



Taxonomic and functional distinctness of the fish assemblages in three coastal environments (bays, coastal lagoons and oceanic beaches) in Southeastern Brazil



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ABSTRACT

Several species of marine fish use different coastal systems especially during their early development. However, these habitats are jeopardized by anthropogenic influences threatening the success of fish populations, and urgent measures are needed to prioritize areas to protect their sustainability. We applied taxonomic ($\Delta+$) and functional ($X+$) distinctiveness indices that represent taxonomic composition and functional roles to assess biodiversity of three different coastal systems: bays, coastal lagoons and oceanic beaches. We hypothesized that difference in habitat characteristics, especially in the more dynamism and habitat homogeneity of oceanic beaches compared with more habitat diversity and sheltered conditions of bays and coastal lagoons results in differences in fish richness and taxonomic and functional diversity. The main premise is that communities phylogenetically and functionally more distinct have more interest in conservation policies. Significant differences ($P < 0.004$) were found in the species richness, $\Delta+$ and $X+$ among the three systems according to PERMANOVA. Fish richness was higher in bays compared with the coastal lagoons and oceanic beaches. Higher $\Delta+$ was found for the coastal lagoons compared with the bays and oceanic beaches, with the bays having some values below the confidence limit. Similar patterns were found for $X+$, although all values were within the confidence limits for the bays, suggesting that the absence of some taxa does not interfere in functional diversity. The hypothesis that taxonomic and functional structure of fish assemblages differ among the three systems was accepted and we suggest that coastal lagoons should be prioritized in conservation programs because they support more taxonomic and functional distinctiveness.

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1. Introduction

Understanding the links between species distribution and habitat characteristics is often the first step in unraveling the mechanisms that control biodiversity distribution (Matthews and Whittaker, 2015; Vasconcelos et al., 2015; Whitfield and Patrick, 2015; McLean et al., 2016). In this sense, the investigation of species composition and functional traits has been proposed as a means to assess the structure and dynamics of ecological communities. Species richness is practically always used as an explanatory variable for ecosystem function because it is easy to estimate and assumed to be a good estimator for functional diversity

(Tilman, 1999). The introduction of functional groups was an important step in estimating functional diversity, with species being grouped by similar function, similar effects on ecosystem processes or similar responses to environmental pressures (Wilson, 1999; Walker and Langridge, 2002). Therefore, classifying species into groups based on taxonomic relationship and similar function is a useful approach to studying species environmental or perturbation influences on the coastal systems.

Several species of marine fish use sandy beaches in different coastal systems especially during their early development. However, this kind of habitat is at risk because of anthropogenic activities, which jeopardize the success of fish populations, and urgent measures are needed to prioritize areas to protect the sustainability of such natural resources. The traditional diversity indices have been used in the last decades to quantify changes in communities, reducing complexity for ecological groups to numbers that are

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based on species composition and their relative abundances. Such indices are poor predictors of communities' structure and function. One of their inconsistency is the premise that all species are equivalent in composition and function, that is, all species have the same importance in respect to quantified information that they carry, irrespective of their degree of relatedness, and role in the community processes. The development of more efficient tools to assess diversity, both taxonomic and functional, and their relation with environmental constraints has been proposed. The main premise is that communities phylogenetically (average taxonomic distinctiveness) and functionally (average functional distinctiveness) more distinct have more interest in conservation policies.

Taxonomic distinctness does not measure the number of species per se but rather the taxonomic relatedness of species in a community (Clarke and Warwick, 1998, 1999; Leonard et al., 2006). This is done by defining the path length along the taxonomic hierarchy of each species pair in the community and then averaging across all species pairs. A major benefit of this index over species richness is its virtual independence of sampling effort. Rogers et al. (1999) applied to an extensive dataset of bottom-dwelling fish in the coastal waters of NW Europe, suggesting that the use of taxonomic distinctness measures provided additional insights of relevance to biodiversity assessment. O'Connell et al. (2009) calculated taxonomic distinctness of fish assemblages from multiple estuarine regions of Southeastern Louisiana, and concluded that this method is more useful for large scale than other diversity measures. Lefcheck et al. (2014) analyzing demersal fishes in Chesapeake Bay concluded that an index of diversity derived from taxonomic hierarchy served well as a practical surrogate for functional and phylogenetic diversity of the demersal fish community. Barjau-González et al. (2016) analyzed rocky reef fish in southwestern Gulf of California and found greater anthropogenic impact would cause differences in taxonomic distinctness. To date, such approaches have not been applied for the tropics.

Functional diversity is by sure an important component of biodiversity that quantifies the difference in functional traits between organisms and explains the roles that organisms play within ecosystems. A trait-based approach to diversity is attractive because functional traits can, in principle, be directly linked to ecosystem processes (Mouillot et al., 2005, 2007; Somerfield et al.,

2008; Mouchet et al., 2010, 2013; Stuart-Smith et al., 2013; Laureto et al., 2015). Villéger et al. (2010) studied changes in taxonomic and functional diversity in the Términos Lagoon (Gulf of Mexico) of estuarine fish communities facing environmental and habitat alterations and found that three, among the four largest bay zones, did not show strong functional changes but in one of them there was an increase in fish richness but a significant decrease of functional diversity. They explained this result by a decline of specialized species, while newly occurring species are redundant with those already present. Wiedmann et al. (2014) found that trait-based methods detect substantial spatial variation in functional diversity of fish community in Barent Sea partly associated with hydrographic characteristics.

