NEOTROPICAL BIOLOGY AND CONSERVATION

Neotropical Biology and Conservation
14(2): 361–380(2019)
doi: 10.3897/neotropical.14.e38088

RESEARCH ARTICLE

Alternatives for the biomonitoring of fish and phytoplankton in tropical streams

Hugo de Oliveira Barbosa[1], Karine Borges Machado[2], Maisa Carvalho Vieira[2], Hasley Rodrigo Pereira[1], Leonardo Fernandes Gomes[1], João Carlos Nabout[3], Fabrício Barreto Teresa[3], Ludgero Cardoso Galli Vieira[1]

1 *Núcleo de Estudos e Pesquisas Ambientais e Limnológicas (NEPAL), Faculdade UnB de Planaltina (FUP), Universidade de Brasília (UnB), Área Universitária 1, Vila Nossa Senhora de Fátima, 73345-010 – Universidade de Brasília (UnB), Planaltina – DF, Brasília, Brazil*
2 *Programa de Pós-Graduação em Ecologia e Evolução, Universidade Federal de Goiás, Av. Esperança s/n, CEP 74690-900, Goiânia, Brazil*
3 *Laboratório de Biogeografia e Ecologia Aquática (Bioecol), Câmpus de Ciências Exatas e Tecnológicas, Universidade Estadual de Goiás (UEG), Br 153, 3105, Fazenda Barreiro do Meio, CEP 75132-903, Anápolis, Brazil*

Corresponding author: *Hugo de Oliveira Barbosa* (hgobarbosa@gmail.com)

Academic editor: *A.M. Leal-Zanchet* | Received 9 July 2019 | Accepted 9 October 2019 | Published 7 November 2019

Citation: Barbosa HO, Machado KB, Vieira MC, Pereira HR, Gomes LF, Nabout JC, Teresa FB, Vieira LCG (2019) Alternatives for the biomonitoring of fish and phytoplankton in tropical streams. Neotropical Biology and Conservation 14(2): 1–20. https://doi.org/10.3897/neotropical.14.e38088

Abstract

Biomonitoring programs need to balance accurate responses in assessments of changes in biological communities with sampling that is fast and low cost. In this study, we evaluated the concordance among fish and phytoplankton communities of streams. We tested the cross-taxa surrogacy, taxonomic, numerical resolution and ecological substitute group (habitat use and trophic guilds) resolution with Procrustes analyses aim of simplifying the biomonitoring process. We collect a total fish abundance of 8,461 individuals, represented by the ecological classes of habitat, including benthic, nektonic, nektobenthic, marginal and trophic guilds by detritivore, terrestrial invertivore, aquatic invertivore, piscivore, algivore and herbivore. We sampled a phytoplankton total density of 1,466.68 individuals/ml, represented by four Morphology-Based Functional Groups and nine Reynolds Functional Groups. Our results don't support the use of substitute groups among fish and phytoplankton. For fish, habitat

use and trophic guild are good surrogates for species-level data. Additionally, our results don't support the use of functional groups as surrogates for phytoplankton. We suggest the use of higher taxonomic levels (genus and family) and record only the occurrence of species and/or genus for fish and phytoplankton. Our findings contribute to decreasing the costs and time of biomonitoring programs assessments and/or conservation plans on fish and phytoplankton communities of headwater streams.

Keywords
biological surrogates, Cerrado, ecological classification, environmental monitoring, functional groups

Introduction

Environmental changes are primarily caused by anthropogenic drivers. As a consequence, we experience an accelerated global loss of species (Ceballos et al. 2015, 2017; Crist et al. 2017). In this sense, it is urgent to develop strategies to understand and monitor the consequences of environmental changes on biodiversity (Maćkiewicz et al. 2018). Sampling species along an area of interest and over time is often used as a tool for environmental assessment and monitoring. However, financial and human resources used for these activities are often limited. These resources require optimizing sampling protocols that are less expensive yet do not compromise the quality of information (Kallimanis et al. 2012; Maćkiewicz et al. 2018).

Biodiversity estimates can be time-consuming and expensive (Bates et al. 2007), mainly in regions with large territorial extensions, such as Brazil (Bessa et al. 2011). These factors impose several limitations when associated with the low availability of financial resources for these purposes (Kallimanis et al. 2012). Therefore, many studies investigate alternative approaches to simplify the procedure of obtaining information in biomonitoring, i.e., to reduce the time of identification and associated costs (Landeiro et al. 2012). Proposals for the simplification of biomonitoring programs may include: i.) taxonomic resolution, where higher taxonomic levels (genus or family) are used as surrogates for species (Heino and Soininen 2007; Carneiro et al. 2010; Machado et al. 2015); ii.) numerical resolution, where species presence/absence data are used as surrogates for abundance data (Landeiro et al. 2012; Rosa et al. 2014; Gomes et al. 2015); iii.) substitute groups, where a group can replace another when they are present in concordance with species distribution variation (Bini et al. 2007; Gioria et al. 2011; Ruhí and Batzer 2014); iv.) ecological substitute group, where the community composition is based on easily recognizable ecological characteristics (e.g. ecomorphology) and a strong power to replace the taxonomic composition, reducing the need for identification at the species level (Carneiro et al. 2010; Trigal et al. 2014; Machado et al. 2015).

Despite the importance and utility of aquatic groups in biomonitoring programs, a great part of simplification protocols have investigated only isolated taxonomic groups. This approach ignores the interaction between assemblages and the potential concordance (Padial et al. 2014). The spatial concordance among aquatics groups can occur because groups respond to similar drivers; for example, water

transparency and nutrient limitation (phosphorus and nitrogen) for phytoplankton and periphyton (e.g., Rodrigues and Bicudo 2004). Furthermore, groups with different drivers (e.g. fish and phytoplankton) (Mazaris et al. 2010; Sharma et al. 2016; Erős et al. 2016) may also have concordance due to their links in the trophic web (Thomson et al. 2014). Concordant spatial distribution among different taxocenoses could provide the opportunity for sampling simplification by sampling a single taxonomic group.

The proposed simplification protocols for sampling, identification and characterization of species have involved different water bodies (e.g., streams, rivers, lakes, ponds) and several aquatic groups, such as phytoplankton (Gallego et al. 2012; Carneiro et al. 2010; Machado et al. 2015), zooplankton (Gomes et al. 2015; Vieira et al. 2017), macroinvertebrates (Sanchez-Moyano et al. 2006; Tataranni et al. 2009) and mollusks (Zuschin et al. 2015). However, it is noteworthy that most studies mainly focus on evaluating the use of substitute groups. In a few cases, studies have used other approaches, such as numerical and taxonomic resolution (Grenouillet et al. 2008, see more in Suppl. material 1: Table S1). In this context, we evaluated the concordance of the spatial ordering among fish and phytoplankton communities of streams through four strategies (substitute group, taxonomic, numerical resolution and ecological substitute group) with the aim of simplifying the biomonitoring process. Therefore, our objectives were guided by the following questions: i.) Is there a spatial concordance between species and coarser taxonomic resolution (i.e., genus, family and order)? ii.) Is it possible to replace the abundance/density of species/genus/family data by merely the presence/absence of data? iii.) Is there a concordance between the taxonomic level (species) and the ecological classification of species? And iv.) is there concordance between the spatial distribution of fish and phytoplankton species?

