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Thematic Review

Building knowledge to save species: 20 years of ichthyological studies in the Tocantins-Araguaia River basin

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Abstract: The Tocantins-Araguaia River basin is the largest basin located entirely in the Brazilian territory. The high degree of endemism of its ichthyofauna has been revealed in several studies, with the upper Tocantins River having the largest absolute number of endemic taxa within the Amazon basin. Here we provide an accurate review of the ichthyofauna of the Tocantins-Araguaia River basin, based on collections made between 2000-2020, including an extensive list of valid fish species occurring in the basin and a discussion of the major threats to its ichthyofauna. Ichthyofauna diversity was further refined based on web searches. Protected Areas and hydropower plants were mapped using shape files or coordinates from the responsible government agencies. 751 species of fishes are currently known from the Tocantins-Araguaia River basin. A considerable increase in fish diversity knowledge occurred in the last 20 years, in parallel with significant anthropic alterations in the basin and its surroundings. Dams constructed along the basin are ranked as the major threats to ichthyofauna. Although the drainage-basin holds several conservation units and indigenous lands, they have not been sufficient to guarantee the preservation of fish species. Our compilation emphasizes that the upper Tocantins River must be considered as a priority area to preserve fish species. Some mitigation actions that may achieve satisfactory results concerning ichthyofauna conservation are proposed.
Keywords: *Amazon basin; Cerrado; Conservation; Diversity; Ichthyofauna.*

Construindo conhecimento para salvar espécies: 20 anos de estudos ictiológicos na bacia do rio Tocantins-Araguaia

Resumo: A bacia do rio Tocantins-Araguaia é a maior bacia localizada completamente no território brasileiro. O elevado nível de endemismo de sua ictiofauna foi atestado em vários estudos, com o alto rio Tocantins possuindo o maior número absoluto de táxons endêmicos da bacia Amazônica. Aqui, fornecemos uma acurada revisão sobre o conhecimento da ictiofauna da bacia do rio Tocantins-Araguaia entre 2000-2020; uma extensa lista das espécies válidas de peixes ocorrentes na bacia, assim como uma discussão sobre as maiores ameaças para sua ictiofauna. Dados sobre a diversidade da ictiofauna foram refinados por meio de buscas na internet. O mapeamento das Áreas Protegidas e das hidrelétricas foi realizado utilizando os arquivos de área ou coordenadas fornecidas pelas agências governamentais responsáveis. 751 espécies de peixes são atualmente conhecidas para a bacia do rio Tocantins-Araguaia. Um aumento considerável no conhecimento sobre a diversidade de peixes ocorreu nos últimos 20 anos em paralelo com significativas alterações antrópicas na bacia e seu entorno. As represas ao longo da bacia são consideradas a maior ameaça à ictiofauna. Embora a região hidrográfica abrigue diversas unidades de conservação e terras indígenas, estas não têm sido suficientes para garantir a preservação das espécies de peixes. Nossa compilação enfatiza que o alto rio Tocantins precisa ser considerado como área prioritária para a conservação das espécies de peixes. Algumas ações mitigatórias, que podem atingir resultados satisfatórios em relação à conservação da ictiofauna, são também propostas.
Palavras-chave: *Bacia Amazônica; Cerrado; Conservação; Diversidade; Ictiofauna.*

Introduction

The Neotropical fish fauna is extremely rich, harboring 20 to 25% of world freshwater fish diversity. More than 6,000 known species and an expected 2000–3000 species left to be described in the Neotropics (Reis et al. 2016; Malabarba & Malabarba 2020). Most of this diversity is in the Amazon River basin, home to the richest freshwater ichthyofauna on Earth, with more than 2,700 known species (Dagosta & de Pinna 2019). The Tocantins-Araguaia River basin is the largest Brazilian exclusive basin (MMA 2006; ANA 2020). Two thirds of its waters drain the Cerrado domain (IBGE 2014) to discharge directly to the Atlantic Ocean, in the Amazon domain. The composition of the ichthyofauna of the Tocantins-Araguaia River basin is traditionally considered closely related to the Amazon basin, especially in its lower course (Goulding et al. 2003). Recently, most of the composition of the Tocantins-Araguaia fish fauna was proposed as more closely related to Amazon-draining Brazilian Shield rivers, forming a biogeographical region together with the Xingu, Tapajós, and some shield tributaries of the rio Madeira (Lima & Ribeiro 2011; Dagosta et al. 2020). According to these authors, the upper Tocantins and the upper Araguaia represent two smaller bioregions of the Amazonian fish fauna. Although with fish richness knowledge far from complete and sharing a number of species with other Amazonian rivers, the high degree of endemism of the Tocantins-Araguaia River basin is corroborated in several studies (*e.g.* Santos et al. 2004; Hubert and Renno 2006; Lucinda et al. 2007; Abell et al. 2008; Bertaco & Carvalho 2010; Carvalho et al. 2010; Bertaco et al. 2011; Hales and Petry 2013; Dagosta and de Pinna 2017, 2019). In fact, the upper rio Tocantins holds the largest absolute number of endemic taxa within the Amazon basin (Dagosta & de Pinna 2017, 2019) and the Araguaia River, the major fluvial artery of central Brazil and the Amazon-Cerrado ecotone, is home to more fish species than any other basin in the Cerrado (Latrubesse et al. 2019).

The Cerrado consists of tropical savannah mainly along the northern slop of the Brazilian Shield. It is well documented that the Cerrado is among the most threatened domains in the American continent (*e.g.* Silva & Bates 2002; Strassburg et al. 2017; Latrubesse et al. 2019; Colli et al. 2020). Concerningly, the rich and endemic ichthyofauna from the Tocantins-Araguaia River basin is also under severe threats from anthropic action, which has increased in the last two decades with the construction of several dams, expansion of agriculture and mining, introduction of exotic species, and waterway projects (*e.g.* Claro-Garcia & Shibatta 2013; Lees et al. 2016; Lima et al. 2016; Akama 2017; Pelicice et al. 2014; Pelicice et al. 2017; Latrubesse et al. 2019; Dagosta et al. 2020; Pereira et al. 2020; Perônico et al. 2020; Azevedo-Santos et al. 2021; Pelicice et al. 2021). Along with the huge hydropower plants advanced, the area drained by the Tocantins-Araguaia River basin is inserted on the newest Brazilian agricultural frontier, the MATOPIBA region. This new frontier was created from the Republic Presidency decree (nº. 8,447/2015), which provides for the Brazilian agricultural development plan in regions of the States of Maranhão, Tocantins, Piauí, and Bahia; whose intensive occupation for agricultural production began in the 1980s and has been increasing (Araújo et al. 2013; Barros & Stege 2019). Several reports have indicated major changes to fish species composition as a result of dams, an increase in species considered at risk, and a reduction of commercial species as a result of restriction and even loss of migratory species (*e.g.* Santos et al. 2004; Lucinda et al. 2007; Mérona et al. 2010; Bartolette et al. 2017; ICMBio 2018; Perônico et al. 2020). On the other hand, the scientific knowledge of the ichthyofauna from the Tocantins-Araguaia River basin and the consequences of the aforementioned environmental alterations are far from satisfactory (*e.g.* Hunke et al. 2014; Akama 2017; Pereira et al. 2020), although an increase of the number of publications investigating fish species under the influence of dams is notable. Pereira et al. (2020) highlighted gaps of scientific research on the matter, particularly involving the potential cumulative impacts of dams on phylogenetic diversity, and they pointed to the need of studies focusing on these areas. According to Agostinho et al. (2009), the growth in the number of hydroelectric dams was faster than that of scientific knowledge about ecological aspects of the Tocantins-Araguaia River basin, including its fish fauna. Therefore, the disparity between the rate of scientific knowledge of diverse aspects of the ichthyofauna and the increasing threats in this basin needs to be evaluated. A review of the knowledge of the ichthyofauna of the Tocantins-Araguaia River basin in the last 20 years is provided in the present study. We aim to evaluate the growing knowledge of the ichthyofauna in parallel with the increase in anthropic alterations in the basin and its surroundings. Additionally, a list of valid fish species occurring in the basin is also provided and the major threats to its ichthyofauna is discussed.

Materials and Methods

1. *Study area*

As the name states, the Tocantins-Araguaia River basin is composed mainly of the Tocantins and Araguaia rivers. The hydrographic region is the largest basin located entirely in the Brazilian territory, comprising 918,273 km^2 (about 11% of the Brazilian territory), encompassing the States of Goiás, GO (26.8%), Tocantins, TO (34.2%), Pará, PA (20.8%), Maranhão (3.8%), Mato Grosso, MT (14.3%), and the Federal District, DF (0.1%). Most of the basin is located in the Midwest region, where its headwaters are formed. Downstream from the confluence of the Tocantins and Araguaia rivers, the basin enters the North region until its mouth (MMA 2006; ANA 2020).

The Tocantins River is formed by the das Almas and Maranhão rivers, constituting one of the main rivers in the Cerrado of Central Brazil. From its headwaters, in the Goiás Plateau, about 1,000 m of altitude, to its mouth in the Atlantic Ocean, this river runs about 2,400 km. Major right margin tributaries are the Bagagem, Tocantinzinho, Paranã, dos Sonos, Manoel Alves, and Farinha rivers; major left margin tributaries are the Santa Teresa, Araguaia and Itacaiúnas rivers (MMA 2006; ANA 2020). Traditionally, the Tocantins River is divided in three stretches: the upper Tocantins, which extends from its headwaters to the Lajeado rapids, 1,060 km and an elevation change of 925 m (about 0.87 m/km); the median Tocantins, between Lajeado rapids and São João do Araguaia waterfalls, 980 km and an elevation change of 149 m (about 0.15 m/km); and the lower Tocantins, that runs from São João do Araguaia until its mouth, 360 km and an elevation change of 26 m (about 0.07m/km) (Paiva 1982; Agostinho et al. 2009; ANA 2020). However, although the aforementioned traditional division of the Tocantins River is widely used, here we follow what was proposed by Dagosta & de Pinna (2019), which divided the entire system in three stretches: lower Tocantins (downstream of Imperatriz, State of Maranhão, MA, and Itaguatins, State of Tocantins, TO), upper Tocantins (upstream Imperatriz and Itaguatins), and Araguaia (include upper, median, and lower stretches).

The upper course environment is frequently composed of rapid waters and waterfalls, while the lower course, especially downstream of Tucuruí, has a low gradient, which allow the formation of large backwaters and flood plains (Paiva 1982; Agostinho et al. 2009).

