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ECOLOGY

# Temporal patterns of fish occurrence of the euryhaline sector of a subtropical estuary, southern Brazil

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**ABSTRACT.** Fish fauna was studied in five sites of the shallow infralittoral of the Paranaguá Bay during the period from October 1999 to September 2000. At each sampling site, fish were sampled with other trawls, salinity and temperature were measured, water samples were taken from the bottom of the water column for determination of dissolved oxygen, dissolved inorganic nitrogen and phosphate. The spatial and temporal behavior of the environmental variables was analyzed by a Principal Component Analysis; Cluster Analysis was used to gather the sampling sites, and Factorial Correspondence Analysis was applied to the most abundant species. Temperature was the most important variable for the distribution of the months, allowing the division of the study period into hot and cold months. The temporal variation in the fish fauna composition was indicated by cluster analysis, with highest percentages of dissimilarity between the sampling sites during hot months. The variation in dissimilarity between the sites occurred due to differences in the number of individuals and species of the catches. The high frequencies of occurrence of *Anisotremus surinamensis, Etropus crossotus, Genidens genidens, Micropogonias furnieri* and *Sphoeroides greeleyi* were related to high temperatures. The greatest number of fish and species observed in hot months may be related to the life cycle of many species, which reproduce in warmer months, and whose offspring use estuaries as breeding areas.

**Keywords:** fish assemblages; coastal area; abiotic conditions.

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## Introduction

Fish comprise the largest fraction of estuarine nekton due to numerical predominance and motility (Kennish, 1990). They found an environment with large variations in abiotic conditions (salinity, temperature, turbidity, pH, inorganic nutrients and organic matter), which together with biological factors such as reproduction, recruitment, and biotic interactions, such as interspecific interaction and predation, define distribution patterns, abundance and composition of the estuarine fish fauna (Kennish, 1990; Jareguizar, Menni, Guerrero, & Lasta, 2004; Barletta, Barletta-Bergan, Saint-Paul, & Hubold, 2005; Barletta et al., 2008).

According to the life cycle, estuarine fish can be divided into: freshwater species that eventually invade brackish water, truly estuarine species, migrants (anadromous or catadromous), occasional visitors and marine migrants. The latter correspond to the group of fish that reproduce in the sea, whose larvae and juveniles migrate to the estuary in search of food and shelter (Potter, Tweedley, Elliott, & Whitfield, 2015, Elliott et al., 2007).

The life cycle strategies described above and the large variation in the environmental conditions in estuaries make the fish fauna living in these environments present a great fluctuation, higher than those found in more stable environments, such as the coastal regions or coral reefs (McConnell, 1987).

The aim of this study was to examine the temporal variation of the demersal fish fauna composition in the shallow infralittoral of the Paranaguá Bay, seeking to identify the biotic and abiotic factors related, which may allow a better understanding of the ecosystem functioning, important for the adoption measures for conservation and preservation.

## Material and methods

### Study area

As for the hydrography, the coast of the State of Paraná can be divided into two major basins: Paranaguá, with 3882 $km^2$ length, and Guaratuba, with 1886 $km^2$ (Bigarella, Becker, Matos, & Werner, 1978). The Guaratuba Bay has 15 km in length where the bathymetry can reach 20 m depth near to the only one mouth (Marone, Machado, Lopes, & Silva, 2005), where occurs the main connection between the estuary and the Atlantic Ocean (500m wide), between two rocky outcrops. The hydrography basin has 1724 $km^2$, mainly supported by São João and Cubatão rivers, that inflow 80 $m^3\ s^{-1}$ on the head of the estuary (Noernberg et al., 2004). The saline stratification depends strongly on tides (spring and/or neap) and the inflow river discharge (Noernberg et al., 2006; Marone et al., 2005).

Contrasting in this context, the Paranaguá Estuarine Complex (PEC) has been classified as a coastal plain estuary (Lessa, Angulo, Giannini, & Araújo, 2000), being considered the most important estuary in the region due to its size and water flow (Knoppers, Brandini, & Thamm, 1987). The east-west axis of the PEC is influenced by river input, responding to processes related to water-column stratification, salinity intrusion, sediment supply, and the turbidity maximum zone (TMZ) (Cattani & Lamour, 2016) in addition to port dredging. The tide follows a semi-diurnal mixed pattern (type B) with hypersynchronous lateral heterogeneity (Marone et al., 1997), that can be influenced by random meteorological phenomena, resulting in amplification of amplitude and tidal currents towards the estuary head (Miranda, Castro, & Kjerfve, 2002). The maximum amplitude of the tide can reach 2.0 m with an average of 0.84 m (Knoppers et al., 1987).

