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Fish assemblage structure on sandy beaches with different anthropogenic influences and proximity of spawning grounds

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Keywords

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Abstract

Fish assemblages in an insular (preserved) and a continental (disturbed) sandy beach were compared to assess any changes that could be attributed to anthropogenic influences and/or the proximity of the fish spawning grounds. We expected that the closer geographical position to the spawning grounds and the small amount of anthropogenic disturbance on the insular beach would be likely to provide more suitable conditions for early fish development compared with the continental beach. A total of 192 samples (96 in each beach) were taken, yielding 68 fish species, mostly young-of-the-year. Fish assemblage structure differed significantly between the two beaches. Moreover, the insular beach had higher number of species, number of individuals and biomass compared with the continental beach. The commercially important Clupeiformes *Harengula clupeiola*, *Anchoa tricolor* and *Anchoa januaria*, Perciformes *Micropogonias furnieri* and Mugiliformes *Mugil liza* were typical species on the insular beach, partitioning the seasonal use of the beach. On the other hand, a few abundant non-commercial species, mainly the Atheriniformes *Atherinella brasiliensis* and the Perciformes *Eucinostomus argenteus* and *Diapterus rhombeus*, occurred all year round at the continental beach. The high fish richness and abundance and the more conspicuous species turnover across seasons on the insular beach are probable indications of more complex and dynamic organization of the communities favored by better geographical position and less anthropogenic disturbance in the area.

Introduction

Sandy beaches support diverse and abundant fish assemblages dominated by a small number of species made up largely of juveniles (Gibson *et al.* 1996; Wilber *et al.* 2003). Many of these beaches are considered important fish nurseries because they provide advantageous conditions for fish growth such as food and shelter. A large number of juvenile fishes utilize sandy beaches due to the presence of rich food resources such as components of zooplankton and benthic macrofauna, taking advantage of the protection from predation provided by the shallowness, turbidity and turbulence of these areas (Lasiak

1986; Clark *et al.* 1996; Pessanha *et al.* 2003; Vasconcellos *et al.* 2010).

The seasonal replacement of species in the shallow areas has been related to environmental variation, spawning time of species, and the time needed for their larval and juvenile stages to recruit into these areas (Maes *et al.* 2005). Moreover, the structure and composition of fish assemblages at sandy beaches are determined by natural and human processes. Coastal areas are particularly sensitive to regional environmental changes because they may be considered an ecotone where land and ocean interactions take place. Thus, they may suffer stresses from both on-site and land-based activities that affect the flow of

materials through the coastal zone (Molisani *et al.* 2006). On the other hand, protected beaches, especially those located on islands or far from disturbing human activities, are likely to have better conditions for fish assemblage use, since they are less likely to suffer impacts from anthropogenic influences. Generally species richness decreases with environmental degradation (Araújo *et al.* 2000; Whitfield & Elliott 2002).

In the last few decades, the continental margin of the Sepetiba Bay suffered an increasing degradation process due to industrial outflows and municipal effluents brought into the bay by rivers and drainage channels from the outskirts of Rio de Janeiro City (Araújo *et al.* 2002; Pessanha & Araújo 2003). On the other hand, some islands in the bay have better environmental conditions because of limited access, which has resulted in less impacted areas. Furthermore, these islands are closer to the reproductive grounds of many fish species that spawn in deeper areas of the inner continental shelf and bring their eggs and larvae to enclosed bay areas to develop during early life stages (Johannes 1978). This could constitute a more favored site for fish recruitment and fish early life cycle development.

We sampled the fish assemblage of an insular and a continental beach in the Sepetiba Bay, using a standardized fishing effort across four seasons. The aim was to describe and compare the composition and structure of the ichthyofauna and fish distribution on spatial and seasonal scales. We expected that the closer geographical position to spawning grounds and the smaller amount of anthropogenic disturbance on the insular beach would be likely to provide more suitable conditions for fish recruitment compared with the continental beach. Specifically, the following questions were posed, aiming to distinguish the suitability of the two sandy beaches for early development of the ichthyofauna: (i) Are there differences in fish

assemblage structure between the continental and insular beaches? (ii) Are there significant differences in assemblage richness, abundance and biomass between the two beaches? (iii) Is there any seasonal turnover for dominant species in each beach that could be related to anthropogenic changes?

Material and Methods

Study area

Sepetiba Bay ($22^{\circ}54'–23^{\circ}04' S$; $43^{\circ}34'–44^{\circ}10' W$) is a sedimentary embayment with an area of $\sim 450 \text{ km}^2$ on the coast of Rio de Janeiro State in Southeastern Brazil (Fig. 1). The bay has a long sandbank barrier in its southern end, which finishes at Marambaia Island. The island is 42 km^2 and has a sandy zone of around 40 km in length. This microtidal system has tide range of approximately 1 m and wave height of generally $<0.75 \text{ m}$. Predominant northeasterly and southwesterly winds activate thermal currents between the bay and the ocean. A clockwise circulation pattern promotes the permanent water exchange with the sea (Signorini 1980; Barcellos & Lacerda 1994; Copeland *et al.* 2003).