The Araguaia River, the principal tributary of the left margin of the Tocantins River, is 2,600 km long and originates in the Brazilian central Plateau. The biggest fluvial island in the world is located in the Araguaia River system, the Ilha do Bananal (350 km long by 80 km wide). The Araguaia River runs parallel to the Tocantins River, until they meet at the city of Marabá, Patá State (Goulding et al. 2003; ANA 2020).

The Tocantins River originally had many rapids and waterfalls environments, because of that it has been a target of the hydroelectric sector and several projects of this type have been implemented in the last decades. On the other hand, the geography of the Araguaia River basin, without major differences in altitudes or accidents, has been preferred for waterways and agriculture.

2. *Ichthyofauna diversity*

The list of fishes occurring in the Tocantins-Araguaia River basin includes species described after the last update provided by Dagosta and de Pinna (2019) and others that were missing in their study, with updates on synonyms and species occurrence. New records were based on the ichthyological collection of Universidade Federal do Tocantins and literature sources (*e.g.* Bichuette & Trajano, 2003; Miranda & Mazzoni, 2003; Benedito-Cecílio et al. 2004; Agostinho et al. 2009; Lima & Caires 2011; Lucinda et al. 2007; Soares et al. 2009; Silva et al. 2019; and taxonomic descriptions). Authorships of the species analyzed are available in the supplementary material (see Supplementary file 1).

Since *Apareiodon machrisi*, *Archolaemus blax*, *Astyanax goyacensis*, *Leporinus bimaculatus*, and *Stictorhinus potamius* were recorded in basins other than Tocantins-Araguaia by Dagosta & de Pinna (2019) they were not considered herein as endemic to the Tocantins-Araguaia River basin. In the list, the subfamily category was applied only for Characidae and Loricariidae, which are the most species-rich families. Classification follows Nelson et al. (2016) for orders and the Eschmeyer's Catalog of Fishes for families (Fricke et al. 2020). Families and subfamilies were organized in alphabetical order. Endangered species were screened from the most recent list of the Threatened Brazilian Fauna (Fishes) (ICMBio 2018). For the distribution map of these species, we included type localities based on the original descriptions plus additional distribution data provided by Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio). These data were obtained during the assessment process of Brazilian fauna using the Red List method led by the ICMBio between 2009 and 2014 (ICMBio 2018).

3. *Data survey*

To gather information about the ichthyofauna from the Tocantins-Araguaia River basin over the last 20 years, a search of the literature published between January 2000 and December 2020 was conducted on the following research platforms: Google Scholar, Scientific Electronic Library Online (SciELO), and Web of Science (Thomson Reuters). In addition, Eschmeyer's Catalog of Fishes (Fricke et al. 2020) was consulted to confirm the validity of the species. Searches for taxonomic studies including new taxa and/or taxonomic review articles were conducted with the words: "new species AND [order] AND Tocantins AND/OR Araguaia''; "Taxonomic review AND [order]"; "Taxonomic revision AND [order]", in which all orders listed for the basin were included: Myliobatiformes, Anguiliformes, Osteoglossiformes, Clupeiformes, Characiformes, Gymnotiformes, Siluriformes, Batrachoidiformes, Gobiiformes, Cichliformes, Beloniformes, Cyprinodontiformes, Synbranchiformes, Pleuronectiformes, Acanthuriformes, and Tetraodontiformes. For each article were recorded: number of species described, author(s), year, type-locality, coordinates of the holotype, stretch of occurrence (upper Tocantins, lower Tocantins, and/or Araguaia), species with occurrence in other basins, and journal where it was published. Literature searches for phylogenetic studies were conducted using the following word combinations: "Phylogeny OR Systematic Phylogeny OR Systematic OR Phylogenomic AND [order]". In [order], were included all orders listed above. Only articles that analyzed specimens or samples of tissue of vouchers from the Tocantins-Araguaia River basin were recorded. Search for ecological studies were conducted using the following words combination: "Araguaia-Tocantins River Basin Fish Ecology"; "Tocantins Fish Ecology"; "Araguaia Fish Ecology"; "Fish communities Tocantins"; "Fish communities Araguaia"; "Fish assemblages Tocantins Basin"; "Fish assemblages Araguaia Basin"; "Ichthyofauna Inventory Tocantins"; "Ichthyofauna Inventory"; "Feeding habits Fish Tocantins"; "Feeding Habits fish Araguaia"; "Trophic Guilds Fish Tocantins"; "Trophic Guilds Fish Araguaia"; "Reproductive habits fish Tocantins"; and "Reproductive habits Araguaia". The literature search included both articles and books/or book chapters.

4. *Hydroelectric plants*

Information on hydroelectric plants in operation through December 2020 was taken from databases of the Agência Nacional de Energia Elétrica (ANEEL 2020). Dams were categorized as follows: Hydroelectric Plant Station (UHE), with energy production capacity between 5.000 and 50.000 KW greater than 30 MW and requires granting authorization or concession large reservoirs; Small Hydroelectric Central (PCH), with production capacity between 5.000 and 30.000 MKW, and reservoirs of up to 13 km^2; and Hydraulic Power Plant (CGH), with generation capacity of up to 5.000 MKW, with or without dams but without a reservoir (ABRAPCH 2020; ANEEL 2020). The map was created based on these categories and localities (coordinates) supplied by ANEEL's data records (ANEEL 2020).

5. *Mapping of Protected Areas (conservation units, CUs and indigenous lands, ILs)*

All conservation units (CUs) in which total or partial area is included in the Tocantins-Araguaia hydrographic region were plotted (regardless of category). Thus, CUs from both Cerrado and Amazon domains were included. Area shape files (.kml) for CUs and ILs were obtained from the ICMBio website (https://www.icmbio.gov.br/portal/unidadesdeconservacao/biomas-brasileiros). Some State CUs that were missing in the ICMBio shape files, were also included. For CUs without shape area files, a single point was plotted at the city/area of occurrence.

6. *Institutional abbreviations*

Auburn University (AU), Museu Paraense Emílio Goeldi (MPEG), Museu de Zoologia da Universidade de São Paulo (MZUSP), Universidade Estadual de Londrina (UEL), and Universidade Federal do Pará (UFPA).

Results

1. *Ichthyofauna diversity and conservation*

The ichthyofauna of the Tocantins-Araguaia River basin is composed of 751 species, in 314 genera, 51 families, and 16 orders (Supplementary file 1). The most species-rich orders are Characiformes (303 species, 40.3% of the ichthyofauna), Siluriformes (249 species, 33.2%), and Cichliformes (58 species, 7.7%) (Figure 1a). The most representative families are Characidae (138 species, 18.4%), Loricariidae (86 species, 11.5%), and Cichlidae (58 species, 7.7%), respectively (Figure 1b).

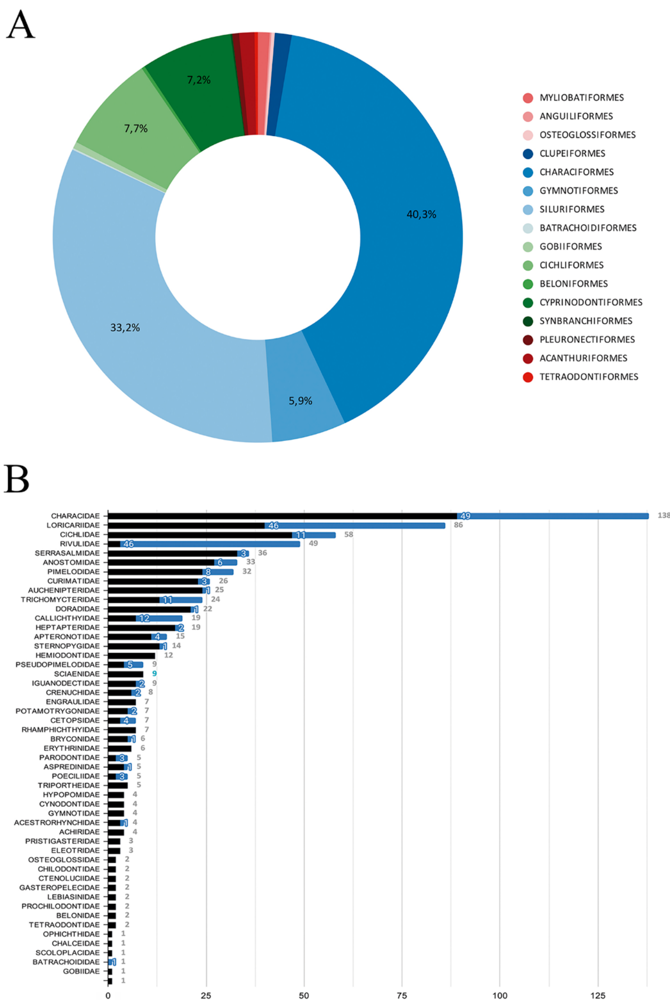

Figure 1. Freshwater fish species recorded per **A.** order in the Tocantins-Araguaia River basin, and **B.** family, where total number of species in gray, non-endemic species in black, endemic species in blue.

There are 229 fish species endemic to the Tocantins-Araguaia River basin from 26 families, corresponding to 30.5% of the total number of fish species from the basin (see examples of endemic species in Figure 2). Characidae is the family with the highest absolute number of endemic species (49 of 138 species, 35.5%), followed by Rivulidae (46 of 49, 93.9%) and Loricariidae, with (46 of 86, 53.5%). It is important to highlight the case of *Hypsolebias brunoi* (Costa), with type locality said to be at "Brazil: Estado de Goiás: temporary pool near the city of Vila Boa, ribeirão Canabrava floodplains, upper rio Urucuia drainage, rio São Francisco basin (15°0'0.4"S, 47°04'3.3"W; 449 m above sea level)" (see Costa 2003, pg.55). However, coordinate data indicate that it occurs in the upper portions of the Tocantins River basin. If this is correct, its type locality is at Canabrava River at the Tocantins-Araguaia River basin and, as far as we know, the species is only known from the type material. Considering each river stretch, the largest absolute number of endemic species is that of the upper Tocantins, which harbors 91 endemic species, followed by the Araguaia River and lower Tocantins stretches, with 69 and 21 endemic species exclusive to each, respectively.

