



A new inventory for fishes of headwater streams from the rio das Cinzas and rio Itararé basins, rio Paranapanema system, Paraná, Brazil

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Abstract: The rio das Cinzas and rio Itararé basins are important tributaries of the rio Paranapanema, a major left-bank tributary of the upper rio Paraná basin. The upper reaches of both drainages intersect the northern portion of the APA Escarpa Devoniana (Devonian Escarpment Environment Protection Area, EPA), an area considered crucial for the preservation of biodiversity. This study aimed to provide an ichthyofaunistic inventory for headwater streams of the rio das Cinzas and rio Itararé basins, both within and off of the borders of the EPA, increasing the knowledge about the species already known from streams in the rio Paranapanema system. We found 32 fish species, representing five orders and 12 families. Siluriformes was the richest order followed by Characiformes. Ten species presented high abundance of sampled individuals, contributing with 85.0% of all specimens. Most species were classified as occasional (captured in less than 25% of the samples) and only two species were classified as constant (captured in more than 50% of samples), which may reflect the altitudinal gradient. We did not record any introduced species in the sampled streams, reinforcing the need of, at least, maintaining the original area of the EPA. We expanded the geographic distribution of *Astyanax bifasciatus* to the upper rio Paraná system, confirming the cases of faunal exchange among several drainage systems in the limits of the Ponta Grossa Arch. Finally, we identified three putatively undescribed species that show a large biodiversity knowledge shortfall for the region studied.

Keywords: *Altitudinal gradient, Devonian Escarpment, faunal exchange, upper rio Paraná.*

Um novo inventário para peixes de riachos de cabeceira das bacias dos rio das Cinzas e rio Itararé, sistema do rio Paranapanema, Paraná, Brasil

Resumo: As bacias do rio das Cinzas e do rio Itararé são afluentes importantes do rio Paranapanema, um dos principais afluentes da margem esquerda do alto rio Paraná. Os trechos superiores de ambas as drenagens interceptam a porção norte da Área de Proteção Ambiental (APA) da Escarpa Devoniana, uma área considerada crucial para a preservação da biodiversidade. Este trabalho teve como objetivo fornecer um inventário ictiofaunístico para riachos de cabeceira das bacias do rio das Cinzas e do rio Itararé, dentro e fora das fronteiras da APA, aumentando o conhecimento sobre as espécies já conhecidas dos riachos do rio Paranapanema. Encontramos 32 espécies de peixes, representando cinco ordens e 12 famílias. Siluriformes foi a ordem mais rica seguida por Characiformes. Dez espécies apresentaram alta abundância de indivíduos amostrados, contribuindo com 85,0% de todos os espécimes. A maioria das espécies foi classificada como ocasional (capturada em menos de 25% das amostras) e apenas duas espécies foram classificadas como constantes (capturadas em mais de 50% das amostras), o que pode refletir o gradiente altitudinal. Não registramos nenhuma espécie introduzida nos riachos amostrados, reforçando a necessidade de, pelo menos, manter a área original do APA. Expandimos a distribuição geográfica de *Astyanax bifasciatus* para o sistema do alto rio Paraná, confirmando os casos de intercâmbio faunístico entre vários sistemas de drenagem nos limites do Arco de Ponta Grossa. Finalmente, identificamos três espécies supostamente não descritas que mostram um grande déficit de conhecimento da biodiversidade para a região estudada.

Palavras-chave: *Alto rio Paraná, Escarpa Devoniana, gradiente altitudinal, intercâmbio faunístico.*

Introduction

Freshwater environments provide numerous ecosystem goods and services that will be lost due to the rapid degradation of aquatic bodies by human activity (Azevedo-Santos et al. 2019a). Local biodiversity inventories are essential in environmental management projects, and provide support for studies involving ecological or biogeographic aspects (Oliveira et al. 2014; Frota et al. 2019). Given that many species in the Neotropical region remain undescribed (Ota et al. 2015) or poorly known, species inventories are essential for widening the known geographic range of the species, and also favor the discovery of new species (Carvalho 2009; Whittaker et al. 2005). In this way, the conservationist practice can only be realized knowing the biodiversity that is intended to be conserved, and inventories are crucial for this finality (Carvalho 2009).

The Neotropical region, the most ichthyologically rich biogeographical domain in the world, comprises about 9,000 fish species (Birindelli & Sidlauskas 2018). Of these, many are small and inhabit mostly low-order watercourses (Castro 1999; Winemiller et al. 2008), which are estimated to harbor about 50% of the freshwater fish richness in the tropics (Lowe-McConnell 1999; Winemiller et al. 2008). Even the highly impacted upper rio Paraná system has an estimated 310 species (236 natives), a number outdated by twelve years (Langeani et al. 2007).

Most of the sampling effort that yielded specimens from the rio Paraná basin is due to projects sponsored by the electrical sector, as a consequence of the intense damming to which the basin is subject (Baumgartner et al. 2012). However, these projects focused mostly on larger rivers and, until recently, low-order streams (especially in the Paraná State) still lacked samplings. This scenario changed in recent years as researchers started to focus ecological and biogeographical aspects of several sub-basins of the alto rio Paraná system, increasing our knowledge about the fish species resident in its streams (e.g., Castro et al. 2003; Cetra et al. 2012; Cionek et al. 2012; Pagotto et al. 2012; Costa et al. 2013; Hoffmann et al. 2015; Cetra et al. 2016; Frota et al. 2016a,b; Larentis et al. 2016; Cavalli et al. 2018; Delariva et al. 2018; Claro-García et al. 2018; Frota et al. 2019).

The rio Paranapanema covers about 900 km (most of which defining the border between Paraná and São Paulo states) from its headwaters in the Serra de Paranapiacaba (São Paulo State) to its mouth in the rio Paraná, being one of its major left-bank tributaries (Ziesler & Ardizzone 1979). Ichthyofaunistic inventories are available for some of the main sub-basins of the rio Paranapanema system within the Paraná State (Shibatta et al. 2002; Castro et al. 2003; Cetra et al. 2012; Cionek et al. 2012; Pagotto et al. 2012; Costa et al. 2013; Hoffmann et al. 2015; Cetra et al. 2016; Claro-García et al. 2018), but the fishes from the rio das Cinzas and rio Itararé basins remain unknown to the scientific literature, except for one tributary of the former (Costa et al. 2013) and a few streams draining into the latter (Cetra et al. 2016). Thus, this study aimed to provide a new, more inclusive fish inventory for headwater streams of the rio das Cinzas and rio Itararé basins in the Paraná State.

Material and Methods

1. Study area

The rio das Cinzas basin is the main watercourse of the Norte Pioneiro mesoregion of the Paraná State. Its headwaters are located in the Serra de Furnas, in the municipality of Pirai do Sul, west of the

Devonian Escarpment. With a 9,613 km² watershed encompassing about 5% of the area and 3% of the population of Paraná State (Paraná 2010) and a 240 km course, it forms the border between the municipalities of Santa Mariana and Itambaracá and is one of the main tributaries of the Capivara dam, situated in the rio Paranapanema main channel. The ribeirão Grande, ribeirão Jaboticabal, ribeirão Vermelho, and the rio Laranjinha are the main tributaries of the rio das Cinzas.

