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Article

Fish fauna from the Paranapanema River basin, Brazil

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Abstract: The Paranapanema River is an important, extensively explored tributary of the Upper Paraná River basin. The fish fauna of the Paranapanema River has been investigated since the 1990s; however, no study has characterized the richness of fish species throughout the basin, including the main channel of the river, marginal lagoons, its tributaries, and sub-tributaries. Thus, we performed a review with 90 independent studies conducted at the upper, middle, and lower sections of the basin. We recorded 225 species, of which 165 were native, and 60 were non-native. We found that 77% of the species within the basin are composed by Siluriformes and Characiformes. Cichliformes had a significant number of non-native species established in impoundment sections of the basin. Incidence-Based Estimators (Bootstrap and Chao 2) demonstrated that the richness of native species is still underestimated. Some native (*e.g.*, *Hypostomus ancistroides*) and non-native species (*e.g.*, *Plagioscion squamosissimus*) are widely distributed in the basin, while others had a more restricted distribution. Among the registered species, the family Bryconidae had the highest number of representatives with threatened conservation status. In addition, we observed that the Capivara Reservoir and its tributaries were the most sampled regions, with the majority of studies performed in the Lower Paranapanema basin. The species richness recorded in large tributaries, such as Tibagi, Cinzas, Congonhas, and Pirapó rivers is critical for maintaining the fish fauna in the Paranapanema River. Our contribution may be used to support management actions and conservation strategies, as well as to indicate regions in the basin that need to be better inventoried.
Keywords: *freshwater, Neotropical region, species inventory, Upper Paraná River.*

Fauna de peixes da bacia do rio Paranapanema, Brasil

Resumo: O rio Paranapanema é um importante tributário, amplamente explorado da bacia do Alto rio Paraná. A fauna de peixes do rio Paranapanema vem sendo investigada desde a década de 1990; no entanto, nenhum estudo caracterizou a riqueza de espécies de peixes em toda a bacia, incluindo o canal principal do rio, lagoas marginais, seus tributários e sub-tributários. Assim, realizamos uma revisão com 90 estudos independentes conduzidos nas regiões superior, média e inferior da bacia. Foram registradas 225 espécies, das quais 165 eram nativas e 60 eram não nativas. Verificamos que 77% das espécies dentro da bacia são compostas por Siluriformes e Characiformes. Cichliformes apresentou um número significativo de espécies não nativas estabelecidas em áreas de represamento da bacia. Estimadores de riqueza baseados em incidência (Bootstrap e Chao 2) demonstraram que a riqueza de espécies nativas ainda é subestimada. Algumas espécies nativas (*e.g.*, *Hypostomus ancistroides*) e não nativas (*e.g.*, *Plagioscion squamosissimus*) estão amplamente distribuídas na bacia, enquanto outras tem sua distribuição mais restrita. Entre as espécies registradas, a família Bryconidae obteve o maior número de representantes com status de conservação ameaçado. Além disso, observamos que o reservatório de Capivara e seus afluentes foram as regiões mais amostradas, sendo a maioria dos estudos realizados na bacia do baixo Paranapanema. A riqueza de espécies registrada em grandes afluentes, como os rios Tibagi, Cinzas, Congonhas e Pirapó, é fundamental para a manutenção da ictiofauna no rio Paranapanema. Nossa contribuição pode ser usada para apoiar ações de manejo e estratégias de conservação, bem como para indicar regiões na bacia que precisam ser melhor inventariadas.
Palavras-chave: *água doce, região Neotropical, inventário de espécies, Alto rio Paraná.*

Introduction

South America has the greatest diversity of freshwater fish fauna in the world, with a high taxonomic, phylogenetic, and functional variety (Barletta et al. 2010, Reis et al. 2016, Vitule et al. 2017). Such diversity is sheltered mainly in the Amazon (Santos & Ferreira 1999), and Paraná (Brea & Zucol 2011) river basins. The Upper Paraná River basin is one of most studied basins in terms of fish fauna (Agostinho et al. 2007a), being composed of between 270 to 310 species (Agostinho et al. 2007b, Langeani et al. 2007). The Upper Paraná River basin is the second largest basin in South America (Lowe-McConnell 1999) and is composed of sub-basins originating in the Brazilian states of Goiás, Minas Gerais, São Paulo, Mato Grosso do Sul, and Paraná. The basin is constituted from the confluence of major tributaries, such as the Paranaíba, Grande, Tietê, and Paranapanema rivers.

The Paranapanema River - one of the most important tributaries of the left margin of the Paraná River (Maack 2002, Duke Energy 2008) - hosts a significant part of this diversity, as evidenced by several fish inventories and ecological studies performed on its main course (Carvalho et al. 1998, Pelicice et al. 2005, Britto & Carvalho 2006, Orsi 2010, Orsi & Britton 2014, Pelicice et al. 2018), tributaries, and sub-tributaries (Castro et al. 2003, Cerqueira & Smith 2015, Vidotto-Magnoni et al. 2015, Rosa et al. 2016). Past works suggest that species compilations from the Paranapanema River alone vary from 155 (Duke Energy 2008) to 161 (Pelicice et al. 2018).

This novel study investigates the richness of fish species throughout the Paranapanema River basin, including its main channel, marginal lagoons, tributaries, and sub-tributaries. An accurate assessment of the species within this ecosystem is a necessary step towards the maintenance of its biodiversity (Cudmore-Vokey & Crossma 2000). To gain the most benefit from previous surveys, updates are needed to indicate changes over time. These changes can include the establishment of species (both native and introduced), introductions that are not established (Garcia et al. 2018), and species that become extirpated or extinct. Thus, an updated fish inventory on the Paranapanema River basin is fundamental to optimize its management in relation to low impact actions, resources conservation, and recovering degraded ecosystems (Melo 2008). Therefore, we aimed to complement the knowledge of the fish fauna diversity present in the Paranapanema basin through a compilation of all survey studies and species descriptions from all aquatic environments. Our study may help the understanding of the richness and distribution of species present along the basin.

Material and Methods

1. Study area

The Paranapanema River headwater is located within the state of São Paulo, municipality of Capão Bonito, is protected by the State Parks of Intervales and Carlos Botelho. The basin has an area of 106.500 km^2 and crosses 247 municipalities, 115 in the state of São Paulo, and 132 in the state of Paraná (ANA 2016). Its waters run for approximately 930 km inland to the west until draining into the left margin of the Paraná River. Starting the mouth of the river Itararé, the Paranapanema forms a border (330 km) between the states of São Paulo and Paraná. According to Sampaio (1944), its course is divided into three main sections: the Upper, Middle, and Lower Paranapanema. The Upper Paranapanema constitutes a 180 km extension from its headwater until the confluence with the Apiaí-Guaçu River, this, together with the Itapetininga River, are the main tributaries of this stretch. The Middle Paranapanema is a 328 km extension from the Apiaí-Guaçu mouth to the Salto Grande Dam. The Lower Paranapanema comprises of a 421 km stretch from the Salto Grande Dam, to its mouth in the Paraná River, also known as Pontal do Paranapanema (Figure 1).

In recent past, the drainage area of the Paranapanema River basin was predominantly covered by Atlantic Rainforest and Brazilian Savannah biomes (Sampaio 1944, Huek & Seibert 1972). However, following deforestation, the basin is now an agricultural region, with margins generally surrounded by narrow and degraded riparian forest (Castro et al. 2003). Throughout the entire basin, the only significant and continuous forests fragments along its margins are the Intervales, Carlos Botelho, and the Morro do Diabo State Parks (Inventário Florestal do Estado de São Paulo 1993).