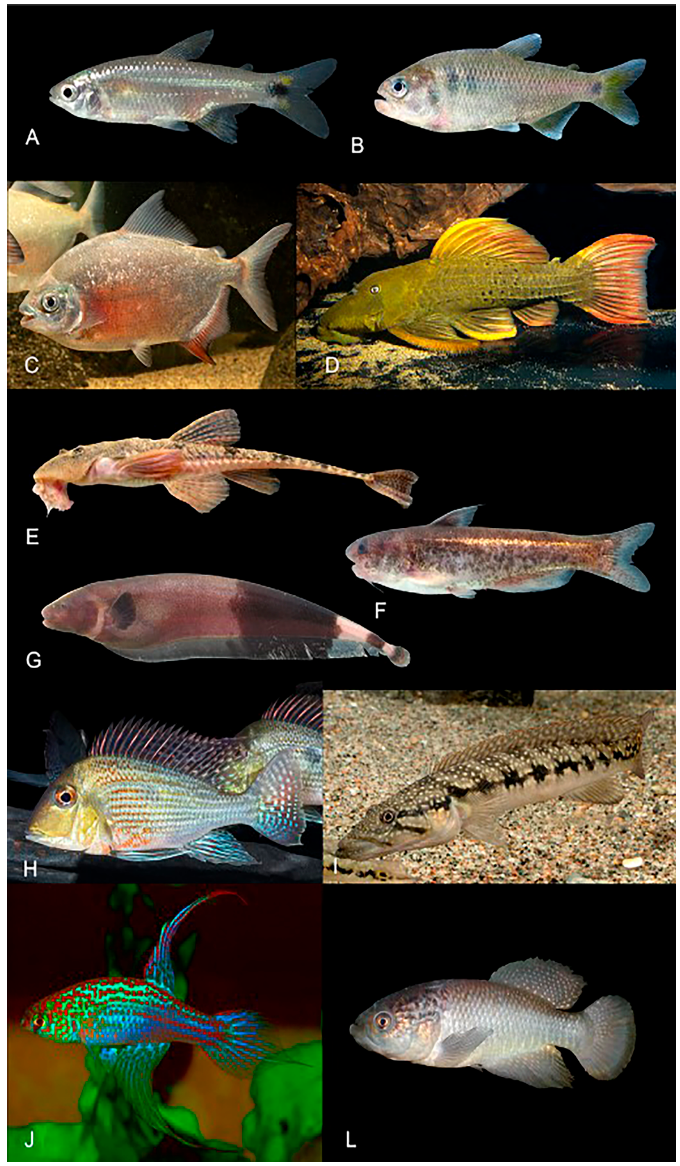

Figure 2. Some species endemic to the Tocantins-Araguaia River basin. **A.** *Ctenocheirodon pristis* MZUSP 113680, upper Tocantins River at Monte Alegre De Goiás, **B.** *Moenkhausia dasalmas* MZUSP 113910, upper Tocantins River at Alto Paraíso de Goiás, **C.** *Mylesinus paucisquamatus*, aquarium specimen not preserved, **D.** *Pseudacanthicus pitanga*, aquarium specimen not preserved, **E.** *Rineloricaria osvaldoi* MZUSP 114137, upper Tocantins River at Arraias, **F.** *Cetopsis arcana* MZUSP (uncatalogued), **G.** *Apteronotus camposdapazi*, MZUSP 114134, upper Tocantins River at Arraias, **H.** *Geophagus sveni*, aquarium specimen not preserved, **I.** *Crenicichla jegui*, aquarium specimen not preserved, **J.** *Maratecoara lacortei*, aquarium specimen not preserved, **L.** *Cynolebias griesei*, aquarium specimen not preserved. Photos by José Birindelli (A, B, E, F, G), Oliver Lucanus (C, D, H, I), and André Carletto (J, L).

Regarding endangered fish fauna, 51 threatened species occur in the Tocantins-Araguaia River basin according to the Brazilian Red List (ICMBio 2018). Of them, 47 (92.1%) are endemic to the basin. A list of threatened species from the Tocantins-Araguaia River basin, categorized according to the International Union for Conservation of Nature (IUCN) methodology, with distribution data, type-locality, and main threats is provided in Table 1. Regarding the IUCN threat categories, 22 species (43.1%) are considered vulnerable (VU); 22 (39.2%) endangered (EN), and nine (17.6%) critically endangered (CR). The majority of the threatened species belong to the orders Cyprinodontiformes (22, 43.1%) and Siluriformes (19, 37.3%). Regarding families, most threatened species belong to Rivulidae (22, 43.1%), Loricariidae (seven, 13.7%), Trichomycteridae (five, 9.8%), and Pimelodidae (four, 7.8%). Other families are represented by less than three species (6%). Threatened fish species in the basin are mostly from the upper Tocantins River (27, 52.9%).

Several threatened species belong to genera represented by only one species in the basin, such as: *Aguarunichthys* Stewart, *Cynolebias* Steindachner, *Mylesinus* Valenciennes, *Potamobatrachus* Collette, *Rhynchodoras* Klausewitz & Rössel, *Roestes* Günther, *Sartor* Myers & Carvalho, *Scobinancistrus* Isbrücker & Nijssen, *Simpsonichthys* Carvalho, and *Teleocichla* Kullander. In the case of *Potamobatrachus*, *P. trispinosus* Collette is the unique representative of the order Batrachoidiformes in the basin. Genera with few representatives in the basin include *Baryancistrus* Rapp Py-Daniel and *Lamontichthys* Miranda Ribeiro (two species each, both threatened); *Pimelodella* Eigenmann & Eigenmann and *Trigonectes* Myers (two species each, one threatened); *Maratecoara* Costa (three species, two threatened). Thus, 42 of 51 (82.3%) threatened species have restricted genera diversity, most of them occurring in the upper Tocantins River stretch.

Table 1. List of threatened fish species from the Tocantins-Araguaia River basin with IUCN category, distribution along the basin, type-locality, and main threats to each one. Species with (*) are additionally found outside the basin: *Brycon nattereri* (Paraná River), *Hyphessobrycon coelestinus* (upper São Francisco River), *Rhynchodoras xingui* (Xingu River), and *Scobinancistrus pariolispos* (Xingu and Tapajós rivers). Sources of information include ICMBio (2018), original descriptions, and Catalog of Fishes/CAS (Fricke et al., 2020).

Threatened species	IUCN Category	Distribution	Type-locality	Main threats
CHARACIFORMES				
Anostomidae				
Sartor tucuruiense Santos & Jégu, 1987	EN	Lower	Tucuruí, PA	UHEs Tucuruí and Lajeado
Bryconidae				
Brycon gouldingi Lima, 2004	EN	Upper/Lower/Araguaia	Parauapebas, Serra dos Carajás, PA	Successive dams along the species distribution, sport and commercial fishing
Brycon nattereri Günther, 1864 (*)	VU	Upper	Oriçanga, SP	Dams and deforestation of ciliary forests
Characidae				
Hyphessobrycon coelestinus Myers, 1929 (*)	EN	Upper	Lagoa Bonita,São Bartholomeu, GO	Urban expansion
Serrasalmidae				
Mylesinus paucisquamatus Jégu & Santos, 1988	EN	Upper/Lower	Jatobal, PA	Successive dams along the species distribution, mining
Cynodontidae				
Roestes itupiranga Menezes & Lucena, 1998	VU	Lower	Itupiranga, Lago Grande, PA	UHEs Tucuruí and Marabá
SILURIFORMES				
Doradidae				
Rhynchodoras xingui Klausewitz & Rössel, 1961 (*)	EN	Upper Tocantins/Araguaia	Upstream of Xingu River	Successive dams along the species distribution
Heptapteridae				
Pimelodella spelaea Trajano, Reis & Bichuette, 2004	EN	Upper	São Bernardo Cave, São Domingos, GO	Non-organized tourism in the cave area, trampling and silting the river
Loricariidae				
Ancistrus cryptophthalmus Reis, 1987	EN	Upper	Passa Três cave, São Domingos, GO	Non-organized tourism in the cave area, trampling and silting the river
Ancistrus minutus Fisch-Muller, Mazzoni & Weber, 2001	EN	Upper	Córrego Batéias, Minaçu, GO	UHE serra da Mesa, urban and agriculture expansion, mining
Baryancistrus longipinnis (Kindle, 1895)	CR	Upper/Lower/Araguaia	Tocantins River	Successive dams along the species distribution
Baryancistrus niveatus (Castelnau, 1855)	CR	Upper/Lower/Araguaia	Araguaia River, GO	Successive dams along the species distribution
Lamontichthys avacanoeiro Paixão & Toledo-Piza, 2009	EN	Upper	Serra da Mesa, GO	Successive dams along the species distribution
Lamontichthys parakana Paixão & Toledo-Piza, 2009	CR	Lower	Tucuruí, PA	UHE Tucuruí
Scobinancistrus pariolispos Isbrücker & Nijssen, 1989 (*)	VU	Lower Tocantins/Araguaia	Jatobal, PA	Successive dams along the species distribution

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Threatened species	IUCN Category	Distribution	Type-locality	Main threats
Pimelodidae				
Aguarunichthys tocantinsensis Zuanon, Rapp Py-Daniel & Jégu, 1993	EN	Upper/Lower/Araguaia	Rapids above Marabá, PA	Successive dams along the species distribution
Pimelodus halisodous Ribeiro, Lucena & Lucinda, 2008	VU	Upper	Paranã River, Fazenda Traçadal, Paranã, TO	Successive dams along the species distribution
Pimelodus joannis Ribeiro, Lucena & Lucinda, 2008	VU	Upper	Ipueiras, TO	Successive dams along the species distribution
Pimelodus sterwartii Ribeiro, Lucena & Lucinda, 2008	VU	Upper	Paranã River, Fazenda Traçadal, Paranã, TO	Successive dams along the species distribution
Pseudopimelodidae				
Microglanis robustus Ruiz & Shibatta, 2010	CR	Lower	Jatobal, Tucurí, PA	UHEs Tucuruí
Trichomycteridae				
Ituglanis bambui Bichuette & Trajano, 2004	CR	Upper	Angélica Cave, Parque Estadual da Terra Ronca, São Domingos, GO	Non-organized tourism in the cave area, trampling and silting the river
Ituglanis epikarsticus Bichuette & Trajano, 2004	VU	Upper	São Mateus Cave, Parque Estadual da Terra Ronca, São Domingos, GO	Non-organized tourism in the cave area, trampling and silting the river
Ituglanis mambai Bichuette & Trajano, 2008	EN	Upper	Lapa do Sumidouro Cave, Posse, GO	Non-organized tourism in the cave area, trampling and silting the river
Ituglanis passensis Fernandez & Bichuette, 2002	VU	Upper	Passa Três cave, São Domingos, GO	Non-organized tourism in the cave area, trampling and silting the river
Ituglanis ramiroi Bichuette & Trajano, 2004	VU	Upper	São Bernardo Cave, Parque Estadual da Terra Ronca, GO	Non-organized tourism in the cave area, trampling and silting the river
BATRACHOIDIFORMES				
Batrachoididae				
Potamobatrachus trispinosus Collette, 1995	EN	Lower Tocantins/Araguaia	Jatobal, PA	UHE Tucuruí
CICHLIFORMES				
Cichlidae				
Crenicichla cyclostoma Ploeg, 1986	CR	Lower	Tucuruí, PA	UHE Tucuruí, UHE Santa Isabel (preview)
Crenicichla jegui Ploeg, 1986	EN	Lower	Itupiranga, PA	UHE Tucuruí, UHE Santa Isabel (preview), possible illegal ornamental exportation
Teleocichla cinderella Kullander, 1988	EN	Lower Tocantins/Araguaia	Tucuruí, PA	UHE Tucuruí, UHEs Santa Isabel and Marabá (preview)

continue...

