Sentinels of environmental change: shifts in fish diversity through the lens of artisanal fishers

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River regulation has caused significant shifts in fish diversity, with severe impacts on small-scale artisanal fisheries, which depend on fishing resources for income, employment and food security. This study investigated how artisanal fishers perceive changes in fish diversity in response to river regulation, considering four facets: (i) fish abundance, (ii) species records, (iii) capture patterns, and (iv) most valued fish. Between August and October 2018, we conducted systematic interviews with 30 artisanal fishers that operate in the area impounded by Lajeado Dam (middle Tocantins River). Fishers mentioned 60 common names of fish, totaling 51 independent ethnospecies. According to fishers, non-migratory fishes flourished in the reservoir, while migratory fishes declined. Fishers mentioned nine taxa that appeared in the impounded area, and 20 that disappeared, mainly large migratory catfishes. Fishery catches before river regulation were composed of large migratory characids and catfishes, while landings in the reservoir were composed of mid-sized non-migratory fish. Fishers also reported changes in the composition of the most valued fish. These results expand the evidence that artisanal fishers identify major shifts in fish diversity following river regulation, demonstrating that they can act as permanent sentinels of environmental change and degradation.

Keywords: Fishing, Impoundment, LEK, Migratory fish, River regulation.

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O barramento dos rios tem provocado mudanças significativas na diversidade de peixes, com impactos severos sobre a pesca artesanal de pequena escala, a qual depende dos recursos pesqueiros como fonte de renda, emprego e segurança alimentar. Este estudo investigou como os pescadores artesanais percebem mudanças na diversidade de peixes em resposta à regulação dos rios, considerando quatro facetas: (i) abundância de peixes, (ii) registros de espécies, (iii) padrões de captura, e (iv) valor do pescado. Entre agosto e outubro de 2018, realizamos entrevistas sistemáticas com 30 pescadores artesanais que operam na área represada pela barragem de Lajeado (médio rio Tocantins). Os pescadores mencionaram 60 nomes comuns de peixes, totalizando 51 etnoespécies independentes. De acordo com os pescadores, os peixes não-migradores floresceram no represamento, enquanto os peixes migratórios diminuíram. Os pescadores mencionaram nove táxons que apareceram na área represada e 20 que desapareceram, principalmente grandes bagres migradores. As capturas da pesca antes do barramento eram compostas por grandes caracídeos e bagres migradores, enquanto que os desembarques no represamento passaram a ser compostos por peixes não-migradores de médio porte. Os pescadores também relataram alterações na composição das espécies mais valorizadas. Estes resultados ampliam a evidência de que os pescadores artesanais identificam fortes mudanças na diversidade de peixes após o represamento dos rios, demonstrando que podem atuar como sentinelas permanentes da mudança e degradação ambiental.

Palavras-chave: LEK, Peixe migrador, Pesca, Regulação fluvial, Represamento.

INTRODUCTION

The construction of hydroelectric dams has impacted the structure and functioning of river systems all across the Earth (Grill *et al*., 2019). River regulation has pronounced effects on aquatic biodiversity, and has contributed decisively to the loss of freshwater fish diversity (Dudgeon *et al*., 2006). This process is ongoing across the tropics (Castello *et al*., 2013; Winemiller *et al*., 2016; Latrubesse *et al*., 2021), a region characterized by spectacular biodiversity, vast drainages (*e.g*., Amazon, La Plata, São Francisco, Mekong, Congo), and the existence of remote and pristine areas. In the Neotropical region, the most diverse on the planet (Albert *et al*., 2020), freshwater fishes have been severely impacted by these dams, with permanent effects on diversity patterns, demography and fishery stocks (Agostinho *et al*., 2016; Pelicice *et al*., 2017). The ubiquitous decline of rheophilic migratory fish raises concerns, as these fishes have historically supported an array of fishery activities (Duponchelle *et al*., 2021; Scarabotti *et al*., 2021).

Small-scale artisanal fishers, in particular, have been highly impacted by river regulation, as they rely on fishing for income, employment and food security (Agostinho *et al*., 2007; Doria *et al*., 2018; Lopes *et al*., 2021). Small-scale artisanal fishing is a spontaneous and autonomous activity found in most river systems of the planet, characterized by limited technical, economic and social power (Béné, 2006; Rousseau *et al*., 2019), with family and traditional roots and motivated by subsistence and commercial purposes

(Tregidgo *et al*., 2020). Changes in the quality and size of fish stocks have profound effects on the activity, with consequences on fishery landings, gears, transport, fishing effort, income, commercialization, social organization, among other aspects (Petrere Jr., 1996; Hoeinghaus *et al*., 2009; Santos, Pelicice, 2023). In impounded areas, artisanal fishers adapt to catch remaining stocks, usually composed of lentic-adapted species and non-native fish, characterized by smaller sizes, non-migratory behavior, and lower economic value (Agostinho *et al*., 2016). This is a global trend, but well characterized in several Neotropical reservoirs (Okada *et al*., 2005; Agostinho *et al*., 2007; Hoeinghaus *et al*., 2009; Novaes, Carvalho, 2013).

One important aspect is that small-scale artisanal fishers perceive environmental changes caused by river regulation, as they understand several aspects of fish biology and ecosystem functioning (Silvano *et al*., 2006; Silvano, Begossi, 2016; Pereyra *et al*., 2021; Rabuffetti *et al*., 2023). This body of knowledge, obtained through empirical and traditional approaches, is collectively known as Local Ecological Knowledge (LEK), a cultural dimension that characterizes small-scale fishers. For example, fishers perceive resource degradation (D'avilla *et al*., 2021; Nunes *et al*., 2023) or changes in the abundance of fish species, identifying those that increase or decline after river regulation (Hallwass *et al*., 2013; Arantes *et al*., 2023). However, studies that investigate LEK in contexts of environmental degradation are still incipient, which limits our understanding on how artisanal fishers respond to large-scale disturbances and the loss of resources. Understanding whether artisanal fishers perceive main impacts caused by river regulation, such as the decline of migratory fish and changes in the composition and value of fish (*e.g*., Agostinho *et al*., 2016), has great potential to assist fisheries management plans, complementing technical information or even taking the lead when scientific knowledge is limited or absent (Johannes *et al*., 2000; Pinnegar, Engelhard, 2008; Baird *et al*., 2021; Silvano *et al*., 2022; Castello *et al*., 2023), which is the case of several regions of South America (*e.g*., Hallwass *et al*., 2020). There are sound examples of community-based management of fishery resources (*e.g*., Castello *et al*., 2009), stressing the need to integrate fisher's knowledge with scientific information, management initiatives, and policies (Rabuffetti *et al*., 2023; Silvano, Kurien, 2023). Yet, LEK has been largely ignored in scenarios of hydropower expansion (Dória *et al*., 2018), whose management practices remain based on common solutions (*e.g*., fish stocking and passages; Lira *et al*., 2017; Pelissoli *et al*., 2023). This approach misses opportunities to assess environmental impacts and manage fishery resources based on local solutions (Lopes *et al*., 2021), and ignores the potential of fishers to work as sentinels of environmental change and degradation.

