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Impacts on fisheries assessed by local ecological knowledge in a reservoir cascade in the lower São Francisco River, northeastern Brazil

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Our study assessed the fishers' perception (local ecological knowledge, LEK) concerning environmental impacts on fisheries and fish species in the final portion of Sub-Middle and Lower São Francisco. The river was divided into four areas where 107 fishers from 22 locations (4 states) were surveyed. The dam was the most significant impact on fisheries. The loss of connectivity, changing the environmental complexity, and its secondary effects (*e.g.*, flow control, interruption of migratory routes) were determining factors. Other impacts were pointed out, such as pollution, macrophytes, overfishing, non-native species, and aquaculture. Among migratory species, *Pseudoplatystoma corruscans* and *Salminus franciscanus* have been absent from fishery catches for decades. *Prochilodus argenteus* records in fisheries are likely associated with migration routes to small tributaries. The environmental disturbance favored the establishment of non-native species such as *Oreochromis niloticus*, *Cichla monoculus*, and *Metynnis lippincottianus* along the studied section. Over the final portion of the São Francisco River, the more significant seawater intrusion changed the target species for fisheries activities. Thus, our data validate the importance of fishers' LEK and reinforce the adverse effects of the reservoir cascade on fishing and migratory fishes.

Keywords: Anthropogenic impacts, Ethnoecology, Migratory fishes, Non-native species, Small-scale fisheries.

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Nosso estudo avaliou a percepção dos pescadores (conhecimento ecológico local, CEL) em relação aos impactos ambientais sobre a pesca e peixes no trecho final do Submédio e Baixo São Francisco. O rio foi dividido em quatro áreas onde foram entrevistados 107 pescadores de 22 localidades (4 estados). Barragem foi o impacto mais significativo sobre a pesca. A perda da conectividade alterando a complexidade ambiental e seus efeitos secundários (*e.g.*, controle da vazão, interrupção da rota migratória) foram fatores determinantes. Outros impactos foram apontados, como poluição, macrófitas, sobrepesca, espécies introduzidas e piscicultura. Dentre as espécies migradoras, *Pseudoplatystoma corruscans* e *Salminus franciscanus* estão ausentes da pesca há décadas. Os registros de *Prochilodus argenteus* nas pescarias provavelmente estão associados às rotas migratórias para pequenos tributários. A perturbação ambiental favoreceu o estabelecimento de espécies introduzidas como *Oreochromis niloticus*, *Cichla monoculus* e *Metynnis lippincottianus* ao longo do trecho estudado. No trecho final do rio São Francisco, a maior intrusão de água do mar mudou as espécies-alvo da pesca. Dessa forma, nossos dados validam a importância do conhecimento ecológico local dos pescadores e reforçam os efeitos adversos das cascatas de reservatórios sobre a pesca e peixes migratórios.

Palavras-chave: Espécies não-nativas, Etnoecologia, Impactos antrópicos, Peixes migradores, Pesca em pequena escala.

INTRODUCTION

Dams are responsible for alterations in morphology and hydrology of rivers (Agostinho *et al*., 2007). Their effects on freshwater biodiversity are expressed by the shifts in aquatic productivity, ecosystem services, ecological process, composition and abundance of species, and even local extinction (Agostinho *et al*., 2007; Santos, 2010; Hallwass *et al*., 2013; Winemiller *et al*., 2016). The alterations caused by dams transform a dynamic system with high structural complexity into a homogeneous and less productive environment (Agostinho *et al*., 2007). These changes contribute to increased sedentary, generalist, and tolerant species and the decline of migratory species (Santos, 2010; Pelicice *et al*., 2018). The river fragmentation process also interferes in flood pulses, reducing river connectivity and access to floodplains that correspond to fundamental nurseries and feeding grounds (Agostinho *et al*., 2007). Blocking migratory routes is another impact that, combined with the previous ones, can generate failures in recruiting and maintaining viable populations (Sato, Godinho, 2003; Pompeu *et al*., 2012; Pelicice *et al*., 2015).

These issues are intensified in rivers with reservoir cascades. The restructuring of fish communities in these reservoirs has shown the prevalence of small-medium-sized species (Santos, 2010; Petesse *et al*., 2014; Loures, Pompeu, 2018; Pelicice *et al*., 2018) with trophic plasticity to explore the new areas, using their reproductive strategies for rapid colonization (Petesse *et al*., 2014). In these new environments, non-native piscivores also find favorable conditions for their establishment (Lockwood *et al*., 2007)

and follow the same pattern of population increase (Santos, 2010; Pelicice *et al*., 2018). On the other hand, the decline in migratory fish populations is increasingly evident, mainly in the downstream direction (Santos, 2010; Petesse *et al*., 2014; Pelicice *et al*., 2018), except for reservoirs with lotic stretches above the flooded area or tributary (Loures, Pompeu, 2018). The consequences are also observed in social and economic dimensions since small-scale fishing represents the primary source of income and food for the riverine population (Hallwass *et al*., 2013; Doria *et al*., 2021).