The two studied beaches (insular beach and continental beach) are located in the outer bay zone (Fig. 1) and are influenced by oceanic waters. The substrate is mainly sandy and the water has a comparatively lower temperature and higher salinity and transparency compared with the inner bay zone (Araújo *et al.* 2002). Several small towns and villages located near to the continental beach lack proper sewage treatment and drain untreated effluents to coastal areas nearby. The speed of the water currents is greater on the continental beach because this area lies between the mainland and the Itacuruçá Island in a narrow channel. A boatyard nearby is a likely source of

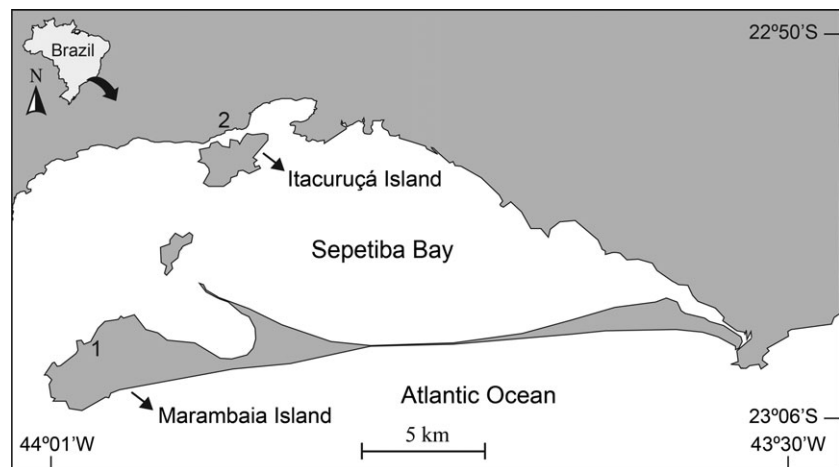


Fig. 1. Map of Sepetiba Bay, with indication of the two sampling areas: 1, insular beach; 2, continental beach.

organotin compounds, increasing pollution in the area (Quadros *et al.* 2009). The insular beach is located on Marambaia Island, a less impacted area because of restricted human use and its distance from urban and industrial sources of disturbance. Along the Marambaia Island coastline there is a tidal–mixing–front recirculation caused by the confluence of currents entering and leaving the bay (Signorini 1980).

Sampling design

Fish surveys were carried out in October 2004 (spring) and January (summer), April (autumn) and July 2005 (winter) in the two beaches. Hauls were carried out using a beach seine (10 × 2.5 m; stretch-mesh 7.5 mm) set parallel to the shoreline in waters <1.5 m deep, and then hauled straight to the shore, covering an area of approximately 240 m². After each haul, temperature, salinity and dissolved oxygen were measured with a Horiba W-21 immersed approximately 0.5 m under the water surface. Transparency, expressed as% of the water depth, was recorded using a Secchi disc and depth was measured with a meter. Eight sites were sampled in each beach, in four seasons with three replicates. This design resulted in a total of 192 samples (two beaches × eight sites × three replicates × four seasons). Fishes were fixed in 10% formalin, identified to species, counted, measured for total length (in millimeters) and weighed (in grams).

Data analysis

Environmental data were log₁₀(x + 1) transformed to meet assumptions of normality and homoscedasticity for statistical tests. Differences between beaches and seasons were examined by one-way analysis of variance (ANOVA, $P < 0.05$). This analysis was used to compare environmental variables among seasons for each beach and among beaches for each season. Where ANOVA showed a significant difference, an *a posteriori* Tukey's HSD test was used to determine which means were significantly different at the 0.05 level (Zar 1999).

Fish data were heteroscedastic and deviated from a normal distribution, and therefore a two-way non-parametric permutational multivariate analysis of variance (PERMANOVA; Anderson 2001) was used. PERMANOVA based on Euclidean distance and permutation of residuals under a reduced model was performed to compare the number of species, abundance and biomass between beaches (fixed) and seasons (fixed). Significant factors were followed by PERMANOVA pairwise comparison tests.

One-way analysis of similarity (ANOSIM; Clarke & Warwick 1994) was used to compare significant differences in the structure assemblages between the two

beaches and among seasons. Abundances were fourth-root transformed and then converted to triangular matrices of similarity using the Bray–Curtis similarity coefficient. The typical species responsible for similarity/dissimilarity among factors (beaches, seasons) were determined by the similarity percentages analysis (SIMPER; Clarke 1993). Non-metric multidimensional scaling (MDS) was used for ordination of the data, using sampling sites and seasons as factors. In this analysis, we averaged the three replications of each sampling site in a single value; this yielded 64 samples (2 beaches × 8 sites × 4 seasons). Multivariate analyses were performed with the software PRIMER version 6.02.

Results

Environmental variables

Although some significant differences in temperature, salinity and dissolved oxygen between the two beaches were found in some seasons, they were not consistent over time and had narrow range of variation (Table 1). However, seasonality was clear for these environmental variables. Temperature ranged from 20.5 to 29.0 °C, with the highest significant differences between autumn (means = 26.0–27.1 °C) and winter (22.5–23.1 °C) for both beaches. Salinity ranged from 23.7 to 35.2 psu, with the highest mean values found in spring (33.2–34.3 psu) and lowest in winter (27.3–30.4 psu). Dissolved oxygen ranged from 4.2 to 9.0 mg·l⁻¹ with the highest significant values found in summer (7.8–8.2 mg·l⁻¹) and the lowest in autumn (5.2–6.0 mg·l⁻¹) for the two beaches.

Transparency ranged from 33.3% to 100% of depth and was significantly different between the two beaches in summer and winter. Significantly higher values were found in autumn (mean = 87.1–96.2%) and winter (mean = 76.1–97.9%), and lower in spring (mean = 52.1–63.6%) and summer (mean = 44.2–67.5%) for both beaches. Depth ranged from 0.4 to 1.5 with significant differences between the two beaches during all seasons except summer. Significantly higher values were found in spring (1.16–1.47 m) and summer (1.19–1.30 m), and lower values in autumn (0.65–1.04 m) and winter (0.63–0.96.8 m) for the two beaches.

