Biota Neotropica 23(2): e20221387, 2023
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Article

Patterns in composition and occurrence of the fish fauna in shallow areas of the São Francisco River mouth

Renato Luiz Bot Neto[1], André Pereira Cattani[2], Henry Louis Spach[2], Riguel Feltrin Contente[3,4], Olímpio Rafael Cardoso[2], Camila Marion[5] & Roberto Schwarz Júnior[6]

[1]Universidade Federal do Paraná, Programa de Pós-graduação em Ecologia e Conservação, Laboratório de Ecologia de Peixes, Av. Coronel Francisco Heráclito dos Santos, 100, Jardim das Américas, 81531980, Curitiba, PR, Brasil.
[2]Universidade Federal do Paraná, Centro de Estudos do Mar, Laboratório de Ecologia de Peixes, Av. Beira-mar, Pontal do Sul, 83255976, Pontal do Paraná, PR, Brasil.
[3]Instituto Federal do Pará, Campos Marabá Industrial, Quadra Especial, 68508970, Nova Marabá, Marabá, PA, Brasil.
[4]Universidade Federal do Paraná, Centro de Estudos do Mar, Programa de Pós-graduação em Sistemas Costeiros e Oceânicos, Av. Beira-mar, Pontal do Sul, 83255976, Pontal do Paraná, PR, Brasil.
[5]Instituto Federal de Educação, Ciência e Tecnologia do Pará, Campus Parauapebas, Rodovia PA 275, 68515000, Parauapebas, PA, Brasil.
[6]Universidade Federal de Sergipe, Departamento de Engenharia de Pesca e Aquicultura, Laboratório de Ictiologia Estuarina e Marinha, Av. Marechal Rondon, Jd. Rosa Elze, 49100000, São Cristóvão, SE, Brasil.
**Corresponding author: rafael.bioufrgs@gmail.com*

BOT NETO, R.L., CATTANI, A.P., SPACH, H.L., CONTENTE, R.F., CARDOSO, O.R., MARION, C., SCHWARZ JÚNIOR, R. **Patterns in composition and occurrence of the fish fauna in shallow areas of the São Francisco River mouth.** Biota Neotropica 23(2): e20221387. https://doi.org/10.1590/1676-0611-BN-2022-1387

Abstract: The construction of dams causes changes in river variables, as a result of direct changes in their hydrological and biogeochemical cycles. One of the most notable changes is the flow regulation, which reduces seasonal events and the hydrostatic pressure exerted by freshwater, increasing the saltwater wedge intrusion into the system. Changing the salinity regime causes modifications in downstream ecosystems as well as in the distribution and composition of the fish fauna. In Brazil, the São Francisco River stands out, which has a system of cascading dams, built between the 70's and 90's. Because of these changes caused in the natural course of the river, this study aimed to analyze the patterns of composition and occurrence of the ichthyofauna at the mouth of the São Francisco River and relate them to the physical and chemical variables of the region. In order to evaluate the patterns of composition and occurrence of the fish fauna at the mouth of the São Francisco River, monthly trawls were conducted along the bank and physical and chemical variables were analyzed in the river channel over a period of one year. The relationship between abundance and species richness with environmental variables was verified using Generalized Linear Models. A total of 101,958 fish belonging to 87 taxa were caught, with emphasis on marine fish, both in number of individuals (99.92%) and in biomass (99.31%). A spatial gradient was detected, in which sites 1 and 2 were under marine influence, sites 3 and 4 represented the transition between the environments and site 5 was under the influence of brackish and freshwater. In general, the effect of the São Francisco River dams on the fish fauna was observed, with a predominance of fauna with more estuarine and less freshwater characteristics.
Keywords: *Salinization; fish assemblage; seine net.*

Padrões de composição e ocorrência da ictiofauna em áreas rasas da foz do rio São Francisco

Resumo: A construção de barragens provoca alterações nas variáveis dos rios, em decorrência de mudanças diretas em seus ciclos hidrológicos e biogeoquímicos. Uma das mudanças mais notáveis é a regulação do fluxo, que reduz os eventos sazonais e a pressão hidrostática exercida pela água doce, aumentando a intrusão das cunhas da água salgada no sistema. Mudar o regime de salinidade causa modificações nos ecossistemas a jusante, bem como na distribuição e composição da ictiofauna. No Brasil, destaca-se o Rio São Francisco, que possui um sistema de barragens em cascata, construído entre as décadas de 70 e 90. Por causa dessas alterações causadas no curso natural do rio, o presente estudo teve por objetivo analisar os padrões de composição e ocorrência da ictiofauna da foz do rio

São Francisco e relacioná-los com as variáveis físicas e químicas da região. Para avaliar os padrões de composição e ocorrência da ictiofauna foram realizados arrastos mensais ao longo da margem e analisadas as variáveis físicas e químicas no canal do rio ao longo de um ano. A relação entre abundância e riqueza de espécies de peixes com as variáveis ambientais foi verificada por meio de Modelos Lineares Generalizados. Foram capturados 101.958 peixes pertencentes a 87 táxons, com destaque para peixes marinhos, tanto em número de indivíduos (99,92%) quanto em biomassa (99,31%). Um gradiente espacial foi detectado, em que os pontos 1 e 2 estavam sob influência marinha, os pontos 3 e 4 representavam a transição entre os ambientes e o ponto 5 estava sob a influência de água doce e salobra. De maneira geral, foi observado o efeito das barragens do rio São Francisco sobre a ictiofauna, com predomínio de fauna com características mais estuarinas e menos dulcícolas.

Palavras-chave: *Salinização; Assembleia de peixes; Picaré.*

Introduction

Several factors have a direct influence on the composition and structure of the ichthyofauna, among them it is possible to highlight factors related to physicochemical characteristics of the environment such as the type of habitat, salinity, temperature and dissolved oxygen (Haedrich & Hall 1976, Blaber & Blaber 1980, Loneragan & Potter 1990, Whitfield 1999). Biological interactions such as competition (intra and interspecific) and predation also play an important role in driving the fish fauna composition (Kennish 1990). In addition to the abiotic and biological factors, the distribution and structure of the ichthyofauna can also be governed by factors such as the climate of the region, the geomorphology of the environment, the slope of the coast, the amplitude of the tide, the cycle of the tide, the tidal currents and the waves (Reise 1985).

The variation of environmental factors changes the primary productivity, causing changes in the fish fauna composition through bottom-up effects (Blaber et al. 1995, Morrison et al. 2002, Oliveira Neto et al. 2004). However, the abundance and specific composition of the ichthyofauna are also closely linked to a group of biological factors such as physiological differences, prey availability, foraging success, competitor density, predation pressure and availability of spawning sites (Baltz et al. 1998, Taylor & Rand 2003).

According to some authors, the distribution and abundance of fish is primarily influenced by physical-chemical factors in the environment, with great emphasis on temperature and salinity, and secondarily by biological interactions (Moyle & Cech 1988, Vieira & Musick 1993). Temperature plays a very important role in the intensity and seasonal variation in the spawning of several species of fish (Ramos & Vieira 2001), however, salinity had a direct influence on the specific composition of the ichthyofauna (Jaureguizar et al. 2003). In this way, the spatial and temporal differences in temperature and salinity characterize the diversity of habitats that exist in ecotones (Matic-Skoko et al. 2005).

The existence of fish with similar niches in ecosystems can occur through the development of strategies that allow the temporal or spatial separation in the use of habitats. In this way, phylogenetically-close species can live in the same area using different habitats (or microhabitats) or being active in different periods (Azevedo et al. 1999). The spatial distribution of species guarantees non-uniformity throughout the environment, however there is also temporal variation that acts on the first. This temporal variation can have both short and long periods. Short-term variations occur mainly as a result of tidal cycles, moon phases and the alternation between day and night. The most common and noticeable long-term variations are seasonal. Most fish fauna found in ecotones have reproductive cycles linked to long-term variations (Oliveira Neto et al. 2004).

Coastal regions are constantly under stress due to various human activities such as overfishing, tourism, urbanization, agriculture and industrial development (Raz-Guzman & Huidobro 2002). Environments located in regions close to urban centers are heavily affected by human activities, leading to a pronounced degradation of these regions (Miranda et al. 2002). In this way, changes arising from anthropic activities may compromise the maintenance of species in the aquatic environment.

The construction of dams causes considerable changes in the physical, chemical (in both water and sediment) and biological variables of the rivers, since their presence conspicuous changes the hydrological and biogeochemical cycles of the river course where they are built (Medeiros et al. 2011). One of the most notable changes is the river flow regulation, which decreases seasonal events (i.e., floods) (Medeiros et al. 2007) and causes a reduction in the hydrostatic pressure exerted by freshwater. The near-coast reduction in hydrostatic pressure exerted by the reduced river flow results in increased penetration of water from the oceans and increase the intrusion of the saline wedge into river systems (Fontes 2002, Coelho 2008), which consequently reduces both the intermediate salinity zones and the estuarine plume (Bennett 1994). Any changes in the inflow of freshwater will cause changes in the structure and functioning of downstream systems and in extreme cases of flow reduction there may be total salinization of this stretch, which will behave like a gulf, with salinities much higher than those found previously in the system (Bate & Adams 2000).

The reduction in freshwater inflow and the alteration in the salinity regime cause several changes in the ecosystems downstream of the dam, which also include changes, both in the distribution and composition of the fish fauna (Chícharo et al. 2006). Under such conditions, fish species with lower tolerance to saline water tend to migrate to upstream areas, while species with higher tolerance tend to increase their abundance in the downstream regions. This can cause direct changes in food webs as a consequence of changes in prey-predator relationships (Baptista et al. 2010). At the same time, there will be a decrease in the estuarine plume, reducing the chemical cues for migration and orientation of species entering the river channel (Bennett 1994), altering migration and spawning patterns in adults and hindering access of larvae and juveniles to nursery areas (Chícharo et al. 2003, 2006). Thus, changes in freshwater inflow caused by dams can impact fisheries in adjacent coastal areas (Chícharo et al. 2003).

In Brazil, we can highlight the case of the São Francisco River, which suffers from impacts to which rivers with dams are subjected, as it has in its course a system of cascading dams, built between the 70's and 90's (Medeiros et al. 2007, Oliveira et al. 2012). However, only after the construction of the Xingó Hydropower Plant (180 km from the coast) in 1994, these impacts intensified, as there was a definitive regulation of the flow of freshwater to the region of the mouth of the São Francisco River (Knoppers et al. 2006, Medeiros et al. 2007, 2011), allowing there greater intrusion of saline (Fontes 2002, Oliveira et al. 2008). In addition, the construction of this plant also generated other impacts in the region, causing changes in other characteristics of this system, due to the retention of nutrients and sediments, causing this stretch of the river to remain in a constantly oligotrophic and highly transparent condition (Medeiros et al. 2007, 2011).

In addition to compromising the permanence of some fish species in these environments, changes in the environment downstream of the dams caused by human activities can facilitate the invasion of allochthonous species. Thus, it is important to identify the structure of the fish fauna, in order to understand how environmental disturbances (natural or anthropogenic) can alter the distribution of resident and transient fish species (Whitfield & Elliot 2002, Vendel et al. 2003). Furthermore, having knowledge about the composition of the fish fauna and how it varies (both temporally and spatially) is fundamental for decision-making and for the sustainable management of species, as well as for preservation actions (Kupschus & Tremain 2001). Understanding and evaluating the impact that these environments are subjected to is of great importance for the maintenance of these regions (Chapman & Wang 2001). Thus, the aim of this study was to describe the spatial and temporal variations in the structure and composition of the fish fauna in shallow areas of the São Francisco River mouth.

