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LOUISE CRISTINA GOMES

Limitações e tendências no uso de atributos funcionais em estudos com peixes de água doce: estudo de caso em uma bacia hidrográfica Neotropical

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Orientadora: Profª. Drª Evanilde Benedito

Coorientador: Prof. Dr. Pitágoras Augusto Piana

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FOLHA DE APROVAÇÃO

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O tear do tempo

"A vida do homem é urdida no tear do tempo em um padrão que ele nem mesmo vê, enquanto os tecelões trabalham e as lançadeiras voam até a aurora da eternidade. Algumas lançadeiras sustentam fios de prata enquanto outras deslizam fios de ouro embora muitas vezes os matizes mais escuros sejam tudo o que se possa ver. Mas os tecelões observam com olho hábil cada lançadeira correr de cá para lá, e veem o padrão surgir tão destramente no movimento lento e certo do tear. É Deus decerto quem planeja a trama: Cada fio, o escuro e o claro, é escolhido por Sua habilidade mestra e colocado na urdidura com esmero. Ele, que só lhes conhece a beleza, guia as lançadeiras em que passam tanto os fios menos atraentes como os do mais puro ouro. Só quando cada tear houver silenciado e a lançadeira deixar de deslizar, Deus irá revelar a trama e a cada um explicar o porquê de os fios escuros serem necessários na hábil mão do tecelão tanto quanto os de ouro e prata para a trama que Ele planejou". (Autor desconhecido).

"*Carpe Diem! Façam de suas vidas uma coisa extraordinária!* "

(Sociedade dos Poetas Mortos)

Limitações e tendências no uso de atributos funcionais em estudos com peixes de água doce: estudo de caso em uma bacia hidrográfica Neotropical

RESUMO GERAL

As abordagens clássicas utilizadas para avaliar as relações entre o ambiente e a biodiversidade têm sido baseadas em riqueza de espécies, abundância e índices de diversidade. Porém, as medidas tradicionais de diversidade não levam em consideração as diferentes funções ecológicas entre os táxons. Nas últimas décadas, a abordagem funcional tem sido utilizada, especialmente, para melhor compreender as respostas das espécies frente às perturbações, bem como o papel das espécies no funcionamento dos ecossistemas. Essa abordagem é baseada em atributos funcionais, os quais podem ser definidos como características morfológicas, ecológicas, fisiológicas ou comportamentais, mensuráveis a nível individual ou de espécie. Assim, o objetivo geral desse trabalho foi: i) identificar as tendências e limitações dos estudos sobre diversidade funcional de peixes de água doce e; ii) investigar a estrutura taxonômica e funcional de assembleias de peixes nativas e não nativasda bacia do rio Iguaçu. A primeira questão foi investigada por meio de uma revisão sistemática da literatura, enquanto que na segunda questão foram avaliados os componentes taxonômicos (beta diversidade) e funcionais (riqueza, dispersão e singularidade funcional) da ictiofauna que ocorre nos trechos baixo, médio e alto da bacia do rio Iguaçu. A partir da revisão sistemática foi possível observar um aumento na publicação de estudos sobre diversidade funcional de peixes de água doce e essa abordagem tem sido utilizada especialmente para avaliar impactos antrópicos sobre as comunidades. Os principais atributos utilizados foram aqueles relacionados a alimentação e a locomoção. Dentre os vários índices disponíveis para mensurar a diversidade funcional, destaca-se a riqueza funcional. Com relação ao segundo objetivo, o trecho baixo apresentou maior riqueza taxonômica e a partição da beta diversidade apresentou maior contribuição do componente *turnover* na composição das assembleias. O alto Iguaçu apresentou maior riqueza funcional e em todos os trechos foram observados altos valores de dispersão e singularidade funcional, indicando baixa redundância funcional entre as espécies. Este trabalho identificou as tendências e limitações em estudos com diversidade funcional de peixes de água doce, fornecendo, dessa forma, informações relevantes para o direcionamento de futuras pesquisas.

Palavras-chave: Diversidade funcional. Bacia do Iguaçu. Impacto. Endemismo. Invasão

Limitations and trends in the use of functional traits in studies of freshwater fish: a case study in a Neotropical hydrographic basin

ABSTRACT

The classical approaches used to assess the relationships between the environmental and biodiversity have been based on species richness, abundance, and diversity indexes. However, traditional diversity measures do not take into account the different ecological functions among taxa. In the last decades, the functional approach has been used especially to better understand the role of species in the functioning of ecosystems. This tool uses species-specific attributes or characteristics in the analyzes. Attributes may be morphological, ecological, physiological or behavioral, measurable at individual or species level. Thus, the general objective of this study was i) to identify trends in studies of functional diversity in freshwater fish, ii) to evaluate the taxonomic and functional structure of native and non - native fish assemblages of a Neotropical watershed. The first question was investigated from a systematic review of the literature, while the second question evaluated the taxonomic (beta diversity) and functional (richness, dispersion and functional singularity) components of the ichthyofauna occurring in the lower, middle and upper sections of the Iguaçu basin. From the systematic review, it was possible to observe an increase in the publication of studies on functional diversity of freshwater fish and this approach has been used especially to evaluate anthropic impacts on the communities. The main attributes used were those related to food and locomotion. Among the various indexes available to measure functional diversity, the functional richness stands out. In relation to the second objective, the lower section presented higher taxonomic richness and the beta diversity partition presented greater contribution of the *turnover* component in the composition of the assemblies. Upper Iguaçu showed higher functional richness and high dispersion and functional singularity values were observed in all the stretches, indicating low functional redundancy among the species. This study identified the trends and limitations in studies with functional diversity of freshwater fish, thus providing information relevant to the direction of future research.

Keywords: Functional diversity. Iguaçu Basin. Impact. Endemism. Invasion

SUMÁRIO

INTRODUÇÃO GERAL

Compreender as relações entre o ambiente e a biodiversidade é uma das questões centrais em Ecologia. Devido ao rápido incremento das alterações nos biomas do planeta causadas principalmente pelo aumento das atividades antrópicas, há urgente necessidade de prever as consequências biológicas de tais modificações sobre o funcionamento dos ecossistemas (RIBEIRO; TERESA; CASATTI, 2016). As abordagens clássicas utilizadas para avaliar essas relações têm sido baseadas em riqueza de espécies, abundância e índices de diversidade e equitabilidade (MORIN, 2011). Contudo, as medidas tradicionais de diversidade não levam em consideração as diferentes funções ecológicas entre os táxons (VILLÉGER et al., 2010). Desse modo, nas últimas décadas, a abordagem funcional tem sido utilizada especialmente para melhor compreender o papel das espécies no funcionamento dos ecossistemas (CALAÇA; GRELLE, 2016). Essa abordagem é baseada em atributos funcionais, os quais podem ser definidos como características morfológicas, ecológicas, fisiológicas ou comportamentais, mensuráveis a nível individual ou de espécie. (VIOLLE et al., 2007).

Ainda há um amplo debate entre os ecólogos sobre a maneira mais adequada de se calcular a diversidade funcional, e diante disso, diversos autores propuseram uma variedade de índices para mensurar a diversidade funcional, como por exemplo a regularidade funcional (*functional regularity*) utilizada como uma medida de uniformidade funcional em situações que as espécies são representadas apenas por um único valor de atributo (MOUILLOT; MASON; DUMAY, 2005), a riqueza funcional (*functional richness*), uniformidade funcional (*functional evenness*) e divergência funcional (*functional divergence*) são índices multidimensionais os quais exploram diferentes aspectos da diversidade funcional (VILLÉGER; MASON; MOUILLOT, 2008); a dispersão funcional que representa a distância média ao centroide ponderada pela abundância (ANDERSON, 2006; LALIBERTÉ; LEGENDRE, 2010), a singularidade funcional (*functional uniqueness*) aplicada como uma medida de redundância funcional (RICOTTA et al., 2016).

Apesar dos avanços sobre o tema, os estudos utilizando a abordagem baseada em atributos funcionais apresentam alguns desafios, como por exemplo a falta de informações acerca das características biológicas e ecológicas de muitas espécies que pode limitar inclusive, a aplicação de determinados índices (DÍAZ; CABIDO, 2001; LAURETO; CIANCIARUSO; SAMIA, 2015). Uma das principais vantagens da abordagem baseada em atributos funcionais é verificar como as espécies participam dos processos ecológicos, ou seja, caracterizar a sua função no ecossistema (MIMS et al., 2010). Assim, outro desafio para os ecólogos é que essas informações sejam implementadas nos planos de manejo para conhecimento dos tomadores de decisão a fim de melhorar as ações conservacionistas da ictiofauna.

Os ecossistemas aquáticos continentais estão entre os ambientes mais degradados (NAIMAN; DUDGEON, 2011) comprometendo a ictiofauna especialmente devido a impactos como barramentos (WINEMILLER et al., 2016), introdução de espécies (GUBIANI et al., 2018), desmatamento da vegetação ripária e urbanização (CUNICO; ALLAN; AGOSTINHO, 2011; TERESA; CASATTI, 2012). Dessa forma, é notável o crescente número de publicações que investigaram a diversidade funcional de peixes em diversos contextos, como por exemplo para avaliar a degradação de habitat em riachos (GOLDSTEIN; MEADOR, 2005), investigar mudanças temporais na diversidade taxonômica e funcional de peixes (HITT; CHAMBERS, 2014), examinar as relações da diversidade funcional com os fatores ambientais (PEASE et al., 2015), avaliar padrões na estrutura de metacomunidades (TORRES; HIGGINS, 2016). Porém diante da grande diversidade taxonômica de peixes de água doce, muitas regiões e ambientes ainda permanecem pouco explorados no âmbito funcional.

Diante desse contexto, o objetivo geral deste trabalho foi: *i*) investigar as tendências e limitações em estudos sobre diversidade funcional de peixes de água doce e, *ii*) avaliar a estrutura taxonômica e funcional de peixes de uma bacia hidrográfica Neotropical. Assim, o estudo foi dividido em dois capítulos. No primeiro capítulo foi realizada uma revisão sistemática da literatura sobre os estudos que utilizaram a abordagem funcional em peixes de água doce, buscando investigar especificamente, em quais regiões biogeográficas se concentram os estudos, quais são os principais objetivos das pesquisas realizadas, quais os atributos funcionais mais utilizados e os índices mais aplicados. No segundo capítulo foi avaliada a estrutura taxonômica e funcional das assembleias de peixes nativas e não nativas ao longo do gradiente longitudinal da bacia do rio Iguaçu. A estrutura taxonômica das assembleias foi investigada a partir da riqueza de espécies em cada trecho da bacia (baixo, médio e alto) e pela partição da β diversidade. Os índices de riqueza, dispersão e singularidade funcional foram aplicados para mensurar a diversidade funcional das assembleias em cada trecho. Adicionalmente, o índice de espécies indicadoras foi utilizado para determinar os atributos funcionais característicos das assembleias em cada trecho da bacia.

De modo geral, este trabalho apresenta resultados que ao identificar as principais limitações em estudos com diversidade funcional de peixes, fornece informações relevantes para o direcionamento para novas pesquisas. Além disso, contribui para o entendimento do papel da ictiofauna Neotropical no funcionamento e na manutenção da biodiversidade e dos serviços ecossistêmicos em ambientes aquáticos continentais.

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CAPÍTULO 1

Functional diversity of fish: a review of key approaches in freshwater ecosystems

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Functional diversity of fish: a review of key approaches in freshwater ecosystems

ABSTRACT

Functional diversity is a component of biodiversity that measures the attributes of species and individuals, taking into account the morphological, ecological and behavioral characteristics. Studies with this approach have gained wide acceptance by the scientific community and have been used for several purposes. Therefore, we present a systematic review of the literature, summarizing both the main trends and gaps in studies with functional diversity of freshwater fish. In general, studies with functional diversity have been carried out in the Palearctic and Nearctic biogeographic realms, with predominance of studies conducted in streams. Functional diversity has been applied specially to evaluate environmental impacts and the structure of the fish communities. Most of the functional traits evaluated by scientists are related to the acquisition of food and the most used traits include the standard length and trophic guild. Functional richness was by far the most functional index applied. The main gap found in this review was in terms of terminology of functional traits. Some terms have the same ecological meaning, but with ambiguous terminology. Therefore, we suggest a standardized terminology of the ambiguous traits. A unified terminology should facilitate communication of research finds among fish ecologists, as well to allow a better comparability among traits-based studies in functional diversity of fish.

Keywords: functional ecology, aquatic environments, functional traits, terminology, biodiversity

2.1 INTRODUCTION

One of the main issues in ecology is to understand how species respond to environmental impacts and which processes regulate the functioning of biological communities (Carvalho and Tejerina-Garro 2015). Thus, in the last decades, one of the most important advances to answer these questions was the emergence of ecology based on functional traits (Martin and Isaac 2015). Studies with this approach have gained wide acceptance by the scientific community (Petchey and Gaston 2006) and have been used for several taxonomic groups such as for plants (Violle et al. 2007), birds (Luck et al. 2012), macroinvertebrates (Moretti et al. 2017) and fish (Fitzgerald et al. 2017), and for different purposes, providing an innovative and useful perspective on ecosystem ecology (Chalmandrier et al. 2015; Laureto et al. 2015).

One of the most used concepts of functional diversity is the one proposed by Tilman (2001), which refers to the value and amplitude of attributes of species or organisms that influence the functioning of ecosystems. The attributes or functional traits can be defined as the biological characteristics of the organisms or species (McGill et al. 2006; Weiher et al. 2011), which can provide a basis for understanding community patterns in different gradients of environmental variation (Poff et al. 2006; Martin and Isaac 2015). Functional traits may be morphological traits that represent adaptations to different diets or habitats, physiological traits (e.g., tolerance to temperature), reproductive traits (e.g. egg numbers and egg diameter) or behavioral traits (e.g., migratory behavior or parental care) (Bremner et al. 2003; Dumay et al. 2004; Lepš et al. 2006). In a recent review, Villéger et al (2017) pointed out the main functions performed by the fish and the several characteristics available to describe them, for example, measuring swimming performance, assessing reproduction strategies, measuring prey consumption rates, among others. The authors also mention that, as functional traits reflect species-environment relationships, functional ecology has been used as an important tool to improve conservation plans. However, there is still some gaps unfilled, for example a definition of adequate terminology of the functional traits.

The application of functional diversity is a way of interpreting community responses to environmental disturbances, and thus better understanding the functioning of ecosystems (Mouillot et al. 2013; Dolbeth et al. 2015; Strong et al. 2015). Functional diversity encompasses different components for impact assessment and several methods have been proposed to check how communities modulate ecosystem processes (Naeem et al. 2012). Despite extensive discussions among ecologists on the subject, there is still no consensus on the most appropriate way of calculating functional diversity (Tilman et al. 1997; Tilman 2001; Hooper et al. 2005), once functional diversity can be quantified through a variety of measures that capture different aspects of the distribution of trait values within a community (Lavorel et al. 2008). Given these conditions, studies on functional ecology remain very limited (Díaz and Cabido 2001; Laureto et al. 2015), especially for freshwater environments (Calaça and Grelle 2016).

Inland aquatic ecosystems represent one of the most degraded environments (Naiman and Dudgeon 2011), mainly due to human interference. Impacts such as species introduction, dam construction and habitat degradation increase rates of biodiversity loss, which can compromise the ecological processes of fish assemblages as well as reduce ecosystem services (Taylor et al. 2006). In the last decades, fish functional ecology has focused mainly on biological functions that represent the acquisition of food, reproduction, locomotion, defense and nutrient processing (Winemiller et al. 2015). These characteristics have been used by researchers to assess the fish communities in different ecological contexts such as for evaluating the responses of stream fish communities to the gradient of environmental degradation (Teresa and Casatti 2017), to identify priority areas for conservation (Maire et al. 2016), and to investigate temporal changes in functional diversity of communities (Hitt and Chambers 2014). However, investigating the functional diversity of fish can be difficult, considering that many species play several ecological roles that cannot be easily estimated or compared (Vitule et al. 2017).

Here, we performed a systematic review to synthesize the trends in studies on functional diversity of fish in freshwater ecosystems. There have been several literature review on trait-based approach in fish, especially in streams (Villéger et al. 2017; Frimpong and Angermeier, 2010). However, to the best of our knowledge, this study presents the first systematic review on functional diversity of fish that include several inland aquatic environments and which traits the researchers used in each environment. The study focuses on: a) How is the distribution of research effort among biogeographic regions? b) For what purpose do scientists use functional diversity? c) What are the main functional traits applied in the studies? d) What are the limitations in studies with functional diversity of fish?

