ROSALVA SULZBACHER

FISH DISTRIBUTION IN A BASIN AFFECTED BY DAMMING: SPATIAL AND LOCAL EFFECTS SHAPING FISH ASSEMBLAGES IN STREAMS AND RESERVOIR

LAVRAS-MG
2025

ROSALVA SULZBACHER

FISH DISTRIBUTION IN A BASIN AFFECTED BY DAMMING: SPATIAL AND LOCAL EFFECTS SHAPING FISH ASSEMBLAGES IN STREAMS AND RESERVOIR

Dissertação apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ecologia Aplicada, área de concentração em Ecologia e Conservação de Recursos em Paisagens Fragmentadas e Agrossistemas, para a obtenção do título de Mestre.

Prof. Dr. Paulo dos Santos Pompeu
Orientador

LAVRAS-MG

2025

Ficha catalográfica elaborada pela Catalogação da Biblioteca Universitária da UFLA

Sulzbacher, Rosalva.
Fish distribution in a basin affected by damming: spatial and local effects shaping fish assemblages in streams and reservoir / Rosalva Sulzbacher. - 2025.
66 p. : il.

Orientador(a): Paulo dos Santos Pompeu.

Dissertação (mestrado) - Universidade Federal de Lavras, 2025.
Bibliografia.

1. Rio Grande. 2. UHE Furnas. 3. Peixes não nativos. 4. Reservatórios. 5. Riachos. I. Pompeu, Paulo dos Santos. II. Título.

Ficha elaborada por André Felipe Calsavara (CRB6/3137)

ROSALVA SULZBACHER

FISH DISTRIBUTION IN A BASIN AFFECTED BY DAMMING: SPATIAL AND LOCAL EFFECTS SHAPING FISH ASSEMBLAGES IN STREAMS AND RESERVOIR

DISTRIBUIÇÃO DE PEIXES EM UMA BACIA AFETADA POR REPRESAMENTO: EFEITOS ESPACIAIS E LOCAIS NA FORMAÇÃO DE ASSEMBLEIAS DE PEIXES EM RIOS E RESERVATÓRIOS

Dissertação apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ecologia Aplicada, área de concentração em Ecologia e Conservação de Recursos em Paisagens Fragmentadas e Agrossistemas, para a obtenção do título de Mestre.

APROVADA em 14 de fevereiro de 2025.
Dr(ª). Rafael Dudeque Zenni, Universidade Federal de Lavras
Dr(ª). Naraiana Loureiro Benone, Universidade do Estado de Minas Gerais

Prof. Dr. Paulo dos Santos Pompeu
Orientador

LAVRAS-MG

2025

AGRADECIMENTOS

Agradeço, de forma especial, a quem esteve comigo desde sempre. A quem me trouxe até aqui e em nenhum momento sequer me desamparou. Ao meu Pai do céu, obrigada por tudo e por tanto. À minha família, agradeço pelo apoio e pelo amor generoso. Porque o amor não respeita limites interestaduais. Ainda bem.

A Dissertação pronta é o resultado de muito aprendizado, leituras, coletas de dados, conversas, mais leituras… e em todos esses momentos eu tive o apoio de pessoas incríveis. Incríveis mesmo. Falando em pessoas incríveis, não tem como não começar pelo Paulo, o orientador que me acolheu tão bem desde o início, me ensinou e me ensina tanta coisa. Paulo é um professor-biólogo que inspira. E quem o conhece sabe do que eu estou falando. Obrigada Paulo. De verdade.

Agradeço também, com o coração cheio de alegria, aos companheiros de campo que se tornaram amigos nessa caminhada. Ao Cacá, Giba e Formagio, da equipe de peixes do IBI-FURNAS, por tornarem esse trabalho possível e pela amizade construída. Agradeço também aos colegas de Laboratório pelas risadas e conversas diárias. Em especial, ao Pedro. O carioca que virou meu companheiro de mestrado, de rotina, de choro e de alegrias. Obrigada por estar aqui.

Agradeço, por fim, ao financiamento que me deu a oportunidade de tornar esse trabalho possível. Ao Projeto IBI-FURNAS (Eletrobrás) pelo apoio logístico e suporte em todos os momentos. E à Fundação de Amparo À Pesquisa do Estado de Minas Gerais (FAPEMIG) pela concessão da bolsa de mestrado.

Agradeço ao Programa de Pós-Graduação em Ecologia Aplicada e à Universidade Federal de Lavras pelo apoio e suporte. E à Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG) pela concessão da bolsa de mestrado.

RESUMO

Os impactos causados por reservatórios de usinas hidrelétricas nas assembleias de peixes podem ser influenciados por diversos fatores locais e espaciais. Para além das alterações bióticas geradas pela formação do reservatório em si, os demais corpos d'água da bacia, tais como riachos, também podem ser afetados pelos barramentos. Sendo assim, o objetivo geral deste trabalho é investigar a estrutura e distribuição da assembleia de peixes do reservatório da UHE FURNAS e dos seus riachos afluentes. No capítulo 1 avaliamos como as assembleias nativas e não nativas respondem ao efeito da distância da barragem e variáveis locais de qualidade da água e habitat físico. No capítulo 2, identificamos nos riachos o papel da conectividade (medida através da distância do reservatório) e dos índices de distúrbio locais e regionais na ocorrência de espécies não nativas e na riqueza compartilhada com o reservatório. Os dados foram coletados em 40 pontos na região marginal do reservatório e em 40 riachos da respectiva bacia de drenagem. No reservatório, a distância da barragem foi a principal variável explicativa da riqueza e abundância. Para as espécies nativas, tanto a riqueza como a abundância reduziram em direção à barragem. Este mesmo padrão foi observado para a abundância de espécies não nativas. Nos riachos, o impacto local aumentou a probabilidade de ocorrência de espécies não nativas e a riqueza compartilhada, independente da distância até o reservatório. Destaca-se, desta forma, a importância de incluir variáveis locais e espaciais no estudo da ictiofauna de reservatórios, bem como avaliar a dinâmica de riachos e reservatórios de forma integrada.

Palavras-chave: rio Grande; UHE Furnas; peixes não nativos; reservatório; riachos.

ABSTRACT

The impacts of hydroelectric reservoirs on fish assemblages can be influenced by several local and spatial factors. In addition to the biotic changes caused by the formation of the reservoir itself, other water bodies in the basin, such as streams, can also be affected by damming. The main goal of this study is to investigate the structure and distribution of fish assemblages in the UHE FURNAS reservoir and its tributary streams. In the chapter 1 we assesses how native and non-native assemblages respond to the effects of distance from the dam and local variables related to water quality and physical habitat. The aim of chapter 2 was identify, on streams, the role of connectivity (measured by distance to the reservoir) and local and regional disturbance indices on the occurrence of non-native species and their shared richness with the reservoir. Data were collected at 40 sites along the reservoir's shoreline and at 40 streams within the corresponding drainage basin. In the reservoir, distance from the dam was the main explanatory variable for species richness and abundance. For native species, both richness and abundance decreased towards to the dam. A similar pattern was observed for the abundance of non-native species. In the streams, local impacts increased the probability of non-native species occurrence and shared richness, regardless of distance from the reservoir. This highlights the importance of incorporating local and spatial variables in studies of reservoir's ichthyofauna, as well as considering the dynamics of streams and reservoirs in an integrated manner.

Keywords: Grande river; UHE Furnas; non-native fish; reservoir; streams.

Impactos sociais, tecnológicos, econômicos e culturais

Os impactos dos reservatórios de usinas hidrelétricas sobre as assembleias de peixes podem ser influenciados por uma variedade de fatores locais e espaciais. Além das alterações bióticas resultantes da formação do reservatório, outros corpos d’água da bacia, como os riachos, também podem ser afetados pelos barramentos. Atualmente, as usinas hidrelétricas desempenham um papel fundamental no fornecimento de energia elétrica no Brasil. No entanto, diversos estudos têm apontado os impactos negativos dos barramentos sobre a ictiofauna local. Um dos principais efeitos observados é a redução das populações de peixes de maior porte, que são essenciais para a pesca artesanal em comunidades ribeirinhas. Além do próprio reservatório, os demais corpos d’água da bacia hidrográfica, como os riachos, podem sofrer alterações em função da presença dos barramentos. Diante desse cenário, o estudo da ictiofauna em bacias hidrográficas com hidrelétricas é essencial para compreender a magnitude desses impactos e para subsidiar estratégias de mitigação, tanto do ponto de vista ecológico quanto socioeconômico. Este estudo teve como objetivo investigar a estrutura e a distribuição da assembleia de peixes do reservatório da UHE Furnas e de seus riachos afluentes. Especificamente, avaliamos como as assembleias de espécies nativas e não nativas respondem à distância da barragem e às variáveis locais relacionadas à qualidade da água e ao habitat físico. Além disso, analisamos, nos riachos, o papel da conectividade e dos índices de distúrbio locais e regionais na ocorrência de espécies não nativas e na riqueza compartilhada com o reservatório. No reservatório, a distância da barragem foi a principal variável explicativa da riqueza e da abundância de peixes. Para as espécies nativas, ambas as métricas diminuíram em direção à barragem. Esse mesmo padrão foi observado para a abundância de espécies não nativas. Nos riachos, o impacto local aumentou a probabilidade de ocorrência de espécies não nativas e a riqueza compartilhada, independentemente da distância em relação ao reservatório. Os resultados deste estudo ressaltam a importância de considerar variáveis locais e espaciais na análise da ictiofauna de reservatórios, bem como a necessidade de avaliar a dinâmica entre riachos e reservatórios de forma integrada. Do ponto de vista socioeconômico, os achados indicam que o gradiente espacial do reservatório deve ser considerado no planejamento e na implementação de estratégias de recuperação da ictiofauna nativa, especialmente no que se refere às espécies de maior porte exploradas pela pesca. Este estudo insere-se na área temática de meio ambiente da Política Nacional de Extensão e seus resultados estão alinhados ao Objetivo de Desenvolvimento Sustentável 14 – Vida na Água (ODS/ONU).

Social, technological, economic and cultural impacts

The impacts of hydroelectric reservoir construction on fish assemblages can be influenced by a variety of local and spatial factors. In addition to the biotic changes resulting from reservoir formation, other water bodies within the basin, such as streams, may also be affected by damming. Currently, hydroelectric plants play a fundamental role in electricity generation in Brazil. However, several studies have highlighted the negative impacts of damming on local ichthyofauna. One of the most significant effects observed is the decline of large-bodied fish populations, which are essential for artisanal fisheries in riverine communities. Beyond the reservoir itself, other water bodies within the hydrographic basin, such as streams, may undergo alterations due to the presence of dams. Given this scenario, studying ichthyofauna in hydrographic basins with hydroelectric plants is crucial to understanding the magnitude of these impacts and informing mitigation strategies from both ecological and socio-economic perspectives. This study aimed to investigate the structure and distribution of the fish assemblage in the Furnas Hydroelectric Reservoir and its tributary streams. Specifically, we evaluated how native and non-native fish assemblages respond to dam distance and local variables related to water quality and physical habitat. Additionally, we analyzed, within streams, the role of connectivity and local and regional disturbance indices in the occurrence of non-native species and in the richness shared with the reservoir. In the reservoir, dam distance was the main explanatory variable for fish richness and abundance. For native species, both richness and abundance decreased toward the dam. The same pattern was observed for the abundance of non-native species. In streams, local disturbance increased the likelihood of non-native species occurrence and shared richness, regardless of the distance from the reservoir. The findings of this study highlight the importance of incorporating both local and spatial variables in the analysis of reservoir ichthyofauna, as well as the need for an integrated assessment of stream and reservoir dynamics. From a socio-economic perspective, the results indicate that the spatial gradient of the reservoir should be considered in the planning and implementation of native ichthyofauna recovery strategies, particularly for large-bodied species exploited by fisheries. This study falls within the environmental theme of the National Extension Policy, and its findings align with Sustainable Development Goal 14 – Life Below Water (SDG/UN).

SUMÁRIO

PRIMEIRA PARTE

1 INTRODUÇÃO GERAL

A maior parte das bacias de drenagens brasileiras estão impactadas por barramentos, e seus reservatórios apresentam ictiofauna formada essencialmente por espécies capazes de colonizar e sobreviver às novas condicões ambientais. Algumas das principais alterações impostas pelos barramentos incluem a alteração dos regimes de inundação e transformação de um ambiente lótico para lêntico, mudanças na qualidade da água, perda de habitats de desova e interrupção de rotas migratórias (Agostinho *et al*., 2015; Agostinho; Gomes; Pelicice, 2007; Agostinho; Pelicice; Gomes, 2008). A resposta das assembleias de peixes a estes impactos depende da escala temporal e espacial analisada. Espacialmente, o gradiente longitudinal em grandes reservatórios tem se mostrado um importante preditor tanto da abundância de espécies nativas (Sanches *et al*., 2016) como da riqueza de espécies nativas e não nativas (Lin *et al*., 2019). Temporalmente, uma das principais alterações na ictiofauna de reservatórios é a redução de espécies nativas e proliferação de espécies não nativas (Loures; Pompeu, 2019).

Os reservatórios, ainda que alterem a dinâmica natural dos ambientes fluviais, permanecem conectados à sua bacia de drenagem e, por conta disso, podem interferir em processos ecológicos importantes em ecossistemas aquáticos tais como os fluxos de migração e dispersão de espécies não nativas. Considerando que reservatórios são amplamente reconhecidos por abrigar espécies não nativas (Lin *et al*., 2019; Loures; Pompeu, 2019; Muniz *et al*., 2021), estes ambientes podem servir como fonte doadora de propágulos destas espécies para os demais corpos d’água da bacia, tais como riachos.

Os dados analisados nesta dissertação são parte do Projeto “Impacto Líquido Positivo: Integridade Biótica e Monitoramento Participativo para Conservação de Biodiversidade e Serviços Ecossistêmicos na UHE Furnas” financiado pela Eletrobrás e desenvolvido pela Universidade Federal de Minas Gerais (UFMG) em parceria com a Universidade Federal de Lavras (UFLA).

O primeiro capítulo encontra-se formatado de acordo com as normas da revista *Water Biology and Security*, na qual foi submetido em 04.10.2024. O estilo de formatação da revista refere-se às citações, referências bibliográficas e estruturação do texto. O restante da formatação (tipo e tamanho da fonte, espaçamento e margens) do primeiro capítulo, bem como o segundo capítulo e demais partes desta dissertação foram formatados de acordo com o manual de trabalhos acadêmicos da UFLA.

O objetivo geral deste trabalho é investigar a estrutura e distribuição da assembleia de peixes do reservatório da UHE FURNAS e dos seus riachos afluentes. No capítulo I avaliouse a resposta das espécies nativas e não nativas do reservatório ao gradiente longitudinal (distância da barragem) e variações de qualidade da água e hábitat físico. No capítulo II buscou-se compreender o papel da conectividade (distância do reservatório) e dos índices de distúrbio locais e regionais na ocorrência de espécies não nativas em riachos e no compartilhamento de espécies entre riachos e reservatório.

2 CONCLUSÃO

No reservatório de Furnas, o gradiente espacial é mais importante que os fatores locais na determinação das riquezas e abundâncias de espécies nativas e não nativas. As características limnológicas do reservatório respondem ao gradiente de distância da barragem, o que pode intensificar ainda mais este efeito espacial.

O habitat físico no reservatório teve baixo poder explicativo nos modelos de riqueza e abundância, mas parece ser um bom preditor da ocorrência de peixes. Neste sentido, o habitat pode estar servindo como refúgio para a ictiofauna local pré-existente e moldada, dentre outros fatores, pelo gradiente de distância.

O reservatório não parece estar atuando como fonte doadora de propágulos de espécies não nativas para os riachos da bacia. Por outro lado, o distúrbio local é o principal preditor da ocorrência de peixes não nativos nos riachos, enfatizando a plasticidade das espécies não nativas em colonizarem e permanecerem em ambientes perturbados.

Todas as espécies não nativas dos riachos foram compartilhadas com o reservatório, mas não o contrário. Tal fato sugere que tais espécies ou são generalistas, ou típicas de ambientes lênticos.

REFERÊNCIAS

AGOSTINHO, A. A.; GOMES, L. C.; SANTOS, N. C.; ORTEGA, J. C.; PELICICE, F. M. Fish assemblages in Neotropical reservoirs: Colonization patterns, impacts and management. **Fisheries Research**, v. 173, p. 26-36, 2015.

AGOSTINHO, A. A.; GOMES, L. C.; PELICICE, F. M. **Ecologia e manejo de recursos pesqueiros em reservatórios do Brasil**. Maringá: EDUEM, 2007.

AGOSTINHO, A. A.; PELICICE, F. M.; GOMES, L. C. Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. **Brazilian journal of biology**, v. 68, p.1119-1132, 2008.

SANCHES, B. O.; HUGHES, R. M.; MACEDO, D. R.; CALLISTO, M.; SANTOS, G. B. Spatial variations in fish assemblage structure in a southeastern Brazilian reservoir. **Brazilian Journal of Biology**, v. 76, p. 185-193, 2016.

LIN, P.; GAO, X.; LIU, F.; LI, M.; LIU, H. Long-term monitoring revealed fish assemblage zonation in the Three Gorges Reservoir. **Journal of Oceanology and Limnology**, v. 37, p. 1258-1267, 2019.

LOURES, R. C.; POMPEU, P. S. Temporal changes in fish diversity in lotic and lentic environments along a reservoir cascade. Freshwater Biology, v. 64, n. 10, p. 1806-1820, 2019.

MUNIZ, C. M.; GARCÍA-BERTHOU, E.; GANASSIN, M. J. M.; AGOSTINHO, A. A.; GOMES, L. C. Alien fish in Neotropical reservoirs: Assessing multiple hypotheses in invasion biology. **Ecological Indicators**, v. 121, p. 107034, 2021.

SEGUNDA PARTE – ARTIGOS

CAPÍTULO 01 – Artigo submetido à revista *Water Biology and Security*

The longitudinal gradient prevails over local characteristics in shaping the fish distribution in a large neotropical reservoir

Reservatório da UHE Furnas, abril de 2023.