The 650 km extent of the coast of Rio de Janeiro State, Southeastern Brazil, encompasses different coastal systems, with oceanic coastal beaches predominating in the North, coastal lagoons in the Center, and large bays in the South (Fig. 1). In this study, we focused on comparing fish assemblages richness and taxonomic ($\Delta+$) and functional ($X+$) distinctiveness of fish community in these three different coastal systems that have different environmental conditions: (1) the oceanic beaches with more dynamisms and wave exposure; (2) the coastal lagoons with marked stable salinity gradient, low hydro dynamism and well protected habitats due to the narrow sea connection; and (3) the bays with a slight salinity gradient and more tidal influence. We hypothesized that these differences in the environmental conditions result in differences on richness, taxonomic and functional distinctiveness of the fish assemblages of these different systems. The following questions were postulated: 1) Do differences in environmental conditions among the three systems result in different fish assemblages? 2) Do taxonomic and functional distinctness changes among the systems? With the answers to these questions we will test our raised hypothesis and we hope to provide useful information for conservation managers.

2. Material and methods

2.1. Study area

The coast of Rio de Janeiro State, located near to the southern

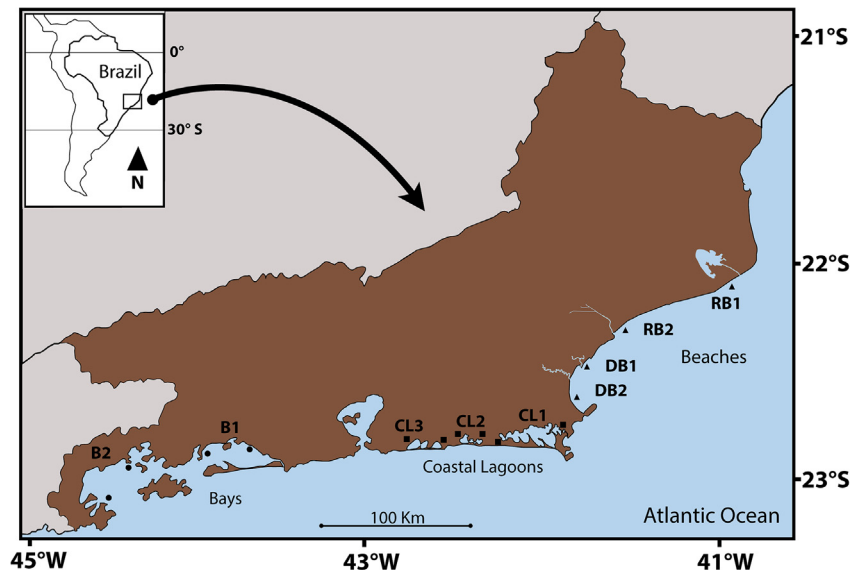


Fig. 1. Map of the study area with indication of the three coastal systems along the Rio de Janeiro State: 1) oceanic beaches, RB1 and RB2 (reflective beaches) and DB1 and DB2 (dissipative beaches); 2) coastal lagoons, Araruama (CL1) Saquarema (CL2) and Maricá (CL3); 3) bays, Sepetiba (B1) and Ilha Grande (B2).

limit of tropical region (22–23°S), have an extension of ca. 650 km, encompassing different coastal systems determined by geomorphological and ecological characteristics (Fig. 1). In the north, between Cape São Tomé Cape and Cape Frio, there is a predominance of oceanic beaches (dissipative, DB; and reflective, RD) interspersed by small estuaries; in the central area, between Cape Frio and Guanabara Bay, there is a predominance of coastal lagoons with different sea water influences (e.g., Araruama, CL1; Saquarema, CL2; and Maricá, CL3); whereas the southern area is characterized by large bays areas (e.g., Sepetiba Bay, B1; and Ilha Grande Bay, B2). Each of these three geographical areas has a shoreline extension of ca. 150–200 km and the coastal systems are ca. 80 km apart.

The sediment granulometric fractions change among the beaches. Very fine sand was higher in the outer zones of bays and coastal lagoons whereas silt and clay were higher in the inner zones. Most of the sediment in the bays was classified as fine sand according to Silva-Camacho et al. (2015). Granules and very coarse sand were comparatively higher in reflective oceanic beaches, whereas in dissipative beaches sediment had coarse sand and medium sand (Veloso et al., 2003).

2.2. Sampling design

Samplings were carried out during the day, between 10 and 16 h, twice a year (January and July), during two-yearly period (2011/2012; and 2012/2013). For the coastal lagoon and bays, four sandy beaches with different morphodynamic characteristics were sampled with four replicates, totaling 64 samples (2 years x 2 seasons x 4 beaches x 4 replicates) in each coastal lagoon (CL1, CL2 and CL3) and in each bay (B1 and B2). In the oceanic beaches, four beaches were sampled, two reflective (RB) and two dissipative beaches (DB). At each beach, hauls were performed at two sites with four replicates, totaling 58 samples (2 years x 2 seasons x 2 beaches x 2 sites x 4 replicates). Six hauls were missed because of bad weather.

The fish assemblages were sampled using a beach seine (12 × 2.5 m; 5-mm mesh size). The net was fitted with 30-m hauling ropes and set perpendicular to the shore at approximately 1.5 m depth. Seine hauls were performed by two persons, one on each end of the rope, covering an extension of approximately 30 m; hauling lasted an average of 15 min. The distance seined and the time required for each haul was standardized, thus allowing comparison among samplings. The total sampled area was taken to be the distance the net was laid offshore multiplied by the mean width of the haul, resulting in an effective fishing area of approximately 300 m². Fish were fixed in 10% formalin, and after 48 h, preserved in 70% ethanol. All fishes were identified to the species level, counted, measured (total length in millimeters) and weighed (g). Voucher specimens were deposited in the Ichthyological Collection of the Laboratory of Fish Ecology of the Universidade Federal Rural do Rio de Janeiro.

