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**Programa de Pós-Graduação em Ciências Ambientais**

# INVENTÁRIO DA ICTIOFAUNA DA BACIA DO RIO MUNIM, MARANHÃO, NORDESTE DO BRASIL

Pós-Graduando: Lucas de Oliveira Vieira

Orientador: Prof. Dr. Felipe Polivanov Ottoni

Coorientador: Pedro Henrique Negreiros de Bragança

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Isaac Newton

## SUMÁRIO

# LISTA DE SIGLAS

**CICCAA -** Coleção Ictiológica do Centro de Ciências Agrárias e Ambientais.

**CLOFFBR-MA -** Checklist dos peixes de água doce do Maranhão.

**CNPq -** Conselho Nacional de Desenvolvimento Científico e Tecnológico – Ministério da Ciência e Tecnologia.

**FAPEMA -** Fundação de Amparo à Pesquisa e Desenvolvimento Científico do Maranhão.

**MA** – Maranhão.

**MRN –** Maranhão.

**PI –** Piauí.

**PRN –** Parnaíba.

**UFMA –** Universidade Federal do Maranhão.

**ICMBio -** Instituto Chico Mendes de Conservação da Biodiversidade.

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# RESUMO

A região Neotropical, que compreende a região desde a América do Sul até o Sul do México, compreende uma ampla variedade de habitats, além de uma fauna e flora muito diversificada, compreendendo 7 dos 35 *hotspots* mundiais. Essa região possui uma enorme riqueza de peixes de água doce, com mais de 6.000 espécies válidas e com estimativas de 8.000 a 9.000 espécies (incluindo espécies não descritas). O Brasil, maior país da região Neotropical, se destaca pela sua diversidade de peixe de água doce, possuindo mais de 2.500 espécies descritas. Essa grande diversidade é composta majoritariamente por peixes de pequeno e médio porte, que estão distribuídos em diferentes ambientes aquáticos (rios, riachos, córregos, lagos, brejos, entre outros). No entanto, mesmo o Brasil possuindo uma rica diversidade de peixes nativos, nas últimas décadas, espécies não nativas vem sendo introduzidas, cada vez mais frequentemente, nas bacias hidrográficas brasileiras. Essas introduções são oriundas de diferentes atividades humanas, tais como: aquicultura, introduções e solturas intencionais, aquarismo, intervenções de controle biológico de larvas de mosquitos, transposição de água entre bacias hidrográficas isoladas, pesca esportiva, dentre outras atividades. O estado do Maranhão possui uma extensa rede hidrográfica, que inclui os seguintes sistemas hídricos: Gurupi, Maracaçumé, Turiaçu, Pericumã, Mearim, Itapecuru, Munim, Periá, Preguiças, Parnaíba, além de outros rios costeiros isolados menores, e os trechos baixo e médio rio Tocantins. Tal fato torna o estado extremamente relevante para estudos taxonômicos, ecológicos e de conservação de organismos de água doce. Sendo assim, esse trabalho realizou um inventário, com base em dados provenientes de 12 anos de coleta, e 84 localidades amostradas, das espécies de peixes que ocorrem na bacia do Rio Munim, Maranhão, Nordeste do Brasil. Ao todo foram registradas 123 espécies, sendo duas não nativas. Esse estudo aumentou o número de espécies conhecidas para a para do Rio Munim em 64 espécies, quando comparado a estudos publicados anteriormente. A bacia do Rio Munim foi subdividida em 4 seções (Alto, médio, baixo e estuário), e a diversidade dessas seções foi camparada. As seções médio e baixo tiveram suas diversidades mais similares, enquanto que a seção estuário apresentou a maior diferença entre as diversidades das demais seções.

**Palavras-chave:** América do Sul, Biodiversidade, Peixes, Região Neotropical.

**ABSTRACT**

The Neotropical region, which comprises the region from South America to southern Mexico, comprises a great variety of habitats, in addition to a very diverse fauna and flora, comprising 7 of the 35 world's *hotspots*. This region posses a huge freshwater fish species richness species, with more than 6,000 valid species and with estimates of 8,000 to 9,000 species (including undescribed species). Brazil, the largest country in the Neotropical region, stands out for its freshwater fish diversity, with more than 2,500 described species. This great diversity is mainly composed of small and medium-sized fish, which are distributed in different aquatic environments (rivers, streams, streams, lakes, swamps, and others). However, even though Brazil has a rich native fish diversity, in recent decades, non-native species have been introduced, more and more frequently, into Brazilian freshwater systems. These introductions come from different human activities, such as: aquaculture, intentional introductions and releases, aquarium trade, mosquito larvae biological control interventions, transposition of water between isolated river basins, sport fishing, amongst other activities. The state of Maranhão has an extensive hydrographic network, which includes the following freshwater systems: Gurupi, Maracaçumé, Turiaçu, Pericumã, Mearim, Itapecuru, Munim, Periá, Preguiças, Parnaíba, in addition to other smaller isolated coastal rivers, and parts of the lower and middle Tocantins River. This fact makes the state extremely relevant for taxonomic, ecological and conservation studies of freshwater organisms. Therefore, this work carried out an inventory, based on data from 12 years of collection, and 84 sampled locations, of fish species that occur in the Munim River basin, Maranhão, Northeastern Brazil. A total of 123 species were recorded, two of them are non-native species. This study increased the number of known species for the Munim River basins to 64 species, when compared to previously published studies. The Munim River basin was subdivided into 4 sections (upper, middle, lower and estuary), and the diversity of these sections was compared. The middle and lower sections had the most similar diversities, while the estuary section had the greatest difference between the diversities of the other sections.

**Keyword:** Biodiversity, Fish, Neotropical Region. South America

# CAPÍTULO I

## 1.1 FUNDAMENTAÇÃO TEÓRICA

### Região neotropical

A região Neotropical abrange as áreas tropicais da América do Sul, América Central, Centro e Sul do México e as ilhas Antilhas (MURPHY; LUGO, 1986; CONSERVANCY, 2005; ANTONELLI; SANMARTIN, 2011; LIMA et al., 2018; ANTONELLI et al., 2018; MORRONE, 2013, 2018, 2022). Essa região se destaca por ter em seu território o maior número de animais e plantas do planeta, além de 7 dos 35 *hotspots* (áreas com grande biodiversidade e alto grau de endemismo com elevado grau de ameaça) de biodiversidade do mundo (MYERS et al., 2000; TUNDISI; TUNDISI, 2008; WILLIAMS et al., 2011; LIMA et al., 2018).

A região Neotropical possui uma variedade de ecossistemas, tais como: as florestas Amazônicas e Atlântica, Prados de alta altitude Andinos, Paramos, Puna, Jalca, Pampas, Florestas sazonalmente secas, Savanas, Campos rupestres, Chaco, Desertos e o Pantanal (PRADO, 1993; ROIG et al., 2009; HUGHES et al., 2013; POTT et al., 2011; PENNINGTON; LAVIN, 2016; LIMA et al., 2018, FLORA; FUNGA DO BRASIL, 2022). Atrelado a isso, a mesma tem uma ampla variedade de habitats aquáticos, desde lagos alpinos, corredores torrenciais dos Andes, amplas planícies fluviais, savanas, estuários inundados sazonalmente, florestas inundadas, canais profundos de grandes rios de planície, canais subterrâneos, cavernas de carste, e as mais diversas paisagens do escudo Brasileiro (REIS et al., 2016). Todos esses fatores contribuem para que a região Neotropical tenha fauna e flora amplamente diversificada e endêmica (HUGHES et al., 2013; ANTONELLI et al., 2018).

A região Neotropical, em seu território, possui grandes redes hidrográficas, cpom diferentes características entre as mesmas, compreedendo as principais assembleias de peixes neotropicais. Essas diferenças entre as redes hidrográficas estão associados aos processos químicos da água, que são influenciados pela geoquímica do substrato das nascentes, cobertura vegetal dominante e tipos de solo, tais como: os rios de águas brancas, ricos em sedimentos (rios Madeira, Marañon, Meta e Napo); rios de água preta ricos em tanino (rios Atabapo, Japurá, Negro e Tefé); rios de águas claras que drenam das rochas cristalinas antigas e bem intemperizadas dos Escudos da Guiana e do Brasil (rios Tapajós, Tocantins, Ventuari e Xingu), (ALBERT; REIS, 2011b; CRAMPTON, 2011; REIS et al., 2016), além de diversas áreas de endemismo (REIS et al., 2016).

## Ictiofauna da América do Sul

A América do Sul é o principal continente do mundo em ictiofauna de água doce abrigando mais de 5.100 espécies descritas (REIS et al., 2016). Essa diversidade corresponde a cerca de uma terço das espécies de peixes dulcícolas do mundo, no entanto, estimativas sugerem que esse número ainda possa crescer. As hipóteses mais conservadoras propõem um crescimento próximo a 30% (REIS et al., 2003), enquanto outras apontam um aumento de até 75% na medida em que o conhecimento taxonômico avança, o que resultaria em mais de 9.000 espécies (REIS et al., 2016).

A origem de uma ictiofauna tão diversa está possivelmente ligada à formação das florestas tropicais há cerca de 100 milhões de anos atrás, com sua grande heterogeneidade de habitats e nichos (ALBERT et al., 2011). Ademais, esse número não seria tão grande se a América do Sul não tivesse sido poupada dos grandes eventos de extinção que marcaram o cenozoico (ALBERT et al., 2011). O continente sul-americano sofreu de forma bastante atenuada os efeitos oriundos do resfriamento global ocorrido na presente Era, como formação de desertos no equador e zonas temperadas em altas latitudes, possibilitando assim o acúmulo gradual de diferentes linhagens e espécies que resultou na grande biodiversidade atual (HOORN et al., 2010). Além disso, a região possui três grandes bacias hidrográfica de água doce: Amazonas, Orinoco e Paraná-Paraguai, que juntas abrangem uma área de 11.300.000 $km^2$ e 3.599 espécies de peixes, respectivamente (REIS et al., 2016). Além dessas três grandes bacias hidrográficas, o território sul-americano ainda possui várias outras bacias menores, muitas delas com elevado grau de espécies endêmicas (MONTOYA-BURGOS, 2003; SIGRIST; CARVALHO, 2008; RIBEIRO et al., 2011; REIS et al., 2016; SILVA et al., 2016).

## Ictiofauna de água doce do Brasil

O Brasil possui a maior extensão territorial da América do Sul (IBGE, 2022), e é considerado um país megadiverso (MITTERMEIER et al., 2005; ICBIO, 2018). Dentre todos os países da Região Neotropical, o Brasil se destaca com a maior diversidade de peixes de água doce, com mais de 2.500 espécies descritas válidas (BUCKUP et al., 2007; FRICKE et al., 2022). Esse valor representa aproximadamente 50% de todas as espécies de peixes de água doce da região Neotropical (BUCKUP et al., 2007; REIS et al., 2016). Essa grande diversidade pode ser justificada, principalmente, pelo País possuir em seu território grandes redes hidrográficas e áreas de endemismo (AGOSTINHO et al., 2005; BUCKUP et al., 2007; REIS et al., 2016). A maior parte dessa biodiversidade é constituída por peixes de pequeno e médio porte, que estão distribuídos em vários ecossistemas aquáticos, como rios, riachos, córregos e lagos (VAZZOLER, 1996; CASTRO, 1999; LOWE-MCCONNEL, 1999; CASTRO; POLAZ 2020; CÔRREA; CASTRO, 2021). Além disso, o País possui várias espécies de peixes que tem o hábito migratório em seu ciclo de vida (CAROLSFELD et al., 2003)

Atualmente o número de descrições e novos registros a cada ano vem aumentando exponencialmente (REIS et al., 2003; NELSON et al., 2016; REIS et al., 2016; LONDOÑO-BURBANO et al., 2021). O crescente número de descrições de novas espécies nos últimos anos em território brasileiro (*e.g.*, ROXO et al., 2017; ZAWADZKI et al., 2017; GUIMARÃES et. al., 2018a,2018b; 2019; 2020; LEÃO et al., 2019; BRITO et al., 2019; COSTA et al., 2020; KATZ et al., 2020; SARAIVA et al., 2021; DIAS; ZAWADZKI, 2021; COSTA et al., 2022; NEUHAUS et al., 2022; AGUIAR et al., 2022; LIMA et al., 2022; STAECK et al., 2022) revela que ainda são necessários mais estudos para se compreender a rica e complexa ictiofauna brasileira (VARI; MALABARBA, 1998). Estas lacunas de conhecimento se dão principalmente no nordeste do Brasil, já que a maior parte dos estudos sobre peixes, no Brasil, se concentram, principalmente, na região sul e sudeste do País, e na Amazônia (BUCKUP et al., 2007; GUIMARÃES et al., 2018b; VAN DER SLEEN; ALBERT, 2018).

