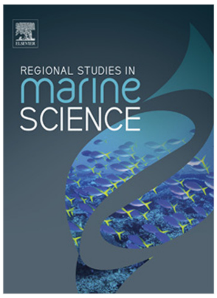

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Highlights

Highlights

Surf-zone fish communities may be influenced by estuarine and marine contributions.
Distance from estuaries, salinity, temperature, and rainfall best predicted spatial and seasonal changes.
The presence of juveniles and recruits from most species supports the surf-zone nursery hypothesis.

Spatial and Seasonal Patterns of the Surf-Zone Ichthyofauna on a Tropical Atlantic Dissipative Coastline

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Abstract

The surf-zone of twelve sandy beaches on a tropical Atlantic dissipative coastline (Sergipe, Brazil) was studied to assess whether fish assemblages may be affected by spatial (proximity to estuaries) and seasonal (wet vs. dry) variations. Sampling locations were classified into sites of greater estuarine (EC) and marine (MC) contribution according to the coastal geomorphology. Samples were obtained by beach seining, and selected environmental variables including distance from estuarine mouths were recorded for each location. A total of 2134 fishes belonging to 21 families and 33 species were collected. The eight most abundant species were *Mugil liza, Anchoa januaria, Polydactylus virginicus, Atherinella brasiliensis, Caranx latus, Trachinotus carolinus, Menticirrhus littoralis,* and *Trachinotus goodei*. Species abundance varied significantly between sites and seasons, and taxonomic distinctness only between sites. Distance from estuaries, water salinity and temperature, and rainfall were the best predictors of the spatial and seasonal changes of fish assemblages in the surf-zone of tropical Atlantic dissipative sandy beaches. The occurrence of juveniles and recruits from most of the species recorded supports the nursery habitat hypothesis of shallow surf-zones.

Keywords: Fish, Sandy beaches, Taxonomic Diversity, Brazil

1. Introduction

The surf-zone of sandy beaches is a highly dynamic environment (Calliari et al., 2003) characterized by low diversity and high dominance of fish species that are evolutionarily adapted to the high wave energy, and constant changes in environmental conditions (Monteiro-Neto et al., 2003; Palmeira and Monteiro-Neto, 2010; Olds et al., 2018). The shallow depths and high turbulence of surf-zones provide favorable conditions with high growth potential and low mortality risk for juvenile fishes (Rodrigues and Vieira, 2013; Oliveira and Pessanha, 2014). Able et al. (2013) observed that in exposed beaches, several species successfully used surf-zone habitats as nurseries, meeting all of the functional criteria as a nursery, such as juvenile and larval occurrence, growth and survival.

Surf zones may favor connectivity for migrating species between coastal habitats and nearshore waters (Olds et al., 2018; Gutierrez-Martinez et al. 2021). According with Mosman et al. (2020), they serve as corridors connecting estuaries, seagrass meadows, and coral and rocky reefs as fish move through these zones to feed, spawn and disperse. Nevertheless, while some species of anchovies (*Anchoa* spp.), herrings (*Sardinella brasiliensis*), and mullets (*Mugil* spp.)

are transient migrants within surf-zones (Felix et al. 2007), others such as pompanos (*Trachinotus* spp.) and kingcroaker (*Menticirrus* spp.) show greater site fidelity remaining in this habitat for longer periods (Monteiro-Neto et al., 2003; Able et al., 2013).

Surf zones are not homogeneous habitats for fish, and may be influenced by adjacent habitats as species and individuals move across seascapes (Mosman et al., 2020). Those beaches located in the vicinity of estuaries may be specially affected, accumulating juvenile fishes during migrations between marine and estuarine habitats (Able et al., 2013, Araújo et al., 2018). Still, studies addressing the influence of estuaries on fish assemblages along a distance gradient from the estuarine mouth across open ocean surf zones are scarce. Strydom and d'Hotman (2005) found a high proportion of estuarine dependent fish larvae in a non-estuary associated surf zone in South Africa. Mosman et al., (2020) observed that fish assemblages differed in species richness and abundance between offshore bars and nearshore troughs in relation with distance from estuaries, among other factors.

Proximity to adjacent habitats (e.g., rivers, rocky shore lines, islands) may also determine seasonal patterns on surf zone fish assemblages, often related to food availability, presence of predators, and breeding periods (Gutiérrez-Martínez et al., 2021). These, in fact, may be controlled by seasonal changes in multiple environmental factors including, but not limited to, water temperature and salinity, currents, waves and tides (Monteiro-Neto et al., 2003; Felix et al., 2007; Olds et al., 2018).

This study used the surf zones of dissipative ocean beaches to assess and compare if marine surf zone fish assemblages may be affected by the proximity of estuaries. We further explored possible seasonal effects as an additional factor modulating assemblage structure. We used as a model system, ocean beaches on the State of Sergipe in the tropical Brazilian coast of the southwestern Atlantic, in which long stretches of sandy beaches are interrupted by five estuarine systems. Furthermore, this is one of the least studied beaches stretches from the tropical southwestern Atlantic, and from which records are limited, mostly or coming from fisheries data (Freire and Araújo, 2016; Freire et al., 2014, 2017). To investigate these questions the following hypotheses were formulated: a) are there any differences in fish assemblages between sandy beach surf zones beaches under estuarine (near) and marine (far) influence? b) do seasonal changes affect fish assemblages? c) What environmental variables are the most correlated drivers responsible for these changes?

2. Materials and Methods

2.1. Study Area

The coastline of the state of Sergipe is part of the East Brazil Shelf Large Marine ecosystem, located in the northeastern Brazil marine ecoregion (Spalding et al., 2007; Freire et al., 2008). Sandy beaches of unconsolidated sands overlapping the Barreiras formation characterize the shoreface. The coastal plain is interrupted by five estuarine systems (São Francisco, Japaratuba, Sergipe, Vaza Barris, Piauí/Real) formed during the last Holocene transgression (Rossetti and Góes, 2009). Samples were collected from twelve sites distributed along the following dissipative beaches throughout the coast: Saco, Dunas, Abaís, Caueira, Viral, Aruana, Havaizinho, Farol, Atalaia Nova, Jatobá, Pirambu and Ponta dos Mangues (Fig. 1). Sampling locations were classified based on the greater contribution of estuarine (less than or equal to 2 km from estuaries) and marine waters (more than 2 km from estuaries). Saco (2.0 km), Viral (2.0 km), Farol (1.0 km), Atalaia Nova (1.5 km), Pirambu (1.0 km), and Ponta dos Mangues (0.5 km) received a greater contribution from the closest adjacent estuary (estuarine contribution sites – EC) and were subject to less wave exposure. Other sites (Dunas – 10.0 km, Abaís – 14.0 km, Caueira – 6.0 km, Aruana – 9.5 km, Havaizinho – 9.0 km, and Jatobá 20.0 km) showed a well-developed surf-zone (more than 100 m wide) with several bars and waves reaching as high as 2 m in the outside breakers (marine contribution sites – MC).