In this context, this study aims to advance the understanding of LEK in scenarios of environmental degradation, investigating the potential role of artisanal fishers as permanent *in loco* sentinels of environmental change. Through the lens (LEK) of small-scale artisanal fishers, we investigated how the construction of a large hydropower dam impacted fish diversity in the middle Tocantins River, a major river in the Amazon region. Seven large dams currently regulate the main channel of this river (Swanson *et al*., 2021), and previous studies have shown substantial changes in fish diversity (Mérona *et al*., 2001; Araújo *et al*., 2013; Perônico *et al*., 2020; Pereira *et al*., 2021). This study focused on the area affected by the impoundment (*i.e*., reservoir) created by Lajeado Dam, considering changes in (i) species abundance, (ii) species records, (iii) capture patterns, and (iv) the most valued species. We investigated the hypothesis that fishers, based on their experience and knowledge (LEK), recognize changes in fish diversity in the impoundment, as reported by scientific studies (*e.g.*, Agostinho *et al*., 2016); this behavior has been characterized in the lower Tocantins (Hallwass *et al*., 2013; Nunes *et al*., 2023) and elsewhere (Baird *et al*., 2021; D'avilla *et al*., 2021; Arantes *et al*., 2023). Particularly, we predicted that fishers are able to report (i) the replacement of migratory fish by non-migratory species in the impounded area, (ii) the disappearance of large fish with rheophilic behavior, especially large catfishes, (iii) changes in capture patterns, with increasing importance of non-migratory and sedentary fish, and (iv) the valorization of species previously considered of lower commercial relevance.

MATERIAL AND METHODS

Study area. The Tocantins-Araguaia Basin drains approximately 760,000 km² of central/northern Brazil, with an average discharge of *ca*. 11,000 m³/s (Ribeiro *et al*., 1995). The Tocantins River is a main axis of the basin, running *ca*. 2,500 km in the south-north direction towards the Marajó Island, in the estuarine region of the Amazon River. Currently, its main channel is regulated by seven large hydroelectric dams, which created large impoundments and changed the natural flow regime (Akama, 2017; Pelicice *et al*., 2021). Small dams are found throughout the basin, but large ones were built mainly in the upper and middle sections during the last twenty years.

The study area (Fig. 1) is under the influence of the Luís Eduardo Magalhães Hydroelectric Plant (Lajeado Dam), with an installed capacity of 902.5 MW, located in the middle Tocantins (09°45'26.90"S 48°22'19.21"W). This dam is the 5th in the cascade of dams along the river, constructed between 1998 and 2002. It formed a large impoundment (630 km² surface area, 150 km long, 8.8 m average depth, 24 days retention time) that flooded vast areas of savanna vegetation. A long river segment of about 190 km exists between the upper zone of the reservoir and the next dam upstream (Peixe Angical Dam), where some important tributaries flow into the Tocantins River, such the Manuel Alves, Santa Teresa and São Valério (Fig. 1). Both the Lajeado and Peixe Angical dams are equipped with fish ladders (weir and pool type), but which were closed due to operational problems related to malfunctioning and potential impacts on migratory fish (Agostinho *et al*., 2011; Pelicice, Agostinho, 2012).

Commercial fisheries in the Tocantins State has been permitted only recently (after 2008), because state legislation considered professional fishing as predatory (Miranda *et al*., 2017). Yet, fishing activities have been historically conducted in the Tocantins-Araguaia Basin, including subsistence, recreational, and small-scale commercial fishing (Ribeiro *et al*., 1995). Current legislation recognizes different fishing modalities, including small-scale artisanal fisheries, but has imposed some restrictions (gears, period, transportation, species). At present there are 36 fishing colonies in the Tocantins State, which operate small-scale fisheries for subsistence, trade and commercialization.

The investigation was conducted in the upper segment of the reservoir (Fig. 1), in the municipality of Porto Nacional, Tocantins State, Brazil. The Colony Z-04, located in Porto Nacional, is an association of artisanal fishers created in 2004 to provide support and organize the fishing activity. The number of associated members has fluctuated

