Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

River dams, free stretches and migratory fish species: a review of the state of the art in the state of São Paulo, Brazil

Barragens fluviais, trechos livres e espécies de peixes migradores: uma revisão do estado da arte no estado de São Paulo, Brasil

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Abstract

Population growth combined with the need for electrical energy resulted in the construction of hundreds of hydroelectric plants in the state of São Paulo, Brazil. The consequence of these interventions was the fragmentation of rivers, forming barriers, that hinder the mobility of migratory fish species, generating an impact on the life cycle of these species, especially about movement between breeding and feeding areas. For this reason, this article aimed to evaluate the state-of-the-art knowledge regarding dams, free stretches, and migratory species in the three main river basins of the state of São Paulo and its tributaries. Through a systematic review from 2003 to 2023, 89 articles were obtained, 48 of which were about dams, 5 which addressed fish transposition systems, and 36 portraying migratory species. In the first half, research focused more on the impacts of dams on fish fauna, while in the second half of the period studied, studies of migratory fish were dominant. Most research was conducted in the main rivers, with few in the tributaries. Finally, 16 migratory species, considered long-distance, were studied, the most studied being *P. lineatus*, *P. maculatus*, *L. friderici*, *M. obtusidens* and *S. hilarri* and the ones that occurred most frequently in rivers are *Prochilodus lineatus*, *Pimelodus maculatus*, *Megaleporinus obtusidens* and *Salminus hilarii*. Therefore, we recommend maintaining the natural flow regime that still exists in the main rivers and tributaries of the state of São Paulo, to maintain healthy populations of the inventoried species.

Keywords: river fragmentations, tributaries, free rivers, fish migrations.

Resumo

O crescimento populacional aliado à necessidade de energia elétrica resultou na construção de centenas de usinas hidrelétricas no estado de São Paulo, Brasil. A consequência dessas intervenções foi a fragmentação dos rios, formando barreiras, que dificultam a mobilidade das espécies de peixes migradores, gerando impacto no ciclo de vida dessas espécies, principalmente no que diz respeito à movimentação entre áreas de reprodução e alimentação. Por esse motivo, objetivou-se atraves desse artigo avaliar o estado da arte do conhecimento a cerca dos barramentos, trechos livres e espécies migradoras nas três principais bacias hidrográficas do estado de São Paulo e seus tributários. Através de uma revisão sistemática do periodo de 2003 a 2023 foram obtidos 89 artigos, sendo 48 sobre barramentos, 5 que abordavam sistemas de transposição de peixes e 36 retratando as espécies migradoras. Na primeira metade as pesquisas focaram mais os impactos dos barramentos na ictiofauna, enquanto que na segunda metade do período estudado, estudos dos peixes migradores foram dominantes. A maioria das pesquisas foram conduzidas nos rios principais, sendo poucas nos trinutários. E por fim 16 espécies migradoras, consideradas de longa distância foram estudadas, sendo que as mais estudadas foram *P. lineatus*, *P. maculatus*, *L. friderici*, *M. obtusidens* and *S. hilarri* e as que ocorreram com maior frequência nos rios são *Prochilodus lineatus*, *Pimelodus maculatus*, *Megaleporinus obtusidens* and *Salminus hilarii*. Assim, recomendamos a manutenção do regime de fluxo natural ainda existente nos principais rios e tributários do estado de São Paulo, para manter populações saudáveis of migratory species inventoried.

Palavras-chave: fragmentação de rios, afluentes, rios livres, migração de peixes.

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Received: December 7, 2023 – Accepted: June 7, 2024

1. Introduction

The growing expansion of the population and economy made necessary, from the 17th century, the construction of Hydroelectric Power Plants, which fragmented and changed the natural course of rivers (Nilsson et al., 2005; Opperman et al., 2015; Winemiller et al., 2016; Grill et al., 2019), and has affected virtually every watershed on the planet (Winemiller et al., 2016; Alò et al., 2020). In Brazil, all basins have rivers with some type of damming to serve mainly for power generation and water supply (Agostinho et al., 2008). Fragmentation, along with river degradation is recognized as the main cause of aquatic biodiversity loss (Grill et al., 2019).

The effects of these dams on fish fauna are widely described in the literature. We can mention those that directly affect migratory fish species, as they interfere with the movement of populations, intercept migratory routes, hinder spawning, and extinguish sections necessary for reproduction (Pompeu and Zambaldi, 2020) and feeding (Capeleti and Petrere Junior, 2006). The interruption of the connectivity of a river caused by dams, blocks access to specific habitats for the life cycle of many fish species (Vasconcelos et al., 2014), interfering and causing damage to reproductive strategies and migration patterns (Agostinho et al., 2007).

