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Inventory

Fish fauna in low-order streams of the Piquiri River, Upper Paraná River basin, Brazil

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Abstract: The South America ichthyofauna encompasses the highest diversity of the world, however is highly threatened by anthropogenic actions. The fish fauna of nine low-order streams, tributaries of the Piquiri River and impacted by aquaculture, agriculture and urbanization were sampled in the present study. Samplings were done quarterly from December 2017 to September 2018 at three sites in each stream, using a portable electric fishing device in 50-meter segments. A total of 14,507 individuals were collected, belonging to six orders, 20 families, 46 genera, and 70 species. The highest richness and abundance were found for the orders Characiformes and Siluriformes. In this study, nine species that had not been recorded were found, totaling 163 for the basin. In addition, 14 non-native species were captured. The presented list of species contributes to the existing database of ichthyofauna distribution in Neotropical streams, denoting that it is underestimated in the region, mainly in low-order tributaries. The present study reinforces the importance of inventories and monitoring in environments with high biodiversity and sensitive to anthropogenic actions.
Keywords: *Biodiversity; Streams; Land use.*

Fauna de peixes em riachos de pequena ordem do rio Piquiri, bacia do alto rio Paraná, Brasil

Resumo: A ictiofauna sul-americana abrange a maior diversidade do planeta, no entanto, encontra-se altamente ameaçada pela ação antrópica. Nesse estudo, a fauna de peixes de nove riachos de pequena ordem foi amostrada. Esses riachos são afluentes do Rio Piquiri e afetados pela atividade aquícola, agrícola e urbanização. As coletas foram realizadas trimestralmente de dezembro/2017 a setembro/2018 em três pontos amostrais de cada riacho, utilizando-se equipamento portátil de pesca elétrica em segmentos delimitados de 50 metros. Foram coletados 14.507 indivíduos, pertencentes a seis ordens, 20 famílias, 46 gêneros e 70 espécies. Os maiores valores de riqueza e de abundância foram obtidos nas ordens Characiformes e Siluriformes. Neste estudo, foram encontradas nove espécies ainda não registradas, totalizando 163 para a bacia. Além disso, 14 espécies não-nativas foram capturadas. Ressalta-se que a lista de espécies apresentada contribui com o banco de dados existente sobre os padrões de distribuição da ictiofauna em riachos Neotropicais e demonstra como a mesma ainda pode ser subestimada na região, principalmente em tributários de pequena ordem. Esse estudo reforça a importância de inventários e do monitoramento em ambientes altamente diversos e sensíveis à ação antrópica.
Palavras-chave: *Biodiversidade; Riachos; Uso do solo.*

Introduction

South America has the highest fish diversity of the world, which encompasses more than nine thousand described species and approximately one third of all freshwater fish species (Reis et al. 2016). However, the conservation of the continental ichthyofauna of South America is an increasing challenge because of continuous losses of habitats caused by anthropogenic changes resulted from different soil uses, such as urbanization, agriculture, mining and hydroelectric dams (Pelicice et al. 2017), as well as overfishing and introduction of non-native species (Rios-Touma & Ramírez 2019). Therefore, the rate of species extinction can be higher than the actual information of number of species and their geographical distribution. Thus, ichthyofauna inventories are essential for a significant analysis of the biodiversity, especially in environments that have no significant sampling of their fauna, such as low-order streams (Frota et al. 2019).

The Piquiri River basin comprises a drainage area of 31,000 km² in the Upper Paraná Ecoregion (Abell et al. 2008), its sources are located in the São João Mountains and it runs 485 km before reaching the Paraná River, forming the third largest hydrographic basin in the State of Paraná, Brazil. The Piquiri River is one of the last tributaries free of damming in the Upper Paraná River basin, which reinforces its ecological importance (Agostinho et al. 2004a, Affonso et al. 2015) and makes it an important environment for migratory species (Gubiani et al. 2010). Considering its importance for the conservation of the Brazilian continental ichthyofauna and the occurrence of 152 fish species in this river basin in research developed by Cavalli et al. (2018), and 154 according to Reis et al. (2020), studies on low-order streams are necessary, mainly because of their importance for freshwater biodiversity, role in contributing to ecosystem service and sensitivity and vulnerability to anthropogenic disturbances (Biggs et al. 2017).

Rivers and streams of the region are intensely affected by the increased environmental degradation resulted from human activities, such as agricultural production (intensive crop production, livestock, and aquaculture) and urbanization (industrial and household effluents, and habitat changes) (Gubiani et al. 2010, Pereira et al. 2014). Thus, a continuous monitoring and inventorying of their ichthyofauna are essential for the development of a database that contributes to a better understanding of the species distribution in changed environments, and assists in defining and implementing practices for biodiversity management and conservation.

