Research, Society and Development, v. 12, n. 1, e1112139271, 2023
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v12i1.39271

Artisanal fishing and fish fauna changes in the lower São Francisco, after seven years of reduced flow at the Xingó hydroelectric plant

Pesca artesanal e ictiofauna no baixo São Francisco, após sete anos de redução de vazões na hidroelétrica de Xingó

La pesca artesanal y fauna de peces en el bajo río São Francisco, después de siete años de reducción de flujo de agua en la central hidroeléctrica de Xingó

Received: 12/13/2022 | Revised: 12/24/2022 | Accepted: 12/25/2022 | Published: 01/02/2023

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Abstract
Because of hydrological changes in the lower São Francisco River, the objective of this research was to identify socio-cultural aspects among artisanal fishers and their understanding of fish species dynamics in the fluvial plain. The study was conducted in the micro-region of Penedo by using semi-structured interviews. We also collected fish during low tide using cast nets or gill nets to survey the ichthyofauna of the river plain, identifying the dominant fish species and their diversity. There is a substantial dependence of fishermen's families on fishing activities, which are associated with the region's low education level and limited employment opportunities. The remuneration for the activity is low, which negatively affects the food security of these individuals. There is a perception of changes in the dynamics and decline in the occurrence of fish species, resulting from decreased flows and destructive fishing methods. A total of 3,055 individuals comprising 82 taxa and 30 families were collected. The fish fauna on the fluvial plain is composed mainly of species associated with estuaries, especially near the municipalities of Piaçabuçu and Penedo. The environmental mitigations of the hydropower plants and the revitalization program were insufficient to solve the problems in the region.
Keywords: Environmental impacts; Fish fauna; Traditional community; Fluvial plain.

Resumo
Devido as mudanças no baixo curso do rio São Francisco, o objetivo do trabalho foi identificar os aspectos sociocultural da pesca artesanal e compreender a dinâmica das espécies de peixes na planície fluvial. O estudo foi realizado na microrregião de Penedo através de entrevistas semiestruturadas. Os peixes foram coletados durante a maré vazante usando malhadeiras e redes de arrasto. O levantamento da ictiofauna da planície fluvial foi realizado identificando as espécies de peixes dominantes e sua diversidade. Há uma dependência substancial das famílias de pescadores das atividades pesqueiras, que estão associadas ao baixo nível de escolaridade da região e às limitadas oportunidades de emprego. A remuneração pela atividade é baixa, o que afeta negativamente a segurança alimentar desses indivíduos. Há uma percepção de mudanças na dinâmica e declínio na ocorrência de espécies de peixes, decorrentes da diminuição das vazões e métodos de pesca irracionais. Foram coletados 3.055 indivíduos compreendendo 82 táxons e 30 famílias. A ictiofauna da planície fluvial é composta principalmente por espécies associadas aos estuários, principalmente próximo aos municípios de Piaçabuçu e Penedo. As ações ambientais das hidrelétricas e o programa de revitalização foram insuficientes para solucionar os problemas da região.
Palavras-chave: Impactos ambientais; Ictiofauna; Comunidade tradicional; Planície fluvial.

Resumen
Con los cambios en el bajo río São Francisco, el objetivo del proyecto fue evaluar los aspectos socioculturales en la pesca artesanal e comprender el flujo de las especies de peces en el plane fluvial. El estudio fue hecho en pequeña región de Penedo, por intermedio de entrevistas. Las cosechas de los peces fueran hechas en la maré seca con uso de redes de pesca. La fauna de peces fue identificada, valorando las especies con gran diversidad. Hay fuerte relación de los pescadores y sus familias con la actividad de pesquerías, además con bajo nivel de escolaridad y poca oportunidad de empleo. El sueldo es bajo y posee efectos en la seguridad alimentar. Los cambios y la dinámica de rio, además la depleción de las especies, están relacionadas con la disminución de los flujos de agua y la pesca sin gestión. Fueran cosechados 3.055 peces de 82 taxones y 30 familias. La fauna de peces en la región, se compone de especies adjudicadas a la rías, cerca de los ajuntamientos de Penedo e Piaçabuçu. Las acciones em medio ambiente de la hidroeléctrica y el programa de recuperación del rio São Francisco no tuvieron éxito para solucionar los problemas.
Palabras clave: Médio ambiente; Fauna de peces, Comunidad tradicional; Plane del rio.

1. Introduction

The São Francisco River is Brazil's largest entirely national hydrographic basin, and is approximately 2,800 km long, the third-longest in the country. In addition, it flows through three biomes (Mata Atlântica, Cerrado, Caatinga), and is divided geomorphically into four segments: Upper, Middle, Lower-Middle, and Lower São Francisco (Medeiros et al., 2014; Soares et al., 2020a). The lower segment extends from Paulo Afonso (BA) to the river mouth and includes the Xingó hydroelectric plant, located between Sergipe and Alagoas 240 kilometers upriver of the São Francisco River. This region suffers most from the consequences of the predatory development model imposed on the entire São Francisco River (Marques & Tomáz 2015). The dams, the deforestation of riparian forests, pollution by domestic and industrial sewage, contamination by pesticides, and the introduction of non-native species have all contributed to changes in the basin dynamics.

