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Ichthyofauna of streams of the Lower Paranapanema River basin, state of Paraná, Brazil

Ana Paula Vidotto-Magnoni[1], **Diego Azevedo Zoccal Garcia**[1, 2], **Alexandro Derly Augusto Costa**[1, 2], **Jaqueline Garcia de Souza**[1], **Marcelo Hideki Shigaki Yabu**[1, 2], **Fernanda Simões de Almeida**[3] and **Mário Luís Orsi**[1]

1 Universidade Estadual de Londrina – Laboratório de Ecologia de Peixes e Invasões Biológicas. Centro de Ciências Biológicas, Departamento de Biologia Animal e Vegetal, Rodovia Celso Garcia Cid, PR 445, Km 380, CEP 86.057-970 – Londrina, Paraná, Brazil

2 Programa de Pós-Graduação em Ciências Biológicas, AC: Biodiversidade e Conservação de Habitats Fragmentados. Universidade Estadual de Londrina, Centro de Ciências Biológicas, Rodovia Celso Garcia Cid, PR 445, Km 380, CEP 86.057-970 – Londrina, Paraná, Brazil

3 Universidade Estadual de Londrina – Laboratório de Genética e Ecologia Animal. Centro de Ciências Biológicas, Departamento de Biologia Geral, Rodovia Celso Garcia Cid, PR 445, Km 380, CEP 86.057-970 – Londrina, Paraná, Brazil

* Corresponding author. E-mail: anavidotto@gmail.com

Abstract: Several studies of small watersheds of in the Upper Paraná River basin are currently available. However, the number and extent of its tributary streams still pose a challenge to enhancing current knowledge of their ichthyofauna. This study aimed to survey the fish fauna of three streams of the Lower Paranapanema River basin, state of Paraná, Brazil (Capim, Tenente and Centenário streams). The sampling included 3,167 specimens belonging to five orders, 17 families and 56 species. The streams presented differences in species richness (Centenário Stream: 41 species; Tenente Stream: 33 species; Capim Stream: 30 species). Two species occurred at all collection sites (*Astyanax bockmanni* and *Hypostomus ancistroides*). Nine non-native species were recorded, four of them found exclusively in the Centenário Stream.

Key words: Upper Paraná River basin, non-native species, small order rivers

INTRODUCTION

The Paranapanema River is situated in the upper portion of the Paraná River basin. It rises on the mountain slopes of the Planalto Cristalino Ocidental (Castro et al. 2003) near the Serra de Paranapiacaba, municipality of Capão Bonito, state of São Paulo, at an altitude of 903 m (Sampaio 1944). Its approximate length is 930 km. It flows west forming a natural border of nearly 390 km between the states of Paraná and São Paulo from the mouth of the Itararé River to its outflow into the Paraná River (Maack 2012). Due to its high elevational drop between the source and the mouth (600 m; Sampaio 1944) it has been intensively exploited by the Brazilian hydroelectric sector. The Paranapanema River basin has an area of approximately 109,600 km^2, with about 2% flooded for the installation of 11 hydroelectric cascade power plant stations in the main channel of the river. The installed capacity is 2,500 MW, which represents 2.5% of the electricity generation in Brazil (Duke Energy 2008; Arcifa and Esguícero 2012; Duke Energy 2013).

The ichthyofauna of the Paranapanema River includes approximately 155 species (Duke Energy 2008), but this number is likely underestimated. Prior studies covered areas flooded by reservoirs (Brandão et al. 2009; Vidotto-Magnoni 2009; Orsi 2010; Kurchewski and Carvalho 2014) besides rivers, streams and creeks (Galves et al. 2007; Cunico et al. 2012; Pagotto et al. 2012; Cetra et al. 2012; Cionek et al. 2012; Costa et al. 2013).

Small order rivers often harbor high richness of small-bodied fish species (Castro et al. 2003), many of which may be new to science and require identification and description (Langeani et al. 2007). Thus, new inventories are necessary to improve information about the fish diversity of the region. Furthermore, knowledge of ichthyofaunal structure in small order rivers can inform the usage and regulation of water resources by suggesting alternatives to minimize impacts and degradation (Langeani et al. 2007). Several streams of the Paranapanema River basin have never been inventoried, and given this lack of information, the current study aims to present an inventory of the ichthyofauna of three streams of the Lower Paranapanema River basin.