Materials and methods

Study area

Sampling was performed during the dry period of 2013 in 29 Cerrado streams, in the Tocantins River basin (Fig. 1). The Tocantins River extends over 1,960 km, with spring in the Goiás plateau, at about 1,000 m altitude. It is formed by the union of Almas and Maranhão rivers, with its mouth in Marajó Bay (Meirelles et al. 2007). The predominant climate of this region is tropical and humid, with two well defined seasons. The rainy period dominates between October and April and the dry period between May and September (MMA 2006). The average annual temperature of the Tocantins-Araguaia basin is 26 °C (MMA 2006). Sampled streams in the sub-basin of the Santa Teresa River, North region of Goiás state are mostly of headwater ranging from first to third order (Strahler 1957). In general, the sub-basin of the Santa Teresa River presents a near pristine condition with the maintenance of 75% of the native vegetation remaining in its watershed (Borges et al. 2016). Therefore,

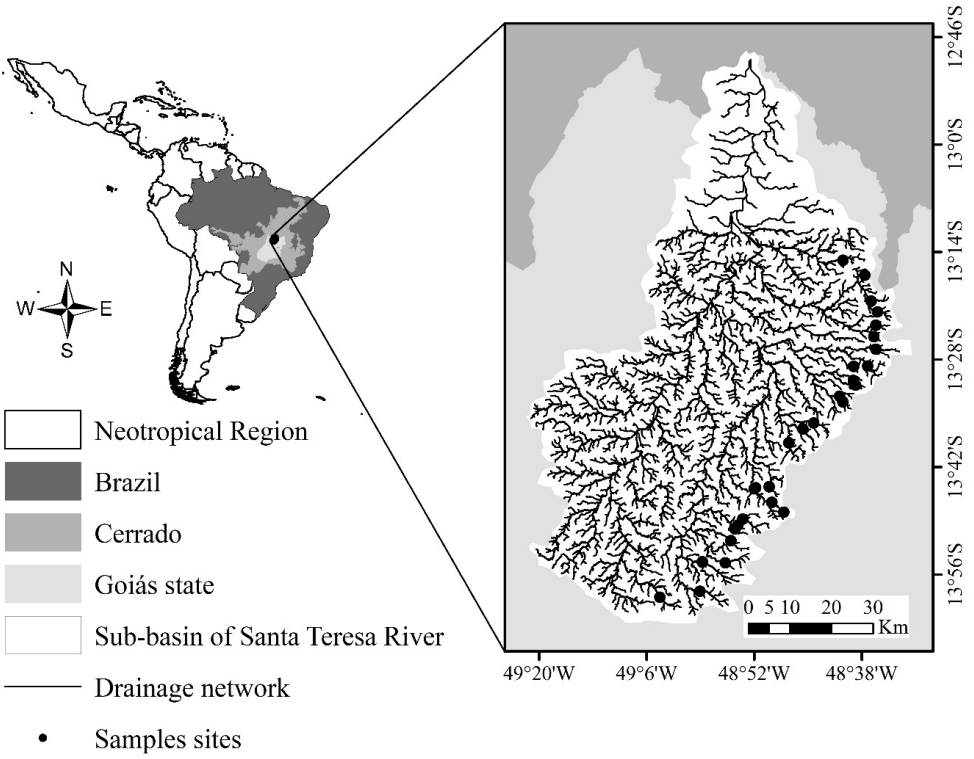

Fig. 1. Location of streams sampled in the upper Tocantins River basin, sub-basin of the Santa Teresa River, region of the Brazilian Cerrado.

although the sampled streams reach a short environmental gradient, 40% of the streams present more than 20% of the land use with anthropogenic activities for cattle raising in the watershed (see Suppl. material 1: Fig. S1). The stretches of streams studied are mainly mesohabitats of backwaters and riffles, a neutral pH, low concentrations of nutrients and chlorophyll-*a* (Suppl. material 1: Table S2).

Biological data

We used a protocol widely employed for sampling of phytoplankton and fish communities (Uieda and Castro 1999; Bicudo and Menezes 2006; Bellinger and Sigee 2010). Since the planktonic communities are widely dispersed, and greater diversity and abundance occur mainly in lentic environments, we prioritize the mesohabitats of backwaters for phytoplankton collection. In each stream, a phytoplankton sample was performed by collecting approximately 100 ml of water in the subsurface (0.5 m depth) and storing the sample in dark jars. After collection, each sample was fixed with modified acetic acid (Vollenweider 1974). Individual counting was performed in an inverted microscope (Zeiss Axiovert 25), at 400× magnification, following the Utermöl sedimentation method (Utermöhl 1958). Identification was conducted to

the lowest possible taxonomic level and organisms were classified according to genus, family and order according to Round (1965), Round (1971) and Round et al. (1990). Afterwards, fish were collected with an electrofishing apparatus along an 80 meter stretch in each stream. Electrofishing was conducted from downstream to upstream, exploring all types of microhabitats along the 80 m reaches (Barbosa et al. 2019). The individual fish captured were fixed in a 10% formalin solution and transferred to 70% ethanol after 72 h. The species were identified to the lowest possible taxonomic level by consulting specialized literature (Claro-García and Shibatta 2013; Lima and Caires 2011; Miranda and Mazzoni 2003) and specialist (Carvalho FR).

Ecological classification data

Phytoplankton species were grouped into two functional groups (Morphology-Based Functional Groups – MBFGs and Reynolds Functional Groups – RFGs) according to the classification proposed by Kruk et al. (2010) updated by Reynolds et al. (2014) and Reynolds et al. (2002) revised by Padisák et al. (2009). The MBFG approach classifies species into eight functional groups according to their morphological characteristics, such as cell size (e.g., biovolume and surface area), silica structure, biological form (unicellular, colonies, filaments) and the presence of flagella, aerotops, heterocysts and mucilage. The RFG group classifies the species by their morphological characteristics, environmental and physiological tolerances, habitat preferences and life history.

The fish species were classified ecologically into three groups: i.) habitat use guilds, according to ecomorphological characteristics, ii.) trophic data, according to diet information, and iii.) habitat use in conjunction with trophic data (see Suppl. material 1: Table S3). In relation to habitat use, fish were classified as benthic, nektonic, nektobenthic and marginal, based on their ecomorphological characteristics, as well as from the literature (Teresa and Casatti 2012). The benthic fish usually have a dorso-ventrally flattened body, long caudal peduncle and ventral mouth (Breda et al. 2005; Oliveira et al. 2010; Negret 2016). The nektonic fish usually present a compressed body, a high, compressed caudal peduncle and a short, terminal mouth (Oliveira et al. 2010). The species of nektobenthic fish are more diverse and generally have a relatively low cylindrical body and a subterminal mouth (Breda et al. 2005), but are also composed of fish with a very high and compressed caudal peduncle, mainly those species of the family Cichlidae. The marginal fish guild is composed of fish with morphological characteristics of other guilds (benthic, nektonic and nektobenthic), but they explore predominantly stream margins and not the main channel. The trophic information was obtained by analyzing the stomach content of fish of the size considered to be at adult stage. For this, three steps were followed: i.) the stomachs were extracted by dissection; ii.) empty stomachs were excluded from the analysis; and iii.) the contents of the remaining stomachs were exposed to Petri dishes and examined under a microscope. The food items were separated into six trophic categories: detritivore, terrestrial invertivore, aquatic invertivore, piscivore,

algivore and herbivore. The volume of food items larger than 1mm in height was estimated from the known water volume displacement in the water column. For items smaller than 1mm, the volume was estimated from the area occupied in Petri dish with the aid of the graph paper (Hyslop 1980). To describe the species diet, the Alimentary Index (AI_i) was calculated for each food item (Kawakami and Vazzoler 1980), determined by the following equation:

$$AI_i = \frac{F_i \times V_i}{\sum_{i=1}^{n}\left(F_i \times V_i\right)} \times 100 \quad ,$$

where *AIi* = alimentary index, n = food item, *Fi* = frequency of occurrence (%) of each item, *Vi* = volume of each item in percentage.