The fish fauna of the São Francisco River comprises many species of environmental, social, and economic importance, but stocks have been declining because of fishing pressure (Campeche et al., 2011) and reduced flows. Thus, marine and estuarine species are currently found in areas where freshwater species previously dominated (Soares et al., 2016; 2020b). Salt water currently reaches approximately 10-16 km up the lower São Francisco River, expanding its estuary by 4 km (Soares et al., 2020a; 2020c). Salinity is most important for governing the distribution of estuarine fish (Blaber, 2000). Some species migrate to tributaries or the mouth of a river in response to changes in salinity (Cowan, et al., 2013; Cruz et al. 2020).

Artisanal fishermen have been the most affected by the above changes (Nogueira & Sá, 2015; Soares et al., 2020a) and the lower segment concentrates the largest and poorest fishing population in Brazil (Silva 2014). According to Freitas et al. (2015), artisanal fishing is of paramount importance for countless families. Besides providing their primary source of income, fishihg is an important component of their culture and food supply. However, reduced fish populations in all São Francisco segments have contributed to the impoverishment of these riverside dwellers, which has created one of the most dramatic

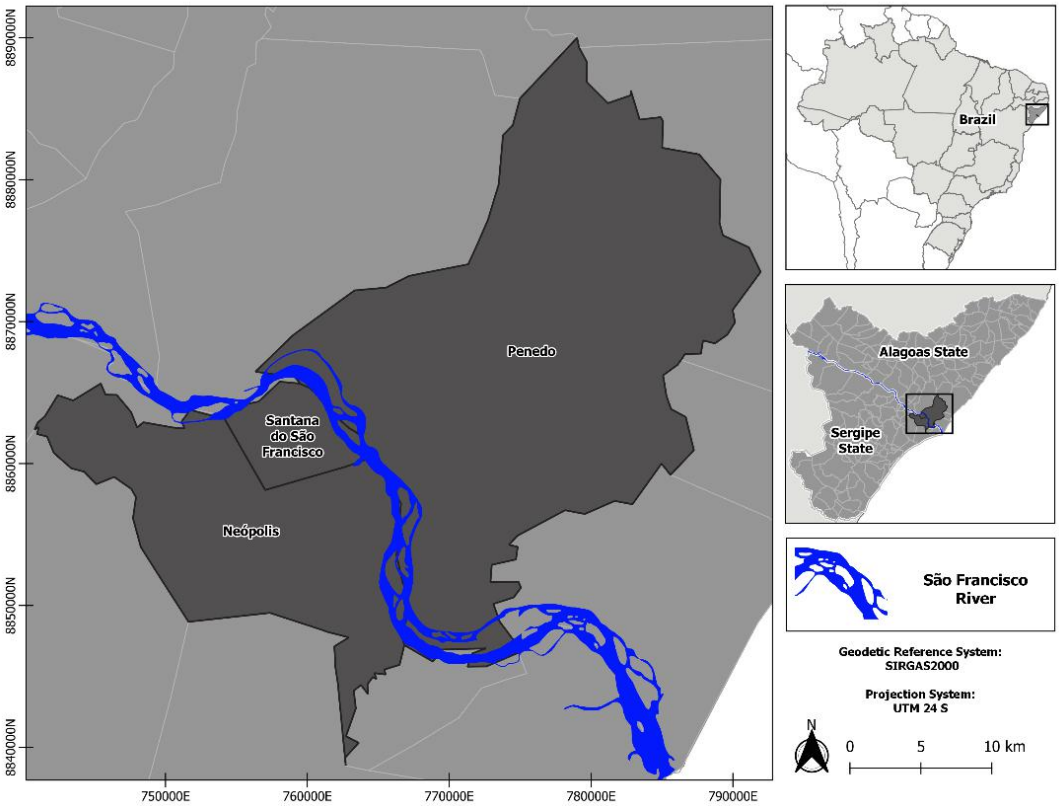
socio-environmental dilemmas in the basin. Artisanal fishermen face many problems, such as housing conditions, health, education, communication, and territorial disputes (Cardoso, 2009). These problems affect the fishing practiced by riverside populations which, given the overall unemployment situation that occurs along the São Francisco, has great importance (Oliveira & Mata-Oliveira, 2020). Therefore, the objective of this study was to identify the socio-cultural insights of artisanal fishermen and their knowledge of fish fauna dynamics after seven years of reduced flows.

2. Methodology

2.1 Study area

We surveyed artisanal fishermen who live on the banks of the São Francisco River in the municipalities of Penedo (AL), Neopólis (SE), Santana do São Francisco (SE) and Piaçabuçu (AL) and collected fish at 15 points along the channel (Figure 1).

Figure 1 - Locations of Penedo, Santana do São Francisco and Neópolis municipalities. The fishes were collected at 15 points (between Long -36.582383 and Lat -10.299611 and Long -36.430666 and Lat -10.412070), in the main channel of the river, between the upstream and downstream borders of the municipalities of Penedo and Neopólis. (Dark gray area).