Material and Methods

1. Study area

The lower course of the São Francisco River is the easternmost region of the basin (Costa 2003), it has the shortest length when compared to other stretches of the river (274 km), it extends from the Paulo Afonso Hydroelectric complex (state of Bahia) to the mouth into the Atlantic Ocean, between the municipalities of Piaçabuçu (state of Alagoas) and Brejo Grande (state of Sergipe) (Diegues 1994, Sato & Godinho 1999, 2004) and occupies 30,377 km^2 area (5% basin area), which covers the states of Bahia, Pernambuco, Alagoas and Sergipe (CODEVASF 1991, Junqueira 2002). According to Köppen classification, the climate of the Lower São Francisco is AS' (hot and humid, with winter rains) (Bernardes 1951) with an average annual temperature of 25°C (Aguiar Netto et al. 2011) and showing two distinct periods: rainy (between April and August) and dry (between September and March) (Knoppers et al. 2006).

From Paulo Afonso (BA), the vegetation of the Lower São Francisco, although there is a predominance of the formation of Steppe Savannah up to the mouth of the Ipanema river (AL), has areas of ecological tension (Steppe Savannah– Seasonal Forest) with patches of Semideciduous Seasonal Forest from Propriá (SE) and as the São Francisco approaches its mouth, pioneer formations of fluvio-marine influence occur that form the mangroves (MMA 2006).

The coastal region of the Lower São Francisco presents a semi-diurnal mesotide regime (with the spring tide reaching 2.6 m). The wave regime has high energy, with a predominance of NE, E and SE waves throughout the year, with the northeast and east waves being more important during the summer, fall and spring, while the southeast waves occur more markedly in winter (Dominguez 1996). The depth in the region of the São Francisco River mouth is variable, reaching 18 m in the channel located near the municipality of Piaçabuçu (state of Alagoas) and approximately 14 m in the regions close to the mouth (Medeiros et al. 2007).

The modulation or total regulation of flow, aiming at constant water supply, is one of the most notable modifications in dam construction and causes drastic effects by reducing flows and smoothing or interrupting the natural pulsation of the river system (Medeiros et al. 2007). Through the construction of dams, energy generation activity caused major changes in the Lower São Francisco (Medeiros et al. 2007; 2011; 2014). Before the construction of the dams, the flow of the São Francisco River varied according to the natural rainfall pulses in the Upper and Middle São Francisco region, with peaks between 8,000 and 18,000 m^3/s and lows of 600 m^3/s (Santos et al. 2009). After the completion of the last plant (Xingó – 1994) the flow was definitively regulated in 1995 by the Sobradinho dam. Currently, the flow is kept constant at an average volume of 1,850 m3/s, 35% less than in the period prior to the dams (Oliveira 2003; Medeiros et al. 2007; 2011; 2014). The flood peaks that naturally occurred from January to March were eliminated between 1995 and 2001 (Medeiros et al. 2011; 2014). After the construction of the dams, the Lower São Francisco became transparent and oligotrophic (MMA 2006; Medeiros et al. 2007; 2011; Knoppers et al. 2006) and areas that previously had high turbidity became totally transparent (Medeiros et al. 2003; 2007). The lakes and floodplains located on their banks are no longer flooded and seasonally fertilized, which altered their biogeochemical functioning, and due to the lack of nutrients, the areas downstream of the dams had their biological productivity reduced (Santos et al. 2009). Dam-mediated nutrient retention also reduced drastically the local fisheries, resulting in the extinction of species and the reduction of fish stocks (Nascimento, Ribeiro & Aguiar Netto 2013).

2. Data collection

Data were collected monthly, during the daytime, both at high tide and at low tides, and extended over a one-year period (from May 2017 to April 2018) in the region of the Lower São Francisco River.

For fish fauna collection, manual trawls were carried out parallel to the margin, at five sites distributed along the environmental gradient of the Lower São Francisco River between the mouth and the municipality of Brejo Grande (Figure 1) on the river banks. At each site, two trawls were carried out on each tide, totaling 20 monthly trawls (10 at high tide and 10 at low tide). The net used (30 m x 2.8 m; 5 mm mesh) was pulled parallel to the margins for a distance of 50 m to a maximum depth of 3 m.

Concomitantly with the collection of biological material, the physical and chemical variables of the water were also monitored: temperature, pH, dissolved oxygen, salinity and total dissolved solids (both under the water surface and near the bottom), in 13 sampling sites in the channel of the river along the environmental gradient (Figure 1) using a multiparameter probe (Hanna HI9828). Simultaneously, water transparency was measured using a Secchi Disk. In addition to monitoring environmental data, time series (for the study period) and historical series of flow and rainfall for the Lower São Francisco region were obtained from the Hidroweb database of the National Water

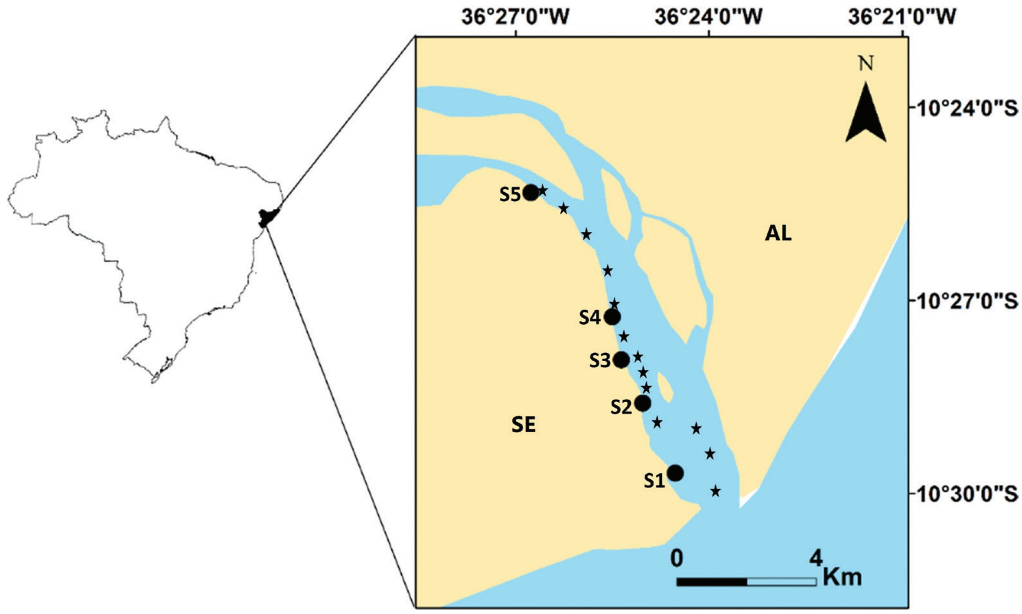

Figure 1. Map of the mouth of the São Francisco River. The circular points marked on the map represent the five sampling sites. And the star-shaped dots represent the thirteen locations where soundings were carried out with the multiparameter probe.

Agency (ANA). These data were important both for the description of seasonal periods and for helping to explain possible differences in the fish fauna associated with the mouth of the São Francisco River dynamics.

3. Data analysis

Statistical analyses were performed in a computational environment R (R DEVELOPMENT CORE TEAM 2019). The representativeness of the fish community samples was evaluated by drawing a species accumulation curve in the Vegan package, using the "specaccum" function (Oksanen 2019), based on all collected samples. A modeled curve was also drawn, based on the species richness estimator presented by Coleman et al. (1982).

In order to reduce the bias caused by samples with very high abundances, those considered outliers were removed, specifically two samples collected at site 3 during the low tide.

The relationships between abundance and species richness with factorial variables (tide, site and month), as well as with environmental variables (temperature, pH, dissolved oxygen, salinity, rainfall, flow and total dissolved solids) were evaluated using Generalized Linear Models (GLM). The use of these models allows the use of data with a probability frequency distribution different from the normal or Gaussian distribution (Zuur et al. 2010). For the richness data, the Poisson distribution was used, through the "glm" function, and for the abundance data, the adopted distribution was the negative binomial through the "glm.nb" function of the Mass package (Venables & Ripley 2002).

The VIF (Variation Inflation Factor) function of the Car package (Fox & Weisberg 2011) was applied to test the multicollinearity of environmental variables (Zuur et al. 2010). Variables with high VIF (>5) were excluded from the model. To select the most explanatory models, the "dredge" function of the MuMin package was used (Barton 2018). The models were selected using the corrected Akaike information criterion (AICc), the delta AIC and the Akaike weights among models. Those with a delta AIC value less than 3 were selected. The greater the Akaike weights, the greater the explanatory power of the models among all those tested.

The graphics were created using the "effect" function of the Effects package (Fox 2003) and the "stripchart" function of the Vegan package (Oksanen 2019). In the elaboration of the abundance graphs, data were transformed into log (n+1) for a better visualization of the patterns.

Finally, the Canonical Correspondence Analysis (CCA) (Ter Braak 1986) was developed with the "cca" function of the Vegan package to assess the influence of environmental variables on the most abundant species. Collinearity between predictive environmental variables was tested using the "ordistep" function also of the Vegan package. Thus, the non-collinear variables that were important for the variability of the most abundant species were plotted on the graph.

Results

A total of 101,958 fish specimens belonging to 87 different taxa were caught. Marine fish accounted for the majority in abundance with 77 different taxa (99.92%) and biomass (99.31%) (Table 1); only 10 taxa were associated with freshwater fish (Table 2). The most abundant taxa were *Rhinosardinia bahiensis* (77.27%), *Atherinella brasiliensis* (7.63%) and *Lycengraulis grossidens* (3.95%). For biomass, the most representative taxa were *R. bahiensis* (36.11%), *A. brasiliensis* (8.42%) and *Sphoeroides testudineus* (13.55%).

The species accumulation curve stabilized from the 200th sample, in line with the modeled curve, and the decrease in variability between samples, demonstrated by the observed values (Figure 2).

Considering the raw values of abundance and species richness over the months, higher abundances were found in April 2018 and lower values in January 2018. As for richness, higher and lower values

Table 1. Species composition, family, number of individuals and percentage of occurrence, total biomass and percentage of biomass of marine and estuarine fish caught at the mouth of the São Francisco River.