...continue

Threatened species	IUCN Category	Distribution	Type-locality	Main threats
CYPRINODONTIFORMES				
Rivulidae				
Cynolebias griseus Costa, Lacerda & Brasil, 1990	CR	Upper	Nova Roma, GO	Urban expansion
Hypsolebias flammeus (Costa, 1989)	EN	Upper	Arraias, TO	UHE Paranã
Hypsolebias marginatus (Costa & Brasil, 1996)	CR	Upper	Barro Alto, GO	Pastures and/or agriculture expansion
Hypsolebias multiradiatus (Costa & Brasil, 1994)	CR	Upper	Brejinho de Nazaré, TO	UHE Lajeado
Hypsolebias notatus (Costa, Lacerda & Brasil, 1990)	EN	Upper	Alvorada do Norte, GO	Urban expansion
Hypsolebias tocantinensis Nielsen, Cruz & Baptista, 2012	EN	Upper	Lajeado River, Campestre do Maranhão, MA	Pastures and/or agriculture expansion
Maratecoara formosa Costa & Brasil, 1995	VU	Upper	Brejinho de Nazaré, TO	UHE Lajeado, Pastures and/or agriculture expansion
Maratecoara splendida Costa, 2007	VU	Upper	Canabrava River, between Alvorada and Peixe, TO	Pastures and/or agriculture expansion
Melanorivulus crixas Costa, 2007	VU	Araguaia	Crixás Mirim River, Nova Crixás, GO	Pastures and/or agriculture expansion
Melanorivulus karaja (Costa, 2007)	VU	Araguaia	Tributary to rio Dueré River, Formosa River drainage, TO	Pastures and/or agriculture expansion
Melanorivulus kayapo (Costa, 2006)	VU	Araguaia	Upper Caiapó River, Jataí GO	Pastures and/or agriculture expansion
Melanorivulus kunzei Costa, 2012	VU	Araguaia	Upper Caiapó River, Jataí, GO	Pastures and/or agriculture expansion
Melanorivulus litteratus (Costa, 2005)	VU	Araguaia	Ribeirão do Sapo, Araguaia River, MT	Pastures and/or agriculture expansion
Melanorivulus pindorama Costa, 2012	VU	Upper	Small tributary to Gameleira River, Sono River, TO	Pastures and/or agriculture expansion
Melanorivulus planaltinus (Costa & Brasil, 2008)	VU	Upper	Coca River floodplains, Planaltina de Goiás, GO	Pastures and/or agriculture expansion
Melanorivulus rubromarginatus (Costa, 2007)	VU	Araguaia	Stream tributary to Espingarda River, Peixe River drainage, GO	Pastures and/or agriculture expansion
Melanorivulus salmonicaudus (Costa, 2007)	VU	Araguaia	Crixás River Mirim, Nova Crixás, GO	Pastures and/or agriculture expansion
Melanorivulus ubirajarai Costa, 2012	VU	Araguaia	Tributary of Babilônia River, Mineiros, GO	Pastures and/or agriculture expansion
Plesiolebias canabravensis Costa & Nielsen, 2007	VU	Upper	Canabrava River floodplains, TO	Pastures and/or agriculture expansion
Plesiolebias xavantei (Costa, Lacerda & Tanizaki, 1988)	EN	Upper	Tocantins River, Porto Nacional, TO	UHE Lajeado, UHE Ipueiras (preview), Pastures and/or agriculture expansion
Simpsonichthys cholopteryx Costa, Moreira & Lima, 2003	EN	Araguaia	Ribeirão do Sapo, MT	Pastures and/or agriculture expansion
Trigonectes strigabundus Myers, 1925	EN	Upper	Porto Nacional, TO	UHE Lajeado, extraction of clay and gravel, urban expansion

2. *Knowledge on ichthyofauna*

Studies on the ichthyofauna from the Tocantins-Araguaia River basin over the last 20 years were published in a total of 278 articles and five books, including species descriptions and taxonomic reviews (123 articles), phylogenetic studies (60 articles), species inventory (14 articles and five books), and ecological studies (53 articles). Between January 2000 and December 2020, 185 new species of fishes were described based on material from the Tocantins-Araguaia River basin. Of them, 167 (90.3%) are currently considered endemic to the system. Recently described species are from seven orders, 25 families, and 78 genera. The most representative orders were Siluriformes (73 species, 39.5%), Characiformes (67, 36.2%), and Cyprinodontiformes (31, 16.8%); other orders were less representative (less than 5%) (Figure 3a). Most representative families were Characidae (50 species, 27%), Loricariidae (35, 18.9%), and Rivulidae (29, 15.7%); while other families were less representative (less than 5%) (Figure 3b). In addition to the 185 new species described from the system, 29 species originally described from other basins had their distributions later expanded to the Tocantins-Araguaia River basin.

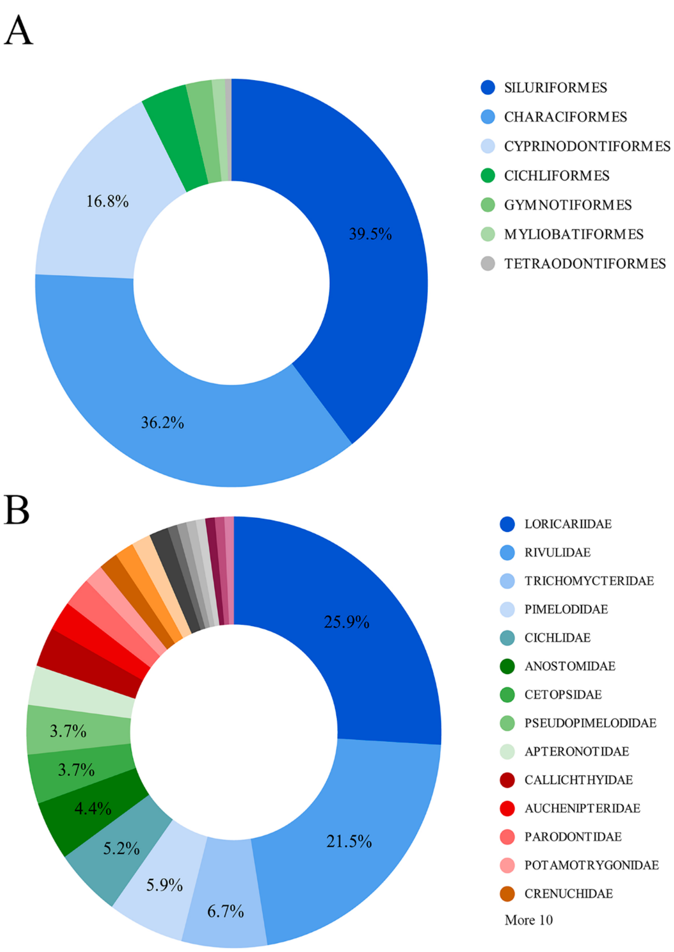

Figure 3. Described species in the last 20 years from the Tocantins-Araguaia River basin per **A.** order, and **B.** family.

The upper Tocantins River is the stretch with the highest number of species described in the last 20 years (Figure 4a). Of the 185 species described, 91 (49.2%) were described based on material from that stretch, corresponding to 24.7% of the total species richness of that basin. That preponderance is followed in descending order by the Araguaia River stretch (42 species, 22.7%), the lower Tocantins River stretch (17, 9.2%), the upper Tocantins plus Araguaia River stretches (15, 8.1%), the upper plus lower Tocantins River stretches (10, 5.4%), the whole system (nine, 4.9%), and the lower Tocantins plus Araguaia stretches (one, 0.5%). Since 2001, at least five species were described for the whole system per year, except in 2019 (four species). Higher numbers of species descriptions were observed in 2005, 2007, and 2008 with 14 species described per year, followed by 2003 and 2010 with 13 species described each year, and 2016 with 12 species described (Figure 4b). Species descriptions were published in a total of 22 journals, concentrated mainly in four: Neotropical Ichthyology (49 articles with new species, 26.5%), Zootaxa (40, 21.6%), Ichthyological Exploration of Freshwaters (37, 20%), and Ichthyology & Herpetology (formerly Copeia) (14, 7.6%). Other journals are less representative, with less than eight articles with species description (less than 4%).