2.2. Sampling

Six sampling events were conducted between January and August 2013, including three in the dry season (dry period - January, February and March; average rainfall = 37 mm) and three in the wet season (wet period - June, July and August; average rainfall = 253 mm). Fishes were collected with a trawl-type beach seine 9.0 m long; 2.5 m high, with a bar mesh size varying from 13.0 mm in the body to 5.0 mm in the cod-end (Lombardi et al., 2014, Araújo et al., 2018). At each collection point, three hauls of approximately 40 m parallel to the coast were conducted mostly at low tide, but always within the late ebbing – early flooding tides, at a maximum depth of approximately 1.5 m (about 20 m from the swash zone). Seine hauls were separated from each other by a distance of five meters to minimize contagion between samples (Felix et al., 2007). The total number of samples was equal to 216. Samples with zero occurrences of species (n = 26) were removed from further analyses. A species accumulation curve, based on the bootstrap estimator, was used to evaluate whether the sampling effort was adequate (Colwell, 2013).

In each sampling location, seawater salinity and temperature (°C) were measured with a YSI Model 30 handheld salinity, conductivity and temperature system. Dissolved oxygen (mg/L) was measured with a WTW Oxi 315i handheld oxygen meter in combination with a DurOx® 325 galvanic sensor. Daily rainfall data from seven meteorological stations located in the coastal zone of Sergipe were obtained from the Brazilian center for weather forecast and climate studies (Sistema Integrado de Dados Ambientais do Instituto Nacional de Pesquisas Espaciais - SINDA-

INPE). These data were used to calculate average values of accumulated rain, five days prior to each sampling day, following a procedure similar to that adopted by Tubino et al. (2007). Distances between sampling points and the nearest estuary were obtained from the Google Earth measuring tool, and GPS coordinates (Garmin 76 CSX) taken at sampling sites.

The samples were packed in labeled plastic bags, fixed in buffered formalin diluted to 10% with local seawater, and transported to the Necton Biology and Fisheries Ecology Laboratory (Laboratório ECOPESCA – UFF), where they were identified to species level using appropriate literature (Figueiredo and Menezes, 1978, 1980a, 1980b; Menezes and Figueiredo, 1980, 1985; Cervigón et al., 1992; Silva et al., 2004). After identification, all specimens were counted, measured (total length, mm), weighed (g), and placed in the ECOPESCA-UFF ichthyologic collection (LNEP-UFF). The project was approved by the congregation of the marine biology and coastal ecosystems Graduate Program from Universidade Federal Fluminense, and collections conducted under the SISBIO (Sistema de Autorização e Informação em Biodiversidade) collection permit # 15787-1, issued by ICMBio – Instituto Chico Mendes de Conservação da Biodiversidade, the Brazilian agency for biodiversity conservation. All procedures were performed in compliance with ethical issues and relevant laws.

2.3. Statistical Analysis

Fish abundance data and environmental variables were log transformed [log (x + 1)] to reduce skewness (Zar, 2010) before conducting statistical analyses. A two-factor fixed-effect permutational analysis of variance (PERMANOVA) was used to test the effects of season (dry versus wet) and site classification (EC, MC) on the following variables: abundance (number of individuals per species per haul), richness (number of species per haul), taxonomic diversity (AvTD) and distinctness (VarTD) indices, temperature, salinity, dissolved oxygen and rainfall.

PERMANOVA is a univariate or multivariate method that uses permutation to obtain p-values based on similarity measures. The method also calculates a pseudo-F, analogous to the ANOVA F-statistic, allowing a posteriori pairwise multiple comparisons between factor levels and the identification of significant interactions when present (Anderson et al., 2008). All variables were tested with 9999 permutations considering season and site classification as fixed factors. Similarity matrices were calculated using the Bray-Curtis dissimilarity index for species abundance and the Euclidean distance for other variables. To complement PERMANOVA results, and further evaluate similarities on species composition between seasons and sites, similarity percentage analysis (SIMPER) was conducted on PRIMER-E v.6 (Clarke and Gorley, 2006). Only species showing overall abundance greater than or equal to 1.0 % were included in the analysis.

Taxonomic diversity (AvTD) and distinctness (VarTD) were calculated using the master species list obtained in this work (Table 2). Species were placed within a taxonomic hierarchy following Nelson's 'Fishes of the World' (Nelson et al., 2016). The AvTD is simply the mean number of steps up the hierarchy that are taken to reach a taxonomic rank common to two species and is computed across all possible pairs of species in an assemblage (Clarke and Warwick, 2001). VarTD is a complementary index of AvTD and encompasses the evenness of the taxonomic or phylogenetic relationships between taxa. Assemblages with the same AvTD could have very different VarTD values depending on the relative proportions of taxa within each level of the taxonomic hierarchy. Like AvTD, VarTD is not dependent on sampling effort (Clarke and Warwick, 2001). To estimate taxonomic diversity indices, a hierarchical Linnean classification was used as a proxy for cladograms representing the relatedness of individual species. These analyses are an indicative measure of the taxonomic distance of an assemblage and the relatedness of its constituent species based on presence/absence data and are not dependent on sampling effort (Clarke and Warwick, 2001).

The relationship between fish community and environmental variables (water temperature - ^{o}C, salinity and dissolved oxygen – mg/L, average rainfall in the preceding five days before sampling – mm, and distance from nearest estuary – km) was investigated by Canonical Correspondence Analysis (CCA) (Legendre and Legendre, 2012). The primary matrix consisted of log transformed [$\log_{10}(x+1)$] abundance data of fish species (row) per sample (column), and the secondary matrix included the log transformed environmental variables. Monte Carlo permutation tests were employed to determine the statistical significance of the main correlations, and their relative contribution to the final model. Only statistically significant variables were maintained. A similar procedure was applied to determine the statistical significance of the first four canonical axes. This analysis was entirely performed on CANOCO for Windows 4.5 (ter Braak and Smilauer, 1998).

3. Results

The PERMANOVA showed significant differences between seasons for water temperature, dissolved oxygen and rainfall. Average water temperature was higher during the dry season, and dissolved oxygen in the wet season when temperatures were low and rainfall reached an average of 252.29 mm. Salinity showed significant interaction between seasons and sites. In the dry season average salinity remained around 32, regardless of the sites, whereas in the wet season EC sites showed an average salinity of 28, about two points below when compared to MC sites (Table 1, supplemental material T1).

