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Importance of fish biodiversity in conservation planning of Brazilian National Parks

Importância da biodiversidade de peixes no planejamento da conservação dos Parques Nacionais Brasileiros

Importancia de la biodiversidad de peces en la planificación de la conservación de los Parques Nacionales Brasileños

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Abstract
Protected areas are essential for the maintenance of biodiversity. In Brazil, national parks encompass one of the most important portions of this area (26.864.003,74ha) that needs to be adequately managed to achieve conservation. Aiming to understand how the ichthyofauna data is included in management plans of Brazilian National Parks, we review 55 Brazilian national parks management plans to compare how data of freshwater fish fauna are included in these documents. The data evaluated from management plans were Hydrography, ichthyofauna list, participation of professionals trained in rapid ecological assessment and species richness, endangered and invasive species. This information was used to categorize the management plans through two sets of assessing: quality of rapid ecological assessment and coverage of species diversity. The categorization results were assumed as an indicator of the potential for biodiversity conservation of the management plans. We compare obtained results between biomes. We were able to understand that many of the Brazilian National Parks do not have management plans, and among the plans that are prepared, the lack of essential information compromises their potential for the conservation of biodiversity. We highlight the need to improve management plans for the Caatinga parks and expand the analysis of invasive species for all biomes.
Keywords: Conservation; Management; Protected areas; Freshwater fishes.

Resumo
As áreas protegidas são essenciais para a manutenção da biodiversidade. No Brasil, os parques nacionais abrangem uma das partes mais importantes dessas áreas (26.864.003,74 ha) que precisam ser manejadas de forma adequada para se alcançar a conservação. Para compreender como os dados a respeito da ictiofauna são abordados nos planos de manejo de parques nacionais brasileiros e o potencial dessas informações para a conservação, revisamos 55 planos de manejo. As variáveis utilizadas foram: plano de manejo disponível, hidrografia, dados da ictiofauna de água doce, profissionais treinados em avaliação ecológica rápida e riqueza de espécies. Além disso, dados sobre espécies ameaçadas e invasoras, usando uma matriz binária (ausência / presença). Comparamos nossas classificações com dados disponíveis na literatura especializada para cada bioma brasileiro. Pudemos apreender que muitos dos Parques Nacionais brasileiros ainda não possuem planos de manejo, e entre os planos já elaborados a falta de informações essenciais compromete seu potencial para a conservação da biodiversidade. Destacamos a necessidade de melhoria dos planos de manejo para os parques da Caatinga e a ampliação da análise de espécies invasoras para todos os biomas.

Palavras-chave: Conservação; Gestão; Áreas protegidas; Peixes de água doce.

Resumen
Las áreas protegidas son esenciales para el mantenimiento de la biodiversidad. En Brasil, los parques nacionales abarcan una de las porciones más importantes de esta área (26.864.003,74ha) que necesita ser manejada adecuadamente para lograr la conservación. Para comprender cómo se abordan los datos sobre la ictiofauna en los planes de manejo de los Parques Nacionales de Brasil y el potencial de esta información para la conservación. revisamos 55 planes de gestión de parques nacionales brasileños para comparar cómo se incluyen en estos documentos los datos de la fauna de peces de agua dulce. Los datos evaluados de los planes de manejo fueron Hidrografía, listado de ictiofauna, participación de profesionales capacitados en valoración ecológica rápida y riqueza de especies, especies amenazadas e invasoras. Esta información se utilizó para categorizar los planes de manejo a través de dos conjuntos de evaluaciones: la calidad de la evaluación ecológica rápida y la cobertura de la diversidad de especies. Los resultados de la categorización se asumieron como un indicador del potencial de conservación de la biodiversidad de los planes de manejo. Comparamos los resultados obtenidos entre biomas. Pudimos aprehender que muchos de los Parques Nacionales brasileños aún no cuentan con planes de manejo, y entre los planes ya preparados, la falta de información esencial compromete su potencial para la conservación de la biodiversidad. Destacamos la necesidad de mejorar los planes de manejo de los parques de Caatinga y ampliar el análisis de especies invasoras para todos los biomas.
Palabras clave: Conservación; Gestión; Áreas protegidas; Peces de agua dulce.

1. Introduction

Protected areas (PAs) are those reserved for the preservation of biological diversity and the use of natural and cultural resources, managed by legal means (Scherl et al., 2006). Around the world, PAs are important for in *situ* conservation, which is fundamental to the maintenance of the integrity of species, populations and ecosystems, including traditional means of survival in the human population (Ervin, 2003, Rylands & Brandon, 2005; Lovejoy, 2006)**.**

Brazilian National System of Conservation Units (SNUC) (Ministry of the Environment, 2000) is the main environmental law that regulates the establishment of protected areas in Brazillian territory. National Parks (NP) are one category of PAs which are intended to contribute to the maintenance of genetic resources, providing a refuge for endemic and threatened species (Brunner et al., 2001, Le Saout et al., 2013, Coetzee et al., 2014; Ministry of the Environment, 2000a). Most PAs in Brazil are NPs that together encompass 26.864.003,74 ha of Brazillian lands (ICMBio, 2020) and include portions of all main river basins of the country. To achieve the goal of conservation, Brazillian law determines that all the PAs need to create a management plan (MP) a guide that rules the uses and actions for the area and must be implemented by the environmental agency.

The fishes are the major group among the vertebrates (Pough et al., 2008), with a total of 33,000 species (Roskov et al., 2020)**,** that presents high diversity and degree of endemism in the neotropical region. Brazil has 2,587 species of freshwater fish, representing 43% of the species of the world (Buckup et al., 2007).

Here, we review the data available for the freshwater fish on management plans of Brazillian National Parks to understand the scope of the information contained in these documents and the employment possibilities in biological conservation.

2. Methodology

2.1 Data collection

Management plans were obtained from the databases of ICMBio (Chico Mendes Institute for Biodiversity Conservation – Brazilian Agency for Protected Areas). Data from 74 National Parks were investigated, from which 55 management plans were assessed (the others are not publicly available). Management plans were grouped by their local biome:

Amazon (AM), Atlantic forest (AF), Cerrado (CE), Caatinga (CA), Pampa (PAM) and Pantanal (PAN) as defined in the Ministry of the Environment (2020b).

2.2 Data analysis

Collected data were organized in two sets of evaluation as follows:

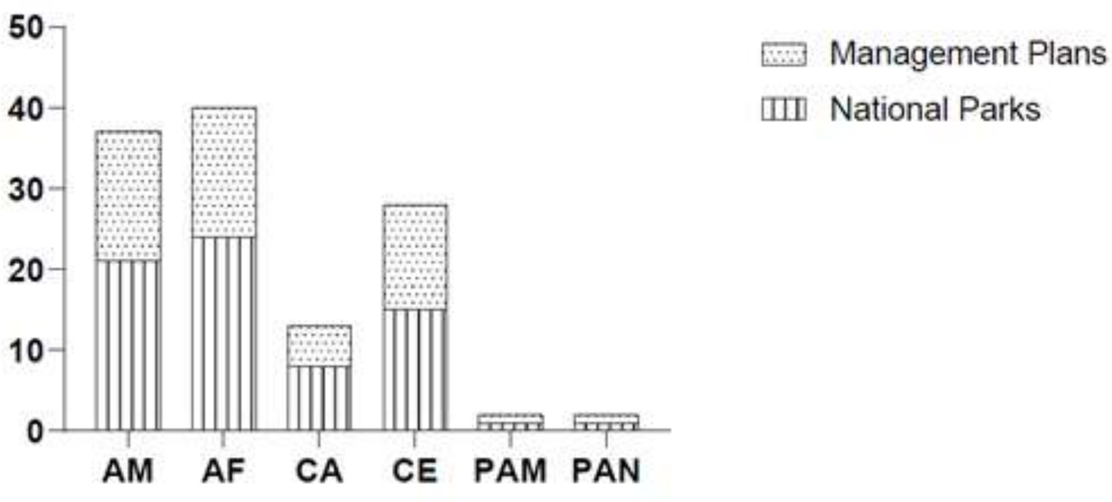
1. Quality of rapid ecological assessment: the elaboration of each MP were compared with the criteria required in the Rapid Ecological Assessment - the official guide of Brazilian Institute of Environment and Nonrenewable Natural Resources (IBAMA, 2002) and scored/in the range: (1) No quality– MP includes only Hydrography; (2) Low quality– MP includes Hydrography, Ichthyofauna data; (3) Medium quality - MP includes hydrography, Ichthyofauna data, species richness and (4) High quality - MP includes hydrography, Ichthyofauna data, species richness and was elaborated by trained professionals (as described for each professional in the *curriculum lattes* of CNPQ).

2. Coverage of species diversity: absolute species diversity (number of species), in each MP were compared with data from literature review. We access articles since 2000 to compile a most complete list of fish available for each Protected Area and results were scored and expressed as: (score 1) Underestimated when MP<Specialized literature, (2) overestimated when MP>Specialized literature, (3) compatible when MP include the same information of specialized literature, (4) MP as the only source of data. Non-native and threatened species were also considered and compared with the specialized literature.

3. Results

Regarding the distribution of NP by biomes, our results demonstrate greater number of MP in the Atlantic Forest (32%, 875.611,11 ha total area) and Amazon (28%, 21.411.309,46 ha total area) biomes, including 45 of the total parks. The other biomes presented: Cerrado (20%, 3.612.137,96), Caatinga (10,6%, 682.065,22 ha), Pampa (1,3%, 176.496,00 ha) and Pantanal (1.3%,135.992,65 ha) of the NP (Figure1).

Figure 1 - Number of national parks and management plans by biome.



CA= Caatinga; CE= Cerrado; AM= Amazon; AF= Atlantic Forest; PAM= Pampa; PAN= Pantanal.
Source: Authors.

Considering that all National Parks included hydrographic networks, a gap was observed between the number of management plans and ichthyofauna data. Only 74.32% of the MPs present studies of ichthyofauna in their official documents.

