

Polychaetes and fish in a tropical bay in southeastern Brazil: Community concordance and influence of environmental variables

Rafaela de Sousa Gomes-Gonçalves¹  | Vinícius da Rocha Miranda²  |
Leonardo Almeida Freitas¹  | Francisco Gerson Araújo¹ 

¹Laboratório de Ecologia de Peixes, Universidade Federal Rural do Rio de Janeiro, Rio de Janeiro, Brazil

²Laboratório de Polychaetas, Universidade Federal Rural do Rio de Janeiro, Rio de Janeiro, Brazil

Correspondence

Francisco Gerson Araújo, Laboratório de Ecologia de Peixes, Universidade Federal Rural do Rio de Janeiro, BR 465, Km 7, 23970-030, Seropédica, Rio de Janeiro, Brazil.

Email: gersonufrjr@gmail.com

Funding information

Brazilian Biodiversity Fund, Grant/Award Number: 16/2017

Abstract

The distribution of species depends on the relationship with other species and the influence of abiotic factors, modulated by long-term evolutionary and biogeographic processes. Polychaetes and fish are important components of the biota that inhabit estuarine systems, coexisting in various habitats, although the relationship between these groups and their responses to environmental variables is poorly understood. This study aimed to assess the concordance between fish and polychaete communities in three zones (inner, middle, and outer) of a tropical bay and to determine environmental influences on these communities. The raised hypothesis is that benthic fish is associated with polychaetes and that these taxonomic groups respond differently to environmental conditions. Environmental characteristics were the main drivers determining the occurrence of fish species and polychaetes families; however, no consistent relationship was observed between fish and polychaetes. Sediment granulometry seems to be an essential driver in determining polychaetes and fish distribution while turbidity and phosphorus were also important for fish. The three zones differed in both water physicochemical and sediment (nutrients and granulometry) variables, which determined their uses by different fish and polychaetes species. Only one fish species, the gerreid *Eucinostomus argenteus* showed a weak but significant association with the Goniadidae and Spionidae polychaetes, which may be associated with similar environmental preferences of both taxa. The lack of a consistent relationship between benthic fish and their likely invertebrate prey may be associated with the small spatial scale of this study and the early fish life stages. Most fish in shallow coastal areas are still in their early life, feeding mainly on polychaetes and other benthic macroinvertebrates, and as the area is shallow, planktonic organisms may be included in their diet, thus relieving predation pressure on benthic organisms. These findings are important to unveil relationships among different taxonomical groups and their environment.

KEYWORDS

benthic habitats, biodiversity, polychaeta–fish relationships, spatial patterns

1 | INTRODUCTION

The biological composition at the local scale is the result of a set of interactions between species and their relationship with abiotic conditions, which are important drivers of evolutionary and biogeographic processes (Johnson & Hering, 2010; Kilgour & Barton, 1999; Yeung et al., 2010). Thus, the relationships between biological communities and their environment provide strong evidence of the importance that various abiotic drivers have in determining species distribution and abundance (Moore et al., 2010) and studies on the relationship between different taxonomic assemblages are essential to uncover biotic interactions and abiotic influences that dictate the distribution patterns (Kilgour & Barton, 1999).

Concordance is the degree of similarity in community patterns among taxonomic groups across a set of sites (Paavola et al., 2006). Community concordance describes organisms from different taxonomic groups across a region of interest, with highly concordant communities, which are assumed to respond similarly to major environmental gradients, including anthropogenic stressors (Infante et al., 2009). Other mechanisms result in concordance between taxa, such as similar simultaneous species loss along stress gradients and biotic interactions (Heino, 2010). Co-occurrence patterns between different taxonomic groups have been investigated to assess whether changes in certain taxonomic groups can be used to predict variations in others (Johnson & Hering, 2010; Kilgour & Barton, 1999). For example, changes occurring in the ichthyofauna could be extrapolated to benthic invertebrates or vice-versa (Kilgour & Barton, 1999). If there is a close correlation or concordance between these two taxonomic groups, one could evaluate one or another group, to understand the local dynamics, which would be faster and less expensive. The impacts on benthic communities seem to be predictive of impacts on other ecological groups, such as fish, reflecting on their diversity and abundance (Aguar et al., 2020; Maia et al., 2018).

Fish and invertebrates are taxonomic groups occupying different compartments in coastal environments and are expected to respond differently to environmental conditions. Fish were influenced mainly by the physicochemical variables, being positively correlated with salinity and dissolved oxygen, and negatively with temperature, whereas invertebrate richness was related mainly to granulometric variables, decreasing in fine and very fine sediment (Aguar et al., 2020). Fish and invertebrate richness in Mediterranean rivers were not correlated across sites, with the Mantel test has showed no significant correlation between these two groups after controlling for the effects of environmental variables and site proximity (Larsen et al., 2012). Macroinvertebrates respond to local environmental changes and less to the local presence of fishes indicating the surrogate taxa approach has little use in the rivers and streams of Indiana, USA (Backus-Freer & Pyron, 2015).

Benthic invertebrates are present in high abundance in estuarine areas, being important components of the marine food web as intermediate vectors in both benthic and demersal food webs and by participating in nutrient cycling, and by changing the composition of

sediments (Josefson & Rasmussen, 2000). For example, in environments where productivity is increased at the base of the food chain, an increase in the abundance of benthic invertebrates is expected to occur, benefiting higher trophic levels (Gilliam et al., 1989). In contrast, some invertebrates may have limited abundance due to direct predation by fish or even present high abundance due to reduced predation (Jackson & Harvey, 1993).

Polychaetes represent one of the main groups of marine invertebrates in shallow coastal zones (Fauchald & Jumars, 1979; Musco, 2012). They are important feeding resources for several fish species and have an important role in the transfer of energy to coastal ecosystems because of their contribution to the fish diet (Guedes et al., 2015; Rosa et al., 2008; Yeung et al., 2010). The Polychaetae families Syllidae and Dorvilleidae predominated in semi-protect beaches of the Sepetiba Bay, a tropical estuarine area in southeastern Brazil, and are influenced by different environmental variables, but no significant correlation was found between invertebrates and fish (Aguar et al., 2020). When present in high densities, fish seem to have a strong impact on *Hediste diversicolor*, one of the most important polychaete species that is prey for a variety of fish in many temperate estuaries (Rosa et al., 2008). Fish have a preference for errant and carnivorous polychaete species, probably due to the more active behavior of these prey (Serrano et al., 2003). Despite their great importance, the knowledge of these benthic invertebrates is scarce, with increasing demands for information on the biodiversity of these groups and their ecological roles.

In this study, we assessed relationships between polychaetes, one of the most representative groups of the benthic fauna, and benthic fishes, and the influence of environmental variables, namely sediment nutrients, granulometry, and water physicochemical variables. We tested for a correlation between fish and polychaetes in three zones (inner, middle, and outer) of the Sepetiba Bay, Southeastern Brazilian coast, and evaluated the environmental influences on each taxonomic group. The following questions were postulated: (1) Is there any significant relationship between fish and polychaetes with environmental predictors? and (2) Is there any significant concordance between these two biological groups? We expect that our results will provide important information on the links between these two taxonomic groups of marine fauna, allowing us a more comprehensive view of the general functioning of this ecosystem of great ecological and economic importance. We also expect that this baseline knowledge will contribute to the monitoring of this ecosystem.

2 | MATERIALS AND METHODS

2.1 | Study area

Sepetiba Bay (22°54′–23°04′S; 43°34′–44°10′W) is a 450 km² sedimentary embayment system located in the south of the State of Rio de Janeiro, which was originated by extensive sand deposition, which formed a barrier beach as its southern boundary

(Araujo et al., 2016; Figure 1). The bay has a narrow connection with the sea on the east side, and a wide connection on the west and has a mean depth of 8.6 m, a maximum depth of 30 m, and a drainage area of 2700 km². Some coastal islands are located near the sea connection, thus enhancing habitat diversity in the bay (Cunha et al., 2006). The bottom is predominantly muddy. The mean water temperature ranges from 21.5°C in the winter to 26.5°C in the summer. Average salinity ranges from 29 in the inner bay to 33 in the outer bay. This microtidal system has tides ranging from 0.5 to 1.5 m. Small rivers and streams drain into the bay, contributing to decrease salinity and increasing turbidity in the inner bay areas. Predominant northeasterly and southwesterly winds activate thermal currents between the bay and the ocean. The annual rainfall varies between 1000 and 2100 mm (Lima et al., 2021).

