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The ichthyofauna of the Potiritá River basin: assessing the conservation status in a mining area in the Eastern Amazon

A ictiofauna da bacia do Rio Potiritá: avaliando o status de conservação em uma área de mineração na Amazônia Oriental

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Abstract: Aim: Considering the importance of knowing the organisms that make up the environments impacted by human activities, we aimed to create an inventory of the ichthyofauna of a bauxite mining area in the Eastern Amazon in this work. **Methods:** Specimens were collected with sieves, trawls, and gill nets at 37 points in rivers and streams during two expeditions (July 2017 and September and October 2017). After euthanasia and laboratory processes, we identified each individual to the lowest possible taxonomic level, and samples were deposited in scientific collections. We analyzed the conservation status of the species on state, national, and international lists. **Results:** A total of 109 species were identified, belonging to 28 families and six orders, emphasizing the Characiformes order (57 species) and the Characidae family (22 species). We identified two new species, and none are threatened with extinction. **Conclusions:** The high species richness recorded in the Potiritá River basin is noteworthy, considering its relatively small area. This diversity should be considered in future environmental impact studies and in monitoring the ichthyofauna in areas affected by human activities.

Keywords: bauxite; fish richness; inventory; neotropical region; taxonomy.

Resumo: Objetivo: Considerando a importância de se conhecer os organismos que compõem os ambientes impactados por atividades humanas, o presente trabalho trata-se de um inventário da ictiofauna de uma área de mineração de bauxita na Amazônia Oriental. **Métodos:** Os espécimes foram coletados com peneiras, redes de arrasto e de espera em 37 pontos localizados em rios e riachos durante duas expedições (julho de 2017 e setembro e outubro de 2017). Após a eutanásia e processos de laboratório, cada indivíduo foi identificado até o menor nível taxonômico possível e amostras estão sendo depositadas em coleções científicas. O status de conservação das espécies foi analisado em listas no âmbito estadual, nacional e internacional. **Resultados:** Foram identificadas 109 espécies pertencentes a 28 famílias e seis ordens, com destaque para as ordens Characiformes (57 espécies) e para a família Characidae (22 espécies). Duas espécies novas foram identificadas e nenhuma encontra-se ameaçada de extinção. **Conclusões:** Destaca-se a alta riqueza de espécies registrada na bacia do Rio Potiritá em contraste com sua área relativamente pequena. Esta diversidade deve ser considerada em futuros estudos de impacto ambiental e em monitoramentos da ictiofauna em áreas afetadas por atividades antrópicas.

Palavras-chave: bauxita; riqueza de peixes; inventário; região neotropical; taxonomia.

1. Introduction

In recent decades, the Amazon region has become one of the main areas of expansion of economic activities in Brazil (Carvalho & Domingues, 2016; Ometto et al., 2016; Siqueira-Gay et al., 2020). Concomitantly, with this expansion, there was an increase in the impacts caused by different human activities on the aquatic and terrestrial environments in the region (Sonter et al., 2017; Siqueira-Gay et al., 2020). This scenario created the need to develop and implement biomonitoring programs and techniques, mainly to assess biodiversity in these areas and possible natural and anthropogenic variations in ecosystems (Artaxo et al., 2014).

The issue involving the relationship between the exploitation of natural resources and the need to mitigate socio-environmental impacts still requires attention from the various sectors of society (Fearnside, 1997; Nepstad et al., 2006). The negative impacts related to the exploitation of natural resources, such as the extraction of minerals, are caused mainly by deforestation, changes in the physical-chemical characteristics of water, and aggradation of water bodies, which result in changes in the structure and dynamics of animal and plant assemblages (Foley et al., 2007; Lobo et al., 2016). These are affected by changes in the richness and abundance of its populations, in addition to being impacted by changes in the availability of resources (shelters, food, among others) in altered environments (Bojsen & Barriga, 2002; Arantes et al., 2017; Brejão et al., 2018).