Free-flowing rivers are the main drivers of productivity in deltas and floodplains and are one of the most important conditions for fish (Opperman et al., 2015). When main rivers have tributaries free of dams, these are an important condition for maintaining or even enriching the diversity of fish in dammed systems (Silva et al., 2019; Azevedo-Santos et al. 2020), especially migratory species (Silva et al., 2017). This condition offers important habitats for fish spawning and growth, as well as areas with protection and shelter, which can be an alternative route for these species (Luz et al., 2012; Vasconcelos et al., 2020) and is recognized as vital for access to spawning sites and refuges for the early stages of life (Silva et al., 2019; Azevedo-Santos et al., 2021).

The state of São Paulo has three major formations of the Paraná River. Furthermore, these are deeply dammed – with cascades of reservoirs in the main courses and can be considered one of the states most degraded by dams. The rivers in the state of São Paulo present themselves largely dammed, the main ones being the Tietê River and the Paranapanema River and its tributaries. The consequences of damming in the rivers of the state of São Paulo are also well described in the literature, with mention being made of the works developed by Agostinho et al. (2007), Petesse and Petrere Junior (2012), Smith et al. (2014), Smith et al. (2018a, b), Garcia et al. (2018), Pelicice et al. (2018) and Pompeu and Zambaldi (2020). Therefore, considering the problems related to the construction of dams reported above, and given the amplitude and scale of the pressures faced by migratory species in the state's rivers, we organized in this manuscript the information available in the literature so that they can support new research, subsidize decision makers and promote public policies.

This contribution offers an assessment of the state of the art regarding the knowledge of the distribution of dams, fish transposition systems, and possible free stretches in the rivers of the state of São Paulo, based on a systematic review carried out in the period from 2003 to 2023. In addition, inventories were made which migratory species occur in rivers, considering long-distance ones, which could use the still existing stretches free of dams. We also discuss the challenges and opportunities to advance future research, as the state's rivers could gain new dams and decision-making could be based on the information contained in this article.

2. Material and Methods

The area researched is located in the State of São Paulo, Brazil (Figure 1), covering four ecoregions, namely: Upper Paraná (Paranapanema Basin, Tietê Basin, and Grande River Basin), Paraíba do Sul, Ribeira de Iguape and Southeastern Mata Atlantica (Abell et al., 2008). The Upper Paraná basin is the largest of the four ecoregions in the State of São Paulo, its main river, the Paraná River, and three of its largest tributaries, the Tietê River, Paranapanema River, and the Grande River, are in the State of São Paulo.

Considering the upper Paraná ecoregion described above, the following rivers were analyzed in this study: (I) Tietê River (main river) and its main tributaries: Sorocaba River, Piracicaba River, Jaú River, Jacaré-Guaçú River, Jacaré-Pepira River, and Peixe River. The Tietê River is 955 km long and is divided into six sub-basins: Upper Tietê River (São Paulo Metropolitan Region); Piracicaba River; Sorocaba River/Middle Tietê River; Tietê River/Jacaré River; Tietê River/ Batalha River and Lower Tietê River; (II) Grande River (main river), its main tributaries: Cubatão River, Mogi-Guaçu River, and Pardo River. The Grande River is 600 km long, begins in the Serra da Mantiqueira region, and flows through the states of Minas Gerais and São Paulo; (III) Paranapanema River (main river), and its main tributaries: Itapetininga River, Taquari River, Apiaí-Guaçu River, Itararé River, Guareí River, and Guapiara River. The 785 km long Paranapanema River is a large tributary of the left bank of the Paraná River, which is inserted in its upper section in the Upper Paraná Basin, subdivided into the Upper Paranapanema; Middle Paranapanema, and Lower Paranapanema; and (IV) Fish River, with 279 km long.

The information presented in this manuscript was obtained through a systematic review. Article selection and exclusion criteria were used, these being: i) addressing the issue of dams and Fish Transposition Systems (FTS) about fish communities, ii) portraying studies carried out on the Tietê, Grande, and Paranapanema rivers, as well as its tributaries and iii) have complete access to the articles. Publications from 2003 to 2023 were analyzed with the support of electronic databases of indexed journals, such as Scopus, Web of Science, and Google Scholar, and for each river and their respective dams, FTSs, and fish communities, different searches were carried out (n=9), as explained in Figure 2.

