



The structure of shallow water fish assemblages in sandy beaches of a tropical bay in the southwestern Atlantic

Samara Macedo Pinto¹ · Cassiano Monteiro-Neto¹ · Elisabete Barbarino¹ · Rafael de Almeida Tubino² · Marcus Rodrigues da Costa¹

Received: 21 September 2020 / Revised: 11 June 2021 / Accepted: 12 June 2021
© The Ichthyological Society of Japan 2021

Abstract

The spatial and seasonal dynamics of shallow water fish assemblages and their relationship with physical-chemical variables were investigated on Guanabara Bay, one of the largest coastal bays in Brazil, southwestern Atlantic. Fishes were collected monthly between June 2016 and May 2018, in the shallow waters of six beaches distributed in four sectors along the major axis of the bay (adjacent and entrance - one site each, middle and inner - two sites each), using a beach seine net. A total of 79 fish species was recorded, mostly juveniles. Marine estuarine dependent, marine estuarine opportunist, solely estuarine and marine straggler were the most representative ecological guilds in the bay during the sampling period. Following the index of relative importance (IRI) categories, top dominant species ($IRI \geq 10\%$) within sector beaches were: the solely estuarine *Atherinella brasiliensis* from the inner to the entrance; marine estuarine dependent *Eucinostomus argenteus* in the middle; marine estuarine dependent *Harengula clupei* and marine straggler *Diplodus argenteus* at the entrance, and marine stragglers *Umbrina coroides*, *D. argenteus*, and marine estuarine dependent *Dactylopterus volitans* in the adjacent sector beach. All analyses identified distinct fish assemblages that were distributed in two main areas: adjacent/entrance and middle/inner. Transparency and chlorophyll *a* were responsible for most of the spatial variability and played an important role in structuring fish assemblages. Water temperature was responsible for seasonal fluctuations indicating the distinct habitat use from different life cycle stages of fish species. This investigation suggests the importance of all sector beaches as nursery and growth areas due to the high representation of juvenile individuals.

Keywords Nursery grounds · Spatial distribution · Functional guilds · Environmental influences · Seasonality

Introduction

Tropical coastal bays are large bodies of water which play a critical role as breeding and nursery areas for many marine organisms, especially fish (Araújo et al. 2002; Azevedo et al. 2007). These systems are modulated by many factors including environmental changes, continental runoff, connection with the adjacent sea, tidal regime and anthropogenic activities (Kjerfve et al. 1997; Castro et al. 2005; Barletta and

Blaber 2007; Silva et al. 2016). Different environments may be found in bays, including beaches (sandy and/or muddy), mangroves, islands and estuaries (Meniconi et al. 2012; Castello and Krug 2015).

The shallow waters of sandy beaches represent physically dynamic environments, providing habitats for a diverse and abundant fauna, and deliver essential ecosystem services such as water filtration, nutrient cycling, wildlife support, and nurseries for fish and crustaceans (Marin Jarrin et al. 2017). High numbers of juvenile fishes from several species utilize these areas for feeding, and protection from predation (Blaber and Blaber 1980; Layman 2000; Araújo et al. 2016, 2018), provided by the habitat shallowness and turbidity (Pessanha and Araújo 2003; Vilar et al. 2011; Rishworth et al. 2015).

Guanabara Bay is one of the most relevant systems in the southwest Atlantic, offering shelter, food and living space for many species of economic importance, and harboring

✉ Samara Macedo Pinto
smp.bio@gmail.com

¹ Departamento de Biologia Marinha, Universidade Federal Fluminense, Outeiro de São João Batista S/N, Niterói, Rio de Janeiro 24020-141, Brazil

² Departamento de Biologia Animal, Universidade Federal Rural do Rio de Janeiro, Rodovia BR465-Km 07, Seropédica, Rio de Janeiro 23890-000, Brazil

important regional fisheries (Soares-Gomes et al. 2016). It is also highly urbanized, surrounded by the metropolitan region of Rio de Janeiro, with a population of approximately 16 million inhabitants (Fistarol et al. 2015) and an average annual growth of 0.86% in the last decade (Chediek 2014). The high spatial and physical heterogeneity within the bay include both, structural (e.g., vegetation, rocky outcrops and islands) and non-structural (e.g., substrate type and bathymetry) components that provide shelter and protection, playing a relevant role in the distribution of ichthyofauna (Manderson et al. 2002; Selleslagh et al. 2009). Eutrophic and polluted mixohaline waters prevail in the inner sectors of Guanabara Bay where water circulation is restricted. At the entrance and outer sectors, saline and oxygen saturated waters predominate, and eventually enter into the bay through the deep main channel. As this water mass moves inward, it spills over from the channel, and advection processes provide the mixing of water masses into the shallow areas (Villac et al. 1991; Castro et al. 2005; Baptista Neto et al. 2006; Fistarol et al. 2015).

Spatial and temporal changes in the physical-chemical environment may influence the structure of fish assemblages at different scales (local and regional), and across a latitudinal gradient (Pessanha and Araújo 2003; Lima and Vieira 2009). Recent studies on the structure of nearshore water fish assemblages have described the spatial patterns along the estuarine gradient in different regions of the Brazilian coast (Araújo et al. 2018). Within estuaries, the ichthyofauna seems highly dynamic, changing constantly due to interactions between species-specific physiological limitations, and life history strategies (Vilar et al. 2011; Pereira et al. 2015; Franco et al. 2016). Furthermore, several authors have observed that species composition on shallow waters of sandy beaches varies according to different environmental attributes (e.g., temperature, salinity, transparency), physical attributes (e.g., wave action, rocky reefs, algae banks) and anthropogenic environmental impacts (presence of solid residues, population density and fishing impacts) supporting different fish assemblages (Whitfield and Patrick 2015; Franco et al. 2016; Araújo et al. 2018; Chaves et al. 2018). Despite the several studies already developed on shallow water fishes in Guanabara Bay, the identification of drivers responsible for the species' distribution patterns in space and time is still not fully understood. In this context, this study aims to describe these shallow water (≤ 1.5 m deep) fish assemblages associated with sandy beaches of Guanabara Bay and to investigate the influences of environmental drivers on species composition.

Materials and methods

Study site. Guanabara Bay ($22^{\circ}42'$, $22^{\circ}58'S/43^{\circ}18'$, $42^{\circ}58'W$) is one of the largest coastal bays in Brazil, southwestern Atlantic, with a relatively narrow mouth (1.6 km),

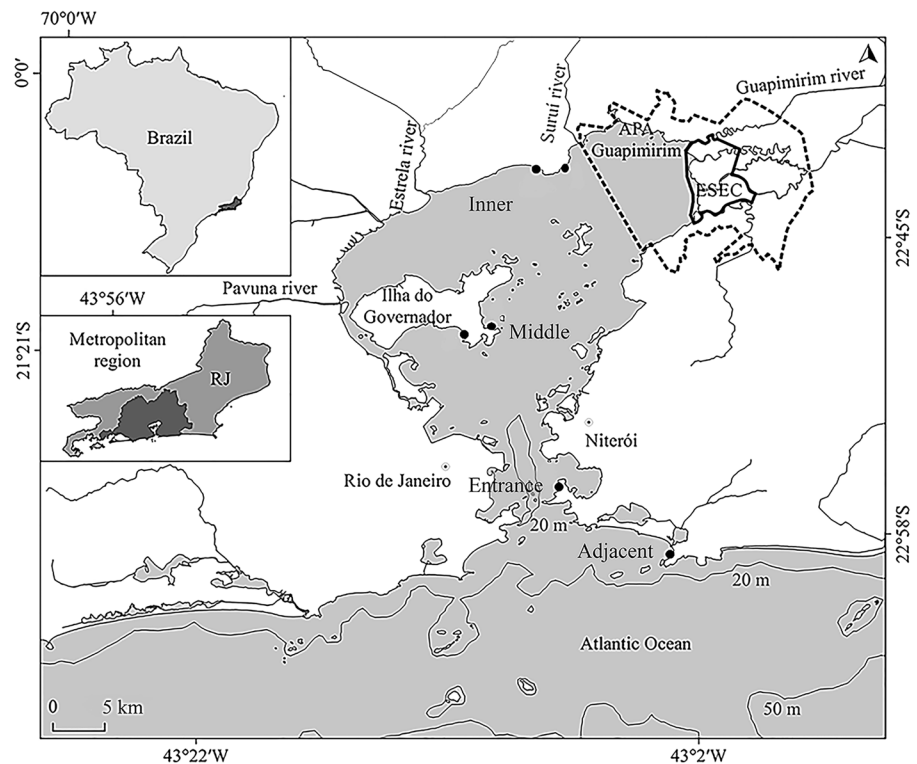
an extension of 30 km on its largest N-S direction axis, and a maximum width in the E-W direction of 28 km in its innermost part (Fig. 1). The perimeter is 153 km and the total area is 396 km^2 , with a water volume and a drainage basin of approximately $3 \times 10^9 \text{ m}^3$ and $4,000 \text{ km}^2$, respectively (Amador 1997; Meniconi et al. 2012). The regional climate is tropical and humid with a rainy season in the austral summer (December to February) and dry in winter (July and August) (Paranhos and Mayr 1993; Meniconi et al. 2012). Depth varies from 58 m in the central channel and < 1 m in the innermost areas (Mayr et al. 1989). Water circulation is intense and dominated by semi-diurnal tidal currents (i.e., 1.4 m of amplitude), achieving $80\text{--}150 \text{ cm s}^{-1}$ near the mouth of the bay, decreasing to $30\text{--}50 \text{ cm s}^{-1}$ over the central areas, and falling down to $< 30 \text{ cm s}^{-1}$ in the inner sectors. Freshwater inflow, originating from the ~50 small rivers and streams and especially the urban and industrial effluents, combined with cyclic intrusions of oceanic waters through the tidal regime, affect significantly the hydrological regime of Guanabara Bay (Mayr et al. 1989; Fistarol et al. 2015).