Mineral exploration in the Amazon region is one of the most important economic activities for regional and national development (Araújo & Fernandes, 2016; Ribeiro & Silva, 2018). However, due to its potential to cause impacts due to the removal of forests, contamination of rivers and streams, and even recent accidents with tailings dams, this type of exploration needs attention (Salvador et al., 2020a; Azevedo-Santos et al., 2021;). In this sense, mitigating measures for the conservation and recovery of ecosystems must be taken when considering the sustainable development of the activity in the social, economic, and environmental spheres (Santos, 2002; Monteiro, 2005).

As mentioned above, the process of extracting ores, such as bauxite, can also have an impact on the aquatic environment. Waste from this activity can be carried by rain and introduced into these ecosystems (Carvalho et al., 2017; Santos et al., 2021). The changes suffered by aquatic environments involve impacts on the structure of habitats, which can result in limiting the occurrence and distribution of organisms, in addition to interfering with the availability of resources and the integrity of food webs (Callisto & Esteves, 1998; Azevedo-Santos et al., 2021).

Brazilian ecosystems are home to the greatest diversity of species in the world, and the Amazon region concentrates a large part of this biodiversity. This biome has the largest area of tropical forest on the planet, covering nine countries in South America (Myers et al., 2000). Estimates indicate that, in the Amazon, there are at least 50,000 species of plants, 399 of mammals, 1,292 of birds, 381 of reptiles, 388 of amphibians, and between 1,300 and 3,500 of fish (Paglia et al., 2012; Aleixo, 2016; Cardoso et al., 2017; Prudente, 2017; Ávila-Pires, 2018, 2021; Hoogmoed, 2018; Dagosta & de Pinna, 2019) In addition, it is believed that there is a much larger number of species that have not yet been described. Therefore, fauna and flora inventories represent indispensable sources of information for implementing management, conservation and mitigation actions of environmental impacts in mineral exploration areas (Costello et al., 2013).

The Amazonian water bodies have a high diversity of fish. This species richness and the abundance of individuals may vary due to changes that occur naturally in the environment, such as flood pulses (Claro-Junior et al., 2004; Barbosa et al., 2015). However, variations can also affect anthropic activities, such as mining (Brejão et al., 2018; Siqueira-Gay et al., 2020). Thus, it is important to know the organisms that make up these environments, and in this work, we present an inventory of the ichthyofauna based on primary and secondary data, aiming to obtain a better understanding about the conservation status of the Ichthyofauna under the influence of a bauxite mining area in the Potiritá River region, in the Capim River basin, Eastern Amazon.

2. Material and Methods

2.1. Study area

The Potiritá River basin has 1.834 km^2 and is part of the Capim drainage located northeast of Pará, Brazil (Figure 1). It drains a major axis of economic circulation in Pará, the Belém-Brasília Road (BR 010), which is important for activities related to industry, logging, and agriculture (Lima & Ponte, 2012).

In general, the vegetation is composed of secondary forests and open grassland due to agricultural activities. Some forests in various regeneration processes also occur. In addition, floodplains are abundant and have low vegetation, subject to seasonal flooding. These areas suffer impacts related to sand dredging, agriculture, livestock and settlements (Lima, 2007).

The region's climate is classified as Aw4, with a well-defined dry winter, according to the Köppen classification (Peel et al., 2007). Precipitation varies between 1500 and 2000 mm per year, with the greatest rainfall from February to April and the driest months between August and September. The average annual temperature is 26 °C and the annual humidity is around 75% (Lima, 2007). The region has a low slope and an irregular drainage network. The flow of the Potiritá River varies between 200 and 1,000 m^3/s (Lima, 2005).