The Start 3.0.3 program was used to screen the articles, which aims to choose the information obtained according to the inclusion and exclusion criteria of the protocol adopted in the review. In the software, the works went through two

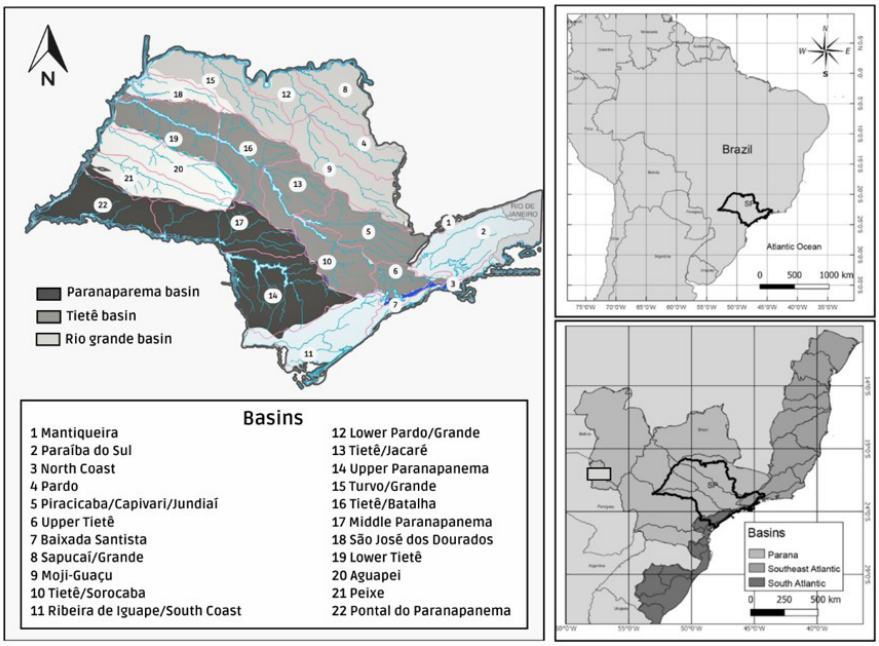

Figure 1. Location of the study area, indicating the main watershed that is the focus of this study.

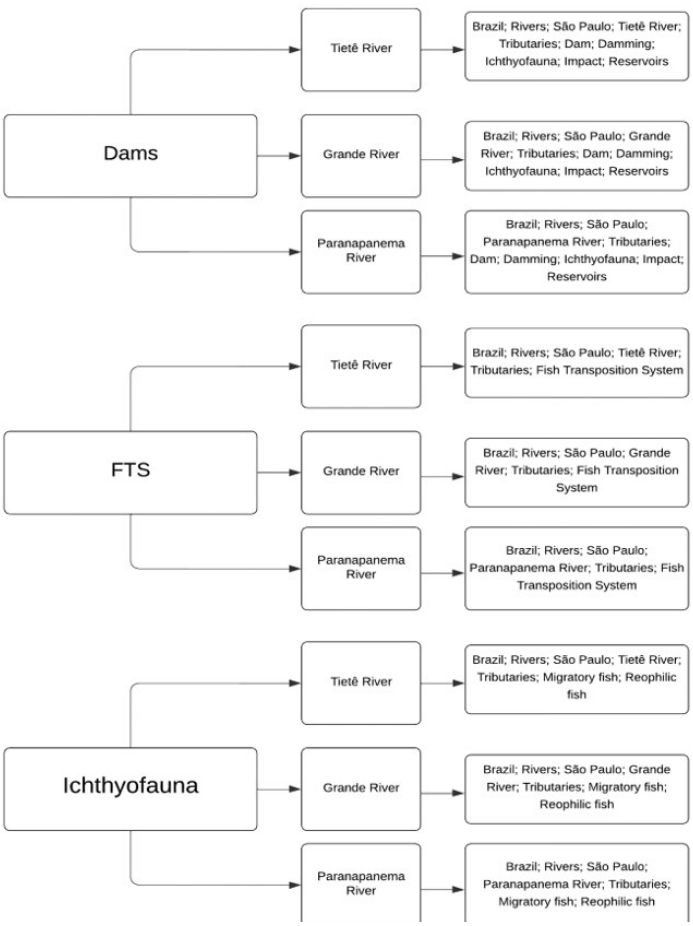

Figure 2. Routine searches carried out in databases, referring to each topic: dams, FTSs and migratory fish.

main stages: selection, where all articles found with the application of keywords were exported and only primary studies were selected, and extraction, a stage that consists of the final selection of articles that met the criteria for selection. The publications were obtained with a subsidy from the CAPES Periodicals Portal due to the agreement with the Universidade Paulista (UNIP), which allowed access to the periodicals. Furthermore, the following information was extracted from each article: a) year; b) species; c) river; d) location, and e) study category (Table 1).

Based on the data obtained regarding migratory species distributed in the three basins studied, we used relevant literature to assign species as long-distance (>100km) migrants (Suzuki et al., 2002; Agostinho et al., 2003; Ghiraldelli et al., 2007; Ramos et al., 2012; Queiroz et al., 2015; Pelicice et al., 2018; Galindo et al., 2020; Bailly et al., 2021; Azambuja et al., 2022.