**Espécies não nativa**

A introdução de espécies não nativas (espécies que ocorrem fora de sua distribuição natural), vem aumentando em todo o mundo (LATINI et al., 2016). Embora o Brasil possua uma grande diversidade de peixes nativo, as espécies de peixes não nativos vêm se proliferado nos sistemas hidrográficos brasileiros. Essa introduções são oriundas de diferentes ações antrópicas, tais como: aquicultura, introduções e solturas intencionais, aquariofilismo, intervenções biológicas para controle de mosquitos, transposição de água entre bacias hidrográficas isoladas, pesca esportiva, entre outras atividades (FIGUEREDO; GIANI, 2005; AZEVEDO-SANTOS et al., 2011; VITULE et al., 2015; LATINI et al., 2016; PADIAL et al., 2017; BRAGANÇA et al., 2020; DORIA et al., 2021, OTTONI et al., 2021; FRANCO et al., 2022). Espécies não nativas podem causar mudanças na composição das assembleias locais e na abundância das populações de espécies nativas, causando grandes impactos ambientais (GIACOMINI et al., 2011; LATINI et al., 2016, PADIAL et al., 2017, DORIA et al., 2021, OTTONI et al., 2021).

**Ictiofauna do Maranhão**

O Maranhão é o estado mais ocidental do nordeste do Brasil, fazendo fronteira com o Piauí a leste, separado pelo rio Parnaíba, Tocantins ao sul e sudeste, separado pelo rio Tocantins, e Pará a oeste, separado pelo rio Gurupi. Seu território abrange uma área de cerca de 330.000 km$^2$, ocupando cerca de 3,9% do território nacional (RÊBELO, 1966; RÊBELO et al., 2003; MARTINS; OLIVEIRA, 2011; BATISTELLA et al., 2014; SPINELLI-ARAÚJO et al., 2016). Em termos de biodiversidade, o estado do Maranhão é extremamente relevante, já que em seu território abriga três dos principais biomas Brasileiros (Amazônia, Cerrado e Caatinga), assim como áreas de transições entre esses biomas. Os biomas no Maranhão estão distribuídos da seguinte forma: a Amazônia, em sua porção oeste e central; o Cerrado, na região Sul, central e leste; e Caatinga, em seu extremo leste. Sendo assim, o estado possui representantes faunísticos e florísticos desses três biomas, o que o torna extremamente relevante em termos ecológicos, de biodiversidade e conservação (AB'SÁBE, 2003; REBÊLO et al., 2003; OLSON et al., 2001; FIASCHI; PIRANI, 2009; PIORSKI, 2010; MIRANDA et al., 2012).

O Estado do Maranhão compreende uma extensa rede hidrográfica, incluindo os seguintes sistemas: Gurupi, Maracaçumé, Turiaçu, Pericumã, Mearim, Itapecuru, Munim, Periá, Preguiças, Parnaíba, além de outros rios costeiros isolados menores, e os trechos baixo e médio do rio Tocantins, um importante afluente do sul do rio Amazonas. Esses sistemas fluviais são subdivididos em três principais regiões hidrográficas brasileiras (Tocantins-Araguaia, Atlântico Nordeste Ocidental e Parnaíba) (PIORSKI, 2010; RAMOS et al., 2014; GUIMARÃES et al., 2018; ABREU et al. 2019; GUIMARÃES et al., 2020; KOERBER et al., 2022).

Nas últimas duas décadas no estado do Maranhão foram conduzidos vários levantamentos de peixes, incluindo corpos de água doce e região estuarinas, ampliando o conhecimento da ictiofauna do estado. (e.g., CASTRO, 2001; CASTRO et al., 2002; PIORSKI et al., 2003; PINHEIRO-JÚNIOR et al., 2005; SOARES 2005; PIORSKI et al., 2007; CASTRO et al., 2010; BARROS et al., 2011; SOUSA et al. 2011; FRAGA et al., 2012; ALMEIDA et al., 2013; RIBEIRO et al., 2014; RAMOS et al., 2014; LIMA et al., 2015; MATAVELLI et al., 2015, MELO et al., 2016; PIORSKI et al., 2017; BRITO et al., 2019, LIMA et al., 2019; TEIXEIRA et al., 2019; NUNES et al., 2019; GUIMARÃES et al., 2020; BRITO et al., 2020; OLIVEIRA et al., 2020; GUIMARÃES et al., 2021a; 2021b; 2021c). No entanto, ao observamos os trabalhos percebemos que as bacias mais estudadas foram Mearim e Itapecuru, mesmo com uma série de trabalhos realizados ao longo de duas décadas, sobre risco de muitas áreas poderem sua biodiversidade antes mesmo de ser conhecida pela ciência (BROOK et al., 2006; WHEELER, 2008; PIORSKI et al., 2017; GUIMARÃES et al., 2018).

## 1.2 OBJETIVOS

### 1.2.1 Objetivo geral

Realizar um inventário das espécies de peixes que ocorrem na bacia do Rio Munim, Maranhão, Nordeste do Brasil.

### 1.2.2 Objetivos específicos

- Criar uma lista de espécies para a bacia do Rio Munim;
- Identificar as espécies que possuem comportamento migratório;
- Classificar as espécies por habitat de ocorrência;
- Caracterizar e subdividir a bacia rio Munim por seção;
- Identificar as espécies não nativas para a bacia.

## 1.3 REFERÊNCIAS

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# CAPÍTULO II

## Checklist of the fish fauna of the Munim River basin, Maranhão, Northeastern Brazil

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# Checklist of the fish fauna of the Munim River basin, Maranhão, Northeastern Brazil

Lucas O. Vieira[1,2], Diego S. Campos[2,3], Rafael F. Oliveira[2,4], Josie South[5], Marcony S.P. Coelho[2], Maurício J.S. Paiva[2], Pedro H.N. Bragança[4,6], Erick C. Guimarães[7,8,9], Axel M. Katz[10], Pâmella S. Brito[1,8,9], Jadson P. Santos[9], Felipe P. Ottoni[1,2,3,4]

[1]Universidade Federal do Maranhão, Centro de Ciências de Chapadinha, Campus de Chapadinha, Programa de PósGraduação em Ciências Ambientais, BR-222, KM 04, Boa Vista, CEP: 65500-000, Chapadinha, Brazil

[2]Universidade Federal do Maranhão, Centro de Ciências de Chapadinha, Campus de Chapadinha, Laboratório de Sistemática e Ecologia de Organismos Aquáticos, BR-222, KM 04, S/N, Boa Vista, CEP: 65500-000, Chapadinha, Brazil

[3]Universidade Federal do Maranhão, Programa de Pós-Graduação em Biodiversidade e Biotecnologia da Amazônia Legal, Av. dos Portugueses, 1966, Cidade Universitária Dom Delgado, 65080-805, São Luís, Brazil

[4]Universidade Federal do Maranhão, Programa de Pós-Graduação em Biodiversidade e Conservação, Av. dos Portugueses, 1966, CEP: 65085-580, São Luís, Brazil

[5]School of Biology, Faculty of Biological Sciences, University of Leeds, Leeds, United Kingdom

[6]South African Institute for Aquatic Biodiversity, Grahamstown, South Africa

[7]Universidade Federal do Oeste do Pará, Instituto de Ciências da Educação, Programa de Pós-graduação Sociedade Natureza e Desenvolvimento, Av. Marechal Rondon s/n, CEP: 68040-070, Santarém, PA, Brasil, Belém, Brazil

[8]Universidade Federal do Maranhão, Departamento de Biologia, Laboratório de Genética e Biologia Molecular, Av. dos Portugueses 1966, Cidade Universitária do Bacanga, CEP: 65080-805, São Luís, Brazil

[9]Universidade Estadual do Maranhão, Laboratório de Ictiofauna e Piscicultura Integrada, Centro de Ciências Agrárias, Campus Paulo VI, avenida Lourenço Vieira da Silva, n. 1000, bairro Jardim São Cristóvão, CEP: 65.055-310, São Luís, Brazil

[10]Universidade Federal do Rio de Janeiro, Laboratório de Sistemática e Evolução de Peixes Teleósteos, Programa de PósGraduação em Biodiversidade e Biologia Evolutiva, Instituto de Biologia, CEP: 21.941-902, Rio de Janeiro, Brazil

**Corresponding author:** Felipe P. Ottoni (fpottoni@gmail.com)

**ABSTRACT:**

**Background**

The Maranhão State harbours great fish diversity, but some areas are still undersampled or little known, such as the Munim River Basin in the northeast of the State. This lack of knowledge is critical when considering anthropogenic impacts on riverine systems especially in the face of major habitat destruction. These pressing threats mean that a comprehensive understanding of diversity is critical and fish checklists extremely relevant. Therefore, the present study provides a checklist of the fish species found in the Munim River Basin, Maranhão State, north-eastern Brazil, based on collected specimens.

**New information**

A total of 123 species were recorded for the Munim River Basin, with only two non-native species, Oreochromis niloticus and Colossoma macropomum, showing that the fish assemblage has relatively high ecological integrity. In addition, 29 species could not be identified at the species level, indicating the presence of species that are probably new to science in the Basin. A predominance of species belonging to the fish orders Characiformes and Siluriformes, with Characidae being recovered as the most species-rich family (21 species) agrees with the general pattern for river basins in the Neotropical Region. The total fish diversity was estimated by extensive fieldwork, including several sampling gears, carried out in different seasons (dry and rainy) and exploring different environments with both daily and nocturnal sampling, from the Basin's source to its mouth. A total of 84 sites were sampled between 2010 and 2022, resulting in 12 years of fieldwork. Fish assemblages were distinct in the Estuary and Upper river basin sections and more similar in the Lower and Middle sections indicating environmental filtering processes. Species were weakly nested across basin sections, but unique species were found in each section (per Simpsons Index). High variability of species richness in the Middle river basin section is likely due to microhabitat heterogeneity supporting specialist fish communities.


**Keyword:** Biodiversity, endemism, freshwater, migratory species, taxonomy.

**Introduction**

The Neotropical Region comprises the most biodiverse freshwater ichthyofauna on the planet, with more than 6000 described species (Reis et al. 2016, Albert et al. 2020). Within the Neotropics, South America harbours the world's greatest diversity of freshwater fishes, including about 5160 described species, which represents about one-third of all known freshwater species (Reis et al. 2016, Pelicice et al. 2017, Castro and Polaz 2020). Studies on diversity of the region have produced estimates which are much higher, predictions being between 8000 to 9000 described and undescribed freshwater fish species (Reis et al. 2016, Birindelli and Sidlauskas 2018, Castro and Polaz 2020, Albert et al. 2020, Koerber et al. 2022). This high diversity is mainly comprised of medium- to small-sized species (species that do not surpass 15 cm standard length), corresponding to 70% of the species (Reis et al. 2003, Castro and Polaz 2020). Small and medium-sized species are broadly distributed throughout all aquatic habitats, which is most likely due to niche partitioning, life history traits adapted to stochastic environments and high trophic plasticity (Vazzoler 1996, Castro 1999, Lowe-Mcconnell 1999, Abelha et al. 2001, Guimarães et al. 2020, Castro and Polaz 2020, Corrêa and Castro 2021). Despite the description of smalland medium-sized fish diversity in scientific journals, they remain largely unnoticed by the general public and neglected by conservation agencies and policies (Castro 1999, Castro et al. 2005, Abell et al. 2011, Albert et al. 2011, Castro and Polaz 2020).

Brazil possesses the highest number of freshwater fish species in South America (Buckup et al. 2007, Castro and Polaz 2020), with about 100 new species being described every year over the last decade (Nelson et al. 2016, Reis et al. 2016, Fricke et al. 2022). However, several of these species represent endemics, with narrow distributions and some are highly threatened due to increased anthropogenic pressure on their natural habitats (Reis et al. 2003, Nogueira et al. 2010, Darwall et al. 2018, Reid et al. 2019). Brazilian freshwaters are subject to multitude anthropogenic threats, such as: deforestation resulting in suppression or reduction of the original vegetation cover, due to logging and expansion of agricultural and urban areas; release of domestic and industrial effluents and chemical products from agricultural activities in aquatic environments, resulting in pollution; irregular water abstraction for different urban, industrial and agricultural uses; soil erosion and silting of the environments; river damming and construction of hydroelectric power plants, disrupting fish migration routes and destroying the natural habitats of fish species; extraction of sand from the riverbeds; mining, resulting in modification of habitats and water pollution and contamination; modification and diversion of the river channels; introduction of non-native species; overharvesting for the aquarium trade; ghost fishing; and overfishing of food fishes (Dudgeon et al. 2006, Pereira et al. 2016, Pelicice et al. 2017, Reid et al. 2019, Zarfl et al. 2019, Zeni et al. 2019, Bergmann et al. 2020, Castro and Polaz 2020, Ottoni et al. 2021, Azevedo-Santos et al. 2021, Doria et al. 2021, Vitorino et al. 2022, Rocha et al. 2023). Despite the high freshwater native fish diversity, non-native fish species have proliferated in Brazil and in Brazilian hydrographic systems where they do not occur naturally due to several human activities, such as: aquaculture, intentional introductions and release, aquarium trade, mosquito larvae biological control interventions, transposition of water between isolated river basins, sport fishing, amongst other activities (Figueredo and Giani 2005, Azevedo-Santos et al. 2011, Vitule et al. 2015, Latini et al. 2016, Padial et al. 2017, Bragança et al. 2020, Doria et al. 2021, Ottoni et al. 2021, Franco et al. 2022, Rocha et al. 2023). Non-native species have caused changes in the local assemblage composition and in the abundance of native species populations, causing major environmental impacts (Giacomini et al. 2011, Latini et al. 2016, Padial et al. 2017, Doria et al. 2021, Ottoni et al. 2021, Rocha et al. 2023).