Netto and Lana (1997) defined three sectors of salinity in the east-west direction of the bay: a) the euryhaline sector (average salinities higher than 30), ranging from the access bars in Ilha do Mel to Cotinga Island; b) the polyhaline sector (salinity ranging from 18 to 30), ranging from Cotinga Island to Pedras Island; c) the mesohaline sector (salinity varying between 5 and 18), comprising the region of Antonina. This study was carried out in the euryhaline sector of the bay. In this region, there are higher values of temperature, salinity, pH and dissolved oxygen compared to the innermost area of the bay (Machado, Daniel, Brandini, & Queiroz, 1997). These environmental characteristics are due to the stronger influence of sea water in this region.

### Sampling

Fish were sampled between October 1999 and September 2000, in the euryhaline sector of the shallow infralittoral of the Paranaguá Bay at five sampling sites (Figure 1). An otter trawl with lead-a-head opening length of 8 m, 6.6 m long, mesh size of one centimeter in the body and codend and two flat rectangular otter boards (0.70 x 0.47 m and 8 Kg each) were used for monthly trawls in high tide quadrature, lasting 20 minutes each. The fish caught were preserved in ice and transported to the laboratory, where they were counted and identified to the species level, whenever possible.

At each sampling site, water samples were taken from the bottom of the water column, using a Van Dorn bottle, for the determination of dissolved oxygen and nutrients (dissolved inorganic nitrogen and phosphate). Salinity and temperature were recorded with a STD SENSORDATA-SD200. Samples for nutrient determination were stored in styrofoam box with ice and transported to the laboratory. Samples for determination of oxygen were fixed in situ and kept in a dark container. In the laboratory, they were analyzed by the Winkler method according to Grasshoff, Ehrhardt, and Kremling (1983). Concentrations of ammonium (inorganic nitrogen) and phosphate were determined by calorimetric techniques according to Grasshoff et al. (1983).