MATERIAL AND METHODS

Study site

The three surveyed streams belong to the Lower Paranapanema River basin and flow into the left bank of the hydroelectric plant reservoir Escola Politécnica (Taquaruçu), between the municipalities of Porecatu and Centenário do Sul, northern Paraná (22°32′ – 22°42′ S, 052°01′ – 051°22′ W) (Figure 1). The region is embedded in extensive sugar cane crop, the main agricultural activity in the area since 1970.

The sampled streams differ from each other in vegetational composition, bed substrate granulometry and other geomorphological characteristics (Table 1). The greatest stream width was recorded in the Tenente

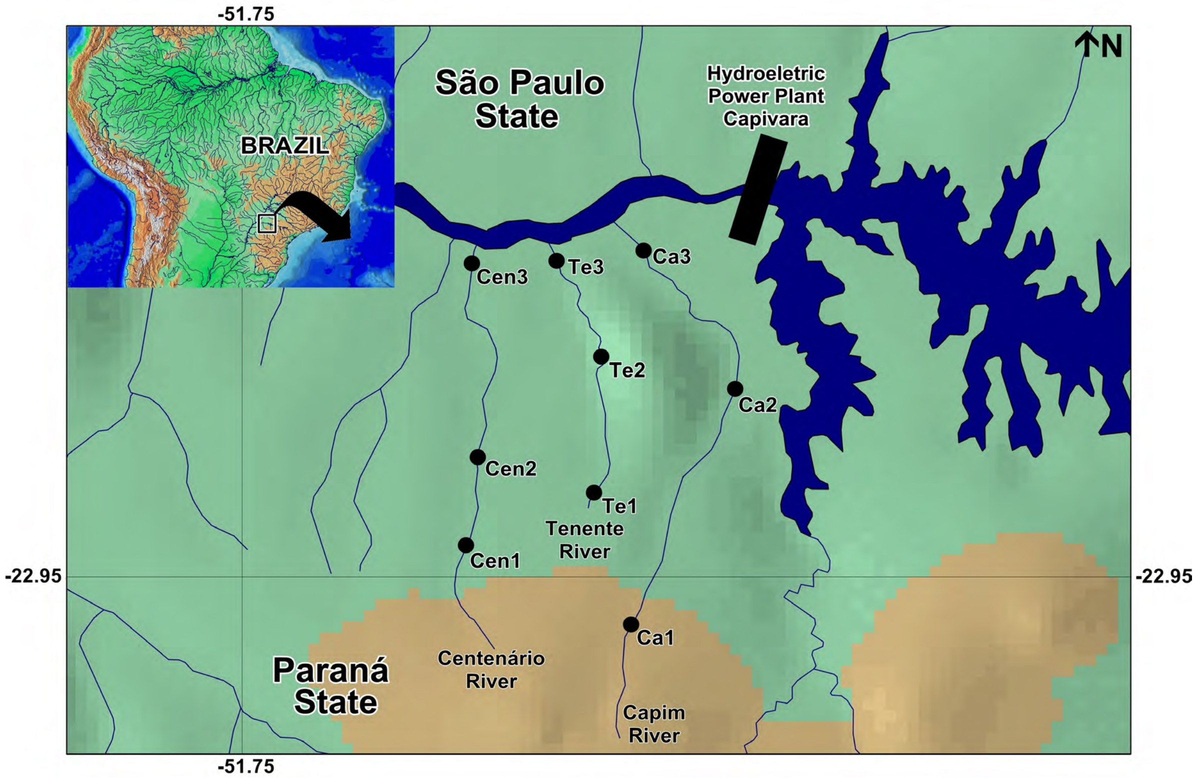

Figure 1. Location of the Lower Paranapanema River showing the Capivara Reservoir upstream and the Taquaruçu Reservoir downstream of the collection sites of the Capim (Ca1, Ca2, Ca3), Tenente (Te1, Te2, Te3) and Centenário (Cen1, Cen2, Cen3) streams. Scale: 1: 350,000. Geographic coordinates: Capim Stream - lower stretch (Ca3) 22°58′58.0″ S, 051°27′36.2″ W; middle stretch (Ca2) 22°48′45.8″ S, 051°23′00.6″ W; upper stretch (Ca1) 22°42′23.6″ S, 051°26› 42.6″ W; Tenente Stream - lower stretch (Te3) 22°53′22.9″ S, 051°28′57.2″W; middle stretch (Te2) 22°47′11.2″ S, 051°29′14.6″ W, upper stretch (Te1) 22°43′00.2″ S, 051°30′36.0″ W; Centenário Stream - lower stretch (Cen3) 22°43′00.2″ S, 051°33′46.5″ W; middle stretch (Cen2) 22°53′31.4″ S, 051°33′46.5″ W; and upper stretch (Cen1) 22° 55′11.6″ S, 051°34′46.8″ W.

Table 1. Maximum and minimum width, depth, water speed and physical characterization of streams and their surroundings at the sampling stretches of the Capim, Tenente and Centenário streams, Lower Paranapanema River basin, Paraná**.**

	Stretch	Width (m)	Depth (m)	Water speed (m/s)	Predominant substrate at the bottom	Riparian vegetation	Surroundings
Capim Stream (Length: 60 km)	Ca1	4.15 - 6.30	0.5 - 1.40	0.13 - 0.85	Fine sediment	Absent	Agriculture (Sugar cane)