To complement the research, two maps were created indicating the targets of interest, with the entire hydrography of the state of São Paulo, obtained through the Metadata Catalog of the National Water Agency (ANA), and all hydroelectric dams available in the Report of Dam Safety, 2022 Edition, of the National Dam Safety Information System (SNISB).

For the first map, the data was processed using the geoprocessing software QGIS 3.30.2, through which the main rivers that run through the state of São Paulo were extracted and identified, namely Grande River, Tietê River, Rio do Peixe River, and Paranapanema River. In addition, the main tributaries and the location of the dams were indicated.

The second map was used to delineate the free-flowing stretches of rivers present in each main watercourse and its tributaries. This delineation was carried out by breaking the features of the river indicator lines, with the interruption occurring at the contact vertices between the watercourse and the dam point. From this breaking process, the size of each resulting segment was calculated using the field calculator available in the attribute table. Based on this data, the largest stretches present in each river were identified and highlighted on the map.

3. Results

A total of 439 articles were divided as follows in the databases: Web of Science 330 results; Scopus 35 results; Google Scholar 74 results. In total 89 articles dealt with the impacts of dams on ichthyofauna and were validated to compose this literature review for addressing the dams in the chosen rivers. The review of dams in the three river basins returned a total of 48 articles. Regarding the FTS, 5 articles were found according to the inclusion and exclusion criteria, and 36 articles were considered on the topic of migratory fish species (Figure 3). In summary,

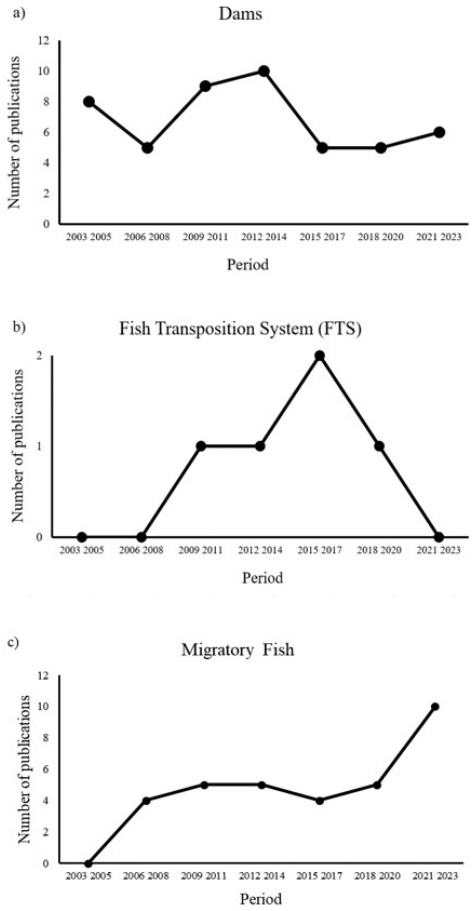

Figure 3. Number of publications that have been analyzed per year from 2003 until 2023. Panels show the number of studies with dams (a), fish transposition systems (b), and migratory fish (c).

Table 1. Data extracted from the articles, description of the classification, and application for each theme analyzed.

Data obtained	Classification	Application
Year	2003 to 2023	Used to determine the time trend of posts
Species	Migratory species	Used to separate the target species of study from other species studied in the basin
River	Located in the studied area	Used to define the rivers where the studied species are found
Locality	Geographic coordinate	Used to identify the location of rivers, dams and species studied
Study Category	Ecology, biology, reproduction, genetics, population dynamics	Classification based on the main objectives of the studies

over the years, we can see the predominance of studies on the effects of dams on fish fauna (2008-2014) and their decrease in subsequent years. Furthermore, we can see the increase in studies focusing on migratory species from 2016 onwards, and the scarcity of research focusing on transposition mechanisms and fish.

From the data obtained, we can verify that in the State of São Paulo there is a high number of dams on the rivers studied. Overall, 42 dams were surveyed for the main rivers and tributaries. The largest number of dams is present in the Tietê River and Paranapanema River (Table 2; Figure 4). Furthermore, approximately 4901 km of river length was estimated, with 2960 km of rivers remaining without the influence of dams, which represents a decrease of 40% of the hydrographic network available for migratory species.

The Tietê and Paranapanema rivers have few stretches free of dams (28.6% and 30.3% respectively), while the Grande, despite the existing dams, has a considerable extension of 72.5% of the original (Table 2; Figure 5). Compared to the tributaries, these still have important extensions free of dams. In the Tietê basin, the extensions vary from 55.8% to 100%, in the Paranapanema River from 62.5% to 100%, and in the Grande River from 66.3% to 91.3%. We can confirm that the majority of the tributaries of the large ones in the state of São Paulo have sections ≥ 100 km. For the rivers in the state of São Paulo, the numbers of Fish Transposition Systems (FTS) are scarce and mostly old. In the Tietê River there are 5 FTS and in its tributaries a total of 8. In the Paranapanema River there are 3 STFs while in the Grande River, there is only one transposition system, and in its tributaries 3. In the Rio do Peixe there is only one (Table 2).