The longitudinal gradient prevails over local characteristics in shaping the fish distribution in a large neotropical reservoir

Rosalva Sulzbacher [1]*, Gilberto N. Salvador [2], Carlos B. M. Alves [3], Paulo S. Formagio [4],
Robert M. Hughes [5, 6] and Paulo S. Pompeu [7]

[1] Programa de Pós-Graduação em Ecologia Aplicada, Departamento de Ecologia e Conservação, Instituto de Ciências Naturais, Universidade Federal de Lavras, CEP 37200-900, Lavras, MG, Brazil; rosalva.sulzbacher@estudante.ufla.br

[2] Programa de Pós-Graduação em Ecologia, Laboratório de Ecologia e Conservação, Universidade Federal do Pará, CEP 66075-110, Belém, PA, Brazil; curimata_gilbert@hotmail.com

[3] Laboratório Nuvelhas, Projeto Manuelzão, Universidade Federal de Minas Gerais, CEP 31270-901, Belo Horizonte, MG, Brazil; cbmalves@ufmg.br

[4] Biólogo Consultor do Projeto IBI-Furnas - Eletrobrás, 37900-150, Passos, MG, Brazil. formagiopaulosergio@gmail.com

[5] Amnis Opes Institute, 2895 SE Glenn, Corvallis, OR, 97333, USA; hughes.bob@amnisopes.com

[6] Department of Fisheries, Wildlife, & Conservation Sciences, Oregon State University, Nash 104, Corvallis, OR, 97331, USA; hughes.bob@amnisopes.com

[7] Laboratório de Ecologia de Peixes, Departamento de Ecologia e Conservação, Instituto de Ciências Naturais, Universidade Federal de Lavras, 37200-900 Lavras, MG, Brazil. pompeu@ufla.br

ABSTRACT: In large reservoirs, spatial gradient is the primary driver of fish fauna distribution. However, local characteristics can also influence assemblage structure. We assessed the roles of distance from the dam, water quality characteristics, and physical habitat complexity in determining the richness and abundance of native and non-native fish species in Furnas Reservoir. Sampling in April 2023, we collected 22 native and 11 non-native species, increasing the reservoir's richness to 65 species, comprising 51 native and 14 non-native species. Both the richness and abundance of native species were higher in the upper reservoir. These species were predominant throughout the entire longitudinal gradient except in the most lacustrine portion (50 km from the dam), where non-native species prevailed. Physical habitat condition had little influence in the tested models. Except for total solids, water quality variables were correlated with distance from the dam. Total solids were associated with increased richness and abundance of both native and non-native fish species. We recommend protecting riverine zones in large reservoirs, because of the greater prevalence of native species in them.

Keywords: Spacial distribution, ichthyofauna, native species, non-native species, Furnas Reservoir.

1. Introduction

Brazil stands out for its huge hydroelectric energy matrix (Pereira and Neto, 2020), with the presence of large reservoirs distributed across all its main river basins (Agostinho et al, 2015). Despite their economic benefits, reservoirs have substantial impacts on aquatic ecosystems. Their ichthyofauna effects are well-known, reflected in the composition and abundance of species, often resulting in the reduction or local extinction of rheophilic species and the proliferation of sedentary species (Pelicice et al, 2015; Agostinho et al, 2015; Lin et al, 2019; Yang et al, 2021). Because of expected ichthyofaunal alterations, several studies have sought to understand the primary drivers of fish assemblages in large hydropower reservoirs. Among these factors, spatial gradient (Gido et al, 2002; Okada et al, 2005; Lin et al, 2019), habitat complexity (Gois et al, 2012), and water quality (Gido et al, 2002; Yang et al, 2021) stand out.

One of the most well-established patterns in the literature is the longitudinal gradient inside reservoirs (Gido et al, 2002; Matthews et al, 2004; Okada et al, 2005; Oliveira et al, 2005; Smith et al, 2023). Over time, narrower and turbid riverine zones develop in upper reservoir arms, and a typically wide, deep, oligotrophic lacustrine zone develops near the dam (Araujo Lima et al, 1995; Santos et al, 2019). The riverine zones, by retaining some of the lotic characteristics and habitat complexity of natural rivers, tend to support higher species richness (Agostinho et al, 2007; Lin et al, 2019; Smith et al, 2023). Abundance follows a similar trend, decreasing towards the lacustrine zones (Gido et al, 2002; Okada et al, 2005). However, this decline is not consistent among species. The abundance variation of sedentary species does not necessarily follow the gradient, unlike migratory species, which generally decrease in lacustrine regions (Okada et al, 2005; Silva-Sene et al, 2023). Recent studies have shown that the longitudinal gradient, whether within the same reservoir or in cascading reservoir systems, also establishes different distribution patterns for native and non-native species. Sedentary and non-native species successfully colonize and persist in the intermediate and lacustrine zones (Okada et al, 2005; Agostinho et al, 2007; Lin et al, 2019). On the other hand, migratory and rheophilic species are confined to the riverine zones (Agostinho et al, 2003a; Lin et al, 2019; Yang et al, 2021; Silva-Sene et al, 2023). This species turnover occurs gradually over decades (Loures and Pompeu, 2018; 2019).

Although reservoir longitudinal gradient is an important driving factor, other factors also influence fish distribution in reservoirs, such as habitat structure and complexity (Agostinho et al, 2007). For example, wood from riparian trees can serve as shelter for fish

(Miranda, 2017) and provide food resources (Agostinho et al, 2007). So, the presence of macrophytes and submerged vegetation tends to support higher richness, biomass and abundances (Durocher et al, 1984; Bettoli et al, 1993; Agostinho et al, 2003b; Gois et al, 2012). However, even though highly complex habitats are associated with greater species richness (Agostinho et al, 2003b), foraging efficiency may be compromised in highly structured regions (i.e., high densities of macrophytes; Carniatto et al, 2020).

Water quality gradients are also important in determining biodiversity in large reservoirs (Gido et al, 2002; Yang et al, 2020) and they follow longitudinal gradients (Ribeiro Filho et al, 2011; Santos et al, 2019; Yang et al, 2021). However, depending on land use and proximity to residential areas, small regions with high nutrient concentrations may establish regardless of their position in the reservoir. In these environments, the input of nutrients regulates and enhances local productivity (Kennedy and Walker, 1990; Agostinho et al, 1999; 2007), which leads to increased richness and abundance of native and non-native fish species in reservoirs (Muniz et al, 2021). Despite nutrient contributions to assemblage structuring, untreated sewage discharges tend to raise water temperature and conductivity, thereby reducing local water quality in reservoirs (i.e., Furnas reservoir, Prado et al, 2011) and impairing aquatic ecosystems. Local trophic enrichment resulting from the discharge of domestic effluents and agricultural fertilizers often favors the abundance of non-native species, whose densities increase in such areas (Silva et al, 2012).

Despite being one of the largest reservoirs in Brazil and installed in a basin that harbors over 340 species of native fish (Dagosta et al, 2024), there are few studies describing the fish faunal structure of Furnas Reservoir (e.g., Dagosta et al, 2024; Nobile et al, 2024). Therefore, we aimed to characterize the small-sized fish fauna associated with the shore region of this reservoir and provide an updated species list. Regarding the structuring of the fish assemblage, we tested three hypotheses: (i) Richness and abundance of native species are higher in reservoir riverine zones, whereas non-native species are higher in the lacustrine zone (ii) Physical habitat complexity is important in determining richness and abundance of both native and non-native species (iii) Poorer water quality is more associated with abundance than richness because of the positive effects of nutrient enrichment on abundance.

2. Materials and Methods

2.1. Study area

Furnas Reservoir is formed by the Grande and Sapucaí Rivers and their tributaries. It has a shoreline length of 220 km long, a filled volume of 22.95 billion cubic meters and an inundated surface of 1.440 km². The dam has a maximum height of 127 meters. In addition to hydroelectric power generation, the reservoir is used for tourism and aquaculture (Azevedo-Santos et al, 2011). Its dendritic shape, combined with an average water residence time of 160 days, favors the occurrence of different limnological patterns and trophic states (Júnior, 1994). The upper Grande River basin drains a crystalline plateau (Corgosinho and Pinto-Coelho, 2006), is intensively farmed, and hosts a series of large hydroelectric plants. The Sapucaí River arm features long riverine remnants and extensive floodplains (Silva et al, 2009) but receives untreated sewage from larger cities. Despite these differences, the reservoir is considered oligotrophic, except for few regions along the Grande River, where domestic sewage is frequently discharged (Silva et al, 2012). In April 2024, during the sampling period, the reservoir was operating at 76% of its useful volume.

Data were collected at 40 littoral sites around the entire reservoir (Fig. 1). Of these, 24 were randomly sorted respecting a minimum distance of 1 km, ensuring that the sampling was representative. Another 16 sites were hand-picked to ensure that they encompassed relatively undisturbed conditions (i.e., preserved shoreline and/or presence of native vegetation; 8 sites) and degraded conditions (i.e., proximity to residences, crops, or pasture; 8 sites) (Fig. 1)

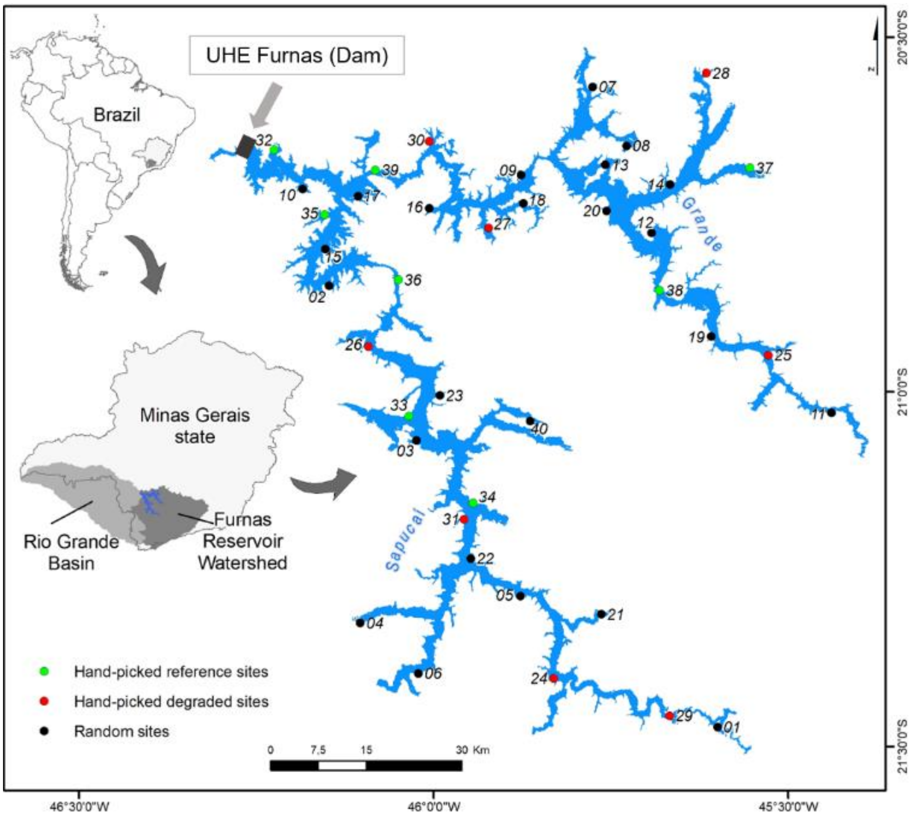

Fig. 1. Map showing the 40 sampling sites in Furnas reservoir’s shoreline.

2.2. Assessment of physical habitat complexity

Three 15-m sections were established in each site, sequentially arranged along the reservoir's shoreline. The physical habitat assessment followed the protocol proposed by the US Environmental Protection Agency (EPA) and adapted for Brazilian Neotropical freshwater ecosystems (Callisto et al, 2014). This protocol measures both agricultural and non-agricultural human impacts, vegetation structure in riparian and floodplain zones, and fish shelter. Human influence was evaluated based on the presence or absence of pipes, buildings, commercial activities, ramps, docks, walls, litter, highways and power lines (non-agricultural impacts) and grain crop agriculture, pastures, orchards, and parks (agricultural impacts). The riparian zone vegetation structure considered the presence of trees, shrubs, herbs and grasses, and was measured across canopy (>5m height), understory (0.5 to 5m), and ground cover (<0.5m) strata. In the floodplain zone, ground cover plants were considered. For macrophyte coverage, both emergent and floating macrophytes were included. Fish shelters were assessed based on coverage of submerged herbaceous vegetation, live trees inundated (>0.3m DBH), large wood debris (>0.3m DBH), small woodland shrubs (<0.3m DBH), overhanging vegetation (<1m above water surface), excavated banks, and large rocks. Field quantification of vegetation, macrophytes, and fish shelter metrics considered values from 0 to 4 to characterize the density of each structural component, where 0 indicated absence and 4 indicated components with coverage >75%.

2.3. Assessment of water quality

We measured water quality parameters based on their recognized influence on fish assemblage structure (Basavaraja et al, 2014; Koushlesh et al, 2023) Therefore, nitrate, dissolved oxygen, temperature, turbidity, and total suspended solids were assessed. Water samples were collected, and physical-chemical parameters were measured only in the first section of each sampling site, prior to fish sampling.

Nitrate anions (NO3-) were measured at laboratory and determined by ion chromatography (IC). Initially, the samples were filtered using a 0.45µm filter. The equipment used was a Metrohm ion chromatograph model ECO IC1, equipped with a self-regenerating suppressor system and conductivity detector. Subsequently, the anions were separated on a Metrosep A Supp 17 analytical column (250mm x 4.0mm), using an eluent solution of 4mM Na2CO3 and 1mM NaHCO3 at a flow rate of 0.8 mL/min. Dissolved oxygen (mg/L) and Temperature (°C) were measured in situ using a YSI ProSolo portable oximeter. Turbidity was assessed in situ using a Digimed DM TU portable turbidimeter, measured in Nephelometric Turbidity Units (NTU). Total suspended solids were measured at laboratory following the protocols from American Public Health Association (APHA) (Lipps et al, 2023). Water samples collected were filtered using a pre-weighed dry glass fiber filter. The residue retained was dried at a constant temperature between 103 and 105°C, with the weight representing the suspended solids (mg/L).

2.4. Fish sampling

Fish were collected using an 8-m x 1.5-m seine with a mesh size of 5 mm between opposite knots. Seining was conducted in the littoral region of the reservoir, with three trawls executed at each site corresponding to the three sections of the physical habitat protocol. The sampling effort per site was 36 m^2. Collected fish were anesthetized with clove oil (Fernandes et al, 2017) and then fixed in 10% formalin. In the laboratory, species were identified using taxonomic keys from Ota et al. (2018) and Ribeiro et al. (2019) and classified as native or non-native according to Bueno et al. (2021). Voucher specimens were deposited in the fish collection at UFLA (CI-UFLA).

2.5. Data analysis

The reservoir longitudinal gradient was established using hydrological distance (km) between sampling sites and the dam, measured from an imaginary line along the reservoir axis calculated using Google Earth Pro. Physical habitat complexity was assessed using the Lakeshore Physical Habitat Quality Index for lacustrine environments (LkShoreHQ_2c). This index incorporates information on the average of indices for intensity and extent of agricultural and non-agricultural disturbances, riparian woody cover and flooded vegetation, and physical shelters for fish (Kaufmann et al, 2014).

Some water properties in reservoirs are related to distance from the dam versus local influences (Ribeiro Filho et al, 2011; Yang et al, 2021). Therefore, we determined Pearson correlations between distance from the dam and water quality variables, excluding those with more than 70% correlation. The probability of fish capture (native, non-native, and total), as a function of distance from the dam, water quality variables, and physical habitat index, was evaluated using Generalized Linear Models (GLMs) with a binomial distribution. Values of 0 and 1 were assigned to sites without and with capture, respectively.

The variations in total richness and abundance, as well as native and non-native species in relation to distance from the dam, water quality variables, and physical habitat index were evaluated using Generalized Linear Models (GLM). Poisson distributions were used for richness and Gaussian distributions for abundance. Abundance data were logarithmically transformed prior to analysis. All analyses were conducted with R software version 4.2.2 (R Development Core Team, 2021).

3. Results

A total of 2.036 fish were collected belonging to 6 orders, 12 families, 25 genera, and 33 species (Table 1). The most abundant individuals were the Characiformes (93.42%), Cichliformes (2.95%), Cyprinodontiformes (1.67%), and Siluriformes (1.13%). The remaining orders accounted for < 1% of the total abundance. There were 22 native species (47.88% of total abundance) and 11 non-native species (52.11% of total abundance) recorded.

The most widely distributed native species was *Astyanax lacustris*, present in 20 sites with a percent abundance of 19.84%. *Knodus* aff. *moenkhausii* was the most widely distributed non-native species, recorded in 10 sites with a percent abundance of 12.97%.

Only total solids was not correlated with distance from the dam (r = 0.25; p = 0.106). Turbidity (r = 0.43; p = 0.006) and nitrate (r = 0.36; p = 0.022) were positively correlated with distance. Conversely, temperature (r = -0.33; p = 0.036) and dissolved oxygen (r = -0.57; p < 0.001) were negatively correlated. However, none of these correlations exceeded 70%, so all variables were retained for model construction.

Table 1. Origin, abundance, and distribution of fish species in Furnas Reservoir. N = Total abundance; N % = Percent abundance; SitesN = number of sites where each species occurred; Record = species whose occurrence was previously recorded for the reservoir.

