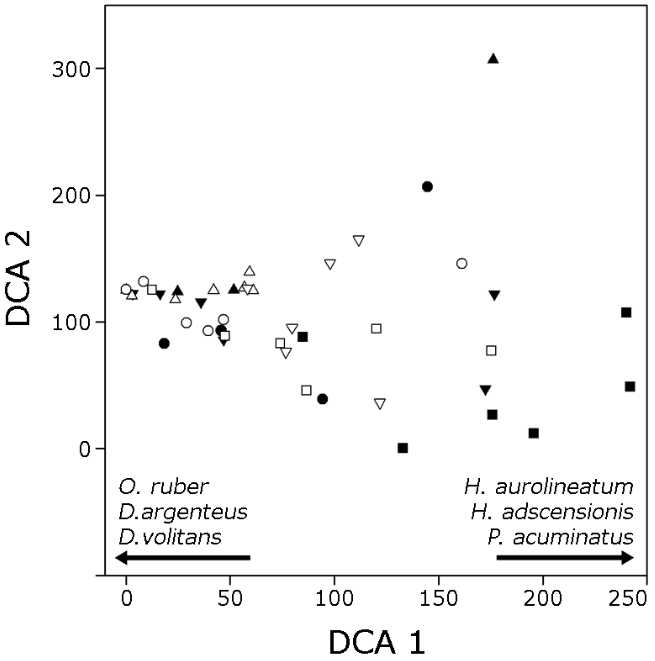

Fig. 5 Ordination diagram of the detrended correspondence analysis (DCA) with samples coded by seasons in Vermelha beach (● - Winter 2011; ■ - Spring 2011; ▲ - Summer 2012; ▼ - Autumn 2012; ○ - Winter 2012; □ - Spring 2012; △ - Summer 2013; ▽ - Autumn 2013).

The scores of DCA axis 1 differed significantly among seasons (PERMANOVA; $F_{3, 47} = 2.1$; $P < 0.05$; Fig. 6), with no differences among year or year × season interaction. The winter differed significantly from all other seasons (PERMANOVA *post-hoc* test; $P < 0.05$), which not differed from each other.

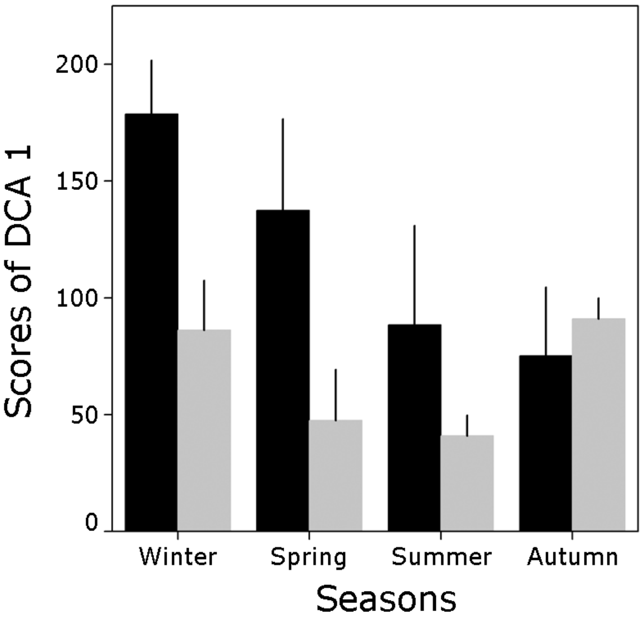

Fig. 6 Mean values of the scores of DCA axis 1 by seasons (■ - first sampling year – 2011/2012; ■ - second sampling year – 2012/2013). Vertical lines are standard errors.