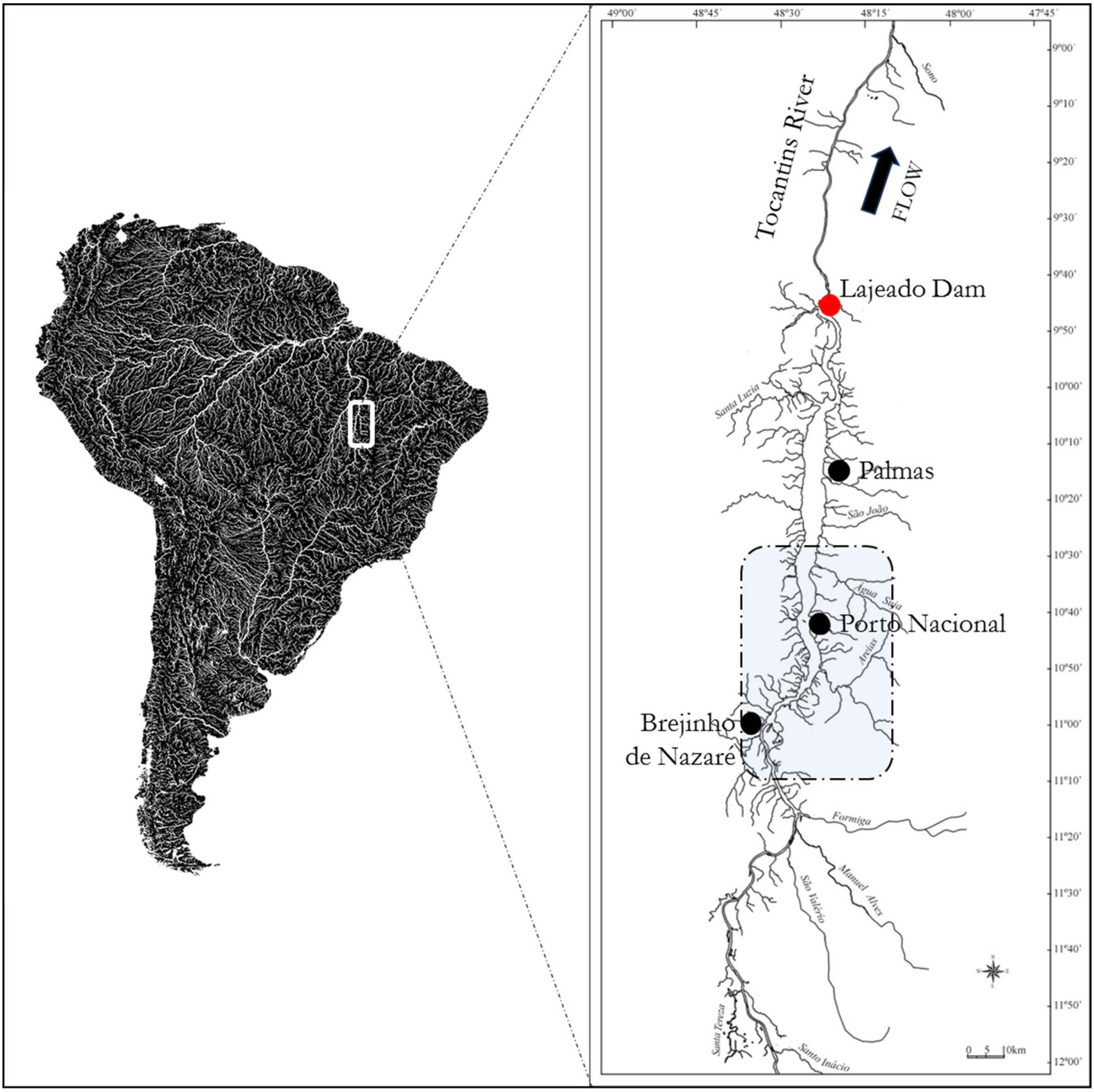

FIGURE 1 | The study area in the middle Tocantins River, indicating Lajeado Dam (Luis Eduardo Magalhães hydropower plant) and main urban centers along the reservoir (Palmas, Porto Nacional and Brejinho de Nazaré). The small rectangle indicates the main fishing area of artisanal fishers from Colony Z4 (based on Santos, Pelicice, 2023), which covers the upper segment of the reservoir. Peixe Angical Dam is the next dam upstream (not shown in the map), located about 190 km upstream from Porto Nacional. The large arrow indicates flow direction.

over the years. Originally, it had 300 members, but this number reduced significantly in the following years, *ca*. 50 in 2014 (Foschiera, Pereira, 2014). At the time of this study (2018), the Colony had 115 members, but currently (November 2023) it has *ca*. 60.

Santos, Pelicice (2023) investigated social aspects of the fishers and their interaction with the dam. According to this study, fishers reside in Porto Nacional and have fishing as the main activity, with an average fishing effort of *ca*. 15 days/month. Most fishers work in group (two or more people) and involve family members to aid in activities like fishing, processing, and selling. Fish is usually sold in urban areas or at their homes. Main fishing sites are located between Porto Nacional and Brejinho de Nazaré (Fig. 1), in the upper stretch of the impoundment. Fishing is conducted mainly with boats, hand lines, longlines, gillnets and cast nets. However, fishers reported significant changes in the fishery system after the impoundment, including shifts in fishing equipment, effort, costs, and well-being, with an overall perception of impact and damage.

Data collection. We conducted systematic interviews with artisanal fishers associated with Colony Z-04, through the application of a structured questionnaire. Interviews took place between August and October 2018, collecting data on socioeconomic aspects (*e.g*., Santos, Pelicice, 2023) and LEK about dam impacts on fish diversity (this research).

This research was supported by the president of the Colony, who provided registration data of all members, including full names and contact information (residence and telephone). The selection criterion considered the experience of fishers in the region, selecting only those with a long history of fishing activities (more than 20 years), sufficient to cover periods before and after the construction of Lajeado Dam.

To approach and interview the fishers, this research followed ethical recommendations widely applied in ethnobiological and social studies (*e.g*., Cetra, Petrere Jr., 2001; Silvano *et al*., 2006; Hallwass *et al*., 2013; Catelani *et al*., 2021), and the research protocol followed the main guidelines of the Declaration of Helsinki for research with humans. Each fisher was invited individually to participate in the research, and the decision to collaborate was voluntary. The fishers who agreed to participate signed a free and informed consent term (Tab. **S1**). We first explained the objectives of the research and its potential relevance for fisheries management. We also clarified that participants would remain anonymous, and that data collected would be used to support scientific investigations and knowledge dissemination. The interview was conducted always by the same investigator (MAAS), and occurred individually at the home of each fisher.

The structured questionnaire intended to assess the perception of each fisher about four questions: (i) main species that increased or decreased in abundance after river regulation; (ii) species that appeared (new records) and disappeared after river regulation; (iii) main species captured by fishing before and after river regulation; (iv) the most valued species by artisanal fisheries before and after river regulation. Each question was asked sequentially, and the fishers were allowed to provide as many names as they could recall.

Data analysis. Based on all common names reported during the interviews, we constructed the list of species (ethnospecies), combining possible synonyms. The resulting list (Tab. 1) was the basis for all analyses. The potential taxonomic affiliation of each ethnospecies was determined considering the lowest possible resolution (family, genus or species), based on Lucinda *et al*. (2007) and fisher's information. The reproductive strategy was assigned for each ethnospecies (*i.e*., long-distance migratory or non-migratory) based on Campos (2023).

We applied Non-Metric Multidimensional Scaling (NMDS) analyses to investigate changes in the composition of ethnospecies according to each question: (i) ethnospecies that increased or decreased in abundance after river regulation, (ii) those that appeared or disappeared in the impoundment, (iii) the composition of fish landings before and after river regulation, and (iv) the most valued ethnospecies before and after river regulation. A "fisher by species" matrix (presence/absence) was used for these analyses, based on Jaccard similarity; each fisher was considered as a replicate. Differences between groups (according to questions i to iv) were tested with Permutation Multivariate Analysis of Variance (PERMANOVA), and differences in data dispersion (spread) between multivariate groups was assessed through PERMDISP (Anderson, Walsh, 2013), both based on Jaccard similarity.

To characterize the main ethnospecies associated with each question, we calculated the number of citations received by each; the same procedure was conducted considering reproductive strategies (*i.e.*, long-distance migratory and non-migratory species).

Analyses were conducted in the software Past 4.13 (Hammer *et al*., 2001). The inference of statistical significance followed the concept of statistical clarity of Dushoff *et al*. (2019).

RESULTS

We interviewed 30 artisanal fishers, being 28 men and two women. They were 53 years-old on average (29 to 77), with experience in artisanal fishing of 41 years on average (21 to 67). They mentioned 60 common names of fish during the interviews, totaling 51 independent taxonomic units (ethnospecies) after grouping potential synonyms (Tab. 1). Of this list, 30 were classified as long-distance migrants, and 21 as non-migratory.