The rio Itararé basin is located in the Paraná and São Paulo states. It is born on the border between the municipalities of Bom Sucesso de Itararé (São Paulo State), and Sengés (Paraná State), and runs through much of Northeast of Paraná State until it empties into the rio Paranapanema between the municipalities of Ribeirão Claro (Paraná State) and Timburi (São Paulo State). This watershed has a total area of approximately 4,845 km², encompassing about 3% of the area and 1% of the population of the Paraná State. Its main tributaries situated in the Paraná State are the rio Jaguariaíva and rio Jaguaricatu, which flow into its left bank (Paraná 2010).

Within the rio das Cinzas and rio Itararé basins some protected areas are guaranteed by the National System of Conservation Units of Nature in Brazil, despite of imminent political attacks that are underway (see Alves et al. 2019). Between the municipalities of Cornélio Procópio and Santa Mariana is the Mata São Francisco State Park with 833 ha of Seasonal Forest, in addition to the Mina Velha State Park, in the municipality of Ibaiti, which has remnants of Araucaria forest (Paraná 2010). The Southern portion of the basin, in the municipalities of Pirai do Sul and Jaguariaíva, composes the Environment Protection Area (EPA) of Devonian Escarpment, whose Northern portion includes the rio Itararé, between the municipalities of Jaguariaíva and Sengés. This EPA is a crucial area for biodiversity preservation because it comprises within its limits important State and National Parks, Private Reserve of Natural Heritage, and integrates important Brazilian river basins such as the rio Paranapanema system (Alves et al. 2019).

2. Data collection

In all, 24 streams of low orders (less than three) were sampled (Table 1; Figure 1) on two collection trips: June 2017, and July 2018. Of these, seven streams are located in the rio das Cinzas basin, and 17 in the rio Itararé basin (Table 1; Figure 1). A 100-m stretch (the wadeable stream stretches have at least one sequence of riffle-run-pool meso-habitats) was defined at each site, which were georeferenced (Table 1) and sampled by electrofishing. This technique employs two electrified dip nets, producing an electric discharge between 200 and 400 V and current of 2 A, that stun the fish temporarily (Lobón-Cervia 1991). The specimens were anesthetized in benzocaine hydrochloride and fixed in 10% formalin in the field. After a few days, the fishes were transferred to 70% ethanol in the laboratory, identified in species-level, and deposited in the Coleção Ictiológica do Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura (NUP).

Fish species were classified based on Van der Laan et al. (2019), species validity was based on Fricke et al. (2019), and species determinations were accomplished by comparison of the specimens with original descriptions or with specimens reported from the streams of rio Paranapanema system in Paraná State (Castro et al. 2003; Cetra et al. 2012; Cionek et al. 2012; Pagotto et al. 2012; Costa et al. 2013; Hoffmann et al. 2015; Cetra et al. 2016; Claro-García et al. 2018) and

Fishes from rio das Cinzas and rio Itararé basins

Table 1. Information on the headwater streams sampled in the rio das Cinzas and rio Itararé basins, Paraná State, Brazil. Numbers in parentheses after each species name indicates abundance.

Sampled site	Remarks	Altitude (meters)	Coordinates	Municipality	Species caught
1	Rio do Tigre, affluent of rio das Cinzas, rio das Cinzas basin	~783	24°10'24.1"S, 49°53'54.6"W	Arapoti	<i>Phalloceros harpagos</i> (3) and <i>Rhamdia quelen</i> (2)
2	Unnamed river, affluent of rio Perdizes, rio das Cinzas basin	~926	24°13'47.2"S, 49°53'53.6"W	Arapoti	<i>Astyanax</i> aff. <i>paranae</i> (145), <i>Geophagus</i> aff. <i>brasiliensis</i> (3) and <i>Gymnotus inaequilabiatus</i> (2)
3	Unnamed river, affluente of rio do Tigre, rio das Cinzas basin	~820	24°11'4.9"S, 49°52'14"W	Arapoti	<i>Astyanax</i> aff. <i>paranae</i> (4), <i>Geophagus</i> aff. <i>brasiliensis</i> (2) and <i>Rhamdia quelen</i> (3)
4	Córrego Água Fria, affluent of rio Pinhalão, rio das Cinzas basin	~600	23°48'44.1"S, 50°7'55.14"W	Japira	<i>Bryconamericus</i> aff. <i>iheringii</i> (7), <i>Cambeva diabola</i> (5), <i>Hypostomus ancistroides</i> (7), <i>Imparfinis mirini</i> (19), <i>Phalloceros harpagos</i> (104) and <i>Rhamdia quelen</i> (3)
5	Córrego do Café, affluent of rio Pinhalão, rio das Cinzas basin	~606	23°56'9.25"S, 50°2'16.1"W	Pinhalão	<i>Astyanax bockmanni</i> (6), <i>Astyanax</i> aff. <i>paranae</i> (28), <i>Bryconamericus</i> aff. <i>iheringii</i> (11), <i>Cambeva davisii</i> (14), <i>Hypostomus ancistroides</i> (5), <i>Neoplecostomus selenae</i> (4) and <i>Rhamdia quelen</i> (26)
6	Unnamed river, affluent of rio das Pedras, rio das Cinzas basin	~626	23°57'28.05"S, 50°14'5.9"W	Ibaiti	<i>Astyanax</i> aff. <i>paranae</i> (3), <i>Cambeva diabola</i> (13), <i>Geophagus</i> aff. <i>brasiliensis</i> (11), <i>Hypostomus ancistroides</i> (6), <i>Imparfinis mirini</i> (1) and <i>Neoplecostomus selenae</i> (3)
7	Rio das Pedras, affluent of rio das Cinzas, rio das Cinzas basin	~624	23°56'4.6"S, 50°14'41.4"W	Ibaiti	<i>Astyanax bockmanni</i> (51), <i>Astyanax</i> aff. <i>paranae</i> (8), <i>Bryconamericus</i> aff. <i>iheringii</i> (78), <i>Cambeva davisii</i> (6), <i>Geophagus</i> aff. <i>brasiliensis</i> (42), <i>Gymnotus inaequilabiatus</i> (1), <i>Hoplias</i> aff. <i>malabaricus</i> (3), <i>Hypostomus ancistroides</i> (19), <i>Neoplecostomus selenae</i> (17), <i>Phalloceros harpagos</i> (11) and <i>Rhamdia quelen</i> (2)
8	Rio Lajeado, affluent of rio Barra Mansa, rio Itararé basin	~725	24°5'24.5"S, 49°47'14.9"W	Arapoti	<i>Astyanax</i> cf. <i>bifasciatus</i> (1), <i>Geophagus</i> aff. <i>brasiliensis</i> (22), <i>Hoplias</i> aff. <i>malabaricus</i> (1), <i>Hypostomus ancistroides</i> (1) and <i>Rhamdia quelen</i> (1)
9	Unnamed river, affluent of rio das Mortes, rio Itararé basin	~811	24°12'20.2"S, 49°38'8.7"W	Jaguariaíva	<i>Cambeva davisii</i> (10) and <i>Characidium schubarti</i> (4)
10	Unnamed river, affluent of rio do Bugre, rio Itararé basin	~770	24°7'5.1"S, 49°32'50.5"W	Sengés	<i>Astyanax</i> aff. <i>paranae</i> (51) and <i>Cambeva iheringi</i> (13)
11	Unnamed river, rio Itararé basin	~949	24°27'43.8"S, 49°31'27.8"W	Jaguariaíva	<i>Astyanax</i> aff. <i>paranae</i> (7), <i>Cambeva davisii</i> (4), <i>Characidium schubarti</i> (3), <i>Neoplecostomus selenae</i> (8), <i>Phalloceros harpagos</i> (3) and <i>Rhamdia quelen</i> (4)
12	Rio Preto, affluent of rio Jaguariaíva, rio Itararé basin	~567	24°4'25.8"S, 49°38'53.8"W	Jaguariaíva	<i>Apareiodon ibitiensis</i> (15), <i>Bryconamericus turiuba</i> (4), <i>Bryconamericus</i> aff. <i>iheringii</i> (9), <i>Cambeva davisii</i> (2), <i>Characidium</i> aff. <i>zebra</i> (1), <i>Imparfinis mirini</i> (2), <i>Neoplecostomus selenae</i> (16) and <i>Rhamdia quelen</i> (2)
13	Rio da Serrinha, affluent of rio Jaguariaíva, rio Itararé basin	~789	24°12'49.5"S, 49°41'9.1"W	Jaguariaíva	<i>Apareiodon ibitiensis</i> (5), <i>Cambeva davisii</i> (1), <i>Geophagus</i> aff. <i>brasiliensis</i> (2), <i>Neoplecostomus selenae</i> (11) and <i>Phalloceros harpagos</i> (20)
14	Rio das Samambaias, affluent of rio Jaguariaíva, rio Itararé basin	~813	24°10'43.7"S, 49°36'55.85"W	Jaguariaíva	<i>Cambeva davisii</i> (18), <i>Characidium schubarti</i> (1), <i>Neoplecostomus selenae</i> (8) and <i>Phalloceros harpagos</i> (11)

