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Article

Headwater Stream Fish Assemblages: What its Diversity and the Environment Tell us About their Structure and Organization?

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ABSTRACT

Understanding the relationship among descriptors of community diversity and the response of these descriptors to the environment is a cornerstone to ecological studies. In this study, we used a set of headwater stream's fish assemblages to answer two questions: 1) How do distinct descriptors of fish assemblage's diversity are related to each other at headwater streams? 2) How does environment influences each descriptor of fish assemblage's diversity at headwater streams? As metrics of community structure/diversity, we used the number of species (species richness, S) and individuals (abundance, N), taxonomic distinctiveness (taxonomic diversity, $\Delta+$), and the mean pairwise distance (functional diversity, MPD). The environmental variables evaluated were the following: channel depth and channel width, altitude, riparian vegetation cover, water turbidity and water temperature, dissolved oxygen, pH, and conductivity. The relationship among descriptors of fish assemblage's diversity and between these descriptors with the environment was tested with a Spearman's correlation analysis. We found a positive correlation between i) $\Delta+$ and MPD; and ii) N and $\Delta+$ with channel width and temperature, respectively. These findings provide evidence that different descriptors of fish assemblage's diversity are correlated to different variables of the environment at headwater streams. Moreover, we observed the existence of a spatial congruence between $\Delta+$ e MPD, suggesting that the development of strategies for protecting one of these descriptors may also help to preserve the other one. Our study provides important information for a region of the Central Brazil, the Upper Paraná River basin, that remains not well known regarding to its fish fauna when compared to other localities in this same region or within its hydrological domain.

Keywords: Brazil, functional diversity, species richness, taxonomic diversity, Upper Paraná basin.

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RESUMO

A compreensão da relação entre descritores da diversidade das comunidades e a resposta destes descritores ao ambiente é uma questão central dos estudos ecológicos. Neste estudo, utilizamos um conjunto de assembleias de peixes de riachos de cabeceira para responder duas questões: 1) Como diferentes descritores da diversidade das assembleias de peixes estão relacionados nos riachos de cabeceira? 2) Como o ambiente influencia cada descritor da diversidade nas assembleias de peixes em riachos de cabeceira? Como medidas da estrutura/diversidade da comunidade, utilizamos o número de espécies (riqueza de espécies, S) e indivíduos (abundância, N), distinção taxonômica (diversidade taxonômica, Δ^+) e distância média par-a-par (diversidade funcional, MPD). As variáveis do ambiente utilizadas foram a profundidade e a largura do canal, cobertura ripária, altitude, turbidez e temperatura da água, oxigênio dissolvido, condutividade e pH. A relação entre as diferentes facetas da diversidade e destas com o ambiente foi testada com uma correlação de Spearman. Encontramos uma correlação positiva entre: *i*) Δ^+ e MPD; e de *ii*) N e Δ^+ com largura do canal e temperatura, respectivamente. Estes resultados indicam que diferentes descritores da diversidade nas assembleias de peixes são afetados por variáveis ambientais distintas e de que existe uma tendência à congruência espacial entre Δ^+ e MPD, indicando que o desenvolvimento de uma estratégia de conservação eficaz para um destes dois descritores da diversidade pode proteger o outro. Nosso estudo fornece importantes informações para uma região do Brasil Central, a Bacia do Alto Rio Paraná, que permanece pouco estudada em relação à sua ictiofauna quando comparada a outras localidades desta mesma região ou dentro de seu domínio hidrológico.

Palavras-chave: Brasil, diversidade funcional, riqueza de espécies, diversidade taxonômica, Alto rio Paraná.

1. Introduction

Species richness has been used to describe community and ecological processes acting on its structure (Pavoine & Bonsall 2010). However, species richness is often a blind measure when describing how the number of individuals is distributed among species in natural communities, and to detect taxonomic or ecological differences among them (Cianciaruso et al. 2009). In this way, a high speciose natural community may be composed by species with complementary functional traits while another may be formed by a group of species with redundant functional traits. In this case, understanding how such components of community diversity are related to each other is important since their spatial congruence can form a solid baseline to guide freshwater systems' conservation and management actions (Strecker et al. 2011; Carvalho & Tejerina-Garro 2015a; Cadotte & Tucker 2018; Martin-Regalado et al. 2019).