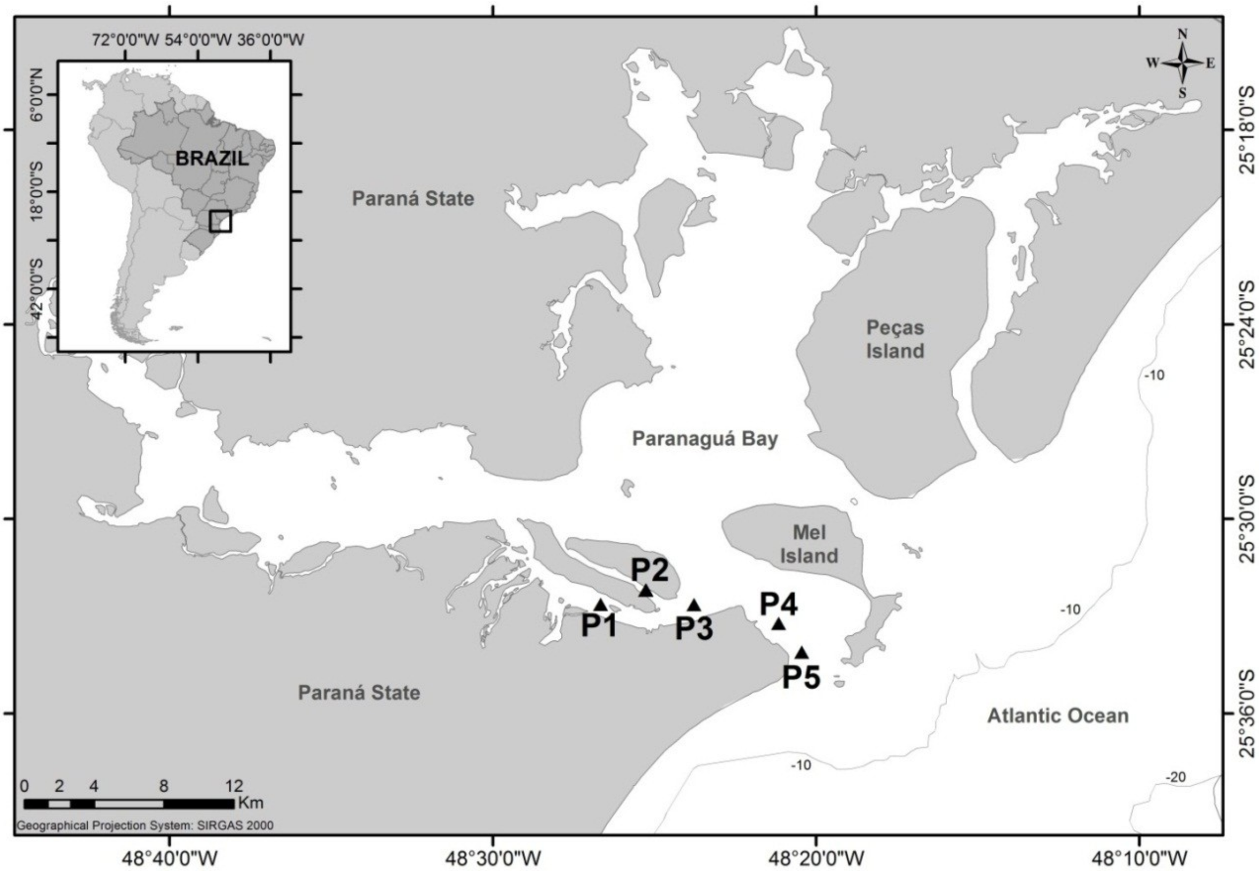


**Figure 1.** Map of the Paranaguá Estuarine Complex showing sampling sites (P1 = Papagaio, P2 = Sucuriu, P3 = Baguaçu, P4 = Ponta do Poço and P5 = Pontal do Sul)

### Statistical analysis

The spatial and temporal behavior of the environmental variables was analyzed by a Principal Component Analysis (PCA), from the standardized data matrix ((x - x) $s^{-1}$). The Cluster Analysis was used to gather the sampling sites according to the number of individuals and species, allowing the comparison of these groups in the 12 sampling months. Data were previously transformed (log x + 1) and the dissimilarity percentage coefficient was used for the analysis. A Factorial Correspondence Analysis was applied to the most abundant species aiming to check the relationship between the frequency of individuals and temperature. This analysis was performed from a contingency table, where the rows corresponded to the frequency of individuals (rare - less than 10, abundant - between 10 and 30, very abundant - greater than 30) and the columns corresponded to the temperatures (low – below 20°C, moderate - between 20°C and 25°C, high - above 25°C) (Legendre & Legendre, 1983).

## Results

### Environmental

Data of temperature, salinity, dissolved oxygen, phosphorus ($PO_4$) and diluted inorganic nitrogen (DIN) were plotted for the five sampling sites and 11 sampling months (Figure 2). The first two components explained 70% data variability, 45% explained by C1 and 25% explained by C2. The major contributions to the formation of C1 were the temperature (positive) and the concentration of dissolved oxygen (negative). In C2, the major contributions were DIN and phosphate (positive), and salinity (negative). It is possible to observe a trend of temporal distribution in the horizontal direction and a spatial distribution in the vertical direction. The points referring to the months of November, December, January, February, March and May were influenced by temperature. In the months of April, June, July, August, September and October, the greatest influence was the concentration of dissolved oxygen. In axis two, the sites located more internally in the bay (Papagaio, Sucuriu and Baguaçu) were influenced by DIN and phosphate and the most external sites (Ponta do Poço and Pontal do Sul) were more influenced by salinity.

