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Ichthyofauna in Three Reservoirs of the Apodi-Mossoró River, Brazilian Semiarid, Before the Transposition of the São Francisco River

Ictiofauna em três reservatórios do Rio Apodi-Mossoró, semiárido brasileiro, antes da transposição do Rio São Francisco

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Abstract: The São Francisco River Transposition Project may impact receiving reservoirs due to changes in environmental characteristics and the potential introduction of new species, leading to biotic homogenization and alterations in water features. This study aimed to analyze fish composition in three reservoirs (Santa Cruz, Umari, and Pau dos Ferros) in the Apodi-Mossoró River basin before transposition. Quarterly sampling at various locations was conducted using gillnets. Fish were identified and assessed based on their origin (native, allochthonous, or exotic). Species accumulation curves were generated for each reservoir to evaluate the capture methodology's effectiveness, estimating species richness over months. Twenty-two species belonging to 11 families and three orders were recorded, with 81.82% being native, 13.64% allochthonous, and 4.54% exotic. Characiformes was the most representative order, followed by Perciformes and Siluriformes. The most diverse families within these orders were Characidae, Cichlidae, and Loricariidae. Similarity in abundance was observed among native, allochthonous, and exotic species across reservoirs. Considering the scarcity of taxonomic composition studies in semi-arid ecosystems, this research provides a significant reference for future studies on native fish conservation.

Keywords: Conservation; Northeast; Fish.

Resumo: O projeto de Transposição do Rio São Francisco poderá afetar os reservatórios receptores devido à modificação das características ambientais e a possível introdução de novas espécies, ocasionado a homogeneização biótica e das características da água. Este estudo teve como objetivo analisar a composição de peixes em três reservatórios (Santa Cruz, Umari e Pau dos Ferros) da bacia do Rio Apodi-Mossoró antes da transposição. A amostragem foi realizada trimestralmente em vários pontos, utilizando redes de emalhar. Os peixes foram identificados e avaliados quanto a sua origem (nativos, alóctones e exóticos). Para avaliar a eficácia da metodologia de captura, foram geradas curvas de acumulação de espécies para cada reservatório, estimando a riqueza de espécies ao longo dos meses. Foram registradas 22 espécies pertencentes a 11 famílias e três ordens, sendo 81,82% nativas, 13,64% alóctones e 4,54% exóticas. A ordem Characiformes foi a mais representativa, seguida por Perciformes e Siluriformes. As famílias mais diversas foram Characidae, Cichlidae e Loricariidae. Houve similaridade na abundância de espécies nativas, alóctones e exóticas entre os reservatórios. Considerando a escassez de estudos sobre a composição taxonômica em ecossistemas semiáridos, os resultados deste estudo fornecem uma referência importante para futuras pesquisas sobre a conservação de peixes nativos.

Palavras-chave: Conservação; Nordeste; Peixes.

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1. Introduction

The São Francisco River Transposition Project presents significant environmental impacts on reservoirs and rivers in the semi-arid region of Northeast Brazil. Changes in hydrological regimes, ecosystem degradation, and effects on fauna, flora, water, and soil quality resulting from the construction of canals, dams, and pumping stations are crucial factors in this process (ROSSITER et al., 2021). Furthermore, transposition plays a relevant role in homogenizing the physical and chemical characteristics of water (LUCENA BARBOSA et al., 2021). The transposition project may have negative impacts on the region's ecology, including the introduction of exotic species and alterations in fish assemblages in the receiving basins (SILVA et al., 2023). Modifications in the availability of food resources, changes in reproductive conditions, and competition with native species are among the key factors influencing the composition and population dynamics of local ichthyofauna (TERRA et al., 2021).

Non-native species pose a significant threat to global biodiversity, having altered native communities in various regions (GAVIOLI et al., 2019). The replacement of endemic and native species by widely spread exotic species has been the main driver of biological homogenization due to their ease of establishment in introduction areas (JIANG et al., 2019). As discussed by Moi et al. (2021), species introduction also results in the impoverishment of ecosystem multifunctionality and leads to the homogenization of fish species over time.

