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ECOLOGY

Rising and Spreading: First record and ecological aspects of *Platanichthys platana* (Regan, 1917) in a major tributary of the Upper Paraná River, Brazil

João Daniel Ferraz[1,2*], Armando César Rodrigues Casimiro[1,2], Lucas Ribeiro Jarduli[2,3], Diego Azevedo Zoccal Garcia[2,4], Matheus Chueire Luíz[1,2] and Mário Luís Orsi[1,2]

[1]Laboratório de Ecologia de Peixes e Invasões Biológicas, Programa de Pós-Graduação em Ciências Biológicas, Universidade Estadual de Londrina, Rodovia Celso Garcia Cid, PR-445, km 380, Cx. Postal 10.011, Campus Universitário, 86057-970, Londrina, Paraná, Brazil. [2]Laboratório de Ecologia de Peixes e Invasões Biológicas, Departamento de Biologia Animal e Vegetal, Centro de Ciências Biológicas, Universidade Estadual de Londrina, Londrina, Paraná, Brazil. [3]Secretaria de Estado de Educação do Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul, Brazil. [4]Faculdade de Medicina, Universidade Federal de Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul, Brazil. *Author for correspondence. E-mail: joao.daniel.ferraz@uel.br

ABSTRACT. This study presents the first record of the sardine *Platanichthys platana* (Regan, 1917) in the Paranapanema River basin and provides insights into the species' ecological traits. A total of 164 juveniles and adults were sampled in 2019 and 2020 in the Lower Paranapanema River. Morphological analyses confirmed species identification, while reproductive analyses revealed different age classes among individuals, with higher sex ratio of females and mature gonads. Additionally, stomach analyses indicated a diet primarily composed of insects, followed by microcrustaceans. This species has been dispersing rapidly in the Upper Paraná River, where its reproductive characteristics may help its establishment, especially in reservoirs. Also, its feeding ecology favors its survival. However, interactions with large-sized invasive predators and influx of heavy metals in the food chain can occur, in addition to competition with small-sized native species.

Keywords: fish introduction; fish invasion; neotropical reservoir; non-native species; Paranapanema River.

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Introduction

Previously considered a subfamily of Clupeidae, Dorosomatidae became a valid family in 2023 (Froese & Pauly, 2024). With 30 genera and 116 species (Fricke, Eschmeyer, & Van der Laan, 2024), Dorosomatidae encompasses coastal marine fish of varied sizes, where some also inhabit freshwater or exhibit anadromous behavior (Froese & Pauly, 2024). Within this family, the genus *Platanichthys* is monogeneric, that is, its only representative is the species *Platanichthys platana* (Regan, 1917), popularly known as “Sardine” or “River plate sprat” (Whitehead, 1985).

Platanichthys platana is a small-sized fish with an elongated and laterally compressed body and an approximate standard length of 70 mm (SL) (Whitehead, 1985). It has an anterior ventral keel formed by scales modified into conspicuous spines (Marceniuk, Hilsdorf, & Langeani, 2011) and differs morphologically from the species *Ramnogaster arcuata* (Jenyns, 1842) (with which it is commonly mistaken) by displaying only one lateral silver stripe (Campello & Bemvenuti, 2002). Ecologically, the species form large schools close to the water surface to feeding, being preferentially planktivorous (Nanini-Costa, Quináglia, Petesse, & Esteves, 2017). However, it may exhibit opportunistic behavior regarding food resource availability (Aguiaro, Castelo Branco, Verani, & Caramaschi, 2003; Costa, Silva, Ventura, Ostrensky, & Angelo, 2009). There is limited research on the reproduction of this species. Thus, previous research indicates the species' flexibility behavior, being able to reproduce throughout the year (Lopes, Reynalte-Tataje, & Nuñer, 2017; 2024).