Despite the influences of cold front passages, rainfall and tidal regimes, hydrological conditions in Guanabara Bay rely mostly on two interconnected gradients: (i) a land-ocean, ranging from typical marine conditions near the entrance of the bay to more estuarine and eutrophic waters in its innermost areas (Chaves et al. 2018); (ii) a bathymetric gradient, in which greater depths (~60 m) are generally found along the central channel, decreasing to the east and west sides of the bay (Mayr et al. 1989; Fistarol et al. 2015). The combined influence of these factors leads to strong variability of environmental conditions (Fig. 1).

Fish sampling. Samples were collected monthly from June 2016 to May 2017 (Year one = Y1) and June to May 2018 (Year two = Y2) on six beach sites distributed in four sectors of the bay: adjacent and entrance (one beach each); middle and inner (two beaches each), distributed along the longest N-S axis, taking into account physicochemical, hydrodynamic, physiographic and sedimentary characteristics (Ribeiro and Kjerfve 2002; Fistarol et al. 2015; Chaves et al. 2018). Austral seasons were defined as follows: winter - June to August; spring - September to November; summer - December to February; autumn - March to May.

At each sampling site, three beach seine hauls of approximately 20 m were carried parallel to the shore at depths less than 1.5 m during the day. The beach seine used was 9 m long, 2.6 m high, with a 13 mm bar mesh on the wings and 5 mm on the cod end, covering a total swept area of about 180 m^2 per tow. The sampling design was structured considering the total number of fishes caught per haul, with replicate hauls at each site (3 consecutive replicate tows $\times$ 24 months = 72 hauls per site). Prior to biological sampling, water salinity and temperature ($^{\circ}\text{C}$ - YSI Pro 30), dissolved oxygen (mg/L - WTW Oxi 3205), Chlorophyll *a* (mg/m^3

Fig. 1 Study area with indication of the six beaches sampled in four sector beaches (adjacent, entrance, middle and inner) in Guanabara Bay, Rio de Janeiro (RJ), Brazil. *Dotted and solid lines* indicate the Guapimirim Environmental Protection Area (APA Guapimirim) and Ecological Station (ESEC), respectively



- Spectrophotometer Q798U2M), transparency (% - Secchi disk) and sediment grain size (μm - Camsizer XT) were recorded once at each sampling site. Additionally, pluviosity (mm - monthly accumulated, 30 days) data were obtained from the system Alerta Rio: <http://alertario.rio.rj.gov.br>. All collected specimens (license SISBIO #15787-1) were placed in plastic bags, labeled and stored on ice during transport to the laboratory where they were screened and identified at the lowest taxonomic level (e.g., Figueiredo and Menezes 1978, 1980, 2000; Menezes and Figueiredo 1980, 1985). All fishes were measured for total length (to the nearest 0.1 mm) and weighed with an electronic scale (± 0.001 g precision). The electronic dataset of FishBase (Froese and Pauly 2019), and the classifications of habitat use provided in Elliott et al. (2007) and Potter et al. (2015), were also used to assign each fish species a degree of dependency of habitat use, according to the following guilds: (1) freshwater straggler; (2) freshwater estuarine opportunist; (3) solely estuarine; (4) marine estuarine dependent; (5) marine estuarine opportunist; and (6) marine straggler. In addition, the size of the first sexual maturity recorded in the literature was used as a criterion to determine the life history stages of each species (juvenile or adult), following a similar approach as other authors have done (Félix et al. 2007; Lajud et al. 2016; Costa et al. 2018; Froese and Pauly 2019; IUCN 2019). Vouchers of reference specimens collected in this study are available in the ichthyological collection of Laboratório de Biologia do Nécton e Ecologia Pesqueira (ECOPESCA-LNEP-UFF).

Data analysis. The environmental data were normalized and the fish abundance and weight data were transformed into $\log_{10}(x + 1)$ to generate the Euclidean Distance and Bray Curtis similarity matrices, respectively. A two-way permutational analysis of variance (PERMANOVA) was used to evaluate the differences in environmental variables, abundance, species richness, biomass and fish assemblage (multivariate matrices with species as variables) between sector beaches and seasons for each year, separately. Subsequently, significant terms were investigated using a posteriori pairwise comparisons to determine which pairs of sector beaches and seasons were significantly different. The multivariate dispersion homogeneity test (PERMDISP) (Anderson et al. 2006) was used to test the data dispersion between sector beaches and seasons. Together, PERMANOVA and PERMDISP helped to interpret the nature of the variability/effect (i.e., only local, dispersion, either effects or none). In addition, principal component analysis (PCA) was applied to environmental variables to detect spatial or temporal patterns along the environmental gradient (largest axis N-S of the bay). The full set of available environmental variables was tested for collinearity (Draftsman plot and Spearman correlation matrix), and redundant variables with correlations (r) > 0.7 were omitted from the model.

The index of relative importance (IRI%) (Pinkas 1971; Cortés 1998) was used to evaluate the importance of each species along the spatial gradient, as follows: $(N\% + W\%) \cdot FO\%$, where $N\%$ = percentage of the number of

individuals of each species relative to the total number of individuals, $W\%$ = percentage of weight of each species relative to the total weight, and $FO\% = n/N \times 100$, where n = number of samples in which the species was present and N = total number of samples (Selleslagh et al. 2009). The species were classified according with following IRI cut-off levels: a) top-dominant ($IRI \geq 10\%$); b) dominant ($10.0\% > IRI \geq 5.0\%$); occasional ($5.0\% > IRI \geq 1.0\%$); rare ($< 1.0\%$). The non-metric multi-dimensional scaling (nMDS) was used to detect spatial and temporal biotic patterns for each year. The vectors of the species that presented Spearman correlations above 0.40 were projected on the ordination. To test the association between the abiotic variables and the biotic similarity matrix, we applied the distance-based linear models (DistLM) analysis for each annual cycle. DistLM relates and generates models between a set of multivariate data, such as those described in a similarity matrix, and one or more predictor variables (Anderson et al. 2008). The predictive variables were correlated with Bray-Curtis similarity matrices, using the stepwise model and the adjusted R^2 as the selection criterion. For the selected model, the distance-based redundancy analysis (dbRDA), which performs an ordering of the variables in a multidimensional space, was applied.

The PCA, nMDS and dbRDA were drawn for each factor separately because there was no significant interaction between seasons and sector beaches. With the samples analyzed in nMDS and dbRDA, we calculated the average of the three replicates of each sampling site in a single value (Pereira et al. 2015; Araújo et al. 2017); this yielded 72 samples for each year (6 beach sites $\times$ 12 months). Multivariate analyses were performed with the resources of the statistical package PRIMER 6.0 (Clarke and Gorley 2006) and PERMANOVA+ for PRIMER (Anderson et al. 2008).

Results

Environmental variables. In both years, a similar spatial pattern was observed, where salinity (Y1: Pseudo- F = 15.58, P = 0.0001; Y2: Pseudo- F = 21.35, P = 0.0001), transparency (Y1: Pseudo- F = 41.58, P = 0.0001; Y2: Pseudo- F = 44.43, P = 0.0001) and gravelly sand sediments (Y1: Pseudo- F = 5.67, P = 0.003; Y2: Pseudo- F = 6.30, P = 0.002) showed the higher values in the adjacent and entrance sectors than in the middle and inner sector beaches. Temperature (Y1: Pseudo- F = 15.98, P = 0.0001; Y2: Pseudo- F = 26.54, P = 0.0001) and sand gravel sediments (Y1: Pseudo- F = 14.12, P = 0.0001; Y2: Pseudo- F = 16.36, P = 0.0001) showed an opposite pattern, with lower values in adjacent and entrance compared middle and inner sector beaches. Dissolved oxygen showed significant spatial differences only in the Y2 (Pseudo- F = 4.98, P = 0.004) with higher values observed in adjacent and entrance compared

to inner and middle sector beaches. Chlorophyll *a* showed distinct patterns between years with lower values in adjacent and entrance compared to middle and inner sector beaches in the Y1 (Pseudo- F = 9.00, P = 0.002) and higher values in middle compared to the others sector beaches in the Y2 (Pseudo- F = 7.15, P = 0.0007).