The São Francisco River (~2,800 km in length) has large hydroelectric plants throughout its main course, and a reservoir cascade has caused numerous socio-environmental impacts in the final portion of the basin (Godinho, Godinho, 2003; Brito, Magalhães, 2017). Significant water flow restrictions over the past decades (2,800 m^3/s – 550 m^3/s) have also favored the establishment of invasive species such as the Peacock bass *Cichla monoculus* Spix & Agassiz, 1831, Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758), and Spotted silver dollar *Metynnis lippincottianus* (Cope, 1870) (Assis *et al*., 2017; Brito, Magalhães, 2017). The absence of flood pulses has hampered connections of lagoons and floodplains to the main river channel, with adverse effects on the subsistence agriculture (*e.g*., rhiziculture) and the economy of the riverine population (Sato, Godinho, 2003; Martins *et al*., 2011; CBHSF, 2016; Santana *et al*., 2016; Brito, Magalhães, 2017). The reduction of river discharge has also led to more significant seawater intrusion, increasing salinity close to the river mouth, and intensifying the problems associated with a water supply and public health issues (Brito, Magalhães, 2017).

Implications over artisanal fisheries after the construction of reservoirs have been recurrent throughout the São Francisco River Basin (SFRB). In the Upper-Middle São Francisco, Três Marias hydroelectric power plant (HPP) construction caused changes in fishing productivity and the floodplains (Thé, 2012; Lopes *et al*., 2019). Sobradinho dam in the Sub-Middle São Francisco (SMSF) river altered the river discharge and its original functionality and importance for fish migration (Sato, Godinho, 2003), becoming more complex in the final portion with the construction of reservoirs from the Apolônio Sales and Luís Gonzaga HPPs. In the Lower São Francisco (LSF) portion, water control was intensified with the Paulo Afonso Hydroelectric Complex (I, II, III, IV) and the Xingó HPP (CHESF, 2020). The impacts over artisanal fisheries have been irreparable, causing changes in the structure of the ichthyofauna and the disappearance of important migratory and commercial species (Assis *et al*., 2017; Brito, Magalhães, 2017; D'avilla *et al*., 2017).

Studies developed with artisanal fishers have provided relevant data for the management of fishing resources, making it possible to meet the demands of a given area more effectively with local ecological knowledge (LEK) (Marques, 2001; Thé *et al*., 2003; Costa-Neto, Marques, 2008; Azevedo-Santos *et al*., 2010; Silvano, Begossi, 2012; Hallwass *et al*., 2013; Ramires *et al*., 2015). Artisanal fishers provide theoretical and practical information, which they have observed concerning the behavior, food habits, reproduction, and ecology of fish species (Costa-Neto, 2000). Also, fishers are aware of the relationships between biotic and abiotic environments, understanding where, when, and why organisms are found in specific environments (Marques, 2001).

LEK can support the study of environmental changes caused by human actions, as these changes are perceived by the actors who carry out subsistence and

recreational fishing activities in impacted environments. The survey of information from ethnoecological studies makes it possible to understand the magnitude and evolution of social and biological impacts, especially in data-deficient and dammed areas (Hallwass *et al*., 2013). In this sense, we address the fishers' perception (LEK) concerning environmental impacts on fisheries and fish species in the highly modified final portion of Sub-Middle and Lower São Francisco.

MATERIAL AND METHODS

Sampling sites. The SFRB has an area of 645,000 km², and drains the states of Minas Gerais, Goiás, Bahia, Pernambuco, Sergipe, Alagoas, also including the Distrito Federal (MMA, 2006). The basin is divided into four regions: Upper, Middle, Sub-Middle, and Lower São Francisco. The SMSF and part of the LSF are inserted in the Caatinga Biome (semi-arid climate), and the final portion of the LSF is situated in the Atlantic Forest Biome (humid tropical climate). The rainfall precipitation mainly influences the regional climate of the basin (400–1500 mm/year), with an average annual temperature varying between 20–26.5 °C (Silva, Clarke, 2004).

The study was carried out with artisanal fishing communities in the final portion of the SMSF and the LSF, between Luís Gonzaga HPP and the mouth of the São Francisco River. Four areas were defined according to river morphology and hydrology in order to assess if the impacts on fisheries would differ among areas based on their features (Fig. 1):

Area 1. Downstream of Luís Gonzaga HPP to the upstream area of Xingó HPP (~90 km). It is characterized by the reservoirs of Apolônio Sales and Paulo Afonso HPPs, and the lotic portion between the Paulo Afonso Hydroelectric Complex and the reservoir of Xingó HPP. The area is composed of remobilized massifs from the flattened soil surfaces of Paulo Afonso (BA) municipality, which expands into waterfalls and rocky beds of approximately 100 km in length (Cavalcante, 2011). Visited communities: Glória (BA) – Nova Glória, Povoado Quixaba, Povoado Queimadas; Paulo Afonso (BA) – Paulo Afonso, Povoado Rio do Sal, and Povoado Xingozinho; Jatobá (PE) – Jatobá.