Continuation Table 1.

Sampled site	Remarks	Altitude (meters)	Coordinates	Municipality	Species caught
15	Rio Funil, affluent of rio Itararé, rio Itararé basin	~620	24°7'15.9"S, 49°23'28.8"W	Sengés	<i>Astyanax bockmanni</i> (4), <i>Geophagus</i> aff. <i>brasiliensis</i> (5), <i>Hoplias</i> aff. <i>malabaricus</i> (3) and <i>Neoplecostomus selenae</i> (50)
16	Rio Pelame, affluent of rio Itararé, rio Itararé basin	~609	24°7'6.9"S, 49°24'40.4"W	Sengés	<i>Apareiodon ibitiensis</i> (33), <i>Astyanax bockmanni</i> (2), <i>Astyanax</i> aff. <i>paranae</i> (1), <i>Bryconamericus turiuba</i> (20), <i>Cambeva diabola</i> (10), <i>Cambeva iheringi</i> (2), <i>Cetopsorhamdia iheringi</i> (2), <i>Characidium</i> sp. (3), <i>Eigenmannia</i> sp. (3), <i>Geophagus</i> aff. <i>brasiliensis</i> (5), <i>Hypostomus hermanni</i> (3), <i>Hypostomus tietensis</i> (5), <i>Imparfinis borodini</i> (5), <i>Neoplecostomus selenae</i> (15), <i>Otothyropsis biannicus</i> (8), <i>Phenacorhamdia tenebrosa</i> (5) and <i>Piabarchus stramineus</i> (2)
17	Rio Jaguaricatu, affluent of rio Itararé, rio Itararé basin	~630	24°8'17.5"S, 49°29'48.1"W	Sengés	<i>Astyanax</i> aff. <i>paranae</i> (5), <i>Cambeva davisii</i> (20), <i>Geophagus</i> aff. <i>brasiliensis</i> (1) and <i>Neoplecostomus selenae</i> (52)
18	Riacho do Bugre, affluent of rio Jaguaricatu, rio Itararé basin	~585	24°7'55.2"S, 49°29'7.7"W	Sengés	<i>Apareiodon ibitiensis</i> (6), <i>Astyanax lacustris</i> (1), <i>Astyanax</i> aff. <i>paranae</i> (1), <i>Bryconamericus turiuba</i> (8), <i>Cetopsorhamdia iheringi</i> (7), <i>Hypostomus ancistroides</i> (4), <i>Hypostomus iheringii</i> (6), <i>Hypostomus strigaticeps</i> (3), <i>Imparfinis mirini</i> (1) and <i>Neoplecostomus selenae</i> (2)
19	Rio Lajeado Grande, affluent of rio Jaguaricatu, rio Itararé basin	~1092	24°20'25.8"S, 49°43'37.9"W	Jaguariaíva	<i>Astyanax</i> aff. <i>paranae</i> (1), <i>Characidium schubarti</i> (1) and <i>Phalloceros harpagos</i> (124)
20	Unnamed river, affluent of rio Espigão Alto, rio Itararé basin	~910	24°25'34.3"S, 49°40'42.4"W	Jaguariaíva	<i>Astyanax</i> aff. <i>paranae</i> (32), <i>Cambeva davisii</i> (18), <i>Cambeva iheringi</i> (3), <i>Characidium schubarti</i> (10), <i>Characidium</i> sp. (4), <i>Phalloceros harpagos</i> (8) and <i>Rhamdia quelen</i> (1)
21	Rio Espigão Alto, affluent of rio Jaguaricatu, rio Itararé basin	~899	24°24'19.4"S, 49°38'53.9"W	Jaguariaíva	<i>Astyanax</i> aff. <i>paranae</i> (80), <i>Cambeva davisii</i> (3), <i>Cambeva iheringi</i> (5), <i>Characidium</i> sp. (7), <i>Corydoras ehrhardti</i> (1), <i>Phalloceros harpagos</i> (2) and <i>Rhamdia quelen</i> (3)
22	Rio das Lanças, affluent of rio Jaguaricatu, rio Itararé basin	~889	24°24'40.7"S, 49°37'24.7"W	Jaguariaíva	<i>Astyanax</i> aff. <i>paranae</i> (5), <i>Cambeva iheringi</i> (2), <i>Characidium schubarti</i> (45), <i>Corydoras ehrhardti</i> (26), <i>Geophagus</i> aff. <i>brasiliensis</i> (22), <i>Hoplias</i> aff. <i>malabaricus</i> (4), <i>Hypostomus tietensis</i> (1), <i>Neoplecostomus selenae</i> (15), <i>Phalloceros harpagos</i> (5) and <i>Rhamdia quelen</i> (7)
23	Unnamed river, affluent of rio Jaguaricatu, rio Itararé basin	~942	24°28'18.8"S, 49°29'28.4"W	Jaguariaíva	<i>Astyanax</i> aff. <i>paranae</i> (55), <i>Bryconamericus</i> aff. <i>iheringii</i> (1), <i>Cambeva davisii</i> (6), <i>Cetopsorhamdia iheringi</i> (1), <i>Characidium schubarti</i> (3), <i>Characidium</i> sp. (6), <i>Neoplecostomus selenae</i> (3) and <i>Phalloceros harpagos</i> (19)
24	Riacho do Tombo, affluent of rio Jaguaricatu, rio Itararé basin	~956	24°29'33.9"S, 49°29'53.5"W	Jaguariaíva	<i>Astyanax</i> aff. <i>paranae</i> (15), <i>Cambeva davisii</i> (10), <i>Cetopsorhamdia iheringi</i> (6), <i>Characidium</i> sp. (6), <i>Neoplecostomus selenae</i> (4) and <i>Phalloceros harpagos</i> (11)

from the rio Paraná floodplain (Ota et al. 2018). Whenever possible, the determinations of the species were checked by specialists of each taxonomic group. The species were categorized by their frequency of occurrence (hereafter, constancy), which was calculated for all sampled streams according to Dajoz (1983). Species with a constancy up to 25%

were classified as occasional, between 25 and 50% as accessory, and higher than 50% as constant. In addition, the species were categorized by origin to distinguish native and introduced species to the upper rio Paraná system, following Langeani et al. (2007), Frota et al. (2016a), Cavalli et al. (2018) and Ota et al. (2018).