Fishers mentioned 37 ethnospecies (359 mentions) that decreased (25 taxa) or increased (24 taxa) in abundance after the construction of Lajeado Dam. The composition of these groups was clearly different, as evidenced by the NMDS analysis (stress = 0.2922; Fig. 2A) and confirmed by PERMANOVA ($F = 27.7$; $p < 0.0001$). However, responses about which species declined were more heterogenous, indicating lower agreement among fishers (PERMDISP: $F = 17.56$; $p < 0.0001$). Main species that declined (most cited) were barbado, surubim, caranha, cachorra-verdadeira, pacu, fidalgo and jaú, while main species that increased were curvina, corró, tucunaré, mandi-moela, baiacu and piranha (Fig. 2B). Almost all mentions to declines (98.8%) referred to migratory fish, while most mentions to increases (72.4%) referred to non-migratory fish (Fig. 2C).

Fishers mentioned 29 ethnospecies (176 mentions) that disappeared (20 taxa) or appeared (9 taxa) in the impounded area. The NMDS analysis separated the two groups (Fig. 3A), although the high stress value (0.4189) indicates poor representation. However, the composition of groups was clearly different according to PERMANOVA ($F = 38.9$; $p < 0.0001$); responses regarding species that disappeared were more heterogeneous (PERMDISP: $F = 33.3$; $p < 0.0001$). The most cited species that disappeared involved large catfishes (Siluriformes) such as filhote, dourada de couro, jaú and pernambuco, in addition to piabanha; main species that appeared were mapará and dourada de escama (Fig. 3B). Most mentions to ethnospecies that appeared (84.3%) and disappeared (97.6%) involved migratory fish (Fig. 3C).

Fishers mentioned 41 ethnospecies (400 mentions) among the most captured fish before (31 taxa) and after (24 taxa) the construction of Lajeado Dam. The composition of these groups was clearly different between periods, as evidenced by the NMDS

TABLE 1 | Common names (fish) mentioned by artisanal fishers during the interviews, used as ethnospecies in this work. Different names potentially associated with the same taxon were grouped as synonyms (in parenthesis). Taxonomic affiliation is the probable affiliation considering the lowest possible resolution (family, genus or species), based on Lucinda *et al*. (2007) and fisher's information. Migratory behavior (LDM = long distance migratory) followed Campos (2023).

Common names (synonyms)	Taxonomic affiliation	LDM
Arraia	Potamotrygonidae	
Baiacu	*Oxydoras niger* (Valenciennes, 1821)	X
Barbado	*Pinirampus pirinampu* (Spix & Agassiz, 1829)	X
Bico de pato	*Sorubim lima* (Bloch & Schneider, 1801)	X
Bicuda	*Boulengerella cuvieri* (Spix & Agassiz, 1829)	
Fidalgo (Boca larga, mandubé)	Auchenipteridae	
Cachorra-verdadeira (Cachorra)	*Hydrolycus armatus* (Jardine, 1841), *Hydrolycus tatauaia* Toledo-Piza, Menezes & Santos, 1999	X
Cachorra-facão	*Raphiodon vulpinus* Spix & Agassiz, 1829	X
Candiru	*Cetopsis* spp.	
Caranha (Pacu caranha)	*Piaractus brachypomus* (Cuvier, 1818)	X
Cara-pirosca	*Astronotus crassipinnis* (Heckel, 1840)	
Cari	Loricariidae	
Corró	Small cichlids, *e.g.*, *Geophagus* spp., *Satanoperca* spp., *Cichlasoma* spp.	
Curvina (Pescada)	Sciaenidae	
Dourada de couro	*Brachyplatystoma rousseauxii* (Castelnau, 1855)	X
Dourada de escama	*Pellona flavipinnis* (Valenciennes, 1837), *Pellona castelnaeana* Valenciennes, 1847	X
Filhote (Branquim)	*Brachyplatystoma filamentosum* (Lichtenstein, 1819)	X
Jaraqui	*Semaprochilodus brama* (Valenciennes, 1850)	X
Jaú	*Zungaro zungaro* (Humboldt, 1821)	X
Ladina	*Brycon falcatus* Müller & Troschel, 1844	X
Mandi-cabeça de ferro	*Pimelodus blochii* Valenciennes, 1840, *Pimelodus tetramerus* Ribeiro & Lucena, 2006	X
Mandi-moela	*Pimelodina flavipinnis* Steindachner, 1876	X
Mapará	*Hypophthalmus marginatus* Valenciennes, 1840	X
Pacu (crupeté)	Serrasalminae, excluding piranhas	X
Pacu-branca	*Myloplus torquatus* (Kner, 1858)	X
Pacu-dente seco	*Myleus setiger* Müller & Troschel, 1844	X
Pacu-manteiga	*Mylossoma duriventre* (Cuvier, 1818)	X
Papa-terra	*Prochilodus nigricans* Spix & Agassiz, 1829	X
Peixe-folha	*Hypoclinemus mentalis* (Günther, 1862)	
Pernambuco	*Aguarunichthys tocantinsensis* Zuanon, Rapp Py-Daniel & Jégu, 1993	X
Piabanha	*Brycon gouldingi* Lima, 2004	X
Piau	Anostomidae	X
Piau-cabeça gorda	*Leporinus friderici* (Bloch, 1794)	X
Piau-flamengo	*Leporinus affinis* Günther, 1864, *Leporinus tigrinus* Borodin, 1929	
Piau-pirco	Hemiodontidae	
Piau-vara	*Schizodon vittatus* (Valenciennes, 1850)	
Piranha	*Serrasalmus* spp., *Pygocentrus nattereri* Kner, 1858	
Piranha-preta	*Serrasalmus rhombeus* (Linnaeus, 1766)	
Piranha-vermelha	*Pygocentrus nattereri* Kner, 1858	
Pirarara	*Phractocephalus hemioliopterus* (Bloch & Schneider, 1801)	X
Pirosca	*Arapaima gigas* (Schinz, 1822)	
Pocomom	*Tocantinsia piresi* (Miranda Ribeiro, 1920)	
Porca	*Pterodoras granulosus* (Valenciennes, 1821)	X
Sardinha	Diffuse designation, usually associated to *Triportheus* spp. and other small fish	
Sardinha-gato	*Lycengraulis batesii* (Günther, 1868)	
Surubim (Pintado, Pintadim)	*Pseudoplatystoma fasciatum* (Linnaeus, 1766)	X
Surubim-chicote	*Sorubimichthys planiceps* (Spix & Agassiz, 1829)	X
Tabarana	*Salminus hilarii* Valenciennes, 1850	X
Tambaqui	*Colossoma macropomum* (Cuvier, 1816)	X
Tilápia	*Oreochromis niloticus* (Linnaeus, 1758)	
Tucunaré	*Cichla kelberi* Kullander & Ferreira, 2006, *C. piquiti* Kullander & Ferreira, 2006	