2. Data Collection

A list of species was generated from an extensive search of available scientific literature about the Paranapanema River basin. This list included species descriptions, inventories, and ecological studies. We performed searches between April to September 2018 in online databases (Web of Science, Scopus, Scielo, and Google Scholar), private libraries, and cross-reference searches using the keyword 'Paranapanema', combined with the keywords 'fish', 'survey', 'ichthyofauna', 'fish fauna', and 'diversity'. All different types of aquatic environments were considered in our search, including reservoirs, rivers, streams, marginal lagoons, and fish ladders. The survey resulted in 90 studies, comprising 74 articles, nine book chapters, two books, and five Ph.D. theses published between 1995 to 2018. Subregions were hierarchically delimited according to the main tributaries of the Paranapanema River basin, as assessed by the studies inventoried herein. Some studies investigated more than one site, resulting in our samples covering 57 subregions (Table 1).

Taxonomic classification and species naming were determined following the studies from Eschmeyer & Fong (2018) and Eschmeyer et al. (2018). Updates on species identification, valid names, and new combinations were performed when necessary. A list of species that have had their taxonomic status modified over the past years has been provided in Table 3. Unprecise species identification recorded as 'sp.' or 'spp.' were not considered in the study. The species identification was not checked for all surveyed literature. The conservation status of the species was derived from works by Mikich & Bérnils (2004) for the state of Paraná, Bressan et al. (2009) and ALESP (2014) for the state of São Paulo; and ICMBio (2014, 2018) for Brazil. Threat categories were defined according to Gärdenfors et al. (2001).

The non-native species were classified according to the possible cause of occurrence in the Paranapanema River basin (the introduction vector). These were: (1) fish stocking via sport-angling, (2) bait, live-bait fishes used in sport angling; (3) fish farming, escapes from fish farms; (4) biological control, primarily mosquito control; (5) Itaipu Dam, invasion of non-native fish upstream following flooding of the natural biogeographic barrier of the Sete Quedas Falls between the Medium and Upper Paraná River regions; and (6) the aquarium trade. The identification of the introduction vector was based in CESP (1997), Orsi & Agostinho (1999), Bennemann et al. (2000), Graça &

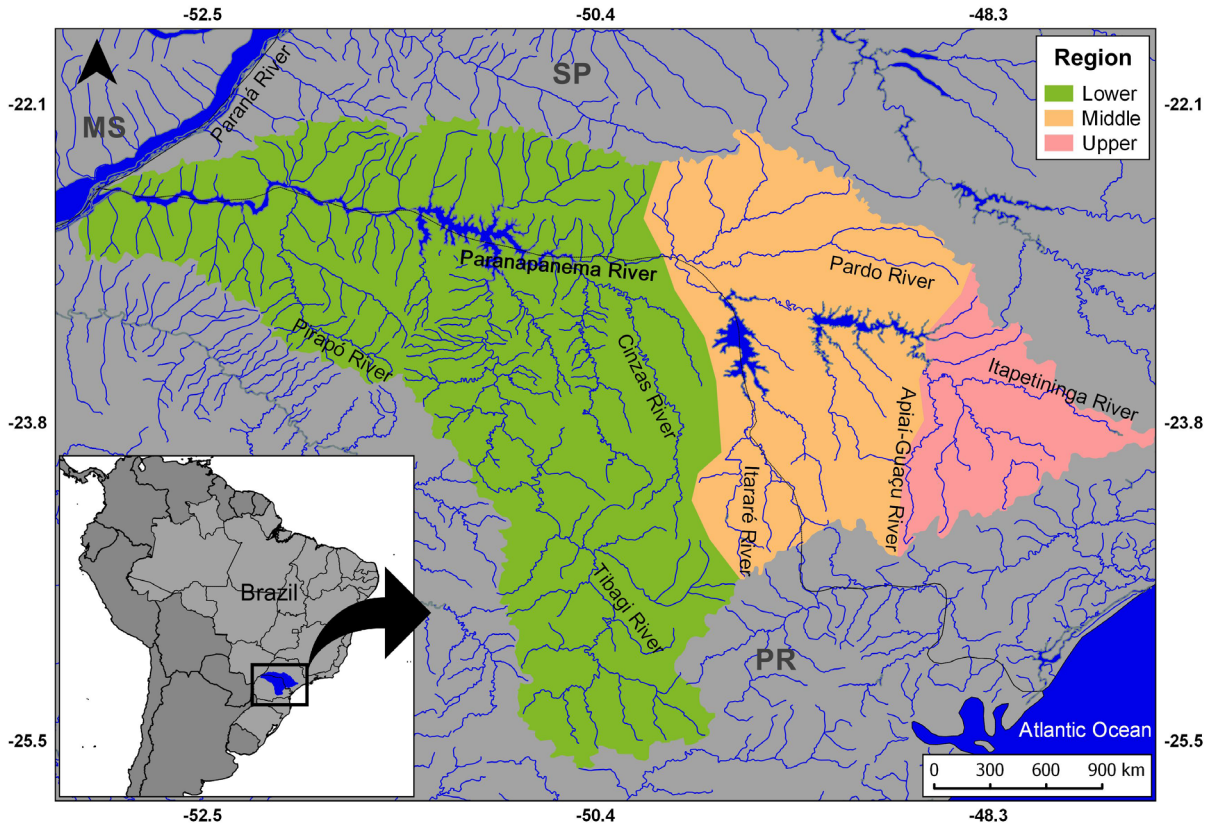

Figure 1. Inset: Location of the study area in Brazil. Main: the Paranapenema River basin divided in its three main regions according to Sampaio (1944). MS: state of Mato Grosso do Sul; SP: state of São Paulo; PR: state of Paraná.

Pavanelli (2007), Langeani et al. (2007), Júlio Júnior et al. (2009), Pelicice & Agostinho (2009), Britton and Orsi (2012), Ortega et al. (2015), Azevedo-Santos et al. (2016), and Ota et al. (2018).

3. *Data Analysis*

The total taxonomic richness was assessed using species accumulation curves. Non-parametric Incidence-Based Estimators: Bootstrap (Smith & van Belle 1984) and Chao 2 (Chao 1984), were used to obtain estimates of native species richness from Paranapanema River basin, considering the species presence/absence distribution in the subregions. For this analysis, we used the *EstimateS 9.1* software (Colwell 2006). For generating the map of Paranapanema River basin and their regions, the *Quantum GIS 2.18* software was employed (QGIS Development Team 2018).

Results

The compilation of 90 studies resulted in the identification of 10 orders, 40 families, 118 genera, and 225 species within the Paranapanema River basin. Of these, 165 species were identified as native, while 60 were non-native species introduced into the basin through several vectors (Table 2). Siluriformes (91 species) and Characiformes (83 species) represented the most species-rich orders, accounting together for 77% of all species from the basin. Cichliformes were the third species-rich order with 20 species found. The families with the highest number of species in the basin were Loricariidae (39 species), and Characidae (33 species), followed by Cichlidae (20 species), Anostomidae (16 species) and Pimelodidae (13 species).

Hypostomus was the richest genus with 16 identified species (four of which were non-native) distributed along the basin. Most species of this genus were present in the Tibagi River with 13 species, followed by Cinzas River (10 species), and finally Paranapanema River (Capivara Reservoir) and Pirapó River both with eight species. The next richest genera were *Astyanax* (eight species), *Leporinus,* and *Crenicichla* (both with six species each). Among the non-native species, the genus *Cichla* had five species, all introduced due to fish stocking for recreational fishing. There were no records of *Cichla* on the Upper Paranapanema River (Table 2).