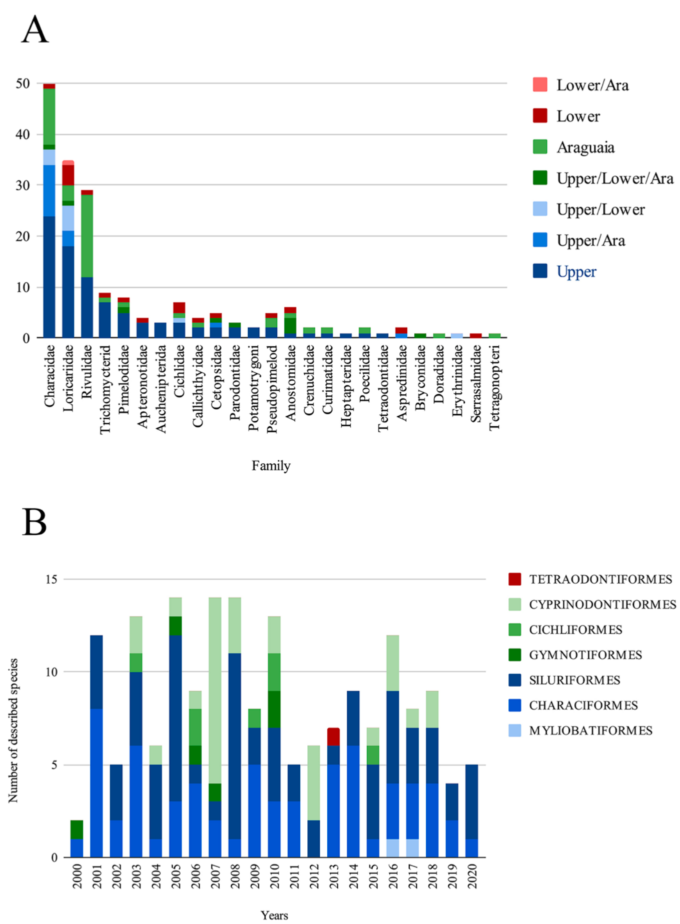

Figure 4. Described species in the last 20 years at Tocantins-Araguaia River basin per **A.** family and stretches, and **B.** order and year.

Ecological studies on the fishes from the Tocantins-Araguaia River basin published in the last 20 years included the following subjects: general ecology and community studies (19 articles, 35.8%), dam effects (14, 26.4%), feeding habitats and/or reproductive biology (10, 19.9%), fisheries (five, 9.4%), and others (five, 9.4%). Most ecological studies were conducted in the upper Tocantins River stretch (37, 69.8%), followed by lower Tocantins (nine, 17%), and Araguaia stretches (seven, 13.2%).

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3. *Major threats to the ichthyofauna*

Considering all main threats to the endangered species of fishes from the Tocantins-Araguaia River basin, the major threat is the hydroelectric plants. Twenty-six of 51 (50.9%) of endangered species are directly affected by dam construction (Figure 5a). The second major threat is habitat loss by expansion of pastures and/or agriculture activities (affecting 15 species, 29.4%), followed by unorganized tourism activities (seven, 13.7%), which primarily affect cave species, and by urban expansion (three, 5.9%). Mining activities and sport and commercial fishing were also listed as threats for endangered fish species from this basin. Concerning mining activities, most of them are concentrated in the Carajás region (Silva et al. 2014), which could directly impact the Itacaiunas River basin. Another important factor is that the basin has always been considered for the use of its main watercourses with axis for waterway transport (PNE 2030).

There are 73 hydroelectric plants in operation along the Tocantins-Araguaia River basin, of which, eight are UHEs, 29 are PCHs, and 36 are CGHs, distributed in five Brazilian states (Goiás, Tocantins, Mato Grosso, Maranhão, and Pará). Most hydroelectric plants (43) are located in the upper Tocantins River stretch (seven UHEs, 20 PCHs, and 16 CGHs), 29 are located in the Araguaia River stretch (nine PCHs and 20 CGHs), and only one in the lower Tocantins River stretch (UHE Tucuruí) (Figure 5b, Supplementary file 2).

The majority (60%) of hydroelectric power generation projects in the Tocantins-Araguaia River basin started to operate in the last 20 years. The UHE Tucuruí (lower stretch, Pará State), the largest enterprise in the system, is the first significant dam in operation since 1984. The UHE São Domingos (upper stretch, Goiás State) started operations in 1991 and, in 1998, UHE Serra da Mesa (upper stretch, Goiás State), the second largest of the basin, started operations. Since then, five others UHEs are now in operation: Lajeado (upper stretch, Tocantins State) since 2001, Cana Brava (upper stretch, Goiás State) since 2002; Peixe Angical (upper stretch, Tocantins State) since 2006, São Salvador (upper stretch, Tocantins State) since 2009; and Estreito (limit of lower and upper stretch, Maranhão State) since 2011. Further five dams are under construction or will be built in the short term in the Tocantins-Araguaia River basin: four PCHs in the upper Tocantins and one CGH in the Araguaia stretch. In addition to those already in operation or under construction, there are 51 new hydroelectric projects being studied for possible implementation in the Tocantins-Araguaia River basin, being 42 PCHs (21 in Tocantins River and 21 in Araguaia River) and nine UHEs (seven in the Tocantins and two in the Araguaia).

4. *Protected areas (CUs and ILs)*

According to our survey, there are at least 41 CUs in the Tocantins-Araguaia hydrographic region (Figure 5a, Supplementary file 3). Among them, 13 are of integral protection, *i.e.* units conserved free from human interference, where only the indirect use of their natural attributes are allowed (see SNUC - Brazilian law 9,985/2000). Most of the CUs (28) are located along the Tocantins River and six along the Araguaia River.

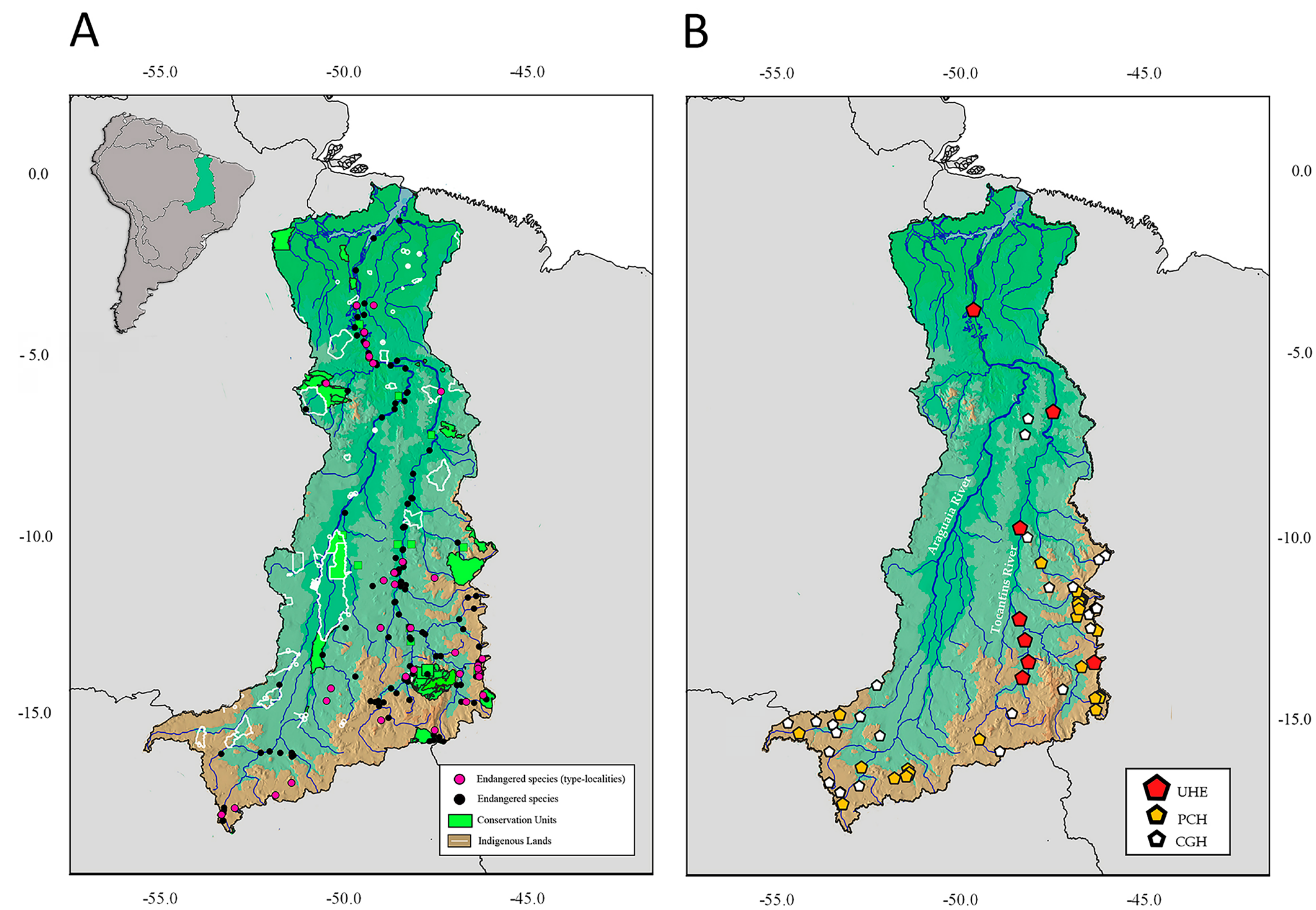

Figure 5. Distribution maps of **A.** endangered species*, Conservation Units, and Indigenous Lands, and **B.** hydroelectric plants already installed at Tocantins-Araguaia River Basin. (*) One point could represent more than one locality.

Concerning CUs along the Tocantins River stretch (28), half of them (11) are distributed among areas near the Federal District area (PARNA de Brasília, APA Planalto Central), areas further north in Goiás State (PARNA Chapada dos Veadeiros; and RPPNs Soluar, Serra do Tombador I and II) and the remaining four in the east corner of the basin (FLONA Mata Grande, PES Terra Ronca, RESEX Recanto das Araras de Terra Ronca, and APA Nascentes do rio Vermelho). To the north, along the Tocantins River course, there are sequential but disconnected CUs, most of them created as compensation to the UHEs implemented in the region (APAs Lago de São Salvador, Lago de Peixe Angical, Lago de Palmas and Serra do Lajeado). To the east of Palmas city, there are other important CUs such as PES do Jalapão, ESEC Serra Geral do Tocantins, and PARNA Nascentes do rio Parnaíba. Information about CUs are summarized in Supplementary file 3. Furthermore, there are at least 36 Indigenous Lands along the Tocantins-Araguaia River basin, 26 of them along the Araguaia River and 13 along the Tocantins River, in which six are in the upper and seven in the lower stretches of this river.