Taxa	**Origin**	**N**	**N %**	**SitesN**	**Voucher Number (CIUFLA)**	**Record**	
						Dagosta et al, (2024)	**Nobile et al, (2024)**
Characiformes							
Acestrorhynchidae							
Oligosarcus argenteus (Günther, 1864)	Native					X	
Anostomidae							
Megaleporinus obtusidens (Valenciennes, 1836)	Native					X	X
Leporinus friderici (Bloch, 1794)	Native	15	0.74	3	2427	X	X
Leporinus octofasciatus (Steindachner, 1915)	Native					X	
Leporinus striatus (Kner, 1858)	Native	2	0.10	1	2428	X	X
Schizodon nasutus (Kner, 1858)	Native	7	0.34	4	2437	X	X
Bryconidae							
Salminus hilarii (Valenciennes, 1850)	Native					X	
Characidae							
Astyanax lacustris (Lütken, 1875)	Native	404	19.84	20	2418	X	X
Hasemania cf. *nana* (Lütken, 1875)	Native	1	0.05	1			
Bryconamericus turiuba (Langeani et al, 2005)	Native					X	
Galeocharax gulo (Cope, 1870)	Native					X	X
Moenkhausia bonita (Benine et al, 2004)	Native	6	0.29	1	2424		
Hyphessobrycon eques (Steindachner, 1882)	Non-native	696	34.18	9	2426		
Knodus aff. *moenkhausii* (Eigenmann and Kennedy, 1903)	Non-native	264	12.97	10			
Piabarchus stramineus (Eigenmann, 1908)	Native	130	6.39	3	2430	X	
Piabina argentea (Reinhardt, 1867)	Native	2	0.10	1	2431	X	
Psalidodon fasciatus (Cuvier, 1819)	Native	26	1.28	5	2435	X	X

Psalidodon paranae (Eigenmann, 1914)	Native					X	
Serrapinnus heterodon (Eigenmann, 1915)	Native	22	1.08	4	2438	X	
Serrapinnus notomelas (Eigenmann, 1915)	Native	110	5.40	5	2439		
Curimatidae							
Cyphocharax naegelii (Steindachner, 1881)	Native					X	
Cyphocharax modestus (Fernández-Yépez, 1948)	Native					X	X
Steindachnerina insculpta (Fernández-Yépez, 1948)	Native	33	1.62	4	2440	X	X
Crenuchidae							
Characidium gomesi (Travassos, 1956)	Native					X	
Characidium aff. *zebra* (Eigenmann, 1909)	Native					X	
Erythrinidae							
Hoplerythrinus unitaeniatus (Agassiz, 1829)	Non-native						X
Hoplias intermedius (Günther, 1864)	Native	3	0.15	2	2425	X	
Parodontidae							
Apareiodon affinis (Steindachner, 1879)	Native	147	7.22	6		X	
Apareiodon piracicabae (Eigenmann, 1907)	Native	20	0.98	4	2417	X	
Parodon nasus (Kner, 1859)	Native	1	0.05	1		X	
Prochilodontidae							
Prochilodus lineatus (Valenciennes, 1837)	Native					X	X
Serrasalmidae							
Metynnis lippincottianus (Cope, 1870)	Non-native	13	0.64	6	2429		X
Cichliformes							
Cichlidae							
Cichla kelberi (Kullander and Ferreira, 2006)	Non-native	7	0.34	6	2419		
Cichla piquiti (Kullander and Ferreira, 2006)	Non-native	2	0.10	2	2420		X
Cichlasoma paranaense (Kullander, 1983)	Native					X	
Coptodon rendalli (Boulenger, 1897)	Non-native	35	1.72	9	2421		X
Crenicichla haroldoi (Luengo and Britski, 1974)	Native					X	
Crenicichla jaguarensis (Haseman, 1911)	Native					X	
Geophagus iporangensis (Haseman, 1911)	Native	2	0.10	2	2423	X	X
Oreochromis niloticus (Linnaeus, 1758)	Non-native						X
Saxatilia britskii (Kullander, 1982)	Native	14	0.69	4	2422		
Cyprinodontiformes							
Poeciliidae							
Poecilia reticulata (Peters, 1859)	Non-native	1	0.05	1	2433		
Poecilia vivipara (Bloch and Schneider, 1801)	Non-native	33	1.62	3	2434		

Gymnotiformes							
Sternopygidae							
Eigenmannia dutrai (Peixoto et al, 2021)	Native					X	
Eigenmannia cf. *trilineata* (López and Castello, 1966)	Native						X
Gymnotidae							
Gymnotus aff. *inaequilabiatus* (Valenciennes, 1839)	Native	1	0.05	1	2442		
Gymnotus cf. *pantanal* (Fernandes et al, 2005)	Non-native	3	0.15	2	2443		
Gymnotus cf. *paraguensis* (Albert and Crampton, 2003)	Non-native	4	0.20	1	2444		
Gymnotus aff. *sylvius* (Albert and Fernandes-Matioli, 1999)	Native	6	0.29	4	2445		
Siluriformes							
Auchenipteridae							
Trachelyopterus galeatus (Linnaeus, 1766)	Native					X	X
Callichthyidae							
Hoplosternum littorale (Hancock, 1828)	Native					X	X
Cetopsidae							
Cetopsis gobioides (Kner, 1858)	Native					X	
Heptapteridae							
Cetopsorhamdia iheringi (Schubart and Gomes, 1959)	Native					X	
Pimelodella avanhandavae (Eigenmann, 1917)	Native					X	
Pimelodella gracilis (Valenciennes, 1835)	Native					X	
Rhamdia quelen (Quoy and Gaimard, 1824)	Native					X	
Loricariidae							
Hypostomus ancistroides (Ihering, 1911)	Native					X	
Hypostomus margaritifer (Regan, 1908)	Native					X	
Hypostomus nigromaculatus (Schubart, 1964)	Native					X	
Hypostomus regani (Ihering, 1905)	Native					X	
Pterygoplichthys ambrosettii (Holmberg, 1893)	Non-native	3	0.15	3	2436		
Pimelodidae							
Iheringichthys labrosus (Lütken, 1874)	Native					X	
Pimelodus maculatus (Lacepède, 1803)	Native	20	0.98	6	2432	X	X
Synbranchiformes							
Synbranchidae							
Synbranchus aff. *marmoratus* (Bloch, 1795)	Native	3	0.15	2	2441		

Total richness	64
Native richness	51 (79.7%)
Non-native richness	13 (20.3%)

Unique species from this study	15
Unique native species from this study	7
Unique non-native species from this study	8

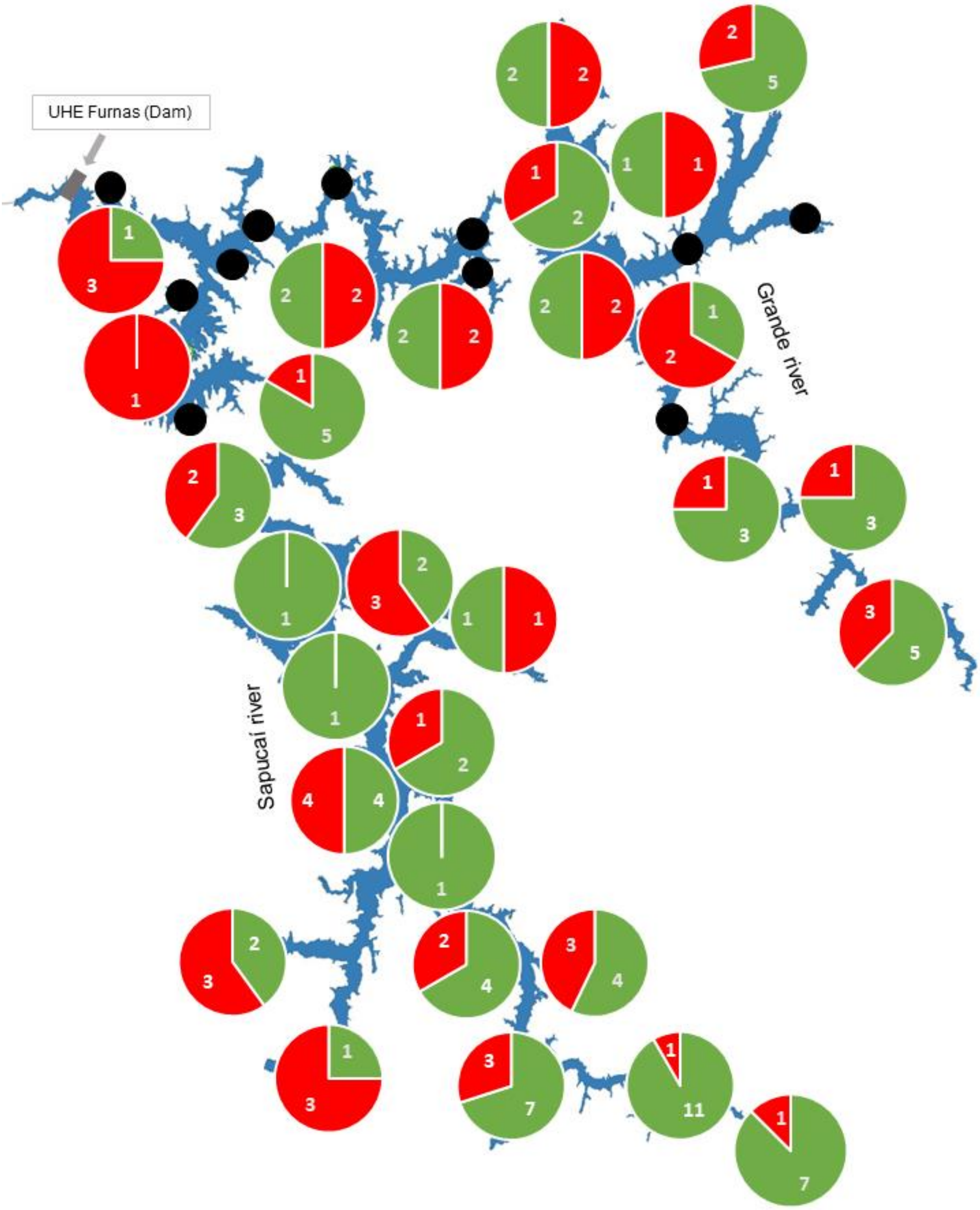

Fig. 2. Proportions of native species (green) and non-native species (red) along the longitudinal gradient of Furnas Reservoir. Black dots indicate locations where no fish were captured. Numbers indicate the absolute richness of native and non-native species for each sampling site.

Both native and non-native species were distributed throughout the reservoir littoral zone. No fish were captured at 11 sites, most of which were located closer to the dam (Fig. 2). Distance from the dam, physical habitat index, total solids, nitrate, and dissolved oxygen, were the most important variables in explaining the capture of at least one fish at the sampled sites (Table 2). The presence of fish in the reservoir was positively associated with locations farther from the dam and with higher habitat complexity indices and total solids concentrations (Figs. 3A, B, C). Higher concentrations of dissolved oxygen were associated with absence of captures (Fig. 3E).

Table 2. Results of Generalized Linear Models (GLM) for fish occurrence, total richness, and native and non-native species (Interc = Intercept; Dist = Distance to the dam, LKS = Physical Habitat Quality Index, ST = Total Solids, Nit = Nitrate, OD = Dissolved Oxygen, Temp = Temperature, Turb = Turbidity. AICC = Akaike Information Criterion, Delta = Model selection criterion (Delta < 2), Weight = Influence of each observation, R2 = Model explanatory power).

Model	Int	Dist	LKS	ST	Nit	OD	Temp	Turb	AICc	Delta	Weight	R2
Probability of capture	-2.41	0.05	-	0.74	-4.43	-	-	-	33.3	0.00	0.16	0.69
	-2.02	0.04	0.51	0.81	-4.42	-	-	-	33.8	0.49	0.13	0.71
	-15.48	0.06	0.98	1.10	-5.83	1.60	-	-	34.7	1.40	0.08	0.80
Native richness	-3.52	0.02	-	0.06	-	0.24	-	-	134.9	0.00	0.10	0.59
	-1.42	0.01	-	0.06	-	-	-	-	134.9	0.01	0.10	0.57
	-1.35	0.02	-	-	-	-	-	-	136.1	1.25	0.05	0.57
	-3.01	0.02	-	-	-	0.19	-	-	136.7	1.87	0.04	0.57
	-3.60	0.02	0.05	0.07	-	0.25	-	-	136.9	2.00	0.04	0.59
Non-native richness	-0.55	0.01	-	0.10	-0.97	-	-	-	109.8	0.00	0.23	0.29
Total richness	-0.42	0.01	-	0.06	-	-	-	-	176.3	0.00	0.12	0.58
	-0.46	0.01	-	0.07	-0.2	-	-	-	176.4	0.07	0.12	0.61
	-1.95	0.01	-	0.08	-0.3	0.17	-	-	177.0	0.71	0.08	0.63
	1.74	0.01	-	0.09	-0.5	0.28	-0.15	-	177.5	1.20	0.06	0.61
	-1.39	0.01	-	0.07	-	0.11	-	-	177.9	1.59	0.05	0.58

Table 3. Results of Generalized Linear Models (GLM) for total abundance, and native and non-native species (Interc = Intercept; Dist = Distance to the dam, LKS = Physical Habitat Quality Index, ST = Total Solids, Nit = Nitrate, OD = Dissolved Oxygen, Temp = Temperature, Turb = Turbidity. AICC = Akaike Information Criterion, Delta = Model selection criterion (Delta < 2), Weight = Influence of each observation, R2 = Model explanatory power).

Model	**Int**	**Dist**	**LKS**	**ST**	**Nit**	**OD**	**Temp**	**Turb**	**AICc**	**Delta**	**Weight**	**R2**
Native abundance	-2.74	0.01	0.07	0.10	-	0.27	-	-0.02	65.2	0.00	0.11	0.57
	-2.42	0.01	-	0.10	-	0.23	-	-0.02	65.4	0.20	0.09	0.55
	-0.08	0.01	-	0.10	-	0.28	-0.09	-0.02	66.3	1.12	0.06	0.56

	-2.15	0.01	0.07	0.07	-	0.20	-	-	66.5	1.38	0.05	0.54
	-0.40	0.01	-	0.06	-	-	-	-	66.5	1.38	0.05	0.49
	-0.76	0.01	0.06	0.10	-	0.31	-0.07	-0.02	66.8	1.67	0.04	0.58
	-0.40	0.01	-	0.09	-	-	-	-0.01	66.9	1.77	0.04	0.51
	-1.75	0.01	-	0.06	-	0.16	-	-	67.2	2.00	0.04	0.51
Non-native abundance	0.10	0.00	-	-	-	-	-	-	82.1	0.00	0.06	0.11
	-1.87	0.01	-	-	-0.41	0.24	-	-	82.3	0.15	0.06	0.20
	-1.58	0.00	-	-	-	0.20	-	-	82.6	0.49	0.05	0.14
	0.19	0.00	-	-	-0.33	-	-	-	82.8	0.63	0.04	0.14
	-1.87	0.00	-	0.04	-0.47	0.24	-	-	83.4	1.24	0.03	0.22
	-2.48	0.00	-	-	-	-	0.09	-	83.5	1.35	0.03	0.13
	0.06	0.00	-	0.03	-	-	-	-	83.7	1.51	0.03	0.12
	0.15	0.00	-	0.04	-0.39	-	-	-	83.7	1.55	0.03	0.17
	-2.27	0.01	-	0.07	-	0.27	-	-0.02	83.8	1.66	0.02	0.17
Total abundance	-2.95	0.01	-	0.11	-	0.32	-	-0.03	81.3	0.00	0.15	0.48
	-3.18	0.01	0.05	0.11	-	0.35	-	-0.03	83.2	1.87	0.06	0.48

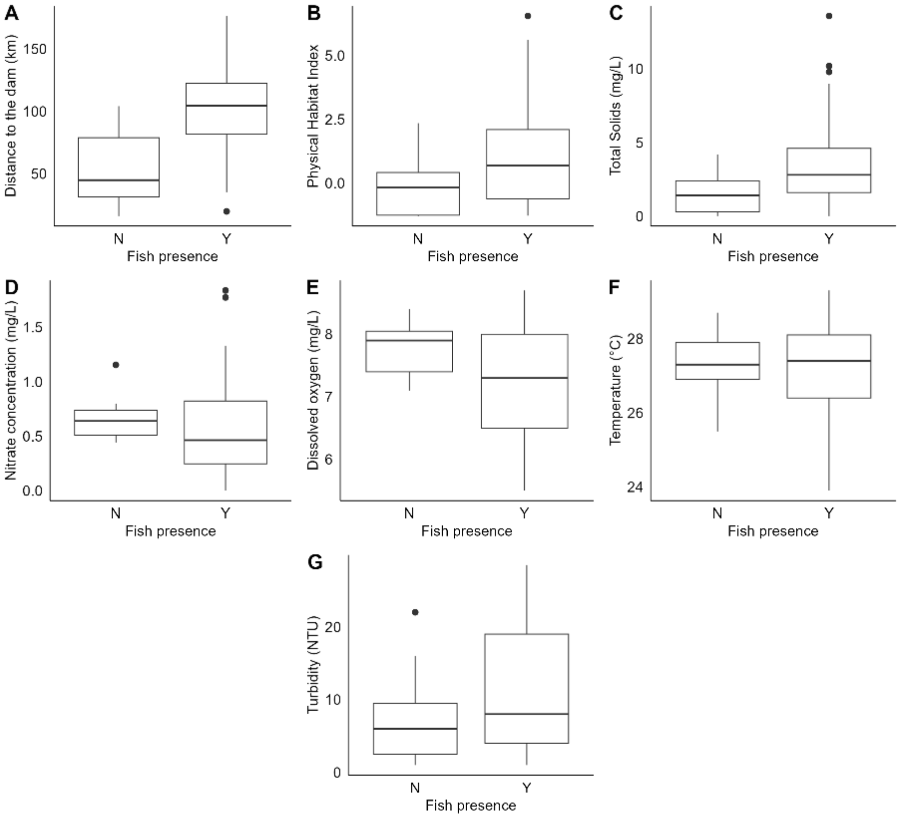

Fig. 3. Probability of fish capture in response to Distance from the dam (A), Physical Habitat Quality Index (B), Total Solids (C), Nitrate concentration (D), Dissolved Oxygen (E), Temperature (F), and Turbidity (G). Y = yes, N = no.

Distance from the dam was present in all richness models, thus being the most important variable in their explanation. Also, physical habitat index, total solids, and dissolved oxygen were included in the models explaining native species richness. The only selected model for non-native species included distance from the dam, total solids, and nitrate. Total species richness was mainly explained by distance and all water quality variables except turbidity (Table 2).

Both total richness and native species richness tended to increase with distance from the dam, whereas non-native species richness remained relatively constant along the reservoir (Fig. 4A). Neither richness measure was associated with physical habitat index scores (Fig. 4B), whereas total solids concentration was positively correlated with all richness measures (Fig. 4C). Total and native species richness increased with nitrate concentration; the opposite occurred for non-natives (Fig. 4D). Dissolved oxygen showed a weak negative relationship with richness (Fig. 4E). Higher temperatures were associated with lower total and native species richness (Fig. 4F), whereas the opposite occurred for turbidity (Fig. 4G).

As with the richness models, distance from the dam was the most important predictor variable in determining total abundance, native species abundance, and non-native species abundance (Table 3). Physical habitat index score was included in some of the selected models for total abundance and native species abundance. The most important water quality variables determining native species abundances were total solids, dissolved oxygen, and turbidity. For non-native species, the most important variables were total solids, nitrate, and dissolved oxygen. In addition to distance from the dam, total abundance was explained by total solids, dissolved oxygen, and turbidity (Table 3).