The most common native species, widely distributed in the Paranapanema River basin, were *Astyanax lacustris* and *Hypostomus ancistroides* - present in 43 subregions - followed by *Rhamdia quelen* (34 subregions), *Hoplias* cf. *malabaricus* (33), *Geophagus brasiliensis* (30), *Astyanax* aff. *fasciatus* (29) and *Steindachnerina insculpta* (24). A comprehensive summarized list of species, with their current taxonomic status, are shown in Table 3.

In the Paranapema River basin, 22 species were classified as being threatened (Table 2), with the family Bryconidae having the highest number of threatened species in the basin. *Brycon nattereri* and *Brycon orbignyanus* are considered Critically Endangered in the state of São Paulo (Table 2). *Brycon nattereri* was found only

Table 1. Subregions sampled by 90 studies that investigated fish diversity in the Paranapanema River basin.

Subregion	Site	Source
	Lower Paranapanema	
1	Conceição Stream	Cionek et al. (2012)
2	Scherer Stream	Cionek et al. (2012)
3	Paranapanema (downstream of Rosana Reser-voir)	Barrella & Petrere Jr. (2003)
4	Paranapanema (Rosana Reservoir)	Barrella & Petrere Jr. (2003), Casatti et al. (2003), Abilhôa & Bastos (2005), Pelicice et al. (2005), Pelicice & Agostinho (2009), Garcia & Benedito (2010), Ferrareze & Nogueira (2011), Pelicice et al. (2014), Kipper et al. (2011), Almeida et al. (2017), Garcia et al. (2017)
5	Águas Claras Stream	Casatti (2004)
6	São Carlos Stream	Casatti (2004, 2005)
7	Diamante Stream	Garcia & Benedito (2010)
8	Pirapó River	Cunico et al. (2006, 2009), Garcia et al. (2012), Pagotto et al. (2012), Souza et al. (2014), Almeida et al. (2017)
9	Pirapozinho River	Almeida et al. (2017), Garcia et al. (in prep)
11	Santa Clara Stream	Castro et al. (2003)
12	Estação Stream	Castro et al. (2003)
13	Água Mole Stream	Castro et al. (2003)
14	Piau River	Castro et al. (2003)
15	Paranapanema (Taquaruçu Reservoir)	Carvalho et al. (2005b), Britto & Carvalho (2006), Almeida et al. (2017)
15	Anhumas River	Almeida et al. (2017), Garcia et al. (in prep)
16	Centenário Stream	Vidotto-Magnoni et al. (2015)
17	Tenente Stream	Vidotto-Magnoni et al. (2015)
18	Capim Stream	Vidotto-Magnoni et al. (2015)
19	Boa Esperança Stream	Castro et al. (2003)
20	Unnamed stream, municipality of Narandiba	Castro et al. (2003)
21	Paranapanema (Capivara Reservoir)	Barrella & Petrere Jr. (2003), Dias (2003), Carvalho et al. (2005b), Hoffmann et al. (2005), Bennemann et al. (2006, 2011), Orsi (2010), Orsi & Britton (2014)
22	Tibagi River	Bennemann et al. (1995, 2000, 2006, 2011), Dias (2003), Luiz et al. (2003), Shibatta & Cheida (2003), Hoffmann et al. (2005, 2015), Oliveira & Bennemann et al. (2005), Jerep et al. (2006), Sant'Anna et al. (2006), Shibatta et al. (2002, 2006a, b, 2007, 2008), Galves et al. (2007), Vieira & Shibatta (2007), Orsi (2010), Raio & Bennemann (2010), Garcia et al. (2012, 2014, 2015), Silva et al. (2015), Frantine-Silva et al. (2015), Almeida et al. (2017), Jerep & Shibatta (2017), Claro-Garcia et al. (2018)
23	Congonhas River	Frantine-Silva et al. (2015), Almeida et al. (2017), Garcia et al. (2019)
24	Cinzas River	Hoffmann et al. (2005), Vianna & Nogueira, (2008), Orsi (2010), Bennemann et al. (2011), Garcia et al. (2012), Costa et al. (2013), Galindo (2014), Frantine-Silva et al. (2015), Almeida et al. (2017)
25	Água Seca Stream	Castro et al. (2003)
26	Água do Macaco Stream	Castro et al. (2003)
27	Água da Laranjinha Stream	Castro et al. (2003)
28	Congonha Stream	Castro et al. (2003)
29	Canoas I Reservoir (Fish ladder)	Britto & Sirol (2005)
30	Paranapanema (Canoas I Reservoir)	Dias (2003), Orsi (2010), Almeida et al. (2013, 2017), Britto & Carvalho (2013), Frantine-Silva et al. (2015), Casimiro et al. (2017)
31	Canoas II Reservoir (Fish ladder)	Britto & Sirol (2005)

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Continuation Table 1.

Subregion	Site	Source
32	Paranapanema (Canoas II Reservoir)	Dias (2003), Souto et al. (2011), Almeida et al. (2013, 2017), Britto & Carvalho (2013), Frantine-Silva et al. (2015), Casimiro et al. (2017)
33	Pau D'alho Stream	Shibatta & Benine (2005)
	Middle Paranapanema	
34	Paranapanema (Salto Grande Reservoir)	Dias & Garavello, 1997, Dias (2003), Vianna (2008), Brandão et al. (2009), Deprá et al. (2018)
35	Pardo River	Roxo et al. (2012)
36	Novo River	Brandão et al. (2009)
37	Turvo River	Brandão et al. (2009)
38	Santana Stream	Castro et al. (2003)
39	Água das Antas Stream	Castro et al. (2003)
40	Ourinhos Fish ladder	Arcifa & Esguícero (2012).
41	Paranapanema (Chavantes Reservoir)	Vidotto-Magnoni (2009), Zanatta et al. (2010)
42	Verde River	Vidotto-Magnoni (2009)
43	Itararé River	Vidotto-Magnoni (2009)
44	Cruz Stream	Rosa et al. 2016
45	Taquaruçu Stream	Rosa et al. 2016
46	Taquaruçu II Stream	Barrella & Petrere Jr. (2003), Rosa et al. (2016)
47	Paranapanema (Jurumirim Reservoir)	Carvalho et al. (1998), Carvalho & Silva (1999), Barrella & Petrere Jr. (2003), Carvalho et al. (2003), Carvalho et al. (2005a, b), Novaes & Carvalho (2013) Kurchevski & Carvalho (2014), Sousa et al. (2016), Chuctaya et al. (2018), Nobile et al. (2018)
48	Veados Stream	Sousa et al. (2016)
49	Tamanduá River	Ochoa et al. (2017)
50	Taquari River	Nobile (2015), Sousa et al. (2016), Nobile et al. (2017), Nobile et al. (2018)
51	Unnamed stream, municipality of Paranapanema	Castro et al. (2003)
52	Virado Stream	Castro et al. (2003)
53	Unnamed stream, municipality of Pirajú	Castro et al. (2003)
54	Claro Stream	Castro et al. (2003)
	Upper Paranapanema	
55	Itapetininga River	Cerqueira & Smith (2015), Cerqueira et al. (2016)
56	Poço dos Patos Stream	Castro et al. (2003)
57	Alto Paranapanema Streams	Castro et al. (2004), Martins & Barrella (2008), Zawadzki et al. (2008), Cetra et al. (2012, 2016)

in the Tibagi and Cinzas rivers (Lower Paranapanema), and *Brycon orbignyanus* was also found only in two tributaries – the Cinzas, and Ribeirão dos Veados rivers of the Middle Paranapanema. *Salminus brasiliensis* is considered Vulnerable in Brazil and state of Paraná (only in the Lower Paranapanema). Members of Pimelodidae, such as the migratory catfishes *Steindachneridion scriptum* and *Zungaro jahu* are also Endangered in the state of São Paulo, and Vulnerable in the state of Paraná. Other species that are Critically Endangered in at least one of the lists are *Piaractus mesopotamicus* (Serrasalmidae) and *Crenicichla jupiaensis* (Cichlidae), which were found only in the Cinzas River (Table 1).