Connecting different aquatic systems, species dispersal between these water bodies promotes biotic homogenization, divided into taxonomic, genetic, and functional categories (*e.g.*, OTTO et al., 2020), and the colonization of new habitats. This could result in increased similarity in species composition and community structure of fish, reducing differences between rivers and reservoirs in the affected region (BRITO; DAGA; VITULE, 2020). Furthermore, the loss of genetic diversity may reduce the adaptive capacity of fish populations to future environmental changes (MARQUES; CUNICO, 2021).

The São Francisco River transposition to the region presents different mechanisms that can influence the diversity of local ichthyofauna. Propagule pressure, such as the introduction of exotic species, can alter fish community composition and negatively affect native species (PEOPLES et al., 2020). Additionally, transposition creates a new dispersal route, allowing fish species to colonize new habitats and promote genetic mixing between different populations. It is essential to consider that transposition may also result in the breaking of natural physical barriers in the São Francisco River basin, which could negatively impact genetic diversity, population structure, and, primarily, gene flow (migration) (*e.g.*, PIMENTEL et al., 2020).

Considering the lack of detailed knowledge about taxon distribution in the Northeast region represents a significant challenge for understanding the biogeography and freshwater fish diversity in this area (RAMOS et al., 2013). The present study aims to document fish assemblages in three reservoirs (Santa Cruz, Umari, and Pau dos Ferros) located in the Apodi-Mossoró River basin, Rio Grande do Norte, Brazil, which receive water from the São Francisco River, before transposition.

2. Methodology

The study area is characterized by a hot semi-arid climate (BSh) according to the Köppen climate classification (RAMALHO, 2013). This region experiences a high average annual temperature, typically above 25°C, and an annual average precipitation ranging between 300 and 800 mm. The Apodi-Mossoró River basin, the largest in Rio Grande do Norte, covers an area of 14,276 km², accounting for 27% of the state's territory (IGARN, 2009).

The research was conducted in the three main reservoirs of the Apodi-Mossoró River basin: Santa Cruz, Umari, and Pau dos Ferros (Figure 1). Santa Cruz and Pau dos Ferros reservoirs are formed by the Apodi-Mossoró River dam, with a hydrographic basin of 4,264.00 km², while the Umari reservoir is formed by the Carmo River dam, with a hydrographic basin of 1,533.00 km² (ANA, 2007).