	Ca2	3.80 - 19.0	0.45 - 2.50	0.13 - 0.91	Fine sediment	Absent	Agriculture (Sugar cane)
	Ca3	3.35 - 25.0	0.4 - 0.90	0.18 - 0.94	Fine sediment	Absent	Agriculture (Sugar cane)
Tenente Stream (Length: 31 km)	Te1	2.47 - 3.60	0.44 - 0.80	0.11 - 0.86	Fine sediment	Absent	Agriculture (Sugar cane)
	Te2	9.50 - 17.50	0.25 - 1.10	0.18 - 0.41	Pebbles	Present	—
	Te 3	9.80 - 16.0	0.7 - 1.25	0.19 - 0.53	Fine sediment	Absent	Agriculture (Sugar cane)
Centenário Stream (Length: 50 km)	Cen1	2.75 - 7.76	0.40 - 1.0	0.08 - 0.30	Fine sediment	Absent	Agriculture (Sugar cane)
	Cen2	7.4 - 12.0	0.48 - 0.75	0.10 - 0.23	Fine sediment	Absent	Agriculture (Sugar cane)
	Cen3	4.5 - 9.0	0.80 - 1.20	0.19 - 0.59	Fine sediment	Absent	Agriculture (Sugar cane)

stretch two (Te2 = 17.5 m). The depth varied between 0.25 m (Te2 stretch) and 2.5 m (Te1 stretch) and the current velocity between 0.08 m/s (Cen 1) and 0.94 m/s (Ca3).

Data collection

Fish collection occurred quarterly, between May 2012 and August 2013, using a standardized experimental fishing technique in three sampling points at each stream (upper, middle and lower portions). Two hours of sampling effort were employed at each site, covering an extension of 100 meters. The use of trawls, sieves (2 mm mesh) and cast nets (2 cm mesh), with approximately 25 square meters of sampling effort per hour, enabled the evaluation of a high number of existing microhabitats.

Collected fish were anesthetized and euthanized by immersion in a water solution with clove oil and then fixed in 10% formalin. Fish were identified in the laboratory following to Graça and Pavanelli (2007) and transferred to 70% ethanol. Eschmeyer (2015) was used to verify the validity of the taxonomic names and provide the classification used. Voucher specimens were deposited in the Museu de Zoologia da Universidade Estadual de Londrina (MZUEL). The inventory includes the number of species in each stream and the percentage of species per taxonomic family and order.