Source: Authors.

2.2 Socioeconomic and environmental data

Artisanal fisher families were interviewed between October 2019 and January 2020. Data collection on socioeconomic and environmental issues and access to public policies was performed using semi-structured interviews, with a combination of closed and open questions. Such interviews permit informants to talk about their experiences, based on the

main foci proposed by the researchers, and facilitates free and spontaneous responses from informants (Triviños, 1987). An adaptation of the free listing technique was also used. Each fisher was encouraged to name the fished/captured species regardless of purpose, classifying them as frequent or rare/uncommon. Free listing is considered a well-established method, related to cultural domain boundaries, which assumes that when people list freely, they tend to cite terms in order of familiarity. Individuals who know more about the requested content list more than those who know less and the terms that are most remembered indicate their local prominence. The species mentioned frequently exhibit a common knowledge among individuals, or consensus, within a particular culture or group (Quinlan, 2005).

2.3 Fish sampling and classification

Fish were collected in 2017, 2018, and 2019. The cast net (3.6 meters long, 17 mm mesh between adjacent knots) was cast 10 times; three consecutive beach seine (22 x 2 m, 8 mm mesh between adjacent knots) hauls were deployed for eight minutes. The seine was manually pulled by two individuals parallel to the shore and dragged to the bank for removing fish. All collections were authorized by the Brazilian Authorization System and Information on Biodiversity (SISBIO) under process numbers 22211-1 and 75591-2 and ethics committee under process number 0024-2020.

3. Results and Discussion

3.1 Fisher socioeconomic profiles

There was a wide range in ages and education levels amongst fishers and their families. The ages of 60% of both male and female fishers was >40 y, 20% were between 16 and 20 years. All working-age family members, including women, were fishers, indicating their essential roles in maintaining family incomes. Regarding education level, most men had little formal education, and most who were studying were school-age children.

Living conditions were basic. All fisher families live in masonry houses, with electricity, garbage collection offered by the government, and water provided by the Companhia de Abastecimento. However, 50% of homes lacked sewage collection and 11% lacked basic sanitation systems, resulting in the discharge of untreated sewage directly into the river. Water was collected from rainwater via cisterns or taken directly from the river. No family had an income above the minimum wage. The primary public programs available to fishers are the Seguro Defeso (about 90% have a fishing license and receive the benefit), the Bolsa Família (50% of families), and retirement benefits (25%).

3.2 Fishing activity and fisher perceptions of species dynamics

Fish species that were once common are now rare or non-existent in the Lower São Francisco, and estuarine or coastal species have increased occurrences 20 to 40 km upriver from the river mouth (Table 1). Fisher perceptions of such changes were evident, as were their difficulties in surviving by fishing, as was seen in their comments:

"A year ago, I was able to catch 10 to 15 kilos in one day; today I catch 1 kilo, sometimes it's not even enough to eat" (42-year-old interviewee)

"The fish that we used to catch but that have now disappeared from the São Francisco River were the piaba, mandim, xira, and surubim, the tubarana has also disappeared from the Lower São Francisco. We can still see it in the backwaters, jumping in the water. Today in the Lower, there is only tucunaré, piranha, robalo, just those little things; fishing is very weak, but it's all gone, it's all over." (Retired interviewee)

"The fish that we find very frequently in the São Francisco River are the pirambeba, the tucunaré, the cará-boi, the

piau branco, the piau preto, robalo, carapeba, and robalo flecha. There are also fish that have disappeared from the river, such as the piau amarelo, xira, dourada, tubarana, and the mandim, both the yellow and the white, and the pintado is no longer seen." (38-year-old interviewee).

Table 1 - Species listed by fishers in order of listing frequency.