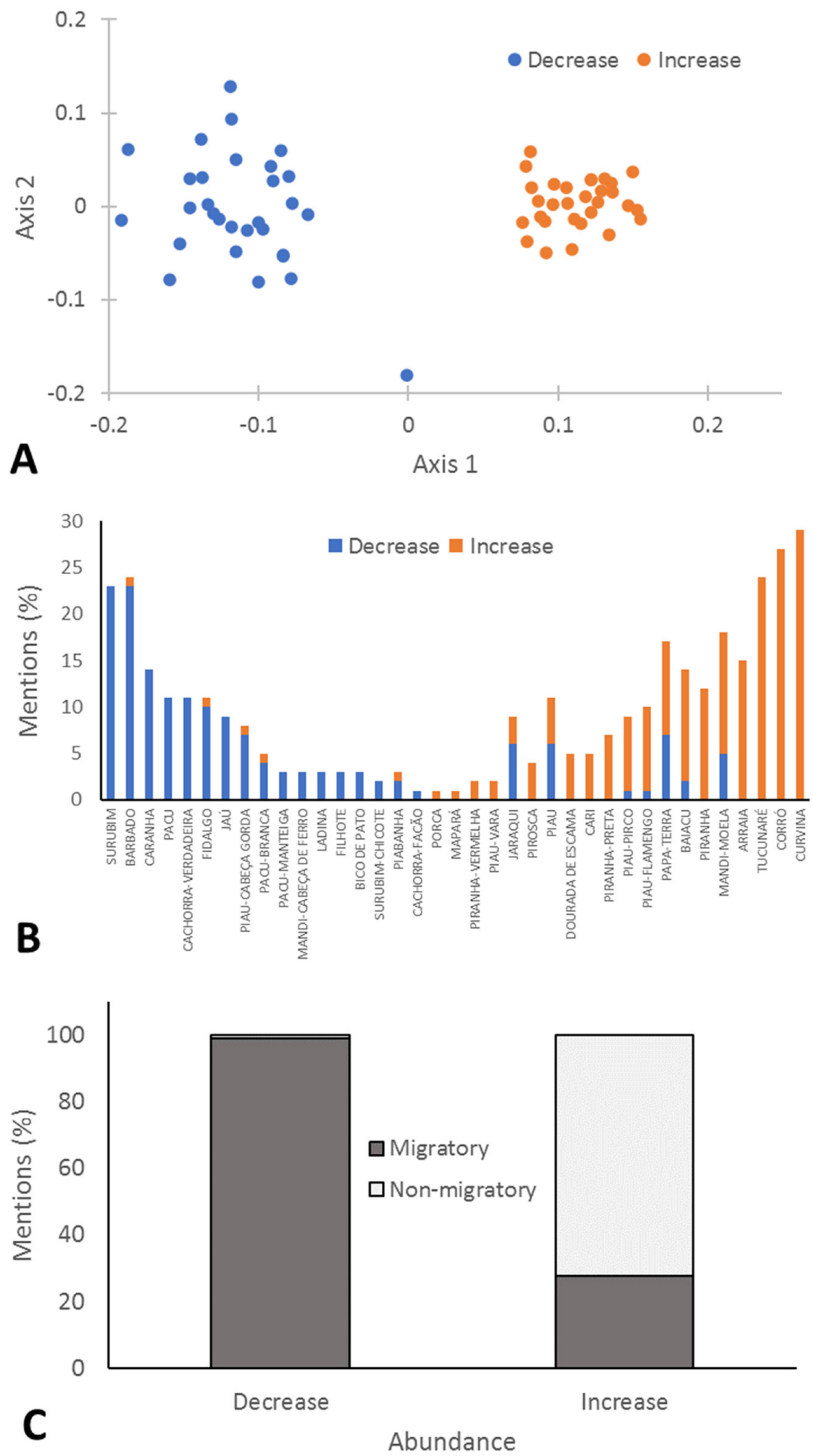

FIGURE 2 | Changes in fish abundance in the area impounded by Lajeado Dam, according to the LEK of artisanal fishers. **A.** Non-Metric Multidimensional Scaling applied to investigate variations in the composition of ethnospecies that increased or decreased (stress = 0.2922); **B.** Ethnospecies that increased or decreased (% of mentions); **C.** Ethnospecies grouped according to their reproductive behavior (migratory and non-migratory).