2.2. Sampling and data analysis

We sampled 37 sites of rivers and streams within the Norsk Hydro company area and along the Potiritá River basin. Specimens were collected in two field expeditions. The first one took place from July 10 to 24, 2017 (19 sample sites), and fish were sampled from a specific manual for

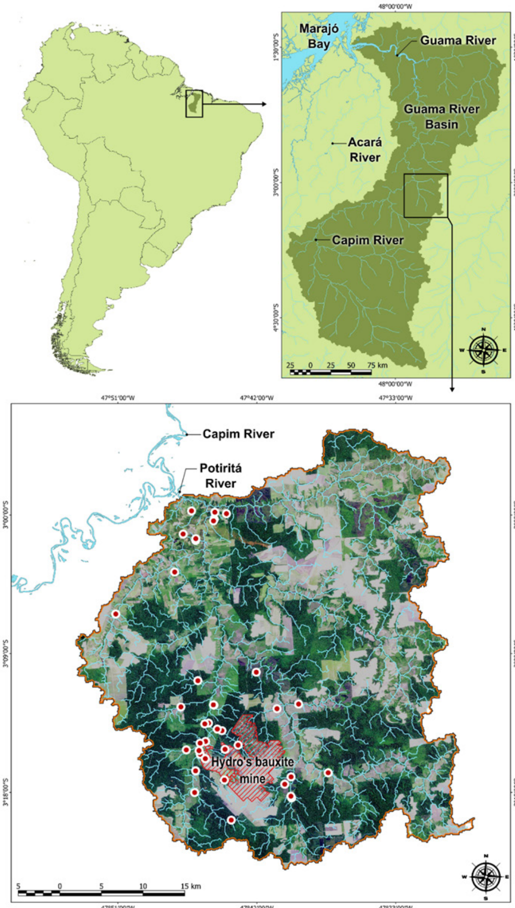

Figure 1. Sample sites located in rivers and streams along the Potiritá River basin, Paragominas district, State of Pará, northern Brazil, where the specimens were sampled during two expeditions in 2017.

streams (Peck et al., 2006), which also includes the collection of macroinvertebrates and assessment of the physical habitat of the streams. The second expedition was carried out from September 25 to October 3, 2017 (18 sample sites) to increase knowledge of fish diversity. Both expeditions took place during the dry season.

During the first expedition, specimens were collected in a 150 m segment of the streams for three hours using two 55 cm diameter sieves with a 3 mm mesh between opposite nodes. In the second expedition, we sampled fish using various methods such as sieves, trawls (5 m long, 1.5 m high, and a 3 mm mesh between opposite nodes), and gillnets (10 m long, 2 meters high and meshes varying between 3 and 5 cm between opposite nodes).

We defined the rivers and streams sampled in the second expedition according to the possibility of access from roads or trails, seeking to cover the largest possible area along the Potiritá River basin.

The sampling effort was defined according to the environmental characteristics of the stream and river, aiming to access all the aquatic microhabitats observed in the sampling site.

After collection, the fishes were euthanized using eugenol following the technical guidelines of the National Council for Animal Experimentation Control (Brasil, 2018a) (CEUA/UFPA number 8293020418), fixed with a 10% formalin solution, and, after 48 hours, transferred and preserved into 70% alcohol. We identified all individuals to the lowest taxonomic level possible, using dichotomous keys and specialized bibliography (e.g. Géry, 1977; Planquette et al., 1996; Queiroz et al., 2014). Samples of some species are deposited in Museu Paraense Emílio Goeldi (MPEG) and Museu de Zoologia da UFPA (MZUFPA). Some of the samples are in the process of accessioning and do not yet have a voucher.

To assess the conservation status of the species, we searched state, national and international lists (e.g., Pará, 2007; Brasil, 2018b, 2023; IUCN, 2021;). The status of native or exotic species was based on Tedesco et al. (2017), while endemism was evaluated according to the proposal of Dagosta & de Pinna (2019).

3. Results

We identified a total of 109 species belonging to 81 genera, 28 families and six orders (Table 1; Figures 2-4). Characiformes was the most representative order (57 species), followed by Siluriformes (20 species), Cichliformes (15 species) and Gymnotiformes (13 species). The orders Cyprinodontiformes and Synbranchiformes were represented by two and one species, respectively. The most representative families were Characidae (22 species), followed by Cichlidae (15 species) and Hypopomidae (five species). Five or fewer species represented the remaining families. Two possible new species were found (*Characidium* sp. and *Moenkhausia* sp.) and will be described in future papers.