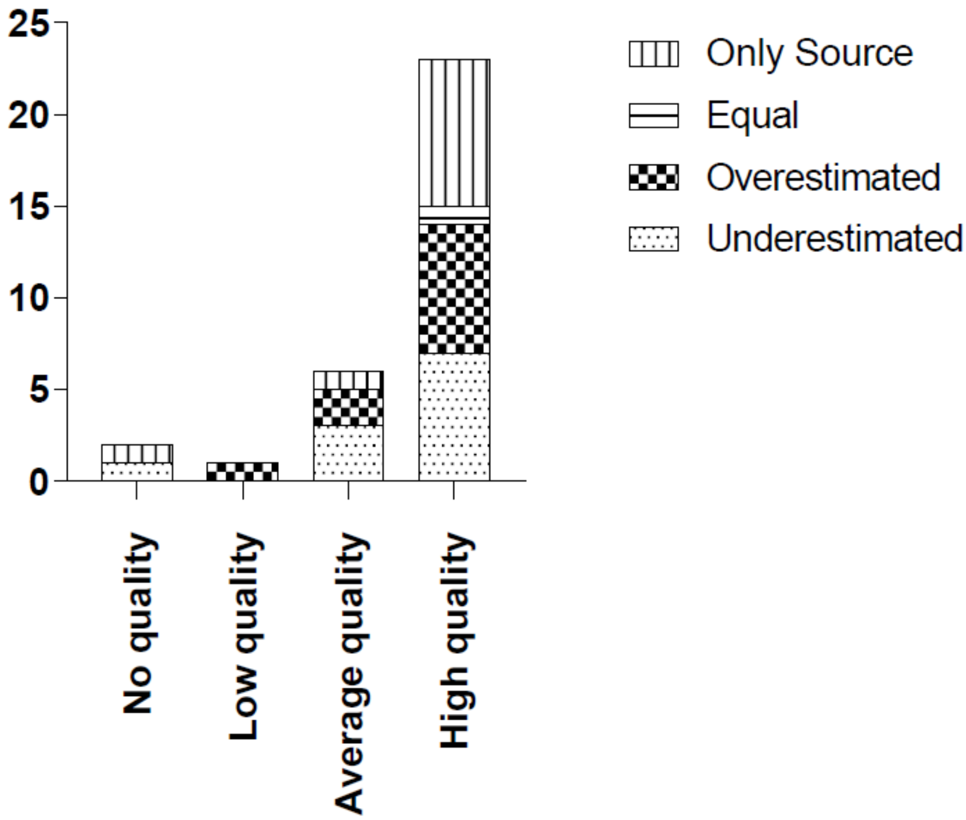
In assessing the quality of management plans for biodiversity conservation, 41.81% of MP was considered as high quality; 14.54% as medium quality, 3.63% low quality as, with no quality 41.81%, according to set 1.

Regarding the period of elaboration of the management plan, we found that only 52.6% of NP had it's MP in five years after the official creation. Among these MPs, 43.63 % were elaborated by specialists. For the parks created before the SNUC requirement (Ministry of the Environment, 2000), the average period of MP publication was 15 years and 63.6% of than present ichthyofauna data produced by the Rapid Ecological Assessment, the others include only compilations of previously published data.

For the second set, data on species richness, 90.1% of NP do not present compatible information with inventories carried out and published for the biome: the fauna were underestimated in 30.3% of the MP, overestimated in 33.3%, and compatible in 9,09%. For 33.3% of the NP, the PM is the only source of data available.

In the association of the sets, we observed that the management plans with high quality showed: overestimated fauna (31.8%), underestimated (31,8%) and 36.3% represented the plans that are the only available data source (Fig.2).

Figure 2 - Associated distribution of management plans in the evaluated criteria (Quality of Assessment Rapid Ecology and Species Richness).



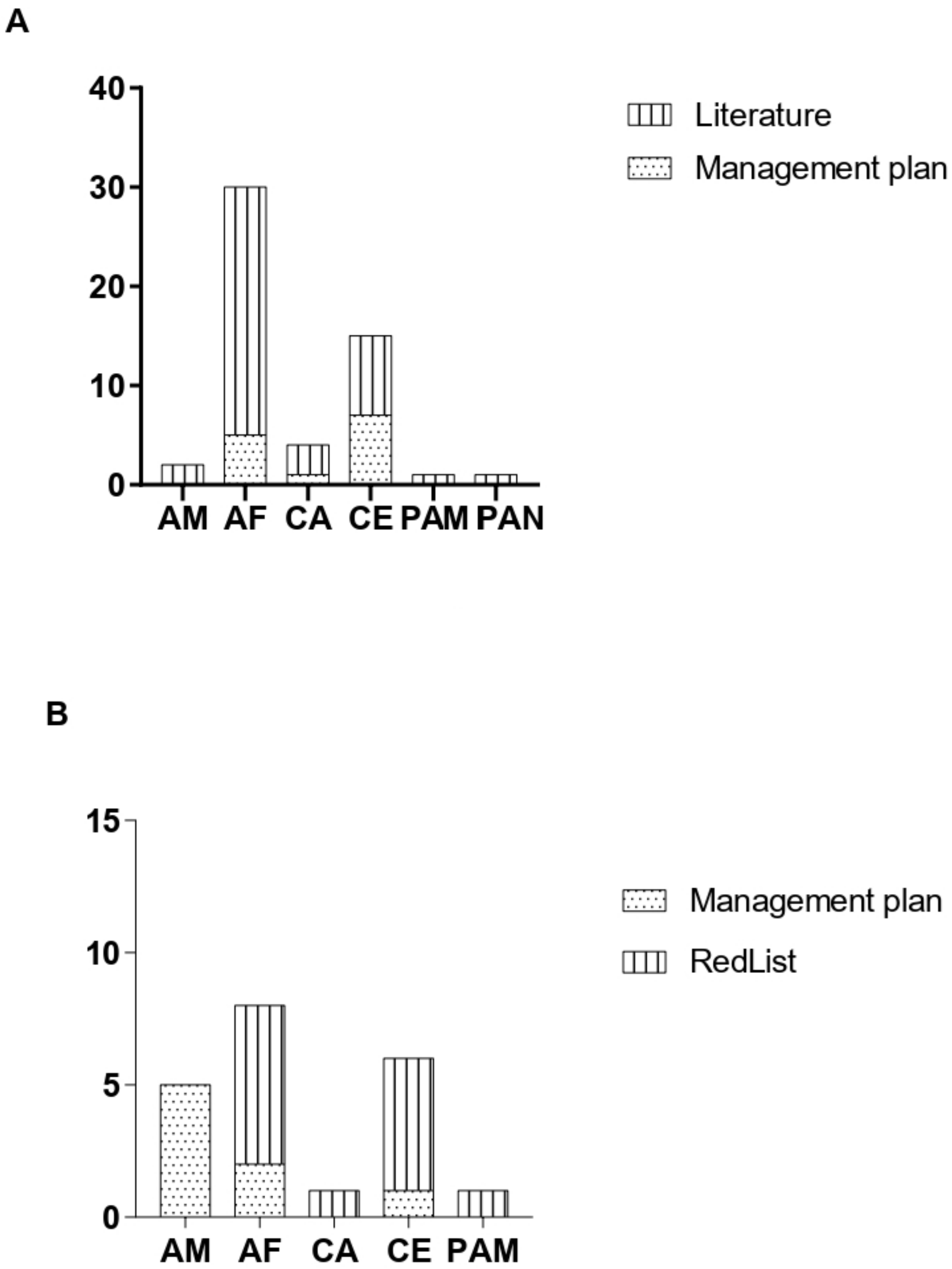
Source: Authors.

When analyzing the distribution of high quality management plans by biome, it is possible to observe the weaknesses in the caatinga and pampa areas that do not have high quality management plans. Considering the underestimated data, in the cerrado (42.8%), in the Atlantic Forest (28.5%), which represent the majority of its management plans, followed by the pantanal (14.2%).

For overestimated data, the Amazon (50%), Cerrado (37.5%) and Atlantic Forest (12.5%) stand out. It is also important to highlight that for some biomes, the management plan is the only source of information about iconic biodiversity, such as the Amazon (75%), Cerrado and Atlantic Forest (12.5%).

The analysis of non-native and endangered species verified non-conformities between data management plans and specialized literature (Figure 3).

Figure 3 - Comparison between data obtained from management plans and specialized literature. A= Alien species; B= Threatened species



CA= Caatinga; CE= Cerrado; AM= Amazon; AF= Atlantic Forest; PAM= Pampa; PAN= Pantanal.
Source: Authors.

Management plans for 12 national parks recorded alien species, with emphasis on the Cerrado (28 species) and Atlantic Forest (12 species) biomes, followed by the Caatinga (5 species). For threatened, only 12.9% of the management plans include data, however, this percentage is underestimated in comparison with the specialized literature in 37% of the plans.

4. Discussion

Our study provides a systematic overview of the information used in the management of the ichthyofauna biodiversity in Brazilian national parks. We found that most management plans have low and medium potential for the conservation of continental fish species (63.9%), in contrast to one of the main objectives of the NP: to protect and recover water resources and edaphic (Ministry of the Environment, 2010).

We found that 27% of National Parks do not have management plans, however, Cifuentes et al. (2000) estimate that less than 30% of protected areas in the world have a management plan. Although not ideal, considering previous studies, where 78% of federal conservation units did not have a management plan (Ministry of the Environment 2011), there was a significant decrease in the absence of management plans, demonstrating the effort to meet the targets established in the National System of Conservation Units.

We also identified that national park management plans were drawn up an average of 15 years after creation, in contrast to what was established by the Ministry of the Environment (2000), that all conservation units must have a management plan within up to 5 years after the creation of the UC. According to Medeiros & Araujo (2011), this gap also demonstrates a limitation in the management and implementation of protected areas.

Despite efforts to expand protected areas in Brazil that, between 2003 and 2010 the country housed 75% of the total protected area in the world (WWF, 2011), some objections to the effectiveness of these areas in relation to freshwater ichthyofauna should be considered. Our results demonstrate that, for ictic biodiversity in national parks, park planning, in its minority, has a high potential for biodiversity conservation (40%). And when evaluating the plans with high potential by biome, we highlight the criticality in the caatinga and pampa (0%).

The caatinga is the only biome exclusively Brazilian (IBGE, 2002), therefore, it should be one of the most effective biomes in conservation units, nonetheless, our data reveal that from eight national parks the management plans were classified in categories 1, 2 and 3 (no potential, low potential and average potential) for the conservation of ichthyofauna.

This data is worrying, given that the ichthyofauna data presented are secondary data, from a bibliographic review (145 species of fish), none of them prepared by specialists, in addition to the registration of 5 invasive species. On the other hand, when considering the study carried out by Braga (2016) that identified 255 ict species, 6 invasive species and 86 endemic species in the biome, we conclude that the data available in the management plan for managing the biome are outdated.

Considering that the biome has a high rate of endemicity (Ramos et al., 2014), and threats to iconic biodiversity, such as overfishing and dam construction, our data corroborate with Casarim, Caldeira & Pompeu (2019) when verifying that national parks have low representativeness in the conservation of the caatinga ichthyofauna. Thus, we indicate the need to prioritize protected areas in the biome, in addition to the effort to inventory the species that occur in these areas, as well as the analysis of endemic and threatened species. As for the Amazon and Atlantic Forest biomes, our assessment showed different patterns, despite the fact that the biomes have the largest number of national parks (43) and present the same number of management plans (15).

The Amazon was also the biome that presented most of the management plans with high potential), however, for the associated analysis only 13.3% have more robust data than those available in the specialized literature, while 75% of the plans contain the only information regarding the freshwater ichthyofauna in protected areas.

In this sense, we can verify that despite the estimate of the iconic diversity of the Amazon (c. 3000 species), proportionally, few studies are carried out in the region. Although there are inventories for the Amazon basin, data on protected areas are incipient, corroborating with Junk et al. (2001).

This has direct implications for the conservation of ecological biodiversity, since impacts in the Amazon have grown, such as the demarcation of protected areas, overfishing, and hydroelectricity. Given our data, we recommend the robust inventory and monitoring of ichthyofauna in protected Amazonian areas.

In contrast, the situation of the Atlantic Forest requires caution, both because of the history of resource exploitation and human pressure (Jones et al., 2018) and because it is considered a biodiversity hotspot (Myers et al., 2000). Despite having the largest number of protected areas, only 25% of management plans were categorized with high potential, and of these, 50% have underestimated data in relation to specialized literature.