Maranhão is the westernmost state in north-eastern Brazil, bordered by the Piauí State in the east, from whom it is separated by the Parnaíba River; by Tocantins State in the south and southeast, from which it is separated by the Tocantins River; and by Pará State in the west, from which it is separated by the Gurupi River (Rebêlo et al. 2003). Maranhão total area is about 330000 km, corresponding to 3.9% of Brazil's territory (Rebêlo et al. 2003, Rios 2005, Batistella et al. 2014, Spinelli-Araújo et al. 2016). Maranhão is an extremely important State in terms of biodiversity, housing three of the main Brazilian biomes, as well as transition areas between them. The Cerrado biome is present in the central, eastern and southern portion of the State; the Amazon biome is present in the western and central portion; and the Caatinga biome is found in the easternmost portion of the State (Rebêlo et al. 2003, Rios 2005, Batistella et al. 2014, Spinelli-Araújo et al. 2016). Thus, Maranhão includes a phytogeographic mosaic due to the presence and overlap of floral elements typical of these three distinct biomes, besides the presence of complex transition areas, making the State extremely biodiverse, ecologically relevant and a key area for conservation (Rebêlo et al. 2003, Rios 2005, Batistella et al. 2014, Spinelli-Araújo et al. 2016).

In the past two decades, several fish surveys were carried out in Maranhão, in both freshwater and estuarine environments, increasing the knowledge of the State's fish fauna (Castro 2001, Castro et al. 2002, Piorski et al. 2003, Pinheiro-Júnior et al. 2005, Soares 2005, Piorski et al. 2007, Castro et al. 2010, Barros et al. 2011, Sousa et al. 2011, Fraga et al. 2012, Almeida et al. 2013, Ribeiro et al. 2014, Ramos et al. 2014, Lima et al. 2015, Matavelli et al. 2015, Melo et al. 2016, Nascimento et al. 2016, Piorski et al. 2017, Brito et al. 2019, Lima et al. 2019, Teixeira et al. 2019, Nunes et al. 2019, Guimarães et al. 2020, Brito et al. 2020, Oliveira et al. 2020, Guimarães et al. 2021c, Guimarães et al. 2021a, Guimarães et al. 2021b). Information about the ichthyofauna of the coastal Munim River Basin, however, is scarce. At the same time, this river basin is under severe anthropogenic pressure from deforestation of marginal vegetation, pollution, contamination of the water, erosion, siltation and even the loss of water bodies (Ribeiro et al. 2006, Ribeiro and Nunes 2017). The Munim River Basin has only five published studies documenting its fish diversity (Ribeiro et al. 2014, Matavelli et al. 2015, Nunes et al. 2019, Oliveira et al. 2020, Guimarães et al. 2021c). These, however, focused on specific localities and environments and, in many cases, surveying only similar and neighbouring sites within this river basin. As a consequence, the fish fauna of the Munim River Basin still awaits a more comprehensive checklist.

The main goal of the present study is to present a detailed inventory of the fish diversity in the Munim River Basin, through the analysis and study of data sampled over 12 years of fieldwork, providing species-level identifications when possible. The study covered the entire river basin and includes relevant information about the importance of checklists in contributing to the knowledge of the river basin, species conservation and distribution. In addition, we provide here ecological and biogeographical comments.

## Materials and methods

### Study área

Sampling was carried out in rivers, streams, lagoons, swamps, marshes, lakes and the estuary of the Munim River Basin, northeast of the Maranhão State, north-eastern Brazil. The Munim River Basin source is at the Caxias Municipality, in the Cerrado Biome and its mouth is at baía of São José in a region known as "Golfão Maranhense" between the Axixá and Icatu municipalities, within the Cerrado and Amazon biomes (Fig. 1). The Munim River Basin has an area of about 15918.04 km, with 331.74 km from its source to its mouth (Nugeo 2016, Rios 2005).

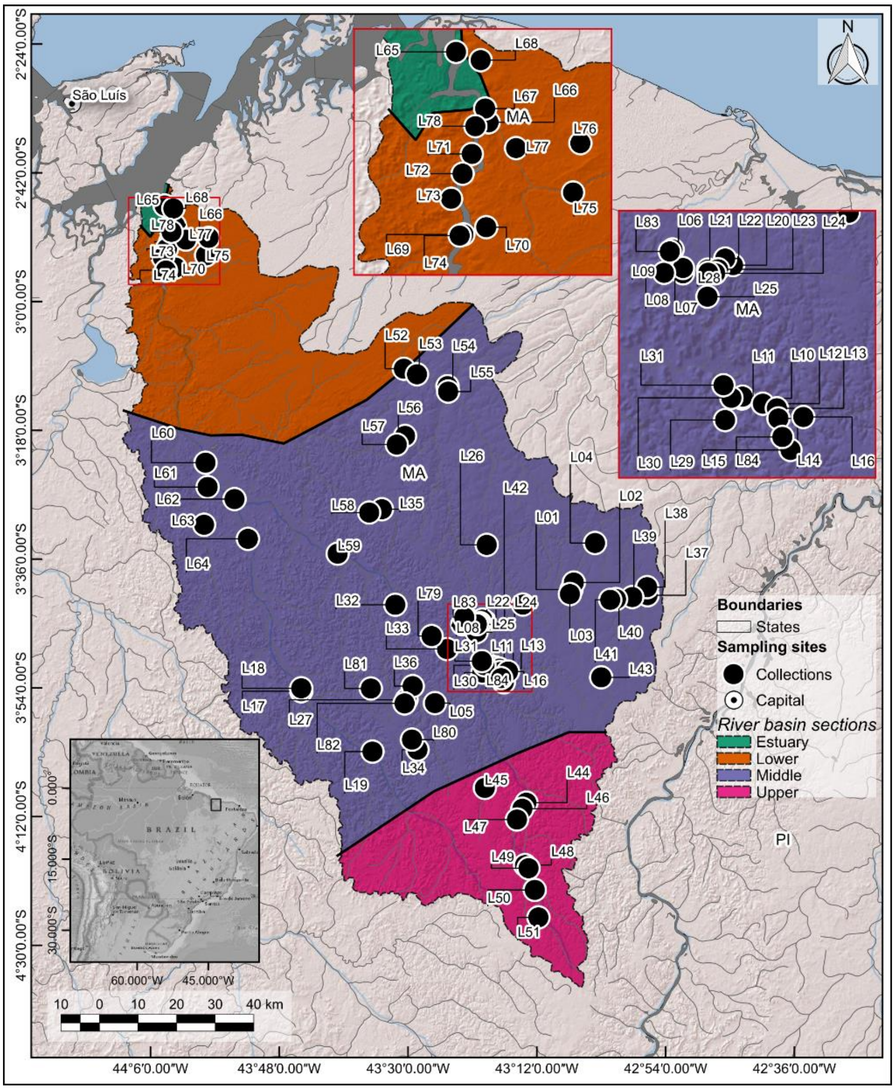


**Figure 1.** Map with sampling sites along the Munim River basin. Sample sites are listed in table 1, and illustrated on the map as L1-L84. MA = State of Maranhão, and PI = State of Piauí. In the highlighted squares are the geographically close sample sites, for a better visualization. River basin sections: Estuary section (green), Lower section (orange), Middle section (lilac), and Upper section (pink).

**Sampling sites**

Sampling was carried out in 84 collecting sites, covering four different sections of the Munim River Basin, in both rainy (January to May) and dry (June to December) seasons according to Passos et al. (2016). The sampling was done between 2010 and 2022 (about 65% of the surveys were carried out between 2019 and 2022), including sites close to its source and to its mouth (Fig. 1). The sampled environments included rivers, streams, lagoons, swamps, marshes, lakes and the estuary (Table 1, Fig. 2, Suppl. material 1).

**Table 1.** Sampling sites at the Munim River basin, Maranhão, Brazil. *Localities with the presence of nonnative species.

| Locality number (L) | Locality | Municipality | Coordinates | Altitude | River basin section |
|---|---|---|---|---|---|
| 1 | Stream in the balneário at the entrance of Anapurus | Anapurus - MA | 03°40'15.28"S 043°07'9.7"W | 81 m | Middle |
| 2 | *Stream at balneário São Lourenço | Anapurus - MA | 03°39'16.30"S 043°6'50.2"W | 75 m | Middle |
| 3 | Stream at balneário Recanto do Buriti | Anapurus - MA | 03°40'53.04"S 043°7'23.0"W | 76 m | Middle |
| 4 | Riacho crossing the road at Poços community | Anapurus - MA | 03°33'44.61"S 043°3'52.4"W | 71 m | Middle |
| 5 | Stream at Caraíbas community | Chapadinha - MA | 03°56'7.71"S 043°26'14.8"W | 51 m | Middle |
| 6 | Riacho Xororó at Aparecida neighborhood | Chapadinha - MA | 03°44'2.23"S 043°22'1.21"W | 81 m | Middle |
| 7 | Stream at Aldeia neighborhood | Chapadinha - MA | 03°45'7.75"S 043°21'32.7"W | 74 m | Middle |
| 8 | Stream at Aldeia neighborhood | Chapadinha - MA | 03°44'53.1"S 043°21'32.6"W | 80 m | Middle |
| 9 | Stream at Terra Duras neighborhood | Chapadinha - MA | 03°45'6.42"S 043°22'24.7"W | 65 m | Middle |
| 10 | Riacho Feio, Boa Vista community | Chapadinha - MA | 03°50'51.8"S 043°18'50.5"W | 44 m | Middle |

| Locality number (L) | Locality | Municipality | Coordinates | Altitude | River basin section |
|---|---|---|---|---|---|
| 11 | *Riacho Feio, Boa Vista community | Chapadinha - MA | 03°50'46.8"S 043°18'48.9"W | 40 m | Middle |
| 12 | Riacho Feio, São José community | Chapadinha - MA | 03°51'6.30"S 043°17'53.0"W | 45 m | Middle |
| 13 | *Riacho Feio, São José community | Chapadinha - MA | 03°51'18.7"S 043°17'14.4"W | 47 m | Middle |
| 14 | Riachinho, Cumbre community | Chapadinha - MA | 03°51'46.8"S 043°17'10.2"W | 52 m | Middle |
| 15 | Riachinho, Água Branca community | Chapadinha - MA | 03°53'13.5"S 043°16'37.1"W | 59 m | Middle |
| 16 | Riacho Feio, Riacho Feio community | Chapadinha - MA | 03°51'42.84"S 043°16'1.7"W | 52 m | Middle |
| 17 | Rio Iguará, Malhadinha community | Vargem Grande - MA | 03°54'27.8"S 043°44'55.8"W | 30 m | Middle |
| 18 | Rio Iguará, Malhadinha community | Vargem Grande - MA | 03°54'3.25"S 043°44'55.8"W | 32 m | Middle |
| 19 | Rio Iguará, Poço Cumprido community | Chapadinha - MA | 04°2'54.24"S 043°34'58.4"W | 41 m | Middle |
| 20 | Stream at Itamacaoca forest | Chapadinha - MA | 03°44'45.2"S 043°19'15.0"W | 90 m | Middle |
| 21 | Stream at balneário Repouso do Guerreiro | Chapadinha - MA | 03°44'57.4"S 043°20'24.0"W | 66 m | Middle |
| 22 | Stream at Itamacaoca forest | Chapadinha - MA | 03°44'27.2"S 043°19'36.5"W | 85 m | Middle |
| 23 | Itamacaoca dam | Chapadinha - MA | 03°44'56.5"S 043°19'55.8"W | 74 m | Middle |
| 24 | Stream just after Itamacaoca dam | Chapadinha - MA | 03°45'7.42"S 043°20'4.05"W | 68 m | Middle |
| 25 | Jabuti community, Tinguis road | Chapadinha - MA | 03°46'11.9"S 043°20'25.2"W | 50 m | Middle |

| Locality number (L) | Locality | Municipality | Coordinates | Altitude | River basin section |
|---|---|---|---|---|---|
| 26 | Rio Preto at Bom Sucesso community | Mata Roma - MA | 03°34'0.40"S 043°19'0.40"W | 45 m | Middle |
| 27 | Swampy areas at Brejo do Meio community | Chapadinha - MA | 03°55'38.7"S 043°30'13.1"W | 53 m | Middle |
| 28 | Stream behind the Mix Atacarejo Mateus store | Chapadinha - MA | 03°45'6.00"S 043°20'23.0"W | 59 m | Middle |
| 29 | Rio Munim, Carnaúba Amarela community | Chapadinha - MA | 03°51'51.3"S 043°19'36.8"W | 39 m | Middle |
| 30 | Rio Munim, Porções bridge | Chapadinha - MA | 03°50'50.0"S 043°19'19.4"W | 41 m | Middle |
| 31 | *Rio Munim, Cedro community | Chapadinha - MA | 03°50'15.5"S 043°19'41.1"W | 41 m | Middle |
| 32 | Rio Munim, Riacho Fundo community | Chapadinha - MA | 03°42'22.7"S 043°31'47.1"W | 25 m | Middle |
| 33 | Rio Munim, bridge at Mangabeira community | Chapadinha - MA | 03°48'34.1"S 043°24'33.2"W | 33 m | Middle |
| 34 | Stream at Pai Gonçalo community | Chapadinha - MA | 04°2'38.12"S 043°28'40.7"W | 82 m | Middle |
| 35 | Stream at Mucambo community | São Benedito do Rio Preto - MA | 03°29'1.01"S 043°33'39.5"W | 92 m | Middle |
| 36 | Riacho da Raiz | Chapadinha - MA | 03°53'45.1"S 043°29'21.3"W | 45 m | Middle |
| 37 | Riacho São João, São João dos Pilão | Brejo - MA | 03°41'2.64"S 042°56'31.9"W | 89 m | Middle |
| 38 | Riacho Pau Preto, Pau Preto community | Brejo - MA | 03°39'54.9"S 042°56'35.5"W | 84 m | Middle |
| 39 | Riacho da Cruz, close to Palestina | Brejo - MA | 03°41'18.0"S 042°58'39.8"W | 88 m | Middle |
| 40 | Rio Preto, Água Rica community | Brejo - MA | 03°41'34.92"S 043°0'56.1"W | 78 m | Middle |

