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Inventory

Update on the ichthyofauna of the Piquiri River basin, Paraná, Brazil: a conservation priority area

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Abstract: Knowledge of the fish species in river basins is among the minimum requirements for the management of water and fish resources. Therefore, the aim of this study was to update the fish species composition of the Piquiri River basin, upper Paraná River basin. Data were gathered from recent information published in specialized literature and records for ichthyology collections. This update reports the occurrence of 152 fish species distributed in 8 orders, 31 families, and 89 genera. Non-native species accounted for 20% of all species, and the construction of the Itaipu Power Plant and its fish ladder were the main vectors of introduction. Three percent of the species were endangered, and 11% were classified as migratory. The Piquiri River basin harbors a large number of species, some of which are rare, endangered, migratory, endemic, and even unknown by science. Because of this, maintaining the integrity of this river basin will support the persistence of regional biodiversity.

Keywords: *Ichthyofaunal survey, species knowledge, preservation, upper Paraná River basin.*

Atualização da ictiofauna da bacia do rio Piquiri, Paraná, Brasil: uma área prioritária para conservação

Resumo: O conhecimento das espécies de peixes existentes em uma bacia hidrográfica é condição mínima necessária para a implantação de qualquer medida de manejo dos recursos hídricos e pesqueiros. Dessa forma, o objetivo deste estudo foi realizar uma atualização da composição das espécies de peixes da bacia do rio Piquiri, sistema do alto rio Paraná, proveniente de recentes informações contidas em estudos divulgados na literatura especializada e registros de espécies depositadas em coleções ictiológicas. A atualização do levantamento ictiofaunístico da bacia do rio Piquiri revelou a ocorrência de 152 espécies, as quais foram distribuídas em oito ordens, 31 famílias e 89 gêneros. Vinte por cento das espécies foram consideradas não nativas. O principal vetor de introdução foi a construção da barragem de Itaipu e seu sistema de transposição. Três por cento das espécies apresentaram alguma ameaça de extinção e 11% foram classificadas como migradoras. A bacia do rio Piquiri comporta grande número de espécies, algumas delas raras, ameaçadas de extinção, migradoras, endêmicas e até mesmo desconhecidas pela ciência. Dessa forma, a manutenção da integridade da bacia promoverá a persistência da biodiversidade regional.

Palavras-chave: *Levantamento ictiofaunístico, conhecimento das espécies, preservação, bacia do alto rio Paraná.*

Introduction

Knowing the fish species in a river basin is essential for any amount of water and fishery management (Oliveira et al. 2014, Agostinho et al. 2016). Spatial and temporal fish assemblage patterns can be understood by biotic, abiotic and spatial factors that determine fish assemblage biodiversity (Jackson et al. 2001), enabling the assessment of the environmental quality of a river system. Although much sampling has been carried out in basins to record existing ichthyofaunal compositions, several species are still unknown by science (Langeani et al. 2007, Galves et al. 2009, Frota et al. 2016a). Recent fish inventories in previously sampled areas have revealed new species (Pavanelli 2006, Frota et al. 2016a); consequently, the number of descriptions of new species has increased in recent years. It is thought that a full description of existing species is still far from being achieved (Ota et al. 2015).

In this regard, the upper Paraná River basin is no different; although recent studies have recorded 310 valid fish species and approximately 50 likely new fish species (Langeani et al. 2007), little is known about the fish fauna of the main tributaries of the upper Paraná River basin (Galves et al. 2009). Thus, information on fish assemblages, especially in the tributaries, is still scarce and most likely should be greater than currently known.

The Piquiri River is one of the main tributaries of the left bank of the upper Paraná River basin (Affonso et al. 2015), the third largest drainage area in the State of Paraná. It is highlighted as one of the last tributaries free of damming in the upper Paraná River basin (Agostinho et al. 2004, Gubiani et al. 2010, Affonso et al. 2015). This area is one of the last environments used by migratory fish during breeding displacement (Gogola et al. 2010, 2013, Gubiani et al. 2010). Despite its importance for fish assemblages, studies on its ichthyofauna composition are still scarce. Agostinho et al. (1997, 2004) registered 57 species. In Gubiani et al. (2006), the number increased to 62 species. Later, in Gubiani et al. (2010), 69 species were recorded. Additionally, recent studies have sampled small-order streams and larger tributaries of this river, increasing the specific richness of fish in the basin (Delariva & Silva 2013, Dei Tos et al. 2014).

In view of the abovementioned, this study aims to update the fish species composition of the Piquiri River, upper Paraná River basin, by scrutinizing the latest information in the literature and species records from ichthyology collections. In addition, the threat level, origin, biogeography, migratory behavior, and main current and future human impacts that may affect fish biodiversity in the basin are also discussed.

Material and Methods

1. Study area

The Piquiri River basin comprises a drainage area of approximately 25,000 km^2 (SEMA, 2010), the third largest in the State of Paraná (geographical coordinates 23°65' - 25°25' S and 51°59' - 54°07' W; Figure 1), which is approximately 12% of the Paraná state area (SEMA 2010). According to Maack (2012), its sources are located at an altitude of 1,237 m in the São João Mountains at the third plateau, south-central region of the state, and it runs 485 km before reaching the Paraná River on the border between the municipalities of Altônia and Terra Roxa. The river comprises several rapids, waterfalls, and narrow stretches, with a total fall of approximately 1,000 m from its headwaters to its mouth (Agostinho & Júlio Jr. 1999). The main tributaries of the Piquiri River are the Cantú, Tricolor, Goioerê, and Xambrê rivers on the right bank and the Sapucaia and Melissa rivers on the left bank (Paiva 1982).

Local land use is based on farming, fish farming and livestock, and soybeans, wheat, corn, sugarcane, and cassava are the primary crops. The industrial segment is related to livestock and includes industries such as dairy and cold stores. The region has undergone several changes, with few forest remnants near the municipalities of Guaraniaçu, Laranjal, and Altamira do Paraná. In the basin, there are key conservation units, such as the São Camilo Biological Reserve in Palotina, the Area of Relevant Ecological Interest of São Domingos between Roncador and Nova Cantú (Paraná 2010), and the Perobas Biological Reserve, which is located in the municipalities of Cianorte and Tuneiras do Oeste (Delariva & Silva 2013). The landscape is divided into intensive farming areas, artificial grasslands, and natural fields with small forest, urban, and industrial areas. The urban population living in the basin is approximately half a million inhabitants, of which 99% have a public water supply and only 28% have domestic effluent collection services (SEMA 2010).