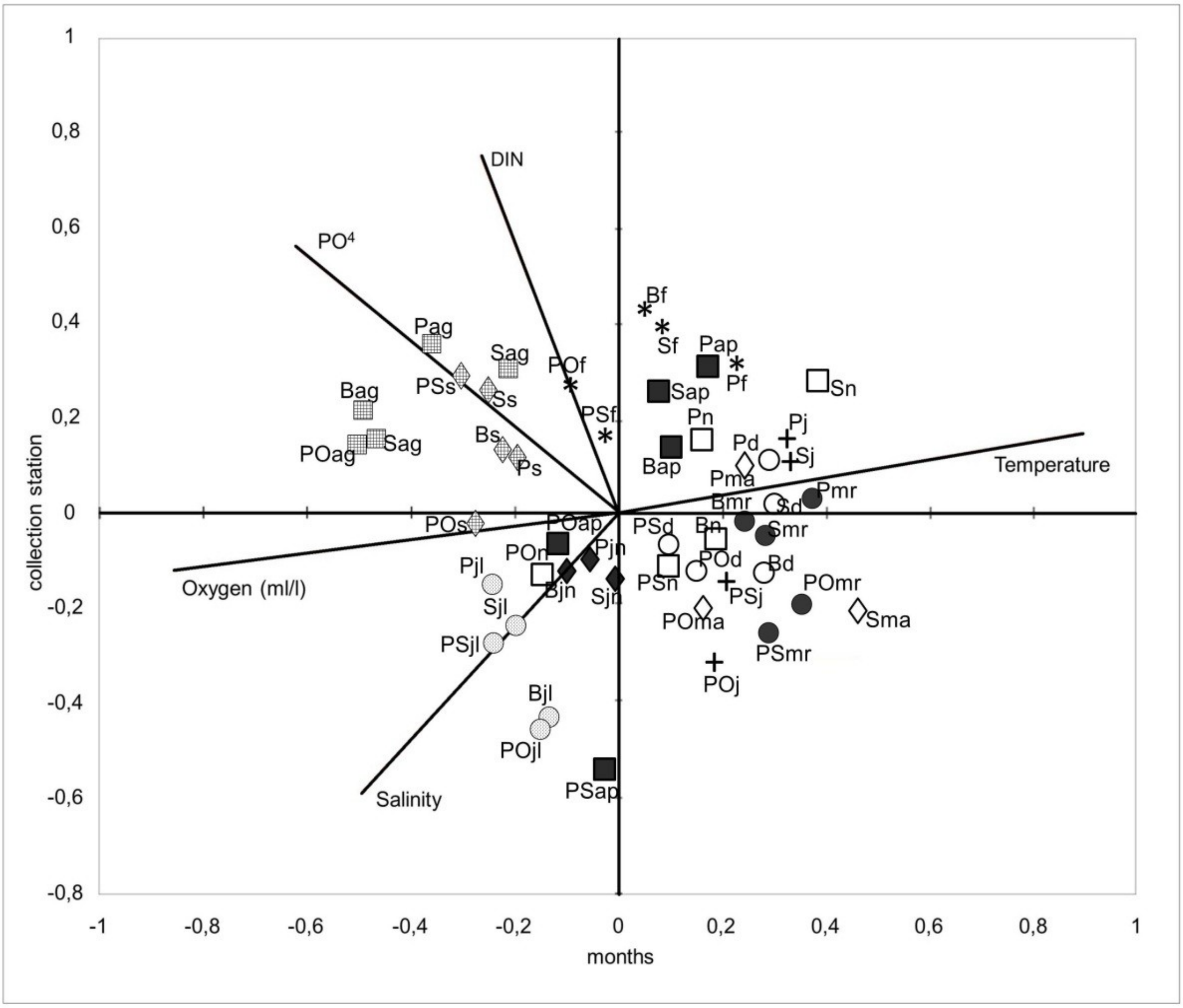


**Figure 2.** Scatterplot of PCA scores representing the distribution of sampling sites, during 11 sampling months, according to environmental variables. The sites were represented by capital letters: Papagaio (P), Sucuriu (S), Baguaçu (B), Ponta do Poço (PO) and Pontal do Sul (PS). The months were represented by symbols: November (□), December (○), January (+), February (*), March (●), April (■), May (◊), June (♦), July ( ), August ( ), September ( ). Eigenvectors with weights of the variables corresponding to axes 1 and 2 of the principal component analysis: Oxygen (F1 = -0.574, F2 = -0.107), Salinity (F1 = -0.332, F2 = -0.524), Temperature (F1 = 0.598, F2 = 0.148), $PO_4$ (F1 = -0.414, F2 = 0.495) and DIN (F1 = -0.178, F2 = 0.668).

## Species assemblage

The temporal variation in the fish fauna composition was analyzed by cluster analysis (Figures 3 and 4). In the grouping of the sampling sites, based on the composition of the fish fauna, and considering dissimilarity of 25%, it was observed that in November, December, January, March and May, three groups were formed: 1) Papagaio, 2) Baguaçu, Ponta do Poço and Pontal do Sul and 3) Sucuriu.

This pattern of grouping was not found in February and April. In February, as all sites presented dissimilarity above 25%, each site was characterized as an individual group. In all sites, a large number of species caught was observed. In April, four groups of sampling sites were formed, from the distance of 25%: 1) Papagaio, 2) Sucuriu, 3) Baguaçu and Ponta do Poço and 4) Pontal do Sul.

In June, July, August, September and October, a similar behavior was observed for the formation of clusters. From 25% dissimilarity, two groups were highlighted. The first group was represented by Sucuriu and the second group was formed by Papagaio, Baguaçu, Ponta do Poço and Pontal do Sul.