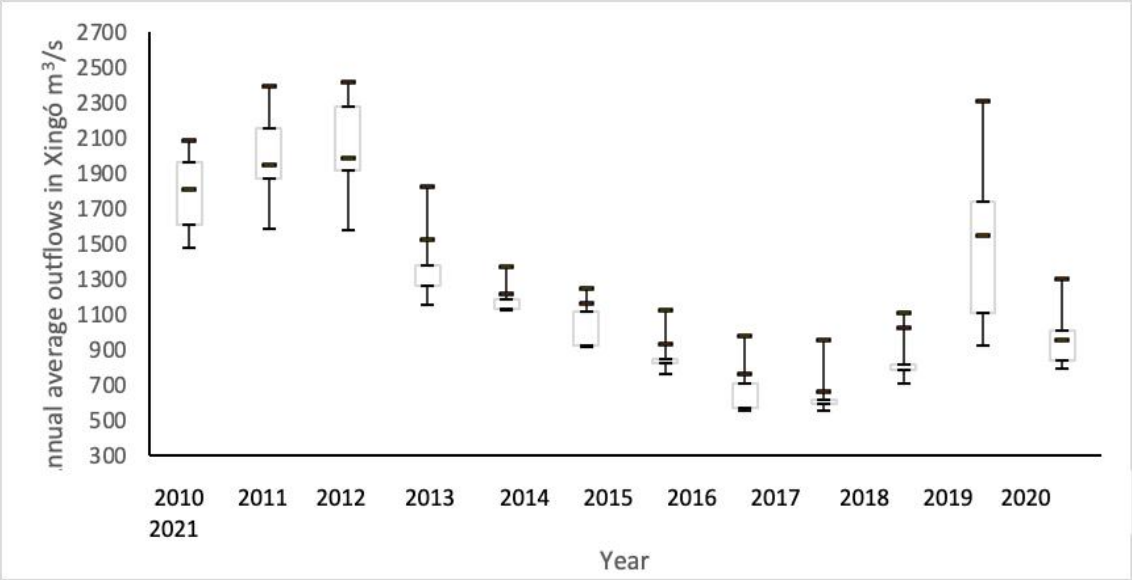
	Common name	N° of listings	Scientific name	Habitat
Found more often	Robalo	12	*Centropomus parallelus, C. undecimalis*	Coastal
	Tucunaré	10	*Cichla monoculus*	Non-native
	Piau	10	*Megaleporinus obtusidens, Schizodon knerii*	Native
	Piranha	7	*Pygocentrus piraya*	Native
	Tilapia	7	*Oreochromis niloticus*	Non-native
	Carapeba	8	*Eugerres brasilianus, Eucinostomus melanopterus, Diapterus rhombeus*	Native - estuary and freshwater
	Pirambeba	6	*Serrasalmus brandtii*	Native
	Bagre	6	*Cathorops agassizii*	Coastal
	Traíra	5	*Hoplias microcephalus*	Native
	Camarão	4	*Macrobrachium acanthurus, M. carcinus*	Native
	Siri	4	*Callinectes sp.*	Coastal
	Pacu	3	*Metynnis maculatus*	Native
	Cara boi	3	*Astronotus ocellatus*	Non-native
No longer found	Xira	9	*Prochilodus argenteus*	Native
	Surubim	8	*Pseudoplatystoma corruscans*	Native
	Tubarana	7	*Salminus hilarii*	Native
	Mandi	6	*Pimelodus maculatus*	Native
	Dourado	4	*Salminus franciscanus*	Native
	Curimã	3	*Mugil curema*	Coastal
	Pilombeta	3	*Anchoviella vaillanti, A.lepidentostole*	Native

Source: Authors.

3.3 Flow effects of the Xingó Hydroelectric Power Plant

During the period of water scarcity (2013 to 2019) several debates and studies were promoted with specialists, culminating in the creation of the resolution, ANA no 2.081/2017 (National Water Agency). This document made the flow policy more flexible, promoting facilities for reducing the volume of water used by the hydroelectric plants of the National Electric System – ONS/Brazil, in the São Francisco River and increased the problems in the lower river, such as: increased salinity, less dilution of pollutants, formation of new islands, disappearance of marginal lakes and negative effect on the reproduction of migratory fish. However, after severe droughts in the 2010s, there was a small recovery in the basin with an increase in flows from 2020, reaching 1.441±444 m3/s (Figure 1).

Figure 2 - Box plot of annual outflows at the Xingó Hydroelectric Power Plant, 2010-2021.



Source: Authors.

3.4. Fish collected in 2017, 2018 and 2019 in the Penedo reach

A total of 3,055 individuals comprising 82 taxa (80 identified to species and two to genus) and 30 families were collected. The individuals represented 54 new records (NR) for estuarine or marine species in the São Francisco River basin (Table 2). Fishes associated with estuaries, especially those in the juvenile phase, were present throughout the entire floodplain (Table 2), predominating both in terms of abundance (63.56% of the total number of individuals collected) and richness (72.50% of the total number of species). Moreover, Astronotus ocellatus, Cichla monoculus and Oreochromis niloticus are non-native species.

Table 2 - Fish taxa collected on the fluvial plain of São Francisco River estuary. Fish species were classified by preferred habitat after Froese and Pauly (2015) as freshwater (F), freshwater-estuarine (FE), marine (M), marine-freshwater-estuarine (MFE) and marine-estuarine (ME). n = number of individuals; NR = new records of occurrence in São Francisco River basin; H= habitat.