RESULTS

This survey collected 3,167 specimens belonging to five orders, 17 families and 56 species. The Centenário Stream harbored the greatest number of species (41), followed by the Tenente (33) and the Capim (30) (Table 2). Comparing the three stretches of each stream, the Capim exhibited the greatest number of species recorded in the lower stretch (Ca3 = 18 species). The Tenente showed the largest number of species in the middle stretch (Te2 = 21 species) and the Centenário in the upper stretch (Cen1 = 26 species). There is an increase of species richness from the upper to the lower portion of the Capim Stream, and a decrease of the number of species downstream of the Tenente and Centenário streams.

Two species occurred in all stretches: *Astyanax bockmanni* Vari & Castro, 2007 and *Hypostomus ancistroides* (Ihering, 1911). Other species had a widespread occurrence, being found in at least six collection points: *Astyanax altiparanae* Garutti & Britski, 2000, *Astyanax fasciatus* (Cuvier, 1819), *Astyanax paranae* Eigenmann, 1914, *Bryconamericus iheringii* (Boulenger, 1887), *Bryconamericus stramineus* Eigenmann, 1908 and *Poecilia reticulata* Peters, 1859. Contrastingly, 31 species occurred only at one or two collection sites. Fourteen species were collected exclusively in the Centenário Stream, all in the upper stretch (Cen1).

Three species are not listed in the inventory of Paraná River Basin (Langeani et al. 2007): *Astyanax bockmanni, Gymnotus omarorum* Richer-de-Forges, Crampton & Albert, 2009 and *Phalloceros harpagos* Lucinda, 2008 (Table 2). *Hisonotus francirochai* (Ihering, 1928), *Hypostomus nigromaculatus* (Schubart, 1967), *Hypostomus paulinus* (Ihering, 1905), *Hypostomus strigaticeps* (Regan, 1908), *Apteronotus* cf. *caudimaculosus* (de Santana, 2003) and *Crenicichla jaguarensis* Haseman, 1911 also are not included in the catalog of species of the Paranapanema River (Duke Energy 2008) (Table 2).

Table 2. Taxonomic status (Eschmeyer 2015), occurrence and voucher number of fish species collected in the Capim, Tenente and Centenário streams, Lower Paranapanema River basin, Paraná. †: non-native species in the Paranapanema River basin.

	Capim			Tenente			Centenário			
Species	**Ca1**	**Ca2**	**Ca3**	**Te1**	**Te2**	**Te3**	**Cen1**	**Cen2**	**Cen3**	**Voucher number**
Characiformes										
Parodontidae										
Apareiodon ibitiensis Campos, 1944		X			X				X	MZUEL 6570
Apareiodon affinis (Steindachner, 1879)	X	X		X			X			MZUEL 6587
Parodon nasus Kner, 1859		X								MZUEL 6587
Curimatidae										
Steindachnerina insculpta (Fernández-Yépez, 1948)		X		X	X		X			MZUEL 6586
Crenuchidae										
Characidium gomesi Travassos, 1956			X							MZUEL 9413
Characidae										
Aphyocharax dentatus Eigenmann & Kennedy, 1903 †							X		X	MZUEL 6559
Astyanax altiparanae Garutti & Britski, 2000	X	X	X	X	X	X	X			MZUEL 6561
Astyanax bockmanni Vari & Castro, 2007	X	X	X	X	X	X	X	X	X	MZUEL 6562
Astyanax fasciatus (Cuvier, 1819)	X	X	X	X				X	X	MZUEL 6592
Astyanax paranae Eigenmann, 1914	X	X	X	X	X	X		X	X	MZUEL 6568
Bryconamericus iheringii (Boulenger, 1887)	X	X	X	X	X				X	MZUEL 6583
Bryconamericus stramineus Eigenmann, 1908	X	X	X	X	X		X	X	X	MZUEL 6560
Hyphessobrycon eques (Steindachner, 1882) †							X			MZUEL 9399
Moenkhausia sanctaefilomenae (Steindachner, 1907) †							X			MZUEL 6564
Oligosarcus paranensis Menezes & Géry, 1983		X		X	X					MZUEL 6595