A total of 2,134 individuals belonging to 33 fish species and 21 families were captured. Families with higher species richness included Carangidae (7), Sciaenidae (3), Gerreidae, Mugilidae, Clupeidae, and Tetraodontidae (2). The remaining families were represented only by a single species. Eight species together comprised more than 90% of total numerical abundance, and with the exception of *Trachinotus goodei* Jordan and Evermann, 1896, showed frequency of occurrence above 25%. The five most abundant species *Mugil liza* Valenciennes, 1836, *Anchoa januaria* (Steindachner, 1879), *Polydactylus virginicus* (Linnaeus, 1758), *Atherinella brasiliensis* Quoy & Gaimard, 1825, *Caranx latus* Agassiz, 1831 together represented nearly 75% of the total numerical abundance, whereas 21 species with individual numerical abundances of less than 1% accounted for 64.5% of the total catch (Table 2). The species accumulation curve and bootstrap analysis was not fully stabilized, despite of the sampling effort implemented (supplemental material F1).

Two-Way PERMANOVA on species abundance showed significant differences for both, sites and seasons, with non-significant interaction. Between sites, species abundance on EC was higher than MC (pairwise test: 2.14, P = 0.02). Seasonally, abundance on the wet period was nearly twice as high than the dry period (pairwise test: 2.37, P = 0.008) (Tables 2 and 3).

Species richness did not show significant differences between any of the factors analyzed (Table 3). Nevertheless, 29 species (11 exclusive occurrences) occurred in EC sites, against 22 species (four exclusive occurrences) in MC sites. In the wet season 26 species (11 exclusive) were recorded, whereas in the dry season 22 species (seven exclusive) were observed. Most of the exclusive occurrences were represented by one or two individuals, with the exception of *Diapterus rhombeus* (Cuvier, 1829) (dry), *Mugil curema* Valenciennes, 1836 (wet), *Sphoeroides testudineus* (Linnaeus, 1758) (EC, wet), *Elops saurus* Linnaeus, 1766 (EC, wet), *Opisthonema* *oglinum* (Lesueur, 1818) (EC, dry), and *Astroscopus y-graecum* (Cuvier, 1829) (EC, wet) (Table 2).

Only taxonomic distinctness (VarTD) varied significantly between sites (Table 3). PERMANOVA pairwise comparisons between EC and MC sites indicated a greater influence of EC sites on taxonomic distinctness (pairwise test: 3.001, P = 0.004). For both sites and seasons, the average taxonomic diversity (AvTD) and the variation in taxonomic distinctness (VarTD) were within the confidence interval calculated from 1000 simulations for each index, with very few exceptions. Observed differences occurred in the number of species (Fig. 2). In general, the AvTD and VarTD values were higher in wet (41.04 and 77.30) than in dry (39.87 and 38.10) seasons. Regarding the different sites, AvTD and VarTD values were higher in EC sites (41.24, 82.34) than in MC sites (39.67, 77.45). Within seasons, the AvTD for EC sites was evenly distributed in relation to the master species list, whereas for MC sites, most samples occurred above the expected value (greater taxonomic variability) in the dry season and below the expected value in the wet season (Fig. 3). In the dry season, the VarTD of most samples was below the expected variability within the master species list for MC sites but was evenly distributed for EC sites. In the wet season, most of the samples from the EC sites were below average while MC sites were evenly distributed. The bivariate simulations of AvTD and VarTD also showed a negative correlation in the samples, i.e., the greater the AvTD was, the lower the VarTD (Fig. 3).

The SIMPER analysis showed that four species, *Anchoa januaria*, *Mugil liza*, *Atherinella brasiliensis*, *Polydactylus virginicus* and *Caranx latus* contributed most to EC site, and all but *C. latus* to the wet season dissimilarities. *Trachinotus carolinus* and *M. littoralis*, contributed most for MC sites, one in the dry and the other in the wet season, respectively (Table 4).

The first two axes of CCA analysis explained 23.7% of data variation. All variables considered in the analysis were significant, and included in the model. The cumulative percentage variance of the species–environment relationship within both axes accounted for 61.0% of the biotic matrix explanation. The first axis alone explained 14.9% of the variation in species data, and accounted for 38.3% of the species-environment relation. It showed a strong negative correlation with salinity (-0.95), and positive correlation with rainfall (0.30). The second axis explained 8.8% of species data variability, and accounted for 22.7% of the species-environment relation. The axis was positively correlated with both, distance from estuaries (0.83) and dissolved oxygen (0.50), and negatively correlated with water temperature (0.60) (Fig. 3). Samples from MC sites loaded on the upper quadrants of the diagram, and EC samples loaded on the lower quadrants, showing a clear discontinuity between sites. Although seasonal patterns are less evident, EC sites showed a clear distribution towards the positive side of axis one, correlated with increased rainfall and lower salinities, and the negative side of axis two, correlated with higher water temperatures. Marine associated species (*e.g*. *Harengula clupeola*, *Trachinotus carolinus*, *Diapterus rhombeus*, *Menticirrhus littoralis*) occurred mainly in highly oxygenated waters of MC sites, away from estuaries. Estuarine associated species (*e.g*. *Polydactylus virginicus*, *Anchoa januaria*, *Mugil liza*, *Sciades herzbergii*) were present in less saline and warmer waters of EC sites.

4. Discussion

The spatial patterns of the surf-zone fish community of dissipative beaches on the coastline of the state of Sergipe were most evident than the seasonal variability. These differences were mostly related to changes in the abundance of dominant species, associated with the environmental gradients of measured variables, especially the distance from estuaries and salinity.

Species richness in the present study (33 fish species) was very low for a tropical marine habitat. Olds et al. (2018) provided a global review on surf-zone fishes and reported that areas showing an average of 33 species may be considered species-rich communities. Nevertheless, the authors also remarked that 85% of the literature reviewed was from temperate and subtropical sites. Most of the studies in surf-zones in the Southwest Atlantic reported more than 35 species per site Gaelzer and Zalmon (2008a, 2008b), Costa et al. (2017). For instance, Monteiro-Neto et al. (2003) and Lima and Vieira (2009) found 37 and 43 species, respectively, at Cassino Beach, Rio Grande do Sul. Araujo et al. (2008) captured 45 species in Ilha do Frade, Espírito Santo. Teixeira and Almeida (1998) observed 63 species occupying the surf zone of beaches in Maceió, northeastern Brazil. Another recurrent pattern of the surf-zone fish community is the numerical dominance of a small group of species (*e.g.*, mullets, pompanos, sardines) (Monteiro-Neto et al., 2003; Olds et al., 2018). Species of the genera *Mugil, Anchoa, Polydactylus, Atherinella, Caranx*, *Menticirrhus* and *Trachinotus* present in our study often occur within the ten most abundant species in surf-zones (Santana et al., 2013a; Favero and Dias, 2013; Oliveira and Pessanha, 2014; Favero and Dias, 2015).