Fish composition

A total of 44 778 individuals weighing 34 623.76 g and comprising 68 species and 26 families was recorded (Table 2) in the 192 beach-seine hauls (96 on the insular and 96 on the continental beach). There were 8985 individuals recorded on the continental beach, weighing a total of 15 756.62 g and comprising 37 species (eight

Table 1. Mean \pm standard error of environmental variables on the continental and insular beach by seasons.

| Variable/Beaches | Spring | Summer | Autumn | Winter |
|--|---------------------|---------------------|---------------------|---------------------|
| Temperature (°C) | | | | |
| Continental | 24.8 \pm 0.15 C a | 25.4 \pm 0.19 B a | 26.0 \pm 0.07 A b | 22.5 \pm 0.06 D a |
| Insular | 23.1 \pm 0.07 C a | 25.3 \pm 0.19 B a | 27.1 \pm 0.21 A a | 23.1 \pm 0.28 C a |
| Salinity (psu) | | | | |
| Continental | 33.2 \pm 0.02 A b | 30.1 \pm 0.28 C b | 32.3 \pm 0.09 B a | 30.4 \pm 0.06 D a |
| Insular | 34.3 \pm 0.09 A a | 33.6 \pm 0.20 B a | 31.2 \pm 0.15 C b | 27.3 \pm 0.22 D b |
| Dissolved oxygen (mg·l ⁻¹) | | | | |
| Continental | 7.5 \pm 0.10 B a | 8.2 \pm 0.12 A a | 5.2 \pm 0.08 D b | 6.7 \pm 0.07 C a |
| Insular | 6.4 \pm 0.09 B b | 7.8 \pm 0.08 A b | 6.0 \pm 0.29 C a | 6.5 \pm 0.13 B a |
| Transparency (% depth) | | | | |
| Continental | 63.6 \pm 4.12 B a | 67.5 \pm 4.10 B a | 96.2 \pm 2.16 A a | 97.9 \pm 1.47 A a |
| Insular | 52.1 \pm 5.16 B a | 44.2 \pm 0.83 B b | 87.1 \pm 3.92 A a | 76.1 \pm 4.73 A b |
| Depth (m) | | | | |
| Continental | 1.47 \pm 0.03 A a | 1.30 \pm 0.07 A a | 1.04 \pm 0.07 B a | 0.96 \pm 0.03 B a |
| Insular | 1.16 \pm 0.07 A b | 1.19 \pm 0.04 A a | 0.65 \pm 0.03 B b | 0.63 \pm 0.03 B b |

Capital letters indicate significant equality/differences ($P < 0.05$) among seasons for each beach. Small letters indicate significant equality/differences ($P < 0.05$) between beaches in each season.

exclusives). The respective numbers for the insular beach were 35 793 individuals, 18 867.14 g weight and 60 species (31 recorded only on the insular beach). Fish catches were dominated by juveniles, especially young-of-the-year for most species. Individuals showed a wide range of sizes (3–672 mm total length, TL), consisting of post larval to adult stages. Nevertheless, the majority of fish collected were smaller than 100 mm TL, most of them being recorded on the insular beach.

The most numerous fish species on the continental beach were Gerreidae [*Diapterus rhombeus* (23.7% of the total number of fishes) and *Eucinostomus argenteus* (38.9%)], Atherinopsidae [*Atherinella brasiliensis* (23.9%)], and Engraulidae [*Anchoa januaria* (2.6%) and *Anchoa tricolor* (2.2%)], whereas on the insular beach these were Clupeidae [*Harengula clupeiola* (28.6%), *Sardinella brasiliensis* (12.4%) and *Brevoortia aurea* (11.7%)], Engraulidae [*A. januaria* (17.4%), *A. tricolor* (5.1%) and *Cetengraulis edentulus* (1.4%)], Sciaenidae [*Micropogonias furnieri* (4.9%), *Larimus breviceps* (1.6%)], Mugilidae [*Mugil liza* (9.0%)], Gerreidae [*D. rhombeus* (1.6%)] and Atherinopsidae (*A. brasiliensis* (1.2%)).

The number of species (Pseudo-F = 154.89), fish abundance (Pseudo-F = 109.37) and the biomass (Pseudo-F = 12.943) were higher on the insular beach than on the continental beach (PERMANOVA, $p_{\text{perm}} = 0.001$). However, there was a significant interaction between beach and season (PERMANOVA, $p_{\text{perm}} = 0.001$). Therefore, pairwise PERMANOVA multiple comparisons were used to compare the seasons within each beach. In the insular beach, only the number of species changed seasonally, being higher in autumn and winter compared with spring and summer ($P < 0.01$). In the continental beach, the

number of species, number of individuals, and biomass differed among seasons ($P < 0.001$), being higher in summer and autumn compared with winter and spring (Fig. 2).

Fish assemblage structure

Fish assemblages differed significantly ($R = 0.818$, $P < 0.001$) between the two beaches according to ANOSIM. Species composition on the insular beach was significantly different from that on the continental beach (78.05% average dissimilarity), largely due to greater abundance of *Anchoa januaria*, *Harengula clupeiola*, *Micropogonias furnieri*, *Mugil liza* and *Anchoa tricolor* on the insular beach, and *Eucinostomus argenteus* on the continental beach. The MDS ordination showed a clear separation between the continental and the insular beach samples. The wide scattering within the grouping comprising the continental beach samples on the right side of the diagram and high stress (0.16) in the nMDS plot indicated highly variable assemblages in this beach. In contrast, the insular beach samples were clustered together on the left side of the diagram, indicating less within-group variability (Fig. 3).