Originally, this fish was distributed throughout the Southwest Atlantic, inhabiting lagoons, estuarine areas, and lower regions of the La Plata River (Argentina), Uruguay River (Uruguay) (Ramos, Scorsim, Pavanelli, & Oliveira, 2023), and Brazil in the State of Rio de Janeiro (Lima, Costa, & Zalmon, 2021). However, more recent studies listed the species in the estuary and freshwater environments of the states of Rio Grande do Sul (Bertaco, Ferrer, Carvalho, & Malabarba, 2016; Giora, Silva, Cavalheiro, Wingert, & Fialho, 2022), Santa

Catarina (Chaves, 2022; Lopes et al., 2024) and Paraná (Costa et al., 2009; Contente, Stefanoni, & Spach, 2011). The species have been recorded in the freshwater Upper Paraná River basin since 2007 (Langeani et al., 2007; Ota, Deprá, Graça, & Pavanelli, 2018). According to Marceniuk et al., 2011 and Nanini-Costa et al., 2017, the species has already been reported in the headwaters of Upper Paraná River tributaries (such as Tietê River in the State of São Paulo), indicating that it has been continually introduced in freshwater environments.

Paranapanema River is one of the main tributaries of the Upper Paraná River (Langeani et al., 2007). However, its primary channel was transformed into a cascade of eleven reservoirs, resulting in significant environmental impact and biological invasion (Jarduli et al., 2021), especially in the portion close to the mouth (lower portion) (Garcia, Britton, Vidotto-Magnoni, & Orsi, 2018a). Thus, the Lower Paranapanema River received the most significant number of allochthonous species in the entire basin, which rising to Upper Paraná River after the transposition of the Sete Quedas Falls by Itaipu impoundment (1982) (Júlio Júnior, Dei Tós, Agostinho, & Pavanelli, 2009). The spread of these species to the Middle and Upper Paranapanema River was prevented with the construction of the Capivara Dam (1979) and later Rosana (1987) and Taquaruçu (1989) dams (Casimiro, Garcia, Costa, Britton, & Orsi, 2017). However, the number of allochthonous species continue to increase in fish fauna surveys in the Lower Paranapanema over the years (Garcia et al., 2018a), with records of a new trend of small-sized species (Garcia et al., 2017; Ferraz et al., 2021a; Jarduli et al., 2021).

It is known that small-sized fish are less studied or even ignored in research (Castro & Polaz, 2020; Chaves, 2022), being uncommon the investigation of interactions between native and invasive species (Garcia, Vidotto-Magnoni, & Orsi, 2019; Jarduli et al., 2021). In this sense, we aimed to describe the first record of the sardine *P. platana* in the Paranapanema River basin and analyze and discuss aspects of its ecology that may contribute to its establishment and impacts on the native fish assemblage, as well as their introduction vectors.

Material and methods

Study area

The Paranapanema River rises in the "Serra de Paranapiacaba", located in the Atlantic Plateau of the municipality of Capão Bonito (state of São Paulo) in the southeastern region of Brazil (Sampaio, 1944). It flows for 930 km until it joins the left bank of the Upper Paraná River, with approximately 330 km of its main channel forming the border between the southeastern region of the state of São Paulo (SP) and the northern region of the state of Paraná (PR) (Maack, 1981). The study areas are within the influence zones of the last two dams, Rosana and Taquaruçu (Figure 1).