Order	Family	*Taxa*	N		Biomass	
			Total	%	Total (g)	%
Elopiformes	Elopidae	*Elops saurus*	13	0.013	460.0	0.178
Albuliformes	Albulidae	*Albula vulpes*	17	0.017	207.6	0.080
Anguilliformes	Ophichthidae	*Mirophis punctatus*	2	0.002	4.00	0.002
Clupeiformes	Engraulidae	*Anchoa spinifer*	6	0.006	96.3	0.037
		Anchoa tricolor	259	0.254	256.2	0.099
		Anchovia clupeoides	45	0.044	543.5	0.210
		Cetengraulis edentulus	614	0.602	10,647.3	4.110
		Lycengraulis grossidens	4,026	3.949	5,941.5	2.294
	Clupeidae	*Harengula clupeola*	27	0.026	51.9	0.020
		Lile piquitinga	281	0.276	1,114.2	0.430
		Opisthonema oglinum	6	0.006	152.8	0.059
		Rhinosardinia bahiensis	78,787	77.274	93,544.4	36.111
Siluriformes	Ariidae	*Cathorops spixii*	14	0.014	502.3	0.194
		Genidens barbus	749	0.735	13,685.1	5.283
Aulopiformes	Synodontidae	*Synodus foetens*	2	0.002	13.9	0.005
Gobiiformes	Eleotridae	*Dormitator maculatus*	13	0.013	19.3	0.007
		Eleotris pisonis	29	0.028	42.7	0.016
		Erotelis smaragdus	2	0.002	5.1	0.002
	Gobiidae	*Bathygobius soporator*	92	0.090	459.6	0.177
		Ctenogobius boleosoma	45	0.044	15.5	0.006
		Gobionellus oceanicus	34	33	294.6	0.114
		Gobionellus stomatus	14	0.014	18.1	0.007
Mugiliforme	Mugilidae	*Mugil curema*	203	0.199	1,799.5	0.695
		Mugil curvidens	286	0.281	2,857.8	1.103
		Mugil liza	27	0.026	348.6	0.135
		Mugil spp	202	0.198	61.7	0.024
	Polynemidae	*Polydactylus virginicus*	409	0.401	2,447.9	0.945
Atheriniformes	Atherinopsidae	*Atherinella brasiliensis*	7,782	7.633	21,808.7	8.419
		Atherinella blackburni	4	0.004	25.3	0.010
Beloniformes	Hemiramphidae	*Hyporhamphus unifasciatus*	909	0.892	9,509.9	3.671
	Belonidae	*Strongylura marina*	167	0.164	2,510.7	0.969
Caragiformes	Carangidae	*Caranx hippos*	1	0.001	37.4	0.014
		Caranx latus	407	399	1,810.0	0.699
		Oligoplites palometa	25	0.025	35.3	0.014
		Oligoplites saliens	22	0.022	326.7	0.126
		Oligoplites saurus	164	0.161	461.6	0.178
		Selene vomer	20	0.020	63.7	0.025
		Trachinotus falcatus	31	0.030	478.6	0.185
Istiophoriformes	Sphyraenidae	*Sphyraena barracuda*	2	0.002	210.4	0.081

Continue...

...Continuation

Order	Family	*Taxa*	N		Biomass	
			Total	%	Total (g)	%
Pleuronectiformes	Paralichthyidae	*Citharichthys arenaceus*	290	0.284	931.9	0.360
		Citharichthys spilopterus	473	0.464	697.9	0.269
		Paralichthys brasiliensis	1	0.001	148.3	0.057
	Achiridae	*Achirus lineatus*	429	0.421	1,946.6	0.751
		Trinectes microphthalmus	20	0.020	47.5	0.018
		Trinectes paulistanus	3	0.003	16.3	0.006
	Cynoglossidae	*Symphurus tessellatus*	196	0.192	1,189.1	0.459
Syngnathiformes	Syngnathidae	*Cosmocampus elucens*	5	0.005	4.5	0.002
		Microphis lineatus	18	0.018	8.1	0.003
		Pseudophallus mindii	6	0.006	3.0	0.001
Scombriformes	Trichiuridae	*Trichiurus lepturus*	2	0.002	80.3	0.031
	Scombridae	*Scomberomorus brasiliensis*	10	0.010	212.4	0.082
	Centropomidae	*Centropomus ensiferus*	41	0.040	434.1	0.168
		Centropomus parallelus	2	0.002	204.7	0.079
		Centropomus undecimalis	338	0.332	12,846.3	4.959
Perciformes	Gerreidae	*Diapterus auratus*	1,907	1.870	11,353.4	4.383
		Eucinostomus argenteus	147	0.144	744.2	0.287
		Eucinostomus gula	1	0.001	9.2	0.004
		Eucinostomus melanopterus	634	622	8,739.8	3.374
	Serranidae	*Rypticus randalli*	3	0.003	66.2	0.026
	Chaetodontidae	*Chaetodon striatus*	1	0.001	0.4	0.000
	Haemulidae	*Conodon nobilis*	2	0.002	29.2	0.011
		Haemulopsis corvinaeformis	83	0.081	541.0	0.209
		Pomadasys crocro	3	0.003	14.0	0.005
		Pomadasys ramosus	63	0.062	1,239.1	0.478
	Lutjanidae	*Lutjanus griseus*	149	0.146	2,064.7	0.797
		Lutjanus jocu	226	0.222	2,681.8	1.035
		Lutjanus spp	12	0.012	2.0	0.001
		Lutjanus synagris	4	0.004	59.8	0.023
Moroniformes	Ephippidae	*Chaetodipterus faber*	24	0.024	60.6	0.023
Acanthuriformes	Sciaenidae	*Bairdiella ronchus*	23	0.023	279.5	0.108
		Cynoscion leiarchus	1	0.001	566.9	0.219
		Menticirrhus americanus	19	0.019	281.0	0.108
		Stellifer rastrifer	52	0.051	519.1	0.200
Spariformes	Sparidae	*Archosargus probatocephalus*	2	0.002	24.9	0.010
Tetraodontiformes	Tetraodontidae	*Colomesus psittacus*	10	0.010	143.6	0.055
		Lagocephalus laevigatus	8	0.008	601.8	0.232
		Sphoeroides greeleyi	114	0.112	485.5	0.187
		Sphoeroides testudineus	816	0.800	35,099.2	13.549
	Diodontidae	*Chilomycterus spinosus*	1	0.001	0.5	0.000

* Classification of the table according to Nelson et al. (2016).

Table 2. Species composition, number of individuals and percentage of occurrence, total biomass and percentage of biomass of freshwater fish caught at the mouth of the São Francisco River. With an asterisk the non-native species.

Order	Family	*Taxa*	N		Biomass	
			Total	**%**	**Total (g)**	**%**
Characiformes	Characidae	*Astyanax lacustris*	33	0.032	60.6	0.023
		*Orthospinus franciscensis**	1	0.001	1.2	0.0005
	Iguanodectidae	*Bryconops affinis*	2	0.002	10.8	0.004
	Serrasalmidae	*Metynnis lippincottianus**	8	0.008	230.8	0.089
Cichliformes	Cichlidae	*Cichla kelberi**	5	0.005	915.2	0.353
		Cichlasoma sanctifranciscense	2	0.002	17.5	0.007
		Oreochromis niloticus	10	0.010	530.3	0.205
Gymnotiformes	Gymnotidae	*Gymnotus carapo*	4	0.004	21.4	0.008
Cyprinodontiformes	Poeciliidae	*Poecilia vivipara*	15	0.015	8.9	0.003
Gymnotiformes	Sternopygidae	*Eigenmannia virescens*	1	0.001	0,7	0.0003
		Total	81	0.079	1,797.4	0.694

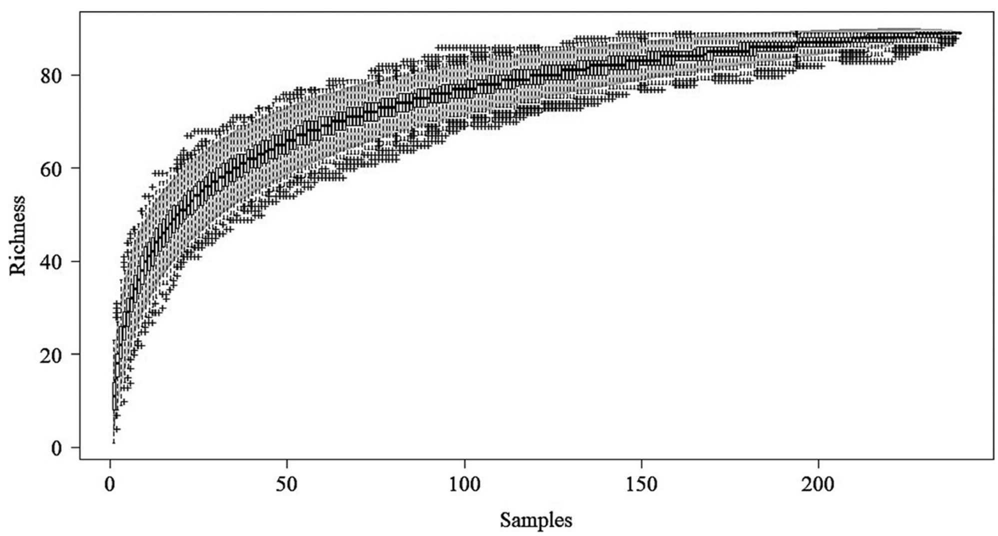

Figure 2. Cumulative curve of species constructed with the fish samples (n = 242) collected in the mouth of the São Francisco River. In gray, the modeled curve based on the Coleman estimator (Coleman et al, 1982). Boxplots were built from mean values. Crosses represent outliers.

Table 3. Descriptive summary of total numeric abundance (n) and richness (s) and mean (μ) ± standard deviation (SD) of fish caught in 2017 and 2018.

Year	Month	n Total	n (μ ± DP)	s Total	s (μ ± DP)
2017	May	13,170	2,947.55 ± 8447.06	247	10.7 ± 4.11
	Jun	4,141	180.5 ± 316.62	243	9.7 ± 3.51
	Jul	2,062	84.95 ± 56.24	223	10.1 ± 3.09
	Aug	3,610	155.85 ± 272.05	194	11.15 ± 4.77
	Sep	2,247	74.4 ± 59.62	214	11.75 ± 3.55
	Oct	2,563	103.1 ± 75.37	225	11.15 ± 3.96
	Nov	2,430	207.05 ± 186.54	220	12.15 ± 5.24
	Dec	1,699	658.5 ± 1612.47	202	12.35 ± 5.16
2018	Jan	1,488	324 ± 628.29	235	12.65 ± 4.97
	Feb	3,117	121.5 ± 131.23	223	11 ± 3.16
	Mar	6,480	128.15 ± 120.4	253	11.25 ± 3.16
	Apr	58,951	112.35 ± 75.07	214	10.7 ± 4.11

occurred respectively in March 2018 and August 2017 (Table 3). As for sites and tides, the high abundances and richness observed in site 3 (P3) at low tide and the low values of these descriptors in site 2 (P2) at high tide are highlighted (Table 4).

In the selection of Generalized Linear Models (GLM) for richness, considering the tide, site and month factors, the selected model (delta < 3; weight = 0.986) listed, in descending order of importance, the tide and the site, with an observed trend of higher values at low tide and in sites S1 and S3 (Figure 3).

In the analysis of abundance, the selected model (delta < 3; weight = 0.932) listed, in descending order of importance, the tide, the month and the site, with an observed trend of higher values at low tide, in

Table 4. Descriptive summary of total abundance (n) and richness (s) and mean (µ) ± standard deviation (SD) of fish caught at five sampling sites at high and low tides.