Discussion

1. Building knowledge on fish diversity

The actual ichthyofaunal composition of the Tocantins-Araguaia River basin, as well as the whole Amazon basin, is a result of historical geomorphological processes and landscape changes (Dagosta & de Pinna 2019) that, together with ecological factors and evolutionary processes, molded the great fish diversity we find nowadays. Dagosta & de Pinna (2019) conducted an extensive study of distribution and biogeographical patterns of Amazon fishes and recorded 705 species for the entire Tocantins-Araguaia River basin. Our results show an absolute number of 751 species, which corresponds to 27.6% of the species richness of the whole Amazon basin (2,716 species according to Dagosta & de Pinna 2019) and 23.8% of the Brazilian freshwater fish species (3,148 according to ICMBio 2018). Interestingly, exotic and/or invasive species were not recorded in the literature as a substantial problem in the Tocantins-Araguaia River basin. For instance, *Oreochromis niloticus* (Linnaeus) has been detected in the basin, but it has not since been recaptured and the species is not established, probably as a consequence of the high biotic resistance provided by the elevated diversity of the system (Agostinho et al. 2017).

The fishes from the Tocantins-Araguaia River basin are more diverse than those from entire geographic regions such as Oceania, Central America, and Europe (see Dagosta & de Pinna 2019). Furthermore, our data show that 22% of the entire ichthyofauna of this basin is endemic, corroborating its high degree of endemism repeatedly mentioned in the literature (*e.g.* Santos et al. 2004; Hubert & Renno 2006; Lucinda et al. 2007; Abell et al. 2008; Bertaco & Carvalho 2010; Carvalho et al. 2010; Bertaco et al. 2011; Hales & Petry 2013; Dagosta & de Pinna 2017, 2019).

The outstanding number of species records in the Tocantins-Araguaia River basin is continuously increasing due to new species descriptions. According to our results, 185 new species were described from the basin in the last 20 years, and another 20 probably new species are in the process of description by ourselves and other Brazilian taxonomists (*e.g.* Guilherme Dutra, Naércio Menezes, 2020, pers. comm.). Such an increase of species description in the last 20 years could be explained by multiple factors. One of them is the increase of ichthyofaunal inventories, which are required as part of the documentation necessary for the installation of hydroelectric plants and other enterprises.

In the Tocantins-Araguaia system, 60% (five of eight) of the UHEs were installed in that period, and all of them in the upper stretch of the basin (ANNEL 2020). Among the 185 described species in the last 20 years, 43 (23.2%) descriptions were based on material (considering only holotype and/or paratypes) from inventory or monitoring associated to UHEs installed in the Tocantins River basin, since there is no UHE in the Araguaia River basin. Considering only the upper Tocantins stretch, where most impoundments were installed, this number increased considerably to 37 (40.6%) descriptions out of 91 species described for this stretch.

Another determining factor is certainly the existence of a higher number of taxonomists examining fishes from the basin. Until 2015, there was high incentive from the Brazilian government for research in taxonomy, such as the Support Program for Research Projects for Capacity and Training of Human Resources in Biological Taxonomy (PROTAX) and the Biodiversity Research Program (PPBio), both supported by the Ministério da Ciência, Tecnologia e Inovações (MCTI). In addition, in that period, there were many public tenders as a response to the demand created by the Support Program for Federal University Restructuring and Expansion Plans (REUNI), which ensured that many taxonomists settled in the northern university centers in the country (MEC 2020).

Although these incentives have been essential to the increase in taxonomists and teaching/research institutions in the country, the current situation of Brazilian science is worrying. The drastic reduction of the research budget proposed by the Brazilian government in 2019 caused significant financial cuts in the MCTI, which directly affected support for Brazilian research (see Escobar, 2019; Santos & Carbayo, 2021). According to recent data from the Instituto de Pesquisa Econômica Aplicada (IPEA), investments in science and technology have been systematically reduced in the last few years (De Negri & Koeller 2019; Santos & Carbayo, 2021) and the forecast for next years is for more budget cuts (Sociedade Brasileira para o Progresso da Ciência; portal.sbpcnet.org.br, consulted in Dec 2020 and Jan 2021). Environmental policies are also catastrophic, the Ministério do Meio Ambiente (MMA) has been operating on an extremely reduced budget. In addition, there are several procedures that impact the local environment directly, such as end of land demarcations and permission to mine in Indigenous Lands; flexible environmental licensing; dismantling of environmental defense agencies; changes in the Forest Code and increased allowance for the use of hazardous pesticides. Unfortunately, this scenario represents a setback for the growth of Brazilian science, which could have negative consequences for the formation and settlement of taxonomists in general (see Santos & Carbayo, 2021) including ichthyologists.

2. Major environmental impacts affecting ichthyofauna

Endangered species of the Tocantins-Araguaia River basin are directly affected by two major threats: dam constructions and habitat loss by expansion of pastures and/or agriculture activities (Table1).

2.1. Dams

Many developing countries, such as Brazil, have adopted economic developmental policies based on major infrastructure works (Latrubesse et al. 2017; Winemiller et al. 2016). The Brazilian option for hydroelectric energy can be explained by the great hydroelectric potential still available in the nation (Moretto et al. 2012; Serra & Oliveira 2020). Currently, there has been a great expansion of hydroelectric projects in the midwest and northern regions by virtue of the large volume of water discharge of the drainage channels, because rivers in these regions maintain minimum flows for the supply reservoirs throughout the year (Barletta et al. 2010; Moretto et al. 2012; Fearnside 2015; Serra & Oliveira 2020). According to the Brazilian National Energy Plan (PNE 2030), the total energetic potential of the Tocantins-Araguaia River basin is 11,297 MW, however just about 8% of this potential could be utilized without environmental restrictions. The Brazilian Ten-Year Energy Expansion Plan (PDE 2017-2021) included UHE Marabá (PA, made operational this year) and other hydroelectric plants that are approved or in viability studies, such as UHEs Ipueiras (TO), Serra Quebrada (TO/MA), and Tupirantins (TO). In the PDE 2021-2030, the scenario is even more drastic with five hydroelectric plants potentially being built in the tributaries: UHE Buriti Queimado (Almas River, GO), UHEs Maranhão and Porteiras (Maranhão River, GO), UHEs Mirador (Tocantizinho River, GO), and Paranã (Paranã River, TO).

The increased demand for electricity and the option to produce it using water sources has led to the exploration not only of large water bodies, but also to a recent increase in exploring new possibilities, such as small rivers and tributaries (Barletta et al. 2010; Frederico et al. 2021). Although the damming of rivers is one of the main human activities that cause the reduction of fish diversity, there are several gaps in the knowledge on the biological impact of small dams when compared to large ones (Pereira et al. 2020).

In addition to the large dams on the Tocantins River, the Tocantins-Araguaia River basin has many smaller dams installed on its upper stretch (Figure 5b), and several others are under study to be installed in the basin (ANEEL 2020). These small dams are often located in streams which generally harbor restricted-range species of fishes, and which may be important bioindicators of anthropogenic changes in environments. When are installed in sequence, these smaller dams may create a cascade effect, which increases negative environmental impacts in the structure and function of fish communities (Alexandre & Almeida 2010; Pereira et al. 2020; Teresa & Casatti 2017).

Regardless of size and complexity, the presence of a barrier is often associated with changes in the physical structure of rivers, mainly causing the homogenization of several micro-habitat characteristics such as current speed, depth, and substrate among other changes (Alexandre & Almeida 2010). Consequently, according to the authors, any change in habitat stability can alter the life cycle of fish species and the local structuring of their assemblages. Lees et al. (2016) carried out a survey of studies with generalized impacts for several aquatic and terrestrial taxa across the Amazon lowlands, such as the habitat loss and degradation, regional climate changes stimulated by deforestation and accentuated by increased methane output. Specifically, regarding fish assemblages, drastic alterations are notorious, because the environmental changes occur right after the reservoir filling phase, with a reduction time of water renewal and the consequent transformation of a lotic environment to a lentic ecosystem (Agostinho et al. 2007).

Migratory fish perform seasonal migrations to spawn, which requires free stretches of rivers. The reproductive success of these species is related to access to free-flowing spawning areas upstream (in the main channel or tributaries) and nursery areas (downstream floodplain) (Agostinho et al. 2008). The construction of physical barriers blocks the fish movement, preventing the dispersion, isolating populations and breaking the sequence of displacements and stimuli necessary for reproduction for migratory species (Barthem et al. 1991; Agostinho et al.2005; Barletta et al. 2010; Pelicice et al. 2014). Successive dams along the river are even worse, interrupting the migration routes for migratory fish species, which are unable to complete their life cycle, which leads to large decrease in their populations or even local extinctions (Ribeiro et al. 1995; Lees et al. 2016).

Particularly within the upper Tocantins River stretch, Perônico et al. (2020) demonstrate that fish diversity patterns changed significantly after construction of the Peixe Angical dam, with several shifts in the taxonomic assemblages in the first five years after the impoundment. These authors reported a significant change in composition and abundance of the fish fauna, for example, a total of 27 species of migratory fishes were recorded in the stretch. However, 23 of these species were recorded before the river regulation and only 12 after seven years of the impoundment. Abundance of migratory fish also declined consistently (87%) and several species that were abundant, before the impoundment, had their abundance decline by 90% or even completely disappeared (*e.g. Argonectes robertsi*, *Hemisorubim platyrhynchus*, *Myleus setiger*, *Myleus torquatus*, *Pimelodus blochii*, *Pinirampus pirinampu*, *Prochilodus nigricans*, *Oxydoras niger*, and *Rhaphiodon vulpinus*).

For the lower Tocantins River stretch, Santos et al. (2004) reported a decline in the population of 22 commercial species of fishes after the Tucuruí dam construction. Later, Mérona et al. (2010) concluded that the Tucuruí Lake formation resulted in major changes in the composition of fishes in the extension of the river studied, and also demonstrated that the disruption of migratory routes is one of the main factors that negatively affected the fish community. The presence of the dam accentuated the isolation of the river downstream, preventing displacement upstream of migratory species for reproduction and limiting the recolonization of the lower portions of the river by juveniles dispersing from the upstream area.

Fishways were employed as a main solution in several impoundments to mitigate impacts over the migration and dispersion dynamics, especially for long distance migratory species. In the Tocantins River, fish ladders were installed in Lajeado and Peixe Angical dams (Pompeu et al. 2012). However, studies have demonstrated that these ladders are not effective and fail to support the downstream and upstream passage for both migratory and non-migratory fishes (*e.g.* Agostinho et al. 2007, 2012; Pelicice & Agostinho 2012). In fact, there is no scientific evidence that any fish passage existing plays an efficient role in fish and fisheries conservation (Pompeu et al. 2012; Pelicice et al. 2014).