Freshwater habitats are among the most impacted ecosystems in the world with many emerging threats jeopardizing its biodiversity (Reid et al. 2019), but many regions remain unknown regarding its freshwater fish fauna (Alofs et al. 2014; Carvalho & Tejerina-Garro 2019), as is the case of the Neotropical region (Castro & Polaz 2020). Therefore, ecological studies addressing issues related to fish assemblage's diversity are still needed. Several studies have focused on the congruence of diversity facets at broader scales in temperate regions (Cilleros et al. 2016; Kuczynski et al. 2018), although some recent efforts have been conducted at finer scales in tropical regions (Carvalho & Tejerina-Garro 2015a; Vitorino Jr. et al. 2016; Péláez & Pavanelli 2019). The low-order streams (also namely headwater streams) are appropriate to this kind of ecological investigation, which has started to grow only in the last two decades (Dias et al. 2016; Buckup 2021).

Environment is considered a fundamental driver of the community structure, and the high environmental variability found among headwater habitats leads to the predominance of the abiotic factors over biological interactions in structuring fish assemblages (Grenouillet et al. 2004; Carvalho & Tejerina-Garro 2015b). In this context, environmental drivers tend to function as ecological filters defining which species and traits will persist in headwater streams (Poff 1997; Carvalho & Tejerina-Garro 2015b; Borges et al. 2020). In tropical watercourses, environmental factors such as water velocity, channel depth and width, altitude, and canopy cover are important to determine fish occurrence and abundance in headwaters (Súarez et al. 2007; Súarez et al. 2011; Ilha et al. 2019), whereas the channel depth, water velocity, dissolved oxygen, and turbidity determine their functional organization (Carvalho & Tejerina-Garro 2015b, 2015c). Despite the growing interest of ecologists on the environment-fish assemblage's structure relationship in headwater habitats, the upper section of the Paraná River basin at Goiás State figures as an example of a region where ecological studies of fish assemblages are still incipient (Langeani et al. 2007; Tejerina-Garro 2008; Carvalho & Tejerina-Garro 2019), mainly those addressing the relationships of different facets in the same place.

In this study, we investigated the relationship among four descriptors of fish assemblages (species richness, abundance, taxonomic and functional diversity) and how they are related to environmental factors using 19 headwater streams located at the Upper Paraná River basin, Brazil. More specifically, our aim was to answer the following questions: i) How do different descriptors of fish assemblage's diversity are related to each other at headwater streams?; ii) How does the environment influences each descriptor of fish assemblage's at headwater streams?. Intuitively, it is expected that abundance, taxonomic and functional diversity of fish assemblages will be higher because of the increase of species richness, but relationships among different facets of fish specie's diversity are not necessarily positive and may vary within habitats (Carvalho & Tejerina-Garro 2015a). Moreover, more than one environmental variable may affect fish diversity descriptors in headwater stream habitats at the same time (Carvalho & Tejerina-Garro 2015a), thus multiple relationships among fish diversity facets and environmental variables could be expected.

2. Material and Methods

2.1 Study area and sampling protocol

The drainage area of the upper section of the Paraná River basin located at Goias State is represented by tributaries of the Paranaiba River, and it presents a well-defined dry (May to September) and wet seasons (October to April; Cardoso et al. 2014). Its main vegetation cover is composed by Cerrado sensu stricto (Ratter et al. 1997), and this natural vegetation is interspersed by anthropized areas resulting of urbanization, agriculture, and cattle-ranching (Strassburg et al. 2017; Pelicice et al. 2021). Despite that, its fish fauna remains not well known when compared to other regions of the Paraná River basin (Langeani et al. 2007).