The matrices of ecological classification were obtained by multiplying the abundance data (species relative abundance by site matrix) by habitat use (species by habitat use matrix), trophic data (species by diet items matrix) or habitat use together with trophic data (see Suppl. material 1: Table S3) resulting in matrices of ecological groups (habitat use, diet or habitat use together with diet) by site (Lavorel et al. 2008).

Data analysis

The abundance of fish, habitat use and trophic data, and density data of phytoplankton, MBFGs and RFGs were log-transformed (x+1) to minimize the effect of extreme values (Legendre and Legendre 2012). Then, these data were used to build distance matrices using Bray-Curtis (abundance/density data) and Jaccard (presence/absence) coefficients. Subsequently, we applied the Principal Coordinate Analysis (PCoA) to build the fish and phytoplankton matrix to be compared in Procrustes analysis (see more details in Suppl. material 1: Fig. S2). We used a Procrustes analysis to evaluate the concordance between the compared matrices (Legendre and Legendre 2012).

In order to evaluate the taxonomic resolution (proposal of using higher levels), we performed pairwise comparisons of species, genera, families and orders matrices. In this case, we compared the different taxonomic resolutions with fish abundance and phytoplankton density. For numerical resolution (proposal of using occurrence data), the matrices compared were: abundance matrix versus presence/absence matrix for fish and density matrix versus presence/absence matrix for phytoplankton. Numerical resolution was also performed among all taxonomic levels combinations (i.e., species, genera, families and orders). In order to analyze the ecological substitute group (proposal of using ecological classifications), the matrices compared for fish were: species abundance matrix *versus* habitat use guild, trophic guild, and combined trophic data with habitat use. The analysis of the ecological substitute group for phytoplankton compared the following matrices: density matrix *versus*

MBFGs and RFGs ecological classification. In order to evaluate the concordance between fish and the spatial distribution of phytoplankton (surrogate group proposal), we used both fish abundance matrices versus phytoplankton density and the presence/absence matrices for fish versus presence/absence matrix for phytoplankton.

The Procrustes analysis correlation values (r) range from 0 to 1 (Legendre and Legendre 2012). In general, we considered values of $r \geq 0.7$ to indicate highly concordant values (Heino 2010). The significance of the *r* values was evaluated through 9,999 permutations. All analyses were performed in the R (R Core Team 2018) statistical software. For PCoA ordination analysis, we used the *cmdscale* function in the *stats* package. For Procrustes analysis, we used the *protest* function in the *vegan* package (Oksanen et al. 2016).

Results

We identified 47 fish species, comprising 39 genera, 16 families and five orders, with a total abundance of 8,461 individuals (see more details about distribution by point in Suppl. material 1: Fig. S3). The most abundant families were Characidae with 5,012 individuals, Crenuchidae with 1,353 and Loricariidae with 1,314 individuals. Regarding the fish ecological classification, based on the position in water column (habitat use guild), we observed 17 benthic, 10 nektonic, 13 nektobenthic and seven marginal species and for trophic guilds we provide the proportions for items found in fish stomachs (Suppl. material 1: Table S3). Regarding phytoplankton, we identified 65 species, distributed in 27 genera, 20 families and 10 orders. The taxonomic class with highest density was Bacillariophyceae, with 1,371.65 individuals/ml, followed by Chlorophyceae, with 91.23 individuals/ml (see more details about distribution by point in Suppl. material 1: Fig. S4). We observed representatives of four MBFGs (Groups III, IV, VI and VII) and nine RFGs (Groups J, F, MP, P, A, D, B, H1, S1). We observed representatives of five MBFGs (Groups III, IV, VI, VII and VIII, Suppl. material 1: Fig S5) and the epilithon species of group VI showed the highest abundance. We also found nine RFGs (Groups J, F, MP, P, A, D, B, H1, S1, Suppl. material 1: Fig. S6), being the MP group, represented by planktonic and epilithon species, the most abundant in most areas of streams.

In general, the taxonomic resolution presented significant results up to the order level (Table 1), although the concordance values decreased with the increase in taxonomic resolution level. Species versus genus and species versus family resolutions were highly correlated for fish (presented greater *r* values than 0.8). For phytoplankton, only taxonomic resolutions of species versus genus showed significant correlations and $r > 0.7$ (Table 1). For numerical resolution, although the fish and phytoplankton groups also presented significant results up to the level of order, both indicated the possibility of using presence/absence data as a surrogate for species abundance/density data, genus and family ($r > 0.7$; $P < 0.05$) (Table 1).

Among the ecological classification groups for fish, the concordance tests between species abundance and ecological classification by habitat use together with trophic guilds presented a high concordance ($r > 0.7$; $P < 0.05$). The test of concord-

Table 1. Procrustes tests using abundance (ab), density (den) and presence/absence (pa) matrices, fish ecological classification and phytoplankton functional groups. Significant *r* values greater than 0.7 marked in bold.

Tested matrices	Procrustes	
	r	***P***
Fish taxonomic resolutions		
Species *vs*. Genus	**0.97**	0.001
Species *vs*. Family	**0.84**	0.001
Species *vs*. Order	0.68	0.001
Fish numerical resolutions		
Species (ab) *vs*. Species (pa)	**0.92**	<0.001
Species (ab) *vs*. Genus (pa)	**0.89**	<0.001
Species (ab) *vs*. Family (pa)	**0.71**	<0.001
Species (ab) *vs*. Order (pa)	0.39	0.015
Phytoplankton taxonomic resolutions		
Species *vs*. Genus	**0.71**	<0.001
Species *vs*. Family	0.68	<0.001
Species *vs*. Order	0.63	<0.001
Phytoplankton numerical resolutions		
Species (den) *vs*. Species (pa)	**0.97**	<0.001
Species (den) *vs*. Genus (pa)	**0.75**	<0.001
Species (den) *vs*. Family (pa)	**0.7**	<0.001
Species (den) *vs*. Order (pa)	0.59	<0.001
Fish ecological substitute group		
Species (ab) *vs*. Ecological classification (habitat use guild)	0.69	<0.001
Species (ab) *vs*. Ecological classification (trophic guild)	**0.72**	<0.001
Species (ab) *vs*. Ecological classification (habitat use guild + trophic guild)	**0.75**	<0.001
Phytoplankton ecological substitute group		
Species *vs*. MBFGs	0.58	<0.002
Species *vs*. RFGs	0.56	<0.001
Fish *vs.* phytoplankton concordance		
Fish (ab) *vs*. Phytoplankton (den)	0.61	0.964
Fish (pa) *vs*. Phytoplankton (pa)	0.57	0.925

ance between species abundance and habitat use group presented significant results with correlation coefficient marginally lower than 0.7 (Table 1). The concordance between species abundance and trophic guild was significant ($r > 0.7$; Table 1). For phytoplankton, despite significant results for MBFGs and RFGs, correlations were low ($r < 0.6$) (Table 1). Fish and phytoplankton data generated non-concordant ordination patterns ($P > 0.05$) (Table 1).