2.2 MATERIAL AND METHODS

In June 2017, we performed a systematic review using the Thomson Reuters database (ISI Web of Knowledge, apps.isiknowledge.com) searching for all publications that addressed the topic “functional diversity of freshwater fish”. The search terms in the “Topic” field were as follows: (*fish**) AND (*freshwater** OR *river** OR *stream** OR *reservoir** OR *aquatic** OR *lake** OR *lagoon** OR *floodplain**) AND ("*function** *diversit**" OR "*function** *trait**" OR "*environmental trait**" OR "*function** *richness**" OR "*ecological trait**"), and the timespan included all years up to 2016. Two criteria were required to be met for a study to be included in this systematic review: i) the study was carried out in freshwater environments; ii) the study was carried out only with fish. Non-related articles were excluded based on the title, abstract, or, if necessary, after a careful reading of the entire text. Previous reviews and comments were excluded. The articles that met the above-mentioned criteria were select and included in our analysis.

We tabulated the papers in a spreadsheet, read carefully and then we extracted the following data: a) year of publication, which was used to determine the trend in the time of publications; b) biogeographic realm, which was used to identify the highest number of articles published per region. For this, we classified the regions in Palearctic, Nearctic, Neotropical, Oriental, Australian and Afrotropical. When the same study evaluated more than one region, it was grouped into "various realms"; c) freshwater environment, which identified the most studied environment in terms of functional diversity. When the same study evaluated more than one environment, it was grouped into "various environments" d) general objective of the study, which was classified into four categories: 1) evaluation and/or comparison functional and taxonomic structure of the community; 2) impact assessment; 3) evaluation of biogeographic and/or phylogenetic patterns; and 4) methodological (i.e. articles that proposed new methodologies to evaluate functional diversity); e) functional category, which was classified into five groups (feeding, locomotion, life history, habitat use and physiology) according to Pease et al. 2012 and Villéger et al. 2017. When the same trait represented more than one category, they were grouped separately. This step was carried out to identify which the main functional category with the greatest number of traits studied; f) functional trait, which were used to quantify the most commonly used traits and verify the limitations of studies with functional diversity. For quantification of the traits used in the studies, they were classified in ecomorphological measures and ecological attributes.

2.3 RESULTS

In total, 503 articles were found and examined, and 75 papers satisfied the selection criteria and constituted the final list for this review (Appendix A – Table 1). The number of articles on functional diversity of freshwater fish has significantly increased over the years (non-linear fit; r = 0.89; P < 0,001), especially after 2011 (Fig. 1). Most of the studies was concentrated in the Palearctic, Nearctic and Neotropical regions, and the lowest number of articles was recorded for the Afrotropical region (Fig. 2). Regarding the freshwater enviroment, the most studied environments were streams and rivers (Fig. 2). The studies analyzed are mostly aimed at evaluating or comparing the functional structure of assemblages and identifying how communities respond to environmental disturbances (impact) (Fig. 3A). In terms of the functional category, the traits that reflect feeding were the most used (Fig. 3B) (Appendix B – Table 2).

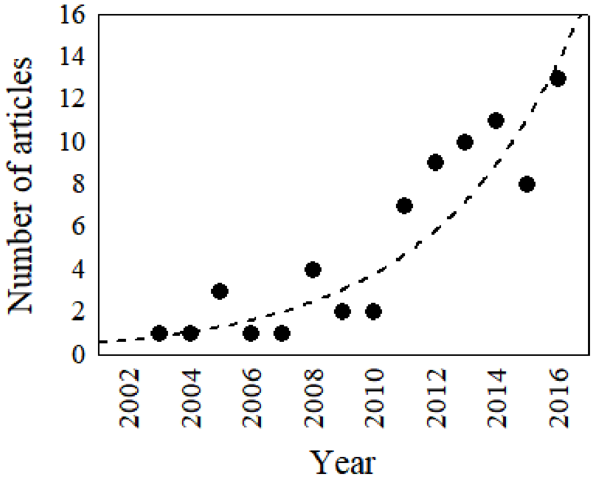

Figure 1: Temporal trend of the number of published articles on functional diversity of fish in inland aquatic ecosystems.

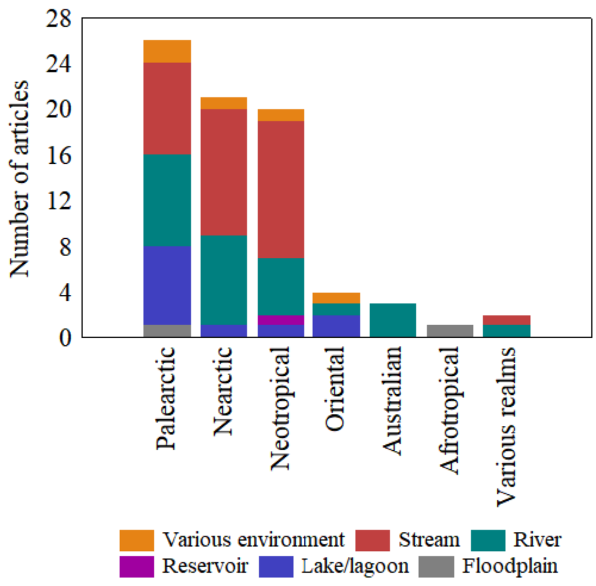

Figure 2: Biogeographic realms and freshwater environments most evaluated in studies with fish functional diversity.

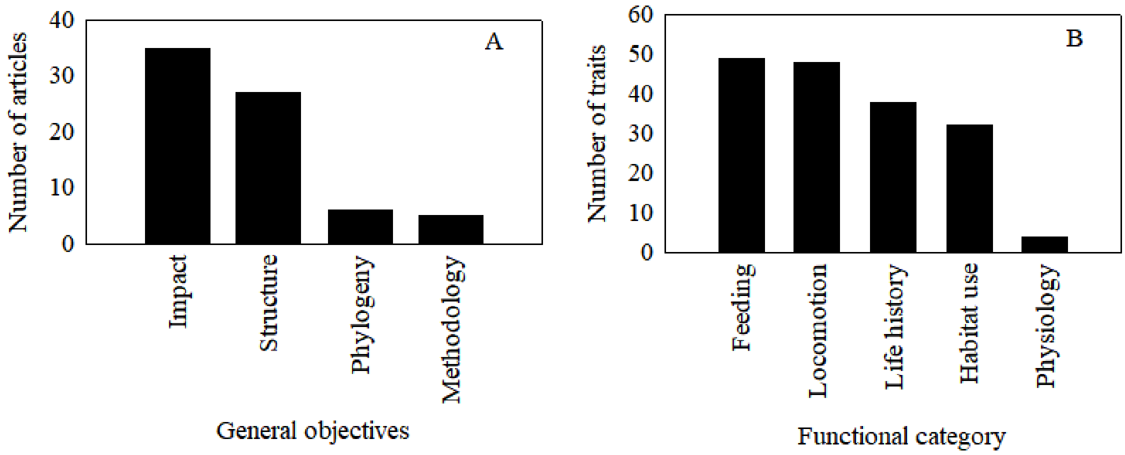

Figure 3: A) Distribution of the major objectives in studies on functional diversity of fish; B) Distribution of the most evaluated functional category.

Traits reflecting physiological conditions were poorly evaluated in the articles analyzed. Among the ecological traits the most commonly used were trophic guild, living habitat, parental care, and longevity. The trophic guild was the only trait used in all types of environments. (Fig 4A). Regarding morphological functional traits, standard length, total length, eye position and egg diameter were the most addressed in the studies (Fig. 4B). The indices most used to quantify functional diversity were those based on continuous measures. The functional richness index (FRic) was the most used (n = 16), followed by the functional evenness index (FEve, n = 12) and functional divergence (FDiv, n = 7) (Fig 5).

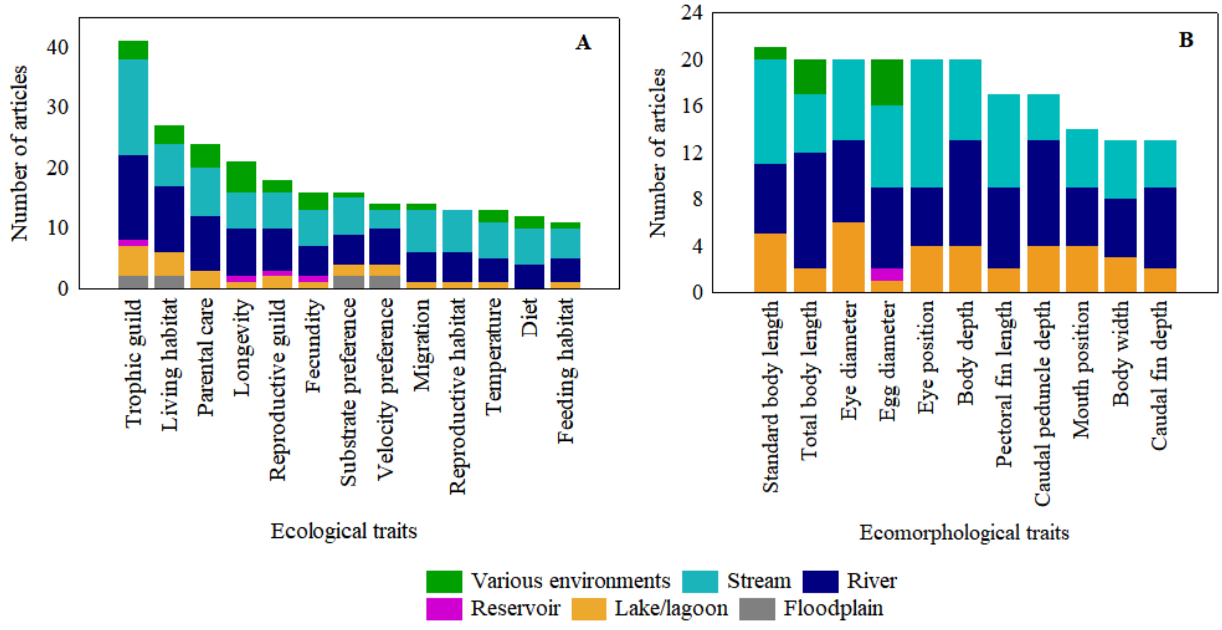

Figure 4: A) Ecological and B) Ecomorphological traits per environmental most used in studies on functional diversity of fish.

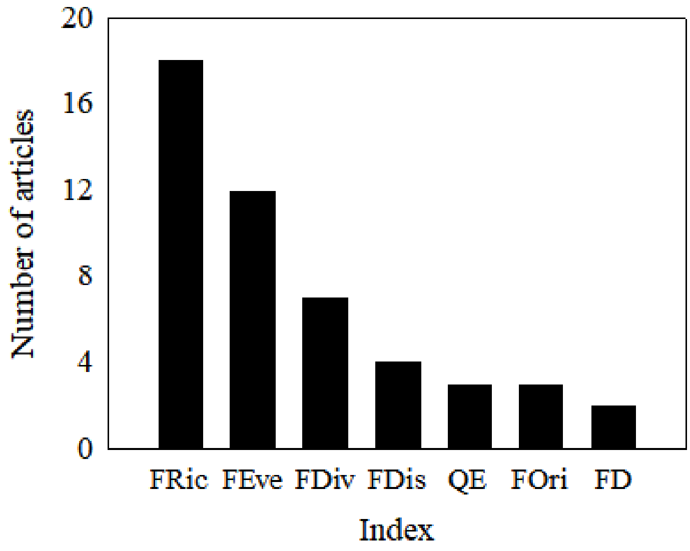

Figure 5: Indexes used for quantifying functional diversity of freshwater fish. FRic=Functional Richness; FEve=Functional Evenness; FDiv=Functional Divergence; FDis=Functional Dispersion; QE=Rao's quadratic entropy; FOri=Functional Originality; FD=Functional Diversity.

2.4 DISCUSSION

In general, our results show that the Palearctic region presents the most of the studies with functional diversity of freshwater fish. The most of the studies was carried out in streams and rivers and the main objectives of the studies focuses on evaluation of impacts on the fish communities. Papers quantified functional diversity using biological traits, among which feeding habits were the most common traits probably due to the assumed links between feeding and ecosystem functions. A large number of diversity measures have been applied for quantifying functional diversity of freshwater fish assemblages, among which functional richness looks like the most frequent.

The functional organization of biodiversity has become an important topic within ecology (Laureto et al. 2015) mainly from 2010, which justifies the increase of publications from this period. This growth persists in recent years, indicating that this is a methodology that has helped in understanding the functioning of ecosystems and in proposing more efficient conservation and management measures. The functional organization characterizes different aspects of the community structure (Hoeinghaus et al. 2007; Higgins and Strauss 2008), and the functional traits allow to compare biogeographic regions with different taxa (Simberloff and

Dayan 1991). These advantages have attracted great interest from ecologists in using functional diversity to evaluate several taxonomic groups and different environments.

Palearctic, Nearctic and Neotropical biogeographic realms have the greatest number of studies on fish functional diversity. The Neotropical region includes about 4,000 species of freshwater fish, and the Nearctic and Palearctic have slightly more than 600 and 900 species, respectively (Toussaint 2016). Although the Afrotropical region presents more than 2,000 species, and the Eastern region approximately 1,500 species (Toussaint 2016), these regions have few studies on functional diversity. This may be related to the political, economic and social issues that developing countries face, especially in the conservation area (Vitule et al. 2017). In addition, the study of functional diversity requires a great number of information on the biology and ecology of species and this may be a limiting factor for the development of the studies in this region, since many of this information, especially of new or rare species, is scarce in the literature. It is worth noting that the absence of studies in certain regions or journals not indexed in the Web of Science database may have biased this result.

The human pressures causes changes in biodiversity of the freshwater ecosystems and threaten the services provided to the human population (Villéger et al. 2017). The greatest number of studies on functional diversity in streams can be attributed to the fact that these environments are remarkably threatened by several anthropic actions, such as degradation of riparian vegetation (Teresa et al. 2015), introduction of species (Villéger et al. 2014) and agriculture (Casatti et al. 2015). In addition, streams harbor a small to medium sized fish fauna, and many species are extremely sensitive to these changes. Therefore, there is a great concern of the ecologists to know and to conserve the fish fauna of streams. With respect to rivers, one of the main anthropic impacts is the construction of dams, which alter the composition, structure and interactions of the communities, thus, to know the functional structure of the assemblages present in dam-free rivers and to understand the relation of the traits with the environment can help to set goals for the management or restoration of these ecosystems (Laughlin 2014).

Historically, studies using traits have been conducted mainly to answer two questions: how species influence the ecosystem functioning and how species respond to environmental changes (Laureto et al. 2015). Most of the articles analyzed in this review focuses on assessing impacts on biological communities and about the functional structure of the community. Among the most investigated impacts are those related to deforestation or land use (Bordignon et al. 2015; Casatti et al. 2015; Dala-Corte et al. 2016) and impoundments (Strecker et al. 2011; Helms et al. 2011; Parks et al. 2016; Macnaughton et al. 2016). In the context of the current biodiversity situation, these issues have been the focus of ecologists, mainly to improve conservation plans (Villéger et al. 2017) and to predict consequences of species loss for ecosystem functioning and community persistence in ecosystems (Flynn et al. 2011; Mouillot et al. 2013).

Considering the traits function, most are related to the acquisition of food, locomotion and life history. Among the traits that reflect the feeding habits, stands out the trophic guild. According to Mouillot et al. (2014), this classification is not very efficient to evaluate differences between assemblages, in this way Villéger et al. (2017) suggest an alternative to describe the acquisition of resources more effectively may be a diet-based classification. Locomotion is a major function that represents how fish occupy the water column and the habitats available on a horizontal scale (Villéger et al. 2017). In this trait function, the most used traits were those of morphological measures, such as pectoral fin length and caudal peduncle depth.

Life history traits have been used for several purposes such as identifying characters for invasive species success (Vila-Gispert et al. 2005), classifying species strategy (Winemiller and Rose 1992) and evaluating the sensitivity of populations to environmental changes (Olden et al. 2006). Reproduction influences the organism's fitness and population demographics (Winemiller 2015), thus, life history traits may represent a dimension of the species ecological niche (Olden et al. 2006). The use of traits such as egg diameter and parental care has been very common in studies with fish functional diversity. Villéger et al. (2017) suggest the use of traits based on reproductive investment, such as the proportion of biomass allocated to reproductive organs or gametes, or the frequency of reproduction and relative investment in terms of energy.

One of the important points in studies with functional diversity is the adequate choice of the traits to be used (Petchey and Gaston 2006). The number and type of traits (i.e continuous, binary, categorical data) can influence the appropriate choice of the index to be used, since the number of traits can generate different results (Petchey and Gaston 2002; Lohbeck et al. 2012), in this way, different interpretations of the results may be due to a different methodologies. Although there is a growing interest of researchers in seeking patterns in the functional distribution of communities, there is still no consensus as to which traits are most appropriate because the selection of traits depends on the purpose of the study as well as on the species in question (Rosado et al. 2013).