The type and size of fishing gear (Monteiro-Neto and Musick, 1994) may influence direct comparisons of abundance data. Furthermore, the sampling strategy may influence catch efficiency of beach seines (Monteiro-Neto and Prestrelo, 2013; Lombardi et al., 2014), thereby reducing both abundance and species richness. Santana and Severi (2009) found 95 species of fish in the surf-zone at Itamaracá, Pernambuco, whereas Lira and Teixeira (2008) obtained a total of 25 species in the same area. Santana et al. (2013b) pointed out that meshes of different dimensions and the time of year that both studies were conducted were responsible for the uneven results. Nevertheless, when comparing patterns of relative abundance and fish community structure, data collected with seines of slightly different dimensions may be useful, since species diversity and catch size composition seems to be independent of gear size, within limits (Monteiro-Neto and Musick, 1994).

Our study covered an extensive geographical area, under two seasonal regimes, with the standard replicate number of hauls (*e.g*., Lasiak, 1986; Azevedo et al., 2017). Nevertheless, the species accumulation curve did not stabilize. Sampling effort directly influences the number of species found. Olds et al. (2018) found that low species richness (< 9 species) was reported in studies of short duration, limited spatial coverage or low replication. In contrast, high species richness (up to 165 species) is a common finding in studies that sample the same location over multiple years, and using multiple sampling methods. This increase in richness is a consequence of capturing rare species. The increment of rare species may have been a limiting factor to achieve a stabilized accumulation curve, since more than half of the species collected in our experiment were represented by less than 10 individuals. Freire et al. (2014, 2017), analyzing historical data of onshore competitive fishing events in the state of Sergipe, recorded a maximum of 29 species captured during all fishing events taking place on ocean beaches or close to estuaries. Several reported species, including *Caranx* spp., *Menticirrhus* spp., *Trachinotus* spp., and *Polydactylus* spp., were recurrent in our study, reinforcing our findings.

The natural variation of the observed taxonomic structure was within the confidence intervals for the expected AvTD and VarTD values, indicating low variation in richness between sites and seasons. However, the EC sites had a higher taxonomic distinctness, primarily during the wet season, than the MC sites. Similarly, a pattern of greater abundance of individuals at EC sites and the wet season was also evident, and mostly determined by changes in abundance of the top dominant species. For instance, *Mugil liza*, *Anchoa januaria*, *Polydactylus virginicus*, and *Atherinella brasiliensis*, nearly doubled their absolute number of individuals on EC sites and during the wet season. These patterns may be a consequence of their broader environmental gradient, reinforcing the importance of estuarine contribution for coastal marine habitats (Able, 2005). Many brackish water fish species of the families Mugilidae, Engraulidae, Gerreidae, Atherinopsidae, and Sciaenidae are often recorded in great abundance in estuarine areas. Thus, fish distribution can be influenced by changes in their local habitat features, with salinity being an important factor influencing the distribution of fish species at the local scale (Barletta et al., 2005; Pichler et al., 2015; Souza et al., 2018). Furthermore, Souza et al. (2018) observed that precipitation and wind direction/intensity further influenced the distribution and abundance of fish species within coastal assemblages.

CCA analysis further evidenced the influence of site discontinuities upon species abundance and richness, suggesting that distance from estuaries, water salinity and temperature, and rainfall were the best predictors of the fish assemblage within Sergipe’s surf-zone. Nevertheless, such variability in fish assemblages may be modulated by seasonal changes regulated by the rainfall season, causing changes in water salinity, mostly in EC sites. The semiarid climate and the continental shelf of the Sergipe-Alagoas basin provide a pathway for the contribution of tropical marine waters into coastal systems (Fontes et al., 2017). At the same time, estuaries with low freshwater input throughout most of the year, may behave as high-salinity coastal marine systems (Janardanan et al. 2015, Valentim et al. 2018). Nevertheless, during the wet season, continental runoff increases, and estuarine waters reach the marine boundary (Menéndez et al., 2016), disrupting the predominant homogeneity condition of the adjacent surf-zone environment. For instance, Monteiro-Neto et al. (1995) observed that rainfall played a major role for determining coastal productivity cycles in lower latitudes in the Brazilian coast. According to them, *Pomadasys corvinaeformis,* an abundant surf-zone species at Ceará state, showed changes in abundance and recruitment pulses strongly correlated with rainfall and increases in coastal productivity. A similar pattern was observed by Oliveira-Silva et al. (2008), who studied the ichthyofaunal composition of the Cubuçu and Belingue beaches in the state of Bahia, also on the Brazilian northeast coast. Souza et al. (2018), studying coastal fish assemblages and fishing yields in the neighboring state of Alagoas, observed that precipitation and wind direction/intensity determined consistent seasonal changes in the distribution and abundance of fish species. On the other hand, some estuarine species (*sensu* Monteiro-Neto et al., 2003), including Mugilidae, may use the surf-zone as a pre-recruitment habitat before moving towards estuaries (Vieira and Scalabrin, 1991). Araújo and Silva (2013) studied the biology and fishery of *Mugil curema* in the Vasa Barris River in Sergipe and reported that the species' spawning period was from March to October, with major peaks from June to September. In the present study, the congeneric *Mugil liza* occurred on EC sites in the wet season, with abundances almost two times greater than MC sites and the dry period, corroborating the previously observed patterns.

The shallow surf-zone of sandy beaches, at depths less than 1.2 m, may function as nurseries or breeding areas for some fish species (Lasiak, 1986; Able et al., 2013). In our study, recruits of *M. liza*, *M. littoralis*, *T. carolinus* and *A. brasiliensis* were dominant. These species are either geographically widely distributed or replaced by ecological equivalents such as *Trachinotus marginatus*, *Menticirrhus americanus* and *Odontesthes bonariensis* in temperate regions (Monteiro-Neto et al., 2003; Lima and Vieira, 2009; Rodrigues et al., 2014). Favero and

Dias (2013) found a high abundance of *Trachinotus, Mugil, Atherinella* and *Anchoa* off Cardoso Island in the state of São Paulo. Similarly, Oliveira and Pessanha (2014) found high abundances of *Atherinella, Lycengraulis, Polydactylus, Trachinotus* and *Mugil* off several beaches in the Mamanguape River estuary in the state of Paraiba. These data suggest that such genera are frequent and strongly linked to the surf-zone off several beaches of the Brazilian coast, across a latitudinal gradient.