Area 2. Downstream from Xingó HPP to Poço Redondo municipality (SE) (~35 km). It is characterized by a rocky and lotic portion that runs through a narrow channel (*ca*. 50 m) widening as the river follows its course (600 m). Visited communities: Piranhas (AL) – Piranhas Nova, Piranhas Velha, and Povoado Entremontes; Poço Redondo (SE) – Povoado Angico, Povoado Cajueiro, Povoado Curralinho, and Povoado Bom Sucesso.

Area 3. Pão de Açúcar (AL) to Gararu (SE) (~50 km). Floodplain area, with an increase of river width (over 600 m). The margin slope is reduced with the presence of meanders, sandy banks, and sedimentary banks on the river channel (Silva, 2009; Cavalcante, 2011). Visited communities: Pão de Açúcar (AL) – Pão de Açúcar; Porto da Folha (SE) – Povoado Niterói, and Povoado Ilha do Ouro; Gararu (SE) – Povoado Jenipatuba.

Area 4. Penedo (AL) to the mouth of the river in the Atlantic Ocean (~40 km). It is a coastal plain formed by the interaction between the river and the sea. Major influence of the sea with small islands close to its mouth. The area has flat surfaces of recent sediments, alluvial, wind, and beaches (Medeiros *et al*., 2007). Visited communities: Penedo (AL) – Penedo, and Povoado Ponta Mufina; Brejo Grande (SE) – Brejo Grande; Piaçabuçu (AL) – Piaçabuçu, and Pontal do Peba.

Four expeditions (75 days) were carried out between March and August/2017. The respondents were selected using the Snowball method (Bailey, 1982), which identifies a referenced specialist recognized by the community, who, after being interviewed, recommends another specialist, and so on (Albuquerque *et al*., 2010a). To survey the ethnoecological data, free and semi-structured interviews (Tab. **S1**), visual stimulus, and guided tours were conducted.

Free interviews consist of informal conversations with the studied population by establishing proximity and detecting relevant information to the research (Bernard, 2006). Semi-structured interviews involve asking targeted questions with a survey, leading to an effective method for gathering specific information (Huntington, 1998; Silvano *et al*., 2008). The semi-structured interviews were recorded with a SONY ICD PX333 recorder and later transcribed for content analysis. Personal information of fishers (*e.g*., age, time of fishing activity, and birthplace) and the status of fishes (*e.g*., distribution, introduction, and disappearance) were registered in interviews. Furthermore, additional information on environmental impacts was obtained to verify if changes observed in the ichthyofauna were related to the impacts mentioned above.

Visual stimulus occurred by displaying a manual of photographs of fishes from the SFRB to identify ethno-species and obtain ethnoecological information. The guided tour is a method that relies on the help of a local guide with extensive knowledge to elucidate information in the field (Albuquerque *et al*., 2010b) through tours conducted with fishers during the fishery activity (Marques, 1991). The specimens caught by the fishers were identified using identification keys, and taxonomical status following Fricke *et al*. (2020).

Statistical analyses. We analyzed all data by "Union of all individual competencies" (Hays, 1976) even if containing discrepancies. Tests to verify the consistency and validity of the information were performed through interviews in synchronous and diachronic situations. The first consists of making the same question to different respondents over a short time, and the second is applied when the same question is asked to the same respondent over a longer interval (Marques, 1991).

The Frequency, Word Cloud and Similitude analyses were performed with the software IRAMUTEQ version 0.7 alpha 2 (Ratinaud, 2009), using the R environment (R Core Team, 2019). A Frequency test demonstrated the expression of the impacts mentioned by the fishers according to the number of citations. Then, the Word Cloud analysis was performed, positioning the lexical groups according to repetitions (Camargo, Justo, 2013). This analysis exhibits the weight of the words mentioned by respondents, showing them in more extensive and centralized positions according to the highest frequency of citations.

To verify the relationship between the impacts mentioned by the fishers, the Similitude Analysis was carried out, which identifies co-occurrences between