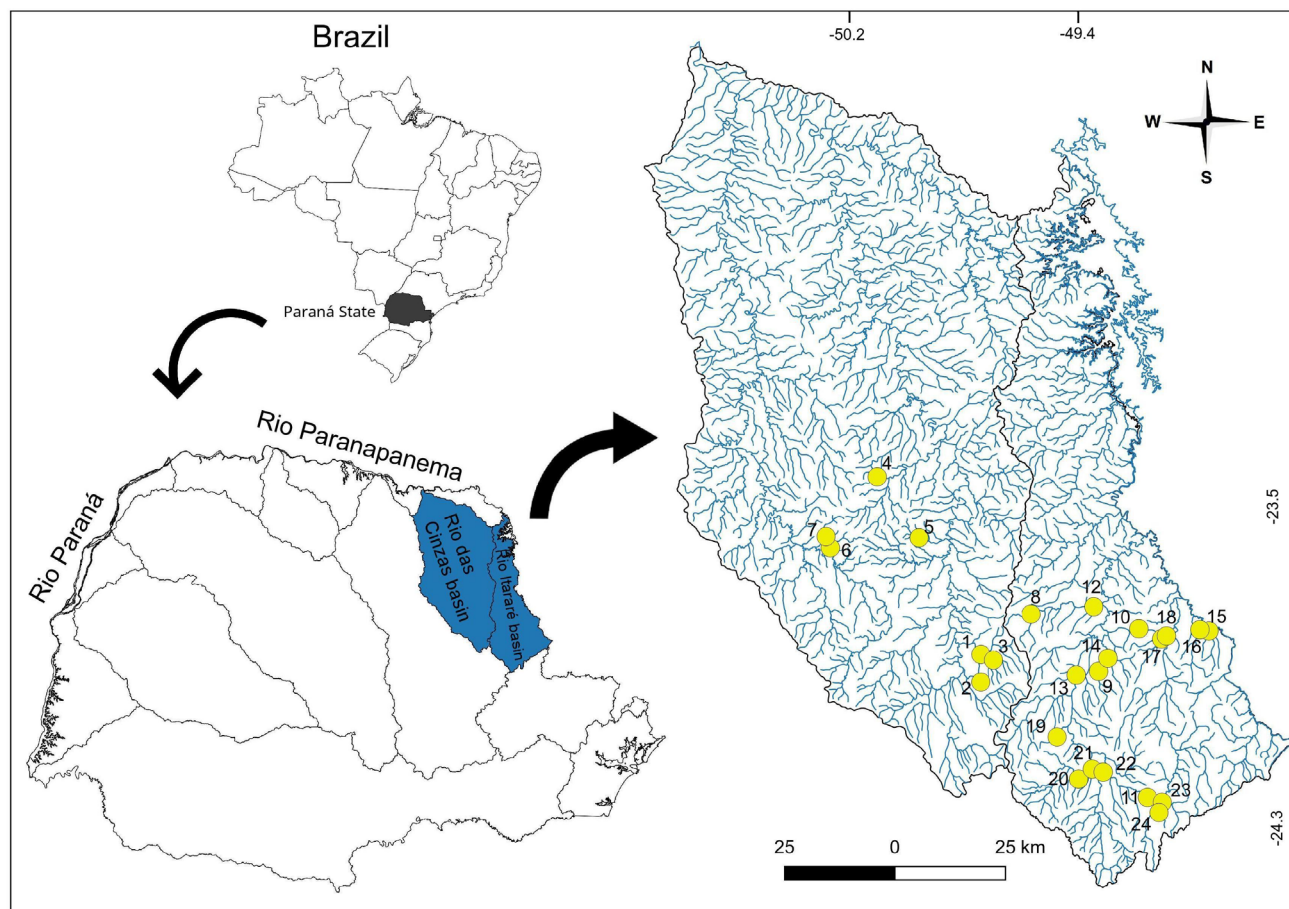


Figure 1. Map of the study area showing the location of the rio das Cinzas and rio Itararé basins within Paraná State and the 24 sampled sites (yellow circles), with its numbers corresponding to Table 1.

Results

A total of 1,823 individuals were collected, distributed in five orders, 12 families, and 32 species (Tables 1 and 2; Figures 2 and 3). Siluriformes (Figure 2) was the most representative order with 16 species (50.0% of all collected species) and four families, followed by Characiformes (Figure 3) with 12 species and four families. Among the families, Characidae and Loricariidae (both with seven species) presented higher richness contributing together with approximately 43.8% of all collected species, followed by Heptapteridae (five species) with approximately 15.6% of all collected species, Crenuchidae and Trichomycteridae (three species each) with approximately 8.8% of all collected species, and the other families (Table 2) that were represented by only one species.

Regarding the abundance of the sampled individuals (Figure 4), *Astyanax* aff. *paranae* Eigenmann, 1914 (447 individuals), *Phalloceros harpagos* Lucinda, 2008 (321 individuals), *Neoplecostomus selenae* Zawadzki, Pavanelli & Langeani, 2008 (208 individuals), *Geophagus* aff. *brasiliensis* (Quoy & Gaimard, 1824) (115 individuals), *Cambeva davisi* (Haseman, 1911) (112 individuals), *Bryconamericus* aff. *iheringii* (Boulenger, 1887) (106 individuals), *Characidium schubarti* Travassos, 1955 (67 individuals), *Astyanax bockmanni* Vari & Castro, 2007 (63 individuals), *Apareiodon ibitiensis* Amaral Campos, 1944

(59 individuals), and *Rhamdia quelen* (Quoy & Gaimard, 1824) (54 individuals) were the most abundant species, contributing with approximately 85.0% of all collected individuals. On the other hand, the other 22 species counted less than 50 individuals, representing approximately 15.0% of all collected individuals (Figure 4).

As for constancy (Table 2) most of the species were categorized as occasional (25 species). Five species (*C. schubarti*, *R. quelen*, *C. davisi*, *G.* aff. *brasiliensis*, and *P. harpagos*) were categorized as accessory, and only two species (*A.* aff. *paranae* and *N. selenae*) were categorized as constant. Regarding the origin of species (Table 2) none was considered as introduced to the rio Paranapanema system. It is noteworthy that the capture of *Astyanax bifasciatus* Garavello & Sampaio, 2010 represents the first record of this species from the upper rio Paraná system. Lastly, three putatively undescribed species (approximately 9.4% of all collected species) were also collected: *A.* aff. *paranae* (*sensu* Ota et al. 2018), *Characidium* sp., and *Eigenmannia* sp.