The abundance of *O. ruber* changed among seasons (PERMANOVA; $F_{3,\ 47}$ = 2.76; $P < 0.05$). Winter was significantly different from all seasons, while spring differed only from summer (PERMANOVA *post-hoc* test; $P < 0.05$). Greater abundances of *O. ruber* were recorded in autumn of 2012 and summer of 2013 (Fig. 7a). *H. aurolineatum* showed differences only among years ($F_{1,\ 47}$ = 3.86; $P < 0.05$), with the first year presenting a greater abundance. Higher abundances were recorded in spring and in the summer (Fig. 7b). On the other hand, low captures occurred in the winter and spring of both years. *D. argenteus* differed among years ($F_{1,\ 47}$ = 2.83; $P < 0.05$), with greater captures in the second year. Highest abundances was recorded during summer 2013 (Fig. 7c).

The abundance of *H. adscensionis* did not differ among any factor, with highest captures in the autumn and winter of 2012 (Fig. 7d). A significant difference among seasons was found for the abundance of *D. volitans* ($F_{3,\ 47}$ = 5.97; $P < 0.05$). The autumn was different from all seasons, with greater captures occurring in the winter of 2012, summer of 2013, and autumn of 2013 (Fig. 7e). The abundance of *P. acuminatus* changed with years (PERMANOVA; $F_{1,\ 47}$ = 4.7; $P < 0.05$), with greater captures in the first year. The autumn was the season with the highest abundance in both sampled years (Fig. 7f).