Discussion

The distribution patterns of fish and phytoplankton species are maintained at the taxonomic level of genus comparable to those revealed at the species level. For fish, we find concordance with similar predictability power at the family level. Nu-

merical resolution (presence/absence) tests on species/genus/family levels for both groups (fish and phytoplankton) presented high concordance values. The ecological substitute group for fish presented *r* values above that recommended to indicate highly concordant values (Heino 2010). In this sense, we consider these results promising and suggest further tests to evaluate the reliability in using this information as an efficient alternative approach. We support the substitution of taxonomic and numerical resolutions for fish and phytoplankton, as well as ecological substitute group for fish. We also highlight that our results do not support the use of fish as a substitute group for phytoplankton. Nevertheless, we acknowledge the need of caution when applying these coarser measures and suggest them as a potential tool for use at species and genus level. These alternatives are indicated mainly for adverse situations when there is a shortage of resources necessary to implement environmental assessment and monitoring strategies and/or difficulty in accessing expert taxonomists for the identification of fish and phytoplankton.

Taxonomical resolution

Our results indicated that the use of coarser taxonomic resolutions of genus (phytoplankton and fish) and family (fish) may be possible when rapid environmental assessments are required for streams. This is because reaching the species level during identification may be a problem for inexperienced researchers (Williams et al. 2006) and it takes less time to identify taxonomic levels such as genus and family (Kallimanis et al. 2012). In addition, some groups are difficult to identify, generating a dependence on taxonomists. The identification of species by a taxonomist is important; however, access to specialists is not always easy for ecologists and conservation biologists (Bevilacqua et al. 2009; Halme et al. 2015). For example, for fish identification in the Loricariidae family, it is necessary to observe bony structures that require diaphanization with more costly and time-consuming procedures (see Loricariidae fish identification keys in Covain and Fisch-Muller 2007; Vera-Alcaraz et al. 2012). Identification is also difficult for phytoplankton, as it may involve recognizing structures that are not always present in samples (e.g., depending on the algae sample fixation and preservation, some structures can be lost; for example, formalin causes flagella to fall off, hindering the identification of flagellated organisms) (Bicudo and Menezes 2006). Moreover, the identification process also involves groups with different morphologies and requires knowledge of the life cycle (e.g., type of sexual or asexual reproduction) (Carneiro et al. 2013). Therefore, with accelerated biodiversity loss and from a biological and statistical point of view, coarser identification may be more suitable than incorrect species identification (James et al. 1995; Rimet and Bouchez 2012).

Other studies have also found similar results regarding the use of higher taxonomic levels for aquatic organisms, such as benthic macroinvertebrates and diatoms (Heino and Soininen 2007), phytoplankton (Carneiro et al. 2010, 2013), aquatic Nepomorpha (Giehl et al. 2014), zooplankton (Gomes et al. 2015; Mis-

sias et al. 2017), phytoplankton, periphyton, zooplankton, aquatic macrophytes and fish (Ribas and Padial 2016). A study with marine mollusks has shown that beta diversity is maintained for genus and family (Terlizzi et al. 2009), demonstrating that heterogeneous patterns are maintained at coarser levels. The use of family as a surrogate for species has already been approached in another study as an important way to decrease the effect of dominant species in a sample (Khan 2006). In case of replacement by a higher level, many studies show that the closer this ratio to 1, the better the higher taxa approach (Bevilacqua et al. 2012; Rosser 2017). Thus, our results support the use of genus for phytoplankton, and genus and family for fish.

Numerical resolution

Our results show that the use of abundance and presence/absence matrices generates concordant patterns. Other studies with different groups such as phytoplankton (Carneiro et al. 2010), plants (Landeiro et al. 2012) and zooplankton (Gomes et al. 2015) agree with the use of presence/absence data instead of abundance/density data. Therefore, the use of presence/absence data for fish and phytoplankton is recommended for streams at species and/or genus levels. As *r* value for family was very close to 0.7, we understand that in this case the use of numerical resolution for family is a bold and optimistic proposal (Bevilacqua et al. 2012; Rosser 2017). In any case, it is interesting to record solely the occurrence of the species and/or genus, reducing analysis time by dispensing the complete sample count. It is also worth highlighting that the numerical resolution of the presence/absence data approach requires fewer animals to be captured, avoiding unnecessary sacrifice.

Ecological substitute group

Our results found a significant concordance between species abundance/density with the ecological classification for fish and phytoplankton, respectively. However, the low correlation coefficient value of MBFG and RFG ecological classification indicates a non-correspondence of the ecological ordination for phytoplankton species. Therefore, we do not suggest its use as a surrogate for species taxonomic information (Gallego et al. 2012; Machado et al. 2015). For fish, the ecological classification of the habitat, together with trophic guilds, showed higher concordance with species abundance data. Whenever possible, it's interesting to prioritize the application of this classification to monitor streams. A negative point that should be highlighted is that the data obtained may be more complex, especially trophic data. Classification with the trophic guild also presented a high concordance, but to analyze the diet of fish requires a more experienced professional with specific knowledge. We understand that other classifications considering functional fish traits related to breeding and life cycle would contribute to a more robust un-

derstanding of the biological response to environmental changes. However, these approaches demand knowledge about the species and this is unavailable in some cases. Therefore, it would not facilitate the application in biomonitoring programs by a less qualified person. Considering the cost-effectiveness of monitoring biological communities in streams, using this ecological classification may be more interesting to complement the assessment of anthropic impacts than to replace species-level taxonomic resolution. The ecological substitute group based on habitat use presented *r* values marginally lower than 0.7. Thus, we highlight the advantages of this proposal for future studies to facilitate the ease of classification of fish, for the independence in identifying fish at the species level, and the possibility of it being conducted by a trained technician.

Classifying fish in terms of their ecomorphological pattern considers their morphotypes (Casatti and Castros 2006; Oliveira et al. 2010). That is, body characteristics can be easily visually observed (e.g., body compression, caudal peduncle compression and mouth orientation). Nektonic fish, for example, have a terminal mouth, compressed caudal body and a peduncle (i.e., laterally flattened) (Gatz 1979; Watson and Balon 1984; Oliveira et al. 2010). Therefore, a trained technician would be able to work in different regions, without having prior knowledge of a species that occurs in different river basins. Moreover, biological monitoring with an ecomorphological approach for fish encompasses a variety of ecological niches and can provide an impact measurement on aquatic ecosystems, as it may reflect the effect of anthropic pressures (Karr et al. 1986; Barbour et al. 1999; Oliveira et al. 2010). Therefore, the ecological classification of fish is a potential tool that requires further testing to ultimately support this approach in biomonitoring assessments and conservation plans.