For the associated analysis, 36.3% of management plans with high potential in the biome present more robust and unique data for the region. This fact reflects the conditions for the proper management of the iconic freshwater species. To this end, the Chico Mendes Institute for Biodiversity Conservation (Ministry of the Environment, 2019) created the National Action Plan for the Conservation of Endangered Atlantic Forest Fish and Eglas - PAN Fish and Eglas of the Atlantic Forest, with the objective of improving the conservation status and popularize fish, eglas, rivers and streams of the Atlantic Forest, in 5 years.

Another biome considered a hotspot for biodiversity is the cerrado. For this biome, our analyzes show that in relation to the categorization referring to ERA, 69.2% of the 13 available management plans have high potential. Nevertheless, when the categorizations are combined, 44.4% have underestimated data and 50%, more robust and unique data. The data presented here are essential for the scientific community and managers, since a biome relevant to the global biodiversity of the ichthyofauna needs monitoring and reinforcement for the inventory in protected areas, thus indicating a need for expansion and effectiveness of protected areas.

Unlike what has been exposed so far, the Pantanal biome stands out because despite having only one national park in its extension, the management plan contemplates all categories of rapid ecological assessment and has a high potential. Although when in combined analysis, diversity data are underestimated. Communicating, however, that the park management plan was published 17 years ago, indicating the need to update data.

Additionally, our data demonstrate the incipient knowledge of endangered and invasive species in Brazilian protected areas. In this context, we observed that of the 33 management plans with ichthyofauna data, 21.2% mention endangered and endemic species. However, the literature records 60.6% of the park's endangered and endemic species.

There are 312 listed endangered species in Brazil (Ministry of the Environment, 2018), so it is important to highlight the possibility of creating more protected areas to ensure the conservation of these species. For example, Nogueira et al. (2010) found that most of the endemic-restricted species detected by them are found in watersheds in the Cerrado and Atlantic forest biomes, considered global conservation priorities due to high endemism and habitat loss (Nogueira et al., 2010).

5. Conclusion

We conclude then that based on the data obtained here, Brazilian National Parks in general lack essential information available in management plans. And when available, in a few cases they have a high potential for the conservation of biodiversity. This indicates the need for a careful review of the management plans already prepared, in order to include updated data analyzed by experts. It is especially necessary to consider the biological invasions that are one of the main threats to native species.

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Inventory reveals non-native species and variation in spatial-temporal dynamics of fish community in a Brazilian protected area

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Original Article

Inventory reveals non-native species and variation in spatial-temporal dynamics of fish community in a Brazilian protected area

Inventário revela espécies não nativas e variação na dinâmica espaço-temporal da comunidade de peixes em uma área protegida brasileira

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Abstract

The increase in the number of Brazilian protected areas has been progressive and, although it is essential for the conservation of biodiversity, it is important to monitor and properly manage these areas, as they present several cases of biological invasions. The Lençóis Maranhenses constitute the peculiar delta of the Americas and are under the consequences of the bioinvasion of tilapias and peacock bass. Collections were carried out in the Lençóis Maranhenses National Park from March/2016 to November/2020, with the aid of gill nets and cast nets. The species were identified with the help of specialized literature and a historical comparison with previous works was carried out. Cytochrome oxidase subunit I was sequenced to confirm identification of non-native species. We recorded the expansion of the occurrence of *Oreochromis niloticus*, and the first record of the species *Oreochromis mossambicus* and *Cichla monoculus.* A total of 31 species belonging to eight orders, eighteen families and twenty-nine genera were identified, indicating a lag in the diversity of species found in relation to previous studies. After 20 years of the first record of invasive fish, there is an expansion of bioinvasion and new cases that indicate a lack of monitoring and containment measures for the species, indicating the fragility of conservation in the area

Keywords: National Park, Cichlidae, neotropical freshwater fish, species richness.

Resumo

O aumento do número de áreas protegidas brasileiras tem sido progressivo e, embora seja essencial para a conservação da biodiversidade, é importante o monitoramento e o manejo adequado dessas áreas, já que apresentam diversos casos de invasões biológicas. Os Lençóis Maranhenses constituem o peculiar delta das Américas e estão sob as consequências da bioinvasão de tilápias e tucunarés. Foram realizadas coletas no Parque Nacional dos Lençóis Maranhenses no período de março/2016 a novembro/2020, com o auxílio de redes de emalhe e tarrafas. As especies foram identificadas com o auxilio de literatura especializada e uma comparacao historica com trabalhos anteriores foi realizada. O Citocromo oxidase subunidade I foi sequenciado para confirmar a identificação das espécies não nativas. Registramos a expansão da ocorrência de *Oreochromis niloticus*, e o primeiro registro das espécies *Oreochromis mossambicus* e *Cichla monoculus*. Um total de 31 espécies pertencentes a oito ordens, dezoito famílias e vinte e nove gêneros foram identificadas, indicando uma defasagem na diversidade de espécies encontradas em relação a estudos anteriores. Após 20 anos do primeiro registro de peixes invasores, constata-se a expansão da bioinvasão e novos casos que assinalam ausência de monitoramento e de medidas de contenção para as espécies indicando a fragilidade na conservação da área

Palavras-chave: Parque Nacional, Cichlidae, peixes neotropicais, riqueza de espécies.

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1. Introduction

Maintaining ecosystem services is the global strategic plan for biodiversity until 2050 (CDB, 2019). And to achieve this goal, indirect and direct factors of biodiversity loss and its consequences for humanity must be considered, in addition to the concern with the effectiveness of protected areas, which are essential for the maintenance of species, populations and ecosystems (UNEP, 2018).

However, the global panorama shows that the fulfillment of these objectives is still far from what was proposed (Azevedo-Santos et al., 2019; Mormul et al., 2022). In Brazil, despite advances related to the creation of protected areas, preventing biological invasion has become a main challenge, and around $104.33 billion was spent due to damage and loss caused by trespassers in the period 1984 to 2019 (Adelino et al., 2021). Biological invasion is known to cause the loss of 50% of the world's native fish species, and 11 non-native fish species are registered in the protected areas of the Brazilian federation (Sampaio and Schmidt, 2014).

As in the whole globe, several fish species have been introduced in Brazil (Frehse et al., 2016; Ziller et al., 2020; Bueno et al., 2021), such as African Cichlids (Forneck et al., 2016), which are among the most cultivated species in aquaculture and active predators that have been translocated by sport fishing (Fugi et al., 2008) in the country. Among these cichlids, we highlight the representatives of the genera: *Cichla* (Schneider, 1801), endemic to the Amazon region with 15 described species (Kullander and Ferreira, 2006) and *Oreochromis* Gunther with 32 native African species.

In this context, we highlight the Lençóis Maranhenses National Park, created by decree No. 86060 (June 2, 1981), in the Lençóis region with an area of 155,000 hectares (Brasil, 2003). The Management Plan of PNLM presents data on freshwater fish fauna, such as the list of species. However, these data refer to studies conducted in the year 1999 reporting the occurrence of *Oreochromis* sp. as a non-native species (Brasil, 2003). Additionally, Brito et al. (2019) increased the occurrence of other native species and reinforced the occurrence of *Oreochromis* sp. in the region.

Therefore, this paper provides a current list of freshwater fish species in the Lençóis Maranhenses National Park, as well as the first record of *Cichla monoculus* and *Oreochromis mossambicus*, adding the spatial expansion of the occurrence of *Oreochromis niloticus*. In addition to a historical comparison with data on richness and spatial dynamics, contributing to updating the record of native and alien species and subsidizing actions for the management and conservation of species in the region.

2. Methods

2.1. Study area

The state of Maranhão, located on the North Equatorial Coast of Brazil, corresponds to an ecotone between the Amazon, Cerrado and Caatinga biomes. It houses the Lençóis Maranhenses National Park (PNLM), an international tourist destination peculiar to the delta of the Americas, crucial for global biodiversity (Figure 1).

The region has a megathermal climate, very hot and ranging from humid to sub-humid, with annual precipitation of 1,600.00 to 1,800.00 mm and temperatures ranging from 26 °C to 38 °C (Brasil, 2003).

The Maranhão sheets are made up of areas of free and fixed dunes, in addition to being a mosaic of ecosystems such as mangroves, cerrado and restinga (Brasil, 2003). Several water bodies are present in the park, rivers, creeks, streams, lakes, ponds, lagoons, supplied by the Periá and Preguiças rivers (Silva, 2008)

With an area of 155,000 ha, located between the municipalities of Primeira Cruz and Barreirinhas (IBAMA, 1989), the Lençóis Maranhenses National Park moves around 150,000 tourists per year (ICMBIO, 2020) and presents conflicts such as artisanal fishing versus industrial

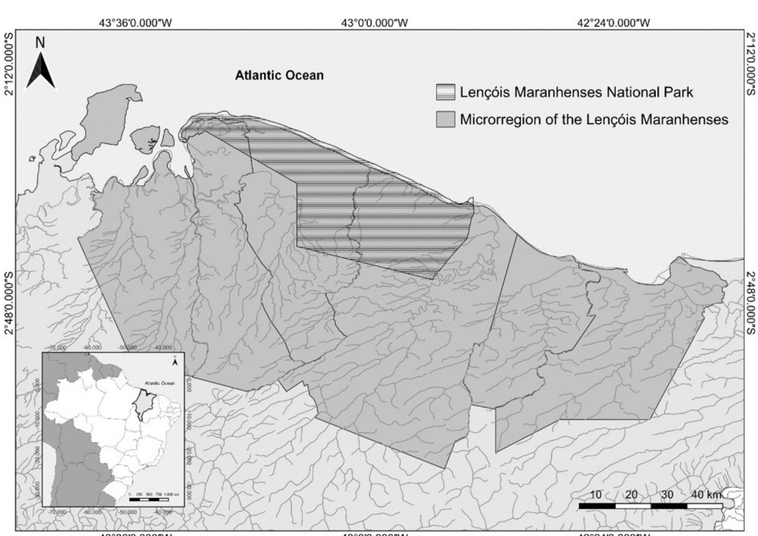

Figure 1. Map of the location of the Lençóis Maranhenses National Park and region on the equatorial coast of Brazil.

fishing, mangrove cutting, extractivism, hunting, rally, irregular occupation and public use activities as bathing, camping, hiking, boat trips, surfing and windsurfing (Brasil, 2003).

The limnological characteristics were obtained from the park management plan (Brasil, 2003).

2.2. Sampling

All collections for this study were done with authorization from the Brazilian Institute of the Environment and Non-Renewable Natural Resources (SISBIO-Number 53224-1). The collections were taken from March/2016, March and July/2017, July/2019 and November/2020 in twenty sampled points among rivers, creek, lakes, ponds and lagoons (Figure 2), in the four campaigns distributed in dry and rainy seasons (Supplementary Material).

Captures were developed through passive fishing using gillnets with spacing of 10 and 20 mm between nodes, during the day, twilight and night, with an average permanence time of 4 hours and review every two hours. It was then followed by active fishing using gear such as trawl nets with spacing between opposing nodes of 1.5mm, cast nets with 50mm between nodes and sieves with an average effort of 15 minutes per gear, adapted from Magnusson et al. (2005).

The identifications were carried out from the specialized literature for each group: Fowler (1954); Mago-Leccia (1994), Piorski et al. (2017) and taxonomic review articles.