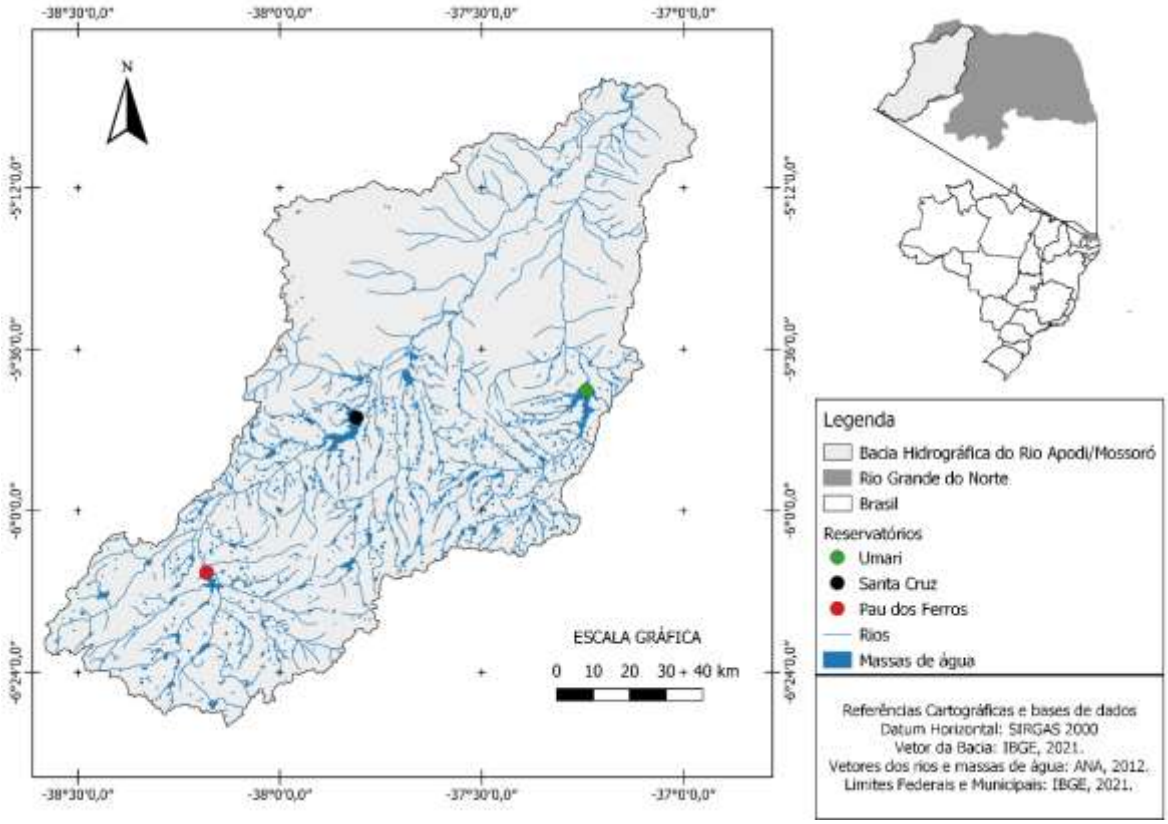

Figure 1 – Location of the Santa Cruz, Umari, and Pau dos Ferros reservoirs in the Apodi-Mossoró River basin, Northeast Brazil.
Source: The current authors (2023)

The fish sampling was authorized (SISBIO no. 27046) and conducted quarterly between February and November at various sites distributed across the reservoirs. Eleven gill nets with mesh sizes ranging from 12 to 70 mm, totaling 301.8 m², were used. The nets were set at 5:00 PM, inspected at 11:00 PM, and the fish were removed at 5:00 AM. Sampling occurred in the following years: 2010 to 2016 in Santa Cruz (8 sites); 2013 and 2014 in Umari (5 sites); and 2011 and 2012 in Pau dos Ferros (4 sites).

Fish were identified in the laboratory, and the species' origin was classified as native (from the semi-arid hydrographic basin), allochthonous (introduced from other Brazilian basins), and exotic (originating from basins in other countries), following the categories proposed by Rosa et al. (2003) and Nascimento et al. (2014). Some samples were sent to a taxonomist and deposited in the ichthyology collection at the Federal University of Paraíba (UFPB: 8933-8997).

The efficiency of the capture method was assessed through a rarefaction-based sample analysis, using a species accumulation curve. This approach estimates species diversity concerning the collection months, evaluating the rate of new species inclusion with increased sampling effort. The curve was generated using PAST software version 4.13 (HAMMER, 2023), applying the "Mao tau" analytical solution and considering standard deviation (with standard errors converted to 95% confidence intervals).

3. Results and Discussion

In the three reservoirs (Santa Cruz, Umari, and Pau dos Ferros) of the Apodi-Mossoró River basin in the Brazilian semi-arid region, a stabilization in the species accumulation curve was observed at different sampling points. Specifically, in Santa Cruz, this stabilization occurred at the seventeenth collection, while in Umari and Pau dos Ferros, it occurred at the seventh collection, indicating that no new species were captured over time (Figure 2).