All species sampled are native to the Amazon region, and there was no endemic taxon. In addition, considering the state, national and international lists of threatened species, just *Gymnotus anguillaris* had Data Deficit (DD) status on the international

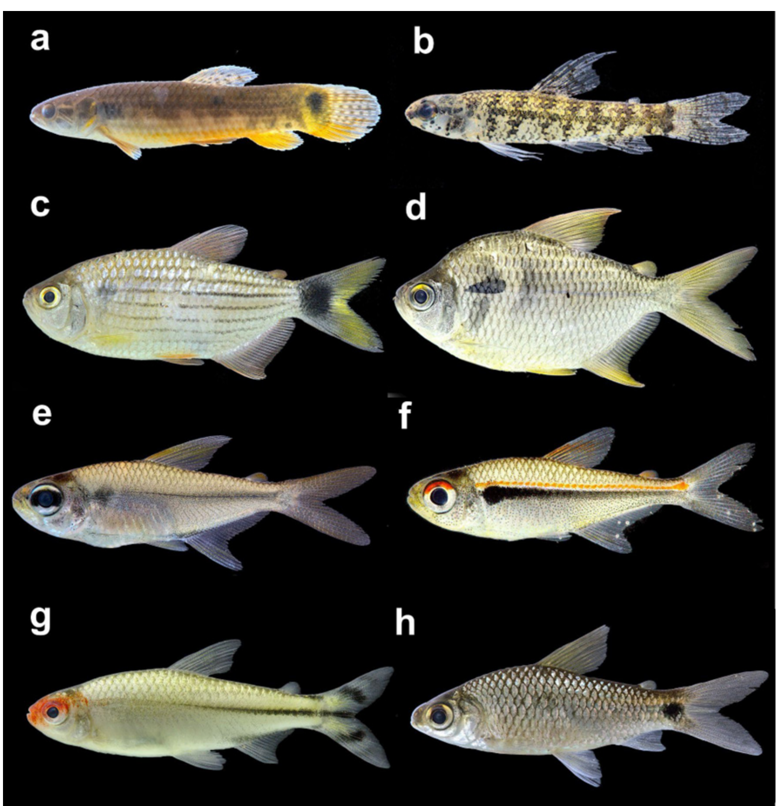

Figure 2. Species of the Potiritá River basin photographed just after the fixation process. (a) *Erythrinus erythrinus*; (b) *Microcharacidium weitzmani*; (c) *Bario steindachneri*; (d) *Moenkhausia comma*; (e) *Moenkhausia collettii*; (f) *Hyphessobrycon heterorhabdus*; (g) *Hemigrammus rhodostomus*; (h) *Curimatopsis crypticus*.