Figure 2. Heterogeneous sampled points in Lençóis Maranhenses. (A) and (B) Pond in Paulino Neves, sandy substrate; (C) Tutóia, Delta das Américas, sandy substrate; (D) Lago de Santo Amaro, muddy substrate; (E) Prainha do amor, Barreirinhas, muddy substrate; (F) Tamacão Creek, Tutóia, muddy substrate.

The vouchers of identified fishes were deposited in the Tissue and DNA Collection of Maranhenses Fauna (CoFauMA) of the State University of Maranhão, Brazil. The identification of specimens obtained in this work followed the classification of Fricke et al. (2022).

2.3. Data analysis

For historical verification of diversity, we accessed published data from the work carried out in the 2000s for the Management Plan of the Lençóis Maranhenses National Park (Brasil, 2003) and from the work carried out in 2017 (Brito et al., 2019). Considering the same sampling points, we noted the collection methodologies in order to compare the species richness, as well as the absence/presence of native and non-native species recorded over the last 20 years.

2.4. Molecular procedures

For non-native species, total genomic DNA was extracted from individuals by the salting out method based on proteinase K digestion, followed by sodium chloride extraction and ethanol precipitation (Aljanabi and Martinez, 1997). A fragment (635 bp) of the mitochondrial cytochrome oxidase I subunit (COI) locus was amplified from six specimens (MW694823-MW694824 and MW692108 to MW692111).

The fragment was amplified using two pairs of universal primers FishF1 and FishR1, described by Ward et al. (2005). For amplification, 0.4 µL of DNA, 0.1 µL of each primer, 1.0 µL of buffer (10X), 0.4 µL of $MgCl_2$ (50 nM), 1.6 µL of dNTP, 0 were used in each sample., 1 µL of Taq DNA polymerase and 6.3 µL of ultrapure water to complete the reaction.

The PCR reaction followed an initial denaturation at 94 °C for 5 min followed by 35 cycles of 1 min of denaturation at 94 °C, 30s of hybridization at 56 °C and 1 min of extension at 72 °C, in addition to a final extension of 7 min at 72 °C. Amplified fragments were purified using the Wizad/Promega Purification Kit following the manufacturer's protocol and recommendations. The samples sequencing by the company ACTGene Analytical Moleculars Ltda. (Biotechnology Center, UFRGS, Porto Alegre, RS) using the automatic sequencer ABI-PRISM 3100 Genetic Analyzer armed with 50 cm capillaries.

COI sequences were visually checked and manually corrected. The statistical method chosen for the phylogenetic analyzes and tree assembly was neighbor-joining (K2P) which is recommended as a standard methodology. Additionally, the identification tool available in the Barcode of Life Data System was used, considering as an identification criterion, the similarity above 98% within the same species (BOLD, 2023).

3. Results

In this work, we obtained a total of 1010 specimens collected in the Lençóis Maranhenses National Park, distributed in 08 orders, 18 families, 29 genera and 31 species (Supplementary Material).

The most representative Orders were Characiformes (n=12), Cichliformes (n=8) and Siluriformes (n=5), followed by the orders Clupeiformes, Mugiliformes, Pleuronectiformes and Synbranchiformes, Gymnotiformes (n=1).

In our records, the most abundant species were *Oreochromis niloticus* (Linnaeus, 1758) (n= 148), *Bryconops* sp. and *Astyanax* sp. (n= 139). We also highlight that 16.4% of the total captured correspond to the occurrence of non-native species: *Oreochromis niloticus, Oreochromis mossambicus* (Peters, 1852) and *Cichla monoculus* Spix & Agassiz 1831 (Figure 3).

The identification of these taxa was confirmed by the similarity of the COI gene sequences with the data available in GenBank. The COI gene cluster for the species found, as proposed by Hebert et al. (2003), presents a similarity superior to 98% (Figure 4).

We also observed that in the Lençóis Maranhenses National Park *Oreochromis* spp. was found in 94.11% of the sampled points and in all campaigns.

As for the record of *Cichla monoculus*, it initially occurred in a lotic environment of the Preguiça River near the mouth in 2016, however, the occurrence in lentic environments was also recorded in the following years (Supplementary Material).

In our comparison of the distribution and occurrence of invasive species in two distinct moments: the occasion of the elaboration of the management plan, in 1999 and the collections carried out in this work, we verified the

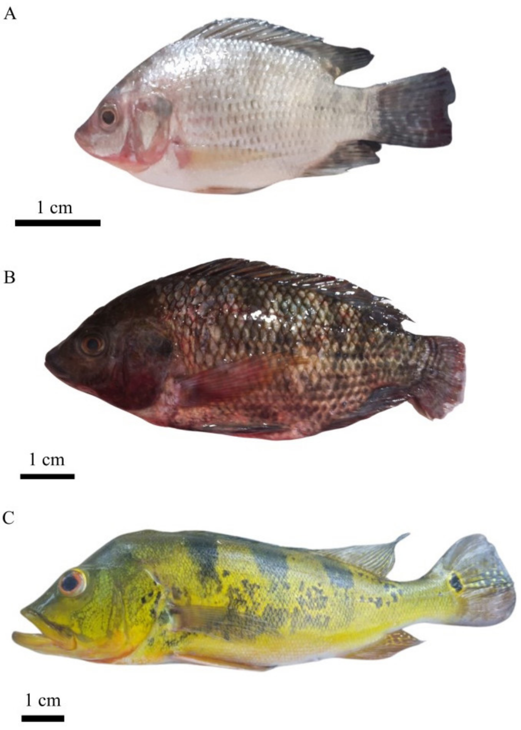

Figure 3. Non-native specimens collected in Lençóis Maranhenses National Park: (A) *Oreochromis niloticus*; (B) *Oreochromis mossambicus*; (C) *Cichla monoculus*.

spatial expansion of *Oreochromis niloticus* in the Park and in the adjacent areas (Figure 5).

In addition to the increase in the number of non-native species, we found a gap in native fish species in Lençóis Maranhenses, as can be seen in the comparison of species captured in the work of the Brasil (2003) and Brito et al. (2019) (Figure 6).

According to the Brasil (2003), in six expeditions in 2000, carried out preferably during the day with trawls and sieves, 43 species of fish were captured, with the first record of Oreochromis sp. While in the work by Brito et al. (2019) 49 species were collected with two trawl nets (20 m long, 2.5 m high, 10 mm mesh; and 4 m long, 2 m high, 5 mm mesh), cast nets (2 m high, 15 mm mesh), gill nets of various mesh sizes (15, 25, 35, 45 and 55 mm) and dip nets (5 and 10 mm mesh) in three expeditions, also indicating the occurrence of *Oreochromis* sp.

Five families registered in 2000, with the representatives *Awaous tajasica* (Lichtenstein 1822), *Polydactylus virginicus* (Linnaeus 1758), *Lycengraulis batesii* (Günther 1868), *Mugil curema* Valenciennes, 1836 e *Eucinostomus argenteus* Baird & Girard 1855, have a marine habit and were not found in this survey.

Other species such as: *Brachychalcinus parnaibae* Reis, 1989, *Hyphessobrycon piorskii* Guimarães, Brito, Feitosa, Carvalho-Costa & Ottoni 2018, *Hemigrammus* spp., *Serrapinus* sp., *Steindachnerina notonota* (Miranda Ribeiro, 1937), *Aequidens tetramerus* (Heckel, 1840), *Poecilia*

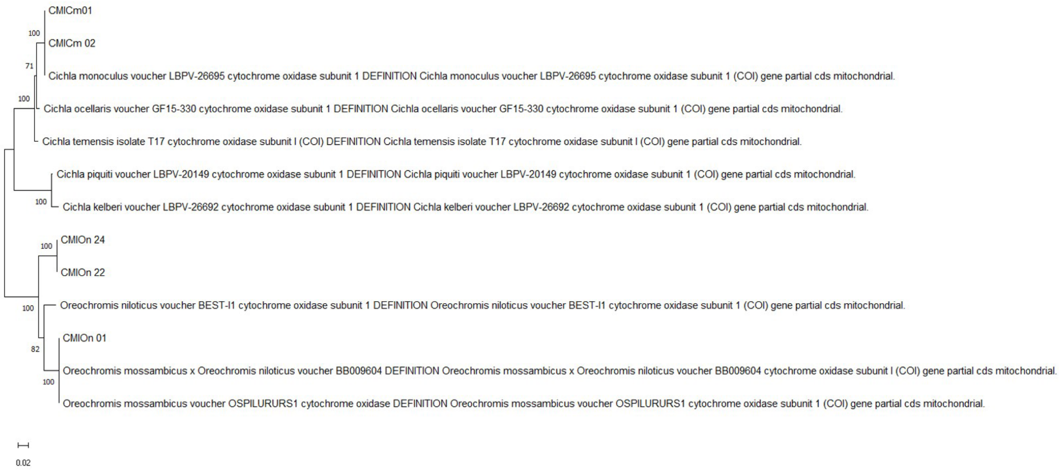

Figure 4. Phenogram generated by the MEGA X program for the COI gene sequences, by the neighbor joining method with 1000 replicates to support the clusters, demonstrating the identification of *Cichla monoculus, Oreochromis niloticus* and *Oreochromis mossambicus*.

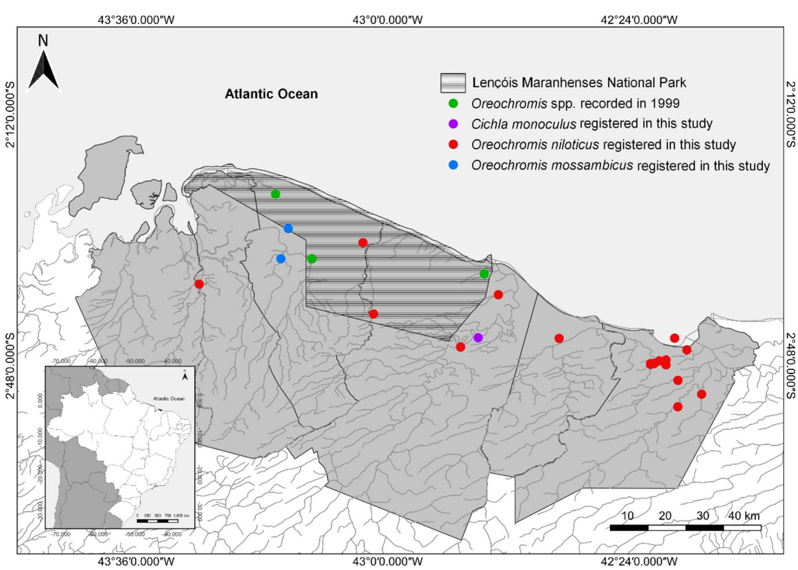

Figure 5. Distribution of allochthonous species *Oreochromis* spp. and *Cichla* spp. collected in Lençóis Maranhenses National Park recorded in 1999 and this work.