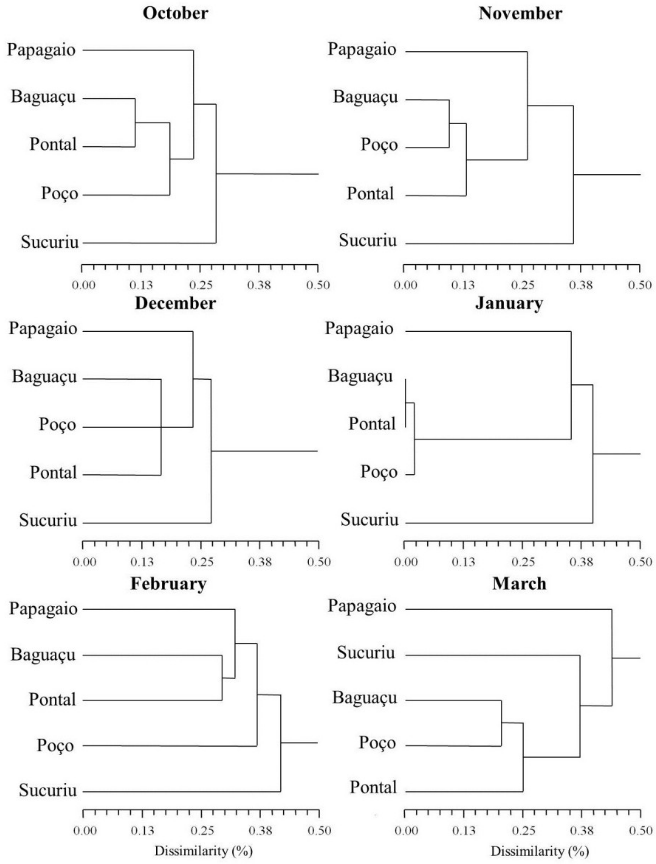


**Figure 3.** Grouping of sampling sites from October 99 to March 2000, based on the composition of the fish fauna. Cophenetic correlation coefficient varying between 0.87 and 0.89.

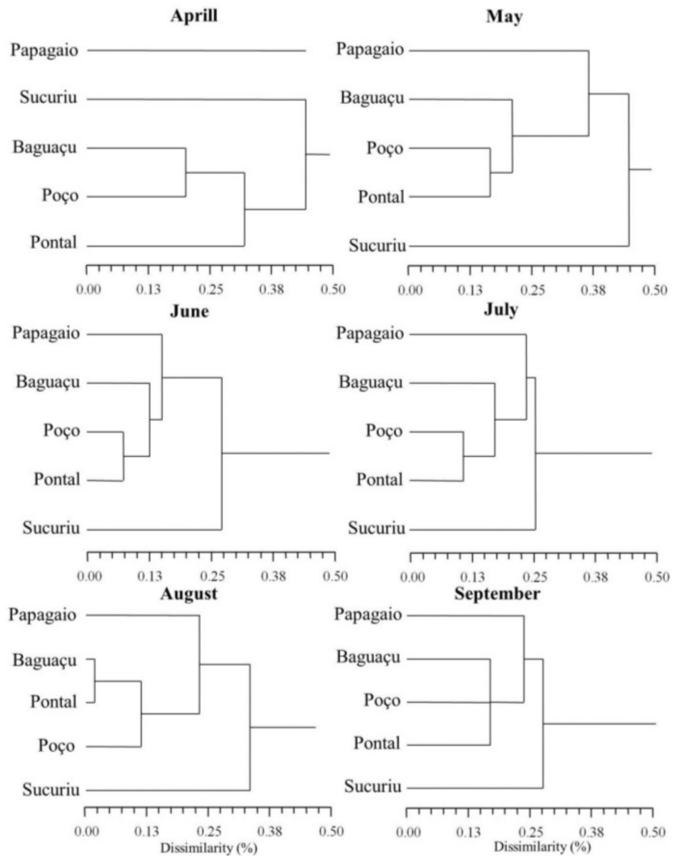


**Figure 4.** Grouping of sampling sites from April 00 to September 2000, based on the composition of the fish fauna. Cophenetic correlation coefficient varying between 0.87 and 0.89.

Considering the influence of temperature on the grouping of the sampling sites, a factorial correspondence analysis was performed (Figures 5 and 6). The objective of this analysis was to check the relationship between the frequency of occurrence of the species and the water temperature. It was considered species associated with higher temperatures those whose “abundant” and “very abundant” frequencies were related to “high” and “moderate” temperatures. They were: *Anisotremus surinamensis, Cathorops spixii, Etropus crossotus, Genidens genidens, Micropogonias furnieri, Sphoeroides greeleyi* and *Stephanolepis hispidus*. The species *Diplectrum radiale* had the “abundant” frequency related to “low” temperatures. No relation with temperature was detected for *Chaetodipterus faber, Chloroscombrus crysurus, Eucinostomus argenteus* and *Sphoeroides testudineus*. Factorial Correspondence Analysis was not run for those species whose contingency table contained at least one row or column with all null values. However, by observing the numbers of specimens caught during the sampling months, it was possible to verify that *A. lineatus, C. gracilicirrhus, C. spinosus, C. microlepdotus. H. reidi, M. americanus, M. littoralis, Orthopristis ruber, S.vomer* and *S. tesselatus* were present in larger number in the months of moderate and high temperatures (November to May).