Continued

Table 2. *Continued.*

Species	Capim			Tenente			Centenário			Voucher number
	Ca1	Ca2	Ca3	Te1	Te2	Te3	Cen1	Cen2	Cen3	
Oligosarcus pintoi Campos, 1945							X			MZUEL 9400
Piabina argentea Reinhardt, 1867	X	X	X	X	X					MZUEL 6590
Roeboides descalvadensis Fowler, 1932 †				X			X			MZUEL 6565
Serrapinnus notomelas (Eigenmann, 1915)		X				X				MZUEL 9408
Erythrinidae										
Hoplias aff. *malabaricus* (Bloch, 1794)						X			X	MZUEL 7430
Lebiasinidae										
Pyrrhulina australis Eigenmann & Kennedy, 1903							X			MZUEL 9401
Siluriformes										
Cetopsidae										
Cetopsis gobioides Kner, 1857	X									MZUEL 9411
Trichomycteridae										
Trychomycterus sp.								X		MZUEL 7427
Callichthyidae										
Callichthys callicthys (Linnaeus, 1758)							X			MZUEL 9402
Corydoras aeneus (Gill, 1858)	X						X			MZUEL 9397
Loricariidae										
Hisonotus francirochai (Ihering, 1928)			X		X	X			X	MZUEL 9603
Hypostomus albopunctatus (Regan, 1908)								X		MZUEL 7429
Hypostomus ancistroides (Ihering, 1911)	X	X	X	X	X	X	X	X	X	MZUEL 6574
Hypostomus nigromaculatus (Schubart, 1967)			X	X	X			X		MZUEL 6576
Hypostomus paulinus (Ihering, 1905)				X						MZUEL 6585
Hypostomus strigaticeps (Regan, 1908)	X		X	X	X			X		MZUEL 6581
Hypostomus sp. 1					X					MZUEL 9406
Hypostomus sp. 2					X					MZUEL 9405
Hypostomus sp. 3						X	X			MZUEL 7433
Imparfinis schubarti (Gomes, 1956)						X				MZUEL 6578
Loricariichthys platymetopon Isbrücker & Nijssen, 1979 †	X									MZUEL 9410
Neoplecostomus sp.			X		X			X		MZUEL 6575
Heptaperidae										
Cetopsorhamdia iheringi Schubart & Gomes, 1959				X	X					MZUEL 6582
Phenacorhamdia tenebrosa (Schubart, 1964)				X	X					MZUEL 7434
Rhamdia quelen (Quoy & Gaimard, 1824)			X	X	X	X			X	MZUEL 6569
Auchenipteridae										
Trachelyopterus galeatus (Linnaeus, 1766) †							X			MZUEL 9404
Gymnotiformes										
Gymnotidae										
Gymnotus omarorum Richer-de-Forges, Crampton & Albert, 2009 †			X				X		X	MZUEL 6573
Gymnotus inaequilabiatus (Valenciennes, 1839)							X			MZUEL 9412
Gymnotus sylvius Albert & Fernandes-Matioli, 1999			X			X			X	MZUEL 6573
Sternopygidae										
Eigenmannia trilineata López & Castello, 1966							X			MZUEL 8722
Sternopygus macrurus (Bloch & Schneider, 1801)							X			MZUEL 9403
Apteronotidae										
Apteronotus cf. *caudimaculosus* de Santana, 2003							X			MZUEL 6567
Cyprinodontiformes										
Poeciliidae										
Phalloceros caudimaculatus (Hensel, 1868)				X			X			MZUEL 6567
Phalloceros harpagos Lucinda, 2008		X	X							MZUEL 9414
Poecilia reticulata Peters, 1859 †			X	X		X	X	X	X	MZUEL 6580
Perciformes										
Cichlidae										
Cichlasoma paranaense Kullander, 1983						X	X		X	MZUEL 6571
Crenicichla britskii Kullander, 1982		X					X	X		MZUEL 6563
Crenicichla jaguarensis Haseman, 1911							X			MZUEL 6566
Crenicichla sp.					X					MZUEL 9407
Geophagus brasiliensis (Quoy & Gaimard, 1824)		X			X				X	MZUEL 6572
Oreochromis niloticus (Linnaeus, 1758) †	X							X		MZUEL 9409
Number of species (stretches)	**14**	**17**	**18**	**20**	**21**	**13**	**26**	**13**	**16**	
Number of species (stream)		**30**			**33**			**41**		