On the Sergipe coast, most of the abundant species of this shallow surf-zone were represented by recruits. Only three species, *A. brasiliensis, A. januaria* and *M. littoralis*, were represented by both juveniles and adults above the size of the first maturity, supporting the nursery habitat hypothesis. The high abundance of juveniles indicates habitat use by young-of-the-year moving from offshore spawning grounds to estuarine sheltered waters. For instance, *M. liza* (Vieira and Scalabrin, 1991), among other species (Monteiro-Neto et al., 2003) have shown this movement pattern along the coast of Rio Grande do Sul State.

Understanding the distribution, abundance and diversity of surf-zone fishes in the state of Sergipe is of great relevance for species management and conservation. Many fishery resources depend on surf-zones at least during part of their life cycle (Polunin and Roberts, 1993; Dahlgren et al., 2006). Additionally, surf-zone fisheries may be locally important as recreational or subsistence activities. In fact, artisanal fisheries using trammel nets are common along the coast of Sergipe. Many species caught in the surf-zone in the present study as juveniles represent economically important species for the recreational and commercial fisheries of the state of Sergipe, including, *T. carolinus, T. goodei, T. falcatus, P. virginicus, C. latus, M. littoralis, C. chrysurus, M. liza, M. curema, Conodon nobilis, Oligoplites* spp., *Diapterus* spp. and *Caranx* spp. (Souza et al., 2012; Freire et al., 2014, 2017). Freire and Araujo (2016) reviewed a historical series (1950-2010) of the marine fishery production in the state of Sergipe, raising awareness about the exploitation of species without knowledge of their stocks, which may lead to the local extinction of endangered species. Thus, our study may help fisheries management by establishing minimal mesh sizes to reduce undersized fishes in fisheries catches within the surf-zone habitat.

The present study provides the first contribution for understanding surf-zone fish assemblages from the Sergipe coast, northeast Brazil, in Southwestern Atlantic. It also highlights the importance of the surf-zone for the maintenance and rehabilitation of marine fish community stocks, as most of the world's fisheries comprise species that spend part of their life cycle in these areas (Polunin and Roberts, 1993; Gaelzer and Zalmon, 2008a and b; Olds et al., 2018).

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FIGURE LEGENDS

Fig. 1 Coastline of the state of Sergipe and location of the 12 sampling points along the coast. Blue and green dots indicate estuarine (EC) and marine (MC) contribution sites, respectively.

Fig. 2 Seasonal taxonomic diversity (a) and distinctness (b) of the surf-zone ichthyofauna from 12 locations in the state of Sergipe, Brazil, Southwest Atlantic, classified into sites of greater estuarine (EC) and marine (MC) contribution. The central dotted line and the 95% confidence interval limit represent the expected average by the funnel-shaped solid lines.

Fig. 3 Canonical Correspondence Analysis CCA) ordination diagram (triplot) on the first two axes based on samples, species, and significant environmental variables ($P < 0 \cdot 05$) data matrices. Length and direction of arrows indicate the relative importance and direction of change of environmental variables.

Figure 1

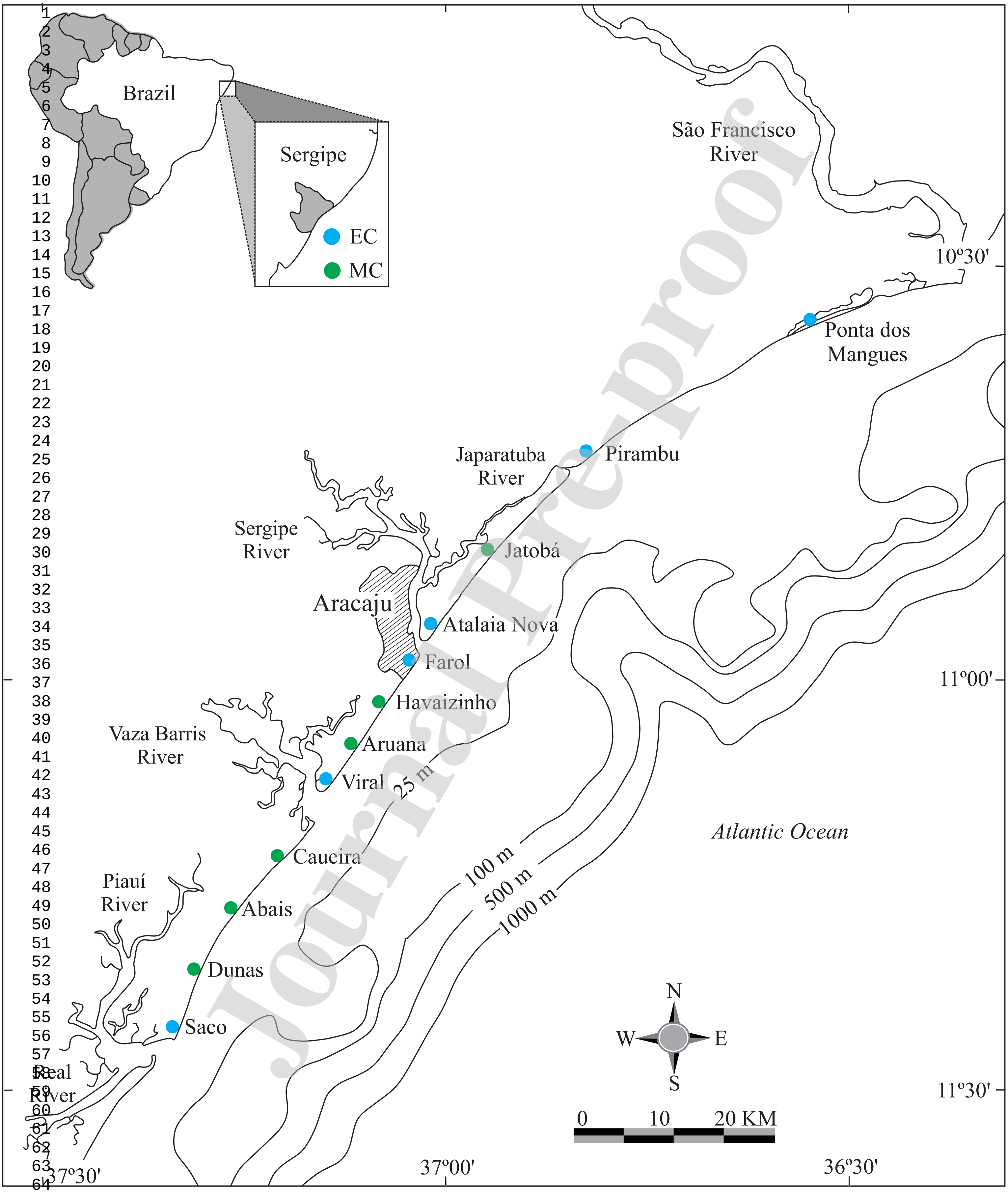
Brazil
Sergipe
EC
MC
São Francisco River
10°30'
Ponta dos Mangues
Japaratuba River
Pirambu
Sergipe River
Jatobá
Aracaju
Atalaia Nova
Farol
11°00'
Havaizinho
Vaza Barris River
Aruana
Viral
25 m
Atlantic Ocean
Caueira
Piauí River
100 m
500 m
1000 m
Abais
Dunas
N
W
E
S
Saco
Real River
11°30'
0
10
20 KM
37°30'
37°00'
36°30'