Seasonally, water temperature showed higher values in summer compared to winter in the Y1 (Pseudo- F = 26.05, P = 0.0001) and higher values in summer and autumn compared to winter in the Y2 (Pseudo- F = 38.36, P = 0.0001) (Table 1). The pluviosity showed higher values in spring, summer and autumn compared to winter in the Y1 (Pseudo- F = 4.50, P = 0.006) and showed higher values in the summer compared to the others seasons in the Y2 (Pseudo- F = 33.46, P = 0.0001). Salinity showed significant seasonal differences only in the Y2 (Pseudo- F = 3.61, P = 0.01) with higher values observed in winter and spring compared to summer and autumn. Remaining variables did not show significant differences ($P > 0.05$) between seasons, regardless of the year.

The PCA ordination using sector beaches and seasons for environmental variables showed a similar variation pattern in both years (Fig. 2). The first two axes of the PCA explained 56.3% (PC1 = 39.3 and PC2 = 17.0%) of the total variance in the Y1 and 57.3% (PC1 = 41.7 and PC2 = 15.6%) in the Y2. In both years, the transparency (Y1: r^2 = 0.44; Y2: r^2 = 0.39), temperature (Y1 and Y2: r^2 = 0.42) and salinity (Y1: r^2 = 0.42; Y2: r^2 = 0.44) were associated with axis 1, and chlorophyll *a* (Y1: r^2 = 0.39; Y2: r^2 = 0.68) and pluviosity (Y1: r^2 = 0.41; Y2: r^2 = 0.60) with the second axis. Dissolved oxygen, sandy gravel and gravelly sand were associated with axis 2 in the Y1 (r^2 = 0.39, 0.45 and 0.45, respectively) and with the axis 1 in the Y2 (r^2 = 0.34, 0.38 and 0.38, respectively). Spatially, we observed the presence of two main sectors (adjacent/entrance and inner) in both years, with lower salinities, transparency and gravelly sand in adjacent and entrance sectors and higher temperatures, dissolved oxygen, sandy gravel and chlorophyll *a* in inner sector beaches. Only dissolved oxygen showed an opposite pattern between years, with high values in the inner sectors in Y1 and outer sectors in Y2. Samples from middle were highly dispersed in the diagram reflecting the transition between the outer and inner sector beaches (Fig. 2). Seasonality was marked by high salinity, transparency and chlorophyll *a* in the winter, and high temperature and pluviosity in the summer. Spring and autumn were scattered in the diagram characterizing the transition between both extremes (Fig. 2).

Fish assemblage structure. A total of 29,613 individuals were captured in the two years (Y1 = 13,263; Y2 = 16,350) and 79 species distributed in 62 genera and 34 families were recorded, totaling a biomass of 58,511 g in the study period (Table 2). Twenty-four species were exclusive from Y1, 12

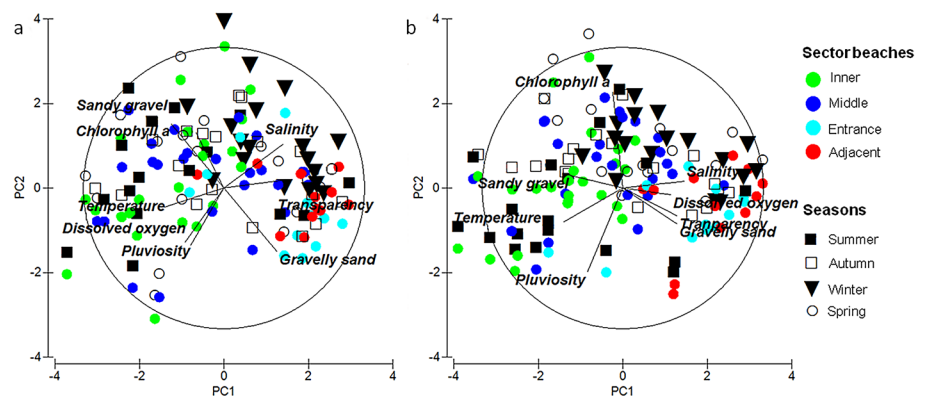
Table 1 Means (and *SD*) of environmental variables among sector beaches and seasons comparisons according to PERMANOVA in two annual cycles in Guanabara Bay

Sector beaches	Y1				Y2			
	Adjacent	Entrance	Middle	Inner	Adjacent	Entrance	Middle	Inner
Temperature (°C)	23.0 (0.7) ^c	25.2 (0.7) ^b	26.8 (0.6) ^a	26.6 (0.7) ^a	22.5 (0.8) ^c	23.7 (0.7) ^c	25.8 (0.5) ^b	27.0 (0.6) ^a
Salinity	30.0 (0.4) ^a	29.3 (0.3) ^a	27.4 (0.5) ^b	26.2 (0.6) ^b	32.3 (0.5) ^a	30.3 (0.4) ^b	27.7 (0.6) ^c	26.4 (0.5) ^c
Dissolved oxygen (mg/L)	9.1 (0.4) ^a	9.1 (0.4) ^a	9.7 (0.5) ^a	10.1 (0.6) ^a	8.7 (0.2) ^a	8.2 (0.2) ^a	7.1 (0.3) ^b	7.3 (0.3) ^b
Transparency (%)	97.2 (2.7) ^a	98.6 (1.4) ^a	59.9 (4.5) ^b	44.0 (4.5) ^c	91.0 (4.0) ^a	98.6 (1.4) ^a	67.2 (5.1) ^b	37.5 (3.4) ^c
Chlorophyll <i>a</i> (mg/m ³)	301.3 (37.7) ^b	187.6 (16.4) ^c	652.4 (77.0) ^a	448.5 (96.3) ^a	229.1 (54.3) ^b	179.6 (32.8) ^b	613.5 (32.8) ^a	285.3 (75.2) ^b
Sandy gravel (μm)	344.6 (235.9) ^c	744.8 (194.7) ^c	1112.5 (237.7) ^b	1710.0 (215.2) ^a	344.6 (235.9) ^b	735.4 (314.7) ^b	1296.4 (234.7) ^a	1744.1 (198.6) ^a
Gravelly sand (μm)	815.6 (145.9) ^a	861.3 (194.7) ^a	318.3 (111.7) ^b	347.9 (127.9) ^b	844.6 (152.1) ^a	861.3 (194.7) ^a	276.2 (108.2) ^b	243.9 (143.9) ^b
Pluviosity (m.a.)	63.3 (12.1) ^a	63.7 (12.1) ^a	63.7 (8.4) ^a	59.2 (8.5) ^a	77.6 (19.5) ^a	77.6 (19.5) ^a	77.6 (13.5) ^a	77.6 (13.5) ^a

Seasons	Y1				Y2			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Temperature (°C)	22.9 (0.4) ^c	25.9 (0.4) ^b	29.0 (0.9) ^a	25.8 (0.5) ^b	21.9 (0.3) ^c	24.9 (0.6) ^b	27.5 (0.7) ^a	27.1 (0.5) ^a
Salinity	28.4 (0.2) ^a	27.3 (0.7) ^a	27.2 (0.8) ^a	28.3 (0.5) ^a	29.6 (0.5) ^a	29.6 (0.5) ^a	27.1 (0.9) ^b	27.6 (0.9) ^b
Dissolved oxygen (mg/L)	8.5 (0.4) ^a	9.9 (0.5) ^a	10.0 (0.6) ^a	9.2 (0.4) ^a	7.9 (0.4) ^a	8.1 (0.3) ^a	7.2 (0.4) ^a	7.4 (0.3) ^a
Transparency (%)	70.1 (5.3) ^a	60.0 (7.4) ^a	66.4 (7.11) ^a	68.05 (7.5) ^a	76.9 (7.5) ^a	62.0 (7.2) ^a	62.6 (6.5) ^a	64.4 (6.8) ^a
Chlorophyll <i>a</i> (mg/m ³)	476.4 (82.6) ^a	496.7 (76.5) ^a	513.2 (124.8) ^a	363.5 (81.1) ^a	358.2 (82.4) ^a	481.1 (101.8) ^a	338.4 (95.1) ^a	293.0 (62.5) ^a
Sandy gravel (μm)	702 (239.2) ^a	1084.7 (289.0) ^a	1600.4 (240.9) ^a	1084.7 (289.0) ^a	812.0 (252.2) ^a	1084.7 (297.4) ^a	1651.7 (223.2) ^a	1225.5 (273.6) ^a
Gravelly sand (μm)	480.0 (132.2) ^a	457.3 (129.1) ^a	276.3 (125.1) ^a	418.0 (168.2) ^a	426 (131.6) ^a	457.3 (129.1) ^a	261.0 (120.6) ^a	418.0 (168.2) ^a
Pluviosity (m.a.)	30.6 (6.1) ^b	72.8 (10.9) ^a	75.1 (9.8) ^a	71.9 (7.3) ^a	49.1 (6.9) ^b	50.4 (8.3) ^b	169.2 (14.3) ^a	41.8 (2.0) ^b

m.a. monthly accumulated

Values having the same superscript letter were not significantly different within each sector beach and seasons

Fig. 2 Principal component analysis (PCA) of environmental variables in sector beaches and seasons in the Guanabara Bay. **a** Y1, **b** Y2

were exclusive from Y2, and 43 were common in both years (Table 2).