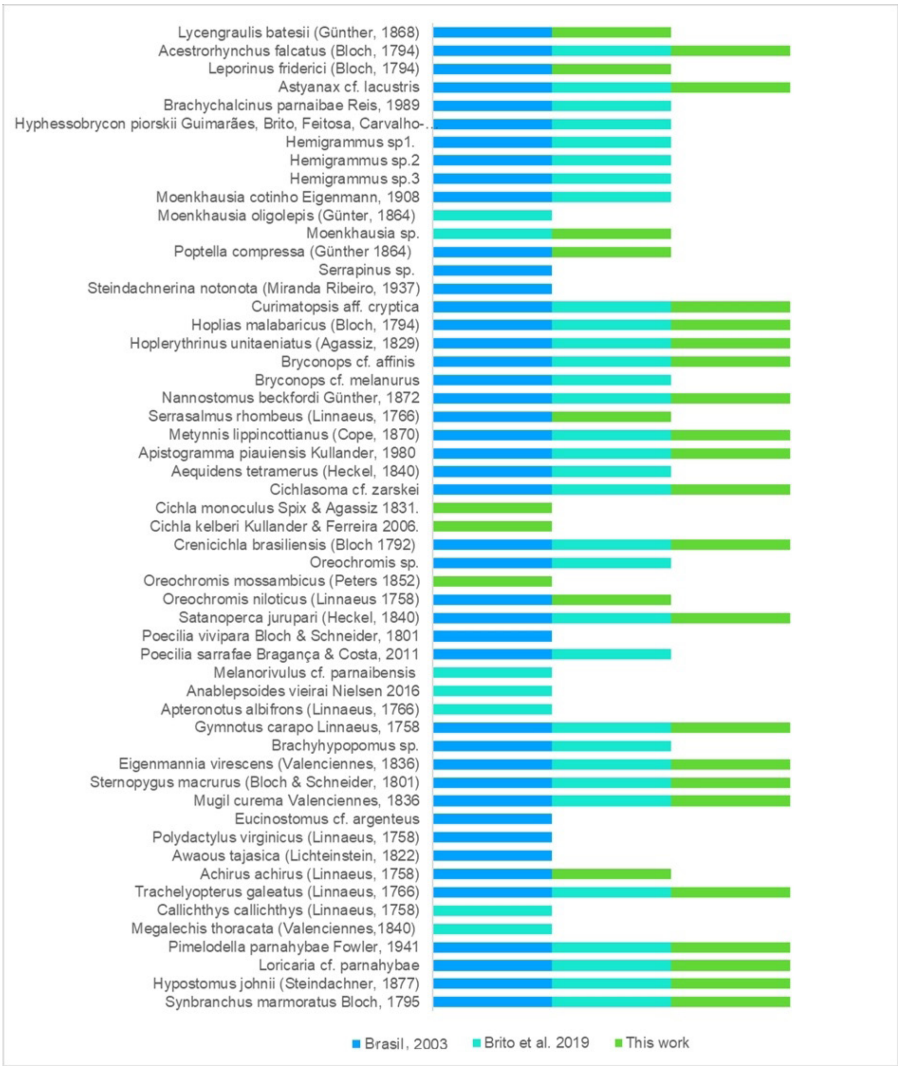

Figure 6. Graph of the historical comparison of the species registrated of freshwater fish collected in the Maranhão wetlands by the authors Brasil (2003), Brito et al. (2019) and this work.

vivipara Bloch & Schneider, 1801, *Poecilia sarrafae* Bragança & Costa, 2011, *Melanorivulus* cf. *parnaibensis*, *Anablepsoides vieirai* Nielsen 2016, *Apteronotus albifrons* (Linnaeus, 1766), *Brachyhypopomus* sp., *Megalechis thoracata* (Valenciennes, 1840) and *Callichthys callichthys* (Linnaeus, 1758) were not recorded in our work.

On the other hand, the Cichliformes had an increase in representativeness, due to the capture of representatives such as *Oreochromis mossambicus* and *Cichla monoculus*.

4. Discussion

The representativeness pattern of the taxa recorded in this study, despite being consistent with what was expected for semi-arid areas of the Neotropical region (Reis et al., 2016) and similar to the patterns of the next ones: Parnaíba, Itapecuru and Tocantins (Melo et al., 2016; Barbosa et al., 2017; Ramos et al., 2014), reveals the presence of three non-native species: *Oreochromis niloticus, Oreochromis mossambicus* and *Cichla monoculus*.

Oreochromis niloticus was introduced in Brazil in 1953 in lakes in the Northeast region (Oliveira et al., 2007; Leão et al., 2011) and *Oreochromis mossambicus,* the red tilapia, a modified strain was introduced in 1981 (Oliveira et al., 2007). In 1940, *Cichla monoculus*, *Cichla kelberi* Kullander & Ferreira 2006, *Cichla piquiti* Kullander & Ferreira 2006 and *Cichla temensis* Humboldt 1821 were introduced to control invasive species and sport fishing in the northeast region with the first record by Peixoto (1954).

The introduction of tilapia in the PNLM was recorded in 1999, at the time of the rapid ecological assessment for the management plan, while peacock bass is probably recent, as there is no record in surveys of the local ichthyofauna (Brasil, 2003; Brito et al., 2019).

In the park region, the main factors for the occurrence and expansion of these species were fish farming and sport fishing. And the success of these introductions is due to the increase and intensity of human activity acting as propagation pressure for these bioinvasions, corroborating with other cases cited by Lima Júnior et al. (2018), Latini et al. (2016) and Magalhães et al. (2017). The high propagation pressures are attributed to the size of the propagule in the case of tilapia and the frequency in the case of peacock bass, making the environment more unstable and susceptible to new invasions (Ricciardi, 2007).

Due to the ecological characteristics of the environments in the Lençóis Maranhenses region, such as the presence of lakes, rivers and small bodies of water (Brasil, 2003), the occurrence of these species is favored and, associated with phenotypic, feeding and reproductive plasticity, culminates in the establishment of these organisms, such as Kovalenko et al. (2010) and Diamante et al. (2017) report for other regions.

In our temporal analysis, we verified a variation in the number of native and non-native species recorded. An increase in non-native species and a reduction in the occurrence of native species. Like species that were cited in historical data (Brito et al., 2019; Brasil, 2003) *Hemigrammus* spp. and *Hyphessobrycon* spp. and were not recorded in our expeditions. Both have opportunistic habits, being omnivores with a preference for insects, microcrustaceans and filamentous algae (Barreto et al., 2018), a factor that may be associated with competition with *O. niloticus*.

A scenario similar to that reported by Attayde et al. (2007), in which Nile tilapia causes a reduction in the abundance of certain planktonic microcrustaceans, an increase in the biomass of nanoplanktonic algae and a reduction in water transparency. These effects of Nile tilapia can negatively affect the recruitment of other fish species that feed essentially on zooplankton in the juvenile stage and are visually oriented to locate and capture their prey (Attayde et al., 2007).

Furthermore, the presence of tucunaré may be associated with the non-registration of these species, since this invader hunts and devours whole prey (Ellis et al., 2011; Sales et al., 2018; Bajer et al., 2019; Santos et al., 2019). Also considering that most of the species not recorded in this study are small Characids and Cyprinids, corroborating Pelicice and Agostinho (2009) when they found a reduction in small fish, mainly Characiformes, such as *Hemigrammus* spp. and *Hyphessobrycon* spp. in environments invaded by peacock bass.

A scenario similar to that reported by Attayde et al. (2007), in which Nile tilapia causes a reduction in the abundance of certain planktonic microcrustaceans, an increase in the biomass of nanoplanktonic algae and a reduction in water transparency. These effects of Nile tilapia can negatively affect the recruitment of other fish species that feed essentially on zooplankton in the juvenile stage and are visually oriented to locate and capture their prey (Attayde et al., 2007).

Another bias to be considered is the impact of climate change such as the implications of increased temperature and its effect on reducing the oxygen content of aquatic systems (Jenny et al., 2016; Blaszczak et al., 2019), compromising the species most sensitive to abiotic changes. The climate is also associated with the increase, loss or changes in areas suitable for various species of fish, being a factor that can directly interfere with the maintenance of aquatic biota (Heino et al., 2009) impacting the increase in organic matter and pollution (MacNeil et al., 2004) can generate differential effects in bioinvasions (Dickey et al., 2021).

Additionally, one should take into account the growing impact of tourism in the region, which in 2022 was visited by 367,000 people (Brasil, 2003), the construction of roads and facilitation of access contributes to transport of species and increased impact on the local ichthyofauna due to effects in synergy with the aspects mentioned above due to the complexity of the study in this scenario.

Given the potential and environmental dynamics of Lençóis Maranhenses, it is necessary to establish monitoring of populations of *Oreochromis niloticus, O. mossambicus* and *Cichla monoculus* and together with native species, mainly associated with the endemicities of *Anablepsoides vieirai* Nielsen 2016, *Apistogramma piauienses* Kullander 1980, *Hyphessobrycon worstskii* Guimarães, Brito, Feitosa, Carvalho-Costa and Ottoni 2018, *Hypostomus johnii* (Steindachner, 1877), *Poecilia sarrafae* Bragança e Costa 2011 and *Pimelodella parnahybae* Fowler, 1941 registered by Brito et al. (2019) in the region.

Considering the management plan as a tool to protect the protected area, the information has not been sufficient to contain the advance of non-native species (Monroe et al., 2021). This fact contributes to intensifying the impacts on the park's biodiversity, which, although it stands out for having more severe restrictions and controls, should bring greater visibility to policies and practices in this protected area (Pressey et al., 2015).

Mainly in a territory highlighted by areas of endemism and biodiversity hotspots, with approximately 20% of its ichthyofauna endemic (Abell et al., 2008), it is necessary to advance in relation to the maintenance of this diversity, given the lack of studies, with data considered underestimated for the area by some authors (Dagosta and Pinna, 2019; Brito et al., 2019). We also indicate environmental education actions for the local and tourist population, in order to sensitize social actors to the consequences of these invasions. In addition to constant vigilance to avoid the release and exchange of species between the park and adjacent areas, considering that Brazilian legislation establishes the need for a routine of eradication, containment, control and monitoring of invasions.

Acknowledgements

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Supplementary Material

Supplementary material accompanies this paper.

Table S1. Details of surveys conducted in 2016/2020 in Lençóis Maranhenses National Park: location name and coordinates, habitat features, presence of non native species and habitat features.

Table S2. Comparison of species richness between this study, Brasil (2003) and Brito et al. (2019).

Table S3. Details of collection campains conducted in 2016/2020 in Lençóis Maranhenses region: Campain and date of capture.