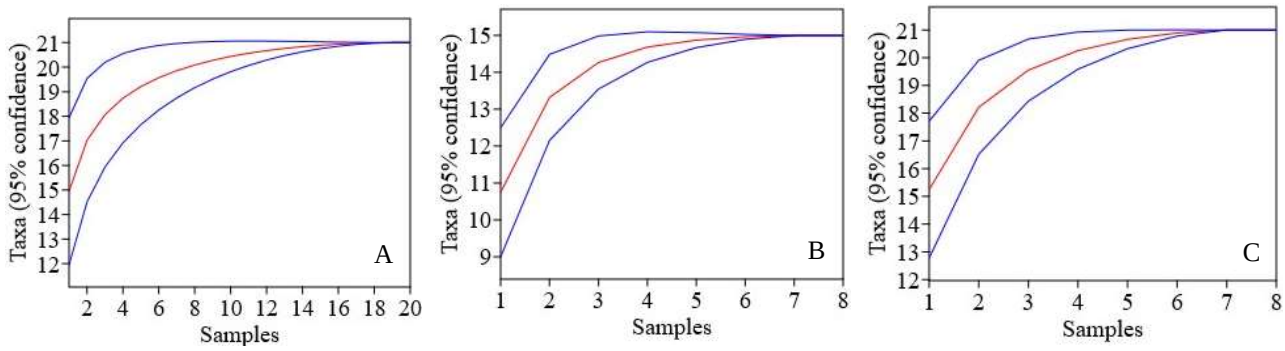

Figure 2 – Species accumulation curve (red line), 95% confidence intervals (blue line) for the Santa Cruz (A), Umari (B), and Pau dos Ferros (C) reservoirs in the Apodi-Mossoró River basin, Northeast Brazil.
Source: The current authors (2023)

Twenty-two fish species were found in the three analyzed reservoirs, distributed among 19 genera, 11 families, and four orders (Table 1). The majority of species (82%) are native to the region, indicating the significant presence of local biodiversity in the reservoirs. However, the occurrence of allochthonous (14%) and exotic species (4%) was observed. The order Characiformes was the most representative (54%, with six families, nine genera, and 12 species), followed by Cichliformes (23%, with one family, five genera, and five species) and Siluriformes (18%, with three families, four genera, and four species), while Perciformes had minimal representation, with only one species (0.5%).

Table 1 – List of fish species present in the Santa Cruz (SC - 1), Umari (UM - 2), and Pau dos Ferros (PF - 3) reservoirs, Apodi-Mossoró River basin, Northeast Brazil. Origin: native (Na), allochthonous (Al), and exotic (Ex).

Taxonomic Group	Location (Origin)	Catalog
Order Characiformes (6)		
Curimatidae (2)		
1. *Curimatella lepidura* (Eigenmann & Eigenmann, 1889)	1, 2, 3 (Na)	8969 UFPB
2. *Steindachnerina notonota* (Miranda Ribeiro, 1937)	1, 3 (Na)	8949 UFPB
Prochilodontidae (1)		
3. *Prochilodus brevis* Steindachner, 1875	1, 2, 3 (Na)	8974 UFPB
Characidae (5)		
4. *Astyanax* aff. *bimaculatus* (Linnaeus, 1758)	1, 2, 3 (Na)	8965 UFPB
5. *Astyanax fasciatus* (Cuvier, 1819)	1, 3 (Na)	8980 UFPB
6. *Moenkhausia dichroura* (Kner, 1858)	1, 2, 3 (Na)	8958 UFPB
7. *Moenkhausia costae* (Steindachner, 1907)	1, 3 (Na)	8979 UFPB
8. *Psellogrammus kennedyi* (Eigenmann, 1903)	3 (Na)	8964 UFPB
Triportheidae (1)		
9. *Triportheus signatus* (Garman, 1890)	1, 2 (Na)	8982 UFPB
Anostomidae (2)		
10. *Leporinus piau* Fowler, 1941	1, 2, 3 (Na)	8967 UFPB
11. *Leporinus taeniatus* Lütken, 1875	1, 3 (Na)	8937 UFPB
Erytrinidae (1)		
12. *Hoplias* gr. *malabaricus* (Bloch, 1794)	1, 2, 3 (Na)	8946 UFPB
Order Perciformes (1)		
Sciaenidae (1)		
13. *Plagioscion squamosissimus* (HECKEL, 1840)	1, 2, 3 (Al)	8966 UFPB
Order Cichliformes (1)		
Cichlidae (5)		
14. *Cichlasoma orientale* Kullander, 1983	1, 3 (Na)	8939 UFPB
15. *Cichla monoculus* Spix & Agassiz, 1983	1, 2, 3 (Al)	8955 UFPB