Site	Tide	n Total	n (µ ± DP)	s Total	s (µ ± DP)
S1	High	2,107	87.79 ± 62.69	267	11.13 ± 3.29
	Low	3,109	129.54 ± 91.81	326	13.58 ± 3.72
S2	High	815	33.96 ± 19.07	150	6.25 ± 2.57
	Low	10,201	425.04 ± 1,402.35	268	11.17 ± 3.38
S3	High	8,807	366.96 ± 924.17	309	12.88 ± 3
	Low	57,594	2,399.75 ± 7,740.79	356	14.83 ± 3.55
S4	High	2,391	99.63 ± 85.8	210	8.75 ± 3.38
	Low	6,542	272.58 ± 546.86	277	11.54 ± 5.17
S5	High	6,233	259.71 ± 380.7	272	11.33 ± 2.9
	Low	4,159	173.29 ± 201.37	258	10.75 ± 3.42

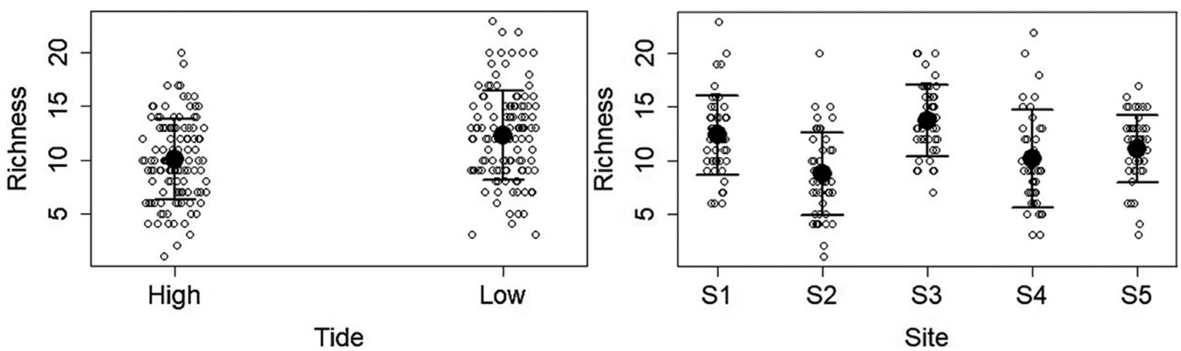

Figure 3. Comparison of mean richness between tides and sampling sites. Black dots represent means and bars represent standard errors.

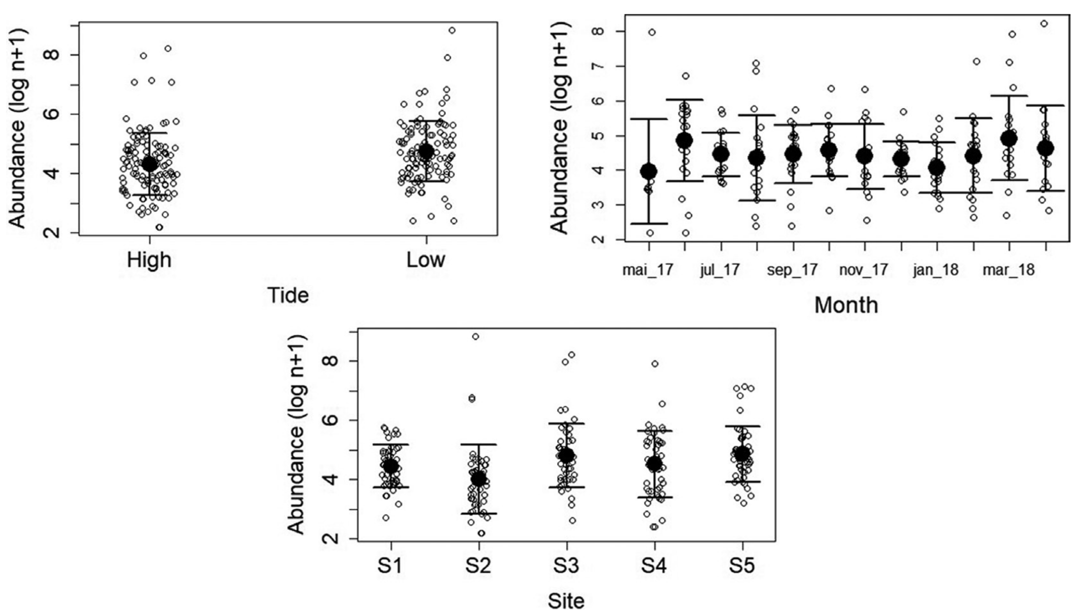

Figure 4. Comparison of mean abundance (log n + 1) of species between tides, months and sampling sites. Black dots represent means and bars represent standard errors.

Table 5. Selection of generalized linear models (GLM) of fish richness according to environmental variables. rich = richness; rain = rainfall; sal = salinity; temp = temperature; flow = flow.

	Richness models	df	logLik	AICc	delta	weight
1	rich ~ pH + rain + temp + flow	5	–671.672	1353.6	0	0.205
2	rich ~ pH + rain + sal + temp + flow	6	–671.851	1354.1	0.46	0.163
3	rich ~ pH + rain + temp +	4	–671.403	1355	1.38	0.103
4	rich ~ pH + temp + flow	4	–671.421	1355	141	0.101
5	rich ~ DO +pH +rain+temp + flow	6	–671.411	1355.2	1.58	0.093
6	rich ~ pH + rain + sal + temp + flow	5	–671.914	1356.1	2.48	0.059
7	rich ~ DO + pH + rain + sal + temp + flow	7	–671.846	1356.2	2.58	0.057
8	rich ~ pH + sal + temp + flow	5	–671.144	1356.5	2.94	0.047

Table 6. Selection of generalized linear models (GLM) of fish abundance according to environmental variables. abu = rabundance; rain = rainfall; sal = salinity; temp = temperature; flow = flow.

	Abundance models	df	logLik	AICc	delta	weight
1	abu ~ DO + rain + sal + temp + flow	7	–1463.208	2940.9	0	0.373
2	abu ~ rain + sal + temp + flow	6	–1464.897	2942.2	1.25	0.199
3	abu ~ DO + rain + sal + temp + flow	8	–1462.939	2942.5	1.60	0.167
4	abu ~ pH + temp + flow	7	–1464.673	2943.8	2.93	0.086

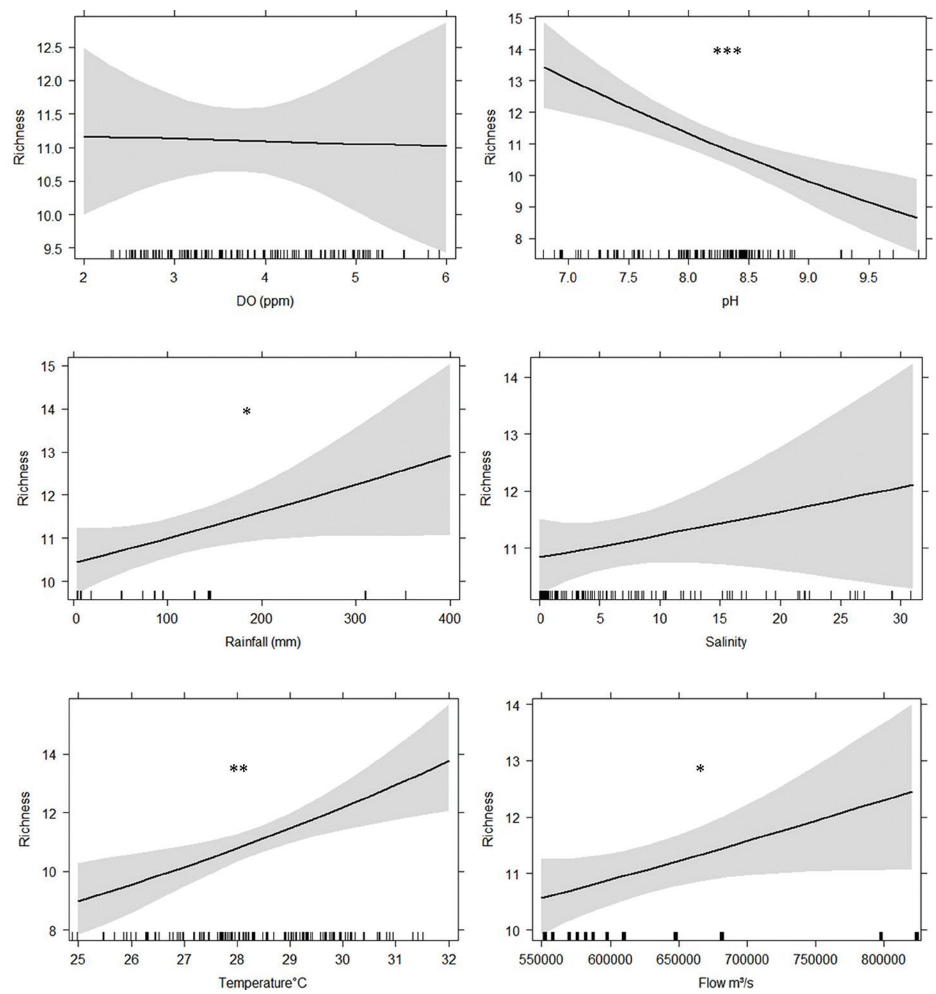

Figure 5. Relationship between richness and selected environmental variables in generalized linear models. The line represents the modeled values and the gray area corresponds to the standard deviation. Asterisks (*) correspond to the significance in the correlation (***p-value < 0.001; **p-value < 0.01; *p-value < 0.05).

May and June 2017 and March and April 2018 and in sites S1, S4 and S3 (Figure 4).

In the model of richness according to environmental variables, the VIF analysis detected collinearity (VIF > 5) of the variable “total dissolved solids”, which was removed from the final model. Eight models were selected (Table 5), and the one with the highest weight (0.205) considered, in decreasing order of importance, the variables pH, rainfall, temperature and flow.

For abundance, the VIF analysis also detected collinearity (VIF > 5) of the variable “total dissolved solids”, which was removed from the final model. Four models were selected (Table 6), in which dissolved oxygen, rainfall, salinity, temperature and flow were selected in order of importance in the model with the highest weight (0.373).

In the model of species richness according to the selected environmental variables, there was a weak correlation with dissolved oxygen (DO), a significant negative correlation with pH and a significant positive correlation with rainfall, temperature and flow. As for salinity, there was a positive correlation, but without statistical significance (Figure 5). It is noteworthy that salinity was not selected in the model with the greatest weight.

In the species abundance model with selected environmental variables, dissolved oxygen and pH were negatively correlated with abundance, while the other variables were positively correlated with abundance (Figure 6). Only for pH, the correlation was not significant.

In the analysis with the most abundant species (n > 0.5%), the variables selected to explain the variability were salinity, pH and temperature, which correlated equally with both axes (Figure 7). However, the variables with the greatest influence on the most abundant fish assemblage were salinity and pH. The total cumulative percentage of explanation of the first two axes corresponded to 94.56%. The first axis represented a spatial gradient, with samples from the sites on the left side of the graph closest to the mouth of the river, positively correlated with the highest values of salinity (sal) and pH (ph) and with the abundance of *Cetengraulis edentulus* (Cede). On the other hand,