Thus, the objective of the present study was to survey the ichthyofauna of nine low-order streams (second and third orders; Strahler, 1957) that compose the Piquiri River basin (Upper Paraná Ecoregion) and are affected by agricultural, aquaculture and urbanization activities, and to inventory the occurring fish species in these environments to contribute to the improvement of information about the biodiversity of the region.

Material and Methods

1. Study area

The study was conducted in nine second and third-order streams that compose the Piquiri River basin and are located in the West and Northwest of the state of Paraná, South of Brazil (Figure 1). These regions comprise an area of 47,000 km² (23% of the total area of the state) and encompass 111 municipalities (IPARDES 2019). The regions have a humid subtropical climate, and its soil was classified as dystrophic Typic Hapludox (Latossolo Vermelho-Escuro; EMBRAPA - SNLCS 1984), which has good fertility and is highly favorable to agriculture (Pereira et al. 2014). The main economic activity in the regions is agriculture, but aquaculture is also an important activity. The West region is the main aquaculture production center of the state (Marengoni et al. 2007) and one of the three highest national aquaculture production regions (Becker et al. 2015). The main produced species in this region is *Oreochromis niloticus* L. (1758) (Nile tilapia). The aquaculture is less expressive in the Northwest region (SEAB 2018).

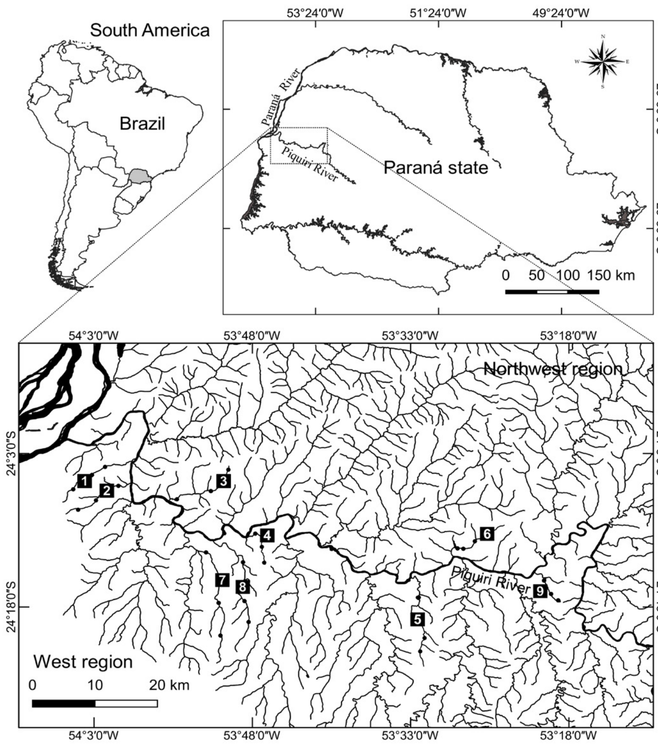

Figure 1. Sampled streams in the Piquiri River basin, Paraná, Brazil: 1) Córrego Tapera; 2) Córrego Taquari; 3) Rio do Bagre; 4) Sanga 16 de Janeiro Stream; 5) Rio Baiano; 6) Rio das Antas; 7) Arroio Santa Fe; 8) Arroio Pioneiro; and 9) Córrego Tatu. Dots indicate local of samplings over the longitudinal gradient of the streams (headwater, middle and mouth).

2. Ichthyofauna sampling and data analysis

The ichthyofauna was sampled quarterly from December 2017 to September 2018 at three sites of each stream in their longitudinal gradient (headwater, middle and mouth – Table 1). Fish assemblages were sampled using an electrofishing equipment (portable generator of alternating current of 2.5 kW, 400 V, 2A) in 50-meter segments delimited by multifilament nets f 0.5-centimeter mesh. Three successive downstream-to-upstream catches were established in each segment (Esteves & Lobón-Cerviá 2001).

The captured specimens were anesthetized in a eugenol solution (100 mg. L^{-1}) and fixed in a 10% formalin solution. The fishes were identified in a laboratory, according to Ota et al. (2018). Sample specimens were preserved in 70% alcohol and deposited in the ichthyological collection of the Nucleus of Research in Limnology, Ichthyology and Aquaculture (NUPELIA) of the State University of Maringá, Paraná State, Brazil. The sampling of the biological material was authorized by the Chico Mendes Institute for Conservation of

Biodiversity (ICMBIO; License no. 24680-1). The sampling protocol used in the present study was subjected to a process of ethical review and approved by the Ethics Committee on the Use of Animals of the Federal University of Paraná (CEUA – UFPR), in Palotina, PR, Brazil, under the Protocol no. 01/2018.