2. Database

The update of the fish species was performed by consulting fish collections with a vast amount of material such as the Londrina State University Museum in Londrina (MZUEL), the Museum of Zoology of the University of São Paulo in São Paulo (MZUSP), the Capão da Imbuia Natural History Museum in Curitiba (MHNCI), the PUCRS Museum of Science and Technology in Porto Alegre (MCP), the Nupélia Ichthyology Collection of the State University of Maringá in Maringá (NUP), and the Ichthyology Collection of GERPEL of the Western Paraná State University in Toledo (CIG). The species records of these collections came from online databases, e.g., Species Link, which is an information distribution network integrating live data from diverse scientific collections (CRIA 2016). In addition, to complement the information, in September 2016, bibliographical research was performed using articles in the Thomson Reuters (ISI Web of Knowledge, apps.isiknowledge.com), Elsevier – ScienceDirect (http://www.sciencedirect.com), and Scielo (http://www.scielo.org) databases that addressed the topic of "ichthyofauna of the Piquiri River basin." The search terms in the "Topic" field were "fish* OR ichthyo* OR check list AND Piquiri River", and the searched timespan included all years up to the date of the search. The search was then refined according to the following research areas: Environmental Sciences, Ecology, Zoology, Freshwater Biology, Biodiversity, Conservation, and Fisheries and Water Resources. In addition, all articles including lists of fish species of the Piquiri River basin that were published in the journal *Check List: Journal of Species Lists and Distributions*, which is not indexed in the aforementioned databases were also included in our review. For this, the search was carried out using the option "search for articles" at the journal website (http://www.checklist.org.br/search) and searching all categories and volumes.

For a study to be included in this bibliographical research it needed to show a list of fish species caught in the Piquiri River, upper Paraná River basin, Brazil. Non-related articles were excluded based on their title, abstract or, if necessary, after a careful reading of the entire text. The articles that met the required criteria were selected and tabulated in a spreadsheet to compose the final list of fish species. After the final

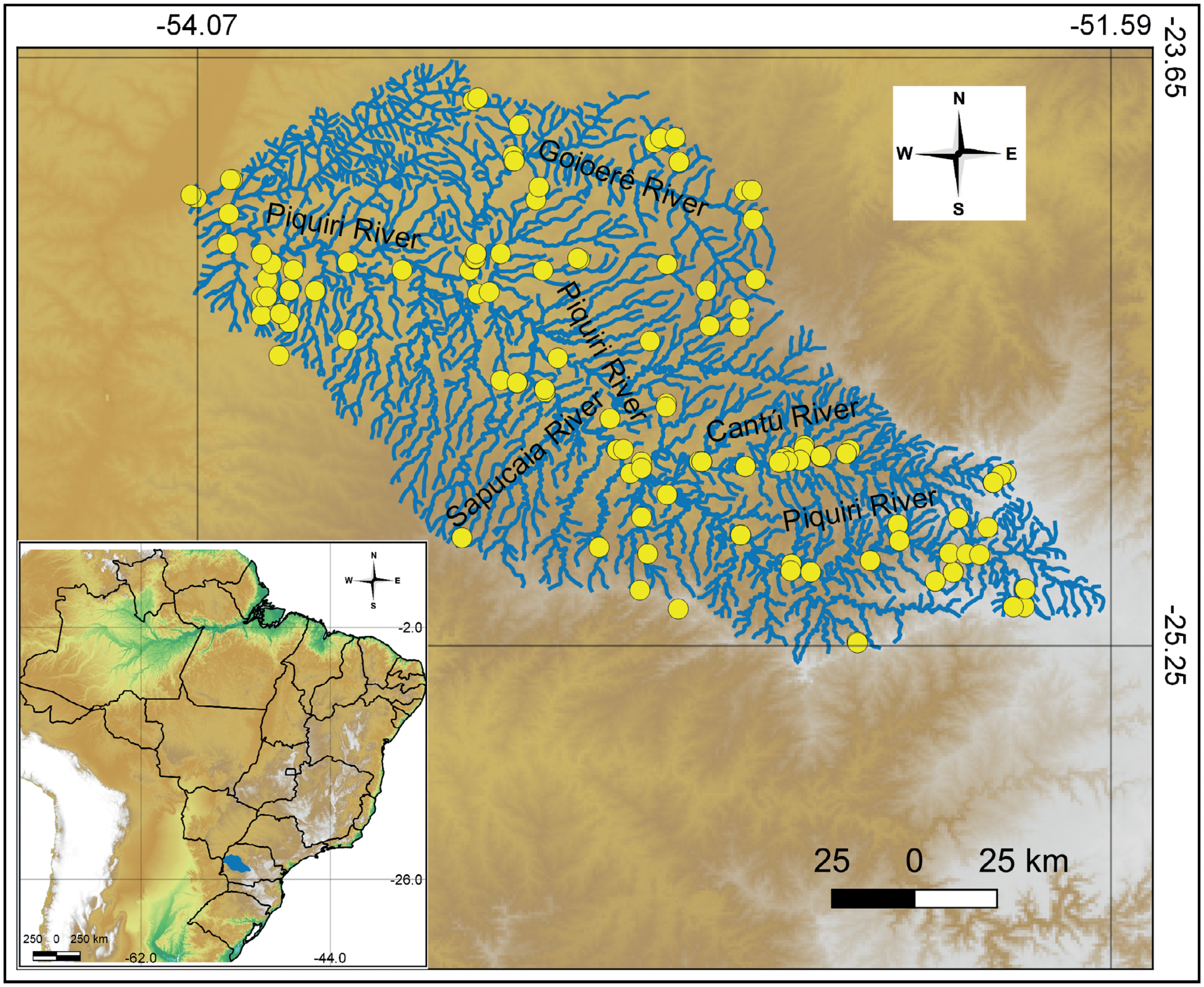

Figure 1. Map of the Piquiri River basin showing its location in Brazil and in the state of Paraná. Yellow dots indicate the sampling sites within the basin that were georeferenced and cataloged in the ichthyologic collections. Each point may correspond to more than one sampling site.

tabulation of the complete list of fish species recorded for the Piquiri River basin, the list was reviewed by experts to correct possible doubts about the occurrence or identification of fish species.

Fish species were classified based on Eschmeyer et al. (2016). However, the threat level for each species was set according to the Portaria do Ministério do Meio Ambiente, nº 445 (December 17 of 2014) (BRASIL 2014), which was amended by Decree nº 98 (April 28 of 2015) (BRASIL 2015). These regulations classify the endangered species of fish and aquatic invertebrates from the Brazilian fauna with the following categories: Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), and Vulnerable (VU). In addition, the species were categorized by origin based on the Langeani et al. (2007) method and grouped into autochthonous (native to the upper Paraná River basin), allochthonous (introduced species belonging to the Neotropical region), and exotic (from other continents) categories. If introduced, the introduction vectors were determined based on the species occurrence and distribution, as well as relevant literature, according to Reis et al. (2003), Langeani et al. (2007), Graça & Pavanelli (2007), Júlio Jr. et al. (2009) and Frota et al. (2016a). The possible causes of the occurrence of these species in the Piquiri River basin were grouped into seven categories: 1) Itaipu, species first recorded shortly after the construction of the Itaipu Dam with its native populations from the lower Paraná River basin; 2) Itaipu channel, species also coming from the lower Paraná River basin and introduced as a result of the construction and operation of the Itaipu Piracema Channel; 3) aquaculture, species widely used in the fish farms in the region; 4) baiting, species introduced by the use of natural baits for sport fishing; 5) mosquito control and aquarium purposes, species introduced for mosquito population control and species highly represented in fishkeeping; 6) sport-fishing, species introduced for sport fishing; 7) stocking, species introduced for fish stocks. In addition, species were classified according to their migratory status as proposed by Vazzoler (1996), Nakatani et al. (2001), and Agostinho et al. (2003), although only species with migratory behavior were evaluated in this way and shown in the results. Lastly, to discuss the main current and future human impacts on the region, predictions for the construction of small power plants (SPPs) and power plants (PPs) in the Piquiri River basin were mapped and computed by geographic maps of the Brazilian electric power sector (ANEEL 2016).