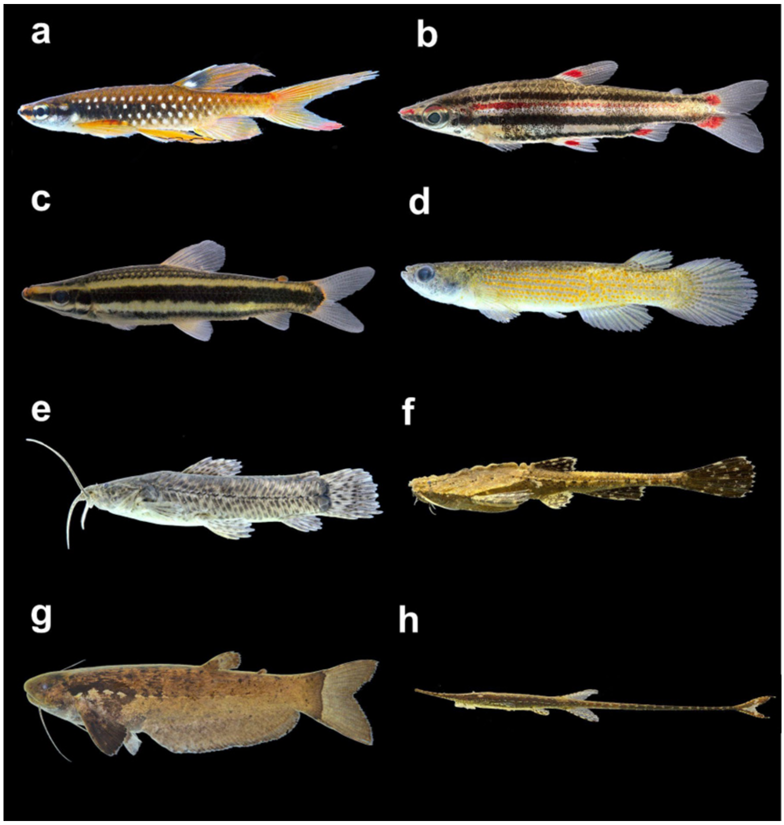

Figure 3. Species of the Potiritá River basin photographed just after the fixation process. (a) *Copella arnoldi*; (b) *Nannostomus trifasciatus*; (c) *Anostomus anostomus*; (d) *Anablepsoides urophthalmus*; (e) *Megalechis thoracata*; (f) *Bunocephalus coracoideus*; (g) *Helogenes marmoratus*; (h) *Farlowella amazonum*.

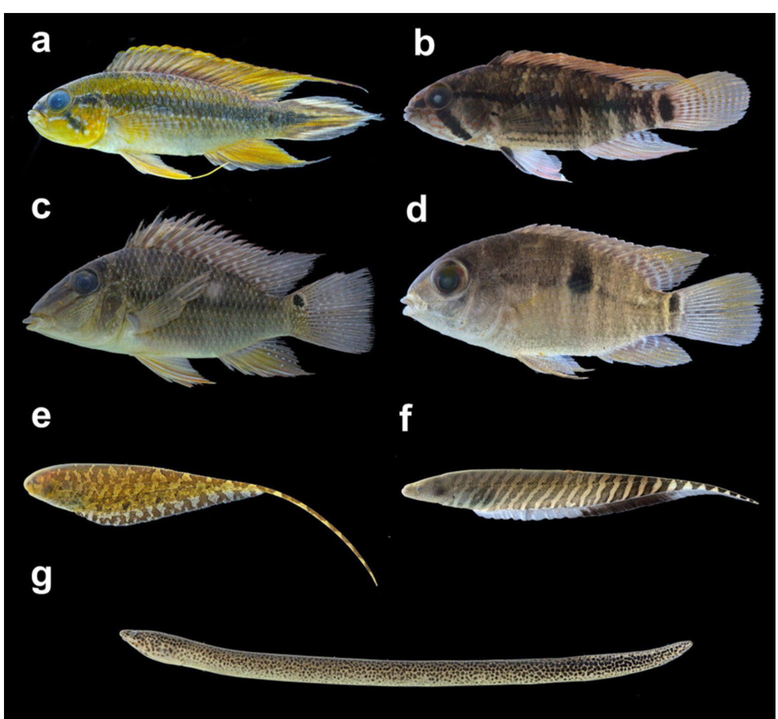

Figure 4. Species of the Potiritá River basin photographed just after the fixation process. (a) *Apistogramma agassizii*; (b) *Apistogramma* gr. *Regain*; (c) *Satanoperca jurupari*; (d) *Aequidens tetramerus*; (e) *Steatogenys duidae*; (f) *Gymnotus anguillaris*; (g) *Synbranchus marmoratus*.

Table 1. List of species sampled at 37 sites located in rivers and streams in the Potiritá River basin, Pará, Brazil, in 2017.