Overall, abundances tended to decrease towards the dam and increased with total solids concentration (Fig. 5A, C). Total abundances and native species abundances were positively related to higher physical habitat index scores (Fig. 5B). Total and native species abundances increased with higher nitrate concentration and turbidity (Figs. 5D, G), whereas the relationships were opposite for temperature and dissolved oxygen (Figs. 5F, E).

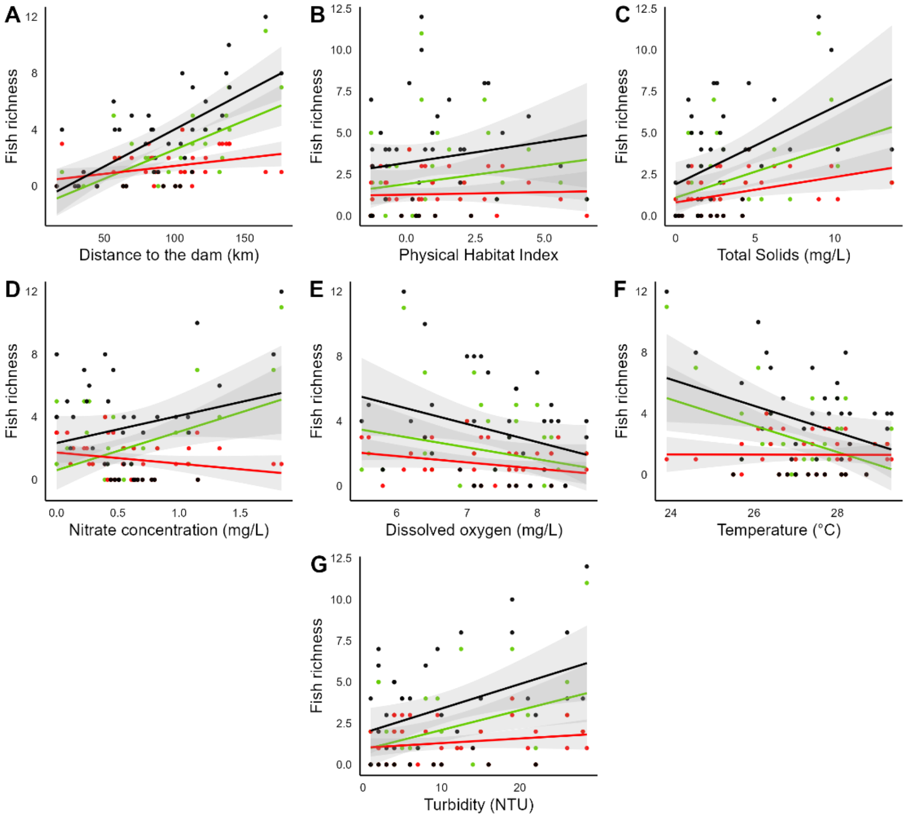

Fig. 4. Variation in fish richness in response to Distance from the dam (A), Physical Habitat Quality Index scores (B), Total Solids (C), Nitrate concentration (D), Dissolved Oxygen (E), Temperature (F), and Turbidity (G). Black = total species; green = native species; red = non-native species.

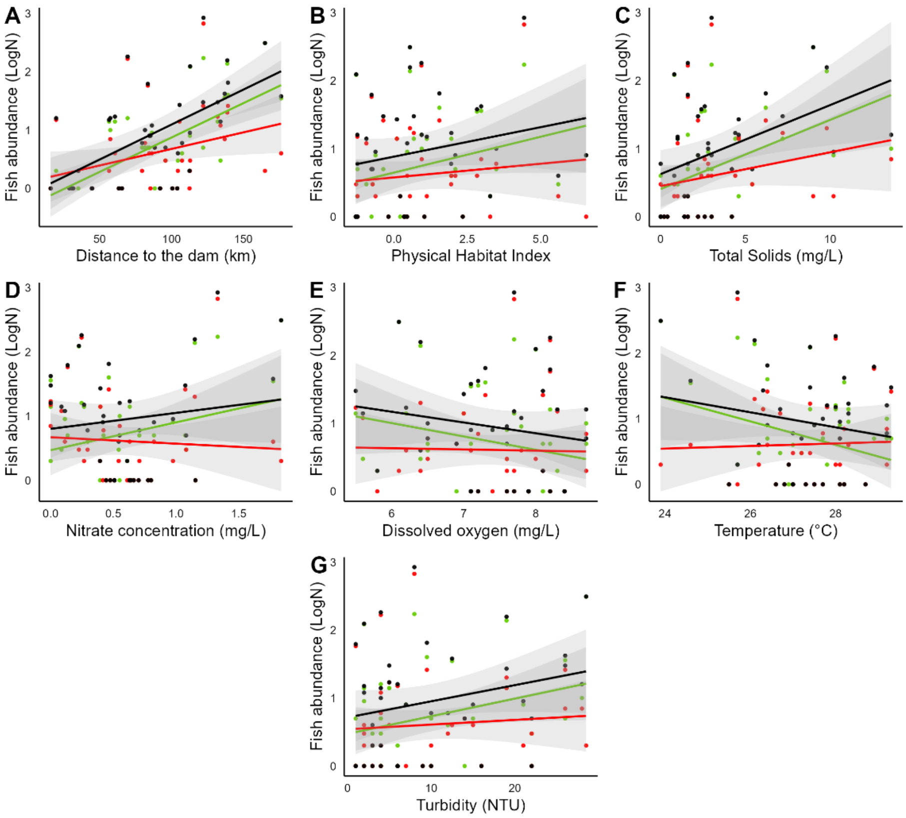

Fig. 5. Variation in fish abundance in response to Distance from the dam (A), Physical Habitat Quality Index scores (B), Total Solids (C), Nitrate concentration (D), Dissolved Oxygen (E), Temperature (F), and Turbidity (G). Black = total species; green = native species; red = non-native species.

4. Discussion

As expected, both richness and abundance of native species were higher in the riverine zones, as well as total richness and abundance. Non-native species also increased towards the riverine region, but exceeded native species in richness and abundance only in the lacustrine region (<50 km from the dam). Among these variables, distance from the reservoir was primarily responsible for most of their variation. Physical habitat index scores contributed to some models for native species but had little influence on increasing richness and abundance. Water quality was associated with the richness and abundances of both native and non-native species. Among the water quality variables, total solids were the least correlated with distance from the dam and positively related to increases in richness and abundances of both native and non-native species. For native species, dissolved oxygen and total solids were more important in abundance models than in richness models. Both temperature and turbidity were important only in abundance models. The probability of capturing at least one fish was higher in the riverine region of the reservoir and in locations with higher physical habitat index scores and higher total solids concentrations.

This study identified 15 new records for the Furnas Reservoir species list, representing an increase of 13.46% in native richness and 61.53% in non-native richness. Nearly half of the species in this study were recorded for the first time in the Furnas Reservoir. It is noteworthy that most of these new species are non-native, which may be related to their recent introduction or establishment. The species collected in this study, combined with those previously recorded in recent Furnas ichthyofauna studies (Dagosta et al, 2024; Nobile et al, 2024) and the record of *Arapaima gigas* (Personal observation), increase the reservoir's richness to 65 species, comprising 51 native and 14 non-native species.

The species identified in this study represent 37.5% of the known richness for the Rio Grande basin (Casarim et al, 2012), with native species accounting for just over 6% of the Upper Paraná basin richness (Dagosta et al, 2024). This magnitude is comparable to other Rio Grande reservoirs, such as Itutinga and Camargos, which have 26 and 29 recorded species, respectively (Silva-Sene et al, 2022; 2024). Therefore, the richness recorded in this study can be considered high, especially considering that only seining produced more species than in other reservoirs in the same basin where seines and gillnets were used (Silva-Sene et al, 2022). However, such comparisons should be made cautiously because of the distinct selectiveness of different fish capture and sampling methods (Agostinho et al, 2007) and unequal study designs and sampling efforts (Pompeu et al, 2021; Becker et al, 2016; Sanches et al, 2016).

In some sites, particularly in regions closer to the dam and in the arm of the Rio Grande, which is the principal dammed tributary upstream, no fish were captured. It is known that the presence of upstream dams can reduce richness and abundance in reservoir lacustrine zones (Ganassin et al, 2021), although the gradient itself is even more important in shaping assemblages distribution than cascade effects (Yang et al, 2021). Because of thermal and chemical stratification and reduced habitat availability, occupancy of such zones close to the dam can be severely compromised (Oliveira et al, 2004). The lacustrine zone of the Furnas reservoir, where most of the sampling sites without fish captures were concentrated, is characterized by low primary productivity (Silva et al, 2012), which may have influenced this result. Moreover, the high transparency of the lacustrine zone may reduce fish vulnerability to capture; however, the effect of this variable could only be tested with nighttime sampling (Matthews et al, 2004). A sampling bias cannot be ruled out either, as in some of these sites the slopes were steeper. Although such an effect is incorporated into the habitat variable, the lower effectiveness of using seines under these conditions cannot be dismissed.

The prevalence of non-native species in the lower portion of the reservoir was expected, as these species are commonly associated with lacustrine zones (Loures and Pompeu, 2018; Lin et al, 2019; Silva-Sene et al, 2022) and tend to reduce native fish fauna (Lin et al, 2019). The relative abundance of non-native species captured in this study is similar to that found in Camargos Reservoir (approximately 51%), which is the most upriver reservoir in the Rio Grande basin (Silva-Sene et al, 2022). However, there is wide variation among reservoirs in the Rio Grande basin and Upper Paraná basin, where relative abundances of non-native species range from 10% to 70% (Sanches et al, 2014; Rosa et al, 2021; Silva-Sene et al, 2022; 2024).

The most abundant non-native species was *Hyphessobrycon eques*, primarily captured in macrophyte beds. Several studies have demonstrated the association of *H. eques* with this habitat type (Esguícero and Arcifa, 2010; Teresa et al, 2011; Quirino et al, 2021), including in reservoirs (Casatti et al, 2003). *K.* aff. *moenkhausii*, also invasive in the Upper Paraná basin (Bueno et al, 2021), was the second most abundant species and is known for its trophic opportunism, which helps explain its abundance and wide distribution (Ceneviva-Bastos and Casatti, 2007; Carvalho et al, 2019). In addition to the non-native species captured in this study, occurrences of *Hoplerythrinus unitaeniatus* were recorded (Nobile et al, 2024), along with escapes of *Oreochromis niloticus* from fish cages cultures (Azevedo-Santos et al, 2011), and recent videos indicate the presence of *A. gigas* (Personal observation). Species introductions in this reservoir are not limited to fish, as there are several records of non-native phytoplankton (Santos-Wisniewski et al, 2007), zooplankton (Reid and Pinto-Coelho 1994; Bezerra-Neto et al, 2004), crustaceans (Azevedo-Santos and Lima-Stripari, 2010; Chaves et al, 2023) and molluscs *Melanoides tuberculata*, *Corbicula fluminea* and *Limnoperna fortunei* (Personal observation).

Studies describing distribution patterns, richness, and abundances of fish assemblages in reservoirs have shown that the impact of these impoundments responds to a longitudinal gradient, especially in large reservoirs (>30 km2) (Matthews et al, 2004; Oliveira et al, 2004; Britto and Carvalho 2006; Sanches et al, 2016; Yang et al, 2021). In general, it is observed a reduction in richness, abundance, and diversity from the riverine zone towards the dam (Oliveira et al, 2004; Sanches et al, 2016; Smith et al, 2023). Some studies have also shown that intermediate zones may exhibit high richness, sometimes even greater than riverine (Aliko et al, 2010; Terra et al, 2010; Sandhya et al, 2019). In these cases, the transition between fluvial and lacustrine conditions may create an ecotone that favors the coexistence of lotic and lentic species, thereby increasing richness in these locations (Oliveira et al, 2004; Santos et al, 2010; Buckmeier et al, 2014). Despite the significance of such a gradient, distribution patterns may diverge depending on the species. While some species are well-distributed throughout the reservoir, others are typically found in lacustrine environments (Smith and Petrere, 2008; Aliko et al, 2010).

In this context, the gradual increase in abundances and richness towards the riverine zone, particularly for native species, reinforces the importance of this gradient in structuring the fish assemblage in one of Brazil's largest reservoirs. It is worth noting that the arms comprising Furnas Reservoir, despite being predominantly oligotrophic (Silva et al, 2012), differ in their degree of urbanization. The Sapucaí arm is notably affected by human activities and sewage discharges. Nevertheless, the longitudinal gradient remained a determining factor in fish abundance and richness, also influencing the probability of capture. The dendritic shape of the reservoir enhances its connectivity with the lotic remnants of the basin, which are crucial for maintaining species richness in these environments (Agostinho et al, 1999;

Sanches et al, 2016; Silva-Sene et al, 2022; Liao et al, 2023). However, in the case of Furnas, the size and lateral extent of the reservoir may be reducing the relative importance of such remnants, especially in the lacustrine region.

In our results, habitat complexity increased the probability of capture and the abundance of native species. Non-native species, on the other hand, did not respond to this variable. Habitat structuring is recognized as important for increasing species richness and abundance in reservoirs, whether through natural components (Durocher et al, 1984; Agostinho et al, 2003b; Gois et al, 2012) or artificial structures (Bolding et al, 2004; Freitas et al, 2005; Santos et al, 2011). A study conducted in the Mourão (11.3 km2) and Itaipu (1,350 km2) Reservoirs, evaluating the importance of submerged logs on fish abundance, found higher catches per unit effort in regions with greater habitat structure (Gois et al, 2012). Given the role of physical habitat structure in increasing capture probability and the longitudinal gradient in determining the richness and distribution of native and non-native species, we recommend that artificial structures, when implemented in reservoirs, should be placed in the riverine and intermediate regions.

The influence of water quality on assemblage structure was largely captured by the longitudinal gradient. In the case of Furnas, this factor may be so strong that even sampling sites with reasonable water quality (i.e., higher oxygen concentration) show lower capture probabilities, because of the lacustrine nature of these locations. Total solids were positively related to species richness, abundance, and fish capture probability. Similar results have been observed in several reservoirs within the Paraná River basin, where both native and non-native species seem to respond positively to increased productivity, mainly associated with nutrient concentration and water temperature (Muniz et al, 2021). Reservoir productivity is linked to nutrient input, which vary with watershed morphology and land use (Kennedy and Walker, 1990), incorporation of organic matter from flooded areas soon after impoundment (Agostinho et al, 2007), and effluent discharges (Silva et al, 2012). In both arms of the reservoir, point source sewage input altered water quality, either by increasing conductivity and temperature (Prado et al, 2011) or locally enhancing trophic status (Silva et al, 2012). Accordingly, intense land use throughout the watershed, including agricultural activities, urban development, and aquaculture (Melo et al, 2017), likely contribute to elevated total solids in some areas, thereby leading to increased local productivity.

5. Conclusions

The distance from the dam was the primary explanatory variable in this study, accounting for most of the variation in total richness and abundance, as well as for native and non-native species. Such results reinforce the importance of this factor in structuring fish assemblages, suggesting that the spatial gradient influence is greater in large reservoirs, such as Furnas, than in small reservoirs. Most water properties were correlated with the distance variable, further emphasizing its importance in determining the limnological characteristics of the reservoir. Although less related to richness and abundance patterns, physical habitat complexity increased the chances of capturing at least one fish species as well as the abundance of native species. Considering that habitat enrichment in reservoirs is a management measure currently under discussion, such structures may serve as shelters for the existing fauna. However, the homogeneous distribution pattern of non-native species throughout the reservoir may hinder the restriction of these artificial habitats solely to native species.

6. Ethical Statement

This study was approved by the Ethics Committee for Animal Use of the Federal University of Lavras (CEUA/UFLA) under collection license number 11/13 and authorized by the Chico Mendes Institute for Biodiversity Conservation (ICMBio/SISBIO) permit number 10327-6.

Declaration of competing Interest

RMH examines the English and content of some manuscripts, but he was not involved in the manuscript editorial or peer reviews or the decision to publish this article. All authors declare no known competing financial interests or personal relationships that could potentially influence the work reported in this paper.

Funding

This work is a part of IBI-FURNAS project funded by the Brazilian Electricity Company (Eletrobras). RS was granted a research scholarship from Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG). GNS was supported by Fundação de Amparo à Pesquisa do Estado de Minas Gerais [grant number 00401-19]. RMH received a Fulbright Brasil Distinguished Scholarship. PSP was granted a research fellowship [grant number 302328/2022–0] by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

Acknowledgments

The authors thank Dr. Diego Macedo for creating the map and Msc. Anderson Santos for describing the methods of water collection and analysis.

Author Contributions

Rosalva Sulzbacher: Conceptualization, Methodology, Writing – original draft. Gilberto N. Salvador: Methodology, Writing – review & editing. Carlos B. Mascarenhas Alves: Funding acquisition, Writing – review & editing. Paulo S. Formagio: Funding acquisition, Methodology, Writing – review & editing. Robert M. Hughes: Writing – review & editing. Paulo Santos Pompeu: Conceptualization, Writing – review & editing, Supervision.

References

Agostinho, A.A., Gomes, L.C., Pelicice, F.M., 2007. Ecologia e manejo de recursos pesqueiros em reservatórios do Brasil, 1st ed. Eduem, Maringá, Brazil, pp 501.

Agostinho, A.A., Gomes, L.C., Santos, N.C.L., Ortega, J.C.G., Pelicice, F.M., 2015. Fish assemblages in Neotropical reservoirs: Colonization patterns, impacts and management. Fish. Res. 173, 26–36. https://doi.org/10.1016/j.fishres.2015.04.006 0165-7836.

Agostinho, A.A., Gomes, L.C., Suzuki, H.I., Júlio-Júnior, H.F., 2003a. Migratory Fishes of the Upper Paraná River Basin Brazil. In: Carolsfeld, J., Harvey, B., Ross. C., Baer, A., eds. Migratory fishes of South America: biology, fisheries and conservation status. Victoria, Canada: International Development Research Centre/World Bank/World Fisheries Trust, pp. 19–98.