Results

The update on ichthyofauna diversity for the Piquiri River basin revealed 152 species distributed in 8 orders, 31 families, and 89 genera (Table 1). The orders with the highest species richness were Siluriformes (69 species) and Characiformes (59 species), representing approximately 84% of all species recorded in the basin (Figure 2). The families showing the largest species richness were Loricariidae (26 species), Characidae (23 species), Pimelodidae (14 species), Anostomidae (12 species), and Heptapteridae (10 species), comprising nearly 56% of all species (Figure 2). Fifteen of the discovered species are believed to be new to science (Table 1), representing approximately 12% of the basin's total native species.

Of all the registered species, 80% (122) are autochthonous, 18% (28) are allochthonous, and 1% (2) is exotic. Allochthonous and exotic species are considered to be non-natives in the Piquiri River basin. Among the 30 non-native species, 23 (70%; Figure 3) allochthonous fish species originated from the ichthyofauna belonging to the lower Paraná River and were introduced to the upper Paraná River during the construction of the dam and the operation of the Itaipu Piracema channel (Table 1) and are now recorded in the Piquiri River basin. *Megaleporinus macrocephalus* (Garavello & Britski, 1988), considered an allochthonous fish species, was introduced by fish farming (Table 1). In addition, *Gymnotus pantanal* Fernandes, Albert, Daniel-Silva, Lopes, Crampton, & Almeida-Toledo, 2005, *Poecilia reticulata* Peters,

Table 1. Piquiri River basin ichthyofauna according to species, voucher specimens, the origin of each species, threat level, migratory behavior, and introduction vector. The asterisk (*) represents species with migratory behavior. VU = vulnerable; EN = endangered

Species	Voucher	Origin/Threat level	Introduction Vector
ELASMOBRANCHII			
Myliobatiformes			
Potamotrygonidae			
1 *Potamotrygon amandae* Loboda & Carvalho, 2013		Allochthonous	Itaipu
2 *Potamotrygon falkneri* Castex & Maciel, 1963		Allochthonous	Itaipu
ACTINOPTERYGII			
Cypriniformes			
Cyprinidae			
3 *Cyprinus carpio* Linnaeus, 1758	CIG 2852	Exotic	Fish farming
Characiformes			
Parodontidae			
4 *Apareiodon affinis* (Steindachner, 1879)	NUP 4198	Autochthonous	–––
5 *Apareiodon piracicabae* (Eigenmann, 1907)	NUP 7090	Autochthonous	–––
6 *Apareiodon vladii* Pavanelli, 2006	NUP 15731	Autochthonous/VU	–––
7 *Parodon nasus* Kner, 1859	NUP 14654	Autochthonous	–––
Curimatidae			
8 *Cyphocharax modestus* (Fernández-Yépez, 1948)	NUP 16762	Autochthonous	–––
9 *Cyphocharax nagelii* (Steindachner, 1881)	MZUSP 42963.0	Autochthonous	–––
10 *Steindachnerina insculpta* (Fernández-Yépez, 1948)	NUP 16775	Autochthonous	–––
Prochilodontidae			
11 *Prochilodus lineatus* (Valenciennes, 1836)	NUP 14606	Autochthonous*	–––
Anostomidae			
12 *Leporellus vittatus* (Valenciennes, 1850)	NUP 4211	Autochthonous	–––
13 *Leporinus amblyrhynchus* Garavello & Britski, 1987	NUP 18154	Autochthonous	–––
14 *Leporinus friderici* (Bloch, 1794)	NUP 18152	Autochthonous	–––
15 *Leporinus lacustris* Campos, 1945		Autochthonous	–––
16 *Leporinus octofasciatus* Steindachner, 1915	CIG 2165	Autochthonous	–––
17 *Leporinus striatus* Kner, 1858	MZUSP 43092	Autochthonous	–––
18 *Megaleporinus macrocephalus* (Garavello & Britski, 1988)		Allochthonous*	Fish farming
19 *Megaleporinus obtusidens* (Valenciennes, 1836)	NUP 4206	Autochthonous*	–––
20 *Megaleporinus piavussu* (Britski, Birindelli & Garavello, 2012)	NUP 1899	Autochthonous*	–––
21 *Schizodon altoparanae* Garavello & Britski, 1990	NUP 1690	Autochthonous	–––
22 *Schizodon borellii* (Boulenger, 1900)	NUP 1768	Autochthonous	–––

Continued Table 1.

Species	Voucher	Origin/Threat level	Introduction Vector
23 *Schizodon nasutus* Kner, 1858	NUP 2481	Autochthonous	–––
Crenuchidae			
24 *Characidium* aff. *zebra* Eigenmann, 1909	NUP 16048	Autochthonous	–––
25 *Characidium gomesi* Travassos, 1956	NUP 17236	Autochthonous	–––
Characidae			
26 *Astyanax bockmanni* Vari & Castro, 2007	NUP 16689	Autochthonous	–––
27 *Astyanax* aff. *fasciatus* (Cuvier, 1829)	NUP 15622	Autochthonous	–––
28 *Astyanax* aff. *paranae* Eigenmann, 1914	NUP 16056	Autochthonous	–––
29 *Astyanax lacustris* (Lütken, 1875)	NUP 18271	Autochthonous	–––
30 *Astyanax schubarti* Britski, 1964	NUP 39	Autochthonous	–––
31 *Oligosarcus paranensis* Menezes & Géry, 1983	NUP 16052	Autochthonous	–––
32 *Oligosarcus pintoi* Campos, 1945	NUP 16739	Autochthonous	–––
33 *Oligosarcus* sp.	NUP 18992	Autochthonous	–––
34 *Psellogrammus kennedyi* (Eigenmann, 1903)	NUP 18649	Autochthonous	–––
Pristellinae			
35 *Moenkhausia gracilima* Eigenmann 1908	NUP 18648	Autochthonous	–––
36 *Moenkhausia* aff. *intermedia* Eigenmann, 1908		Autochthonous	–––
37 *Moenkhausia forestii* Benine, Mariguela & Oliveira, 2009	NUP 10680	Autochthonous	–––
38 *Moenkhausia sanctaefilomenae* (Steindachner, 1907)	NUP 10681	Autochthonous	–––
Characinae			
39 *Galeocharax knerii* (Steindachner, 1879)	NUP 257	Autochthonous	–––
40 *Roeboides descalvadensis* Fowler, 1932	NUP 4192	Allochthonous	Itaipu
Cheirodontinae			
41 *Serrapinnus notomelas* (Eigenmann, 1915)	NUP 14596	Autochthonous	–––
42 *Odontostilbe* sp.	CIG 2156	Autochthonous	–––
Stevardiinae			
43 *Bryconamericus exodon* Eigenmann, 1907	CIG 100	Allochthonous	Itaipu channel
44 *Bryconamericus* aff. *iheringii* (Boulenger, 1887)	NUP 18277	Autochthonous	–––
45 *Bryconamericus* sp.	NUP 7777	Autochthonous	–––
46 *Piabarchus stramineus* (Eigenmann, 1908)	NUP 16614	Autochthonous	–––
47 *Piabina argentea* Reinhardt, 1867	NUP 4190	Autochthonous	–––
48 *Planaltina* sp.	NUP 52	Autochthonous	–––
Bryconidae			
Bryconinae			
49 *Brycon orbignyanus* (Valenciennes, 1850)	NUP 2031	Autochthonous*/EN	–––
Salmininae			
50 *Salminus brasiliensis* (Cuvier, 1816)	NUP 1880	Autochthonous*	–––
51 *Salminus hilarii* Valenciennes, 1850	NUP 2475	Autochthonous*	–––
Serrasalmidae			
52 *Myloplus tiete* (Eigenmann & Norris, 1900)	NUP 2484	Autochthonous/EN	–––
53 *Piaractus mesopotamicus* (Holmberg, 1887)		Autochthonous*	–––
54 *Serrasalmus maculatus* Kner, 1858	NUP 4208	Autochthonous	–––
55 *Serrasalmus marginatus* Valenciennes, 1837		Allochthonous	Itaipu
Acestrorhynchidae			
56 *Acestrorhynchus lacustris* (Lütken, 1875)	NUP 18026	Autochthonous	–––