We sampled 19 headwater streams located inside the upper section of the Paraná River basin (Figure 1). Fish sampling was conducted during the dry season (April to August 2015) when the relationship between fishes and habitat structure is stronger (Willis et al. 2005). In each stream, fishes were sampled along stretches of 50 m using the electrofishing method (Mazzoni et al. 2000) with a sampling effort of 3persons/50m/stretch, covering this stretch three times for 2 hours. All collected specimens were stored in plastic barrels containing formaldehyde 10% and taken to the laboratory to be separated and identified according to taxonomic keys. After that, they were stored in alcohol 70% at the Aquatic Biology Center of the Pontifícia Universidade Católica de Goiás. The license for collection of biological material was granted to the second author by Instituto Brasileiro do Meio Ambiente e Recursos Naturais Renováveis (IBAMA; license n° 20226).

2.2 Fish and environmental data

For each stream sampled, we collected the following data: number of species (species richness), number of individuals (abundance), taxonomic and functional diversity. Taxonomic and functional diversity were respectively based on taxonomic (order, class, family, and genus) and functional data (maximum length, trophic guild, parental care, period of activity, water column position, foraging method, foraging locality, and migratory habit; Table I). For data's fish functional traits, we consulted the FishBase database (Froese & Pauly 2017), and specialized literature available (scientific articles and books). When information was not available for one species trait, we extrapolated the data for genus level; when it was not possible, we considered the functional trait as not available (NA).

Environmental data was represented by nine variables: altitude (m), channel depth (m), channel width (m), pH, dissolved oxygen (mg.L-1), water turbidity (NTU), water conductivity (µS.cm-1), water temperature (°C) and riparian vegetation cover (%). To measure these variables, we delimited six equidistant transversal transects along 50 m of each stream stretch (from 0 m to 50 m). The altitude was measured only in the first upper transect (GPS Garmin eTrex) and variables as turbidity (turbidimeter LaMotte 2020), water conductivity (conductivity meter WTW 315i), dissolved oxygen, water temperature (oximeter Lutron YK-22DO) and pH (pHmeter Lutron PH-208) in the first, the fourth and sixth transects. Channel depth and channel width (measuring rope), and the riparian vegetation cover (spherical densitometer) were all measured in the six transects. For analyses, we used the coefficient of variation (CV) of each environmental variable calculated considering the values measured in sampled transects.

2.3 Data analyses

Taxonomic diversity was calculated using the taxonomic distinctness index (Δ+) which captures taxonomic relatedness of species considering the average distance between all pairs of species within composing one sample (Warwick & Clarke 1998). The Δ+ value varies between 0 (high relatedness among species) to 100 (low relatedness; García-Martínez et al. 2015).

Functional diversity was measured using the mean pairwise distance (MPD; Webb 2000). MPD is used for phylogenetic diversity but, given that both the phylogeny and dendrogram have similar properties (Pavoine & Bonsall 2010), it is possible to substitute the phylogeny by a functional dendrogram for functional diversity calculation (Kembel et al. 2010; Pavoine & Bonsall 2010). To that, we used the following steps: i) conversion of the species traits matrix into a functional distance matrix; ii) clustering the distance matrix into a functional dendrogram; iii) transformation of the functional dendrogram into an object with phylogenetic properties (phylogeny); iv) extraction of the distance matrix ("cophenetic matrix"); v) calculation of the MPD based on the mean functional distances among all taxa found in a sample. We used Gower's distance to construct the functional distance matrix since we had qualitative and quantitative functional traits (Pavoine et al. 2009), while unweighted pair group method with arithmetic averages (UPGMA) was used as the clustering method to create the dendrogram. The MPD values oscillate between 0 (high functional relatedness among species) and 1 (low functional relatedness among species). To calculate taxonomic and functional diversity we used, respectively, taxondive (vegan package; Oksanen et al. 2019) and mpd function (picante package; Kembel et al. 2010) in the R Software (R Development Core Team 2017).