Urbanization and industrialization are recent trends in the region. An increased degradation by organic and industrial pollution is occurring in the drainage bay area, altering habitat structure and water quality. Such alterations expanded during the 1980s, mainly because of new industrial development in chemical and metallurgical factories (Araújo et al., 2017; Castelo et al., 2021; Molisani et al., 2006). These changes cause concerns and increase the demand for information on biotic communities and their ecological relationships. Araujo et al. (2016) evaluated temporal changes in the ichthyofauna in Sepetiba Bay over three decades (1983–1985, 1993–1995, and 1999–2001) and observed significant differences in the community composition and decreases in the fish richness, abundance, and biomass over time.

The bay can be divided into three zones (inner, middle, and outer) (Figure 1), according to environmental conditions and human influences. These zones are geographically contiguous and reflect hydrology and sedimentology. The inner zone (IZ) is influenced by discharges from small perennial rivers, which contribute to increased water turbidity and temperature, and decreased salinity (Leal Neto et al., 2006). This zone receives the most impact from industrial plants on the shoreline (Barcellos et al., 1997; Borges & Nittrouer, 2016; Gonçalves et al., 2020). The outer zone (OZ), near the limit of the ocean, has a comparatively lesser influence of anthropogenic activities and exhibits more stable environmental conditions. The middle zone (MZ) presents intermediate environmental conditions between the inner and outer zone.

2.2 | Biological sampling

Five field trips (sampling time) were carried out in September 2017 (winter), January and March 2018 (summer), and July and September 2018 (winter), in the three zones of the shallow coastal areas of northern Sepetiba Bay. On each occasion, three sites were sampled with three replicates in each zone, totaling 135 samples (5 sampling times × 3 zones × 3 sites × 3 replicates) for fish and sediment that were used for biological assessment, and nutrient and granulometric analyses.

Fishes were collected with a beach seine (12 × 2.5 m; 5-mm mesh size) set parallel to the shore at approximately 1.5-m depth, dragging perpendicular to the shore (30-m long) for about 15 min and

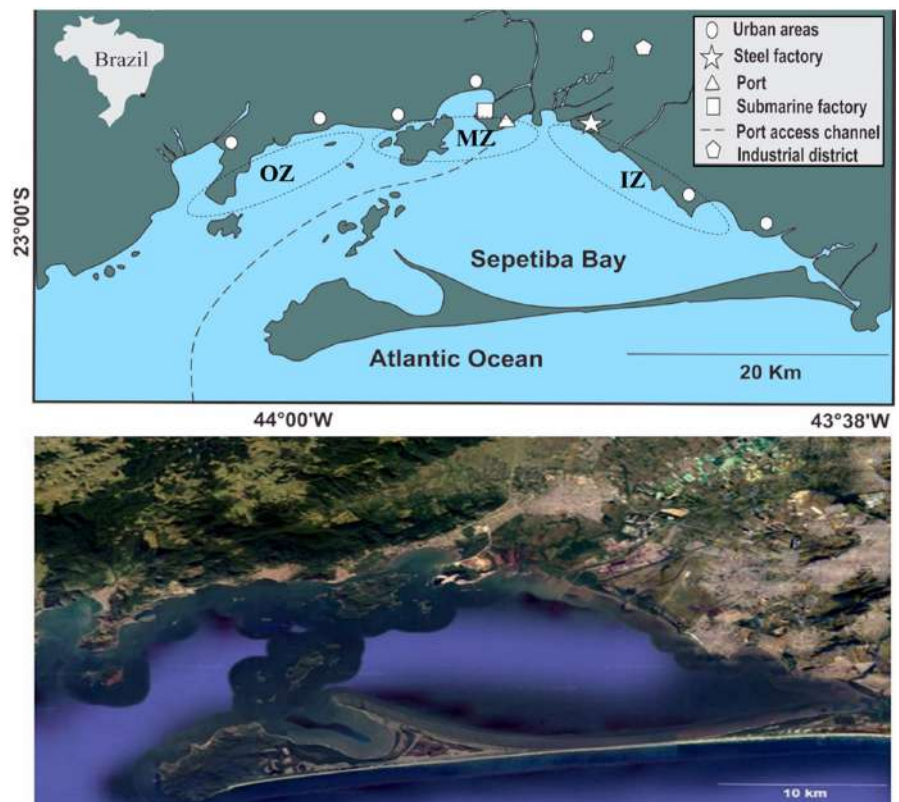


FIGURE 1 Study area, Sepetiba Bay, indicating the three sampling zones (inner, IZ; middle zone, MZ; and outer, OZ). The urbanized areas, mainly in the inner bay shoreline, can be seen in the image extracted from Google Earth (2020).

covering a swept area of approximately 300 m². The collected fishes were fixed in 10% formalin and, after 48 h, preserved in 70% ethanol. All fishes were identified to species level, and voucher specimens were deposited in the Ichthyological Collection of the Laboratory of Fish Ecology of the Universidade Federal Rural do Rio de Janeiro, available at the Global Biodiversity Facility (Araújo & Guedes, 2020; <https://doi.org/10.15468/srsucy>).

Sediment samples were taken with a PVC “corer” (50 cm long, 10 cm diameter) with a collecting area of 0.00785 m² at a depth of 15 cm with three replicates. Biological samples were initially screened in plastic trays (80 × 40 × 7 cm) using tap water for removal of the largest specimens, then sieved through a 0.5 mm mesh, and examined under a light stereo microscope for identification of polychaetes to family level. The family level is considered a sufficiently taxonomic resolution for polychaetes in many ecological studies (Checon & Amaral, 2016; Grebmeier et al., 1988; Olsgard et al., 2003; Soares-Gomes et al., 2012). All identified specimens were preserved in 70% ethanol solution.

2.3 | Environmental variables

Environmental measurements of water physicochemical variables were performed concurrently with the biological sampling. Temperature (°C), salinity, turbidity (Nephelometric Turbidity Units—NTU), and dissolved oxygen (mg L⁻¹) were measured using a multiprobe Horiba U50 (Horiba Trading Co. Ltd.) immersed approximately 0.5 m under the water surface.

Granulometric and nutrient analyses were performed with samples being collected using a PVC corer (10 cm in diameter and 50 cm in length) in a collecting area of 0.00785 m² at a depth of 15 cm with three replicates. The collected sediment was weighed (precision of 0.01 g) and dried at 80°C on a stove. A portion of the sediment (300 g) was used in the granulometric analyses, and another part (150 g) was used for the nutrient analyses. The granulometric parameters were calculated according to Folk and Ward (1957) and classified according to Shepard (1954). The mean granule size was determined from each granulometric fraction weight retained in each sieve using the software SysGran 3.0 (Camargo, 2006). The following size sediment classes were determined following Wentworth (1922): granules (2–4 mm), very coarse sand (1–2 mm), coarse sand (500 μm–1 mm), medium sand (250–500 μm), fine sand (125–250 μm), very fine sand (63–125 μm), and silt + clay (<63 μm).

The concentrations of the following nutrients in the sediment were determined: organic carbon (g kg⁻¹), total nitrogen (%), and total phosphorus (mg dm⁻³). The organic carbon was determined using the Walkley and Black (1934) method by oxidation of the wet organic matter with potassium dichromate in a sulfuric acid medium, employing the heat given off from the sulfuric acid and/or applied heat as the energy source. The excess dichromate after oxidation was titrated with a standard solution of ammoniacal ferrous sulfate (Mohr salt). The total nitrogen was determined using the Kjeldahl nitrogen method with a diffusion camera. The total nitrogen was converted

to ammonium sulfate by oxidation with a mixture of CuSO₄, H₂SO₄, and Na₂SO₄ or K₂SO₄ (mineralization). Later, in an alkaline medium, the ammonium sulfate converted from the organic matter released ammonia, which was complexed in a boric acid solution containing a mixed indicator in a diffusion chamber and was finally determined using acidimetry (H₂SO₄ or HCl). The total phosphorus was determined using a spectrophotometer after digestion with HNO₃–HCl (3:1, V/V) at 200°C. The solubilization of the mineral and organic phosphate forms was conducted using 1:1 H₂SO₄ (Bowman, 1988) with the phosphorus contained in the sulfuric extract representing the total concentration of this element. The mean values of the environmental variables obtained at each sampling location were calculated for each zone.

2.4 | Data analyses

The relative abundance, considered as the number of individuals per sample unit, and the frequency of occurrence were calculated for the components of the benthic and fish communities. Before multivariate analyses, environmental data were normalized, that is, the data were converted into a z-score, by subtracting the raw data from the mean and dividing by the standard deviation, to eliminate the effects of different measurement scales, thus making the data dimensionless and perfectly comparable. The environmental variables were compared between the zones (fixed factor, three levels) with sampling time as a random factor (two levels) and site as a random factor nested within zone (15 levels), using the Permutational Analysis of Variance (PERMANOVA) on the Euclidean distance matrix (Anderson, 2001; McArdle & Anderson, 2001). In addition, a principal component analysis (PCA) was applied to the abiotic data to depict the variables that drive on the Bay's zonation and seasonal variation.