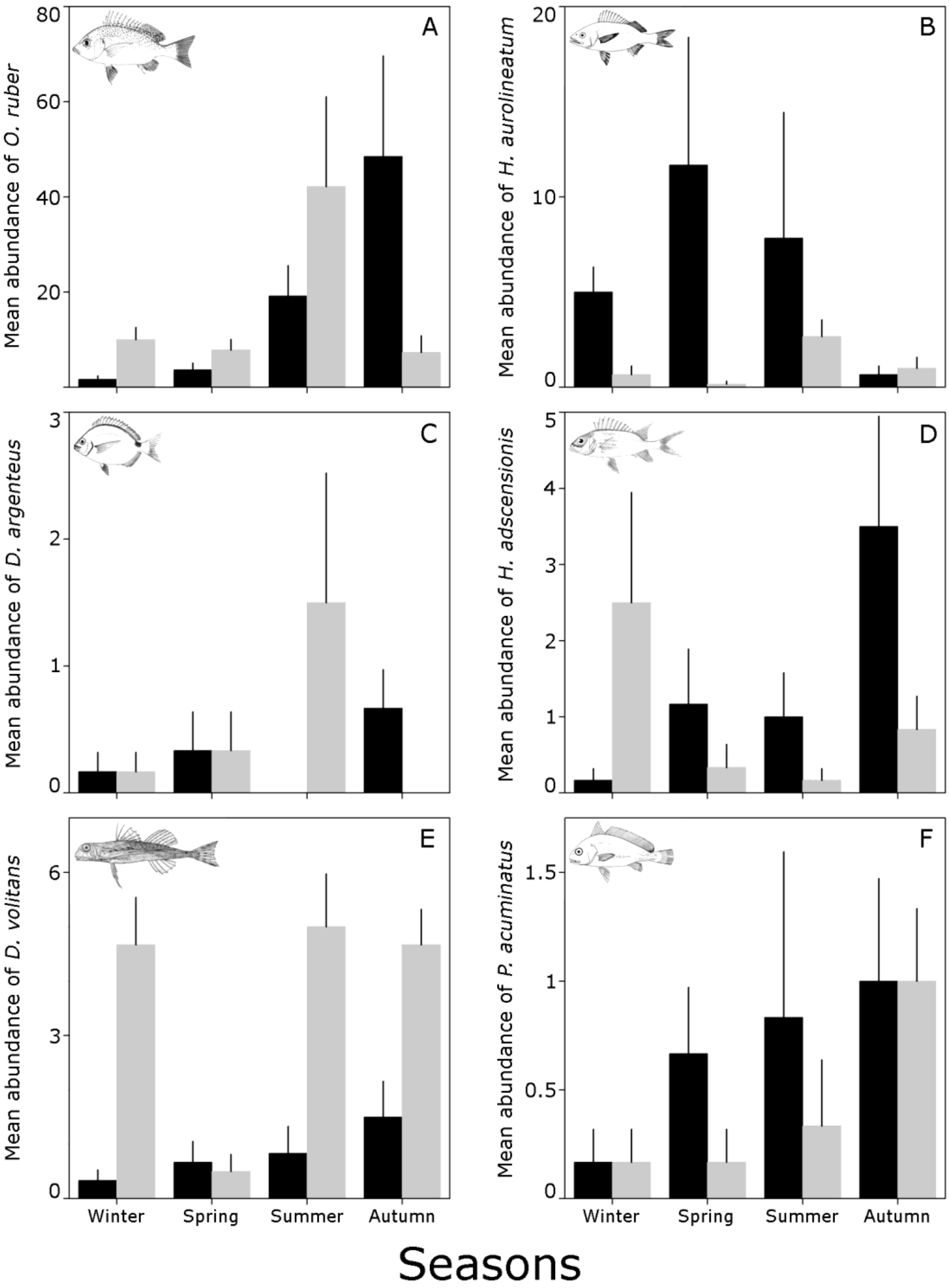

Fig. 7 Mean values of the abundance of the six species selected by DCA among seasons. Vertical lines are standard errors.

Fish assemblage response to environmental variables

The Akaike Information Criterion (AIC) selected a non-linear relationship among total fish biomass and the first axis of PCA ($F_{2,\ 47} = 3.77$; $P = 0.06$; Fig. 8a), indicating greater biomass with increased values of temperature and lower values of pH and salinity. AIC also selected a positive non-linear relationship between fish abundance and PCA 1 ($F_{2,\ 47} = 2.8$; $P = 0.1$; Fig. 8b), with increased fish abundance in high values of pH and salinity and low values of temperature. A linear relationship was found for richness and the first axis of PCA ($F_{1,\ 47} = 8.69$; $P < 0.05$; Fig. 8c), with greater number of species in high temperatures and low pH and salinity.

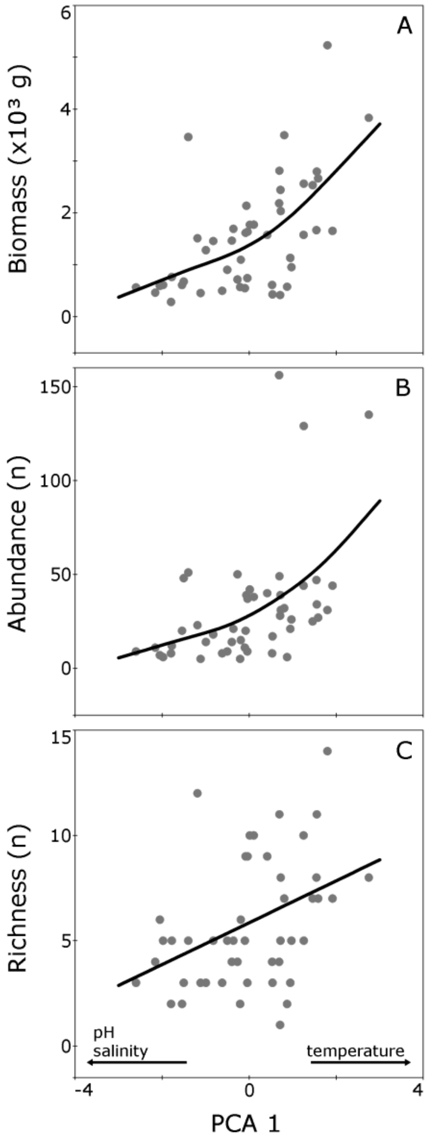

Fig. 8 Relation between values of biomass (a), abundance (b), and richness (c) with the first axis of PCA. Lines represent the generalized additive models selected by the Akaike information criterion.