Agostinho, A.A., Miranda, L.E., Bini, L.M., Gomes, L.C., Thomaz, S.M., Suzuki, H.I., 1999. Patterns of colonization in neotropical reservoirs, and prognoses on aging. In: Tundisi, J.G., Straskraba, M., eds. Theoretical Reservoir Ecology and its applications. São Carlos, Brazil: IIE/Backhuys Publishers/Brazilian Academy of Sciences, pp. 227–265.

Agostinho, A.A., Gomes, L.C., Júlio Júnior, H.F., 2003b. Relações entre macrófitas aquáticas e fauna de peixes. In: Thomaz, S.M., Bini, L.M., eds. Ecologia e Manejo de Macrófitas Aquáticas. Maringá, Brazil: EDUEM, pp. 261–279.

Aliko, N.G., Costa, K.S., Konan, K.F., Ouattara, A., Gourène, G., 2010. Fish diversity along the longitudinal gradient in a man–made lake of west Africa, Taabo hydroelectric reservoir, Ivory Coast. Croat. J. Fish. 68, 47–60.

Araujo-Lima, C.A.R.M., Agostinho, A.A., Fabre, N.N., 1995. Trophic aspects of fish communities in Brazilian rivers and reservoir. In: Tundisi, J.G., Bicudo C.E.M., Matsumura-Tundisi, T., eds. Limnology in Brazil. São Paulo, Brazil: ABC/SBL, pp. 105–136.

Azevedo-Santos, V.M., Lima-Stripari, N., 2010. Primeiro registro de *Dilocarcinus pagei* Stimpson, 1861 (Decapoda, Trichodactylidae) no estado de Minas Gerais. Biotemas. 23, 199–202. https://doi.org/10.5007/2175-7925.2010v23n2p199.

Azevedo-Santos, V.M., Rigolin-Sá, O., Pelicice, F.M., 2011. Growing, losing or introducing? Cage aquaculture as a vector for the introduction of non-native fish in Furnas Reservoir, Minas Gerais, Brazil. Neotrop. Ichthyol. 9, 915–919. https://doi.org/10.1590/S1679-62252011000400024.

Basavaraja, D., Narayana, J., Kiran, B.R., Puttaiah, E.T., 2014. Fish diversity and abundance in relation to water quality of Anjanapura reservoir, Karnataka, India. Int. J. Curr. Microbiol. Appl. Sci. 3, 747–757.

Becker, B., Galhardo, B.D.O.S., Macedo, D.R., Hughes, R.M., Callisto, M., Santos, G.B., 2016. Influence of limnological zones on the spatial distribution of fish assemblages in three Brazilian reservoirs. J. Limnol. 75, 156–168. https://doi.org/0.4081/jlimnol.2015.1266.

Bettoli, P.W., Maceina, M.J., Noble, R.L., Betsill, R.K., 1993. Response of a reservoir fish community to aquatic vegetation removal. N. Am. J. Fish. Manage. 13, 110–124. https://doi.org/10.1577/1548-8675(1993)013<0110:ROARFC>2.3.CO;2.

Bezerra-Neto, J.F., Aguila, L.R., Landa, G.G., Pinto-Coelho, R.M., 2004. The exotic rotifer *Kellicottia bostoniensis* (Rousselet, 1908) (Rotifera: Brachionidae) in the zooplankton community in a tropical reservoir. Lundiana Int. J. Biodivers. 5, 151–153. https://doi.org/10.35699/2675-5327.2004.22017.

Bolding, B., Bonar, S., Divens, M., 2004. Use of artificial structure to enhance angler benefits in lakes, ponds, and reservoirs: a literature review. Rev. Fish. Sci. 12, 75–96. https://doi.org/10.1080/10641260490273050.

Britto, S.G.C., Carvalho, E.D., 2006. Ecological attributes of fish fauna in the Taquaruçu Reservoir, Paranapanema River (Upper Paraná, Brazil): composition and spatial distribution. Acta Limnol. Bras. 18, 377–388.

Buckmeier, D.L., Smith, N.G., Fleming, B.P., Bodine, K.A., 2014. Intra-annual variation in river–reservoir interface fish assemblages: implications for fish conservation and management in regulated rivers. River Res. Appl. 30, 780–790. https://doi.org/10.1002/rra.2667.

Bueno, M.L., Magalhães, A.L.B., Neto, F.R.A., Alves, C.B.M., Rosa, D.M., Junqueira, N.T., Pessali, T.C., Pompeu, P.S., Zenni, R.D., 2021. Alien fish fauna of southeastern Brazil: species status, introduction pathways, distribution and impacts. Biol. Invasions. 23, 3021–3034. https://doi.org/10.1007/s10530-021-02564-x.

Callisto, M., Alves, C.B.M., Lopes, J.M., Castro, M.A., 2014. Condições ecológicas em bacias hidrográficas de empreendimentos hidrelétricos. Cemig, Belo Horizonte, Brazil, pp. 264.

Carniatto, N., Cunha, E.R., Thomaz, S.M., Quirino, B.A., Fugi, R., 2020. Feeding of fish inhabiting native and non-native macrophyte stands in a Neotropical reservoir. Hydrobiologia. 847, 1553–1563. https://doi.org/10.1007/s10750-020-04212-2.

Carvalho, D.R., Castro, D.M.P., Callisto, M., Chaves, A.J.M., Moreira, M.Z., Pompeu, P.S., 2019. Stable isotopes and stomach content analyses indicate omnivorous habits and opportunistic feeding behavior of an invasive fish. Aquat. Ecol. 53, 365–381. https://doi.org/10.1007/s10452-019-09695-3.

Casarim, R., Bueno, M.L., Pompeu, P.S., 2012. Ichthyofauna of the Aiuruoca River basin, Minas Gerais, Brazil. Check List. 8, 1166–1171. https://doi.org/10.15560/8.6.1166.

Casatti, L., Mendes, H.F., Ferreira, K.M., 2003. Aquatic macrophytes as feeding site for small fishes in the Rosana Reservoir, Paranapanema River, Southeastern Brazil. Braz. J. Biol. 63, 213–222. https://doi.org/10.1590/S1519-69842003000200006.

Ceneviva-Bastos, M., Casatti, L., 2007. Oportunismo alimentar de *Knodus moenkhausii* (Teleostei, Characidae): uma espécie abundante em riachos do noroeste do Estado de São Paulo, Brasil. Iheringia. Sér. Zool. 97, 7–15. https://doi.org/10.1590/S0073-47212007000100002.

Chaves, A.J.P., Zara, F.J., Paschoal, L.R.P., 2023. Long-term monitoring of the non-native giant river prawn *Macrobrachium rosenbergii* (De Man, 1879) in the Furnas mega reservoir (southeastern Brazil). Nauplius. 31, e2023025. https://doi.org/10.1590/2358-2936e2023025.

Corgosinho, P.H.C., Pinto-Coelho, R.M., 2006. Zooplankton biomass, abundance and allometric patterns along an eutrophic gradient at Furnas Reservoir (Minas Gerais, Brazil). Acta Limnol. Bras. 182, 213–224.

Dagosta, F.C.P., Monção, M.S., Nagamatsu, B.A., Pavanelli, C.S., Carvalho, F.R., Lima, F.C.T., Langeani, F., Dutra, G.M., Ota, R.R., Seren, T.J., et al. 2024. Fishes of the upper rio Paraná basin: diversity, biogeography and conservation. Neotrop. Ichthyol. 22, e230066. https://doi.org/10.1590/1982-0224-2023-0066.

Durocher, P.P., Provine, W.C., Kraai, J.E., 1984. Relationship between abundance of largemouth bass and submerged vegetation in Texas reservoirs. N. Am. J. Fish. Manage. 4, 84–88. https://doi.org/10.1577/1548-8659(1984)4<84:RBAOLB>2.0.CO;2.

Esguícero, A.L.H., Arcifa, M.S., 2010. Which is the best environment for the development of the early life stages of fish during the dry season?. Acta Limnol. Bras. 22, 267–275. https://doi.org/10.4322/actalb.02203003.

Fernandes, I.M., Bastos, Y.F., Barreto, D.S., Lourenço, L.S., Penha, J.M., 2017.The efficacy of clove oil as an anaesthetic and in euthanasia procedure for small-sized tropical fishes. Braz. J. Biol. 77, 444–450. https://doi.org/10.1590/1519-6984.15015.

Freitas, C.E.C., Petrere, M., Barrella, W., 2005. Natural and artificially-induced habitat complexity and freshwater fish species composition. Fish. Manage. Ecol. 12, 63–67. https://doi.org/10.1111/j.1365-2400.2004.00420.x.

Ganassin, M.J.M., Muñoz-Mas, R., Oliveira, F.J.M., Muniz, C.M., Santos, N.C.L., García-Berthou, E., Gomes, L.C., 2021. Effects of reservoir cascades on diversity, distribution, and abundance of fish assemblages in three Neotropical basins. Sci. Total Environ. 778, 146246. https://doi.org/10.1016/j.scitotenv.2021.146246.

Gido, K.B., Hargrave, C.W., Matthews, W.J., Schnell, G.D., Pogue, D.W., Sewell, G.W., 2002. Structure of littoral-zone fish communities in relation to habitat, physical, and chemical gradients in a southern reservoir. Environ. Biol. Fishes. 63, 253–263. https://doi.org/10.1023/A:1014359311188.

Gois, K.S., Antonio, R.R., Gomes, L.C., Pelicice, F.M., Agostinho, A.A., 2012. The role of submerged trees in structuring fish assemblages in reservoirs: two case studies in South America. Hydrobiologia. 685, 109–119. https://doi.org/10.1007/s10750-011-0843-9.

Júnior, W.P.S., 1994. Production of planktonic biomass for feed of alevins at the Furnas Hydrobiology and Hatchery Station. In: Pinto-Coelho, R.M., Giani, A., Von Sperling, E., eds. Ecology and Human Impact on Lakes and Reservoirs in Minas Gerais. Belo Horizonte: SEGRAC, pp. 133–139.

Kaufmann, P.R., Peck, D.V., Paulsen, S.G., Seeliger, C.W., Hughes, R.M., Whittier, T.R., Kamman, N.C., 2014. Lakeshore and littoral physical habitat structure in a national lakes assessment. Lake and Reservoir Management. 30, 192–215. https://doi.org/10.1080/10402381.2014.906524.

Kennedy R.H., Walker W.W., 1990. Reservoir nutrient dynamics. In: Thornton, K.W., Kimmel, B.L., Payne, E.F., eds. Reservoir Limnology: Ecological Perspectives. New York: John Wiley & Sons, pp. 109–131.

Koushlesh, S.K., Johnson, C., Sarkar, U.K., Das, A.K., Das, B.K., Lianthuamluaia, L., Puthiyottil, M., Naskar, B.K., 2023. Exploring fish assemblage structure, feeding guild, and water quality in a typical river-reservoir interface of tropical large reservoir environment, Central India. Environ. Sci. Pollut. Res. 30, 2179–2204. https://doi.org/10.1007/s11356-022-22267-7.

Liao, C., Ye, S., Zhai, D., Yu, L., Correa, S.B., Wen, F., Zhang, C., Fang, L., Guo, C., Liu, J., 2023. Tributaries create habitat heterogeneity and enhance fish assemblage variation in one of the largest reservoirs in the world. Hydrobiologia. 850, 4311–4326. https://doi.org/10.1007/s10750-023-05306-3.

Lin, P., Gao, X., Liu, F., Li, M., Liu, H., 2019. Long-term monitoring revealed fish assemblage zonation in the Three Gorges Reservoir. J. Oceanol. Limnol. 37, 1258–126. https://doi.org/10.1007/s00343-019-8165-2.

Lipps, W.C., Braun-Howland, E.B., Baxter, T.E., 2023. Standard Methods for the Examination of Water and Wastewater, 24th ed. American Public Health Association (APHA), Washington, EUA, pp. 1516.

Loures, R.C., Pompeu, P.S., 2018. Long-term study of reservoir cascade in south-eastern Brazil reveals spatio-temporal gradient in fish assemblages. Mar. Freshw. Res. 69, 1983–1994. https://doi.org/10.1071/MF18109.

Loures, R.C., Pompeu, P.S., 2019. Temporal changes in fish diversity in lotic and lentic environments along a reservoir cascade. Freshw. Biol. 64, 1806–1820. https://doi.org/10.1111/fwb.13372.

Matthews, W.J., Gido, K.B., Gelwick, F.P., 2004. Fish assemblages of reservoirs, illustrated by Lake Texoma (Oklahoma-Texas, USA) as a representative system. Lake and Reservoir Management. 20, 219–239. https://doi.org/10.1080/07438140409354246.

Melo, R.R.R., Coelho, P.N., Santos-Wisniewski, M.J., Wisniewski, C., Magalhães, C.S., 2017. Morphological abnormalities in cladocerans related to eutrophication of a tropical reservoir. J. Limnol. 76, 94–102. https://doi.org/10.4081/jlimnol.2016.1395.

Miranda, L.E., 2017. Reservoir fish habitat management. Lightning Press, New Jersey, EUA, pp. 306.

Muniz, C.M., García-Berthou, E., Ganassin, M.J.M., Agostinho, A.A., Gomes, L.C., 2021. Alien fish in Neotropical reservoirs: Assessing multiple hypotheses in invasion biology. Ecol. Indic. 121, 107034. https://doi.org/10.1016/j.ecolind.2020.107034.

Nobile, A.B., Azevedo-Santos, V.M., Soares, C.L., Manzano, F.V., Oliveira, C., Lima, F.P., 2024. Ichthyofauna of the Marimbondinho river, Furnas reservoir, Minas Gerais, Brazil. Oecol. Austral. 28, 71–80. https://doi.org/10.4257/oeco.2024.2801.07.

Okada, E.K., Agostinho, A.A., Gomes, L.C., 2005. Spatial and temporal gradients in artisanal fisheries of a large Neotropical reservoir, the Itaipu Reservoir, Brazil. Can. J. Fish. Aquat. Sci. 62, 714–724. https://doi.org/10.1139/F05-015.

Oliveira, E.F., Goulart, E., Minte-Vera, C.V., 2004. Fish diversity along spatial gradients in the Itaipu Reservoir, Paraná, Brazil. Braz. J. Biol. 64, 447–458. https://doi.org/10.1590/S1519-69842004000300008.

Oliveira, E.F, Minte-Vera, C.V., Goulart, E., 2005. Structure of fish assemblages along spatial gradients in a deep subtropical reservoir (Itaipu Reservoir, Brazil-Paraguay border). Environ. Biol. Fishes. 72, 283–304. https://doi.org/10.1007/s10641-004-2582-5.

Ota, R.R., Deprá, G.C., Graça, W.J.G., Pavanelli, C.S., 2018. Peixes da planície de inundação do alto rio Paraná e áreas adjacentes: revised, annotated and updated. Neotrop. Ichthyol. 16, e170094. https://doi.org/10.1590/1982-0224-20170094.

Pelicice, F.M., Pompeu, P.S., Agostinho, A.A., 2015. Large reservoirs as ecological barriers to downstream movements of Neotropical migratory fish. Fish and Fisheries. 16, 697–715. https://doi.org/10.1111/faf.12089.

Pereira, S.D., Neto, R.S., 2020. Matriz elétrica brasileira: uma análise na distribuição de geração da matriz elétrica. Bol. Obs. Ambient. Alberto Ribeiro Lamego. 14, 369–385. https://doi.org/10.19180/2177-4560.v14n22020p369-385.

Pompeu, P.S, Carvalho, D.R., Leal, C.G., Leitão, R.P., Alves, C.B.M., Braga, D.F., Castro, M.A., Junqueira, N.T., Zuanon, J., Hughes, R.M., 2021. Sampling efforts for determining fish species richness in megadiverse tropical regions. Environ. Biol. Fish. 104, 1487–1499. https://doi.org/10.1007/s10641-021-01184-7.

Prado, P.S., Souza, C.C., Bazzoli, N., Rizzo, E., 2011. Reproductive disruption in lambari *Astyanax fasciatus* from a Southeastern Brazilian reservoir. Ecotoxicol. Environ. Saf. 74, 1879–1887. https://doi.org/10.1016/j.ecoenv.2011.07.017.

Quirino, B.A., Mello, F.T., Deosti, S., Bonecker, C.C., Cardozo, A.L.P., Yofukuji, K.Y., Aleixo, M.H.F., Fugi, R., 2021. Interactions between a planktivorous fish and planktonic microcrustaceans mediated by the biomass of aquatic macrophytes. J. Plankton Res. 43, 46–60. https://doi.org/10.1093/plankt/fbaa061.

R Development Core Team., 2021. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Available online: https://www.r-project.org/ (accessed on 09 July 2024).

Reid, J.W., Pinto-Coelho, R.M., 1994. An Afro-Asian continental copepod, *Mesocyclops ogunnus*, found in Brazil; with a new key to the species of *Mesocyclops* in South America and a review of intercontinental introductions of copepods. Limnologica. 24, 359–368.

Ribeiro Filho, R.A., Petrere Junior, M., Benassi, S.F., Pereira, J.M.A., 2011. Itaipu Reservoir limnology: eutrophication degree and the horizontal distribution of its limnological variables. Braz. J. Biol. 71, 889–902. https://doi.org/10.1590/S1519-69842011000500010.

Ribeiro, D.C., Chagas, J.M.A., Thereza, M.R., Langeani, F., 2019. Checklist and key for the identification of fish fauna of the Uberaba River, Upper Paraná River system, Brazil. ZooKeys. 875, 129–155. https://doi.org/10.3897/zookeys.875.31977.

Rosa, D.M., Sene, A.M., Moreira, M.Z., Pompeu, P.S., 2021. Non-native prey species supporting fish assemblage biomass in a Neotropical reservoir. Biol. Invasions. 23, 2355–2370. https://doi.org/10.1007/s10530-021-02510-x.

Sanches, B.O., Becker, B., Gomes, P.L.A., Santos, G.B., 2014. A ictiofauna de quatro reservatórios da CEMIG: caracterização das comunidades. In: Callisto, M., Alves, C.B.M., Lopes, J.M., Castro, M.A., eds. Condições ecológicas em bacias hidrográficas de empreendimentos hidrelétricos. Belo Horizonte, Brazil: Cemig, pp. 186–213.

Sanches, B.O., Hughes, R.M., Macedo, D.R., Callisto, M., Santos, G.B., 2016. Spatial variations in fish assemblage structure in a southeastern Brazil reservoir. Braz. J. Biol. 76, 185–193. https://doi.org/10.1590/1519-6984.16614.