Fish and polychaetes data were also compared between the zones (fixed factor, three levels) with sampling time as a random factor (two levels) and site as a random factor nested within zones (15 levels) using PERMANOVA. Samples with no fish and/or no polychaetes were eliminated from the analyses. A permutational analysis of variance (PERMANOVA) on the Bray–Curtis similarity matrix of the data transformed by the square root was used. A PERMANOVA with a Type I (sequential) sum of squares using 999 permutations to calculate p-values was used, where biological abundance was the response variable. The transformation of biological data by square root seeks to reduce the effect of the most abundant species but preserves information on their relative abundance. A non-metric multidimensional scaling (nMDS) ordination was used to detect spatial patterns of the fish and polychaetes groups. In addition, a Similarity Percentage—SIMPER—analysis was used to determine the species/families that most contributed to within-group average similarity for each zone.

Exclusive and shared effects of environmental variables (water physicochemical, granulometry, and nutrients in the sediment) on fish and polychaete abundance and composition were quantified

by variation partitioning. Canonical correspondence analysis was used to assess relationships between taxa (polychaetes or fish) and environmental variables. Taxa that had a frequency of occurrence less than 3% were removed from these analyses following Ter Braak (1989). In addition, only species of fish that include invertebrates in their diet were selected as we are interested in detecting the direct relationship between the components of the fish community that have a close and direct association with benthic invertebrates. A detrended correspondence analysis (DCA) analysis was previously performed to determine the gradient length of the first ordination axis of biological data and to select the appropriate direct ordination method (redundancy or canonical correspondence analysis). In this study, the canonical correspondence analysis was used after verifying that the length generated by the DCA analysis was >4 . We used a Monte Carlo permutation test (generating 999 permutations) in each analysis to test the significance of each environmental variable and only significant variables ($p < .05$) were considered for the canonical correspondence analysis.

The correlation between benthic invertebrates and ichthyofauna was assessed through the Mantel test. In addition, a partial Mantel test was also used to examine the relationship between these two biotic distance matrices, eliminating the effects of environmental data (Smouse et al., 1986). Furthermore, a multiple regression analysis was performed aiming to assess the eventual dependence relationship between fish species (response variables) and polychaetes families (predictor variables).

The PERMANOVA, nMDS, and SIMPER analyses were performed using the PRIMER 6+PERMANOVA statistical packages, and the canonical correspondence analysis was carried out using the CANOCO FOR WINDOWS 4.5 statistical program.

3 | RESULTS

3.1 | Environmental characteristics

Considering all environmental variables, no significant differences were found between zones (Pseudo- $F = 1.46$, $p = .15$), but significant differences were observed between the random factors sampling periods (Pseudo- $F = 3.93$, $p = .003$) and sites (nested in zones, Pseudo- $F = 2.06$, $p = .001$). The granulometric composition had a low classification value, ranging from poor to moderately selected, which reflects their heterogeneous composition. The inner and middle zones had comparatively higher proportions of the coarse fractions compared to the outer zone (Table 1).

The phosphorus concentration was comparatively higher in the middle zone, whereas carbon and nitrogen had the highest values in the inner zone (Table 2). Concerning the water physicochemical variables, only turbidity showed significant differences between the zones, with lower values in the middle zone when compared to the other two zones (Table 2).

The sample distribution in the PCA ordination diagram discriminated both zones and sampling time although with several

TABLE 1 Mean \pm SD of granulometric sediment fractions (%) in the three Sepetiba zones

Sediment fraction (%)	Inner	Middle	Outer
Granules	19.5 \pm 20.1	16.8 \pm 9.7	2.1 \pm 4.9
Very coarse sand	17.8 \pm 13.3	24.6 \pm 8.3	13.5 \pm 22.7
Coarse sand	18.7 \pm 6.1	26.1 \pm 7.6	19.8 \pm 24.4
Medium sand	21.2 \pm 17.5	11.91 \pm 6.8	9.7 \pm 9.2
Fine sand	9.6 \pm 6.7	6.82 \pm 3.4	8.8 \pm 6.7
Very fine sand	6.8 \pm 4.5	7.05 \pm 3.8	14.8 \pm 10.9
Silt + clay	6.2 \pm 4.5	6.75 \pm 6	31.4 \pm 28.2

overlaps (Figure 2). Samples from the middle zone were located between the outer and the inner zones, with phosphorus being positively associated with the middle zone, whereas the inner zone had samples with both coarse and fine sands. Most samples from the outer zone were characterized by fine sediment. The highest temperatures were associated with sampling time during the summer, whereas the highest concentrations of carbon and nitrogen and higher turbidity were associated with sampling time during the winter.

3.2 | Polychaetes composition

A total of 2459 individuals, distributed in 16 polychaete families (Table S1), were recorded. The inner zone had the greatest abundance, with 1557 individuals distributed in eight families, with Capitellidae being the numerically dominant family, and the Nereididae being the most frequent in the samples. The middle zone presented 506 individuals distributed in 14 families. Of these, only three families (Spionidae, Capitellidae, and Syllidae) accounted for more than 10% of the relative abundance. The outer zone had 11 families and a total of 396 individuals, with the Syllidae accounting for 55% of the relative abundance (Table S1). Significant differences in polychaete composition among the three zones were found according to PERMANOVA (Pseudo- $F = 2.25$; $p = .002$), but not between the sampling time (Pseudo- $F = 1.38$; $p = .254$) and sites (nested in zone Pseudo- $F = 0.89$, $p = .65$) (Table 3). Polychaete composition from the outer zone differed significantly from the middle ($t = 1.44$, $p = .041$) and inner zones ($t = 1.53$, $p = .034$), whereas the latter two zones did not differ significantly ($t = 1.53$, $p = .065$). Therefore, further analyses on polychaetes will only address the patterns of spatial variation. Samples from the inner and outer zones were separated, whereas the samples from the middle zone were spread in an intermediate position in the ordination diagram overlapping with samples of the inner and outer zones according to the nMDS ordination (Figure 3a).

The outer zone showed the lowest within-group average similarity according to SIMPER (Table 4) suggesting high variability in the species composition among the samples. Syllidae and Polygordiidae families had the greatest contribution to the within-group similarity

TABLE 2 Mean \pm SD of nutrient concentrations in the sediment and water physicochemical variables and PERMANOVA results of comparisons among the three zones in Sepetiba Bay

Variables	Inner	Middle	Outer	Pseudo-F; p	Pairwise test
Nutrient sediment					
Phosphorous (mg dm^{-3})	28.0 \pm 17.5	48.3 \pm 18.83	27.9 \pm 19.2	17.13; .001	MZ > IZ; OZ
Carbon (g kg^{-1})	0.60 \pm 0.5	0.26 \pm 0.25	0.16 \pm 0.13	22.4; .001	IZ > MZ > OZ
Nitrogen (%)	0.13 \pm 0.05	0.10 \pm 0.04	0.10 \pm 0.02	8.58; .001	IZ > MZ, OZ
Water physicochemical					
Temperature ($^{\circ}\text{C}$)	26.0 \pm 16.9	24.7 \pm 3.8	25.6 \pm 2.9	1.8; .17	-
Dissolved oxygen (mg L^{-1})	6.3 \pm 5.6	6.3 \pm 4.71	7.3 \pm 4.76	0.4; .65	-
Salinity	31.9 \pm 3.5	31.6 \pm 2.6	32.2 \pm 2.4	0.4; .7	-
Turbidity (NTU)	19.8 \pm 12.42	8.32 \pm 11.3	14.9 \pm 15.8	5.32; .004	MZ < IZ; OZ

Abbreviations: IZ, inner zone; MD, middle zone; OZ, outer zone.

in the outer zone (Table 4). The family Nereididae contributed more than 50% to the within-group similarity in the inner zone, whereas Spionidae contributed 38.7% to the within-group similarity in the middle zone (Table 4).

3.3 | Fish composition

The ichthyofauna was composed of 41,851 individuals distributed in 71 species of which approximately 20% feed preferably on benthic invertebrates (Table S1). The middle zone had the most numerical abundance (29,968 individuals), mainly larvae of species of the genus *Anchoa* accounting for 63.98% of the total number of individuals, being also found in a high frequency of occurrence (34.9%). In contrast, the outer zone had the lowest abundance (3659 individuals). In this zone, *Atherinella brasiliensis* was the dominant species, being found in 82% of the samples and representing 18% of the relative abundance. In addition, the gerreid *Eucinostomus argenteus* was also found in high frequency (51%).