The most widely distributed non-native species were *Plagioscion squamosissimus*, present in 17 subregions, and *Oreochromis niloticus* which was registered in 16 subregions in the three primary areas of the basin. In the lower area, the Tibagi River was the subregion with the greatest diversity of non-native species (29 species), followed by the Rosana Reservoir (19 species), Cinzas River (17 species), and the Capivara Reservoir (16 species). In the middle area, the non-native species were concentrated in Salto Grande (15 species), and Jurumirim reservoirs (15 species). In the Upper Paranapanema River, only four non-native species were recorded: *Misgurnus anguillicaudatus*, *Cyprinus carpio*, *Satanoperca pappaterra* and *Poecilia vivipara*.

Table 2. Fish fauna from the Paranapanema River basin. Taxonomic classification followed Eschmeyer & Fong (2018). Vector introduction: (AT) Aquarium trade, (B) Bait, (BC) Biological control, (FF) Fish farming, (FS) Fish stocking, (ID) Itaipu Dam and (UK) Unknown. Conservation Status: (CR) Critically Endangered, (EN) Endangered, (VU) Vulnerable, (NT) Near Threatened. State of Paraná (PR) followed Mikich & Bérnils (2004). State of São Paulo (SP) followed Bressan et al. (2009) and ALESP (2014). Brazil (BR) followed ICMBio (2014, 2018). * = non-native species.

Class/Order/Species	Region			Vector	Conservation Status
	Lower	Middle	Upper		
Elasmobranchii					
Rajiformes					
Potamotrygonidae					
Potamotrygon motoro (Müller & Henle 1841)*	X			ID	
Actinopteri					
Cypriniformes					
Cobitidae					
Misgurnus anguillicaudatus (Cantor 1842)*		X	X	AT	
Cyprinidae					
Ctenopharyngodon idella (Valenciennes 1844)*	X			FF	
Cyprinus carpio Linnaeus 1758*	X	X	X	FS/FF	
Characiformes					
Crenuchidae					
Characidium fasciatum Reinhardt 1867		X			
Characidium gomesi Travassos 1956	X		X		
Characidium oiticicai Travassos 1967			X		VU (BR)
Characidium schubarti Travassos 1955	X		X		
Characidium aff. *zebra* Eigenmann 1909	X	X	X		
Erythrinidae					
Erythrinus erythrinus (Bloch & Schneider 1801)*	X			ID/B	
Hoplias cf. *malabaricus* (Bloch 1794)	X	X	X		
Hoplias intermedius (Günther 1864)*	X	X		UK	
Hoplias lacerdae Miranda Ribeiro 1908*	X	X		FS	VU (SP)
Parodontidae					
Apareiodon affinis (Steindachner 1879)	X	X			
Apareiodon ibitiensis Amaral Campos 1944	X		X		
Apareiodon piracicabae (Eigenmann 1907)	X	X			
Parodon nasus Kner 1859	X	X	X		
Cynodontidae					
Raphiodon vulpinus Spix & Agassiz 1829	X				
Serrasalmidae					
Metynnis lippincottianus (Cope 1870)*	X	X		ID	
Metynnis cf. *maculatus* (Kner 1858)*	X			ID	
Metynnis mola Eigenmann & Kennedy 1903		X			
Myloplus tiete (Eigenmann & Norris 1900)	X	X			EN (BR)
Piaractus mesopotamicus (Holmberg 1887)	X	X			CR (SP)
Serrasalmus maculatus Kner 1858	X	X	X		
Serrasalmus marginatus Valenciennes 1837*	X	X		ID	
Anostomidae					
Leporellus pictus (Kner, 1858)		X			
Leporellus vittatus (Valenciennes 1850)	X	X			
Leporinus amblyrhynchus Garavello & Britski 1987	X	X			

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Continuation Table 2.

Class/Order/Species	Region			Vector	Conservation Status
	Lower	Middle	Upper		
Leporinus friderici (Bloch 1794)	X	X	X		
Leporinus lacustris Amaral Campos 1945	X	X			
Leporinus octofasciatus Steindachner 1915	X	X	X		
Leporinus paranensis Garavello & Britski 1987	X	X	X		
Leporinus striatus Kner 1858	X	X	X		
Megaleporinus elongatus (Valenciennes 1850)	X	X			
Megaleporinus macrocephalus (Garavello & Britski 1988)*	X	X		FF/FS	
Megaleporinus obtusidens (Valenciennes 1837)	X	X			
Megaleporinus piavussu (Britski, Birindelli & Gara-vello 2012)		X			
Schizodon altoparanae Garavello & Britski 1990	X	X			
Schizodon borellii (Boulenger 1900)*	X	X		ID/FS	
Schizodon intermedius Garavello & Britski 1990	X	X			
Schizodon nasutus Kner 1858	X	X	X		
Curimatidae					
Cyphocharax modestus (Fernández-Yépez 1948)	X	X	X		
Cyphocharax naegelii (Steindachner 1881)	X	X			
Steindachnerina brevipinna (Eigenmann & Eigen-mann 1889)*	X			ID	
Steindachnerina insculpta (Fernández-Yépez 1948)	X	X	X		
Prochilodontidae					
Prochilodus lineatus (Valenciennes 1837)	X	X	X		
Lebiasinidae					
Pyrrhulina australis Eigenmann & Kennedy 1903	X	X			
Triportheidae					
Triportheus angulatus (Spix & Agassiz 1829)*	X	X		FS	
Triportheus nematurus (Kner 1858)*	X	X		ID/FS	
Bryconidae					
Brycon nattereri Günther 1864	X				CR (SP)/VU (BR)
Brycon orbignyanus (Valenciennes 1850)	X	X			CR (SP)/EN (BR) (PR)
Salminus brasiliensis (Cuvier 1816)	X				VU (BR) (PR)/NT (SP)
Salminus hilarii Valenciennes 1850	X	X	X		NT (BR) (SP)
Acestrorhynchidae					
Acestrorhynchus lacustris (Lütken 1875)	X	X			
Characidae					
Aphyocharax anisitsi Eigenmann & Kennedy 1903	X				
Aphyocharax dentatus Eigenmann & Kennedy 1903*	X			ID	
Astyanax biotae Castro & Vari 2004			X		
Astyanax bockmanni Vari & Castro 2007	X	X	X		
Astyanax aff. *fasciatus* (Cuvier 1819)	X	X	X		
Astyanax lacustris (Lütken 1875)	X	X	X		
Astyanax aff. *paranae* Eigenmann 1914	X	X	X		
Astyanax paranae Eigenmann 1914	X				
Astyanax aff. *scabripinnis* (Jenyns 1842)	X	X	X		

Continuation Table 2.