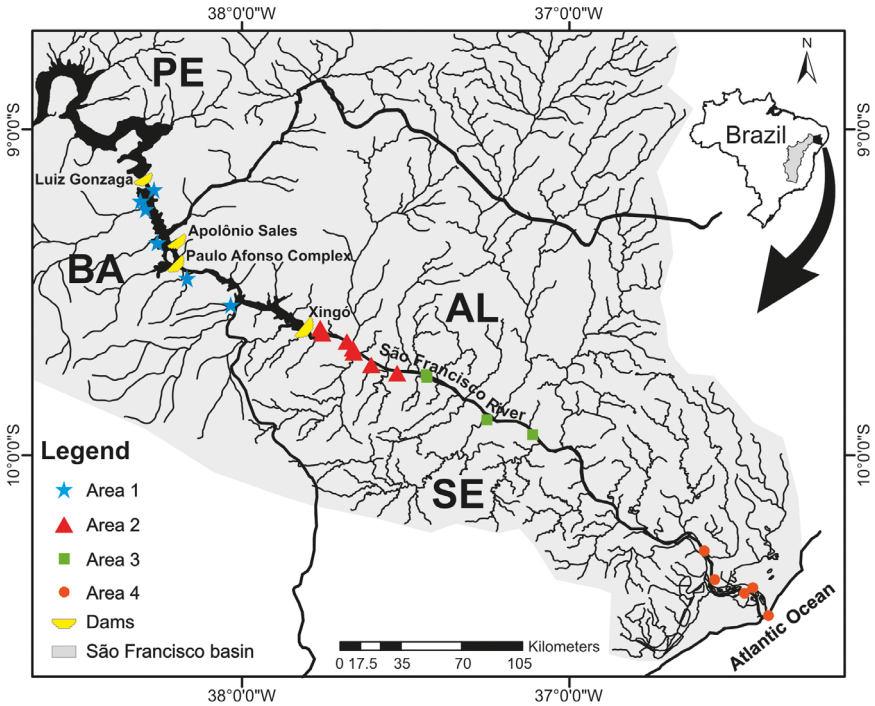

FIGURE 1 | Fishers' communities on the four areas visited on the Sub-Middle and on Lower São Francisco, Northeastern Brazil. PE = Pernambuco State; BA = Bahia State; AL = Alagoas State; SE = Sergipe State.

words and graphically demonstrates their connection through the presentation of trees — groups of words that are related to each other —, and the intensity of their connections illustrated by the line thickness (increased thickness = higher intensity) (Marchand, Ratinaud, 2012; Camargo, Justo, 2013). The difference from mentioned impacts between the surveyed areas was observed through a multivariate analysis of Non-Metric Multidimensional Scaling (NMDS) with Jaccard distribution and the Similarity Analysis (ANOSIM) using the free software Past version 21.7c (Hammer *et al*., 2001). P values < 0.05 were considered significant.

The status of fishes was defined regarding the frequency of mentions and the recognition of species by fishers during interviews and visual stimulus. The categories were classified in: Frequent = most mentioned and recognized species (51–100%), with occurrence confirmed by the fishers; Rare = species with intermediate mention and identification frequency (26–50%), with occurrence related to reducing stocks or local disappearance; Imprecise = species with low mention and identification frequency (0–25%), whose status was imprecise due to insufficient data; Probably extinct = species recognized and reported for the study area, but missing.

RESULTS

A total of 107 fishers were interviewed from 22 locations over 11 municipalities in the states of Alagoas, Bahia, Pernambuco, and Sergipe. The average age was 53.2±10.44

years, and the time of experience performing the fishery activity was 40.3±11.68 years. Most of the fishers (68%) were born and have lived in the communities where they were surveyed. A portion of them (18%) reported having migrated from adjacent locations when they were younger, while 14% of respondents migrated from locations that were flooded during the construction of reservoirs of Luís Gonzaga and Xingó HPPs.

Impacts on the ichthyofauna. The surveyed fishers have pointed out 13 impacts responsible for altering the ichthyofauna and reducing fish stocks in the region. The frequency analysis of the mentioned impacts in all sampled areas showed that the dam construction (93%) was the most significant one (Fig. 2A), corroborated by its prevalence in the Word Cloud analysis (Fig. 2B).

The analysis of impacts by area also highlighted dams as the significant impact (Fig. 3). For example, at areas 1 and 2, the shift in river dynamics caused by the construction of reservoirs (Figs. 3A,B) eliminated lotic environments that included waterfalls and rapids. Fishers reported that dams also interfere on migratory routes of essential species for artisanal fisheries, such as *Pseudoplatystoma corruscans* (Spix & Agassiz, 1829), *Salminus franciscanus* Lima & Britski, 2007, *Prochilodus argenteus* Spix & Agassiz, 1829, and *Conorhynchus conirostris* (Valenciennes, 1840), claiming that after its construction there was a reduction of their populations culminating in the disappearance of some of them.

Fishers from Area 1 also mentioned impacts such as aquaculture and overgrowth of macrophytes (*Egeria densa* and *Eichornia crassipes*) (Fig. 3A). Statements made by the fishers associated these macrophytes with introduced Amazonian fish *C. monoculus* and *Colossoma macropomum* (Cuvier, 1816) after the construction of dams. Macrophyte overgrowth was associated with the formation of lakes (lentic section), low river flow (lotic section), as well as pollution from the cultivation of *O. niloticus* in aquaculture cages (Area 1) and domestic and industrial effluents.

Overfishing was also among the most representative impacts (Fig. 3B), with the harpoon device identified as predominantly used to capture breeding individuals. However, the target species reported were non-native primarily species, such as *O. niloticus*, *C. monoculus*, *C. macropomum*, and *Astronotus ocellatus* (Agassiz, 1831), though *P. argenteus* was also mentioned as a target.

The synergy of factors such as reduced rainfall, intense water use, water flow restriction through reservoirs, and diversion was listed as responsible for the compromised flow of the São Francisco River. These factors have contributed to the increase in the salinity of Area 4 with the increased intrusion of seawater over freshwater habitats (Fig. 3D). Fishers from Brejo Grande (SE) and Piaçabuçu (AL) highlighted the reduction and disappearance of some freshwater species, the increase of marine species in the region, and problems associated with saline water capture in communities near to the river mouth.