We performed separately a Spearman's correlation (rs) analysis between each pair of fish diversity descriptors, and between each diversity descriptor and environmental variables to test whether environment influences on headwater stream's fish assemblage's diversity. Previously to Spearman's correlation between fish diversity and environment, we performed a correlation analysis followed by Holm's method of adjusting multiple tests for investigating multicollinearity among the environmental variables (Aickin & Gensler 1996). Turbidity was excluded from analysis because it was strongly correlated with conductivity. All analysis and functions used are available in the R Development Core Team (2020).

3. Results

We found 51 species from six orders (Characiformes, Cyprinodontiformes, Gymnotiformes, Perciformes, Siluriformes, Synbranchiformes) and 20 families, their functional traits are all listed in Table I.

Headwater streams displayed an oscillation of fish species richness (min.=5 species; max.=16) and fish abundance (min.=35 individuals; max.=284; Table II) with high taxonomic (Δ+ values ranging from 75.356 to 96.879) and functional diversity (MPD values oscillating from 0.567 to 0.701).

We observed a positive correlation between taxonomic and functional fish diversity (rs=0.463; df=17; p=0.046; Table II). The relationship between fish diversity descriptors and environment indicated that no environmental variable influenced on more than one diversity index at the same time, and there were positive relationships between fish abundance and channel width (rs=0.683; df=17; p=0.001), and taxonomic diversity of fish assemblages and water temperature (rs=0.476; df=17; p=0.040; Table II).

4. Discussion

Environmental turnover among sites is high at finer spatial scales (Wang et al. 2003), and this is especially true for headwater habitats where environmental differences among streams are expected to structure fish assemblages (Brown et al. 2016; Vitorino Jr. et al. 2016). Our findings indicate that the variation in the number of individuals (abundance) among fish assemblages of headwaters is correlated to channel width, reinforcing an ecological pattern already observed by Súarez (2008). Stream width influences on the quantity of submerged vegetation and light availability (Kemenes & Fosberg 2014), and larger streams tend to have a low amount of vegetation and a high exposure to light. According to Jackson et al. (2001) and Casatti (2010), the exposure of stream fishes to the sunlight may affect their metabolism, fish tolerance to toxic substances, reproduction, and ability to hide from predators. This scenario may favor the occurrence of tolerant fish species to higher temperatures in headwater streams as it was observed for the Upper Paraná River basin by Araújo & Tejerina-Garro (2009), a pattern that is reinforced by the presence of fish species described as tolerant to warmer temperatures in the streams sampled, such as Parodon nasus and Hypostomus sp. In this case, these tolerant species could predominate in streams with larger channel width and increase their abundance, explaining the positive relationship found between fish abundance and channel width. Despite that, the channel width may also help to control the variability of water temperature in headwater streams, alleviating temperature effects and allowing the existence of different taxa in fish assemblages. Similar results were found by Súarez & Petrere Jr. (2005) that showed a positive correlation between water temperature and species diversity.

In recent years, scientists have initiated a debate on the spatial congruence among different descriptors of fish diversity at aquatic ecosystems (Strecker et al. 2011; Carvalho & Tejerina-Garro 2015a; Peláez & Pavanelli 2019; Carvalho et al. 2021). Our findings suggest a congruence between the spatial patterns of functional and taxonomic fish diversity in headwater streams, and it means that headwater stream's fish assemblages with high taxonomic diversity also display high functional diversity. This ecological pattern follows the same trend between taxonomic and functional diversity of Neotropical headwater streams observed for a neighboring basin, the Tocantins-Araguaia River (Carvalho & Tejerina-Garro 2015a). For conservation purposes, such findings indicate that strategies in this domain and in the Neotropical region that privilege the preservation of one of these two aspects of diversity is enough to protect the other. However, such assumption must be taken cautiously since the spatial congruence among different aspects of fish assemblage's diversity seems to be limited in some way, mainly in headwater streams where environmental filters may constrain species and functional traits occurrence in different manners (Carvalho & Tejerina-Garro, 2015b, 2015c).