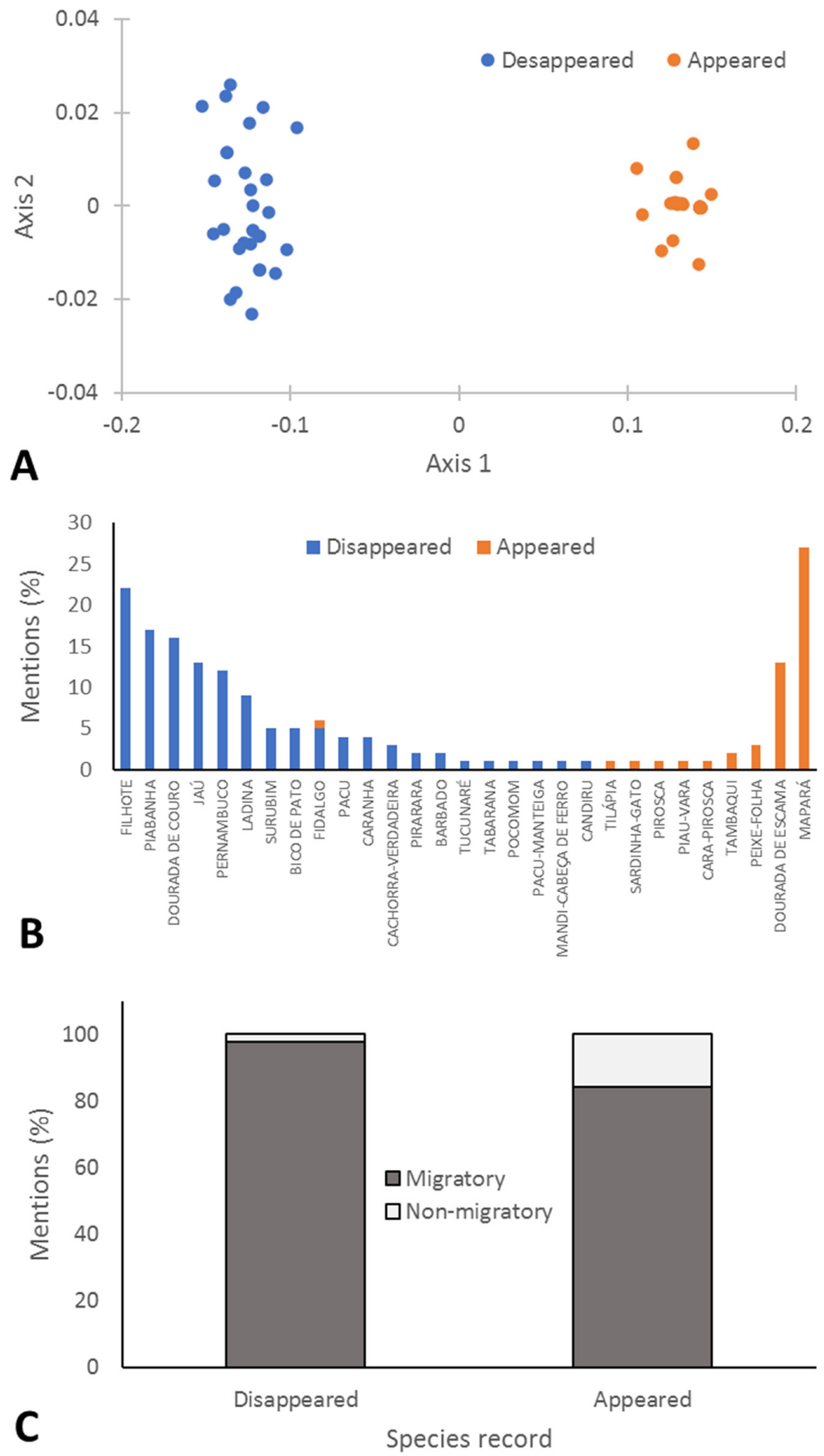

FIGURE 3 | Species that disappeared or appeared in the area impounded by Lajeado Dam, according to the LEK of artisanal fishers. **A.** Non-Metric Multidimensional Scaling applied to investigate the composition of ethnospecies that disappeared or appeared (stress = 0.4189); **B.** Ethnospecies that disappeared or appeared (% of mentions); **C.** Ethnospecies grouped according to their reproductive behavior (migratory and non-migratory).

analysis (stress = 0.2169; Fig. 4A) and confirmed by PERMANOVA ($F = 22.8$; $p < 0.0001$); responses were more heterogeneous regarding the composition of catches before the impoundment (PERMDISP: $F = 10.3$; $p < 0.001$). The main species landed before river regulation were barbado, caranha, jaú, filhote, pacu and surubim, while main species captured in the impoundment were curvina, corró, tucunaré and mandi-moela, mentioned by almost all respondents (Fig. 4B). Most mentions (90.3%) to ethnospecies caught before referred to migratory fish, while the majority of mentions (64.5%) to catches after involved non-migratory fish (Fig. 4C).

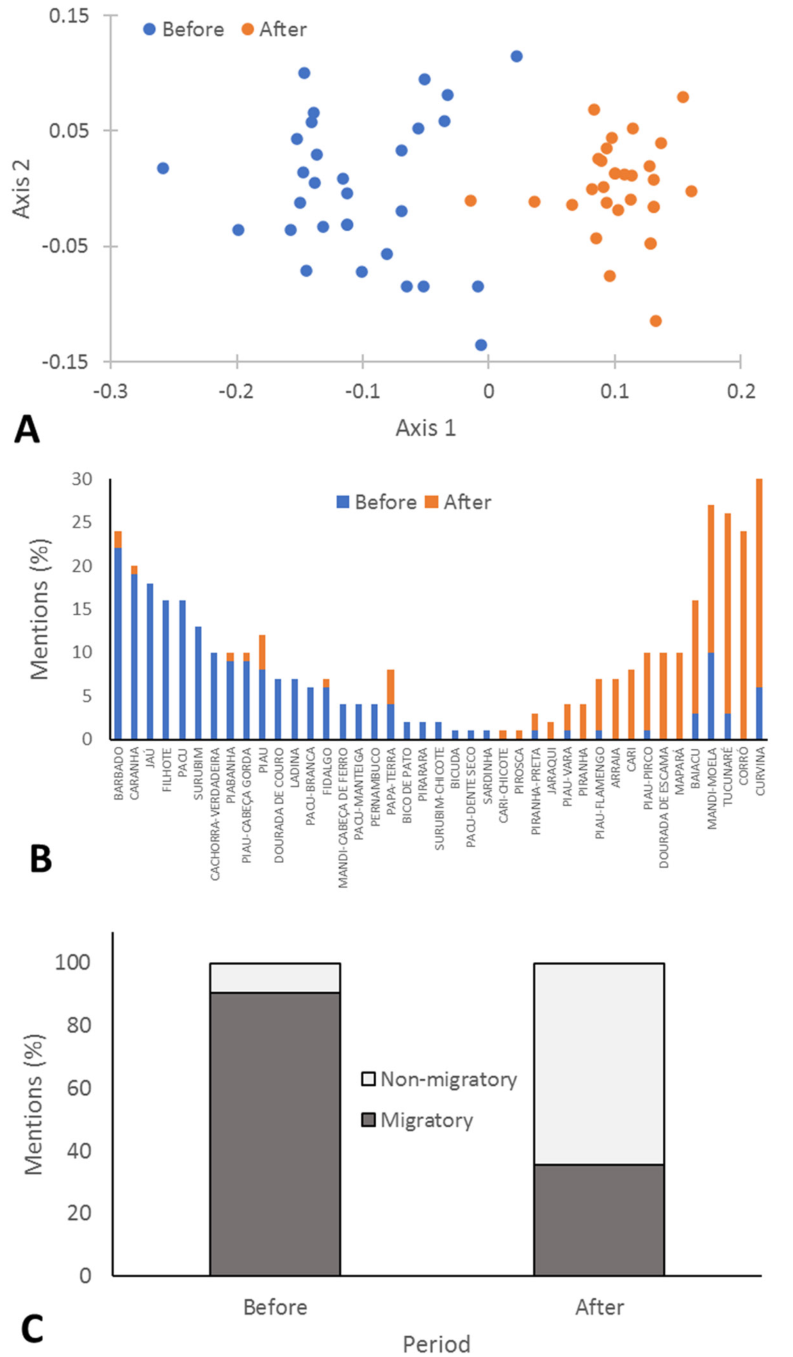

FIGURE 4 | Fishery catches before and after the construction of Lajeado Dam, according to the LEK of artisanal fishers. **A.** Non-Metric Multidimensional Scaling applied to investigate the composition of main ethnospecies captured before and after river regulation (stress = 0.2169); **B.** Main ethnospecies captured before and after (% of mentions); **C.** Ethnospecies grouped according to their reproductive behavior (migratory and non-migratory).