Figure 2

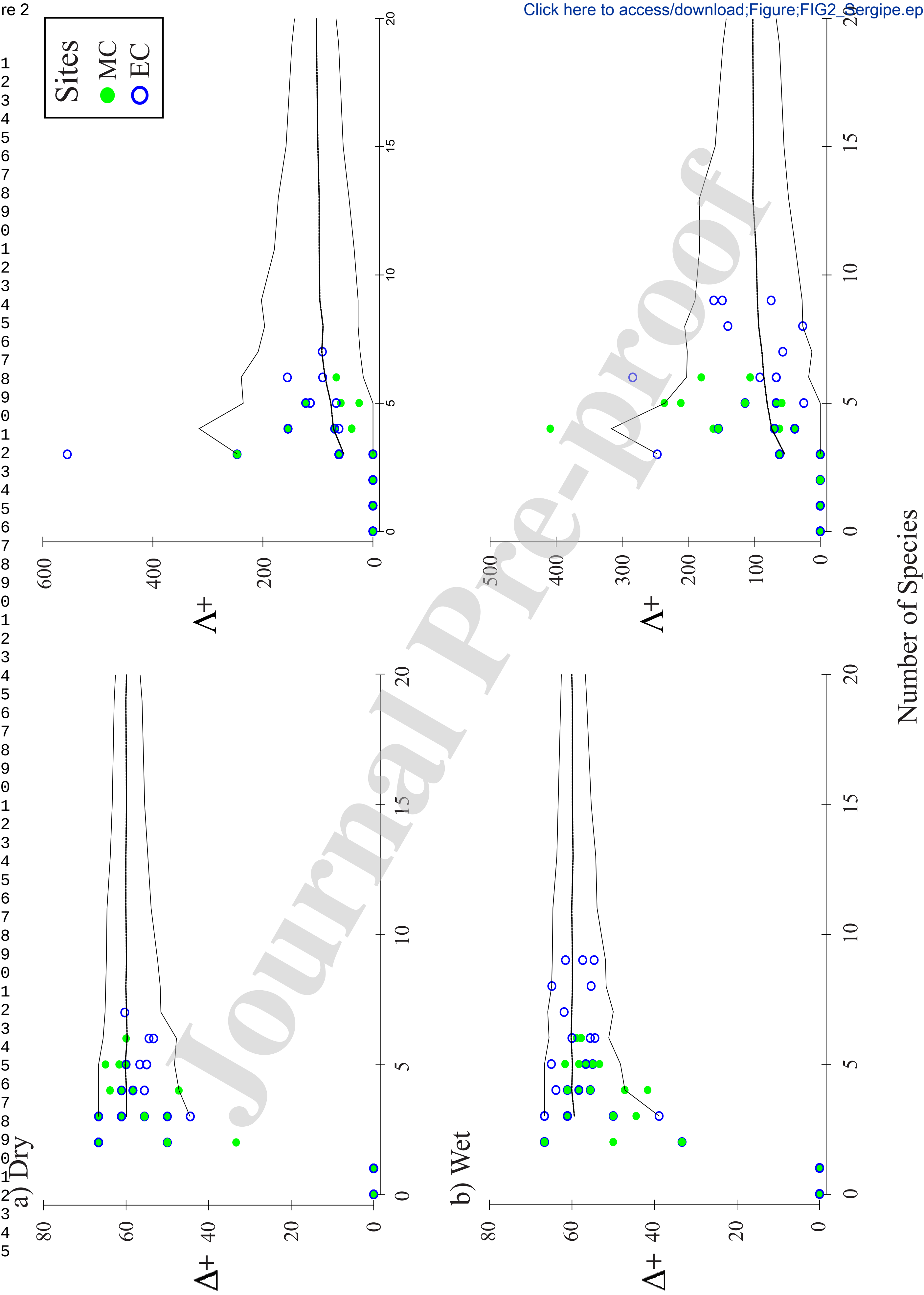
Sites
● MC
○ EC
a) Dry
b) Wet
Δ+
Λ+
Δ+
Λ+
Number of Species
0
5
10
15
20
0
20
40
60
80
0
200
400
600
0
100
200
300
400
500