Our findings give support to the idea that fish assemblages of headwater streams are influenced by environmental factors, reinforcing the results found in several other ecological studies. Moreover, they suggest that different aspects of the Neotropical fish assemblage's diversity are affected by distinct environmental drivers and the main relationships are related to fish abundance and taxonomic diversity to channel width and water temperature, respectively. The comprehension of such relationships at local scales is essential because of the multiple relationships among the distinct aspects of fish diversity (Carvalho & Tejerina-Garro 2015a). Therefore, conservation actions in headwater habitats should consider this to the development of their strategies to deal with human impacts. Finally, our study provides information for a region of the Paraná River basin that remains not well known when compared to other localities.

Table I. List of species found in the headwater streams of the Upper Paraná River basin and description of their functional traits. Species' maximum length=ML (cm); Trophic guild=TG (A=Algivorous, C=Carnivorous; D=Detritivorous, H=Herbivorous, I=Invertivorous; O=Omnivorous, NA=Not Available); Parental care=PC; Period of activity=PA (D=Diurnal, N=Nocturnal); Water column position=WCP (BP=Benthonic-pelagic, B=Benthonic, P=Pelagic); Foraging method=FM (E=Eyes, B=Barbells, El=Electricity); Foraging location=FL (Lo=Lotic, LE=Lentic); Migration=MI; NA=data not available. The references' list consulted for fish traits is presented at the end of the table.

Species	**ML**	**TG**	**PC**	**PA**	**WCP**	**FM**	**FL**	**Mig**
Apareiodon affinis (Steindachner, 1879)	14.3	O	No	NA	BP	E	Le	No
Apareiodon ibitiensis (Amaral Campos, 1944)	11.3	O	No	D	BP	E	Lo	No
Apareiodon piracicabae (Eigenman, 1907)	12.0	H	No	D	BP	E	Lo	Yes
Aspidoras fuscoguttatus (Nijssen & Isbrücker, 1976)	3.8	I	Yes	D	BP	B	Lo	No
Astyanax altiparanae (Garutti & Britski, 2000)	12.6	O	No	D	BP	E	Le	Yes
Astyanax eigenmaniorum (Cope, 1894)	5.7	O	No	D	BP	E	Lo	No
Astyanax fasciatus (Cuvier, 1819)	16.8	O	No	D	BP	E	Le	Yes
Bryconamericus sp.	11.4	I	No	D	BP	E	Lo	No
Bryconamericus stramineus (Eigenman, 1908)	11.4	I	No	D	BP	E	Lo	No
Cetopsis gobioides (Kner, 1858)	10.9	I	No	NA	B	B	Lo	No
Cetopsorhamdia iheringi (Schubart & Gomes, 1959)	10.6	I	No	N	B	B	Lo	No
Cetopsorhamdia sp.	10.6	I	No	N	B	B	Lo	No
Characidium fasciatum (Reinhardt, 1867)	6.7	I	No	D	BP	E	Le	No
Characidium gomesi (Travassos, 1956)	6.5	I	No	D	BP	E	Lo	No
Characidium sp.	6.5	I	No	D	BP	E	NA	No
Characidium zebra (Eigenmann, 1909)	6.4	I	No	D	BP	E	Lo	No
Cichlasoma paranaense (Kullander, 1983)	7.4	I	Yes	NA	BP	E	Lo	No
Crenicichla britskii (Kullander, 1983)	14.5	I	Yes	NA	BP	E	Le	No
Crenicichla haroldoi (Luengo & Britski, 1974)	9.8	I	Yes	NA	BP	E	Lo	No
Eigenmannia trilineata (López & Castello, 1966)	25.0	I	Yes	NA	BP	El	Lo	No
Galeocharax knerii (Steindachner, 1879)	29.8	C	No	D	BP	E	Lo	No
Gymnotus carapo (Linnaeus, 1758)	76.0	C	Yes	N	BP	El	Lo	No