2.3. Data analysis

The taxonomic distinctness index (Δ^+) was calculated according to Clarke and Warwick (1998) and Warwick and Clarke (2001) following the formula:

$$\Delta^+ = \left[\sum_{i < j} \omega_{ij} \right] / [S(S-2)/2]$$

where, ω_{ij} is the branch length between species pairs linking species *i* and *j* in the hierarchical classification, and *S* is the number of observed species in the sample. Species were placed within a

taxonomic hierarchy, according to Nelson et al. (2016) classification into species, genus, family and order. The average taxonomic distinctiveness ($\text{AvTD} = \Delta^+$) is simply the mean number of steps up the hierarchy that are taken to reach a taxonomic rank common to two species, and the computation across all possible pairs of species in an assemblage (see Clarke and Warwick, 1998, 1999; Warwick and Clarke, 2001). Thus, if two species are congeneric, one step (species-to-genus) is necessary to reach a common node in the taxonomic tree; if the two species belong to different genera but to the same family, two steps will be necessary (species-to-genus and genus-to-family), and so on, with the number of steps average across all species pairs. The various branch lengths in the ontogenetic phylogeny are determined by species richness in every taxonomic category. By default, equal step lengths are assumed, with branch lengths standardized so that the shortest path and the longest path in the tree are set from zero to 100. AvTD is not dependent on sampling effort (Clarke and Warwick, 2001). The randomization test was applied to indices to test the null hypothesis that the species present in any system represent a random selection from the master species list (Clarke and Warwick, 1998, 2001). Taxonomic distinctness indices and 95% confidence funnel curve were performed by routine TAXDTEST in the software PRIMER version 6 (Clarke and Warwick, 2001; Clarke and Gorley, 2006).

To identify which taxa influenced patterns of taxonomic distinctness, we compared taxonomic trees across three systems to examine how the branching patterns differed. We calculated the frequency of occurrence for each species in each system and constructed trees for each that comprised those species which occurred in at least 20% of the hauls for that system. This '20% trees' cut-level does not completely describe the classification tree for the three systems, but they do provide a qualitative guide to the type of transitions in relatedness among taxa that occurs between the systems. A similar procedure was used by Tolimieri and Anderson (2010), that studying taxonomic distinctness of demersal fishes of the California Current selected only those species which occurred in at least 50% of the hauls.

The Average functional distinctness ($\text{AvFD} = X^+$) was calculated according to Somerfield et al. (2008). They describe how the idea of taxonomic relatedness among species may be extended to incorporate functional relatedness among species, and consider how this may be used to derive functional indices. The index is supposed to reflect the similarity among species, in terms of functional traits, within each sample. Information on life history and ecological traits for each species (Supplementary Data, Table SM-1) was compiled using a range of sources, starting with Fishbase (Froese and Pauly, 2013), then searches of primary literature, regional guidebooks, and species catalogues. We converted all traits to a series of binary possibilities by scoring the trait as 1 if a species falls within a trait category and 0 if it does not.

We defined average functional distinctness (X^+) simply as the average resemblance among species in a sample. Calculation of relatedness measures and associated simulations using resemblance matrices and calculation of resemblance matrices from an aggregation file. Routines were implemented in TAXDTEST in the software PRIMER version 6 (Clarke and Warwick, 2001; Clarke and Gorley, 2006).

A Principal Component Analysis was used to represent species groups sharing similar functional traits and was performed with the software Statistica for Windows (release 7.0; StatSoft, Tulsa, Oklahoma, U.S.A.). A Permutational Analysis of Variance (PERMANOVA) based on Euclidean distance and permutation of residuals under a reduced model was performed to compare the indices among the three systems (fixed factors). Significant differences among the factors were followed by PERMANOVA pairwise comparison tests. PERMANOVA was performed with the software

PRIMER version 6.02 (Anderson et al., 2008).

3. Results

A total of 103 fish species in 16 orders, 38 families and 76 genera was found. The total number of species differed among the three systems, with 69 species being recorded in the bays, 55 species in the coastal lagoons and 46 species in the oceanic beaches (Table 1;

Table 1
Number of taxonomic categories of the three systems.

| Taxonomic level | Coastal lagoons | Bays | Oceanic beaches |
|-----------------|-----------------|------|-----------------|
| Species | 55 | 69 | 46 |
| Genus | 45 | 53 | 35 |
| Family | 26 | 31 | 22 |
| Order | 14 | 15 | 10 |
| Class | 1 | 2 | 1 |

Table 2
Means ± SE and results of PERMANOVA for comparisons of the number of species (Spp) per sample, taxonomic and functional distinctiveness indices among the three coastal systems in Rio de Janeiro State. Significant differences ($p < 0.01$) indicated in bold. CL, coastal lagoons; B, bays; OB, oceanic beaches. dg, degree of freedom; MS, mean square.

| Source of variation | df | MS | Pseudo-F | P (perm) | Pair-wise test |
|---------------------|----|--------|----------|--------------|--|
| Spp/sample | 2 | 179.23 | 12.3 | 0.001 | CL (11.9 ± 0.52) > B (10.0 ± 0.71), OB (7.3 ± 0.69) |
| Taxonomic index | 2 | 72.2 | 6.3 | 0.004 | CL (75.4 ± 0.33) > B (73.1 ± 0.75), OB (72.9 ± 0.68) |
| Functional index | 2 | 221.49 | 13.7 | 0.001 | CL (41.6 ± 0.47) > B (37.4 ± 0.67), OB (37.5 ± 0.96) |

Supplementary Data, Table SM-2).