Figure 3

Click here to access/download;Figure;FIG 3_Sergipe.eps

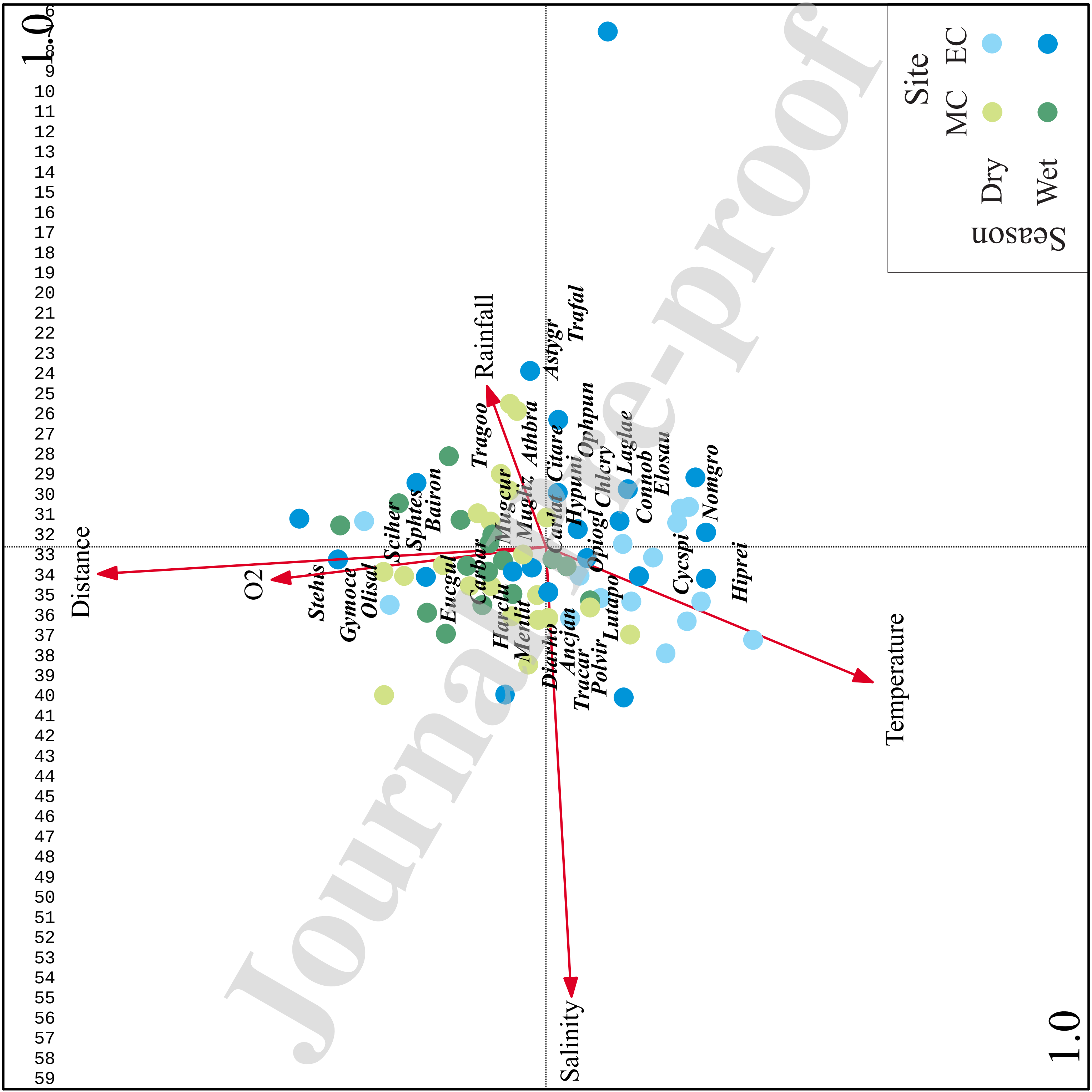

Table 1. Mean +/- one standard deviation of environmental variables for sites (EC, MC), seasons (Dry, Wet), and the interaction of sites within seasons for the sampling period in sandy beach surf zones of the state of Sergipe, Brazil, southwestern Atlantic.

Variables	Sites		Seasons		Interaction			
					Dry		Wet	
	EC	MC	Dry	Wet	EC	MC	EC	MC
Temperature (ºC)	28.2±1.5	28.3±1.2	29.2±1.1	27.4±0.9	28.2±1.5	29.2±1.0	27.2±1.0	27.5±0.9
Salinity	30.1±3.5	30.9±2.3	31.8±2.2	29.2±3.1	32.0±1.6	31.5±2.6	28.1±3.8	30.2±1.7
Disolved Oxygen (mg/L)	7.2±1.1	7.2±1.1	6.3±0.4	8.1±0.9	6.2+0.4	6.3+0.4	8.1±0.9	8.2±0.8
Rainfall (mm)	149.8±117.2	140.4±109.8	37.9±16.1	252.3±48.7	38.1+16.2	37.7±16.1	261.6±44.9	243.0±50.9

Table 2. Numerical abundance (N, %), and minimum and maximum total length (TL) of fish species captured in the surf-zone of sandy beaches on the coast of Sergipe, Brazil, distributed by sites (Estuarine – EC and Marine – MC contribution) and seasons (Dry, Wet), and ordered by their total abundance (N, %). %C is the cumulative total percent abundance. %FO is the percent frequency of occurrence of species in the total sampling effort.

Species	Family	Sites				Seasons				Total				TL (mm)
		MC		EC		Dry		Wet						
		N	%	N	%	N	%	N	%	N	%	%C	%FO	Min - Max
Mugil liza Valenciennes, 1836	Mugilidae	144	19.0	312	22.6	88	12.0	368	26.2	456	21.4	21.4	31.9	15 - 65
Anchoa januaria (Steindachner, 1879)	Engraulidae	135	17.9	231	16.8	134	18.3	232	16.5	366	17.2	38.5	39.8	22 - 171
Polydactylus virginicus (Linnaeus, 1758)	Polynemidae	87	11.5	254	18.4	112	15.3	229	16.3	341	16.0	54.5	25.9	24 - 165
Atherinella brasiliensis (Quoy and Gaimard, 1825)	Atherinopsidae	89	11.8	153	11.1	102	14.0	140	10.0	242	11.3	65.8	31.9	15 - 128
Caranx latus Agassiz, 1831	Carangidae	71	9.4	115	8.3	102	14.0	84	6.0	186	8.7	74.6	31.5	30 - 180
Trachinotus carolinus (Linnaeus, 1766)	Carangidae	82	10.8	76	5.5	81	11.1	77	5.5	158	7.4	82.0	30.6	11 - 156
Menticirrhus littoralis (Holbrook, 1847)	Sciaenidae	58	7.7	60	4.4	29	4.0	89	6.3	118	5.5	87.5	26.9	25 - 240
Trachinotus goodei Jordan and Evermann, 1896	Carangidae	15	2.0	42	3.0	5	0.7	52	3.7	57	2.7	90.2	7.4	45 - 203
Sciades herzbergii (Bloch, 1794)	Ariidae	14	1.9	22	1.6	8	1.1	28	2.0	36	1.7	91.8	7.9	82 - 157
Trachinotus falcatus (Linnaeus, 1758)	Carangidae	7	0.9	24	1.7	4	0.5	27	1.9	31	1.5	93.3	6.5	15 - 125
Chloroscombrus chrysurus (Linnaeus, 1766)	Carangidae	3	0.4	21	1.5	19	2.6	5	0.4	24	1.1	94.4	4.2	20 - 151
Harengula clupeola (Cuvier, 1829)	Clupeidae	16	2.1	8	0.6	8	1.1	16	1.1	24	1.1	95.5	3.7	52 - 90
Diapterus rhombeus (Cuvier, 1829)	Gerreidae	17	2.2	2	0.1	19	2.6	0	0.0	19	0.9	96.4	0.9	12 - 18
Mugil curema Valenciennes, 1836	Mugilidae	8	1.1	9	0.7	0	0.0	17	1.2	17	0.8	97.2	4.2	25 - 49
Sphoeroides testudineus (Linnaeus, 1758)	Tetraodontidae	0	0.0	16	1.2	0	0.0	16	1.1	16	0.7	98.0	2.3	94 - 193
Citharichthys arenaceus Evermann and Marsh, 1900	Paralichthyidae	3	0.4	6	0.4	6	0.8	3	0.2	9	0.4	98.4	3.7	68 - 149
Elops saurus Linnaeus, 1766	Elopidae	0	0.0	6	0.4	0	0.0	6	0.4	6	0.3	98.7	1.4	45 - 54
Opisthonema oglinum (Lesueur, 1818)	Clupeidae	0	0.0	5	0.4	5	0.7	0	0.0	5	0.2	98.9	0.5	180 - 196
Astroscopus y-graecum (Cuvier, 1829)	Uranoscopidae	0	0.0	4	0.3	0	0.0	4	0.3	4	0.2	99.1	1.4	31 - 42
Carangoides bartholomaei (Cuvier, 1833)	Carangidae	1	0.1	1	0.1	2	0.3	0	0.0	2	0.1	99.2	0.9	53 - 97
Conodon nobilis (Linnaeus, 1758)	Haemulidae	0	0.0	2	0.1	0	0.0	2	0.1	2	0.1	99.3	0.9	108 - 114
Hyporhamphus unifasciatus (Ranzani, 1841)	Hemiramphidae	0	0.0	2	0.1	1	0.1	1	0.1	2	0.1	99.4	0.9	48 - 140
Lagocephalus laevigatus (Linnaeus, 1766)	Tetraodontidae	1	0.1	1	0.1	1	0.1	1	0.1	2	0.1	99.5	1.4	17 - 54
Oligoplites saliens (Bloch, 1793)	Carangidae	1	0.1	1	0.1	2	0.3	0	0.0	2	0.1	99.6	0.9	179
Bairdiella ronchus (Cuvier, 1830)	Sciaenidae	1	0.1	0	0.0	1	0.1	0	0.0	1	0.0	99.6	0.5	108
Chilomycterus spinosus spinosus (Linnaeus, 1758)	Diodontidae	0	0.0	1	0.1	0	0.0	1	0.1	1	0.0	99.7	0.5	46
Eucinostomus gula (Quoy and Gaimard, 1824)	Gerreidae	1	0.1	0	0.0	0	0.0	1	0.1	1	0.0	99.7	0.5	125
Gymnothorax ocellatus Agassiz, 1831	Muraenidae	1	0.1	0	0.0	1	0.1	0	0.0	1	0.0	99.8	0.5	100
Hippocampus reidi Ginsburg, 1933	Syngnathidae	0	0.0	1	0.1	0	0.0	1	0.1	1	0.0	99.8	0.5	19
Lutjanus apodus (Walbaum, 1792)	Lutjanidae	1	0.1	0	0.0	0	0.0	1	0.1	1	0.0	99.9	0.5	189