Continued Table 1.

Species	Voucher	Origin/Threat level	Introduction Vector
Hemiodontidae			
57 *Hemiodus orthonops* Eigenmann & Kennedy, 1903	NUP 18153	Allochthonous	Itaipu channel
Cynodontidae			
58 *Rhaphiodon vulpinus* Spix & Agassiz, 1829		Autochthonous*	–––
Erythrinidae			
59 *Hoplias intermedius* (Günther, 1864)	NUP 271	Autochthonous	–––
60 *Hoplias mbigua* Azpelicueta, Benítez, Aichino & Mendez, 2015	NUP 4253	Allochthonous	Itaipu
61 *Hoplias* sp. 2	NUP 18042	Autochthonous	–––
62 *Hoplias* sp. 3	NUP 15792	Autochthonous	–––
Siluriformes			
Cetopsidae			
63 *Cetopsis gobioides* (Kner, 1858)	NUP 16777	Autochthonous	–––
Trichomycteridae			
64 *Trichomycterus* aff. *davisi* (Haseman, 1911)	NUP 16086	Autochthonous	–––
65 *Trichomycterus* cf. *stawiarski* (Miranda Ribeiro, 1968	NUP 18858	Autochthonous	–––
Callichthyidae			
Callichthyinae			
66 *Callichthys callichthys* (Linnaeus, 1758)	NUP 16088	Autochthonous	–––
67 *Hoplosternum littorale* (Hancock, 1828)		Autochthonous	–––
Corydoradinae			
68 *Corydoras aeneus* (Gill, 1858)	NUP 16087	Autochthonous	–––
Loricariidae			
Hypoptopomatinae			
69 *Hisonotus* sp.	NUP 16050	Autochthonous	–––
Hypostominae			
70 *Ancistrus* sp.	NUP 15757	Autochthonous	–––
71 *Hypostomus albopunctatus* (Regan, 1908)	NUP 13532	Autochthonous	–––
72 *Hypostomus ancistroides* (Ihering, 1911)	NUP 17235	Autochthonous	–––
73 *Hypostomus cochliodon* Kner, 1854	NUP 5604	Allochthonous	Itaipu
74 *Hypostomus commersoni* Valenciennes, 1836	CIG 1514	Allochthonous	Itaipu
75 *Hypostomus hermanni* (Ihering, 1905)	NUP 9085	Autochthonous	–––
76 *Hypostomus iheringii* (Regan, 1908)	NUP 5594	Autochthonous	–––
77 *Hypostomus margaritifer* (Regan, 1908)	NUP 5602	Autochthonous	–––
78 *Hypostomus* aff. *paulinus* (Ihering, 1905)	NUP 5583	Autochthonous	–––
79 *Hypostomus regani* (Ihering, 1905)	NUP 13534	Autochthonous	–––
80 *Hypostomus strigaticeps* (Regan, 1908)	NUP 14441	Autochthonous	–––
81 *Hypostomus* cf. *topavae* (Godoy, 1969)	NUP 11430	Autochthonous	–––
82 *Hypostomus* cf. *tietensis* (Ihering, 1905)	NUP 18045	Autochthonous	–––
83 *Hypostomus* sp. 1	NUP 5581	Autochthonous	–––
84 *Hypostomus* sp. 2	NUP 9656	Autochthonous	–––
85 *Hypostomus* sp. 3	NUP 9653	Autochthonous	–––
86 *Megalancistrus parananus* (Peters, 1881)	NUP 14680	Autochthonous	–––
87 *Pterygoplichthys ambrosettii* (Holmberg, 1893)	NUP 16708	Allochthonous	Itaipu
88 *Rhinelepis aspera* Spix & Agassiz, 1829		Autochthonous*	–––

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Continued Table 1.