A positive linear relationship was found for the mean abundance of *P. arenatus* and the first axis of PCA ($F_{1,\ 47} = 7.03$; $P < 0.05$; Fig. 9a), and also for the mean abundance of *S. greeleyi* and PCA 1 ($F_{1,\ 47} = 3.77$; $P = 0.05$; Fig. 9b), indicating that the abundances of both species increased with high values of temperature and low pH and salinity. AIC selected non-linear relationships for the mean abundance of *O. ruber* ($F_{2,\ 47} = 3.62$; $P = 0.06$; Fig. 9c), *D. volitans* ($F_{2,\ 47} = 3.07$; $P = 0.08$; Fig. 9d), and *H. adscensionis* ($F_{2,\ 47} = 2.23$; $P = 0.14$; Fig. 9e) with the first axis of PCA. The mean abundance of *O. ruber* increased exponentially with temperature. The same pattern was found with the mean abundance of *H. adscensionis*, but with a smooth increase. The abundance of *D. volitans* increased sharply until intermediate values of temperature, becoming constant after that. AIC did not select any relationship for mean abundances of *D. argenteus*, *H. aurolineatum*, and *P. acuminatus* with the first axis of PCA.

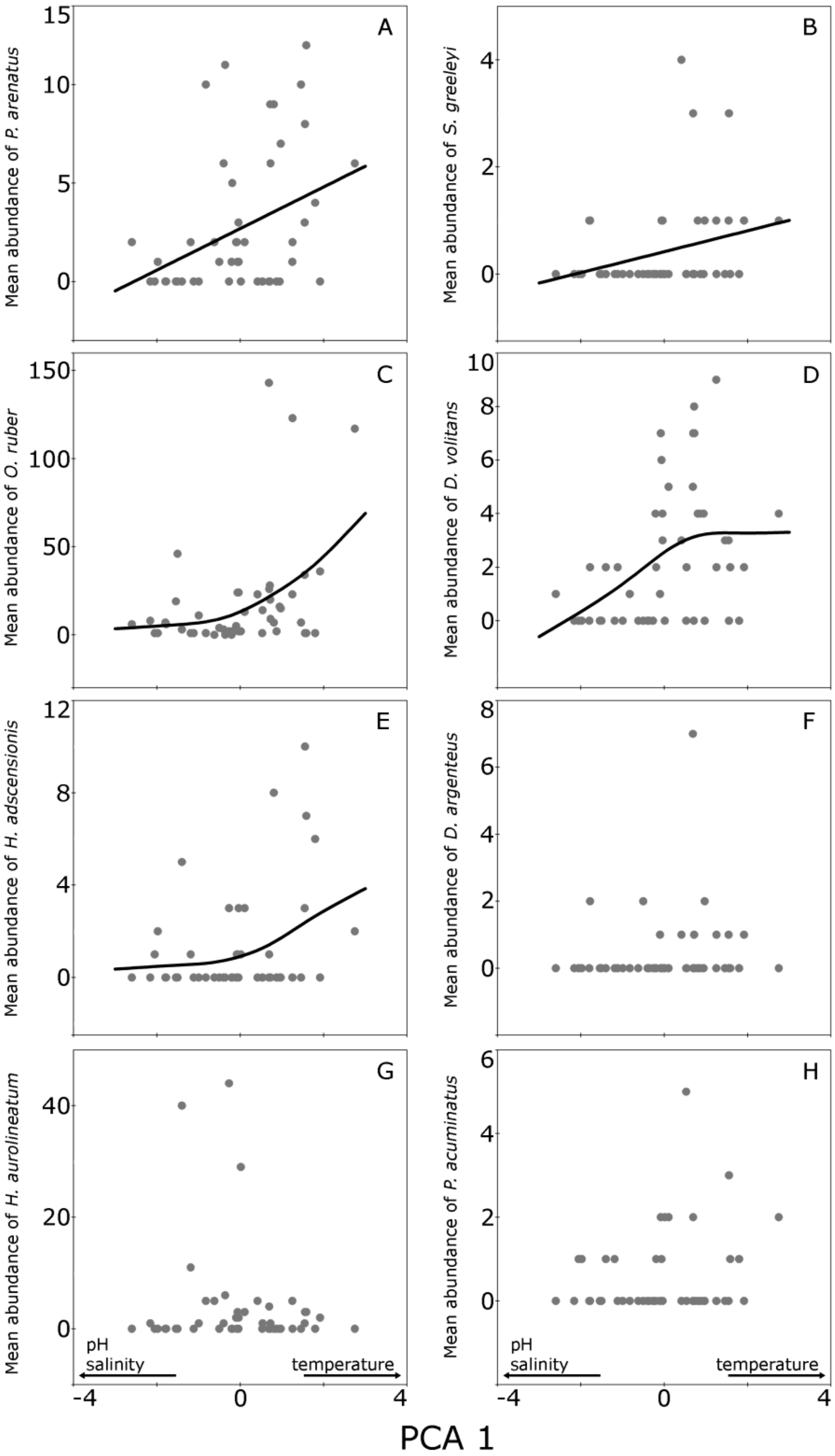

Fig. 9 Relation between the mean abundance of *P. arenatus* (a), *S. greeleyi* (b), *O. ruber* (c), *D. volitans* (d), *H. adscensionis* (e), *D. argenteus* (f), *H. aurolineatum* (g), and *P. acuminatus* (h) with the first axis of PCA. Lines represent the generalized additive models selected by the Akaike information criterion.

DISCUSSION

Environmental variables did not present any seasonal pattern, and fluctuations seem to be more related to stochastic processes than to seasons influence. Spring was the only season with a clear correlation with environmental variables, being related to increased salinity and pH, and decreased temperature. These factors are indicative of the prevalence of oceanic waters, which was described by Kjerfve et al. (1997) for Guanabara Bay. According to these authors, during spring occurs an upwelling event, related to the nearing of South Atlantic Central Waters to the coast. The other seasons did not display any clear pattern, which is probably related to , the alternating influence of estuarine and oceanic waters in Vermelha beach. This characteristic of the study area as a transitional zone between inner bay zones and the adjacent ocean can be confirmed by the wide range of the recorded values of temperature and salinity. The absence of abiotic seasonal pattern can be also related to the few number of environmental variables measured in the present study. Araújo et al. (2002) and Azevedo et al. (2007) indicated depth, transparency, salinity, and temperature as the most important environmental variables influencing the fish spatial distribution in Sepetiba Bay. In this sense, further studies on fish assemblage of Vermelha beach that include other variables may broaden the environmental knowledge of the study area.

