The potential of fish families as surrogates for species and functional diversity in biomonitoring impacted Amazonian streams

Luciana Lameira dos Santos[1,2], Naraiana Loureiro Benone[3], Lidia Brasil Seabra[2] Cleonice Maria Lobato[2] and Luciano Fogaça de Assis Montag[2]

[1]Programa de Pós-graduação em Zoologia, Instituto de Ciências Biológicas, Universidade Federal do Pará, R. Augusto Corrêa, 01, Guamá, 66075-110 Belém, PA, Brazil. lucianalameira@yahoo.com.br, ORCID 0000-0002-8966-7471 (corresponding author)

[2]Laboratório de Ecologia e Conservação, Instituto de Ciências Biológicas, Universidade Federal do Pará, R. Augusto Corrêa, 01, Guamá, 66075-110 Belém, PA, Brazil. (LBS) lidia_brasil@yahoo.com, ORCID 0000-0002-8844-2799, (LFAM) lfamontag@gmail.com, ORCID 0000-0001-9370-6747, (CMCL) lobatocmc@gmail.com, ORCID 0000-0001-7306-2569

[3]Laboratório de Ecologia Aquática, Universidade do Estado de Minas Gerais, Av. Juca Stockler, 1130, Belo Horizonte, 37900-106 Passos, Brazil. nbenone@gmail.com, ORCID 0000-0003-4155-9938

Abstract

Compared to the accelerated progress of environmental degradation in Amazonian ecosystems, the development of studies to support conservation efforts is slow, because it demands substantial financial and logistical investment. Intending to contribute to stream monitoring with rapid analyses, this study aimed to test the feasibility of using species composition for taxonomic families as biological surrogates of species and functional diversity in stream fish assemblages in an impacted region of the Brazilian Amazon during two seasonal periods. Sampling was conducted in 18 streams in northern Brazil, in a region heavily impacted by industrial activities and urbanization. We observed a high potential for using families Acestrorhamphidae and Cichlidae as biological surrogates. Overall, the family Cichlidae showed potential in representing species composition and functional structure in stream fish across seasonal variation. The congruence between Acestrorhamphidae, Cichlidae, and the fish assemblages was particularly high during the rainy season, in both taxonomic and functional dimensions. During the dry season, Acestrorhamphidae showed high congruence only with species

abundance. These findings contribute to monitoring strategies for impacted streams in a scenario of limited financial resources and expert availability.

Keywords: Biological surrogates, Congruence, Species diversity, Functional structure, Rapid monitoring.

Statements and Declarations

Acknowledgements

The authors are grateful to B. E. Soares, F. Valente-Neto, G. L. Brejão, J. C. G. Ortega, K. B. Machado, R. L. B. Santos, and T. M. S. Freitas for the constructive comments on the manuscript. We also acknowledge the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the PhD scholarship of L.L.S (protocol number 1840342/2019-4), the Alumina do Norte do Brasil for funding, logistic support and scholarships for LLS, CMCL, LBS, NLB, the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for research scholarship of LFAM (protocol number 302881/2022-0), and the Universidade do Estado de Minas Gerais for the research scholarship to NLB (PAPq/UEMG 15/2024).

Authors contributions

All authors contributed to the study conception and design. Fieldwork and sample collection were performed by LLS, NLB, LBS, and CML. LLS conducted formal analysis and wrote the first draft of the manuscript. LFAM supervised all stages of the project. All authors critically reviewed, edited, and approved the final manuscript.

Ethical Approval

The collection and euthanasia of fish specimens were conducted under approval from the Ethics Committee on Animal Use of the Universidade Federal do Pará (CEUA UFPA; protocol no. 8293020418).

Consent to Participate

This is not applicable

Consent to Publish

This is not applicable

Data availability

All data and code used in this study are available in a curated dataset on Figshare (https://doi.org/10.6084/m9.figshare.30862277).

Competing Interests

The authors declare no competing interests.

Introduction

The conservation of freshwater biodiversity is closely linked to human well-being as environmental damages are converted into social losses through impacts on ecosystem services (Cunha et al., 2022a; Pelicice et al., 2022; Lynch et al., 2023). However, scientific evidence of these losses has not been sufficient to reduce anthropogenic impacts on the environment, especially in streams, which are among the most threatened ecosystems in the world (Graziano et al., 2022).

In the Brazilian Amazon, the intense modification of natural ecosystems due to anthropogenic actions and the reduction in federal funding for conservation research are alarming (Rodrigues, 2022). Around urban and/or industrial centers, there are several streams impacted by fragmentation of water bodies or degradation of riparian vegetation (Freitas et al., 2022; Albert et al., 2023). Currently, about 14% of the Brazilian Amazonian forest has been converted for production activities, highlighting the threats to which the aquatic biota is exposed (Albert et al., 2023).

In this scenario, the search for efficient, rapid, and inexpensive analyses has become more important for monitoring and preventing the loss of ecosystem services (Heino, 2010).

Biological surrogacy is a valid alternative, which consists of using diversity patterns (e.g., abundance or incidence) of a group as indicators of local diversity, thereby reducing time and effort needed in studies (Caro & O'Doherty, 1999). In situations where the financial, logistics, and time resources are limited, the use of biological surrogates may enable implementation of biomonitoring (Sato et al., 2019). Nonetheless, the efficacy of this approach requires previous studies to test the potential of the target group as a biological surrogate (Stewart et al., 2018; Sato et al., 2019). The most common way to perform such tests is through the congruence analysis (Fattorini et al., 2012).

Generally, low congruence has been found between taxonomic groups of freshwater organisms (Stewart et al., 2018; Faquim et al., 2021). This results from the divergence in the organism's responses to spatial and environmental constraints. However, if a more restricted taxon is considered, this divergent response is expected to be higher between subgroups than within subgroups. Thus, congruence analysis using subgroups of the same taxon has been more successful in identifying potential indicators of biodiversity (Stewart et al., 2018). For instance, Slimani et al. (2019) suggested that Coleoptera and Ephemeroptera are good indicators of species diversity in macroinvertebrate communities. Additionally, high congruence was observed between families and species of Odonata insects in Amazonian streams (Mendoza-Penagos et al., 2021). In studies of stream fish assemblages, the congruence between taxonomic levels (family and genus or species and genus) and taxonomic subsets (Characiformes order) was tested and demonstrated high potential in representing species diversity (Faquim et al., 2021; Martins et al., 2022; Valente-Neto et al., 2025).

The success of a biological surrogate group is related to its capacity to adapt to various habitat types, occupy different niches, and have a significant contribution to the community structure (Barbosa et al., 2019; Slimani et al., 2019; Santos et al., 2022). Considering these aspects, analyses of potential biological surrogates should include sources of natural and anthropogenic perturbations that alter the environment and the availability of resources for the organisms (Borba et al., 2021; Cantanhêde & Montag, 2023). The effect of human impacts on the selection of indicators in stream ecosystems can be exemplified by the study of Arimoro and Keke (2021), who analyzed communities of aquatic macroinvertebrates and suggested different indicators for impacted and non-impacted streams.

To the best of our knowledge, there have been no studies on the effects of seasonal variations on biological surrogacy until now. However, the seasonal variation is associated with important changes in stream structure and physicochemical properties of water, which influence the stream biota (Brimacombe et al., 2021; Lafuente et al., 2023). For example, solar incidence and water temperature decrease during the rainy season, while water volume and turbidity increase (Brimacombe et al., 2021; Ferreira et al., 2021; Resende et al., 2021). Additionally, the stream overflow and heavy rain during this season increase the availability of terrestrial resources for aquatic organisms (Barreto et al., 2018; Benone et al., 2020). Particularly in impacted streams, the quality of water is affected by

seasonal changes, leading to the dilution of pollutants (Groh et al., 2019; Ferreira et al., 2021).

The taxonomic and functional structure of ichthyofauna is closely related to the environmental dynamics of streams and plays a key role in essential ecosystem processes and services, such as nutrient cycling and providing food for human populations (Peressin & Cetra, 2014; Dala-Corte et al., 2020; Torres-Bejarano et al., 2022). This close relationship with the environment increases the potential of stream fish to be used as indicators in biological surrogacy (Santos et al., 2022). Nevertheless, there are several challenges linked to fish research in the Amazon biome, such as the difficulty in identifying organisms at the species level (Jézéquel et al., 2020). The megadiversity of fish in the Amazon is coupled with a significant knowledge gap (Freitas et al., 2021), and these factors make fish identification lengthy and often require experts who are not always available (Jézéquel et al., 2020; Freitas et al., 2021). To expedite the development of studies, biological surrogacy can be used as an alternative to reduce the number of individuals that need to be identified (Morais et al., 2018). This approach was tested in conserved Amazonian streams where taxonomic families showed great potential as indicators of the local species diversity (Santos et al., 2022).

This study aimed to test the feasibility of using species composition of taxonomic families as biological surrogates of species and functional diversity of stream fish assemblages in an impacted region in the eastern Brazilian Amazon during two seasonal periods. We expect that the families Cichlidae and Lebiasinidae will exhibit high potential as indicators due to their high plasticity in trophic habits and habitat occupation, which allows them to tolerate environmental changes over time (Brejão *et al.*, 2013; Zuanon *et al.*, 2015; Soares *et al.*, 2020). Furthermore, it is expected that seasonal variation will influence the potential of families as biological surrogates, with the family Lebiasinidae exhibiting higher potential during the rainy season because it is composed of fish species that efficiently explore both the main channel and lateral pools formed during this period (Espírito-Santo & Zuanon, 2017; Borba et al., 2021).

Material and Methods

Study area

Eighteen streams were sampled in the Itaporanga and Murucupi river basins, located in Barcarena, Pará State, in northern Brazil (Fig. 1). The region's climate is classified as tropical warm and humid, with an average temperature of 27 °C and low

annual variability (Porfírio et al., 2020). The total annual rainfall is 2,532 mm. The dry season occurs between June and November, while the rainy season extends from December to May (Moraes et al., 2005). Barcarena is an important industrial center; therefore, the local environment has been strongly altered by urbanization, industrial activities, and port operations (Silveira et al., 2019).

Landscape transformation in the Barcarena region began in 1985 with the establishment of international mining companies (Furtado et al., 2020). To meet the demands of these industrial facilities, the local population grew rapidly, leading to the simultaneous expansion of urban and peri-urban areas across the municipality (Nascimento & Hazeu, 2015; Nahum, 2017).

The aquatic environments have also been affected by these anthropogenic pressures, especially the Murucupi River basin, where most of the industrialized areas are located (Furtado et al., 2020). In this basin, approximately 40% of the natural vegetation has been deforested, and the lack of basic sanitation has led to illegal dumping sites and the discharge of domestic sewage into tributaries draining the urbanized center (Almeida-Junior et al., 2019; Furtado et al., 2020). Additionally, water quality in the Murucupi River basin is frequently degraded by environmental accidents originating from the industrialized region (Medeiros et al., 2017).

The Itaporanga River basin is located farther from urban areas, with vegetation cover predominantly consisting of native forests. In this region, landscape alterations mainly originate from traditional communities' farming lands, family farming, and small-scale pastures (Da Silva Junior et al., 2023).

Previous analyses have shown that the studied streams share similar environmental conditions, often exhibiting signs of degradation and eutrophication (Bastos et al., 2021; Cunha et al., 2022b; Sousa et al., 2024). On average, the local vegetation cover is 75%, and the water is acidic (average pH 5.35), with a conductivity of 0.057 mS/cm and a temperature of 25.5 °C (Bastos et al., 2021; Cunha et al., 2022b; Sousa et al., 2024). According to the standards established by the Brazilian Environmental Council (CONAMA Resolution number 357/2005), these streams are classified as having poor water quality due to exceeding the permissible limits of toxic metals such as chromium, aluminum, barium, and manganese (Cunha et al., 2022b).

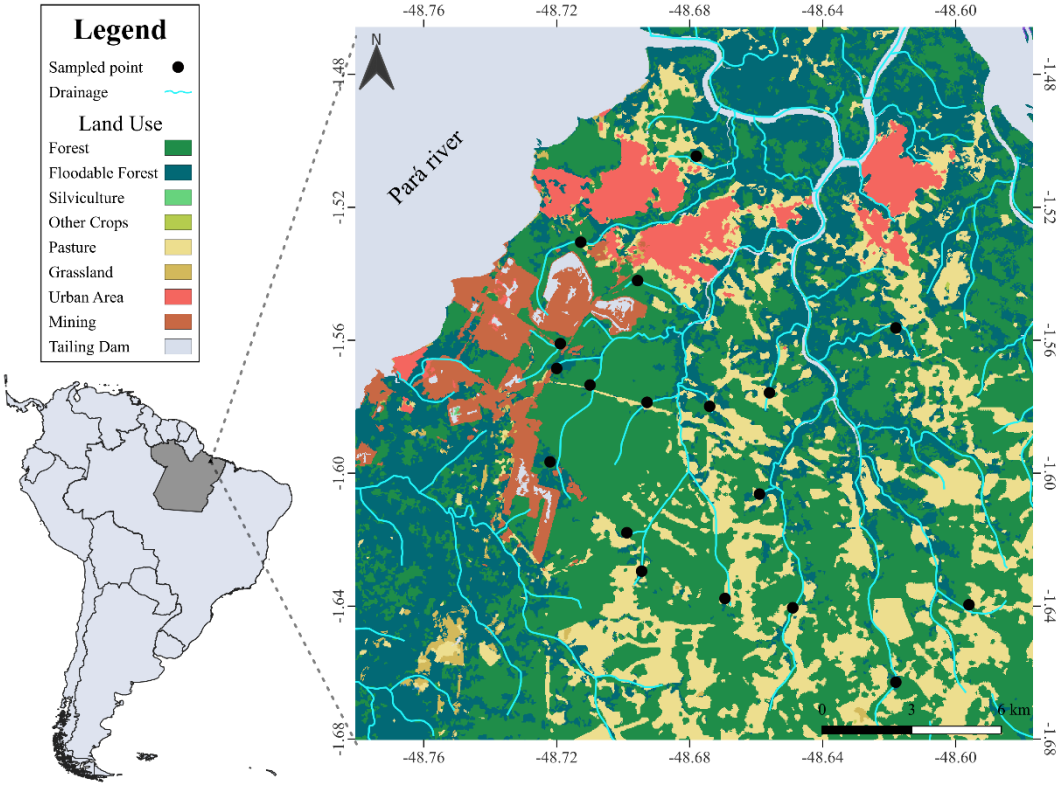

Fig. 1 Localization of 18 streams sampled during the rainy seasons of 2018–2019, the dry season of 2019, the dry season of 2023, and the rainy season of 2024 in Barcarena, Pará State, northern Brazil.

Sampling design

Sampling was conducted during five expeditions: three in the rainy seasons of 2018, 2019, and 2024, and two in the dry seasons of 2019 and 2023. In total, 18 streams were sampled: two in the Murucupi basin and sixteen in the Itaporanga River basin. The rainy season expeditions of 2018 and 2019 included eight streams; six streams were sampled during the dry season of 2019; and thirteen streams were sampled during the dry season of 2023, and the rainy season of 2024.

This uneven distribution reflects both the greater availability of accessible streams in the Itaporanga basin and logistical limitations for repeated sampling in the industrialized Murucupi basin. Notably, there was an interruption in field activities between 2020 and 2022 due to the COVID-19 pandemic and associated logistical restrictions.

In each stream, a 50-meter stretch was sampled, subdivided into five longitudinal sections of 10 meters each. Each 50-meter stretch constitutes a sample unit. In the

220 statistical analysis, the data from the five expeditions were analyzed separately. The
221 variation in the number of streams sampled across expeditions was due to a combination
222 of factors, including field access restrictions, stream conditions, and safety issues.
223
224 **Sampling of fish specimens**
225 The fish were captured using sieve nets and seine nets. First, circular sieve nets
226 measuring 55 cm in diameter and 3 mm mesh were used. The sampling effort was two
227 hours per 50-meter stretch, with the time divided among the collectors. Subsequently, a
228 seine net measuring 2 meters, a height of 1.5 meters, and a 3 mm mesh was used to sample
229 each 50-meter stretch 10 times.
230 After capture, the fish specimens were euthanized with a lethal dose of eugenol
231 anesthetic, fixed in 10% formalin, and then, after 48 hours, conserved in 70% alcohol. In
232 the laboratory, the specimens were identified using taxonomic keys and consultations
233 with specialists.
234 The expeditions were authorized by the Brazilian environmental agency Instituto
235 Chico Mendes de Conservação da Biodiversidade, under license number 4681-1 and
236 SISBIO N°. 17070-3/2021. The procedures for capturing and conserving fish specimens
237 were approved by the Ethics Committee of the Universidade Federal do Pará (CEUA
238 UFPA protocol no. 8293020418). All the captured fish were deposited in the university
239 collection at the Museu de Zoologia do Instituto de Ciências Biológicas, in the city of
240 Belém, Pará state, northern Brazil.
241
242 **Functional traits**
243 The description of the assemblage functional structure was based on seven
244 functional traits, comprising both qualitative and quantitative measures related to feeding,
245 habitat use, locomotion, and life history (Table 1). All traits were obtained from scientific
246 publications by searching for combinations of species names and specific trait terms, such
247 as 'feeding' or 'parental care,' as keywords. When species-level information was
248 unavailable, data at the genus or family level were used.
249
250 **Table 1** Type, values, ecological interpretation, and functional category of functional
251 traits used to describe the functional structure of fish assemblages.

Trait	Type	Values	Ecological interpretation	Functional category

Diet	Fuzzy	Autochthonous invertivore Allochthonous invertivore Carnivore Algivore Herbivore Detritivore 0 = absent; 1 = rarely consumed; 2 =frequently consumed; 3 = dominant	Fish diets are related to nutrient cycling in the environment (Villéger et al., 2017). In addition, the food items consumed are influenced by local and regional environmental characteristics (Zeni *et al*., 2019).	Feeding
Feeding habit	Categorical	Grazer Surface feeder Backwater feeder Substrate speculators Ambush predator Active predator	Feeding habits indicate the fish's strategy for food acquisition and the water layer in which feeding activities occur (Brejão *et al*., 2013).	Feeding, Habitat use
Mouth position	Ordinal	Inferior Superior Terminal Subterminal Protactil	The mouth position indicates the type of environment in which the species forages (Gatz Jr., 1979; Watson & Balon, 1984).	Feeding, Habitat use
Vertical position	Ordinal	Nektonic Nektobenthic Benthic	The main habitat used by the fish species is related to species coexistence, feeding habits, and vertical translocation of nutrients (Villéger *et al*., 2017).	Habitat use
Body form	Categorical	Compressed Depressed Fusiform Elongated Anguilliform	Fish body shape is related to swimming endurance and maneuverability capacity (Gatz Jr., 1979).	Locomotion , Habitat use
Body size	Quantitative	Standard length (cm)	Fish body size affects its ability to swim and prey size (Watson & Balon, 1984; Villéger *et al*., 2017).	Habitat use, Locomotion
Parental care	Binary	Careless Carefully	The presence of parental care indicates a high reproductive investment, these species are usually associated with highly structured habitats (Espírito-Santo *et al*., 2013).	Life history

252
253 Our dataset includes information from the FishBase database (Froese & Pauly,
254 2025) and 85 relevant scientific articles (Supplementary Table S1). The diet trait
255 encompasses six trophic guilds: autochthonous invertivore, allochthonous invertivore,
256 carnivore, algivore, herbivore, and detritivore. Each species was assigned a value from 0
257 to 3 for each guild, where 0 indicates no affinity and 3 indicates a high degree of affinity.
258 These data were subsequently transformed using fuzzy logic (Chevene et al., 1994). The
259 parental care trait was converted into binary values, with 1 indicating the presence and 0
260 the absence of parental care behaviors.
261
262 **Data analysis**
263 To accurately represent the ichthyofauna, we selected families with at least three
264 species that occur in a minimum of six streams within the same sampling period.
265 Subsequently, the congruence between the patterns of species distribution and functional
266 structure organized per family and assemblage was analyzed.
267 The species abundance and incidence data were analyzed, with the abundance data
268 transformed using log (x+1) to reduce the influence of extreme values. To test the
269 congruence between the functional structure represented by families and assemblages,
270 community-weighted means (CWM) were calculated to determine the contribution of
271 each functional trait to each stream for both groups. Dissimilarity matrices were created
272 using the Bray-Curtis method for abundance data, Jaccard coefficients for incidence data,
273 and Gower distances for functional composition.
274 The data were then summarized using Principal Coordinate Analysis (PCoA,
275 Legendre & Legendre, 2012). The congruence between the distribution of taxonomic and
276 functional composition matrices for each family and the matrix of all species was assessed
277 using Procrustes analysis with 10,000 permutations ($p < 0.05$) (Rohlf & Bookstein, 1990).
278 In the Procrustes analysis, the abundance and incidence matrices of families were
279 compared to a matrix that included all species (family abundance *vs.* species abundance
280 and family incidence *vs.* species incidence). Additionally, the functional structure of
281 families and species was tested using the CWM matrices. Families showing congruence
282 higher than 50% in the comparisons were considered to have good potential as biological
283 surrogates.
284 All analyses were performed using the R program (R Core Team, 2024), with the
285 packages FD and vegan (Laliberté et al., 2014; Oksanen et al., 2024). CWM matrices

were calculated using the *functcomp* function, dissimilarity matrices were computed using the *vegdist* function, PCoA was conducted using the *cmdscale* function, and Procrustes analysis was performed using the *protest* function.

Results

In total, 4,198 fish specimens were captured: 875 during the rainy season of 2018, 996 during the rainy season of 2019, 645 during the dry season of 2019, 1,159 during the dry season of 2023, and 523 during the rainy season of 2024. These fish belong to eight orders, 22 families, and 51 species (Supplementary Table S2). The most speciose families were Cichlidae and Acestrorhamphidae, with nine and eight species, respectively. The most abundant species was *Hyphessobrycon heterorhabdus* with 1,923 individuals, representing 45.8% of the total catch.

During the rainy seasons of 2018 and 2019, *H. heterorhabdus* was the most abundant species (426 and 478 individuals, respectively), followed by *Copella arnoldi* (97 and 104, respectively). In the dry season of 2019, *H. heterorhabdus* was again the most abundant (326 individuals), followed by *Iguanodectes rachovii* (88). In the dry season of 2023, *H. heterorhabdus* (546 individuals) was followed by *Apistogramma* gr. *regani* (209), and during the rainy season of 2024, *H. heterorhabdus* (147 individuals) and *Hemigrammus rodwayi* (58) were the most abundant species (Supplementary Table S2).

Only the families Acestrorhamphidae, Cichlidae, and Lebiasinidae met the predefined requirements (containing at least three species and occurring in at least six streams) in at least one of the analyzed periods. In the Procrustes analysis, the family Acestrorhamphidae showed similarity with the species abundance matrix in all periods, except for the dry season of 2019, with congruence varying from 73% to 94% (Table 2, Fig.2). Regarding incidence and functional patterns, the family Cichlidae was congruent with the species matrix during all periods, with congruence levels ranging from 64% to 84% for incidence and from 56% to 77% for functional data (Table 2, Fig.2).

However, when considering the three approaches used (family abundance vs. species abundance, family incidence vs. species incidence, and family functional structure vs. species functional structure), both Acestrorhamphidae and Cichlidae showed consistent results during the rainy seasons of 2019 and 2024. During these periods, the extreme congruence values were detected for Acestrorhamphidae: functional congruence

reached 63% in rainy season of 2024, reaching up to 83% with abundance data from the rainy season of 2019 (Table 2, Fig. 2).

In general, patterns for the family Lebiasinidae showed low congruence with the species matrix, though isolated high concordance levels were detected using abundance and incidence data (Table 2, Fig. 2).

Table 2 Results of the Procrustes analysis between families and assemblages of fish captured at 18 streams sampled during the rainy seasons of 2018–2019, the dry season of 2019, the dry season of 2023, and the rainy season of 2024 in Barcarena, Pará State, northern Brazil.

Season	Year	Family	Samples	Species	Abundance data		Incidence data		Functional data	
					r	p	*r*	p	*r*	p
Rainy	2018	Acestrorhamphidae	8	3	**0.94**	**< 0.001**	0.68	0.054	0.59	0.104
Rainy	2018	Lebiasinidae	6	3	**0.80**	**0.020**	0.66	0.133	0.70	0.133
Rainy	2019	Acestrorhamphidae*	8	3	**0.83**	**0.003**	**0.78**	**0.009**	**0.63**	**0.047**
Rainy	2019	Cichlidae	6	4	0.77	0.080	**0.84**	**0.030**	**0.77**	**0.047**
Rainy	2019	Lebiasinidae	7	3	0.51	0.407	**0.79**	**0.012**	0.39	0.692
Rainy	2024	Acestrorhamphidae	13	6	**0.73**	**< 0.001**	**0.59**	**0.012**	0.17	0.920
Rainy	2024	Cichlidae*	11	6	**0.64**	**0.021**	**0.64**	**0.017**	**0.66**	**0.047**
Rainy	2024	Lebiasinidae	7	3	0.32	0.825	**0.76**	**0.030**	0.57	0.292
Dry	2019	Acestrorhamphidae	6	3	0.75	0.079	0.61	0.233	0.59	0.341
Dry	2023	Acestrorhamphidae	13	4	**0.70**	**0.006**	0.35	0.409	0.47	0.131
Dry	2023	Cichlidae	12	5	0.50	0.096	**0.79**	**0.002**	**0.56**	**0.032**
Dry	2023	Lebiasinidae	12	3	**0.66**	**0.030**	0.49	0.124	0.50	0.077

*Congruence between the family and the assemblages was higher than 50% ($p < 0.05$) in all three comparisons.

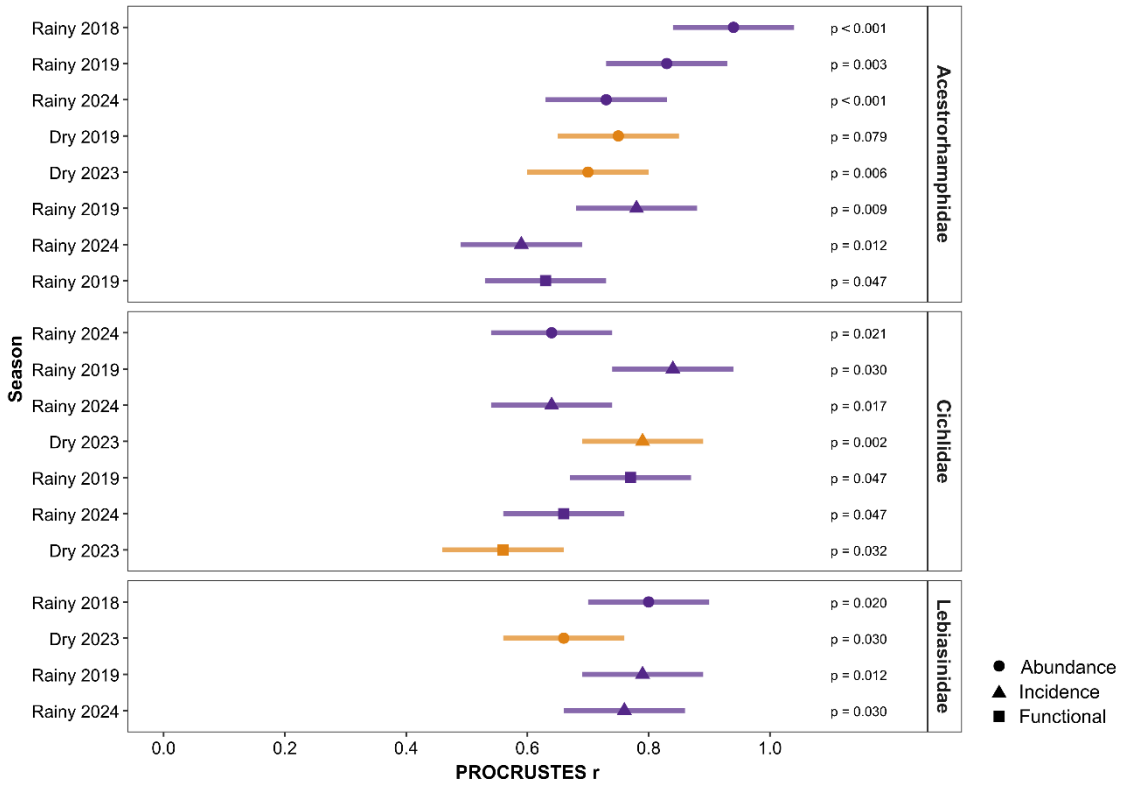

Fig. 2 Significant associations in the Procrustes analysis between families and assemblages of fish captured at 18 streams sampled during the rainy seasons of 2018–2019, the dry season of 2019, the dry season of 2023, and the rainy season of 2024 in Barcarena, Pará State, northern Brazil. Colors represent the rainy (purple) and dry (orange) seasons.

Discussion

In our search for biological surrogates, we identified the families Acestrorhamphidae and Cichlidae as having particularly high potential to represent the taxonomic and functional diversity of stream fish species in a region affected by urbanization and industrial activities. Across seasonal variations, the Cichlidae family consistently represented the species taxonomic composition and functional structure.

The congruence between Acestrorhamphidae, Cichlidae, and the fish assemblages was particularly high during the rainy season, in both taxonomic and functional dimensions. During the dry season, Acestrorhamphidae showed high congruence only with species abundance. These patterns support our hypothesis that seasonal variations influence the selection of indicators for use in biological surrogacy. Considering these effects, this study's suggestion of using families as indicators of species diversity is a

valid approach for the rapid monitoring of impacted streams in the eastern Amazon region.

Our results agree with studies that assessed the congruence between fish species diversity and taxonomic subsets, which found that the order Characiformes serves as a good surrogate for stream fish assemblages in a gradient of riparian deforestation (Martins et al., 2022; Valente-Neto et al., 2025). In addition, findings from Amazonian conserved streams suggest particularly the families Cichlidae and Acestrorhamphidae (previously part of Characidae) as potential biological surrogates (Santos et al., 2022).

This potential attributed to both families, Acestrorhamphidae and Cichlidae, is a result of their strong contribution to the structure of stream fish assemblages, combined with high plasticity in feeding and functional traits of their component fish species (Barros et al., 2017; Santos et al., 2019; Benone et al., 2020). The assemblage structure was also a relevant factor for the selection of indicator families in this study. Cichlidae and Acestrorhamphidae are the most speciose families among the captured fish. Nonetheless, the family Lebiasinidae, despite its significant contribution to species richness and abundance, did not show good potential as a biological surrogate, partially contradicting our hypothesis.

Anthropogenic impacts on the studied streams are likely the reason for the low potential as an indicator observed for the family Lebiasinidae, given its association with heterogeneous habitats (Santos et al., 2019; Severo-Neto et al., 2023). This makes Lebiasinidae fish less representative of the assemblages in impacted streams, where environmental heterogeneity is low, and habitats are consequently favorable to colonization by habitat-generalist fish species (Cantanhêde & Montag, 2023). In the studied streams, human impacts promote an increase in the abundance of omnivorous species, with opportunist habits and high trophic plasticity, such as species from the genera *Apistogramma* (Cichlidae), *Hyphessobrycon*, and *Hemigrammus* (both Acestrorhamphidae) (Gonçalves et al., 2013; Barreto et al., 2018; Benone et al., 2020; Virgilio et al., 2020), which are more tolerant to common environmental changes in impacted streams, like reduction in riparian vegetation cover, siltation, and substrate homogenization (Cantanhêde et al., 2021; Jacob et al., 2021).

The consistent potential of the Cichlidae family to represent both species taxonomic composition and functional structure across seasonal changes is linked to its capacity to sustain high diversity throughout all periods in Amazonian streams (van der Sleen & Albert, 2017; Fróis et al., 2021). Such stability is provided by the versatility of

384 the family Cichlidae (Kuhn et al., 2020). For instance, species like *Aequidens tetramerus*
385 and *Acaronia nassa* are omnivorous, feed on heterogeneous substrates along stream
386 margins, and can change their diet according to the food items available in that habitat
387 through seasonal variations (Hawlitschek et al., 2013; Costa & Soares, 2015). Another
388 mechanism adopted by the family Cichlidae is active predation, exemplified by species
389 of the genus *Saxatilia*, which possess high swimming capacity and explore different
390 habitats during environmental fluctuations (Montaña & Winemiller, 2009, 2013).
391 Cichlids may also adopt these strategies in streams impacted by human activities (Costa
392 & Soares, 2015; Barbosa et al., 2020).
393 The effect of seasonal variation on the selection of biological surrogates was
394 particularly evident in changes in the congruence of the family Acestrorhamphidae with
395 the fish assemblage over time. Due to its ecological particularities, Acestrorhamphidae
396 fish showed particularly high congruence with the taxonomic and functional aspects
397 during the rainy season, a moment when the stream environment is favorable for the
398 exploration by nektonic fish species (Espírito-Santo et al., 2013; van der Sleen & Albert,
399 2017). During the rainy season, increased rainfall causes intense structural and
400 hydrological alterations in the streams (Espírito-Santo et al., 2009), especially through
401 stream overflow, which changes existing fish habitats and expands the area inhabited by
402 nektonic fish (Espírito-Santo & Zuanon, 2017; Benone et al., 2020). Additionally, the
403 stream characteristics during the rainy season also benefit tetras because of their
404 opportunistic feeding habitats, which may include a diet mainly composed of terrestrial
405 insects (Gonçalves et al., 2013; Barreto et al., 2018). The diet, reproductive strategies,
406 and morphology of the family Acestrorhamphidae allow its species to adapt to seasonal
407 variation and intense habitat degradation (Lourenço et al., 2012; Zeni et al., 2020;
408 Cantanhêde et al., 2021).
409 During the dry season, the family Acestrorhamphidae demonstrated strong
410 potential as biological surrogates for the abundance, but not for the taxonomic
411 composition and functional structure of fish assemblages. This is largely due to their high
412 and consistent abundance across all seasons (Supplementary Table S2). In this period,
413 fish are restricted to the stream channel, where a balanced distribution of microhabitats
414 supports a diverse community of species with specialized traits (Espírito-Santo et al.,
415 2009). This condition makes Acestrorhamphids less representative of the fish assemblage
416 due to their low specialized features, characteristics of small tetras, such as those from

the genera *Hyphessobrycon* and *Hemigrammus* (Brejão et al., 2013; van der Sleen & Albert, 2017).

Conclusion

The selection of potential families to be used as biological surrogates in this study represents an alternative to rapid biomonitoring in Amazonian streams. Considering seasonal variations, it is valid to use the families Acestrorhamphidae and Cichlidae surrogates in impacted streams to reduce the time and costs of ichthyofauna analysis. Additionally, the congruence observed here between families and assemblages suggests that responses of fish assemblage may also be represented by taxonomic families (Griffith & McManus, 2020). Based on this principle, the applications of biological surrogacy include, for example, the detection and monitoring of impacts caused by urbanization, industrialization, and habitat fragmentation, which are commonly found in the Amazonian biome (Peterson et al., 2011; Gardner et al., 2013; Griffith & McManus, 2020). Recently, the funding of Brazilian science has experienced severe decay, while the environmental degradation due to human activities continues to accelerate and reach notably high levels (Hallal, 2021; Rodrigues, 2022). The consequence of this imbalance is expected to extend for several years. During this period, the planning of emergency strategies, such as the use of biological surrogates, may be crucial to accelerate the implementation of biodiversity monitoring.

References

Albert, J. S., A. C. Carnaval, S. G. A. Flantua, L. G. Lohmann, C. C. Ribas, D. Riff, J. D. Carrillo, Y. Fan, J. J. P. Figueiredo, J. M. Guayasamin, C. Hoorn, G. H. De Melo, N. Nascimento, C. A. Quesada, C. Ulloa Ulloa, P. Val, J. Arieira, A. C. Encalada, & C. A. Nobre, 2023. Human impacts outpace natural processes in the Amazon. Science 379: eabo5003. https://doi.org/10.1126/science.abo5003.

Almeida-Junior, C. F. D., L. P. Silva, M. A. B. Santos, & R. P. Ribeiro, 2019. Análise físico-química da água do rio Murucupi localizado no município de Barcarena-PA. Brazilian Journal of Development 5: 21292–21301. https://doi.org/10.34117/bjdv5n10-287.

Arimoro, F. O., & U. N. Keke, 2021. Stream biodiversity and monitoring in North Central, Nigeria: the use of macroinvertebrate indicator species as surrogates. Environmental Science and Pollution Research 28: 31003–31012. https://doi.org/10.1007/s11356-021-12922-w.

452 Barbosa, A. S., M. M. Pires, & U. H. Schulz, 2020. Influence of Land-Use Classes on the
453 Functional Structure of Fish Communities in Southern Brazilian Headwater Streams.
454 Environmental Management 65: 618–629. https://doi.org/10.1007/s00267-020-01274-9.

455 Barbosa, H. O., K. Borges Machado, M. Carvalho Vieira, H. Rodrigo Pereira, L.
456 Fernandes Gomes, J. Carlos Nabout, F. Barreto Teresa, & L. C. G. Vieira, 2019.
457 Alternatives for the biomonitoring of fish and phytoplankton in tropical streams.
458 Neotropical Biology and Conservation 14: 361–380.
459 https://doi.org/10.3897/neotropical.14.e38088.

460 Barreto, S. B., A. T. Silva, F. B. Souza, & R. Jucá-Chagas, 2018. Diet of Hemigrammus
461 marginatus (Characiformes: Characidae) in the Upper Contas River, Diamantina Plateau
462 (Bahia, Brazil). Iheringia. Série Zoologia 108:. https://doi.org/10.1590/1678-
463 4766e2018036.

464 Barros, G., J. Zuanon, & C. Deus, 2017. Effects of species co-occurrence on the trophic-
465 niche breadth of characids in Amazon forest streams. Journal of Fish Biology 90: 326–
466 340. https://doi.org/10.1111/jfb.13183.

467 Bastos, R. C., J. Brito, E. Cunha, G. M. Cruz, J. L. S. Pereira, J. Vieira, & L. Juen, 2021.
468 Environmental impacts from human activities affect the diversity of the Odonata (Insecta)
469 in the Eastern Amazon. International Journal of Odonatology 24: 300–315.
470 https://doi.org/10.23797/2159-6719_24_22.

471 Benone, N. L., C. M. C. Lobato, B. E. Soares, & L. F. de A. Montag, 2020. Spatial and
472 temporal variation of the diet of the flag tetra *Hyphessobrycon heterorhabdus*
473 (Characiformes: Characidae) in streams of the Eastern Amazon. Neotropical Ichthyology
474 18: e200078. https://doi.org/10.1590/1982-0224-2020-0078.

475 Borba, G. C., F. R. C. Costa, H. M. V. Espírito-Santo, R. P. Leitão, M. S. Dias, & J.
476 Zuanon, 2021. Temporal changes in rainfall affect taxonomic and functional composition
477 of stream fish assemblages in central Amazonia. Freshwater Biology 66: 753–764.
478 https://doi.org/10.1111/fwb.13675.

479 Brejão, G. L., P. Gerhard, & J. Zuanon, 2013. Functional trophic composition of the
480 ichthyofauna of forest streams in eastern Brazilian Amazon. Neotropical Ichthyology 11:
481 361–373. https://doi.org/10.1590/S1679-62252013005000006.

482 Brimacombe, C., K. Bodner, & M. Fortin, 2021. Inferred seasonal interaction rewiring of
483 a freshwater stream fish network. Ecography 44: 219–230.
484 https://doi.org/10.1111/ecog.05452.

485 Cantanhêde, L. G., A. Luiza-Andrade, H. Leão, & L. F. de A. Montag, 2021. How does
486 conversion from forest to pasture affect the taxonomic and functional structure of the fish
487 assemblages in Amazonian streams? Ecology of Freshwater Fish 30: 334–346.
488 https://doi.org/10.1111/eff.12589.

489 Cantanhêde, L. G., & L. F. D. A. Montag, 2023. Effects of deforestation on environmental
490 heterogeneity and its role in the distribution of fish species and functional groups in
491 Amazonian streams. Hydrobiologia . https://doi.org/10.1007/s10750-023-05201-x.

492 Caro, T. M., & G. O'Doherty, 1999. On the use of surrogate species in conservation
493 biology. Conservation Biology 13: 805–814. https://doi.org/10.1046/j.1523-
494 1739.1999.98338.x.

495 Chevene, F., S. Doleadec, & D. Chessel, 1994. A fuzzy coding approach for the analysis
496 of long-term ecological data. Wiley Online Library. Freshwater biology 31: 295–309.
497 https://doi.org/10.1111/j.1365-2427.1994.tb01742.x.

498 Costa, I. D. da, & M. O. Soares, 2015. The seasonal diet of Aequidens tetramerus
499 (Cichlidae) in a small forest stream in the Machado River basin, Rondônia, Brazil. Acta
500 Amazonica 45: 365–372. https://doi.org/10.1590/1809-4392201500223.

501 Cunha, D. G. F., W. A. Saltarelli, J. M. M. Bega, N. R. Finkler, M. Souza Ferreira, T. H.
502 Furley, D. Schiller, & W. K. Dodds, 2022a. Assessing Restoration of Ecosystem
503 Functioning in Brazilian Subtropical and Tropical Streams. Limnology and
504 Oceanography Bulletin 31: 6–11. https://doi.org/10.1002/lob.10480.

505 Cunha, E. J., G. M. Cruz, A. P. J. Faria, J. N. D. Oliveira, & L. Juen, 2022b. Urban
506 development and industrialization impacts on semiaquatic bugs diversity: A case study in
507 eastern Amazonian streams. Water Biology and Security 1: 100061.
508 https://doi.org/10.1016/j.watbs.2022.100061.

509 Da Silva Junior, O. G., M. A. M. Vasconcelos, P. C. S. Bittencourt, L. C. Miranda, P. A.
510 De Melo, A. V. F. Dos Santos, K. C. P. Melo, L. V. Cecim, & J. A. B. Pimentel, 2023.
511 Uso e cobertura da terra da bacia hidrográfica do Rio Itaporanga – Barcarena na
512 Amazonia Paraense. OBSERVATÓRIO DE LA ECONOMÍA LATINOAMERICANA
513 21: 4861–4885. https://doi.org/10.55905/oelv21n6-090.

514 Dala-Corte, R. B., A. S. Melo, T. Siqueira, L. M. Bini, R. T. Martins, A. M. Cunico, A.
515 M. Pes, A. L. B. Magalhães, B. S. Godoy, C. G. Leal, C. S. Monteiro-Júnior, C. Stenert,
516 D. M. P. Castro, D. R. Macedo, D. P. Lima-Junior, É. A. Gubiani, F. C. Massariol, F. B.
517 Teresa, F. G. Becker, F. N. Souza, F. Valente-Neto, F. L. Souza, F. F. Salles, G. L. Brejão,
518 J. G. Brito, J. R. S. Vitule, J. Simião-Ferreira, K. Dias-Silva, L. Albuquerque, L. Juen, L.
519 Maltchik, L. Casatti, L. Montag, M. E. Rodrigues, M. Callisto, M. A. M. Nogueira, M.
520 R. Santos, N. Hamada, P. A. Z. Pamplin, P. S. Pompeu, R. P. Leitão, R. Ruaro, R.
521 Mariano, S. R. M. Couceiro, V. Abilhoa, V. C. Oliveira, Y. Shimano, Y. Moretto, Y. R.
522 Súarez, & F. de O. Roque, 2020. Thresholds of freshwater biodiversity in response to
523 riparian vegetation loss in the Neotropical region. Journal of Applied Ecology 57: 1391–
524 1402. https://doi.org/10.1111/1365-2664.13657.

525 Espírito-Santo, H. M. V., W. E. Magnusson, J. Zuanon, F. P. Mendonça, & V. L.
526 Landeiro, 2009. Seasonal variation in the composition of fish assemblages in small
527 Amazonian forest streams: evidence for predictable changes. Freshwater Biology 54:
528 536–548. https://doi.org/10.1111/j.1365-2427.2008.02129.x.

529 Espírito-Santo, H. M. V., M. A. Rodríguez, & J. Zuanon, 2013. Reproductive strategies
530 of Amazonian stream fishes and their fine-scale use of habitat are ordered along a
531 hydrological gradient. John Wiley & Sons, Ltd. Freshwater Biology 58: 2494–2504.
532 https://doi.org/10.1111/fwb.12225.

Espírito-Santo, H. M. V., & J. Zuanon, 2017. Temporary pools provide stability to fish assemblages in Amazon headwater streams. Ecology of Freshwater Fish 26: 475–483. https://doi.org/10.1111/eff.12292.

Faquim, R. C. P., K. B. Machado, F. B. Teresa, P. H. F. de Oliveira, G. F. Granjeiro, L. C. Galli Vieira, & J. C. Nabout, 2021. Shortcuts for biomonitoring programs of stream ecosystems: Evaluating the taxonomic, numeric, and cross-taxa congruence in phytoplankton, periphyton, zooplankton, and fish assemblages. PLOS ONE 16: e0258342. https://doi.org/10.1371/journal.pone.0258342.

Fattorini, S., R. L. H. Dennis, & L. M. Cook, 2012. Use of Cross-Taxon Congruence for Hotspot Identification at a Regional Scale. PLoS ONE 7: e40018. https://doi.org/10.1371/journal.pone.0040018.

Ferreira, S. J. F., S. Pinel, E. A. Ríos-Villamizar, S. Á. F. Miranda, D. Pascoaloto, A. R. T. Vital, M. T. F. Monteiro, M. D. S. R. Da Silva, T. R. B. Da Cunha, A. S. Dos Santos, S. Bender, & H. B. Da Cunha, 2021. Impact of rapid urbanization on stream water quality in the Brazilian Amazon. Environmental Earth Sciences 80: 316. https://doi.org/10.1007/s12665-021-09621-7.

Freitas, C. E., M. De Almeida Mereles, D. V. Pereira, F. Siqueira-Souza, L. Hurd, J. Kahn, G. Morais, & R. G. C. Sousa, 2022. Death by a thousand cuts: Small local dams can produce large regional impacts in the Brazilian Legal Amazon. Environmental Science & Policy 136: 447–452. https://doi.org/10.1016/j.envsci.2022.07.013.

Freitas, T. M. D. S., J. Stropp, B. B. Calegari, J. Calatayud, P. De Marco, L. F. D. A. Montag, & J. Hortal, 2021. Quantifying shortfalls in the knowledge on Neotropical Auchenipteridae fishes. Fish and Fisheries 22: 87–104. https://doi.org/10.1111/faf.12507.

Froese, R., & D. Pauly, 2025. FishBase. World Wide Web electronic publication.

Fróis, R. D. P. D. S., B. O. Ribeiro, J. Zuanon, & A. F. Mortati, 2021. Fish fauna of small-order streams of savannah and forest fragments landscape in the lower Tapajós River basin, Amazonia. Biota Neotropica 21: e20201179. https://doi.org/10.1590/1676-0611-bn-2020-1179.

Furtado, L. G., G. P. Morales, D. F. Da Silva, & A. N. Pontes, 2020. Transformações do uso e cobertura da terra na bacia hidrográfica do rio Murucupi, Barcarena, Pará. Revista Brasileira de Geografia Física 13: 2340. https://doi.org/10.26848/rbgf.v13.5.p2340-2354.

Gardner, C., S. M. Coghlan Jr, J. Zydlewski, & R. Saunders, 2013. Distribution and abundance of stream fishes in relation to barriers: Implications for monitoring stream recovery after barrier removal. John Wiley & Sons, Ltd. River Research and Applications 29: 65–78. https://doi.org/10.1002/rra.1572.

Gonçalves, A. F. G., B. D. S. Prudente, F. D. S. Carvalho Filho, & L. F. D. A. Montag, 2013. Feeding ecology of Dash-dot Tetra *Hemigrammus belottii* (Steindachner 1882) (Characiformes: Characidae) in the streams of the Urucu River basin, central Amazonia, Brazil. Biota Neotropica 13: 141–147. https://doi.org/10.1590/S1676-06032013000300018.

573 Graziano, M. P., A. K. Deguire, & T. D. Surasinghe, 2022. Riparian Buffers as a Critical
574 Landscape Feature: Insights for Riverscape Conservation and Policy Renovations.
575 Diversity 14: 172. https://doi.org/10.3390/d14030172.

576 Griffith, M. B., & M. G. McManus, 2020. Consideration of spatial and temporal scales in
577 stream restorations and biotic monitoring to assess restoration outcomes: A literature
578 review, part 1. River Research and Applications 36: 1385–1397.
579 https://doi.org/10.1002/rra.3692.

580 Groh, T. A., M. P. Davis, T. M. Isenhart, D. B. Jaynes, & T. B. Parkin, 2019. In Situ
581 Denitrification in Saturated Riparian Buffers. Journal of Environmental Quality 48: 376–
582 384. https://doi.org/10.2134/jeq2018.03.0125.

583 Hallal, P. C., 2021. SOS Brazil: science under attack. The Lancet 397: 373–374.
584 https://doi.org/10.1016/S0140-6736(21)00141-0.

585 Hawlitschek, O., K. Yamamoto, & F. G. Carvalho Neto, 2013. Composición de la dieta
586 de un ensamble de peces del lago tupe, Amazonas, Brasil. Revista Colombiana de Ciencia
587 Animal - RECIA 5: 313. https://doi.org/10.24188/recia.v5.n2.2013.296.

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

591 Jacob, L. L., B. S. Prudente, L. F. A. Montag, & R. R. Silva, 2021. The effect of different
592 logging regimes on the ecomorphological structure of stream fish assemblages in the
593 Brazilian Amazon. Hydrobiologia 848: 1027–1039. https://doi.org/10.1007/s10750-020-
594 04508-3.

595 Jézéquel, C., P. A. Tedesco, W. Darwall, M. S. Dias, R. G. Frederico, M. Hidalgo, B.
596 Hugueny, J. Maldonado-Ocampo, K. Martens, H. Ortega, G. Torrente-Vilara, J. Zuanon,
597 & T. Oberdorff, 2020. Freshwater fish diversity hotspots for conservation priorities in the
598 Amazon Basin. Conservation Biology 34: 956–965. https://doi.org/10.1111/cobi.13466.

599 Kuhn, F., M. P. Neves, K. O. Bonato, & C. B. Fialho, 2020. Relationship between diet
600 and pharyngeal jaw morphology of *Crenicichla* species (Cichliformes: Cichlidae) in
601 streams from Uruguay and Jacuí basins, Southern Brazil. Environmental Biology of
602 Fishes 103: 377–388. https://doi.org/10.1007/s10641-020-00963-y.

603 Lafuente, W., A. J. Carpio, C. Alcácer, & J. L. Moreno, 2023. Spatio-temporal variability
604 of physicochemical conditions in the headwaters of neotropical streams. Journal of South
605 American Earth Sciences 126: 104361. https://doi.org/10.1016/j.jsames.2023.104361.

606 Laliberté, E., P. Legendre, & B. Shipley, 2014. FD: measuring functional diversity from
607 multiple traits, and other tools for functional ecology. R package version 1.0-12.3.

608 Legendre, P., & L. F. J. Legendre, 2012. Numerical Ecology. Elsevier, Oxford.

609 Lourenço, L. D. S., I. M. Fernandes, & Y. R. Súarez, 2012. Spatial and temporal variation
610 in population structure of *Hemigrammus marginatus* (Characiformes: Characidae) in
611 streams of the Ivinhema River Basin, Brazil. Zoologia (Curitiba) 29: 300–307.
612 https://doi.org/10.1590/S1984-46702012000400003.

613 Lynch, A. J., S. J. Cooke, A. H. Arthington, C. Baigun, L. Bossenbroek, C. Dickens, I.
614 Harrison, I. Kimirei, S. D. Langhans, K. J. Murchie, J. D. Olden, S. J. Ormerod, M.
615 Owuor, R. Raghavan, M. J. Samways, R. Schinegger, S. Sharma, R. Tachamo-Shah, D.
616 Tickner, D. Tweddle, N. Young, & S. C. Jähnig, 2023. People need freshwater
617 biodiversity. WIREs Water 10: e1633. https://doi.org/10.1002/wat2.1633.

618 Martins, R. T., J. Brito, K. Dias-Silva, C. G. Leal, R. P. Leitão, V. C. Oliveira, J. M. B.
619 Oliveira-Júnior, F. R. De Paula, F. O. Roque, N. Hamada, L. Juen, J. L. Nessimian, P. S.
620 Pompeu, & R. M. Hughes, 2022. Congruence and responsiveness in the taxonomic
621 compositions of Amazonian aquatic macroinvertebrate and fish assemblages.
622 Hydrobiologia 849: 2281–2298. https://doi.org/10.1007/s10750-022-04867-z.

623 Medeiros, A. C., K. R. F. Faial, K. do C. F. Faial, I. D. da S. Lopes, M. de O. Lima, R.
624 M. Guimarães, & N. M. Mendonça, 2017. Quality index of the surface water of
625 Amazonian rivers in industrial areas in Pará, Brazil. Marine Pollution Bulletin 123: 156–
626 164. https://doi.org/10.1016/j.marpolbul.2017.09.002.

627 Mendoza-Penagos, C. C., L. B. Calvão, & L. Juen, 2021. A new biomonitoring method
628 using taxonomic families as substitutes for the suborders of the Odonata (Insecta) in
629 Amazonian streams. Ecological Indicators 124: 107388.
630 https://doi.org/10.1016/j.ecolind.2021.107388.

631 Montaña, C. G., & K. O. Winemiller, 2009. Comparative feeding ecology and habitats
632 use of Crenicichla species (Perciformes: Cichlidae) in a Venezuelan floodplain river.
633 Neotropical Ichthyology 7: 267–274. https://doi.org/10.1590/S1679-
634 62252009000200019.

635 Montaña, C. G., & K. O. Winemiller, 2013. Evolutionary convergence in Neotropical
636 cichlids and Nearctic centrarchids: evidence from morphology, diet, and stable isotope
637 analysis: Evolutionary Convergence in Perciform Fishes. Biological Journal of the
638 Linnean Society 109: 146–164. https://doi.org/10.1111/bij.12021.

639 Moraes, B. C. D., J. M. N. D. Costa, A. C. L. D. Costa, & M. H. Costa, 2005. Variação
640 espacial e temporal da precipitação no Estado do Pará. Acta Amazonica 35: 207–214.
641 https://doi.org/10.1590/S0044-59672005000200010.

642 Morais, G. F., L. G. dos S. Ribas, J. C. G. Ortega, J. Heino, & L. M. Bini, 2018. Biological
643 surrogates: A word of caution. Ecological Indicators 88: 214–218.
644 https://doi.org/10.1016/j.ecolind.2018.01.027.

645 Nahum, J. S., 2017. Modernization and political actions in the Brazilian Amazon: the city
646 of Barcarena, Pará. Springer, Switzerland.

647 Nascimento, N. S. F., & M. T. Hazeu, 2015. Grandes empreendimentos e contradições
648 sociais na Amazônia: a degradação da vida no município de Barcarena, Pará.
649 Argumentum 7: 288. https://doi.org/10.18315/argumentum.v7i2.10533.

650 Oksanen, J., F. G. Blanchet, M. Friendly, R. Kindt, P. Legendre, P McGlinn, P. R.
651 Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, E. Szoecs, H.
652 Wagner, M. Barbour, M. Bedward, B. Bolker, D. Borcard, G. Carvalho, M. Chirico, M.
653 De Caceres, S. Durand, H. Evangelista, R. FitzJohn, M. Friendly, B. Furneaux, G.
654 Hannigan, M. Hill, L. Lahti, D. McGlinn, M. Ouellette, E. Ribeiro Cunha, T. Smith, &

A. Stier, 2024. FD: measuring functional diversity from multiple traits, and other tools for functional ecology. R package version 1.0-12.3.

Pelicice, F. M., A. A. Agostinho, V. M. Azevedo-Santos, E. Bessa, L. Casatti, D. Garrone-Neto, L. C. Gomes, C. S. Pavanelli, A. C. Petry, P. dos Santos Pompeu, R. E. Reis, F. de Oliveira Roque, J. Sabino, L. M. de Sousa, F. S. Vilella, & J. Zuanon, 2022. Ecosystem services generated by Neotropical freshwater fishes. Hydrobiologia . https://doi.org/10.1007/s10750-022-04986-7.

Peressin, A., & M. Cetra, 2014. Responses of the ichthyofauna to urbanization in two urban areas in Southeast Brazil. Urban Ecosystems 17: 675–690. https://doi.org/10.1007/s11252-014-0352-5.

Peterson, M. J., R. A. Efroymson, & S. M. Adams, 2011. Long-Term Biological Monitoring of an Impaired Stream: Synthesis and Environmental Management Implications. Environmental Management 47: 1125–1140. https://doi.org/10.1007/s00267-011-9665-9.

Porfírio, D. M., L. R. Monteiro, & M. L. da Costa, 2020. Rainwater geochemistry inside the Barcarena power station at the mouth of the Tocantins River. Environmental Technology 41: 981–996. https://doi.org/10.1080/09593330.2018.1516801.

R Core Team, 2024. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Resende, B. O., V. R. S. Ferreira, L. Juen, D. Silvério, & H. S. R. Cabette, 2021. Seasonal fluctuations in the structure of the larval odonate community of a stream in the Cerrado–Amazon forest transition zone. Aquatic Ecology 55: 861–873. https://doi.org/10.1007/s10452-021-09865-2.

Rodrigues, M., 2022. Bolsonaro's troubled science legacy. Nature 609: 890–891. https://doi.org/10.1038/d41586-022-03038-3.

Rohlf, F. J., & F. L. Bookstein (eds), 1990. Proceedings of the Michigan morphometrics workshop. University of Michigan Museum of Zoology, Ann Arbor.

Santos, L. L. dos, N. L. Benone, L. S. Brasil, T. H. S. Pires, T. O. Begot, D. D. F. Dantas, & L. F. de A. Montag, 2022. The use of taxonomic families as biological surrogates of the diversity of the Amazonian stream fish. Ecological Indicators 141: 109094. https://doi.org/10.1016/j.ecolind.2022.109094.

Santos, L. L., N. L. Benone, B. E. Soares, R. B. Barthem, & L. F. A. Montag, 2019. Trait–environment relationships in Amazon stream fish assemblages. Ecology of Freshwater Fish 28: 424–433. https://doi.org/10.1111/eff.12465.

Sato, C. F., M. J. Westgate, P. S. Barton, C. N. Foster, L. S. O'Loughlin, J. C. Pierson, J. Balmer, J. Chapman, G. Catt, T. Detto, A. Hawcroft, R. P. Kavanagh, D. Marshall, M. McKay, K. Moseby, M. Perry, D. Robinson, M. Schroder, K. Tuft, & D. B. Lindenmayer, 2019. The use and utility of surrogates in biodiversity monitoring programmes. Journal of Applied Ecology 56: 1304–1310. https://doi.org/10.1111/1365-2664.13366.

694 Severo-Neto, F., G. L. Brejão, & L. Casatti, 2023. Fish functional trophic groups in
695 headwater karst streams from the Upper Paraguay River basin. SciELO Brasil.
696 Neotropical Ichthyology 21: e220103. https://doi.org/10.1590/1982-0224-2022-0103.

697 Silveira, G. S., L. A. B. Nascimento, R. M. da S. Castro, L. N. Correa-Junior, M. A. M.
698 Vasconcelos, P. C. S. Bittencourt, D. L. Correa, & D. da C. Palheta, 2019. Socio-
699 environmental sustainability: a case study in the good future community in Barcarena in
700 the Paraense Amazon. Brazilian Journal of Development 5: 18344–18354.
701 https://doi.org/10.34117/bjdv5n10-093.

702 Slimani, N., D. Sánchez-Fernández, E. Guilbert, M. Boumaïza, S. Guareschi, & J.
703 Thioulouse, 2019. Assessing potential surrogates of macroinvertebrate diversity in North-
704 African Mediterranean aquatic ecosystems. Ecological Indicators 101: 324–329.
705 https://doi.org/10.1016/j.ecolind.2019.01.017.

706 Sousa, R. L. M. de, F. F. Bomfim, N. L. Franco, E. J. Cunha, R. C. Bastos, A. A. S. Costa,
707 R. N. C. Cardoso, & T. S. Michelan, 2024. Drivers of macrophytes species richness and
708 composition in Amazon streams inserted in a land use gradient. SciELO Brasil. Acta
709 Botanica Brasilica 38: e20230267.

710 Stewart, D. R., Z. E. Underwood, F. J. Rahel, & A. W. Walters, 2018. The effectiveness
711 of surrogate taxa to conserve freshwater biodiversity. Wiley Online Library. Conservation
712 Biology 32: 183–194. https://doi.org/10.1111/cobi.12967.

713 Torres-Bejarano, A. M., S. M. P. Sulliván, W. González-Daza, C. Cáceres, & G. J.
714 Colorado Z., 2022. Riparian vegetation structure and seasonality influence functional
715 diversity more than taxonomic diversity of stream fish assemblages in the Colombian
716 Amazon. Aquatic Ecology 56: 153–172. https://doi.org/10.1007/s10452-021-09904-y.

717 Valente-Neto, F., R. B. Dala-Corte, A. M. Cunico, A. L. B. Magalhães, B. S. Godoy, C.
718 G. Leal, D. M. P. Castro, D. R. Macedo, D. P. Lima-Junior, É. A. Gubiani, F. D. O.
719 Roque, F. B. Teresa, F. J. M. Oliveira, F. G. Becker, G. L. Brejão, J. Brito, J. Zuanon, J.
720 R. S. Vitule, K. Dias-Silva, L. Casatti, L. B. Lima, L. F. A. Montag, M. Callisto, M. R.
721 Dos Santos, N. Hamada, P. A. Z. Pamplin, P. S. Pompeu, R. P. Leitão, R. Ruaro, S. R.
722 M. Couceiro, V. Abilhoa, Y. R. Súarez, & R. T. Martins, 2025. Cost-effective alternatives
723 to facilitate biomonitoring and bioassessment of neotropical streams. Science of The
724 Total Environment 965: 178654. https://doi.org/10.1016/j.scitotenv.2025.178654.

725 van der Sleen, P., & J. S. Albert, 2017. Field guide to the fishes of the Amazon, Orinoco,
726 and Guianas. Princeton University Press, Princeton.

727 Virgilio, L. R., C. H. D. Brito, M. D. S. Suçuarana, & L. J. S. Vieira, 2020. Forest
728 fragmentation influences the diet of cichlids *Apistogramma agassizii* (Steindachner,
729 1875) and *Aequidens tetramerus* (Heckel, 1840) (Actinopterygii: Cichliformes) in
730 streams of the Western Amazon. Acta Limnologica Brasiliensia 32: e28.
731 https://doi.org/10.1590/s2179-975x2618.

732 Zeni, J. O., L. M. Sensato-Azevedo, E. F. dos Santos, G. L. Brejão, & L. Casatti, 2020.
733 Habitat use, trophic, and occurrence patterns of *Inpaichthys kerri* and *Hyphessobrycon*
734 *vilmae* (Pisces: Characidae) in Amazonian streams. Neotropical Ichthyology 18:
735 e200006. https://doi.org/10.1590/1982-0224-2020-0006.

Supplemental Files

Fish taxonomic families as potential indicators of biodiversity in biomonitoring of impacted Amazonian streams

Luciana Lameira dos Santos, Naraiana Loureiro Benone, Lidia Brasil Seabra, Cleonice Maria Cardoso Lobato and Luciano Fogaça de Assis Montag
Corresponding author: lucianalameira@yahoo.com.br

TABLE S1. Values of the functional traits of fish species captured in 18 streams sampled during the rainy seasons of 2018–2019, the dry season of 2019, the dry season of 2023, and the rainy season of 2024 in Barcarena, Pará State, northern Brazil. Codes: AutoInv = Autochthonous invertivore, AloInv = Allochthonous invertivore, Carn = Carnivore, Algi = Algivore, Herb = Herbivore, Det = Detritivore, FeedHab = Feeding habit, MouthPos = Mouth position, VertPos = Vertical position, BodyForm = Body form, SL = Standard length, ParentCare = Parental care. Species codes are available in Table 2.

Species	AutoInv	AloInv	Carn	Algi	Herb	Det	FeedHab	MouthPos	VertPos	BodyForm	SL	ParentCare
Aequtetr	0	3 [1]	0	0	1 [1]	1 [1]	substrate_speculator [1]	terminal [2]	nektobenthic [2]	compressed [2]	3.35 [3]	carefully [4]
Anaburop	2 [5]	3 [5]	0	0	0	0	surface_feeder [5]	superior [5]	nektonic [5]	fusiform [5]	3.46 [3]	careless [6]
Ancisp1	0	0	0	3 [3]	0	2 [5]	grazer [7]	inferior [5]	benthic [5]	depressed [8]	5.77 [3]	carefully [4]
Apisagas	2 [9]	3 [9]	0	0	1 [9]	0	substrate_speculator [9]	terminal [2]	nektobenthic [2]	compressed [2]	2.72 [3]	carefully [10]
Apisrega	3 [11]	0	0	0	0	2 [11]	substrate_speculator [11]	terminal [12]	nektobenthic [11]	compressed [12]	3.01 [3]	carefully [4]
Apissp1	2 [9]	3 [9]	0	0	1 [9]	0	substrate_speculator [9]	terminal [2]	nektobenthic [2]	compressed [2]	2.72 [3]	carefully [10]
Bracsp1	3 [7]	0	0	0	0	0	substrate_speculator [7]	terminal [4]	nektobenthic [7]	anguilliform [4]	11 [3]	careless [13]
Bracsp2	3 [7]	0	0	0	0	0	substrate_speculator [7]	terminal [4]	nektobenthic [7]	anguilliform [4]	11 [3]	careless [13]

Bracsp3	3 [7]	0	0	0	0	0	substrate_speculator	[7]	terminal	[4]	nektobenthic	[7]	anguilliform	[4]	11	[3]	careless	[13]
Bryccaud	1 [14]	3 [14]	0	1 [14]	1 [14]	0	surface_feeder	[14]	terminal	[15]	nektonic	[14]	fusiform	[15]	7.2	[15]	careless	[16]
Brycmela	1 [17]	3 [17]	0	0	2 [17]	1 [17]	surface_feeder	[7]	terminal	[17]	nektonic	[7]	fusiform	[18]	7.63	[19]	careless	[20]
Carnsp1	2 [21]	3 [21]	0	0	1 [21]	1 [21]	surface_feeder	[7]	superior	[5]	nektonic	[7]	compressed	[5]	3.29	[22]	careless	[23]
Charsp1	3 [24]	0	0	0	0	1 [24]	predator	[7]	terminal	[24]	benthic	[7]	elongated	[5]	3.37	[22]	careless	[25]
Copearno	0	2 [26]	0	1 [26]	0	3 [26]	surface_feeder	[7]	superior	[27]	nektonic	[7]	fusiform	[5]	2.4	[3]	carefully	[4]
Eryteryt	3 [5]	0	3 [5]	0	0	0	predator	[28]	terminal	[29]	nektobenthic	[7]	elongated	[5]	7.98	[3]	carefully	[20]
Fluvisp1	3 [4]	3 [4]	0	3 [4]	0	3 [4]	surface_feeder	[7]	superior	[30]	nektonic	[7]	fusiform	[30]	2	[4]	careless	[23]
Gladsp1	3 [31]	0	0	0	0	0	active_predator	[7]	terminal	[32]	benthic	[7]	elongated	[32]	2.65	[3]	careless	[5]
Gymnrond	3 [33]	1 [33]	0	0	0	1 [33]	substrate_speculator	[7]	subterminal	[34]	nektobenthic	[7]	anguilliform	[4]	21.52	[22]	careless	[35]
Gymnsp	3 [36]	1 [36]	1 [36]	0	0	0	active_predator	[7]	superior	[37]	nektobenthic	[7]	anguilliform	[4]	12	[3]	carefully	[38]
Helomarm	0	3 [39]	0	0	0	0	backwater_feeder	[7]	subterminal	[40]	nektonic	[7]	elongated	[5]	5.7	[22]	careless	[41]
Hemibell	2 [42]	3 [42]	0	0	3 [42]	0	backwater_feeder	[7]	terminal	[43]	nektonic	[7]	compressed	[43]	2.64	[43]	careless	[16]
Hemicoll	1 [44]	3 [44]	0	1 [44]	2 [44]	0	backwater_feeder	[7]	terminal	[43]	nektonic	[7]	compressed	[45]	2.78	[44]	careless	[16]
Hemirodw	2 [34]	3 [34]	0	0	0	0	backwater_feeder	[7]	terminal	[34]	nektonic	[7]	compressed	[46]	2.82	[3]	careless	[23]
Hemiunil	2 [34]	3 [34]	0	0	0	0	backwater_feeder	[7]	terminal	[34]	nektonic	[7]	compressed	[46]	3.88	[47]	careless	[23]
Herosp1	3 [48]	3 [48]	0	0	1 [48]	0	substrate_speculator	[9]	terminal	[2]	nektobenthic	[2]	compressed	[2]	12	[49]	carefully	[50]
Hoplmala	0	0	3 [51]	0	0	0	predator	[4]	terminal	[51]	nektobenthic	[7]	elongated	[5]	11.7	[22]	carefully	[52]
Hyphagul	1 [53]	1 [53]	0	3 [53]	3 [53]	0	backwater_feeder	[7]	terminal	[54]	nektonic	[7]	compressed	[54]	2.93	[54]	careless	[55]
Hyphhete	1 [34]	3 [5]	0	3 [34]	0	0	backwater_feeder	[7]	terminal	[56]	nektonic	[7]	compressed	[56]	2.99	[3]	careless	[55]
Hyphmoni	1 [53]	1 [53]	0	3 [53]	3 [53]	0	backwater_feeder	[7]	terminal	[57]	nektonic	[7]	compressed	[57]	2.59	[57]	careless	[55]

Hypolept	3 [58]	1 [58]	0	0	0	0	substrate_speculator	[7]	subterminal	[5]	nektobenthic	[7]	anguilliform	[5]	15	[4]	careless	[35]
Hyposp	0	2 [59]	0	1 [59]	0	3 [59]	grazer	[59]	inferior	[59]	benthic	[7]	depressed	[60]	5.78	[61]	carefully	[55]
Iguarach	0	2 [5]	0	3 [62]	0	0	surface_feeder	[7]	terminal	[63]	nektonic	[7]	fusiform	[4]	4.76	[3]	careless	[20]
Itugamaz	3 [64]	0	0	0	0	0	active_predator	[7]	subterminal	[65]	benthic	[5]	elongated	[5]	4.11	[22]	careless	[66]
Itugsp1	3 [64]	0	0	0	0	0	active_predator	[7]	subterminal	[65]	benthic	[5]	elongated	[5]	4.11	[22]	careless	[66]
Laimstri	2 [5]	3 [5]	0	0	0	0	surface_feeder	[5]	superior	[5]	nektonic	[5]	fusiform	[5]	2.61	[3]	careless	[20]
Megathor	3 [62]	0	1 [62]	0	0	2 [62]	substrate_speculator	[7]	subterminal	[5]	nektobenthic	[7]	elongated	[5]	11.13	[3]	carefully	[67]
Mesoacor	3 [68]	0	1 [68]	2 [68]	0	2 [68]	substrate_speculator	[7]	terminal	[2]	nektobenthic	[7]	compressed	[2]	7.1	[69]	carefully	[5]
Micrbili	3 [28]	3 [28]	0	0	0	0	substrate_speculator	[7]	terminal	[70]	nektobenthic	[7]	anguilliform	[70]	8.67	[70]	careless	[13]
Nanneque	0	3 [28]	0	2 [28]	0	2 [28]	surface_feeder	[7]	terminal	[4]	nektonic	[7]	fusiform	[5]	2.69	[3]	careless	[4]
Nanntaen	1 [71]	3 [71]	0	0	0	0	substrate_speculator	[7]	terminal	[2]	nektobenthic	[7]	compressed	[71]	2.95	[3]	carefully	[4]
Pimesp1	3 [72]	1 [72]	1 [72]	0	1 [72]	2 [72]	active_predator	[7]	terminal	[34]	benthic	[7]	elongated	[4]	9	[69]	careless	[55]
Poecsp1	3 [4]	3 [4]	0	3 [4]	0	3 [4]	surface_feeder	[7]	superior	[30]	nektonic	[7]	fusiform	[30]	2	[4]	careless	[23]
Polyscho	3 [71]	1 [71]	2 [71]	0	0	0	predator	[4]	protactil	[4]	nektonic	[4]	compressed	[4]	5.5	[69]	carefully	[73]
Potahase	3 [74]	1 [59]	2 [59]	0	0	0	active_predator	[7]	subterminal	[65]	benthic	[7]	elongated	[4]	1.35	[3]	careless	[66]
Prismaxi	3 [75]	0	0	0	0	0	backwater_feeder	[7]	terminal	[76]	nektonic	[76]	compressed	[76]	2.9	[76]	careless	[55]
Pseumicr	1 [77]	1 [77]	3 [77]	0	0	0	surface_feeder	[77]	terminal	[4]	nektonic	[77]	elongated	[77]	29.8	[78]	careless	[79]
Pyrrcapi	0	3 [28]	0	2 [28]	0	2 [28]	surface_feeder	[7]	superior	[80]	nektonic	[7]	fusiform	[80]	4.04	[80]	careless	[4]
Saxainpa	3 [2]	0	2 [2]	0	0	0	active_predator	[7]	terminal	[2]	nektobenthic	[7]	elongated	[2]	7.38	[3]	carefully	[5]
Saxasaxa	3 [2]	0	2 [2]	0	0	0	active_predator	[7]	terminal	[2]	nektobenthic	[7]	elongated	[2]	7.38	[3]	carefully	[5]
Synbmarm	3 [81]	0	3 [81]	0	0	0	predator	[4]	terminal	[82]	nektobenthic	[4]	anguilliform	[4]	16.5	[82]	carefully	[82]

Tatisp1	2	[83]	3	[84]	0	0	0	0	surface_feeder	[83]	terminal	[84]	nektonic	[83]	elongated	[84]	3.88	[84]	careless	[85]

References

[1] Costa IDD, Soares MO. The seasonal diet of Aequidens tetramerus (Cichlidae) in a small forest stream in the Machado River basin, Rondônia, Brazil. Acta Amaz 2015;45:365–72. https://doi.org/10.1590/1809-4392201500223.

[2] Montaña CG, Winemiller KO. Evolutionary convergence in Neotropical cichlids and Nearctic centrarchids: evidence from morphology, diet, and stable isotope analysis: Evolutionary Convergence in Perciform Fishes. Biol J Linn Soc Lond 2013;109:146–64. https://doi.org/10.1111/bij.12021.

[3] Santos LL, Benone NL, Soares BE, Barthem RB, Montag LFA. Trait–environment relationships in Amazon stream fish assemblages. Ecol Freshw Fish 2019;28:424–33. https://doi.org/10.1111/eff.12465.

[4] van der Sleen P, Albert JS. Field guide to the fishes of the Amazon, Orinoco, and Guianas. vol. 115. Princeton: Princeton University Press; 2017.

[5] Zuanon JAS, Mendonça FP, Espírito Santo HMV, Dias MS, Galuch AV, Akama A. Guia de peixes da reserva Ducke: Amazônia Central. Manaus: Editora INPA; 2015.

[6] Turko AJ, Wright PA. Evolution, ecology and physiology of amphibious killifishes (Cyprinodontiformes): amphibious cyprinodontiforms. J Fish Biol 2015;87:815–35. https://doi.org/10.1111/jfb.12758.

[7] Brejão GL, Gerhard P, Zuanon J. Functional trophic composition of the ichthyofauna of forest streams in eastern Brazilian Amazon. Neotrop Ichthyol 2013;11:361–73. https://doi.org/10.1590/S1679-62252013005000006.

[8] Bifi AG, Pavanelli CS, Zawadzki CH. Three new species of Ancistrus Kner, 1854 (Siluriformes: Loricariidae) from the Rio Iguaçu basin, Paraná State, Brazil. Zootaxa 2009;2275:41–59. https://doi.org/10.11646/zootaxa.2275.1.3.

[9] Virgilio LR, Brito CHD, Suçuarana MDS, Vieira LJS. Forest fragmentation influences the diet of cichlids *Apistogramma agassizii* (Steindachner, 1875) and *Aequidens tetramerus* (Heckel, 1840) (Actinopterygii: Cichliformes) in streams of the Western Amazon. Acta Limnol Bras 2020;32:e28. https://doi.org/10.1590/s2179-975x2618.

[10] Silva NCDS, Soares BE, Teresa FB, Caramaschi ÉP, Albrecht MP. Fish functional diversity is less impacted by mining than fish taxonomic richness in an Amazonian stream system. Aquat Ecol 2022. https://doi.org/10.1007/s10452-022-09946-w.

[11] Kullander SO, Ferreira EJG. Two new species of Apistogramma Regan (Teleostei: Cichlidae) from the rio Trombetas, Pará State, Brazil. Neotrop Ichthyol 2005;3:361–71. https://doi.org/10.1590/S1679-62252005000300003.

[12] Römer U, Beninde J, Duponchelle F, Carmen Rosa García Dávila, Antonia Vela Díaz, Jean-François Renno. Description of Apistogramma paulmuelleri sp. n., a new geophagine cichlid species (Teleostei: Perciformes) from the Amazon river basin in Loreto, Peru. VERTEBRATE ZOOLOGY 2013:20.
[13] Waddell JC, Njeru SM, Akhiyat YM, Schachner BI, Correa-Roldán EV, Crampton WGR. Reproductive life-history strategies in a species-rich assemblage of Amazonian electric fishes. PLoS ONE 2019;14:e0226095. https://doi.org/10.1371/journal.pone.0226095.
[14] Costa-Pereira R, Severo-Neto F. Dining out: Bryconops caudomaculatus jumps out of water to catch flies. Revista Chilena de Historia Natural 2012;85:241–4.
[15] Chernoff B, Machado-Allison A. Bryconops magoi and Bryconops collettei (Characiformes: Characidae), two new freshwater fish species from Venezuela, with comments on B. caudomaculatus (Günther). Zootaxa 2005;1094. https://doi.org/10.11646/zootaxa.1094.1.1.
[16] Cantanhêde LG, Luiza-Andrade A, Leão H, Montag LF de A. How does conversion from forest to pasture affect the taxonomic and functional structure of the fish assemblages in Amazonian streams? Ecol Freshw Fish 2021;30:334–46. https://doi.org/10.1111/eff.12589.
[17] Sánchez RM, Galvis G, Victoriano PF. Relacion entre caracteristicas del tracto digestivo y los habitos alimentarios de peces del Rio Yucao, sistema del rio meta (Colombia). Gayana (Concepc) 2003;67. https://doi.org/10.4067/S0717-65382003000100010.
[18] Sidlauskas B, Chernoff B, Machado-Allison A. Geographic and environmental variation in Bryconops sp. cf. melanurus (Ostariophysi: Characidae) from the Brazilian Pantanal. Ichthyol Res 2006;53:24–33. https://doi.org/10.1007/s10228-005-0310-6.
[19] Silva-Oliveira C, Ota RP, Lima FCT, Py-Daniel LR. Rediscovering species: redescription of Bryconops gracilis (Characiformes: Iguanodectidae), an often-misidentified species. Neotrop Ichthyol 2021;19:e211054. https://doi.org/10.1590/1982-0224-2021-0054.
[20] Espírito-Santo HMV, Rodríguez MA, Zuanon J. Reproductive strategies of Amazonian stream fishes and their fine-scale use of habitat are ordered along a hydrological gradient. Freshwater Biology 2013;58:2494–504. https://doi.org/10.1111/fwb.12225.
[21] Santos SM, Aride PHR, Pantoja-Lima J, Oliveira AT, Zuanon JAS. Trophic relationships among three species of ornamental fish from the region of Lake Amanã, Amazon. Braz J Biol 2022;82:e232701. https://doi.org/10.1590/1519-6984.232701.
[22] Bower LM, Winemiller KO. Intercontinental trends in functional and phylogenetic structure of stream fish assemblages. Ecology and Evolution 2019;9:13862–76. https://doi.org/10.1002/ece3.5823.
[23] Alkins-Koo M. Reproductive Timing of Fishes in a Tropical Intermittent Stream. Environmental Biology of Fishes 2000;57:49–66. https://doi.org/10.1023/A:1007566609881.
[24] Guglielmetti R, Silva MR, Higuti J, Fugi R. Diet of benthivorous fish and prey availability in streams of the Pirapó River basin-PR. Acta Limnol Bras 2019;31:e7. https://doi.org/10.1590/s2179-975x4518.
[25] Ticiani D, Delariva RL, Iquematsu MS, Bialetzki A. Larval development of Characidium orientale (Actinopterygii: Crenuchidae) a small Neotropical fish. Iheringia, Sér Zool 2022;112:e2022003. https://doi.org/10.1590/1678-4766e2022003.

[26] Soares BE, Benone NL, Rosa DCO, Montag LF de A. Do local environmental factors structure the trophic niche of the splash tetra, *Copella arnoldi*? A test in an Amazonian stream system. Acta Amaz 2020;50:54–60. https://doi.org/10.1590/1809-4392201802681.
[27] Marinho MMF, Menezes NA. Taxonomic review of Copella (Characiformes: Lebiasinidae) with an identification key for the species. PLoS ONE 2017;12:e0183069. https://doi.org/10.1371/journal.pone.0183069.
[28] Sabino J, Zuanon J. A stream fish assemblage in Central Amazonia: Distribution, activity patterns and feeding behavior. Ichthyological Exploration of Freshwaters 1998;8:201–10.
[29] Furtado SNM, Brito GJS, dos Santos Sousa K, Ramos TA. Fishes from the Private Natural Heritage Reserve Pacatuba Farm and its surrounding areas, Paraíba State, Northeastern Brazil. Revista Nordestina de Biologia 2018;26.
[30] Costa WJEM, Bail P-YL. Fluviphylax palikur: A New Poeciliid from the Rio Oiapoque Basin, Northern Brazil (Cyprinodontiformes: Cyprinodontoidei), with Comments on Miniaturization in Fluviphylax and Other Neotropical Freshwater Fishes. Copeia 1999;1999:1027. https://doi.org/10.2307/1447977.
[31] Ferraris CJ, Mago-Leccia F. A New Genus and Species of Pimelodid Catfish from the Río Negro and Río Orinoco Drainages of Venezuela (Siluriformes: Pimelodidae). Copeia 1989;1989:166–71. https://doi.org/10.2307/1445617.
[32] Lundberg JG, Bornbusch AH, Mago-Leccia F. Gladioglanis conquistador N. Sp. from Ecuador with Diagnoses of the Subfamilies Rhamdiinae Bleeker and Pseudopimelodinae N. Subf. (Siluriformes: Pimelodidae). Copeia 1991;1991:190–209. https://doi.org/10.2307/1446263.
[33] Virgilio LR, Gomes RS, Suçuarana M da S, Vieira LJS. Analysis of the use of microhabitats, spatial distribution and diet of Gymnorhamphichthys rondoni (Miranda-Ribeiro, 1920) (Rhamphichthyidae) in low-order streams in western Amazon 2019:12.
[34] Ramírez F, Davenport TL, Mojica JI. Dietary–morphological relationships of nineteen fish species from an Amazonian terra firme blackwater stream in Colombia. Limnologica 2015;52:89–102. https://doi.org/10.1016/j.limno.2015.04.002.
[35] Kirschbaum F, Schugardt C. Reproductive strategies and developmental aspects in mormyrid and gymnotiform fishes. Journal of Physiology 2002:10.
[36] Crampton WGR, Thorsen DH, Albert JS. Three New Species from a Diverse, Sympatric Assemblage of the Electric Fish Gymnotus (Gymnotiformes: Gymnotidae) in the Lowland Amazon Basin, with Notes on Ecology 2005:18.
[37] Albert JS, Crampton WG. Seven new species of the Neotropical electric fish Gymnotus (Teleostei, Gymnotiformes) with a redescription of G. carapo (Linnaeus) 2003.
[38] Crampton WGR, Hopkins CD. Nesting and Paternal Care in the Weakly Electric Fish Gymnotus (Gymnotiformes: Gymnotidae) with Descriptions of Larval and Adult Electric Organ Discharges of Two Species 2005:13.
[39] Cardoso AC, Couceiro SRM. Insects in the diet of fish from Amazonian streams, in western Pará, Brazil. Mar Freshwater Res 2017;68:2052. https://doi.org/10.1071/MF16173.

[40] Vari RP, Ferraris Jr. CJ. New species of Cetopsidium (Siluriformes: Cetopsidae: Cetopsinae) from the upper rio Branco system in Guyana. Neotrop Ichthyol 2009;7:289–93. https://doi.org/10.1590/S1679-62252009000300001.
[41] López-Rodríguez NC, Leão AHF, Rocha RM, Prudente BS, Montag LFA. Environmental influence on the reproductive strategy of Helogenes marmoratus (Siluriformes: Cetopsidae) in the Amazonian streams. Neotrop Ichthyol 2021;19:e210092. https://doi.org/10.1590/1982-0224-2021-0092.
[42] Piraquive EFP, Taphorn D, Sabogal A, Duque SR, Damaso Yoni J. Food Habits of Five Fish Species from A Blackwater Creek in The Colombian Amazon. Mundo Amazon 2023;14:197–210. https://doi.org/10.15446/ma.v14n1.90159.
[43] Faria TC, Lima FCT, Wosiacki WB. A New Hyphessobrycon (Characiformes: Characidae) from the Guiana Shield in Northern Brazil. Copeia 2020;108:369. https://doi.org/10.1643/CI-19-311.
[44] Barros HKS, Barbosa TAP, Prudente BDS. Feeding ecology of *Moenkhausia collettii* (STEINDACHNER , 1882) (CHARACIFORMES: CHARACIDAE) in streams in the eastern AMAZON : Environmental factors and body size. Journal of Fish Biology 2024;104:2008–21. https://doi.org/10.1111/jfb.15743.
[45] Rosa FDAS, Baillie C, Medeiros TDN, Ready JS. Habitat and host associations of the fish-burrowing parasite *Artystone minima* (Cymothoidae: Isopoda) in eastern Amazonia. Biotropica 2021;53:307–16. https://doi.org/10.1111/btp.12876.
[46] Zarske A, Bail PL, Géry J. New and poorly known Characiform fishes (Teleostei: Characiformes: Characidae) from French Guiana. 1. Two new Tetras of the genera Hemigrammus and Hyphessobrycon 2006:15.
[47] Valdiviezo-Rivera J, Carriel MB, Escobar-Camacho D. Rediscovery of Hemigrammus unilineatus (Gill, 1858) (Characiformes, Characidae) in Ecuador after more than three decades. CheckList 2021;17:1181–5. https://doi.org/10.15560/17.4.1181.
[48] Sousa JAD, Bazilio DBB, Da Costa RAAM, Brabo MF, Campelo DAV, Nunes ZMP, et al. Protein requirement in the diet of *HEROS SEVERUS* (Heckel, 1840): An Amazonian ornamental fish. J World Aquaculture Soc 2021;52:482–95. https://doi.org/10.1111/jwas.12764.
[49] Steele SE, López-Fernández H. Body Size Diversity and Frequency Distributions of Neotropical Cichlid Fishes (Cichliformes: Cichlidae: Cichlinae). PLoS ONE 2014;9:e106336. https://doi.org/10.1371/journal.pone.0106336.
[50] Abe HA, Sousa NDC, Couto MVS, Paixão PEG, Filho RMN, Reis RGA, et al. Growth performance and hematological parameters of banded cichlid *Heros severus* fed at different feeding rates and feeding frequencies. J Appl Ichthyol 2022;38:93–100. https://doi.org/10.1111/jai.14283.
[51] Bialetzki A, Nakatani K, Sanches PV, Baumgartner G, Makrakis MC, Taguti TL. Desenvolvimento inicial de Hoplias aff. malabaricus (Bloch, 1794) (Osteichthyes, Erythrinidae) da planície alagável do alto rio Paraná, Brasil. Acta Sci Biol Sci 2008;30:141–9. https://doi.org/10.4025/actascibiolsci.v30i2.3608.

[52] Leal ME, Klein GF, Schulz UH, Albornoz PL. Primeiro registro e aspectos ecológicos de Hoplerythrinus unitaeniatus (Agassiz, 1829) (Characiformes, Erythrinidae) como espécie introduzida na Bacia do Rio dos Sinos, RS, Brasil. Biota Neotrop 2010;10:33–7. https://doi.org/10.1590/S1676-06032010000300002.
[53] Ohara WM, Abrahão VP, Espíndola VC. *Hyphessobrycon platyodus* (Teleostei: Characiformes), a new species from the Rio Madeira basin, Brazil, with comments on how multicuspid teeth relate to feeding habits in Characidae. Journal of Fish Biology 2017;91:835–50. https://doi.org/10.1111/jfb.13383.
[54] García-Alzate CA, Lima F, Taphorn DC, Mojica JI, Urbano-Bonilla A, Teixeira TF. A new species of *Hyphessobrycon* Durbin (Characiformes: Characidae) from the western Amazon basin in Colombia and Peru. Journal of Fish Biology 2020;96:1444–53. https://doi.org/10.1111/jfb.14319.
[55] Winemiller KO, Agostinho AA, Caramaschi ÉP. Fish Ecology in Tropical Streams. Tropical Stream Ecology, Elsevier; 2008, p. 107–III. https://doi.org/10.1016/B978-012088449-0.50007-8.
[56] Ingenito LFS, Lima FCT, Buckup PA. A new species of Hyphessobrycon Durbin(Characiformes: Characidae) from the rio Juruena basin, Central Brazil, with notes on H. loweae Costa & Géry. Neotrop Ichthyol 2013;11:33–44. https://doi.org/10.1590/S1679-62252013000100004.
[57] Moreira CR, Lima FC, Costa W. Hyphessobrycon moniliger, a new characid fish from rio Tocantins basin, Central Brazil (Ostariophysi: Characiformes). Ichthyological Exploration of Freshwaters 2002;13:73–80.
[58] De Santana CD, Crampton WGR. Phylogenetic interrelationships, taxonomy, and reductive evolution in the Neotropical electric fish genus Hypopygus (Teleostei, Ostariophysi, Gymnotiformes): HYPOPYGUS: PHYLOGENY AND TAXONOMIC REVISION. Zoological Journal of the Linnean Society 2011;163:1096–156. https://doi.org/10.1111/j.1096-3642.2011.00736.x.
[59] Hahn NS, Fugi R. Environmental changes, habitat modifications and feeding ecology of freshwater fish. Feeding and digestive functions of fishes, New Hampshire, USA: Science Publishers; 2008, p. 35–65.
[60] Armbruster JW, Souza LSD. Hypostomus macushi, a new species of the Hypostomus cochliodon group (Siluriformes: Loricariidae) from Guyana. Zootaxa 2005;920:1. https://doi.org/10.11646/zootaxa.920.1.1.
[61] Weber C, Covain R, Fisch-Muller S. Identity of Hypostomus plecostomus (Linnaeus, 1758), with an overview of Hypostomus species from the Guianas (Teleostei: Siluriformes: Loricariidae) 2012:35.
[62] Zuanon J, Ferreira E. Feeding ecology of fishes in the Brazilian Amazon-a naturalistic approach. Feeding and Digestive Functions of Fishes Science Publishers Inc, USA, 589p 2008:1–34.
[63] Vari RP. Notes on the Characoid Subfamily Iguanodectinae, With a Description of a New Species 1977:12.
[64] Ibañez C, Tedesco PA, Bigorne R, Hugueny B, Pouilly M, Zepita C, et al. Dietary-morphological relationships in fish assemblages of small forested streams in the Bolivian Amazon. Aquat Living Resour 2007;20:131–42. https://doi.org/10.1051/alr:2007024.

[65] de Pinna MCC. The dawn of phylogenetic research on Neotropical fishes: a commentary and introduction to Baskin (1973), with an overview of past progress on trichomycterid phylogenetics. Neotrop Ichthyol 2016;14. https://doi.org/10.1590/1982-0224-20150127.
[66] Casatti L. Biology of a Catfish, Trichomycterus sp. (Pisces, Siluriformes), in a Pristine Stream in the Morro do Diabo State Park, Southeastern Brazil. Studies on Neotropical Fauna and Environment 2003;38:105–10. https://doi.org/10.1076/snfe.38.2.105.15928.
[67] Hadjiaghai O, Ladich F. Sex-Specific Differences in Agonistic Behaviour, Sound Production and Auditory Sensitivity in the Callichthyid Armoured Catfish Megalechis thoracata. PLoS ONE 2015;10:e0121219. https://doi.org/10.1371/journal.pone.0121219.
[68] Röpke CP, Ferreira E, Zuanon J. Seasonal changes in the use of feeding resources by fish in stands of aquatic macrophytes in an Amazonian floodplain, Brazil. Environ Biol Fish 2014;97:401–14. https://doi.org/10.1007/s10641-013-0160-4.
[69] Froese R, Pauly D. FishBase 2025.
[70] Fernarndes CC, Williston A. Redescription of Microsternarchus bilineatus (Fernández-Yépez, 1968) (Gymnotiformes: Hypopomidae, Microsternarchini), with the designation of a neotype. Proceedings of the Academy of Natural Sciences of Philadelphia 2017;165:105–15. https://doi.org/10.1635/053.165.0107.
[71] Merigoux S, Ponton D. Body shape, diet and ontogenetic diet shifts in young fish of the Sinnamary River, French Guiana, South America 1998:14.
[72] Gomiero LM, Braga FM de S. Feeding habits of the ichthyofauna in a protected area in the State of São Paulo, southeastern Brazil. Biota Neotrop 2008;8:41–7. https://doi.org/10.1590/S1676-06032008000100004.
[73] Barlow GW. Social Behavior of a South American Leaf Fish, Polycentrus schomburgkii, with an Account of Recurring Pseudofemale Behavior. American Midland Naturalist 1967;78:215. https://doi.org/10.2307/2423382.
[74] Wosiacki WB, Pinna M de. Trichomycterus igobi, a new catfish species from the rio Iguaçu drainage: the largest head in Trichomycteridae (Siluriformes: Trichomycteridae). Neotrop Ichthyol 2008;6:17–23. https://doi.org/10.1590/S1679-62252008000100003.
[75] Roa EZD, Palacios-Cáceres M, Pardo MJ. Zooplankton as dietary components of small fish species in a flooded savanna of Venezuela. SIL Proceedings, 1922-2010 1998;26:1359–63. https://doi.org/10.1080/03680770.1995.11900944.
[76] Conde-Saldaña CC, Albornoz-Garzón JG, García-Melo JE, Villa-Navarro FA, Mirande JM, Lima FCT. A New Pristella (Characiformes: Characidae) from the Río Orinoco Basin, Colombia, with a Redefinition of the Genus. Copeia 2019;107:439. https://doi.org/10.1643/CI-18-147.
[77] Goulding M, Carvalho ML. Ecology of Amazonian needlefishes (Belonidae). Rev Bras Zool 1984;2:99–111. https://doi.org/10.1590/S0101-81751983000300002.
[78] Kolmann MA, Burns MD, Ng JYK, Lovejoy NR, Bloom DD. Habitat transitions alter the adaptive landscape and shape phenotypic evolution in needlefishes (Belonidae). Ecol Evol 2020;10:3769–83. https://doi.org/10.1002/ece3.6172.

[79] Angulo-Valencia MA, Agostinho AA, Suzuki HI, da Luz-Agostinho KD, Agostinho CS. Impoundments affect fish reproduction regardless of reproductive strategy. Lakes & Reservoirs: Research & Management 2016;21:362–74.
[80] Vieira LS, Netto-Ferreira AL. New species of Pyrrhulina (Teleostei: Characiformes: Lebiasinidae) from the eastern Amazon, Pará, Brazil. Neotrop Ichthyol 2019;17:e190013. https://doi.org/10.1590/1982-0224-20190013.
[81] Mol JH. The freshwater fishes of Suriname. Leiden ; Boston: Brill; 2012.
[82] Favorito SE, Zanata AM, Assumpção MI. A new Synbranchus (Teleostei: Synbranchiformes: Synbranchidae) from ilha de Marajó, Pará, Brazil, with notes on its reproductive biology and larval development. Neotrop Ichthyol 2005;3:319–28. https://doi.org/10.1590/S1679-62252005000300001.
[83] Freitas PV, Montag LFA, Ilha P, Torres NR, Maia C, Deegan L, et al. Local effects of deforestation on stream fish assemblages in the amazon-savannah transitional area. Neotrop Ichthyol 2021;19:e210098. https://doi.org/10.1590/1982-0224-2021-0098.
[84] Souza J de S e, Sarmento-Soares LM, Canto ALC, Ribeiro FRV. Description of a new species of Tatia from rio Tocantins drainage, central Brazil, with notes on Tatia simplex Mees, 1974 (Siluriformes, Auchenipteridae). Neotrop Ichthyol 2020;18:e190111. https://doi.org/10.1590/1982-0224-2019-0111.
[85] Bulla CK, Gomes LC, Miranda LE, Agostinho AA. The ichthyofauna of drifting macrophyte mats in the Ivinhema River, upper Paraná River basin, Brazil. Neotrop Ichthyol 2011;9:403–9. https://doi.org/10.1590/S1679-62252011005000021.

Fish taxonomic families as potential indicators of biodiversity in biomonitoring of impacted Amazonian streams

Luciana Lameira dos Santos, Naraiana Loureiro Benone, Lidia Brasil Seabra, Cleonice Maria Cardoso Lobato and Luciano Fogaça de Assis Montag
Corresponding author: lucianalameira@yahoo.com.br

TABLE S2 Abundance of fish species captured in 18 streams sampled during the rainy seasons of 2018–2019, the dry season of 2019, the dry season of 2023, and the rainy season of 2024 in Barcarena, Pará State, northern Brazil. [1]Removed from the Procrustes analysis due to containing fewer than three species per expedition.

Taxon/Authority	Species code	Rainy 2018	Rainy 2019	Dry 2019	Dry 2023	Rainy 2024	Total
Beloniformes							
Belonidae[1]							
Pseudotylosurus microps (Günther 1866)	Pseumicr		1				1
Characiformes							
Acestrorhamphidae							
Hemigrammus cf. *bellottii*	Hemibell					1	1
Hemigrammus cf. *unilineatus* (Gill 1858)	Hemiunil	20	21	11			52
Hemigrammus collettii (Steindachner, 1882)	Hemicoll					13	13
Hemigrammus rodwayi Durbin 1909	Hemirodw	68	12	33		58	171
Hyphessobrycon cf. *moniliger*	Hyphmoni				35		35
Hyphessobrycon gr. *agulha*	Hyphagul				86	58	144
Hyphessobrycon heterorhabdus (Ulrey 1894)	Hyphhete	426	478	326	546	147	1923
Pristella maxillaris (Ulrey, 1894)	Prismaxi				4	11	15
Crenuchidae[1]							

Characidium sp. 1	Charsp1					2	2
Erythrinidae[1]							
Erythrinus erythrinus (Bloch & Schneider, 1801)	Eryteryt		3				3
Hoplias malabaricus (Bloch 1794)	Hoplmala	1	16		3		20
Gasteropelecidae[1]							
Carnegiella sp. 1	Carnsp1					1	1
Iguanodectidae[1]							
Bryconops caudomaculatus (Günther, 1864)	Bryccaud				24	17	41
Bryconops melanurus (Bloch 1794)	Brycmela	5	12	3			20
Iguanodectes rachovii Regan 1912	Iguarach	18	100	88	84	39	329
Lebiasinidae							
Copella arnoldi (Regan 1912)	Copearno	97	104	34	71	20	326
Nannostomus eques Steindachner 1876	Nanneque	3	3	4	6	3	19
Pyrrhulina capim Vieira & Netto-Ferreira, 2019	Pyrrcapi	2	101	28	4	3	138
Cichliformes							
Cichlidae							
Aequidens tetramerus (Heckel 1840)	Aequtetr		5	5	6	17	33
Apistogramma agassizii (Steindachner, 1875)	Apisagas				6	3	9
Apistogramma gr. *regani* Kullander 1980	Apisrega	95	41	43	209	51	439
Apistogramma sp. 1	Apissp1				1	1	2
Heros sp. 1	Herosp1					45	45
Mesonauta acora (Castelnau 1855)	Mesoacor	1					1
Nannacara taenia Regan 1912	Nanntaen	13	1	8			22
Saxatilia gr. *saxatilis*	Saxasaxa				1	7	8
Saxatilia inpa Ploeg 1991	Saxainpa	1	2				3
Polycentridae[1]							
Polycentrus schomburgkii Müller & Troschel 1849	Polyscho				2		2
Cyprinodontiformes							

Fluviphylacidae[1]							
Fluviphylax sp.	Fluvisp1	1		1			2
Poeciliidae[1]							
Poecilia sp. 1	Poecsp1					1	1
Rivulidae[1]							
Anablepsoides urophthalmus (Günther, 1866)	Anaburop	1	1		32	16	50
Laimosemion cf. *strigatus*	Laimstri	32	11	2			45
Gymnotiformes							
Gymnotidae[1]							
Gymnotus sp.	Gymnsp		1				1
Hypopomidae[1]							
Brachyhypopomus sp. 1	Bracsp1			5			5
Brachyhypopomus sp. 2	Bracsp2	2	10				12
Brachyhypopomus sp. 3	Bracsp3					1	1
Microsternarchus bilineatus Fernández-Yépez, 1968	Micrbili				1		1
Rhamphichthyidae[1]							
Gymnorhamphichthys rondoni (Miranda Ribeiro 1920)	Gymnrond	7	1		26	2	36
Hypopygus lepturus Hoedeman 1962	Hypolept	6	2		4	1	13
Perciformes							
Polycentridae[1]							
Polycentrus schomburgkii Müller & Troschel 1849	Polyscho	9	30	17			56
Siluriformes							
Auchenipteridae[1]							
Tatia sp. 1	Tatisp1					1	1
Callichthyidae[1]							
Megalechis thoracata (Valenciennes 1840)	Megathor	1	6	2			9
Cetopsidae[1]							
Helogenes marmoratus Günther 1863	Helomarm	4		1	7		12

Heptapteridae[1]							
Gladioglanis sp.	Gladsp1		1	1			2
Pimelodella sp. 1	Pimesp1					1	1
Loricariidae[1]							
Ancistrus sp. 1	Ancisp1				1	1	2
Hypostomus sp.	Hyposp		1				1
Trichomycteridae[1]							
Ituglanis amazonicus (Steindachner 1882)	Itugamaz	4	3	2			9
Ituglanis sp. 1	Itugsp1					1	1
Potamoglanis hasemani (Eigenmann 1914)	Potahase	57	26	15			98
Synbranchiformes							
Synbranchidae[1]							
Synbranchus marmoratus Bloch 1795	Synbmarm	1	3	16		1	21
Total		875	996	645	1159	523	4198