Species	ML	TG	PC	PA	WCP	FM	FL	Mig
Heptapterus mustelinus (Valenciennes, 1835)	20.9	I	No	NA	B	B	NA	No
Hoplerythrinus unitaeniatus (Spix & Agassiz, 1829)	25.0	O	Yes	D	P	E	Le	No
Hoplias malabaricus (Bloch, 1794)	55.2	C	Yes	N	BP	E	Le	No
Hyphessobrycon anisitsi (Eigenman, 1907)	6.0	O	No	NA	BP	E	Le	NA
Hypostomus ancistroides (Ihering, 1905)	21.0	D	Yes	N	B	B	Lo	No
Hypostomus regani (Ihering, 1905)	39.7	A	Yes	N	B	B	Lo	No
Hypostomus sp.	30.35	NA	Yes	N	B	B	Lo	No
Imparfinis longicauda (Borodin, 1927)	11.7	O	NA	NA	B	B	NA	NA
Imparfinis mirini (Haseman, 1911)	8.5	I	Yes	N	B	B	Lo	No
Imparfinis schubarti (Gomes, 1956)	9.3	I	NA	NA	B	B	Le	NA
Leporinus friderici (Bloch, 1794)	40.0	O	Yes	D	BP	E	Lo	Yes
Leporinus microphthalmus (Garavello, 1989)	11.8	O	No	D	BP	E	NA	No
Metynnis lippincottianus (Cope, 1870)	13.0	H	No	D	P	E	Lo	No
Moenkhausia intermedia (Eigenman, 1908)	8.0	O	No	NA	BP	E	Le	No
Moenkhausia sanctaefilomenae (Steindachner, 1879)	7.0	O	No	D	BP	E	Lo	No
Neoplecostomus paranensis (Langeani, 1990)	9.3	O	NA	NA	B	B	NA	No
Parodon nasus (Kner, 1859)	12.7	O	No	NA	BP	E	Lo	No
Phenacorhamdia tenebrosa (Schubart, 1964)	6.7	I	NA	N	B	B	Lo	NA
Piabina argentea (Reinhardt, 1867)	6.8	I	No	D	BP	E	Lo	No
Pimelodus maculatus (Lacepède, 1803)	51.0	O	No	N	BP	B	Lo	Yes
Poecilia reticulata (Peters, 1859)	5.0	I	No	D	BP	E	Le	No
Pseudopimelodus mangurus (Valenciennes, 1835)	69.0	C	Yes	NA	B	B	Le	Yes
Pyrrhulina australis (Eigenman & Kennedy, 1903)	5.0	I	No	NA	BP	E	Le	No
Rhamdia quelen (Quoy & Gaimard, 1824)	47.4	C	No	N	BP	B	Lo	Yes
Satanoperca pappaterra (Heckel, 1840)	19.2	O	Yes	N	BP	E	Le	No
Steindachnerina corumbae (Pavanelli & Britski, 1999)	11.7	D	No	NA	BP	E	NA	NA
Steindachnerina insculpta (Fernández-Yépez, 1948)	13.0	D	No	D	BP	E	Le	Yes
Synbranchus marmoratus (Bloch, 1975)	150.0	C	Yes	N	BP	E	Lo	No
Tatia neivai (Ihering, 1930)	8.2	O	Yes	N	BP	B	Lo	No

ML: Froese & Pauly 2017. **TG:** Santos et al. 1984; Santos & Jegú 1989; Hahn et al. 1998; Pavanelli & Britski 1999; Ferreira et al. 2002; Vilella et al. 2002; Albrecht & Pellegrini-Caramaschi 2003; Smith et al. 2003; Fialho & Tejerina-Garro 2004; Santos et al. 2004; Bichuette & Trajano 2005; Ferreira & Casatti 2006; Graça &