Fishers mentioned 30 ethnospecies (352 mentions) among the most valued before (22 taxa) and after (20 taxa) the construction of Lajeado Dam. Some were mentioned in both periods, but the composition of the groups was clearly different, as evidenced by the NMDS analysis (stress = 0.2237; Fig. 5A) and confirmed by PERMANOVA ($F = 19.7$; $p < 0.0001$); responses regarding the after period were more heterogeneous (PERMDISP: $F = 6.9$; $p < 0.01$). The most valued species before river regulation were filhote, surubim, barbado, caranha, piabanha, pacu and jaú, while the most valued after were tucunaré, barbado, mandi-moela and pirosca (Fig. 5B). Migratory fish accounted for most mentions before (96.1%) and after (64.9%), but mentions to non-migratory fish increased in the after period (Fig. 5C).

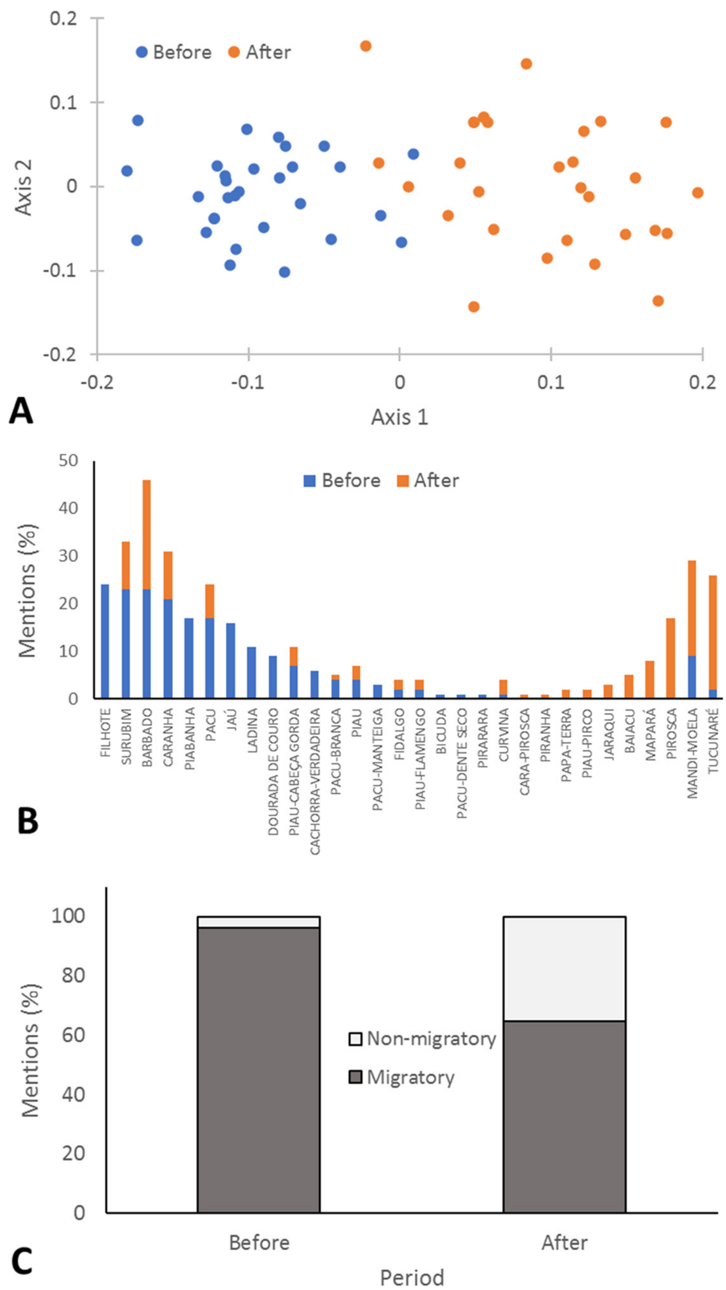

FIGURE 5 | The most valued fish before and after the construction of Lajeado Dam, according to the LEK of artisanal fishers. **A.** Non-Metric Multidimensional Scaling applied to investigate the most valued ethnospecies before and after river regulation (stress = 0.2237); **B.** The most valued ethnospecies before and after (% of mentions); **C.** Ethnospecies grouped according to their reproductive behavior (migratory and non-migratory).

DISCUSSION

Small-scale artisanal fishers reported significant changes in fish diversity (*i.e.*, fish abundance, species records, capture patterns, and valuation) following the construction of Lajeado Dam, which supports the hypothesis that artisanal fishers recognize environmental changes caused by river damming and identify major shifts in fish diversity. In general, fishers indicated the decline and loss of migratory fish in the area affected by the impoundment, especially large catfishes, with effects on fishing landings and the valuation of fish species. These results are in line with scientific studies conducted in the Neotropical region (*e.g.*, Petrere Jr., 1996; Agostinho *et al*., 2016; Santos *et al*., 2018; Pelicice *et al*., 2022) and, especially, with studies conducted in the Tocantins River, which report the decline of migratory fish and the dominance of non-migratory species in large impoundments (Mérona *et al*., 2001; Araújo *et al*., 2013; Perônico *et al*., 2020; Pereira *et al*., 2021). Our results support previous investigations about the importance of LEK for impact assessment (*e.g.*, Hallwass *et al*., 2013; D'avilla *et al*., 2021; Arantes *et al*., 2023), demonstrating that artisanal fishers may act as *in loco* sentinels of environmental impacts induced by river regulation.

According to fishers, different species declined or flourished in the impoundment, indicating significant shifts in fish composition between periods. Species that declined or disappeared included mainly large-sized migratory fish with rheophilic behavior, such as surubim, barbado, caranha, filhote, piabanha, dourada, jaú, and pernambuco. Large migratory catfishes (Siluriformes) were the most cited among those that declined and disappeared, emphasizing the vulnerability of the group (Barthem *et al*., 2017; Van Damme *et al*., 2019). These results support the predictions that artisanal fishers are able to report (i) the substitution of migratory fish by non-migratory species in the reservoir, and (ii) the loss of large fish with rheophilic behavior, especially large catfish. The complex life cycle of migratory fishes explains why the group is so vulnerable to environmental degradation, habitat loss, and hydrological fragmentation (Castello *et al*., 2013; Pelicice *et al*., 2017; Duponchelle *et al*., 2021). Migratory fishes usually migrate over long distances (> 50 km) to complete their life cycles, and they depend on the natural flow regime and specific habitats for spawning, growing and feeding (Carolsfeld *et al*., 2003). The decline and loss of migratory fish is a global trend (Deinet *et al*., 2020; Huang, Li, 2024), reported in different Neotropical drainages subjected to river regulation and other stressors (Agostinho *et al*., 2016; Pelicice *et al*., 2018; Loures, Pompeu, 2019; D'avilla *et al*., 2021), including the Tocantins River drainage (Perônico *et al*., 2020; Pereira *et al*., 2021). Our results show, therefore, that artisanal fishers can provide valuable information about the status of migratory fishes, including temporal shifts in composition and the interaction with environmental conditions.