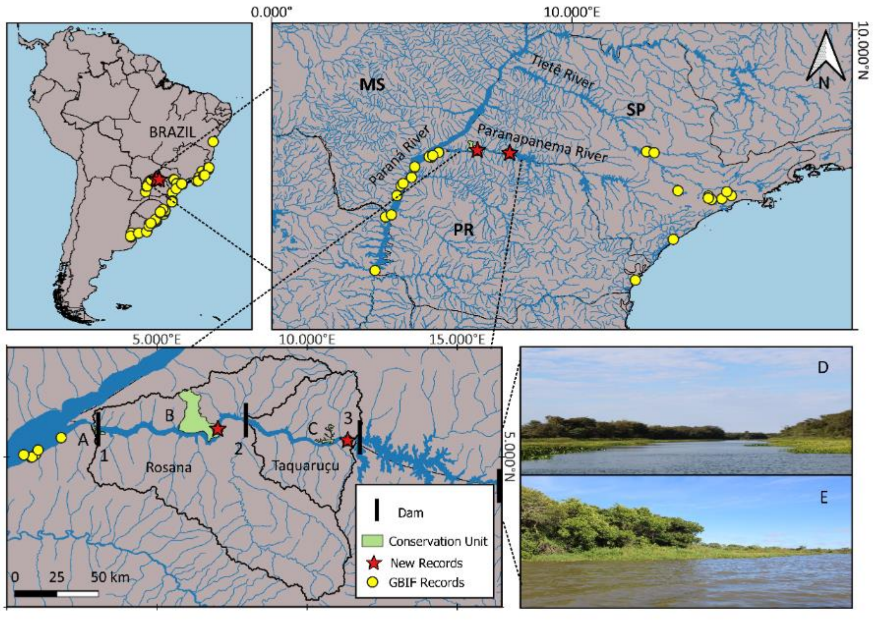

Figure 1. *Platanichthys platana* South America records; Upper Paraná River stretch; Lower Paranapanema River stretch; GBIF records (yellow circle); new records (red star). CU = Conservation Unit; MS = State of Matro Grosso do Sul; PR = State of Paraná; SP = State of São Paulo; 1= Rosana Dam; 2 = Taquaruçu Dam; 3 = Capivara Dam; A = Caiuá Conservation Unit; B = Morro do Diabo Conservation Unit; C = Mosquito Forest; D = Rosana Reservoir Sampling Site; E = Taquaruçu Reservoir Sampling Site.

The hydroelectric power plant of Rosana (Rosana Dam) is located between the municipalities of Diamante do Norte (PR) and Primavera (SP). The reservoir has a run-of-river flow, a length of 110 km, a maximum depth of 26 m, and a flooded area of 220 km^2. There are two conservation units (CU's) in its surroundings: Morro do Diabo State Park on the right bank (SP) and Caiuá Ecologic Station on the left bank (PR). As tributaries, there are the Pirapó River (left bank), Pirapozinho River (right bank), and three main streams (all on its right bank), the Iancã, Cuiabá, and Bonito. The hydroelectric power plant "Escola Politécnica" (Taquaruçu Dam) is located between the municipalities of Itaguajé (PR) and Sandovalina (SP). The reservoir has a run-of-river flow, a length of 80 km, a maximum depth of 18 m, and a flooded area of 105.5 km^2 (Britto & Carvalho, 2006). The most significant tributaries are the Capim, Centenário, and Tenente Rivers on the left bank (PR) and the Anhumas River (the largest tributary in the reservoir) on the right bank (SP). Only this tributary has undergone reforestation efforts (Mosquito Forest) (Leme, Costa, Garcia, Yabu, & Orsi, 2015).

Sampling

The monitoring of ichthyofauna in the Lower Paranapanema River (Project nº 11218/2018, UEL/FAUEL) was conducted quarterly from September 2018 to September 2020. The samplings covered the pelagic and marginal zones using gillnets ranging from 20 to 120 mm between opposed knots. The gillnets were set for 24 hours and checked every 12 hours. Trawls, sieves, and cast nets were also used to capture fish in marginal zones and along aquatic macrophyte beds. Sampling sites included coordinates 22°36'05.6" S, 52°09'54.1" W (Rosana Reservoir) and 22°40'06.3" S, 51°24'12.4" W (Taquaruçu Reservoir). In these sampling sites, a standardized effort of two hours was exerted, covering a distance of 100 m to explore the environment effectively. All captured individuals were anesthetized and euthanized (Eugenol 1 g ml-1). Subsequently, they were fixed in 10% formaldehyde for 48 hours and preserved in 70% ethanol. The sampling license (license number 16.578) and the Animal Ethics Committee authorized the field sampling (CEUA N 30992.2014.33).