Taxon/Authority	Acronym	Status
CHARACIFORMES		
Acestrorhynchidae		
Acestrorhynchus falcatus (Bloch 1794)	MPEG 023532	LC
Acestrorhynchus falcirostris (Cuvier 1819)	MPEG 036447	LC
Acestrorhynchus nasutus Eigenmann 1912	MPEG 009833	LC
Anostomidae		
Anostomus anostomus (Linnaeus 1758)	MPEG 036489	LC
Leporinus friderici (Bloch 1794)	MPEG 006883	LC
Leporinus granti Eigenmann 1912	*	LC
Bryconidae		
Brycon falcatus Müller & Troschel 1844	*	LC
Characidae		
Aphyocharacidium sp. 1	*	-
Aphyocharacidium sp. 2	*	-
Bario steindachneri (Eigenmann 1893)	MZUFPA00127	LC
Bryconamericus orinocoensis Román-Valencia 2003	*	LC
Charax pauciradiatus (Günther 1864)	*	LC
Hemigrammus bellottii (Steindachner, 1882)	MZUFPA00128	LC
Hemigrammus levis Durbin 1908	MZUFPA00129	LC
Hemigrammus ocellifer (Steindachner, 1882)	MZUFPA00130	LC
Hemigrammus rhodostomus Ahl 1924	*	LC
Hemigrammus rodwayi Durbin 1909	MZUFPA00131	LC[1]
Hemigrammus microstomus Durbin 1918	*	LC
Hyphessobrycon heterorhabdus (Ulrey, 1894)	MZUFPA00132	LC
Jupiaba aff. *zonata*	*	-
Jupiaba anteroides (Géry 1965)	*	LC
Microschemobrycon sp.	*	-
Moenkhausia aff. *mikia*	*	-
Moenkhausia collettii (Steindachner 1882)	MZUFPA00124	LC
Moenkhausia comma Eigenmann 1908	MZUFPA00125	LC
Moenkhausia oligolepis (Günther, 1864)	MZUFPA00126	LC
Moenkhausia sp.	*	-
Phenacogaster cf. *pectinatus*	MZUFPA00133	-
Poptella brevispina Reis 1989	*	LC
Chilodontidae		
Chilodus punctatus Müller & Troschel 1844	*	LC
Crenuchidae		
Ammocryptocharax elegan Weitzman & Kanazawa 1976	*	LC
Characidium sp.	MZUFPA00134	-
Crenuchus spilurus Günther 1863	MZUFPA00135	LC
Microcharacidium weitzmani Buckup, 1993	MPEG 36149	LC
Curimatidae		
Curimatopsis crypticus Vari 1982	MZUFPA00137	LC
Curimatopsis evelynae Géry 1964	MZUFPA00138	LC
Cyphocharax gouldingi Vari 1992	*	LC
Erythrinidae		
Erythrinus erythrinus (Bloch & Schneider 1801)	MZUFPA00139	LC
Hoplerythrinus unitaeniatus (Spix & Agassiz 1829)	MZUFPA00140	LC
Hoplias curupira Oyakawa & Mattox 2009	*	LC
Hoplias malabaricus (Bloch 1794)	MZUFPA00141	LC
Gasteropelecidae		
Carnegiella strigata (Günther, 1864)	MZUFPA00142	LC
Hemiodontidae		
Hemiodus cf. *semitaeniatus*	*	-
Hemiodus unimaculatus (Bloch 1794)	*	LC
Iguanodectidae		
Bryconops caudomaculatus (Günther 1864)	*	LC
Bryconops melanurus (Bloch 1794)	*	LC
Iguanodectes rachovii Regan, 1912	MZUFPA00144	LC

Acronym of the species listed in the ichthyological collection of the Museu Paraense Emílio Goeldi (MPEG) and Museu de Zoologia da Universidade Federal do Pará (MZUFPA) (Pará, Brazil); and the Status of conservation for International (IUCN, 2021), National (Brasil, 2023) and Regional (Pará, 2007). LC = Least Concern; DD = Data Deficient; NE = Not Evaluated; - = Unclassified due to lack of species confirmation. *Samples in the process of accessioning and do not yet have a voucher. [1]Not available in ICMBio; available in IUCN.

Table 1. Continued...