2.2. Agribusiness

Undoubtedly, agribusiness plays a huge importance to the Brazilian economy and it has been a great challenge to reconcile environmental conservation with economic development. The Cerrado domain is the largest and richest Neotropical savanna, considered a hotspot conservation area (Myers et al. 2000). Despite accounting for 30% of Brazilian biodiversity, only a small portion of the Cerrado is protected (Françoso et al. 2015).

The expansion of commodity monocultures and pastures is ranked as the major cause of Cerrado deforestation and land degradation, while hydroelectric plants and urban expansion constitute secondary issues (Faleiro et al. 2013).

The Tocantins-Araguaia River basin holds about 90% of its area in this domain, with the remaining 10% composed of the ecotone area between the Cerrado and Amazon domains. In the year 2000, there were 52,259,267.15 ha (56.9%) of natural forest (including forest and savanna formations) in the Tocantins hydrographic region, in 2019, this area was reduced to 43,479,134.27 ha (47.3%). On the other hand, the agricultural area grew from 29,323,418.73 ha (31.9%), in 2000, to 38,473,772.61 ha (41.9%), in 2019 (Souza et al. 2020).

In the heart of Cerrado, at the MATOPIBA region, soybean agriculture expanded 253% from 2001 to 2014 (Carneiro-Filho & Costa 2016) and is expected to expand by 318% by 2050 compared to 2015 (Soterrone et al. 2019). In 2018, most of the deforestation of the Cerrado occured in the Tocantins, a state that holds 34.2% of the Tocantins-Araguaia River basin, with 153,320 ha, 23% of total forest loss. A total of 947,287 ha of natural Cerrado formations were converted to soy cultivation and livestock pastures between 2008 and 2017, with soy and beef being the main commodities that lead to deforestation in Tocantins State in the period (Drost et al. 2019).

Deforestation reflects directly in hydrology through the soil erosion and silting of the rivers and loss of natural riparian forests related to surface temperature increase. Other concerns about land transformation for agricultural practices is the change of pH, density and availability of P and K in the soil (Hunke et al. 2014; Latrubesse et al. 2019). Hunke et al. (2014) reviewed field studies in Cerrado areas, between 1977 and 2012, and found that most soil and water parameters were affected by land use changes caused by crops, specifically parameters related to soil hydraulic properties, such as pH and soil phosphorus content, as well as nutrient (mainly nitrogen) and pesticide contamination in surface waters. Such changes in water parameters directly affects fish fauna (Dala-Corte et al. 2016; Teresa & Casatti, 2017). Furthermore, the removal of riparian vegetation affects species adapted to shaded streams that feed mainly allochthonous items provided by the forest (Menezes et al. 2007; Teresa et al. 2015).

3. *Threatened species*

The Tocantins-Araguaia River basin is home to a high number of threatened fish species. According to the most recent list of the Brazilian endangered fishes, 311 continental fish species are considered threatened (ICMBio 2018); 51 of them (16.4%) occur in the Tocantins-Araguaia River basin, with 47 endemic to the system and 27 restricted exclusively to the upper Tocantins stretch (Figure 6, Table 1). In addition, it is important to highlight that most of the threatened species (42; 82.3%) have restricted generus-level diversity in the basin, mostly also from the upper Tocantins River stretch. Therefore, it is important to reinforce the area with priority of conservation actions, targeted to ichthyofauna, to avoid loss of phylogenetic and taxonomic diversity.

As mentioned above, dam construction is the main threat for the ichthyofauna. It is responsible for the decrease of populations of most threatened characiforms, siluriforms, and all threatened cichliforms. Rapids and bedrock background environment are crucial for these taxa, such as the anostomid *Sartor tucuruiensis*, the siluriforms *Aguarunichthys tocantinensis* (rare species), *Baryancistrus longipinnis*, *B. niveatus*, *Lamontichthys avacanoeiro*, *L. parakana*, and *Microglanis robustus*; and the cichlids *Crenicichla cyclostoma*, *C. jegui*, and *Teleocichla cinderella.*

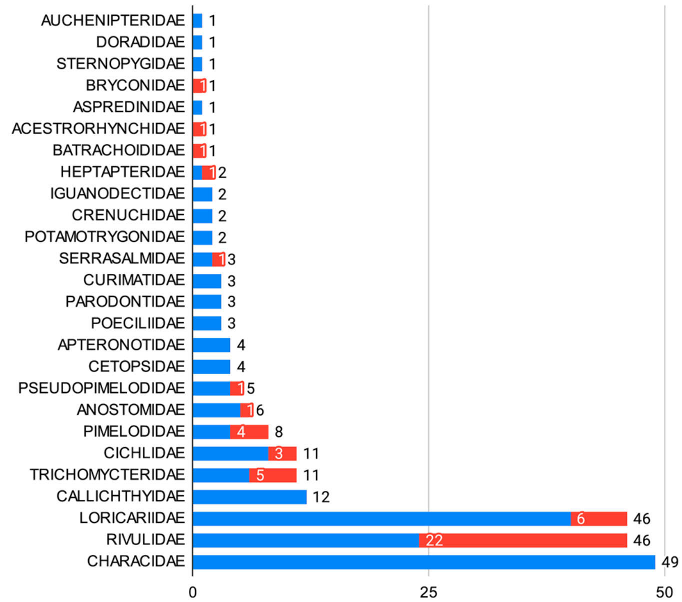

Figure 6. Total of species endemic to the Tocantins-Araguaia River basin per family. Number of threatened species are shown in red.

All these species were reported from strong rapids. In the case of *M. robustus*, despite the species description being relatively recent, only the type specimens collected before the construction of the UHE Tucuruí reservoir are known (Ruiz & Shibatta 2010). However, no sample effort has been made since then to evaluate occurrence, abundance, and conservation status of the species (ICMBio 2018). Similarly, *L. parakana* was described in 2009 based solely on three specimens (Paixão & Toledo-Piza 2009) collected in 1984, when the Tucuruí reservoir was filled. Since then, the species was exclusively manually collected by diving under about 18 m deep in 2019, in a field expedition to Pedral do Lourenço (Marabá, PA). Other threatened species (Figure 7) such as *Baryancistrus longipinnis*, *Crenicichla jegui*, *Potamobatrachus trispinosus*, *Sartor tucuriensis* and *Teleocichla cinderella*, were also collected in the same event. (Alberto Akama, 2020, pers. comm.). The Pedral do Lourenço seems to be the main bedrock refuge to these species in the lower Tocantins and is in danger of being channelized to make the river navigable during the dry season.

In addition, migratory species were also affected by dam construction in the basin of interest, resulting in large decreases in their populations. The three threatened species of *Pimelodus* (*P. halisodous*, *P. joannis*, and *P. sterwartii*) are short to medium distance migratory species (Tiago Costa e Silva, 2020, pers. comm.). Today, they are uncommon and not abundant, with restricted occurrence to the upper Tocantins River (Ribeiro et al. 2008; ICMBio 2018), a stretch directly affected by the UHEs Peixe Angical, São Salvador, and Lajeado dams. Species of the order Characiformes are also impacted by the disruptive routes, such as *Brycon* spp. and *Mylesinus paucisquamatus*. The latter is considered rare, with just 81 specimens reported along 200 km in the upper Tocantins stretch over a decade of monitoring between 1998 and 2009 (Victorino Júnior et al. 2016).

The agribusiness plus urban expansion are responsible for the population decrease of most rivulids occurring in the Tocantins-Araguaia River basin and the characid *Hyphessobrycon coelestinus* (Table 1). Rivulidae includes 22 (43%) of the threatened species in the basin.

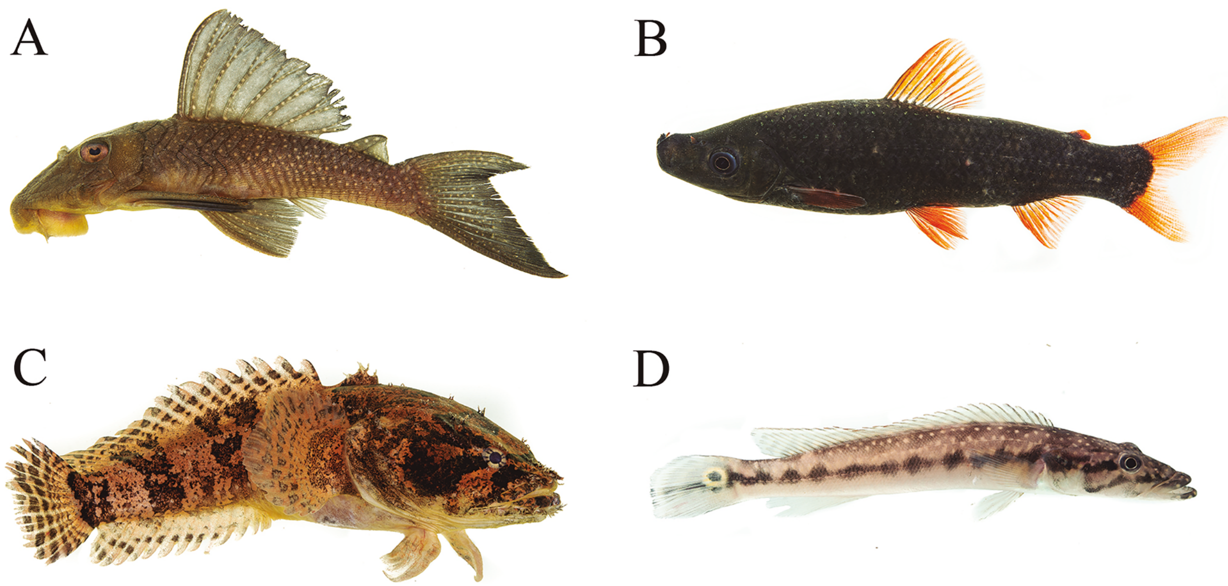

Figure 7. Some threatened species from Pedral do Lourenço, lower Tocantins River. **A.** *Baryancistrus longipinnis*, **B.** *Sartor tucuruiensis*, **C.** *Potamobatrachus trispinosus* and **D.** *Crenicichla jegui.* All images by Leandro Sousa.