Specimens were identified with specialized literature: Ota et al. (2018). After, specimens were deposited at the *Museu de Zoologia da Universidade Estadual de Londrina* (MZUEL). Occurrence records of *P. platana* were obtained from online databases of species in zoological collections by searching the Global Biodiversity Information Facility (584 records) (Global Biodiversity Information Facility [GBIF] 2024). Only georeferenced records containing voucher specimens were considered valid for elaborating the distribution map.

Analyses

In the laboratory, total length (mm), standard length (mm), and biomass (g) were determined for all individuals to define age classes. For adult individuals, the gonads were removed and stored in 70% alcohol for weighing (g), sex determination, sexual proportion, and gonadal stage of maturation (Vazzoler, 1996). Thus, the stages of maturation were considered immature, developing, mature, or resting (Vazzoler, 1996). Reproductive activity was analyzed based on the stages of maturity and the gonadosomatic index (GSI). The GSI expresses the percentage of gonad weight in relation to total fish weight. GSI was calculated according to the equation proposed by Vazzoler (1996): GSI = 100 X [Wo/(Wt-Wo)], where Wo is the weight of the ovary/testicle and Wt is the total weight of the fish.

Afterward, 30 randomized individuals had their stomachs removed and stored in 70% alcohol, being the content analyzed under a stereomicroscope and identified at the lowest possible taxonomic level, based on Thomaz, Pagioro, Bini, and Souza (2002), Mugnai, Nessimian, and Baptista (2010), and Biolo and Rodrigues (2011). Each prey item's volume (V) was obtained by compression in a millimeter Petri dish, with a volume given in mm^3 and later transformed into ml (Hellawell & Abel, 1971). Prey items were grouped into food categories: Insects (Diptera larvae, Ephemeroptera larvae, Odonata larvae, and Insect Fragments), Microcrustaceans (Ostracoda, Cladocera, and Microcrustacean Fragments), Detritus (Organic and Inorganic) and Unidentified.

Results

Platanichthys platana (Regan, 1917) – New Record

Figure 1-2: New records. BRAZIL – State of Paraná. Paranapanema River basin; Taquaruçu Reservoir; Porecatu Municipality; 22°40'06.3" S, 51°24'12.4" W; 12 March 2020; *Laboratório de Ecologia de Peixes e Invasões Biológicas* (LEPIB); MZUEL 22717 (Figure 2). BRAZIL – State of São Paulo. Paranapanema River basin; Rosana Reservoir; Teodoro Sampaio Municipality; 22°36'05.6" S, 52°09'54.1" W; 12 July 2019; *Laboratório de Ecologia de Peixes e Invasões Biológicas* (LEPIB); MZUEL 22716.

Figure 2. Female individual of *Platanichthys platana* captured in the Taquaruçu Reservoir, Lower Paranapanema River, during the spring of 2020. Total length = 82 mm. Scale bar equal to 70 mm. Voucher = MZUEL 22717.

Identification

We confirmed the identification based on the descriptions by Ota et al. (2018). *Platanichthys platana* has an elongated and laterally compressed body with an upper mouth. The dorsal fin has 14 rays, the pectoral fin has 11 to 12 rays, the pelvic fin has 7 rays, the anal fin has 18 to 20 rays, and the caudal fin has 19 rays. The scales are small and delicate, with the dorsal fin base commonly covered with small scales. The lateral line is absent. The origin of the dorsal fin is almost always equidistant between the snout's anterior end and the caudal fin's beginning. The origin of the pectoral fin is in front of the dorsal fin, sometimes with a base covered with small scales. The origin of the pelvic fin is slightly in front of, below, or behind the dorsal fin. The origin of the anal fin is behind the last rays of the dorsal fin, with the base often covered with small scales. The caudal fin is bifurcated, the longitudinal silver strip is present, and the body color is whitish.