Significant differences in the number of species per sample ($P = 0.001$), in the average taxonomic distinctiveness AvTD ($P = 0.001$), and in the average functional distinctiveness AvFD ($P = 0.004$) were found among the three systems according to PERMANOVA (Table 2). The number of species per sample was higher in the coastal lagoons compared with the bays and oceanic beaches. Similarly, the highest AvTD and AvFD were found for the coastal lagoons compared with the bays and oceanic beaches. Most of the AvTD and AvFD samples were located within the 95% confidence limit funnel. The coastal lagoons had most samples above the AvTD and AvFD average, whereas some samples of the Bays were located below the funnel significance level (Fig. 2).

3.1. Taxonomic distinctiveness

The taxonomic trees provided here, based on those species

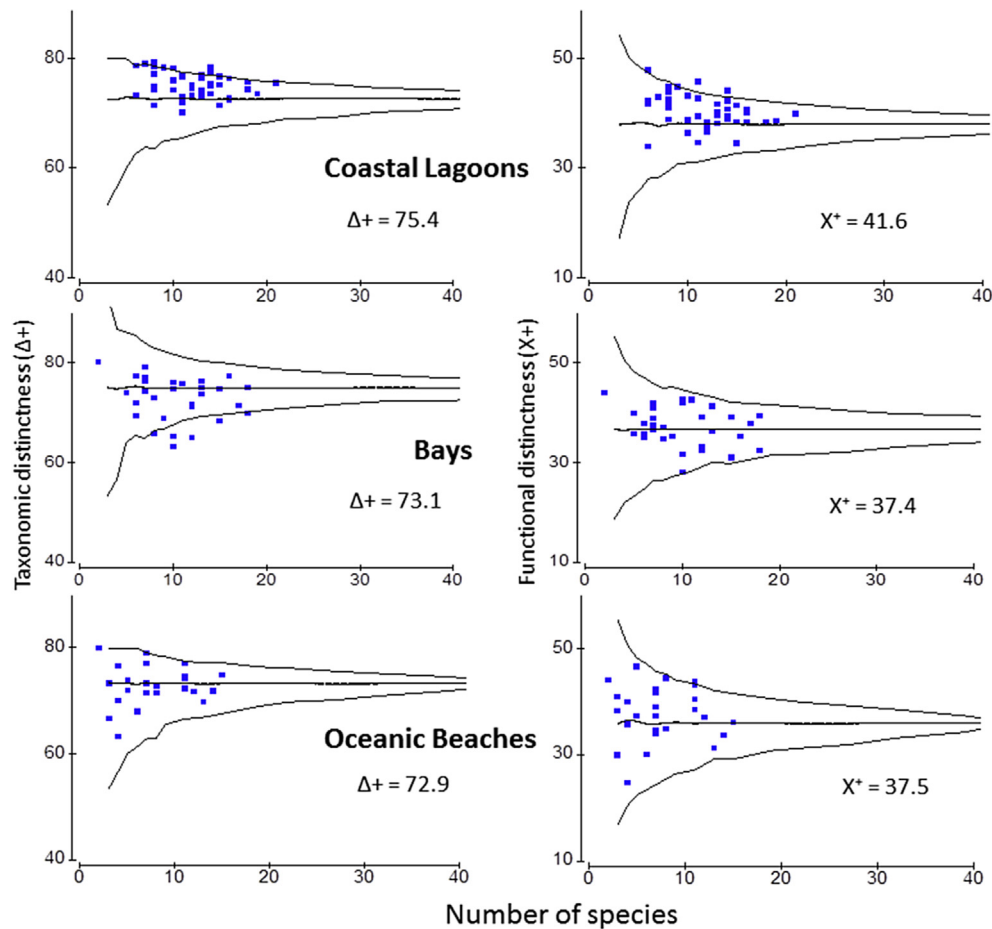


Fig. 2. Average taxonomic distinctness ($\Delta+$) and Average functional distinctness ($X+$) of fish communities from the three coastal areas in the Rio de Janeiro State. The 'expected' taxonomic distinctness and functional distinctness, in random subsamples of the fish species included in the study (dashed line) and the 95% probability limits (continuous lines) also showed.

found in at least 20% of the samples within a given system, was comprised by 20 species for the coastal lagoons, 15 species for the bays and 11 for the oceanic beaches (Fig. 3). Six orders (Cyprinodontiformes, Clupeiformes, Tetraodontiformes, Mugiliformes, Siluriformes and Perciformes) showed differences in their branching patterns. The highest number of species belongs to Perciformes (13 species) and Clupeiformes (5 species), and some orders had only one species, as the case of Atheriniformes, Elopiformes, Pleuronectiformes, Beloniformes and Syngnathiformes. The trees contained a combination of short branches and long branches, and differed in their taxa composition among the three systems. The Cyprinodontiformes order was represented by two families (Anablepidae and Poeciliidae) with a single species for each family being recorded in the coastal lagoons only. The Clupeiformes order was represented in the coastal lagoon by two families (Engraulidae and Clupeidae) with two species in each family, and the Clupeidae family containing two different genera. In the bays, this family was represented by three species in two families (*Harengula clupleola*, Clupeidae; *Anchoa tricolor* and *A. januaria*, Engraulidae), whereas in the oceanic beaches only two

species (*A. tricolor* and *A. januaria*, Engraulidae). The Tetraodontiformes order (family Tetraodontidae) had two species in a single genus in the bays (*Sphoeroides testudineus* and *S. greleeyi*) and was not recorded in the coastal lagoons and in the oceanic beaches.