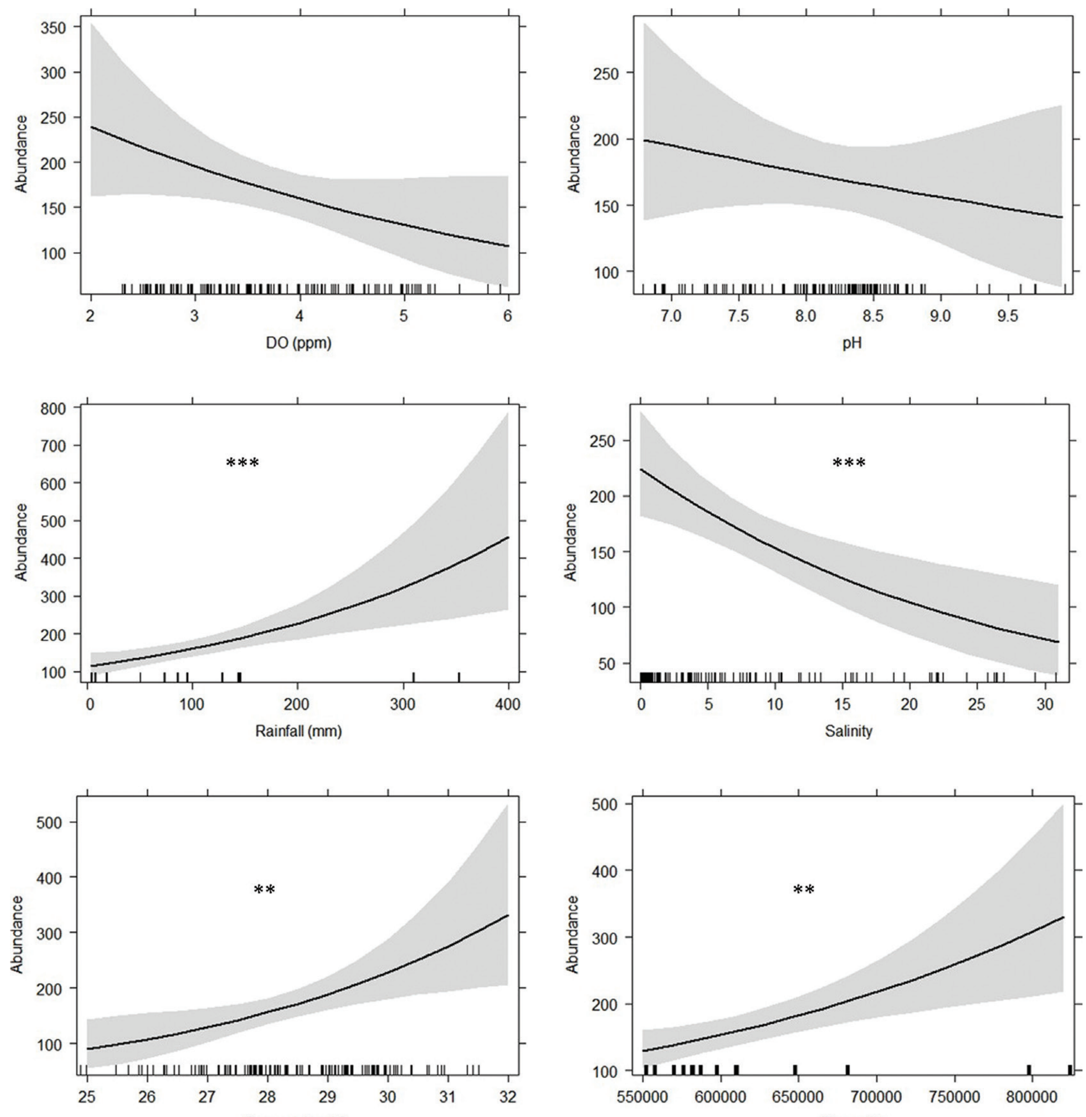

Figure 6. Relationship between abundance and selected environmental variables in generalized linear models The line represents the modeled values and the gray area corresponds to the standard deviation. Asterisks (*) correspond to the significance in the correlation (***p-value < 0.001; **p-value < 0.01; *p-value < 0.05).

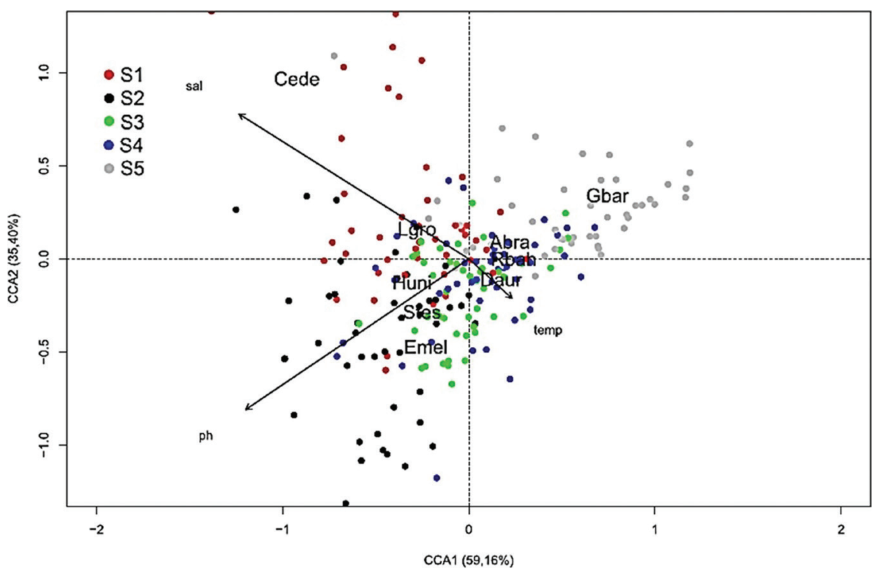

Figure 7. Canonical Correspondence Analysis (CCA) for the most abundant species in relation to the physicochemical parameters of the water. Cede = *Cetengraulis edentulus*; Gbar = *Genidens barbus*; Lgro = *Lycengraulis grossidens*; Huni = *Hyporhamphus unifasciatus*; Stes = *Sphoeroides testudineus*; Emel = *Eucinostomus melanopterus*; Abra = *Atherinella brasiliensis*; Rbah = *Rhinosardinia bahiensis*; Daur = *Diapterus auratus*.

on the right side, the samples collected at site 5 (S5) in the innermost region of the river predominated, correlated with the abundance of *Genidens barbus* (Gbar). The species *Lycengraulis grossidens* (Lgro), *Hyporhamphus unifasciatus* (Huni), *Sphoeroides testudineus* (Stes), *Eucinostomus melanopterus* (Emel) were more associated with external sites and the species *Atherinella brasiliensis* (Abra), *Rhinosardinia bahiensis* (Rbah) and *Diapterus auratus* (Daur) were weakly correlated with sampling sites, which suggests a homogeneous occurrence in the sampling sites.

Discussion

Despite the great economic and cultural importance of the São Francisco River, some areas of the river still lack studies that characterize the distribution of fish species along the environmental gradients (Silva et al. 2006, Barbosa & Soares 2009). This does not mean that the region's ichthyofauna is completely absent from studies, but studies in the region tend to focus on a few species (Assis et al. 2017) or use fishing landing data (D'avilla et al. 2021) which does not always represent the natural spatial distribution of species. A good part of the studies on the Ichthyofauna of the São Francisco River is located in the Alto São Francisco region (Trajano, Secutti & Bichuette 2009, Loures & Pompeu 2012, Dagosta, Marinho & Camalier 2014, Belei et al. 2016). Although there is a lack of ichthyological information referring mainly to the Lower São Francisco, some species associated with brackish/salt water environments have already been cited as visitors to the region, entering the river channel and being caught in freshwater areas (Barbosa & Soares 2009). However, according to these authors, both the number of these species as well as their abundance and participation in fish landings are described as reduced compared to freshwater species. Nevertheless, our results showed a very different situation for the region, since in our samples there was a massive presence of species associated with brackish/saline environments, both in abundance (99.92%) and in biomass (99.31%). According to Barbosa & Soares (2009), only six taxa associated with brackish/saline environments are present in the Lower São Francisco region, namely: *Anchoviella lepidentostole* (Fowler 1911), *Lycengraulis grossidens* (Cuvier 1829), *Eucinostomus melanopterus* (Bleeker 1863), *Eugerres brasilianus* (Cuvier 1830), *Centropomus sp.* and *Bothus sp.* In the present study it was possible to verify in the region the presence of 77 taxa associated with the brackish/saline environment, presenting a species composition similar to other estuarine environments in the northeast region, such as the Parnaíba River estuary in the state of Piauí (De Oliveira 1974) and the Contas River estuary in the state of Bahia (Lima 2010). This discrepancy observed between the study by Barbosa & Soares (2009) and the present study in the ichthyofauna composition of the São Francisco River mouth may be directly linked to the changes caused by the presence of dams in the course of the river and by the constant reduction in the natural flow caused by them, as the reduction of river flow in the system reduces the hydrostatic pressure exerted by the river and allows the penetration of salt water into the river (Coelho 2008) justifying the current expressive presence of the fish fauna in saline/brackish environments.

According to Santos (2009), some species of marine and estuarine fish have always been present in fishing landings in the Lower São Francisco region, but it was only after the installation of the Xingó hydropower plant (in 1994) that the influence of these species became increasingly greater. The presence of dams is also directly linked to the decrease in freshwater fish fauna, as the regulation of the freshwater flow eliminated the effects of floods and consequently extinguished the marginal lakes, which were extremely important grounds for reproduction of fish species native to the São Francisco River (MMA 2006, Nascimento et al. 2013). In addition, studies investigating the action of dams indicate that changes in river flow cause a decrease in native fauna (Granzotti et al. 2018, Pelicice et al. 2018, Ferreira et al. 2020; dos Santos et al. 2022).

Our abundance data denotes the numerical dominance of a few species, since the sum of the percentages of the three most abundant taxa (*R. bahiensis*, *A. brasiliensis* and *L. grossidens*) exceeds 88% total number of individuals caught, largely due to the massive presence of *R. bahiensis* (77.27%). This pattern is very typical for estuarine fish faunas, as few taxa can deal with the highly variable conditions of the estuarine environments and, consequently, reach abundant populations (Kennish 1990, Chaves & Bochereau 1999). This dominance leads to an uneven distribution of the community (Spach et al. 2007). This pattern of dominance of few species is common in other estuaries on the Brazilian coast (Paiva-Filho & Toscano 1987, Teixeira & Falcão 1992, Garcia & Vieira 1997, Vilar et al. 2017, Gurgel-Lourenço et al. 2023) and in various surface saline/brackish environments.

Over the months, the greatest abundance was found in April 2018, mainly due to the large catch of the clupeid *R. bahiensis* during this month, and this increase in abundance may be correlated with the proximity of the beginning of the rainy season in the region, since the period of greatest rainfall for the Lower São Francisco is from May/June to August/September (Knoppers et al. 2006). During periods of greater rainfall, there is an increase in continental drainage and an increase in the availability of nutrients to the aquatic environment, which increases primary productivity and causes a "bottom-up" effect on food webs, increasing the abundance of species. The lowest abundance was observed in January 2018. This month is characterized by lower rainfall for the region, which affects the supply of nutrients. Consequently, there may be a decrease in the abundance of the shallow area community, since the nutrients that would naturally be carried by the river flow to these areas are trapped by the dams in the river course (Bennett 1994, Gillanders & Kingsford 2002, Chícharo et al. 2006, MMA 2006, Silva et al. 2010, Mendes et al. 2021). Thus, the Lower São Francisco region is considered an oligotrophic environment, due to the artificial influence of nutrient retention caused by dams (Medeiros et al. 2007, 2011, Knoppers et al. 2006), considering that the sources are terrestrial, and nutrient input occurs through continental drainage.

The species richness curve reached the asymptote with a smaller number of samples (200) than the total number of samples taken (242) and coincides with the curve modeled according to the estimator present in Coleman et al. (1982). This indicates that the sampling effort used in the present study was sufficient to represent the fish community in shallow areas of the São Francisco River mouth.

Temporally, richness showed the highest values in March 2018, which coincides with the dry period indicated by Knoppers et al. (2006). The decrease in freshwater inflow into the system probably causes greater penetration of salt water and allows for greater occupation of species of marine or estuarine origin, thus increasing local richness. In contrast, the lowest richness was found in August 2017 coinciding with the rainy season in the Lower São Francisco (Knoppers et al. 2006).