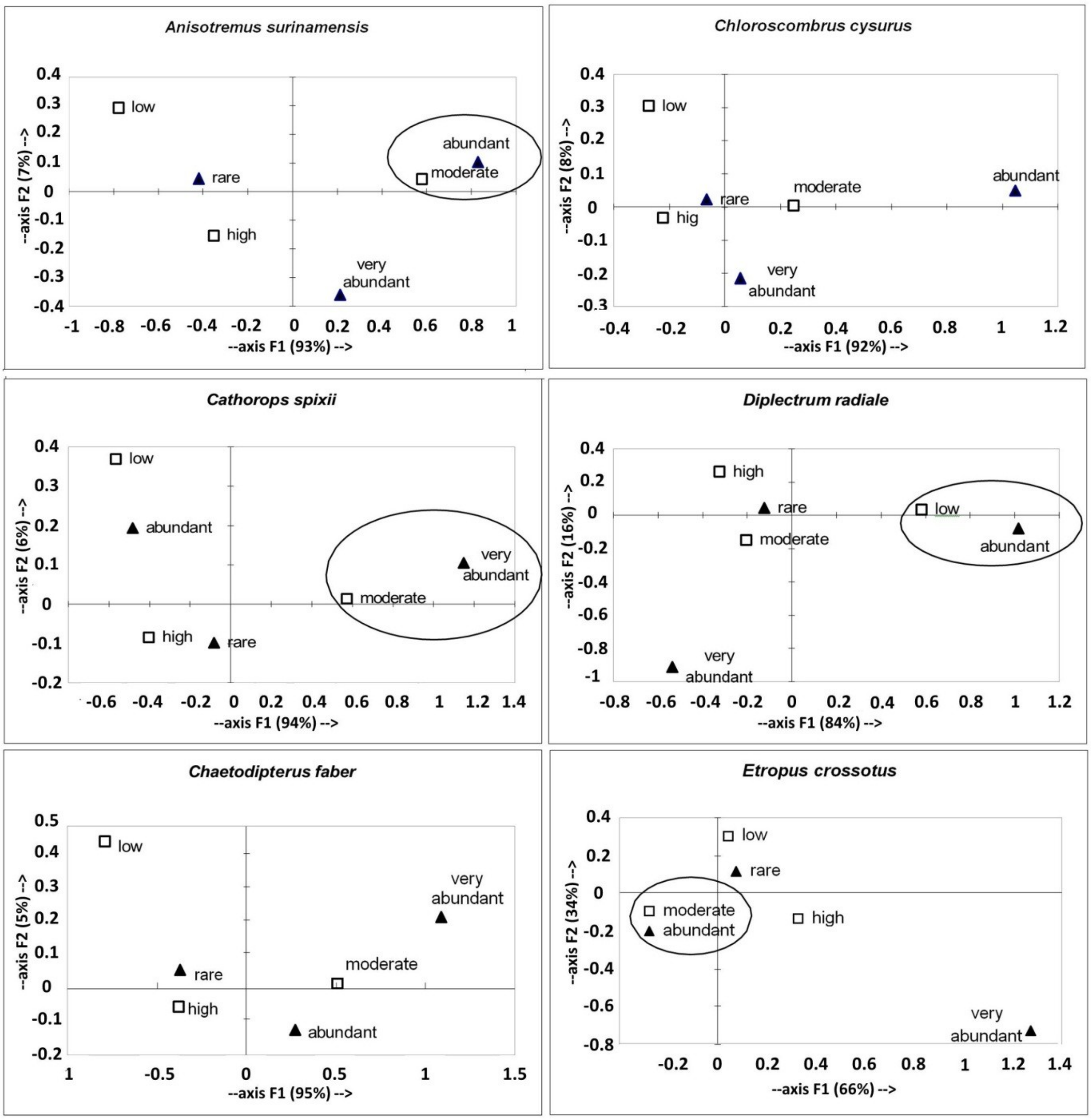


**Figure 5.** Multidimensional projection of Factorial Correspondence Analysis representing the relationship between frequency of occurrence by catch of the most representative species with water temperature. Frequency of specimens caught: rare - less than 10, abundant - between 10 and 30 and very abundant - greater than 30). Temperatures: low - below 20˚C, moderate - between 20 and 25˚C, high - above 25˚C.