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Ichthyofauna composition and bioinvasion in the baixada maranhense environmental protection area, a ramsar site in Brazil

Diversidade e estrutura em área protegida invadida por ciclídeos

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The Baixada Maranhense is considered a wetland for the conservation of biodiversity and an economically important region for fishing activities, with a set of floodable fields supplied by the Pindaré and Mearim rivers, which are home to a diversity of fish essential to the region's population. In this context, we describe the richness and diversity of the ichthyofauna of five lakes in the Baixada Maranhão environmental protection area, in addition to recording non-native species. The collections were carried out in 2014 and 2015, with the aid of gill nets measuring 20,30,40,50,60 and 80 mm between opposite nodes and the specimens were identified based on specialized literature. We characterize diversity based on Hill numbers calculated in the R program (4.1.3). Specimens belonging to fifty fish species distributed across ten orders, twenty-six families and fifty genera were captured. Of these, four non-native species were identified: *Cichla kelberi*, *Cichla monoculus*, *Oreochromis mossambicus* and *Oreochromis niloticus*. The least diverse lakes were the smallest, with the greatest fishing pressure and which showed a dominance of non-native species.
Keywords: Diversity; Wetland; Freshwater fish; Bioinvasion
A Baixada Maranhense é considerada uma zona úmida para a conservação da biodiversidade e uma região importante economicamente na atividade pesqueira, com um conjunto de campos alagáveis abastecidos pelos rios Pindaré e Mearim, dentre outros, que abrigam uma diversidade de peixes essenciais para a população da região. Nesse contexto, nós descrevemos a riqueza e diversidade da ictiofauna de cinco lagos na área de proteção ambiental da baixada maranhense, além de registrar espécies não nativas. As coletas foram realizadas nos anos de 2014 e 2015, com auxílio de redes de emalhe de 20,30,40,50,60 e 80 mm entre nós opostos e os espécimes foram identificados com base em literatura especializada. Caracterizamos a diversidade com base nos números de Hill calculados no programa R (4.1.3). Foram capturadas espécimes pertencentes a cinquenta espécies ícticas distribuídas em dez ordens, vinte e seis famílias e cinquenta gêneros. Destas, quatro espécies não nativas foram identificadas: *Cichla kelberi*, *Cichla monoculus*, *Oreochromis mossambicus* e *Oreochromis niloticus*. Os lagos menos diversos foram os menos extensos, com maior pressão de pesca e que apresentaram dominância de espécies não nativas.
Palavras-chave: Diversidade; Zona úmida; Peixes dulcícolas; Bioinvasão

1. INTRODUÇÃO

Anthropogenic actions have been reported as one of the main factors impacting biodiversity and ecosystem balance [1,2,3], and concern about the exploitation and depletion of natural resources is at the core of conservation efforts [4,5,6].

Aquatic ecosystems serve as biological models for population studies, and the fragility of these environments [7], in conjunction with a lack of knowledge about existing diversity and anthropogenic impacts, underscores the importance of developing studies focused on ichthyological biodiversity [8].

The neotropical region stands out for its diversity, owing to its history of biogeographic processes. Currently, there are approximately 5160 described fish species in the South American continent [9]. The Amazon basin particularly distinguishes itself in this context [10], housing around 2,700 species, representing approximately 15% of all freshwater species [11,12]. However, the relationship between existing diversity and knowledge of species distribution and occurrence in Brazilian basins is tenuous and disproportionate, this is linked to the lack of taxonomic studies at the national, regional, and local levels [13,14,15,16].

The Baixada Maranhense, located in the Eastern Amazon, is a Ramsar site with highly threatened conservation targets (State Decree No. 11,900), It is known for its water and fishery potential, where the balance between sustainability and the conservation of fish species has been a constant challenge [17]. The region is supplied with a set of lakes bathed by the Pindaré and Mearim rivers (Figure 1) in a cycle of floods that connect them, in addition its flooded fields witness common practices such as rice cultivation, buffalo farming, and fish farming [18,19]

Human actions have been reported as one of the main factors impacting biodiversity and ecosystem balance (Castelo and Macedo 2016, Chapman et al. 2019, Li et al. 2021), and concern about the exploitation and depletion of natural resources is at the core of conservation efforts (Agostinho et al. 2005, Silveira et al. 2010, Reid et al. 2019).

Aquatic ecosystems are biological models used for population studies, and the fragility of these environments (Castello et al. 2012), related with a lack of knowledge about existing diversity and anthropogenic impacts, underscores the importance of developing studies focused on ichthyic biodiversity (Silveira et al. 2010).

Considering that these flood and drought dynamics are the main ecological driving force shaping evolutionary and adaptive processes in the Amazon [20,21], it is crucial to understand the impacts and processes occurring in the region.

Thus, this study identified freshwater fish species in five lakes within the Pindaré-Mearim lacustrine system, examining their composition, diversity, and distribution in relation to environmental factors. It also documented the occurrence of non-native species of the *Cichla* and *Oreochromis* genera, providing information for an internationally significant protected area.

2. MATERIAL E MÉTODOS

2.1 Study área

This study was carried out in five lakes, in the three zones of the lake system formed by the rivers Pindaré and Mearim, located in the State of Maranhão, Eastern Amazon. In the pre-confluence zone (lakes Cajari and Viana), confluence zone (lake Aquiri) and post confluence zone (lakes Itans and Coqueiro), according figure 1

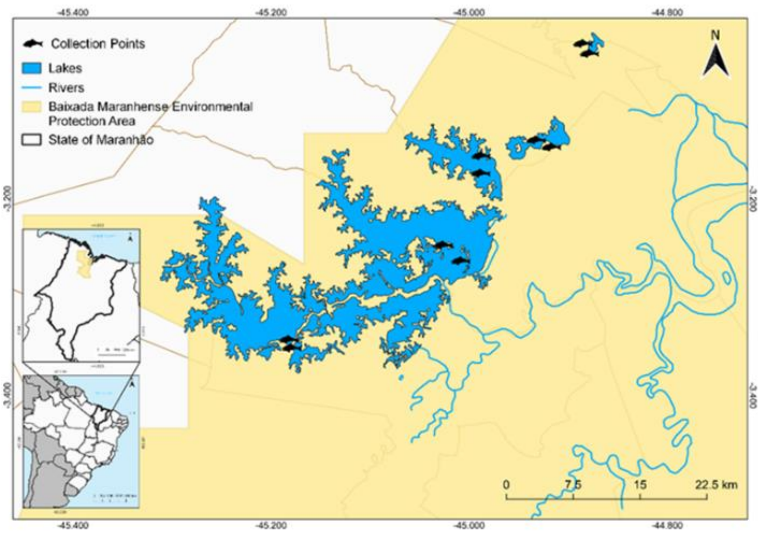

Figure 1. Map of the location of collection points for the lakes sampled in the Baixada Maranhense wetland

The dynamics of the natural fields of the Baixada Maranhense, according to Costa Neto [22], involve two cycles of energy exchange that cover two different periods, according to the season of the year. During the rainy season (January to June), the rivers and perennial lakes overflow, flooding the grasslands and transforming them into extensive shallow lakes. And during the dry season (July to December), the fields remain dry, which promotes the growth of vegetation consisting mainly of Gramineae and Cyperaceae [23].

The lakes Cajari and Viana are located at the pre-confluence of the Pindaré and Mearim rivers, according to Franco [18], the lacustrine indentation of Cajari covers an area of 283.1 km², this considerable size allows large and deep lakes to stand out, such as Lake Cajari [24]. The region of this lake receives the two most important pulses of surface flooding, originating from the lacustrine systems of the Monção region and the tributary rivers of Lake Formoso.

As for Lake Viana, it has an extension of 255.2 km² and is formed by floodplain lakes through the flooding of the waters of the Pindaré River, a tributary on the left bank of the Mearim River (Piorski et al., 2005). The lacustrine region of Viana is composed of the lakes Maracu, Viana, and Maracassumé, without defined divisions by geographic accidents. During the rainy season, they form a single liquid mass, but in droughts, the divisions become apparent.

The region of this lake receives the two most important surface flood pulses, the lake systems of the Monção region and the tributary rivers of Lake Formoso. The Viana lake is 255.2km² in length and is formed by floodplain lakes, through the flooding of the waters of the Pindaré river, a tributary of the left bank of the Mearim river (PIORSKI et al., 2005). The lake region of Viana is formed by the Maracu, Viana and Maracassumé lakes, without divisions defined by geographical features. During the rainy season they form a single liquid mass, but during droughts the divisions become apparent.

The Aquiri lake recess is located in the Pindaré-Mearim post-confluence zone, interfering with the estuarine area of the Mearim river (approximately a straight distance of 18 km) [18]. The recess of Lake Coqueiro has contiguous plains and forms an immense mouth through which flood pulses are conducted. Lake Itans is part of a set of lakes juxtaposed between the floodplains of the Belém and Coqueiro recesses and the large floodplain of the Mearim river, functioning as a distribution axis, releasing the water surplus to other recesses [18].

2.2 Sampling and identification

The monthly collections were carried out from August 2014 to June 2015, in Lakes Cajari (pre-confluence), Aquiri and Viana (confluence), Coqueiro and Itans (post-confluence) of the Pindaré-Mearim lake system. For each lake, lentic and lotic collection points were plotted, obtaining a sample number of 4,956 specimens, under license No. 32643 SISBIO.

At each sampling point, abiotic parameters such as water temperature (TºC), precipitation, pH, and Dissolved Oxygen (mg/I) were measured. Nets of different lengths and meshes were used in bodies of lentic water, for example, nets 100 to 150 m long with meshes between opposite nodes varying from 2 cm to 5 cm. In lotic environments, 50m meshes with meshes between opposite nodes varying from 2 cm to 5 cm. In general, the meshes remained in the water for a period of 4 to 8 hours, between twilight periods in order to sample nocturnal and diurnal fauna.

For taxonomic identification, specialized bibliography was used for each group. The ichthyological material was deposited in the Maranhão Fauna DNA and Tissue Collection (CoFauMA) at the State University of Maranhão. The taxonomic classification, name, author, year of publication, validity, distribution of each species was checked in Van der Laan, Fricke and Eschmeyer [26].

2.3 Species composition

To characterize the species diversity of the lakes studied, we used three integrated rarefaction/extrapolation curves based on the first three Hill numbers (matrix ii). Hill numbers are a mathematically unified family of diversity indices (differing only by one exponent, q) that incorporate relative abundance and species richness [27]. This method is based on the multinomial probability distribution of Hill numbers: species richness (q = 0), exponential Shannon entropy (which we refer to as Shannon diversity, q = 1), and inverse Simpson concentration (a which we refer to as Simpson diversity, q = 2). Shannon diversity weights species in proportion to their frequency, whereas Simpson diversity places more weight on the frequencies of abundant species and discounts rare species.

We estimated species richness and diversity at each site using rarefaction curves and extrapolation of Hill numbers to incidence data, according to the procedures and functions proposed by Chao et al. [27] and using the "iNEXT.Sam" and "plot.iNEXT" functions from the iNEXT package version 2.0.9 [28] of R 4.3.1 [29]. This analysis, based on incidence data, allows the systematic comparison of different sets in time or space, given the dardization of the sample size [27]. The data were plotted with a 95% confidence interval obtained using the bootstrap method, to ensure the robustness of comparisons between different samples [27].

3. RESULTS

Fifty-four (54) species of fish were identified, distributed in ten (10) orders (Myliobatiformes, Elopiformes, Clupeiformes, Characiformes, Gymnotiformes, Siluriformes, Synbranchiformes, Carangiformes, Cichliformes, Achanturiformes), twenty-six (26) families and forty and nine (49) genera, according to Van der Laan, Fricke and Eschmeyer [26]. (Table 1).