The Grande River has the largest number of works related to migratory species, with 11 articles, the Paranapanema River has just one less, with 10 articles, and the Tietê River has 6 articles. About tributaries, those of the Grande River stand out, with the Mogi-Guaçu River and the

Table 2. Main rivers of the state of São Paulo and data on their length in kilometers (km), the amount of damming in their courses, stretches of the river free of damming in kilometers (km), and presence/absence of Fish Transposition Systems (FTSs) from articles inventoried between the years 2003 to 2023.

Rivers	Length (km)	Number of dams	Largest stretches free (km)	FTS
Main river				
Tietê	955	10	273	5
Tributaries				
Sorocaba River	170	1	95	0
Piracicaba River	156	3	104	0
Jaú River	56	0	56	0
Jacaré-Guaçú River	178	1	152	0
Jacaré-Pepira River	143	1	131	0
Peixe River	78	0	78	0
Main river				
Grande River	600	3	435	1
Tributaries				
Cubatão River	46	1	33	0
Mogi-Guaçú River	344	3	314	0
Pardo River	392	6	260	0
Main river				
Paranapanema River	785	8	238	3
Tributaries				
Itapetininga River	122	0	122	0
Taquari River	174	1	155	0
Apiaí-Guaçú River	160	2	100	0
Guareí River	71	0	71	0
Guapiara River	27	0	27	0
Itararé River	165	0	165	0
Main river				
Peixe River	279	2	151	1

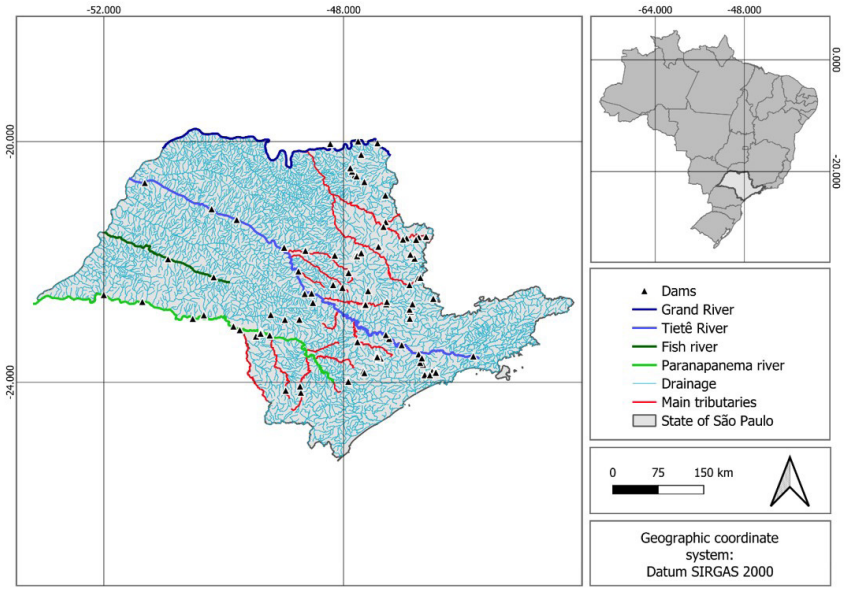

Figure 4. Dams on the main rivers in the state of São Paulo and tributaries.

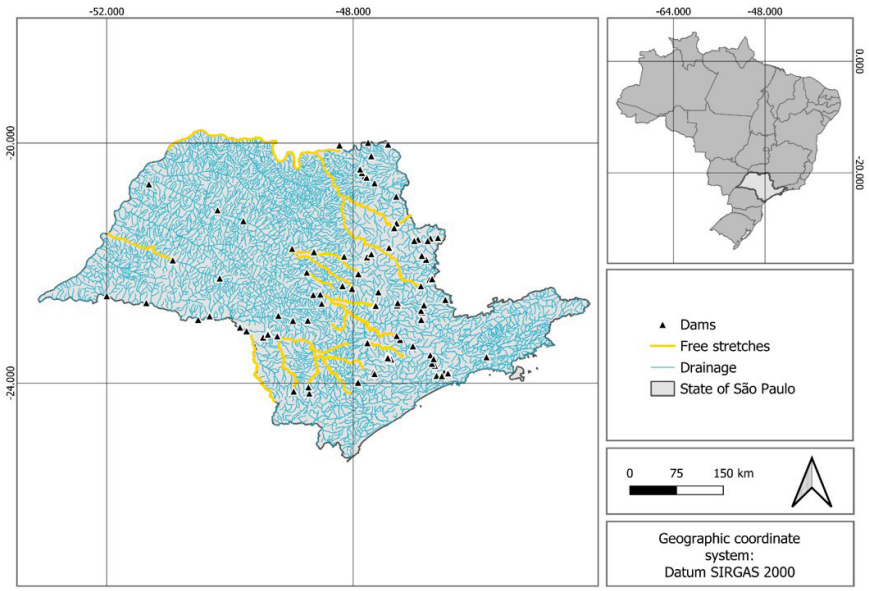

Figure 5. Largest areas of free stretches in the main rivers and tributaries of the state of São Paulo.