Sandhya, K.M., Lianthuamluaia, L., Karnatak, G., Sarkar, U.K., Kumari, S., Mishal, P., Kumar, V., Panda, D., Ali, Y., Naskar, B.K., 2019. Fish assemblage structure and spatial gradients of diversity in a large tropical reservoir, Panchet in the Ganges basin, India. Environ. Sci. Pollut. Res. 26, 18804–18813. https://doi.org/10.1007/s11356-019-05314-8.

Santos, J.A., Sousa, K.N.S., Santos, P.R.B., Lima, J.L., Bacelar, R.J., 2019. Habitat, limnological signatures and spatial modeling: a zoning proposal for the Curuá-Una hydroelectric reservoir, Pará, Brazil. Acta Limnol. Bras. 31, e22. https://doi.org/10.1590/S2179-975X12017.

Santos, A.B.I., Terra, B.D.F., Araújo, F.G., 2010. Influence of the river flow on the structure of fish assemblage along the longitudinal gradient from river to reservoir. Zoologia. 27, 732–740. https://doi.org/10.1590/S1984-46702010000500010.

Santos, L.N., García-Berthou, E., Agostinho, A.A., Latini, J.D., 2011. Fish colonization of artificial reefs in a large Neotropical reservoir: material type and successional changes. Ecol. Appl. 21, 251–262. https://doi.org/10.1890/09-1283.

Santos-Wisniewski, M.J., Silva, L.C., Leone, I.C., Laudares-Silva, R., Rocha, O., 2007. First record of the occurrence of *Ceratium furcoides* (Levander) Langhans 1925, an invasive species in the hydroelectricity power plant Furnas Reservoir, MG, Brazil. Braz. J. Biol. 67, 791–793. https://doi.org/10.1590/S1519-69842007000400033.

Smith, S.W., Petrere Jr, M., 2008. Spatial and temporal patterns and their influence on fish community at Itupararanga Reservoir, Brazil. Rev. Biol. Trop. 56, 2005–2020. https://doi.org/10.15517/rbt.v56i4.5775.

Silva, A.C., Van Den Berg, E., Higuchi, P., Oliveira-Filho, A.T., Marques, J.J.G.S.M., Appolinário, V., Pifano, D.S., Ogusuku, L.M., Nunes, M.H., 2009. Florística e estrutura da comunidade arbórea em fragmentos de floresta aluvial em São Sebastião da Bela Vista, Minas Gerais, Brasil. Rev. Bras. Bot. 32, 283–297. https://doi.org/10.1590/S0100-84042009000200008.

Silva, L.C., Leone, I.C., Santos-Wisniewski, M.J., Peret, A.C., Rocha, O., 2012. Invasion of the dinoflagellate *Ceratium furcoides* (Levander) Langhans 1925 at tropical reservoir and its relation to environmental variables. Biota Neotrop. 12, 93–100. https://doi.org/10.1590/S1676-06032012000200010.

Silva-Sene, A.M., Loures, R.C., Neto, F.R.A., Pompeu, P.S., 2022. Fish assemblage distribution along free-flowing rivers entering a reservoir cascade. Environ. Biol. Fishes. 105, 1535–1547. https://doi.org/10.1007/s10641-022-01345-2.

Silva-Sene, A.M., Fontes, R.C.L., Prado, I.G., Pompeu, P.S., 2023. Migratory fishes from rivers to reservoirs: seasonal and longitudinal perspectives. Zoologia. 40, e22044. https://doi.org/10.1590/S1984-4689.v40.e22044.

Silva-Sene, A.M., Prado, I.G., Porto, C.P., Pompeu, P.S., 2024. The fish fauna of Itutinga reservoir, 30 years after the first survey. Acta Limnol. Bras. 36, e11. https://doi.org/10.1590/S2179-975X2922.

Smith, N.G., Buckmeier, D.L., Fleming, B.P., Grubh, A.R., Homer Jr, M.D., Robertson, S.M., 2023. Spatial variability in the fish assemblage of a large river–reservoir ecosystem. N. Am. J. Fish. Manage. 43, 313–326. https://doi.org/10.1002/nafm.10804.

Teresa, F.B., Romero, R.M., Casatti, L., Sabino, J., 2011. Fish as indicators of disturbance in streams used for snorkeling activities in a tourist region. Environ. Manage. 47, 960–968. https://doi.org/10.1007/s00267-011-9641-4.

Terra, B.F., Santos, A.B.I., Araújo, F.G., 2010. Fish assemblage in a dammed tropical river: an analysis along the longitudinal and temporal gradients from river to reservoir. Neotrop. Ichthyol. 8, 599–606. https://doi.org/10.1590/S1679-62252010000300004.

Yang, Z., Pan, X., Hu, L., Xu, W., Jin, Y., Zhao, N., Yang, Q., Chen, X., Liu, H., 2021. Effects of upstream cascade dams and longitudinal environmental gradients on variations in fish assemblages of the Three Gorges Reservoir. Ecol. Freshw. Fish. 30, 503–518. https://doi.org/10.1111/eff.12600.

CAPÍTULO 02 – Artigo redigido conforme a NBR 6022 (ABNT 2018)

Local impacted streams share more species with a big tropical reservoir

Riachos da bacia de drenagem da UHE Furnas, julho de 2023.

Local impacted streams share more species with a big tropical reservoir

Rosalva Sulzbacher[1], Carlos Bernardo Mascarenhas Alves[2], Paulo Sérgio Formagio[3], Gilberto Nepomuceno Salvador[4], Paulo Santos Pompeu[5]

[1]Programa de Pós-Graduação em Ecologia Aplicada, Departamento de Ecologia e Conservação, Instituto de Ciências Naturais, 6 Universidade Federal de Lavras, CEP 37200-900, Lavras, MG, Brazil; rosalva.sulzbacher@estudante.ufla.br

[2]Laboratório Nuvelhas, Projeto Manuelzão, Universidade Federal de Minas Gerais, CEP 31270-901, Belo Horizonte, MG, Brazil; 10 cbmalves@ufmg.br

[3]Biólogo Consultor do Projeto IBI-Furnas - Eletrobrás, 37900-150, Passos, MG, Brazil. formagiopaulosergio@gmail.com

[4]Programa de Pós-Graduação em Ecologia, Laboratório de Ecologia e Conservação, Universidade Federal do Pará, CEP 66075-8 110, Belém, PA, Brazil; curimata_gilbert@hotmail.com

[5]Laboratório de Ecologia de Peixes, Departamento de Ecologia e Conservação, Instituto de Ciências Naturais, Universidade Federal de Lavras, 37200-900 Lavras, MG, Brazil. pompeu@ufla.br

ABSTRACT: In aquatic ecosystems, the response to anthropogenic disturbances can vary depending on the scale analyzed and the degree of connectivity between natural and impacted environments. Moreover, local impacts may select similar species even in distinct environments, such as streams and reservoirs. This study aimed to: (i) assess native and non-native shared fish species between the reservoir and streams in the hydrological unit of the Furnas Hydroelectric Power Plant, considering local, regional, and spatial factors; (ii) investigate the role of disturbance indices and distance to the reservoir in the occurrence of non-native species in streams. Fish were collected at 40 sites in the marginal region of the reservoir and at 40 streams within the same drainage basin. A total of 61 species were recorded, with 16 species shared. Local impact and the percentage richness of non-native species in the streams increased the number of species shared with the reservoir. Streams with local impacts were those with the highest likelihood of non-native species occurrence. The distance variable did not explain shared species richness or the occurrence of non-natives in streams, suggesting its low predictive power as a proxy for connectivity in a basin impacted by a reservoir. The importance of local impact as a driver for non-native species occurrence in streams highlights the facility of these species in colonizing and persisting in disturbed habitats.

Key-words: Non-native species, Disturbance indices, Furnas reservoir.

1 Introduction

One of the main concerns in community ecology is to understand the patterns of species composition and distribution, as well as their main drivers. In aquatic ecosystems, several studies have sought to understand the importance of local, spatial, and temporal variables in shaping fish communities, whether in natural enviroments, such as streams (Blanchet *et al*., 2014; Costa; Rocha, 2017; Mondal; Bach, 2020; Rodrigues-Filho *et al*., 2018;), or artificial, such as reservoirs (Franco *et al*., 2024; Loures; Pompeu, 2019; Sanches *et al*., 2016). Due to the recognized distinct nature of this environments, studies assessing the interaction between streams and reservoirs are rare, and the existing ones primarily explore the impacts of dams on temperate stream fish assemblages (e.g., Cooper *et al*., 2017; Falke; Gido, 2006a, 2006b; Faucheux *et al*., 2023).

Reservoirs are well-documented for their significant alterations on fish fauna (Agostinho *et al*., 2008, 2016; Fráguas; Pompeu, 2021), characterized by the presence of generalist and non-native species due to its artificial lentic environment (Agostinho *et al*., 2007; Lin *et al*., 2019; Muniz *et al*., 2021). In contrast, preserved streams support rich (Costa; Rocha, 2017) and functionally specialized communities (Barbosa *et al*., 2020). However, the increasing advancement of urbanization and significant changes in land use have threatened the assemblages of these environments. In streams, anthropogenic impacts lead to reductions in diversity, biotic homogenization, and increases in non-native species (Cruz; Pompeu, 2020; Ortega *et al*., 2021). Therefore, despite their distinct and varying impact scales, both reservoirs and impacted streams can support fish assemblages with similar characteristics, formed, for example, by omnivorous/generalist, tolerant, and non-native species (Agostinho *et al*., 2007; Blabolil *et al*., 2016; Cunico *et al*., 2011; Cruz; Pompeu, 2020; Engman; Ramírez, 2012; Sulzbacher *et al*., *in press*).

In tropical streams, studies that explore the role of environmental characteristics in shaping fish assemblages have focused on both local-level variables (e.g., instream habitat, water quality) and catchment-level variables related to human disturbance (e.g., land use) (Barbosa *et al*., 2019; Leal *et al*., 2018; Terra *et al*., 2016). In these studies, local factors tend to be more important than spatial and catchment factors in explaining species composition (Barbosa *et al*., 2019) and the taxonomic and functional characteristics of the assemblages (Terra *et al*., 2016). Species responses to instream factors are variable. For example, flow velocity may be positively related to Loricariidae species or negatively associated with small-sized characids (Barbosa *et al*., 2019). Tolerant species may be associated with water quality variables such as conductivity and turbidity (Terra *et al*., 2016), suggesting that local factors in streams can also act as key drivers in the functional structure of fish assemblages.

In addition to local and catchment variables, connectivity is also an important driver of fish assemblages in aquatic ecosystems (Leal *et al*., 2020; Shao *et al*., 2019). In streams, connectivity influences patterns of fish richness and diversity (Borges *et al*., 2020; Cruz; Pompeu, 2020), with its loss negatively impacting the functional attributes of the assemblages (Leitão *et al*., 2018). In reservoirs, connectivity with remaining lotic environments is fundamental for maintaining diversity, allowing the persistence of rheophilic and migratory species in the transition areas between the two environments (Agostinho *et al*., 2016; Silva-Sene *et al*., 2022). In natural environments, connectivity appears to be related to the dispersal and richness of non-native species (Amo *et al*., 2021; Paillex *et al*., 2017). In these cases, the permanent connection of habitats can increase the propagule pressure of these species (Amo *et al*., 2021), which are widely distributed in neotropical reservoirs (Muniz *et al*., 2021). In regulated basins, riverine reaches near reservoirs can harbor invaded assemblages (Hermoso *et al*., 2011). This is likely due to the fact that reservoirs remain connected to the river system (Havel *et al*., 2005), potentially facilitating the dispersal of non-native species from these environments to other water bodies within the basin (e.g., streams).

In streams, the presence of non-native species is frequently associated with human impact. Urban streams, for example, tend to support high abundances of *Poecilia reticulata* (Cruz *et al*., 2020; Ortega *et al*., 2021), an invasive and highly pollution-tolerant species (Carvalho *et al*., 2019a). Agricultural land use, unlike urbanization, can influence invasions indirectly. On a catchment scale, agricultural land use affects physicochemical instream conditions by reducing flow velocity and increasing temperature and macrophyte coverage. Thus, while catchment variables explain the occurrence of non-native species in streams, local conditions are important predictors of the abundance of these species (Lee *et al*., 2017). Non-native species have been identified as important drivers of the decline or even extinction of native species (Hermoso *et al*., 2011; Light; Marchetti, 2007). In river systems, fish invasions can lead to an almost complete turnover of native species by non-natives (Haubrock *et al*., 2021), which can potentially affect the aquatic biota. Non-native species, as a group, tend to be functionally less diverse (Milardi *et al*., 2019), and their dominance leads to biotic homogenization and the loss of ecosystem functions (Moi *et al*., 2021).

Although reservoirs and streams are subject to similar anthropogenic pressures, the integrated assessment of these environments remains underexplored compared to studies that evaluate fish community structuring in streams and reservoirs separately. Therefore, the aim of this study is to evaluate the importance of distance to reservoir and human disturbance on shared richness between a large neotropical reservoir and its adjacent streams, and to identify the role of these variables in the occurrence of non-native fish in streams. The following hypotheses were tested: (i) More disturbed streams and those closer to the reservoir will have more shared species; (ii) Impacted streams near to the reservoir will have a higher probability of non-native fish occurrence; (iii) Local disturbance will be more important than catchment disturbance on explaining non-native richness in streams.

2 Materials and Methods

2.1 Study area

The Grande river drains an area of approximately 145.000 km² and is one of the primary headwater tributaries of the Paraná River. Its elevation ranges from 200 to 1.800 meters above mean sea level. The predominant land use is agricultural, with forested areas covering about 20% of the region (Nóbrega *et al.*, 2011). The Rio Grande flows through a transitional zone between the Cerrado and Atlantic Forest biomes, both affected by agricultural and livestock exploitation, urban expansion, and artificial water reservoirs (Souza Jr *et al.*, 2020).

The UHE Furnas hydrological region has a stream network situated within a predominantly Cerrado region. In this area, annual precipitation varies between 1.600 and 1.900 millimeters, and the climate is classified as humid subtropical according to the Köppen classification (Alvares *et al.*, 2013). The land use matrix at UHE Furnas drainage basin is primarily composed of pasture and urban areas, although some regions contain preserved riparian vegetation. The Furnas reservoir, one of Brazil's largest reservoirs, extends for 220 km and encompasses a flooded area of 1.440 km², with a total volume of 22.95 billion cubic meters. The dam has a height of 127 meters. The reservoir is formed by the impoundment of the Grande and Sapucaí rivers, along with several smaller tributaries. The Grande River, which is the reservoir's central body, features a cascading dam series located upstream of Furnas. Meanwhile, the Sapucaí River is characterized by an extensive floodplain (Silva *et al.*, 2009) but is adversely affected by sewage discharge from major urban areas. Despite these variations, the reservoir is generally classified as oligotrophic, except in regions directly influenced by sewage inflow (Silva *et al.*, 2012).

In the reservoir, 40 sites were selected along its shoreline. For the stream sampling, 40 sites ranging from first to third order were selected within a 35 km buffer, as described by Macedo *et al*. (2014). Each stream was considered as a site. For both environments, 24 sites were randomly sorted and 16 were hand-picked to encompass a broad range of land use conditions, since less disturbed sites (i.e., preserved shoreline with native vegetation, 8 sites) and more disturbed sites (i.e., proximity to urban areas, crops and livestock, 8 sites). Data collection occurred in the end of rain season (for the reservoir) and in during the dry season of 2023 (for the streams).

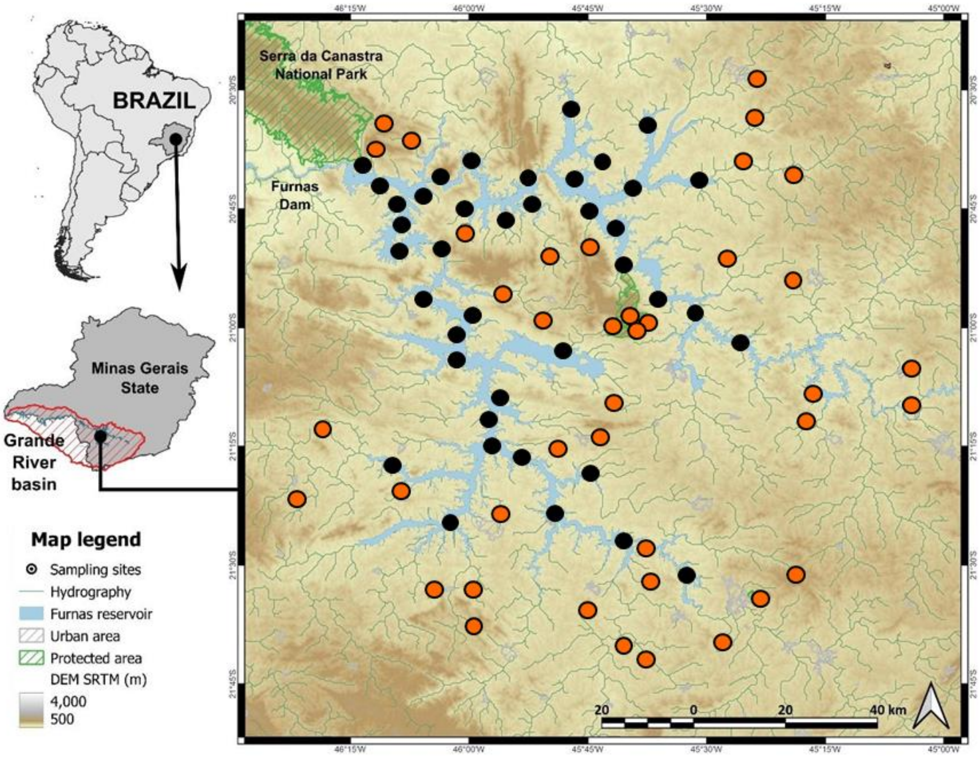

Figure 1 – Map of the sampling sites in the reservoir and streams of the UHE Furnas drainage basin, Upper Paraná River. Black dots = reservoir sites; orange dots = streams sites.
Fonte: da autora, 2025.

2.2 Local and Buffer Disturbance Indices

The Local Disturbance Index (LDI) was calculated using the *RDis_IX* metric (Kaufmann *et al*., 2014), which describes the intensity and extent of the Lakeshore Anthropogenic Disturbance Index. Agricultural disturbances (crops, pasture, orchards, and parks) and non-agricultural disturbances (buildings, commercial areas, ramps, docks, walls, litter, highways, and transmission lines) present in the riparian zone were considered, according to formula (1). The Buffer Disturbance Index (BDI) (Anacléto *et al.*, 2018) was calculated considering land uses surrounding the basin, according formula (2).