The number of indexes for measuring functional diversity has grown over time (Calaça and Grelle 2016), since the 1990s, researchers have developed and improved various qualitative and quantitative indexes, but there are still divergences among ecologists, since no index meets all criteria for general use (Villéger et al. 2008). Some factors such as the species richness, number and type of the trait, groupings and distance measures used can influence the choice of the index and, consequently, the results obtained (Podani and Schmera 2006; Petchey and Gaston 2007; Poos et al. 2009; Mouchet et al. 2010; Schleuter et al. 2010). Several of these characteristics may limit the usefulness of indices (Laliberté and Legendre 2010) however, some have gained prominence in functional ecology. Mason et al. (2005) suggest the use of an approach in which functional diversity is divided into three components - functional richness, functional evenness and functional divergence -, these indices describe the distribution of species and their abundances in functional space. Functional richness represents the portion of the functional space filled by species communities and does not take into account the abundance of species (Villéger et al. 2008). Changes in functional evenness measure the modifications in the regularity of abundance distributions in the functional space (along the shortest minimum spanning tree linking all the species and changes in functional divergence reflect changes in the proportion of the total abundance that is supported by the species with the most extreme functional traits (Mouillot et al. 2013). The so-called functional dispersion index (FDis), proposed by Laliberté and Legendre (2010) is the average distance to the centroid weighted by the relative abundance of the species and is not affected by species richness.

Evidently, there are still several gaps and controversies about the use of indexes to measure functional diversity. It is worth mentioning that all factors are interlinked, since the objective of the study, the choice of traits and, consequently, the choice of indexes (Fig. 6). So, due to the largely inaccessible and unconsolidated functional traits information of freshwater fish fauna (Frimpong and Angermeier 2009), it is essential to carry out research aimed at elucidating these issues and to develop tools for a better understanding of the relationship between biodiversity and the functioning of ecosystems.

In short, the application of functional ecology aims to understand the relationships that permeate anthropogenic interference-biodiversity- ecosystem functioning and services (Laureto et al. 2015). Studies that relate diversity to ecosystem functioning are the most traditional and are addressed from the beginning of research with functional diversity (Tilman et al. 1997). In the last two decades, there has been an expansion in the complexity of the studies that used functional ecology to evaluate several aspects of freshwater ecosystems (Calaça and Grelle 2016). In the face of methodological impasses, new approaches were developed with the aim of contributing to the search for knowledge of the patterns that maintain biodiversity-environment relationships (Mouchet et al. 2010; Ricotta et al. 2016), but some gaps still need to be filled, taking into account that the approach with functional diversity and its evaluation remains very arbitrary.

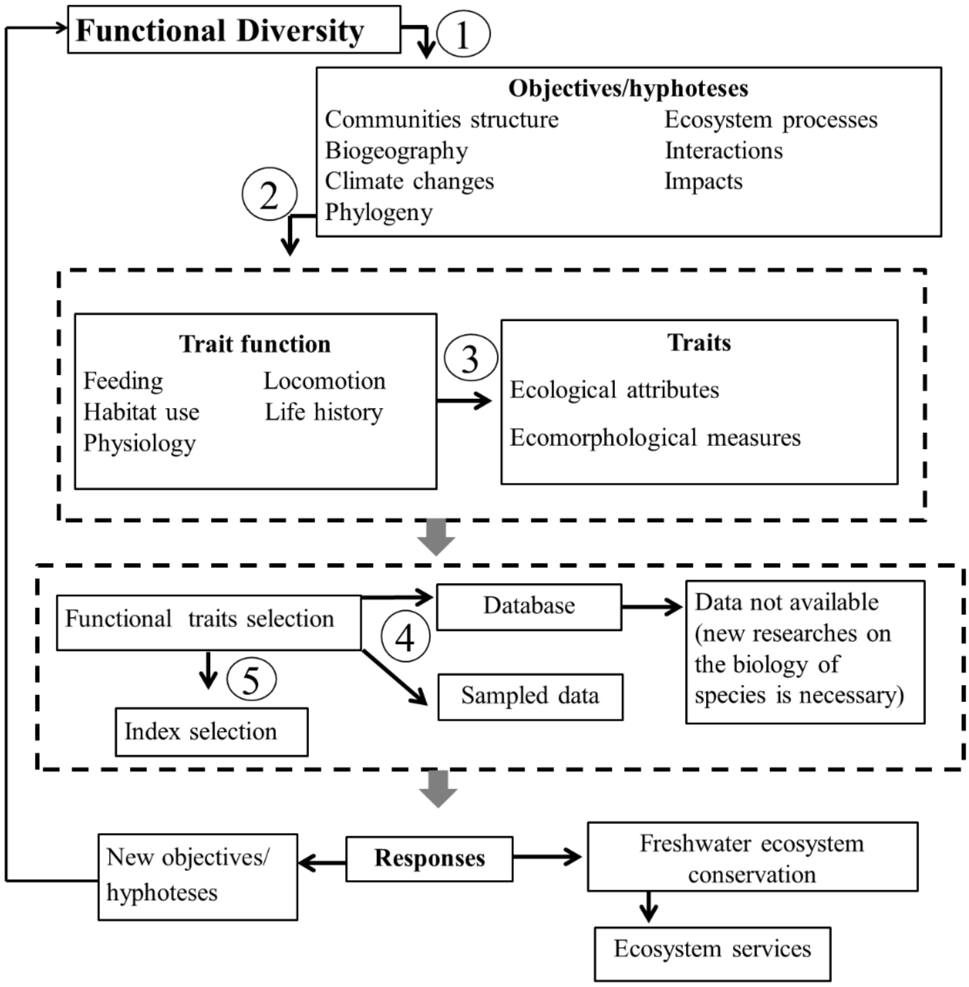

Figure 6: Schematic illustration summarizing the main steps to define studies with functional diversity. First step is to define the objectives and what is intended to respond to the study (arrow 1). This step is important because it will direct the selection of the traits to be used in the study. According to the questions of the study, the next step (arrow 2) is to identify the ecological functions that can answer these questions and then to select the functional traits (arrow 3), which can be based on ecomorphological measures or ecological attributes. Functional traits may be available in databases or may be obtained from new samples (arrow 4). With this set of informations it is possible to delineate the analyzes and select the appropriate index, according to its variables (arrow 5). Assessing functional diversity of fish contributes to the development of management plans and conservation of aquatic ecosystems, which provide diverse ecosystem services to the human population. In addition, the study can generate new questions or hypotheses, thus directing future approaches in functional ecology.

Moreover, the trends in studies on functional diversity of fish, our review presents some shortcomings in relation to the terminology of the functional traits that can cause confusion or difficulties to understand and compare the studies. As an example, the terms "trophic guild" and "trophic category" or the terms "parental care" and "type of parental care" (see more examples in table 3) have the same ecological meaning, in addition, many studies do not clearly explain how a certain measure was taken. For example, the trait in relation to body length is not always specified if it is the standard or total length, but the description of this information is important in order to contribute to improve the approaches and research in the functional field in further studies. Thus, we suggested a standardization of the terminology of some terms, according to the frequency in which the terms were used in the articles analyzed, in order to facilitate the understanding of the reading and use of functional traits in future studies (Table 3). Schmera et al. (2015) pointed out some shortcomings and proposed a unified nomenclature for macroinvertebrates. However, the standardization of the terminology is inexistent for freshwater fish and this point can be a challenge for ecologists.

The standardization of terminology of functional traits, aims to improve the studies, especially in order to facilitate the comparison and replication of the studies. In order to do so, it is interesting that the researchers give a description of how the traits were measured or classified, because these specifications are relative and, in most cases, the set of traits used in a given research can be the basis for future studies. For an effective standardization of the functional traits, a starting point would be the creation of lists of databases with the functional characteristics of the species, such as the existing list for freshwater fish of the United States (Frimpong and Angermeier 2009). In this list, the authors compiled a database with more than 100 traits for 809 fish species found in freshwaters of the conterminous United States. It is worth mentioning that different terminologies for the same trait can be derived from translations into several languages. Despite this, we emphasize the importance of creating a database with standardized functional trait terminology, because species traits will remain instrumental in future studies of fish ecology, management, and conservation (Frimpong and Angermeier 2009).

The evaluation through the functional attributes of the species is particularly challenging, since it covers a range of ecological, morpho-anatomical, behavioral and physiological characteristics that can be measured at individual or species level and that can be related to several aspects of ecosystems (McGill et al. 2006; Weiher et al. 2011). Nonetheless, this approach has not been used in its entirety due to difficulties in finding a set of traits that explain species responses to different types of disturbances (Mouillot et al. 2013). Despite the great taxonomic diversity of freshwater fish in the world, the global distribution of functional traits remains poorly known and the description of traits for a large number of species is another challenge for researchers (Villéger et al. 2017). Moreover, anthropic changes, biological invasions and climate change accelerate rates of biodiversity loss, and consequently, local extinctions. Thus, it is important to investigate the traits that may be associated with the resistance and resilience of communities, and it is essential to use functional diversity in practice, that is, to use this approach to subsidize the long-term monitoring of biological communities, with the purpose of describing as many functional attributes as possible of the species so that these data are actually taken into account in the management and conservation plans of freshwater fish.

Table 3: Traits with different terminologies, but with the same ecological meaning and suggestion of terminology (based on the articles analyzed in this review).

Functional traits	**Suggested terminology**
Velocity preference, flow preference, affinity for flow velocity, fluvial dependence	Velocity preference
Feeding behavior, feeding tactics	Feeding tactics
Foraging locality, foraging local, feeding location, feeding habitat, feeding position, feeding strata,	Feeding habitat
Living habitat, water column position, vertical position, habitat preference, habitat use, habitat type, microhabitat use, behavior	Living habitat
Trophic guild, trophic category, trophic status, feeding types, trophic level, feeding diet, trophic position, feeding guild, trophic groups	Trophic guild
Diet, dietary component, type of diet, main diet, feeding, trophic ecology	Diet
Parental care, type of parental care, parental protection	Parental care
Longevity, life span	Longevity
Migration behavior, migration status, migration, migratory behavior	Migration
Mouth position, mouth orientation	Mouth position
Reproduction habitat, breeding habitat, spawning habitat, reproductive habitat, reproductive ecology, reproductive behavior	Spawning habitat

2.5 CONCLUSION

Functional ecology has gained space over time, especially to help clarify the processes that determine the functioning of communities. The approach with functional diversity presents some biases that deserve attention of the researchers so that there is a significant advance within the Ecology. This review presented some trends in studies on functional diversity of freshwater fish, pointing out some shortcomings found in the articles analyzed, with emphasis on the terminology of the functional traits. The incorrect interpretation of the data, due to the type of trait or index used, may jeopardize future actions for the conservation and maintenance of freshwater ecosystems.

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Appendix A

Table 1: List of articles used for this review obtained in the Thomson Reuters database (ISI Web of Knowledge, apps.isiknowledge.com).

1	Blanchet S, Helmus MR, Brosse S, Grenouillet G (2014) Regional vs local drivers of phylogenetic and species diversity in stream fish communities. Freshw Biol 59:450–462
2	Bordignon CR, Casatti L, Pérez-Mayorga MA, Teresa FB, Brejão GL (2015) Fish complementarity is associated to forests in Amazonian streams. Neotrop Ichthyol 13:579-590
3	Brind' Amour A, Boisclair D, Dray S, Legendre P (2011) Relationships between species feeding traits and environmental conditions in fish communities: a three-matrix approach. Ecol Appl 21:363–377
4	Brosse S, Grenouillet G, Gevrey M, Khazraie K, Tudesque L (2011) Small-scale gold mining erodes fish assemblage structure in small neotropical streams. Biodivers Conserv 20:1013–1026
5	Burcher CL, McTammany ME, Benfield EF, Helfman GS (2008) Fish assemblage responses to forest cover. Environ Manage 41:336–346
6	Casatti L, Teresa FB, Zeni JO, Ribeiro MD, Brejão GL, Ceneviva-Bastos M (2015) More of the same: High functional redundancy in stream fish assemblages from tropical agroecosystems. Environ Manage 55:1300–1314
7	Carvalho RA, Tejerina-Garro FL (2014) Environmental and spatial processes: what controls the functional structure of fish assemblages in tropical rivers and headwater streams? Ecol Freshw Fish 24: 317–328
8	Carvalho RA, Tejerina-Garro FL (2015) Relationships between taxonomic and functional components of diversity: implications for conservation of tropical freshwater fishes. Freshw Biol 60:1854–1862
9	Cheng L, Blanchet S, Loot G, Villéger S, Zhang T, Lek S, Lek-Ang S, Li Z (2014) Temporal changes in the taxonomic and functional diversity of fish communities in shallow Chinese lakes: the effects of river–lake connections and aquaculture. Aquat Conserv 24:23–34
10	Cilleros K, Allard L, Grenouillet G, Brosse S (2016) Taxonomic and functional diversity patterns reveal different processes shaping European and Amazonian stream fish assemblages. J Biogeogr 43:1832-1843
11	Clavel J, Poulet N, Porcher E, Blanchet S, Grenouillet G, Pavoine S, Biton A, Seon-Massin N, Argillier C, Daufresne M, Teillac-Deschamps P, Julliard R (2013) A New Freshwater Biodiversity Indicator Based on Fish Community Assemblages. PLoS ONE 8: e80968
12	Córdova-Tapia F, Zambrano L (2016) Fish functional groups in a tropical wetland of the Yucatan Peninsula, Mexico. Neotrop Ichthyol 14: e150162
13	Cruz BB, Miranda LE, Cetra M (2013) Links between riparian landcover, instream environment and fish assemblages in headwater streams of southeastern Brazil. Ecol Freshw Fish 22:607–616
14	Cunico AM, Allan JD, Agostinho AA (2011) Functional convergence of fish assemblages in urban streams of Brazil and the United States. Ecol Indic 11:1354–1359
15	Dala-Corte RB, Giam X, Olden JD, Becker FG, Guimarães TF, Melo AS (2016) Revealing the pathways by which agricultural land-use affects stream fish communities in South Brazilian grasslands. Freshw Biol 61:1921–1934
16	Dumay O, Tari PS, Tomasini JA, Mouillot D (2004) Functional groups of lagoon fish species in Languedoc Roussillon, southern France. J Fish Biol 64:970–983
17	Erõs T, Heino J, Schmera D, Rask M (2009) Characterising functional trait diversity and trait–environment relationships in fish assemblages of boreal lakes. Freshw Biol 54:1788–1803
18	Fitzgerald DB, Winemiller KO, Pérez MHS, Sousa LM (2016) Seasonal changes in the assembly mechanisms structuring tropical fish communities. Ecology 98: 21–31
19	Goldstein RM (2005) Multilevel Assessment of Fish Species Traits to Evaluate Habitat Degradation in Streams of the Upper Midwest. N Am Fish Manag 25:180–194

20	Helms BS, Werneke DC, Gangloff MM, Hartfield EE, Feminella JW (2011) The influence of low-head dams on fish assemblages in streams across Alabama. J North Am Benthol 30:1095–1106
21	Hitt NP, Chambers DB (2014) Temporal changes in taxonomic and functional diversity of fish assemblages downstream from mountaintop mining. Freshw Sci 33: 915–926
22	Jiang Z, Brosse S, Jiang X, Zhang E (2015) Measuring ecosystem degradation through half a century of fishspecies introductions and extirpations in a large isolated lake. Ecol Indic 58:104–112
23	Keck BP, Marion ZH, Martin DJ, Kaufman JC, Harden CP, Schwartz JS, Strange RJ (2014) Fish Functional Traits Correlated with Environmental Variables in a Temperate Biodiversity Hotspot. PLoS ONE 9: e93237
24	Launois L, Veslot J, Irz P, Argillier C (2011) Development of a fish-based index (FBI) of biotic integrity for French lakes using the hindcasting approach. Ecol Indic 11:1572–1583
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26	Logez M, Pont D (2013) Global warming and potential shift in reference conditions: the case of functional fish-based metrics. Hydrobiologia 704: 417–436
27	Logez M, Bady P, Melcher A, Pont D (2013) A continental-scale analysis of fish assemblage functional structure in European rivers. Ecography 36:080–091
28	Looy KV, Tormos T, Souchon Y (2014) Disentangling dam impacts in river networks. Ecol Indic 37: 10– 20
29	Macnaughton CJ, Senay C, Dolinsek I, Bourque G, Maheu A, Lanthier G, Harvey-Lavoie S, Asselin J, Legendre P, Boisclair D (2016) Using fish guilds to assess community responses to temperature and flow regimes in unregulated and regulated Canadian rivers. Freshw Biol 61: 1759–1772
30	Maire A, Buisson L, Biau S, Canal J, Laffaille P (2013) A multi-faceted framework of diversity for prioritizing the conservation of fish assemblages. Ecol Indic 34:450– 459
31	Maire A, Laffaille P, Maire JF, Buisson L (2016) Identification of priority areas for the conservation of stream fish assemblages: implications for river management in france. River Res Appl 33:524-537
32	Mason NWH, Lanoiselée C, Mouillot D, Irz P, Argillier C (2007) Functional characters combined with null models reveal inconsistency in mechanisms of species turnover in lacustrine fish communities. Oecologia 153: 441–452
33	Mason NWH, Lanoiselée C, Mouillot D, Argillier C (2008) Does niche overlap control relative abundance in French lacustrine fish communities? A new method incorporating functional traits. J Anim Ecol 77: 661–669
34	Mason NWH, Irz P, Lanoiselée C, Mouillot D, Argillier C (2008) Evidence that niche specialization explains species–energy relationships in lake fish communities. J Anim Ecol 7:285–296
35	Matono P, Bernardo JM, Ferreira MT, Formigo N, Raposo de Almeida P, Cortes R, Ilhéu M (2012) Fish-based groups for ecological assessment in rivers: the importance of environmental drivers on taxonomic and functional traits of fish assemblages. Knowl Manag Aquat Ecosyst 405: 04
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38	Mérona B,_Vigouroux R (2012) The role of ecological strategies in the colonization success of pelagic fish in a large tropical reservoir (Petit-Saut Reservoir, French Guiana). Aquati Living Resour 25: 41–54