Most of the captured specimens were juveniles (67.1%) when compared to adults (15.2%) (Table 2). Thirty-eight species were considered marine estuarine dependent, followed by marine estuarine opportunists (17 species), solely estuarine (12 species) and marine stragglers (10 species). Lower contributions were registered for freshwater marine opportunists and freshwater stragglers (one species on each guild, respectively) (Table 2).

The index of relative importance (IRI) calculated for the whole system indicated that *Atherinella brasiliensis* and *Eucinostomus argenteus* were the top-dominant species (IRI = 71.2% and 10.7%, respectively (Table 2). Considering the sectors separately, *A. brasiliensis* remained top-dominant from the inner to the entrance sector beaches, whereas *E. argenteus* was top-dominant in the middle and dominant in the inner sector beaches. *Sphoeroides greeleyi* showed up as dominant in the middle and entrance sector beaches. *Harengula clupei* and *Diplodus argenteus* were top-dominant at the entrance followed by *Umbrina coroides* and *Trachinotus carolinus* as dominant. *Umbrina coroides*, *D. argenteus* and *Dactylopterus volitans* were top-dominant and *T. carolinus* was dominant in the adjacent sector beach. Six species (*S. greeleyi*, *H. clupei*, *D. argenteus*, *U. coroides*, *Micropogonias furnieri* and *T. carolinus*) were considered occasional in the whole system. Occasional species occurred in inner (5 species), middle (2 species), entrance (4 species) and adjacent sectors (5 species). Remaining species were considered rare throughout the system (Table 2). *Atherinella brasiliensis*, *E. argenteus*, *S. greeleyi*, *H. clupei*, *U. coroides*, *T. carolinus*, *Sphoeroides testudineus*, *Anchoa lyolepis*, *Sardinella brasiliensis*, *Albula vulpes*, *Pomatomus saltatrix*, *Chaetodipterus faber*, *Menticirrhus americanus*, *Trachinotus falcatus* and *Stephanolepis hispidus* occurred in all sector beaches. From the total of 79 species, 13 were exclusive to the inner, nine to the middle, four to the entrance and eight to the adjacent sector beaches (Table 2).

Species richness was lower in the inner sector compared to other sector beaches in Y1 (Pseudo- $F = 3.71$, $P = 0.008$). In Y2 species richness did not show significant differences among sectors (Pseudo- $F = 2.05$, $P = 0.054$). The abundance was lower in adjacent and entrance sectors when compared with middle and inner sector beaches (Y1: Pseudo- $F = 0.90$, $P = 0.466$; Y2: Pseudo- $F = 8.21$, $P = 0.001$) (Table 3), and biomass presented an opposite pattern (Y1: Pseudo- $F = 1.76$, $P = 0.104$; Y2: Pseudo- $F = 4.17$, $P = 0.001$), depending on the year. Seasonally, higher abundance (Y1: Pseudo- $F = 12.02$, $P = 0.0001$; Y2: Pseudo- $F = 9.25$, $P = 0.0001$) was found in winter and spring in Y1, and spring in Y2. Species richness presented higher values in the winter, spring and autumn (Y1: Pseudo- $F = 7.07$, $P = 0.0004$; Y2: Pseudo- $F = 6.55$, $P = 0.0001$) (Table 3).

In both years, the PERMANOVA analysis detected significant differences on fish assemblages between sector beaches (Y1: Pseudo- $F = 7.55$, $P = 0.0001$; Y2: Pseudo- $F = 6.76$, $P = 0.0001$), but the PERMDISP analysis did not detect significant differences between sector beaches (Y1: $F = 1.56$, $P = 0.30$; Y2: $F = 0.91$, $P = 0.91$). Both analyses suggested that local effects (sector beaches) influenced fish assemblages, collaborating with the presence of two main sectors (entrance/adjacent and inner sector beaches) along of the major axis of the bay. The nMDS ordination applied to those data in both years (Fig. 3) showed correlations above 40% between adjacent and entrance sector beaches, mainly contributed by the marine stragglers species (*T. carolinus*, *U. coroides*, *D. argenteus* and *P. saltatrix*), followed by marine estuarine dependent (*H. clupei*) and the marine estuarine opportunist (*Menticirrhus littoralis*). Middle and inner sector beaches samples had a higher correlation, determined by the occurrence of marine estuarine dependent (*Polydactylus virginicus*, *C. faber*, *M. furnieri*, *E. argenteus*, *Oligoplites saurus* and *Brevoortia aurea*) and estuarine species (*A. brasiliensis*) species. Seasonally, the segregation pattern of the samples was not detected (Fig. 3).

Environmental influences on assemblage structure. A clear spatial distribution was observed, similar to that shown on the PCA and nMDS forming two distinct sector beaches in both years: adjacent/entrance and middle/inner (Fig. 4). Transparency and chlorophyll *a* were responsible for most of the spatial variability. Temperature was the most significant variable determining seasonal discontinuities in fish assemblages. The step-wise/ R^2 -adjusted linear regression model (DistLM) explained 21.0% and 20.0% of the total spatial variation in the Y1 and Y2, respectively. The sequential test, only transparency, temperature and chlorophyll *a* variables were significant in both years. The first two axes of dbRDA explained 74.1% in Y1 and 67.9% in Y2 of the relationship between fish assemblages and environmental variables. Transparency showed a positive and chlorophyll *a* a negative correlation with first axis, with higher and lower values in winter, respectively. Temperature showed a positive correlation with the second axis, indicating higher temperatures in summer. A similar pattern was observed in the Y2 (Fig. 4).

Discussion

Spatial and temporal patterns of fish assemblages on sandy beaches distributed in four sectors in Guanabara Bay were noticeable in the two years. Outer sectors (entrance and adjacent) were influenced by the adjacent marine environment whereas inner sectors (inner and middle) were mostly characterized by estuarine conditions. Water transparency and chlorophyll *a* were mostly correlated with this spatial pattern, whereas water temperature contributed to the