Species richness and total fish biomass did not display any seasonal or interannual patterns, indicating that these two attributes are more conservative than abundance, which showed a seasonal pattern. Most correlated studies did not record or test community attributes among seasons, especially those focusing on spatial patterns (Ferreira et al. 2001; Floeter et al. 2007; Gibran and Moura, 2012). Although this lack of knowledge, it is possible to infer that seasons variation did not determine the community structure, but had an influence, especially for some individual species. The seasonal pattern probably affected species abundance, but not enough to lead to extinctions or relevant losses in biomass. Besides, richness and fish biomass are probably more influenced by biological processes related to species life history, or complex interactions among members of the community, such as competition and predation Azevedo et al. (2007).

Our study recorded a total of 39 reef fish species, through gillnets, in Vermelha beach rocky shores. Barreto (2013) was the only study on fish assemblage of Vermelha beach, in which 29 reef species were recorded through visual censuses. The low number species than those found in our study is probably related to the use of snorkelling dives, which limit the underwater time, but some cryptic species not collected through gillnets were found in Barreto's (2013) study, such as *Scartella cristata* and *Malacoctenus delalandii*. Similar species richness were found in other Brazilian studies, such as Monteiro-Neto et al. (2008), which recorded 41 fish species through visual censuses in coastal islands of Guanabara Bay entrance. On the other hand, Chaves and Monteiro-Neto (2009) recorded 67 fish species in three coastal islands (47 species in Pedra Vermelha, 37 species in Mãe Island, and 49 species in Comprida Island). Floeter et al. (2007) found 99 species in three locations of Espírito Santo (47 species in Itatiaia Archipelago; 68 species in Três Ilhas Archipelago, and 75 species in Escalvada Island) also through visual censuses. Rangel *et al*. (2007) recorded 99 species in Cagarras Archipelago, an oceanic archipelago near Urca region. These studies covered larger sampling areas, which could influence in richness. Besides, visual censuses are a species-directed method, differently from gillnets, which are a passive method not effective for sampling sedentary species.