Analyses

During the monitoring of ichthyofauna in the Lower Paranapanema River, 159 individuals of *P. platana* were collected in the Rosana Reservoir, and five individuals were captured in the Taquaruçu Reservoir. All the Rosana Reservoir specimens were juveniles captured in marginal lagoons associated with lateral channels of the river with the help of trawl nets and sieves. Taquaruçu Reservoir individuals were caught in the main river channel with gillnets, and all these adults were in reproductive activity. Our results showed that the population structure was divided into seven age classes between 20.00 and 95.00 mm (Table 1). In adults, the sexual proportion showed predominance of females (80%), and gonadal activity was observed on 60% of individuals (Table 2). The Gonadosomatic Index revealed 60% of adults with results above 10% of total body weight (Table 2). As for feeding results, nine food items were recorded, and the insects was mostly consumed (70%), followed by microcrustacean (16%) and detritus (13%) (Table 3).

Table 1. Age class, sex, and sex ratio of *Platanichthys platana* in Rosana and Taquaruçu reservoirs, Lower Paranapanema River, Upper Paraná River basin.

Age classes Lt mm (min-max)	Abundance (n)	Sex	Sex ratio (F:M)
20.0-25.0	44	Juvenile	None
25.0-30.0	47	Juvenile	None
30.0-35.0	40	Juvenile	None
35.0-40.0	25	Juvenile	None
40.0-50.0	3	Juvenile	None
80.0-85.0	2	Adult	1:1
85.0-95.0	3	Adult	3:0

Lt = Total length; F = Female; M = Male.

Table 2. Length, weight, sex, gonadal stage of maturation, and GSI from adults of *Platanichthys platana* from Taquaruçu Reservoir, Lower Paranapanema River, Upper Paraná River basin.

Adult	Sex	Gonadal stage	Lt (mm)	Ls (mm)	Wt (g)	Wg (g)	GSI (%)
Adult 1	Female	Mature	95.0	93.2	7.118	0.741	13.14%
Adult 2	Female	Mature	94.0	92.1	7.711	0.769	12.45%
Adult 3	Female	Developing	92.0	89.7	7.234	0.689	10.52%
Adult 4	Male	Mature	85.0	83.0	7.333	0.067	1.22%
Adult 5	Female	Developing	82.0	80.5	5.698	0.387	7.28%

Lt = total length; Ls = standard length; Wt = total weight; Wg = gonadal weight.

Table 3. Volume (%) of food items identified in stomach contents of *Platanichthys platana* in Rosana and Taquaruçu reservoirs, Lower Paranapanema River, Upper Paraná River basin.

Resources	Volume (%)
Insects (sum)	0.70
Ephemeroptera (Larvae)	0.26
Diptera (Larvae)	0.12
Odonata (Nymph)	0.22
Insect Fragments	0.10
Microcrustacean (sum)	0.16
Cladocera	0.10
Ostracoda	0.06
Microcrustacean Fragments	0.01
Detritus (sum)	0.13
Inorganic	0.10
Organic	0.03
Unidentified (sum)	0.01

Discussion

Although initially the introduction source of *P. platana* in the Upper Paraná River was unknown (Langeani et al., 2007), the species probably ascended through the *Canal da Piracema*. This fish ladder connects the river downstream of the Itaipu hydroelectric plant to the reservoir upstream of the dam (Ota et al., 2018). This hypothesis was corroborated by the genetic determination of the populations from the Upper Paraná River, which originates from the basin stretch in Argentina (Ramos et al., 2023). After the flooding of the reservoir related to the Itaipu hydroelectric plant, the loss of the Sete Quedas Falls barrier allowed hydrological connectivity between the Lower and Upper Paraná portions (Júlio Júnior et al., 2009). Thus, many fishes from the Lower region accessed and colonized the Upper stretch (Vitule, Skóra, & Abilhoa, 2012), including the Paranapanema River (Garcia et al., 2018a). On the other hand, *P. platana* had never been captured in the Paranapanema River basin, even with old and continuous monitoring in the Lower stretch (Casatti, Mendes, & Ferreira, 2003; Britto & Carvalho, 2006; Pelicice & Agostinho, 2009; Garcia et al., 2018a; Jarduli et al., 2019; Ferraz et al., 2021a). In addition, constructing Rosana and Taquaruçu dams in the 1990's could prevent the species' dispersal upstream (Casimiro et al., 2017). Therefore, a secondary possibility is that *P. platana* arrival through an alternative route of introduction. In the headwater of the Upper Paraná River, the species may have been introduced accidentally, possibly as accompanying fauna in the fish stocking programs or accidental escapes from fish farms (where it is used as food for larger species). This seems to be the most accepted possibility of dispersion to sardine in tributaries of the Upper Paraná River, such as the Tietê River, which also has dams that could prevent the rising of the species (Marceniuk et al., 2011; Nanini-Costa, Quináglia, Held, Petesse, & Esteves, 2016).