16. *Crenicichla brasiliensis* (Bloch, 1972)	1, 2, 3 (Na)		8935 UFPB
17. *Oreochromis niloticus* (Linnaeus, 1758)	1, 2, 3 (Ex)		8986 UFPB
18. *Astronotus ocellatus* (Agassiz, 1831)	1, 2 (Al)		8960 UFPB
Order Siluriformes (3)			
Loricariidae (2)			
19. *Loricariichthys* sp.	1, 3 (Na)		8942 UFPB
20. *Hypostomus pusarum* (Starks, 1913)	1, 2, 3 (Na)		8934 UFPB
Auchenipteridae (1)			
21. *Trachelyopterus galeatus* (Linnaeus, 1766)	1, 2, 3 (Na)		8961 UFPB
Heptapteridae (1)			
22. *Pimelodella dorseyi* Fowler, 1941	1, 2, 3 (Na)		8940 UFPB
Total	**SC**	**UM**	**PF**
Species	21	15	20
Genera	18	15	17
Families	11	11	10
Orders	4	4	4

Source: The current authors (2023)

These results are consistent with studies conducted in dams in the semi-arid region of Rio Grande do Norte, where Characiformes and Cichliformes were also the most representative orders. In the Trairí River basin, a similar pattern was observed, with Characiformes being the most representative order, followed by Siluriformes and Cichliformes (MEDEIROS et al., 2019). Within the Characiformes order, there was a prevalence of a group of small fish from the Characidae family, locally known as tetras, including *Astyanax* aff. *bimaculatus* (Linnaeus, 1758), *Astyanax fasciatus* (Cuvier, 1819), *Moenkhausia dichroura* (Kner, 1858), *Moenkhausia costae* (Steindachner, 1907), and *Psellogrammus kennedyi* (Eigenmann, 1903). Tetras are opportunistic in the reservoir colonization process due to their low longevity and high reproductive rate (ABUJANRA; AGOSTINHO; HAHN, 2009). Studies conducted by Oliveira et al. (2016a) in Santa Cruz and Oliveira et al. (2016b) in Pau dos Ferros highlighted those dry conditions in the reservoirs led to the accumulation of resources such as organic matter and debris, favoring the establishment of detritivores from the Loricariidae, Curimatidae, and Prochilodontidae families. This indicates that these families have a lower probability of local extinction, even under unfavorable environmental conditions.

The higher number of species in the Santa Cruz (N = 21) and Pau dos Ferros (N = 20) reservoirs, compared to the Umari reservoir (N = 15), can be explained by the species-area relationship, which characterizes the increase in the number of species with the increment of the area (O'DWYER; GREEN, 2010). This occurs because the Santa Cruz and Pau dos Ferros reservoirs are located in the Apodi River (larger area), while the Umari reservoir is situated in the Carmo River (smaller area), as shown in Figure 1. The analysis of species richness in the Santa Cruz (11 families, 18 genera, and 21 species) and Pau dos Ferros (10 families, 17 genera, and 20 species) reservoirs reveals a similarity in the ichthyofauna composition. Both reservoirs show significant overlap, with proximity in terms of families, genera, and species found. This similarity can be attributed to factors such as similar environmental conditions and geographic proximity (Figure 1), as well as water flow between the reservoirs during floods (Santa Cruz receives water from the Pau dos Ferros reservoir during overflow). In the review article on the ichthyofauna of the hydrographic basins of Rio Grande do Norte, conducted by Nascimento et al. (2014), a total of 51 species were found, of which 20 are present in the Apodi-Mossoró River. However, introduced species were not recorded by the authors.