| Locality number (L) | Locality | Municipality | Coordinates | Altitude | River basin section |
|---|---|---|---|---|---|
| 41 | Córrego Água Rica | Anapurus - MA | 03°41'41.24"S 043°1'44.8"W | 86 m | Middle |
| 42 | Riacho do Muquém | Mata Roma - MA | 03°42'21.2"S 043°13'57.1"W | 68 m | Middle |
| 43 | Stream, Laranjeira community | Buriti - MA | 03°52'31.09"S 043°3'0.60"W | 96 m | Middle |
| 44 | Rio Munim, Capoeira Grande community | Afonso Cunha - MA | 04°10'2.79"S 043°13'28.0"W | 54 m | Upper |
| 45 | Rio São Gonçalo | Afonso Cunha - MA | 04°7'58.77"S 043°19'16.1"W | 64 m | Upper |
| 46 | Stream crossing the road | Afonso Cunha - MA | 04°10'53.63"S 043°14'1.5"W | 58 m | Upper |
| 47 | Stream crossing the road | Afonso Cunha - MA | 04°12'23.9"S 043°14'46.8"W | 68 m | Upper |
| 48 | Riacho barrigudinho | Afonso Cunha - MA | 04°18'46.1"S 043°13'39.1"W | 67 m | Upper |
| 49 | Riacho do boi | Afonso Cunha - MA | 04°19'12.38"S 043°13'9.8"W | 67 m | Upper |
| 50 | Stream crossing the road | Aldeias Altas - MA | 04°22'14.3"S 043°12'17.6"W | 69 m | Upper |
| 51 | Riacho do boi | Aldeias Altas - MA | 04°26'4.96"S 043°11'46.9"W | 82 m | Upper |
| 52 | *Rio Bandeira, Belágua | Belágua - MA | 03° 9'22.7"S 043°30'35.4"W | 65 m | Middle |
| 53 | Riacho Água Fria on the road MA-110 | Belágua - MA | 03°10'9.49"S 043°28'45.3"W | 68 m | Middle |
| 54 | Rio Bandeira | Urbano Santos - MA | 03°11'49.0"S 043°24'29.3"W | 41 m | Middle |
| 55 | Rio Mocambo | Urbano Santos - MA | 03°12'34.6"S 043°24'23.8"W | 38 m | Middle |
| 56 | Stream on the road MA-224 | São Benedito do Rio Preto - MA | 03°18'46.2"S 043°30'25.1"W | 40 m | Middle |
| 57 | Rio Preto, São Benedito do Rio Preto | São Benedito do Rio Preto - MA | 03°19'59.0"S 043°31'34.8"W | 29 m | Middle |
| 58 | Stream on the road MA-224 | São Benedito do Rio Preto - MA | 03°29'29.0"S 043°35'25.9"W | 50 m | Middle |
| 59 | Rio Munim, on the road MA-224 | Nina Rodrigues - MA | 03°35'14.1"S 043°39'50.4"W | 21 m | Middle |

| Locality number (L) | Locality | Municipality | Coordinates | Altitude | River basin section |
|---|---|---|---|---|---|
| 60 | Rio Munim, at the quilombola community Evienã | Presidente Vargas - MA | 03°22'31.0"S 043°58'18.5"W | 14 m | Middle |
| 61 | Riacho Paulica on the road MA-020 | Presidente Vargas - MA | 03°25'54.98"S 043°58'1.0"W | 16 m | Middle |
| 62 | Rio Munim at Nina Rodrigues city | Nina Rodrigues - MA | 03°27'36.1"S 043°54'15.1"W | 14 m | Middle |
| 63 | Riacho Paulica on the road BR-222 | Vargem Grande -MA | 03°31'11.5"S 043°58'30.7"W | 23 m | Middle |
| 64 | Rio Iguará on the road BR-222 | Vargem Grande - MA | 03°33'9.64"S 043°52'23.0"W | 22 m | Middle |
| 65 | Rio Munim mouth at Icatu | Icatu - MA | 02°46'33.86"S 044° 4'1.3"W | 1 m | Estuary |
| 66 | Rio Una, between the municipalities of Morro and Icatu | Morros - MA | 02°50'3.06"S 044°2'24.82"W | 8 m | Lower |
| 67 | Rio das Cobra, Santa Helena community | Morros - MA | 02°49'22.1"S 044° 2'34.8"W | 9 m | Lower |
| 68 | Riacho at the entrance to Icatu | Icatu - MA | 02°46'58.50"S 044°2'48.2"W | 19 m | Lower |
| 69 | Rio Munim, Cachoeira Grande | Cachoeira Grande - MA | 02°55'36.25"S 044°3'39.2"W | 4 m | Lower |
| 70 | Stream crossing the road MA-020 | Cachoeira Grande - MA | 02°55'14.62"S 044°2'31.5"W | 34 m | Lower |
| 71 | Stream next to the road MA-402 | Axixá - MA | 02°51'37.1"S 044° 3'14.5"W | 4 m | Lower |
| 72 | Rio Munim between the municipalities of Axixá and Presidente Juscelino | Axixá - MA | 02°52'35.63"S 044°3'41.8"W | 15 m | Lower |
| 73 | Stream between the municipalities | Axixá - MA | 02°53'50.06"S 044°4'15.9"W | 4 m | Lower |

| **Locality number (L)** | **Locality** | **Municipality** | **Coordinates** | **Altitude** | **River basin section** |
|---|---|---|---|---|---|
| | of Axixá and Presidente Juscelino | | | | |
| 74 | Rio Munim, Presidente Juscelino | Presidente Juscelino - MA | 02°55'39.38"S 044°3'50.5"W | 6 m | Lower |
| 75 | Rio Una, Cachoeira do Arruda | Morros - MA | 02°53'31.5"S 043°58'13.8"W | 28 m | Lower |
| 76 | Riacho das Pacas | Morros - MA | 02°51'4.94"S 043°57'52.1"W | 28 m | Lower |
| 77 | Stream next to the road MA-402 | Morros - MA | 02º51'19.5"S 044º01'03.0"W | 19 m | Lower |
| 78 | Rio Munim, Axixá | Axixá - MA | 02°50'14.60"S 044°3'3.81"W | 1 m | Lower |
| 79 | Rio Munim, Balceiro community | Chapadinha - MA | 03°46'44.9"S 043°26'42.7"W | 33 m | Middle |
| 80 | Stream at the Paiol community | Chapadinha - MA | 04°1'13.56"S 043°29'27.6"W | 74 m | Middle |
| 81 | Stream at São Pedro community | Chapadinha - MA | 03°54'4.66"S 043°35'12.3"W | 73 m | Middle |
| 82 | Stream crossing a road in the Resex | Chapadinha - MA | 03°56'10.0"S 043°30'29.5"W | 61 m | Middle |
| 83 | Riacho Xororó at Aparecida neighborhood | Chapadinha - MA | 03°44'7.77"S 043°22'8.94"W | 69 m | Middle |
| 84 | Riachinho, Água Branca community | Chapadinha - MA | 03°52'37.67"S 043°16'59.3” W | 60 m | Middle |


**Figure 2.** Samples sites: L1, L18, L19, L30, L31, L36, L38, L43, L49, L53, L54, L55, L62, L65, L66, L69, L75, L77, L78, and L84 according to Table 1. Photographed by Lucas Vieira and Rafael Oliveira, edited by Axel Katz.

**Sampling and specimens identification**

All (about 160) sampling events were carried under the permits issued by Instituto Chico Mendes de Conservação da Biodiversidade (ICMBIO; License nº 54949, 57258, 57787, 64415, 73267). In addition, material already housed at the Coleção Ictiológica do Centro de Ciências Agrárias e Ambientais (CICCAA) of the Universidade Federal do Maranhão, was also used in this study. The specimens were sampled by using different sampling gear, such as fishing line, hand net, seine net, cast net, gill nets and crayfish-type traps (Souza and Auricchio 2002). All the sampling activities and procedures followed the best practices and standards for animal welfare as presented in Leary et al. (2020). Specimens were euthanised by immersion in a 250 mg/l Tricaine methane sulphonate (MS-222) solution until the cessation of opercular movements.

Following the euthanasia, the specimens for morphological studies were preserved in formalin (10%) and moved to a 70% ethanol solution after 10-15 days. Specimens selected for future molecular studies were preserved in 99% ethanol. The processing and identification of specimens were made at the Laboratório de Sistemática e Ecologia de Organismos Aquáticos (LASEOA), at the Universidade Federal do Maranhão, by the use of specialised bibliography for each taxonomic group and by consulting specialists. The specimens were identified to the lowest taxonomic rank possible. All biological material is catalogued and housed at the Coleção Ictiológica do Centro de Ciências Agrárias e Ambientais (CICCAA) of the Universidade Federal do Maranhão (UFMA) (Suppl. materials 1, 2). The taxonomic classifications, species names, authorship and year, original descriptions, habitat of occurrence and geographic distributions were verified and presented according to Fricke et al. (2022a), Fricke et al. (2022b) and Froese and Pauly (2022).

**Map and Munin River basin sections distinction**

The geographic coordinates of each collection site along the Munim River Basin were registered from a GPS device and then converted to the shapefile format, with place names and respective codes in the attribute table. Additional data on boundaries from river basins and political division of territory were acquired from the official data service IBGE (Brazilian Institute for Geography and Statistics). The map was composed in QGIS 3.22.12 (Qgis development team 2022). Due to scale, each point on the map may correspond to one or more collection sites, depending on the geographic proximity.

The Munim River Basin was divided into four sections: Estuary section with an area of 78.89 km, comprising one collecting site; Lower river basin section with an area of 2891.89 km, comprising 13 collecting sites; Middle river basin section with an area of 10722.29 km, comprising 62 collecting sites; and Upper river basin section with an area of 2224.90 km, comprising eight collecting sites (Fig. 1, Table 1, Suppl. material 2). The criterion for the sectorisation of the basin was based on the average slope calculated from the elevation values (meters above sea level) of the digital elevation model SRTM/USGS, available at the TOPODATA/INPE project (http://www.dsr.inpe.br/topodata/). Based on the analysed area, this river basin varies from 0 to 162 meters above the sea level. The parameters considered for the sectorisation were: Estuary section - average slope of 1.09 (standard deviation 1.59); Lower river basin section - average slope of 1.41 (standard deviation 1.33); Middle river basin section - average slope of 2.63 (standard deviation:

2.43); and Upper river basin section - average slope of 3.11 (standard deviation 2.61) (Fig. 1, Table 1, Suppl. material 2).

**Species photographs**

Specimens of some species were photographed in the laboratory to illustrate the diversity of species that occur in the Munim River Basin (Fig. 3, Fig. 4 and Fig. 5). Additional photographs of Munim River fish species can be seen in Guimarães et al. (2018b): figs. 1, 2, Oliveira et al. (2020): fig. 3, Guimarães et al. (2021c) and Aguiar et al. (2022): fig.2b.