Reservoirs are known worldwide as hotspots for invaders (Johnson, Olden, & Vander Zanden, 2008; Daga et al., 2019). Thus, reservoir colonization by small-sized species is well documented in the literature, especially species associated with macrophytes in the marginal zone (Casatti et al., 2003; Pelicice & Agostinho, 2009). After the massive record of medium and large species that colonized the Upper Paraná River (Júlio Junior et al., 2009; Vitule et al., 2012), new records of non-native small-sized species continue to be reported in the Paranapanema River (Ferraz et al., 2021a), such as small cichlid *Laetacara araguaiae* Ottoni and Costa (2009) (Garcia et al., 2017) and characid *Psellogrammus kennedyi* (Eigenmann, 1903) (Jarduli et al., 2021). In this sense, we now report the presence of *P. platana* in the Lower Parapanema River. This record is of particular concern in the Rosana Reservoir, which is surrounded by Morro do Diabo State Park. This Atlantic Forest Conservation Unit is the home of several small-sized native species in its marginal lagoons (Cassati et al., 2003; Pelicice & Agostinho, 2009). Studies with small-sized fish species in general are less common in scientific literature (Castro & Polaz 2020; Chaves, 2022). In this sense, research about interactions between small-sized native and invasive species is even rarer (Garcia et al., 2019; Jarduli et al., 2021). Therefore, the record of *P. platana* in the Lower Paranapanema River is worrisome in face of the unknown implications to the native community.

The sardine *P. platana* is a planktivore/zooplanktivore but displayed a broad trophic niche and opportunistic behavior in response to environmental conditions and seasonality (Nanini-Costa et al., 2017). Thus, it can also feed on filamentous algae, detritus, benthic invertebrates' eggs, chironomids, and bivalves' larvae (Aguiaro et al., 2003; Costa et al., 2009), plasticity proved in our results through the consumption of insects (larvae of Ephemeroptera, Diptera and Odonata) and, in less scale, microcrustaceans (Cladocera and

Ostracoda). Generalistic/opportunistic feeding behavior of non-native species is expected as a strategy for establishment in new environments (Johnson et al., 2008; Daga et al., 2019), results also observed in invasive populations of the Lower Paranapanema River (Garcia, Vidotto-Magnoni, & Orsi, 2018b). Studies showed that the diet of *P. platana* varies significantly with resource availability and environmental conditions, as well as in response to season and ontogeny. For example, in Cabiúnas Lagoon, *P. platana* consumed calanoid copepods, shrimp larvae, cladocerans, and other invertebrates (Aguiaro et al., 2003). In contrast, in Imboassica Lagoon, the main diet included rotifers, detritus, and benthic invertebrates, reflecting the diet flexibility (Aguiaro et al., 2003). Therefore, competition for resources can occur with native Characidae of similar diet (for example, *Aphyocharax*, *Astyanax*, *Bryconamericus*, *Hemigrammus*, *Hypressobrycon*, *Moenkhausia*, *Piabarchus*, and *Serrapinnus*) (Cassati et al., 2003). In addition to interactions with small-sized native species, positive feedback may occur with large-sized invaders of the basin, such as peacock bass *Cichla kelberi* Kullander and Ferreira (2006). The large-sized predator uses small-sized species to feed and sustain viable populations in the region (Pelicice & Agostinho, 2009).