The relationship between species introduction and the richness of Cichliformes in the semi-arid region is significant. Of the five representatives of this order, three (*Cichla monoculus*, *Oreochromis niloticus*, and *Astronotus ocellatus*) were introduced through stocking programs by DNOCS (*e.g.*, Leão et al., 2011). Information available on the impacts caused by fish introduction in Northeast Brazil, especially in the semi-arid reservoirs of Rio Grande do Norte, is still limited. Molina et al. (1996) observed that the peacock bass, *Cichla ocellaris* (Bloch & Schneider, 1801), after being introduced into Lagoa Redonda, Rio Grande do Norte, quickly extinguished several populations of native fish. Therefore, an introduced species of peacock bass (*Cichla monoculus*) recorded in the three studied reservoirs may be competing with native species, but due to the lack of information before its introduction or additional studies, it is not possible to determine the impact it may be causing.

Another introduced species occurring in the three reservoirs is the Nile tilapia (*Oreochromis niloticus*). A study in the Gargalheiras reservoir, Rio Grande do Norte, showed that after the introduction of Nile tilapia, there was a reduction in

the abundance of other species (ATTAYDE; BRASIL; MENESCAL, 2011). One of the impacts is the reduction of zooplankton and an increase in phytoplankton abundance, which decreases water transparency, inhibiting the recruitment of other fish species that primarily feed on zooplankton (ATTAYDE et al., 2007). Moura et al. (2018) studied the biomanipulation process in the Serra Negra Ecological Station reservoir by introducing *O. niloticus*. The authors observed a change in the diet composition of native species. Therefore, in the long term, the presence of Nile tilapia may have altered the local trophic structure and negatively influenced bottom-up and top-down effects in the introduced semi-arid environments. Similarly, the transposition of the São Francisco River could introduce new species and affect the ecosystem services of the receiving rivers and reservoirs.

Comparing the percentage of shared native fish species between the São Francisco River basin and the Apodi-Mossoró River basin reveals a value of 52.46%, based on the records of Silva et al. (2020) for the São Francisco basin. This indicates that just over half of the native fish species are common to these two hydrographic basins. The remaining percentage of native fish species that do not occur in the Apodi-Mossoró River basin raises concerns about potential impacts resulting from the transposition of the São Francisco River and the introduction of species into the receiving basin. Recently, the introduction of a non-native species into the Paraíba do Norte River Basin through the canal originating from the São Francisco River has been documented. This introduction poses a threat to the endemic ichthyofauna of lentic and lotic systems present in the receiving basin, as documented by Ramos et al. (2021).

Therefore, the transposition could lead to significant changes in environmental conditions, such as water quality, flow regime, and habitat availability, directly affecting native species adapted to the original characteristics of the Apodi-Mossoró basin and its reservoirs. This may result in the homogenization of physical, chemical, and biological water characteristics, leading to the loss of ecosystem services. Thus, it is crucial to establish appropriate management measures, implement continuous monitoring, and adopt conservation strategies to protect the biodiversity and integrity of the aquatic ecosystems in the semi-arid region in the face of the São Francisco transposition project.

4. Final considerations

Considering the lack of studies on taxonomic composition in the semi-arid reservoirs of Northeast Brazil, the obtained results are highly valuable and serve as a reference for the semi-arid region of Rio Grande do Norte. Following events such as the São Francisco River transposition, introduction of species, or other anthropogenic processes, this work will be of great importance for monitoring the currently present communities and those that may establish in the future. It serves as a foundation for management and conservation studies of the native ichthyofauna in the region. Therefore, it is a source of information that can support new research aiming to compare the conditions before and after the São Francisco River transposition.

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