Taxon/Authority	Acronym	Status
CHARACIFORMES		
Lebiasinidae		
Copella arnoldi (Regan, 1912)	MZUFPA00145	LC
Nannostomus eques Steindachner 1876	*	LC
Nannostomus nitidus Weitzman, 1978	MZUFPA00146	LC
Nannostomus trifasciatus Steindachner, 1876	MZUFPA00147	LC
Pyrrhulina capim Vieira & Netto-Ferreira, 2019	MZUFPA00149	NE
Serrasalmidae		
Catoprion mento (Cuvier 1819)	*	LC
Metynnis sp.	*	-
Mylopus sp.	*	-
Pristobrycon sp.	*	-
Serrasalmus sp.	*	-
CYPRINODONTIFORMES		
Rivulidae		
Anablepsoides urophthalmus (Günther, 1866)	MZUFPA00160	LC
Melanorivulus sp.	MZUFPA00159	-
GYMNOTIFORMES		
Gymnotidae		
Gymnotus anguillaris Hoedeman 1962	MZUFPA00161	DD[1]
Gymnotus carapo Linnaeus 1758	MZUFPA00162	LC
Gymnotus coropinae Hoedeman, 1962	MZUFPA00163	LC
Hypopomidae		
Brachyhypopomus brevirostris (Steindachner, 1868)	MZUFPA00163	LC

Acronym of the species listed in the ichthyological collection of the Museu Paraense Emílio Goeldi (MPEG) and Museu de Zoologia da Universidade Federal do Pará (MZUFPA) (Pará, Brazil); and the Status of conservation for International (IUCN, 2021), National (Brasil, 2023) and Regional (Pará, 2007). LC = Least Concern; DD = Data Deficient; NE = Not Evaluated; - = Unclassified due to lack of species confirmation. *Samples in the process of accessioning and do not yet have a voucher. [1]Not available in ICMBio; available in IUCN.

list (IUCN, 2021), but was not evaluated on the national list. Only *Pyrrhulina capim* have not been evaluated on any list (regional, national and international).

4. Discussion

The species richness observed in this study (109) is similar to that expected for the region, with records ranging from 20 to more than 1,400 species (Dagosta & de Pinna, 2019; Jézéquel et al., 2020). However, the species richness recorded in the Potiritá River basin may be considered high, given its relatively small area (1,834 km^2).

Species richness may be related to the area sampled in a given system (Matthews & Robison, 1998), as found in the present study. However, works in other Neotropical basins indicate a lower relationship between species richness and drainage area, as is the case of tributaries of the São Francisco River (Alves & Leal, 2010; Salvador et al., 2020b) and even of the Paraná River, another megadiverse Neotropical basin (Langeani et al., 2007; Ribeiro et al., 2019; Jarduli et al., 2020;). Our results may be due to the dedicated sampling effort in the basin (Hughes et al., 2012; Pompeu et al., 2021), but other studies carried out with a great collection effort concerning the drainage area indicate a different richness/area ratio (Azevedo-Santos et al., 2020), even in the Amazon region itself (Casatti et al., 2013).

The distribution of species recorded in the Potiritá River basin, about the Orders, follows the pattern predicted for the Neotropical region, with a predominance of Characiformes and Siluriformes (Lowe-McConnell, 1999; Albert et al., 2020). This pattern is widely observed in South America and has already been recorded in other basins, such as rivers in the Amazon (Vari et al., 2009; Dutra et al., 2020), Paraná (Langeani et al., 2007; Ota et al., 2018), Mearim (Guimarães et al., 2020), Munim (Vieira et al., 2023), and São Francisco (Alves & Leal, 2010; Salvador et al., 2020b). Furthermore, these are species-rich fish families, and many more species are being described. Thus, Characiformes and Siluriformes are fish families with wide distribution (Dutra et al., 2020).

In our study, two species considered new to science were registered, which shows the importance of systematic surveys to expand knowledge about the biodiversity of freshwater fish. In the Capim River basin, some works were carried out in small-order stream environments (Leal et al., 2018; Maia, 2019), but they were focused on ecological issues and assessments of the effects of land use on the fish community. Still, such studies can be considered as efforts to understand how freshwater biodiversity is distributed along the Capim River basin. It is worth mentioning that in-depth studies of a small watershed can reveal many clues to understanding not only the environmental impacts on small streams, but also how the entire watershed can be affected. Thus, to expand knowledge, it is also necessary to study higher-order freshwater bodies, similar to the study carried out by Carvalho et al. (2007).