In relation to the Perciformes order, five families were recorded in these three systems, but differences in families were found among the systems. In the coastal lagoons, the Gerreidae family had 2 genera and four species (*Diapterus rhombeus*, *Eucinostomus melanopterus*, *E. argenteus*, *Eucinostomus* sp.), Sciaenidae had only one species (*Micropogonias furnieri*) and Gobiidae had two genera and two species (*Microgobius meeki* and *Ctenogobius boleosoma*) in the coastal lagoons. In the bays, the Sciaenidae family had three 3 species and 3 genera (*Menticirrhus littoralis*, *M. furnieri* and *U. coroides*), Gerreidae had one species (*E. argenteus*) and Carangidae had two genera and two species (*Oligoplites saurus* and *Trachinotus carolinus*). In the oceanic beaches, the Sciaenidae family had 2 species and 2 genera (*Menticirrhus littoralis* and *Umbrina*

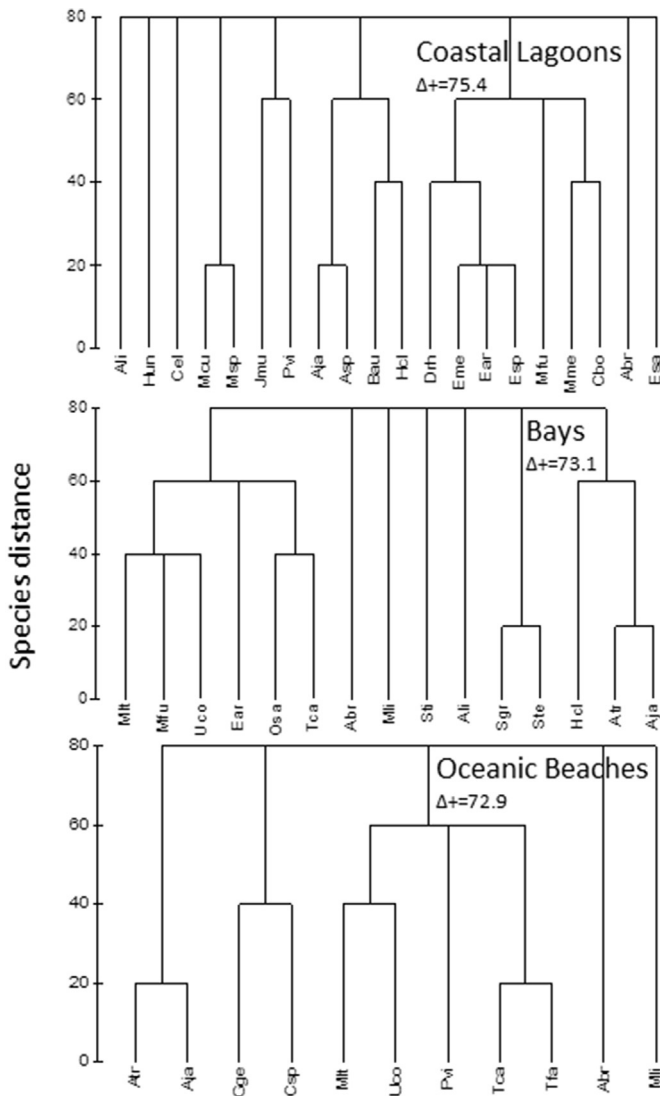


Fig. 3. Taxonomic trees for the three coastal areas in the Rio de Janeiro State. Species are those found in at least 20% of the trawls in a given system. Species code indicated in Table A3, Supporting Information.

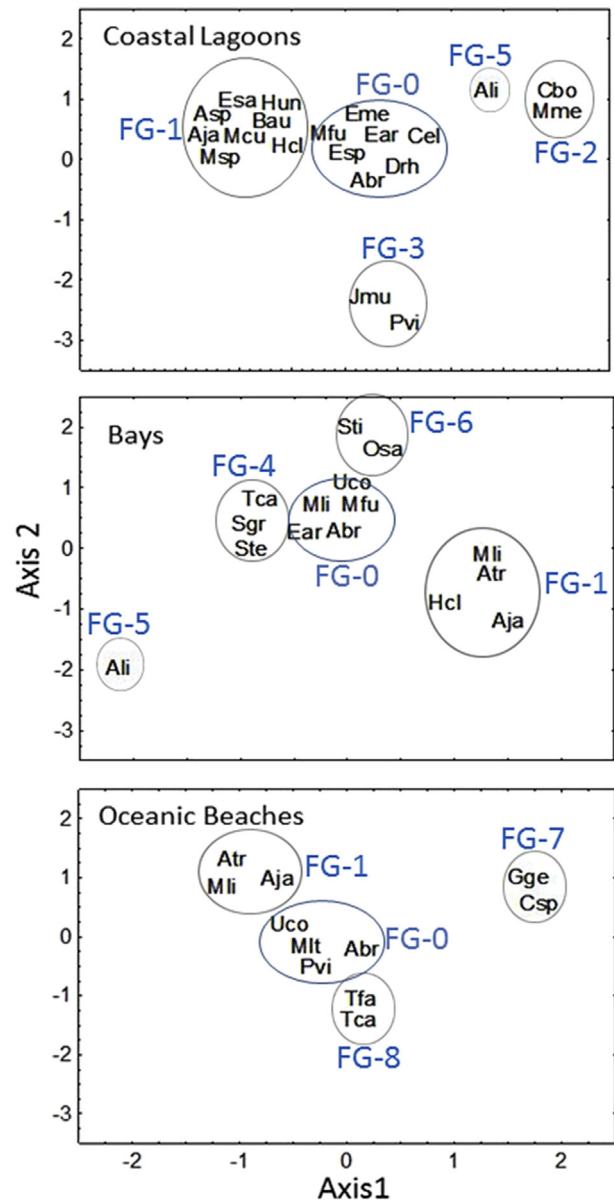


Fig. 4. Principal Component Analysis on functional traits for the three coastal areas in the Rio de Janeiro State. Species are those found in at least 20% of the trawls in a given system. Species code indicated in Table A3, Supporting information.

coroides), Carangidae had only one genus and two species (*Trachinotus falcatus* and *T. carolinus*) and Polynemidae had one species (*Polydactylus virginicus*). The Ariidae family was represented by 2 species and two genera (*Genidens genidens* and *Cathorops spixii*) only in the oceanic beaches whereas Mugilidae was represented by two species in the coastal lagoons (*Mugil curema* and *Mugil* sp.) and one species (*Mugil liza*) in the bays and in the oceanic beaches.