Discussion

With the predominance of Siluriformes and Characiformes, the taxonomic composition of the 24 sampled streams follows the pattern described for the Neotropical freshwater fish fauna (Castro 1999; Lowe-McConnell 1999; Albert et al. 2011). The number of species

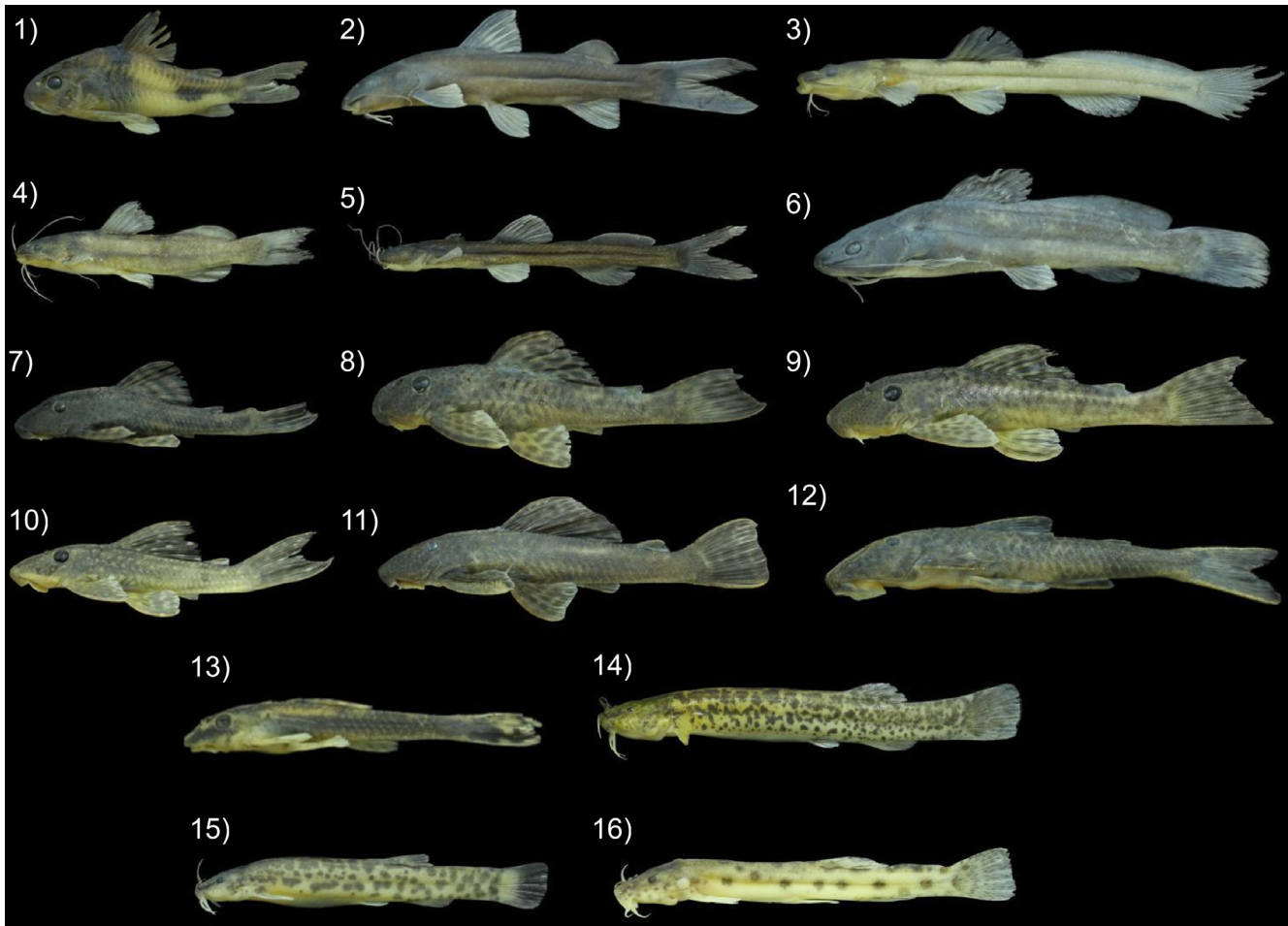


Figure 2. Representative individuals of the Siluriformes collected to the headwater streams from the rio das Cinzas and rio Itararé basins, rio Paranapanema system, Paraná State, Brazil. Their catalogue numbers in the Coleção Ictiológica do Nupélia (NUP) and standard lengths are presented after the names of species. 1) *Corydoras ehrhardti*, NUP 20473, 43.9 mm; 2) *Cetopsorhamdia iheringi*, NUP 20490, 70.9 mm; 3) *Imparfinis borodini*, NUP 20434, 105.2 mm; 4) *Imparfinis mirini*, NUP 20393, 68.0 mm; 5) *Phenacorhamdia tenebrosa*, NUP 20437, 59.9 mm; 6) *Rhamdia quelen*, NUP 20479, 94.8 mm; 7) *Hypostomus ancistroides*, NUP 20516, 63.8 mm; 8) *Hypostomus hermanni*, NUP 20432, 99.5 mm; 9) *Hypostomus iheringii*, NUP 20449, 98.6 mm; 10) *Hypostomus strigaticeps*, NUP 20450, 106.8 mm; 11) *Hypostomus tietensis*, NUP 20476, 125.4 mm; 12) *Neoplecostomus selenae*, NUP 20477, 67.3 mm; 13) *Otothyropsis biannicus*, NUP 20436, 27.5 mm; 14) *Cambeva davisi*, NUP 20462, 74.5 mm; 15) *Cambeva diabola*, NUP 20510, 55.7 mm; 16) *Cambeva iheringi*, NUP 20470, 71.7 mm.

recorded in Characidae, Loricariidae, and Heptapteridae also follows the pattern of the most species-rich families in the upper rio Paraná system (Langeani et al. 2007). Similarly, several studies have indicated the prevalence of these families in other streams of this drainage system (e.g., Hoffmann et al. 2015; Bifi et al. 2017; Batista-Silva et al. 2018; Claro-García et al. 2018; Azevedo-Santos et al. 2019b), especially for streams of the rio Paranapanema system, such as the rio das Cinzas (Costa et al. 2013) and the rio Itararé (Cetra et al. 2016) basins.

Our results showed that occasional species dominated the sampled streams. This may be related to the influence of the altitudinal gradient on the species distribution since the species richness tends to decrease with the altitude increase (Fu et al. 2004; Jaramillo-Villa et al. 2010; Askeyev et al. 2017; Frota et al. 2019). As verified in other studies relating fish species richness with the altitudinal gradient (e.g., Askeyev et al. 2017), above 650 m of altitude few species were repeated in the streams sampled (Table 1). These species were classified as constant or accessory, in addition to being among the most abundant species such as

A. aff. paranae, *N. selenae*, *C. davisi*, *R. quelen*, and *C. schubarti*. In fact, members of Heptapteridae, Loricariidae, and Trichomycteridae have morphological structures adapted to fixation in underwater structures, such as fortified pectoral fin rays, subterminal sucker mouths and/or spines in the operculum. These adaptations can guarantee the conquest of higher lands, such as headwater streams (Oyakawa et al. 2006). The great abundance and constancy of *A. aff. paranae* may be related to a short-distance migratory character (<100 km) already evidenced for some species of this genus (Agostinho et al. 2004).