Information about fish communities in water bodies is essential for identifying taxa with different habitat uses, including species from groups known as indicators of environmental degradation, which are essential for assessing and monitoring degraded areas, including the ones affected by mining companies activities (De Paula Gutiérrez & Agudelo, 2020; Azevedo-Santos et al., 2021). Fishes are known as good bioindicators due to the functional role they play in the environment, their high diversity and abundance, in addition to their sensitivity to environmental changes reflected in ecological aspects related to feeding and reproduction (Chovanec et al., 2003; Gadzala-Kopciuch et al., 2004).

In our study, we found several species of fish of the order Characiformes, which have several taxa that inhabit the water column, using vision in foraging activities and, therefore, being good indicators of the condition of this micro-habitat, mainly in relation to water turbidity (Araújo et al., 2003; Masson et al., 2021). Siluriformes has species with benthic habits capable of producing an electric field to detect prey between the banks of leaves and branches of adjacent vegetation (Zuanon et al., 2015). Such species may be considered highly specialized, as they need natural or favorable environmental conditions for their development. Environmental alterations such as marginal erosion, channel sedimentation, and alterations in the electrical conductivity of the water can alter the foraging capacity of these species and, consequently, cause a local extinction (Araújo et al., 2003).

Environmental changes caused by human activities have affected the composition of fish species. Sensitive and more specialized species are harmed and even eliminated from the environment (Zeni & Casatti, 2014; Arantes et al., 2017). Studies carried out in small streams have shown that degraded environments have greater abundance and biomass of aquatic insectivores fish, as well as detritivores and algivores. On the other hand, non-degraded stream environments have a greater abundance and biomass of insectivores and terrestrial herbivores fishes, followed by a greater diversity of trophic guilds (Zeni & Casatti, 2014). In rivers, the reduction of forest cover affects the composition of fish, harming species that are highly dependent on allochthonous material from the forest and favoring the increase in abundance and richness of species with high dispersal capacity and/or classified as ecological generalists (Arantes et al., 2017). Given this, environmental changes caused by human activities can lead fish communities to be less rich and more similar, becoming homogeneous (Petsch, 2016).

Studies in mining areas indicate a reduction in the richness of fish assemblages in streams (Allard et al., 2016; Apriadi et al., 2018; Salvador et al., 2023). Removing natural vegetation and soil excavating along the watersheds are the main modifications. These activities lead to an intense increase in erosive processes and contribute to a high load of suspended sediments deposited on the channel bed, affecting the occurrence of fish specialized in benthic habitats, which hide in banks of leaves, woody debris or use electric fields to detect prey (Mol & Ouboter, 2004; Brosse et al., 2011; Allard et al., 2016; Apriadi et al., 2018). In addition, some mining activities use substances such as mercury, which poison fish and other aquatic animals, also affecting human populations (Berzas Nevado et al., 2010; Faial et al., 2015). This results in the loss of countless contaminated species, economic losses, and human health problems (Faial et al., 2015).

In the Potiritá River basin, the mineral extraction of bauxite, an important ore for industry and local development, takes place. However, the environmental changes caused by this activity affect aquatic environments and contribute to changes in species composition, causing the loss of some (Apriadi et al., 2018; Maia, 2019). A study carried out with fish from streams in the Potiritá River basin region points out that environmental changes related, directly or indirectly, to mining activities, affect fish communities in the evaluated streams (Maia, 2019). This happens because the bauxite mining activity encompasses numerous processes, from the removal of natural vegetation, flow of machinery, excavation of the soil along microbasins, and use of water from tributaries, and all these processes contribute to changes in fish communities (Brosse et al., 2011; Maia, 2019).

Given the current environmental scenario in Brazil, inventories such as the one carried out in this work are essential for the knowledge of the ichthyofauna in impacted areas. The diversity found in the Potiritá River basin should be considered in future environmental impact studies and in monitoring the ichthyofauna in areas affected by human activities. However, it is necessary to carry out research that deepens and expands the information obtained here, including ecological aspects such as feeding and reproduction of the species. In addition, future studies should apply similar methods in the Capim/Guamá basins, allowing comparisons between different areas and reducing the gap in ichthyological knowledge in the Amazon.

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