The predominance of characiform and siluriform species was evident in all streams (Table 3), but when individually analyzing them, the ichthyofaunal pattern is slightly divergent. Among Characiformes, the most represented family in number of species was Characidae, with 25% of the total, representing up to 31% of the species of the Capim Stream. Regarding Siluriformes, Loricariidae was the most represented (21.4% of the total), totaling 30.3% of species in the Tenente Stream. The occurrence of families varied in each of the three streams. Five families occurred exclusively in the Centenário Stream (Lebiasinidae, Trichomycteridae, Auchenipteridae, Sternopygidae and Apteronotidae) and two only in the Capim Stream (Crenuchidae and Cetopsidae), both represented by a single species.

Nine non-native species were recorded in the three streams, i.e., four characiform, two siluriform, one cyprinodontiform and one perciform. *Poecilia reticulata* was the only species recorded in all streams (in six of the nine stretches). *Roeboides descalvadensis* Fowler, 1932 was recorded in the Tenente and Centenário streams, and *Loricariichthys platymetopon* Isbrücker & Nijssen, 1979 was recorded only in the Capim Stream. *Gymnotus omarorum* was recorded in Capim and Centenário streams. Four non-native species were recorded exclusively in the Centenário Stream (*Aphyocharax dentatus* Eigenmann & Kennedy, 1903, *Hyphessobrycon eques* (Steindachner, 1882), *Moenkhausia sanctaefilomenae* (Steindachner, 1907) and *Trachelyopterus galeatus* (Linnaeus, 1766)).

DISCUSSION

The inventory undertaken in the Capim, Tenente and Centenário streams resulted in the identification of 56 fish species. This number exceeds the richness found by Castro et al. (2003) in 17 stretches of the streams of the Paranapanema River basin (52 species).

Three of the species registered are not included in the survey of Langeani et al. (2007) that comprises the Upper Paraná River basin, and nine are new records regarding the inventory of fish species of Paranapanema River basin (Duke Energy 2008). The results of other recent inventories conducted in different sub-basins of the Paranapanema River (Cetra et al. 2012; Cionek et al. 2012; Pagotto et al. 2012) and this study together indicate that the ichthyofaunal diversity of the Paranapanema River is currently underestimated and is likely to undergo a considerable increase in its fish species richness as more studies are conducted.

Most of the recorded species are small to medium-sized individuals exhibiting many rheophilic behaviors (Casatti et al. 2006; Langeani et al. 2007). The occurrence of *A. bockmanni* and *H. ancistroides* in all collection sites may be related to the high tolerance of these species to environmental degradation (Petesse et al. 2007; Furlan et al. 2013). There were also species adapted to the stretches impacted by dams and use both environments. Among the latter are *S. insculpta, A. affinis, H. ancistroides, L. platymetopon* and *E. trilineata* (Agostinho et al. 1995; Bennemann and Shibatta 2002). *Steindachnerina insculpta* inhabits both the flooded area of the Taquaruçu reservoir and the streams, as recorded by Britto and Carvalho (2006).

The dominance of Characiformes and Siluriformes is a taxonomic pattern described for the Neotropical freshwater region as a whole (Lowe-McConnell 1999). This dominance also prevails in other tributaries of

Table 3. Species richness (%) by taxonomic order and family in the Capim, Tenente and Centenário streams, Lower Paranapanema River basin, Paraná.

Order	Family	Total	Capim	Tenente	Centenário
Characiformes	Parodontidae	5.4	10.3	6.1	4.9
	Curimatidae	1.8	3.4	3.0	2.4
	Crenuchidae	1.8	3.4		
	Characidae	25.0	31.0	30.3	26.8
	Erythrinidae	1.8		3.0	2.4
	Lebiasinidae	1.8			2.4
Total Characiformes		**37.5**	**48.3**	**42.4**	**39.0**
Siluriformes	Cetopsidae	1.8	3.4		
	Trichomycteridae	1.8			2.4
	Callichthyidae	3.6	3.4		4.9
	Loricariidae	21.4	20.7	30.3	17.1
	Heptaperidae	5.4	3.4	9.1	2.4
	Auchenipteridae	1.8			2.4
Total Siluriformes		**35.7**	**31.0**	**39.4**	**29.3**
Gymnotiformes	Gymnotidae	5.4	6.9	3.0	7.3
	Sternopygidae	3.6			4.9
	Apteronotidae	1.8			2.4
Total Gymnotiformes		**10.7**	**6.9**	**3.0**	**14.6**
Cyprinodontiformes	Poeciliidae	5.4	6.9	6.1	4.9
Total Cyprinodontiformes		**5.4**	**6.9**	**6.1**	**4.9**
Perciformes	Cichlidae	10.7	6.9	9.1	12.2
Total Perciformes		**10.7**	**6.9**	**9.1**	**12.2**