There were significant differences in fish species composition among the zones (Pseudo-F = 1.89, $p = .012$), sampling time (Pseudo-F = 3.64, $p = .002$), but not among sites (nested within zones, Pseudo-F = 1.22, $p = .14$) (Table 3). The fish composition of the middle zone differed significantly from the inner ($t = 1.45$, $p = .035$) and the outer ($t = 1.54$, $p = .028$) zones, whereas these last two zones did not show significant differences ($t = 1.14$, $p = .273$). Although with high overlap, separation between the samples from the inner and outer zones can be observed, with the samples from the intermediate zone concentrating in an intermediate position in the nMDS ordination plot (Figure 3b). The inner zone showed the lowest within-group average similarity according to SIMPER, suggesting high variability in species composition among the samples, whereas the middle zone had the highest value. *A. brasiliensis* and larvae of *Anchoa* had the most contribution to the within-group average similarity in the three zones, reaching 42.93% and 16.59% of the total average similarity respectively in the middle zone.

3.4 | Environmental influences on biological communities

The exclusive effects of the granulometric variables were associated with 19% of the variation in the abundance and 12% in the composition of polychaete families (Figure 4a,b). In addition, exclusive effects of the physicochemical variables were associated with 8% of the variation in the abundance of the polychaete families, whereas the shared effects of these variables were irrelevant. The environmental variables that most contributed ($p < .05$) to the polychaete-environment model selected by the Monte Carlo test for Polychaetes were particle size fractions (granules, medium sand, and very fine sand), and dissolved oxygen. The environmental variables explained 17.8% of the model (polychaete-environmental variable). Of this value, 46.3% was explained by the first axis (Table S2). The first two axes of CCA explained 82.9% of the total variance of the species-environment correlation. Axis 1 showed a positive correlation with dissolved oxygen and a negative correlation with medium sand, whereas axis 2 showed a positive correlation with very fine sediment fractions (Figure 5). The families Opheliidae, Goniadidae, and Spionidae were associated with fractions of fine sediments, whereas Nereididae, Lumbrinereididae, Magelonidae, and Capitellidae had a great affinity with coarser fractions of sediments, occurring mainly in the middle and inner zones. Syllidae and Polygordiidae were associated with sites with higher dissolved oxygen (Figure 5).

Shared effects of the granulometric and nutrient in the sediment variables were associated with 9% of the variation in the fish abundance (Figure 4c), whereas exclusive effects of the physicochemical variables were associated with 5% of this variation. The exclusive effects of the physicochemical variables and the granulometry were each associated with 4% of the variation in the composition of the ichthyofauna (Figure 4d). Water turbidity and temperature, granulometry (granules, medium sand, and very fine sand), and phosphorus concentration in the sediment were selected by the Monte Carlo test to be used in CCA. Of this value, 51.8% was explained by the first axis (Table S3). The first two axes

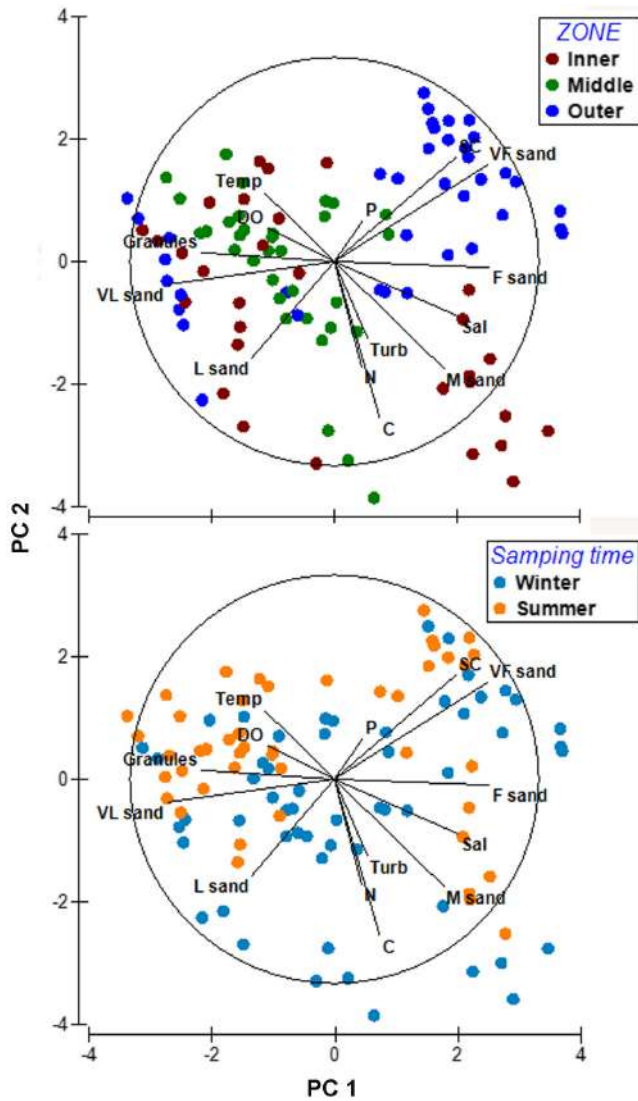


FIGURE 2 Ordination diagram from the two first axes of principal component analysis (PCA) on abiotic data in the Sepetiba Bay, with samples coded by zones and seasons. Variables codes: F sand, fine sand; L sand, large sand; M sand, medium sand; Sal, salinity; SC, silt + clay; VF sand, very fine sand; VL sand, very large sand.

of the CCA ordination explained 70% of the total variance in the species-environment correlation, with the first axis being positively correlated with medium sand and negatively correlated with very fine sand (Table S3). The second CCA axis was positively correlated with granules and phosphorous. *Trachinotus carolinus*, *T. falcatus* and *Menticirrhus littoralis* had a negative correlation with phosphorus and coarse sediment, occurring mainly in the outer zone. *Spherooides testudineus* and *Micropogonias furnieri* were associated with sites with higher temperatures and turbidity, whereas *E. argenteus* and *Achirus lineatus* were found mainly in the middle zone that had high phosphorus concentrations. *Diapterus rhombeus* and *Ctenogobius boleosoma* were associated with sites where the sediment is dominated by medium sand (Figure 6).

3.5 | Polychaetes versus fish relationship

No significant correlation was found between the Bray–Curtis similarity matrices of polychaetes and fish according to the Mantel test ($r = .03$; $p = .17$). This non-significant result was maintained when the effect of environmental variables was removed, in the partial Mantel test ($r = .03$; $p = .15$). The only significant relationship between fish species (response variable) and polychaetes families (predictor variables) detected by the regression analysis was found for *E. argenteus*, which showed a weak but significant dependence on the Goniadidae and Spionidae polychaetes families ($R^2 = .32$; $p < .05$).

4 | DISCUSSION

No clear relationship between polychaete families and fish species was detected, with both groups responding in a different way to environmental variables. The granulometric sediment composition seems to be an essential driver for the occurrence and distribution of polychaetes and fish. Association of polychaetes with sediment granulometry has been reported in previous studies that also pointed out that water physicochemical variables seem to play a minor role in polychaete distribution (Aguar et al., 2020; Silva et al., 2017; Yeung et al., 2010). Differences in sediment type are crucial for most benthic animals, as their feeding strategies tend to be highly adapted to sediment granulometry (Yeung et al., 2010). Capitellidae and Magelonidae, for example, are deposit feeders found in fine fractions of sediments (Yeung et al., 2010). However, in our study they were positioned in the center of the ordination diagram, suggesting a wider range of distribution across the different types of sediment. These two families (Capitellidae and Magelonidae) were found mainly in the inner and middle zone, which despite having predominant coarse sediment in the shallow areas, had predominant muddy sediment in deep areas (Borges & Nittrouer, 2016). This sedimentary change observed in the sediment granulometry may be directly associated with anthropogenic activities. For example, the reconstruction of an artificial shoreline in the inner zone favored the deposition of coarse sediment in the shallow areas. This new sedimentary composition may be affecting the biological community and may also be a limiting factor for the establishment of several species, leading to an ecological imbalance (Pagán et al., 2016).

The inner and middle zones had higher concentrations of nutrients stored in the sediment. These two areas present a marked influence of urbanization in their surroundings. As a consequence, anthropogenic activities carrying organic loads into the Bay may be responsible for increases in phosphorus and nitrogen in the inner and middle zone. Areas with higher concentrations of nutrients had high abundance of individuals of the Spionidae family, which is known for having high tolerance to pollution (Dean, 2008; Omena et al., 2012). The occurrence of Spionids seems to be favored by high levels of nutrients, mainly phosphorus and nitrogen, which are important macronutrients for primary production. Sandman et al. (2018) evaluated

Source	df	MS	Pseudo-F	p(perm)
Polychaetes				
Zone	2	11,237	2.25	.002
Sampling time	1	7379	1.38	.25
Site (zone)	12	5137	0.89	.65
Zone × sampling time	2	2464	0.46	.95
Residual	44	2539		
Fish				
Zone	2	17,499	1.89	.012
Sampling time	1	22,481	3.640	.002
Site (zone)	12	7331	1.22	.14
Zone × sampling time	2	6160	1.00	.45
Residual	102	2426		

TABLE 3 PERMANOVA results for testing differences in the structure of polychaete and fish communities in the Sepetiba Bay between zones (fixed factor) with sampling time and site (nested in zones) as random factors

Abbreviations: df, degree of freedom; MS, mean square.

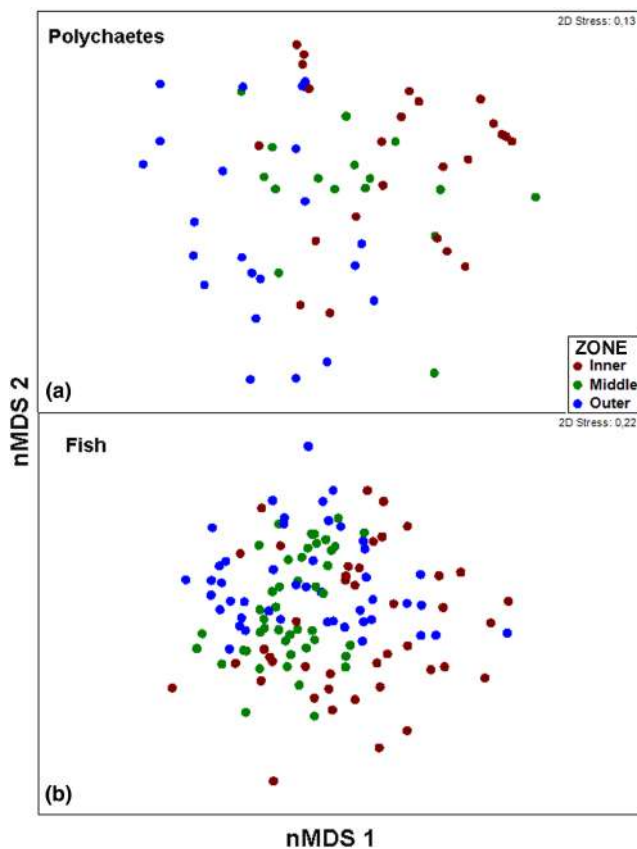


FIGURE 3 Ordination diagram of non-metric multidimensional scaling on families polychaete (a) and species of fish (b) abundances, with samples coded by zones: Red, inner zone; green, middle zone; blue, outer zone.

the effects of the invasive polychaetes of the Spionidae family and the *Marenzelleria* genus on phosphorus cycling. They observed that these organisms can increase the flow of phosphorus from the sediment to the water column through bioturbation. However, they also pointed out that high densities of *Marenzelleria* spp. can increase phosphorus retention locally, causing a decrease in the self-cleaning

capacity of marine environments, which contradicts human efforts to mitigate eutrophication in the region. Despite benefiting a series of organisms and being growth stimulators, the increasing concentration of nutrients must be viewed with caution, as they can confer certain limitations, reaching lethal levels for some species of the benthic community, and causing changes in the high trophic levels (Nielson & Jernakoff, 1996).

The Nereididae family showed a high abundance in the inner zone with high affinity for coarse sediment. This type of sediment is unstable and with high mobility, being occupied by biota specialized in niches with greater space between the grains (Silva et al., 2017). In contrast, Polygordiidae and Syllidae were the families that most contributed to the average similarity of the outer zone, showing a greater affinity for dissolved oxygen. According to Dean (2008), the presence of species of the Syllidae family has been used as an indicator of high environmental quality, whereas the presence of species of the Capitellidae family in a community is an indication of poor environmental conditions. The outer zone seems to have less influence from anthropogenic activities due to the lower level of urbanization in its surroundings, which may be contributing to the lower values of nutrients in the sedimentary compartment and favoring the establishment of groups sensitive to urban pollution.

As with polychaetes, there was a significant relationship between ichthyofauna and the granulometric sediment composition, as well as with the phosphorus concentration in the sediment. In addition, water physicochemical variables such as high turbidity also proved to be essential for ichthyofauna occurrence. Although fish do not have an intuitive direct relationship with sediment granulometry, unlike benthic invertebrates, it is possible to understand several reasons why fish were associated with the granulometric sediment fractions. Yeung et al. (2010) highlight that part of this relationship must be due to the important structuring role of the benthic infauna, which comprises the main prey for several fish species. In addition, Vasconcellos et al. (2018) evaluated the trophic ecology of three species of Gerreidae (*E. argenteus*, *Eucinostomus gula*, and *D. rhombeus*) in Sepetiba Bay and identified that polychaetes and Bivalvia siphons

were the most important food items for these fish species. These species likely have a preference for coarse sediment, with foraging facilitated by the large mouth expansion that stirs the sediment in search of food (Ramos et al., 2014; Vasconcellos et al., 2018).

Although we did not find any significant correlation between the ichthyofauna and polychaetes families, according to the Mantel and

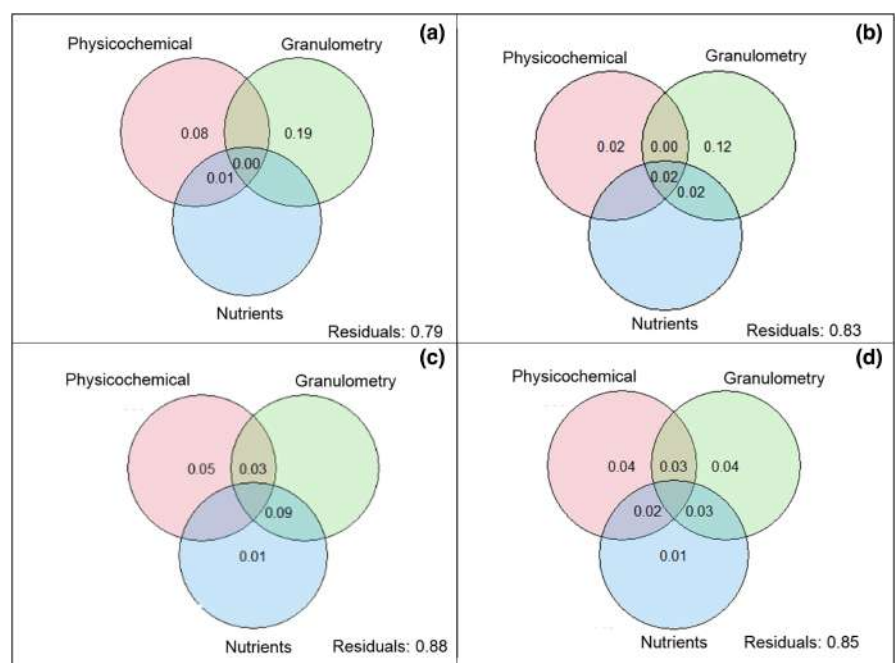
partial Mantel tests even after controlling environmental influences, only the gerreid *E. argenteus* showed a weak but significant correlation with the Goniadidae and Spionidae families, which may be associated to the similar environmental preferences of both taxa. The absence of a consistent relationship between other benthivores fish species and their potential prey can be explained by the low depth in the shallow coastal areas that these species use as rearing ground during their early life stages (Vasconcellos et al., 2018). Food availability is generally high during early development. In shallow coastal areas, juvenile benthic fish also use abundant planktonic items, such as copepods (Pessanha & Araujo, 2003, 2012). The low depth of these areas favors the plankton components to be reached by the fish, thus relieving predation on polychaetes, which also reduces the potential for competition, and does not favor association between these two biological groups. Guedes et al. (2015) evaluated the diet of the 24 most abundant fish in deeper areas of the Sepetiba Bay and observed that Polychaeta was the most important resource for nine of the 24 examined fish species. They also observed that *M. furnieri* and species of *Eucinostomus* fed mainly on Polychaeta in the inner bay zone, changing to crustaceans in the middle and outer zones.

Although new insights on the fish-polychaete relationship have been uncovered from this study, for example, sediment granulometry seems to be an essential driver in determining polychaetes and fish distribution, we should consider some limitations that also come together. It is necessary to consider that, because we used the family level to describe polychaetes, the environmental relations with these invertebrates may be underestimated. However, previous studies have investigated taxonomic sufficiency and concluded that analyses performed based on the identification of Polychaeta exclusively at the family level are adequate to assess their distribution over environmental gradient (Chapman, 1998; Checon & Amaral, 2016). Overall, polychaetes are dominant in both species diversity and

TABLE 4 Discriminant species for each zone of the Sepetiba Bay, according to SIMPER analysis

Species	Inner	Middle	Outer
Polychaetes			
Average similarity (%)	28.3	28.1	19.9
Nereididae	52.3	8.2	
Capitellidae	16.06	18.3	
Spionidae	27.1	38.74	20.48
Magelonidae		7.05	
Syllidae			30.9
Polygordidae			27.71
Goniadidae			18.8
Fish			
Average similarity (%)	15.7	29.66	21.44
<i>Genidens genidens</i>	19.91		
<i>Atherinella brasiliensis</i>	5.87	42.93	16.64
<i>Anchoa</i> sp.	13.62	16.59	12.7
<i>Eucinostomus argenteus</i>	7.93	16.39	
<i>Anchoa januaria</i>	6.21		10.94
<i>Ctenogobius boleosoma</i>	6.49		
<i>Oligoplites saurus</i>		6.58	
<i>Menticirrhus littoralis</i>			5.99
<i>Trachinotus carolinus</i>			28.71

FIGURE 4 Venn diagrams showing the results of variation partitioning analyses performed on the exclusive and shared effects of the environmental variables (water physicochemical, granulometry, and nutrients in sediment) on the abundance and composition of polychaetes (a and b) and fish (c and d), respectively.



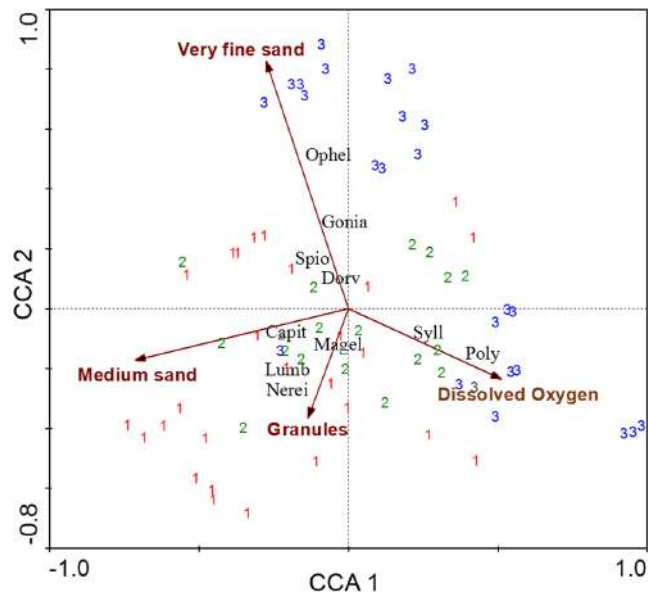


FIGURE 5 Ordination diagram of polychaete families and environmental variables according to canonical correspondence analysis. Codes: 1, inner zone; 2, middle zone; 3, outer zone. Polychaetes: Capit, Capitellidae; Dorv, Dorvilleidae; Gonia, Goniadidae; Lumb, Lumbrineridae; Magel, Magelonidae; Nerei, Nereididae; Ophel, Ophelidae; Poly, Polygordiidae; Spio, Spionidae; Syll, Syllidae.

abundance in benthic communities (Giangrande, 1997) and because of this, the lack of correlation between benthivorous fish and certain families of polychaetes may be also related to the trophic plasticity of the ichthyofauna (Lowe-McConnell, 1999). This allows the use of different families, as this food item is in great abundance in the environment, making the species competition less likely to occur and favoring the coexistence of fish with a similar trophic niche.

Our results corroborate the findings of Yeung et al. (2010), who did not identify clear links between fish species and polychaetes families. In addition to the scarcity of studies that seek to investigate the agreement between these groups, a clear description of their trophic relationship is also scarce. This lack of information does not allow us to assess the level of selectivity of species. Kilgour and Barton (1999) evaluated the associations between fish and benthic invertebrates in different environmental gradients and stated that fish and benthos reflect environmental conditions at different spatial scales. The degree of community concordance among groups of organisms depends critically on the spatial scale, with concordance being generally weak at the scale of individual drainages, but strong across multiple drainage systems and ecoregions (Paavola et al., 2006). The small spatial scale could also contribute to the lack of concordance between fish and polychaetes in the present study. Fish integrate environmental conditions on a broader spatial scale, as they have a greater capacity for locomotion. In contrast, invertebrates are relatively more sessile, thus better reflecting local conditions (Kilgour & Barton, 1999). Aguiar et al. (2020) also assessed the environmental and biological relationships between fish and invertebrates in tropical marine environments and also did

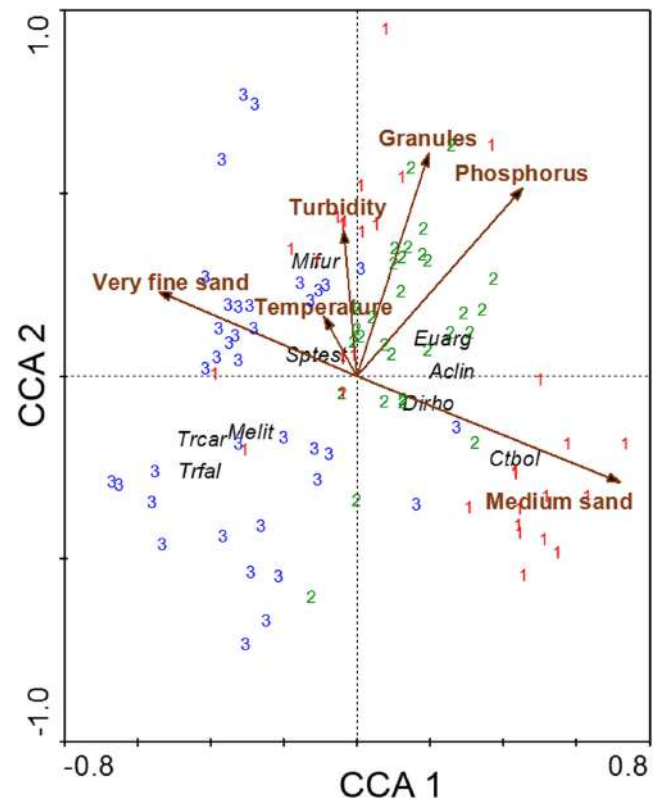


FIGURE 6 Ordination diagram of the fish data and environmental variables according to canonical correspondence analysis (CCA). Codes: 1, inner zone; 2, middle zone; 3, outer zone. Fish: Aclin, *Achirus lineatus*; Dirho, *Diapterus rhombeus*; Ctbol, *Ctenogobius boleosoma*; Euarg, *Eucinostomus argenteus*; Melit, *Menticirrhus littoralis*; Mifur, *Micropogonias furnieri*; Sptest, *Spherooides testudineus*; Trcar, *Trachinotus carolinus*; Trfal, *Trachinotus falcatus*.

not observe a clear relationship between fish and invertebrates. In addition, these two taxonomic groups were influenced by the same environmental abiotic variables but responded differently. Fish respond mainly to the physicochemical water variables, such as turbidity, and to sedimentary variables, such as granulometry and phosphorus. Invertebrates, in turn, were mainly related to the granulometric characterization of the sediment and dissolved oxygen in the water. These inherent specificities of each group, in a single study, give a more holistic view of different ecosystem compartments. In this way, a joint survey of the ichthyofauna and the benthic community can be fundamental for more comprehensive knowledge of the marine coastal areas, as the evaluation of a certain biological group does not exclude the need for effort to learn about another.

Although the study was carried out in only one bay, it has a robust sampling design and is a step to understanding both the relationships between fish and polychaetes communities and the environmental influences (physical-chemical, sediment chemistry, and granulometry) on both groups. Rare studies have been published with these different approaches. We believe that it is an important contribution carried out at a local scale that can be considered and compared

with other areas, thus helping to form a broader understanding of this important aspect of the biodiversity in tropical estuarine areas.