ANOSIM showed that significant differences in the assemblage structure occurred among seasons (Table 3) on the continental beach ($R = 0.508$, $P < 0.001$) and on the insular beach ($R = 0.684$, $P < 0.001$). SIMPER analysis revealed the species that most contributed to the similarity in each season. In the continent, *A. brasiliensis* and *E. argenteus* were dominant throughout the year, and *D. rhombeus* also contributed greatly to the similarity in spring, summer and autumn (Table 4). In the insular

Table 2. Total abundance (number and% n), weight (in g and% W), frequency of occurrence (FO) and range of total length (TL, mm) of fish species in the continental and insular beaches.

| Families/species | Continental beach | | | Insular beach | | | TL (min–max) |
|----------------------------------|-------------------|---------------|------|---------------|---------------|------|--------------|
| | n (%) | W (%) | FO | n (%) | W (%) | FO | |
| Dasyatidae | | | | | | | |
| <i>Dasyatis guttata</i> | – | – | – | 1 (<0.1) | 380.6 (2.0) | 1.0 | 672 |
| Elopidae | | | | | | | |
| <i>Elops saurus</i> | – | – | – | 14 (<0.1) | 250.3 (1.3) | 10.4 | 27–325 |
| Ophichthidae | | | | | | | |
| <i>Ophichthus gomesii</i> | 4 (<0.1) | 49.2 (0.3) | 3.1 | – | – | – | 51–195 |
| Clupeidae | | | | | | | |
| <i>Harengula clupeola</i> | 62 (0.7) | 481.2 (3.1) | 14.6 | 10,242 (28.6) | 2984.7 (15.8) | 58.3 | 16–163 |
| <i>Sardinella brasiliensis</i> | 5 (0.1) | 0.8 (<0.1) | 1.0 | 4456 (12.4) | 1221.7 (6.5) | 27.1 | 20–63 |
| <i>Brevoortia aurea</i> | – | – | – | 4182 (11.7) | 786.9 (4.2) | 12.5 | 20–59 |
| Engraulidae | | | | | | | |
| <i>Cetengraulis edentulus</i> | – | – | – | 519 (1.4) | 148.5 (0.8) | 14.6 | 21–77 |
| <i>Anchoa januaria</i> | 232 (2.6) | 300.7 (1.9) | 31.2 | 6220 (17.4) | 2267.4 (12.0) | 79.2 | 10–80 |
| <i>Anchoa tricolor</i> | 203 (2.2) | 653.5 (4.1) | 18.7 | 1811 (5.1) | 1103.1 (5.8) | 75.0 | 10–113 |
| <i>Anchoa lyolepis</i> | – | – | – | 5 (<0.1) | 1.7 (<0.1) | 2.1 | 37–46 |
| Ariidae | | | | | | | |
| <i>Genidens genidens</i> | – | – | – | 16 (<0.1) | 1696.1 (9.0) | 8.3 | 163–288 |
| Synodontidae | | | | | | | |
| <i>Synodus foetens</i> | 11 (0.1) | 37.9 (0.2) | 9.4 | 5 (<0.1) | 21.8 (0.1) | 4.2 | 45–115 |
| Exocoetidae | | | | | | | |
| <i>Hemiramphus brasiliensis</i> | 1 (<0.1) | 23.8 (0.1) | 1.0 | 5 (<0.1) | 29.0 (0.1) | 3.1 | 152–212 |
| <i>Hyporhamphus unifasciatus</i> | 2 (<0.1) | 7.4 (<0.1) | 2.1 | 7 (<0.1) | 26.6 (0.1) | 5.2 | 76–155 |
| Belonidae | | | | | | | |
| <i>Strongylura marina</i> | 16 (0.2) | 365.5 (2.3) | 9.4 | 7 (<0.1) | 182.7 (1.0) | 6.2 | 80–475 |
| <i>Strongylura timucu</i> | 4 (<0.1) | 35.5 (0.2) | 3.1 | 12 (<0.1) | 4.4 (<0.1) | 8.3 | 34–274 |
| Atherinopsidae | | | | | | | |
| <i>Atherinella brasiliensis</i> | 2147 (23.9) | 8451.7 (53.6) | 80.2 | 419 (1.2) | 567.5 (3.0) | 49.0 | 12–139 |
| Syngnathidae | | | | | | | |
| <i>Syngnathus elucens</i> | 2 (<0.1) | 0.5 (<0.1) | 2.1 | 44 (0.1) | 7.7 (<0.1) | 21.9 | 45–130 |
| <i>Syngnathus folletti</i> | – | – | – | 12 (<0.1) | 5.5 (<0.1) | 4.2 | 45–57 |
| <i>Oostethus lineatus</i> | – | – | – | 1 (<0.1) | 0.1 (<0.1) | 1.0 | 88 |
| Triglidae | | | | | | | |
| <i>Prionotus punctatus</i> | 2 (<0.1) | 10.9 (0.1) | 2.1 | 3 (<0.1) | 27.9 (0.1) | 3.1 | 45–103 |
| Centropomidae | | | | | | | |
| <i>Centropomus undecimalis</i> | – | – | – | 2 (<0.1) | 2.6 (<0.1) | 2.0 | 52–55 |
| Serranidae | | | | | | | |
| <i>Diplectrum radiale</i> | 1 (<0.1) | 0.7 (<0.1) | 1.0 | 1 (<0.1) | 11.6 (<0.1) | 1.0 | 43–107 |
| Carangidae | | | | | | | |
| <i>Caranx bartholomaei</i> | 1 (<0.1) | 0.5 (<0.1) | 1.0 | – | – | – | 36 |
| <i>Oligoplites saliens</i> | – | – | – | 75 (0.2) | 17.8 (0.1) | 14.6 | 8–43 |
| <i>Oligoplites saurus</i> | 30 (0.3) | 27.9 (0.2) | 13.5 | 230 (0.6) | 83.3 (0.4) | 26.0 | 20–128 |
| <i>Selene vomer</i> | – | – | – | 3 (<0.1) | 5.2 (<0.1) | 3.1 | 50–56 |
| <i>Trachinotus carolinus</i> | – | – | – | 22 (0.1) | 9.3 (<0.1) | 14.6 | 10–41 |
| <i>Trachinotus falcatus</i> | 1 (<0.1) | 0.4 (<0.1) | 1.0 | 43 (0.1) | 16.9 (<0.1) | 11.4 | 12–45 |
| Gerreidae | | | | | | | |
| <i>Eucinostomus melanopterus</i> | 22 (0.2) | 23.0 (0.1) | 9.4 | – | – | – | 29–116 |
| <i>Eucinostomus gula</i> | 367 (4.1) | 525.9 (3.3) | 31.2 | 8 (<0.1) | 9.9 (<0.1) | 4.2 | 12–115 |
| <i>Eucinostomus argenteus</i> | 3500 (38.9) | 2617.3 (16.6) | 70.8 | 205 (0.6) | 41.0 (0.2) | 22.9 | 7–119 |
| <i>Diapterus rhombeus</i> | 2125 (23.7) | 1508.6 (9.6) | 51.0 | 568 (1.6) | 160.2 (0.8) | 55.2 | 6–106 |
| <i>Diapterus olisthostomus</i> | 1 (<0.1) | 3.2 (<0.1) | 1.0 | – | – | – | 13 |
| Haemulidae | | | | | | | |
| <i>Pomadasys corvinaeformis</i> | – | – | – | 10 (<0.1) | 7.1 (<0.1) | 6.2 | 22–60 |