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40	Mims MC, Olden JD, Shattuck ZR, Poff NL (2010) Life history trait diversity of native freshwater fishes in North America. Ecol Freshw Fish 19:390–400
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45	Olden JD, Poff NL, Bestgen KR (2008) Trait synergisms and the rarity, extirpation, and extinction risk of desert fishes. Ecology 89: 847–856
46	Oliveira JM, Segurado P, Santos JM, Teixeira A, Ferreira MT, Cortes RV (2012) Modelling Stream-Fish Functional Traits in Reference Conditions: Regional and Local Environmental Correlates. PLoS ONE 7: e45787
47	Parks TP, Quist MC, Pierce CL (2016) Anthropogenic disturbance and environmental associations with fish assemblage structure in two nonwadeable rivers. River Res Appl 32: 66–84
48	Pease AA, González-Díaz AA, Rodiles-Hernández R, Winemiller KO (2012) Functional diversity and trait–environment relationships of stream fish assemblages in a large tropical catchment. Freshw Biol 57:1060–1075
49	Pease AA, Taylor JM (2015) Ecoregional, catchment, and reach-scale environmental factors shape functional-trait structure of stream fish assemblages. Hydrobiologia 753: 265–283
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51	Pool TK, Olden JD (2012) Taxonomic and functional homogenization of an endemic desert fish fauna. Divers Distrib 18: 366–376
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53	Pool TK, Cucherousset J, Boulêtreau S, Villéger S, Strecker AL, Grenouillet G (2016) Increased taxonomic and functional similarity does not increase the trophic similarity of communities. Glob Ecol Biogeogr 25:46–54
54	Ribeiro MD, Teresa FB, Casatti L (2016) Use of functional traits to assess changes in stream fish assemblages across a habitat gradient. Neotrop Ichthyol 14: e140185
55	Ross RM, Bennett RM, Snyder CD, Young JA, Smith DR, Lemarie DP (2003) Influence of eastern hemlock (*Tsuga canadensis* L.) on fish community structure and function in headwater streams of the Delaware River basin. Ecol Freshw Fish 12: 60–65
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57	Schmera D, Erõs T, Podani J (2009) A measure for assessing functional diversity in ecological communities. Aquatic Ecol 43: 157–167
58	Schwartz JS, Simon A, Klimetz L (2010) Use of fish functional traits to associate in-stream suspended sediment transport metrics with biological impairment. Environ Monit Assess 179: 347–369
59	Skóra F, Abilhoa V, Padial AA, Vitule JRS (2015) Darwin's hypotheses to explain colonization trends: evidence from a quasi-natural experiment and a new conceptual model. Divers Distrib 21: 583–594
60	Sternberg D, Kennard MJ (2013) Environmental, spatial and phylogenetic determinants of fish life-history traits and functional composition of Australian rivers. Freshw Biol 58: 1767-1778

61	Sternberg D, Kennard MJ (2014) Phylogenetic effects on functional traits and life history strategies of Australian freshwater fish. Ecography 37: 54–64
62	Sternberg D, Kennard MJ, Balcombe SR (2014) Biogeographic determinants of Australian freshwater fish life-history indices assessed within a spatio-phylogenetic framework. Glob Ecol Biogeogr 23: 1387–1397
63	Stoll S, Kail J, Lorenz AW, Sundermann A, Haase P (2014) The Importance of the Regional Species Pool, Ecological Species Traits and Local Habitat Conditions for the Colonization of Restored River Reaches by Fish. PLoS ONE 9: e84741
64	Strecker AL, Olden JD, Whittier JB, Paukert CP (2011) Defining conservation priorities for freshwater fishes according to taxonomic, functional, and phylogenetic diversity. Ecol Appl 21: 3002–3013
65	Teresa FB, Casatti L (2012) Influence of forest cover and mesohabitat types on functional and taxonomic diversity of fish communities in Neotropical lowland streams. Ecol Freshw Fish 21: 433–442
66	Teresa FB, Casatti L, Cianciaruso MV (2015) Functional differentiation between fish assemblages from forested and deforested streams. Neotrop Ichthyol 13: 361-370
67	Torres KMM, Higgins CL (2016) Taxonomic and functional organization in metacommunity structure of stream-fish assemblages among and within river basins in Texas. Aquatic Ecol 50: 247-259
68	Toussaint A, Charpin N, Brosse S, Villéger S (2016) Global functional diversity of freshwater fish is concentrated in the Neotropics while functional vulnerability is widespread. Sci Rep 6: 22125
69	Trautwein C, Schinegger R (2013) Divergent reaction of fish metrics to human pressures in fish assemblage types in Europe. Hydrobiologia 718: 207–220
70	Vila-Gispert A, Alcaraz C, García-Berthou E (2005) Life-history traits of invasive fish in small Mediterranean streams. Biol Invasions 7: 107–116
71	Villéger S, Grenouillet G, Brosse S (2014) Functional homogenization exceeds taxonomic homogenization among European fish assemblages. Glob Ecol Biogeogr 23:1450–1460
72	Villéger S, Grenouillet G, Brosse S (2013) Decomposing functional b-diversity reveals that low functional b-diversity is driven by low functional turnover in European fish assemblages. Glob Ecol Biogeogr 22: 671–681
73	Vitorino Júnior OB, Fernandes R, Agostinho CS, Pelicice FM (2016) Riverine networks constrain b-diversity patterns among fish assemblages in a large Neotropical river. Freshw Biol 61:1733–1745
74	Zuluaga-Gómez AA, Fitzgerald DB, Giarrizzo T, Winemiller KO (2016) Morphologic and trophic diversity of fish assemblages in rapids of the Xingu River, a major Amazon tributary and region of endemism. Environ Biol Fish 99: 647-658
75	White SM, Ondračková M, Reichard M (2012) Hydrologic Connectivity Affects Fish Assemblage Structure, Diversity, and Ecological Traits in the Unregulated Gambia River, West Africa. Biotropica 44: 521–530 2012

Appendix B

Table 2: Ecomorphological measures and ecological attributes used to evaluate functional diversity in freshwater fish found in this review. *Traits representing more than one function

Feeding	Locomotion	Life history	Habitat use	Physiology
Biomass*	Anal fin height	Absolute relative fecundities	Body area	Hypoxia tolerance
Barbel maximum Length	Anal fin length	Age at 1st reproduction	Body compression	Salinity
Diet	Aspect ratio of the caudal fin	Age at female maturity	Body depth*	Temperature preferences
Diet breadth	Aspect ratio of the pectoral fin	Age at maturation	Body depth below midline*	Tolerance to environmental perturbation
Diet shift	Body transversal surface	Average fecundity	Body elongation	
Eye diameter	Body width	Clutch size	Body height	
Eye size	Caudal fin area	Egg diameter/size	Body lateral shape	
Feeding habitat	Caudal fin aspect ratio	Female maturity	Body length*	
Feeding niche breadth	Caudal fin depth	Gregariousness referred to the adults	Body shape	
Feeding tactics	Caudal fin height	Growth rate	Body shape ratio	
Foraging method	Caudal fin length	Incubation period	Body transversal shape	
Gape width	Caudal peduncle compression index	Larval length	Cover use type	
Gill raker depth	Caudal peduncle depth	Length at maturation	Cross-sectional morphology	
Gill raker lenght	Caudal peduncle flatness	Life history strategy	Eye position	
Gill-raker shape	Caudal peduncle length	Longevity	Flatness index	

Gut length	Caudal peduncle width	Maturation	Velocity preference
Head depth	Caudal-peduncle throttling	Maximum age	Foraging period
Head height	Dorsal fin area	Maximum age for reproduction	Geographic distribution
Head length	Dorsal fin height	Migration	Habitat breadth
Head size	Dorsal fin length	Number of years of reproduction	Habitat preference /stream or river/eixo longitudinal
Jaw protrusion	Fineness coefficient	Origin guild	Index of ventral flattening
Maxilla size	Fins surface ratio	Parental care	Interorbital distance
Maxillary Jaw Length/ Length of upper jaw	Fins surface to body size ratio	Percentage of mature oocytes	Livin habitat
Mouth depth	Insertion of dorsal fin	Relative fecundities	Longitudinal morphology
Mouth position	Insertion of pelvic fin	Reproductive guild	Middle line height
Mouth width	Insertions of anal fin (anterior)	Reproductive span/ period in months	Potandromous
Number of lower teeth	Insertions of anal fin (posterior)	Reproductive/ spawning habitat	Relative depth
Number of upper teeth	Insertions of caudal fin (dorsal)	Schooling	Rheophily
Opening of mouth	Insertions of caudal fin (ventral)	Size at 1st reproduction	Standard body length*
Oral disk length	Insertions of pectoral fin (dorsal)	Spawning frequency	Substrate preference

Oral gap height	Insertions of pectoral fin (ventral)	Spawning season	Total body length*
Oral gape	Locomotion morphology	Spawning substrate	Turbidity tolerance
Oral-gape position	Pectoral fin area*	Spawning temperature	Vegetation use
Oral-gape shape	Pectoral fin depth	Spawning time	Vertical position of preys
Oral-gape surface	Pectoral fin height	Spawning velocities	Water depth preference
Relative gut length	Pectoral fin length*	Spawning water depth	
Relative head length	Pectoral fin shape	Territorial	
Relative mouth width	Pectoral fin size	Total fecundity	
Snout length	Pectoral fin width		
Snout length closed	Pectoral position		
Snout protrusion	Peduncle depth		
Stomach length	Peduncle length		
Terminus of jaw	Pelvic fin length*		
Tip of snout	Pelvic fin position		
Tooth shape	Relative area of pectoral fin		
Trophic breadth	Relative caudal peduncle depth		
Trophic guild	Relative caudal peduncle length		
Trophic level	Relative fin surface		

Visible barbels	Relative pectoral length
	Shape factors
	Swimming factors
	Ventral fin area*

Anexo 1

Aquatic Ecology

Instruction for Authors

Manuscript submission:

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Always use footnotes instead of endnotes.

Acknowledgments

Acknowledgments of people, grants, funds, etc. should be placed in a separate section on the title page. The names of funding organizations should be written in full.

Important notes:

- Please submit your manuscript in 11-point Times Roman.
- And please use double line spacing.

References

Citation

Cite references in the text by name and year in parentheses. Some examples:

- Negotiation research spans many disciplines (Thompson 1990).
- This result was later contradicted by Becker and Seligman (1996).
- This effect has been widely studied (Abbott 1991; Barakat et al. 1995a, b; Kelso and Smith 1998; Medvec et al. 1999, 2000).

Reference list

The list of references should only include works that are cited in the text and that have been published or accepted for publication. Personal communications and unpublished works should only be mentioned in the text. Do not use footnotes or endnotes as a substitute for a reference list.

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- Journal article

Gamelin FX, Baquet G, Berthoin S, Thevenet D, Nourry C, Nottin S, Bosquet L (2009) Effect of high intensity intermittent training on heart rate variability in prepubescent children. Eur J Appl Physiol 105:731-738. https://doi.org/10.1007/s00421-008-0955-8

Ideally, the names of all authors should be provided, but the usage of "et al" in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al (1999) Future of health insurance. N Engl J Med 965:325–329

- Article by DOI

  Slifka MK, Whitton JL (2000) Clinical implications of dysregulated cytokine production. J Mol Med. https://doi.org/10.1007/s001090000086

- Book

  South J, Blass B (2001) The future of modern genomics. Blackwell, London

- Book chapter

  Brown B, Aaron M (2001) The politics of nature. In: Smith J (ed) The rise of modern genomics, 3rd edn. Wiley, New York, pp 230-257

- Online document

  Cartwright J (2007) Big stars have weather too. IOP Publishing PhysicsWeb. http://physicsweb.org/articles/news/11/6/16/1. Accessed 26 June 2007

- Dissertation

  Trent JW (1975) Experimental acute renal failure. Dissertation, University of California

Always use the standard abbreviation of a journal's name according to the ISSN List of Title Word Abbreviations, see

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-
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- Tables should always be cited in text in consecutive numerical order.
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- Footnotes to tables should be indicated by superscript lower-case letters (or asterisks for significance values and other statistical data) and included beneath the table body.

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CAPÍTULO 2

Estrutura taxonômica e funcional de peixes nativos e não nativos de uma bacia hidrográfica Neotropical

Artigo elaborado e formatado conforme normas para publicação científica do periódico *Ecology of Freshwater Fish*.

Estrutura taxonômica e funcional de peixes nativos e não nativos de uma bacia hidrográfica Neotropical

RESUMO

O estudo da ecologia de peixes de água doce tem sido predominantemente avaliado de acordo com a taxonomia, mas durante as últimas duas décadas, os ecólogos têm apoiado cada vez mais a abordagem baseada em atributos funcionais. O objetivo deste trabalho foi investigar a estrutura taxonômica e funcional de assembleias de peixes nativas e não nativas da bacia do rio Iguaçu. Para tanto, foi realizado o levantamento da ocorrência das espécies em cada trecho da bacia (baixo, médio e alto). A estrutura taxonômica foi avaliada a partir da β diversidade espacial. A diversidade funcional foi mensurada utilizando oito atributos funcionais, e aplicado os índices de riqueza, dispersão e singularidade funcional. Para delimitar os atributos funcionais característicos em cada trecho da bacia foi utilizado uma análise indicadora de valores. Foram registradas 126 espécies, sendo 68 nativas e 58 não nativas. A contribuição do componente *turnover* foi maior para a composição taxonômica em todos os trechos da bacia. Contrariamente ao que era esperado, a riqueza funcional não aumentou com o incremento na riqueza taxonômica. Foram observados altos valores de dispersão e singularidade funcional, indicando baixa redundância funcional entre as espécies. As assembleias nativas e não nativas apresentaram contribuição semelhante de alguns atributos, como comprimento total, migração e corpo fusiforme no trecho baixo; cuidado parental, corpo deprimido, boca inferior, dieta detritívora e herbívora no trecho médio e, corpo comprimido e hábito pelágico no trecho alto. Levando em consideração o alto grau de endemismo da bacia do Iguaçu, sugere-se que os esforços para conservação sejam voltados para toda e bacia, uma vez que cada trecho foi caracterizado por apresentar espécies com atributos únicos e pouco redundantes, ou seja, espécies com funções diferenciadas. Os resultados obtidos para a área de estudo possibilitarão comparar futuros estudos sobre a estrutura taxonômica e funcional em outras bacias hidrográficas submetidas a diferentes impactos antrópicos, especialmente aqueles relacionados a invasão de espécies.

Palavras-chave: Diversidade funcional. Bacia do Iguaçu. Endemismo. Impacto. Conservação.

Taxonomic and functional structure of native and non-native fish from a Neotropical watershed

ABSTRACT

One of the central issues in ecology is to understand the functions that species play in ecosystems. Our objective was to evaluate the taxonomic and functional structure of native and non - native fish assemblages of the Iguaçu basin. For that, a survey of the occurrence of the species in each section of the basin (lower, middle and upper) was carried out. For each assembly, the spatial β diversity was evaluated. Functional diversity was measured from eight functional attributes, using indexes of richness, dispersion and functional singularity. In order to verify the functional attributes indicators in each section of the basin, an indicator of values was used. 126 species were recorded, of which 68 were native and 58 were non-native. The contribution of the *turnover* component was higher for the taxonomic composition in all parts of the basin. Contrary to what was expected, functional richness did not increase with the increase in taxonomic richness. High values of dispersion and functional uniqueness were observed, indicating low functional redundancy among the species. The native and non-native assemblages presented a similar contribution of some attributes, such as total length, migration and fusiform body in the low section; parental care, depressed body, lower mouth, detritivorous and herbivorous diet in the middle stretch, and compressed body and pelagic habit in the upper stretch. The results obtained for the study area will make it possible to compare future studies on taxonomic and functional structure in other watersheds submitted to different anthropic impacts, especially those related to species invasion.