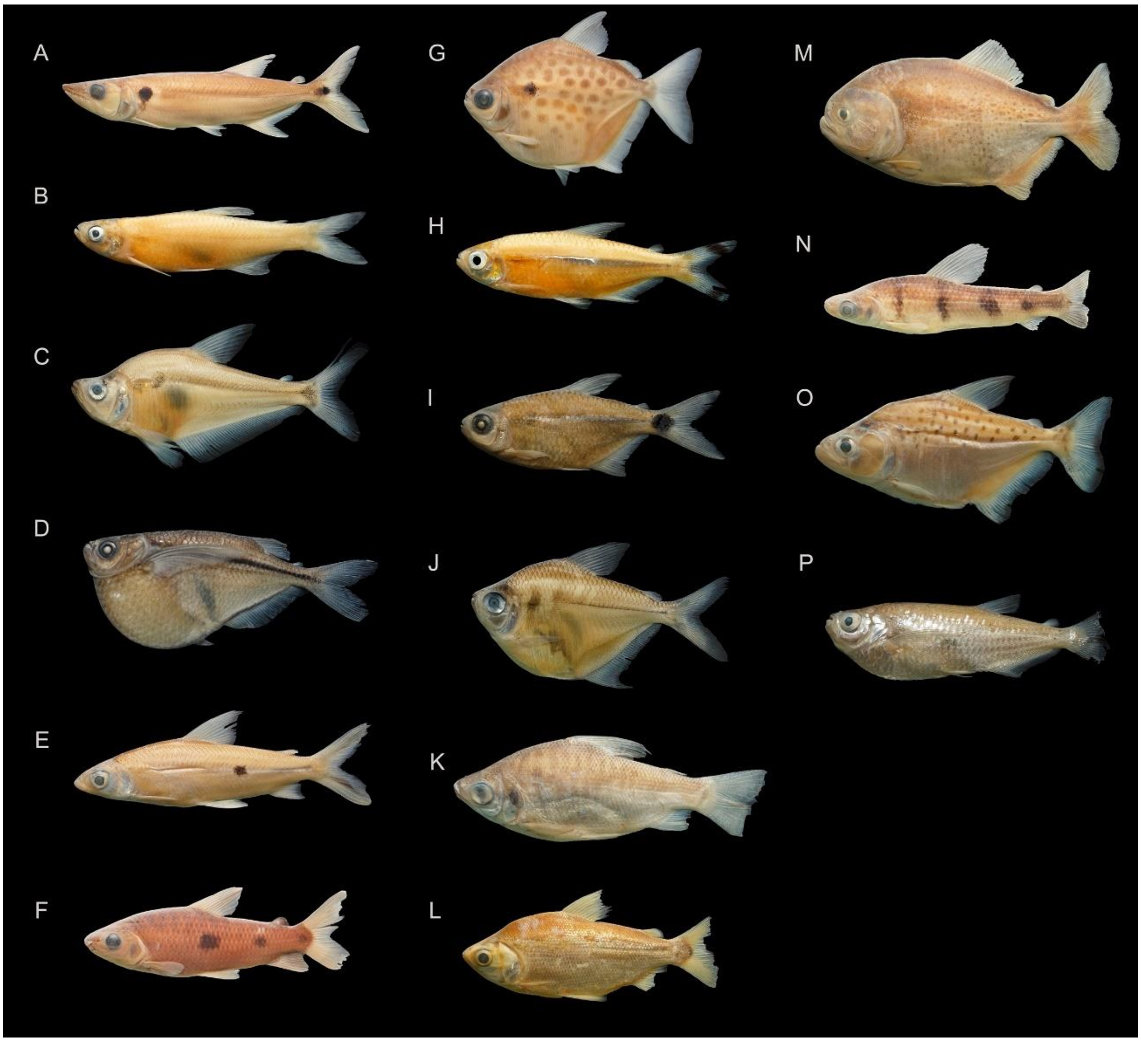


**Figure 3.** Some fish species collected in the Munim River Basin of the Order Characiformes: **A** *Acestrorhynchus falcatus* (CICCAA 06398, 112.60 mm SL), **B** *Aphyocharax* sp. (CICCAA 06636, 32.91 mm SL), **C** *Charax awa* (CICCAA 06430, 80.22 mm SL), **D** *Gasteropelecus sternicla* (CICCAA 06366, 39.50 mm SL), **E** *Hemiodus parnaguae* (CICCAA 06238, 94.99 mm SL), **F** *Leporinus* aff. *friderici* (CICCAA 02755, 102.31 mm SL), **G** *Metynnis lippincottianus* (CICCAA 06383, 64.06 mm SL), **H** *Moenkhausia* cf. *intermedia* (CICCAA 06634, 50.38 mm SL), **I** *Moenkhausia* sp.

(CICCAA 06635, 35.10 mm SL), **J** *Poptella compressa* (CICCAA 06429, 42.46 mm SL), **K** *Prochilodus lacustris* (CICCAA 06340, 84.94 mm SL), **L** *Psectrogaster rhomboides* (CICCAA 06270, 121.08 mm SL), **M** *Pygocentrus nattereri* (CICCAA 06271, 138.08 mm SL), **N** *Schizodon dissimilis* (CICCAA 06344, 99.03 mm SL), **O** *Serrasalmus rhombeus* (CICCAA 06269, 70.99 mm SL), **P** *Triportheus signatus* (CICCAA 06339, 86.62 mm SL). Photographed by Lucas Vieira and Rafael Oliveira, edited by Axel Katz.

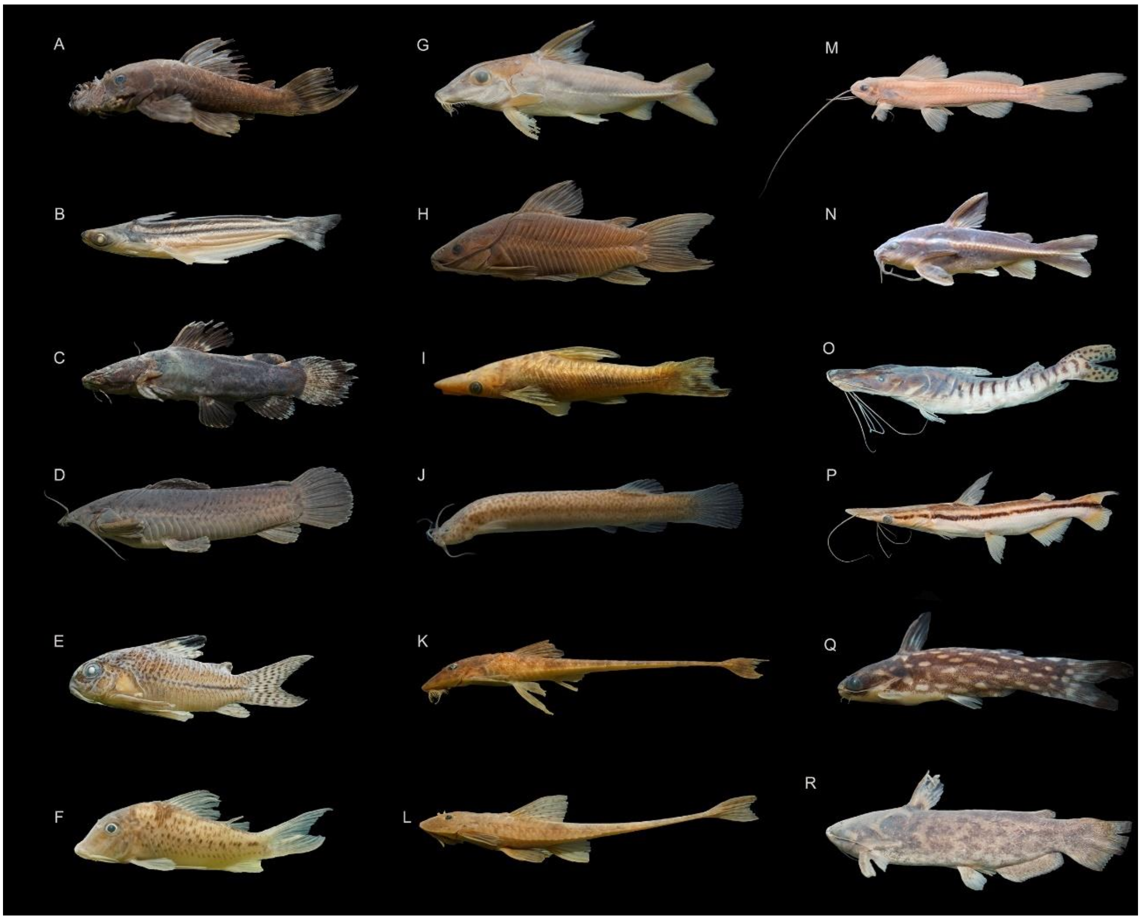


**Figure 4.** Some fish species collected in the Munim River Basin of the Order Siluriformes: **A** *Ancistrus* sp. (CICCAA 06652, 76.85 mm SL), **B** *Auchenipterus menezesi* (CICCAA 06534, 98.38 mm SL), **C** *Batrochoglanis* sp. (CICCAA 06654, 64.16 mm SL), **D** - *Callichthys callichthys* (CICCAA 03927, 102.12 mm SL), **E** *Corydoras julii* (CICCAA 06378, 34.33 mm SL), **F** *Corydoras vittatus* (CICCAA 06418, 34.19 mm SL), **G** *Hassar affinis* (CICCAA 06263, 109.79 mm SL), **H** *Hoplosternum littorale* (CICCAA 06657, 81.91 mm SL), **I** *Hypoptopoma incognitum* (CICCAA 06315, 70.81 mm SL), **J** *Ituglanis* cf. *amazonicus* (CICCAA 06643, 30.53 mm SL), **K** *Loricaria* cf. *cataphracta* (CICCAA 06628, 105.80 mm SL), **L** *Loricariichthys* sp. (CICCAA 06328, 160.18 mm SL), **M** *Pimelodella* sp.1 (CICCAA 06629, 83.02 mm SL), **N** *Platydoras brachylecis* (CICCAA 04608, 58.36 mm SL), **O** *Pseudoplatystoma fasciatum* (CICCAA 04549, 208.39 mm SL), **P** *Sorubim lima* (CICCAA 06272, 204.01 mm SL), **Q** *Tatia intermedia* (CICCAA 02736, 46.17 mm SL), **R** *Trachelyopterus galeatus* (CICCAA 06243, 122.56 mm SL). Photographed by Lucas Vieira and Rafael Oliveira, edited by Axel Katz.


**Figure 5.** Some fish species collected in the Munim River Basin of the Orders Cichliformes and Gymnotiformes: **A** *Geophagus parnaibae* (CICCAA 06229, 98.62 mm SL), **B** *Satanoperca jurupari* (CICCAA 06377, 105.36 mm SL), **C** *Apteronotus albifrons* (CICCAA 06266, 168.59 mm TL), **D** *Eigenmannia robsoni* (CICCAA 06631, 180.36 mm TL), **E** *Sternopygus macrurus* (CICCAA 06261, 183.50 mm TL). Photographed by Lucas Vieira and Rafael Oliveira, edited by Axel Katz.

**Migratory species**

Species were classified as migratory based on Carolsfeld et al. (2003). When any species was not listed in Carolsfeld et al. (2003), we considered the genus to indicate if it is a migratory species.

**Genral species accumulation curve**

A matrix of occurrence and abundance data over the sampling period, for this study, was used to plot the general species accumulation curve with Primer-e statistical software (Clarke and Gorley 2006), based on a spreadsheet containing relevant data for this analysis (Suppl. material 2). Given that the order of samples in the analysis affects the shape of the curve produced, due to heterogeneity amongst the species in the samples (Ugland et al. 2003), 1000 permutations were calculated to overcome this effect.

**Species Richness and Fish assemblage composition**

The statistical and ecological analyses were based on a spreadsheet containing relevant data for these analyses (Suppl. material 2).

## Species Richness

Species richness (Sprich) (i.e. number of species in each river basin section) was compared using Kruskal-Wallis tests, on account of non-normal distribution (per ShapiroWilk test) and Dunn post-hocs with Holm adjusted p-values to account for multiple comparisons were used to determine section level differences. Visualisation was completed through the R package "“ggstatsplot"” (Patil 2021).

## Fish assemblage composition

Fish assemblage composition was compared between basin sections, at the basin section level, using presence-absence data due to surveys not being standardised for sampling methods. Only native species were included in the analysis. First, nestedness was assessed using the NODF method (Almeida-Neto et al. 2008), which is bound between 0 and 100 where 100 is perfect nestedness, via vegan::nestednodf, then Sørensen dissimilarity and Simpsons Index were calculated using vegan::nestedbetasor. Sørensen dissimilarity closer to 0 indicates more shared species. Simpsons Index is not affected by species richness and represents true turnover, i.e. the the replacement of some species by other species from section to section, independent of potential differences in species richness between the sections. Areas with Simpsons Index values over 66% are considered to have similar faunal composition (Sánchez and López 1988). Jaccard Index was calculated using vegan::nestedbetajac where values closer to one indicate higher similarity. A cluster analysis and dendrogram was completed on the section Jaccard coefficients using the Ward.D2 method. All statistical analyses were performed within the R software environment version 4.0.2 and the package “vegan” (Oksanen et al. 2019, R Core Team 2020).