Table 2. Continued

| Families/species | Continental beach | | | Insular beach | | | TL (min–max) |
|-----------------------------------|-------------------|-------------|------|---------------|---------------|------|-----------------|
| | n (%) | W (%) | FO | n (%) | W (%) | FO | |
| Sciaenidae | | | | | | | |
| <i>Menticirrhus americanus</i> | – | – | – | 189 (0.5) | 497.1 (2.6) | 43.7 | 20–205 |
| <i>Menticirrhus littoralis</i> | – | – | – | 187 (0.5) | 385.4 (2.0) | 37.5 | 6–155 |
| <i>Umbrina canosai</i> | – | – | – | 10 (<0.1) | 7.3 (<0.1) | 1.0 | 23–70 |
| <i>Paralonchurus brasiliensis</i> | – | – | – | 2 (<0.1) | 0.7 (<0.1) | 2.0 | 31–33 |
| <i>Micropogonias furnieri</i> | 9 (0.1) | 2.5 (<0.1) | 2.1 | 1755 (4.9) | 1053.4 (5.6) | 87.5 | 3–195 |
| <i>Pogonias cromis</i> | – | – | – | 9 (<0.1) | 1.5 (<0.1) | 3.1 | 35–60 |
| <i>Larimus breviceps</i> | – | – | – | 574 (1.6) | 493.7 (2.6) | 38.5 | 12–90 |
| <i>Isopisthus parvipinnis</i> | – | – | – | 2 (<0.1) | 78.0 (0.4) | 1.0 | 28–195 |
| <i>Cynoscion leiarchus</i> | – | – | – | 21 (0.1) | 25.1 (0.1) | 13.5 | 18–55 |
| <i>Cynoscion acoupa</i> | – | – | – | 1 (<0.1) | 0.9 (<0.1) | 1.0 | 31 |
| <i>Cynoscion jamaicensis</i> | – | – | – | 14 (<0.1) | 39.1 (0.2) | 4.2 | 21–53 |
| <i>Stellifer rastrifer</i> | – | – | – | 12 (<0.1) | 58.8 (0.3) | 5.2 | 15–35 |
| <i>Stellifer brasiliensis</i> | – | – | – | 3 (<0.1) | 0.3 (<0.1) | 1.0 | 30–33 |
| Ephippidae | | | | | | | |
| <i>Chaetodipterus faber</i> | 7 (0.1) | 2.9 (<0.1) | 6.2 | 65 (0.2) | 81.3 (0.4) | 28.1 | 12–65 |
| Mugilidae | | | | | | | |
| <i>Mugil curema</i> | – | – | – | 265 (0.7) | 286.8 (1.5) | 12.5 | 21–128 |
| <i>Mugil gaimardianus</i> | – | – | – | 221 (0.6) | 226.8 (1.2) | 13.5 | 23–75 |
| <i>Mugil liza</i> | 10 (0.1) | 71.0 (0.5) | 7.3 | 3230 (9.0) | 2787.5 (14.8) | 72.9 | 15–180 |
| Uranoscopidae | | | | | | | |
| <i>Astroscopus ygraecum</i> | 1 (<0.1) | 7.9 (<0.1) | 1.0 | – | – | – | 81 |
| Gobiidae | | | | | | | |
| <i>Gobionellus boleosoma</i> | 40 (0.4) | 27.5 (0.2) | 16.7 | 17 (<0.1) | 5.5 (<0.1) | 12.5 | 24–100 |
| <i>Gobionellus oceanicus</i> | 1 (<0.1) | 0.6 (<0.1) | 1.0 | 8 (<0.1) | 3.4 (<0.1) | 6.2 | 40–51 |
| <i>Gobionellus stigmaticus</i> | – | – | – | 1 (<0.1) | 0.6 (<0.1) | 1.0 | 46 |
| <i>Microgobius meeki</i> | 1 (<0.1) | 0.2 (<0.1) | 1.0 | – | – | – | 37 |
| Paralichthyidae | | | | | | | |
| <i>Citharichthys arenaceus</i> | 12 (0.1) | 59.7 (0.4) | 6.2 | 5 (<0.1) | 69.1 (0.4) | 4.2 | 37–155 |
| <i>Citharichthys macrops</i> | 1 (<0.1) | 0.4 (<0.1) | 1.0 | – | – | – | 44 |
| <i>Citharichthys spilopterus</i> | – | – | – | 2 (<0.1) | 3.3 (<0.1) | 1.0 | 53–66 |
| <i>Etropus crossotus</i> | – | – | – | 3 (<0.1) | 10.4 (<0.1) | 2.1 | 27–30 |
| <i>Paralichthys orbignyanus</i> | – | – | – | 1 (<0.1) | 257.6 (1.4) | 1.0 | 51 |
| Achiridae | | | | | | | |
| <i>Achirus lineatus</i> | 27 (0.3) | 30.7 (0.2) | 17.7 | 4 (<0.1) | 3.9 (<0.1) | 3.1 | 19–60 |
| Monacanthidae | | | | | | | |
| <i>Monacanthus ciliatus</i> | 15 (0.2) | 9.6 (0.1) | 12.5 | 3 (<0.1) | 0.8 (<0.1) | 3.1 | 10–41 |
| Tetraodontidae | | | | | | | |
| <i>Lagocephalus lagocephalus</i> | 1 (<0.1) | 2.3 (<0.1) | 1.0 | – | – | – | 51 |
| <i>Sphoeroides greeleyi</i> | 19 (0.2) | 183.2 (1.2) | 10.4 | 22 (0.1) | 253.8 (1.3) | 11.4 | 11–124 |
| <i>Sphoeroides spengleri</i> | 27 (0.3) | 77.1 (0.5) | 7.3 | 5 (<0.1) | 106.0 (0.6) | 4.2 | 17–140 |
| <i>Sphoeroides testudineus</i> | 75 (0.8) | 154.9 (1.0) | 23.9 | 14 (<0.1) | 49.9(0.3) | 11.4 | 10–67 |