Surrogate group

Our results showed no concordance between phytoplankton and fish. Thus, the distribution patterns of both groups can respond differently to preferences and adaptations to available environmental factors. In addition, biotic interactions are possibly weak and may be related to different life history traits (Heino 2002; Bowman et al. 2008; Guareschi et al. 2015). Biological groups that are not phylogenetically related, such as phytoplankton and fish, tend to be irreplaceable (Morais et al. 2018), as corroborated by our results. This finding highlights the unique importance of each taxonomic group in environmental monitoring and biodiversity assessments (Heino 2015). In addition, the lack of concordance among taxa is due to their response to the local environment at different scales (Backus-Freer and Pyron 2015), i.e., the scale may be influencing the lack of concordance. The concordance between groups tends to be larger at large scales, such as several river basins (Grenouillet et al. 2008; Gioria et al. 2011; Backus-Freer and Pyron 2015). In our study, samplings were carried out at a scale relevant to management

(landscape scale), and thus require caution to generalize the results to other scales (Landeiro et al. 2012).

Other studies in aquatic ecosystems also support that environmental monitoring based on a single taxonomic group cannot be easily applied to other biotic groups (Heino et al. 2005; Dolph et al. 2011; Larsen et al. 2012; Padial et al. 2012; Vieira et al. 2015). Caution when using this type of approach stems from the high variability in levels of concordance between substitutes' groups tested in other studies (Morais et al. 2018). Our results suggest that care should be taken when approaches based on one group are extrapolated to other groups in the assessment of the environmental conditions of headwater streams since the power to generate useful predictions regarding other taxonomic groups may be limited. Therefore, from a practical point of view, we suggest that biologists, environmental consultants, environmental managers and conservation planners rely on approaches of monitoring integrating producer groups (e.g. phytoplankton and periphyton) and consumers (e.g. fish). With these approaches, it will certainly be possible to develop more comprehensive and sustainable conservation strategies (e.g., meeting social, environmental and economic demands).

Conclusions

The best alternative approaches for the biomonitoring of fish and phytoplankton in headwater streams are using higher taxonomic levels (genus and family) and recording only species and/or genus occurrence. For fish, the ecological classification provides useful information, but with a lower level of concordance. In a cost-effective perspective, habitat use could be a good option due to its simplicity in classifying fish independently of taxonomic identification, which could make the biological assessment easy for a less qualified professional. The results found for taxonomic and numerical resolution have been consistent in the literature and are therefore strongly recommended.

Acknowledgements

This study was financed by CNPq (process number: 482185/2012-0) and FAPEG (process number: 201210267000703 and AUXPE 2036/2013). KBM, MCV, HRP and LFG, received PhD scholarship frontal CAPES (Finance Code 001); FBT, JCN and LCGV are supported by CNPq productivity fellowships. We thank the CASE-GO for providing paid leave to HOB for his PhD study. Thanks to Dr. Fernando R. Carvalho for his assistance with the identification of fish species and also the anonymous reviewers for the valuable contributions throughout the text. Studies of LCGV, FBT and JCN on aquatic ecology are developed in the context of the National Institute of Science and Technology (INCT) in Ecology, Evolution and Biodiversity Conservation, supported by MCTIC/CNPq (proc. 465610/2014-5).

References

Backus-Freer J, Pyron M (2015) Concordance among fish and macroinvertebrate assemblages in streams of Indiana, USA. Hydrobiologia 758(1): 141–150. https://doi.org/10.1007/s10750-015-2281-6

Barbosa HO, Borges PP, Dala-Corte RB, Martins PTA, Teresa FB (2019) Relative importance of local and landscape variables on fish assemblages in streams of Brazilian savanna. Fisheries Management and Ecology 26(2): 1–12. https://doi.org/10.1111/fme.12331

Barbour MT, Gerritsen J, Snyder BD, Stribling JB (1999) Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish, 2nd edition. EPA 841-B-99-002. U. S. Environmental Protection Agency; Office of Water, Washington, DC.

Bates CR, Scott G, Tobin M, Thompson R (2007) Weighing the costs and benefits of reduced sampling resolution in biomonitoring studies: Perspectives from the temperate rocky intertidal. Biological Conservation 137(4): 617–625. https://doi.org/10.1016/j.biocon.2007.03.019

Bellinger EG, Sigee DC (2010) Freshwater Algae: identification and use as bioindicators. Wiley Blackwell, United Kingdom. https://doi.org/10.1002/9780470689554

Bessa GF, Vieira LCG, Bini LM, Reis DF, Morais PB (2011) Concordance patterns in zooplankton assemblages in the UHE – Luís Eduardo Magalhães reservoir in the Mid-Tocantins river, Tocantins State, Brazil. Acta Scientiarum Biological Sciences 33(2): 179–184. https://doi.org/10.4025/actascibiolsci.v33i2.7336

Bevilacqua S, Fraschetti S, Musco L, Terlizzi A (2009) Taxonomic sufficiency in the detection of natural and human-induced changes in marine assemblages: A comparison of habitats and taxonomic groups. Marine Pollution Bulletin 58(12): 1850–1859. https://doi.org/10.1016/j.marpolbul.2009.07.018

Bevilacqua S, Terlizzi A, Claudet J, Fraschetti S, Boero F (2012) Taxonomic relatedness does not matter for species surrogacy in the assessment of community responses to environmental drivers. Journal of Applied Ecology 49(2): 357–366. https://doi.org/10.1111/j.1365-2664.2011.02096.x

Bicudo CEM, Menezes M (2006) Gêneros de algas de águas continentais do Brasil. 2nd Ed. Rima. São Carlos.

Bini LM, Vieira LCG, Machado J, Velho LFM (2007) Concordance of species composition patterns among microcrustaceans, rotifers and testate amoebae in a shallow pond. International Review of Hydrobiology 92(1): 9–22. https://doi.org/10.1002/iroh.200610865

Borges PPB, Martins PTA, Ferreira AA (2016) Uso e ocupação do solo por meio de uma série histórica na bacia do rio Santa Teresa em Goiás. Revista Brasileira de Geografia Física 9(1): 296–304. https://doi.org/10.5935/1984-2295.20160020

Bowman MF, Ingram R, Reid RA, Somers KM, Yan ND, Paterson AM, Morgan GE, Gunn JM (2008) Temporal and spatial concordance in community composition of phytoplankton, zooplankton, macroinvertebrate, crayfish, and fish on the Precambrian Shield. Canadian Journal of Fisheries and Aquatic Sciences 65(5): 919–932. https://doi.org/10.1139/f08-034

Breda L, Oliveira EF, Goulart E (2005) Ecomorfologia de locomoção de peixes com enfoque para espécies neotropicais. Acta Scientiarum. Biological Sciences 27(4): 371–381. https://doi.org/10.4025/actascibiolsci.v27i4.1271

Carneiro FM, Bini LM, Rodrigues LM (2010) Influence of taxonomic and numerical resolution on the analysis of temporal changes in phytoplankton communities. Ecological Indicators 10(2): 249–255. https://doi.org/10.1016/j.ecolind.2009.05.004

Carneiro FM, Nabout JC, Vieira LCG, Lodi S, Bini LM (2013) Higher taxa predict plankton beta-diversity patters across an eutrophication gradient. Natureza & Conservação 11(1): 43–47. https://doi.org/10.4322/natcon.2013.006