Family	Species	n	NR	H
Acestrorhynchidae	*Acestrorhynchus lacustris* (Lütken, 1875)	7		F
Achiridae	*Achirus lineatus* (Linnaeus, 1758)	11	X	ME
Anostomidae	*Megaleporinus obtusidens* (Fowler, 1941)	145		F
	Schizodon knerii (Steindachner, 1875)	17		F
Ariidae	*Cathorops agassizii* (Eigenmann and Eigenmann, 1888)	2	X	F
	Sciades herzbergii (Bloch, 1794)	215	X	MFE
Atherinopsidae	*Atherinella brasiliensis* (Quoy and Gaimard, 1825)	164	X	ME
Carangidae	*Caranx lugubris* (Poey, 1860)	2	X	M
	Caranx latus (Agassiz, 1831)	24	X	MFE
Centropomidae	*Centropomus parallelus* (Poey, 1860)	97	X	MFE
	Centropomus undecimalis (Bloch, 1792)	72	X	MFE
Characidae	*Astyanax fasciatus* (Cuvier, 1819)	167		F
	Hemigrammus gracilis (Lütken, 1875)	9		F
	Metynnis maculatus (Kner, 1858)	423		F
	Moenkhausia costae (Steindachner, 1907)	4		F
	Triportheus guentheri (Garman, 1890)	6		F
Cichilidae	*Astronotus ocellatus* (Agassiz, 1831)	10		F
	Cichla monoculus (Agassiz, 1831)	105		F
	Cichlasoma sanctifranciscense (Kullander, 1983)	20		F
	Crenicichla lepidota (Heckel, 1840)	32		F
	Oreochromis niloticus (Linnaeus, 1758)	18		FE
Clupeidae	*Harengula clupeola* (Cuvier, 1829)	9	X	ME
Eleotridae	*Dormitator maculatus* (Bloch, 1792)	18	X	MFE
	Eleotris pisonis (Gmelin, 1789)	64	X	MFE
Engraulidae	*Anchoa januaria* (Steindachner, 1879)	4	X	ME
	Anchovia clupeoides (Swainson, 1839)	20	X	ME
	Anchoviella lepidentostole (Fowler, 1911)	40		MFE
	Anchoviella vaillanti (Steindachner, 1908)	2		F
	Cetengraulis edentulus (Cuvier, 1829)	32	X	ME
	Lycengraulis grossidens (Spix and Agassiz, 1829)	15		MFE
Erythrinidae	*Hoplias microcephalus* (Agassiz, 1829)	2		F
Gerreidae	*Diapterus rhombeus* (Cuvier, 1829)	34	X	ME
	Eucinostomus argenteus (Baird and Girard, 1855)	42	X	MFE
	Eucinostomus melanopterus (Bleeker, 1863)	158		MFE
	Eugerres brasilianus (Cuvier, 1830)	256		M
Gobiidae	*Awaous tajasica* (Lichtenstein, 1822)	218	X	FE
	Bathygobius soporator (Valenciennes, 1837)	35	X	MFE
	Gobionellus oceanicus (Pallas, 1770)	32	X	MFE
Haemulidae	*Pomadasys ramosus* (Poey, 1860)	4	X	ME
Hemiramphidae	*Hemiramphus brasiliensis* (Linnaeus, 1758)	17	X	M
	Hyporhamphus unifasciatus (Ranzani, 1841)	3	X	ME

Lutjanidae	*Lutjanus alexandrei* (Moura and Lindeman, 2007)	57	X	M
	Lutjanus analis (Cuvier, 1828)	1	X	ME
	Lutjanus cyanopterus (Cuvier, 1828)	10	X	ME
	Lutjanus jocu (Bloch and Schneider, 1801)	49	X	MFE
Mugilidae	*Mugil curema* (Valenciennes, 1836)	37	X	MFE
	Mugil curvidens (Valenciennes, 1836)	6	X	M
Paralichthyidae	*Citharichthys arenaceus* (Evermann and Marsh, 1900)	1	X	M
	Citharichthys macrops (Dresel, 1885)	12	X	M
	Citharichthys spilopterus (Günther, 1862)	68	X	MFE
Polynemidae	*Polydactylus virginicus* (Linnaeus, 1758)	3	X	ME
Prochilodontidae	*Prochilodus argenteus* (Spix and Agassiz, 1829)	2		F
Scaridae	*Sparisoma radians* (Valenciennes, 1840)	1	X	M
Scianidae	*Bairdiella ronchus* (Cuvier, 1830)	12	X	ME
	Stellifer brasiliensis (Schultz, 1945)	23	X	M
	Stellifer rastrifer (Jordan, 1889)	3	X	ME
Serranidae	*Epinephelus itajara* (Lichtenstein, 1822)	1	X	ME
	Rypticus randalli (Courtenay, 1967)	1	X	M
Serrasalmidae	*Pygocentrus piraya* (Cuvier, 1819)	43		F
	Serrasalmus brandtii (Lütken, 1875)	126		F
Sparidae	*Archosargus probatocephalus* (Walbaum, 1792)	2	X	ME
Sternopygidae	*Sternopygus macrurus* (Bloch and Schneider, 1801)	2		F
Syngnathidae	*Microphis brachyurus* (Bleeker, 1854)	10	X	MFE
Tetraodontidae	*Colomesus psittacus* (Bloch and Schneider, 1801)	1	X	MFE
	Sphoeroides greeleyi (Gilbert, 1900)	3	X	ME
	Sphoeroides testudineus (Linnaeus, 1758)	26	X	ME

Source: Authors.

4. Discussion

4.1. Fisher socioeconomic profiles

Artisanal fishers are aging throughout the São Francisco basin. Freitas et al. (2015), in research with artisanal fishermen in the Lower São Francisco, observed that the predominant age was between 40 and 59 years old. According to Rocha et al. (2011), in the Upper and Middle São Francisco, youth were absent in fishing areas. These studies corroborate our data, where fishers over 40 years old predominated.