Pavanelli 2007; Nonogaki et al. 2007; Novakowski et al. 2008; Brandão-Gonçalves et al. 2009; Casatti et al. 2009; Giora & Fialho 2009; Meschiatti & Arcifa 2009; Rolla et al. 2009; Taguti et al. 2009; Fernández & Bechara 2010; Mazzoni et al. 2010; Rondineli et al. 2011; Silva et al. 2012; Yamada et al. 2012; Smith et al. 2013; Ferrareze et al. 2015; Froese & Pauly 2017; Polaz et al. (2017). **PC:** Blumer 1982; Winemiller 1989; Doria & Andrian 1997; Bialetzki et al. 1998; Lowe-McConnell 1999; Araújo & Garutti 2002; Nakatani et al. 2001; Pavanelli & Caramaschi 2003; Suzuki et al. 2004; Gomiero & Braga 2007; Lassala & Renesto 2007; Giora & Fialho 2009; Meschiatti & Arcifa 2009; Paes 2010; Bulla et al. 2011; Casimiro et al. 2011; Tundisi & Tundisi 2012; Smith et al. 2013; Froese & Pauly 2017. **PA:** Endler 1995; Fugi et al. 1996; Rodriguez & Lewis 1997; Casatti 2002; Fialho & Tejerina-Garro 2004; Bichuette & Trajano 2005; Pelicice & Agostinho 2006; Casatti & Castro 2006; Ferreira 2007; Gomiero & Braga 2008; Sarmento-Soares & Martins-Pinheiro 2008; Casatti et al. 2009; Brejão et al. 2013; Rantin & Bichuette 2013; Casatti et al. 2015; Froese & Pauly 2017; Rodrigues et al. 2017. **WCP**: Fialho & Tejerina-Garro 2004; Froese & Pauly 2017. **FM:** Rodrigues & Lewis 1997; Fialho & Tejerina-Garro 2004; Cohen & Khon 2008; Gomiero & Braga 2008; Casatti et al. 2009; Froese & Pauly 2017. **FL**: Delariva et al. 1994; Mattias et al. 1998; Pavanelli & Britski 1999; Peretti & Andrian 1999; Pavanelli & Caramaschi 2003; Súarez & Petrere-Júnior 2003; Smith et al. 2003; Taphorn 2003; Fialho & Tejerina-Garro 2004; Suzuki et al. 2004; Dias et al. 2005; Graça & Pavanelli 2007; Sarmento-Soares & Martins-Pinheiro 2008; Araújo & Tejerina-Garro 2009; Brandão-Gonçalves et al. 2009; Dala-Corte et al. 2009; Paes 2010; Sampaio et al. 2012; Smith et al. 2013; Carvalho & Tejerina-Garro 2015b; Casatti et al. 2015; Polesel & Poi 2016; Froese & Pauly 2017. **Mig:** Fialho & Tejerina-Garro 2004; Suzuki et al. 2004; Lassala & Renesto 2007; Baumgartner et al. 2008; Meschiatti & Arcifa 2009; Paes 2010; Arcifa & Esguicero 2012; Tundisi & Tundisi 2012; Smith et al. 2013; Carvalho & Tejerina-Garro 2015b; Froese & Pauly 2017.

Table II. Results of the Spearman correlation (r_s and *p*) between four descriptors of fish assemblage's diversity (a), and between each descriptor of fish diversity and the environmental variables studied (b). Significant correlations ($p<0.05$) are in bold. S=richness; AB=abundance; Δ^+=taxonomic distinctness index; MPD=mean pairwise distance; AL=altitude; WT=water temperature; DO=dissolved oxygen; pH= potential of hydrogen; WC=water conductivity; CW=channel width; CD=channel depth; RVC=riparian vegetation cover.

a) Spearman correlation (r_s; lower triangle) and probability values (*p*; upper triangle)

	S	AB	Δ^+	MPD
S	1.000	0.528	0.472	0.569
AB	0.155	1.000	0.318	0.538
Δ^+	0.176	0.318	1.000	**0.046**
MPD	-0.140	0.151	**0.463**	1.000

b) Spearman correlation values (r_s)