Keywords: Functional diversity. Iguaçu Basin. Endemis. Impact. Conservation

3.1 INTRODUÇÃO

Os ecossistemas aquáticos continentais englobam aproximadamente 40% da ictiofauna do planeta (Dudgeon et al., 2006). Com mais de 5.000 espécies válidas e representando um terço da diversidade global (Albert & Reis, 2011; Reis et al., 2016; Pelicice et al., 2017) a região Neotropical compreende a maior diversidade taxonômica de peixes de água doce (Toussaint, Charpin, Brosse, & Villéger, 2016). Os estudos com ecologia de peixes têm sido predominantemente investigados de acordo com a taxonomia (Jackson, Peres-Neto, & Olden, 2001) e as abordagens tradicionais utilizadas para mensurar as relações entre a biodiversidade e o ambiente têm sido baseadas em riqueza de espécies, abundância e índices de diversidade e equitabilidade (Morin, 2011). Outra medida amplamente utilizada especialmente para compreender padrões e processos de mudanças na composição de espécies em escala espacial e temporal é a beta diversidade (β diversidade) (Baselga, 2010; Leprieur et al., 2011). A β diversidade é definida como a variação da composição da comunidade entre locais e usualmente é explorada a partir de índices de dissimilaridade (e.g Jaccard ou Sørensen) (Koleff, Gaston & Lennon, 2003; Tuomisto, 2010). As dissimilaridades na composição das assembleias de espécies podem ser estruturadas de diferentes formas, incluindo a substituição de algumas espécies por outras (i.e *turnover*) ou pela perda de espécies cujas comunidades são subconjuntos de comunidades mais ricas (i.e *nestedness*) (Baselga & Orme, 2012).

Além das medidas usuais de taxonomia, durante as últimas duas décadas, os ecólogos têm apoiado cada vez mais a abordagem baseada em atributos funcionais (Olden et al., 2010) os quais podem ser definidos como características biológicas mensuráveis em nível individual ou de espécie, cujos valores obtidos podem ser variáveis em escala espacial e temporal (Violle, Navas, Vile, Kazakou, & Fortunel, 2007). Essa abordagem é interessante pois leva em consideração as funções ecológicas que as espécies desempenham nos ecossistemas, fornecendo informações adicionais que não seriam obtidas somente pela abordagem taxonômica (Eros, Heino, Schmera, & Rask, 2009). Por exemplo, estabelecer classificações de espécies com base em seus atributos funcionais, presume-se relacionar as espécies direta ou indiretamente ao funcionamento do ecossistema (Lavorel & Garnier, 2002) e ainda, se torna possível comparar sistemas e assembleias compostas por diferentes *pools* de espécies (Logez, Bady, Melcher, & Pont, 2013). Dessa forma, a diversidade funcional tem sido utilizada para melhor compreender as relações entre diversidade, estrutura de comunidades e funcionamento dos ecossistemas (Díaz & Cabido, 2001; Naeem & Wright, 2003).

Os peixes de água doce apresentam uma notável variedade de atributos morfológicos, comportamentais e ecológicos e desempenham um papel essencial nos ecossistemas (Mims, Olden, Shattuck, & Poff, 2010) participando de processos ecológicos chaves, como por exemplo, no fluxo de energia e matéria, estabilidade do ecossistema (resistência e resiliência), interações biológicas e modificação de habitat (Córdova-Tapia & Zambrano, 2016). Assim, os estudos têm utilizado a abordagem funcional para diversos propósitos, como quantificar a diversidade funcional de comunidades (Fitzgerald, Winemiller, Pérez, & Sousa, 2016), investigar como a diversidade funcional modula os processos ecossistêmicos (Cilleros, Allard, Grenouillet, & Brosse, 2016) mensurar impactos antrópicos sobre a diversidade funcional de assembleias (Teresa, Casatti, & Cianciaruso, 2015; Dala-Corte et al., 2016; Oliveira et al., 2018) e avaliar o sucesso de espécies invasoras e os seus efeitos sobre a diversidade funcional de espécies nativas (Vila-Gispert, Alcaraz, & García-Berthou, 2005; Matsuzaki, Sasaki, & Akasaka, 2016).

A fauna de peixes em ecossistemas aquáticos continentais está cada vez mais ameaçada devido à introdução de espécies não nativas. O sucesso no estabelecimento de espécies não nativas varia entre as regiões geográficas, mas geralmente é maior em áreas que são amplamente alteradas pela ação antrópica (Vila-Gispert et al., 2005). A bacia do rio Iguaçu encontra-se severamente impactada, especialmente pela construção de barramentos para fins hidrelétricos, poluição industrial, agricultura e aquicultura (Baumgartner et al., 2012). Estas atividades potencializam a introdução de espécies não nativas, promovendo assim, consequências negativas para a estrutura das comunidades e o funcionamento dos ecossistemas (Vitule, Skóra, & Abilhoa, 2012; Ellender & Weyl, 2014). Considerada uma ecoregião da biodiversidade, a bacia do Iguaçu apresenta elevado grau de endemismo, com uma proporção de aproximadamente 70% de espécies endêmicas (Zawadzki, Renesto, & Bini, 1999). Esse endemismo é atribuído ao isolamento geográfico proporcionado pela formação das Cataratas do Iguaçu, a qual funciona como uma efetiva barreira à dispersão de espécies (Garavello, Pavanelli & Suzuki, 1997; Agostinho et al, 1999; Baumgartner et al., 2006; Alcaraz, Pavanelli & Bertaco, 2009).

Nesse contexto, o objetivo desse estudo foi investigar a estrutura taxonômica e funcional das assembleias de peixes nativos e não nativos da bacia do rio Iguaçu para buscar informações sobre os padrões espaciais na composição taxonômica e organização funcional da ictiofauna ao longo do gradiente longitudinal da bacia. O estudo focou especificamente em: *i)* calcular a β-diversidade das assembleias e examinar se a composição de espécies em cada trecho da bacia (baixo, médio e alto) é aninhada ou substituta (*nestedness* ou *turnover*). Espera-se que as assembleias apresentam um padrão *turnover* devido a construção de inúmeros barramentos na bacia, os quais podem funcionar como barreiras à dispersão das espécies; *ii)* determinar a estrutura funcional e identificar se os trechos com maior riqueza taxonômica apresentam maior diversidade funcional; *iii)* calcular a composição dos atributos funcionais em cada trecho e identificar quais características são mais representativas nas assembleias nativas e não nativas.

Devido a relevância da ictiofauna endêmica da ecoregião do Iguaçu, este trabalho é pioneiro na abordagem funcional nesta área, incluindo todas as espécies para as quais se tem registro na bacia. Os resultados obtidos para a área de estudo possibilitarão comparar futuros estudos sobre a estrutura taxonômica e funcional em outras bacias hidrográficas submetidas a diferentes impactos antrópicos, especialmente aqueles relacionados a invasão de espécies.

3.2 MATERIAL E MÉTODOS

3.2.1 Área de estudo

A bacia do rio Iguaçu ocupa uma área de aproximadamente 72.000 km^2, da qual 79% pertence ao Estado do Paraná, 19% ao Estado de Santa Catarina e 2% à Argentina. A bacia abrange 104 municípios e incluí quase cinco milhões de habitantes, dos quais 80% correspondem à população urbana (Baumgartner et al., 2012). A formação da bacia do Iguaçu remonta a era Mesozoica e início da Paleozoica, e foi associada ao soerguimento da Serra do Mar, dando origem aos três planaltos paranaenses (Maack, 2012). A partir dessas características geomorfológicas, o rio Iguaçu foi subdividido em três regiões: *i)* o alto Iguaçu, localizado no 1º planalto, compreende os trechos desde suas nascentes na região de Curitiba, até o início de suas corredeiras em Porto Amazonas (Ingenito, Duboc, & Abilhoa, 2004). Este trecho é caracterizado pela alta densidade populacional, com predomínio de atividades comerciais e industriais (Júlio Jr, Bonecker, & Agostinho, 1997; Baumgartner et al., 2012); *ii)* o médio Iguaçu, localizado no 2º planalto, compreende o trecho entre Porto Amazonas e União da Vitória, incluindo o Rio Negro e seus afluentes (Júlio Jr, Bonecker, & Agostinho, 1997); *iii)* o baixo Iguaçu, localizado no 3º planalto, a partir de União da Vitória até sua desembocadura no Rio Paraná. É caracterizado pela presença de inúmeras cachoeiras, como Salto Grande (13m), Salto Santiago (40m), Salto Osório (30m) e as Cataratas do Iguaçu (72m) (Maack, 2012), e apresenta grande potencial para o aproveitamento hidrelétrico, resultando na construção de vários reservatórios de pequeno e grande porte. O médio e baixo Iguaçu são também caracterizados especialmente pelas atividades de agricultura e aquicultura (Júlio Jr et al., 1997; Agostinho, Gomes, Suzuki, & Júlio Jr, 1999; Baumgartner et al., 2012) (Figura 1).

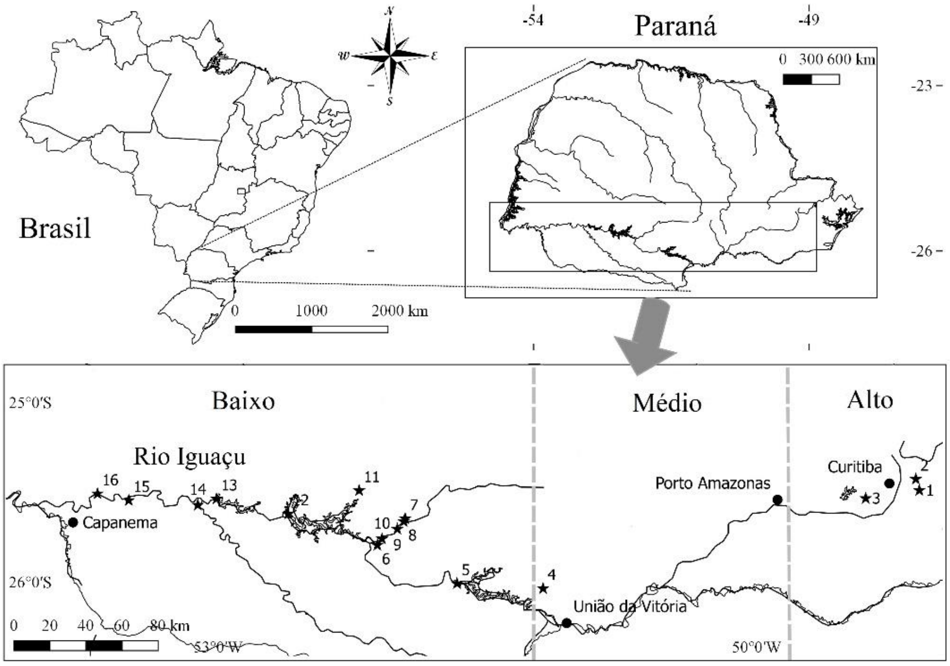

Figura 1: Localização da bacia do rio Iguaçu, Brasil. Os símbolos de estrelas representam os reservatórios construídos na bacia. 1) Piraquara, 2) Iraí, 3) Passaúna, 4) Salto do Vaú, 5) Foz do Areia, 6) Segredo, 7) Curucaca, 8) Santa Clara, 9) Fundão, 10) Derivação do Jordão, 11) Cavernoso, 12) Salto Santiago, 13) Salto Osório, 14) Chopim, 15) Salto Caxias e 16) Baixo Iguaçu.

3.2.2 Dados de ocorrência das espécies

Os registros de ocorrências das espécies de peixes nativas e não nativas da bacia do Iguaçu foram obtidos com auxílio da literatura (Ingenito et al., 2004; Abilhoa, Duboc, & Filho, 2008; Bifi, Pavanelli, & Zawadzki, 2009; Baumgartner et al., 2012; Daga, Debona, Abilhoa, Gubiani, & Vitule, 2016; Frota, Gonçalves, Deprá, & Graça, 2016) e a partir da base de dados *SpeciesLink* (http://www.splink.cria.org.br), a qual fornece informações de coleções ictiológicas de diferentes museus de história natural do mundo. Registros com ambiguidades e espécies com partículas cf., aff., sp. foram excluídos e as divergências de sinonímias e mudança de nome foram corrigidas. Os nomes válidos seguiram Fricke et al. (2018).

3.2.3 Diversidade taxonômica

Para cada assembleia, a riqueza taxonômica foi quantificada como o número de espécies em cada trecho da bacia (baixo, médio e alto). A partir da matriz de presença e ausência das espécies nativas e não nativas em cada trecho, foi calculada a β-diversidade como uma medida de dissimilaridade entre os trechos estudados. A β-diversidade reflete dois componentes diferentes: substituição (*turnover)* e aninhamento (*nestedness*). O *turnover* implica na substituição de algumas espécies por outras, como consequência das condições ambientais ou restrições espaciais e históricas (Baselga, 2010). O aninhamento das assembleias ocorre quando biotas de locais com menor número de espécies são subconjuntos de biotas em locais mais ricos, refletindo um processo não randômico de perda de espécies como consequência de fatores que causam impactos às comunidades. Esses componentes foram calculados no ambiente R (R Core Team, 2018), através da função "beta.pair" utilizando a dissimilaridade de Jaccard, disponível no pacote betapart.

3.2.4 Atributos funcionais

A caracterização funcional da ictiofauna foi baseada nas informações disponíveis na literatura até setembro de 2018, especialmente para o *pool* de espécies nativas e endêmicas da ecoregião do Iguaçu, as quais apresentam poucos estudos sobre sua Biologia e/ou Ecologia. Dessa forma, os atributos funcionais selecionados foram relacionados à alimentação (guilda trófica, posição da boca), morfologia (comprimento total máximo), uso do habitat (formato do corpo, posição na coluna de água) e história de vida (tipo de fecundação, migração e cuidado parental) (Apêndice A - Tabela S1).

As informações dos atributos funcionais das espécies foram obtidas a partir da compilação de dados realizada por Oliveira (2018) e nos casos em que a informação não foi encontrada, a pesquisa foi realizada em demais artigos científicos, teses, dissertações, bases de dados online e comunicação pessoal com especialistas. Para as espécies em que um atributo funcional não estava disponível, foi utilizada a informação descrita a nível de gênero, família ou ordem (Apêndice B - Tabela S2).

3.2.5 Diversidade funcional

Baseado no banco de dados disponível, foram construídas duas matrizes para as análises de diversidade funcional, sendo uma matriz de atributos funcionais (atributos x espécies) e uma matriz de assembleias (espécies x locais), nesse caso, os locais são os trechos de ocorrência das espécies (baixo, médio e alto). As matrizes foram elaboradas e avaliadas separadamente para as assembleias nativas e não nativas.

A estrutura funcional das assembleias de peixes foi analisada utilizando três índices de diversidade funcional: *i)* riqueza funcional (*functional richness* – FRic – (Villéger, Mason, & Mouillot, 2008), *ii)* dispersão funcional (*functional dispersion* – FDis – (Laliberté & Legendre, 2010) e *iii)* singularidade funcional (*functional uniqueness* – FUni - (Ricotta et al., 2016). A riqueza funcional representa a quantidade de espaço multidimensional preenchido pelas espécies na comunidade e não leva em consideração a abundância das espécies (Villéger, Mason, & Mouillot, 2008). A dispersão funcional, originalmente proposta por Anderson et al. (2006) é a distância média ao centroide ponderada pela abundância relativa das espécies. Nos casos em que as espécies têm abundâncias iguais (i.e dados de presença e ausência), a dispersão funcional é simplesmente a distância média ao centroide. A singularidade funcional (FSin) é a razão entre a entropia quadrática de Rao e o índice de diversidade de Simpson, relacionando a diversidade funcional ao valor máximo de dissimilaridade da comunidade (Ricotta et al., 2016). FSin assume que espécies com diferentes características desempenham funções distintas no ecossistema. Quando as espécies possuem combinações únicas de características em relação ao *pool* total de espécies, a singularidade assume valores altos e a assembleia apresenta baixa redundância funcional, que é uma medida contrária à singularidade.

Como a matriz funcional é composta por variáveis mistas, ou seja, tanto dados quantitativos quanto qualitativos (Pavoine, Vallet, Dufour, Gachet, & Daniel, 2009), os índices funcionais foram computados utilizando a dissimilaridade de *Gower* (Gower, 1971) para o cálculo das matrizes de distância, com correção de Cailliez para os autovalores negativos (Legendre & Legendre, 1998; Anderson, Ellingsen, & McArdle, 2006). O cálculo dos índices de riqueza e dispersão funcional foi realizado utilizando a função “dbFD” (*distance based functional diversity*), disponível no pacote FD, no ambiente R, e a singularidade funcional foi calculada utilizando a função “*uniqueness*” (Ricotta et al., 2016).

3.2.6 IndVal

A partir da multiplicação das matrizes de atributos das espécies X presença e ausência das espécies, foi gerada uma matriz T, utilizando a função “matriz.t” (Pillar, Duarte, Sosinski, & Joner, 2009) no ambiente R (pacote SYNCSA), sendo as colunas dessa matriz composta pelos atributos funcionais das espécies e as linhas compostas pelos locais de ocorrência. A matriz T foi utilizada para aplicar um índice de espécies indicadores (IndVal – *Indicator Value Analysis*; (Dufrêne & Legendre, 1997). Este índice combina o grau de especificidade de uma determinada espécie para um *status* ecológico, por exemplo tipo de habitat, e sua fidelidade dentro do *status*. Esse método foi aplicado para identificar a contribuição de cada atributo na composição de cada assembleia nos diferentes trechos da bacia. Os atributos funcionais indicadores são aqueles tanto abundantes (especificidade) quanto frequentes em cada trecho (fidelidade). O nível de significância adotado foi de α = 0,05 e as análises foram realizadas no ambiente R, através do pacote “labdsv”, função “indval” (R Core Team, 2018).