Table 2 List of species recorded on the sector beaches of Guanabara Bay

Family	Species/maturity	Sector beaches				Total %IRI	Year	TL range (mm)	Guild
		Adjacent	Entrance	Middle	Inner				
		%IRI	%IRI	%IRI	%IRI				
Atherinopsidae	<i>Atherinella brasiliensis</i> ^{J, A}	2.2	29.2	71.0	80.3	71.2	1, 2	13–154	SE
Gerreidae	<i>Eucinostomus argenteus</i> ^{J, A}	0.6	0.8	18.4	6.3	10.7	1, 2	11–122	MED
Tetraodontidae	<i>Sphoeroides greeleyi</i> ^{J, A}	1.0	5.0	5.9	0.7	4.2	1, 2	13–135	MED
Clupeidae	<i>Harengula clupeola</i> ^{J, A}	2.6	33.7	0.3	1.3	3.6	1, 2	17–120	MED
Sparidae	<i>Diplodus argenteus</i> ^J	29.9	12.6			1.8	1, 2	83–11	MS
Sciaenidae	<i>Umbrina coroides</i> ^J	35.5	5.0	<0.1	<0.1	1.3	1, 2	14–165	MS
Sciaenidae	<i>Micropogonias furnieri</i> ^J	<0.1		1.2	2.3	1.2	1, 2	18–270	MED
Carangidae	<i>Trachinotus carolinus</i> ^J	6.3	7.3	<0.1	0.2	1.2	1, 2	11–122	MS
Tetraodontidae	<i>Sphoeroides testudineus</i> ^{n.a.}	<0.1	0.1	2.0	0.6	0.9	1, 2	10–152	SE
Dactylopteridae	<i>Dactylopterus volitans</i> ^{n.a., A}	11.0		0.3		0.9	1, 2	94–211	MED
Clupeidae	<i>Brevoortia aurea</i> ^J			0.1	3.9	0.8	1, 2	20–101	MED
Engraulidae	<i>Anchoa lyolepis</i> ^{J, A}	<0.1	1.9	<0.1	1.6	0.6	1, 2	21–85	MED
Clupeidae	<i>Sardinella brasiliensis</i> ^J	4.6	1.0	<0.1	<0.1	0.4	1, 2	20–94	MEO
Gerreidae	<i>Diapterus rhombeus</i> ^J			0.1	1.3	0.3	1	16–66	MED
Carangidae	<i>Caranx latus</i> ^J	0.6	1.5	<0.1		0.1	1, 2	41–163	MED
Sciaenidae	<i>Menticirrhus littoralis</i> ^J	4.3	0.4			0.1	1, 2	12–139	MEO
Albulidae	<i>Albula vulpes</i> ^J	<0.1	0.1	0.1	0.2	0.1	1, 2	19–175	MED
Pomatomidae	<i>Pomatomus saltatrix</i> ^J	0.7	0.3	<0.1	<0.1	0.1	1, 2	30–130	MS
Carangidae	<i>Oligoplites saurus</i> ^{n.a.}		<0.1	0.1	0.1	0.1	1, 2	22–101	MED
Engraulidae	<i>Anchoa tricolor</i> ^{n.a.}	<0.1		<0.1	0.2	0.1	1, 2	31–104	MED
Haemulidae	<i>Orthopristis rubra</i> ^J		0.7	<0.1	<0.1	0.1	1, 2	27–111	MED
Ariidae	<i>Genidens genidens</i> ^{J, A}			<0.1	0.3	<0.1	1, 2	44–250	MED
Ephippidae	<i>Chaetodipterus faber</i> ^J	0.1	<0.1	<0.1	0.1	<0.1	1, 2	14–48	MED
Sciaenidae	<i>Menticirrhus americanus</i> ^J	0.1	<0.1	<0.1	<0.1	<0.1	1, 2	18–86	MEO
Elopidae	<i>Elops saurus</i> ^{n.a.}		<0.1	<0.1	0.1	<0.1	1, 2	28–165	MED
Carangidae	<i>Trachinotus falcatus</i> ^J	<0.1	0.1	<0.1	<0.1	<0.1	1, 2	14–135	MEO
Monacanthidae	<i>Stephanolepis hispidus</i> ^J	<0.1	<0.1	<0.1	<0.1	<0.1	1	14–55	MEO
Gerreidae	<i>Eucinostomus gula</i> ^J		<0.1	<0.1	<0.1	<0.1	1, 2	25–104	MED
Sciaenidae	<i>Pogonias cromis</i> ^J			<0.1	<0.1	<0.1	1, 2	16–80	MEO
Haemulidae	<i>Haemulopsis corvinaeformis</i> ^J		0.2	<0.1		<0.1	1, 2	40–86	MED
Engraulidae	<i>Anchoa januaria</i> ^{J, A}				0.1	<0.1	1, 2	27–65	MED
Sparidae	<i>Archosargus rhomboidalis</i> ^{J, A}			0.1		<0.1	1, 2	18–84	MEO
Carangidae	<i>Selene vomer</i> ^{n.a.}		<0.1	<0.1	<0.1	<0.1	1, 2	42–79	MEO
Gobiidae	<i>Bathygobius soporator</i> ^{J, A}			<0.1		<0.1	1, 2	52–107	SE
Carangidae	<i>Trachinotus goodei</i> ^{n.a.}	0.2	0.1			<0.1	1, 2	42–143	MS
Mugilidae	<i>Mugil</i> spp. ^J	0.1	<0.1	<0.1	<0.1	<0.1	1, 2	13–36	
Engraulidae	<i>Cetengraulis edentulus</i> ^{J, A}			<0.1	<0.1	<0.1	1, 2	84–145	MED
Gobiidae	<i>Ctenogobius boleosoma</i> ^{n.a.}			<0.1		<0.1	1, 2	24–47	SE
Mugilidae	<i>Mugil liza</i> ^J		<0.1	<0.1		<0.1	1, 2	23–72	MED
Centropomidae	<i>Centropomus undecimalis</i> ^J				<0.1	<0.1	2	114–168	MED
Sciaenidae	<i>Cynoscion acoupa</i> ^J				<0.1	<0.1	2	34–82	MEO
Polynemidae	<i>Polydactylus virginicus</i> ^{n.a.}	0.1				<0.1	1	56	MED
Mugilidae	<i>Mugil curema</i> ^J			<0.1	<0.1	<0.1	1, 2	21–53	MED
Carangidae	<i>Chloroscombrus chrysurus</i> ^J			<0.1	<0.1	<0.1	1, 2	20–80	MED
Engraulidae	<i>Anchoviella lepidentole</i> ^J				<0.1	<0.1	1, 2	30–55	MED
Carangidae	<i>Oligoplites saliens</i> ^J			<0.1	<0.1	<0.1	2	14–126	MED
Syngnathidae	<i>Syngnathus pelagicus</i> ^{n.a.}		<0.1	<0.1	<0.1	<0.1	1, 2	54–174	SE

Table 2 (continued)

Family	Species/maturity	Sector beaches				Total %IRI	Year	TL range (mm)	Guild
		Adjacent	Entrance	Middle	Inner				
Ariidae	<i>Cathorops spixii</i> ^{n.a.}				<0.1	<0.1	2	46–85	SE
Carangidae	<i>Oligoplites palometa</i> ^{n.a.}		<0.1	<0.1	<0.1	<0.1	1, 2	23–51	MED
Centropomidae	<i>Centropomus parallelus</i> ^J				<0.1	<0.1	1	72–117	MED
Clupeidae	<i>Opisthonema oglinum</i> ^J			<0.1	<0.1	<0.1	2	37–54	MEO
Diodontidae	<i>Chilomycterus spinosus</i> ^{n.a.}	<0.1		<0.1	<0.1	<0.1	1	30–50	MEO
Gobiidae	<i>Gobionellus oceanicus</i> ^{n.a.}				<0.1	<0.1	2	75–735	SE
Bleniidae	<i>Parablennius pilicornis</i> ^{n.a.}		<0.1		<0.1	<0.1	1	40–116	MS
Serranidae	<i>Diplectrum radiale</i> ^A			<0.1		<0.1	1	147–148	MS
Sciaenidae	<i>Ophioscion punctatissimus</i> ^{J, na}	<0.1				<0.1	1	17–78	MED
Clupeidae	<i>Brevoortia pectinata</i> ^J			<0.1		<0.1	1	55–78	MED
Engraulidae	<i>Anchoa marinii</i> ^J				<0.1	<0.1	1, 2	30–59	MED
Syngnathidae	<i>Cosmocampus elucens</i> ^{n.a.}		<0.1	<0.1	<0.1	<0.1	1, 2	87–135	SE
Achiridae	<i>Achirus lineatus</i> ^{n.a.}			<0.1		<0.1	1	47–64	SE
Belonidae	<i>Strongylura</i> spp. ^{n.a.}			<0.1	<0.1	<0.1	1, 2	30–96	
Carangidae	<i>Caranx bartholomaei</i> ^J	<0.1				<0.1	2	99	MS
Clupeidae	<i>Brevoortia</i> spp.				<0.1	<0.1	2	23–37	
Achiridae	<i>Trinectes paulistanus</i> ^{n.a.}				<0.1	<0.1	1	90	SE
Hemiramphidae	<i>Hemiramphus brasiliensis</i> ^J			<0.1		<0.1	2	73–74	MEO
Triglidae	<i>Prionotus punctatus</i> ^J	<0.1		<0.1		<0.1	1	31–45	MEO
Gerreidae	<i>Eucinostomus lefroyi</i> ^{n.a.}		<0.1			<0.1	1	95	MED
Tetraodontidae	<i>Sphoeroides spengleri</i> ^{n.a.}		<0.1			<0.1	1	84	MEO
Gerreidae	<i>Eucinostomus melanopterus</i> ^{n.a.}	<0.1				<0.1	1	70	MED
Serranidae	<i>Mycteroperca tigris</i> ^J			<0.1		<0.1	2	62	MS
Sciaenidae	<i>Conodon nobilis</i> ^J	<0.1				<0.1	1	60	MEO
Sciaenidae	<i>Cynoscion leiarchus</i> ^J			<0.1		<0.1	2	55	MEO
Polynemidae	<i>Polydactylus oligodon</i> ^J	<0.1				<0.1	1	32–110	MED
Lutjanidae	<i>Lutjanus synagris</i> ^J			<0.1		<0.1	2	46	MED
Paralichthyidae	<i>Etropus crossotus</i> ^J	<0.1				<0.1	1	55	SE
Osphronemidae	<i>Betta splendens</i> ^{n.a.}				<0.1	<0.1	1	50	FS
Carangidae	<i>Oligoplites</i> spp. ^{n.a.}			<0.1		<0.1	2	48	
Poeciliidae	<i>Poecilia vivipara</i> ^{n.a.}				<0.1	<0.1	2	36	FEO
Gerreidae	<i>Diapterus auratus</i> ^{n.a.}			<0.1		<0.1	1	36	MED
Syngnathidae	<i>Bryx dunckeri</i> ^{n.a.}			<0.1		<0.1	1	113	SE
Sciaenidae	<i>Cynoscion</i> spp. ^J				<0.1	<0.1	2	33	
Clupeidae	<i>Clupeidae</i> spp.				<0.1	<0.1	2	21	
Sphyraenidae	<i>Sphyraena tome</i> ^J	<0.1				<0.1	1	54	MS
Sciaenidae	<i>Larimus breviceps</i> ^J				<0.1	<0.1	1	14	MED
Synodontidae	<i>Synodus foetens</i> ^J		<0.1			<0.1	1	67	MEO
Species number		31	35	52	48				
Individual number		3592	4335	13230	8456				
Total biomass		12,298	8,512	13,361	24,340				