3.2. Functional distinctiveness

A principal component analysis on the fish traits (Fig. 4) revealed important functional groups (factor loading > 0.6) in the three coastal systems (Table 3). Generalist species with high occurrence and abundance in most habitats (Functional Group 0, FG-0) were the members of the Sciaenidae (*Menticirrhus litoralis*, *Umbrina coroides*, *Micropogonias furnieri*), the Gerreidae (*Eucinostomus argenteus*, *Eucinostomus melanopterus*, *Eucinostomus* sp., *Diapterus rhombeus*) families and the Atherinidae *A. brasiliensis* that had no significant correlation with the two first axes of the principal component analyses and were positioned near to the center of the diagram (Fig. 4; Supplementary Data, Table SM-3).

3.2.1. Coastal lagoons

Principal Component Analysis on the traits (Fig. 4) revealed that 27.27% of the variance was explained in the first component (PC1), and 17.33% by the second component (PC2). Three functional groups were identified in the first axis. A functional group, represented by the species *H. unifasciatus*, *E. saurus*, *H. clupeiola*, *B. aurea*, *A. januaria*, *Anchoa* sp. *Mugil* sp. and *M. curema* (FG-1), that have pelagic vertical distribution, elongated body shape, high mobility and external fertilization without parental care were negatively correlated with axis 1. Other functional group included the gobiids *C. boleosoma* and *M. meeki* (FG-2) that have benthonic habits, low mobility (sedentary), dorsoventrally flattened body shape, benthophagous feeding guild and external fertilization with parental

care were positively correlated with axis 1. Another functional group was negatively associated to the second axis included the cyprinodontids *Jenynsia multidentata* and *Poecilia vivipara* (FG-3) that use freshwater habitats and have opportunist feeding guilds, internal fertilization (viviparity). This functional group was exclusive of the coastal lagoons.

3.2.2. Bays

Principal Component Analysis on the functional traits (Fig. 4) revealed that 25.13% of the variance was explained by the first component (PC1) and 16.15% by the second component (PC2). Two functional groups were identified along the first axis. The first including the clupeiforms *A. tricolor*, *A. januaria* and *H. clupeiola* and the mullet *M. liza* (FG-1) that had pelagic habits and elongated body shape. These species were positively associated to axis 1. The second functional group included the species *Trachinotus carolinus*, *Sphoeroides greleeyi* and *Sphoeroides testudineus* (FG-4) that had benthonic habits, benthophagous feeding guild, and low mobility (residents) and were negatively correlated with axis 1. The third functional group was inversely associated to axis 2 and were comprised only by the flatfish *Achirus lineatus* (FG-5) that have a flattened laterally asymmetric body shape and low mobility (sedentary). Moreover, the species *Strongylura timicu* and *Oligoplites saurus* formed another functional group (FG-6) that were positively associated with axis 2 and have high mobility and piscivorous feeding guild.

3.2.3. Oceanic beaches

Principal Component Analysis of the traits revealed that 34.84% of the variance was explained by the first component (PC1) and 26.49% by the second component (PC2). Two functional groups were associated with the first axis. The first one was negatively associated to axis 1 and was comprised by the species *A. tricolor*, *A. januaria* and *M. liza* (FG-1) that have pelagic habits, elongated body shape and external fertilization without parental care. The second

Table 3

Factor scores of the principal component analysis on the traits of selected species in the three coastal areas. Species are those found in at least 20% of the trawls in a given system. Values in bold indicate greater scores (>0.6) in each axis.