The sampling efficiency was evaluated based on data of total abundance, using the Chao 1 and Jackknife 1 richness estimators, which consider the actual number of species richness based on rare species shared between groups of samples. Subsequently, species accumulation curves were developed. All analyses were made in the Estimates 9.0 program (Colwell 2013).

Results

A total of 14,507 individuals were collected in the nine streams evaluated. Specimens were from six orders, 20 families, 46 genera, and 70 species (Table 2). The highest species richness was found for the orders Characiformes (34 species) and Siluriformes (21 species), which represented 80% of the total species sampled in the streams evaluated. The families that presented higher species richness were Characidae (18 species), Loricariidae (nine species), and Heptapteridae (seven species), representing 49% of the total species richness (Figure 2).

The streams with higher species richness were the Córrego Tapera (48 species), followed by the Córrego Taquari and Rio do Bagre, both presenting 42 species. Low species richness was found in the Córrego Tatu and Rio das Antas (16 species each). Among the species collected, six were captured in all streams evaluated, while 11 were found exclusively in one of the streams (Table 2).

The highest abundances were found for the orders Siluriformes (42%) and Characiformes (37%). *Pimelodella avanhandavae* and *Psalidodon* aff. *paranae* were the most representatives, with approximately 23% of the total abundance found. *Psalidodon* aff. *paranae* and *Phalloceros harpagos* were more abundant in the Rio das Antas, presenting 51% and 25% total abundance found, respectively. *Pimelodella avanhandavae* represented 61% of the total abundance found in the Arroio Pioneiro Stream, whereas *Poecilia reticulata* represented 66% of the abundance in the Córrego Tatu. *Hypostomus* cf. *tietensis* represented 27% of the abundance in Córrego Santa Fé. All species found in the others streams presented relative abundances lower than 24%.

Nine species identified in the samplings of the present study had not yet been recorded in the basin by other studies, namely *Aequidens plagiozonatus, Apteronotus* cf. *caudimaculosus, Coptodon rendalli, Erythrinus erythrinus, Hoplias misionera, Moenkhausia australe, M. bonita, Pyrrhulina australis* and *Steindachnerina brevipinna.*

Table 1. Geographic coordinates and abiotic variables of sampling sites in low-order streams of the Piquiri River, Upper Paraná River basin, Paraná, Brazil.

Stream	Site	Latitude	Longitude	Depth (m)	Width (m)	Flow (m/s)	Canopy (%)
Tapera	Headwater	24°06'29.9"S	54°04'58.6"W	0.43	4.30	0.7	48
	Middle	24°05'05.8"S	54°03'12.2"W	0.30	3.79	1.3	17
	Mouth	24°04'18.4"S	54°01'57.3"W	0.44	4.18	1.1	7
Taquari	Headwater	24°08'29.8"S	54°04'30.7"W	0.30	1.60	0.2	99
	Middle	24°07'34.7"S	54°02'49.1"W	0.42	3.71	0.6	65
	Mouth	24°06'09.8"S	54°00'41.5"W	0.57	3.50	1.9	25
Bagre	Headwater	24°04'35.0"S	53°50'16.3"W	0.19	2.15	0.7	78
	Middle	24°06'40.4"S	53°51'56.0"W	0,41	4.52	0.8	51
	Mouth	24°07'28.2"S	53°55'08.9"W	0.57	6.21	1.0	53
16 de Janeiro	Headwater	24°13'39.9"S	53°46'52.5"W	0.19	1.13	0.4	76
	Middle	24°12'07.4"S	53°47'06.1"W	0.24	4.23	0.6	98
	Mouth	24°10'49.8"S	53°47'43.2"W	0.34	4.74	0.6	55
Baiano	Headwater	24°22'20.4"S	53°32'5.5"W	0.39	4.04	0.5	100
	Middle	24°21'01.8"S	53°31'40.6"W	0.55	4.80	0.4	100
	Mouth	24°17'03.9"S	53°32'13.9"W	0.78	5.24	1.0	57
Antas	Headwater	24°11'34.6"S	53°26'54.8"W	0.48	3.61	1.0	100
	Middle	24°12'18.6"S	53°28'00.2"W	0.46	4.43	1.0	99
	Mouth	24°12'16.4"S	53°28'33.3"W	0.32	4.80	0.7	12
Santa Fé	Headwater	24°20'47.7"S	53°51'01.3"W	0.25	5.42	1.1	92
	Middle	24°17'36.2"S	53°51'11.6"W	0.37	6.98	1.2	100
	Mouth	24°12'40.0"S	53°52'23.3"W	0.77	5.89	0.7	100
Pioneiro	Headwater	24°19'27.9"S	53°48'21.2"W	0.32	2.90	0.5	99
	Middle	24°17'25.3"S	53°48'44.8"W	0.48	3.95	1.1	99
	Mouth	24°13'37.5"S	53°48'53.2"W	0.70	6.25	0.75	100
Tatu	Headwater	24°17'21.0"S	53°19'01.1"W	0.17	1.12	<0.1	100
	Middle	24°16'43.6"S	53°19'41.2"W	0.22	3.82	0.4	100
	Mouth	24°15'25.0"S	53°20'21.4"W	0.52	3.10	0.4	100