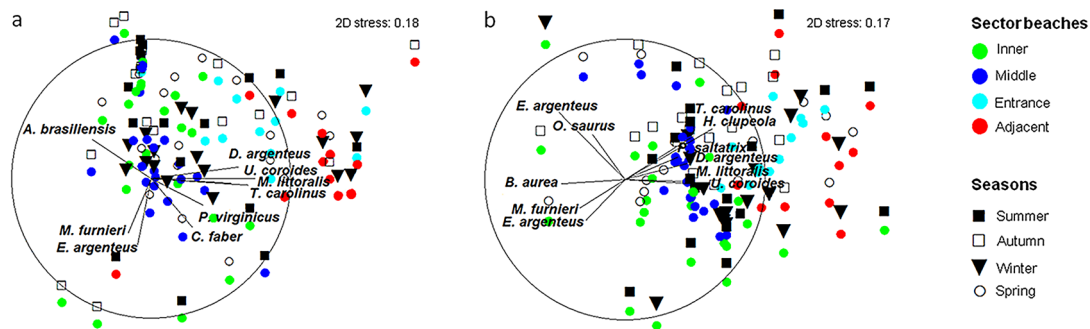
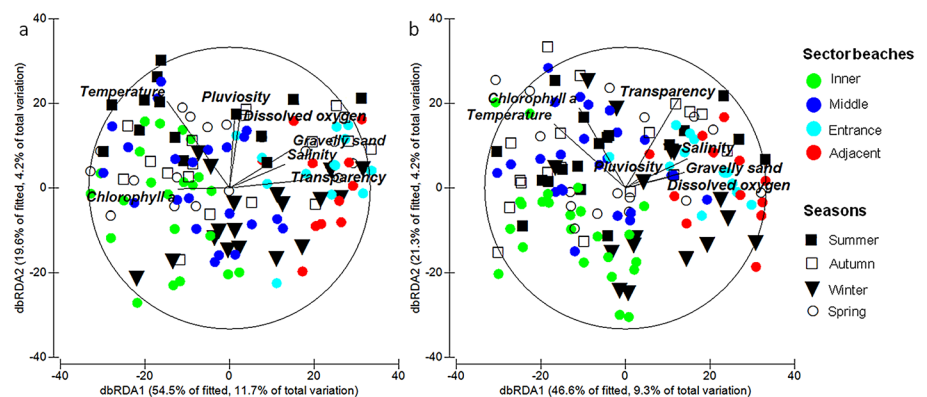
TL total length (mm), %IRI Index of Relative Importance, J juvenile, A adult, n.a. not available, FS Freshwater Straggler, FEO Freshwater Estuarine Opportunist, SE Solely Estuarine, MED Marine Estuarine Dependent, MEO Marine Estuarine Opportunist, MS Marine Straggler, bold highest %IRI in each sector beach, italic species with the highest values of total %IRI

Table 3 Mean (and *SD*) of abundance, species richness and biomass among sector beaches and seasons comparisons according PERMANOVA in two annual cycles in Guanabara Bay

Sector beaches	Y1				Y2			
	Adjacent	Entrance	Middle	Inner	Adjacent	Entrance	Middle	Inner
Abundance	72.3 (16.8) ^a	55.3 (21.1) ^a	85.8 (18.7) ^a	77.5 (23.4) ^a	39.1 (19.1) ^d	76.0 (29.2) ^c	163.0 (33.2) ^a	124 (34.5) ^b
Species richness	3.5 (0.3) ^a	3.6 (0.3) ^a	3.6 (0.3) ^a	2.3 (0.3) ^b	3.5 (0.3) ^a	3.7 (0.3) ^a	3.9(0.3) ^a	4.0 (0.5) ^a
Biomass	73.7 (21.0) ^a	81.0 (19.9) ^a	74.4 (12.6) ^a	34.7 (9.9) ^a	289.9 (64.5) ^a	124.1 (22.1) ^b	181.5 (36.0) ^b	70.0 (13.0) ^c

Seasons	Y1				Y2			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Abundance	139.7 (24.6) ^a	93.0 (19.9) ^a	21.3 (5.8) ^b	17.9 (5.9) ^b	32.9 (14.6) ^c	195 (44.8) ^a	99.6 (27.0) ^b	96.0 (24.2) ^b
Species richness	3.8 (0.3) ^a	4.1 (0.3) ^a	2.9 (0.3) ^b	2.4 (0.3) ^b	2.5 (0.2) ^c	4.1 (0.3) ^b	3.8 (0.4) ^b	4.9 (0.4) ^a
Biomass	69.1 (12.6) ^a	98.8 (25.2) ^a	51.0 (10.7) ^a	47.2 (9.6) ^a	81.8 (18.7) ^a	273.8 (127.5) ^a	135.3 (40.4) ^a	148.6 (33.9) ^a

Values having the same superscript letter were not significantly different within each sector beach and seasons

**Fig. 3** Results of the ordination (nMDS) analysis applied to fish species (abundance data) sampled in four sector beaches of Guanabara Bay. **a** Y1, **b** Y2. Vector of the species that presented Spearman correlations above 0.40**Fig. 4** Diagrams of the first two axes of the dbRDA between sector beaches and seasons, demonstrating the relationship between beaches *versus* fish assemblages in Guanabara Bay. **a** Y1, **b** Y2

seasonal dynamic of juvenile fishes in shallow waters. For instance, Oliveira et al. (2016) observed that the inner bay presents high primary productivity which may influence abundance and recruitment. On the other hand, coastal waters that predominate in the adjacent and entrance sectors may be more dependent on marine productivity,

seasonally affected by upwelling near Guanabara Bay (Quintana et al. 2015; Santos et al. 2019).

The fish responses to environmental variables showed differences between sectors, confirmed by ordination that separated fish guilds by habitat affinity. Adjacent and entrance sector beaches included a typical assemblage of marine

species, whereas middle and inner sectors showed the predominance of an estuarine fish fauna. This pattern reflects the changing character of shallow-water habitats along the natural estuarine gradient. This same pattern of partition between guilds was also observed in other bays, including Sepetiba Bay in southeastern Brazil (Araújo et al. 2016), Babitonga Bay (Vilar et al. 2011) and Paranaguá Estuarine Complex, both in southern Brazil (Félix et al. 2007; Passos et al. 2012).

In general, the presence of distinct guilds represented by species with distinct patterns of habitat use between sectors was observed. The fish assemblage of the outer sectors included marine-associated guilds that use estuarine waters sporadically (e.g., *Diplodus argenteus*, *Umbrina coroides* and *Menticirrhus littoralis*), whereas estuarine related species (e.g., *Atherinella brasiliensis* and *Eucinostomus argenteus*) predominated within inner sectors of the bay. Ubiquitous solely estuarine *A. brasiliensis* occurred in all sites, but decreased in abundance from the inner towards the adjacent sectors. Species guilds normally show an intimate correlation with hydrodynamic and physicochemical characteristics of the water (Arceo-Carranza and Vega-Cendejas 2009; Telesh and Khlebovich 2010), and habitat availability and complexity (Borland et al. 2017).

Transparency, temperature and chlorophyll *a* were the parameters that varied most between the two main sector beaches of the bay, contributing to changes in fish assemblages at Guanabara Bay. Variations in water transparency are predictable in estuarine areas, being associated with variations in tides and contributions from continental drainage (Araújo et al. 2016; Camara et al. 2020; Lima et al. 2020). Paranhos et al. (1998) found that the influence of the tidal pulse is twice as strong as the influence of the rainy/dry seasons, in addition to modifying parameters such as salinity, nutrients, chlorophyll *a* and concentration of fecal coliforms. The central channel of the bay allows intrusion of marine water bodies causing frequent changes in temperature between the sectors of bay which functions as a partially mixed estuary during the dry season (September) and as a salt wedge estuary in the rainy season (March) (Castro et al. 2005).