Pardo River presenting 7 and 6 articles respectively. About the tributaries of the Paranapanema River, the Guareí River has 2 articles while the Itapetininga, Taquari, and Apaí-Guaçu Rivers presented only 1 article each. The tributaries of the Tietê River were represented by the Sorocaba River with 2 articles and the Jacaré-Guaçu and Peixe rivers with only 1 article (Figure 6).

In total, 16 long-distance migratory species were inventoried for the rivers studied (Table 3). The 3 main rivers had the highest number of records, while records in the tributaries were smaller, not exceeding 4 species. The species with the most occurrence in rivers according to the literature were: *Prochilodus lineatus*, *Pimelodus maculatus*, *Megaleporinus obtusidens* and *Salminus hilarii*. Among the selected articles, the most mentioned migratory species were *P. lineatus*, *P. maculatus*, *L. friderici*, *M. obtusidens,* and *S. hilarii* (Figure 7).

The existing knowledge about the impacts of dams on fish fauna is undeniable. In the state of São Paulo, since the implementation of the first dams, studies have warned of the effects of these projects on migratory species. Evidence of local reduction and extinction of these populations

in rivers in the state of São Paulo due to dams has been documented for many decades (Smith et al., 2003, 2018a). Albino (1987) highlighted the absence of several species of migratory fish in the Jacaré-Guaçu River (a tributary of the Tietê River), such as *Salminus brasiliensis*, *Pseudoplatystoma fasciatum* and *Zungaro jahu*, information corroborated by Esguicero and Arcifa (2010). The Paranapanema and Grande River basins present the same situation, as demonstrated by Hoffmann et al. (2005), Apone et al. (2008), and Pelicice et al. (2018).

This article shows that scientific production was focused on these studies in the first half of the period evaluated, which allows us to reinforce that before this period, countless research and published articles also focused on this topic. More recently, studies focused on migratory fish species still existing in the rivers of the state of São Paulo, discussing issues of reproduction and migration. A study carried out by Karling et al. (2012) showed that human influence on the natural systems of the upper Paraná River is interfering with the well-being and health of these species, including *Salminus brasiliensis*. In a study carried out in the Médio and Biaxo Rio Tietê, Smith et al. (2018b) evaluated changes in fish fauna due to numerous impacts, including dams, showing that migratory species were strongly reduced, highlighting the importance of tributaries in maintaining these species.

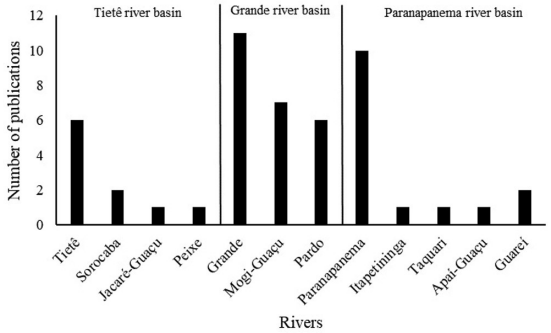

Figure 6. List of rivers inventoried in the state of São Paulo, and the number of articles published with migratory fish species from articles inventoried between the years 2003 to 2023.

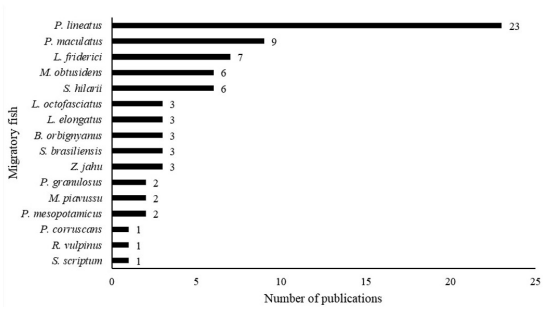

Figure 7. List of the most studied migratory fish species in articles inventoried in the state of São Paulo, from articles inventoried between the years 2003 to 2023.

Table 3. List of the main migratory species of the Tietê, Paranapanema, and Grande River basins. Tietê (TI), Sorocaba (S), Jacaré-Guaçu (JG), Peixe (PE), Grande (GR), Mogi-Guaçu (MG), Pardo (PA), Paranapanema (PP), Itapetininga (I), Taquari (TA), Apaí-Guaçu (AG) and Guareí (GU) from articles inventoried between the years 2003 to 2023.