| Traits | Coastal lagoons | | Bays | | Oceanic beaches | |
|--|-----------------|--------------|--------------|--------------|-----------------|--------------|
| | Axis 1 | Axis 2 | Axis 1 | Axis 2 | Axis 1 | Axis 2 |
| Pelagic | -0.81 | 0.31 | 0.80 | -0.53 | -0.60 | 0.66 |
| Benthonic | 0.81 | -0.31 | -0.80 | 0.53 | 0.60 | -0.66 |
| Elongated | -0.71 | -0.03 | 0.69 | -0.08 | -0.77 | 0.30 |
| Filiform | 0.02 | 0.11 | 0.01 | 0.50 | | |
| Flattened laterally symmetrical | 0.19 | -0.55 | -0.22 | 0.13 | 0.05 | -0.76 |
| Flattened laterally asymmetric | 0.32 | 0.22 | -0.59 | -0.60 | | |
| Cilindric | | | -0.37 | 0.08 | | |
| Flattened dorsoventrally | 0.59 | 0.32 | | | 0.90 | 0.39 |
| Mobile | -0.77 | -0.41 | 0.59 | 0.60 | | |
| Sedentary | 0.77 | 0.41 | -0.59 | -0.60 | | |
| Planktivorous | -0.49 | 0.19 | 0.65 | -0.53 | -0.42 | 0.52 |
| Piscivorous | -0.26 | 0.08 | 0.08 | 0.60 | | |
| Benthophagous | 0.72 | 0.31 | -0.62 | -0.03 | -0.23 | -0.10 |
| Hyperbenthophagous | | | -0.22 | 0.13 | -0.01 | -0.82 |
| Detritivorous | -0.38 | 0.12 | 0.36 | -0.08 | -0.37 | 0.32 |
| Opportunistic | 0.12 | -0.86 | -0.05 | 0.04 | 0.81 | 0.25 |
| External fertilization - parental care | 0.68 | 0.30 | | | 0.90 | 0.39 |
| External fertilization - without parental care | -0.66 | 0.39 | | | -0.90 | -0.39 |
| Internal fertilization - internal development | 0.14 | -0.92 | | | | |
| Resident species | 0.59 | 0.27 | -0.62 | -0.30 | 0.08 | -0.75 |
| Marine migrants | -0.54 | 0.17 | 0.44 | 0.45 | -0.58 | 0.42 |
| Marine stragglers | -0.12 | 0.15 | -0.05 | 0.11 | -0.17 | -0.28 |
| Semi-anadromous species | -0.26 | 0.08 | 0.42 | -0.38 | 0.65 | 0.57 |
| Freshwater | 0.14 | -0.92 | | | | |
| Eigenvalues | 6.27 | 3.99 | 4.76 | 3.04 | 5.57 | 4.24 |
| % total variance | 27.27 | 17.33 | 25.13 | 16.15 | 34.84 | 26.49 |

group was positively associated to axis 1 and was comprised by the marine catfish *Cathorops spixii* and *Genidens genidens* (FG-7) that have benthic habits, flattened body shape, opportunistic feeding guild and external fecundity with parental care. Occurrences of ariids were associated to the proximity of small estuaries in the area. A functional group formed by the carangids *Trachinotus falcatus* and *T. carolinus* (FG-8) have symmetrical laterally flattened body shape, hyperbenthophagous feeding guild, and resident habitat use. This group was negatively correlated with axis 2.

4. Discussion

The coastal lagoons had the highest taxonomic distinctiveness compared with the bays and oceanic beaches, which imply that this type of tropical coastal system has environmental characteristics that enable a more diverse ichthyofauna. Although the bays had the highest total number of recorded species, the AvTD and the number of species/sample was highest in the coastal lagoons, which can be a reflex of their largest environmental gradient. For example, brackish fishes species of the Cyprinodontiformes order were recorded only in coastal lagoons, which is associated to freshwater influences, thus confirming the highest salinity gradient in these systems. Fish distribution is influenced by changes in their local habitat features and salinity is a main factor to influence distribution of fish species at local scale (Barletta et al., 2005). Franco et al. (2006) found strong habitat influence structuring the fish assemblages of the Venice Lagoon (North Adriatic Sea) that support specialized and recognizable fish assemblages, especially the “transition” habitats, with highly variable fish assemblages. Mouillot et al. (2007) reported that salinity was positively related diversity of fishes in two coastal brackish lagoons of southern France. Franco et al. (2014) found a well-defined salinity gradient in all these three studied coastal lagoons, which is likely to be attributed to their narrow connection with the sea and low rainfall in the area (Knoppers, 1999), thus favoring the extended salinity gradient, and consequently diversified fish fauna.

Differently from the coastal lagoons that had values of AvTD within the expected values as indicated by the funnel, some samples from the bays had values below the confidence limit. These samples can be associated to eventual habitat disturbances since some habitat types may have naturally lower values of taxonomic distinctness than others. According to Clarke and Warwick (1998), the taxonomic distinctness values do not fall below the lower boundary of the 'funnel' unless the habitats are degraded in some way. The increased human activity in the Sepetiba Bay and Ilha Grande Bay shorelines probably contributed to degrade habitats and to increase pollution in the area (Copeland et al., 2003; Leal Neto et al., 2006; Molisani et al., 2006; Teixeira-Neves et al., 2015) thus influencing fish richness as reported by Pessanha and Araújo (2003) and by Pereira et al. (2014). However, most of samples in the two bays were within the expected values for taxonomic distinction despite some the sites locations to be near impacted shoreline by human activities.

The oceanic beaches are the systems with higher habitat homogenization compared with coastal lagoons and bays and this was reflected in the lowest total number of species recorded. The surf and swash zones of oceanic beaches are environments where the wave energy is the driving force of most of the physical, chemical and biological processes (Bennett, 1989), with high instability due to wave exposure (Romer, 1990). It is likely that because of the stress in the surf zones, the oceanic beaches, especially the reflective beaches suffer a taxa reduction with predominance of highly adapted species to such dynamic conditions. According to Niang et al. (2010), the continuous wave exposure in these oceanic beaches although cause stress in fish, also contribute to enhance

feeding availability to species that can cope with such dynamics conditions, whereas in dissipative beaches comparatively calmer waters contribute to slight increases in species richness.

Unlike taxonomic distinctiveness, all samples of functional distinctiveness were located within the confidence limits for the bays, suggesting that the absence of some taxa did not interfere in the functional role of the assemblages. Somerfield et al. (2008), also found that changes in taxonomic distinctiveness does not necessarily imply in changes in functional distinctive in fish the North Sea. In this study, the majority of the functional groups are taxonomically related. The Clupeidae and Engraulidae family formed consistently the functional group of planktivorous in all the three systems (FG-1). Moreover, the generalist and wide abundant species also formed another functional group (FG-0) common in the different systems. On the other hand, two species of the Carangidae of the *Trachinotus* genus formed the functional group of hyperbenthivorous (FG-8) in the oceanic beaches only, while the Cyprinodontiformes order were freshwater species (FG-3) recorded in the coastal lagoons only. The species of the Gobiidae family (FG-2) were also present only in the coastal lagoon, associated with low salinity and benthonic habits.