Rivulids are highly adapted to seasonal ponds and floodplains that completely dry out during the dry season, with an annual life-history strategy with eggs resistant to drought and embryonic development with up to three diapauses, phases where development and growth is reversibly suspended (Loureiro et al. 2018). This means that rivulids may complete their life cycle within a single, seasonal pond, that depends on the vegetation to be formed in the rainy season. Deforestation for pasture, agriculture, urbanization, and dam construction has caused habitat loss and threatened 44.8% of all rivulid species of the Tocantins-Araguaia basin. In fact, the high endemism of the group along with strong human impacts impelled Rivulidae to be the most endangered fishes not only in the system, but in Brazil (Rosa & Lima 2008; Volcan et al. 2011; ICMBio 2018). Thus, conservation actions to protect annual fishes should be directed not only to their restricted range area, but also to create large protecting areas that encompass river corridors and associated wetlands, to enable connectivity and dispersal populations (Volcan et al. 2011).

Remaining threatened species are cave inhabitants impacted by unorganized tourism in these areas. All of them are from the karst area of Mambaí and São Domingos region (Goiás State), that is formed by subterranean streams of the Vermelho River, tributary of Paranã River (upper Tocantins River). This region hosts seven threatened siluriforms species: *Ancistrus cryptophthalmus* (Loricariidae), *Ituglanis bambui*, *I. epikarsticus*, *I. mambai*, *I. passensis*, and *I. ramiroi* (Trichomycteridae), and *Pimelodella spelaea* (Heptapteridae). Concern about conservation policies in the region were expressed by Bichuette & Trajano (2008) and Rizzato & Bichuette (2014), specifically for *Ituglanis boticario*, which occurs in the same region of *I. mambai*, but at a smaller population density. The species is not considered threatened, possibly because the most recent list (ICMBio 2018) was made after the species description.

According to Trajano (2000), subterranean ecosystems have special issues for conservation due to their fragility and distinctive features, such as the high degree of endemism associated with morphological, ecological, and behavioral differences among stygobiotic Such fragility is an outcome of the low biological diversity of these ecosystems, which generally rely on nutrients from the surface and the susceptibility to climatic fluctuations because these animals have evolved in a relatively stable environment. Thus, in karst areas other threats, besides deforestation, have to be considered, such as limestone quarrying, pollution from mining, pesticides and even domestic sewage, as well as human visitation due to topoclimatic changes by hot light sources and the opening of artificial passages during cave exploration and management, favoring the introduction of alien epigean organisms and organic matter, soil compaction of sediment banks and direct disturbance and trampling of cavernicole organisms (Trajano 2000).

4. *Protect Areas at the Tocantins-Araguaia River basin*

Conservation units play an essential role in the efforts to reduce degradation of natural environments and maintaining biodiversity (ICMBio 2020; Oliveira et al. 2017). Historically, conservation efforts and policies are concentrated in land habitats and terrestrial vertebrates. However, freshwater ecosystems are even more sensitive and are among the most threatened environments in the world (Azevedo-Santos et al. 2019; Abell & Harrison 2020; Tagliacollo et al. 2021). Leal et al. (2020) demonstrated that terrestrial target conservation strategies provided limited advantages for freshwater species. When freshwater species are prioritized, more terrestrial species benefit than in the reverse. This suggests that a terrestrial-freshwater conservation approach provides maximum achievable benefits rather than targeting only one domain.

As defined by the National Nature Conservation Units System (SNUC, Brazilian law 9,985/2000), Biodiversity or Ecological Corridors are instruments of management and planning in order to secure the integrity of the ecological processes in the CUs areas of connection, allowing the free gene flow and dispersal between these protected natural areas (ICMBio 2020). Although the idea of Ecological Corridors has been considered by the MMA since 2000, projects such as the Ecological Corridor of the Jalapão area (which include PES do Jalapão, ESEC da Serra Geral do Tocantins, and PARNA Nascentes do rio Parnaíba) and the Araguaia Corridor of Biodiversity, have not been fully implemented (Latrubesse et al. 2019; ICMBio 2020).

Along the Araguaia River course, five CUs (APA Meandros do rio Araguaia, PARNA Araguaia, PES do Cantão, and RPPNs Canguçu and Bico do Javaés) could be included in the project of the Araguaia Corridor. This project aims to interlink CUs with Indigenous lands (at least 11), that will guarantee more protection of the Ilha do Bananal, the Araguaia floodplain, and the wetland of the rio das Mortes. Meanwhile, the Ecological Corridor of the Jalapão Region aims to connect National and States CUs located in three important headwaters drainages: Tocantins-Araguaia, Parnaíba, and São Francisco River basins (ICMBio 2020). The importance of these projects is mainly to reinforce the conservation of these regions' ecosystems and strengthen CUs integration. It is important to highlight that the Araguaia River holds 26 of the 36 Indigenous Lands of the basin, most of them near Ilha do Bananal. It means that these lands are probably more efficient to protect the ichthyofauna than the CUs along the basin because this stretch holds 17.6% of the endangered species.

The Tocantins-Araguaia River basin is known for its high endemic ichthyofauna (*e.g*. Lima & Caires 2011; Dagosta & de Pinna 2019). Our results demonstrate that most endangered species are endemic to the upper Tocantins River stretch (27 species, 52.9%). Although most CUs (25) are also located in the same stretch, most threatened species occur outside these areas (Figure 5a). Previous studies have demonstrated that threatened or almost threatened species are most commonly found outside formally protected areas (Azevedo-Santos et al. 2019; Tagliacollo et al. 2021). Thus, either these CUs are not properly inventoried, or they are not efficient in ensuring the preservation of threatened species. In fact, Oliveira et al. (2017) have demonstrated that only 1% of total Protected Areas (including CUs and ILs) in Brazil are well sampled, with 50% of them not sampled at all. Furthermore, the largest absolute number of endemic species is from the upper Tocantins stretch, (91 out of 229 species, 39.7%). Therefore, it is crucial that ichthyofaunal surveys are carried out within the CUs in the upper Tocantins River stretch to make sure that threatened species and endemic species are being protected.

For example, the Mambaí karsts area is inserted from the limit of the PES Terra Ronca (São Domingos, GO) up to the APA das Nascentes do rio Vermelho (Mambaí, GO), where most threatened cavefish species occur. Although the region includes these two CUs, it has not been effective to protect the subterranean systems and the epigean areas nearby (Rizatto & Bichuette 2014), since unorganized tourism still represents a substantial risk to cavefishes.

Likewise, the presence of CUs along the basin seems to not be very effective in protecting migratory Siluriformes (*e.g. Pimelodus* spp.), Characiformes (*e.g. Brycon gouldingi*, *Roestes itupiranga*), and other species that depends on free river stretches, as cichlids (*e.g.*, *Crenicichla* spp., *Teleocichla cinderela*), loricariids (*e.g. Ancistrus minutus, Lamonthichthys* spp., *Scobinancistrus pariolispos*), and pseudopimelodids (*e.g. Microglanis robustus*) because the already installed UHEs constitute a major risk to these species (see more on the UHEs discussion section). Conversely, for annual rivulid species, expansion of CUs, as well as new projects to connect CUs in Ecological Corridors, specially between free stretches of the Paranã and Tocantins rivers, will contribute to the preservation of the floodplains and, thus, ensure that these species can complete their life cycles.

Conclusions

A considerable increase in fish diversity knowledge in the Tocantins-Araguaia River basin occurred in the last 20 years, in parallel with major changes in the basin and its surroundings in the same period. More than a half (54.9%) of the threatened species were described between 2001 and 2012. Meanwhile, considerable urban and agricultural expansion, along with several hydroelectric plants were installed in the basin during this period. The process to get permission to construct dams that includes samplings and some ichthyofaunal reports has contributed, in some way, in generating knowledge on the fish fauna, but unfortunately the environmental alterations due to those enterprises are far more disastrous to the fish community. In view of the anthropic environmental alterations already present in the Tocantins-Araguaia River basin discussed herein, together with the available knowledge on the high endemicity and highly threatened nature of the fish fauna, some mitigation actions should be implemented to avoid an irreversible loss of species. Actions should include: compliance to the environment legislation (*e.g.* Forest Code); compliance to the Indigenous Lands demarcations; expanding soy moratorium for the Cerrado; full implantation of planned Ecological Corridors, with a terrestrial-freshwater conservation approach (see Leal et al. 2020); establishment of new Ecological Corridors in the upper Tocantins-Araguaia basin; preservation of free stretches of rivers for migratory fish routes, especially in the upper Tocantins River; raising awareness of freshwater fish diversity and ecological services (provided by these ecosystems) to the population in general; and increase in investment in science, particularly on biodiversity studies. In addition, actions directed to aquatic biodiversity conservation that were proposed by WWF-Brasil (2016) in the Tapajós River basin, could be implemented in the Tocantins-Araguaia River basin. Among these actions is the Systematic Conservation Planning (PSC) approach, which is based on an information and analysis system that identifies priority areas for conservation and indicates free river stretches that are crucial to maintain the natural flow regimes. Within this context, the Brazilian government should proceed with an integrated strategic plan that defines scenarios and indicators on the conservation state of large rivers and their main tributaries, as well as define a set of rivers to be preserved before the accumulation of countless hydroelectric plants generates disastrous and irreversible impacts.

Supplementary Material

The following online material is available for this article:

Supplementary file 1 - List of 751 freshwater fish species from the Tocantins-Araguaia River basin and their occurrence. X: occurrence according to a taxonomic publication or to direct exam of specimens in collections by Dagosta & de Pinna (2019) or by us, S: secondary literature source (*e.g.* inventories), ?: doubtful occurrence, R: species restrict/endemic to the Tocantins-Araguaia river basin, E. Endangered species.

Supplementary file 2 - List of the enterprises in operation at the Tocantins-Araguaia River basin. All data collected from ABRAPCH (2020) and ANEEL (2020). Brazilian States: GO = Goiás, MA = Maranhão, MT = Mato Grosso, PA = Pará, and TO = Tocantins.

Supplementary file 3 - List of the conservation units at the Tocantins-Araguaia River basin. All data collected from ICMBio and ISA (https://uc.socioambiental.org/pt-br). CUs of integral protection include: National Parks (PARNA), State Parks (PES) Biological Reserves (REBIO), Ecological Estation (ESEC) and Natural Monument (MN). CUs of sustainable use include: Protect Environment Areas (APA), Extractivist Reserves (RESEX), National Forest (FLONA) and Natural Heritage Private Reserves (RPPN). Brazilian States: BA = Bahia, GO = Goiás, MA = Maranhão, MT = Mato Grosso, PA = Pará, PI = Piauí, TO = Tocantins, and Federal district, DF = Distrito Federal, ha = hectare.

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Conflicts of Interest

The authors declared no conflict of interest.

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