Area 1 impacts differed significantly (Fig. 4, ANOSIM; $R = 0.151$; $p < 0.001$) from the other areas, due to the more significant number of citations of the impacts from aquaculture, pollution, and macrophytes overgrowth, enhanced by the transformation from lotic to lentic waters due to the construction of dams (Fig. 4).

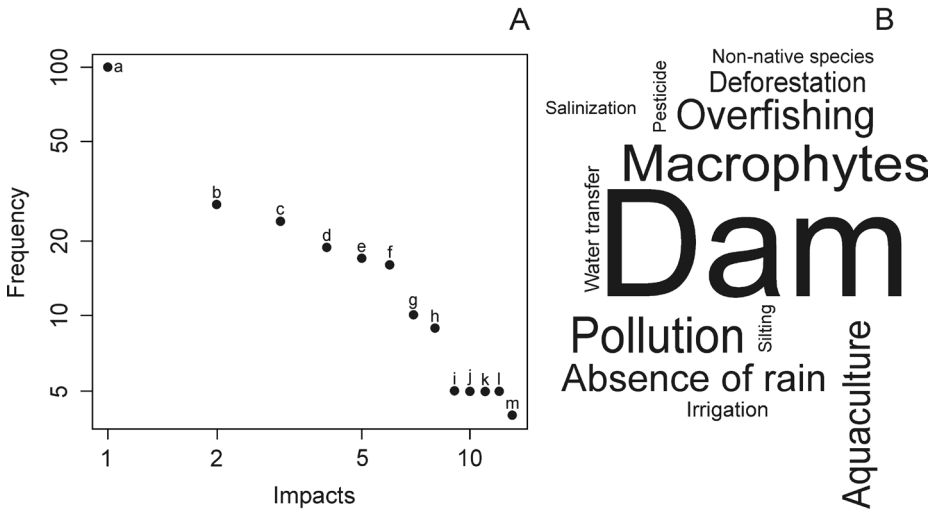

FIGURE 2 | Frequency (**A**) and Word Cloud (**B**) analyses regarding the impacts over the ichthyofauna, according to fishers from the four sampled areas on the Sub-Middle and on Lower São Francisco. a. Dam; b. Macrophytes; c. Pollution; d. Overfishing; e. Absence of rain; f. Aquaculture; g. Deforestation; h. Silting; i. Water transfer; j. Non-native species; k. Irrigation; l. Pesticide; m. Salinization.

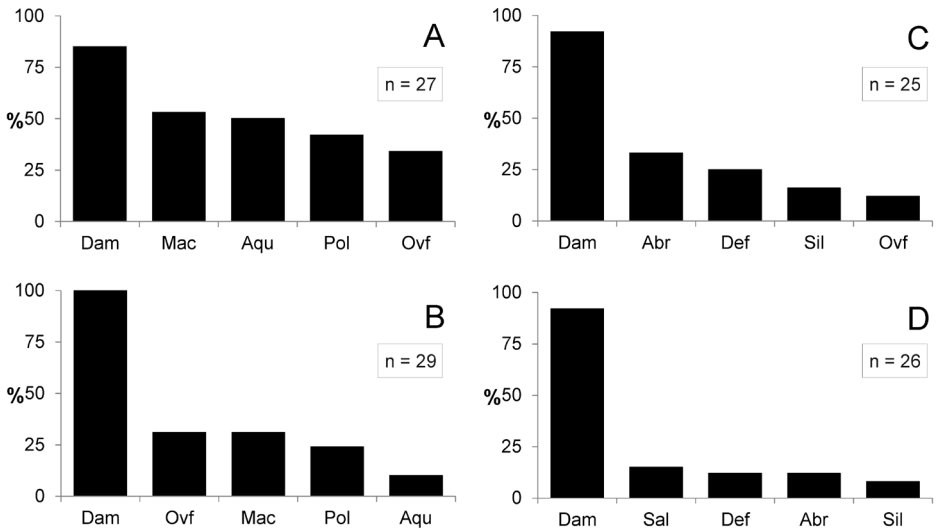

FIGURE 3 | List of main impacts mentioned in **A.** Area 1, **B.** Area 2, **C.** Area 3, and **D.** Area 4, according to fishers from the final portion of the Sub-Middle and Lower São Francisco. Dam: dams; Mac: macrophytes; Aqu: aquaculture; Pol: pollution; Ovf: overfishing; Abr: absence of rain; Def: deforestation; Sil: silting; Salt: salinity.

The maximum similarity tree exhibited three lexical islands, where "Dam" played a central role in the impacts over fisheries, which was associated with the lexical islands "Silting" and "Macrophytes" (Fig. 5). The lexical island "Macrophytes" showed greater linkage power with the central island. The relationships were associated with the proliferation of macrophytes mainly due to water pollution and aquaculture of *O. niloticus* in the region.