Temporal changes in fish assemblages indicated differences in the abundance of some species, which may be associated with reproductive pulses, since most individuals were young of the year or early juveniles. Some authors have reported that summer changes in abundance are associated with recruitment pulses (Pessanha and Araújo 2003; Nanami and Endo 2007). Lasiak (1984) observed that the general seasonal pattern in fish assemblages in shallow waters is the decline in number of individuals and species during the winter, and peak abundance in the spring/summer. Pessanha and Araújo (2003) observed a similar pattern for Sepetiba Bay whose influence of temperature favored the recruitment

of the most abundant species during the summer and winter. The results of the present study in Guanabara Bay partially agree with the registered general patterns reported in the literature, in which abundance peaks occurred around the spring season in both years. However, uncontrolled climatic and oceanographic variations occurring from year to year may cause changes in reproductive seasons, causing shifts in the abundance of particular species influencing the assemblage structure.

The majority of the individuals collected in this study were either juveniles using the shallow waters as a nursery and growth area, or some transient species that are much more common in other marine habitats. The most abundant species are common in the sheltered beaches and shallow surf-zones during the warmer months of the year. These patterns are corroborated by various authors that registered different guilds influenced simultaneously by environmental filters and species dispersal capacity (Vilar et al. 2011; Araújo et al. 2016; Franco et al. 2016; Lima et al. 2020). However, the effects of environmental factors should vary according to each estuary-specific physical and hydrological characteristic (Araújo et al. 2018).

The results generated indicate that, despite the dynamic character of shallow sandy beach environments, the differences in the composition and structure of the fish assemblages in Guanabara Bay are mainly related to an estuarine-marine gradient. This pattern reflects the changing character of habitats along the estuary allowing many fish species to use the shallow waters of the beaches in transitory or permanent ways, following their ecological tolerances and habitat requirements (Layman 2000; Vilar et al. 2011; Araújo et al. 2016; Litvin et al. 2018). Overall, temporal fluctuations demonstrated a clear pattern that may be linked to the use of habitat in some particular stages of fish species life cycles or it may be a response of the food resource partitioning, or even be linked to protection against predators, which significantly influence the spatial organization (Pereira et al. 2015; Da Silva et al. 2018). Finally, our results demonstrated that beaches function as nursery grounds for many species, including some commercially exploited species (*Trachinotus carolinus*, *Harengula clupeiola*, *Micropogonias furnieri*, *Brevoortia aurea*, *Sardinella brasiliensis*, *Caranx latius* and *M. littoralis*). Thus, it is necessary to expand knowledge about species *versus* environment relations to implement conservation strategies for this ecosystem inserted in one of the largest metropolitan areas in the world, displaying a high degree of anthropogenic impacts.

Acknowledgements We would like to thank the friends and volunteers who helped us during the fieldwork and at the laboratory. The first author was financially supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) with a post-graduate scholarship. Cassiano Monteiro-Neto holds a Research Productivity fellowship from CNPq.

References

- Amador ES (1997) Baía de Guanabara e ecossistemas periféricos: homem e natureza. Reproarte Gráfica e Editora Ltda, Rio de Janeiro
- Anderson MJ, Ellingsen KE, McArdle BH (2006) Multivariate dispersion as a measure of beta diversity. *Ecol Lett* 9:683–693
- Anderson MJ, Gorley RN, Clarke KR (2008) PERMANOVA+ for PRIMER. Guide to software and statistical methods. PRIMER-E Ltd, Plymouth, United Kingdom
- Araújo FG, Azevedo MCC, Silva MA, Pessanha ALM, Gomes ID, Cruz-Filho AG (2002) Environmental influences on the demersal fish assemblages in the Sepetiba Bay, Brazil. *Estuaries* 25:441–450
- Araújo FG, Azevedo MCC, Guedes APP (2016) Inter-decadal changes in fish communities of a tropical bay in southeastern Brazil. *Reg Stud Mar Sci* 3:107–118
- Araújo FG, Pinto SM, Neves LM, Azevedo MCC (2017) Inter-annual changes in fish communities of a tropical bay in southeastern Brazil: what can be inferred from anthropogenic activities? *Mar Pollut Bull* 114:102–113
- Araújo FG, Rodrigues FL, Teixeira-Neves TP, Vieira JP, Azevedo MC, Guedes APP, Garcia AM, Pessanha ALM (2018) Regional patterns in species richness and taxonomic diversity of the nearshore fish community in the Brazilian coast. *Estuar Coast Shelf Sci* 208:9–22
- Arceo-Carranza D, Vega-Cendejas ME (2009) Spatial and temporal characterization of fish assemblages in a tropical coastal system influenced by freshwater inputs: northwestern Yucatan peninsula. *Rev Biol Trop* 57:89–103
- Azevedo MCC, Araújo FG, Cruz-Filho AG, Pessanha ALM, Silva MA, Guedes APP (2007) Demersal fishes in a tropical bay in southeastern Brazil: partitioning the spatial, temporal and environmental components of ecological variation. *Estuar Coast Shelf Sci* 75:468–480
- Baptista Neto JA, Gingele FX, Leipe T, Brehme I (2006) Spatial distribution of heavy metals in surficial sediments from Guanabara Bay: Rio de Janeiro, Brazil. *Environ Geol* 49:1051–1063
- Barletta M, Blaber SJM (2007) Comparison of fish assemblages and guilds in tropical habitats of the Embury (Indo-West Pacific) and Caeté (Western Atlantic) estuaries. *Bull Mar Sci* 80:647–680
- Blaber SJM, Blaber TG (1980) Factors affecting the distribution of juvenile estuarine and inshore fish. *J Fish Biol* 17:143–162
- Borland HP, Schlacher TA, Gilby BL, Connolly RM, Yabsley NA, Olds AD (2017) Habitat type and beach exposure shape fish assemblages in the surf zones of ocean beaches. *Mar Ecol Prog Ser* 570:203–211
- Camara EM, de Andrade-Tubino MF, Franco TP, Araújo FG (2020) Multilevel decomposition of spatial and environmental effects on nearshore fish assemblages in tropical semi-enclosed ecosystems. *Estuar Coast Shelf Sci* 237:106691
- Castello JP, Krug LC (2015) Introdução às Ciências do Mar. Editora Textos, Pelotas
- Castro MS, Bonecker ACT, Valentin JL (2005) Seasonal variation in fish larvae at the entrance of Guanabara Bay, Brazil. *Braz Arch Biol Technol* 48:121–128
- Chaves MCNR, Franco ACS, Seixas LB, da Cruz LR, dos Santos LN (2018) Testing the ecocline concept for fish assemblages along the marine-estuarine gradient in a highly-eutrophic estuary (Guanabara Bay, Brazil). *Estuar Coast Shelf Sci* 211:118–126
- Chediek J (2014) Atlas do desenvolvimento humano nas regiões metropolitanas brasileira. PNUD, Brasília
- Clarke KR, Gorley RN (2006) Primer v6: user manual/tutorial. Primer-E, Plymouth, UK
- Cortés E (1998) A critical review of methods of studying fish feeding based on analysis of stomach contents: application to elasmobranch fishes. *Can J Fish Aquat Sci* 54:726–738
- Costa MRD, Tubino RA, Monteiro-Neto C (2018) Length-weight relationships of juvenile and adult fishes from shallow waters in the lower in the Guanabara Bay estuary, Brazil. *Acta Ichthyol Piscat* 48:199–204
- Da Silva VE, Teixeira EC, Batista VS, Fabré NN (2018) Spatial distribution of juvenile fish species in nursery grounds of a tropical coastal area of the south-western Atlantic. *Acta Ichthyol Piscat* 48:9–18
- Elliott M, Whitfield AK, Potter IC, Blaber SJM, Cyrus DP, Nordlie FG, Harrison TD (2007) The guild approach to categorizing estuarine fish assemblages: a global review. *Fish Fish* 8:241–268
- Félix FC, Spach HL, Moro PS, Schwarz R Jr, Santos C, Hackrad C, Hostim-Silva M (2007) Utilization patterns of surf zone inhabiting fish from beaches in Southern Brazil. *Panam J Aquat Sci* 2:27–39
- Figueiredo JL, Menezes NA (1978) Manual de peixes marinhos do sudeste do Brasil, II: Teleostei (1). Museu de Zoologia da Universidade de São Paulo, São Paulo
- Figueiredo JL, Menezes NA (1980) Manual de peixes marinhos do sudeste do Brasil, II. Teleostei (2). Museu de Zoologia da Universidade de São Paulo, São Paulo
- Figueiredo JL, Menezes NA (2000) Manual de peixes marinhos do sudeste do Brasil, II. Teleostei (5). Museu de Zoologia da Universidade de São Paulo, São Paulo
- Fistarol GO, Coutinho FH, Moreira APB, Venas T, Cánovas A, de Paula SEM, Coutinho R, de Moura RL, Valentin JL, Tenenbaum DR, Paranhos R, do Valle RAB, Vicente ACP, Amado Filho GM, Pereira RC, Kruger R, Rezende CE, Thompson CC, Salomon PS, Thompson FL (2015) Environmental and sanitary conditions of Guanabara Bay, Rio de Janeiro. *Front Microbiol* 6:12–32
- Franco ACS, Ramos Chaves MCN, Castel-Branco MPB, Neves Dos Santos L (2016) Responses of fish assemblages of sandy beaches to different anthropogenic and hydrodynamic influences. *J Fish Biol* 89:921–938
- Froese R, Pauly D (2019) FishBase. World Wide Web electronic publication. <http://www.fishbase.org>. Accessed 21 August 2019
- IUCN (2019) The IUCN Red List of Threatened Species. <http://www.iucnredlist.org>. Accessed 10 September 2019
- Kjerfve B, Ribeiro CHA, Dias GTM, Filippo AME, Quaresma VS (1997) Oceanographic characteristics of an impacted coastal bay: Baía de Guanabara, Rio de Janeiro, Brazil. *Cont Shelf Res* 17:1609–1643
- Lajud NA, Astarloa JMD, González-Castro M (2016) Reproduction of *Brevoortia aurea* (Spix & Agassiz, 1829) (Actinopterygii: Clupeidae) in the Mar Chiquita Coastal Lagoon, Buenos Aires, Argentina. *Neotrop Ichthyol* 14:e150064
- Lasiak TA (1984) Structural aspects of the surf-zone fish assemblage at King's beach, Algoa Bay, South Africa: long-term fluctuations. *Estuar Coast Shelf Sci* 18:459–483
- Layman CA (2000) Fish assemblage structure of the shallow ocean surf-zone on the eastern shore of Virginia Barrier Islands. *Estuar Coast Shelf Sci* 51:201–213
- Lima MSP, Vieira JP (2009) Variação espaço-temporal da ictiofauna da zona de arrebentação da Praia do Cassino, Rio Grande do Sul, Brasil. *Zoologia (Curitiba)* 26:499–510
- Lima CSS, Badú MLDAS, Pessanha ALM (2020) Response of estuarine fish assemblages to an atypical climatic event in northeastern Brazil. *Reg Stud Mar Sci* 35:101121
- Litvin SY, Weinstein MP, Sheaves M, Nagelkerken I (2018) What makes nearshore habitats nurseries for nekton? An emerging view of the nursery role hypothesis. *Estuaries Coast* 41:1539–1550
- Manderson JP, Phelan BA, Meise C, Stehlik LL, Bejda AJ, Pessutti J, Arlen L, Draxler A, Stoner AW (2002) Spatial dynamics of habitat suitability for the growth of newly settled winter flounder