As well as in the feeding, *P. platana* demonstrates the same opportunistic behavior in reproduction, with partial spawning and mature males and females during all seasons of the year (Lopes et al., 2017). Nevertheless, autumn and winter are the most favorable periods for *P. platana* reproduction (Lopes et al., 2017; 2024). In the Rosana Reservoir, we observed a population of juveniles structured in different age groups. This may demonstrate that the species reproduces more than once a year (Agostinho, Gomes, Veríssimo, & Okada, 2004). Furthermore, although few adult individuals were captured in Taquaruçu, we observed a higher proportion of females in this sample. Thus, sex ratio and partial spawning appear to be an important reproductive trait for the species, a strategy that other non-native fishes use to establish and disperse in the Lower Paranapanema River (Garcia et al., 2019). It was not possible to capture adult individuals throughout the entire samplings to better characterize specie's reproductive activity, yet 60% of adults presented GSI greater than 10%. According to Vazzoler (1996), GSI is an efficient indicator of the ovaries functional state, where individual values above 10% demonstrate considerable reproductive activity and the spawning should occur between 15% to 25%. However, due to the ecology and morphology of Neotropical species, some fishes reach spawning with lower values (Vazzoler, 1996), where the record of many juveniles in different age classes could provide the significant indication of reproductive success (Agostinho et al., 2004; Chaves, 2022).

The introduction of non-native species can have significant ecological impacts on local ecosystems (Johnson et al., 2008). If *P. platana* becomes established, it could become an additional food resource for *C. kelberi* in the region, where one non-native benefits the other (Schmitt, Peoples, Castello, & Orth, 2019). Hence, it should be noted that this predation relationship was previously observed in the São João River, State of Rio de Janeiro (Mendonça, Santos, Martins, & Araújo, 2018). This interaction may also be worrisome considering *P. platana* is a bioaccumulator of heavy metals (*e.g.,* mercury), representing an additional element for the pollutant transfer to higher trophic levels (Nanini-Costa et al., 2017). Since previous studies suggest problems with chemical pollution in this area (Ferraz et al., 2021b), establishing this species could broaden this situation. On the other hand, the literature shows that *P. platana* compete for food resources and can alter local zooplankton and benthic communities (Lopez et al., 2017), while its seasonal and ontogenetic variations in diet allow the species to survive in different environmental conditions (Aguiaro et al., 2003; Costa et al., 2009). Therefore, our report could be a notable finding on the species' dynamic, with the recording of the initial establishment phase in the study area. In this way, a species' high propagule pressure effort was observed in the Rosana Reservoir through the sudden abundant capture of juveniles (Lockwood, Cassey, & Blackburn, 2006). However, no adults were collected in this sample site, which could indicate a low survival rate of reproductive products (Agostinho et al., 2004; Giora et al., 2022). On the other hand, only adults were captured in reproductive activity (mature gonads) in Taquaruçu Reservoir, with no record of larvae and juveniles to prove reproduction successful, results observed in studies on the southern coast (Chaves, 2022; Lopez et al., 2024). Thus, according to Blackburn et al. (2011), the species could be between the final stages of the establishment (survival and reproduction), or the initial stages of spread (dispersion). Hence, our results are relevant to understanding the presence of *P. platana* in the Lower Paranapanema River.

Conclusion

At this time, we reported the first record of the sardine *P. platana* in the Paranapanema River basin and discussed aspects of his ecology. Despite the strong evidence, we cannot conclude that *P. platana* is established in the Lower Paranapanema River, as only further analysis will allow us to make such a statement.

However, the species' life history and our diet, reproduction and recruitment records indicate it is moving towards establishing and consequent invasion in the studied area. Thus, the invasion risk cannot be ignored, mainly because these are stretches close to conservation units and potential competition with native fish. Therefore, the need for continuous monitoring to understand its impacts on this environment is highlighted.

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