Occurrence status. Fishers recognized 82 species (Tab. **S2**) and stated that some migratory and economically important ones from the São Francisco River have disappeared from the study area, such as *C. conirostris* (±20 years), *P. corruscans* (±10 years), and *S. franciscanus* (±10 years). Other migratory species were restricted to some areas with a reduced population. *Brycon orthotaenia* Günther, 1864 was poorly recognized (27%) and cited as missing in areas 1 and 4. On areas 2 and 3, some fishers have recognized *B. orthotaenia,* stating that the species has disappeared. However, it was captured one time over recent years. During the data collection expedition, a specimen of *B. orthotaenia* was registered from the artisanal fisheries at Povoado Entremontes (Area 2). *Megaleporinus obtusidens* (Valenciennes, 1837) is restricted to the lotic sections on the canyons (Area 1), with specific capture mentions on areas 2 and 3. Despite the low catches, two Prochilodontidae (*P. argenteus* and *Prochilodus costatus* Valenciennes, 1850) seem to be the only migratory species that still occur, possibly in all areas, considering their low abundance. Fishers highlighted the increase of catches during the rainy season and associated their occurrence with the presence of tributaries around the region, such as the rivers Moxotó (Area 1), Capivara, and Ipanema (Area 3), Itiúba, and Marituba (Area 4). The remaining presence of Anostomidae populations was also associated with the tributaries.

Currently, the most common native species in catches is *Serrasalmus brandtii* Lütken, 1875, along with other fish considered in the past as secondary or low value as *Hoplias malabaricus* (Bloch, 1794), *Pygocentrus piraya* (Cuvier, 1819), *Trachelyopterus galeatus* (Linnaeus, 1766), *Hypostomus* sp., *P. etentaculatus*, and now the commercially important *R. aspera (Areas 1-2)*. Non-native species as *Plagioscion squamosissimus* (Heckel, 1840) (Area 1), *C. monoculus*, *O. niloticus*, *A. ocellatus*, *C. macropomum*, and *M. lippincottianus* have established populations in the final section of the SMSF and LSF. Fishers informed about the increase of occurrence of the non-native species, as well as the confirmation on reproductive interactions by finding spawning sites (*e.g.*, nests with eggs and juveniles), and description of the behavior displayed during parental care (*e.g.*, *O. niloticus* and *C. monoculus*). The most abundant species in fisheries activity were *M. lippincottianus* and *S. brandtii*, despite having low commercial value. Catches of *P. squamosissimus* have also been frequent but restricted to the lentic section of the reservoirs (Area 1).

Euryhaline species such as *Caranx* spp., *Megalops atlanticus* Valenciennes, 1847, *Diapterus rhombeus* (Cuvier, 1829), *Mugil curema* Valenciennes, 1836, *Centropomus parallelus* Poey, 1860, and *Centropomus undecimalis* (Bloch, 1792) have become more frequent in catches on areas 2, 3, and 4. The higher occurrence of euryhaline species has been associated with river regulation by dams, leading to an increase of salinity in Area 4 locations.

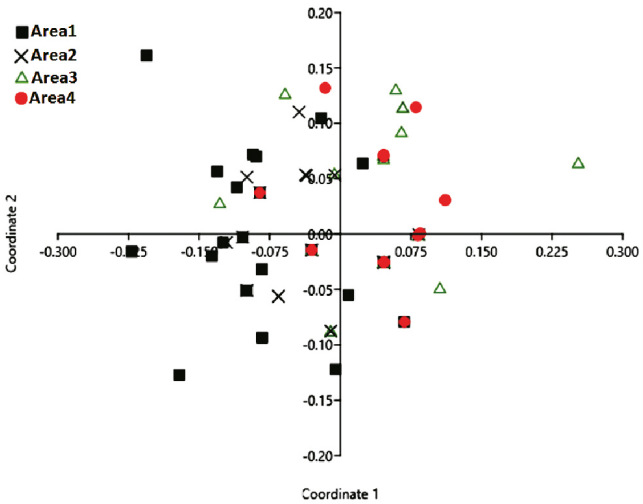

FIGURE 4 | Non-Metric Multidimensional Scaling (NMDS) analysis concerning impacts over the ichthyofauna in the four sampled areas on the Sub-Middle and Lower São Francisco.

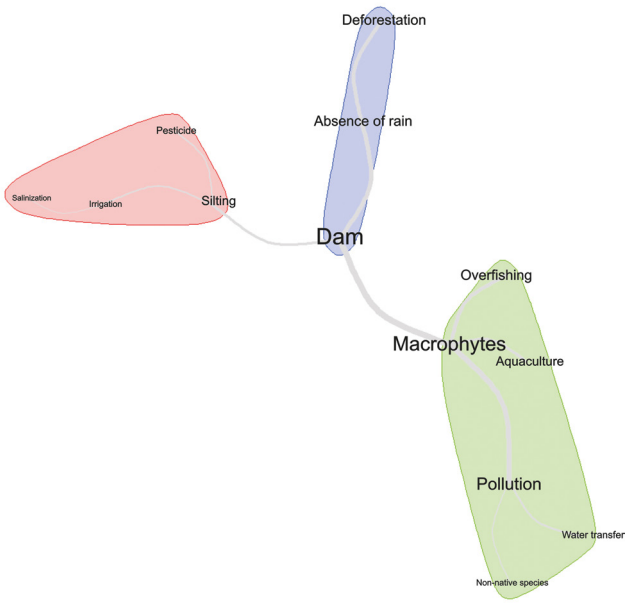

FIGURE 5 | Maximum Similitude Tree showing the expression and relationship of impacts over fisheries in the four areas sampled on the Sub-Middle and on Lower São Francisco, based on fishers' testimonies (n = 107).