Costa et al. (2013) found a few introduced species already inhabiting the waters of the rio das Cinzas basin, such as *Cyprinus carpio* Linnaeus, 1768, *Oreochromis niloticus* (Linnaeus, 1758), and *Poecilia reticulata* Peters, 1859. In contrast, the absence of such species from the headwater streams sampled herein suggests a greater integrity of that fish community, since biological invasions are among the main threats to freshwater environments (Daga et al. 2015; Ruaro et al. 2018), and especially detrimental for the fish fauna of Neotropical

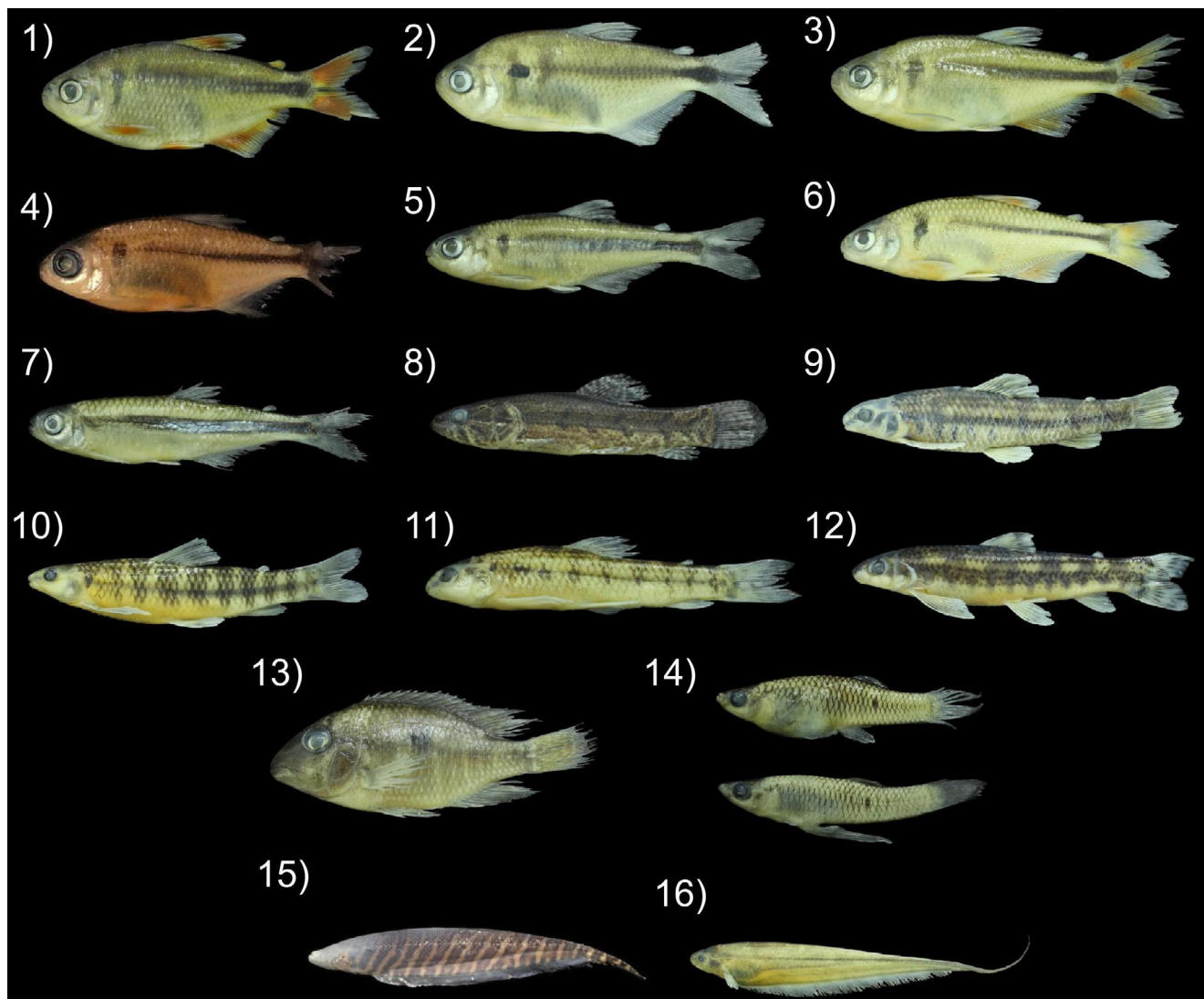


Figure 3. Representative individuals of the Characiformes, Cichliformes, Cyprinodontiformes, and Gymnotiformes collected to the headwater streams from the rio das Cinzas and rio Itararé basins, rio Paranapanema system, Paraná State, Brazil. Their catalogue numbers in the Coleção Ictiológica do Nupélia (NUP) and standard lengths (total lengths for Gymnotiformes) are presented after the names of species. 1) *Astyanax bockmanni*, NUP 20511, 66.3 mm; 2) *Astyanax lacustris*, NUP 20446, 58.2 mm; 3) *Astyanax* aff. *paranae*, NUP 20464, 59.8 mm; 4) *Astyanax* cf. *bifasciatus*, NUP 20405, 38.0 mm; 5) *Bryconamericus turiuba*, NUP 20426, 45.0 mm; 6) *Bryconamericus* aff. *iheringii*, NUP 20513, 45.0 mm; 7) *Piabarchus stramineus*, NUP 20438, 67.5 mm; 8) *Hoplias* aff. *malabaricus*, NUP 20475, 77.1 mm; 9) *Characidium schubarti*, NUP 20472, 68.4 mm; 10) *Characidium* aff. *zebra*, NUP 20409, 70.8 mm; 11) *Characidium* sp., NUP 20491, 48.3 mm; 12) *Apareiodon ibitiensis*, NUP 20414, 89.6 mm; 13) *Geophagus* aff. *brasiliensis*, NUP 20421, 77.5 mm; 14) *Phalloceros harpagos*, NUP 20487, 29.6 mm (above; female), 22.9 mm (below; male); 15) *Gymnotus inaequilabiatus*, NUP 21109, 108.5 mm; 16) *Eigenmannia* sp., NUP 20429, 149.0 mm.

streams (Winemiller et al. 2008; Ruaro et al. 2018). The Devonian Escarpment EPA is directly linked to the maintenance of this integrity, especially in the case of the rio Itararé basin, and conservation efforts are increasingly necessary to at least maintain the original area of this natural reserve (Alves et al. 2019).

Astyanax bifasciatus was thought to be endemic to the rio Iguaçú basin (Garavello & Sampaio 2010; Baumgartner et al. 2012), a drainage system of the lower rio Paraná that encompasses a large area of southern Paraná State and northern Santa Catarina State. In a recent inventory (Frota et al. 2019), this species had its geographical distribution extended to the rio Ribeira de Iguape basin, a coastal drainage bordered to the south by the rio Iguaçú basin and to the north by the rio Itararé basin. Another example of the interesting biogeographic (Ribeiro 2006;

Frota et al. 2016a) and phylogeographic (Morais-Silva et al. 2018) patterns at the boundaries of the Ponta Grossa Arch. In fact, this arch is the most prominent geological structure in the headwater regions of the Paranapanema, Iguaçú and Ribeira de Iguape river basins (Ribeiro 2006).