*Abiotic variables represent mean values of data collections

Table 2. List of species, total abundances and origin of fishes collected in low-order streams of the Piquiri River, Upper Paraná River basin, Paraná, Brazil. 1) Sanga 16 de Janeiro; 2) Rio das Antas; 3) Rio do Bagre; 4) Rio Baiano; 5) Arroio Pioneiro; 6) Arroio Santa Fé; 7) Córrego Tapera; 8) Córrego Taquari; and 9) Córrego Tatu. One asterisk (*) represents non-native species from the Upper Paraná River basin. Two asterisks (**) represent possible non-native species (Ota et al. 2018).

TÁXON	1	2	3	4	5	6	7	8	9	VOUCHER
ACTINOPTERI										
CHARACIFORMES										
Anostomidae										
Leporinus friderici (Bloch, 1794)	3							4		NUP22551, 22475
Characidae										
Characinae										
Galeocharax gulo (Cope, 1870)							1			NUP22361
Cheirodontinae										
Serrapinnus notomelas (Eigenmann, 1915)			24	6	10	4	24	53		NUP22525, 22415, 22382, 22484
Stethaprioninae										
Astyanax lacustris (Lütken, 1875)	281		30	30	129	68	85	188	46	NUP22534, 22494, 22391, 22570, 22348, 22454, 22418
*Moenkhausia australe (*Eigenmann, 1908)**	2						13			NUP22552, 22368
Moenkhausia bonita Benine, Castro, Sabino, 2004							2	21		NUP22369, 22476
Moenkhausia cf. *gracilima* Eigenmann, 1908							1			NUP22370
Moenkhausia sanctaefilomenae (Steindachner, 1907)			2				5	4		NUP22516, 22371, 22477
Oligosarcus paranensis Menezes, Géry, 1983			5				8			NUP22517, 22372
Oligosarcus pintoi Amaral Campos, 1945					1	2	17	6		NUP22373, 22478
Psalidodon bockmanni (Vari, Castro, 2007)		3	1				1			NUP22493, 22347
Psalidodon aff. *fasciatus* (Cuvier, 1819)	53		48	63	15	168	260	102		NUP22532, 22491, 22389, 22569, 22345, 22452
Psalidodon aff. *paranae* (Eigenmann, 1914)	7	1095	20	17	5	34	5	10		NUP22533, 22434, 22492, 22390, 22559, 22453
Stevardiinae										
Bryconamericus coeruleus Jerep, Shibatta 2017				1						NUP22393
Bryconamericus exodon Eigenmann, 1907*	34		34	5			186	442		NUP22535, 22496, 22394, 22349, 22455
Bryconamericus aff. *iheringii* (Boulenger, 1887)			32	10	6	37	15			NUP22495, 22392, 22571, 22346
Bryconamericus turiuba Langeani, Lucena, Pedrini, Tarelho- Pereira, 2005	156		168	13	197	14	192	198		NUP22536, 22497, 22395, 22560, 22350, 22456
Piabarchus stramineus (Eigenmann, 1908)			33	9	33	18	7	4		NUP22522, 22412, 22587, 22378, 22480
Piabina argentea Reinhardt, 1867			50	2						NUP22523, 22413
Crenuchidae										
Characidium gomesi Travassos, 1956							20			NUP22355
Characidium aff. *zebra* Eigenmann, 1909	7	28	31	3			38	110		NUP22539, 22436, 22501, 22398, 22354, 22461