According to artisanal fishers, the main species that flourished in the reservoir were lentic-adapted fish with non-migratory or sedentary behavior, such as curvinas, corrós, tucunarés, stingrays, mandis and piranhas. The proliferation of these fish has been widely reported in Neotropical reservoirs (Petrere Jr., 1996; Agostinho *et al*., 2007; Santos *et al*., 2018; Guedes, Araújo, 2022; Pelicice *et al*., 2022), favored by the environmental filters (lentic and stabilized) created with the impoundment. Lentic-adapted fish tend to dominate local assemblages in shallow littoral areas and deeper zones, especially in older and stabilized reservoirs (Agostinho *et al*., 2007; Gois *et al*., 2012). In fact, fishers cited few species that appeared in the impoundment (while many were lost), usually lentic-adapted species with cryptic abundance in the river period (*e.g*., mapará, dourada de escama). The mapará (*Hypophthalmus marginatus* Valenciennes, 1840) is one of the few species that use the vast pelagic habitat, able to feed on planktonic organisms in the limnetic zone (Carvalho, 1980). It is worth noting also the occurrence of some non-native species, such as tambaqui (*Colossoma macropomum* (Cuvier, 1816)) and pirosca (*Arapaima gigas* (Schinz, 1822)), recorded only in the impounded period. Their contribution to fishing landings has increased (FMP, pers. obs.), and the risk of new introductions (*e.g.*, tilápias, panga) indicates that non-native fish may become more common in Lajeado, as observed in reservoirs located in other drainages of South America (Alves da Silva *et al*., 2009; Novaes, Carvalho, 2013; Pelicice *et al*., 2018; Bueno *et al*., 2021). The dominance of some lentic-adapted fish, as reported by fishers, indicates strong shifts in assemblage structure, a pattern reported for other Amazonian rivers regulated by large dams (Hallwass *et al*., 2013; Arantes *et al*., 2023).

Fishers also reported significant differences in the composition of catches and in the specific value of fish between periods, confirming predictions of (iii) changes in landing patterns, with the prevalence of non-migratory or small sedentary fish in the reservoir; and (iv) the increasing valorization of species with lower commercial value after river regulation. According to fishers, before river regulation, fishing targeted mainly medium to large-sized migratory characids and catfishes, also reported as the most valued. These fishes usually compose fishing landings in South American rivers (Batista *et al*., 2018; Duponchelle *et al*., 2021; Scarabotti *et al*., 2021), being highly valued, with good market acceptance and high commercial value. After river regulation, species once prized tend to decline or disappear, being replaced by others with lower commercial value (Agostinho *et al*., 2007; Hoeinghaus *et al*., 2009; Arantes *et al*., 2023), but which, due to limited options, become prized in the new scenario. In fact, fishing targeted non-migratory and sedentary fish in the impounded area, and some became prized, such as tucunaré, mandi-moela, pirosca, mapará and baiacu. Changes in the valuation scale indicate changes in the fishing system as a whole; in fact, large-scale alterations in fishing systems (*i.e*., landings, target-species, gears, effort, trade), driven by changes in capture patterns, have been commonly observed in large South America (Petrere Jr., 1996; Agostinho *et al*., 2007). Artisanal fisheries in the middle Tocantins River followed this trend, which induced social and economic consequences associated with income, costs and satisfaction (Santos, Pelicice, 2023).

The present work contributed to the understanding of how small-scale artisanal fishers perceive the effects of river regulation on fish diversity and fishing activities. The results expand the evidence that artisanal fishers perceive social, economic and environmental changes caused by dams. The knowledge of artisanal fishers, characterized by empirical and traditional sources, has great potential to provide valuable information about fish, fisheries and ecosystems, especially in data-poor contexts (Baird *et al*., 2021; Silvano *et al*., 2022), serving as permanent *in loco* sentinels of environmental change and degradation. Moreover, fishers and LEK may be the only source of historical data about fish diversity and fishery dynamics (Hallwass *et al*., 2020; Castello *et al*., 2023), especially in sites and countries that lack official monitoring programs and fishery statistics, such as Brazil (Santos *et al*., 2023). This source may provide valuable baseline data for comparisons with current information (Johannes *et al*., 2000; Pinnegar, Engelhard, 2008), clarifying long-term trends, past scenarios, specific disturbances, and several other details that are difficult to access with scientific methods due to logistic, time and cost constraints. The experience of fishers, in particular, may play a valuable role in assessing environmental impacts of hydroelectric dams (Hallwass *et al*., 2013; D'avilla *et al*., 2021), as it generates information on stock size, target species, spatial distribution, life cycle, or fish value. LEK has been fundamental to support resource management based on local solutions and community-based perspectives (Dória *et al*., 2018; Lopes *et al*., 2021), but it may be fully integrated to ecosystem-based approaches, impact assessments, and policies.

It is worth noting, however, that artisanal fishing has been progressively suppressed at a global scale due to conflicts with other activities, especially large-scale commercial and recreational fishing, aquaculture, urbanization, and hydroelectric expansion (Agostinho *et al*., 2007; Gutberlet *et al*., 2007). Artisanal fishers are known to be highly vulnerable to socioeconomic and political issues, but they are also sensitive to changes in fishing stocks and food availability (Tregidgo *et al*., 2020). In a scenario of increasing environmental degradation and social conflicts (Pelicice *et al*., 2021), the culture of artisanal fishers in the Tocantins-Araguaia River Basin has been increasingly endangered, just like aquatic biodiversity. Public policies should pay attention to this condition, especially in tropical regions where fishing plays social roles (*e.g*., Amazon, Congo, Mekong), in order to understand the demands and needs of artisanal fishers, looking for opportunities to preserve their culture and integrate it with other approaches.

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Marco Aurélio Alves Santos: Conceptualization, Data curation, Investigation, Methodology, Validation, Visualization, Writing-original draft.

Fernando Mayer Pelicice: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing-review and editing.

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