# RESULTS

## Checklist of the fish fauna of the Munim River Basin

## Class Actinopteri

**Notes:** The checklist is presented in Table 2.

**Table 2.** List of fish species recorded for the Munim River basin in the present study. *endemic species to the hydrological units Maranhão and Parnaíba *sensu* Hubert and Renno (2006).

| **CLASS/ORDER/FAMILY/SPECIES** | **New records** | **Migratory species** | **Non-native species** | **Common name (Portuguese)** |
|---|---|---|---|---|
| CLASS ACTINOPTERI | | | | |
| **ACANTHURIFORMES** | | | | |
| **Ephippidae** | | | | |
| *Chaetodipterus faber* (Broussonet, 1782) | X | | | Peixe enxada |
| **Gerreidae** | | | | |
| *Eugerres plumieri* (Cuvier, 1830) | X | | | Mojarra |
| **Haemulidae** | | | | |
| *Conodon nobilis* (Linnaeus, 1758) | X | | | |
| *Genyatremus luteus* (Bloch, 1790) | X | | | |
| **Lutjanidae** | | | | |
| *Lutjanus jocu* (Bloch & Schneider, 1801) | X | | | |
| **Sciaenidae** | | | | |
| *Cynoscion steindachneri* (Jordan, 1889) | X | | | |
| *Macrodon ancylodon (Bloch & Schneider, 1801)* | X | | | |
| *Menticirrhus americanus* (Linnaeus, 1758) | X | | | |
| *Micropogonias furnieri* (Desmarest, 1823) | X | | | Curvina |
| *Plagioscion squamosissimus* (Heckel, 1840) | X | X | | Curvina |
| *Stellifer naso* (Jordan, 1889) | X | | | |
| **BATRACHOIDIFORMES** | | | | |
| **Batrachoididae** | | | | |
| *Batrachoides surinamensis* (Bloch & Schneider, 1801) | X | | | Pacamão |
| **BELONIFORMES** | | | | |
| **Hemiramphidae** | | | | |
| *Hyporhamphus roberti* (Valenciennes, 1847) | X | | | Agulha |

| CLASS/ORDER/FAMILY/SPECIES | New records | Migratory species | Non-native species | Common name (Portuguese) |
|---|---|---|---|---|
| **CARANGIFORMES** | | | | |
| **Achiridae** | | | | |
| *Achirus achirus* (Linnaeus, 1758) | X | | | Linguado |
| **Carangidae** | | | | |
| *Chloroscombrus chrysurus* (Linnaeus, 1766) | X | | | Palombeta |
| *Oligoplites palometa* (Cuvier, 1832) | X | | | Tibiro |
| **Centropomidae** | | | | |
| *Centropomus parallelus* Poey, 1860 | X | | | Robalo |
| **CHARACIFORMES** | | | | |
| **Acestrorhynchidae** | | | | |
| *Acestrorhynchus falcatus* (Bloch 1794) | | | | Lubarana |
| **Anostomidae** | | | | |
| *Leporinus* aff. *friderici* | | X | | Piau de coco |
| *Schizodon dissimilis* (Garman 1890) | | X | | Piau de vara |
| **Characidae** | | | | |
| *Aphyocharax* sp. | | | | Enfermerinha |
| *Astyanax* cf. *bimaculatus* | | | | Piaba rabo de fogo |
| *Brachychalcinus parnaibae* Reis 1989 | X | | | Piaba Chatinha |
| *Charax awa Guimarães*, Brito, Ferreira & Ottoni, 2018* | | | | Cacunda |
| *Ctenobrycon* cf. *spilurus* | | | | Piaba |
| *Hemmigramus* sp. 1 *sensu* Oliveira et al. (2020) | | | | Piaba |
| *Hemmigramus* sp.2 *sensu* Oliveira et al. (2020) | | | | Piaba |
| *Hemigrammus* cf. *rodwayi* | | | | Piaba |
| *Hyphessobrycon piorskii* Guimarães, Brito, Feitosa, Carvalho-Costa & Ottoni, 2018* | | | | Tetra |

| CLASS/ORDER/FAMILY/SPECIES | New records | Migratory species | Non-native species | Common name (Portuguese) |
|---|---|---|---|---|
| *Knodus guajajara* Aguiar, Brito, Ottoni & Guimarães, 2022* | | | | Piaba |
| *Microschemobrycon* sp. | | | | Piaba |
| *Moenkhausia* sp. | | | | Piaba |
| *Moenkhausia* cf. *intermedia* | | | | Piaba |
| *Moenkhausia oligolepis* (Günther, 1864) | | | | Piaba rabo preto |
| *Phenacogaster* cf. *pectinata* | | | | Lambarizinho |
| *Poptella compressa* (Günther, 1864) | | | | Piaba chatinha |
| *Psellogrammus kennedyi* (Eigenmann, 1903) | X | | | |
| *Roeboides margareteae* Lucena, 2003* | | | | Cacunda |
| *Roeboides sazimai* Lucena, 2007* | | | | Cacunda |
| *Serrapinnus* sp. | | | | Piabinha |
| *Tetragonopterus argenteus* Cuvier 1816 | X | | | Piaba |
| **Crenuchidae** | | | | |
| *Characidium* sp. | | | | Canivete, mocinha |
| **Curimatidae** | | | | |
| *Curimatopsis* aff. *cryptica* | | | | |
| *Psectrogaster rhomboides* Eigenmann & Eigenmann 1889 | | | | Branquinha |
| *Steindachnerina notonota* (Miranda Ribeiro, 1937) | | | | João duro |
| **Cynodontidae** | | | | |
| *Cynodon gibbus* (Agassiz, 1829) | | | | Gata |
| **Erythrinidae** | | | | |
| *Hoplias malabaricus* (Bloch, 1794) | | | | Traíra |
| *Hoplerythrinus unitaeniatus* (Spix & Agassiz, 1829) | | | | Iú |
| **Gasteropelecidae** | | | | |

| CLASS/ORDER/FAMILY/SPECIES | New records | Migratory species | Non-native species | Common name (Portuguese) |
|---|---|---|---|---|
| *Gasteropelecus sternicla* (Linnaeus, 1758) | | | | Borboleta |
| **Hemiodontidae** | | | | |
| *Hemiodus parnaguae* Eigenmann & Henn, 1916* | | | | Flecheiro |
| **Iguanodectidae** | | | | |
| *Bryconops* aff. *affinis* | | | | Dórico |
| **Lebiasinidae** | | | | |
| *Copella arnoldi* (Regan, 1912) | | | | |
| *Nannostomus beckfordi* Günther, 1872 | | | | Peixe lápis |
| **Triportheidae** | | | | |
| *Triportheus signatus* (Garman, 1890) | | X | | Sardinha de água doce |
| **Prochilodontidae** | | | | |
| *Prochilodus lacustris* Steindachner, 1907* | | X | | Curimatá |
| **Serrasalmidae** | | | | |
| *Colossoma macropomum* (Cuvier, 1816) | X | X | X | Tambaqui |
| *Metynnis lippincottianus* (Cope, 1870) | | | | Pacú |
| *Myloplus rubripinnis* (Müller & Troschel, 1844) | X | | | Pacú folha |
| *Serrasalmus rhombeus* (Linnaeus, 1766) | X | X | | Pirambeba |
| *Pygocentrus nattereri* Kner, 1858 | | X | | Piranha vermelha |
| **CICHLIFORMES** | | | | |
| **Cichlidae** | | | | |
| *Aequidens tetramerus* (Heckel, 1840) | | | | Cará, Acará |
| *Apistogramma piauiensis* Kullander, 1980* | | | | Carazinho |
| *Cichlasoma zarskei* Ottoni, 2011* | | | | Cará preto, Acará, Cará |
| *Crenicichla brasiliensis* (Bloch, 1792) | | | | Lope, Joana, Sabão |

| CLASS/ORDER/FAMILY/SPECIES | New records | Migratory species | Non-native species | Common name (Portuguese) |
|---|---|---|---|---|
| *Geophagus parnaibae* Staeck & Schindler, 2006* | | | | Cará |
| *Oreochromis niloticus* (Linnaeus, 1758*)* | X | | X | Tilápia |
| *Satanoperca jurupari* (Heckel, 1840) | | | | Cará bicudo |
| **CLUPEIFORMES** | | | | |
| **Engraulidae** | | | | |
| *Anchovia surinamensis* (Bleeker, 1865) | X | | | Manjuba |
| *Anchoviella guianensis* (Eigenmann, 1912) | X | | | Manjuba |
| *Anchoviella lepidentostole* (Fowler, 1911) | X | | | Manjuba |
| **Clupeidae** | | | | |
| *Opisthonema oglinum* (Lesueur, 1818) | X | | | Sardinha |
| *Rhinosardinia amazonica* (Steindachner, 1879) | X | | | Sardinha |
| **CYPRINODONTIFORMES** | | | | |
| **Anablepidae** | | | | |
| *Anableps anableps* (Linnaeus, 1758) | X | | | Tralhoto |
| **Poeciliidae** | | | | |
| *Poecilia sarrafae* Bragança & Costa, 2011 | | | | Barrigudinho |
| **Rivulidae** | | | | |
| *Anablepsoides vieirai* Nelson, 2016* | | | | Peixe de poça |
| **GYMNOTIFORMES** | | | | |
| **Apteronotidae** | | | | |
| *Apteronotus albifrons* (Linnaeus, 1766) | | | | Sarapó, Catana |
| **Gymnotidae** | | | | |
| *Gymnotus carapo* Linnaeus, 1758 | | | | Sarapó, Catana |
| **Hypopomidae** | | | | |
| *Brachyhypopomus* sp. | | | | Sarapó, Catana |

| CLASS/ORDER/FAMILY/SPECIES | New records | Migratory species | Non-native species | Common name (Portuguese) |
|---|---|---|---|---|
| **Sternopygidae** | | | | |
| *Eigenmannia robsoni* Dutra, Ramos & Menezes 2022* | | | | Sarapó, Catana |
| *Sternopygus macrurus* (Bloch & Schneider, 1801) | | | | Sarapó, Catana |
| **Rhamphichthyidae** | | | | |
| *Rhamphichthys atlanticus* Triques, 1999* | | | | Tubiba, Sarapó |
| **MUGILIFORMES** | | | | |
| **Mugilidae** | | | | |
| *Mugil curema* Valenciennes, 1836 | | | | Sardinha |
| **SILURIFORMES** | | | | |
| **Ariidae** | | | | |
| *Amphiarius rugispinis* (Valenciennes, 1840) | X | | | Bagre |
| *Aspistor quadriscutis* (Valenciennes, 1840) | X | | | Bagre |
| *Bagre bagre* (Linnaeus, 1766) | X | | | Bagre |
| *Cathorops spixii* (Agassiz, 1829) | X | | | Bagre |
| **Aspredinidae** | | | | |
| *Aspredo aspredo* (Linnaeus, 1758) | X | | | Banjo catfish |
| *Pseudobunocephalus timbira* Leão, Carvalho, Reis & Wosiacki, 2019 | X | | | |
| **Auchenipteridae** | | | | |
| *Auchenipterus menezesi* Ferraris & Vari, 1999* | X | | | Bagre |
| *Tatia intermedia* (Steindachner, 1877) | X | | | Bagrinho |
| *Trachelyopterus galeatus* (Linnaeus, 1766) | | | | Cangati, Bagrinho |
| **Callichthyidae** | | | | |
| *Aspidoras* cf. *raimundi* | | | | Cari |
| *Callichthys callichthys* (Linnaeus, 1758) | | | | Cascudo |
| *Corydoras julii* Steindachner, 1906 | X | | | Cari |

| CLASS/ORDER/FAMILY/SPECIES | New records | Migratory species | Non-native species | Common name (Portuguese) |
|---|---|---|---|---|
| *Corydoras vittatus* Nijssen, 1971* | X | | | Cari |
| *Hoplosternum littorale* (Hancock, 1828) | X | | | Cascudo |
| *Megalechis thoracata* (Valenciennes, 1840) | | | | Cascudo |
| **Doradidae** | | | | |
| *Hassar affinis* (Steindachner, 1881)* | | | | Cabeça de cavalo |
| *Platydoras brachylecis* Piorski, Garavello, Arce H. & Sabaj Pérez, 2008 | X | | | Guirri |
| **Loricariidae** | | | | |
| *Ancistrus* cf. *damasceni* | | | | Mão na cara, Cascudo, Bodó |
| *Ancistrus* sp. | | | | Mão na cara, Cascudo, Bodó |
| *Hemiodontichthys acipenserinus* | | | | Cachimbo |
| *Hypostomus* cf. *krikati* | | | | Boi de carro, Cascudo, Bodó |
| *Hypostomus* sp. | | | | Boi de carro, Cascudo, Bodó |
| *Hypoptopoma incognitum* Aquino & Schaefer, 2010 | X | | | Cachimbo, Cascudo |
| *Loricaria* cf. *cataphracta* | | | | Boi de carro Cascudo |
| *Loricariichthys derbyi* Fowler, 1915 | X | | | Cachimbo, Cascudo |
| *Rineloricaria* sp. | | | | Cachimbo, Cascudo |
| **Heptapteridae** | | | | |
| *Imparfinis* sp. | | | | Mandi |

| CLASS/ORDER/FAMILY/SPECIES | New records | Migratory species | Non-native species | Common name (Portuguese) |
|---|---|---|---|---|
| *Pimelodella parnahybae* Fowler, 1941* | | | | Mandi |
| *Pimelodella* sp1. | | | | Mandi |
| *Pimelodella* sp2. | | | | Mandi |
| *Rhamdia quelen* (Quoy & Gaimard, 1824) | X | | | Jundiá |
| **Pimelodidae** | | | | |
| *Hemisorubim platyrhynchos* (Valenciennes, 1840) | | X | | Mandi três pinta |
| *Pimelodus blochii* Valenciennes, 1840 | X | X | | Mandi |
| *Pimelodus ornatus* Kner, 1858 | | X | | Mandi dourado |
| *Pseudoplatystoma fasciatum* (Linnaeus, 1766*)* | X | X | | Surubim |
| *Sorubim lima* (Bloch & Schneider, 1801) | | X | | Bico de pato |
| **Pseudopimelodidae** | | | | |
| *Batrochoglanis* sp. | | | | |
| **Trichomycteridae** | | | | |
| *Ituglanis* cf. *amazonicus* | | | | |
| **SCOMBRIFORMES** | | | | |
| **Stromateidae** | | | | |
| *Peprilus paru* (Linnaeus, 1758) | X | | | |
| **SYNBRANCHIFORMES** | | | | |
| **Synbranchidae** | | | | |
| *Synbranchus marmoratus* Bloch 1795 | | | | Muçum |
| **TETRAODONTIFORMES** | | | | |
| **Tetraodontidae** | | | | |
| *Lagocephalus* cf. *lagocephalus* | X | | | Baiacu arara |

**Analysis**

The present study recorded about 32500 specimens belonging to 123 fish species (94 identified at the species level) for the Munim River Basin, divided into 49 families and 14 orders (Table 2, Suppl. materials 1, 2). The most diverse orders are the Characiformes, with 43 species (35%); Siluriformes, with 38 species (30.9%); Acanthuriformes, with 11 (8.9%); Cichliformes, with seven species (5.7%) and Gymnotiformes, with six species (4.9%), representing 85.4% of all species known from the river basin. The remaining orders (Clupeiformes, Carangiformes, Cyprinodontiformes, Batrachoidiformes, Beloniformes, Mugiliformes, Scombriformes, Synbranchiformes and Tetraodontiformes) together represent only 14.6% of the Munim River Basin species.