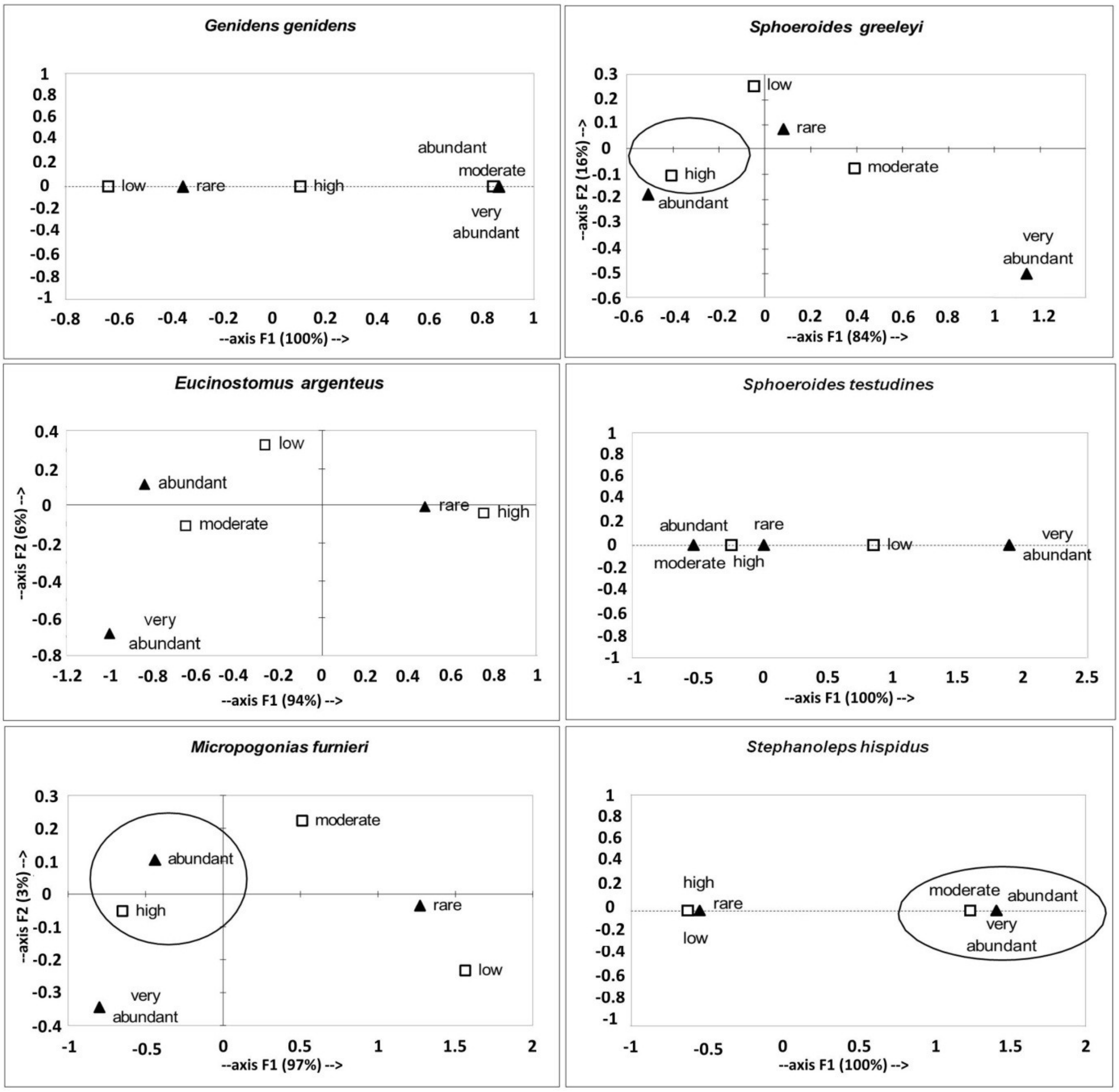


**Figure 6.** Multidimensional projection of Factorial Correspondence Analysis representing the relationship between frequency of occurrence by catch of the most representative species with water temperature. Frequency of specimens caught: rare - less than 10, abundant - between 10 and 30 and very abundant - greater than 30). Temperatures: low - below than 20°C, moderate - between 20 and 25°C, high - above 25°C.

## Discussion

Temperature was the most important variable for the distribution of the months, allowing the division of the study period into hot (November to May, excluding April) and cold months (June to September including April). In the cold months, the importance of salinity, dissolved oxygen, phosphorus and nitrogen (DIN) increased.

The analysis of the fish fauna composition was performed by transformation of the data (log (x + 1)) due to the large coefficient of variation they presented. The objective of the transformation was to minimize the importance of the high values of absolute frequency of occurrence, which corresponds to the shoals that were eventually collected. With this, it was avoided that large shoals of species belonging to a low level of the trophic chain had a much greater importance than those species collected in smaller numbers, but with great ecological importance in relation to the level in the energy pyramid.

The variation of the clusters during the sampling period reflected the temporal oscillation of the fish fauna composition. The highest percentages of dissimilarity between the sampling sites were observed in months from November to May, whose recorded temperatures were higher. In these months, three groupings of sites were found, except in February (five) and April (four). In the months from June to

October, when the temperatures were lower, the dissimilarity between the sampling sites was lower, which resulted in the distribution of the sampling sites in only two clusters. The variation in the dissimilarity between the sites was due to the differences in the number of individuals and species of the catches. The most expressive catches recorded in the months with high temperatures resulted in increased dissimilarity between the sites. An opposite trend was observed in colder months, where the catches were smaller, and consequently the dissimilarity between the sites was reduced.