Species	TI	S	JG	PE	GR	MG	PA	PP	I	TA	AG	GU
Salminus hilarii Valenciennes 1850	X	X	X		X							
Prochilodus lineatus (Valenciennes 1837)	X	X	X	X	X	X	X	X				X
Zungaro jahu (Ihering 1898)	X				X			X				
Salminus brasiliensis (Cuvier 1816)	X							X				
Piaractus mesopotamicus (Holmberg 1887)	X				X							
Brycon orbignyanus (Valenciennes 1850)	X	X			X							
Pimelodus maculatus Lacepède 1803	X				X			X	X	X	X	X
Megaleporinus obtusidens (Valenciennes 1837)	X	X			X			X				X
Leporinus friderici (Bloch 1794)	X		X		X			X				X
Megaleporinus elongatus (Valenciennes 1850)	X				X			X				
Leporinus octofasciatus Steindachner 1915	X				X							
Megaleporinus piavussu (Britski, Birindelli & Garavello 2012)					X			X				
Pterodoras granulosus (Valenciennes 1821)								X				
Steindachneridion scriptum (Miranda Ribeiro 1918)								X				
Rhaphiodon vulpinus Spix & Agassiz, 1829								X				
Pseudoplatystoma corruscans (Spix & Agassiz 1829)								X				

The prolific scientific production found in this study reinforces that we have a consolidated scientific basis regarding dams and migratory fish. It is worth highlighting that Alto Paraná is formed by the most degraded regions in South America (Dagosta et al., 2024) with the state of São Paulo and its three main basins being the most impacted and which deserve attention so that its migratory ichthyofauna, still persistent, may continue to occur. The high number of publications on migratory fish found in the Rio Grande basins, followed by the Paranapanema and Tietê Basins, can be explained by the important role of universities in the states of Minas Gerais, Paraná and São Paulo respectively. A caveat must be made, as most studies were carried out in the main rivers. Few studies have been carried out on tributaries, and future studies should be encouraged.

Through our findings, it became evident the large number of dams in the state of São Paulo, the majority of which are on the Tietê and Paranapanema rivers. The large number of dams present on the main rivers in the State of São Paulo has been drawing the attention of the scientific community for some time and is worrying since the main rivers have a total of 21 dams documented in the research carried out, and their main tributaries such as Sorocaba (Tietê River Hydrographic Basin), Pardo and Mogi -Guaçu (Rio Grande Hydrographic Basin), Apiaí-Guaçú and Itararé (Paranapanema River Hydrographic Basin) also have them. The fragmentation of rivers through dams limits the access of migratory species to important breeding and feeding areas that still exist in the three basins.

The available literature addressing the effects of damming on the ichthyofauna of rivers in the state of São Paulo is precise in its notes on the effects, but superficial in what should be done. How to mitigate such impacts? One of the ways is the construction of Fish Transfer Systems (FTS) as suggested by numerous authors and legislation. And could the maintenance of free stretches still existing in the rivers of the state of São Paulo, so that migratory species can access reproductive and feeding sites, be an alternative?

The results of this manuscript show that FTS in the state's rivers are scarce and old, with few studies that have evaluated their efficiencies. In the state of São Paulo, the law that makes the construction of these mechanisms mandatory dates back to 1997, which explains the small number of systems, since the majority of buses date from before this law. This finding has already been demonstrated by Agostinho et al. (2007) and Makrakis et al. (2007). Furthermore, the few studies listed on the topic in rivers in the state of São Paulo evaluated FTS as inefficient for upriver migration (Sanches et al., 2006; Stevaux et al., 2009; Esguícero and Arcifa, 2010; Wagner et al., 2012; Arcifa and Esguícero, 2012; Marques et al., 2018) in the Porto Primavera (Paraná River), Ourinhos (Paranapanema River) and Gavião Peixoto (Jacaré-Guaçu River, Tietê River Basin) dams. Furthermore, the studies listed in this article state that the topic is incipient and controversial. According to Gutfreund et al. (2018), there are challenges to restoring connectivity in the rivers of the upper Paraná River, through these mechanisms. We can therefore be bold in stating that these mechanisms must be avoided and the resources allocated must be used to preserve essential sites for migratory species, such as floodplains and marginal lagoons.

Migration is essential for numerous species of fish to complete their life cycle, as they need to reach breeding and feeding areas to maintain their energy reserves and complete the cycle (Silva-Sene et al., 2023). This requires considerable stretches of rivers and the fragmentation caused by dams is one of the main threats to this complex and vital process (Caetano et al., 2016; Makrakis et al., 2019). Most research carried out on dammed rivers in the state of São Paulo affirms the importance of considering lotic and tributary remnants to maintain rheophilic populations (Barrella and Petrere Junior, 2003; Petesse and Petrere Junior, 2012; Smith et al., 2018a, b; Pelicice et al., 2018). This fact extends to the entire Upper Paraná basin.