(1) LDI = {1 – [1 / [1 + non-agricultural disturbances + (5 * agricultural disturbances)] + proportion of plots with disturbances] / 2}

(2) BDI = (4 x % residential construction area) + 2 x (% agricultural area + % bare soil area) + (% pasture area)

2.3 Fish sampling

In the reservoir, fish were collected at the littoral zone using an 8m x 1.5m seine net with mesh size of 5 mm between opposite nodes. Three trawls were executed at each site (sampling effort of 36 m²). The streams were divided into 5 sections, each 15 meters long. In each section, fish were collected by two people for 12 minutes using semicircular hand nets (0.8 m² and 5 mm mesh size) and seine nets (3 m x 1.5 m and 5 mm mesh size). Collected fish were anesthetized with eugenol, fixed in 10% formalin, and preserved in 70% ethanol. In the laboratory, species were identified according to the dichotomous keys of Ota *et al.* (2018), Ribeiro *et al.* (2019), and Thereza and Langeani (2019), and classified as native or non-native according to Bueno *et al.* (2021). Family classification was based on Eschmeyer's Catalog of Fishes (Fricke *et al.*, 2025). Voucher specimens of all species recorded in the streams and reservoir were deposited in the fish collection at UFLA (CI-UFLA).

This study was approved by the Animal Ethics Committee of the Federal University of Lavras (CEUA/UFLA) under collection permit number 11/23, and authorized by the Chico Mendes Institute for Biodiversity Conservation (ICMBio/SISBIO – 10327-6) and the State Forest Institute (IEF – 041/2023).

2.4 Data analysis

The hydrological distance between the streams and the reservoir was calculated using ArcGis software. The richness and composition of shared species between streams and the reservoir were assessed using a Venn diagram. To evaluate the role of disturbance indices, distance to the reservoir, and the percentage richness of non-native species in species sharing, a Generalized Linear Model (GLM) with Poisson distribution was performed. To assess the influence of disturbance indices and distance from the reservoir on the probability of capturing at least one non-native fish on streams, a GLM with Binomial distribution was conducted. For each GLM, models with delta < 2 were selected using the *dredge* function. All analyses were conducted with R software version 4.2.2 (R Development Core Team, 2021).

3 Results

A total of 4.940 individuals and 61 species were captured, distributed across 6 orders and 19 families (Table 1). In the streams, 44 species and 2.904 individuals were recorded, with average richness and abundance per site of 5.2 (± 2.6) and 72.6 (± 61.3), respectively. In the reservoir, 33 species and 2.036 individuals were recorded, with average richness and abundance of 3.4 (± 3.1) and 50.9 (± 142.0), respectively. The most abundant species in the streams was *Phalloceros harpagos* (32.33%), recorded in 17 streams. In the reservoir, the most abundant species was *Hyphessobrycon eques* (34.18%), recorded at 9 sites.

The shared fish fauna between the reservoir and the streams consisted of 16 species, most of which were native (Figure 2). The reservoir presented 17 unique species, including 9 natives and 8 non-natives. All species exclusively captured in the streams were native. Species belonging to the families Callichthyidae, Crenuchidae, Heptapteridae, Sternopygidae, and Trichomycteridae were recorded only in the streams. Conversely, the families Anostomidae and Serrasalmidae occurred only in the reservoir (Table 1, Figure 2).

Table 1 – Composition and abundance of species captured in UHE Furnas reservoir and streams of the respective drainage basin. N streams = abundance in the streams; N reservoir = abundance in the reservoir.

(Continua)

Taxon	N streams	N reservoir	Distribution
Characiformes			
Acestrorhamphidae			
Astyanax lacustris (Lütken 1875)	84	404	Native
Hasemania hanseni (Fowler 1949)	15	1	Native
Hemigrammus marginatus Ellis 1911		6	Native
Hyphessobrycon eques (Steindachner 1882)		696	Non-native
Oligosarcus paranensis Menezes & Géry 1983	18		Native
Psalidodon bockmanni (Vari & Castro 2007)	9		Native
Psalidodon fasciatus (Cuvier 1819)	68	26	Native
Psalidodon paranae (Eigenmann 1914)	459		Native
Anostomidae			
Leporinus friderici (Bloch 1794)		15	Native
Leporinus striatus Kner 1858		2	Native
			(Continuação)
Schizodon nasutus Kner 1858		7	Native
Characidae			

Serrapinnus heterodon (Eigenmann 1915)		22	Native
Serrapinnus notomelas (Eigenmann 1915)	1	110	Native
Crenuchidae			
Characidium aff. *zebra* Eigenmann 1909	29		Native
Curimatidae			
Steindachnerina insculpta (Fernández-Yépez 1948)	1	33	Native
Erythrinidae			
Hoplias gr. *malabaricus* (Bloch 1794)	15		Native
Hoplias intermedius (Günther 1864)		3	Native
Parodontidae			
Apareiodon affinis (Steindachner 1879)		147	Native
Apareiodon piracicabae (Eigenmann 1907)	11	20	Native
Parodon nasus Kner 1859	1	1	Native
Serrasalmidae			
Metynnis lippincottianus (Cope 1870)		13	Non-native
Stevardiidae			
Knodus moenkhausii (Eigenmann & Kennedy 1903)	329	264	Non-native
Lophiobrycon weitzmani Castro et al (2003)	138		Native
Piabarchus stramineus (Eigenmann 1908)		130	Native
Piabina argentea Reinhardt 1867		2	Native
Cichliformes			
Cichlidae			
Australoheros oblongus (Castelnau 1855)	13		Native
Cichla kelberi Kullander & Ferreira 2006		7	Non-native
Cichla piquiti Kullander & Ferreira 2006		2	Non-native
Coptodon rendalli (Boulenger 1897)		35	Non-native
Geophagus iporangensis Haseman 1911	125	2	Native
Saxatilia britskii (Kullander 1982)	3	14	Native
Cyprinodontiformes			
Poeciliidae			
Phalloceros harpagos Lucinda 2008	939		Native
Poecilia reticulata Peters 1859	30	1	Non-native
Poecilia vivipara Bloch & Schneider 1801		33	Non-native
Gymnotiformes			
Gymnotidae			
Gymnotus cf. *inaequilabiatus* (Valenciennes 1839)	5	1	Native
Gymnotus cf. *pantanal* Fernandes et al (2005)	34	3	Non-native
Gymnotus cf. *paraguensis* Albert & Crampton 2003		4	Non-native
Gymnotus sylvius Albert & Fernandes-Matioli 1999	44	6	Native
Sternopygidae			
Eigenmannia dutrai Peixoto, Pastana & Ballen 2021	8		Native
Siluriformes			
Callichthyidae			
Aspidoras fuscoguttatus Nijssen & Isbrücker 1976	10		Native
Callichthys callichthys (Linnaeus 1758)	52		Native
Heptapteridae			
Cetopsorhamdia iheringi Schubart & Gomes 1959	29		Native
Pimelodella gracilis (Valenciennes 1835)	1		Native
Rhamdia quelen (Quoy & Gaimard 1824)	32		Native
Rhamdiopsis microcephala (Lütken 1874)	41		Native
Loricariidae			
Hisonotus francirochai (Ihering 1928)	1		Native
			(Conclusão)
Hypostomus ancistroides (Ihering 1911)	8		Native
Neoplecostomus sp.	3		Native

Pareiorhina aff. *pelicicei* Azevedo-Santos & Roxo 2015	30		Native
Pareiorhina sp.	1		Native
Pterygoplichthys ambrosettii (Holmberg 1893)		3	Non-native
Pimelodidae			
Pimelodus maculatus Lacepède 1803	4	20	Native
Trichomycteridae			
Scleronema aff. *auromaculatum* Costa et al (2022)	9		Native
Trichomycterus aff. *Maracaya* Bockmann & Sazima 2004	13		Native
Trichomycterus candidus (Miranda Ribeiro 1949)	68		Native
Trichomycterus maracaya Bockmann & Sazima 2004	3		Native
Trichomycterus pauciradiatus Alencar & Costa 2006	7		Native
Trichomycterus pirabitira Barbosa & Azevedo-Santos 2012	193		Native
Trichomycterus sainthilairei Katz & Costa 2021	5		Native
Trichomycterus septemradiatus Katz, Barbosa & Costa 2013	10		Native
Synbranchiformes			
Synbranchidae			
Synbranchus marmoratus Bloch 1795	5	3	Native
Total abundance	2904	2036	

Fonte: da autora, 2025.

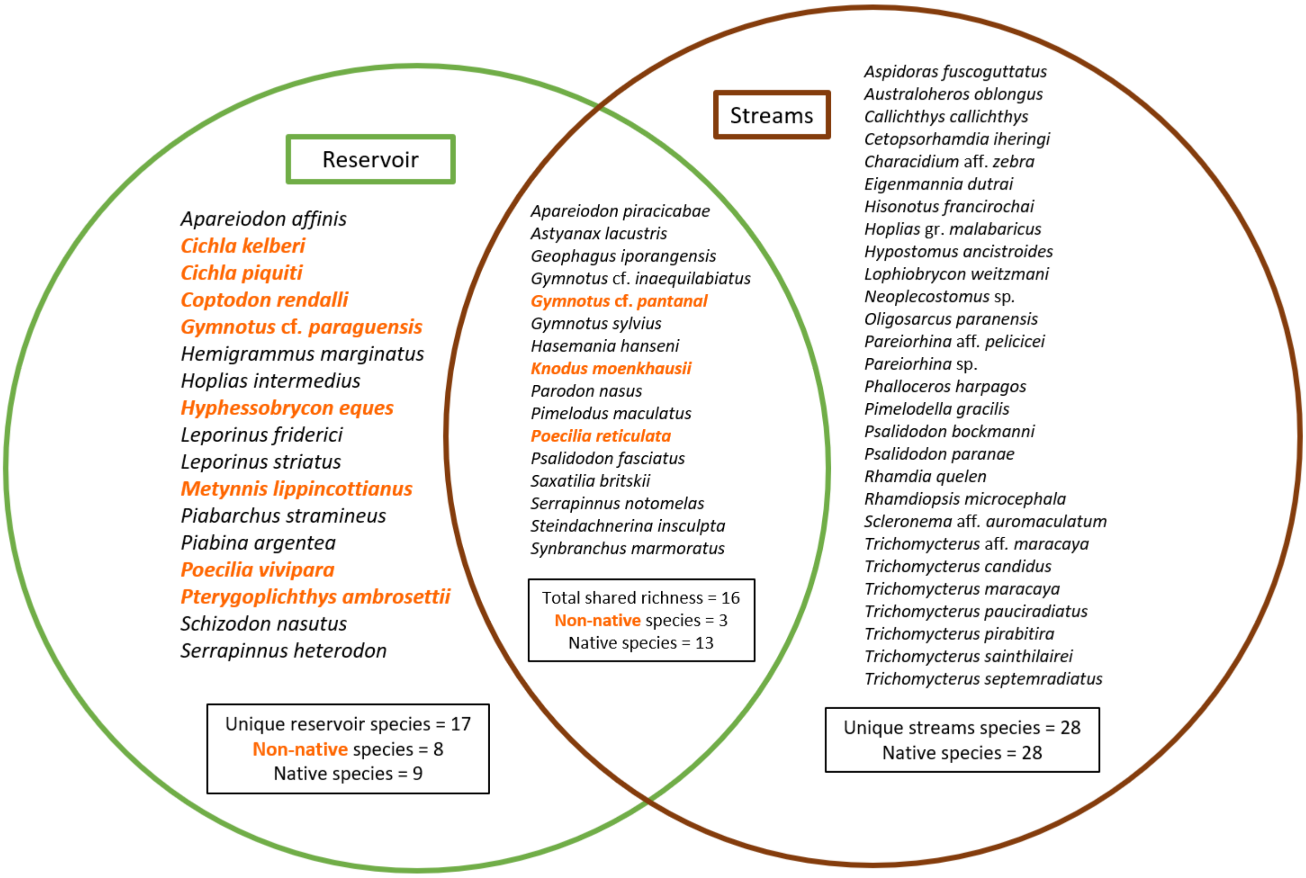

Figure 2 – Venn diagram of fish species captured in the UHE Furnas reservoir and the streams of the respective drainage basin. The species placed on center were shared between reservoir and streams.
Fonte: da autora, 2025.

Higher the disturbance indices and the percentage richness of non-native species on streams, higher was the number of shared species with the reservoir (Figure 3). The local disturbance and the richness of non-native species on streams were the primary explanatory variables of the shared richness (Table 2). Although the buffer disturbance index was included in some models, its significance was marginal. The shared richness model with the highest explanatory power ($R^2 = 0.47$) included both disturbance indices and the percentage richness of non-native species (Table 2).

Both local and regional disturbance increased the probability of capturing at least one non-native fish in the streams (Figure 4), particularly the local disturbance index. The distance from the reservoir was not selected in the models for shared richness or the presence of non-native species in the streams (Table 2).

Table 2 – Results of Generalized Linear Models (GLM) for shared richness and presence of non-native fish on streams. LDI = Local Disturbance Index, BDI = Buffer Disturbance Index, Dist = Distance to the reservoir. AICC = Akaike Information Criterion, Delta = Model selection criterion (Delta < 2), Weight = Influence of each observation, R2 = Model explanatory power. Values in bold are significant ($p<0.05$).

Shared richness ~ LDI + BDI + Dist + %Non-native richness									
Model	Int	BDI	LDI	Dist	%Non-native richness	AICc	Delta	Weight	R^2
Poisson	-1.0140	0.005222	**0.4722**	-	**1.057**	144.7	0.00	0.304	0.47
Poisson	-0.5240	-	**0.4836**	-	**1.087**	145.1	0.41	0.247	0.41
Poisson	-09564	0.005780	**0.4926**	-	**-**	146.3	1.64	0.134	0.43
Non-native presence ~ LDI + BDI + Dist									
Model	Int	BDI	LDI	Dist		AICc	Delta	Weight	R^2
Binomial	-3.0840	0.01423	0.7025	-		51.7	0.00	0.301	0.22
Binomial	-1.8810	-	**0.7906**	-		51.8	0.15	0.280	0.15
Binomial	-2.0250	0.01615	-	-		53.4	1.69	0.130	0.10

Fonte: da autora, 2025.

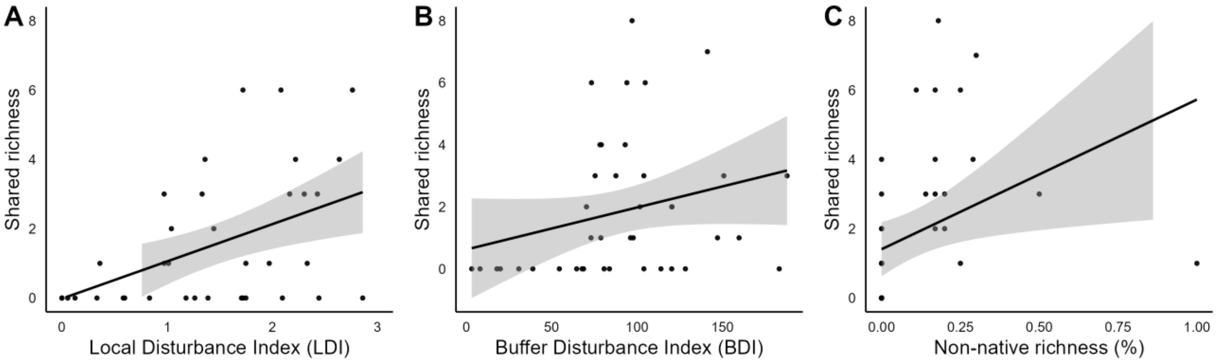

Figure 3 – Variation on shared fish richness between UHE Furnas reservoir and streams in response to disturbance indices and percentual non-native richness. A = Local disturbance index (LDI), B = Buffer Disturbance Index (BDI), C = Percentage of non-native richness on streams.

Fonte: da autora, 2025.

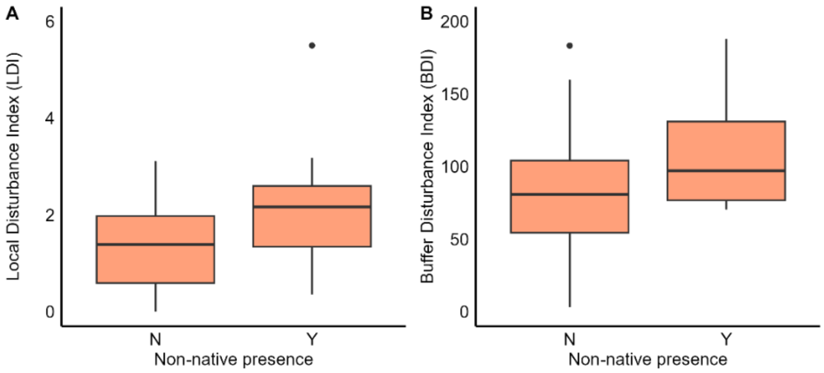

Figure 4 – Presence of non-native fish on streams in response to disturbance indices. A = Local disturbance index (LDI), B = Buffer Disturbance Index (BDI).
Fonte: da autora, 2025.

4 Discussion

As expected, locally impacted streams with a higher percentage of non-native species richness shared a greater number of species with the reservoir. Contrary to expectations, the distance between streams and the reservoir had low explanatory power in the species-sharing models and in the occurrence of non-native species in the streams. Finally, as predicted, locally impacted streams had the highest occurrences of non-native species and the local disturbance was a better predictor than catchment disturbance in explaining non-native species richness in streams.

Although included in some models, the buffer disturbance index had limited predictive power in shared richness. Several studies have shown that, in streams, the response of fish assemblages to environmental variables depends on the scale. In many cases, local factors (i.e., instream habitat) are more important than spatial and/or regional factors (i.e., land cover/use, slope) in shaping assemblage structure (Barbosa *et al*., 2019; Casatti *et al*., 2015; Leal *et al*., 2018; Terra *et al*., 2016). However, it is important to note that local impacts may be linked to land use in the landscape (Larentis *et al*., 2022). Agricultural land use, for example, may be associated with changes in water quality and increased macrophyte cover (Lee *et al*., 2017). Therefore, in this study, it is possible that the influence of buffer disturbance in streams acts indirectly in species sharing by modifying the environment at a local scale.