Nomeus gronovii (Gmelin, 1789)	Nomeidae	0	0.0	1	0.1	1	0.1	0	0.0	1	0.0	99.9	0.5	10
Ophioscion punctatissimus Meek and Hildebrand, 1925	Sciaenidae	0	0.0	1	0.1	0	0.0	1	0.1	1	0.0	100.0	0.5	126
Stephanolepis hispidus (Linnaeus, 1766)	Monacanthidae	0	0.0	1	0.1	0	0.0	1	0.1	1	0.0	100.0	0.5	35
Total number of individuals		756	100.0	1,378	100.0	731	100.0	1,403	100.0	2,134	100.0			
Total number of species		22		29		22		26		33				
Number of species with exclusive occurrences		4		11		7		11						
Total number of samples with records						94		96		190				
Number of empty samples						14		12		26				
Total sampling effort						108		108		216				

Table 3. Two-factor PERMANOVA based on the Bray-Curtis dissimilarity for species abundance and the Euclidean distance for species richness, taxonomic diversity (AvTD) and distinctness (VarTD), with seasons (Dry, Wet) and sites (EC, MC) as fixed factors. Statistically non-significant (NS), significant (*), and highly significant (**) values.

Abundance	df	SS	MS	Pseudo-F	P(perm)	
Sites	1	2,536.2	2,536.2	4.596	0.019	*
Seasons	1	3,092.0	3,092.0	5.603	0.011	*
Interaction	1	479.4	479.4	0.869	0.377	NS
Residuals	187	103,740.0	551.8			
Total	190	109,740.0				
Species Richness						
Sites	1	150.3	150.3	0.514	0.480	NS
Seasons	1	574.2	574.2	1.964	0.157	NS
Interaction	1	12,296.0	12,296.0	0.042	0.916	NS
Residuals	187	54,675.0	292.4			
Total	190	55,397.0				
AvTD						
Sites	1	39.5	39.5	1.708	0.191	NS
Seasons	1	52.2	52.2	2.255	0.138	NS
Interaction	1	0.5	0.5	0.024	0.927	NS
Residuals	187					
Total	190					
VarTD						
Sites	1	33.6	33.6	9.001	0.003	**
Seasons	1	1.3	1.3	0.356	0.551	NS
Interaction	1	0.5	0.5	0.146	0.705	NS
Residuals	187	540.3	3.7			
Total	190	576.2				

Table 4. Results of SIMPER analysis showing the fish species that contributed most to the dissimilarity between sites (EC, MC) and seasons (Dry, Wet) in the state of Sergipe, Brazil, southwestern Atlantic. Percent dissimilarity contribution (PDC). Gray cells indicate the highest average abundance between paired comparisons.

Species	Average Abundance Site		PDC (%)	Average Abundance Season		PDC (%)
	EC	MC		Dry	Wet	
Anchoa januaria	2.14	1.25	16.98	0.94	2.15	17.01
Mugil liza	2.89	1.33	14.48	0.81	3.41	14.52
Atherinella brasiliensis	1.42	0.82	15.49	0.94	1.30	15.03
Polydactylus virginicus	2.36	0.81	10.95	1.04	2.40	10.88
Caranx latus	1.06	0.66	10.62	0.94	0.78	10.53
Trachinotus carolinus	0.70	0.76	8.89	0.75	0.71	9.04
Menticirrhus littoralis		0.54	6.41		0.84	6.66
Cumulative PDC (%)			83.81			83.68
Average dissimilarity between groups		89.02			88.88	

Author Statement

Author Ccntributions

1. Carine Gois do Nascimento – research development, fieldwork, data collection and database organization, writing original draft.
2. Marcus Rodrigues da Costa – Application of statistical analysis and models, data management, writing and editing the final draft.
3. Rafael de Almeida Tubino – writing, reviewing and editing.
4. Cassiano Monteiro-Neto – research conceptual framework, research planning, preparation of data presentation, final writing, reviewing and editing.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: