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Inventory

Streams fish from Upper Araguaia and Middle Rio da Mortes basin, Brazil: generating subsidies for preservation and conservation of this critical natural resource

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Abstract: The Araguaia River basin has the highest fish biodiversity within the Cerrado biome (Brazilian savannah), with many endemic and threatened species by human activities. Despite growing efforts to catalog Neotropical freshwater fish biodiversity, many regions are still undersampled. Our objective is to complement the information about stream fish in two hydrographic basins in the Cerrado. We sampled 72 streams with 50 m stretch in the Upper Araguaia (n = 32) and Middle Rio das Mortes (n = 40) basins. We collected 14,887 individuals distributed in 137 species, 81 genera, 30 families, and six orders. Characidae, Loricariidae, and Cichlidae were the families richer in species. We found a high diversity of rare fish species in the streams sampled, ca. 71.5% of the species had at least five individuals collected, and 18 species had only one collected specimen. The most frequent species were *Astyanax* cf. *goyacensis, Knodus* cf. *breviceps*, and *Characidium* cf. *zebra*. Both basins shared around 43% of the species. We caught 76 species in Upper Araguaia and 120 species in Middle Rio das Mortes. Seventeen exclusive fish species occurred in Upper Araguaia, whereas 61 were found in the Middle Rio das Mortes basin. Our analysis showed lower diversity of fish in Upper Araguaia than in the Middle Rio das Mortes basin. Considering the exclusive fish species of both basins, the human threats in those regions, and the few existent protected areas, we need a better look at the aquatic biodiversity conservation of this ecosystem.
Keywords: *Biodiversity; Cerrado; Freshwater; Neotropical fishes; Headwaters.*

Peixes de riachos das bacias do alto rio Araguaia e médio Rio das Mortes, Brasil: gerando subsídios para preservação e conservação desse importante recurso natural

Resumo: A bacia do rio Araguaia apresenta a maior diversidade de peixes no bioma Cerrado, muitas dessas são endêmicas e ameaçadas pelas atividades antropogênicas. Apesar dos crescentes esforços para catalogar a diversidade de peixes neotropicais muitas regiões ainda permanecem subamostradas. O objetivo do nosso estudo é complementar a informação sobre peixes de riachos para duas importantes bacias hidrográficas no Cerrado. Amostramos um total de 72 trechos de 50 metros em riachos nas bacias alto rio Araguaia (n = 32) e médio Rio das Mortes (n = 40). Coletamos um total de 14.887 indivíduos distribuídos em 137 espécies, 81 gêneros, 30 famílias e seis ordens. As famílias Characidae, Loricariidae e Cichlidae foram as tiveram maior número de espécies. Encontramos uma grande raridade de espécies de peixes nos riachos amostrados, cerca de 71,5% das espécies apresentaram ao menos até cinco indivíduos coletados e 18 espécies tiveram apenas um único exemplar. As espécies com maior ocorrência nos riachos foram, *Astyanax* cf. *goyacensis Knodus* cf. *breviceps* e *Characidium* cf. *zebra*. As duas bacias compartilham aproximadamente 43% das espécies de peixes coletadas. Encontramos 76 espécies para o alto rio Araguaia e 120 espécies para médio Rio das Mortes. Observamos 17 espécies exclusivas para a bacia do alto rio Araguaia e 61 espécies exclusivas para bacia do Médio Rio das Mortes. Nossas análises mostraram que a diversidade de peixes é menor na bacia do alto rio Araguaia quando comparada a bacia do médio Rio das Mortes. Considerando as ameaças antrópicas, o baixo número unidades de conservação e o elevado número de espécies exclusivas presentes em ambas as bacias, existe uma necessidade urgente concentrar esforços na conservação desses ecossistemas.
Palavras-chave: *Biodiversidade; Cerrado; Água doce; Peixes Neotropicais; Riachos de Cabeceiras.*

Introduction

The Cerrado is a Brazilian biome considered one of the global biodiversity *hotspots* due to its high species riches, endemic rates, and human threats to its biodiversity (Myers et al. 2000). The origins of large South American rivers (Amazonica, Tocantins-Araguaia, Paraná, and São Francisco basin) are inserted into this biome, which is informally entitled the Brazilian "berço das águas" (water cradle). The water bodies of Cerrado (e.g., rivers, lakes, and streams) harbor about 1200 cataloged fish species (ICMBio 2020), corresponding to 25% of South American freshwater fish species. It is important to highlight that many of the Cerrado fishes are endemic and represent more than 42% (n = 131) of the threatened Brazilian fish species (Latrubesse et al. 2019). Among the river basins originating within the Cerrado, the Araguaia River basin harbors more considerable fish diversity (Dagosta et al. 2020), with more than 320 currently described species and many with a restricted distribution that mainly occupies the headwaters (first to third order) (Latrubesse et al. 2019). Unfortunately, the Araguaia River basin landscape is undergoing a rapid transformation. Agriculture plantations or pastures replace native vegetation, and water bodies are being dammed for hydropower dam construction and agricultural irrigation intensification (Coe et al. 2011, Latrubesse et al. 2019).

The high number of fish species with restricted distribution and the human-caused environmental degradation in these basins are significant challenges for fish biodiversity conservation (Nogueira et al. 2010, Latrubesse et al. 2019, Dagosta et al. 2020). Therefore, actions addressed to preserve this biodiversity should consider the wide variation in fish community composition among the catchment systems since many of these restricted-distribution fish species are exclusive from streams (Lima 2019).

Stream fish are among the most threatened aquatic organisms (Nogueira et al. 2010, Castro 1999, Castro & Polaz 2020), and one of their main threats concerns habitat degradation (Barletta et al. 2010, Castro & Polaz 2020). The riparian vegetation removal (i.e., the watercourse adjacent buffer zone) is the leading habitat homogenization cause (Casatti, Ferreira & Carvalho 2009, Teresa & Casatti 2012, Zeni et al. 2019). Consequently, the resulting eutrophication and silting of the river channel (Teresa & Casatti 2012) also contribute to biodiversity homogenization. Besides habitat change, the streams fish suffer other kinds of threats, such as introducing non-native species, highway and dam construction, agricultural pesticides, and fertilizer intensification (Winemiller et al. 2008, Reid et al. 2019).

Unfortunately, scientific ecological investigations advance more slowly than changes in natural ecosystems. Thus, many species can be extinct, even before they are formally described by science. Besides, there is data scarcity to fill distinct information gaps for many organisms (Hortal et al. 2015) regarding species proper identification (Linnean shortfalls) and the spatial distribution of the species (Wallacean shortfalls). It is essential to highlight that the Linnean shortfall is the most significant data gap to be solved because it directly affects all other biodiversity knowledge gaps (for more details, see Hortal et al. 2015). Furthermore, due to the growing and constant threat to streams, actions seeking to synthesize information about these ecosystems to guide research and conservation measures are needed (Dudgeon et al. 2006, Barletta et al. 2010, Cetra et al. 2020). Thus, our goal was to complement the information about stream fish in two important hydrographic basins in the Cerrado biome.

Materials and Methods

1. Study Area

We sampled a total of 72 streams ranging from first to fourth order (scale 1:10000 IBGE) according to Strahler's (1957) classification in the Upper Araguaia and Middle Rio das Mortes basin, belonging to the Tocantins–Araguaia ecoregion (Figure 1, Table 1). The Araguaia River is a major fluvial system of the Cerrado, draining 375,000 km^2 and with an average annual streamflow of 6,500 m^3.s^{-1} (Morais et al. 2008, Latrubesse et al. 2009). The Araguaia River sources in slopes of the "Caiapós" mountain, on the boundaries of Goiás and Mato Grosso states, at 850 m elevation above sea level and travels 2110 km up to its confluence with the Tocantins River. Thus, the Araguaia basin can be divided into three stretches: upper, middle, and lower (for more details about division, see Latrubesse & Stevaux 2002, Aquino et al. 2010). The Upper Araguaia River stretch, where a portion of our sampling sites are found, has an approximate extension of 450 km and is located between its source and the "Registro do Araguaia" district, draining an approximate area comprising 375,000 km^2 (Latrubesse & Stevaux 2002, Latrubesse et al. 2009).

The Rio das Mortes source is near to the "São Jerônimo" mountain, in the Mid-Southern Mato Grosso region at 808 m above sea level, flowing the northwest direction of the state for approximately 1,070 km until it flows into the middle section of the Araguaia River, near of São Félix do Araguaia city. The Rio das Mortes is the main tributary river of the Araguaia River basin, with a drainage area of approximately 61,684 km^2 and an average annual flow of roughly 891.53 m^3.s^{-1} (ANA 2020). The initial portion basin is inserted into a landscape with intensive agriculture activity, whereas the native vegetation is restricted to the hydrographic network margins . While in the middle stretch, where a portion of our sampling sites are located, the mainland use activity is livestock. However, due to indigenous lands (TIs) and the sharp slope of relief at the edges of the "Alcantilados" plateau, it is still possible to find relatively sizable native vegetation areas in this stretch (Lima 2009).

Our study area is localized in the upper and middle stretches of the Araguaia and Rio das Mortes basins, respectively. The climate of the region is *Aw,* according to the Köppen classification (Alvares et al. 2013), with two seasonal periods: (i) rainy from October to April and (ii) dry from May to September. The annual mean precipitation ranges from 1200 to 1900 mm, and the yearly average temperature is approximately 24 ºC, with higher temperatures in the rainy period (INMET 2020).

2. Data Sampling

Using geography information systems (GIS) tools, we chose 32 streams in the Araguaia River and 40 in the Rio das Mortes basin, totaling 72 stretches of streams to be sampled. The sites were selected based on the independence between them and accessibility criteria. We used the collection sampling method modified from the Biodiversity Research Program (PPBIO), which consisted of sampling a 50-meter stream stretch (Mendonça et al. 2005). We collected in each stream environmental variables related to the limnological conditions and structural variables related to the environmental characterization of the streams. We measured the limnological conditions (i.e., conductivity, dissolved oxygen, pH, turbidity, and water temperature) of the streams only once at the beginning of the sample stretch using a portable multiparametric probe (Horiba U-50). We divided each sampled

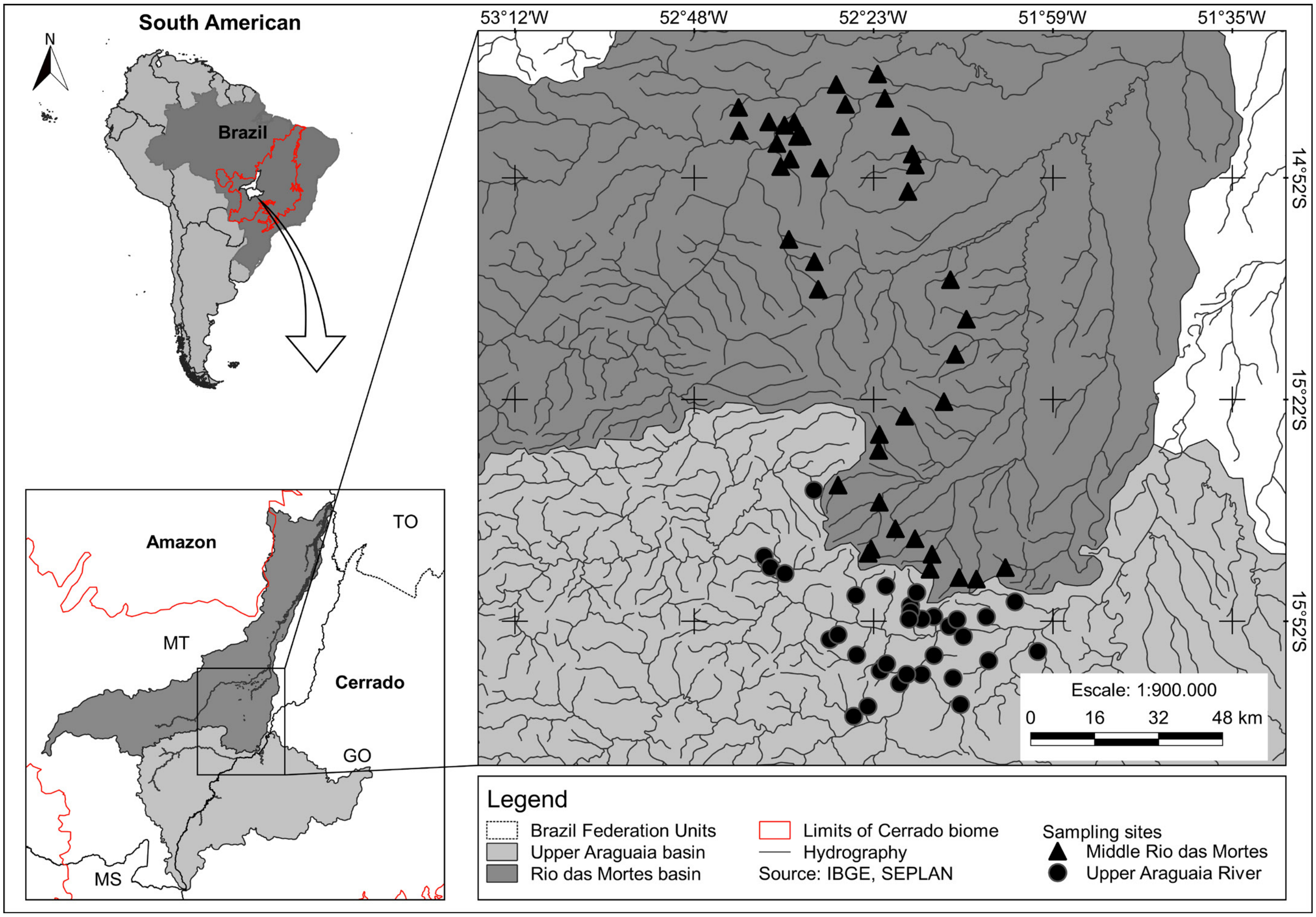

Figure 1. Localization of 72 streams sampled in the Upper Araguaia and Middle Rio das Mortes basin, Tocantins-Araguaia ecoregion.

stretch-50 m into six equidistant transects and recorded the following structural variables, representing the average values of each one of the measured variables in each transect: width, depth obtained from five measurements from one margin to the other, surface water velocity using the method fluctuate material (Teresa & Casatti 2012), and the proportion of substrate structure (i.e., sand, gravel, pebbles, rock, slab, and silt). In addition, we visually quantified the presence of trunks, leaf-litter, and margin structure variables (i.e., thin roots, thick roots, and grass banks) (Cummins 1974, Teresa & Casatti 2012).

We sampled the fish of the streams during the dry periods (May to September) between 2014 – 2017 for more catching efficiency and reduced seasonality effects on collections (Ueida & Castro 1999, Pease et al. 2012). Before initializing the sampling, we blocked the sample stretch limits with 5-mm mesh nets to prevent fish escape. Then, we sampled the fish through the standardized active collection, which consisted of employing four people for approximately one hour. Later, we sampled 35 streams stretch during the day using seine nets (3.0 × 1.5 m × 5.0 mm mesh) and dip nets (0.5 × 0.45 m × 5.0 mm mesh). Next, we used the electrofishing method (Honda EG1000 generator – 220 V, CA) with a single passage downstream, upstream, lasting approximately one hour to sample the other 37 streams. After the sampling, the individuals were anesthetized with benzocaine and sacrificed according to the Federal Council of Veterinary Medicine (in Portuguese CFMV 2012). In the laboratory, we measured the standard length (cm), weighted (g), and identified all specimens collected until the lowest taxonomic level possible using specialized bibliography (Venere & Garutti 2011), and to elaborate the taxonomic list using the Catalogue of Fishes (Fricke et al. 2021).

The Instituto Chico Mendes de Conservação da Biodiversidade(ICMBio; Permit Nº. 45316-1) and the Animal Use Ethics Committee of the Universidade Federal de Mato Grosso (CEUA / UFMT – Nº. 23108.152116) authorized our field collections. We stored the fish collected in the Laboratório de Ecologia e Conservação de Ecossistemas Aquáticos at the Universidade Federal de Mato Grosso, Campus Araguaia, Pontal do Araguaia, Mato Grosso.

3. *Data Analysis*

We used a principal component analysis (PCA) to summarize the environmental characteristics of the streams. After running the PCA, we standardized all environmental variables (except pH) to zero mean and unit variances (z transformation). Next, we analyzed the richness values (number of species) and abundance (total number of individuals by species) of the fish communities using descriptive statistics. We considered as exclusive species those that occurred only within one basin and as unique species those that occurred only in one stream reach, and singletons those with only one specimen (Novotný & Basset 2000). Finally, we evaluated the species richness differences and the efficiency of the sampling effort within both basins using the rarefaction

Table 1. The list of sampled sites in the Upper Araguaia River (UAR) and Middle Rio das Mortes (MRM) basin, Tocantins-Araguaia ecoregion.

Sites	Name	Latitude	Longitude	Order	Width (m)	Depth (cm)	Collection method	Elevation
MRM01	Salgadinho stream	14º40’46.20”S	52º21’53.64”W	Third	4.04	15.78	Electrofishing	263
MRM02	Unnamed stream	14º46’54.48”S	52º36’26.64”W	Second	2.95	15.52	Electrofishing	279
MRM03	Queixada stream	14º44’25.80”S	52º35’25.08”W	Second	3.55	36.39	Electrofishing	273
MRM04	Unnamed stream	14º43’59.52”S	52º34’5.16”W	Second	12.81	21.72	Electrofishing	276
MRM05	Voadeira stream	14º41’35.88”S	52º27’11.88”W	Third	7.23	19.58	Electrofishing	269
MRM06	Unnamed stream	14º45’9.36”S	52º41’30.48”W	Second	2.28	33.65	Electrofishing	322
MRM07	Unnamed stream	14º43’58.80”S	52º37’32.16”W	Third	3.72	21.12	Electrofishing	295
MRM08	Barreira stream	14º38’53.16”S	52º28’26.40”W	Third	2.80	15.68	Electrofishing	277
MRM09	Affluent of the Piau stream	14º42’0.36”S	52º41’36.24”W	Third	2.11	39.65	Electrofishing	334
MRM10	Bacaba stream	14º53’26.16”S	52º18’46.44”W	Third	3.62	22.18	Electrofishing	298
MRM11	Cachoeirinha stream	14º49’50.88”S	52º17’47.40”W	Third	3.67	32.28	Electrofishing	288
MRM12	Duas Pontes stream	14º48’20.88”S	52º18’11.52”W	Fourth	5.66	35.38	Electrofishing	285
MRM13	Estilac stream	14º37’27.84”S	52º22’51.60”W	Second	3.18	30.53	Electrofishing	298
MRM14	Duas Pontes stream	15º5’24.72”S	52º13’2.64”W	Fourth	7.60	29.48	Electrofishing	301
MRM15	Pindaibinha stream	15º10’46.92”S	52º10’53.40”W	Fourth	3.72	32.37	Electrofishing	315
UAR01	Avoadeira stream	15º51’13.32”S	52º15’17.28”W	Third	3.33	30.60	Hand net and Dip net	521
UAR02	Peixinho stream	15º51’32.76”S	52º16’55.20”W	First	3.25	13.62	Hand net and Dip net	373
UAR03	Pitomba stream	15º51’14.76”S	52º8’12.48”W	Third	3.32	12.48	Hand net and Dip net	322
UAR04	Ouro Fino stream	15º49’12.00”S	52º4’19.56”W	Third	3.93	38.14	Hand net and Dip net	335
UAR05	Águas Quentes stream	15º52’31.80”S	52º13’12.36”W	First	3.32	12.88	Hand net and Dip net	325
MRM16	Areia stream	15º44’45.24”S	52º15’47.52”W	First	10.61	23.25	Hand net and Dip net	396
UAR06	Lontra stream	15º49’43.32”S	52º18’25.56”W	First	1.99	12.56	Hand net and Dip net	349
UAR07	Unnamed stream	15º50’33.3”S	52º18’24.9”W	First	6.31	9.36	Hand net and Dip net	345
UAR08	Unnamed stream	15º51’33.48”S	52º18’37.08”W	First	1.99	7.17	Hand net and Dip net	355
MRM17	Grande stream	15º44’31.20”S	52º5’37.68”W	Third	2.90	45.33	Hand net and Dip net	348
MRM18	Grande stream	15º35’39.48”S	52º22’38.28”W	Fourth	7.92	32.57	Hand net and Dip net	355
MRM19	Cava Funda stream	15º39’14.76”S	52º20’27.96”W	Third	5.01	19.20	Hand net and Dip net	398
MRM20	Taquaral stream	15º40’36.48”S	52º17’48.84”W	Third	7.77	43.92	Hand net and Dip net	369
MRM21	Fogaça stream	15º46’4.80”S	52º9’32.40”W	Third	2.66	9.30	Hand net and Dip net	397
MRM22	Ínsula stream	15º45’52.20”S	52º11’52.80”W	Third	3.68	13.27	Hand net and Dip net	388
MRM23	Taquaralzinho stream	15º42’42.48”S	52º15’31.32”W	Third	4.53	37.62	Hand net and Dip net	369
UAR09	Fundo stream	15º47’56.76”S	52º17’35.52”W	Fourth	5.00	21.82	Hand net and Dip net	343
UAR10	Portão stream	15º34’2.64”S	52º31’26.76”W	Second	4.98	27.57	Hand net and Dip net	427
MR24	Capa stream	15º33’19.44”S	52º28’11.64”W	Fourth	4.60	51.30	Hand net and Dip net	421
UAR11	Cambaúva stream	15º43’1.92”S	52º38’9.60”W	First	3.69	56.60	Hand net and Dip net	387
UAR12	Índios stream	15º44’30.84”S	52º37’20.28”W	Third	7.81	31.10	Hand net and Dip net	326
UAR13	Affluent of the Bateia stream	15º45’21.24”S	52º35’21.84”W	First	2.61	17.15	Hand net and Dip net	337
UAR14	Ponte Queimada stream	15º48’20.52”S	52º25’47.64”W	Fourth	5.99	30.70	Hand net and Dip net	377
UAR15	Affluent of the Monte Negro stream	15º58’33.96”S	52º22’30.72”W	First	1.51	22.97	Hand net and Dip net	379
UAR16	Buritirana stream	15º57’37.08”S	52º21’39.60”W	First	2.14	27.70	Hand net and Dip net	360
UAR17	Marimbondo stream	15º54’19.08”S	52º29’17.88”W	Second	3.03	41.00	Hand net and Dip net	344
UAR18	Mangabeira stream	15º53’40.56”S	52º28’12.00”W	Third	2.18	39.30	Hand net and Dip net	326
UAR19	Babilônia stream	15º56’25.44”S	52º25’41.16”W	Fourth	4.49	30.93	Hand net and Dip net	330
UAR20	Buritirana stream	5º51’36.72”S	52º12’8.64”W	Second	6.37	31.27	Hand net and Dip net	338
UAR21	Ribeirão das Mulas stream	15º55’57.00”S	52º1’15.60”W	Fourth	5.23	20.57	Hand net and Dip net	299
UAR22	Ribeirão Capivara stream	15º57’12.60”S	52º7’53.40”W	Fourth	3.99	29.80	Hand net and Dip net	319
UAR23	Affluent of the Avoadeira stream	15º47’3.84”S	52º21’44.64”W	Second	2.70	27.57	Hand net and Dip net	360

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UAR24	Grande stream	15º53’54.24”S	52º11’18.24”W	Third	5.07	14.40	Hand net and Dip net	302
UAR25	Areia stream	15º59’4.20”S	52º16’55.20”W	Fourth	6.33	26.80	Hand net and Dip net	300
UAR26	Jaraguá stream	15º56’29.04”S	52º15’15.48”W	Third	3.52	10.67	Hand net and Dip net	303
MRM25	Sucuri stream	15º15’33.12”S	52º12’23.04”W	Third	4.20	35.35	Electrofishing	338
MRM26	Matrinxã stream	15º21’59.04”S	52º13’55.20”W	Third	5.04	38.30	Electrofishing	363
MRM27	Água Limpa stream	15º23’57.84”S	52º19’12.72”W	Third	4.63	22.47	Electrofishing	415
MRM28	Mineiro stream	15º26’26.16”S	52º22’37.92”W	Third	2.96	22.27	Electrofishing	413
MRM29	Papagaio stream	15º28’35.76”S	52º22’43.32”W	Fourth	6.08	22.28	Electrofishing	388
UAR27	Caixão stream	16º4’45.12”S	52º26’4.92”W	Fourth	3.05	24.05	Electrofishing	320
UAR28	Cambaúva stream	16º3’25.56”S	52º24’10.80”W	Fourth	1.94	11.60	Electrofishing	336
UAR29	Cervo stream	16º0’17.28”S	52º19’53.40”W	Third	2.15	22.54	Electrofishing	326
UAR30	Grota Funda stream	15º59’3.48”S	52º18’56.52”W	Third	4.28	19.28	Electrofishing	332
MRM30	Unnamed stream	14º49’1.20”S	52º34’38.64”W	First	2.03	17.73	Electrofishing	422
MRM31	Unnamed stream	14º45’56.88”S	52º33’39.60”W	First	1.05	41.20	Electrofishing	395
MRM32	Unnamed stream	14º45’53.28”S	52º33’1.80”W	Second	3.23	28.40	Electrofishing	425
MRM33	Chupador stream	14º50’13.92”S	52º30’35.64”W	Second	1.83	27.33	Electrofishing	437
MRM34	Unnamed stream	14º44’34.08”S	52º19’46.20”W	First	6.93	9.57	Electrofishing	306
MRM35	Unnamed stream	15º6’42.84”S	52º30’51.84”W	Second	1.22	46.23	Electrofishing	616
MRM36	Unnamed stream	15º2’58.20”S	52º31’22.80”W	First	1.32	41.80	Electrofishing	575
MRM37	Unnamed stream	14º59’56.40”S	52º34’49.80”W	Second	2.10	65.68	Electrofishing	490
MRM38	Unnamed stream	14º50’2.76”S	52º35’55.32”W	First	1.71	30.92	Electrofishing	353
MRM39	Unnamed stream	15º42’34.92”S	52º24’7.92”W	First	1.34	10.55	Electrofishing	719
MRM40	Unnamed stream	15º42’1.08”S	52º23’43.44”W	First	1.30	16.35	Electrofishing	671
UAR31	Volta stream	16º3’9.72”S	52º11’41.64”W	Second	2.72	29.97	Electrofishing	339
UAR32	Unnamed stream	15º59’33.36”S	52º12’41.40”W	First	1.03	11.68	Electrofishing	356

and extrapolation (R/E) method (Colwell et al. 2012). We based our analyses on incidence data derived from the Hill number series with a 95% confidence interval obtained with the bootstrap method (Hill 1973, Chao et al. 2014, Colwell et al. 2012) using the *iNEXT* function from the *iNEXT* package (Hsieh et al. 2016). We performed all analyses and descriptive statistics with *R* software *version 3.6.1* (R Core Team 2019). We used the *vegan* package (Oksanen et al. 2018) to perform PCA and package *ggplot2* (Wickham 2009) to visualize the results.

Results

In general, the studied streams had low conductivity water (mean = 59.79 µS/cm), high dissolved oxygen levels (mean = 8.02 mg/l), slightly acidic (mean = 5.87 pH), low turbidity (mean = 2.38 NTU), and substrates with sand predominance (mean = 45.58%) and gravel (mean =16.95%). The first two PCA axes explained 27.76% of the environmental variation features in the streams (Figure 2). The first axis explained 16.57% of the variation and was positively associated with water temperature, silt, and grass banks and negatively associated with trunks and leaf-litters (Figure 2). The second axis accounted for 11.19% of the variation and was negatively associated with depth and sand (Figure 2). The first axis distinguished streams with a high proportion of grass banks in margins structures from streams with a high presence internal habits structure (Figure 2). The second axis differentiated streams with a higher proportion of pools and a higher proportion of unconsolidated substrates (sand) from streams with a high proportion of consolidated substrates (rocks) (Figure 2).

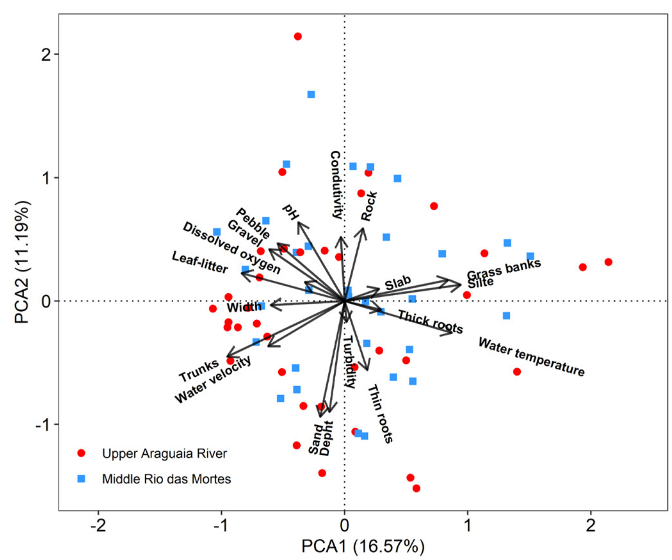

Figure 2. Biplot for principal components analysis (PCA) representing the main environmental variability in the sampling sites in the Upper Araguaia River and Middles Rio das Mortes basin, Tocantins-Araguaia ecoregion.

We collected a total of 14,887 individuals distributed in 137 species, 81 genera, 30 families, and six orders (Figure 3). The most species-rich families were Characidae, Loricariidae, and Cichlidae (40, 25, and 12 species, respectively). More than half of the individuals we sampled were concentrated in eight species (*Astyanax* cf. *goyacensis*, *Psalidodon xavante, Hyphessobrycon* aff. *tenuis*, *Knodus* cf. *breviceps*,

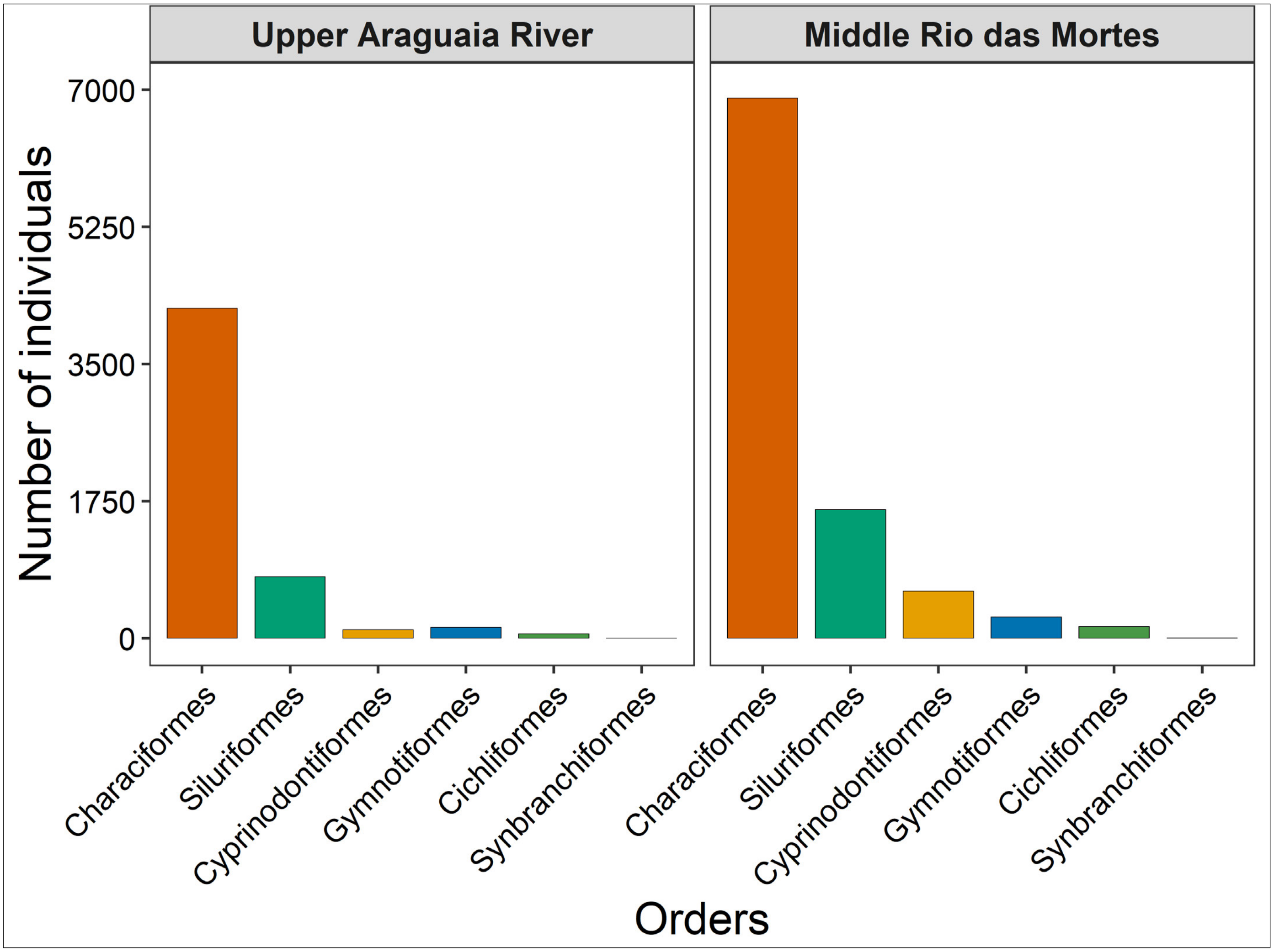

Figure 3. The individual abundance of six orders collected in the Upper Araguaia and Middle Rio das Mortes basins, Tocantins-Araguaia ecoregion.

Odontostilbe sp., *Phenacogaster* sp., *Aspidoras poecilus*, *Melanorivulus zygonectes*) (Table 2, Figure 4). The remaining 98 species (71.5%) had at least five individuals collected, and 18 species were considered singletons. The average richness per stream was 15.5 species (*SD* = 11). The species richness ranged from streams with only one species to streams with 48 species. The most frequent species in our sampled streams were *Astyanax* cf. *goyacensis* (*n* = 51), *Knodus* cf. *breviceps* (*n* = 43), *Characidium* cf. *zebra* (*n* = 40), *Imparfinis mirini* (*n* = 40), and *Moenkhausia oligolepis* (*n* = 40). We found 36 unique species, and 45 species identified only genera level. The *Hypostomus* and *Ancistrus* genera are the richer genera, showing the largest number of species identified up to the genera level.

The basins shared approximately 43% (*S* = 59) of the collected species. When we analyzed the species richness by basin, we found 76 species for Upper Araguaia and 120 in the Middle Rio das Mortes basin. We found 17 exclusives to Upper Araguaia and 61 species exclusive to the Middle Rio das Mortes basin. The rarefaction analysis showed that fish diversity in both Hill diversity series was lower in the Upper Araguaia River compared to the Middle Rio das Mortes basin (Figure 5a). The sampling effort analysis showed that the species richness for both basins was well represented, with a percentage of sample coverage greater than 93% of the estimated species (Figure 5bc). We sampled more than 93% of the Upper Rio Araguaia basin's estimated species richness, and 95% of the Middle Rio das Mortes basin's estimated species richness (Figure 5c).

Discussion

The predominance of the orders and families found in our study aligns with the expected patterns for Neotropical fishes in streams (Castro 1999, Lowe-McConnell 1999, Winemiller et al. 2008, Castro & Polaz 2020). The species richness and abundance of Characiformes, Siluriformes, and Cichliformes recorded in our study also follow the pattern reported in other studies with fish streams to some basins in the Cerrado biome (Leal et al. 2014, Barbosa et al. 2019). This pattern can be explained by the dominance of those orders in the Neotropical region (Lowe-McConnell 1999, Albert et al. 2011, Reis et al. 2016). The predominance of the Characidae family in the studied streams could be because this group is the richest in the Characiformes order, containing over 550 species (Albert et al. 2011) and displaying an extraordinary variation in morphological forms, feeding behaviors, and reproductive strategies (Melo et al. 2004, Winemiller et al. 2008). Such variety allows this group of fish to occur in the most diverse aquatic habitats. In turn, the predominance of Loricariidae fish can be due to the high species

Table 2. Species list with your respective abundance in Upper Araguaia River (UAR) and Middle Rio das Mortes (MRM), Tocantins-Araguaia ecoregion.

	Basin		
ORDER/Family/Species	**UAR**	**MRM**	**Total**
CHARACIFORMES			
Parodontidae			
Apareiodon sp.1		2	2
Apareiodon sp.2	88		88
Parodon pongoensis (Allen, 1942)	6	18	24
Curimatidae			
Curimatella immaculata (Fernández-Yépez, 1948)		1	1
Cyphocharax gouldingi Vari, 1992	25	131	156
Steindachnerina amazonica (Steindachner, 1911)	310	26	336
Prochilondotidae			
Prochilodus nigricans Spix & Agassiz, 1829		7	7
Anostomidae			
Leporinus friderici (Bloch, 1794)	2	2	4
Leporinus klausewitzi Géry, 1960	1	3	4
Leporinus sp.1	10	19	29
Leporinus venerei Britski & Birindelli, 2008		5	5
Erythrinidae			
Hoplerythrinus unitaeniatus (Spix & Agassiz, 1829)		32	32
Hoplias cf. *malabaricus* (Bloch, 1974)	17	58	75
Lebiasinidae			
Pyrrhulina australis Eigenmann & Kennedy, 1903	5	15	20
Gasteropelecidae			
Thoracocharax cf. *stellatus* (Kner, 1853)		107	107
Acestrorhynchidae			
Acestrorhynchus falcatus (Bloch, 1794)		4	4
Acestrorhynchus microlepis (Jardine, 1841)		9	9
Serrasalmidae			
Serrasalmus spilopleura Kner, 1858		1	1
Characidae			
Aphyocharax alburnus (Günther, 1869)	5	2	7
Aphyocharax sp.1		20	20
Astyanax argyrimarginatus Garutti, 1999	165		165
Astyanax cf. *goyacensis* Eigenmann, 1908	482	601	1083
Astyanax elachylepis Bertaco & Lucinda, 2005	15	124	139
Astyanax sp.		272	272
Bryconamericus novae Eigenmann & Henn, 1914		56	56
Creagrutus figueiredoi Vari & Harold, 2001	39	61	100
Creagrutus menezesi Vari & Harold, 2001	99		99
Creagrutus seductus Vari & Harold, 2001	70		70
Hemigrammus aff. *levis* Durbin, 1908	6	8	14
Hemigrammus cf. *rodwayi* Durbin, 1909	253	132	385
Hyphessobrycon aff. *tenuis* Géry, 1964	220	403	623
Hyphessobrycon sp.	261		261

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Jupiaba acanthogaster (Eigenmann, 1911)	18	146	164
Jupiaba elassonaktis Pereira & Lucinda, 2007		39	39
Jupiaba polylepis (Günther, 1864)		141	141
Knodus cf. *breviceps* (Eigenmann, 1908)	600	1233	1833
Knodus sp.		91	91
Microschemobrycon sp.1		8	8
Microschemobrycon sp.2	1		1
Moenkhausia aurantia Bertaco, Jerep & Carvalho, 2011	82	224	306
Moenkhausia cf. *comma* Eigenmann, 1908		27	27
Moenkhausia dichroura (Kner, 1858)		2	2
Moenkhausia lepidura (Kner, 1858)		137	137
Moenkhausia oligolepis (Günther, 1864)	102	234	336
Moenkhausia pyrophthalma Costa, 1994		1	1
Moenkhausia sp.		4	4
Moenkhausia venerei Petrolli, Azevedo-Santos & Benine 2016	46	192	238
Odontostilbe sp.	523	1031	1554
Phenacogaster cf. *pectinata* (Cope, 1870)		48	48
Phenacogaster sp.	11	622	633
Psalidodon xavante Garutti & Venere, 2009	511		511
Roeboexodon geryi Myers, 1960		28	28
Serrapinnus cf. *piaba* (Lütken, 1875)		16	16
Tetragonopterus chalceus Spix & Agassiz, 1829		6	6
Tetragonopterus sp.		9	9
Thayeria boehlkei Weitzman, 1957		4	4
Bryconidae			
Brycon falcatus Müller & Troschel, 1844	1	10	11
Iguanodectidae			
Bryconops alburnoides Kner, 1858		51	51
Bryconops giacopinii (Fernández-Yépez, 1950)	12	170	182
Bryconops melanurus (Bloch, 1794)	2	37	39
Crenuchidae			
Characidium cf. *zebra* Eigenmann, 1909	225	262	487
Characidium mirim Netto-Ferreira, Birindelli & Buckup, 2013		2	2
Characidium sp.1		2	2
Characidium sp.2		1	1
SILURIFORMES			
Auchenipteridae			
Trachelyopterus galeatus (Linnaeus, 1758)		2	2
Pimelodidae			
Pimelodus ornatus Kner, 1858		1	1
Pseudopimelodidae			
Microglanis sp.	49		49
Pseudopimelodus cf. *pulcher* (Boulenger, 1887)	1	23	24
Heptapteridae			
Cetopsorhamdia sp.	6		6
Cetopsorhamdia sp.2		1	1
Imparfinis mirini Haseman, 1911	213	237	450

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Imparfinis sp.	3	9	12
Mastiglanis asopos Bockmann, 1994		38	38
Phenacorhamdia somnians (Mees, 1974)	47	37	84
Pimelodella sp.		1	1
Pimelodella sp.1	11	72	83
Pimelodella sp.2		4	4
Pimelodella sp.3	49	50	99
Rhamdia quelen (Quoy & Gaimard, 1824)	4	25	29
Cetopsidae			
Cetopsis coecutiens (Lichtenstein, 1819)	1	11	12
Cetopsis sp.	2	2	4
Asprendinidae			
Bunocephalus sp.	1	7	8
Trichomycteridae			
Ituglanis macunaima Datovo & Landim, 2005	2		2
Stegophilus sp.	1		1
Callichthyidae			
Aspidoras poecilus Nijssen & Isbrücker, 1976	177	381	558
Callichthys callichthys (Linnaeus, 1758)	3	6	9
Corydoras araguaiaensis Sands, 1990		52	52
Corydoras maculifer Nijssen & Isbrücker, 1971		18	18
Loricariidae			
Ancistrus sp.1	3	118	121
Ancistrus sp.2		28	28
Ancistrus sp.3		1	1
Aphanotorulus emarginatus Valenciennes, 1840	1		1
Farlowella aff. *oxyrryncha* (Kner, 1853)		64	64
Farlowella aff. *schreitmuelleri* Arnold, 1936		28	28
Hisonotus sp.		19	19
Hypoptopoma gulare Cope,1878		2	2
Hypostomus aff. *cochliodon* Kner, 1854		1	1
Hypostomus cf. *atropinnis* (Eigenmann & Eigenmann, 1880)	14		14
Hypostomus faveolus Zawadzki, Birindelli & Lima 2008		10	10
Hypostomus sp.1	27	136	163
Hypostomus sp.2	1		1
Hypostomus sp.3	71	61	132
Hypostomus sp.4	37	1	38
Hypostomus sp.5	3		3
Loricaria sp.1	2	4	6
Loricaria sp.2	23	38	61
Loricaria sp.3		5	5
Otocinclus sp.	1		1
Parancistrus sp.		1	1
Parotocinclus britskii Boeseman, 1974	10	47	57
Parotocinclus sp.		39	39
Rineloricaria hasemani Isbrücker & Nijssen, 1979	18	62	80
Sturisoma nigrirostrum Fowler, 1940	6	2	8

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GYMNOTIFORMES			
Sternopygidae			
Eigenmannia trilineata Lópes & Castello, 1966	89	64	153
Sternopygus macrurus (Bloch & Schneider, 1801)	3	33	36
Apteronotidae			
Apteronotus albifrons (Linnaeus, 1766)	5	28	33
Apteronotus leptorhynchus (Ellis, 1912)		2	2
Rhamphichthyidae			
Gymnorhamphichthys petiti Géry & Vu, 1964	5	124	129
Gymnotidae			
Electrophorus electricus (Linnaeus, 1766)		1	1
Gymnotus cf. *carapo* Linnaeus, 1758	36	11	47
Gymnotus sp.	2	9	11
CYPRINODONTIFORMES			
Rivulidae			
Melanorivulus zygonectes (Myers, 1927)	110	599	709
Plesiolebias lacerdai Costa, 1989		2	2
Poeciliidae			
Pamphorichthys araguaiensis Costa, 1991	1	2	3
SYNBRANCHIFORMES			
Synbranchidae			
Synbranchus marmoratus Bloch, 1795	3	7	10
CICHLIFORMES			
Cichlidae			
Aequidens tetramerus Heckel, 1840	38	83	121
Apistogramma sp.		10	10
Biotodoma aff. *cupido* Heckel, 1840		2	2
Cichlasoma sp.	1		1
Crenicichla labrina (Spix & Agassiz, 1831)	18	20	38
Crenicichla reticulata (Heckel, 1840)		7	7
Crenicichla sp.		5	5
Heros aff. *efasciatus* Heckel, 1840		1	1
Laetacara araguaiae Ottoni & Costa, 2009		8	8
Retroculus lapidifer (Castelnau, 1855)		10	10
Retroculus sp.	2	6	8
Satonoperca jurupari (Heckel, 1840)		3	3
Total	5313	9574	14887

richness and diversity of the family in the Neotropical region (over 830 described species). Species in this family feed mainly on detritus and algae (Lujan et al. 2012). Detritus are abundant resources in tropical streams and are fundamental to ecosystem function (Bowen 1983), allowing those streams to support the high abundance and richness of detritivores fishes (Bowen 1983, Power 1983). In addition, the loricariid catfishes have an extraordinary variation in mouth morphologies, allowing them to forage detritus and periphyton in different types of habitat structures (e.g., rocks, trunks, sands, margins, and fast-water environments) presents in the headwater streams (Power 1983, Lujan et al. 2012).

Although the fish orders and families of the basin are well known, this pattern is not proper to species. We identified approximately 30% of the collected species only at the genera level. Many still need more detailed taxonomic and molecular studies (e.g., *Characidium* cf. *zebra*, *Hoplias* cf. *malabaricus* and *Gymnotus* cf. *carapo*). The significant number of species identified only at the genera level shows the need for further taxonomic studies in this basin. Considering the high fish species endemicity within these basins, there is a significant likelihood that many of these species identified only up to the genera level are new species. Previous studies on stream fish in these basins have also found similar patterns, with a great number of species not yet described

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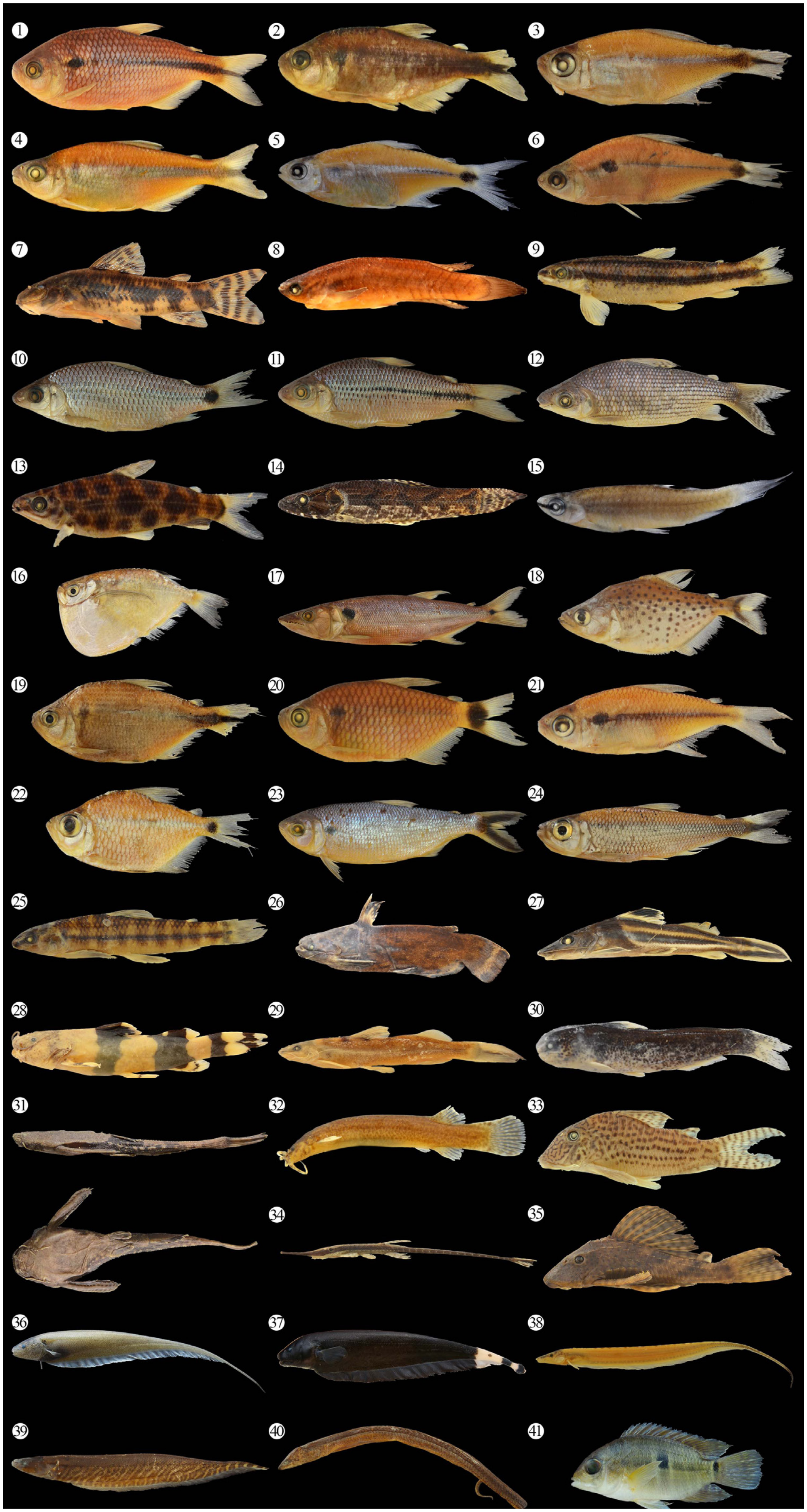
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Figure 4. The eight most abundant sampled species in the Upper Araguaia and the Middle Rio das Mortes basin and representative species of each family. Some families can have more than one more species represented. The total lengths mean are presented after the names of species. 1) *Astyanax* cf. *goyacensis*, 58.9 mm; 2) *Psalidodon xavante*, 45.9 mm; 3) *Hyphessobrycon* aff. *tenuis*, 31.4 mm; 4) *Knodus* cf. *breviceps*, 36.6 mm; 5) *Odontostilbe* sp., 30.9 mm; 6) *Phenacogaster* sp., 36.9 mm; 7) *Aspidoras poecilus*, 31.5 mm; *8) Melanorivulus zygonectes*, 29.6 mm. **Parodontidae** – 9) *Parodon pongoensis*, 64.6 mm; **Curimatidae** – 10) *Cyphocharax gouldingi*, 71.3 mm, 11) *Steindachnerina amazonica*, 105.7 mm; **Prochilondotidae** – 12) *Prochilodus nigricans*, 262.0 mm; **Anostomidae** – 13) *Leporinus* sp.1, 85.7 mm; **Erythrinidae** – 14) *Hoplias* cf. *malabaricus*, 106.3 mm; **Lebiasinidae** – 15) *Pyrrhulina australis*, 37.0 mm; **Gasteropelecidae** – 16) *Thoracocharax* cf. *stellatus*, 58.3 mm; **Acestrorhynchidae** – 17) *Acestrorhynchus falcatus*, 207.5 mm; **Serrasalmidae** – 18) *Serrasalmus spilopleura*, 63.9 mm; **Characidae** – 19) *Moenkhausia aurantia*, 57.3 mm, 20) *Moenkhausia oligolepis*, 57.8 mm, 21) *Moenkhausia venerei*, 34.3 mm, 22) *Tetragonopterus chalceus*, 50.0 mm; **Bryconidae** – 23) *Brycon falcatus*, 250.3 mm; **Iguanodectidae** – 24) *Bryconops giacopinii*, 56.3 mm; **Crenuchidae** – 25) *Characidium* cf. *zebra*, 35.2 mm; **Auchenipteridae** – 26) *Trachelyopterus galeatus*, 112.0 mm; **Pimelodidae** – 27) *Pimelodus ornatus*, 150.5 mm; **Pseudopimelodidae** – 28) *Pseudopimelodus* cf. *pulcher*, 48.5 mm; **Heptapteridae** – 29) *Imparfinis mirini*, 52.3 mm; **Cetopsidae** – 30) *Cetopsis coecutiens*, 57.1 mm; **Asprendinidae** – 31) *Bunocephalus* sp., 79.9 mm; **Trichomycteridae** – 32) *Ituglanis macunaima*, 47.5 mm; **Callichthyidae** – 33) *Corydoras maculifer*, 50.0 mm; **Loricariidae** – 34) *Farlowella* aff. *oxyrryncha*, 102.6 mm, 35) *Hypostomus* sp.3, 53.6 mm; **Sternopygidae** – 36) *Sternopygus macrurus*, 197.6 mm; **Apteronotidae** – 37) *Apteronotus albifrons*, 139.4 mm; **Rhamphichthyidae** – 38) *Gymnorhamphichthys petiti*, 143.9 mm; **Gymnotidae** – 39) *Gymnotus* cf. *carapo*, 150.7 mm; **Synbranchidae** – 40) *Synbranchus marmoratus*, 166.4 mm; **Cichlidae** – 41) *Aequidens tetramerus*, 63.2 mm.

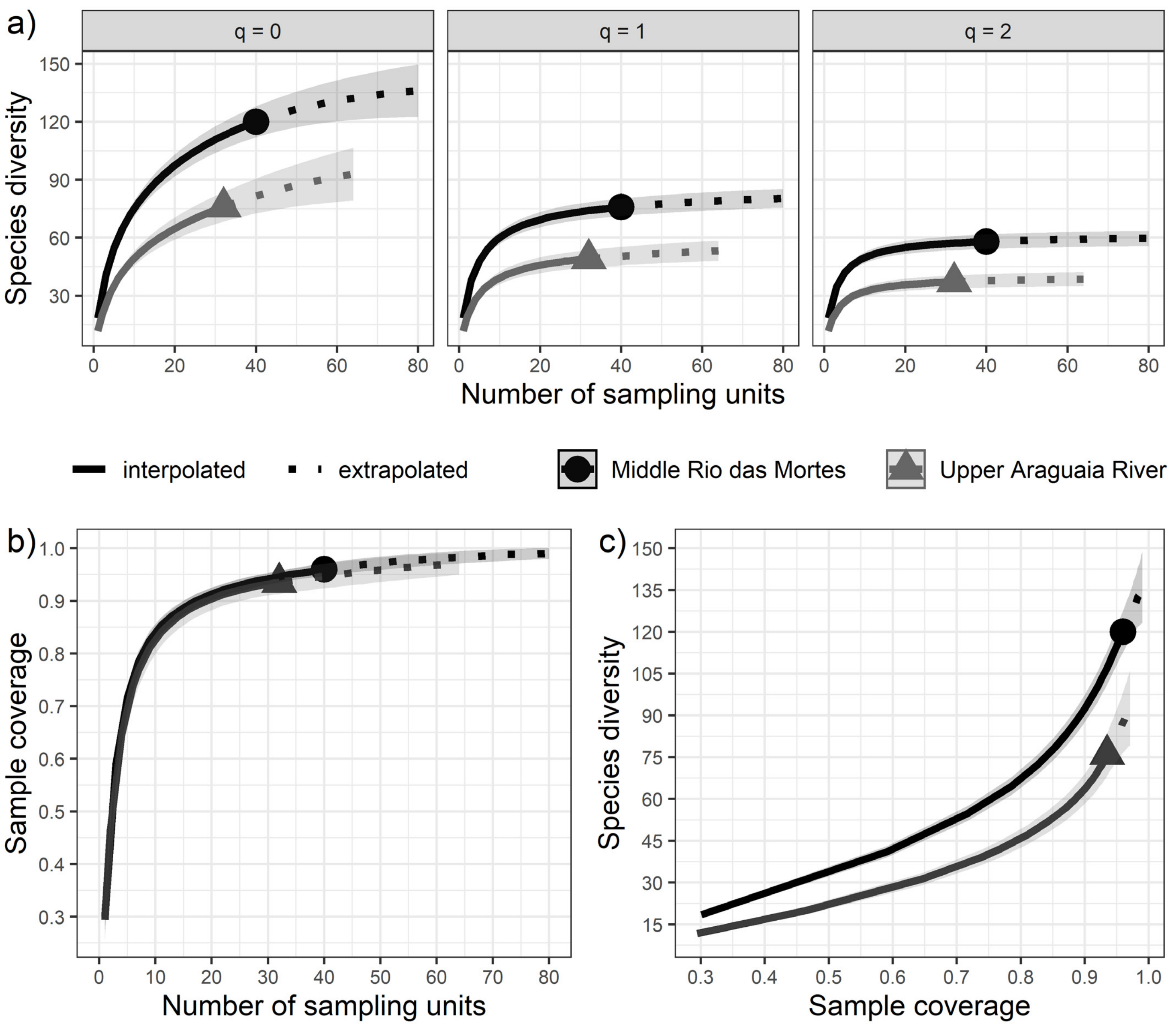

Figure 5. Sampling effort effectiveness for the Upper Araguaia River and the Middle Rio das Mortes basin, using the rarefaction method (solid line) and extrapolation (dotted line) based on Hill's numbers. (a) Incidence-based species accumulation curves, separated by order of diversity: q = 0 (Species richness), q = 1 (Shannon diversity) and q = 2 (Simpson diversity). (b) Sample completeness curves based on the number of sampling sites (c) coverage-based sampling curves based on species richness. We plotted all extrapolation curves to double the sample size, and the shaded area in all figures (a-b) denotes a confidence interval at 95% obtained from a bootstrap method with 999 replications.

(Melo et al. 2004, Matos et al. 2013, Jarduli et al. 2014, Oliveira et al. 2020). This large number of species to be described is one of the most important knowledge gaps in biodiversity (Linnean shortfalls) that needs to be addressed (Hortal et al. 2015). Even after two decades after the first studies with stream fish in the studied region, we still have a long way to know the actual diversity of stream fish in these basins. Although the number of researchers working with stream fish has increased, this advance is based less on taxonomic research than on other stream fish research (Junqueira et al. 2020, Lima 2021).

The average stream fish species richness observed in our study streams was 15 species, like the value found in other stream fish studies in this ecoregion (Melo et al. 2004, Matos et al. 2013, Barbosa et al. 2019, Oliveira et al. 2020). However, our data showed a wide variance in the number of species per stream. We sampled streams with one species and streams with up to 48 species. We believe that such variation in species richness between streams can be explained by environmental heterogeneity and hydrographic network size (Lowe-McConnell 1987, Tedesco et al. 2008, Vieira et al. 2018). The water physicochemical characteristics and habitat structures can vary spatially between nearby streams. This condition increases local environmental heterogeneity and makes fish diversity vary between streams (Benda et al. 2004). Besides, streams with more extensive drainage networks should support more diverse communities than streams with smaller drainage networks (Zbinden & Matthews 2017).

In our study, species with wide distribution (species that occurred in more than 50% of the sites) over the sampled streams belonged to groups of fish with more diversified feeding behaviors and reproductive strategies (Winemiller 1989). For the species present in our samples, we highlight the nektonic omnivores characids that feed on materials drifting in the water column and have split spawning (*Astyanax* cf. *goyacensis*; *Knodus* cf. *breviceps*, and *Moenkhausia oligolepis*), the benthic invertivores with fusiform bodies (*Characidium* cf. *zebra*), and the benthic omnivores catfish (*Imparfinis mirini*).

The species abundance patterns we found in this study are like those observed in streams with lower environmental degradation (Ferreira & Casatti 2006, Casatti, Ferreira & Langeani 2009). The species rarity of our samples is relatively high, with approximately 71.5% of them having at least five individuals collected and 18 having only one sampled specimen. The rare species patterns in ecological communities vary in abundance, where few species are common, some have intermediate abundance, and many are rare (Magurran & Henderson 2003). The number of rare species can vary from site to site because of natural variations in species abundance distributions or anthropogenic stressors (Preston 1948, Magurran & Henderson 2011). It is important to highlight that the rarity pattern for some species found in our study differs between the basins; for example, *Gymnorhamphichthys petiti* was rare in Upper Araguaia, but was abundant in the Middle Rio das Mortes basin. On the other hand, *Hypostomus* sp.4 was abundant in Upper Araguaia and rare in the Middle Rio das Mortes basin. Furthermore, the significant number of exclusive species in each basin shows distinct fish communities between them. Considering that the Araguaia River and Rio das Mortes belong to the same ecoregion (Abell et al. 2008), we assume that species dispersion (capacity for colonizing new habitats) and environmental filters are the main drivers responsible for the differences observed.

In this study, we did not find the fish species endangered. This finding can indicate a good ecological integrity of streams once the most sampled streams still have relatively preserved environmental conditions (Lima 2019). However, this scenario can change in the future. There is a series of threats to fish biodiversity within the basin's streams, mainly due to deforestation and the planned hydropower dams (Coe et al. 2011, Latrubesse et al. 2019, Dagosta et al. 2020, Pelicice et al. 2021). Considering the exclusive fish species of both basins, the human threats in those regions, and the few existent protected areas, we need a better look at this ecosystem's aquatic biodiversity conservation. This study contributes to filling one critical biodiversity knowledge gap (i.e., geographic distribution—Wallacean shortfalls) for fish species in streams in the Araguaia River and Rio das Mortes basins.

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Author Contributions

Luciano B. Lima**:** Substantial contribution in the concept and design of the study; contribution to data collection; contribution to data analysis and interpretation; contribution to manuscript preparation.

Fagner Junior M. Oliveira**:** Substantial contribution in the concept and design of the study; contribution to data collection; contribution to manuscript preparation; contribution to critical revision, adding intelectual content.

Fernando V. Borges**:** Substantial contribution in the concept and design of the study; contribution to data collection; contribution to manuscript preparation.

Fabiano Corrêa**:** Substantial contribution in the concept and design of the study; contribution to manuscript preparation; contribution to critical revision, adding intelectual content.

Dilermando P. Lima-Junior**:** Substantial contribution in the concept and design of the study; contribution to data collection; contribution to manuscript preparation; contribution to critical revision, adding intelectual content.

Conflicts of interest

All authors declare no competing interests.

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