Spatially, the highest richness value was observed at site 3, possibly due to structural differences between sampling sites, and this location had finer sediments than the others (personal observation), which probably increased the availability of organic matter and consequently the availability of food for the fish community. It is noteworthy that the greatest amounts of organic matter are usually correlated with sites that have fine sediments (Hedges & Keil 1995, Burone et al. 2003, Oliveira et al. 2014). The lowest richness was verified at site 2 and may be related to the proximity of this site to human occupation, since this sampling site is located in front of the fisherman village of Saramém, a place of constant movement of people and boats. Richness had the highest value during low tide and the lowest value at high tide, as fish caught at high tide tend to be only those that migrate following the tidal wave, as pointed out by Godefroid et al. (2003). However, the difference in water column height between high tide and low tide can also be the cause of this result, since during low tide the fish fauna is condensed in a smaller amount of water, which can facilitate their capture, while in high tide the greater amount of water can facilitate the escape of some species.

Spatiotemporally, the selected models indicated that richness in the sampled region of the Lower São Francisco is mainly controlled by the tide and the sampling site, with the highest values associated with low tide, which may be influencing the fish fauna as mentioned above, and with sites 1 and 3, suggesting that the greatest richness at these sites occurs due to structural differences among sampling sites (type of sediment, environmental complexity, etc.). For abundance, the models indicate the influence of the tidal state (analogously to richness), the month of collection (which probably influences the abundance through the seasonal pattern of rainfall) and the sampling site (which showed greater abundances in the innermost part of the system that may be related to the environmental gradients presented by the system).

Estuarine environments are places of great dynamics, as there is a convergence of terrestrial, oceanic and atmospheric processes that constantly alter their characteristics (Elliot & Mclusky 2002), this makes these environments complex in terms of geomorphology, hydrography, salinity, tidal characteristics, sedimentation and ecosystem energy, which results in a substantially different ichthyofauna (Kennish 2002). Abrupt changes in salinity, temperature, oxygen and turbidity cause rapid variations in its properties, requiring a great energy demand from the existing biota so that it can remain under these stressful conditions (Day et al. 1989). Making these places inhabited by well-adapted and distinct fauna (Odum 2004), however fragile to changes introduced by man (Yanez-Arancibia 1986). The estuarine ichthyofauna has low species richness, since few species are adapted to tolerate the variations in these areas, however the abundance and biomass are high. Most fish are not adapted to carry out their entire life cycle within estuaries. Fish are usually seasonal members of estuarine communities or use the estuary only as a migration route between spawning and feeding areas (Potter et al. 1986; Costa et al. 1994). Estuarine fish assemblages are dominant over other organisms both in abundance and in biomass and therefore play an important role in the energy flow of the estuarine system. The most abundant developmental stage in estuaries are juvenile forms (Kennish 2002). In estuarine systems endemism is low, which raises questions about which species really depend on estuaries and which use these habitats opportunistically (Lenanton & Potter 1987).

Regarding environmental variables, the selected models indicated that the presence of freshwater in the system (through increased rainfall, flow and pH drop) increases the richness in this environment, in line with what was observed by Lazzari et al. (2003), where it is shown that richness decreases in regions dominated by more saline waters. Small changes in freshwater input can generate changes in the fish fauna, with freshwater input being an important factor mainly in the innermost regions of estuarine systems (Greenwood et al. 2007). Moreover, temperature also appears as an important factor for richness, positively correlated with temperature increase, as in other studies carried out in estuaries (Lin & Shao 1999, Lazzari et al. 2003, Spach et al. 2004, Vendel & Chaves 2006, Ignácio & Spach 2010).

As for richness, the models selected for abundance also indicate that the presence of freshwater in the system (through increased rainfall, flow and decreased salinity) promotes an increase in the abundance of fish fauna. The influx of freshwater is directly linked with the transport of nutrients to the estuarine system, generating an increase in local productivity. This source of nutrients is essential for the maintenance of communities in the Lower São Francisco River, since after the construction of dams, this stretch of the river became oligotrophic as previously mentioned (Medeiros et al. 2007, 2011, Knoppers et al. 2006). Furthermore, the models indicate a negative correlation of abundance, both with salinity and with dissolved oxygen (DO), indicating that abundance varies inversely with the longitudinal gradient of these two variables. In estuarine systems, salinity (Valencia & Franco 2004, Cloern et al. 2017) and DO (Macêdo et al. 2000, Valencia & Franco 2004, Favero et al. 2019) decrease towards upstream.

With respect to the most abundant species, as observed for the entire community, the greater abundances at the mouth of the São Francisco River reflect the environmental gradient present in the region, primarily influenced by the tide and secondarily by the influx of freshwater into the system, which cause variations in environmental parameters, such as salinity and pH. *C. edentulus* is classified according to the guild classification of marine environment use proposed by Elliott et al. (2007), as a marine visitor species (MS), as it enters estuarine environments with strong marine influence during its juvenile phase and returns to the ocean in reproductive periods. According CCA, this species is mainly associated with site 1, a place under a strong influence of water from the ocean through tidal waves. In contrast, *G. barbus* was observed at the opposite end of the estuary, mainly associated with site 5, a place with lower salinity and stronger influence of freshwater. This species is classified in the guild of use as anadromous (AN), that is, it is a fish species that frequents the estuarine and marine environments during its growth, but needs to return to places of lower salinity during the reproductive period. During the study period, several juveniles of *G. barbus* were observed in the region of site 5 and on one occasion a large individual was caught performing parental care (mouthbrooding). The CCA also selected groups of species associated both with sites under strong marine influence (sites 1 and 2) and the estuarine environment (site 3). Among these species, there are two marine migrants (MM; *H. unifasciatus* and *E. melanoptarus*), which use the estuarine environment for growth and the marine environment for reproduction, and an anadromous species (AN; *L. grossidens*), most often with immature individuals, and an estuarine species (ES; *S. testudineus*), the latter species carries out its entire cycle within the estuary.

The last group selected by CCA is formed by species with no strong connection with any region of the sampled area, as they were equally distributed throughout the region, probably because they have great tolerance to changes in salinity along the gradient. Within this group there are two resident estuarine species (*A. brasiliensis* and *R. bahiensis*), which can carry out its entire life cycle within the estuarine environment, and an estuarine migrant species (*D. auratus*), which completes its life cycle outside the estuary or has discrete populations in freshwater or marine environments. *A. brasiliensis* were caught at different reproduction stages (immature, developing and mature), indicating that they complete their entire cycle at the site (Bot Neto et al. 2021).

In general, in relation to the factorial variables, there was a high influence of the tide and site for both models. On the other hand, the month influenced only the abundance of species. As for environmental variables, rainfall and temperature were equally important in structuring the fauna. Specifically for richness, pH was highly important in richness, and for abundance, flow and salinity were relevant. As for the most abundant species, the constancy in the occurrence of *A. brasiliensis*, *R. bahiensis* and *D. auratus* in all sampling sites was evident, but with a preference in sites 3, 4 and 5.

A spatial gradient was detected, with sites 1 and 2 under greater marine influence, sites 3 and 4 representing a transition between the environments and site 5 under the influence of brackish and freshwater. This gradient was mainly influenced by short time scale processes, which is the case of the tide, and secondarily by the river flow, which has shown to have a high relevance for the abundance patterns.

Finally, it is evident that this stretch of the Lower São Francisco River presents a longitudinal gradient and a fauna closer to an estuarine environment than to a river mouth. Furthermore, the intrusion of the saline wedge is probably caused by the reduction and regulation of the flow caused by the various dams along the river course, mainly by the Xingó Dam, which is located only 180 km from the mouth.

Acknowledgements

The authors would like to thank the Coordination for the Improvement of Higher Education Personnel (CAPES) for the scholarship granted to Renato L. Bot Neto (PhD Scholarship) in the Graduate Course in Ecology and Conservation at the Federal University of Paraná (PPG-ECO UFPR); to the students of the Fishery Engineering program at the Federal University of Sergipe (UFS), Luane, Kléverton, Paulo, and Priscilla who assisted in sampling and sorting of the material; to our boatman and friend Ronaldinho (Tito) always happy to sail with us through the Velho Chico; to Barbara Carvalho for always being an excellent friend and a great scientific partner in ichthyology.

Associate Editor

Rosana Mazzoni

Author Contributions

Renato Luiz Bot Neto: contribution to data collection; substantial contribution in the concept and design of the study; contribution to writing – original draft; contribution to data analysis and interpretation; contribution to manuscript preparation; contribution to critical revision, adding intelectual content.

André Pereira Cattani: contribution to data analysis and interpretation; contribution to critical revision, adding intelectual content; contribution to manuscript preparation.

Henry Louis Spach: contribution to data collection; substantial contribution in the concept and design of the study; contribution to manuscript preparation; contribution to critical revision, adding intelectual content.

Riguel Feltrin Contente: contribution to critical revision, adding intelectual content; contribution to data analysis and interpretation.

Olímpio Rafael Cardoso: contribution to writing – review and editing;

Camila Marion: contribution to manuscript preparation; contribution to critical revision, adding intelectual content.

Roberto Schwarz Júnior: contribution to critical revision, adding intelectual content; contribution to manuscript preparation.

Conflicts of Interest

We reiterate have no conflicts of interest to disclose.

Data Availability

Supporting data are available at <https://doi.org/10.48331/scielodata.W0DWQL>.

References

AGUIAR NETTO, A.D.O., LUCAS, A.A.T., SANTOS, A.G.C., & ALMEIDA, C.A.P. 2011. Água e ambiente no baixo São Francisco sergipano. In: Ariovaldo Antonio Tadeu Lucas, Antenor De Oliveira Aguiar Netto (Organizadores). Águas Do São Francisco. São Cristóvão: Editora UFS, 15–32.

ASSIS, D.A.S.D., DIAS-FILHO, V.A., MAGALHÃES, A.L.B., & BRITO, M.F.G. 2017. Establishment of the non-native fish *Metynnis lippincottianus* (Cope 1870) (Characiformes: Serrasalmidae) in lower São Francisco River, northeastern Brazil. Stud. Neotrop. Fauna Environ. 52(3), 228–238.

AZEVEDO, M.C.C., ARAÚJO, F.G., CRUZ-FILHO, A.G., GOMES, I.D. & PESSANHA, A.L.M. 1999. Variação espacial e temporal de bagres marinhos (siluriformes, ariidae) na baía de Sepetiba, Rio de Janeiro. Revista Brasil. Biol. 59(3), 443–454.

BALTZ, D.M., FLEEGER, J.W., RAKOCMSKI, C.F. & MACCALL, J.N. 1998. Food, density, and microhabitat: factors affecting growth and recruitment potential of juvenile saltmarsh fishes. Environ. Biol. Fishes. 53, 89–103.

BAPTISTA, J., MARTINHO, F., DOLBETH, M., VIEGAS, I., CABRAL, H. & PARDAL, M. 2010. Effects of freshwater flow on the fish assemblage of the mondego estuary (Portugal): Comparison between drought and non-drought years. Mar. Freshw. Res. 61(4), 490–501.

BARBOSA, J.M. & SOARES, E.C. 2009 Perfil da ictiofauna da bacia do São Francisco: estudo preliminar. Rev. Bras. Eng. Pesca. 4(1), 155–172.

BARTON, K. 2018. MuMIn: Multi-Model Inference. R package version 1.40.4.

BATE, G.C. & ADAMS, J.B. 2000. The effects of a single freshwater release into the Kromme Estuary. 5. Overview and interpretation for the future. WATER SA. 26(3), 329–332.

BELEI, F. SANTANA SAMPAIO, W.M. GIONGO, P. & DERGAM, J. 2016. Ictiofauna de área prioritária para conservação, Médio São Francisco, Minas Gerais, sudeste do Brasil. Neotrop. Biol. Conserv. 11(2), 94–100.

BENNETT, B.A. 1994 The fish community of the Berg River estuary and an assessment of the likely effects of reduced freshwater inflows. S. Afr. J. Zool. 29(2), 118–125.