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Curimatidae										
Cyphocharax modestus (Fernández-Yépez, 1948)	1				4		3	1		NUP22542, 22563, 22358, 22464
Steindachnerina brevipinna (Eigenmann, Eigenmann, 1889)*	1						3			NUP22383
Steindachnerina insculpta (Fernández-Yépez, 1948)	1				2	2		10		NUP22558, 22592, 22485
Erythrinidae										
Erythrinus erythrinus (Bloch, Schneider, 1801)*	8		5	1			1	2	1	NUP22543, 22505, 22400, 22359, 22466, 22421
Hoplias mbigua Azpelicueta, Benitez, Aichino, Mendez, 2015*	5	5	3		1	1	1	3	5	NUP22546, 22441, 22509, 22577, 22471, 22424
Hoplias misionera Rosso, Mabragaña, González-Castro, Delpiani, Avigliano, Schenone, Días de Astarloa, 2016	1	5	7		7	3	3	2	6	NUP22547, 22442, 22510, 22565, 22578, 22365, 22472, 22425
Hoplias sp.2			2	1						NUP22511, 22404
Lebiasinidae										
Pyrrhulina australis Eigenmann, Kennedy, 1903							1			NUP22380
Parodontidae										
Apareiodon affinis (Steindachner, 1879)			1					3		NUP22490, 22450
Apareiodon cf. *piracicabae* (Eigenmann, 1907)	22		11	6	1		9	76		NUP22530, 22489, 22387, 22342, 22449
Apareiodon vladii Pavanelli, 2006	4							1		NUP22531
Parodon nasus Kner, 1859	7		1	2			19	20		NUP22554, 22519, 22410, 22375
Prochilodontidae										
Prochilodus lineatus (Valenciennes, 1837)						5		2		NUP22482
GYMNOTIFORMES										
Apteronotidae										
Apteronotus aff. *albifrons* (Linnaeus, 1766)**							1			NUP22343
Apteronotus cf. *caudimaculosus* Santana, 2003**				1			1	16		NUP2388, 22344, 22451
Gymnotidae										
Gymnotus inaequilabiatus (Valenciennes, 1839)	71	134	39	125	135	61	36	65	35	NUP22544, 22438, 22506, 22401, 22362, 22468, 22422
Gymnotus pantanal Fernandes, Fernandes, Albert, Daniel-Silva, Lopes, Crampton, Almeida-Toledo, 2005*	33	1	17	5	13	14	8	18	14	NUP22545, 22439, 22507, 22402, 22564, 22576, 22363, 22469, 22423
Gymnotus sylvius Albert, Fernandes-Matioli, 1999		35	6	7	3		13	27		NUP22440, 22508, 22403, 22364, 22470
Sternopygidae										
Eigenmannia trilineata López, Castello, 1966			1					3		NUP22504, 22465
Sternopygus macrurus (Bloch, Schneider, 1801)			9					6		NUP22526, 22486

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SILURIFORMES										
Auchenipteridae										
Tatia neivai (Ihering, 1930)			6				2			NUP22528, 22385
Callichthyidae										
Callichthys callichthys (Linnaeus, 1758)	1		5		6		3	3		NUP22537, 22498, 22561, 22351, 22457
Corydoras aeneus (Gill, 1858)	247		7	8		8	16	59	154	NUP22540, 22502, 22399, 22573, 22356, 22462, 22419
Cetopsidae										
Cetopsis gobioides Kner, 1858			1	1				1		NUP22396, 22459
Heptapteridae										
Cetopsorhamdia iheringi Schubart, Gomes, 1959	10		51	3	11	5	92	32		NUP22538, 22500, 22397, 22353, 22460
Imparfinis mirini Haseman, 1911	1									NUP22549
Imparfinis schubarti (Gomes, 1956)	11		31	27	155	7	338	284		NUP22550, 22515, 22408, 22582, 22367, 22474
Pimelodella avanhandavae Eigenmann, 1917	169				1903	10	47	70		NUP22556, 22588, 22379, 22481
Pimelodella gracilis (Valenciennes, 1835)					4		1			
Phenacorhamdia tenebrosa (Schubart, 1964)			18	8	11	9	7	2		NUP22521, 22411, 22377, 22479
Rhamdia quelen (Quoy, Gaimard, 1824)	130	78	75	14	40	83	44	79	30	NUP22557, 22446, 22524, 22414, 22590, 22381, 22483, 22431
Loricariidae										
Hypostominae										
Ancistrus sp.						1				NUP22568
Hypostomus ancistroides (Ihering, 1911)	52	88	179	65	22	36	60	58	37	NUP22548, 22443, 22512, 22405, 22366, 22473, 22426
Hypostomus sp.1						1				NUP22581
Hypostomus sp.2			8	16	45	264			14	NUP22514, 22407, 22580, 22427
Hypostomus cf. *tietensis* (Ihering, 1905)			58	6	110	347				NUP22513, 22406, 22579
Loricariinae										
Farlowella hahni Meinken, 1937*							6	12		NUP22360, 22467
Loricariichthys platymetopon Isbrücker, Nijssen, 1979*						7				NUP22583
Rineloricaria latirostris (Boulenger 1900)					9	15				NUP22567, 22591
Otothyrinae										
Otothyropsis polyodon Calegari, Lehmann A., Reis, 2013			71				3			NUP22518, 22374
Trichomycteridae										
Cambeva aff. *davisi* (Haseman, 1911)		29	73			15	5	2		NUP22435, 22499, 22572, 22352, 22458
SYNBRANCHIFORMES										
Synbranchidae										