the Upper Paraná River basin (Langeani et al. 2007), including the Paranapanema River (Castro et al. 2003), with Characidae and Loricariidae being the richest families in number of species, confirming other studies for the Upper Paraná River basin (*e.g.* Langeani et al. 2005; Galves et al. 2007).

Monitoring of non-native species with invasive potential is essential, as they may become dominant, especially in environments that are already under disturbance (Casatti et al. 2009; Britton and Orsi 2012), as pointed out by Simberloff (2013) and Orsi and Britton (2014). Among the recorded species, nine were introduced in the basin and sampled mostly in the upper stretches of the Centenário Stream. Some species, such as *L. platymetopon*, are considered invasive. It occurred naturally in the Lower Paraná River (Reis et al. 2003) and became abundant in the Upper Paraná River basin after the flooding of a natural geographical barrier (Sete Quedas) for the construction of the Itaipu Reservoir (Júlio Jr. et al., 2009). Other species, such as *A. dentatus, T. galeatus* and *R. descalvadensis* also followed the same route of introduction. *Gymnotus omarorum* is native to the Uruguay River basin and its introduction may be associated with the commerce of live bait, as has been reported for other *Gymnotus* species (Ortega et al. 2015).

Initially distributed in the Amazon and Paraná-Paraguay basins, *H. eques* started occurring in the Upper Paraná River after the deliberate release by the aquarist industry (Graça and Pavanelli 2007; Magalhães 2015), the same path of introduction of *Poecilia reticulata,* a native species of the Venezuela rivers and present in several Brazilian basins (Graça and Pavanelli 2007; Oliveira et al. 2014). It is a generalist species considered indicative of degraded environments (Casatti et al. 2009; Souza and Tozzo 2013). *Oreochromis niloticus*, the Nile Tilapia, was introduced in several basins of South America and is widely raised for fisheries and in fish culture (Graça and Pavanelli 2007), and has considerable invasive potential reported (Martin et al. 2010; Pelicice et al. 2014).

The increase in species richness along the longitudinal axis observed in Capim Stream has been documented in several other streams (Oliveira and Garavello 2003; Casatti 2005). Species addition seems to prevail in less abrupt transitions of streams gradient (Ferreira and Petrere Jr. 2009), but segments more distant from the headwaters often present a more complex habitat, suggesting a higher number of species able variably to interact with the environment (Silva et al. 2013). The opposite situation observed in Tenente and Centenário streams may be strongly associated with local environmental characteristics (Mazzoni et al. 2006; Teresa and Romero 2010) and can be attributed to the degree of environmental degradation along the whole reach but concentrated in the upper portion. The studied streams have been disrupted by extensive agricultural activities (especially sugar cane agriculture), pastures, dumping of domestic and industrial effluents, and riparian deforestation. The threat of loss of environmental integrity by the suppression of riparian vegetation results in both direct and indirect effects on fish communities (Pusey and Arthington 2003). The occupation of stream margins by grass and sugar cane crops can lead to the simplification of the riverine ecosystem, and result in both the loss of habitats and subsequent decline in the species richness (Casatti et al. 2006; 2009).

Small order water bodies are important for the conservation of fish biodiversity in the Paranapanema River, as well as in the Upper Paraná River basin. The fragility of these environments with their complexity and richness is evident. However, this fragility has apparently been excluded from management and preservation considerations, as evidenced by the environmental disturbance observed in this study. We hope that the results of the current inventory will serve as an incentive for further stream surveys in the region as an aid to efforts to mitigate further impacts.

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