Casatti L, Castro RMC (2006) Testing the ecomorphological hypothesis in a headwater riffles fish assemblage of the rio São Francisco, southeastern Brazil. Neotropical Ichthyology 4(2): 203–214. https://doi.org/10.1590/S1679-62252006000200006

Ceballos G, Ehrlich PR, Barnosky AD, García A, Pringle RM, Palmer TM (2015) Accelerated modern human-induced species losses: Entering the sixth mass extinction. Science Advances 1(5): e1400253. https://doi.org/10.1126/sciadv.1400253

Ceballos G, Ehrlich PR, Dirzo R (2017) Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proceedings of the National Academy of Sciences of the United States of America 114(30): e6089–e6096. https://doi.org/10.1073/pnas.1704949114

Claro-García A, Shibatta OA (2013) The fish fauna of streams from the upper rio Tocantins basin, Goiás State, Brazil. Journal of Species Lists and Distribution 9: 28–33. https://doi.org/10.15560/9.1.28

Covain R, Fisch-Muller S (2007) The genera of the Neotropical armored catfish subfamily Loricariinae (Siluriformes: Loricariidae): a practical key and synopsis. Zootaxa 1462(1): 1–40. https://doi.org/10.11646/zootaxa.1462.1.1

Crist E, Mora C, Engelman R (2017) The interaction of human population, food production, and biodiversity protection. Science 356(6335): 260–264. https://doi.org/10.1126/science.aal2011

Dolph CL, Huff DD, Chizinski CJ, Vondracek B (2011) Implications of community concordance of assessing stream integrity at three nested spatial scales in Minnesota, U.S.A. Freshwater Biology 56(8): 1652–1669. https://doi.org/10.1111/j.1365-2427.2011.02589.x

Erős T, Takács P, Specziár A, Schmera D, Sály P (2016) Effect of landscape context on fish metacommunity structuring in stream networks. Freshwater Biology 62(2): 215–228. https://doi.org/10.1111/fwb.12857

Gallego I, Davidson TA, Jeppesen E, Pérez-Martínez C, Sánchez-Castillo P, Juan M, Fuentes-Rodríguez F, León D, Peñalver P, Toja J, Casas JJ (2012) Taxonomic or ecological approaches? Searching for phytoplankton surrogates in the determination of richness and assemblage composition in ponds. Ecological Indicators 18: 575–585. https://doi.org/10.1016/j.ecolind.2012.01.002

Gatz Jr AJ (1979) Ecological morphology of freshwater stream fishes. Tulane Studies in Zoology and Botany 21: 91–124.

Giehl NFS, Dias-Silva K, Juen L, Batista JD, Cabette HSR (2014) Taxonomic and Numerical Resolutions of Nepomorpha (Insecta: Heteroptera) in Cerrado Streams. PLoS One 9(8): e103623. https://doi.org/10.1371/journal.pone.0103623

Gioria M, Bacaro G, Feehan J (2011) Evaluating and interpreting cross-taxon congruence: Potential pitfalls and solutions. Acta Oecologica 37(3): 187–194. https://doi.org/10.1016/j.actao.2011.02.001

Gomes LF, Vieira LCG, Bonnet MP (2015) Two practical approaches to monitoring the zooplankton community at Lago Grande do Curuai, Pará, Brazil. Acta Amazonica 45(3): 293–298. https://doi.org/10.1590/1809-4392201404453

Grenouillet G, Brosse S, Tudesque L, Lek S, Baraillé Y, Loot G (2008) Concordance among stream assemblages and spatial autocorrelation along a fragmented gradient. Diversity & Distributions 14(4): 592–603. https://www.jstor.org/stable/20172013. https://doi.org/10.1111/j.1472-4642.2007.00443.x

Guareschi S, Abellán P, Laini A, Green AJ, Sánchez-Zapata JA, Velasco J, Millán A (2015) Cross-taxon congruence in wetlands: Assessing the value of waterbirds as surrogates of macroinvertebrate biodiversity in Mediterranean Ramsar sites. Ecological Indicators 49: 204–215. https://doi.org/10.1016/j.ecolind.2014.10.012

Halme P, Kuusela S, Juslén A (2015) Why taxonomists and ecologists are not, but should be, carpooling? Biodiversity and Conservation 24(7): 1831–1836. https://doi.org/10.1007/s10531-015-0899-3

Heino J (2002) Concordance of species richness patterns among multiple freshwater taxa: A regional perspective. Biodiversity and Conservation 11(1): 137–147. https://doi.org/10.1023/A:1014075901605

Heino J (2010) Are indicator groups and cross-taxon congruence useful for predicting biodiversity in aquatic ecosystems? Ecological Indicators 10(2): 112–117. https://doi.org/10.1016/j.ecolind.2009.04.013

Heino J (2015) Approaches, potential and pitfalls of applying bioindicators in freshwater ecosystems. In: Lindenmayer DB, Pierson J, Barton P (Eds) Surrogates and Indicators of Biodiversity and Environmental Change. CSIRO Publishing and CRC Press, Melbourne and London, 91–100.

Heino J, Soininen J (2007) Are higher taxa adequate surrogates for species-level assemblage patterns and species richness in stream organisms? Biological Conservation 137(1): 78–89. https://doi.org/10.1016/j.biocon.2007.01.017

Heino J, Paavola R, Virtanen R, Muotka T (2005) Searching for biodiversity indicators in running waters: Do bryophytes, macroinvertebrates, and fish show congruent diversity patterns? Biodiversity and Conservation 14(2): 415–428. https://doi.org/10.1007/s10531-004-6064-z

Hyslop EJ (1980) Stomach contents analysis-a review of methods and their application. Journal of Fish Biology 17(4): 411–429. https://doi.org/10.1111/j.1095-8649.1980.tb02775.x

James RJ, Lincoln Smith MP, Fairweather PG (1995) Sieve meshsize and taxonomic resolution needed to describe natural spatial variation of marine macrofauna. Marine Ecology Progress Series 118: 187–198. https://doi.org/10.3354/meps118187

Kallimanis AS, Mazaris AD, Tsakanikas D, Dimopoulos P, Pantis JD, Sgardelis SP (2012) Efficient biodiversity monitoring: Which taxonomic level to study? Ecological Indicators 15(1): 100–104. https://doi.org/10.1016/j.ecolind.2011.09.024

Karr JR, Fausch KD, Angermeier PL, Yant PR, Schlosser IJ (1986) Assessing biological integrity in running waters: a method and its rationale. Special publication 5. Illinois Natural History Survey.

Kawakami E, Vazzoler G (1980) Método gráfico e estimativa do índice alimentar aplicado no estudo de alimentação de peixes. Boletim do Instituto Oceanográfico 29(2): 205–207. https://doi.org/10.1590/S0373-55241980000200043

Khan SJ (2006) Is species level identification essential for environmental impact studies? Current Science 91(1): 29–34.