The most diverse family was the Characidae, with 21 species (17.1%), followed by the Loricariidae, with nine (7.3%) and the Cichlidae, with seven (5.7%). Further, from all 123 recorded species, only two, *Oreochromis niloticus* and *Colossoma macropomum* are nonnative species for the studied region and 13 are migratory species (see Table 2). Amongst the species identified at the species level, 16 are endemic to the hydrographic regions of Maranhão and Parnaíba sensu Hubert and Renno (2006) (Mrn and Prn, respectively).

According to the General plotted curves (General species accumulation curve), the sampling effort can be considered sufficient (Fig. 6), given that the observed values of S (125 ±14) are aligned with those calculated in the estimator Chao1 (136.25) and the asymptote estimates of the Michaelis-Menten equation (113), as well as the Bootstrap (140.8) and Jackknife1 (162.85) variation indicators (Fig. 6).

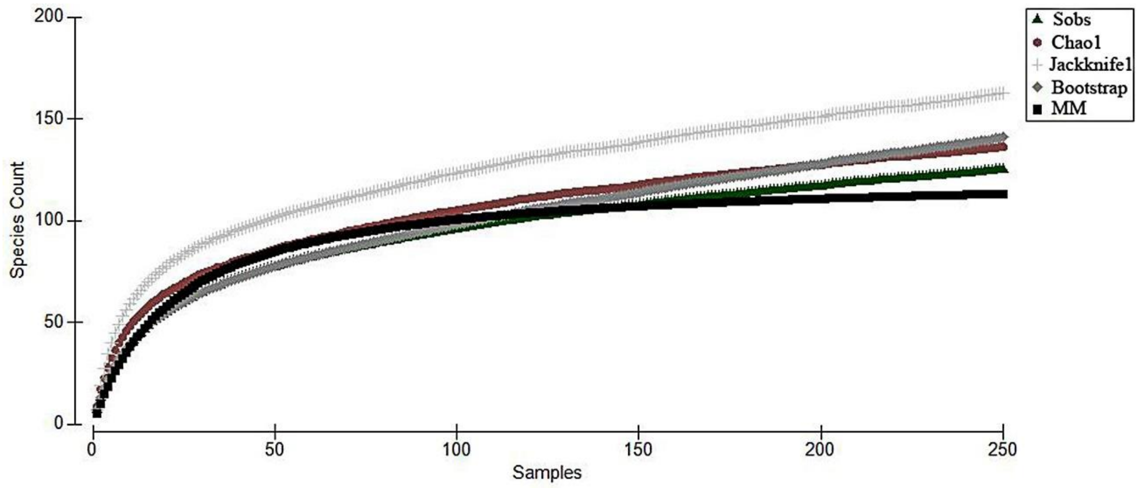


**Figure 6.** General species accumulation curve over the sampling period for this study.

### Species Richness

There were significant differences in species richness between sections (X = 16.207, df = 3, p < 0.001) where the Lower and Upper river basin sections had significantly more species than the Middle river basin section (p < 0.05, p < 0.01 respectively; Fig. 7).

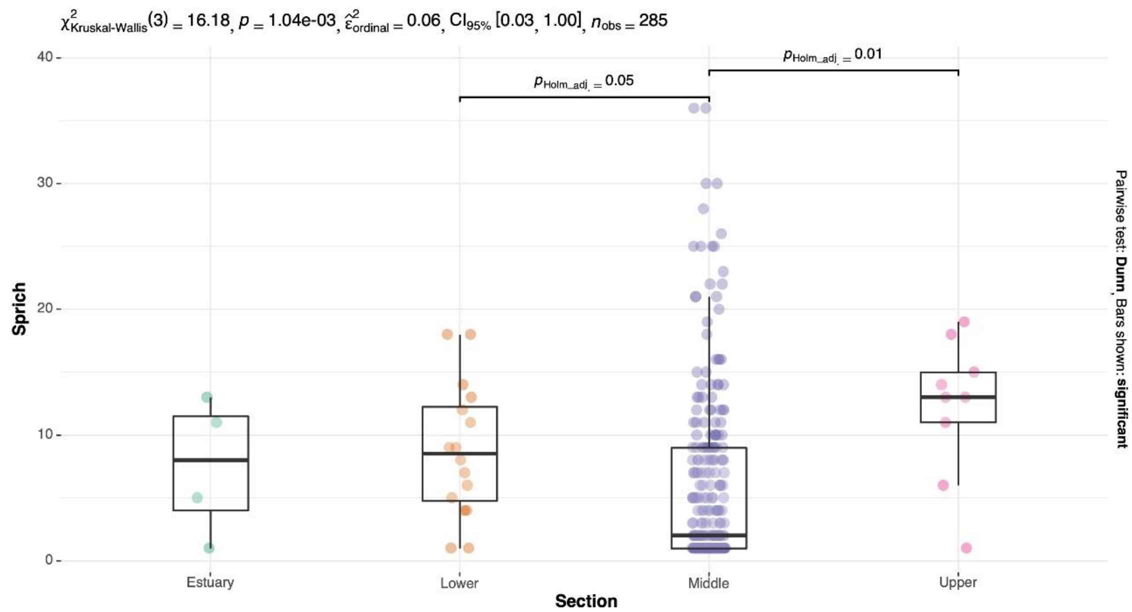


**Figura 7.** Species richness values for all sample sites across river basin sections.

### 2.3.3. Fish assemblage composition

There was weak nestedness across the four basin sections (NODF = 37.67) and indices of species composition similarity and dissimilarity were moderate. Where Sørensen dissimilarity was 0.70 and Simpsons Index (i.e. true turnover) was 56%, suggesting that fish assemblage is distinct between basin sections but only moderately. Jaccard similarity was 83% indicating many shared species compared to unique species across river basin sections. Cluster analysis showed that the Estuary and Upper river sections were more distinct from the Lower and Middle river sections, which formed their own cluster (Fig. 8).

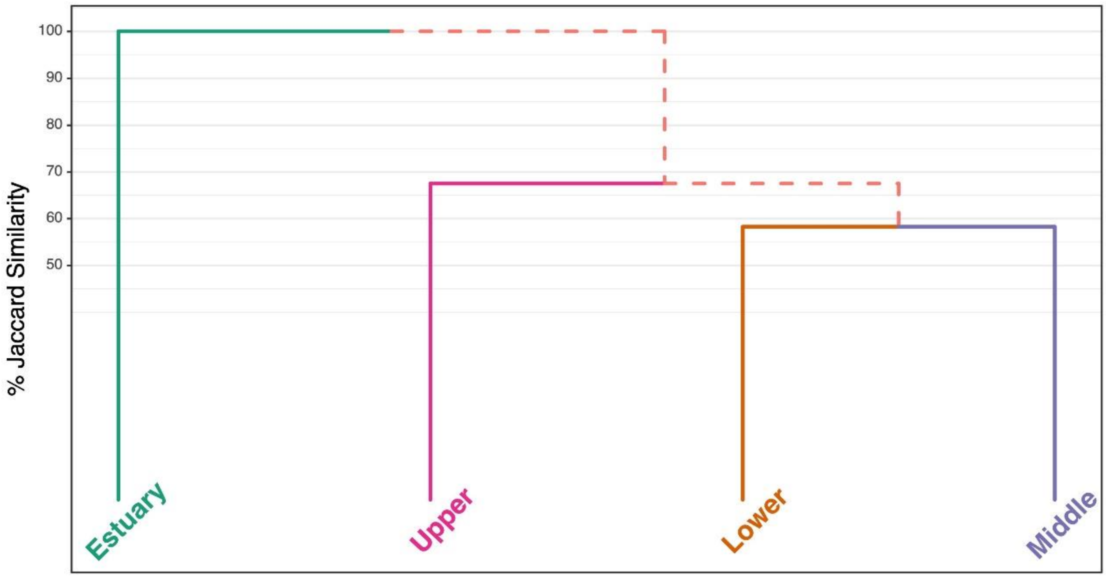


**Figure 8.** Hierachial cluster diagram of fish assemblage based on Jaccard Index per basin section using species presence-absence data.

**Discussion**

This long-term icthyological survey, covering 12 years, conducted between 2010 and 2022 (65% of the surveys were carried out between 2019 and 2022), applied different sampling gears over different water bodies and environments along the Munim River Basin and recorded a predominance of fishes belonging to the Characiformes and Siluriformes, agreeing with a pattern expected for the Neotropics (Lowe-Mcconnell 1999, Pelicice et al. 2005, Langeani et al. 2007, Polaz et al. 2014, Reis et al. 2016, Brito et al. 2019, Dagosta and de Pinna 2019, Guimarães et al. 2020, Castro and Polaz 2020). The study also recorded the predominance of small-sized characid fishes, which have a great diversity in the Neotropical Region, due to several traits, such as their high trophic plasticity (Abelha et al. 2001, Van Der Sleen and Albert 2018, Dagosta and de Pinna 2019, Castro and Polaz 2020, Guimarães et al. 2020, Corrêa and Castro 2021).

A total of 123 species were recorded, with only two of them representing introduced species to the studied river basin (Table 2 and Suppl. materials 1, 2). Colossoma macropomum (tambaqui) occurs naturally in the Amazon and Orinoco River Basins, thus being native to Brazil, but not the Munim River Basin (Latini et al. 2016, Fricke et al. 2022b ); and Oreochromis niloticus (tilápia) which is native to northern and eastern Africa ( Figueredo and Giani 2005, Latini et al. 2016, Fricke et al. 2022b). All the other 121 species are native to the studied area. Therefore, the fish assemblage composition of the Munim River Basin is currently little affected by the presence of alien fish species. However, the policy regarding non-native species and push for economic development indicates this may soon change (Azevedo-Santos et al. 2011, Doria et al. 2021, Faria et al. 2022).

The occurrence of non-native fish species usually comes from fish farming and, in some cases, from intentional release and aquarium trade (Latini et al. 2016, Rocha et al. 2023). Oreochromis nilotus is an omnivorous fish which has broad abiotic tolerances, rapid growth and high survival in environments with high population density, traits which facilitate invasiveness and are favoured in aquaculture species (Figueredo and Giani 2005, Latini et al. 2016). In Brazil, the cultivation of this species is increasing, frequently without any control (Figueredo and Giani 2005, Latini et al. 2016). The species C. macropomum was recorded at only one collection site (a single specimen) (see Suppl. materials 1, 2). This makes us believe that the specimen had probably accidentally escaped from local or home fish-farming. On the other hand, O. niloticus was recorded in four locations (some of these locations far from each other), on different dates (i.e. several specimens). These data suggest establishment in the river basin and, thus, should be considered an established species in the Munim River Basin. Aquaculture initiatives with poor biosecurity are the probable pathway of invasion and rapid expansion facilitated by favourable climatic conditions should be expected and monitored in the Munim River Basin (Charvet et al. 2021, Wilgen et al. 2022). There is likelihood of negative ecological impacts as a result of this burgeoning invasion, in particular O. niloticus is a highly efficient filter feeder and may disrupt the food-web (Vasconcelos et al. 2018, Charvet et al. 2021). Biological invasions are a direct cause of biodiversity decline globally and are an increasing threat, especially in aquatic systems with high endemicity (Havel et al. 2015, Gallardo et al. 2016).

This study reported 13 migratory fish species occurring in the Munim River Basin. Therefore, the eventual construction of dams and hydroelectric plants will undoubtedly negatively impact these species as migration routes will be interrupted. Locally, Oliveira et al. (2020) have already reported this situation occurring in the Mata de Itamacaoca, Chapadinha Municipality, State of Maranhão. They verified that the reservoir dam constructed in the Mata de Itamacaoca inhibits the dispersion of fish occurring below the dam, which possesses higher species diversity. In addition, migratory species were also not found by Oliveira et al. (2020) above the dam, in the reservoir, which would be a suitable habitat for these species. This may illustrate the effects of increased dam construction along the Munim River Basin.