DISCUSSION

The majority of fishers pointed out the impact caused by dams on the São Francisco River as the main responsible for changes in fisheries and fish species, as observed in other large Neotropical rivers (Hallwass *et al.*, 2013; Santos *et al.*, 2018; Runde *et al.*,

2020). Dams interrupt the river connectivity, changing its environmental complexity and triggering a series of side effects that lead to environmental simplification. The formation of a lentic environment upstream, the controlled water flow downstream of the dam, changes in the morphology of the river channel (*e.g.*, silting), limnological variations, and the interruption of migratory routes affect mainly rheophilic and migratory species (Reid *et al*., 2019; Zambaldi, Pompeu, 2020). These species depend on accessible routes to migrate and complete their life cycle (Sato, Godinho, 2003; Godinho *et al*., 2007; Andrade-Neto, 2008). Thus, the construction of reservoirs may lead to consecutive recruitment failures resulting in the disappearance of migratory species, as reported in the present study for *P. corruscans*, *C. conirostris*, and *S. franciscanus*, and the reduction in stocks of *P. argenteus*, *P. costatus*, and *M. obstusidens*.

This environmental change has created an invasion window (Lockwood *et al*., 2007) and enabled the establishment of non-native fish, such as *C. monoculus*, *O. niloticus*, *A. ocellatus*, *P. squamosissimus*, and *M. lippincottianus*. Invasive species characteristics, such as rapid colonization due to reproduction occurring almost year-round (Magalhães *et al*., 1996; Assis *et al*., 2017), parental care, and a generalist diet have enabled their establishment (Pérez *et al*., 2004; Agostinho *et al*., 2007). Besides, propagule pressure should not be ruled out since the introduction of species in Northeastern Brazil is of common practice (Brito *et al*., 2020), as well as escapes from aquaculture cages (*e.g.*, *O. niloticus*) (Azevedo-Santos *et al*., 2010; Lima Junior *et al*., 2018). The absence of an anti-predatory response from the native species to foraging strategies of introduced piscivores (prey naiveté, Cox, Lima, 2006), as *C. monoculus*, may have favored their establishment and resulted in the reduction of small-size species as reported by fishers. The decline of small-size fauna seems inevitable in these cases (Pelicice, Agostinho, 2009). On the other hand, the herbivorous species *M. lippincottianus* was favored by the river regulation that resulted in the growth of filamentous algae (Assis *et al*., 2017), which corresponds to the main item of its diet.

The macrophytes *E. densa* and *E. crassipes* were negatively correlated to fisheries, given their impacts on navigability and equipment handling for fisheries activities. These macrophytes found favorable conditions for establishment in the reservoir lentic environment and the downstream section with controlled water flow. The overgrowth obstructed the water surface in some sections, with greater intensity on small branches of the reservoirs. At Area 1, macrophyte overgrowth was associated with residues from *O. niloticus* farming in aquaculture cages. This region has become one of the leading aquaculture sites for *O. niloticus* farming in Brazil, producing almost 33,000 tons in 2014 (Ribeiro *et al*., 2015). The high solar incidence (Araújo, 2011) and the significant incorporation of phosphorus, nitrogen, and carbon into the system (Kubitza, 1999) contributed to plant propagation. Moreover, macrophyte beds act as reproductive sites, foraging areas, and shelters for the first developmental stages (Delariva *et al*., 1994), which seem to have also collaborated in the establishment of non-native species pre-adapted to lentic environments (Assis *et al*., 2017).

The absence of sewage systems and waste processing are recurrent issues over the study area and the São Francisco basin (Figueiredo *et al*., 2011). In some locations, sewage is released *in natura* into the river channels, affecting water quality while prompting public health implications (Figueiredo *et al*., 2011). The improper disposal of oil from vessels has been another concern. Over the last decade, an investment in

tourism in the canyons region (Area 1), visited by *ca*. 46,000 people in 2008 (Braghini *et al*., 2009), increased boat traffic in the region, possibly affecting water quality with pollution from oil by-products (Freitas *et al*., 2015).