Kruk C, Huszar VLM, Peeters ETHM, Bonilla S, Costa L, Lurling M, Reynolds CS, Scheffer M (2010) A morphological classification capturing functional variation in phytoplankton. Freshwater Biology 55(3): 614–627. https://doi.org/10.1111/j.1365-2427.2009.02298.x

Landeiro VL, Bini LM, Costa FRC, Franklin E, Nogueira A, Souza JLP, Moraes J, Magnusson WE (2012) How far can we go in simplifying biomonitoring assessments? An integrated analysis of taxonomic surrogacy, taxonomic sufficiency and numerical resolution in a megadiverse region. Ecological Indicators 23: 366–374. https://doi.org/10.1016/j.ecolind.2012.04.023

Larsen S, Mancini L, Pace G, Scalici M, Tancioni L (2012) Weak concordance between fish and macroinvertebrates in Mediterranean streams. PLoS One 7(12): e51115. https://doi.org/10.1371/journal.pone.0051115

Lavorel S, Grigulis K, McIntyre S, Williams NSG, Garden D, Dorrough J, Berman S, Quétier F, Thébault A, Bonis A (2008) Assessing functional diversity in field – Methodology matters! Functional Ecology 22: 134–147. https://doi.org/10.1111/j.1365-2435.2007.01339.x

Legendre P, Legendre L (2012) Numerical Ecology. 3 ed. Elsevier Science, Amsterdam.

Lima FCT, Caires RA (2011) Peixes da Estação Ecológica Serra Geral do Tocantins, bacias dos rios Tocantins e São Francisco, com observações sobre as implicações biogeográficas das "águas emendadas" dos rios Sapão e Galheiros. Biota Neotropica 11(1): 231–250. https://doi.org/10.1590/S1676-06032011000100024

Machado KB, Borges PP, Carneiro FM, Santana JF, Vieira LCG, Huszar VLM, Nabout JC (2015) Using lower taxonomic resolution and ecological approches as a surrogate for plankton species. Hydrobiologia 743(1): 255–267. https://doi.org/10.1007/s10750-014-2042-y

Maćkiewicz E, Pawlaczyk A, Szynkowska MI (2018) Trace elements in the environment-law, regulations, monitoring and biomonitoring methods. Recent Advances in Trace Elements, 61–104. https://doi.org/10.1002/9781119133780.ch4

Mazaris AD, Moustaka-Gouni M, Michaloudi E, Bobori DC (2010) Biogeographical patterns of freshwater micro- and macroorganisms: A comparison between phytoplankton, zooplankton and fish in the eastern Mediterranean. Journal of Biogeography 37(7): 1341–1351. https://doi.org/10.1111/j.1365-2699.2010.02294.x

Meirelles EML, Ferreira EAB, Tokarski DJ (2007) Caracterizaçao regional. In: Ferreira EAB, Tokarski DJ (Eds) Bacia Hidrográfica do Alto Tocantis Retratos e Reflexões. ECODATA. WWF – Brasil, 102.

Miranda JC, Mazzoni R (2003) Composição da Ictiofauna de três riachos do alto rio Tocantins -GO. Biota Neotropica 3(1): 1–11. https://doi.org/10.1590/S1676-06032003000100005

Missias ACA, Gomes LF, Pereira HR, Silva LCF, Angelini R, Vieira LCG (2017) Is it possible to simplify environmental monitoring? Approaches with zooplankton in a hydroelectric reservoir. Acta Limnologica Brasiliensia 29(0): e8. https://doi.org/10.1590/s2179-975x6516

MMA (2006) Tocantins-Araguaia Caderno da Região Hidrográfica. http://www.mma.gov.br/estruturas/161/_publicacao/161_publicacao02032011035943.pdf

Morais GF, Ribas LGS, Ortega JCG, Heino J, Bini LM (2018) Biological surrogates: A word of caution. Ecological Indicators 88: 214–218. https://doi.org/10.1016/j.ecolind.2018.01.027

Negret BES (2016) La ecología funcional como aproximación al estudio, manejo y conservación de la biodiversidad: protocolos y aplicaciones. Instituto de investigación de Recursos Biológicos Alexander von Humboldt, 239 pp.

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, Mcglinn D, Minchin PR, O'hara RB, Simpson GL, Solymos P, Stevens MHH, Szoecs E, Wagner H (2016) Vegan: Community Ecology Package. R package version 2.4-1. https://CRAN.R-project.org/package=vegan

Oliveira EF, Goulart E, Breda L, Minte-Vera CV, Paiva LRDS, Vismara MR (2010) Ecomorphological patterns of the fish assemblage in a tropical floodplain: Effects of trophic, spatial and phylogenetic structures. Neotropical Ichthyology 8(3): 569–586. https://doi.org/10.1590/S1679-62252010000300002

Padial AA, Declerck SAJ, Meester L, Bonecker CC, Lansac-Tôha FA, Rodrigues LC, Takeda A, Train S, Velho LFM, Bini LM (2012) Evidence against the use of surrogates for biomonitoring of neotropical floodplains. Freshwater Biology 57(11): 2411–2423. https://doi.org/10.1111/fwb.12008

Padial AA, Ceschin F, Declerck SA, Meester L, Bonecker CC, Lansac-Tôha FA, Rodrigues L, Rodrigues LC, Train S, Velho LFM, Bini LM (2014) Dispersal ability determines the role of environmental, spatial and temporal drivers of metacommunity structure. PLoS One 9(10): e111227. https://doi.org/10.1371/journal.pone.0111227

Padisák J, Crossetti LO, Naselli-Flores L (2009) Use and misuse in the application of the phytoplankton functional classification: a critical review with updates. Hydrobiologia 621(1): 1–19. https://doi.org/10.1007/s10750-008-9645-0

R Development Core Team (2018) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reynolds CS, Huszar VLM, Kruk C, Naselli-Flores L, Melo S (2002) Review: Towards a functional classification of the freshwater phytoplankton. Journal of Plankton Research 24(5): 417–428. https://doi.org/10.1093/plankt/24.5.417

Reynolds CS, Alex Elliott J, Frassl MA (2014) Predictive utility of trait-separated phytoplankton groups: A robust approach to modeling population dynamics. Journal of Great Lakes Research 40: 143–150. https://doi.org/10.1016/j.jglr.2014.02.005

Ribas LGS, Padial AA (2016) Erratum to: The use of coarser data is an effective strategy for biological assessments. Hydrobiologia 779(1): 259–259. https://doi.org/10.1007/s10750-016-2876-6

Rimet F, Bouchez A (2012) Biomonitoring river diatoms: Implications of taxonomic resolution. Ecological Indicators 15(1): 92–99. https://doi.org/10.1016/j.ecolind.2011.09.014

Rodrigues L, Bicudo DC (2004) Periphytic Algae. In: Thomaz SM et al. (Eds) The Upper Paraná River and its Floodplain: physical aspects, ecology and conservation. Backhuys Publishers, Leiden, 125–143.

Rosa BJFV, Rodrigues LFT, Oliveira GS, Alves RG (2014) Chironomidae and Oligochaeta for water quality evaluation in an urban river in southeastern Brazil. Environmental Monitoring and Assessment 186(11): 7771–7779. https://doi.org/10.1007/s10661-014-3965-5

Rosser N (2017) Shortcuts in biodiversity research: What determines the performance of higher taxa as surrogates for species? Ecology and Evolution 7(8): 2595–2603. https://doi.org/10.1002/ece3.2736

Round FE (1965) The Biology of the Algae. Edward Arnold Publishers Ltd, London.