Table 1. table of fish species collected in the environmental protection area of the Maranhão, according to the classification of Van der Laan, Fricke and Eschmeyer (2023)

Order	Family	Specie
Myliobatiformes	Potamotrygonidae	*Potamotrygon motoro* (Müller & Henle 1841)
Elopiformes	Megalopidae	*Megalops atlanticus* Valenciennes 1847
Clupeiformes	Engraulidae	*Pterengraulis atherinoides* (Linnaeus 1766)
		Cetengraulis edentulus (Cuvier 1829)
		Lycengraulis batesii (Günther 1868)
Characiformes	Erythrinidae	*Hoplerythrinus unitaeniatus* (Spix & Agassiz 1829).
		Hoplias malabaricus (Bloch 1794)
	Cynodontidae	*Cynodon gibbus* (Spix & Agassiz 1829)
	Serrasalmidae	*Metynnis lippincottianus* (Cope 1870)
		Pygocentrus nattereri Kner 1858
		Serrasalmus rhombeus (Linnaeus 1766)
	Hemiodontidae	*Hemiodus parnaguae* Eigenmann & Henn 1916
	Anostomidae	*Leporinus friderici* (Bloch 1794)
		Schizodon dissimilis (Garman 1890)
	Curimatidae	*Curimata macrops* Eigenmann & Eigenmann 1889.

		Psectrogaster rhomboides (Eigenmann & Eigenmann, 1889)
	Prochilodontidae	*Prochilodus lacustris* Steindachner 1907
		Prochilodus nigricans Spix & Agassiz 1829.
	Thriportheidae	*Triportheus signatus* (Garman 1890)
	Acestrorhynchidae	*Acestrorhynchus lacustris* (Lütken, 1875)
	Characidae	*Roeboides margareteae* Lucena 2003
Gymnotiformes	Sternopygidae	*Sternopygus macrurus* (Bloch & Schneider 1801)
	Gymnotidae	*Gymnotus carapo* Linnaeus 1758
	Rhamphichthyidae	*Rhamphichthys atlanticus* Triques 1999
Siluriformes	Callichthyidae	*Callichthys callichthys* (Linnaeus 1758)
		Hoplosternum littorale (Hancock 1828)
	Loricariidae	*Loricaria cataphracta* Linnaeus 1758
		Loricariichthys sp.
		Pterygoplichthys parnaibae (Weber, 1991)
		Rineloricaria sp.
	Auchenipteridae	*Ageneiosus ucayalensis* Castelnau 1855
		Auchenipterus menezesi Ferraris & Vari 1999
		Hypostomus cf. *plecostomus*
		Trachelyopterus galeatus (Linnaeus 1766)
	Doradidae	*Hassar affinis* Steidachner, 1881
		Platydoras brachylecis Piorski, Garavello, Arce H. & Sabaj Pérez, 2008
	Heptapteridae	*Pimelodella parnahybae* Fowler, 1941
		Pimelodella cristata (Muller & Troschel, 1849)
	Pimelodidae	*Hemisorubim platyrhynchos* (Valenciennes 1840)
		Pimelodus blochii Valenciennes 1840
		Pimelodus ornatus Kner 1858
		Pseudoplatystoma punctifer (Castelnau 1855)
		Sorubim lima (Bloch & Schneider 1801)
Synbranchiformes	Synbranchidae	*Synbranchus marmoratus* Bloch 1795
Carangiformes	Achiridae	*Achirus lineatus* (Linnaeus 1758)

Cichliformes	Cichlidae	*Cichla monoculus* Spix & Agassiz 1831
		Cichla kelberi Kullander & Ferreira 2006
		Cichlasoma zarskei Ottoni 2011
		Crenicichla brasiliensis (Bloch 1792)
		Geophagus parnaibae Staeck & Schindler 2006
		Satanoperca jurupari (Heckel 1840)
		Oreochromis niloticus (Linnaeus 1758)
		Oreochromis mossambicus (Peters 1852)
Achanturiformes	Sciaenidae	*Plagioscion squamosissimus* (Heckel 1840)

The composition of fish assemblages in the lakes presented 4956 specimens and the most abundant orders were Characiformes (47.09%), Siluriformes (23.82%) and Cichliformes (17.12%), respectively. As for families, Erythrinidae (18.12%), Cichlidae (17.12%) and Doradidae (10.06%) stand out (Figure 2).

A

B

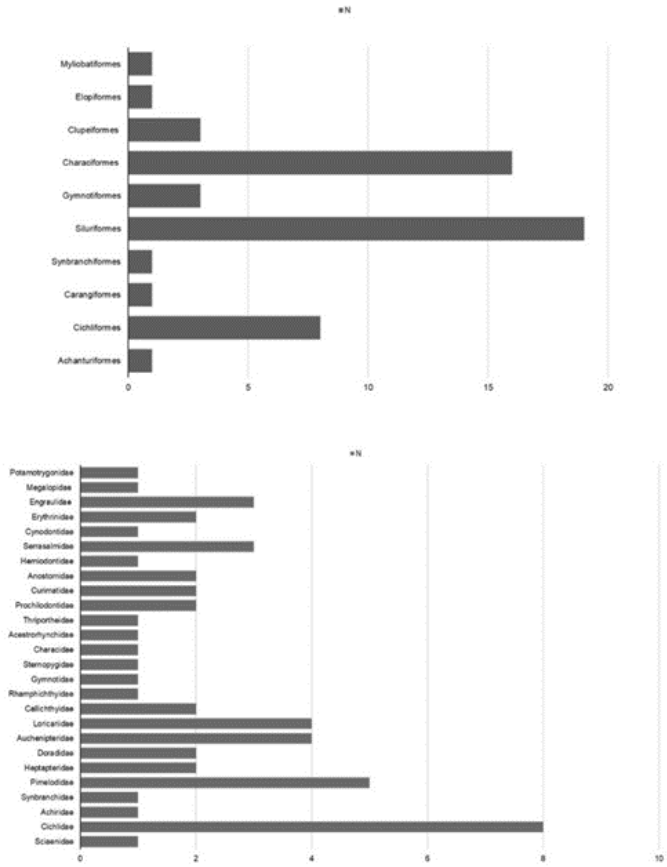

Figure 2. Graphs representing the ichthyofauna of the Baixada Maranhense lakes with emphasis on A- the orders Siluriformes, Characiformes and Cichlifomes with the highest number of species and B- the families Cichlidae, Pimelodidae, Auchenipteridae and Locariidae with the highest number of species.

Regarding species, the most abundant were *Hoplias malabaricus* (n=1026), *Cichlasoma zarskei* (n= 694), *Curimata macrops* (n=354). The greatest richness was recorded in the dry period (50 species) compared to the rainy period (47 species). During the dry season, the highest absolute abundance values were recorded (n=2845), with greater dominance of individuals belonging to the orders Characiformes (n=1296), Cichliformes (n=647) and Gymnotiformes (n=27) and in the rainy season, lower abundance (n=1718), with dominance of the orders Characiformes (n=1019), Clupeiformes (n=219) and Gymnotiformes (n= 53).

Regarding frequency of occurrence, the constant species were *Hoplias malabaricus*, and *Pygocentrus nattereri* (58%), *Plagioscion squamosissimus* (54%), *Schizodon dissimilis* (52%) and *Serrasalmus rhombeus* (50%). The moderate ones were *Geophagus surinamensis* (46%) and *Triportheus signatus* (40%), *Curimata macrops* and *Loricaria cataphracta* (38%). The less constant species were *Pterengraulis athrerinoides* and *Loricariichthys* sp. (28%), *Hoplerythrinus unitaeniatus*, *Ageneisus ucayalensis* and *Cichla monoculus* (26%) and the rare species were *Potamotrygon motoro, Lycengraulis* sp., *Hoplosternum littorale, Pimelodus ornatus, Mugil* sp., *Achirus lineatus* and *Oreochromis niloticus* (2%).

In relation to taxonomic diversity, we can highlight in descending order the lakes Viana, Cajari and Aquiri, distinct from the lakes Coqueiro and Itans. The hill number q=0 indicates that Lake Viana presented greater taxonomic richness, grouped with Lake Cajari. Although the Hill number q=1 point greater diversity in Lake Cajari.

Highlighting here, a different pattern found between the grouping of pre-confluence and confluence lakes of the SLPM, and the post-confluence lakes. This pattern repeats itself when comparing the hydrological cycle of floods and droughts in general. (Figure 3)

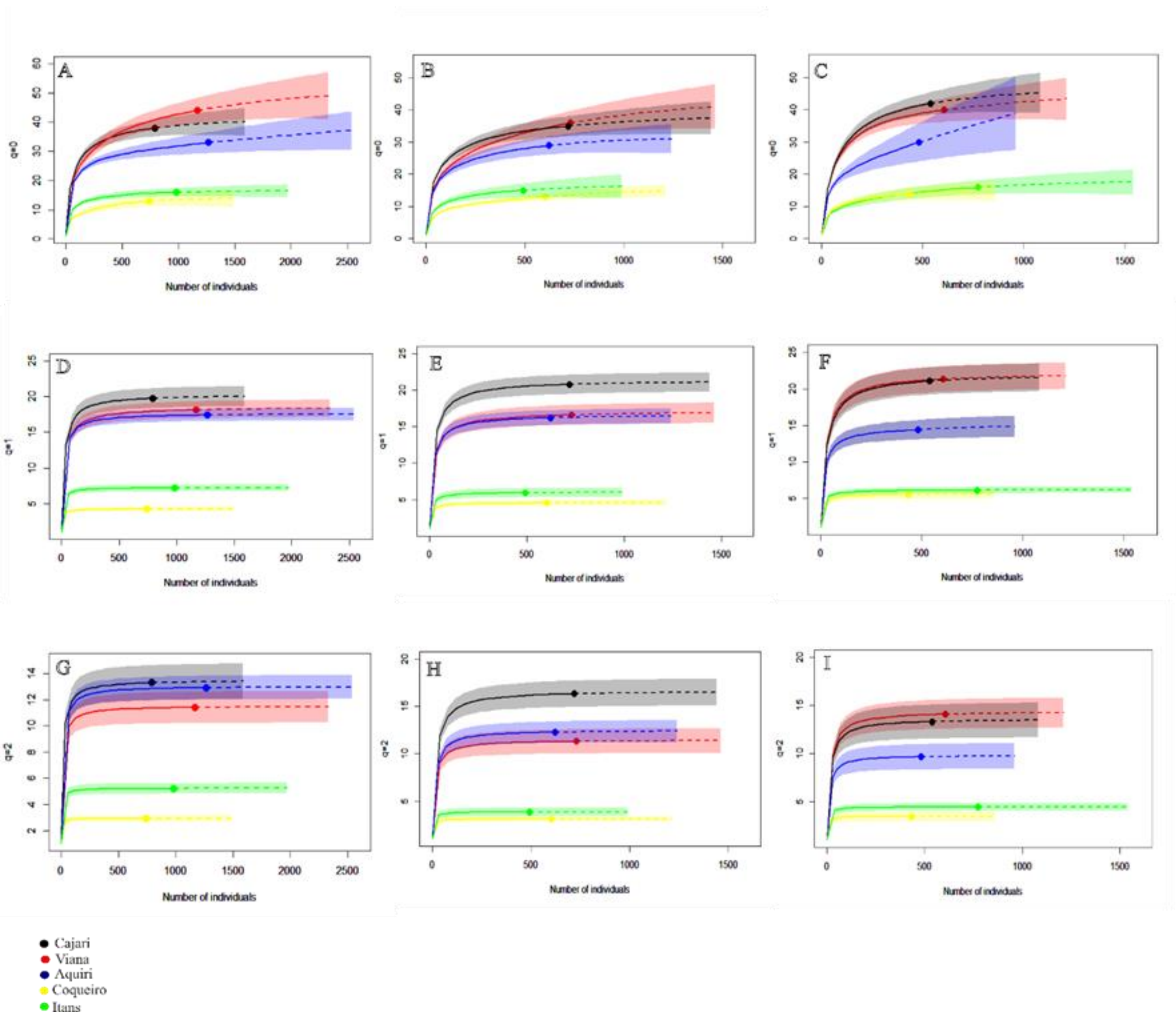

Figure 3. Plots of rarefation (solid lines) and extrapolations (dashed lines), and 95% confidence intervals (shaded areas) for fishes diversity in lakes Cajari (black), Viana (red), Aquiri (blue), Coqueiro (yellow) and Itans (green) of first three Hill numbers for species diversity: species richness (q=0) A - All campaigns B- Rain C- Dry, Shannon diversity (q=1) D- All campaigns E- Rain F- Dry and Simpson diversity (q=2), G- All campaigns H- Rain I- Dry.