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Synbranchus marmoratus Bloch, 1795	2	10	11	115	20	19	8	32	2	NUP22447, 22527, 22416, 22593, 22384, 22487, 22432
CICHLIFORMES										
Cichlidae										
Aequidens plagiozonatus Kullander, 1984*	4	82	13	4	7	3	6	7	2	NUP22529, 22433, 22488, 22386, 22341, 22448, 22417
Coptodon rendalli (Boulenger, 1897)*		11			1					NUP22437, 22562
Crenicichla britskii Kullander, 1982	12		10		12	4	23	14	10	NUP22541, 22503, 22574, 22357, 22463, 22420
Geophagus iporangensis Haseman, 1911						11				NUP22575
Oreochromis niloticus (Linnaeus, 1758)*	29	2		5	210	18			6	NUP22553, 22444, 22409, 22566, 22584, 22428
CYPRINODONTIFORMES										
Poeciliidae										
Phalloceros harpagos Lucinda, 2008	2	530	4			3	22		2	NUP22429, 22445, 22520, 22584, 22376, 22429
Poecilia reticulata Peters, 1859*						9			712	NUP22589, 22430
Total abundance	1367	2136	1201	579	3128	1306	1662	2052	1076	
Richness	32	16	42	31	32	35	48	42	16	

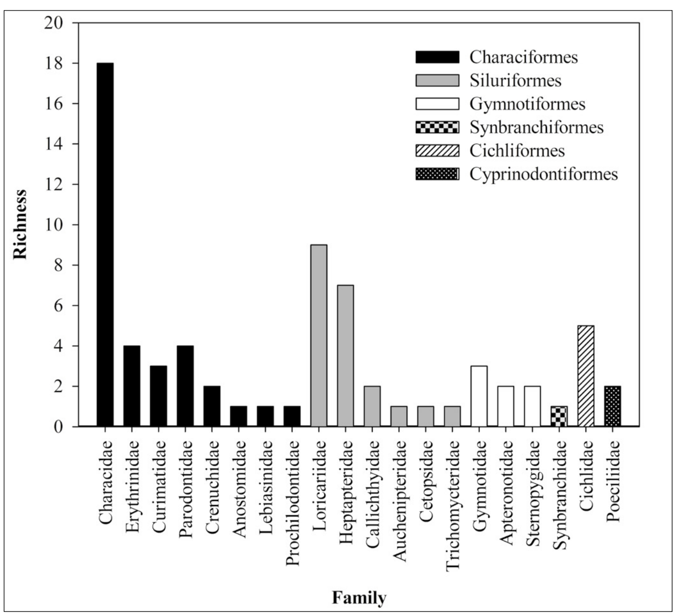

Figure 2. Richness of species by order and family identified in the nine sampled streams of the Piquiri River basin, Paraná, Brazil.

Regarding the origin of the ichthyofauna studied, 14 species were classified as non-native to the Piquiri River basin (Table 2), which represented 14% of the total abundance found. *Poecilia reticulata*, *Bryconamericus exodon*, *Oreochromis niloticus*, *Aequidens plagiozonatus* and *Gymnotus pantanal* presented the highest abundances among these non-native species.

The estimators of richness used indicated a good sampling efficiency, presenting similar values to those found in the samplings (Figure 3).

Discussion

The non-parametric richness estimators indicated a good efficiency in the samplings, since the estimated values of richness approximate the real number of species recorded in each stream. These estimators, despite being sensitive to changes in the distribution of abundance and despite providing estimates of the lower limit of richness at a local scale, consider environmental heterogeneity (Gotelli & Chao 2013, Gwinn et al. 2016, Bevilacqua et al. 2017). This is an important factor in the present study, given the number of sampling sites and the fact that they have different watershed land uses. In this way, nine species identified in the present study had not yet been recorded in the Piquiri River basin, even considering recent studies that updated the ichthyofauna composition of this basin and reported the occurrence of 152 (Cavalli et al. 2018) and 154 fish species (Reis et al. 2020). This indicates that the ichthyofauna diversity of the Piquiri River basin is underestimated, especially that of its low-order tributaries, and denotes a need for continuous researches in these environments. Although the information about ichthyofauna diversity in Neotropical streams has been improved over the years, several species are still unknown to science (Ota et al. 2015, Frota et al. 2019, Mezzaroba et al. 2021).

Neotropical streams in South America are characterized by the occurrence of a high fish diversity due to the geographic isolation of this continent and its drainage basins, and the high diversity of habitats over its longitudinal gradient, with predominance of species from the orders Characiformes and Siluriformes (Lowe-McConnell 1999, Agostinho et al. 2007). The predominance of these orders has been recorded for the Upper Paraná Ecoregion (Langeani et al. 2007, Cavalli et al. 2018), as found in the present study.