beach, four species were typical in spring (*H. clupeiola*, *A. tricolor*, *M. furnieri* and *A. brasiliensis*) and four in summer (*A. januaria*, *A. tricolor*, *M. liza* and *M. furnieri*). Autumn had two typical species (*A. januaria* and *M. furnieri*) and winter four species (*A. januaria*, *M. liza*, *H. clupeiola* and *M. furnieri*).

Discussion

A remarkable difference in assemblage structure was found between the insular and the continental beaches,

with the former having higher fish richness, abundance and biomass compared with the latter. These findings suggest that the insular beach, closer to the marine zone, provides a more accessible area as a transitional habitat for juvenile fish recruiting into the bay compared with the continental beach, which is on a narrow channel. Moreover, the composition of species of the insular beach was dominated by Clupeidae, Engraulidae, Sciaenidae and Mugilidae families, suggesting that this area is an important rearing ground for commercial fish species of high economic value, compared with the continental beach,

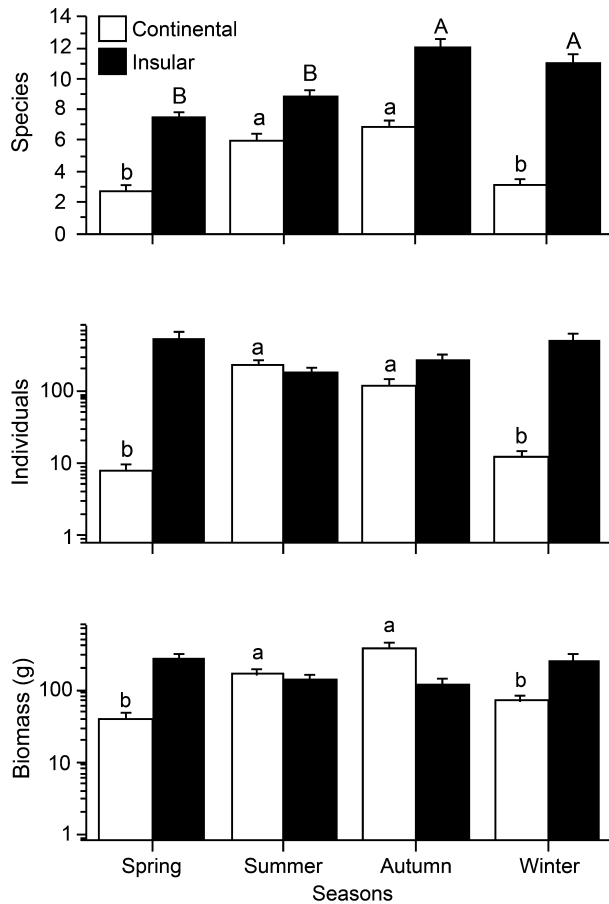


Fig. 2. Means (and standard error, vertical lines) for the number of species, number of individuals and biomass by season on the continental and insular beaches. Capital letters indicate significant equality/differences ($P < 0.01$) among seasons on the insular beach. Small letters indicate significant equality/differences ($P < 0.01$) among seasons on the continental beach (pairwise tests, PERMANOVA).

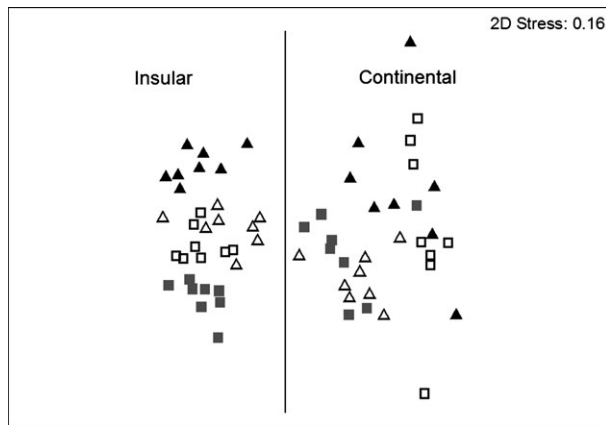


Fig. 3. MDS ordination from species abundance of fish assemblages in the continental and insular beaches. Spring, black triangle; Summer, white triangle; Autumn, gray square; Winter, white square.