Several authors, who studied several environments in the Paranaguá Bay and nearby environments, recorded higher catches in the summer and fall months. Godefroid, Spach, Santos, Mac Lauren, and Schwarz (2004), in an infralittoral close to Paranguá Bay, observed that diversity presented higher values from the beginning of summer until the middle of autumn, with the lowest values occurring in September and October. Esper (1982) and Godefroid, Hofstaetter, and Spach (1997), in studies with fish conducted in the area of Paranaguá Bay and nearby environment, found that, due to the recruitment phase that extends from summer until autumn, indicating a greater activity reproductive, directly reflects a greater capture of individuals in these periods.

Reproductive cycles, in addition to other intra- and inter-specific interactions and the influence of environmental variables, are responsible for the composition of the fish fauna in different environments (Agostinho, Bini, & Gomes, 1997). Reproduction in warmer periods increases survival and favors the development of larvae and juveniles. This is because fish are ectothermic organisms, which because of their inability to regulate body temperature, should behaviorally thermoregulate, avoiding or selecting environmental temperatures (Kennish, 1990). Another important reason that favors reproduction in warmer periods is the higher availability of food due to high productivity, which, in estuaries, is related to not only primary production, but also to organic matter and dissolved nutrients from continental origin (Carmouze, 1994; Machado et al., 1997). The rainy season observed in hot months is related to higher productivity, as the amount of organic material and nutrients in the environment increases

Several authors have reported higher reproductive activity for several species during warmer periods. Greater reproductive activity in warmer periods was observed in *Cathorops spixii* in the Paranaguá Estuarine Complex (Favaro, Frehse, Oliveira, & Schwarz, 2005) and in *Genidens genidens* in Sepetiba Bay, Rio de Janeiro (Gomes, Araujo, Azevedo, & Pesanha, 1999). Rocha, Favaro, and Spach (2002) and Schultz, Favaro, and Spach (2002) studied the reproductive biology of two species of pufferfish, *Sphoeroides testudineus* and *S. greeleyi* respectively, in the Baguaçu tidal creek, Paranaguá Bay. The reproductive period of *S. testudineus* was between September and January, and *S. greeleyi*, from November to January. Spach, Godefroid, Santos, Schwarz Jr., and Queiroz (2004) studied a tidal plain at the Paranaguá Bay inlet and recorded the most intense reproductive activity of the species *Stellifer rastrifer, Diapterus rhombeus, G. genidens, S. testudineus, Citharichthys arenaceus* and *Hyppocampus reidi*, during spring and summer. As a result of the more intense reproductive activity in hot months and the subsequent recruitment of species, larger catches were observed between spring and fall, and lower catches in winter.

Another reason for the greater catch observed between summer and fall, according to Pichler et al. (2015) and Possatto, Broadhurst, Gray, Spach, and Lamour (2017), is the presence in this period of species that have at least a part of the life cycle associated with the estuary. Certain species inhabit the oceans, and larvae and juveniles migrate towards the estuary in search of shelter and food resources (Day Jr., Hall, Kemp, & Yáñez-Arancibia, 1989). Whitemouth croaker (*Micropogonias furnieri*), an important commercial species, uses the estuaries as areas of recruitment (Bruno & Muelbert, 2009). Godefroid, Hofstaetter, and Spach (1999) found the largest number of larvae of this species during winter and spring. According to Flores-Coto & Pérez Argudín (1991), larvae of *M. furnieri* reach the inlet of the estuary at the more advanced stages, when they acquire greater swimming ability and migrate towards the more internal regions. The largest catches of the species recorded in February and April should represent the recruits of the winter cohort.

Black margate (*Anisotremus surinamensis*) was found throughout the sampling period, with the exception of September, with numerically significant catches in February, March and April. This result is corroborated by Spach et al. (2004), who studied the tidal plain of the Balneário de Pontal do Sul, at the entrance of the Paranaguá Bay. In that study, *A. surinamensis* was one of the most abundant species and with the highest catch in March due to the presence of large juvenile aggregates.

## Conclusion

Therefore, it can be concluded that the temporal variation in the fish fauna composition was related to the environmental variables (salinity, dissolved oxygen, phosphorus and inorganic nitrogen), mainly temperature. A greater abundance and richness of fish were found in the hot months. This pattern of occurrence should be related to the life cycle of many species, which reproduce in warmer months, in addition to those marine species that use the estuary as a breeding ground.

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