ACKNOWLEDGMENTS

The authors thank technicians from the Laboratory of Fish Ecology for helping with fieldwork. This study was supported by the Project Pesquisa Marinha e Pesqueira, a compensatory measure established by the Conduct Adjustment Term responsibility of the Chevron Company, conducted by the Federal Public Ministry—MPF/RJ, with the implementation of the Fundo Brasileiro para a Biodiversidade (FUNBIO, Proc. 16/2017). This research was conducted under SISBIO Collection of Species Permit number 10707 issued by ICMBio, Brazilian Environmental Agency.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Rafaela de Sousa Gomes-Gonçalves  <https://orcid.org/0000-0002-8389-9474>

Vinicius da Rocha Miranda  <https://orcid.org/0000-0002-4591-184X>

Leonardo Almeida Freitas  <https://orcid.org/0000-0002-5820-9339>

Francisco Gerson Araújo  <https://orcid.org/0000-0003-4551-1974>

REFERENCES

- Aguiar, F. S., Gomes-Gonçalves, R. S., & Araújo, F. G. (2020). Fish and benthic invertebrate relationship and their association to environmental variables in tropical sandy beaches. *Environmental Biology of Fishes*, 103, 1309–1321. <https://doi.org/10.1007/s10641-020-01024-0>
- Anderson, M. J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology*, 26, 32–46. <https://doi.org/10.1111/j.1442-9993.2001.01070.pp.x>
- Araújo, D. F., Peres, L. G. M., Yopez, S., Mulholland, D. S., Machado, W., Tonhá, M., & Garnier, J. (2017). Assessing man-induced environmental changes in the Sepetiba Bay (southeastern Brazil) with geochemical and satellite data. *Comptes Rendus Geoscience*, 349(6–7), 290–298. <https://doi.org/10.1016/j.crte.2017.09.007>
- Araújo, F. G., & Guedes, G. H. S. (2020). Base de dados da Coleção Ictiológica do LEP-UFRRJ. Version 1.3. Sistema de Informação sobre a Biodiversidade Brasileira – SiBBR. Occurrence dataset accessed via Global Biodiversity Information Facility (GBIF). <https://doi.org/10.15468/srsucy>
- Araujo, F. G., Pinto, S. M., Neves, L. M., & Azevedo, M. C. C. (2016). Inter-annual changes in fish communities of a tropical bay in southeastern Brazil: What can be inferred from anthropogenic activities? *Marine Pollution Bulletin*, 114, 102–113. <https://doi.org/10.1016/j.marpolbul.2016.08.063>
- Backus-Freer, J., & Pyron, M. (2015). Concordance among fish and macroinvertebrate assemblages in streams of Indiana, USA. *Hydrobiologia*, 758, 141–150. <https://doi.org/10.1007/s10750-015-2281-6>
- Barcellos, C., Lacerda, L. D., & Ceradini, S. (1997). Sediment origin and budget in Sepetiba Bay (Brazil) – An approach based on multielemental analysis. *Environmental Geology*, 32(3), 203–209. <https://doi.org/10.1007/S002540050208>
- Borges, H. V., & Nittrouer, C. (2016). Sediment accumulation in Sepetiba Bay (Brazil) during the Holocene: A reflex of the human influence. *Journal of Sedimentary Environments*, 1(1), 90–106. <https://doi.org/10.12957/jse.2016.21868>
- Bowman, R. A. (1988). A rapid method to determine total phosphorus in soils. *Soil Science Society of America Journal*, 52, 1301–1304. <https://doi.org/10.2136/sssaj1988.03615995005200050016x>
- Camargo, M. G. (2006). SYSGRAN: Um sistema de código aberto para análises granulométricas. *Revista Brasileira de Geociências*, 36, 371–378. <https://doi.org/10.25249/0375-7536.2006362371378>
- Chapman, M. (1998). Relationships between spatial patterns of benthic assemblages in a mangrove forest using different levels of taxonomic resolution. *Marine Ecology Progress Series*, 162, 71–78. <https://doi.org/10.3354/meps162071>
- Checon, H., & Amaral, A. (2016). Taxonomic sufficiency and the influence of rare species on variation partitioning analysis of a polychaete community. *Marine Ecology*, 38, e12384. <https://doi.org/10.1111/maec.12384>
- Cunha, C. L. N., Rosmam, P. C. C., Ferreira, A. P., & Monteiro, T. C. N. (2006). Hydrodynamics and water quality models applied to Sepetiba Bay. *Continental Shelf Research*, 26, 1940–1953. <https://doi.org/10.1016/j.csr.2006.06.010>
- Dean, H. (2008). The use of polychaetes (Annelida) as indicator species of marine pollution: A review. *Revista de Biología Tropical*, 56(Suppl 4), 11–38.
- Fauchald, K., & Jumars, P. A. (1979). The diet of worms: A study of polychaete feeding guilds. *Oceanography and Marine Biology: An Annual Review*, 17, 193–284.
- Folk, R. L., & Ward, W. C. (1957). Brazos river bar: A study of significance of grain size parameters. *Journal of Sedimentary Petrology*, 27, 3–26. <https://doi.org/10.1306/74D70646-2B21-11D7-8648000102C1865D>
- Giangrande, A. (1997). Polychaete reproductive patterns, life cycles and life histories: An overview. *Oceanography and Marine Biology: An Annual Review*, 35, 323–386.
- Gilliam, J. F., Fraser, D. F., & Sabat, A. M. (1989). Strong effects of foraging minnows on a stream benthic invertebrate community. *Ecology*, 70, 445–452. <https://doi.org/10.2307/1937549>
- Gonçalves, R. A., Oliveira, D. F., Rezende, C. E., Almeida, P., Lacerda, L. D., Gamaa, B. A. P., & Godoy, J. M. (2020). Spatial and temporal effects of decommissioning a zinc smelter on the sediment quality of an estuary system: Sepetiba Bay, Rio de Janeiro, Brazil. *Journal of the Brazilian Chemical Society*, 31(4), 683–693. <https://doi.org/10.21577/0103-5053.20190232>
- Grebmeier, J. M., McRoy, C. P., & Feder, H. M. (1988). Pelagicbenthic coupling on the shelf of the northern Bering and Chukchi seas. I. Food supply source and benthic biomass. *Marine Ecology Progress Series*, 48, 57–67. <https://doi.org/10.3354/meps048057>
- Guedes, A. P. P., Araujo, F. G., Pessanha, A. L. M., & Milagre, R. R. (2015). Partitioning of the feeding niche along spatial, seasonal and size dimensions by the fish community in a tropical bay in southeastern Brazil. *Marine Ecology*, 36, 38–56. <https://doi.org/10.1111/maec.12115>
- Heino, J. (2010). Are indicator groups and cross-taxon congruence useful for predicting biodiversity in aquatic ecosystems? *Ecological Indicators*, 10, 112–117. <https://doi.org/10.1016/j.ecoli.2009.04.013>
- Infante, D. M., Allan, J. D., Linke, S., & Norris, R. H. (2009). Relationship of fish and macroinvertebrate assemblages to environmental factors: Implications for community concordance. *Hydrobiologia*, 623, 87–103. <https://doi.org/10.1007/s10750-008-9650-3>