3.3 RESULTADOS

3.3.1 Diversidade taxonômica

Foram registradas 126 espécies, sendo 68 nativas e 58 não nativas (Apêndice B – Tabela S2). As ordens mais representativas foram Siluriformes e Characiformes (Fig. 2). O trecho baixo da bacia compreendeu a maior proporção de espécies, tanto nativas (42) quanto não nativas (42) (Fig. 3A e 3B). A partição da β-diversidade resultou em maior contribuição do componente *turnover* para a composição das assembleias em todos os trechos da bacia (Tabela 1).

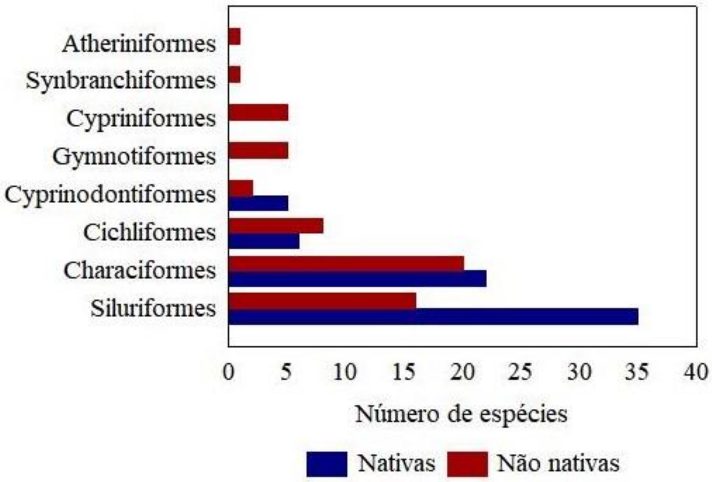

Figura 2: Número total de espécies por Ordem registradas na bacia do Iguaçu.

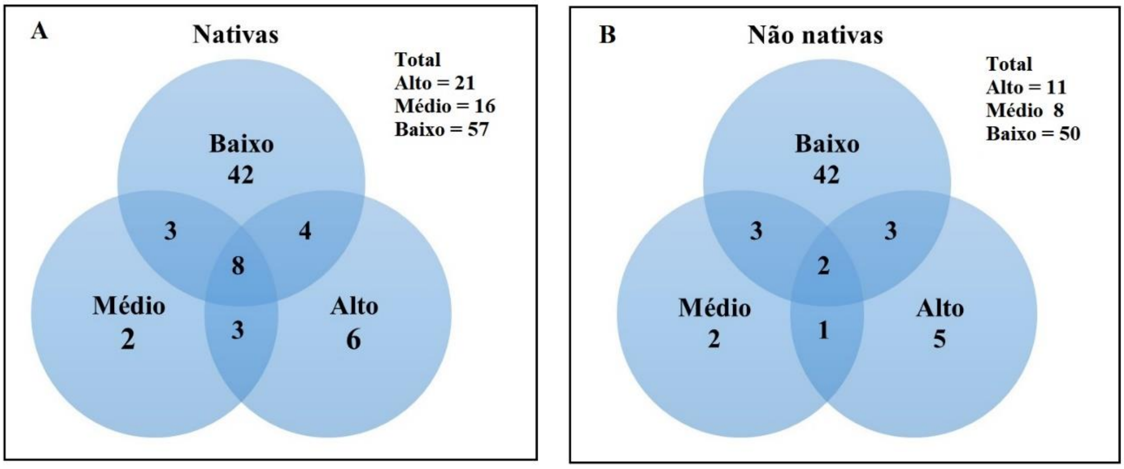

Figura 3: Número de espécies exclusivas, compartilhadas (área de sobreposição dos círculos) e o total de espécies em cada trecho da bacia.

Tabela 1: Componentes da β-diversidade para as assembleias nativas e não nativas ao longo do gradiente longitudinal da bacia. Beta.jtu = *turnover*; Beta.jne = *nestedness*.

Nativas			**Não nativas**		
Beta. jtu	Baixo	Médio	Beta. jtu	Baixo	Médio
Médio	0,47	-	Médio	0,54	-
Alto	0,6	0,47	Alto	0,76	0,76
Beta. jne	Baixo	Médio	Beta. jne	Baixo	Médio
Médio	0,34	-	Médio	0,36	-
Alto	0,22	0,10	Alto	0,15	0,06

3.3.2 Diversidade funcional

Os maiores valores de riqueza funcional foram observados principalmente no trecho alto, tanto para as assembleias nativas quanto não nativas (Fig. 4A e 4B). Foram obtidos altos valores de dispersão (Fig. 4C e 4D) e singularidade funcional (Fig. 4E e 4F) em todos os trechos da bacia.

3.3.3 IndVal

O maior número de contribuição dos atributos funcionais foi observado no trecho baixo para as assembleias nativas e no trecho médio para as não nativas (Tabela 2). De maneira geral, destaca-se alguns atributos que foram semelhantes entre nativas e não nativas nos trechos analisados, como a contribuição dos atributos relacionados ao comprimento total, migração e corpo fusiforme no trecho baixo, o cuidado parental, corpo deprimido, boca inferior, dieta detritívora e herbívora no trecho médio e, corpo comprimido e hábito pelágico no trecho alto. Demais atributos apresentaram contribuição específica em cada trecho para as assembleias nativas e não nativas.

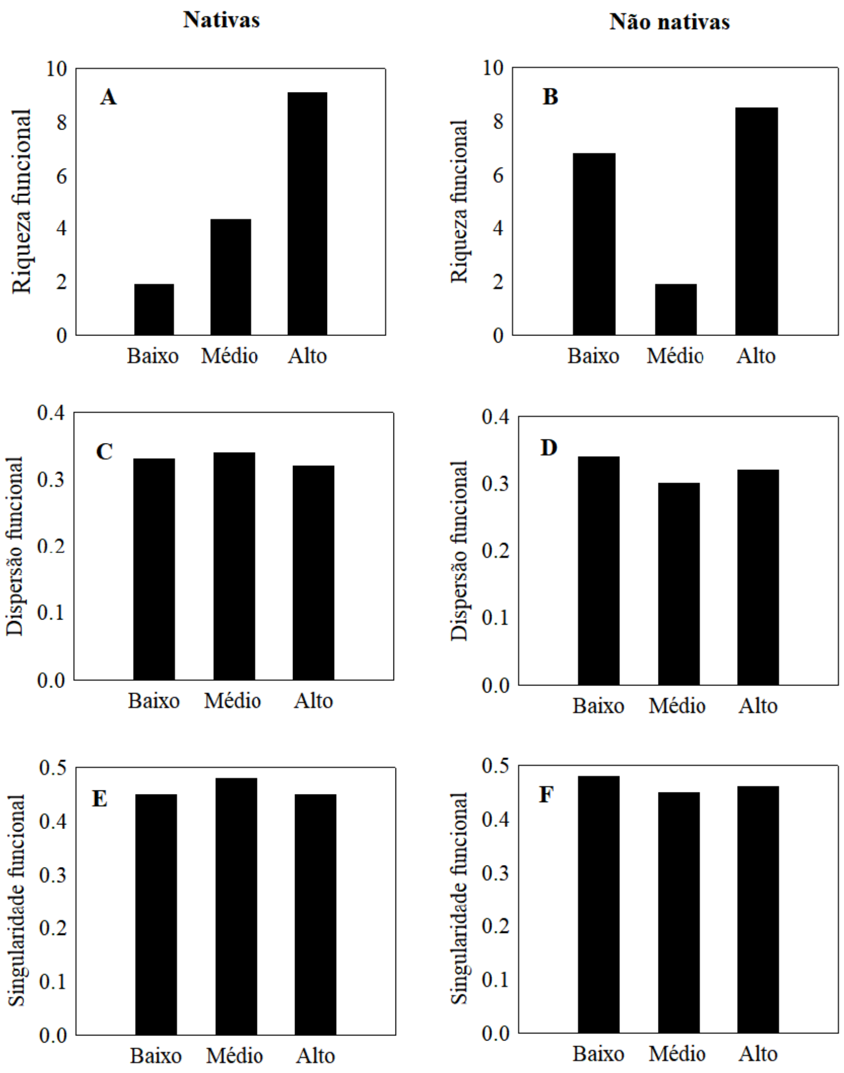

Figura 4: Riqueza, dispersão e singularidade funcional das espéci87es nativas e não nativas em cada trecho da bacia do Iguaçu.

Tabela 2: Índice de espécies indicadoras (IndVal) para os atributos funcionais das espécies nativas e não nativas em cada trecho da bacia do Iguaçu. Os maiores valores (em negrito) indicam alta frequência de ocorrência do atributo em cada trecho. CT = Comprimento total máximo; CPA = Cuidado Parental; FE = Fecundação externa; MIG = Migrador; BENT = Bentopelágico; PEL = Pelágico; DEM = Demersal; ALON = Alongado; COM = comprimido; DEP = deprimido; FUS = fusiforme; ALG = algívoro; DET = Detritívoro; HER = Herbívoro; INS = Insetívoro; INV = Invertívoro; ONI = onívoro; PIS = Piscívoro; INF = Inferior; SUB = Subterminal; SUP = Superior; TER = Terminal.

	Nativas			Não nativas		
	Baixo	Médio	Alto	Baixo	Médio	Alto
CTMM	**0.392**	0.337	0.269	**0.469**	0.226	0.304
CPA	0.288	**0.364**	0.346	0.259	**0.426**	0.314

FE	**0.336**	0.335	0.328	0.346	**0.353**	0.299
MIG	**1**	0	0	**1**	0	0
BENT	0.309	0.315	**0.374**	**0.399**	0.312	0.288
PEL	0.310	0.321	**0.367**	0.342	0	**0.657**
DEM	**0.394**	0.376	0.229	0.240	**0.429**	0.330
ALON	**0.425**	0.268	0.306	0.322	0	**0.677**
COM	0.168	0.366	**0.465**	0.282	0.321	**0.395**
DEP	0.273	**0.451**	0.275	0.242	**0.757**	0
FUSI	**0.379**	0.289	0.330	**0.420**	0.358	0.220
ALG				**1**	0	0
DET	0.319	**0.386**	0.294	0.324	**0.675**	0
HER	0.355	**0.644**	0	0.285	**0.714**	0
INS	0.267	**0.387**	0.344	0.214	0.167	**0.618**
INV	**0.495**	0.199	0.304	0.268	**0.559**	0.172
ONI	0.304	0.275	**0.420**	**0.539**	0	0.460
PIS	**0.466**	0.211	0.322	0.409	0.170	**0.419**
INF	0.260	**0.419**	0.319	0.137	**0.862**	0
SUB	**0.406**	0.294	0.299	0.293	**0.367**	0.338
SUP	0.135	**0.490**	0.373	0.409	0	**0.590**
TER	0.346	0.304	**0.348**	**0.388**	0.251	0.360

3.4 DISCUSSÃO

Em geral, este trabalho registrou grande riqueza taxonômica de espécies nativas e não nativas na bacia do Iguaçu. Representando aproximadamente 74% do total de espécies, a maior riqueza observada em Siluriformes e Characiformes é comum para a região Neotropical (Lowe-McConnel, 1999; Langeani, 2007). Destaque para o elevado número de espécies não nativas, as quais representam 46% do total de espécies. O primeiro registro de introdução de espécie não nativa na ecoregião do Iguaçu foi a ocorrência de *Cyprinus carpio* (carpa-comum) Linnaeus, 1758 em 1947. Desde então, houve um aumento considerável de espécies não nativas oriundas de diversas regiões que foram introduzidas a partir de atividades como aquicultura, uso de isca, pesca esportiva, dentre outras (Daga, et al., 2016). Considerando os trechos estudados, a maior riqueza taxonômica de espécies nativas e não nativas foi registrada no baixo rio Iguaçu, no entanto é importante ressaltar que o registro de ocorrência das espécies, especialmente nos trechos alto e médio, pode ter um viés devido à escassez de estudos nessas regiões.

Em relação aos componentes da β diversidade, o padrão *turnover* pode ocorrer quando uma assembleia apresenta espécies de outras assembleias, mas também possui espécies exclusivas. De acordo com Villéger, Grenouillet, e Brosse (2013) quando ocorre uma baixa proporção de espécies compartilhadas entre as comunidades, observa-se alta contribuição do componente *turnover* e baixos valores do padrão aninhado (*nestedness*). Isso pode explicar o resultado encontrado nesse estudo, uma vez que foram identificadas poucas espécies compartilhadas entre os trechos do baixo, médio e alto do rio Iguaçu. A composição das espécies pode ser determinada por fatores abióticos (condições físicas e químicas, produtividade, heterogeneidade de habitat), filtros bióticos (competição, predação) e filtros espaciais (limites à dispersão, dinâmica neutra) (Zbinden & Matthews, 2017), refletindo assim, tanto padrões históricos como ambientais. No caso do *turnover*, a perda ou ganho de espécies de um local para outro é consequência de restrições espaciais e/ou históricas, incluindo isolamento geográfico devido a barreiras para a dispersão (Leprieur et al., 2011).

Nas últimas três décadas, a bacia do Iguaçu foi altamente impactada pela construção de diversos reservatórios, especialmente na porção do baixo Iguaçu (Baumgartner et al., 2012). Essa cascata de reservatórios provavelmente atua como barreiras à dispersão das espécies, as quais não conseguem se deslocar ao longo do gradiente longitudinal da bacia. Em termos práticos, Xingfeng, Baselga e Ding (2015) explicam que quando o componente *turnover* é superior ao aninhamento, todos os locais devem ser considerados como alvos potenciais à conservação, uma vez que esses ambientes podem abrigar espécies únicas. Dessa forma, ressalta-se a importância da conservação da ictiofauna da bacia do Iguaçu, especialmente das espécies nativas e endêmicas, uma vez que a perda destas espécies se torna irreversível, além de causar grandes danos ao ecossistema.

Apesar da maior riqueza taxonômica ter sido encontrada no trecho inferior (baixo Iguaçu), foi observado que a maior riqueza funcional se concentrou no trecho superior (alto Iguaçu), tanto para as assembleias nativas quanto para as não nativas. De acordo com Toussaint et al. (2018) a mudança na riqueza funcional não pode ser predita baseada somente na mudança na riqueza de espécies. Por exemplo, se as espécies apresentam atributos funcionais únicos, a mudança na riqueza funcional excederá as mudanças na riqueza taxonômica. De fato, esse resultado pode ser confirmado pelos altos valores encontrados para a dispersão e a singularidade funcional em todos os trechos da bacia. Valores elevados na dispersão funcional indicam que as assembleias são compostas por atributos funcionais complementares, ou seja, as espécies apresentam pouca similaridade entre os atributos. Adicionalmente, a singularidade funcional é alta quando as espécies apresentam combinações de atributos únicos comparados com o *pool* de espécies, neste caso, representa baixa redundância funcional (Buisson, Grenouillet, Villéger, & Laffaille, 2013), indicando que a perda de espécies nesses locais pode causar impactos relevantes aos ecossistemas, pois as mesmas funções não poderão ser desempenhadas por outras espécies (Elmqvist et al., 2003).

Em relação ao *pool* de espécies nativas, dentre as que ocorrem no alto Iguaçu, destaca-se aquelas cujos atributos únicos foram relacionados especialmente a alimentação e reprodução. Dessa forma, *Oligosarcus longirostris* (Menezes & Géry, 1983) e *Heptapterus stewarti* Haseman, 1911, foram as únicas espécies registradas com hábito alimentar piscívoro nesse trecho, e *Australoheros angiru* Říčan, Pialék, Almirón & Casciotta, 2011 e *Cnesterodon carnegiei* Haseman, 1911, com hábito invertívoro. *Cnesterodon carnegiei*, juntamente com *Phalloceros harpagos* Lucinda, 2008 e *Mimagoniates microlepis* (Steindachner, 1877) foram as únicas espécies identificadas com fecundação interna. Para o trecho médio, destaca-se *Astyanax dissimilis* Garavello & Sampaio, 2010 com hábito alimentar herbívoro, *Rhamdiopsis moreirai* Haseman, 1911, invertívoro e novamente *O. longirostris*, única espécie piscívora registrada nesse local. *Phalloceros harpagos* e *Mimagoniates microlepis*, também com fecundação interna nesse trecho. Para a porção do baixo Iguaçu, destaca-se *Steindachneridion melanodermatum* Garavello, 2005, sendo a única espécie com comportamento migratório, *Astyanax bifasciatus* Garavello & Sampaio, 2010 com hábito alimentar herbívoro e *Phalloceros harpagos* com a posição da boca superior.