Species	Voucher	Origin/Threat level	Introduction Vector
Loricariinae			
89 *Farlowella hahni* Meinken, 1937	NUP 16781	Autochthonous	---
90 *Loricaria* sp.		Autochthonous	---
91 *Loricariichthys platymetopon* Isbrücker & Nijssen, 1979	NUP 18725	Allochthonous	Itaipu
92 *Loricariichthys rostratus* Reis & Pereira, 2000	NUP 18728	Allochthonous	Itaipu
93 *Rineloricaria* cf. *latirostris* (Boulenger, 1900)	NUP 8936	Autochthonous	---
Neoplecostominae			
94 *Neoplecostomus* sp.	NUP 15758	Autochthonous	---
Pseudopimelodidae			
95 *Pseudopimelodus mangurus* (Valenciennes, 1835)	NUP 2482	Autochthonous	---
96 *Pseudopimelodus pulcher* (Boulenger, 1887)	NUP 18030	Autochthonous	---
Heptapteridae			
97 *Cetopsorhamdia iheringi* Schubart & Gomes, 1959	NUP 16727	Autochthonous	---
98 *Heptapterus mustelinus* (Vallenciennes, 1835)	CIG 1685	Autochthonous	---
99 *Imparfinis borodini* Mees & Cala, 1989	NUP 14641	Autochthonous	---
100 *Imparfinis mirini* Haseman, 1911	NUP 14592	Autochthonous	---
101 *Imparfinis schubarti* (Gomes, 1956)	NUP 16651	Autochthonous	---
102 *Phenacorhamdia tenebrosa* (Schubart, 1964)	NUP 16726	Autochthonous	---
103 *Pimelodella avanhandavae* Eigenmann, 1917	NUP 16692	Autochthonous	---
104 *Pimelodella gracilis* (Valenciennes, 1835)	NUP 14590	Autochthonous	---
105 *Pimelodella taenioptera* Miranda-Ribeiro, 1914	CIG 82	Allochthonous	Itaipu channel
106 *Rhamdia quelen* (Quoy & Gaimard, 1824)	NUP 15759	Autochthonous	---
Pimelodidae			
107 *Hemisorubim platyrhynchos* (Valenciennes, 1840)		Autochthonous*	---
108 *Hypophthalmus oremaculatus* Nani & Fuster, 1947		Autochthonous	---
109 *Iheringichthys labrosus* (Lütken, 1874)	NUP 18726	Autochthonous	---
110 *Iheringichthys* sp.	NUP 14937	Autochthonous	---
111 *Megalonema platanum* (Gunther, 1880)	NUP 4209	Autochthonous	---
112 *Pimelodus microstoma* Steindachner, 1877	NUP 18158	Autochthonous	---
113 *Pimelodus mysteriosus* Azpelicueta, 1998	NUP 17275	Allochthonous	Itaipu
114 *Pimelodus ornatus* Kner, 1858	NUP 4212	Allochthonous	Itaipu
115 *Pimelodus paranaensis* Britski & Langeani, 1988	NUP 14936	Autochthonous	---
116 *Pinirampus pirinampu* (Spix & Agassiz 1829)		Autochthonous*	---
117 *Pseudoplatystoma corruscans* (Spix & Agassiz, 1829)	CIG 89	Autochthonous*	---
118 *Sorubim lima* (Bloch & Shneider, 1801)	NUP 2480	Autochthonous*	---
119 *Steindachneridion scriptum* (Miranda-Ribeiro, 1918)	CIG 1675	Autochthonous*/EN	---
120 *Zungaro jahu* (Ihering, 1898)		Autochthonous*	---
Doradidae			
121 *Ossancora eigenmanni* (Boulenger, 1895)	NUP 1706	Allochthonous	Itaipu
122 *Pterodoras granulosus* (Valenciennes, 1821)		Allochthonous*	Itaipu
123 *Rhinodoras dorbignyi* (Kner, 1855)	NUP 1701	Autochthonous	---
124 *Trachydoras paraguayensis* (Eigenmann & Ward, 1907)	NUP 1696	Allochthonous	Itaipu
Auchenipteridae			
Auchenipterinae			
125 *Ageneiosus inermis* (Linnaeus, 1766)	NUP 2010	Allochthonous	Itaipu

Continued Table 1.

Species	Voucher	Origin/Threat level	Introduction Vector
126 *Ageneiosus militaris* Valenciennes, 1836	NUP 1935	Autochthonous	–––
127 *Ageneiosus ucayalensis* Castelnau, 1855		Allochthonous	Itaipu
128 *Auchenipterus osteomystax* (Miranda-Ribeiro, 1918)		Autochthonous	–––
129 *Trachelyopterus galeatus* (Linnaeus, 1766)	NUP 1702	Allochthonous	Itaipu
Centromochlinae			
130 *Glanidium cesarpintoi* Ihering, 1928	NUP 5455	Autochthonous	–––
131 *Tatia neivai* (Ihering, 1930)	NUP 18031	Autochthonous	–––
Gymnotiformes			
Gymnotidae			
132 *Gymnotus inaequilabiatus* (Valenciennes, 1839)	NUP 18164	Autochthonous	–––
133 *Gymnotus pantanal* Fernandes, Albert, Daniel-Silva, Lopes, Crampton, & Almeida-Toledo, 2005	NUP 14628	Allochthonous	Baiting
134 *Gymnotus sylvius* Albert & Fernandes-Matioli, 1999	NUP 14593	Autochthonous	–––
Sternopygidae			
135 *Eigenmannia trilineata* López e Castello, 1966	CIG 2184	Autochthonous	–––
136 *Eigenmannia virescens* (Valenciennes, 1836)	CIG 103	Autochthonous	–––
137 *Sternopygus macrurus* (Bloch & Shneider, 1801)	CIG 1649	Autochthonous	–––
Rhamphichthydae			
138 *Rhamphichthys hahni* (Meinken, 1937)	NUP 1708	Allochthonous	Itaipu
Apteronotidae			
139 *Apteronotus* aff. *albifrons* (Linnaeus, 1766)	NUP 16760	Allochthonous	Itaipu
140 *Porotergus ellisi* Arámburu, 1957	NUP 2092	Autochthonous	–––
Cyprinodontiformes			
Poeciliidae			
141 *Phalloceros harpagos* Lucinda, 2008	NUP 15967	Autochthonous	–––
142 *Poecilia reticulata* Peters, 1859	NUP 3131	Allochthonous	Mosquito control and aquarism
Synbranchiformes			
Synbranchidae			
143 *Synbranchus marmoratus* Bloch, 1795	NUP 11702	Autochthonous	–––
Perciformes			
Cichlidae			
144 *Cichla piquiti* Kullander & Ferreira, 2006		Allochthonous	Sport-fishing
145 *Cichlasoma paranaense* Kullander, 1983	NUP 14597	Autochthonous	–––
146 *Crenicichla britskii* Kullander, 1982	NUP 16737	Autochthonous	–––
147 *Crenicichla jaguarensis* Haseman, 1911	NUP 18040	Autochthonous	–––
148 *Crenicichla jupiaensis* Britski & Luengo, 1968	NUP 14892	Autochthonous/EN	–––
149 *Crenicichla* sp.	NUP 5446	Autochthonous	–––
150 *Geophagus* aff. *brasiliensis* (Quoy & Gaimard, 1824)	NUP 15643	Autochthonous	–––
151 *Oreochromis niloticus* (Linnaeus, 1758)	NUP 15918	Exotic	Fish farming
Sciaenidae			
152 *Plagioscion squamosissimus* (Heckel, 1840)		Allochthonous	Stocking