For abiotic parameters, the lakes presented O.D values that varied from 4.53 to 6.43 and pH with averages ranging from 4.7 to 6.8. The variation occurred from 18.02 mm in the dry period to 242.34 mm in the rainy period and the temperature varied from 31.4 to 35.18 in the sampling period. There was no variation in variation and temperature parameters among the lakes sampled.

Also noteworthy is the presence of non-native species at the Baixada Maranhense Ramsar Síte, namely, two species of the genus *Cichla* Bloch & Schneider 1801, *Cichla monoculus* Spix & Agassiz 1831 and *C. kelberi* Kullander & Ferreira 2006 and two species of tilapia, *Oreochromis niloticus* and *Oreochromis mossambicus*

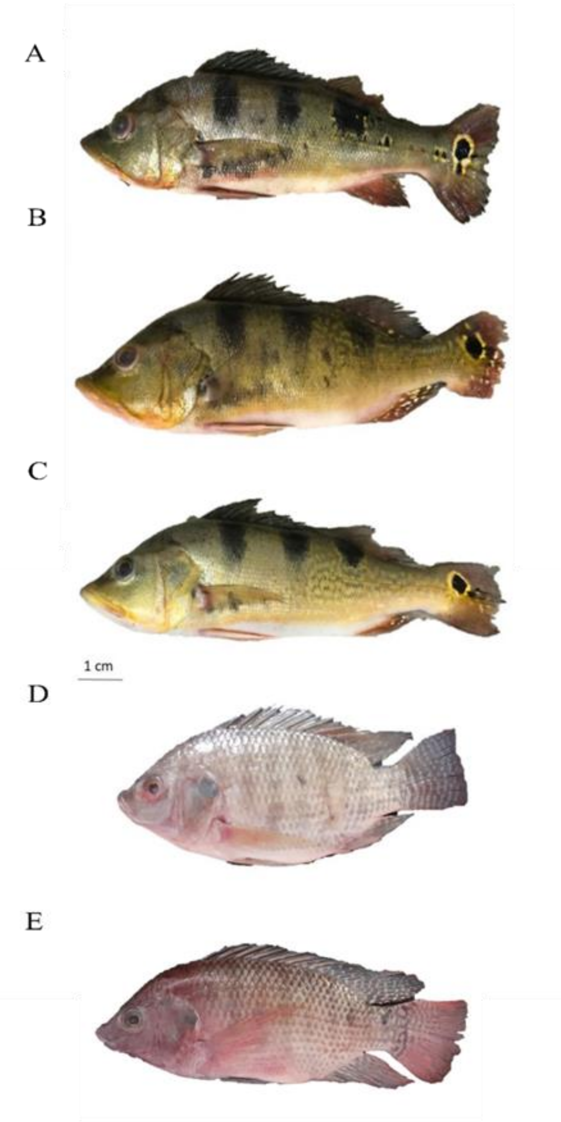

Figure 4. Non-native species collected in the Lakes of the Ramsar Site of Baixada Maranhense: A- Cichla monoculus, B and C- Cichla kelberi, D- Oreochromis niloticus, E- Oreochromis mossambicus

4. DISCUSSION

Our results demonstrate that the lakes studied here can be considered as possible shelter, feeding and reproduction areas for fish from the Pindaré-Mearim lacustrine system, since around 40% of the species recorded for this river basin [31] were found in this inventory.

As these are specific areas that suffer periods of disconnection from the main rivers, a lower species richness is expected than that recorded for the entire hydrographic basin, for example, which includes different environments such as rivers, streams and lakes. Abreu et al. [32] recorded

100 species for the basin, while Guimarães et al. [33] recorded 100 species only for the Pindaré river, one of the main rivers that make up this hydrographic system. In the most recent survey, this number was increased to 136 species [31]

The richness of ichthyofauna in the Pindaré-Mearim lake system can be considered low in comparison to Amazonian inventories, such as that carried out by Guimarães et al. [33], with 101 species identified. This difference must be considered that the local scope of the inventory includes environments of rivers, streams and lakes, distributed across 28 sampling points, while here we consider a limited region of six lakes.

In this way, we can consider other works carried out in Amazonian lakes that obtained a variation in richness compatible with the data found here. Like Gomes et al. (2016) who identified an average of 79 to 26 species in thirteen Amazonian lakes, Silva (2021) who identified 54 species in Lake Papucu, Amazonas, and Freitas et al. (2013) who identified 55 species in the five lakes of the Solimões River.

We also highlight that this compatibility refers to floodplain lakes in the central Amazon, such as the Comada, Praia, Tracajá lakes (Yamamoto, 2004) in contrast to the black water lakes that presented a high diversity (Farias et al. 2018)

Regarding the representation of this diversity, the orders Siluriformes, Characiformes and Cichliformes stand out, which is expected for the Neotropical region, as well as for the Amazon according to Polaz et al. (2014), Reis et al. (2016), Pereira et al. (2019), among others. For the Amazon region, the three main groups that concentrate the region's species are recent: Siluriformes, Characiformes and Cichliformes (Bevilaquia; Soares, 2014, Santos et al. 2006), Morales (2011) corroborated by Silva (2021). Surveys carried out in Maranhão also corroborate this result (Piorski et al., 1998; Ramos et al., 2005, 2014; Barros et al., 2011 Abreu et al., 2019; Koerber et al., 2020).

Another important aspect to be addressed is that this region is extremely complex, presenting diverse environments, such as estuaries, lakes, rivers and floodplains, with high diversity and fishing productivity that provides food for the region's population (Ibañez et al., 2000) and in lakes for commercial use, Siluriformes have a greater representation than in lakes for preservation and management, according to (2019)

It is important to highlight that this pattern changes throughout the lakes' flood pulse, in the dry period we can highlight Curimatidae (n=), and), while in the flood period we highlight the families Serrasalmidae (n= 197), Engraulidae (n = 177) and Auchenipterity (n= 172).

In relation to the most numerous families, we can highlight the Cichlidae (n=1346), Erythrinidae (n=1168) and Serrasalmidae (n=722). This pattern, although it does not agree with what is expected for the Neotropical region, can be justified by the geomorphology of lakes which, similar to African lakes, present a high diversity of cichlids, for example (), also considering that the richness of cichlids is positively associated with quality environmental

We also recorded the invasive species *Cichla monoculus*, *Cichla kelberi*, *Oreochromis niloticus* and *Oreochromis mossambicus* highlighting the importance of carrying out studies that evaluate in detail the impact of these introductions on the local ecosystem as they are highlighted by Almeida-Funo, Pinheiro & Monteles [51] as tensors environmental issues in Baixada Maranhense, in addition to the dams, the introduction and proliferation of the Malaysian giant shrimp (*Macrobrachium rosembergii*).

The occurrence of exotic species of the genus *Cichla* is recorded in our data, and, due to the complexity of the group, it showed discordant inferences between the identification techniques used. The peacock bass is a problematic case for morphological identification, since the species have a reasonable variation and there are morphotypes within these species (Mourão 2013). Kullander et al. [53] states that many authors describe these morphotypes as species or subspecies. For a taxon introduced in most Brazilian basins, this difficulty in identification sets precedents for management actions to be applied incorrectly, due to the fact that, in some cases, it is not the introduction of just one species, but as we inferred for the Baixada Maranhense, two species.

In reference to the group's problems, Willis et al. [54] consider five species of peacock bass to be valid: *Cichla monoculus*, *Cichla ocellaris*, *Cichla temensis*, *Cichla intermedia* and *Cichla orinocensis*, however Kullander & Ferreira [55] revised the genus *Cichla* and further validated nine new species, among them: *Cichla kelberi and Cichla piquiti*. For the latter authors, *Cichla* *kelberi* was mistakenly identified as *Cichla monoculus* and *Cichla ocellaris*, due to their morphological similarities. Mourão (2013) genetically characterizes the species *Cichla kelberi* and *Cichla piquiti*, using the PCR-RFLP technique, in addition to comparing the morphological identifications using the COI gene and RAG1. Morphological and genetic differences support species differentiation.

The peacock bass specimens collected in the study area presented three distinct morphotypes, one of which was identified as *Cichla monoculus* by morphological analysis. However, molecular identification found that despite the phenotypic variation, the specimens belong to two species: *Cichla monoculus* and *Cichla kelberi*.

The occurrence of these exotic species is justified by the increasing number of fish farms in the collection municipalities, also verified by Piorski et al. (2003) who previously recorded *Cichla ocellaris* for the Pindaré River. Leão et al. [57] carried out a survey of species introduced in the Brazilian Northeast, indicating Cichla ocellaris and *Cichla monoculus* as species used in fish farming.

Yellow peacock bass (*Cichla monoculus* and *Cichla kelberi*) are predators and, like most invasive species, resistant to environmental variations [58,59]. Agostinho et al. (2007), when studying the impact of introducing *Cichla kelberi* into the Paranapanema River, they found a reduction in the diversity of native fish. Leão et al. (2011) consider the introduction of peacock bass and tilapia to be the most serious cases of species introduction in northeastern Brazil. In Minas Gerais, around 50% of the richness of native species was documented 10 years after the introduction of peacock bass [61,62]. A worrying fact, as in Baixada Maranhense there is no record of the diversity and richness prior to the introduction of these species.

Another invasive species recorded for the area was *Oreochromis mossambicus* and *Oreochromis niloticus*. Piorski et al [14], despite recording *Oreochromis*, did not define the species of occurrence for this genus. In the inventory for the Mearim and Pindaré rivers carried out by

In 1953, Brazil imported specimens of *Oreochromis rendalli* for fish farming in the State of São Paulo, with the government's encouragement of aquaculture, *Oreochromis niloticus* was introduced into tanks in the Northeast region [63,57] and in 1981 a strain modified from *Oreochromis mossambicus*, the red tilapia.

The species found in the lowland lakes is *Oreochromis mossambicus*, bringing direct implications to the dynamics of the lakes, since in the flood cycle they can be interconnected

5. CONCLUSION

The development of this study is necessary for numerous reasons, such as knowledge of biodiversity and preservation, mainly because fishing is the main economic activity in the area. In addition to the exploitation of several species being evident over the years, the intensification of human activities such as rice cultivation and buffalo breeding, and consequent environmental degradation, introduction of non-native species, some sensitive species tend to disappear before they are even known. In this way, this work contributes to management prognoses, studies of reproductive biology, food, fishing, production chain, among others.

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