Table 3. Results of ANOSIM tests for pairwise comparisons among seasons in the continental and insular beaches.

| Seasonal comparisons | Continental beach ($R = 0.508$) | | Insular beach ($R = 684$) | |
|----------------------|--------------------------------------|---------|--------------------------------|---------|
| | R-statistic | P-value | R-statistic | P-value |
| Spring–Summer | 0.584 | < 0.001 | 0.587 | < 0.001 |
| Spring–Autumn | 0.425 | 0.007 | 0.919 | < 0.001 |
| Spring–Winter | 0.263 | 0.002 | 0.779 | < 0.001 |
| Summer–Autumn | 0.317 | < 0.001 | 0.583 | < 0.001 |
| Summer–Winter | 0.833 | < 0.001 | 0.691 | < 0.001 |
| Autumn–Winter | 0.66 | < 0.001 | 0.689 | < 0.001 |

which has a high proportion of non-commercial fishes, e.g. those of the Atherinopsidae and Gerreidae families. Fish assemblages in several sandy beaches of the Sepetiba Bay have been studied, especially those located along the continental margin (e.g. Araújo *et al.* 1997; Pessanha & Araújo 2003; Pessanha *et al.* 2003), estuarine areas (Gomes & Araújo 2004) and mangrove channels (Neves *et al.* 2006) but none of those beaches seems to have a better potential as rearing grounds for juvenile fish than this insular beach on Marambaia Island. These findings reinforce the expectation that although sandy beaches are homogeneous habitats, their position in coastal systems and human influence can play an important role in fish assemblage structure. The number of recorded species on the insular beach (60), the abundance (200–400 individuals \times 240 m^{-2}) and the biomass (7–12 g \times 240 m^{-2}) are well above those recorded in previous studies for other beaches in Sepetiba Bay. The restricted human use of the Marambaia Island and its distance far from the industrial development of the continental margin must play an important role in its highly favorable conditions for fish occurrence. Moreover, its relative closer proximity to fish spawning grounds (Johannes 1978; Araújo *et al.* 2002; Costa & Araújo 2002; Albieri & Araújo 2010) compared with the continental beach is another factor that may contribute to the comparatively higher fish richness and abundance on the insular beach. Despite this evidence, we should bear in mind that we did not measure directly anthropogenic influences or proximity from spawning grounds, and that other unmeasured factors (e.g. biotic interactions, coastal currents, physical habitat characteristics) could be influencing the findings concerning the patterns of fish distribution.

Fish larval dispersion and retention are determined primarily by coastal currents and the location of the adult spawning populations. Tidal-mixing-front recirculation is believed to play a key role in larval retention and population maintenance, whereas an along-shelf current can transport larvae away from the region (Valesini *et al.* 2004; Tian *et al.* 2009). The encounter of water currents

Table 4. Average similarity and percentage contribution (%) from SIMPER on the most typical species on the continental and insular beaches by season.

| | Continental beach | | | | Insular beach | | | |
|---------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| | Spring (41.68) | Summer (60.58) | Autumn (55.02) | Winter (48.74) | Spring (55.73) | Summer (59.01) | Autumn (59.73) | Winter (57.85) |
| <i>Harengula clupeiola</i> | | | | | 19.20 | | | 10.45 |
| <i>Anchoa tricolor</i> | | | | | 15.83 | 11.81 | | |
| <i>Micropogonias furnieri</i> | | | | | 12.52 | 10.96 | 10.42 | 10.43 |
| <i>Anchoa januaria</i> | | | | | | 18.96 | 14.84 | 13.18 |
| <i>Mugil liza</i> | | | | | | 11.49 | | 12.32 |
| <i>Atherinella brasiliensis</i> | 38.9 | 23.36 | 23.63 | 24.8 | 12.19 | | | |
| <i>Eucinostomus argenteus</i> | 27.05 | 33.27 | 20.33 | 32.83 | | | | |
| <i>Diapterus rhombeus</i> | 10.79 | 22.18 | 10.71 | | | | | |

that enter and leave the bay close to Marambaia Island (Signorini 1980; Copeland *et al.* 2003) could be an important factor that favors egg-laying and larval settlement because it weakens the velocity of the water current. The insular beach is located next to the connection of Sepetiba Bay with oceanic waters, in close proximity to spawning areas of many species (*e.g.* *Mugil liza*, *Micropogonias furnieri* and *Diapterus rhombeus*) that occur at deeper areas in the inner shelf (Araújo & Santos 1999; Costa & Araújo 2002; Albieri & Araújo 2010). This also may favor the large number and high abundance of species on the insular beach. Additionally, the smallest individuals collected in this study were found on the insular beach, further evidence of earlier recruitment in this area. Current circulation in the Sepetiba Bay was studied by Signorini (1980) and Stevenson *et al.* (1998), who found that the continental beach has comparatively heavier and stronger current velocities provided by the entrance of oceanic currents between Itacuruçá Island and the shoreline. This particular characteristic of the continental beach may be responsible for the lower richness and abundance compared with the insular beach.

Differences in the examined physico-chemical variables between the two sandy beaches were recorded for some variables. The insular beach is characterized by lower transparency and depths, and it is known that richness and abundance are positively correlated with gently sloping areas and low transparent waters that protect juvenile fishes from predators (Layman 2000; Barletta-Bergan *et al.* 2002; Neves *et al.* 2011). The encounter of currents nearby the insular beach increases organic matter carried from the inner zone of the bay, increasing primary and secondary productivity in the area (Stevenson *et al.* 1998). When the physical dynamics and nutrients determine the rates of primary and secondary productivity, the best adapted fish species take advantage of the trophic availability of the environment (Abookire *et al.* 2000). Conversely, the straight shape and deeper waters of the

continental beach must make egg-laying and larval settlement difficult.