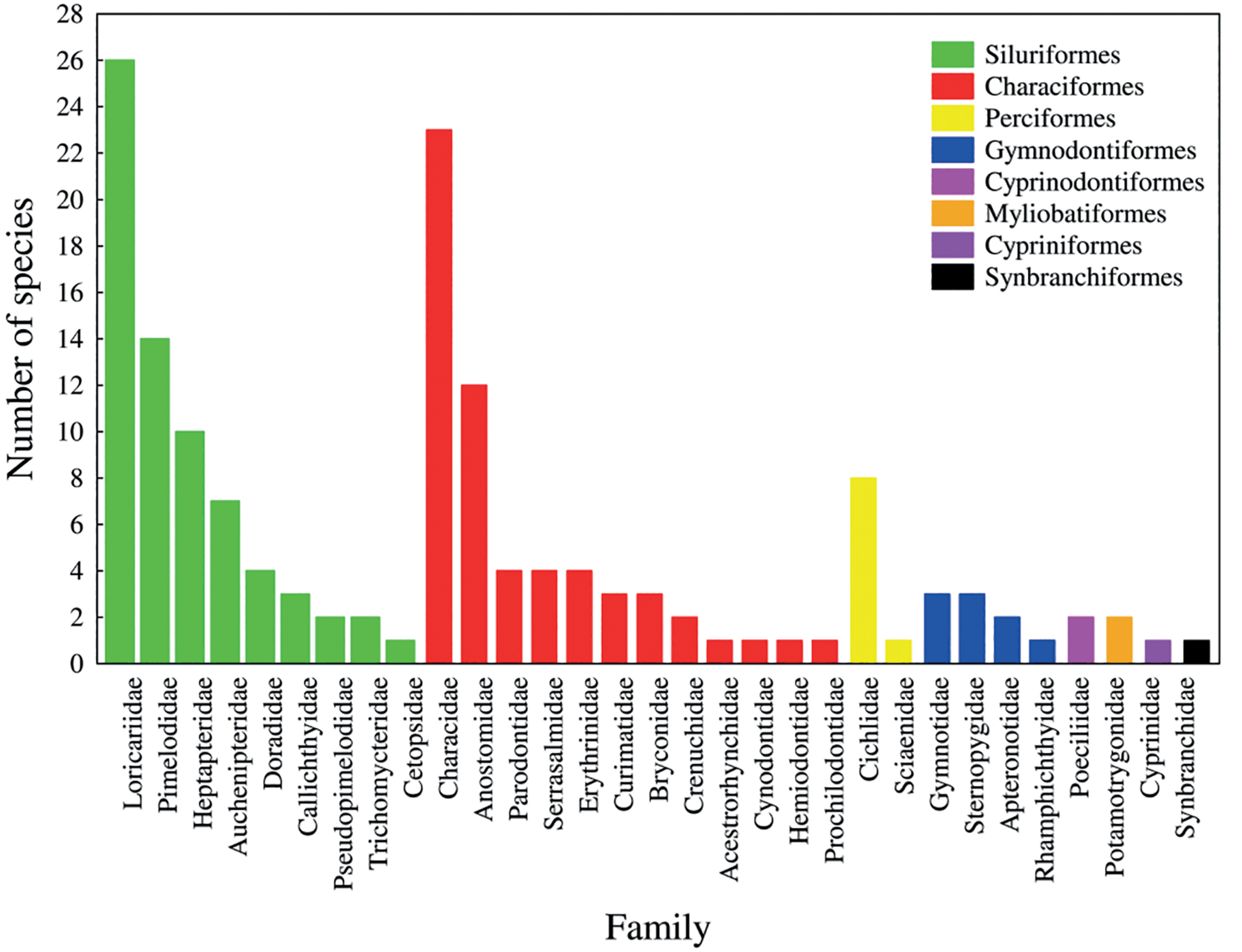

Figure 2. Number of species per family of the ichthyofauna recorded for the Piquiri River basin, upper Paraná River, Brazil. Colors indicate the orders, namely from the most to the less specific.

1859, *Cichla piquiti* Kullander & Ferreira, 2006 and *Plagioscion squamosissimus* (Heckel, 1840), also considered allochthonous fish species, were introduced by baiting, mosquito control and aquarism, sport fishing and stocking, respectively (Table 1). Two other exotic species, *Cyprinus carpio* Linnaeus, 1758 and *Oreochromis niloticus* (Linnaeus, 1758) were introduced by fish farming (Table 1). Thus, the main vectors of introduction of the fish species in the Piquiri River basin were Itaipu (67% of the fish species introduced), Itaipu channel (10%) and fish farming (10%) (Figure 3).

Of the 152 species recorded here, approximately 3% (5 species) were classified with a threat level (Table 1). *Apareiodon vladii* Pavanelli (2006) showed a vulnerable conservation status (VU) and is considered at high risk of extinction in the wild, while *Brycon orbignyanus* (Valenciennes 1850), *Myloplus tiete* (Eigenmann & Norris, 1900), *Steindachneridion scriptum* (Miranda-Ribeiro, 1918), and *Crenicichla jupiaensis* Britski & Luengo (1968) were designated as endangered conservation status (EN), i.e., they face a very high risk of extinction in the wild.

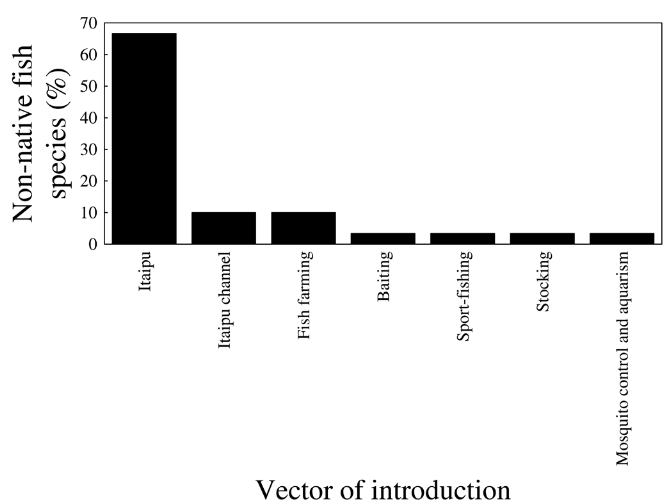

Figure 3. Non-native fish species according to their introduction vectors into the Piquiri River basin, upper Paraná River, Brazil.

Seventeen fish species recorded in the Piquiri River basin have migratory behavior – (11%, Table 1). In addition, *Brycon orbignyanus* (Valenciennes, 1850) and *Steindachneridion scriptum* (Miranda-Ribeiro, 1918) are listed as endangered in threat level status.

Discussion

The outcomes of the update reveal 152 fish species, many which have already been reported by Graça & Pavanelli (2007), in the floodplain of the upper Paraná River and bordering areas. Although the Piquiri River drainage basin is partly within this floodplain, our results point to an intimate association between the basin and the maintenance of ichthyofauna biodiversity in this stretch of the upper Paraná River. This is because the studied river is one of the last refuge areas for a great proportion of the remaining native ichthyofauna (Baumgartner et al. 2004, Antonio et al. 2007, Gubiani et al. 2010, Affonso et al. 2015).

Ichthyofauna survey. The current survey discloses a much higher number of fish species than that recorded by Gubiani et al. (2006, 2010), who reported 62 and 69 species in 2006 and 2010, respectively. This new update represents a nearly 120% increase in the number of species recorded in the basin since the last list was released. When comparing the ichthyofauna found in the basins located in the State of Paraná, the Piquiri River basin has an absolute richness of fish species that is higher than the richness of the Pirapó basin (76 species, Pagotto et al. 2012), the Ivaí River basin (118 species, Frota et al. 2016a), the upper and lower Iguaçu River basin (41 and 106 species respectively, Ingenito et al. 2004, Baumgartner et al. 2012), and the Tibagi River basin (151 species, Raio & Bennemann 2010). Approximately 49% of the species listed here were coincident with those recorded for the upper Paraná River (see Langeani et al. 2007).