The reduction in flow resulting from dams has significantly restricted the flood pulses and led to the more significant seawater intrusion over the region of the mouth of the São Francisco River (Souza, Leitão, 2000). This process was enhanced after constructing the Xingó dam on the main channel of the São Francisco River (Araújo *et al*., 2016). Also, a section of the river's water volume on the final portion has been diverted to irrigate crops (Souza, Leitão, 2000) and shrimp farming, the latter activity having removed an essential portion of the mangrove areas (Carvalho, Fontes, 2007). The circumstances worsened with the ongoing reductions of river flow reaching 550 m^3/s (Brito, Magalhães, 2017). Thus, the capture of marine and euryhaline species became more frequent, with records of *M. atlanticus*, *Mugil* spp., *Cynoscion* spp., *C. parallelus*, *Bagre marinus* (Mitchill, 1815), *Eugerres brasilianus* (Cuvier, 1830), and *D. rhombeus* (Souza, Leitão, 2000; D'avilla *et al*., 2017).

The construction of a reservoir cascade in the final portion of the São Francisco River began in the 1950s with Paulo Afonso I HPP and finished in 1994, with the start of operations of Xingó HPP (CHESF, 2020). As a result, populations of commercial migratory species were driven to decline, and some have disappeared. On the other hand, non-native species (*e.g*., *C. monoculus*, *A. ocellatus*, *O. niloticus*, *P. squamosissimus*, *M. lippincottianus*), and native species with higher tolerance to environmental variations (*e.g*., *S. brandtii*, *L. piau*, *S. knerii*, *Hypostomus* spp.) and affinity to lentic and semi-lentic environments (Santos, 2010) encountered optimal conditions to maintain their populations. The long period without records of *P. corruscans* and *S. franciscanus* attests to the harmful effect of dams on large-distance migratory species since they demand long lotic sections connected to tributaries and marginal lagoons (Godinho *et al*., 2007; Andrade-Neto, 2008). The living area of *S. franciscanus*, for example, can reach 243 km (Andrade-Neto, 2008). Recent records of *B. orthotaenia* in artisanal fisheries from the present study and Brito *et al*. (2016) are due to the stocking actions carried out by Companhia de Desenvolvimento dos Vales do São Francisco e Parnaíba (CODEVASF) in the LSF over the last decade. Similarly, the capture of *C. conirostris* in May/2020 (CBHSF, 2020) is a direct result of fish stocking performed by CODEVASF in 2017 (MFGB, pers. obs.; Video **S3**).

Prochilodus argenteus has been pointed out in the study area among the native commercial species. Recent records highlight the capture of sexually mature fish (Silva *et al*., 2018), suggesting that the species uses tributaries as spawning areas in the region. This migratory behavior has been observed in the upper São Francisco by species of *Prochilodus* (Godinho, Kynard, 2006; Rosa *et al*., 2018) that spawn in the tributaries and the drifting larvae reach the main river (Rosa *et al*., 2018; Lopes *et al*., 2019). We believe that tracing the migratory route of *P. argenteus* over this area can be a source of essential data for future investigations. Nevertheless, the population increase through artificial stocking is not ruled out, as CODEVASF conducts fish stocking with these native species (MFGB, pers. obs.). The native Loricariidae *R. aspera* is a secondary species that has stood out in local cuisine (Area 2) due to the collapse of medium-large commercial fishes. The increase of tourism over the region (Braghini *et al*., 2009) may lead to higher fisheries pressure and depletion of populations of this species in the future.

Integrative planning is essential to balance the potential of electric energy and the sustainability of natural resources to minimize the loss of biodiversity and other environmental, social, and economic effects (Winemiller *et al*., 2016). An old project for constructing another dam on the main channel of Middle São Francisco has been discussed and represents a new threat (Gomes *et al*., 2020). Maintaining the longitudinal connectivity and natural flow regimes of rivers (Zambaldi, Pompeu, 2020), combined with revitalization actions, must be effectively implemented to maintain biodiversity and ecosystem dynamics (Azevedo-Santos *et al*., 2021).

Fishers' LEK represents a reliable data source for investigating biological, ecological, and socio-environmental regards, especially in areas with insufficient data. Our study provides evidence that signals the incidence of anthropic impacts on artisanal fishing in the final stretch of the SFRB in areas under the influence of the reservoir cascade. The data indicate that changes in the environment caused alterations in the ichthyofauna composition, with probable local extinction of migratory species of economic importance, resulting in losses on fishing activities. The information presented here aims to collaborate with management and supervisory agencies and provide subsidies to assist in regulating measures to conserve of fishery resources. The integration of academic knowledge and fishers' knowledge favors a contextualized analysis connected with the reality of these social actors, which can result in management practices that are appropriate to the local fishing resource (Carlsson, Berkes, 2005).

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AUTHORS' CONTRIBUTION

Thiago D'avilla: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing-original draft, Writing-review and editing.

Eraldo M. Costa-Neto: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing-original draft.

Marcelo F. G. Brito: Conceptualization, Data curation, Formal analysis, Project administration, Resources, Supervision, Validation, Visualization, Writing-original draft, Writing-review and editing.

ETHICAL STATEMENT

Samples were taken under approval from the Human Research Ethics Committee at the Hospital Universitário of the Universidade Federal de Sergipe (CAAE nº 64013716.8.0000.5546).

COMPETING INTERESTS

The authors declare no competing interests.

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