- Pseudopleuronectes americanus* in an estuarine nursery. *Mar Ecol Prog Ser* 228:227–239
- Marin Jarrin JM, Vanaverbeke J, Fockede N, Cornejo R de Grunauer MP, Dominguez-Granda L (2017) Surf zone fauna of Ecuadorian sandy beaches: spatial and temporal patterns. *J Sea Res* 120:41–49
- Mayr LM, Tenenbaum DR, Villac MC, Paranhos R, Nogueira CR, Bonecker SLC, Bonecker ACT (1989) Hydrobiological characterization of Guanabara Bay. In: Magoon O, Neves C (eds) *Coastlines of Brazil*. American Society of Civil Engineers, New York, pp 124–138
- Menezes NA, Figueiredo JL (1980) Manual de peixes marinhos do sudeste do Brasil. IV. Teleostei (3). Museu de Zoologia da Universidade de São Paulo, São Paulo
- Menezes NA, Figueiredo JL (1985) Manual de peixes marinhos do sudeste do Brasil. V. Teleostei (4). Museu de Zoologia da Universidade de São Paulo, São Paulo
- Meniconi MFG, Silva TA, Foncesca ML, Lima SOF, Lima EFA, Lavrado HP, Figueiredo AG Jr (2012) Baía de Guanabara: Síntese do conhecimento ambiental. 1. Ambiente e influência antrópica. Petrobras, Rio de Janeiro
- Nanami A, Endo T (2007) Seasonal dynamics of fish assemblage structures in a surf zone on an exposed sandy beach in Japan. *Ichthyol Res* 54:277–286
- Oliveira EN, Fernandes AM, Kampel M, Cordeiro RC, Brandini N, Vinzon SB, Grassi, RM, Pinto FN, Fillipo AM, Paranhos R (2016) Assessment of remotely sensed chlorophyll-*a* concentration in Guanabara Bay, Brazil. *J Appl Remote Sens* 10:026003
- Paranhos R, Mayr LM (1993) Seasonal patterns of temperature and salinity in Guanabara Bay, Brazil. *Fresenius Environ Bull* 2:647–652
- Paranhos R, Pereira AP, Mayr LM (1998) Diel variability of water quality in a tropical polluted bay. *Environ Monit Assess* 50:131–141
- Passos AC, Contente RF, Araujo CCV, Daros FALM, Spach HL, Abilhô V, Fávoro LF (2012) Fishes of Paranaguá estuarine complex, south west Atlantic. *Biota Neotrop* 12:226–238
- Pereira HH, Neves LM, da Costa MR, Araújo FG (2015) Fish assemblage structure on sandy beaches with different anthropogenic influences and proximity of spawning grounds. *Mar Ecol* 36:16–27
- Pessanha AL, Araújo FG (2003) Spatial, temporal and diel variations of fish assemblages at two sandy beaches in the Sepetiba Bay, Rio de Janeiro, Brazil. *Estuar Coast Shelf Sci* 57:817–828
- Pinkas L (1971) Food habits study. In: Pinkas L, Oliphant MS, Iverson IL (eds) *Fish Bulletin* 152. Food habits of albacore, bluefin tuna, and bonito in California waters. State of California, the Resources Agency, Department of Fish and Game, Sacramento, pp 5–10
- Potter IC, Tweedley JR, Elliott M, Whitfield AK (2015) The ways in which fish use estuaries: a refinement and expansion of the guild approach. *Fish Fish* 16:230–239
- Quintana CO, Bernardino AF, de Moraes PC, Valdemarsen T, Sumida PY (2015) Effects of coastal upwelling on the structure of macrofaunal communities in SE Brazil. *J Mar Syst* 143:120–129
- Ribeiro CHA, Kjerfve B (2002) Anthropogenic influence on the water quality in Guanabara Bay, Rio de Janeiro, Brazil. *Reg Environ Change* 3:13–19
- Rishworth GM, Strydom NA, Potts W (2015) Fish utilization of surf-zones. Are they changing? A case study of the Sheltered, warm-temperate King's Beach. *Afr Zool* 49:5–21
- Santos EK, de Grande FR, Júnior TV (2019) Seasonal evaluation of the condition factor in a surf-zone assemblage from southeastern Brazil. *Bol Inst Pesca* 45:e453
- Selleslagh J, Amara R, Laffargue P, Lesourd S, Lepage M, Girardin M (2009) Fish composition and assemblage structure in three Eastern English Channel macrotidal estuaries: a comparison with other French estuaries. *Estuar Coast Shelf Sci* 81:149–159
- Silva DR Jr, Paranhos R, Vianna M (2016) Spatial patterns of distribution and the influence of seasonal and abiotic factors on demersal ichthyofauna in an estuarine tropical bay. *J Fish Biol* 89:821–846
- Soares-Gomes A, Da Gama BAP, Baptista Neto JA, Freire DG, Cordeiro RC, Machado W, Bernardes MC, Coutinho R, Thompson FL, Pereira RC (2016) An environmental overview of Guanabara Bay, Rio de Janeiro. *Reg Stud Mar Sci* 8:319–330
- Telesh IV, Khlebovich VV (2010) Principal processes within the estuarine salinity gradient: a review. *Mar Pollut Bull* 61:149–155
- Vilar CC, Spach HL, Joyeux JC (2011) Spatial and temporal changes in the fish assemblage of a subtropical estuary in Brazil: environmental effects. *J Mar Biol Assoc U K* 91:635–648
- Villac MC, Mayr LM, Tenenbaum DR, Paranhos R (1991) Sampling strategies proposed to monitor Guanabara Bay, RJ, Brazil. In: Magoon OT, Converse HV, Tippie V, Tobin LT, Clarck D (eds) *Coastal Zone'91*. American Society of Civil Engineers, New York, pp 1168–1182
- Whitfield AK, Patrick P (2015) Habitat type and nursery function for coastal marine fish species, with emphasis on the Eastern Cape region, South Africa. *Estuar Coast Shelf Sci* 160:49–59

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.