BERNARDES, L.M.C. 1951. Notas sobre o clima da bacia do Rio são Francisco. Rev. Bras. Geogr. 13(3), 473–489.

BLABER, S.J.M. & BLABER T.G. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. J. Fish Biol. 17, 143–162.

BLABER, S.J.M. BREWER, D.T. & SALINI, J.P. 1995. Fish communities and the nursery role of the shallow inshore waters of a tropical bay in the Gulf of Carpentaria, Australia. Estuar. Coast. Shelf Sci. 40, 177–193.

BOT NETO, R.L. CARVALHO, B.M. SWARZ JÚNIOR, R.S. & SPACH, H.L. 2021. Insights on the influence of phylogenetic on the relative growth using *Atherinella brasiliensis* as a tool. Bol. Inst. Pesca, 47.

BURONE, L., MUNIZ, P., PIRES-VANIN, A.M.S. & RODRIGUES, M. 2003. Spatial distribution of organic matter in the surface sediments of Ubatuba Bay (Southeastern – Brazil). An. Acad. Bras. Ciênc. 75(1), 77–90.

CHAPMAN, P.M. & WANG, F. 2001. Assessing sediment contamination in estuaries. Environ. Toxicol. Chem. 20(1), 3–23.

CHAVES, P.T. & BOUCHEREAU, J.L. 1999. Biodiversity and dynamics of ichthc communities in the mangrove of Guaratuba, Brazil. Oceanol. Acta. 22(3), 353–364.

CHÍCHARO, L., CHÍCHARO, M.A. & MORAIS, P. 2003. Effects of Guadiana river inflow on coastal fisheries. Thalassas. 19, 99–100.

CHÍCHARO, M.A., CHÍCHARO, L. & MORAIS, P. 2006 Inter-annual differences of ichthyofauna structure of the Guadiana estuary and adjacent coastal area (SE Portugal/SW Spain): Before and after Alqueva dam construction. Estuar. Coast. Shelf Sci. 70(1-2), 39–51.

CLOERN, J.E., JASSBY, A.D., SCHRAGA, T.S., NEJAD, E. & MARTIN, C. 2017. Ecosystem variability along the estuarine salinity gradient: Examples from long-term study of San Francisco Bay. Limnol. Oceanogr. 62(S1), S272–S291.

COELHO, A.L.N. 2008. Geomorfologia fluvial de rios impactados por barragens. Camin. Geog. 9(26), 16–32.

COLEMAN, B.D., MARES, M.A., WILLIS, M.R. & HSIEH, Y. 1982. Randomness, area and species richness. Ecology. 63, 1121–1133.

COMPANHIA DE DESENVOLVIMENTO DO VALE DO SÃO FRANCISCO (CODEVASF). 1991. Inventário dos projetos de irrigação. Ministério da Integração Nacional, Brasília.

COSTA, F.J.C. 2003. Subprojeto 1.3 – Recomposição da Ictiofauna Reofílica do Baixo São Francisco. ANA/GEF/PNUMA/OEA, Canindé do São Francisco, SE.

COSTA, M.J., COSTA, J.L., de ALMEIDA, P.R. & ASSIS, C.A. 1994. Do eel grass beds and salt marsh borders act as preferential nurseries and spawning grounds for fish? An example of the Mira estuary in Portugal. Ecol. Eng. 3, 187–195.

DAGOSTA, F.C.P. MARINHO, M.M.F. & CAMELIER, P. 2014. A new species of *Hyphessobrycon durbin* (Characiformes: Characidae) from the middle rio São Francisco and upper and middle rio Tocantins basins, Brazil, with comments on its biogeographic history. Neotrop. Ichthyol. 12(2), 365–375.

D'AVILLA, T., COSTA-NETO, E.M., & BRITO, M.F. 2021. Impacts on fisheries assessed by local ecological knowledge in a reservoir cascade in the lower São Francisco River, northeastern Brazil. Neotrop. Ichthyol. 19(3).

DAY JR, J. W.; HALL, C. A. S.; KEMP, W. M. & YAÑEZ-ARANCIBIA A. 1989. Estuarine Ecology. Wiley, New York.

DE OLIVEIRA, A.M.E. 1974. Ictiofauna das águas estuarinas do rio Parnaíba (Brasil). Arq. Cienc. Mar. 14(1), 41–45.

DIEGUES, A.C. 1994. An inventory of Brazilian wetlands. Switzerland, IUCN.

DOMINGUEZ, J.M.L. 1996. The São Francisco strandplain: a paradigm for wave-dominated deltas. In: Geology of Siliciclastic Shelf Seas. Eds. Geological Society Special Publication. 117, 217–231.

DOS SANTOS, J.A. SILVA, C.B. DE SANTANA, H.S. CANO-BARBACIL, C. AGOSTINHO, A.A. NORMANDO, F.T. CABEZA, J.R. ROLAND, F. & GARCÍA-BERTHOU, E. 2022. Assessing the short-term response of fish assemblages to damming of an Amazonian river. J. Environ. Manage. 307, 114571.

ELLIOT, M. & McLUSKY, D.S. 2002. The need for definitions in understanding estuaries. Estuar. Coast. Shelf Sci. 55, 815–827

ELLIOT M., WHITFIELD, A.K., POTTER, I.C., BLABER, S.J.M., CYRUS, D.P., NORDLIE, F.G. & HARRISON, T.D. 2007. The guild approach to categorizing estuarine fish assemblages: a global review. Fish. Fish. 8, 241–268.

FAVERO, F.D.L.T., DA SILVA ARAUJO, I.M. & SEVERI, W. 2019. Structure of the fish assemblage and functional guilds in the Estuary of Maracaípe, Northeast coast of Brazil. Bol. Inst. Pesca. 45(1), 1–14.

FERREIRA, K. LOPES, T.M. AFFONSO, I.D.P. AGOSTINHO, A.A. & GOMES, L.C. 2020. Dam reverse flow events influence limnological variables and fish assemblages of a downstream tributary in a Neotropical floodplain. River Res Appl. 36(2), 305–313.

FONTES, L.C.S. 2002. Erosão Marginal no Baixo Curso do Rio São Francisco. Um Estudo de Caso de Impactos Geomorfológicos à Jusante de Grandes Barragens. Dissertação de Mestrado, Universidade Federal de Sergipe, Aracaju.

FOX, J. 2003. Effect Displays in R for Generalised Linear Models. J. Stat. Softw. 8(15), 1–27.

FOX, J. & WEISBERG, S. 2011. An {R} Companion to Applied Regression, Thousand Oaks CA, Sage.

GARCIA, A.M. & VIEIRA, J.P. 1997. Abundância e diversidade da assembleia de peixes dentro e fora de uma pradaria de *Ruppia maritima* L., no estuário da Lagoa dos Patos (RS-Brasil). Atlântica. 19, 161–181.

GILLANDERS, B.B. & KINGSFORD, M.J. 2002. Impact of changes in flow of freshwater on estuarine and open coastal habitats and the associated organisms. Oceanogr. Mar. Biol. 40, 233–309.

GODEFROID, R.R., SPACH, H.L., SCHWARZ JR, R., QUEIROZ, G.M.L.N. & OLIVEIRA NETO, J.F. 2003. Efeito da lua e da maré na captura de peixes em uma planície de maré da Baía de Paranaguá, Paraná, Brasil. Bol. Inst. Pesca. 29(1), 47–55.

GRANZOTTI, R.V. MIRANDA, L.E. AGOSTINHO, A.A. & GOMES, L.C. 2018. Downstream impacts of dams: shifts in benthic invertivorous fish assemblages. Aquatic Sciences. 80, 1–14.

GREENWOOD, M.F.D., MATHESON JR, R.E., MCMICHAEL JR, R.H. & MACDONALD, T.C. 2007. Community structure of shoreline nekton in the estuarine portion of the Alafia River, Florida: Differences along a salinity gradient and inflow-related changes. Estuar. Coast. Shelf Sci. 74, 223–238.

GURGEL-LOURENÇO, R.C. DE MEDEIROS, L.S. PINTO, L.M. DE SOUSA, W.A. PEREIRA, F.B. RAMOS, T.P.A. LIMA, S.M.Q. & SÁNCHEZ-BOTERO, J.I. 2023. Fish fauna from the estuaries of Ceará state, Brazil: a checklist in support of conservation of the Brazilian semiarid coast. Check List, 19(1), 63–90.

HAEDRICH, R.L. & HALL, C A.S. 1976. Fishes and estuaries. Estuaries 19, 55–63.

HEDGES, J.I. & KEIL, R.G. 1995. Sedimentary organic matter preservation: An assessment and speculative hypothesis. Mar. Chem. 49, 81–115.

IGNÁCIO, J.M. & SPACH, H.L. 2010. Variação sazonal da ictiofauna do infralitoral raso do Maciel, Baía de Paranaguá, Paraná. Atlântica. 32(2), 163–176.

JAUREGUIZAR, A.J., MENNI, R., BREMEC, C., MIANZAN, H. & LASTA, C. 2003. Fish assemblage and environmental patterns in the Río de la Plata estuary. Estuar. Coast. Shelf Sci. 56, 921–933.

JUNQUEIRA, R.A.C. 2002. Mapeamento temático de uso da terra no baixo São Francisco. Relatório final. Projeto de Gerenciamento Integrado das Atividades Desenvolvidas em Terra na Bacia do São Francisco – GEF São Francisco (ANA/GEF/PNUMA/OEA).

KENNISH, M.J. 1990. Ecology of estuaries. Boca Raton, Florida, CRC Press.

KENNISH, M.J. 2002. Environmental threats and environmental future of estuaries. Environ. Conserv. 29(1), 78–107.

KNOPPERS, B., MEDEIROS, P.R.P., DE SOUZA, W.F.L. & JENNERJAHN, T. 2006. The São Francisco estuary, Brazil. Handbook of Environmental Chemistry, 5: Water Pollution, v. 5(PART H), p. 51–70.

KUPSCHUS, S. & TREMAIN, D. 2001. Associations between fish assemblages and environmental factors in nearshore habitats of a subtropical estuary. J. Fish Biol. 58, 1383-1403.

LAZZARI, M.A., SHERMAN, S. & KANWIT, J.K. 2003. Nursery use of shallow habitats by epibentic fishes in marine nearshore waters. Estuar. Coast. Shelf Sci. 56, 73–84.

LENANTON, R.C.J. & POTTER, I.C. 1987. Contribution of estuarine to commercial fisheries in temperate western Australia and the concept of estuarine dependence. Estuaries. 10, 28–35.

LIMA, M.A.T. 2010. Composição da ictiofauna demersal do estuário do Rio de Contas, Bahia, Brasil. Dissertação de Mestrado. Universidade Estadual de Santa Cruz, Ilhéus.

LIN, H.J. & SHAO, K.T. 1999. Seasonal and diel changes in a subtropical mangrove fish assemblage. Bull. Mar. Sci. 65(3), 775–794.

LONERAGAN, N.R. & POTTER, I.C. 1990. Factors influencing community structure and distribution of different life-cycle categories of fishes in shallow waters of a large Australian estuary. Marine Biology 106, 25–37.

LOURES, R.C. & POMPEU, P.S. 2012. Temporal variation in fish community in the tailrace at Três Marias hydroelectric dam, São Francisco River, Brazil. Neotrop. Ichthyol. 10, 731–740.

MACÊDO, S.D., FLORES-MONTES, M.J. & LINS, I.C. 2000. Características abióticas da área. Gerenciamento participativo de estuários e manguezais. Recife, Editora Universitária da Universidade Federal de Pernambuco.