Round FE (1971) The taxonomy of the Chlorophyta II. British Phycological Journal 6(2): 235–264. https://doi.org/10.1080/00071617100650261

Round FE, Crawford RM, Mann DG (1990) Diatoms: Biology and Morphology of the Genera. Cambridge University Press, Cambridge.

Ruhí A, Batzer DP (2014) Assessing congruence and surrogacy among wetland macroinvertebrate taxa towards efficiently measuring biodiversity. Wetlands 34(6): 1061–1071. https://doi.org/10.1007/s13157-014-0566-6

Sanchez-Moyano JE, Fa DA, Estacio FJ, Garcia-Gomez JC (2006) Monitoring of marine benthic communities and taxonomic resolution: An approach through diverse habitats and substrates along the Southern Iberian coastline. Helgoland Marine Research 60(4): 243–255. https://doi.org/10.1007/s10152-006-0039-2

Sharma RC, Singh N, Chauhan A (2016) The influence of physico-chemical parameters on phytoplankton distribution in a head water stream of Garhwal Himalayas: A case study. Egyptian Journal of Aquatic Research 42(1): 11–21. https://doi.org/10.1016/j.ejar.2015.11.004

Strahler AN (1957) Quantitative analysis of watershed geomorphology. Transactions – American Geophysical Union 38(6): 913–920. https://doi.org/10.1029/TR038i006p00913

Tataranni M, Maltagliati F, Floris A, Castelli A, Lardicci C (2009) Variance estimate and taxonomic resolution: An analysis of macrobenthic spatial patterns at different scales in a Western Mediterranean coastal lagoon. Marine Environmental Research 67(4–5): 219–229. https://doi.org/10.1016/j.marenvres.2009.02.003

Teresa FB, Casatti L (2012) Influence of forest cover and mesohabitat types on functional and taxonomic diversity of fish communities in Neotropical lowland streams. Ecology Freshwater Fish 21(3): 433–442. https://doi.org/10.1111/j.1600-0633.2012.00562.x

Terlizzi A, Anderson MJ, Bevilacqua S, Fraschetti S, Wodarska-Kowalczuk M, Ellingsen KE (2009) Beta diversity and taxonomic sufficiency: Do higher-level taxa reflect heterogeneity in species composition? Diversity & Distributions 15(3): 450–458. https://doi.org/10.1111/j.1472-4642.2008.00551.x

Thomson RJ, Hill NA, Leaper R, Ellis N, Pitcher CR, Barrett NS, Edgar GJ (2014) Congruence in demersal fish, macroinvertebrate, and macroalgal community turnover on shallow temperate reefs. Ecological Applications 24(2): 287–299. https://doi.org/10.1890/12-1549.1

Trigal C, Fernandez-Alaez C, Fernandez-Alaez M (2014) Congruence between functional and taxonomic patterns of benthic and planktonic assemblages in flatland ponds. Aquatic Sciences 76(1): 61–72. https://doi.org/10.1007/s00027-013-0312-9

Uieda VS, Castro RMC (1999) Coleta e fixação de peixes de riachos. In: Caramaschi EP, Mazzoni R, Peres Neto PR (Eds) Ecologia de peixes de riachos. Rio de Janeiro, Programa de Pós-Graduação em Ecologia, Instituto de Biologia, Universidade Federal do Rio de Janeiro, 1–22. https://doi.org/10.4257/oeco.1999.0601.01

Utermöhl H (1958) Zurvervoll kommung der quantitativen phytoplankton-methodik. Mitteilungen Internationale Vereinigung für Theoretische und Angewandte Limnologie, 91–38.

Vera-Alcaraz HS, Pavanelli CS, Zawadzki CH (2012) Taxonomic revision of the *Rineloricaria* species (Siluriformes: Loricariidae) from the Paraguay River basin. Neotropical Ichthyology 10(2): 285–311. https://doi.org/10.1590/S1679-62252012000200006

Vieira LCG, Padial AA, Velho LFM, Carvalho P, Bini LM (2015) Concordance among zooplankton groups in a near-pristine floodplain system. Ecological Indicators 58: 375–381. https://doi.org/10.1016/j.ecolind.2015.05.049

Vieira MC, Bini LM, Velho LFM, Gomes LF, Nabout JC, Vieira LCG (2017) Biodiversity shortcuts in biomonitoring of novel ecosystems. Ecological Indicators 82: 505–512. https://doi.org/10.1016/j.ecolind.2017.07.025

Vollenweider RA (1974) A Manual on Methods for Measuring Primary Production in Aquatic Environments. Blackwell Scientific Publications, London.

Watson DJ, Balon EK (1984) Ecomorphological analysis of fish taxocenes in rainforest streams of northern Borneo. Journal of Fish Biology 25(3): 371–384. https://doi.org/10.1111/j.1095-8649.1984.tb04885.x

Williams ID, Walsh WJ, Tissot BN, Hallacher LE (2006) Impact of observers' experience level on counts of fishes in underwater visual surveys. Marine Ecology Progress Series 310: 185–191. https://doi.org/10.3354/meps310185

Zuschin M, Nawrot R, Harzhauser M, Mandic O (2015) Taxonomic and numerical sufficiency in a Lower and Middle Miocene molluscan metacommunity of the Central Paratethys. Geophysical Research Abstracts 17: EGU2015–EGU10434.

Supplementary material 1

Supplementary tables and figures

Authors: Hugo de Oliveira Barbosa, Karine Borges Machado, Maisa Carvalho Vieira, Hasley Rodrigo Pereira, Leonardo Fernandes Gomes, João Carlos Nabout, Fabrício Barreto Teresa, Ludgero Cardoso Galli Vieira

Data type: Species data.

Explanation note: **Tables: Table S1** List of studies using optimization strategies involving fish biomonitoring. **Table S2** Environmental characterization of streams sampled in the upper Tocantins river basin, sub-basin of the Santa Teresa river, Cerrado biome, Brazil. **Table S3** List of fish species captured in the North region of Goiás, Upper Tocantins system, sub-basin of the Santa Teresa river, Cerrado biome, Brazil. **Figures: Fig. S1** Percentage of land use anthropic and land natural cover in 29 streams watershed of the sub-basin of the Santa Teresa river, Cerrado biome, Brazil. **Fig. S2** Schematic representation of taxonomic and numerical resolution, ecological substitute group, and surrogate group. **Fig. S3** Abundance of fish (number of individuals) found in 29 streams of Upper Tocantins river basin, sub-basin of the Santa Teresa river, Cerrado biome, Brazil, distributed in five orders. **Fig. S4** Density of phytoplankton by taxonomic class found in 29 streams of Upper Tocantins river basin, sub-basin of the Santa Teresa river, Cerrado biome, Brazil. **Fig. S5** Density of phytoplankton by Morphology-Based Functional Groups found in 29 streams of Upper Tocantins river basin, sub-basin of the Santa Teresa river, Cerrado biome, Brazil. **Fig. S6** Density of phytoplankton by Reynolds Functional Groups found in 29 streams of Upper Tocantins river basin, sub-basin of the Santa Teresa river, Cerrado biome, Brazil.

Link: https://doi.org/10.3897/neotropical.14.e38088.suppl1