O conjunto de atributos únicos da comunidade das espécies não nativas também foi associado a guilda trófica e reprodução. No alto Iguaçu, *Callichthys callichthys* (Linnaeus, 1758) foi a única espécie de hábito invertívoro, *Glandulocauda caerulea* Eigenmann, 1911 e *Cambeva perkos* Datovo, Carvalho & Ferrer, 2012 com hábito alimentar onívoro, e ainda *G. caerulea* e com fecundação interna. No trecho médio observa-se *Charax stenopterus* (Cope, 1894) com hábito piscívoro e *Corydoras longipinnis* Knaack, 2007 com hábito insetívoro. Os atributos únicos encontrados no baixo Iguaçu foram o hábito alimentar algívoro de *Ancistrus cirrhosus* (Valenciennes, 1836) e a fecundação interna em *Poecilia reticulata* Peter, 1859. Observa-se em ambas as assembleias nativas e não nativas, que ocorrem espécies com atributos únicos em cada trecho. Diversos estudos têm utilizado a abordagem baseada em traços para identificar áreas prioritárias para a conservação (Strecker, Olden, Whittier, & Paukert, 2011; Maire, Buisson, Biau, Canal, & Laffaille, 2013; Maire, Laffaille, Maire, & Buisson, 2016; Oliveira, 2018). Diante dos resultados deste estudo, sugere-se que os esforços para a conservação sejam voltados para toda a extensão da bacia do Iguaçu, especialmente devido as particularidades das espécies em cada trecho.

É importante mencionar duas possíveis limitações no nosso trabalho. Primeiro, o uso de oito atributos para estimar a diversidade funcional, pode criar uma situação onde o número máximo de combinações de atributos únicos na comunidade seja rapidamente alcançado (Carvalho & Tejerina-Garro, 2015). Por isso, incluir novos atributos pode aprimorar nosso conhecimento sobre os componentes taxonômicos e funcionais das assembleias de peixes de água doce. No entanto, os estudos sobre a biologia básica de muitas espécies do Iguaçu permanecem escassos, dessa forma, são necessárias mais pesquisas que visem caracterizar aspectos da ecologia da ictiofauna, a fim de contribuir para a formação de um banco de dados de atributos funcionais para que a diversidade funcional possa ser compreendida em suas múltiplas facetas. A segunda limitação diz respeito a falta de dados de abundância das espécies para todos os trechos e de forma padronizada, o que consequentemente restringiu o uso dos índices para mensurar a diversidade funcional, excluindo a possibilidade de utilizar aqueles ponderados pela abundância (i.e entropia quadrática de Rao). A inclusão de novos atributos associados as informações de abundância, pode aumentar o poder dos índices funcionais na descrição e representação da estrutura funcional das assembleias de peixes, além de permitir comparações com maior precisão ao longo do tempo.

As assembleias nativas e não nativas apresentaram contribuição semelhante de alguns atributos funcionais. O comprimento total teve importância especialmente no baixo Iguaçu. A fauna nativa desse trecho foi caracterizada por apresentar espécies de pequeno a médio porte, com tamanhos entre 29 – 530mm, enquanto que a fauna não nativa apresentou espécies de maior porte, com seus tamanhos variando entre 36 – 1254 mm. Os maiores comprimentos da fauna não nativa são devido a presença de espécies como *Pseudoplatystoma corruscans* (Spix & Agassiz, 1829), *Hemisorubim platyrhyncos* (Valenciennes, 1840) e *Synbranchus marmoratus* Bloch, 1795. O tamanho do corpo afeta a habilidade natatória dos peixes. Villéger, Brosse, Mouchet, Mouillot, e Vanni, (2017) explicam que peixes de tamanhos maiores são mais rápidos e apresentam maior resistência, isso porque a biomassa de peixes grandes é proporcionalmente maior em relação ao atrito na superfície durante a natação, em contrapartida os peixes menores possuem melhor manobrabilidade, podendo se mover em diversos tipos de habitats, como em meio às plantas aquáticas, galhos de árvores ou raízes.

Dentre os atributos relacionados à alimentação, destaca-se a contribuição dos piscívoros. Para a comunidade nativa do baixo Iguaçu, foram registradas oito espécies com hábito piscívoro e para as não nativas 15 espécies. Os efeitos negativos da introdução de espécies de peixes não nativas são amplamente descritos na literatura (Vitule, Freire, & Simberloff, 2009; Daga et al., 2016; Gubiani et al., 2018), dentre os quais citam-se a redução da diversidade de espécies nativas, competição, predação (Simberloff et al., 2013) e alterações em diversos processos ecológicos e no funcionamento dos ecossistemas (Jeschke et al., 2014). Quando se trata de espécies predadoras de topo de cadeia os efeitos podem ser ainda mais expressivos. Nesse contexto, destaca-se as espécies *Cichla kelberi* Kullander & Ferreira, 2006, *Salminus brasiliensis* (Cuvier, 1816) e *Micropterus salmoides* (Lacépède, 1802), as quais foram introduzidas especialmente para a pesca esportiva (Gubiani et al., 2018) e vários estudos têm relatado os problemas causados por esses predadores e as ameaças à fauna endêmica do Iguaçu (Latini & Petrere Jr, 2004; Agostinho, Gomes, & Pelicice, 2007; Ribeiro et al., 2017).

Atributos associados à dieta também tiveram importância no trecho médio e destaca-se aqueles que remetem às espécies com características adaptadas à obtenção de recursos específicos, como boca inferior, corpo deprimido e dieta detritívora. A contribuição desses atributos se deve a espécies da fauna nativa como *Ancistrus abilhoai* Bifi, Pavanelli & Zawadzki, 2009, *Rineloricaria maaki* Ingenito, Ghazzi, Duboc & Abilhoa, 2008 e *Hypostomus derbyi* (Haseman, 1911), e dentre as não nativas, cita-se *Hisonotus francirochai* (Ihering, 1928) e *Isbrueckerichthys calvus* Jerep, Shibatta, Pereira & Oyakawa, 2006 (para detalhes dos atributos de cada espécie ver Apêndice B – Tabela S2). A presença de espécies com tais características é fundamental para a estrutura trófica nos ecossistemas, uma vez que estas participam da principal rota de fluxo de energia e ciclagem de nutrientes nos ecossistemas a partir da cadeia de detrito (Townsend, Begon & Harper, 2010).

O cuidado parental foi outro atributo indicador das assembleias nativas e não nativas ocorrentes no trecho médio. De maneira geral, para toda a bacia, foi registrado um total de 26 espécies nativas com cuidado parental e 23 não nativas. Os aspectos reprodutivos influenciam o *fitness* e a demografia dos peixes, afetando de forma indireta a resistência e resiliência das comunidades frente às perturbações e também os efeitos dos peixes nos processos ecossistêmicos (Winemiller, 2005; Winemiller, Fitzgerald, Bower, & Pianka, 2015). Dentre as espécies nativas que apresentam cuidado parental no trecho médio, destaca-se *Corydoras ehrhardti* Steindachner, 1910, *Geophagus brasiliensis* (Quoy & Gaimard, 1824), *Mimagoniates microlepis* e não nativas *Coptodon rendalli* (Boulenger, 1897), *Corydoras longipinnis* e *Charax stenopterus*. Estudos têm relatado a importância de atributos relacionados a história de vida a fim de identificar o sucesso de espécies de peixes invasoras (Vila-Gispert et al., 2005; Olden, Poff, & Bestgen, 2006; Grabowska & Przybylski, 2015). Nesse trabalho não foi possível fazer esse comparativo devido à falta de informações disponíveis a respeito da história de vida, como taxa de fecundidade, diâmetro do ovócito, frequência de desova, entre outros. Dessa forma, novos estudos são necessários para preencher essa lacuna e melhor compreender o sucesso das espécies não nativas da bacia do Iguaçu. No alto Iguaçu, atributos como o hábito pelágico e corpo comprimido foram indicadores comuns a fauna nativa e não nativa, destacando espécies como *Astyanax totae* Ferreira Haluch & Abilhoa, 2005, *Australoheros angiru*, *Astyanax lacustris* (Lütken, 1875) e *Glandulocauda caerulea* . De modo gral, estudo realizado por Oliveira (2018) prevê redução da diversidade funcional de peixes da bacia Paraná-Paraguai (incluindo a sub-bacia do Iguaçu) em cenários futuros devido às mudanças climáticas. Nesse contexto, é imprescindível especial atenção à ecoregião do Iguaçu, principalmente devido ao elevado endemismo da bacia.

Em síntese, a presença de espécies com atributos únicos em cada trecho da bacia evidencia a necessidade para que aspectos funcionais da biodiversidade sejam incorporados nos planos de conservação. A bacia do Iguaçu ainda é pouco explorada no âmbito de diversidade funcional, dessa forma, futuras pesquisas devem ser consideradas a fim de investigar outras questões, como por exemplo, quais os efeitos da introdução de espécies para a diversidade funcional da fauna nativa, ou quais os efeitos dos diferentes tipos de impactos em cada trecho da bacia para a estrutura funcional da ictiofauna. Para tanto, sugere-se abordagens que possam incluir dados em escala temporal, adicionando dados de abundância das espécies e informações complementares dos atributos funcionais.

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CONSIDERAÇÕES FINAIS

Este trabalho elucidou as principais tendências no uso de atributos funcionais em estudos com peixes de água doce e quais as limitações do uso dessa abordagem. A diversidade funcional ganhou grande destaque nos últimos anos, no entanto é notável as dificuldades em avaliar a diversidade funcional de forma ampla. Os desafios para o futuro são aqueles relacionados especialmente a obtenção das características funcionais das espécies. Dessa forma, sugere-se que os estudos sobre a biologia e ecologia básica das espécies de peixes de água doce sejam reforçados, a fim de criar um banco de dados com o máximo de características possíveis. Levando em consideração que os ecossistemas aquáticos continentais estão entre os ambientes mais degradados devido às atividades antrópicas, a incorporação de dados relacionados a diversidade funcional torna-se uma medida urgente nos planos de conservação e manejo da ictiofauna.

Apêndice A

Tabela S1: Descrição dos atributos funcionais utilizados para mensurar a diversidade funcional das assembleias de peixes nativas e não nativas da bacia do Iguaçu.

Atributo funcional	Níveis	Descrição	Função ecológica	Escala
Morfométricos	Comprimento total máximo (mm)	Distância entre a extremidade anterior do focinho e a extremidade posterior da cauda.	Uso do habitat, alimentação, história de vida	Contínua
Formato do corpo	Alongado	O comprimento excede em muitas vezes a sua altura.	Uso do habitat	Categórica
	Comprimido	Achatado lateralmente.	Uso do habitat	Categórica
	Deprimido	Achatado dorso-ventralmente; largura do corpo maior que a altura do corpo.	Uso do habitat	Categórica
	Fusiforme	Altura do corpo maior que sua largura e o comprimento maior que ambas.	Uso do habitat	Categórica
Posição da boca	Inferior	Situada ventralmente, ou seja, na região inferior da cabeça.	Alimentação, uso do habitat	Categórica
	Subterminal	Cuja fenda bucal é situada pouco abaixo/atrás do plano transversal que passa pela extremidade mais anterior da cabeça.	Alimentação, uso do habitat	Categórica
	Superior	Cuja abertura é voltada para a região superior da cabeça, acima/atrás do plano transversal que passa pela extremidade mais anterior da cabeça.	Alimentação, uso do habitat	Categórica
	Terminal	Cuja abertura é situada na região mais anterior da cabeça.	Alimentação, uso do habitat	Categórica
Guilda trófica	Algívoro	Espécies que se alimentam predominantemente de algas.	Alimentação	Categórica
	Detritívoro	Espécies que se alimentam predominantemente de detrito e sedimento.	Alimentação	Categórica
	Herbívoro	Espécies que se alimentam predominantemente de vegetais.	Alimentação	Categórica
	Insetívoro	Espécies que se alimentam predominantemente de insetos terrestres (Coleoptera, Hemiptera, Hymenoptera, Isoptera e Orthoptera).	Alimentação	Categórica
	Invertívoro	Espécies que se alimentam de invertebrados.	Alimentação	Categórica
	Onívoro	Espécies que se alimentam de itens vegetais e animais.	Alimentação	Categórica
	Piscívoro	Espécies que se alimentam de peixes.	Alimentação	Categórica
Comportamento reprodutivo	Cuidado parental	Cuidado executado pelos pais para a proteção de sua prole, podendo incluir desde a deposição dos ovos em locais selecionados até a completa proteção da massa de ovos e dos jovens, construção de ninhos, limpeza de ninhos, aeração.	História de vida	Binária
	Fecundação (interna ou externa)	Fecundação interna: espécies nas quais o macho possui um órgão intermitente para depositar o esperma no interior da fêmea, diretamente no ovário, ou em uma estrutura ou área reservatória de esperma. Podem exibir cortejo e copulação.	História de vida	Binária

		Fecundação externa: ocorre fora do corpo das fêmeas, após o macho e a fêmeas expelirem os gametas na água.		
	Migração (presente ou ausente)	Espécies que realizam movimentos de uma região para outra, para fins reprodutivos ou alimentares.	História de vida	Binária
Posição na coluna de água	Bentopelágico	Habitam e se alimentam tanto no fundo quanto na coluna d'água	Uso do habitat, locomoção	Categórica
	Demersal	Habitam e se alimentam em regiões muito próximas ao substrato (fundo) do ambiente aquático.	Uso do habitat, locomoção	Categórica
	Pelágico	Habitam e se alimentam na coluna d'água.	Uso do habitat, locomoção	Categórica

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Apêndice B

Table S2: Lista de espécies da bacia do rio Iguaçu, origem, região de ocorrência e atributos funcionais. Origem: NN = Não nativa, NE = Nativa endêmica, N = Nativa. Região: B= Baixo, M = Médio, A = Alto. Posição na coluna de água: Bent = Bentopelágico, Pel = Pelágico, Dem = Demersal. Formato do corpo: Com = Comprimido, Dep = Deprimido, Fus = Fusiforme, Alon = Alongado. Guilda trófica: Alg = Algívoro, Det = Detritívoro, Oni = Onívoro, Her = Herbívoro, Inv = Invertívoro, Ins = Insetívoro, Pis = Piscívoro. Posição da boca: Inf = Inferior, Ter = Terminal, Sub = Subterminal, Sup = Superior. Atributos funcionais atribuídos ao Gênero (*), Subfamília (**), Ordem (***). 1 e 0 representam presença e ausência do atributo respectivamente.

Ordem/ espécie	Origem	Região	Comprimento total (mm)	Cuidado parental	Fecundação externa	Migração	Posição na coluna de água	Formato do corpo	Guilda trófica	Posição da Boca
SILURIFORMES										
Ancistrus abilhoai Bifi, Pavanelli & Zawadzki, 2009	NE	B/M/A	106	1	1	0	Bent	Dep	Det	Inf
Ancistrus agostinhoi Bifi, Pavanelli & Zawadzki, 2010	NE	B	96	1	1	0	Bent	Dep	Det	Inf
Ancistrus cirrhosus (Valenciennes, 1836)	NN	B	89	1	1	0	Dem	Dep	Alg	Inf
Ancistrus mullerae Bifi, Pavanelli & Zawadzki, 2009	NE	B	125	1	1	0	Bent	Dep	Det	Inf
Ancistrus piriformis Muller, 1989	NN	B	83	1	1	0	Dem	Dep	Det	Inf
Callichthys callichthys (Linnaeus, 1758)	NN	B/M/A	240	0	1	0	Dem	Fus	Inv	Ter
Cambeva castroi de Pinna, 1992	NE	A/M	148	0	1	0	Bent	Alon	Ins	Sub
Cambeva crassicaudata Wosiacki & de Pinna, 2008	NE	B	135	0	1	0	Dem	Alon	Ins	Sub
Cambeva davisi (Haseman, 1911)	N	B/M/A	63	0	1	0	Bent	Alon	Ins	Sub
Cambeva igobi Wosiacki & de Pinna, 2008	NE	B	90	0	1	0	Dem	Alon	Inv	Sub
Cambeva mboycy Wosiacki & Garavello, 2004	NE	B	120	0	1	0	Dem	Alon	Ins	Sub
Cambeva naipi Wosiacki & Garavello, 2004	N	B/A	122	0	1	0	Bent	Alon	Ins	Sub
Cambeva papilliferus Wosiacki & Garavello, 2004	NE	B	127	0	1	0	Dem	Alon	Inv	Sub
Cambeva perkos Datovo, Carvalho & Ferrer, 2012	NN	A	65	0	1	0	Dem	Alon	Oni*	Sub
Cambeva plumbeus Wosiacki & Garavello, 2004	NE	B	127	0	1	0	Dem	Alon	Ins	Sub