- Jackson, D. A., & Harvey, H. H. (1993). Fish and benthic invertebrates: Community concordance and community-environment relationship. *Canadian Journal of Fisheries and Aquatic Sciences*, 50, 2641–2651. <https://doi.org/10.1139/f93-287>
- Johnson, R. K., & Hering, D. (2010). Spatial congruency of benthic diatom, invertebrate, macrophyte, and fish assemblages in European streams. *Ecological Application*, 20(4), 978–992. <https://doi.org/10.1890/08-1153.1>
- Josefson, A. B., & Rasmussen, B. (2000). Nutrient retention by benthic macrofaunal biomass of Danish estuaries: Importance of nutrient load and residence time. *Estuarine Coastal and Shelf Science*, 50(2), 205–216. <https://doi.org/10.1006/ecss.1999.0562>
- Kilgour, B. W., & Barton, D. R. (1999). Associations between stream fish and benthos across environmental gradients in southern Ontario, Canada. *Freshwater Biology*, 41, 553–566. <https://doi.org/10.1046/j.1365-2427.1999.00402.x>
- Larsen, S., Mancini, L., Pace, G., Scalici, M., & Tancioni, L. (2012). Weak concordance between fish and macroinvertebrates in Mediterranean streams. *PLoS One*, 7, e51115. <https://doi.org/10.1371/journal.pone.0051115>
- Leal Neto, A. C., Legey, L. F. L., Gonzalez-Araya, M. C., & Jablonski, S. (2006). A system dynamics model for the environmental management of the Sepetiba Bay watershed, Brazil. *Environmental Management*, 38, 879–888. <https://doi.org/10.1007/s00267-005-0211-5>
- Lima, A. O., Lyra, G. B., Abreu, M. C., Oliveira-Júnior, J. F., Zeri, M., & Cunha-Zeri, G. (2021). Extreme rainfall events over Rio de Janeiro state, Brazil: Characterization using probability distribution functions and clustering analysis. *Atmospheric Research*, 247(1), e105221. <https://doi.org/10.1016/j.atmosres.2020.105221>
- Lowe-McConnell, R. H. (1999). *Estudos ecológicos de comunidades de peixes tropicais* (p. 373). Edusp.
- Maia, H. A., Morais, R. A., Quimbayo, J. P., Dias, M. S., Sampaio, C. L. S., Horta, P. A., Ferreira, C. E. L., & Floeter, S. R. (2018). Spatial patterns and drivers of fish and benthic reef communities at São Tomé Island, Tropical Eastern Atlantic. *Marine Ecology*, 39(6), e12520. <https://doi.org/10.1111/maec.12520>
- Mcardle, B. H., & Anderson, M. J. (2001). Fitting multivariate models to community data: A comment on distance-based redundancy analysis. *Ecology*, 82, 290–297. <https://doi.org/10.1890/0012-9658>
- Molisani, M. M., Kjerfve, B., Silva, A. P., & Lacerda, L. D. (2006). Water discharge and sediment load to Sepetiba Bay from an anthropogenically-altered drainage basin. SE Brazil. *Journal of Hydrology*, 331, 425–433. <https://doi.org/10.1016/j.jhydrol.2006.05.038>
- Moore, C. H., Harvey, E. S., & Van, N. K. (2010). The application of predicted habitat models to investigate the spatial ecology of demersal fish assemblages. *Marine Biology*, 157, 2717–2729. <https://doi.org/10.1007/s00227-010-1531-4>
- Musco, L. (2012). Ecology and diversity of Mediterranean hard-bottom Syllidae (Annelida): A community-level approach. *Marine Ecology Progress Series*, 461, 107–119. <https://doi.org/10.3354/meps09753>
- Nielson, J., & Jernakoff, P. (1996). A review of the interaction of sediment and water quality with benthic communities. Port Phillip Bay environmental study. *Technical Report*, 25, 1–130.
- Olsgaard, F., Brattegard, T., & Holthe, T. (2003). Polychaetes as surrogates for marine biodiversity: Lower taxonomic resolution and indicator groups. *Biodiversity and Conservation*, 12, 1033–1049. <https://doi.org/10.1023/A:1022800405253>
- Omena, E., Lavrado, H., Paranhos, R., & Silva, T. A. (2012). Spatial distribution of intertidal sandy beach polychaete along an estuarine and morphodynamic gradient in a eutrophic tropical bay. *Marine Pollution Bulletin*, 64, 1861–1873. <https://doi.org/10.1016/j.marpolbul.2012.06.009>
- Paavola, R., Muotka, T., Virtanen, R., Heino, J., Jackson, D., & Mäkipetäys, A. (2006). Spatial scale affects community concordance among fishes, benthic macroinvertebrates, and bryophytes in streams. *Ecological Applications*, 16(1), 368–379. <https://doi.org/10.1890/03-5410>
- Pagán, J., Aragonés, L., Tenza-Abril, A., & Pallarés, P. (2016). The influence of anthropic actions on the evolution of an urban beach: Case study of Marineta Cassiana beach, Spain. *Science of the Total Environment*, 559, 242–255. <https://doi.org/10.1016/j.scitotenv.2016.03.134>
- Pessanha, A. L. M., & Araujo, F. G. (2003). Spatial, temporal and diel variations of fish assemblages at two sandy beaches in the Sepetiba Bay, Rio de Janeiro, Brazil. *Estuarine, Coastal and Shelf Science*, 57(5–6), 817–828. [https://doi.org/10.1016/S0272-7714\(02\)00411-0](https://doi.org/10.1016/S0272-7714(02)00411-0)
- Pessanha, A. L. M., & Araujo, F. G. (2012). Spatial and size feeding niche partitioning of the rhomboid mojarra *Diapterus rhombeus* (Cuvier, 1829) in a tropical Brazilian bay. *Marine Biology Research*, 8, 273–283. <https://doi.org/10.1080/17451000.2011.615326>
- Ramos, J. A. A., Barletta, M., Dantas, D. V., Lima, A. R. A., & Costa, M. F. (2014). Trophic niche and habitat shifts of sympatric Gerreidae. *Journal of Fish Biology*, 85, 1446–1469. <https://doi.org/10.1111/jfb.12499>
- Rosa, S., Granadeiro, J. P., Vinagre, C., França, S., Cabral, H. C., & Palmeirim, J. M. (2008). Impact of predation on the polychaete *Hediste diversicolor* in estuarine intertidal flats. *Estuarine, Coastal and Shelf Science*, 78, 655–664.
- Sandman, A., Näslund, J., Gren, I., & Norling, K. (2018). Effects of an invasive polychaete on benthic phosphorus cycling at sea basin scale: An ecosystem disservice. *Ambio*, 47(8), 884–892. <https://doi.org/10.1007/s13280-018-1050-y>
- Serrano, A., Velasco, F., & Olaso, I. (2003). Polychaete annelids in the diet of demersal fish from the southern shelf of the Bay of Biscay. *Journal of the Marine Biological Association of the UK*, 83(3), 619–623. <https://doi.org/10.1017/S0025315403007550h>
- Shepard, F. P. (1954). Nomenclature based on sand-silt-clay ratios. *Journal of Sedimentary Petrology*, 24(3), 151–158. <https://doi.org/10.1306/D4269774-2B26-11D7-8648000102C1865D>
- Silva, D. S., Gomes, R. S., Santos, J. N. S., & Araújo, F. G. (2017). Distribution of benthic fauna in sediment grains and prop roots of a mangrove channel in South-Eastern Brazil. *Journal of the Marine Biological Association UK*, 97, 377–385. <https://doi.org/10.1017/S0025315416000485>
- Smouse, P. E., Long, J. C., & Sokal, R. R. (1986). Multiple regression and correlation extensions of the mantel test of matrix correspondence. *Systematic Zoology*, 35, 627–632. <https://doi.org/10.2307/2413122>
- Soares-Gomes, A., Mendes, C. L. T., Tavares, M., & Santi, L. (2012). Taxonomic sufficiency of polychaete taxocenes for estuary monitoring. *Ecological Indicators*, 15, 149–156. <https://doi.org/10.1016/j.ecolind.2011.09.030>
- Ter Braak, C. J. F. (1989). Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis. *Ecology*, 67, 1167–1179. <https://doi.org/10.2307/1938672>
- Vasconcellos, R. M., Gomes-Gonçalves, R. S., Santos, J. N. S., Cruz Filho, A. G., & Araújo, F. G. (2018). Do closely related species share of feeding niche along growth? Diets of three sympatric species of the mojarra (Actinopterygii: Gerreidae) in a tropical bay in southeastern Brazil. *Environmental Biology of Fishes*, 101, 949–962.
- Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and proposed modification of the chromic acid titration method. *Soil Science*, 37, 29–38. <https://doi.org/10.1097/00010694-193401000-00003>
- Wentworth, C. K. (1922). A scale of grade and class terms for clastic sediments. *Journal of Geology*, 30, 377–392. <https://doi.org/10.1086/622910>
- WFL, C., MVA, M., de Lima Ferreira, P. A., Figueira, R., da Costa, C. F., da Fonseca, L. B., Bergamashi, S., Pereira, E., Terroso, D., AFS, P., Simon, M. B., OAA, S., Frontalini, F., da Silva, L. C., Rocha, F., Geraldés, M., & Guerra, J. V. (2021). Long-term eutrophication



and contamination of the central area of Sepetiba Bay (SW Brazil). *Environmental Monitoring and Assessment*, 193, 100. <https://doi.org/10.1007/s10661-021-08861-1>

Yeung, C., Yang, M., & McConnaughey, R. (2010). Polychaete assemblages in the south-eastern Bering Sea: Linkage with groundfish distribution and diet. *Journal of the Marine Biological Association UK*, 90, 903–917. <https://doi.org/10.1017/S002531541000024X>

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Gomes-Gonçalves, R. d. S., Miranda, V. d. R., Freitas, L. A., & Araújo, F. G. (2022). Polychaetes and fish in a tropical bay in southeastern Brazil: Community concordance and influence of environmental variables. *Marine Ecology*, 00, e12722. <https://doi.org/10.1111/maec.12722>