Class/Order/Species	Region			Vector	Conservation Status
	Lower	Middle	Upper		
Astyanax schubarti Britski 1964		X			
Bryconamericus aff. *iheringii* (Boulenger 1887)	X	X	X		
Bryconamericus coeruleus Jerep & Shibatta 2017	X				
Bryconamericus exodon Eigenmann 1907*	X			ID	
Cheirodon stenodon Eigenmann 1915	X	X			
Galeocharax gulo (Cope 1870)	X	X			
Hemigrammus marginatus Ellis 1911	X	X			
Hyphessobrycon anisitsi (Eigenmann 1907)	X	X	X		
Hyphessobrycon bifasciatus Ellis 1911		X			
Hyphessobrycon eques (Steindachner 1882)*	X	X		AT	
Hyphessobrycon reticulatus Ellis 1911	X				
Mimagoniates microlepis (Steindachner 1877)	X				
Moenkhausia intermedia Eigenmann 1908	X				
Moenkhausia sanctaefilomenae (Steindachner 1907)	X				
Odontostilbe avanhandava Chuctaya, Bührnheim & Malabarba 2018		X			
Oligosarcus paranensis Menezes & Géry 1983	X	X	X		
Oligosarcus pintoi Amaral Campos 1945	X	X			
Piabarchus stramineus (Eigenmann 1908)	X	X	X		
Piabina argentea Reinhardt 1867	X	X	X		
Planaltina britskii Menezes, Weitzman & Burns 2003		X			
Planaltina glandipedis Menezes, Weitzman & Burns 2003		X			
Roeboides descalvadensis Fowler 1932*	X			ID	
Serrapinnus heterodon (Eigenmann 1915)		X			
Serrapinnus notomelas (Eigenmann 1915)	X	X	X		
Gymnotiformes					
Gymnotidae					
Gymnotus carapo Linnaeus 1758	X	X	X		
Gymnotus inaequilabiatus (Valenciennes 1839)*	X	X		UK	
Gymnotus omarorum Richer-de-Forges, Crampton & Albert 2009	X				
Gymnotus pantanal Fernandes, Albert, Daniel-Silva, Lopes, Crampton & Almeida-Toledo 2005*	X			ID/B	
Gymnotus sylvius Albert & Fernandes-Matioli 1999	X	X	X		
Rhamphichthydae					
Rhamphichthys hahni (Meinken 1937)*	X			ID	
Rhamphichthys cf. *rostratus* (Linnaeus 1766)	X				
Hypopomidae					
Brachyhypopomus pinnicaudatus (Hopkins, Comfort, Bastian & Bass 1990)*		X		B	
Sternopygidae					
Eigenmannia trilineata López & Castello 1966	X	X			
Eigenmannia virescens (Valenciennes 1836)	X	X	X		
Sternopygus macrurus (Bloch & Schneider 1801)	X	X			

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Continuation Table 2.

Class/Order/Species	Region			Vector	Conservation Status
	Lower	Middle	Upper		
Apteronotidae					
Apteronotus albifrons (Linnaeus 1766)	X				
Apteronotus brasiliensis (Reinhardt 1852)	X				
Apteronotus caudimaculosus de Santana 2003*	X			ID	
Apteronotus ellisi (Alonso de Arámburu 1957)*	X	X		ID	
Sternarchorhynchus britskii Campos-da-Paz 2000	X				VU (SP)
Siluriformes					
Cetopsidae					
Cetopsis gobioides Kner 1858	X				
Aspredinidae					
Bunocephalus larai Ihering 1930	X				
Auchenipteridae					
Ageneiosus militaris Valenciennes 1835	X	X			
Auchenipterus osteomystax (Miranda Ribeiro 1918)*	X			ID	
Glanidium cesarpintoi Ihering 1928	X				
Tatia intermedia (Steindachner 1877)*	X			UK	
Tatia neivai (Ihering 1930)	X	X			
Trachelyopterus galeatus (Linnaeus 1766)*	X			ID	
Doradidae					
Ossancora eigenmanni (Boulenger 1895)*	X			ID	
Pterodoras granulosus (Valenciennes 1821)*	X			ID	
Rhinodoras dorbignyi (Kner 1855)	X	X			
Trachydoras paraguayensis (Eigenmann & Ward 1907)*	X			ID	
Heptapteridae					
Cetopsorhamdia iheringi Schubart & Gomes 1959	X	X	X		
Imparfinis borodini Mees & Cala 1989	X		X		
Imparfinis mirini Haseman 1911	X	X	X		
Phenacorhamdia hoehnei (Miranda Ribeiro 1914)	X				
Phenacorhamdia tenebrosa (Schubart 1964)	X	X	X		
Pimelodella avanhandavae Eigenmann 1917	X	X	X		
Pimelodella gracilis (Valenciennes 1835)	X	X			
Pimelodella meeki Eigenmann 1910	X	X			
Rhamdia quelen (Quoy & Gaimard 1824)	X	X	X		
Rhamdiopsis moreirai Haseman 1911	X				VU (PR)
Pimelodidae					
Hypophthalmus edentatus Spix & Agassiz 1829*	X			ID	
Iheringichthys labrosus (Lütken 1874)	X	X			
Megalonema platanum (Günther 1880)	X				
Pimelodus absconditus Azpelicueta 1995	X				
Pimelodus maculatus Lacepède 1803	X	X	X		
Pimelodus microstoma Steindachner 1877	X	X			
Pimelodus ornatus Kner 1858*	X			ID	
Pimelodus paranaensis Britski & Langeani 1988	X				VU (SP)
Pinirampus pirinampu (Spix & Agassiz 1829)	X				

Continuation Table 2.

Class/Order/Species	Region			Vector	Conservation Status
	Lower	Middle	Upper		
Pseudoplatystoma corruscans (Spix & Agassiz 1829)	X				VU (SP)/NT (PR)
Sorubim lima (Bloch & Schneider 1801)*	X			ID	
Steindachneridion scriptum (Miranda Ribeiro 1918)	X	X			EN (SP) (BR)/VU (PR)
Zungaro jahu (Ihering 1898)	X				EN (SP)/VU (PR)
Pseudopimelodidae					
Microglanis garavelloi Shibatta & Benine 2005	X				
Pseudopimelodus mangurus (Valenciennes 1835)	X				VU (SP) (PR)
Rhyacoglanis paranensis Shibatta & Vari 2017	X				
Clariidae					
Clarias gariepinus (Burchell 1822)*	X			ID	
Ictaluridae					
Ictalurus punctatus (Rafinesque 1818)*		X		ID	
Trichomycteridae					
Paravandellia oxyptera Miranda Ribeiro 1912	X				
Trichomycterus candidus (Miranda Ribeiro 1949)	X				
Trichomycterus castroi de Pinna 1992	X				
Trichomycterus davisi (Haseman 1911)	X		X		
Trichomycterus diabolus Bockmann, Casatti & de Pinna 2004	X	X	X		
Trichomycterus pascuali Ochoa, Silva, Costa e Silva, Oliveira & Datovo 2017		X			
Callichthyidae					
Callichthys callichthys (Linnaeus 1758)	X	X			
Corydoras aeneus (Gill 1858)	X	X			
Corydoras ehrhardti Steindachner 1910	X				
Corydoras longipinnis Knaack 2007	X				
Corydoras paleatus (Jenyns 1842)	X				
Hoplosternum littorale (Hancock 1828)	X	X	X		
Loricariidae					
Ancistrus cf. *cirrhosus* (Valenciennes 1836)	X				
Curculionichthys insperatus (Britski & Garavello 2003)	X				
Hisonotus depressinotus (Miranda Ribeiro 1918)	X				
Hisonotus francirochai (Ihering 1928)	X				
Hypostomus albopunctatus (Regan 1908)	X				
Hypostomus ancistroides (Ihering 1911)	X	X	X		
Hypostomus hermanni (Ihering 1905)	X	X			
Hypostomus iheringii (Regan 1908)	X	X			
Hypostomus margaritifer (Regan 1908)	X	X	X		
Hypostomus multidens Jerep, Shibatta & Zawadzki 2007		X			
Hypostomus myersi (Gosline 1947)*	X			UK	
Hypostomus nigromaculatus (Schubart 1964)	X	X	X		
Hypostomus paulinus (Ihering 1905)	X	X			
Hypostomus regani (Ihering 1905)	X	X			
Hypostomus cf. *roseopunctatus* Reis, Weber & Malabarba 1990*		X		UK	

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Continuation Table 2.