Artisanal fishers are poorly educated in northeast Brazil and throughout the São Francisco basin. Bezerra et al. (2018) identified in Rio Grande do Norte a predominance of fishers who had not completed elementary school and a significant percentage of illiterate people. Similarly, Freitas et al. (2015) found for the São Francisco canyons that 30% of fishers were illiterate and >50% had attended only early elementary school, similar to what we observed. Moreno and Carvalhal (2013) reported low education levels among artisanal fishers in Ubatuba (SP), as well as insufficient access to infrastructure, economic benefits, and social inclusion for fishers. Perhaps the most important cause for little formal education is the need to work, given restricted family incomes. This information reinforces the importance of the "Bolsa Família" program in keeping children and young people in school, as we observed.

It is noteworthy that approximately 30% of households in the municipalities of Neópolis, Penedo and Santana do São Francisco, have adequate sanitary sewage (IBGE 2020). Our data differ from those from other studies because most of the fishers we studied reside in urban areas, which favors access to more public services. However, Bezerra et al. (2018) reported

the predominance of mud houses lacking basic sanitation in the Lower São Francisco region, close to the river canyons. Also, Freitas et al. (2015) found that most fishers had masonry houses and access to electricity, but about 30% lacked a running water supply. The effects of inadequate sewage treatment are amplified by decreased river flows, removal of riparian vegetation and siloed natural resource management, further reducing the river's natural purification capacity (Soares et al. 2020a; Cunha, 2015).

Artisanal fishing is not a lucrative profession. According to Freitas et al. (2015), the Seguro Defeso is an income support program for fishers during periods of fish reproduction. All fishers in their research accessed the benefit and the Bolsa Família. Bezerra et al. (2018) pointed out that 75% of artisanal fishers in Rio Grande do Norte accessed the Bolsa Família. However, the fishers that we interviewed indicated that Seguro Defeso payments have been delayed and not received until the end of fishing ban periods. Bezerra et al. (2018) identified the predominance of low pay among almost all fishers, with monthly incomes below the minimum wage, similar to what we observed. According to Freitas et al. (2015), fisher monthly income is uncertain because it depends on the availability of fish and the interference of environmental and climatic factors; only 11% of their interviewees received > US$ 150.00. In our study, 25% of respondents had a monthly income > US$150.00. Such incomes do not favor education, sewage treatment, or continuing the profession.

4.2 Fishing activity and fisher perceptions of species dynamics

The fishers that we interviewed observed changes in species dynamics, with the once-common freshwater curimatã-pacu (*Prochilodus argenteus*) being cited as a rare fishing species and the marine/estuarine robalos (Centropomus sp.) and carapebas (Gerreidae) appearing more frequently. In the studies by Soares et al. (2011) and Soares et al. (2016) there were already reports of euryhaline species in waters far from the river mouth. This mainly results from the lower river becoming more brackish, expansion of the saline wedge upriver, and physiological processes of fishes that involve reproduction making some species better adapted to saline waters and some species less adapted. Soares et al. (2011) reported that fish production near Penedo was represented by 22 species, of which five were more common: xira, piau (*Megaleporinus obtusidens*), pilombeta (*Anchoviella vaillantii*), robalo, and carapeba (Eugerres brasilianus). Sampaio et al. (2015) found that the most abundant species caught by fishers were the pilombeta (*Anchoviella* spp.), with an average of 8 kg/fisherman/day, followed by the curimatã-pacu or xira, with an average of 5 kg/fisherman/day, and the piaus (*Megaleporinus* ssp.), with an average of 2.8 kg/fisherman/day. Among the marine species, the authors highlighted the robalos and carapebas. In our survey, fishers mentioned all these species, especially robalo and carapeba, as the most prominent occurrences in addition to the xira, which currently is uncommon (Soares et al. 2016; Soares et al. 2020c). Soares et al. (2011; 2016) and Rodrigues et al., (2017) also reported that robalos and carapebas were among the most captured species around Penedo and Igreja Nova, 40 km from the São Francisco mouth, corroborating the perceptions of artisanal fishers. Soares et al. (2020b; 2020c) noted an impoverishment of native and freshwater species in fishers catches in the years 2018 and 2019, during which they report the disappearance of xiras, pilombetas (*Anchoviella* sp., *Lophiosilurus alexandrii*), and pacamãs and piabas (*Astyanax* sp.)

In addition to range expansions by marine/estuarine fishes, non-natives have been decreasing more recently in lower-river catches. Barbosa et al. (2017), in a survey in the Lower São Francisco, considered non-native tucunarés (Cichla spp.) and tilapia (Oreochromis niloticus and Tilapia rendalli) as invasive. Both species were mentioned as common in our interviews with fishers in the municipality of Sergipe. On the other hand, Freitas et al. (2015) drew attention to non-native species that were considered by fishers as rare or that have disappeared, such as dourado (*Salminus franciscanus*), surubim (*Pseudoplatystoma corruscans*), and pirá (*Conorhynchos conirostris*), in addition to those that have decreased as pacu (*Metynnis maculatus*), mandi (*Pimelodus maculatus*), and piau (*M. obtusidens*, *Schizodon knerii*). Sampaio et al. (2015), found

that fishers captured invasive non-native species, with tilapia (*Oreochromis* sp.), cará-boi (*Astronotus ocellatus*), and tucunaré (*Cichla monoculus*) being the most representative. Tilapia was probably the first invasive species in the region because of its use in fish farms located along this stretch of the river and tucunaré were introduced for sport fishing in reservoirs, from which they have escaped or were transported by anglers (Sampaio et al., 2015).