MATIC-SKOKO, S., PEHARDA, M., PALLAORO, A. & FRANI_EVI, M. 2005. Species composition, seasonal fluctuations, and residency of inshore fish assemblages in the Pantan Estuary of the Eastern Middle Adriatic. Acta Adriatica 46(2), 201–212.

MEDEIROS, P.R.P., KNOPPERS, B.A., DE SOUZA, W.F.L. & OLIVEIRA, E.N. 2011. Aporte de material em suspensão no Baixo Rio São Francisco (Se/Al), em diferentes condições hidrológicas. Braz. Arch. Biol. Technol. 15(1), 42–53.

MEDEIROS, P.R.P., KNOPPERS, B.A. & SANTOS JÚNIOR, R.C. 2007. Aporte fluvial e dispersão de matéria particulada em suspensão na zona costeira do rio São Francisco (Se/Al). Geochim. Bras. 21(2), 212–231.

MEDEIROS, P.R.P., KNOPPERS, B.A., SANTOS JÚNIOR, R.C., DE SOUZA, W.F.L. 2003. Aporte anual do material em suspensão e sua dispersão na zona costeira do rio São Francisco (Se/Al). In: II Congresso sobre Planejamento e Gestão das Zonas Costeiras dos Países de Expressão Portuguesa. Recife.

MEDEIROS, P.R.P., SANTOS, M.M., CAVALCANTE, G.H., DE SOUZA, W.F.L., SILVA, W.F. 2014. Características ambientais do Baixo São Francisco (AL/SE): efeitos de barragens no transporte de materiais na interface continente-oceano. Geochimica Brasiliensis, 28(1), 65–78.

MENDES, Y.A. OLIVEIRA, R.S. MONTAG, L.F. ANDRADE, M.C. GIARRIZZO, T. ROCHA, R.M. & FERREIRA, M.A.P. 2021. Sedentary fish as indicators of changes in the river flow rate after impoundment. Ecol. Indic. 125, 107466.

MINISTÉRIO DO MEIO AMBIENTE. 2006. Caderno da Região Hidrográfica do São Francisco. Brasília, Secretaria de Recursos Hídricos.

MIRANDA, L.B., CASTRO, B.M. & KJERFVE, B. 2002. Princípios de Oceanografia Física de Estuários. Edusp, São Paulo. 424 p.

MORRISON, M.A., FRANCIS, M.P., HARTILL, B.W. & PARKINSON, D.M. 2002. Diurnal and tidal variation in the abundance of the fish fauna of temperate tidal mudflat. Estuar. Coast. Shelf Sci. 54, 793–80.

MOYLE, P.B. & CECH JR., J.J. 1988. Fishes an introduction to ichthyology. 2 ed. Prentice Hall, New Jersey, USA. 560 p. 1988.

NASCIMENTO, M.C.D., RIBEIRO, C.E.J. & AGUIAR NETTO, A.D.O. 2013. Relatório técnico da campanha de avaliação das mudanças socioambientais decorrentes da regularização das vazões no baixo Rio São Francisco. Comitê da Bacia Hidrográfica do rio São Francisco, Alagoas.

NELSON, J.S., GRANDE, T.R. & WILSON, M.V.H. 2016. Fishes of the World. 5. ed. New Jersey: John Wiley & Sons.

ODUM, E.P. 2004. Fundamentos de Ecologia. 7 ed. Rio de Janeiro: Guanabara Koogan,

OKSANEN, J. 2019. Multivariate analysis of ecological communities in R: vegan tutorial. R package version 2.53.

OLIVEIRA, A.M. 2003. Subprojeto 1.2. B – Estudo Hidrodinâmico-sedimentológico do baixo São Francisco, Estuário e zona costeira adjacente-AL/SE. ANA/GEF/PNUMA/OEA, Maceió, AL.

OLIVEIRA, A.M., MEDEIROS, P.R.P., LIMA, E.L.R. & HERNANDEZ, A.O. 2008. Dinâmica da formação da cunha salina no Estuário do rio São Francisco. In: III Congresso Brasileiro de Oceanografia, Fortaleza, Ceará.

OLIVEIRA, E.N., KNOPPERS, B.A., LORENZZETTI, J.A., MEDEIROS, P.R.P., CARNEIRO, M.E. & DE SOUZA, W.F.L. 2012. A satellite view of riverine turbidity plumes on the NE-E Brazilian coastal zone. Braz. J. Oceanogr. 60(3), 283–298.

OLIVEIRA, T.S., BARCELLOS, R.L., SCHETTINI, C.A.F. & CAMARGO, P.B. 2014. Processo sedimentar atual e distribuição da matéria orgânica em um complexo estuarino tropical, Recife, PE, Brasil. J. Integr. Coast. Zone Manag.14(3), 399–411.

OLIVEIRA NETO, J.F., GODEFROID, R.S., QUEIROZ, G.M.L.N. & SCHWARZ JR., R. 2004. Variação diuturna na captura de peixes em uma planície de maré da Baía de Paranguá, PR. Acta Biologica Leopoldensia 26(1), 125–138.

PAIVA-FILHO, A.M. & TOSCANO, A.P. 1987. Estudo comparativo e variação sazonal da ictiofauna na zona entremarés do Mar Casado – Guarujá e Mar Pequeno – São Vicente, São Paulo. Bol. Inst. Oceanogr. 35(2), 153–165.

PELICICE, F.M. AZEVEDO-SANTOS, V. M. ESGUÍCERO, A.L.H. AGOSTINHO, A.A. & ARCIFA, M. S. 2018. Fish diversity in the cascade of reservoirs along the Paranapanema River, southeast Brazil. Neotrop. Ichthyol. 16(2): e170150.

POTTER, I.C., CLARIDGE, P.N. & WARWICK, R.M. 1986. Consistency of seasonal changes in an estuarine fish assemblage. Mar. Ecol. Prog. Ser., [S. I.]. 32, 217–226.

R CORE TEAM. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

RAMOS, L.A. & VIEIRA, J.P. 2001. Composição específica e abundância de peixes de zonas rasas dos cinco estuários do Rio Grande Do Sul, Brasil. Bol. Inst. Pesca 27(1), 109–121.

RAZ-GUZMAN, A. & HUIDOBRO, L. 2002. Fish communities in two environmental different estuarine systems of Mexico. J. Fish Biol. 60, 1–14.

REISE, K. 1985. Tidal flat ecology. Berlin: Spring-Verlag, 191 p.

SANTOS, M.L. 2009. Avaliação de alterações em comunidades de peixes e na pesca do baixo curso do rio São Francisco (Brasil) em função de barramentos. Dissertação de Mestrado, Universidade Federal de Lavras, Lavras.

SANTOS, F.J.M., PEÑA, A.P., LUZ, V.L.F. 2008. Considerações biogeográficas sobre a herpetofauna do submédio e da foz do rio São Francisco, Brasil. Estudos, 35(1), 59–78.

SATO, Y. & GODINHO, H.P. 2004. Migratory fishes of the São Francisco River. In: CAROLSFELD, J., HARVEY, B., BAER, A. & ROSS, C. (Ed.). Migratory fishes of South America. Victoria: World Fisheries Trust. p. 195–232.

SATO, Y. & GODINHO, H.P. 1999. Peixes da bacia do rio São Francisco. In: LOWE-MCCONNELL, R.H. Estudos ecológicos de comunidades de peixes tropicais. São Paulo, EDUSP. p. 401–413.

SILVA, A.R.M., SANTOS, G.B. & RATTON, T. 2006. Fish community structure of Juramento reservoir, São Francisco River basin, Minas Gerais, Brazil. Rev. Bras. Zool. 23(3), 832–840.

SILVA, W.F., MEDEIROS, P.R.P., VIANNA, F.G.B. 2010. Quantificação preliminar do aporte de sedimentos no baixo São Francisco e seus principais impactos. In: X Simpósio de recursos hídricos do Nordeste. Fortaleza.

SOUZA, W.F.L. 2012. A satellite view of riverine turbidity plumes on the NE-E Brazilian coastal zone. Braz. J. Oceanogr. 60(3), 283–298.

SPACH, H.L., GODEFROID, R.S., SANTOS, C., SCHWARZ JR, R. & QUEIROZ, G.M.L. 2004. Temporal variation in fish assemblage composition on tidal flat. Braz. J. Biol. 52(1), 47–58.

SPACH, H.L., SANTOS, C., PICHLER, H.A., IGNÁCIO, J.M., STOIEV, S.B., & BERNARDO, C. 2007. Padrões estruturais da assembleia de peixes em duas áreas do Canal da Cotinga, Baía de Paranaguá, Paraná, Brasil. Bioikos. 21(2), 57–67.

TAYLOR, J.C. & RAND, P.S. 2003. Spatial overlap and distribution of anchovies (Anchoa spp.) and copepods in a shallow stratified estuary. Aquat. Living Resour. 16, 191–196.

TEIXEIRA, R.L. & FALCÃO, G.A.F. 1992. Composição da fauna nectônica do complexo lagunar Mundaú-Manguaba, Maceió, AL, Brasil. Atlântica. 4, 43–58.

TER BRAAK, C.J.F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology. 67, 1167–1179.

TRAJANO, E. SECUTTI, S. & BICHUETTE, M. E. 2009. Natural history and population data of fishes in caves of the Serra do Ramalho karst area, Middle São Francisco basin, northeastern Brazil. Biota Neotrop. 9(1).

VALENCIA, V. & FRANCO, J. 2004. Main characteristics of the water masses. In: BORJA, A. and COLLINS, M. (eds) Oceanography and marine environment of the Basque Country. Elsevier Oceanography Series 70. Elsevier, Amsterdam. p. 197–232.

VENABLES, W.N. & RIPLEY, B.D. 2002. Modern Applied Statistics with S. Fourth Edition. Springer. New York.

VENDEL, A.L. & CHAVES, P.T. 2006. Use of an estuarine environment (Barra do Saí lagoon, Brazil) as nursery by fish. Rev. Bras. Zool. 23(4), 1117–1122.

VENDEL, A.L., LOPES, S.G., SANTOS, C. & SPACH, H.L. 2003. Fish assemblages in tidal flat. Braz. Arch. Biol. Technol. 46(2), 233–242.

VIEIRA, J.P. & MUSICK, J.A. 1993. Latitudinal patterns in diversity of fishes in warm-temperate and tropical estuarine waters of the Western Atlantic. Atlântica 15, 115–133.

VILAR, C.C., JOYEUX, J.C. & SPACH, H.L. 2017. Geographic variation in species richness, rarity, and the selection of areas for conservation: An integrative approach with Brazilian estuarine fishes. Estuar. Coast. Shelf Sci. 196, 134–140.

WHITFIELD, A.K. 1999. Ichthyofaunal assemblages in estuaries: A South African case study. Reviews in Fish Biology and Fisheries 9, 151–186.

WHITFIELD, A.K. & ELLIOTT, M. 2002. Fishes as indicators of environment and ecological changes within estuaries: a review of progress and some suggestions for the future. J. Fish Biol. 61 (Supplement A), 229–250.

YAÑES-ARANCIBIA, A. 1986. Ecologia de la zona costeira. México: AGT Editor. 1986.

ZUUR, A.F., IENO, E.N. & ELPHICK, C.S. 2010. A protocol for data exploration to avoid common statistical problems. Methods Ecol. Evol. 1, 3–14.

Received: 27/06/2022
Accepted: 28/05/2023
Published online: 26/06/2023