Class/Order/Species	Region			Vector	Conservation Status
	Lower	Middle	Upper		
Hypostomus strigaticeps (Regan 1908)	X	X			
Hypostomus ternetzi (Boulenger 1895)*		X		ID	
Hypostomus tietensis (Ihering 1905)	X	X			
Hypostomus topavae (Godoy 1969)	X	X			
Hypostomus variostictus (Miranda Ribeiro 1912)*	X			UK	
Isbrueckerichthys alipionis (Gosline 1947)			X		
Isbrueckerichthys calvus Jerep, Shibatta, Pereira & Oyakawa 2006	X				
Isbrueckerichthys duseni (Miranda Ribeiro 1907)			X		VU (SP)
Isbrueckerichthys saxicola Jerep, Shibatta, Pereira & Oyakawa 2006	X				CR (BR)
Loricaria simillima Regan 1904	X				
Loricariichthys labialis (Boulenger 1895)*	X			UK	
Loricariichthys platymetopon Isbrücker & Nijssen 1979*	X			ID	
Megalancistrus parananus (Peters 1881)	X	X			
Neoplecostomus botucatu Roxo, Oliveira & Zawadzki 2012		X			VU (BR)
Neoplecostomus paranensis Langeani 1990	X		X		VU (SP)/(EN) BR
Neoplecostomus selenae Zawadzki, Pavanelli & Langeani 2008	X		X		VU (SP)
Neoplecostomus yapo Zawadzki, Pavanelli & Lange-ani 2008	X		X		
Otothyropsis biamnicus Calegari, Lehmann A. & Reis 2013	X	X	X		
Paraloricaria vetula (Valenciennes 1835)	X				
Proloricaria prolixa (Isbrücker & Nijssen 1978)	X	X			
Pterygoplichthys ambrosettii (Holmberg 1893)*	X	X		ID/AT	
Rhinelepis strigosa Valenciennes 1840	X				
Rineloricaria latirostris (Boulenger 1900)	X	X			
Rineloricaria pentamaculata Langeani & de Araujo 1994	X	X	X		
Synbranchiformes					
Synbranchidae					
Synbranchus marmoratus Bloch 1795	X	X	X		
Pleuronectiformes					
Achiridae					
Catathyridium jenynsii (Günther 1862)*	X			ID	
Cichliformes					
Cichlidae					
Astronotus crassipinnis (Heckel 1840)*		X		ID/FS/FF/AT	
Astronotus ocellatus (Agassiz 1831)*	X	X		UK	
Australoheros facetus (Jenyns, 1842)	X		X		
Cichla kelberi Kullander & Ferreira 2006*	X	X		FS	
Cichla monoculus Spix & Agassiz 1831*	X	X		FS	
Cichla ocellaris Bloch & Schneider 1801*		X		FS	
Cichla piquiti Kullander & Ferreira 2006*		X		FS	
Cichla temensis Humboldt 1821*		X		FS	

Continuation Table 2.

Class/Order/Species	Region			Vector	Conservation Status
	Lower	Middle	Upper		
Cichlasoma paranaense Kullander 1983	X	X			
Coptodon rendalli (Boulenger 1897)*	X	X		FS	
Crenicichla britskii Kullander 1982	X	X			
Crenicichla haroldoi Luengo & Britski 1974	X	X			
Crenicichla jaguarensis Haseman 1911	X	X			
Crenicichla jupiaensis Britski & Luengo 1968	X				CR (SP)/EN (BR)
Crenicichla lepidota Heckel 1840	X				
Crenicichla niederleinii (Holmberg 1891)	X	X			
Geophagus brasiliensis (Quoy & Gaimard 1824)	X	X	X		
Laetacara araguaiae Ottoni & Costa 2009*	X			AT	
Oreochromis niloticus (Linnaeus 1758)*	X	X	X	FS/FF	
Satanoperca pappaterra (Heckel 1840)*	X			FF/AT	
Cyprinodontiformes					
Cynolebiidae					
Melanorivulus apiamici (Costa 1989)	X				
Poeciliidae					
Cnesterodon hypselurus Lucinda & Garavello 2001	X				EN (BR)
Phalloceros harpagos Lucinda 2008	X	X	X		
Phalloceros reisi Lucinda 2008			X		
Poecilia reticulata Peters 1859*	X	X		BC/AT	
Poecilia vivipara Bloch & Schneider 1801*			X	BC/AT	
Xiphophorus hellerii Heckel 1848*	X			AT	
Perciformes					
Centrarchidae					
Micropterus salmoides (Lacepède 1802)*	X			FS	
Sciaenidae					
Plagioscion squamosissimus (Heckel 1840)*	X	X		FS/FF	

When considering only the species native to the Paranapanema basin (165 species) which occurred in each of the 57 subregions, the accumulation curve tended to stabilize (Figure 2), but non-parametric estimators indicated that the total richness of native species to the basin is underestimated (Bootstrap = 182.29 ± 0.00, Chao-2 = 223.98 ± 25.43). Our compilation from the studies represents 74% (Chao-2) and 91% (Bootstrap) of the native species estimated for the basin.

The Lower Paranapanema was the region with the highest species richness (146 native and 51 non-native species) (Figure 3). Most of its richness was in the Tibagi River which presented 158 species, followed by Cinzas (114 species), Pirapó (76 species) and Congonhas (63 species) rivers respectively. Of these, 79 occurred only in the Lower Paranapanema as a medium to large sized native species including *Brycon nattereri*, *Salminus brasiliensis*, *Megalonema platanum*, *Pimelodus paranaenses*, *Pinirampus pirinampu*, *Pseudoplatystoma corruscans*, *Zungaro jahu,* and *Pseudopimelodus mangurus*.

The middle region presented 103 native and 27 non-native species, with 75 native species recorded to the Salto Grande Reservoir alone. Some of these were recorded only within the middle region, such as *Characidium fasciatum*, *Leporellus pictus,* and *Odontostilbe avanhandava*. In the Upper Paranapanema, 61 species (57 of which are native) were recorded (Figure 3), with the majority of them being small to medium size species, such as *Characidium oiticicai, Isbrueckerichthys duseni* and *Phalloceros reisi.* Most of the species in this region (45 species) were collected in headwater streams.

A majority of the investigated studies were performed within the lower region of the Paranapanema River (56 studies), comprising 61% of those reviewed. The Capivara Reservoir and its direct tributaries presented 32 studies, most of them concentrated in the Tibagi River (29 studies). The Rosana Reservoir and tributaries were the second most studied subregion (17 studies). In the Middle Paranapanema 20 studies were conducted, with the Jurumirim Reservoir and its tributaries (11 studies) being the most studied site. The Upper Paranapanema was the

Table 3. Current taxonomic status of the species names found the literature from the Paranapanema River basin, based on Eschmeyer et al. (2018).