In a preliminary survey near Penedo, Barbosa and Soares (2009) observed that among the native species, several were very important for human consumption. Therefore, they were targeted for intense fishing, especially the curimatã-pacu, dourado, surubim, different species of mandi (*Pimelodus maculatus* and *Duopalatinus emarginatus*), piau, and traíra (*Hoplias microcephalus*). According to Soares et al. (2011), the most valued fish species, included carapeba and piau. Near Penedo and Neópolis, Barbosa and Soares (2009) collected 16 species, with curimatã-pacu (*P. argenteus*) as the main catch, followed by pilombeta (*Anchoviella vaillanti*), piau, carapebas, cará-boi (*Astronotus ocellatus*), pacu, and tucunaré. These data suggest that overfishing endemic species also contributed to reduced natural stocks in the region.

Reduced catches near Neópolis, Penedo and Santana do São Francisco have led to fishers moving to Chinaré (AL, about 15 km away), Porto Real do Colégio (AL), and Propriá (SE), which are 35 to 40 km distant. Freitas et al. (2015) also reported that the scarcity of targeted fish on the margins of the São Francisco led to fishers traveling long distances for long time periods to improve fishing success.

Although fishing is essential to complement fisher family food intake, food insecurity affects about 43% (Freitas et al., 2015). In Neópolis, food insecurity may be related to low remuneration for the activity. Of the total interviewees, 29% responded that in the last year they could not afford to have a varied diet and that 14% ate less than they needed. This situation was reinforced by Bezerra et al. (2018), who observed that most fishers were beneficiaries of the Bolsa Família. However, the prevalence of food insecurity was high, reaching 67%.

Surveys show that changes in species dynamics resulting from environmental impacts have generated considerable negative effects among artisanal fishers, hindering fishing, depressing incomes, and compromising food security. Reduced fishing activity in the Lower São Francisco is reflected in reduced fish diversity and production and low-quality storage and marketing structures (Lima et al. 2010; Soares et al. 2011). Sampaio et al. (2015) reported that fishing effort is applied to a reduced number of species, requiring conservation policies to preserve fish stocks. Likewise, Soares et al. (2011) drew attention to the need for a regional fishery management plan based on the lower volume of fish caught, fishing pressure focused on specific species, clear fishing decline in the Lower São Francisco, and decreasing incidence of a variety of species observed.

4.3 Fish fauna observed

Based on secondary data as well as collections performed in the Mid and Lower São Francisco, Barbosa and Soares (2009) listed 255 fish taxa. The most recent study (Alves et al., 2011) compiled published and unpublished information from different researchers through January 2011, resulting in a list of 208 species from the source to the mouth. However, those surveys omitted marine and estuarine species. Barbosa et al. (2017) listed a total of 304 species, including 241 native freshwater fish species, 35 non-native species, and 28 marine/estuarine species. In our study, 38.5% of the species listed by Alves et al. (2011) were collected from only 1.4% of the entire length of the São Francisco River, and we recorded 54 new records for the basin, which correspond to 67.5% of the species identified on the fluvial plain. Brackish water occurs from the mouth to approximately 10 km upriver (Santos et al., 2013), leading to an estuarine environment, which, includes a partially stratified salinity gradient.

To standardize and update habitat guild categories for fishes that use estuaries and other transitional waters, Elliott et al. (2007) proposed ten categories of ecological use by a given species. That classification was clarified and simplified by Froese and Pauly (2015). Among the fish species identified on the floodplain of the São Francisco River, the majority (72.50%) are associated with estuaries or marine (marine-estuarine, marine-freshwater-estuarine and freshwater-estuarine).

The tendency for increased upriver taxa richness is common in coastal rivers (Teixeira et al., 2005; Sarmento-Soares et al., 2009). However, on the São Francisco River floodplain, greater fish faunal richness was found near the mouth, mainly because of the presence of species that migrate from the sea. In the São Francisco River floodplain, typical estuarine families, such as Carangidae, Clupeidae, Engraulidae, Gerreidae and Lutjanidae were common.

Researchers have associated increased taxonomic diversity along rivers with increased habitat heterogeneity (Langeani et al., 2005) and discharge (McGarvey & Terra, 2016). In the lower 16 km of the São Francisco River, high habitat heterogeneity results from the presence of several channels, lagoons, and salinity gradients. In addition, many different plant species such as *Rhizophora mangle* Linnaeus and *Montrichadia linifera* Schott, and the macroalgae *Elodea* sp. create different microhabitats amongst those waterways.