Mainly due to their recent tectonic activities (Franco-Magalhães et al. 2010), the Ponta Grossa Arch is thought to be responsible for a particularly accelerated river dynamism between these adjacent drainage systems, enabling the faunal exchange between them (Ribeiro 2006). This same scenario can be found for other fish species. For example, adjacent tributaries of the Iguaçú, Paranapanema and Ribeira de Iguape river basins share the presence of *C. davisi* (see Ingenito et al. 2004; Ribeiro 2006; Morais-Silva et al. 2018), *Hyphessobrycon griemi*

Table 2. Fish species collected in headwater streams from the rio das Cinzas and rio Itararé basins, upper rio Paranapanema system, Paraná State, Brazil.

Ordem	Family	Species	Origin/Constancy	Voucher	
Characiformes	Crenuchidae	<i>Characidium schubarti</i> Travassos, 1955	Native/Accessory	NUP 19250, NUP 19265, NUP 20455, NUP 20459, NUP 20472, NUP 20484, NUP 21055	
		<i>Characidium</i> aff. <i>zebra</i> Eigenmann, 1909	Native/Occasional	NUP 20409	
		<i>Characidium</i> sp.	Native/Occasional	NUP 20428, NUP 20458, NUP 20465, NUP 20485, NUP 20491	
	Erythrinidae	<i>Hoplias</i> aff. <i>malabaricus</i> (Bloch, 1794)	Native/Occasional	NUP 20422, NUP 20475, NUP 20515, NUP 21008	
	Parodontidae	<i>Apareiodon ibitiensis</i> Amaral Campos, 1944	Native/Occasional	NUP 20407, NUP 20414, NUP 20425, NUP 20445, NUP 21013, NUP 21017	
	Characidae	<i>Astyanax bockmanni</i> Vari & Castro, 2007	Native/Occasional	NUP 20423, NUP 20431, NUP 20511, NUP 21111	
		<i>Astyanax lacustris</i> (Lütken, 1875)	Native/Occasional	NUP 20446	
		<i>Astyanax</i> aff. <i>paranae</i> Eigenmann, 1914	Native/Constant	NUP 19256, NUP 19258, NUP 19260, NUP 19262, NUP 20398, NUP 20441, NUP 20454, NUP 20457, NUP 20464, NUP 20471, NUP 20481, NUP 20489, NUP 21046, NUP 21054	
		<i>Astyanax</i> cf. <i>bifasciatus</i> Garavello & Sampaio, 2010	Native/Occasional	NUP 20405	
		<i>Bryconamericus turiuba</i> Langeani, Lucena, Pedrini & Tarelho-Pereira, 2005	Native/Occasional	NUP 20426, NUP 20447, NUP 21015, NUP 21041	
		<i>Bryconamericus</i> aff. <i>iheringii</i> (Boulenger, 1887)	Native/Occasional	NUP 20392, NUP 20399, NUP 20408, NUP 20482, NUP 20513, NUP 21080	
		<i>Piabarchus stramineus</i> (Eigenmann, 1908)	Native/Occasional	NUP 20438	
		<i>Gymnotus inaequilabiatus</i> Valenciennes, 1839	Native/Occasional	NUP 19254, NUP 21109	
	Gymnotiformes	Gymnotidae	<i>Gymnotus inaequilabiatus</i> Valenciennes, 1839	Native/Occasional	NUP 19254, NUP 21109
	Sternopygidae	<i>Eigenmannia</i> sp.	Native/Occasional	NUP 20429, NUP 21044	
Siluriformes	Heptapteridae	<i>Cetopsorhamdia iheringi</i> Schubart & Gomes, 1959	Native/Occasional	NUP 20427, NUP 20448, NUP 20483, NUP 20490, NUP 21029, NUP 21087	
		<i>Imparfinis borodini</i> Mees & Cala, 1989	Native/Occasional	NUP 20434, NUP 21033	
		<i>Imparfinis mirini</i> Haseman, 1911	Native/Occasional	NUP 20393, NUP 20410, NUP 20452, NUP 21012	
		<i>Phenacorhamdia tenebrosa</i> (Schubart, 1964)	Native/Occasional	NUP 20437, NUP 21034	
		<i>Rhamdia quelen</i> (Quoy & Gaimard, 1824)	Native/Accessory	NUP 19253, NUP 19259, NUP 19264, NUP 20396, NUP 20402, NUP 20406, NUP 20412, NUP 20461, NUP 20468, NUP 20479	
	Trichomycteridae	<i>Cambeva davisii</i> (Haseman, 1911)	Native/Accessory	NUP 19251, NUP 19267, NUP 20403, NUP 20413, NUP 20420, NUP 20444, NUP 20462, NUP 20469, NUP 20488, NUP 20494, NUP 21003	
			<i>Cambeva diabola</i> (Bockmann, Casatti & de Pinna, 2004)	Native/Occasional	NUP 20397, NUP 20439, NUP 20510, NUP 20999, NUP 21043
			<i>Cambeva iheringi</i> (Eigenmann, 1917)	Native/Occasional	NUP 19261, NUP 20440, NUP 20463, NUP 20470, NUP 20480, NUP 21042, NUP 21059

Continuation Table 2.

Ordem	Family	Species	Origin/Constancy	Voucher
	Callichthyidae	<i>Corydoras ehrhardti</i> Steindachner, 1910	Native/Occasional	NUP 20466, NUP 20473, NUP 21075
	Loricariidae	<i>Hypostomus ancistroides</i> (Ihering, 1911)	Native/Occasional	NUP 20394, NUP 20400, NUP 20451, NUP 20509, NUP 20516
		<i>Hypostomus hermanni</i> (Ihering, 1905)	Native/Occasional	NUP 20432, NUP 21032
		<i>Hypostomus iheringii</i> (Regan, 1908)	Native/Occasional	NUP 20449
		<i>Hypostomus strigaticeps</i> (Regan, 1908)	Native/Occasional	NUP 20450, NUP 21050
		<i>Hypostomus tietensis</i> (Ihering, 1905)	Native/Occasional	NUP 20433, NUP 20476
		<i>Neoplecostomus selenae</i> Zawadzki, Pavanelli & Langeani, 2008.	Native/Constant	NUP 19266, NUP 20401, NUP 20411, NUP 20416, NUP 20418, NUP 20424, NUP 20435, NUP 20443, NUP 20453, NUP 20477, NUP 20486, NUP 20492, NUP 20517, NUP 21035, NUP 21115
		<i>Otothyropsis biamnicus</i> Calegari, Lehmann & Reis, 2013	Native/Occasional	NUP 20436, NUP 21040
Cichliformes	Cichlidae	<i>Geophagus aff. brasiliensis</i> (Quoy & Gaimard, 1824)	Native/Accessory	NUP 19255, NUP 19257, NUP 20404, NUP 20415, NUP 20421, NUP 20430, NUP 20442, NUP 20474
Cyprinodontiformes	Poeciliidae	<i>Phalloceros harpagos</i> Lucinda, 2008	Native/Accessory	NUP 19252, NUP 19263, NUP 20395, NUP 20417, NUP 20419, NUP 20456, NUP 20460, NUP 20467, NUP 20478, NUP 20487, NUP 20493

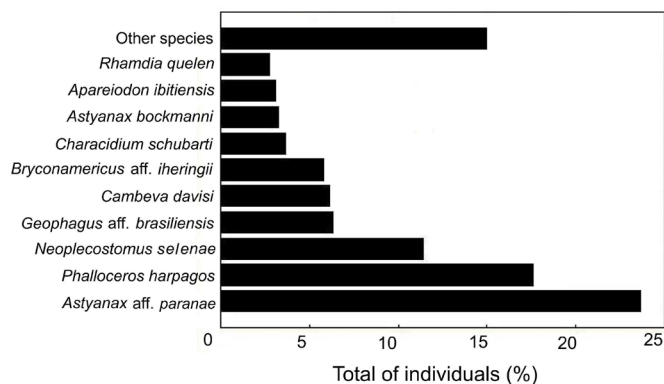


Figure 4. Percentages of number of individuals of each species with more than 50 individuals collected in the headwater streams from rio das Cinzas and rio Itararé basins, rio Paranapanema system, Paraná State, Brazil.