Previous Identification	Current Identification
Ageneiosus valenciennesi Bleeker 1864	Synonym of *Ageneiosus militaris* Valenciennes 1835
Astyanax altiparanae Garutti & Britski 2000	Synonym of *Astyanax lacustris* (Lütken 1875)
Astyanax bimaculatus (Linnaeus 1758)	*Astyanax lacustris* (Lütken 1875)
Astyanax scabripinnis (Jenyns 1842)	*Astyanax paranae* Eigenmann 1914
Bryconamericus stramineus Eigenmann 1908	Valid as *Piabarchus stramineus* (Eigenmann 1908)
Cheirodon notomelas (Eigenmann 1915)	Valid as *Serrapinnus notomelas* (Eigenmann 1915)
Cichlasoma facetum (Jenyns 1842)	Valid as *Australoheros facetus* (Jenyns 1842)
Dysichthys larai (Ihering 1930)	Valid as *Bunocephalus larai* Ihering 1930
Galeocharax knerii (Steindachner 1879)	Synonym of *Galeocharax gulo* (Cope 1870)
Hisonotus insperatus Britski & Garavello 2003	Valid as *Curculionichthys insperatus* (Britski & Garavello 2003)
Imparfinis schubarti (Gomes 1956)	Synonym of *Imparfinis mirini* Haseman 1911.
Leporinus elongatus Valenciennes 1850	Valid as *Megaleporinus elongatus* (Valenciennes 1850)
Leporinus macrocephalus Garavello & Britski 1988	Valid as *Megaleporinus macrocephalus* (Garavello & Britski 1988)
Leporinus obtusidens Valenciennes 1836	Valid as *Megaleporinus obtusidens* (Valenciennes 1837)
Leporinus piavussu (Britski, Birindelli & Garavello 2012)	Valid as *Megaleporinus piavussu* (Britski, Birindelli & Garavello 2012)
Loricaria prolixa (Isbrücker & Nijssen 1978)	Valid as *Proloricaria prolixa* (Isbrücker & Nijssen 1978)
Loricaria vetula (Valenciennes 1835)	Valid as *Paraloricaria vetula* (Valenciennes 1835)
Megalancistrus aculeatus (Perugia 1891)	Synonym of *Megalancistrus parananus* (Peters 1881)
Microlepidogaster depressinotus Miranda Ribeiro 1918	Valid as *Hisonotus depressinotus* (Miranda Ribeiro 1918)
Myleus tiete (Eigenmann & Norris 1900)	Valid as *Myloplus tiete* (Eigenmann & Norris 1900).
Odontostilbe stenodon (Eigenmann 1915)	Valid as *Cheirodon stenodon* Eigenmann 1915
Otocinclus depressicauda Miranda Ribeiro 1918	Valid as *Hisonotus depressicauda* (Miranda Ribeiro 1918)
Parodon tortuosus Eigenmann & Norris 1900	Synonym of *Parodon nasus* Kner 1859
Pimelodus heraldoi Azpelicueta 2001	Synonym of *Pimelodus microstoma* Steindachner 1877
Porotergus ellisi Alonso de Arámburu 1957	Valid as *Apteronotus ellisi* (Alonso de Arámburu 1957)
Pseudocetopsis gobioides (Kner 1858)	Valid as *Cetopsis gobioides* Kner 1858
Pseudopimelodus roosevelti Borodin 1927	Synonym of *Pseudopimelodus mangurus* (Valenciennes 1835)
Pseudopimelodus zungaro (Humboldt 1833)	Valid as *Zungaro jahu* (Ihering 1898).
Rhamdia hilarii (Valenciennes, 1840)	Synonym of *Rhamdia quelen* (Quoy & Gaimard 1824)
Roeboides paranensis Pignalberi 1975	Synonym of *Roeboides descalvadensis* Fowler 1932
Steindachneridion scripta (Miranda Ribeiro 1918)	Valid as *Steindachneridion scriptum* (Miranda Ribeiro 1918)
Tilapia rendalli (Boulenger 1897)	Valid as *Coptodon rendalli* (Boulenger 1897)

least investigated region (seven studies), five of which were species inventories, and two were new species descriptions for *Astyanax biotae* in 2004 and *Neoplecostomus selenae* in 2008.

Discussion

The number of species identified by our study (225) is significantly higher than reports conducted exclusively in reservoirs, which recorded 155 (Duke Energy 2008) and 161 species (Pelicice et al. 2018) for the Paranapanema River, respectively. Here, we have used both basin-wide surveys (*i.e.,* from reservoirs and fish ladders and free-flowing stretches including tributaries, streams, and marginal lagoons), as well as species descriptions to more comprehensively evaluate the species diversity of the region. The accumulation curve indicated that a majority of the native species (165) were represented and we estimate that the total richness would be between 182 and 223 species of native fish in the basin, a higher value than predicted by Pelicice et al. (2018) (125 to 132).

The most species-rich genus in this study, *Hypostomus,* is widely distributed in the rivers of the Paraná-Paraguay system (Weber 2003). The armored catfish species of *Hypostomus* are known for living in clear running water on the rocky bottoms of mostly large South American rivers (Garavello & Garavello, 2004). Within the genus, the species *Hypostomus ancistroides* is a common and widely distributed species, occurring throughout the Upper Paraná River system from where it was initially described (Weber 2003). *Astyanax lacustris* is also widely

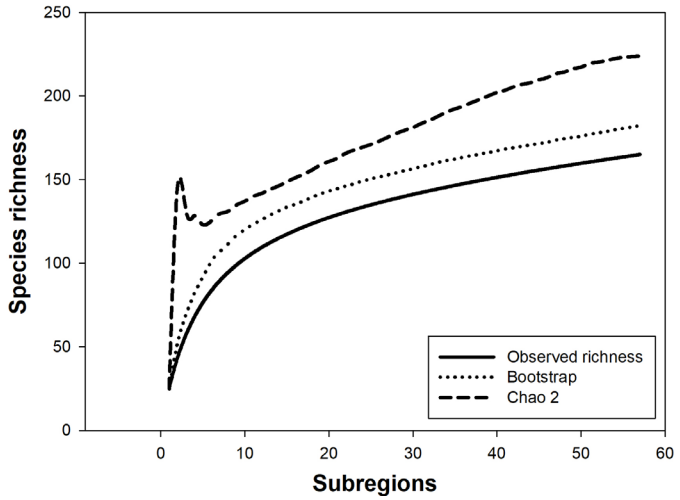

Figure 2. Native species accumulation curves controlled by presence/absence of native species in 57 subregions.

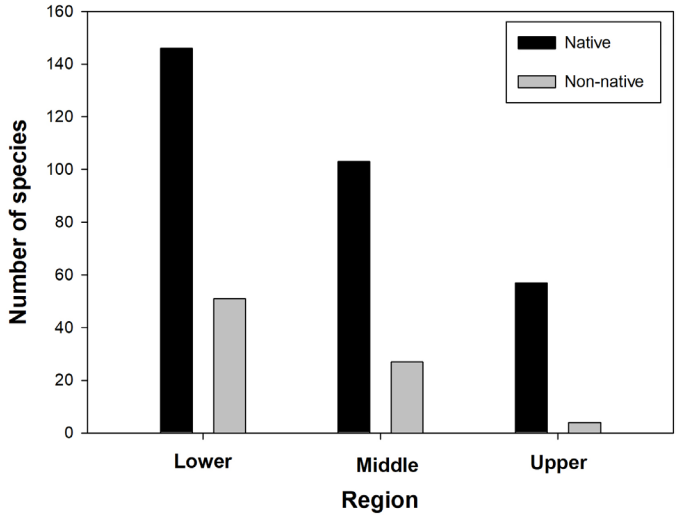

Figure 3. Species richness separated as native and non-native fishes in the Paranapanema River basin.

distributed, and along with its congeners, is the most diversified of the Characidae, comprising more than a hundred species widely distributed and abundant in the Brazilian watersheds. This extensive distribution indicates that the genus probably has significant ecological importance and adaptive plasticity (Orsi et al. 2004).