Some fish families have members that are adapted to the highly variable conditions of estuaries. Indeed, various estuaries around the world share the same taxa (Cowan et al., 2013). In the present study, the natural pool, near the municipality of Piaçabuçu, is an important natural nursery for different species of families associated with estuaries. Mugilidae, Gerreidae and Atherinopsidae predominated in the natural pool, with most individuals being juveniles, respectively representing 36%, 23% and 15% of the total number of specimens. In the São Francisco River basin, marine and estuarine species can occur several kilometers upriver from the mouth (Alves et al., 2011, Soares et al. 2020a). Estuarine fish exhibit diverse degrees of tolerance to changes in salinity (Camargo & Isaac, 2001). Results from studies conducted on Itamaracá Island in the state of Pernambuco (Guedes et al., 2005) demonstrated that most species are found in all portions of the salinity gradient. *Harengula clupeola* was found from freshwater to saline environments.

Among the abundant and very frequent species recorded in the São Francisco, two merit special attention because they are invasive non-native species: tucunaré and pacu. The former is from the Amazon River basin and the latter is from both the Amazon and Paraguay River basins. Invading species are often sighted in the lower São Francisco River and are considered deliberate introductions (Agostinho & Júlio Jr., 1996) as well as the target of local fisheries (Sampaio et al., 2015). Tucunaré are a serious threat to fish species biodiversity (Alves et al., 2007). Súarez et al. (2001) classified this fish as a generalist piscivore. It causes changes in the composition and structure of the biological community as well as the mass extinction of native species (Alves et al., 2007; Leão et al., 2011). The pacu is a small fish (maximum length: 18 cm) with herbivorous habits (Kullander, 2003). This fish was introduced in reservoirs and rivers in southeastern Brazil, where it is well acclimated (Pereira et al., 2013) and a commonly caught species (Langeani et al., 2005; Gomes et al., 2008). Because of its peculiar coloration (silver with numerous black spots along the body and reddish ventral fins), size and rounded shape, the pacu has tremendous potential for ornamental fish farming (Pereira et al., 2013).

Other non-native invasive species of the São Francisco River basin include the Nile tilapia (*Oreochromis niloticus*) and the oscar (*A. ocellatus*). The characteristics of the Nile tilapia that give it considerable invasive potential include a high tolerance to environmental changes, broad diet (from algae and zooplankton to fish) and high population growth rate (Attayde et al., 2007). Populations of this fish can rapidly increase and become dominant, thereby altering the structure of the aquatic community (Attayde et al., 2007; Vitule et al., 2009). Occurring throughout the entire São Francisco River basin, the Nile tilapia also occurred in every area of our study, including near Piacabuçu, which demonstrates its tolerance with brackish waters. Astronotus ocellatus, known as the cara-boi in the Lower São Francisco region, is native to the Amazon River basin in

Peru, Colombia, and Brazil (Leão et al., 2011). It is known to reduce native biodiversity, including aquatic invertebrates and fishes (Leão et al., 2011). The oscar was introduced in lakes and reservoirs in northeastern Brazil for aquaculture (DNOCS, 2002). On the São Francisco River floodplain, A. ocellatus occurred in small numbers at only two sampling sites, demonstrating scarcity and a low frequency of occurrence.

The lower São Francisco River is greatly affected by environmental impacts. The flow from the Xingó Hydroelectric Power Plant is governed by reservoirs in the upper and middle São Francisco River regions (Três Marias and Sobradinho dams). There are problems caused by changes in the hydrological regime, such as lower water flow and volume in the lower course of the river, with a consequent increase of salinity in the region (Soares et al., 2020c). Near the municipality of Piaçabuçu, Cruz et al., (2020) measured a mean surface salinity of 3.55 ± 1.35 ‰ to 2.71 ± 1.54 ‰; both surface and bottom waters were defined as brackish. Also, the native fish fauna is overfished, being replace by non-native and euryhaline species, leading to future extirpation risks. Together, those stressors have altered the ecosystem and human populations (Soares et al., 2011; Medeiros et al., 2016; Barbosa & Soares, 2011; Barbosa et al., 2017; Barbosa et al., 2018; Soares et al., 2020a).

5. Summary

Human actions, especially in the Lower São Francisco, have negatively affected the lives of artisanal fishers. The change in fish species occurrence dynamics is perceived by fishermen and is similar to the ichthyofaunal surveys conducted in the region, emphasizing marine/coastal species becoming increasingly common in our study area.

Difficulties in conducting and maintaining artisanal fishing have had negative economic impacts on families, with low remuneration for the activity contributing to the high rate of food insecurity. Access to public programs has been restricted, with delays in receiving the Seguro Defeso, which was aimed to provide a minimum income to families during periods when fishing is prohibited.

The high potential for environmental degradation and inadequate mitigation programs of the hydropower plants continue to degrade the São Francisco River basin and riverside human populations.

Monitoring the lower river will continue until 2025, with bimonthly collections and modeling to identify the effects of flow variation on the entire ecosystem.

Acknowledgments

The work was financed by the São Francisco River Basin Committee (CBHSF) and the Peixe Vivo River Basin Agency (015/2018), and support from the São Francisco and Parnaíba Valleys Development Company (CODEVASF). RMH received a Fulbright-Brazil grant.

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