Haemulidae was the most abundant family, being represented by five species (*Orthopristis ruber*, *Haemulon aurolineatum*, *Haemulon steindachneri*, *Anisotremus surinamensis*, and *Anisotremus virginicus*), which accounted for 68.9% of total abundance. *O. ruber* and *H. aurolineatum* showed the highest abundance, accounting for 67.1% of total abundance. This prevalence was probably related to its gregarious behavior (Vianna and Verani 2002), corroborating with the findings of Acosta (1997) in Puerto Rico, and Ferreira et al. (2001) at Arraial do Cabo, an upwelling-influenced system. Pessanha et al. (2000) and Santos et al. (2007) also indicated *O. ruber* recruitment occurring on rocky beaches, corroborating our findings, which revealed a great contribution of juveniles (91.4% of 842 individuals) in Vermelha beach rocky shores. Contrasting with our results, Barreto (2013) recorded Sparidae as the most abundant family (accounted to 1.9% of total abundance in the present study), being represented mostly by *Diplodus argenteus*, and also captured during the present study. Barreto (2013) did not found any *O. ruber* during their visual censuses, which is probably due to its similarity with *H. steindachneri*, imposing difficulties to visual identification. The Sparidae family was also the most abundant in two Azorean islands in central North Atlantic, as recorded by Bertoncini et al. (2010).

Our findings revealed a great contribution of rare species (45% of 40 species), which consisted of species with contributions of 0.1% or less of total abundance. In ecological communities, few species are exceptionally abundant, whereas most are rare (Magurran and Henderson 2003). Some authors defend the exclusion of these species from statistical analysis, believing that rare species contribute little to community analysis and add noise to statistical solutions (Reynoldson and Rosenberg 1996; Rodriguez and Lewis 1997; Brazner and Beals 1997). But other authors defend that this exclusion seriously violates general ecological observations and theory, leading to an unacceptable loss of ecological information (Fore et al. 1996; Cao et al. 1998). In the present study, we considered for statistical analysis only the species which accounted for 95% of total abundance. We observed that our sampling gear had an influence in some species abundance, which means that some rare species in the samples are not necessarily rare in the environment, especially cryptic species. Bertoncini et al. (personal observations) recorded a great abundance of *Parablennius pilicornis* in the rocky shores of Vermelha beach, but during our study, this species contributed with only 0.2% of total abundance. According to Cao et al. (2001), whether a species is regarded as rare is influenced by the sampling protocol, including the selected habitat, the time of year sampled, and the sampling gear. In this sense, we chose not to use these data to avoid misinterpretations.

Although richness and biomass did not present any seasonal pattern, DCA scores revealed a seasonal pattern that repeated in both years. Since DCA used species abundance data, these results are directly related to the seasonal pattern of community abundance. Recently, it has been recognized that the observed patterns in community structure can be caused by a variety of ecological processes as well as evolutionary and geographical triggers (Schluter and Ricklefs 1993; Vilar et al. 2013). Nevertheless the amount of unexplained data variation was relatively high (67.6%), probably due to unmeasured factors (biotic and abiotic) which act as underlying causes for this seasonal pattern. Even with the absence of seasonal and interannual patterns, all community attributes seemed to increase with temperature, and low pH and salinity, indicative of more estuarine waters. Biomass was the attribute with better responses to the environmental variables, probably related to the enrichment through the food chain due to the presence of waters rich in organic matter, increasing the primary productivity. Furthermore, favourable conditions allow individuals to reproduce more, also resulting in an increase in abundance. It is also possible to relate richness to Vermelha beach position as an estuarine-oceanic transitional zone, which it can attract species from other regions, especially for feeding purposes, resulting in an increase in the number of species.