Introduced species. Most of the species introduced into the Piquiri River basin dispersed after the construction of the Itaipu Dam. After the dam was closed, the Sete Quedas, a natural geographic barrier separating two ichthyofauna provinces, was flooded. This area comprises the mid-lower and upper Paraná River within the city of Guaíra (Graça & Pavanelli 2007, Vitule et al. 2012). Consequently, many fish species previously isolated by this barrier were introduced into the upper Paraná River basin (Júlio Jr. et al. 2009, Vitule et al. 2012). Hence, after the closing of Itaipu Dam (see Júlio Jr. et al. 2009), 23 of the introduced species were recorded in the Piquiri River basin. Conversely, the occurrence of some species such as *Bryconamericus exodon*, *Hemiodus orthonops*, and *Pimelodella taenioptera*, is not related to the flooding of the Sete Quedas but is related to the functioning of the Itaipu Piracema channel, a passage for fish downstream and upstream of the Itaipu Dam (Graça & Pavanelli 2007, Júlio Jr. et al. 2009). This channel is envisaged as a continuous source of fish species introduced to the upper Paraná River basin (Agostinho et al. 2015).

Transposition systems that can be used as fish passages have been among the main strategies in an endeavor by the Brazilian authorities and electric power sector to reduce the damming effects on populations of migratory fish (Pompeu et al. 2012). Nonetheless, in addition to contributing to the rise of non-native fish, such systems have been identified as true ecological traps in some Brazilian dams, and their closure should be required (Pelicice & Agostinho 2008, Agostinho et al. 2012, Pompeu et al. 2012). These facts, which are related to the construction and functioning of the Itaipu Power Plant, are an indication that a biotic homogenization process is ongoing in the ichthyofauna of the upper Paraná River basin. These processes consequently lead to a decrease in taxonomic, genetic, and/or functional differences in the previously described biota (Olden 2006, Daga et al. 2015). Therefore, the construction of dams are a major form of global biodiversity loss and has been considered an unacceptable environmental alteration (Rockström et al. 2009, Stigall 2010, Vitule et al. 2012).

In addition, there are an alarming number of cases of species introduced by stocking, sport fishing, live bait use, control of mosquitoes, and fishkeeping (see Daga et al. 2015; Ribeiro et al. 2017). For instance, curvina (*Plagioscion squamosissimus*), a species introduced for stocking purposes, poses a threat to the other piscivorous species in the Piquiri River basin because it feeds on the same sources and is, most likely, a strong competitor (Pereira et al. 2015). The excellent visual predator, *Cichla piquiti*, has been illegally introduced throughout the country mainly for sport fishing and represents a threat to the diversity of native fish (Pelicice & Agostinho 2009; Pelicice et al. 2015) in the Piquiri River basin. All *Gymnotus* species are often used as live bait, which might cause releases between basins by ill-informed fishers. Although only *G. pantanal* is considered allochthonous, the other species of the genus have truly uncertain origins (Júlio Jr. et al. 2009). In addition, morphometric data show no differences among populations of *G. inaequilabiatus* from various sites of the upper Paraná River (Frota et al. 2014). *Poecilia reticulata* has been widespread worldwide as an ornamental animal and mosquito larvae control agent (Dussalt & Kramer 1981, Azevedo-Santos et al. 2016). This species is considered to be one of the most abundant in rural and urban streams at present (Oliveira & Bennemann 2005, Cunico et al. 2012, Pereira et al. 2014) likely because of its high resistance and resilience (Gomiero & Braga 2007, Daga et al. 2012) in addition to its high competitive efficiency against competition from invasive and native species (Pompeu & Alves 2003).

Another important vector of species introduction in aquatic environments is the escapes arising from fish farming. The Federal Law nº 5989 of 2009 intends to naturalize non-native fish species by decree in Brazil. Following this proposal, *Cyprinus carpio* and *Oreochromis niloticus*, which are non-native species, would end up being naturalized in the Piquiri River basin; therefore, they would be perceived as natural and can be used without legal restrictions in fish farming (Padial et al. 2017). Around the Piquiri River basin, innumerable fish farms are settled and breeding non-native species that show a high invasion risk (Lima Jr. et al. 2012, Pelicice et al. 2014, Forneck et al. 2016). Several authors have asserted the invading potential arising from fish farms and the negative effects of new introductions (Orsi & Agostinho 1999, Daga et al. 2015, Daga et al. 2016, Lima et al. 2016).

Endangered species. Environments with species listed in the vulnerable and endangered categories should be prioritized for conservation since the most likely evidence assigns them as highly and very highly endangered in the wild, respectively (IUCN 2017). The species of the Piquiri River basin listed in these categories are rare, so their population survival will depend narrowly on their tolerance to the biotic and abiotic changes occurring in the basin. Registered endangered species have rheophilic habits, are migratory (*Brycon orbignyanus* and *Steindachneridion scriptum*), and require allochthonous food sources (*Brycon orbignyanus* and *Myloplus tiete*) (Machado et al. 2008). The construction of dams, therefore, will lead to extreme changes in river habitats, turning rivers into semi-lentic systems, which exerts an intense negative effect on the fish species (Agostinho et al. 2016; Pelicice et al. 2017).

Migratory behavior and construction of electric power stations. Like other major tributaries of the floodplain of the upper Paraná River, the Piquiri River basin is used as a spawning ground for migratory fish (Baumgartner et al. 2004, Gubiani et al. 2010, Gogola et al. 2013). A vast majority of migratory species living in the basin are made up of large fish with relative ecological and economic importance to the region, such as pimelodida catfish, *Salminus* spp., *Leporinus* spp., *Brycon orbignyanus*, *Piaractus mesopotamicus*, and *Prochilodus lineatus* (Hoeinghaus et al. 2009). Recreational fishing of large migratory fish from the Piquiri River basin also poses a serious threat because it can alter the structure and production of the population stocks (Cooke & Cowx 2004).

In the coming years, the construction of 34 SPPs and 6 PPs, which must be installed within the main channel of the Piquiri River and its important tributaries, is expected (Figure 4). Some of these locations will continue to have no ichthyofaunal sampling prior to construction, particularly locations in Piquiri River tributaries such as the Sapucaia River (Figures 1 and 4). The electric power installations planned for the basin area would prevent fish access to ideal habitats, thus affecting fish distribution and reproduction and fishing in addition to influencing the basin landscape, causing serious ecosystemic effects (Affonso et al. 2015). The nature and intensity of the changes on aquatic biota are highly variable between reservoirs and should be studied on a case-by-case basis (Agostinho et al. 2016). However, overall, the dams cause extreme changes in the hydrological regime (Thomaz et al. 2004) as well as changes in the longitudinal distribution of fish species (Petry et al. 2011). Thus, electric power enterprises in the Piquiri River basin should be discussed in public hearings with joint initiatives undertaken by citizens, law specialists, and universities (Affonso et al. 2015).