Different levels of human activity between the two beaches also must be responsible for differences in composition, richness and abundance of fish fauna between the two beaches. The number of species registered on the insular beach was twice the richness on the continental beach, whereas the number of individuals from the insular beach was fourfold that from the continental beach. Increasing urban and industrial development within estuarine areas is leading to significant habitat losses for juveniles (Coleman *et al.* 2008). In addition to the increasing quantities of nutrients and organic matter, sediments accumulate xenobiotics such as heavy metals and organic contaminants (Lima *et al.* 2002; Molisani *et al.* 2006; Quadros *et al.* 2009), which tends to degrade the quality of the habitats for juvenile fishes. Recruitment level and population size of the concerned juvenile fish marine species may then be dramatically affected (Courrat *et al.* 2009). The continental margin of Sepetiba Bay has been suffering from anthropogenic influences over the last few decades (Barcellos & Lacerda 1994; Copeland *et al.* 2003) that have influencing fish richness of their sandy beaches as reported by Pessanha *et al.* (2000). An inherent characteristic of sandy beach ichthyofauna is the dominance of the assemblages by a few species which use the area during early life (McFarland 1963; Modde & Ross 1981; Hajisamae & Chou 2003; Wilber *et al.* 2003; Nanami & Endo 2007). Fish fauna of the two sandy beaches studied in Sepetiba Bay was dominated by species common in Southeastern Brazilian coastal areas (Vendel *et al.* 2002; Félix *et al.* 2007; Vasconcellos *et al.* 2007). A total of 68 species were sampled from the two beaches, with the insular beach having 60 species (31 of them not recorded on the continental beach), many of them numerous, such as *Cetengraulis edentulus*, *Larimus breviceps* and *Brevoortia aurea*. The most abundant families on the insular beach were Clupeidae, Engraulidae, Sciaenidae and Mugilidae,

most species being commercially exploited in Sepetiba Bay, which is characterized as an important area for the maintenance of fisheries resources. On the other hand, the fish fauna on the continental beach had a high relative abundance of species that were widely distributed and resistant to harsh environmental conditions (Pessanha & Araújo 2003; Neves *et al.* 2006), namely, Gerreidae and Atherinopsidae.

A turnover of fish species on the two studied sandy beaches of Sepetiba Bay were observed among seasons, mainly on the insular beach. Previous studies have reported cyclical temporal variation of fish fauna (Pessanha & Araújo 2003; Pessanha *et al.* 2003; Ribeiro *et al.* 2006). Numerous studies have shown that water temperature is related to post-larval and/or juvenile fish assemblage structures in surf zones (*e.g.* Gibson *et al.* 1993; Harris & Cyrus 1996; Lazzari *et al.* 1999). It is suggested that the seasonal variations in fish fauna in surf zones were mainly caused by the timing of the spawning season and/or recruitment peaks (Nanami & Endo 2007). Seasonal patterns differed between the two beaches studied, being related to changes in abundance of dominant species, reflecting the dynamics of the assemblage structure.

Seasonal changes in fish assemblages may be a strategy to resource partitioning that reduces competition for food, or may reflect species responses to suboptimal physical environmental conditions – or a combination of the two (Akin *et al.* 2003). A way to characterize fish assemblages and assess the influence of stress and/or pollution is by the seasonal similarity in species compositions. Unstressed fish assemblages, as on the insular beach, should show low similarities in species composition between seasons, indicating that there is little human-induced pollution stress (Santos & Nash 1995).

Conspicuous seasonal changes in the structure of fish fauna were observed on the insular beach, reflecting changes in abundances of the main species through the year. We observed that planktivorous species dominate in spring and winter, forming large shoals, such as the Clupeidae, whereas in autumn this group of fish was replaced by a high proportion of Engraulidae and invertivorous and omnivorous fish. Large shoals of *Atherinella brasiliensis* occurred in spring and summer, whereas *D. rhombeus* and *M. liza* were more abundant in autumn and winter. The Sciaenidae *M. furnieri* was the most frequently occurring species in this study throughout the year, reflecting a long and continuous recruitment period on the beaches of Sepetiba Bay, as observed in previous studies by Costa & Araújo (2002).

On the continental beach the number of species and individuals increased during the warmest seasons, which is consistent with the findings of other studies in shallow waters (Santos & Nash 1995; Methven *et al.* 2001; Fujita

et al. 2002; Suda *et al.* 2002; Barreiros *et al.* 2004; Godefroid *et al.* 2004; Spach *et al.* 2004; Félix *et al.* 2006, 2007; Veiga *et al.* 2006). Autumn and summer were the warmest and rainy seasons (Molisani *et al.* 2006), which probably favor the increase of freshwater input contributing to primary and secondary productivity in the area. The highest catch rates of the most abundant species, Gerreidae (*Eucinostomus argenteus*, *D. rhombeus* and *Eucinostomus gula*) and Atherinopsidae (*A. brasiliensis*) were found in autumn and summer as previously described by Araújo & Santos (1999), Pessanha & Araújo (2001) and Neves *et al.* (2006) in Sepetiba Bay. The continental beach seems to have a variable assemblage, which could be a consequence of the low diversity and high variability during the year for the most abundant species. Although the fish assemblage showed a strong seasonal change, especially in the number of species, individuals and biomass, results from MDS ordination showed little obvious variation of community structure among seasons.

Our results offer an important glimpse of how the dynamic of fish biodiversity in tropical coastal systems may be influenced by anthropogenic activities, and suggest that urgent measures are needed to recover degraded sandy beaches in continental margins near urban and industrial developments. The protection of sandy beaches through habitat restoration programs should not be seen as a solution replacing conventional management approaches, but needs to be a component of an integrated program of coastal zone and fisheries management in Sepetiba Bay. Such programs have been encouraged in many places (Lasiak 1986; Beck *et al.* 2001; Whitfield & Elliott 2002; Coleman *et al.* 2008). Restoring marine biodiversity through an ecosystem-based management approach – including integrated fisheries management, pollution control, maintenance of essential habitats and creation of marine reserves – is essential to avoid serious threats to global food security, coastal water quality and ecosystem stability.

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