The highest richness was recorded for the orders Siluriformes and Characiformes, as usually found in the Neotropical region (Lowe-McConnell 1999). Cichliformes were the third most species-rich order in the basin, though mainly by the presence of non-native species. Among them, the genus *Cichla,* which was introduced to the basin in 1999 (Orsi & Agostinho 1999) to provide fish stocking for sport-angling, stands out with five introduced species. The species of this group benefit from lentic environments (Franco et al. 2018) provided by the reservoirs of the Paranapanema River. This scenario can be observed in other basins of the Upper Paraná River (Langeani et al. 2007). Many non-native species are more abundant in lentic environments, especially those of the family Cichlidae (Langeani et al. 2007, Franco et al. 2018). Regarding non-native fishes, there still appears to be no consensus on the exact number of species, with previous studies having reported 47 (Garcia et al. 2018), and 50 (Pelicice et al. 2018) non-native species in the basin.

In this study, 60 non-native fish species were registered in the Paranapanema River basin. In addition to the actual number of introduced species, the Paranapanema River basin can be considered the most invaded of the Upper Paraná River basin (Ortega et al. 2015, Garcia et al. 2018). Among the non-native species, 30 species occurred within the Paranapanema River (and Upper Paraná) after the flooding of the Sete Quedas Falls (Júlio Jr. et al. 2009), 16 species were introduced for restocking, nine species due to the aquarium trade, seven by escapes from fish farms, five by live-bait fish used in sport angling, and one for biological control. Among the most distributed non-native species in the basin, *P. squamosissimus* was introduced by stocking, while *O. niloticus* often escapes from fish farms (Ortega et al. 2015). The introduction of non-native species, compounded by other anthropic actions, threaten the richness of fish species present in this critical basin (Pelicice & Agostinho 2009, Garcia et al. 2018).

The occurrence of several species with some degree of threat and restricted distribution indicates that biodiversity conservation in the Paranapanema River is a highly relevant issue. Past studies have shown Bryconidae populations are in decline, with few occurrences in the basin (ICMBio 2018). Meanwhile, *Brycon nattereri* and *B. orgbignyanus* are critically endangered in the state of São Paulo but occur in the rivers Tibagi, Cinzas, and Ribeirão dos Veados (Mikich & Bérnils 2004, Bressan et al. 2009, ALESP 2014). Also, the occurrence of *Piaractus mesopotamicus* and *Crenicichla jupiaensis* in the Cinzas River highlights the importance of dam-free tributaries for the maintenance of native species in the basin (Nunes et al. 2015, Marques et al. 2018). *Salminus brasiliensis*, *Steindachneridion scriptum*, and *Zungaru jahu* – three long distances migratory species – have a low occurrence within this study. This decline in migratory species is demonstrated in several previous works (Okada et al. 2005, Godinho & Kynard 2008, Pelicice & Agostinho 2008; Pompeu et al. 2012, Orsi et al. 2016). The Cascade reservoir system along the Paranapanema River interrupts long-distance migration and creates unsuitable environments for migratory fish resulting from the presence of lentic areas and flow regulation (Agostinho et al. 2003, Agostinho et al. 2008, Pelicice et al. 2018). Among the species with restricted distribution, we found several small species that inhabit small streams of headwaters, namely *Characidium fasciatum* (Carvalho et al. 2005a), *Planaltina* spp. (Brandão et al. 2009, Deprá et al. 2018), *Characidium oiticicai* (Cetra et al. 2012), *Metynnis mola*, *Hyphessobrycon bifasciatus* (Arcifa & Esguícero 2012), *Isbrueckerichthys alipionis* (Martins & Barrella 2008), *Paraloricaria vetula* (Barrella & Petrere Jr. 2003), *Neoplecostomus botucatu* (Roxo et al. 2012), and *Cnesterodon hypselurus* (Silva et al. 2015). These species present a high degree of endemism and restricted geographic distribution, while having no commercial value and being highly dependent on riparian vegetation for food, reproduction, and shelter. They are more likely to have their conservation threatened because theses species tend to pass their entire life cycles in geographically restricted areas (Castro and Menezes, 1998, Castro et al. 2003).

The Tibagi River basin is the most studied region of the Paranapanema River. Together with the Cinzas River, the Tibagi assists in the maintenance of species of the Paranapanema River (Shibatta et al. 2002, Hoffmann et al. 2005, Shibatta et al. 2007). However, it is noteworthy that studies of universities near these sub-basins, such

as Universidade Estadual de Londrina, and Universidade Estadual de Maringá have likely contributed to the highest number of species survey data in these rivers. In the Middle Paranapanema, studies carried out by the Universidade Estadual Paulista within the Jurumirim and Chavantes reservoirs have been especially valuable. Conversely, the Upper Paranapanema region was investigated to a lesser extent. The region is characterized by numerous streams, which are underexplored and serve as shelters for smaller species (Langeani et al. 2007). The previous description of new species in the Upper Paranapanema River (Castro & Vari, 2004, Zawadzki et al. 2008), coupled with a general lack of studies for this region, suggests that there is still great potential for new descriptions in the headwaters of the tributaries (Buckup et al. 2007, Langeani et al. 2007). More importantly, there are also species that have a threatened conservation status, such as *Isbrueckerichthys duseni*, as well as the high percentage of species for which there is little to no scientific knowledge (Castro et al. 2003), reinforcing Castro & Menezes (1998) recommendation to prioritize scientific exploration of streams and headwaters in these regions.

Despite the significant richness of fish species known, the region of the Paranapanema River has the highest population density in Brazil (ANA 2016) as a result of electricity production, agribusiness, industry, and water supply (Novaes & Carvalho 2013) occurring in the area. Additionally, it is also used as a source of livelihood for riverside communities (Agostinho et al. 2007b, 2016). The conservation of fish fauna is one of the greatest challenges faced today (Cerqueira & Smith 2015). It must be emphasized that, despite the importance of developing the country through the exploitation basin's resources, maintenance of its biodiversity is just as crucial.

Tributaries where threatened fishes occur should remain un-dammed (*e.g.,* Tibagi, Cinzas, Pirapó, and Congonhas rivers) to protect such species. Many of these endangered species migrate from long distances and present population decline mainly due to the damming of the mainstem (Agostinho et al 2003). Furthermore, the number of non-native fish species in the Paranapanema River basin is alarming. Urgent actions should be taken to promote awareness and educate the population about the environmental, social, and economic risks caused by these invasive species.

Conservation actions must be carried out by all who depend on the resources of the Paranapanema River Basin, including the appropriate use of water, reduction of fertilizers, and agrochemicals, since the preservation of sources, headwaters, tributaries, and the riparian vegetation relied upon by various species of aquatic fauna. Our findings may be used to support management actions and conservation strategies, and to identify regions within the basin that require better inventories or conservation status updates of its species.

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Author Contributions

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Conflicts of interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

Ethics

We declare that the procedures used in this study have no conflict with the Brazilian Laws regarding the use of vertebrates in scientific research.

Data availability

Our data was compiled from published literature, and appropriated cited along the manuscript.

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