Some species showed fluctuations in their abundance through years or seasons, and even with environmental variables. The abundance of *Orthopristis ruber* followed a seasonal pattern, with greater values in autumn and summer, and low values in winter and spring. Vianna and Verani (2002) described spawning period of *O. ruber* for spring, and Santos et al. (2007) indicated that this species do not use sandy beaches for spawning, but there is a lack of knowledge on its spawning grounds. Great abundances of *O. ruber* were recorded at outer zones in Sepetiba Bay, with a large contribution of juveniles, corroborating with our findings, and also suggesting this species recruitment in these regions (Santos et al. 2007). But this pattern was not corroborated by environmental variables, which related great abundances of *O. ruber* estuarine waters (high temperature, low salinity and pH). According to Santos et al. (2007), *O. ruber* is more limited by biotic factors, as potential competition with *Micropogonias furnieri* and marine catfishes, which limited *O. ruber* colonization of inner Sepetiba Bay zones. These potential competitors are not abundant at Vermelha beach (Franco and Santos *in. prep.*), allowing *O. ruber* to abundantly colonize this outer zone of Guanabara Bay.

Also showing a seasonal pattern, *Dactylopterus volitans* was less abundant in spring, with great abundances in summer and autumn. It is a common species in Brazilian south eastern coast, but there are few studies on its ecology and seasonal fluctuations (Azevedo et al. 2007; Chaves and Monteiro-Neto 2009; Gibran and Moura 2012). Ferreira et al. (2001) and Barreto (2013) related *D. volitans* with oceanic waters (low temperature and high salinity), differing from our findings in which this species was more abundant in warm waters. Our findings also pointed that this species is not favored by estuarine waters, being probably tolerant to high temperature, and low salinity and pH.

H. aurolineatum presented greater abundances in the first year than in the second, peaking in spring and summer months. In most studies on fish associated with rocky substrates *H. aurolineatum* is often captured in a great frequency and abundance (Chaves and Monteiro-Neto 2009; Barreto 2013). According to García-Cagide et al. (1994) autumn is the spawning season of *H. aurolineatum*, when it had the lowest abundance in our study, suggesting that reproduction did not occur in rocky shores. Even so, recruitment seems to occur in rocky substrates, since juveniles are extremely abundant in these sites (73.6% in the present study). *Haemulon aurolineatum* did not have a relevant relation with environmental variables in the present study, but was related with low salinity in Vermelha beach by Barreto (2013), corroborating with the great abundance of this species near estuaries found in other studies (Araújo & Azevedo 2001; Chaves & Monteiro-Neto 2009).

Also presenting a greater abundance in the first year, *Pareques acuminatus* has few numeric contributions in most correlative studies (Floeter et al. 2007; Chaves and Monteiro-Neto 2009; Barreto 2013). The low abundances of this species can be related to its sedentary habitats, often hidden on crevices, which makes difficult its capture through gillnets and visualization during visual censuses (Moe 1992; Barreto 2013). Despite its importance as ornamental fish, there is little information about life history of *P. acuminatus*, especially on its reproduction (Waggy et al. 2006). *Pareques acuminatus* did not respond to environmental variables in any study, but the great abundance during autumn (great temperature and low salinity) could relate this species to estuarine waters.

A significant year × season interaction was found for the abundances of the sparid *Diplodus argenteus*, with greater abundance in the second year, especially in summer. Summer was the period of greatest abundance of *D. argenteus* in other studies, suggesting this season as the recruitment period (Galván et al. 2005; Barreto 2013). No relation with environmental variables was found for *D. argenteus* in the present study, but it was related to warm and more oxygenate waters, and also to low salinity and pH by Barreto (2013), the same conditions in which this species was more abundant in the present study.

Finally, the abundance of *Holocentrus adscensionis* did not differed among years or seasons, but great abundances were recorded in autumn. This pattern was corroborated by environmental variables, where *H. adscensionis* was related to estuarine waters (conditions found also during autumn). Furthermore, Shinozaki-Mendes et al. (2007) recorded reproduction of this species during the entire year, peaking on autumn months. Only adults of *H. adscensionis* were found, but further studies are needed to confirm whether the autumn is the spawning season of *H. adscensionis* in Guanabara Bay.