Our results reveal that average functional distinctness is not independent of taxonomic distinctness. This is expected, but the weakness of the relationship suggests that both indices may prove useful, because they are not constrained to convey the same information. Birkhofer et al. (2015), studying terrestrial arthropods also revealed that functional distinctness increased significantly with increases of taxonomic distinctness suggesting a high functional redundancy, that is, several species can support the same function of taxonomically closely related species. However, Mouillot et al. (2014) indicate that, even in highly diverse systems like coral reefs, we can no longer assume that the loss of species diversity can be discounted by the high probability of functional redundancy. Indeed, they show that fish species tend to disproportionately pack into a few particular functions while leaving many functions highly vulnerable, i. e., they are supported by just one or few species. In the present study, the oceanic beaches seem to be the most vulnerable system, because there are only one or few species fulfilling key functional roles which may be least able to withstand eventual disturbances.

Species of the Sciaenidae and Gerreidae families and the Atherinidae *A. brasiliensis* formed the group of generalist and abundant species common in the three environments, which means that although they are taxonomically different, they share similar traits and behavior in the different systems. According to Guedes et al. (2014), Polychaeta was the most important food source in Sepetiba bay for the gerreids species *Eucinostomus argenteus*, *Eucinostomus gula* and for the Sciaenidae *M. furnieri* categorizing these species in the Polychaeta Eaters guild. The Gerreidae species were better represented in the coastal lagoons than in bays and oceanic beaches, whereas the members of the Sciaenidae family were better represented in the bays and oceanic beaches compared with the coastal lagoons. The Atherinidae *Atherinella brasiliensis* inhabits coastal regions mainly near to mangroves and is considered a resident species in different coastal areas, being widely distributed in different ecosystems in the State of Rio de Janeiro (Pessanha and Araújo, 2001; Neves et al., 2006).

Trophic guild and body shape seem to separate most functional groups of beaches, lagoons and bay. Recent studies have attempted to elucidate trophic pathways on sandy beach ecosystems, pointing out that trophic pathways and food web complexity can be strongly linked to morphodynamic factors (Lercari et al., 2010; Bergamino et al., 2011; Gravel et al., 2016). Bergamino et al. (2013) revealed that the dissipative beaches (wide and flat) and the reflective beaches (narrow and steep) in the Uruguayan coast had differences

in the structural properties of the fish community food web. The reflective beaches had higher degree of connectance and proportion of omnivorous species, but lower trophic levels, lower number of trophic links between species, and proportion of intermediate trophic species than the dissipative beaches. Moreover, consumers in the dissipative beaches seem to have more generalized diets than consumers in the reflective beach, which coincide with our findings, with predominance of planktophagous, benthophagous and piscivorous in bays, and benthophagous and opportunistic in the coastal lagoons and hyperbenthivorous in the oceanic beaches. These suggest differences in the ecosystem functioning, especially in relation to the food web among the three systems.

The body shape of the fish clearly influence its ecological performance and habitat use, corroborating the link between basic form and ecological function (Gibran, 2010; Oliveira et al., 2010; Soares et al., 2013; Pessanha et al., 2015). In our study, fish with larger swimming activity that also have a more elongated body shape occurred in all three systems, with some differences in the attributes for each system. Changes in the fish body shape might be a clear sign of exploitation of the habitat. For example, fishes with depressed bodies exploited the sediment because they reduce hydrostatic pressure that tends to lift them up from the substrate as found in the bays with laterally asymmetric flattened body shape species represented by flatfishes in bays and coastal lagoon, whereas those with dorsoventrally flattened body shape represented by the gobies *C. boleosoma* and *M. meeki* were recorded in the coastal lagoons only. Moreover, the symmetrical laterally compressed fishes dwelling the water column with body position to suck small prey items from the water column were found in the oceanic beaches as the carangid *T. falcatus* and *T. carolinus*.

Different habitat types within each system are likely to offer different resources (e.g. food resources or shelter) and the use of these habitats may be part of species life cycle (Meyer and Posey, 2009; Able, 2005; Sheaves, 2016). Some patterns of habitat use were detected in this study. For example, the abundant opportunist atherinid (*A. brasiliensis*), species of Clupeiformes that form a functional group of mobile pelagic species that are planktophagous, and the Sciaenidae and Gerreidae that form a functional group of benthic benthophagous species are common in the three systems. Moreover, the wide range of salinity favored the use of Cyprinodontiformes and gobies in the coastal lagoons, whereas a more restricted number of species is adapted to the high hydrodynamism and homogeneous habitats of the oceanic beaches, namely the laterally flattened species of the *Trachinotus* genus (benthic) and the anchovies (planktivorous). The bays have some typical species as the low mobile laterally flatted flatfish *Achirus lineatus*, and the high mobile piscivorous *Strongylura timucu* and *Oligoplites saurus*.

Young fishes are often dependent on nearshore coastal habitats for their survival, and protecting these habitats may be crucial for maintaining strong adult stocks. Using taxonomic and functional distinctness for conservation plan is consistent with innovative approaches promoting the protection biodiversity. The three studied systems seem to have differentiated taxonomic and functional structure of fish assemblages and we suggest that the coastal lagoon should be prioritized in conservation programs because they support more taxonomic and functional distinctness. With this understanding, we believe that manage coastal habitats connecting science to conservation and management action is a step forward to protect biodiversity.

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Appendix A. Supplementary data

Supplementary data related to this chapter can be found at <http://dx.doi.org/10.1016/j.marenvres.2017.05.007>.

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