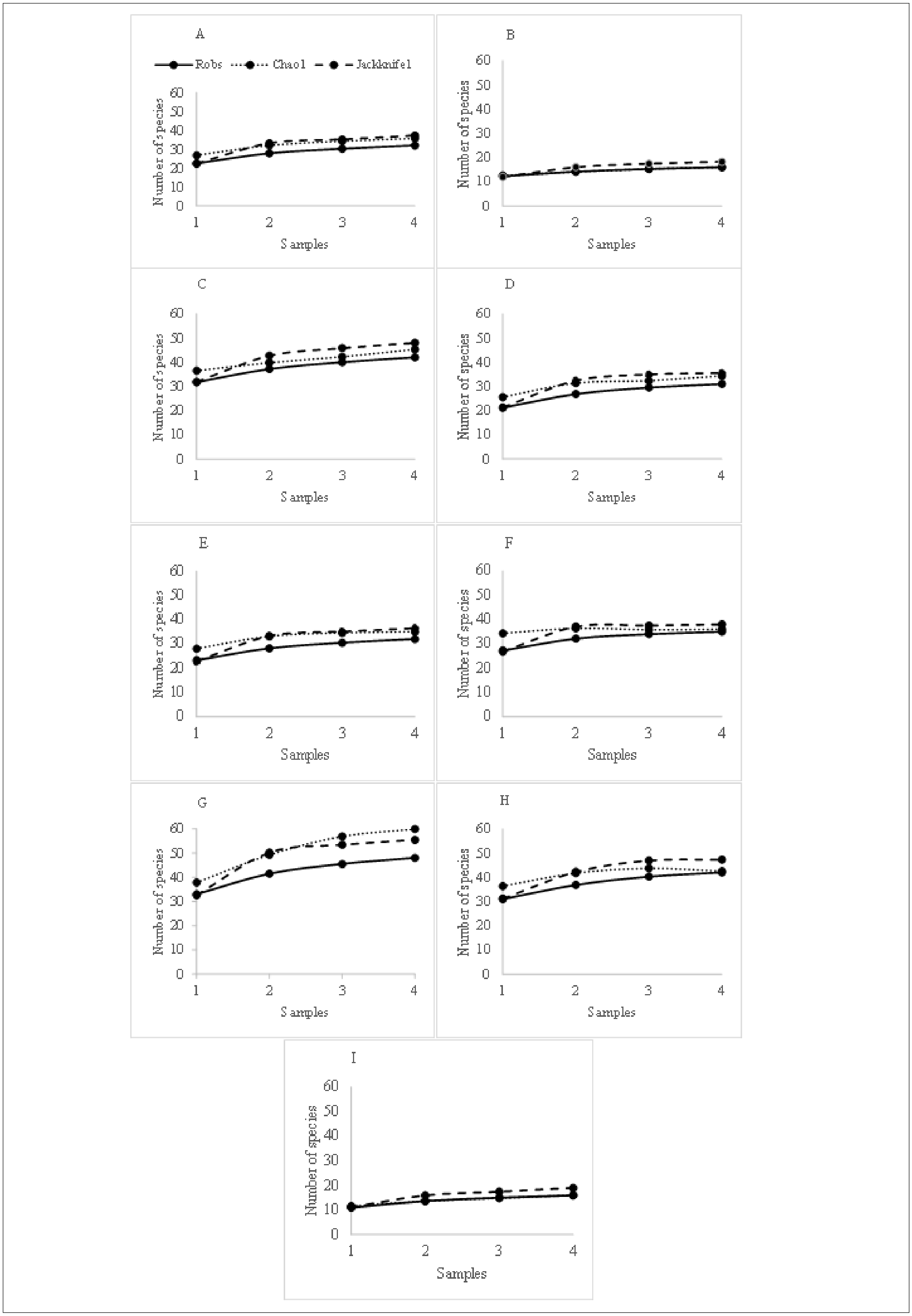

Figure 3. Species accumulation curves (Robs) and richness estimations (Chao 1 and Jackknife 1) for fish samples collected quarterly in streams of the Piquiri River basin, Paraná, Brazil, from December 2017 to September 2018. Sanga 16 de Janeiro (A); Rio das Antas (B); Rio do Bagre (C); Rio Baiano (D); Arroio Pioneiro (E); Arroio Santa Fé (F); Córrego Tapera (G); Córrego Taquari (H); and Córrego Tatu (I).

Regarding the order Characiformes, a high occurrence of small-size species from Characidae was observed, which is highly distributed in freshwater environments, encompasses a large proportion of stream fish species, and presents diverse feeding and reproductive habits (Britski 1972, Lowe-McConnell 1999). The predominance of species of the order Siluriformes is related to habitat characteristics, such as presence of riffles and boulders in the stream bed substrate, which favor the occurrence of Loricariidae and Heptapteridae. The latter is associated with environments near rapids and that have submersed marginal vegetation and cracks between rocks (Bockmann and Guazzelli 2003, Pagotto et al. 2011).