When comparing the present checklist with previous ones listing the fish species found in the hydrographic regions of Maranhão and Parnaíba sensu Hubert and Renno (2006) (Mrn and Prn, respectively) (e.g. Soares (2005), Barros et al. (2011), Nascimento et al. (2016), Piorski et al. (2017), Brito et al. (2019), Brito et al. (2020), Guimarães et al. (2020)), it is evident that the fish diversity from the Munim River Basin has been underestimated. In fact, the present study showed a surprisingly high fish species diversity occurring in the Munim River Basin, when compared to the species richness found in other larger drainage systems and river basins from Maranhão. For example, Munim River Basin outnumbered the Itapecuru River Basin, a larger river basin, with 29 more species being recorded, where 94 fish species are known to occur (e.g. Barros et al. (2011), Nascimento et al. (2016), Koerber et al. (2022)). In addition, we recorded 67 more species than in the Preguiças and Periá River Basin, where 56 fish species are known to occur (e.g. Piorski et al. (2017), Brito et al. (2019), Brito et al. (2020), Koerber et al. (2022)); 22 more fish species than Guimarães et al. (2020) recorded for the Pindaré River drainage (101 fish species); and more than twice the number of fish species for the coastal river basins of Gurupi, Maracaçumé, and Turiaçu, where less than 50 species are known for each of these river basins (Koerber et al. 2022). There are only three studies surveying Maranhão coastal drainage systems, which presented a higher number of species than this study. Ramos et al. (2014), who recorded 146 species for the Parnaíba River Basin and, later, Silva et al. (2015) provided an updated list with six additional species (152). Koerber et al. (2022) published a checklist of the freshwater species in Maranhão (CLOFFBR-MA), listing 136 species for the Mearim River Basin. The Munim River Basin had 13 fewer species than those recorded in the Mearim River Basin, one of the largest river basins in Maranhão and 29 fewer species than the Parnaíba River Basin, which is the largest hydrographic basin in north-eastern Brazil (Ramos et al. 2014, Silva et al. 2015, Koerber et al. 2022).

When analysing the present results in light of the previous surveys in the Munim River Basin, it is clear that all previous studies were geographically restricted to specific localities, extremely close to each other, thus were not able to depict and represent the wider basin diversity. Ribeiro et al. (2014) recorded only 20 fish species (103 less than the present study), using a traditional fishing technique called "moita" commonly used by local traditional communities in the Chapadinha Municipality. However, this method is biased toward the capture of medium to large-sized fishes and is generally applied by subsistence fisheries. Matavelli et al. (2015) surveyed the tadpoles occurring in lentic and lotic environments in Cerrado and Restinga vegetation types, sampling in localities in the Munim and Parnaíba river basins. Fish species were also sampled and a total of 13 species were recorded from the Munim River Basin (110 less than the present study). Nunes et al. (2019) carried out a weight-length ratio study of the fish community in one locality in Munim River Basin, recording 15 fish species (108 less than the present study). More recently, Oliveira et al. (2020) published a freshwater fish species list of a conservation unit in the Chapadinha Municipality after a long monitoring period, with 23 species (100 less than the present study). However, the survey was focused on small streams and consequently recorded mainly small-size species. Guimarães et al. (2021b) published a book from the same area studied by Oliveira et al. (2020), directed at the general public, which focused on species with an estimated high ornamental value. Finally, in the

CLOFFBR-MA, which relied upon literature information, 59 species were identified in the Munim River Basin (64 less than the present study) (Koerber et al. 2022). None of these previous studies had the main goal of identifying the entire species diversity of the Munim River Basin.

Within the 121 native species listed in the present study, 29 were not able to be identified to the species level. Guimarães et al. (2018a) and Guimarães et al. (2020), hypothesised that probably this is a result of the lack of taxonomic knowledge and information about these species and groups occurring in Maranhão. The taxa which could not be identified to the species level, likely belong to species complexes or represent taxonomically challenging and poorly defined groups and may represent new species to science (see Table 2).

Median species richness in the Middle river basin section was lower than in the Upper and Lower river basin sections; however, the Middle section had both more sampling sites and much higher range of species richness. Environmental filtering across river gradients has a strong influence on species richness and diversity (López-Delgado et al. 2019, Walsh et al. 2022). By grouping by section, we are missing local habitat-specific variables which are likely to be driving differences in fish assemblages across a highly heterogenous river network. Investigating habitat specific associations and drivers of beta diversity will vastly improve our understanding of drivers of fish assemblages in the Munim River Basin. Moderate nestedness and similarity/dissimilarity trends, combined with the lack of clear clustering between sites within river basin sections, indicate that fish assemblage structuring in the Munim River Basin is probably driven by both the river continuum concept as well as environmental filtering (Vannote et al. 1980, Heino et al. 2015). However, unobstructed flows facilitating dispersal likely drive high similarity throughout each basin section (Leitão et al. 2018). The Munim River Basin is not high altitude and has neither large rapids nor large waterfalls; therefore, the flow conditions through the sections are also relatively similar, with the lower river section differing through estuarine influence. Further research is needed to understand the specific microhabitats and fish associations throughout the river basin as this is undoubtedly a driving factor of diversity. For example, river slope and flow conditions exert strong environmental filters on fish community and traits in Neotropical and Afrotropical freshwaters and dispersal between heterogenous habitats may be limited by side channels and swamp habitats (Caetano et al. 2021, Walsh et al. 2022). A higher concentration of specialist species is expected to be found in the Upper section as there is more competition for niches (Sternberg and Kennard 2013). The cluster analysis indicated that the Upper section sites were on distinct branches from the other sites, but a standardised sampling methodology combined with implementation of functional trait-based approaches will facilitate our understanding of finer scale processes of environmental filtering in each section (Bower and Winemiller 2019a, Bower and Winemiller 2019b).

Considering all 92 native species which were identified to the species level, 30 of them (*Achirus achirus*, *Amphiarius rugispinis*, *Anableps anableps*, *Anchovia surinamensis*, *Anchoviella guianensis*, *Anchoviella lepidentostole*, *Aspistor quadriscutis*, *Aspredo aspredo*, *Bagre bagre*, *Batrachoides surinamensis*, *Cathorops spixii*, *Centropomus parallelus*, *Chaetodipterus faber*, *Chloroscombrus chrysurus*, *Conodon nobilis*, *Cynoscion steindachneri*, *Eugerres plumieri*, *Genyatremus luteus*, *Hyporhamphus roberti*, *Lutjanus jocu*, *Macrodon ancylodon*, *Menticirrhus americanus*, *Micropogonias furnieri*, *Mugil curema*, *Oligoplites palometa*, *Opisthonema oglinum*, *Peprilus paru*, *Plagioscion squamosissimus*, *Rhinosardinia amazonica* and *Stellifer naso*) are commonly found in brackish water or estuaries. Due to this, no biogeographical considerations will be made about them. From the remaining 62 species identified to the species level, 16 are only known from river drainage systems and basins of the Maranhão State and the Parnaíba River Basin ( *Anablepsoides vieirai*, *Apistogramma piauiensis*, *Auchenipterus menezesi*, *Charax awa*, *Cichlasoma zarskei*, *Corydoras vittatus*, *Eigenmannia robsoni*, *Geophagus parnaibae*, *Hassar affinis*, *Hemiodus parnaguae*, *Hyphessobrycon piorskii*, *Pimelodella parnahybae*, *Prochilodus lacustris*, *Rhamphichthys atlanticus*, *Roeboides margareteae* and *Roeboides sazimai*). Three other species (*Platydoras brachylecis*, *Poecilia sarrafae* and *Schizodon dissimilis*) are also known from other drainages in the northeast of Brazil (Teixeira et al. 2017, Silva et al. 2020, Fricke et al. 2022b). The remaining 43 species are also known from different Amazonian drainage systems (Fricke et al. 2022b), a pattern clearly showing the influence and presence of Amazonian fauna in the Munim River Basin. In addition, when comparing the species listed for the Munim River Basin to the list of species in the Parnaíba River (Ramos et al. 2014, Silva et al. 2015), there are 53 native species cooccurring in both drainage systems, showing a high influence of the larger Parnaíba River Basin over smaller coastal drainage systems. Finally, there are a total of 64 new records of fish species for the Munim River Basin and 48 new records considering only the number of taxa identified at the species level (Table 2), showing that, until the present study, the drainage's diversity was underestimated.

The Munim River Basin, previously a neglected river system, similar to many other coastal systems in Maranhão, is now one of the better known river basins relative to its fish diversity. A detailed taxonomic investigation of specimens sampled over a 12 year period revealed a much diverse fish fauna. The present study is the most comprehensive carried out in the Munim River Basin so far, adding 64 species (including species identified at the species level and species not identified at species level), which were previously considered not to occur in the drainage, resulting in a total of 123 species. Within this species richness, there was a large number of taxa, which could not be identified at the species level, indicating the urgent need for dedicated taxonomic research in the region. This study puts emphasis on the importance of compiling ichthyofaunal lists for poorly-studied or subsampled areas. This achievement represents a first step in understanding the diversity in the Munim River Basin, with the information presented herein allowing the development of future ecology, biogeography and conservation studies. Thus, this is an essential contribution to the effort to better understand the fish diversity of Maranhão in the face of rapid global change and habitat alteration. Despite the high number of species found for the Munim River Basin, more collection efforts are recommended, especially in the Lower and Estuary sections. New collection expeditions may find species that may not have been recorded by this work.

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**Author contributions**

Conceptualisation: Felipe Ottoni, Erick Guimarães, Lucas Vieira. Data collecting, organising and curation: Lucas Vieira, Rafael Oliveira, Diego Campos, Marcony Coelho, Maurício Paiva, Erick Guimarães, Pâmella Brito, Felipe Ottoni. Specimens identification: Lucas Vieira, Rafael Oliveira, Diego Campos, Marcony Coelho, Maurício Paiva, Erick Guimarães, Pâmella Brito, Axel Katz, Felipe Ottoni. Supplementary material: Lucas Vieira. Ecological and statistics analyses: Josie South, Diego Campos. Manuscript writing: Lucas Vieira, Felipe Ottoni, Josie South, Pedro Bragança, Diego Campos, Marcony Coelho, Maurício Paiva, Rafael Oliveira, Erick Guimarães, Pâmella Brito, Jadson Santos, Axel Katz. Map and river basin sectorisation: Diego Campos. Photographs: Lucas Vieira and Rafael Oliveira. Photographs editing: Axel Katz. Supervision: Felipe Ottoni, Pedro Bragança, Josie South. English language review: Pedro Bragança, Josie South. All authors have read and agreed to the published version of the manuscript.

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**Supplementary materials**

Suppl. material 1: Checklist of the fish fauna of the Munim River Basin, Maranhão, north-eastern Brazil

**Authors:** Lucas Vieira

**Data type:** Excel csv spreadsheet

**Brief description:** Spreadsheet in Darwin Core format.

**Disponivel em:** https://arpha.pensoft.net/getfile.php?filename=oo_805945.csv.

Suppl. material 2: Checklist of the fish fauna of the Munim River Basin, Maranhão, north-eastern Brazil

**Authors:** Lucas Vieira

**Data type:** Excel csv spreadsheet

**Brief description:** Spreadsheet used in ecological and statistics analyses.

**Disponivel em:** https://arpha.pensoft.net/getfile.php?filename=oo_805830.csv.

# CAPÍTULO III

## 3.1 CONSIDERAÇÕES FINAIS E PERSPECTIVAS FUTURAS

A bacia do Rio Munim está incluía no Programa “União pelas Águas”, que visa qualificar a comunidade, gestores públicos e usuários da água inseridos nas bacias Hidrográficas do Maranhão, com a finalidade de utilizar os recursos hídricos de forma sustentável e contribuir na organização de futuros comitês de bacias (JÚNIO et al., 2008). No entanto, mesmo inserido neste comitê, a bacia do Rio Munim vem sofrendo com o aumento progressivo de ações antrópicas, tais como: desmatamento, dragas, implementação de projetos agropecuários, ampliação de campos para produção de soja e expansão urbana (RIBEIRO et al., 2006, RIBEIRO e NUNES 2017); esses fatores afetam diretamente a conservação e manutenção da bacia.

Este projeto visou obter informações sobre a ictiofauna da bacia do Rio Munim, através de um extenso inventário que proporcionou um melhor nível de conhecimento da bacia em questão, assim como para a ictiofauna do Maranhão. O trabalho é um marco para a bacia estudada, sendo considerado um dos maiores e mais importantes inventários de peixes conduzidos no estado do Maranhão, juntamente com os trabalho publicados por Soares et al. (2005), Barros et al. (2011); Nascimento et al. (2016), Piorski et al. (2017), Brito et al. (2019, 2020) e Guimarães et al. (2020). Além disso, no acervo do projeto (CICCAA), todo o material está disponível para a comunidade científica. Logo, esse banco de dados disponível no CICCAA proporcionará o desenvolvimento de diferentes trabalhos no futuro, tais como: descrição de novas espécies, analises ecológicas, estudos moleculares, estudos biogeográficos, estudos de parasitas, análise de sazonalidade, estado de conservação da bacia, dentre outros.

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