Cambeva stawiarski (Miranda Ribeiro, 1968)	NE	B	85	0	1	0	Bent	Alon	Ins	Sub
Cetopsis gobioides Kner, 1858	NN	B	109	0	1	0	Dem	Fus	Pis	Ter
Clarias gariepinus (Burchell, 1822)	NN	B	330	0	1	0	Bent	Alon	Oni	Sub
Corydoras carlae Nijssen & Isbrücker, 1983	NE	B	53	1	1	0	Dem	Com	Oni	Sub
Corydoras ehrhardti Steindachner, 1910	Nativa	B/M/A	47	1	1	0	Bent	Com	Ins	Sub
Corydoras longipinnis Knaack, 2007	NN	B/M/A	61	1	1	0	Dem	Com	Ins*	Sub
Glanidium ribeiroi Haseman, 1911	NE	B	193	1	0	0	Bent	Fus	Oni	Ter
Hemisorubim platyrhynchos (Valenciennes, 1840)	NN	B	670	0	1	1	Dem	Dep	Pis	Ter
Heptapterus stewarti Haseman, 1911	Nativa	A	140	0	1	0	Dem	Alon	Pis	Ter
Hisonotus francirochai (Ihering, 1928)	NN	M	36	0	1	0	Bent	Dep	Her	Inf
Hisonotus yasi (Almirón, Azpelicueta & Casciotta, 2004)	NE	B	35	0	1	0	Bent	Dep	Det	Inf
Hoplosternum littorale (Hancock, 1828)	NN	B/M	263	1	1	0	Dem	Dep	Inv	Inf
Hypostomus albopunctatus (Regan, 1908)	N	B	360	1	1	0	Dem	Dep	Det	Inf
Hypostomus commersoni Valenciennes, 1836	N	B	395	1	1	0	Dem	Dep	Det	Inf
Hypostomus derbyi (Haseman, 1911)	N	B/M	305	1	1	0	Dem	Dep	Det	Inf
Hypostomus myersi (Gosline, 1947)	N	B/A	207	1	1	0	Dem	Dep	Det	Inf
Hypostomus nigropunctatus Garavello, Britski & Zawadzki, 2012	N	B	170	1	1	0	Dem	Dep	Det	Inf
Ictalurus punctatus (Rafinesque, 1818)	NN	B	132	1	1	0	Bent	Fus	Pis	Sub
Imparfinis hollandi Haseman, 1911	N	B	230	0	1	0	Dem	Alon	Inv	Ter
Isbrueckerichthys calvus Jerep, Shibatta, Pereira & Oyakawa, 2006	NN	M	90	1	1	0	Dem	Dep	Det	Inf
Ossancora eigenmanni (Boulenger, 1895)	NN	B	130	0	1	0	Dem	Dep	Inv	Ter
Otothyropsis biamnicus Calegari, Lehmann A. & Reis, 2013	N	M	40	1	1	0	Dem	Dep	Det	Inf
Pareiorhaphis parmula Pereira, 2005	NE	A	91	1	1	0	Dem	Dep	Det	Inf
Pariolius hollandi Haseman, 1911	NE	B	230	0	1	0	Dem	Alon	Inv	Ter
Pimelodus britskii Garavello & Shibatta, 2007	NE	B/M	300	0	1	0	Dem	Dep	Ins	Ter
Pimelodus ortmanni Haseman, 1911	NE	B	161	0	1	0	Dem	Dep	Oni	Ter
Pseudoplatystoma corruscans (Spix & Agassiz, 1829)	NN	B	###	0	1	1	Dem	Alon	Pis	Sub
Pseudoplatystoma reticulatum Eigenmann & Eigenmann, 1889	NN	B	605	0	1	1	Dem	Alon	Pis	Sub
Rhamdia branneri Haseman, 1911	NE	B	365	0	1	0	Dem	Alon	Pis	Ter
Rhamdia voulezi Haseman, 1911	NE	B	474	0	1	0	Dem	Alon	Pis	Ter

Rhamdiopsis moreirai Haseman, 1911	N	M	117	0	1	0	Dem	Alon	Inv	Ter
Rineloricaria maaki Ingenito, Ghazzi, Duboc & Abilhoa, 2008	NE	A/M	136	1	1	0	Dem	Dep	Det	Inf
Steindachneridion melanodermatum Garavello, 2005	NE	B	532	0	1	1	Dem	Alon	Pis	Ter
Tatia jaracatia Pavanelli & Bifi, 2009	NE	B	66	1	0	0	Pel	Alon	Pis	Ter
Trichomycterus alternatus (Eigenmann, 1917)	NN	A	81	0	1	0	Bent	Alon	Ins	Sub
Trichomycterus taroba Wosiacki & Garavello, 2004	NE	B	60	0	1	0	Dem	Alon	Ins	Sub
CHARACIFORMES										
Abramites hypselonotus (Günther, 1868)	NN	B	140	0	1	0	Pel	Com	Oni	Ter
Apareiodon vittatus Garavello, 1977	NE	B	89	0	1	0	Bent	Fus	Det	Sub
Aphyocharax dentatus Eigenmann & Kennedy, 1903	N	B	60	0	1	0	Bent	Fus	Oni	Ter
Astyanax bifasciatus Garavello & Sampaio, 2010	NE	B	129	0	1	0	Pel	Fus	Her	Ter
Astyanax dissimilis Garavello & Sampaio, 2010	NE	B/M	136	0	1	0	Bent	Fus	Her	Ter
Astyanax gymnodontus (Eigenmann, 1911)	NE	B	170	0	1	0	Pel	Fus	Ins	Ter
Astyanax gymnogenys Eigenmann, 1911	NE	B	115	0	1	0	Bent	Fus	Ins	Ter
Astyanax jordanensis Vera Alcaraz, Pavanelli & Bertaco, 2009	NE	B	76	0	1	0	Bent	Fus	Oni	Ter
Astyanax lacustris (Lütken, 1875)	NN	B/A	135	0	1	0	Pel	Com	Ins	Ter
Astyanax minor Garavello & Sampaio, 2010	NE	B	108	0	1	0	Bent	Fus	Det	Ter
Astyanax serratus Garavello & Sampaio, 2011	NE	B/M/A	120	0	1	0	Bent	Fus	Oni	Ter
Astyanax totae Ferreira Haluch & Abilhoa, 2005	N	A	82	0	1	0	Pel	Com	Oni	Ter
Astyanax varzeae Abilhoa & Duboc, 2007	N	A	83	0	1	0	Bent	Fus	Oni*	Ter
Brycon hilarii Valenciennes, 1850	NN	B	302	0	1	1	Bent	Fus	Her	Ter
Bryconamericus iheringii (Boulenger, 1887)	NN	B/M	114	0	1	0	Bent	Fus	Det	Sub
Bryconamericus ikaa Casciotta, Almirón & Azpelicueta, 2004	NE	B	60	0	1	0	Bent	Fus	Ins	Sub
Bryconamericus pyahu Casciotta, Almirón & Azpelicueta, 2003	NE	B	51	0	1	0	Bent	Fus	Ins	Sub
Characidium travassosi Melo, Buckup & Oyakawa, 2016	N	B	421	0	1	0	Bent	Fus	Ins	Sub
Charax stenopterus (Cope, 1894)	NN	A/M	94	1	1	0	Bent	Com	Pis	Ter
Curimatella dorsalis (Eigenmann & Eigenmann, 1889)	NN	B	149	0	1	0	Bent	Fus	Det	Ter
Curimatopsis myersi Vari, 1982	NN	B	44	0	1	0	Bent	Fus	Det	Ter
Cynopotamus kincaidi (Schultz, 1950)	NN	B	258	0	1	1	Bent	Fus	Pis	Sup
Galeocharax humeralis (Valenciennes, 1834)	NN	B	305	0	1	0	Bent	Fus	Pis	Ter
Glandulocauda caerulea Eigenmann, 1911	NN	A	55	1	0	0	Bent	Com	Oni	Ter

Hasemania maxillaris Ellis, 1911	N	B	29	0	1	0	Pel	Fus	Oni	Ter
Hasemania melanura Ellis, 1912	N	B	44	0	1	0	Pel	Fus	Oni	Ter
Hoplias argentinensis Azpelicueta, Benítez, Aichino & Mendez, 2015	NN	B	293	1	1	0	Bent	Alon	Pis	Sub
Hyphessobrycon griemi Hoedeman, 1957	N	A	29	0	1	0	Bent	Fus	Oni	Ter
Hyphessobrycon reticulatus Ellis, 1911	N	B/M/A	53	0	1	0	Bent	Fus	Ins	Ter
Hyphessobrycon taurocephalus Ellis, 1911	N	A	55	0	1	0	Bent	Fus	Ins*	Ter
Leporinus friderici (Bloch, 1794)	NN	B	400	0	1	1	Bent	Com	Oni	Ter
Leporinus octofasciatus Steindachner, 1915	NN	B	235	0	1	1	Bent	Fus	Oni	Ter
Megaleporinus macrocephalus Garavello & Britski, 1988	NN	B	684	0	1	1	Bent	Fus	Oni	Ter
Megaleporinus obtusidens (Valenciennes, 1837)	NN	B	490	0	1	1	Bent	Fus	Oni	Sub
Megaleporinus piavussu Britski, Birindelli & Garavello, 2012	NN	B	760	0	1	1	Bent	Com	Oni	Ter
Mimagoniates microlepis (Steindachner, 1877)	N	A/M	61	1	0	0	Pel	Com	Ins	Ter
Oligosarcus longirostris (Menezes & Géry, 1983)	NE	B/M/A	115	0	1	0	Bent	Fus	Pis	Ter
Piabarchus stramineus Eigenmann, 1908	NN	B	84	0	1	0	Bent	Fus	Ins	Ter
Piaractus mesopotamicus (Holmberg, 1887)	NN	B	655	0	1	1	Dem	Com	Her	Ter
Prochilodus lineatus (Valenciennes, 1836)	NN	B	620	0	1	1	Bent	Com	Det	Ter
Salminus brasiliensis (Cuvier, 1816)	NN	B	800	0	1	1	Bent	Fus	Pis	Ter
Stendachnerina brevipinna (Eigenmann & Eigenmann, 1889)	N	B	240	0	1	0	Bent	Fus	Det	Ter
CICHLIFORMES										
Australoheros angiru Říčan, Pialék, Almirón & Casciotta, 2011	N	B/A	150	1	1	0	Bent	Com	Inv	Ter
Australoheros kaaygua (Myers, 1947)	NE	B	94	1	1	0	Bent	Com	Inv	Ter
Cichla kelberi Kullander & Ferreira, 2006	NN	B	510	1	1	0	Bent	Fus	Pis	Ter
Cichlasoma paranaense Kullander, 1983	NN	B	171	1	1	0	Bent	Com	Pis	Ter
Coptodon rendalli (Boulenger, 1897)	NN	B/M	450	1	1	0	Bent	Fus	Her	Ter
Crenicichla iguassuensis Haseman, 1911	NE	B	140	1	1	0	Bent	Alon	Pis	Ter
Crenicichla lepidota Heckel, 1840	NN	B	209	1	1	0	Bent	Alon	Pis	Ter
Crenicichla mandelburgeri Kullander, 2009	NN	B	208	1	1	0	Pel	Alon	Pis	Ter
Crenicichla tesay Casciotta & Almirón, 2008	NE	B	115	1	1	0	Bent	Alon	Pis	Ter
Crenicichla yaha Casciotta, Almirón & Gómez, 2006	N	B	85	1	1	0	Bent	Alon	Pis	Ter
Geophagus brasiliensis (Quoy & Gaimard, 1824)	N	B/M/A	280	1	1	0	Bent	Com	Oni	Ter

Gymnogeophagus setequedas Reis, Malabarba & Pavanelli, 1992	NN	B	98	1	1	0	Bent	Com	Oni	Ter
Micropterus salmoides (Lacépède, 1802)	NN	B/A	970	1	1	0	Bent	Fus	Pis	Sup
Oreochromis niloticus (Linnaeus, 1758)	NN	B	213	1	1	0	Bent	Com	Oni	Ter
CYPRINODONTIFORMES										
Austrolebias carvalhoi Casciotta, Almirón & Gomes, 2006	NN	A	37	0	1	0	Bent	Fus	Ins	Sup
Cnesterodon carnegiei Haseman, 1911	N	B/A	35	1	0	0	Bent	Alon	Inv	Ter
Cnesterodon omorgmatos Lucinda & Garavello, 2001	NE	B	35	1	0	0	Bent	Alon	Inv	Ter
Jenynsia diphyes Lucinda, Ghedotti & Graça, 2006	NE	B	55	1	0	0	Bent	Alon	Oni	Ter
Jenynsia eigenmanni (Haseman, 1911)	NE	B	70	1	0	0	Bent	Alon	Oni	Ter
Phalloceros harpagos Lucinda, 2008	N	B/M/A	34	1	0	0	Pel	Alon	Oni	Sup
Poecilia reticulata Peter, 1859	NN	B	60	1	0	0	Bent	Fus	Det	Sup
GYMNOTIFORMES										
Apteronotus ellisi (Alonso de Arámburu, 1957)	NN	B	280	0	1	0	Bent	Com	Inv	Ter
Eigenmannia trilineata López & Castello, 1966	NN	B	250	0	1	0	Bent	Alon	Ins	Ter
Gymnotus inaequilabiatus (Valenciennes, 1839)	NN	B	920	1	1	0	Bent	Alon	Ins	Sup
Gymnotus pantanal Fernandes, Albert, Daniel-Silva, Lopes, Crampton & Almeida-Toledo, 2005	NN	B	206	1	1	0	Dem	Alon	Ins	Sup
Gymnotus sylvius Albert & Fernandes-Matioli, 1999	NN	B	730	1	1	0	Bent	Alon	Inv	Sup
CYPRINIFORMES										
Ctenopharyngodon idella (Valenciennes, 1844)	NN	B	150	0	1	1	Dem	Dep	Her	Sub
Cyprinus carpio Linnaeus, 1758	NN	B	120	0	1	0	Bent	Fus	Her	Sub
Hypophthalmichthys molitrix (Valenciennes, 1844)	NN	B	180	0	1	1	Bent	Fus	Ins	Sup
Hypophthalmichthys nobilis (Richardson, 1845)	NN	B	195	0	1	1	Bent	Fus	Ins	Sup
Misgurnus anguillicaudatus Cantor, 1842	NN	A	200	0	1	0	Dem	Alon	Ins	Ter
SYNBRANCHIFORMES										
Synbranchus marmoratus Bloch, 1795	NN	B/A	634	1	1	0	Dem	Alon	Pis	Ter
ATHERINIFORMES										
Odontesthes bonariensis (Valenciennes, 1835)	NN	B	500	0	1	0	Pel	Fus	Inv	Ter

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Anexo 1

Ecology of Freshwater Fish

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i. Fresh Perspectives

Description: Fresh Perspectives express new ideas and controversial perspectives on major research topics of current interest. Written for a broad international audience, these papers are concise and clearly presented.

Word limit: 1500 words maximum

References: maximum of 15 references.

Do not include an abstract, keywords, or subheadings.

ii. Articles

Description: Full-length reports of quality current research within any area of fish ecology in freshwater environments.

Introduction: State the purpose of the research, give only strictly pertinent references and do not review the subject extensively.

Material and methods: A concise summary, allowing confirmation of observations and repetition of the study. This may include a 'Study Area' section outlining details of the location where field work was performed

Results: Present your results in a logical sequence in the text, tables and figures and use this section to emphasise or summarise only important observations.

Discussion: summarise the findings without repeating in detail the data presented in Results. Relate your observations to other relevant studies; point out the implications of the results and their limitations and place them in the context of other work.

Word limit: 9000 words maximum (excluding title, abstract, acknowledgements, references, and table and figure legends).

References: maximum of 80 references.

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Description: Reviews present a significant contribution to the discipline, allowing an advance in knowledge by summarizing and integrating novel principles emerging over the past years, and by indicating new venues for future research.

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Authors should submit a cover letter, indicating succinctly why the manuscript is novel and of general interest for an international audience. Authors are encouraged to contrast and compare their research with other recently published studies.

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vi. Abstract and keywords for the manuscript
vii. Main text
viii. Acknowledgments
ix. References
x. Tables (each table complete with title and legend)
xi. Figure legends
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Journal Article

Beers, S. R., & De Bellis, M. D. (2002). Neuropsychological function in children with maltreatment-related posttraumatic stress disorder. *The American Journal of Psychiatry*, 159, 483–486. doi:10.1176/appi.ajp.159.3.483

Book
Bradley-Johnson, S. (1994). *Psychoeducational assessment of students who are visually impaired or blind: Infancy through high school* (2nd ed.). Austin, TX: Pro-ed.

Internet Document
Norton, R. (2006, November 4). How to train a cat to operate a light switch [Video file]. Retrieved from http://www.youtube.com/watch?v=Vja83KLQXZs

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Tables
Tables should be self-contained and complement, but not duplicate, information contained in the text. They should be supplied as **editable files**, not pasted as images, each on a separate page at the end of the main text file. Indicate the approximate location desired in the text.

Table legends should be placed before the body of each table. These should be concise but comprehensive – the table, legend and footnotes must be understandable without reference to the text. All abbreviations must be defined in footnotes. Footnote symbols: †, ‡, §, ¶, should be used (in that order) and *, **, *** should be reserved for P-values. Statistical measures such as SD or SEM should be identified in the headings.

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