Comparing the three main basins through the data collected, among the main rivers, the Grande is the one that maintains the highest percentage of stretch without dams, compared to the Tietê and Paranapanema rivers, which allows us to suggest that in the Rio Grande basin, efforts to Maintenance of these stretches must include the Principal River and its tributaries. In the other two basins, the situation is more critical, and attention should be paid to tributaries that still have large free extensions since the Tietê and Paranapanema rivers are largely dammed.

We emphasize that efforts to avoid dams must be aimed at the Pardo and Mogi-Guaçu rivers in the Rio Grande basin, Sorocaba, Jacaré-Guaçu, and Jacaré-Pepira in the Tietê River basin and Itapetininga, Taquari, Apiai-Guaçu, Guarei and Itararé in Paranapanema river basin. As an example, we can highlight the Itapetininga River, a tributary of the Paranapanema River which, despite one of its formations having two dams, does not have one in its middle and lower reaches, which shows its relevance in the conservation of migratory species in this basin. Furthermore, it has little studied ichthyofauna and is only known in its higher education course, through studies carried out by Cerqueira et al. (2016).

Numerous studies have discussed the real need for the distance that migratory fish from Upper Paraná require to complete their reproductive and/or feeding cycle. These distances vary according to the species, river, and river basin. As an example we can mention the curimbatá (*Prochilodus lineatus*) which travels approximately 450 kilometers along the Paraná River to reproduce, and around 1,000 kilometers on the Mogi-Guaçu River (Agostinho et al., 2003; Hilsdorf and Moreira, 2008; Makrakis et al., 2019). Despite this, in several tributaries such as the Sorocaba River, the main tributary on the left bank of the Tietê, distances shorter than these, approximately between 50 and 100 km, are sufficient to maintain populations of this species (Portella et al., 2021). Antonio et al. (2007), studying the migratory route of *P. lineatus*, showed that this species uses a tributary of the Paranapanema River as an alternative route, which reinforces that the remaining free stretches, even with shorter distances, can be used by migratory species, thus maintaining viable populations.

A study carried out by Pompeu and Zambaldi (2020) found a greater richness of migratory fish in stretches of free rivers longer than 100 kilometers and did not verify the existence of species that migrate in stretches shorter than 50 kilometers in the Rio Grande, citing as an example

the species *Leporinus friderici*, *Pimelodus maculatus*, and *Salminus hilarii*. This last species was studied by Esguícero and Arcifa (2010), and these authors found that they carry out short-distance migrations (below 100 km). In the Ipanema River, a tributary of the Sorocaba River, a population of *Salminus hilarii* remains in a stretch of river less than 30 km long. The rivers Sorocaba, Jaú, Peixe, Cubatão, Guarei, and Guapiara have their largest free stretches, below 100 km, indicating in principle an environment that is not favorable for many long-migrating species, but for species such as *Prochilodus lineatus* and *Salminus hilarii* it is enough to maintain viable populations.

As described above and according to Agostinho et al. (2008) free stretches of less than 50 km make the survival of migratory fish species unfeasible, making their reproduction impossible. Therefore, considering the data collected by the present study, the maintenance of the 16 migratory species listed can still be made compatible with the remaining free stretches. We found that migratory fish fauna in the state of São Paulo has stretches available for migration in the Rio Grande and also in its tributaries, mainly in the tributaries of the Tiete and Paranapanema rivers. Silva et al. (2017) concluded in their study that the Upper Paraná River basin still presents suitable conditions for the reproduction of migratory fish, especially due to the presence of tributaries free from damming, making it necessary to maintain the integrity of these environments. Therefore, this article brings to light the situation of the main rivers and tributaries of the state of São Paulo about dams, migratory fish, and the availability of dam-free courses for them to move to reach breeding areas and food. Efforts to avoid new dams are of vital importance for the maintenance of the 16 species inventoried by this study and still present in the state's rivers.

Furthermore, when we refer to rivers or stretches free from dams, we must also consider the environmental integrity of the rivers of pollution and riparian forests, as well as the habitats relevant to the spawning and growth of migratory species, such as marginal lagoons and the floodplains, as without these the maintenance of these species may not occur. Promoting the recovery of fish migration requires efforts that need to be strengthened and expanded. This should include actions to expand protected areas, particularly those areas of importance to migratory species. Maintaining and improving connectivity between these locations should also be a priority factor, through the restoration of degraded floodplains and marginal lagoons.

Acknowledgements

The authors thank the UNIP/ Laboratory of Structural and Functional Ecosystem Ecology, Vice-rectory of Graduate and Research and Fisheries Institute, Postgraduate Program in Aquaculture and Fisheries for logistical support. Fernando Meyer Pelicice who greatly improved this manuscript.

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