Hoedeman, 1957, *H. bifasciatus* Ellis, 1911, *H. reticulatus* Ellis, 1911 (see Ingenito et al. 2004; Ribeiro 2006), *Mimagoniates microlepis* (Steindachner, 1877) (see Ingenito et al. 2004; Ribeiro 2006; Menezes et al. 2008; Hoffmann et al. 2015), and *Rhamdiopsis moreirai* Haseman, 1911 (see Ferraris 2007; Hoffmann et al. 2015). The slopes of the upper rio Paraná system and the rio Ribeira de Iguape basin share the presence of *Hypostomus ancistroides* (Ihering, 1911) (Oyakawa et al. 2005). The Iguaçú and Ribeira de Iguape river basins share the presence of *Characidium travassosi* Melo, Buckup & Oyakawa, 2016 (Frota

et al. 2016b; Melo et al. 2016). Now, the geographic distribution of *A. bifasciatus* is added to the mentioned examples since this species also occurs in all drainage systems mentioned.

Nine of the 32 fish species records presented herein are new for the Itararé and Cinzas river basins. Those are *Bryconamericus turiuba* Langeani, Lucena, Pedrini & Tarelho-Pereira, 2005, *Corydoras ehrhardti* Steindachner, 1910, *Hypostomus iheringii* (Regan, 1908), *Hypostomus tietensis* (Ihering, 1905), *Cambeva iheringi* (Eigenmann, 1917), *Gymnotus inaequilabiatus* Valenciennes, 1839, and the three putatively new species *A. aff. paranae* (*sensu* Ota et al. 2018), *Characidium* sp., and *Eigenmannia* sp. (compare with Costa et al. 2013; Cetra et al. 2016). Except for the latter two species, which are being reported for the first time herein, all of these species have a wide distribution range within the upper rio Paraná drainage. On the other hand, Costa et al. (2013) reported 11 species not collected by us (introduced species excluded): *Piabina argentea* Reinhardt, 1867, *Apareiodon affinis* (Steindachner, 1879), *Gymnotus sylvius* Albert & Fernandes-Matioli, 1999, *Gymnotus* sp., *Imparfinis schubarti* (Gomes, 1956), *Hypostomus albopunctatus* (Regan, 1908), *H. nigromaculatus* (Schubart, 1964), *H. paulinus* (Ihering, 1905), *Rineloricaria pentamaculata* Langeani & Araujo, 1994, *Crenicichla jaguarensis* Haseman, 1911, and *Synbranchus marmoratus* Bloch, 1795. Cetra et al. (2016) recorded 19 (introduced species excluded): *Astyanax biotae* Castro & Vari, 2004, *A. scabripinnis* (Jenyns, 1842), *Hyphessobrycon anisitsi* (Eigenmann, 1907), *Oligosarcus paranensis* Menezes &

Géry, 1983, *Piabina argentea*, *Characidium gomesi* Travassos, 1956, *Parodon nasus* Kner, 1859, *Gymnotus sylvius*, *Eigenmannia virescens* (Valenciennes, 1836), *Pimelodella avanhandavae* Eigenmann, 1917, *Hypostomus nigromaculatus*, *Hypostomus* sp. 1, *Hypostomus* sp. 2, *Otothyropsis* sp., *Rineloricaria pentamaculata*, *Trichomycterus* sp. 1, *Trichomycterus* sp. 2, *Phalloceros reisi* Lucinda, 2008, and *Synbranchus marmoratus*.

The identification of *A. biotae*, *H. anisitsi*, *P. argentea*, *O. paranensis*, *C. gomesi*, *A. affinis*, *H. albopunctatus*, *H. nigromaculatus*, *R. pentamaculata*, *P. avanhandavae*, *P. reisi*, *C. jaguarensis*, and *S. marmoratus* is pretty straightforward, meaning that at least 13 species, other than those presented by us, could be added to a complete list of the native stream fish fauna from the upper rio Paranapanema system. However, a careful analysis of the remaining species is necessary in order to verify whether they are in fact distinct from the species listed herein. *Gymnotus* species are hardly distinguishable from one another, especially at small sizes. *Imparfinis schubarti* has been considered a junior synonym of *I. mirini* Haseman, 1911, which suggests that the usual diagnostic characters may not be sufficient to distinguish those species, in the case that they are in fact two species. *Hypostomus paulinus* represents a species complex and is easily confused with *H. tietensis* (Zawadzki, personal communication).

Some species considered to be new by other authors (Costa et al. 2013; Cetra et al. 2016) may be variants of other, described species, which cannot be verified presently without the examination of the specimens. For example, regarding the two supposedly new species of *Trichomycterus* (= *Cambeva*), we found among our specimens a wide color-pattern variation, which nonetheless fall within the range of variation observed by Nascimento et al. (2017) for *C. davisii* and by da Silva et al. (2010) for *C. iheringi*. Thus, we cautiously hypothesize *Trichomycterus* sp. 1 and *Trichomycterus* sp. 2 of Cetra et al. (2016) to represent variants of these species.

In any case, in addition to the results of Cetra et al. (2016), our results point to the gap between existing evolutionary knowledge and current biological knowledge, which characterizes a large biodiversity shortfall (Hortal et al. 2015), especially for the stream fish fauna from the rio Paranapanema system. Future taxonomic studies with morphological and molecular methodologies can be conclusive on these issues. Here we have improved knowledge of the fish fauna of the rio das Cinzas and rio Itararé basins, upper rio Paranapanema system. However, we recognize that this inventory likely represents a small fraction of what remains to be sampled within these basins. Once again, sampling at headwater regions of high altitudes revealed possible unknown species to science, interesting biogeographic patterns and alarming biodiversity shortfalls, as well as inherent concerns about anthropogenic actions in Brazilian freshwater environments.

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Author Contributions

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

Renata Rúbia Ota: contributed to analysis and interpretation of data, and critical revision for adding substantive intellectual content.

Gabriel de Carvalho Deprá: contributed to analysis and interpretation of data, and critical revision for adding substantive intellectual content.

Maria Julia Mileo Ganassin: contributed to analysis and interpretation of data, and critical revision for adding substantive intellectual content.

Weferson Júnio da Graça: contributed to data acquisition, analysis and interpretation of data, 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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