New species and biogeography. The species recorded as new in this study account for a total percentage quite near that shown for the entire basin of the upper Paraná River (14% in Langeani et al. 2007). This shows that even with the increasing number of species descriptions over time, the knowledge of the actual number of animal species and respective geographical distributions in the area is far from complete (Ota et al. 2015). A great part of the new findings in the Piquiri River basin arose from an increased sampling effort for several scientific purposes. Therefore, the continuity of these samplings will undoubtedly reveal accurate data on new endangered populations. As such, similar efforts should be carefully extended to sites with no sampling efforts, and sites where the construction of PPs and SPPs are planned.

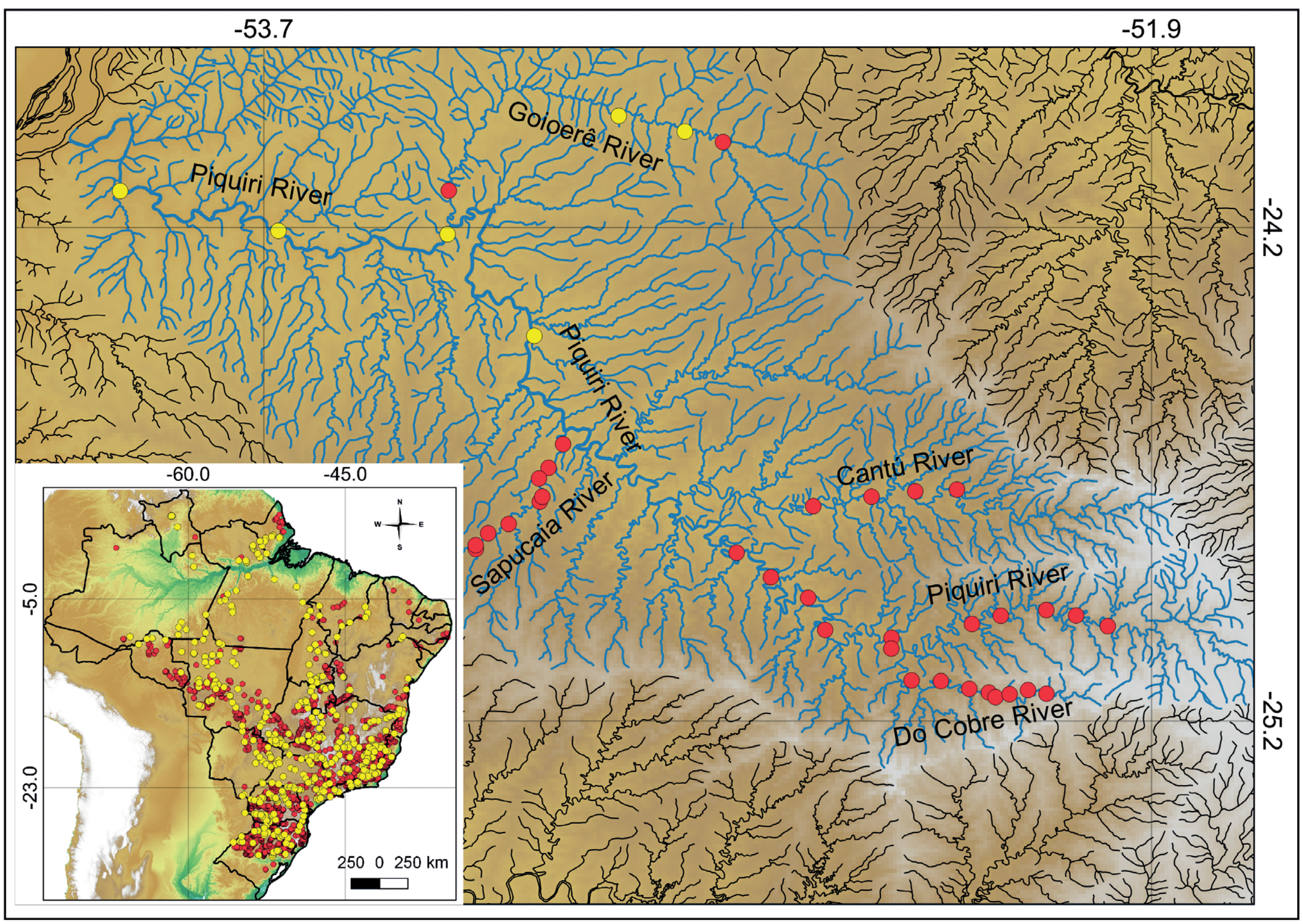

Figure 4. Map showing the locations of small power plants (SPPs, red dots) and power plants (PPs, yellow dots) predicted in Brazil, mainly within the Piquiri River basin (catchment area in blue). The number of localities within the Piquiri River basin represents 34 SPPs and 6 PPs.

From an ichthyofaunal standpoint, the upper Paraná River basin encompasses a unique historical area, which is complex and partly shared with neighboring drainage areas (Langeani et al. 2007). One likely area of endemism exists in the headwater streams, mainly in the upper section of the Piquiri River basin. In such high altitudes, *Trichomycterus* cf. *stawiarski* and *Planaltina* sp. are shared, respectively, with the basins of the Jordão (lower Iguaçu River) and Ivaí (upper Paraná River) Rivers. The former species is reported as endemic to the Iguaçu River basin (Baumgartner et al. 2012), while the latter is regarded as endemic to the upper Ivaí River basin (Frota et al. 2016a). Therefore, the presence of these species in the Piquiri River basin suggests past connections between the upper courses of those basins that might have occurred prior to the uplift of Serra da Esperança, which caused the isolation of the respective headwaters (Frota et al. 2016b). Thus, the identification of an endemic zone in the neighboring region between the Piquiri, Ivaí, and Jordão basins would allow an improved understanding of the local biota evolution (Morrone 1994) in addition to a prioritization of its value for biodiversity conservation purposes (Löwenberg-Neto & Carvalho 2004).

Conclusions

In conclusion, the Piquiri River basin holds a large number of species, and some of these species are rare, endangered, migratory, endemic, and even unknown by science. This study and the various present and future threats to the fish biodiversity of the Piquiri River basin point to the potential disappearance of certain species before their actual distribution patterns are known or before they are known or formally described (e.g., *Wallacean* and *Linnean shortfalls*, Brown & Lomolino 1998). Therefore, this environment must be preserved so that the local and regional fish fauna biodiversity can be maintained, particularly since this area can be considered a high conservation area. Furthermore, ongoing studies on the systematics, biology, and ecology of fish species, as well as suitable strategies to mitigate potential ecological, sociological, and economic impacts on them, may help improve and accomplish the goals of conservationists.

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Author Contributions

Daiane Cavalli and Éder André Gubiani: conceived, designed the samplings and wrote the paper.

Augusto Frota: contributed to data acquisition, analysis and interpretation of data, drafting of the manuscript and wrote the paper.

Weferson Júnio da Graça: contributed to the analysisand interpretation of data, and critical revision for adding substantive intellectual content.

Angelica Dorigon Lira: contributed to data acquisition, analysis of the data and wrote the paper

Vladimir Pavan Margarido: contributed to data acquisition and critical revision for adding substantive intellectual content.

Conflicts of interest

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

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