The abundances of some fish species not selected by DCA were also related to environmental variables in our study. Azevedo et al. (2007) found temperature and salinity as major structuring factors of fish abundance in Sepetiba Bay. These environmental variables are mostly dictated by coastal currents and rainfall on a regional scale (Araújo et al. 2002; Azevedo et al. 2007). *Priacanthus arenatus* was not selected by DCA but its abundances were correlated to the environmental variables. Corroborating with our findings, Tapia-García et al. (1995) related this species to the rainy season in the Gulf of Mexico, indicating low values of salinity. *P. arenatus* is described as a marine non-estuarine dependent species, but in the present study was correlated with more estuarine waters, indicating estuary colonization for feeding purposes (Tapia-García et al. 1995), since we found replete stomachs in all individuals. Another species not selected by DCA was *Sphoeroides greeleyi*, which showed greater abundances in high temperature, and low pH and salinity. Barreto (2013) also found this species more related to estuarine waters in Vermelha beach, whereas Araújo et al. (2002), in contrast, recorded *Sphoeroides greeleyi* associated with low temperature and high salinity in Sepetiba Bay. *S. greeleyi* has an osmoregulatory capacity not being limited by salinity variations, which allows this species to better exploit feeding resources (Ferreira et al. 2004; Prodocimo and Freire 2004). The presence of defensive mechanisms, as high toxicity, and capacity to increase body volume, also contribute to this species be widely spread and dominant throughout Brazilian coast (Barletta and Corrêa 1992).

Overall our findings reveal that seasonal and interannual changes on fish assemblage attributes were related to the alternating influence of estuarine and oceanic waters. The most resident and abundant species, such as *O. ruber*, *P. arenatus*, and *S. greeleyi*, were more abundant in high temperature and low salinity and pH, indicating the importance of estuarine waters for fish assemblages associated with rocky shores in Guanabara Bay. This result suggests that waters from the inner zones of tropical polluted bays might surprisingly favor reef fish assemblages in complex transitional systems, such as Vermelha beach, which are also under influence of oceanic waters.

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CONCLUSÃO GERAL

A partir dos objetivos postulados e dos resultados encontrados é possível concluir que a ictiofauna associada aos costões rochosos da Praia Vermelha é compartilhada por grupos de espécies residentes e transientes, os quais apresentam padrões distintos de abundância e respostas às variações ambientais em função do grau diferenciado de dependência do substrato rochoso. Também foi observado que a caracterização prévia dos grupos de peixes segundo o nível de associação com o substrato rochoso e a escolha do protocolo estatístico a ser adotado para o tratamento dos dados dessa ictiofauna complexa são questões importantes e que devem ser levadas em conta para a identificação de padrões sazonais e respostas às condições ambientais pela ictiofauna. As variações de temperatura, pH e salinidade confirmaram o caráter transicional da Praia Vermelha, a qual sofre influência alternada de águas oceânicas e estuarinas que afetam tanto a ictiofauna associada quanto as características ambientais ao longo das estações ano. Foram detectadas, a partir de análises das respostas da ictiofauna residente às variações de temperatura, pH e salinidade, correlações surpreendentemente positivas das espécies mais abundantes deste grupo com a presença de águas estuarinas na área estudada, revelando a conectividade entre diferentes zonas da Baía de Guanabara e importância da conservação das zonas mais internas desse ecossistema para a sobrevivência dos organismos marinhos. O presente trabalho também destaca a necessidade da realização de estudos adicionais, em especial aqueles de longa-duração, que incluam um maior número de variáveis ambientais, tais como a profundidade, transparência e oxigênio dissolvido, e que testem o protocolo proposto para a separação da ictiofauna entre espécies residentes e transientes e o uso combinado de análises multivariadas do tipo “unconstrained” e “constrained”, a fim de se aprimorar o conhecimento sobre a ictiofauna de ecossistemas transicionais e ambientalmente complexos, como é caso dos costões rochosos da Praia Vermelha.