	AL	WT	DO	pH	WC	CW	CD	RVC
S	-0.006	-0.029	-0.012	0.034	-0.109	0.067	-0.110	-0.110
AB	0.191	-0.034	-0.392	-0.312	-0.291	**0.683**	-0.392	0.126
Δ^+	-0.033	**0.476**	-0.012	0.050	-0.109	0.144	0.256	0.280
MPD	-0.398	0.320	-0.149	0.001	-0.291	0.232	0.018	0.155
Probability values (*p*)								
S	0.980	0.906	0.963	0.890	0.658	0.785	0.653	0.654
AB	0.435	0.892	0.097	0.194	0.226	**0.001**	0.123	0.607
Δ+	0.892	**0.040**	0.881	0.839	0.647	0.557	0.290	0.245
MPD	0.092	0.182	0.542	0.997	0.226	0.340	0.943	0.526

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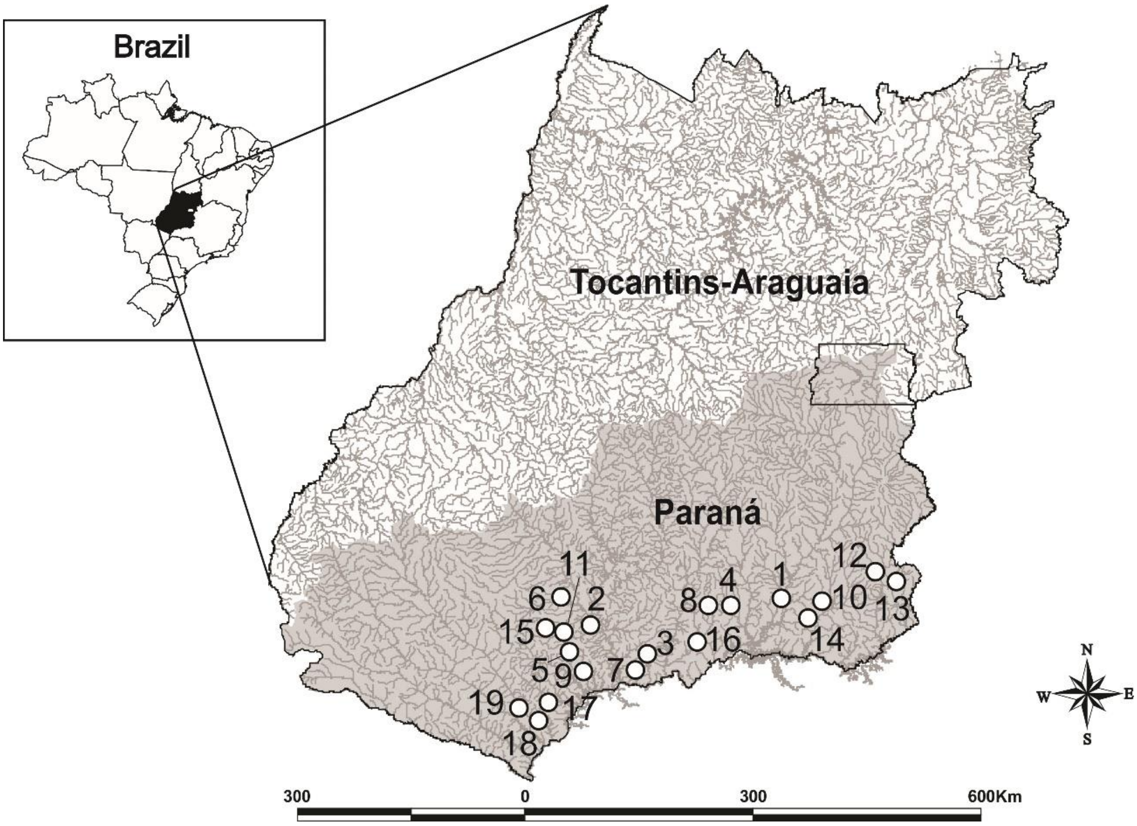

Figure 1. Location of sampled streams (numbered circles) in the Upper Paraná River basin (dark grey color) in the State of Goiás, Central Brazil.

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