The predominance of the *Psalidodon* aff. *paranae* and *Phalloceros harpagos* in the Rio das Antas, whose was dammed to supply water for aquaculture systems, indicates the plasticity of these species in modified habitats by human actions. *Phalloceros harpagos* and species of *Psalidodon* are common in streams of the Upper Paraná River basin (Langeani et al. 2007, Gubiani et al. 2010) and their wide plasticity allows them to explore efficiently changed habitats (Monaco et al. 2014, Pereira et al. 2014). The predominance of the non-native species *Poecilia reticulata* in the Córrego Tatu, where environmental changes occurred due to urbanization near the headwater reach, denotes the plasticity of this species to explore changed environments. Previous studies indicate similar patterns, with predominance of *P. reticulata* in environments that were affected by urbanization (Cunico et al. 2006, Gubiani et al. 2010). Urban development is one of the main factors for biodiversity changes in streams because it fragments natural landscapes, changing hydrological regimes, matter flow, and nutrient cycling. It is associated with the establishment of non-native species that can increase their abundance and dominance under adverse environmental conditions (Cunico et al. 2012).

The occurrence of the non-native *Oreochromis niloticus* and *Coptodon rendalli* is related to the intense aquaculture activity in the region. Aquaculture is the main vector for introducing non-native species into environments around the world (Lima et al. 2018), and highly frequent introductions have great potential of negatively effects on the diversity of native species and the ecosystem services (Pelicice et al. 2017). The high abundance of *O. niloticus* and occurrence of *C. rendalli* found in the streams evaluated are due to escapes from ponds used for aquaculture activities, denoting the need for efficient escape containment mechanisms (Nobile et al. 2019). The occurrence of non-native species due to aquaculture activities is also reported by others studies on the region and can be attributed to the low distances between fish ponds and streams, which allows escapes through effluent waters under inadequate management, rupture or overflow in rainy periods, and intentional releases (Orsi & Agostinho 1999, Forneck et al. 2016, Ribeiro et al. 2018, Casimiro et al. 2018, Forneck et al. 2020).

Other non-native species were found in the present study due to different vectors of species introduction in the basin. The occurrence of *Bryconamericus exodon* is associated with the transposition channel of the Itaipu Hydroelectric Power Plant, which connects the downstream region of the reservoir to the upstream region of the dam (Ota et al. 2018). The presence of the *Gymnotus pantanal* is probably because of accidental introductions due to use of live baits for fishing, and floods in biogeographic barriers, as in the Salto de Sete Quedas, which resulted from the formation of the Itaipu reservoir. The presence of *Aequidens plagiozonatus* is possibly because of the ornamental fish trade. This species is found in the Upper Parana River basin since 2014 (Ota et al. 2018) and was found in all streams evaluated in the present study.

Regarding the native species found, *Prochilodus lineatus* and *Leporinus friderici* stand out. These species are abundant in the Upper Paraná River basin, present ecological and economical importance, and are long-distance migratory species that move from feeding areas to breeding areas (Agostinho et al. 2004b, Agostinho et al. 2007, Makrakis et al. 2012, Silva et al. 2015, Bido et al. 2018). The presence of juveniles of these species in the sampled streams reinforces the need to maintain the Piquiri River basin free from hydroelectric dams, since these barriers hinder migration routes, preventing those juveniles of these species access environments where migratory species breed and grow (Agostinho et al. 2008, Silva et al. 2015).

In view of the results obtained and in agreement with other researches carried out recently in the basin (Cavalli et al. 2018, Reis et al. 2020), 163 fish species are recorded in the Piquiri River basin. Regarding the number of non-native species, it is worth mentioning that Cavalli et al. (2018) recorded 30 species among the 152 sampled and that Reis et al. (2020) recorded 41 species among the 154. Despite the high number already registered, in the present study, five of the nine new records are of non-native species, totaling 48 in the referred basin, which reinforces the importance of knowledge and monitoring of streams that are under strong anthropogenic pressure.

The list of species found in the present study contributes to the existing database of ichthyofauna distribution in Neotropical streams, considering that it shows the presence of species that had been not yet registered for the Piquiri River basin, and a high occurrence of non-native species in the basin. The study basin is in the last stretch free from hydroelectric dams of the Upper Paraná River basin, which is essential for the integrity of biological processes in this environment. Therefore, this study reinforces the importance of inventories and monitoring of highly sensitive environments to anthropogenic changes.

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Author Contributions

Mariele P. Camargo: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Sandra C. Forneck: Substantial contribution in the concept and design of the study; Contribution to data collection, Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Fabrício M. Dutra: Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Leonardo B. Ribas: Contribution to data collection; Contribution to data analysis.

Almir M. Cunico: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation and contribution to manuscript preparation; Contribution to critical revision, adding 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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