Locally impacted streams exhibited the highest number of shared species with the reservoir, which is a lentic environment whose ichthyofauna is primarily composed of sedentary and generalist species (Agostinho *et al*., 2016; Sulzbacher *et al*., *in press*). In contrast, preserved streams tend to support functionally distinct assemblages (Larentis *et al*., 2022), composed, for example, of species associated with higher riparian vegetation cover and dissolved oxygen, such as *Trichomycterus* spp. (Caetano *et al*., 2016; Cruz; Pompeu, 2020). Local impact was also the main explanatory variable for the presence of non-native species in the streams. The association between non-native species and habitat degradation has been largely reported, and urbanization, land use, and climatic variations have been identified as facilitators of invasions in streams worldwide (Lee *et al*., 2017; Milardi *et al*., 2022; Ortega *et al*., 2021). In the Paraná river basin, non-native species have been used in biotic integrity indices both in reservoirs (Sanches *et al*., 2018) and in streams. In the latter, non-native species have proven effective either in the composition of the indices (Carvalho *et al*., 2017) or serving directly as a selection criterion for degraded streams (Ruaro *et al*., 2018).

Trophic opportunism in non-native species may be one of the key factors behind the success of invasions in degraded environments. In impacted streams of the Upper Paraná basin, the invasive species *Knodus moenkhausii* and *Poecilia reticulata* can alter their diet in response to disturbance, either by consuming more abundant items (Carvalho *et al*., 2019b) or by directly assimilating sewage (Carvalho *et al*., 2019a), which is one of the primary sources of pollution in urban streams. In the streams analyzed in this study, *K. moenkhausii* and *P. reticulata* were among the shared species, reinforcing the generalist and opportunistic nature of these invaders, capable of surviving in completely distinct environments, such as streams and reservoir. Among the native species shared, the yellowtail tetra *Astyanax lacustris* was the most abundant. This species is widely distributed in the Upper Paraná basin (Dagosta *et al*., 2024) and is also present in other Brazilian basins (Alonso *et al*., 2019; Bastian *et al*., 2021). It is described as an omnivorous fish that primarily consumes insects, algae, and plants (Alonso *et al*., 2019; Bastian *et al*., 2021; Pini *et al*., 2019) and exhibits high trophic plasticity in response to urban pollution (Alonso *et al*., 2019). It is also noteworthy that all non-native species from the streams were shared with the reservoir, but not the other way around. This also suggests that these species are either habitat generalists or typical of lentic environments.

Contrary to our expectations, the distance from the reservoir did not explain species sharing. Although distance by itself can be used as a proxy for connectivity in the landscape (Kindlmann; Burel, 2008), the presence of barriers between the reservoir and the streams (i.e., artificial ponds, road crossings and waterfalls) not evaluated in this study may be interrupting the hydrological connection between these environments. Furthermore, the stream selection methodology within a 35 km buffer may have reduced the variability in distance, which could have affected the influence of this variable on the shared richness models. Distance also failed to explain the presence of non-native species in the streams, which was expected, given that reservoirs are considered "stepping-stones" for non-native species (Havel *et al*., 2005; Johnson *et al*., 2008). It is possible that there are other source areas for these species in the UHE Furnas drainage basin, and that connectivity between the streams themselves may be favoring dispersion and colonization.

Local impact and the percentage richness of non-native species in streams increased species sharing with the reservoir. The positive relationship between non-native species in streams and shared richness can be explained by the association of these species with disturbance indices, which was the primary explanatory variable of species sharing. The limited predictive power of the distance from the reservoir in shared richness patterns suggests that this variable alone may not be a reliable predictor of connectivity in the UHE Furnas drainage basin.

References

AGOSTINHO, A. A.; GOMES, L. C.; PELICICE, F. M. **Ecologia e manejo de recursos pesqueiros em reservatórios do Brasil**. Maringá: EDUEM, 2007.

AGOSTINHO, A. A.; GOMES, L. C.; SANTOS, N. C.; ORTEGA, J. C.; PELICICE, F. M. Fish assemblages in Neotropical reservoirs: Colonization patterns, impacts and management. **Fisheries Research**, v. 173, p. 26-36, 2015.

AGOSTINHO, A. A.; PELICICE, F. M.; GOMES, L. C. Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. **Brazilian journal of biology**, v. 68, p.1119-1132, 2008.

ALONSO, M. B.; CARVALHO, D. R. D.; ALVES, C. B.; MOREIRA, M. Z.; POMPEU, P. S. Changes in trophic characteristics of two fish species of *Astyanax* (Teleostei: Characidae) in response to aquatic pollution. **Zoologia (Curitiba)**, v. 36, p. e30445, 2019.

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. D. M.; SPAROVEK, G. Köppen’s climate classification map for Brazil. **Meteorologische zeitschrift**, v. 22, n. 6, p. 711-728, 2013.

AMO, V. E.; ERNANDES-SILVA, J.; MOI, D. A.; MORMUL, R. P. Hydrological connectivity drives the propagule pressure of *Limnoperna fortunei* (Dunker, 1857) in a tropical river–floodplain system. **Hydrobiologia**, v. 848, p. 2043-2053, 2021.

ANACLÉTO, M. J. P.; LIGEIRO, R.; BARBOSA, J. E. D. L.; MOLOZZI, J.; CALLISTO, M. Effects of an atypical drought on the benthic macroinvertebrate community in a tropical reservoir. **Biota Neotropica**, v. 18, n. 2, p. e20170352, 2018.

BARBOSA, A. S.; PIRES, M. M.; SCHULZ, U. H. Influence of land-use classes on the functional structure of fish communities in southern Brazilian headwater streams. **Environmental management**, v. 65, n. 5, p. 618-629, 2020.

BARBOSA, H. D. O.; BORGES, P. P.; DALA-CORTE, R. B.; MARTINS, P. T. D. A.; TERESA, F. B. Relative importance of local and landscape variables on fish assemblages in streams of Brazilian savanna. **Fisheries Management and ecology**, v. 26, n. 2, p. 119-130, 2019.

BASTIAN, R.; MASSARO, M. V.; FELDEN, J.; LUZ SOARES, M. D.; SIVERIS, S. E.; REYNALTE-TATAJE, D. A. Daily variation feeding of *Astyanax lacustris* (Lütken 1875) in a subtropical river. **Acta Scientiarum: Biological Sciences**, v. 43, n. 1, 2021.

BLABOLIL, P.; LOGEZ, M.; RICARD, D.; PRCHALOVÁ, M.; ŘÍHA, M.; SAGOUIS, A.; PETERKAA, J.; KUBERČKA, J.; ARGILLIER, C. An assessment of the ecological potential of Central and Western European reservoirs based on fish communities. **Fisheries research**, v. 173, p. 80-87, 2016.

BLANCHET, S.; HELMUS, M. R.; BROSSE, S.; GRENOUILLET, G. Regional vs local drivers of phylogenetic and species diversity in stream fish communities. **Freshwater Biology**, v. 59, n. 3, p. 450-462, 2014.

BORGES, P. P.; DIAS, M. S.; CARVALHO, F. R.; CASATTI, L.; POMPEU, P. S.; CETRA, M.; TEJERINA-GARRO, F. L.; SÚAREZ, Y. R.; NABOUT, J. C.; TERESA, F. B. Stream fish metacommunity organisation across a Neotropical ecoregion: The role of environment, anthropogenic impact and dispersal-based processes. **PLoS One**, v. 15, n. 5, p. e0233733, 2020.

BUENO, M. L.; MAGALHÃES, A. L. B.; ANDRADE NETO, F. R.; ALVES, C. B. M.; ROSA, D. D. M.; JUNQUEIRA, N. T.; PESSALI, T. C.; POMPEU, P. S.; ZENNI, R. D. Alien fish fauna of southeastern Brazil: species status, introduction pathways, distribution and impacts. **Biological Invasions**, v. 23, n. 10, p. 3021-3034, 2021.

CAETANO, D. L.; DE OLIVEIRA, E. F.; ZAWADZKI, C. H. Fish species indicators of environmental quality of Neotropical streams in Southern Brazil, upper Paraná River basin. **Acta Ichthyologica et Piscatoria**, v. 46, n. 2, 2016.

FRICKE, R.; ESCHMEYER, W. N.; FONG, J. D. **Eschmeyer's Catalog of Fishes**: Species by Family. 2025. Available at: https://researcharchive.calacademy.org/research/ichthyology/catalog/SpeciesByFamily.asp?_gl=1*r2cfyw*_ga*MTQ0NTQ1OTM5MS4xNzEyMjM4OTU5*_ga_6Y72VP61VZ*MTcxMzY0NzAzMi4xNC4xLjE3MTM2NDcwNTQuMzguMC4w. Last acess: 05 nov. 2024.

CARVALHO, D. R.; CASTRO, D. M. P.; CALLISTO, M.; CHAVES, A. J. D. M.; MOREIRA, M. Z.; POMPEU, P. S. Stable isotopes and stomach content analyses indicate omnivorous habits and opportunistic feeding behavior of an invasive fish. **Aquatic Ecology**, v. 53, n. 3, p. 365-381, 2019b.

CARVALHO, D. R.; FLECKER, A. S.; ALVES, C. B. M.; SPARKS, J. P.; POMPEU, P. S. Trophic responses to aquatic pollution of native and exotic livebearer fishes. **Science of the Total Environment**, v. 681, p. 503-515, 2019a.

CARVALHO, D. R.; LEAL, C. G.; JUNQUEIRA, N. T.; CASTRO, M. A.; FAGUNDES, D. C.; ALVES, C. B. M.; HUGHES, R. M.; POMPEU, P. S. A fish-based multimetric index for Brazilian savanna streams. **Ecological indicators**, v. 77, p. 386-396, 2017.

CASATTI, L.; TERESA, F. B.; ZENI, J. D. O.; RIBEIRO, M. D.; BREJÃO, G. L.; CENEVIVA-BASTOS, M. More of the same: high functional redundancy in stream fish assemblages from tropical agroecosystems. **Environmental management**, v. 55, p. 1300-1314, 2015.

COOPER, A. R.; INFANTE, D. M.; DANIEL, W. M.; WEHRLY, K. E.; WANG, L.; BRENDEN, T. O. Assessment of dam effects on streams and fish assemblages of the conterminous USA. **Science of the Total Environment**, v. 586, p. 879-889, 2017.

COSTA, I. D.; ROCHA, V. M. The influence of habitat structure on fish assemblages in Amazonian streams of Machado river basin. **Revista de Biología Tropical**, v. 65, n. 1, p. 103-115, 2017.

CRUZ, L. C.; POMPEU, P. S. Drivers of fish assemblage structures in a Neotropical urban watershed. **Urban Ecosystems**, v. 23, n. 4, p. 819-829, 2020.

CUNICO, A. M.; ALLAN, J. D.; AGOSTINHO, A. A. Functional convergence of fish assemblages in urban streams of Brazil and the United States. **Ecological Indicators**, v. 11, n. 5, p. 1354-1359, 2011.

DAGOSTA, F. C. P.; MONÇÃO, M. S.; NAGAMATSU, B. A.; PAVANELLI, C. S.; CARVALHO, F. R.; LIMA, F. C.; LANGEANI, F.; DUTRA, G. M.; OTA, R. R.; SEREN, T. J.; TAGLIACOLLO, V.; MENEZES, N. A.; BRITSKI, H. A.; PINNA, M. Fishes of the upper rio Paraná basin: diversity, biogeography and conservation. **Neotropical Ichthyology**, v. 22, n. 1, p. e230066, 2024.

ENGMAN, A. C.; RAMÍREZ, A. Fish assemblage structure in urban streams of Puerto Rico: the importance of reach-and catchment-scale abiotic factors. Hydrobiologia, v. 693, p. 141-155, 2012.

FALKE, J. A.; GIDO, K. B. Spatial effects of reservoirs on fish assemblages in Great Plains streams in Kansas, USA. **River Research and Applications**, v. 22, n. 1, p. 55-68, 2006a.

FALKE, J. A.; GIDO, K. B. Effects of reservoir connectivity on stream fish assemblages in the Great Plains. **Canadian Journal of Fisheries and Aquatic Sciences**, v. 63, n. 3, p. 480-493, 2006b.

FAUCHEUX, N. M.; MIRANDA, L. E.; TAYLOR, J. M.; FARRIS, J. Impact of dams on stream fish diversity: a different result. **Diversity**, v. 15, n. 6, p. 728, 2023.

FRÁGUAS, P. S., & POMPEU, P. S. Hydropower affects fish trophic structure both downstream of the dam and upstream of the reservoir. **Neotropical Ichthyology**, v. 19, n. 01, p. e200071, 2021.

FRANCO, A. C. S.; PETRY, A. C.; GARCÍA-BERTHOU, E.; SANTOS, L. N. The effect of shoreline habitats on native and non-native fish species in a set of Neotropical reservoirs. **Hydrobiologia**, v. 851, p. 4213–4229, 2024.

HAUBROCK, P. J.; PILOTTO, F.; INNOCENTI, G.; CIANFANELLI, S.; HAASE, P. Two centuries for an almost complete community turnover from native to non-native species in a riverine ecosystem. **Global Change Biology**, v. 27, n. 3, p. 606-623, 2021.

HAVEL, J. E.; LEE, C. E.; VANDER ZANDEN, J. M. Do reservoirs facilitate invasions into landscapes?. **BioScience**, v. 55, n. 6, p. 518-525, 2005.

HERMOSO, V.; CLAVERO, M.; BLANCO-GARRIDO, F.; PRENDA, J. Invasive species and habitat degradation in Iberian streams: an analysis of their role in freshwater fish diversity loss. **Ecological applications**, v. 21, n. 1, p. 175-188, 2011.

JOHNSON, P. T.; OLDEN, J. D.; VANDER ZANDEN, M. J. Dam invaders: impoundments facilitate biological invasions into freshwaters. **Frontiers in Ecology and the Environment**, v. 6, n. 7, p. 357-363, 2008.

KAUFMANN, P. R.; PECK, D. V.; PAULSEN, S. G.; SEELIGER, C. W.; HUGHES, R. M.; WHITTIER, T. R.; KAMMAN, N. C. Lakeshore and littoral physical habitat structure in a national lakes assessment. **Lake and Reservoir Management**, v. 30, n. 2, p. 192-215, 2014.

KINDLMANN, P.; BUREL, F. Connectivity measures: a review. **Landscape ecology**, v. 23, p. 879-890, 2008.

LARENTIS, C.; PAVANELLI, C. S.; DELARIVA, R. L. Do environmental conditions modulated by land use drive fish functional diversity in streams?. **Hydrobiologia,** v. 849, n. 20, p. 4465-4483, 2022.

LEAL, C. G.; BARLOW, J.; GARDNER, T. A.; HUGHES, R. M.; LEITÃO, R. P.; NALLY, M. R., KAUFMANN, P. R.; FERRAZ, S. F. B.; ZUANON, J.; PAULA, F. R.; FERREIRA, J.; THOMSON, J. R.; LENNOX, G. D.; DARY, E. P.; RÖPKE, C. P.; POMPEU, P. S. Is environmental legislation conserving tropical stream faunas? A large-scale assessment of local, riparian and catchment-scale influences on Amazonian fish. Journal of Applied Ecology, v. 55, n. 3, p. 1312-1326, 2018.

LEAL, C. G.; LENNOX, G. D.; FERRAZ, S. F. B.; FERREIRA, J.; GARDNER, T. A.; THOMSON, J. R.; BERENGUER, E.; LEES, A. C.; HUGHES, R. M.; MACNALLY, R.; ARAGÃO, L. E. O. C.; BRITO, J. G.; CASTELLO, L.; GARRETT, R. D.; HAMADA, N.; JUEN, L.; LEITÃO, R. P.; LOUZADA, J.; MORELLO, T. F.; MOURA, N. G.; NESSIMIAN, J. L.; OLIVEIRA-JUNIOR, J. M. B.; OLIVEIRA, V. H. F.; OLIVEIRA, V. C.; PARRY, L.; POMPEU, P. S.; SOLAR, R. R. C.; ZUANON, J.; BARLOW, J. Integrated terrestrial-freshwater planning doubles conservation of tropical aquatic species. **Science,** v. 370, n. 6512, p. 117-121, 2020.

LEE, F.; SIMON, K. S.; PERRY, G. L. Increasing agricultural land use is associated with the spread of an invasive fish (*Gambusia affinis*). **Science of the Total Environment**, v. 586, p. 1113-1123, 2017.

LEITÃO, R. P.; ZUANON, J.; MOUILLOT, D.; LEAL, C. G.; HUGHES, R. M.; KAUFMANN, P. R.; VILLÉGER, S.; POMPEU, P. S.; KASPER, D.; PAULA, F. R.; FERRAZ, S. F. B.; GARDNER, T. A. Disentangling the pathways of land use impacts on the functional structure of fish assemblages in Amazon streams. **Ecography**, v. 41, n. 1, p. 219-232, 2018.

LIGHT, T.; MARCHETTI, M. P. Distinguishing between invasions and habitat changes as drivers of diversity loss among California's freshwater fishes. **Conservation Biology**, v. 21, n. 2, p. 434-446, 2007.

LIN, P.; GAO, X.; LIU, F.; LI, M.; LIU, H. Long-term monitoring revealed fish assemblage zonation in the Three Gorges Reservoir. **Journal of Oceanology and Limnology**, v. 37, p. 1258-1267, 2019.

LOURES, R. C.; POMPEU, P. S. Temporal changes in fish diversity in lotic and lentic environments along a reservoir cascade. Freshwater Biology, v. 64, n. 10, p. 1806-1820, 2019.

MACEDO, D. R.; POMPEU, P. S.; MORAIS, L.; CASTRO, M. A.; ALVES, C. B. M.; FRANÇA, J. S.; SANCHES, B.; UCHÔA, J. Uso e ocupação do solo, sorteio de sítios amostrais, reconhecimento em campo e realização de amostragens. In: CALLISTO, M.; ALVES, C. B. M.; LOPES, J. M.; CASTRO, M. A. (Orgs.). **Condições ecológicas em bacias hidrográficas de empreendimentos hidrelétricos**. Belo Horizonte: Companhia Energética de Minas Gerais, 2014. p. 47-68.

MILARDI, M.; GAVIOLI, A.; SOININEN, J.; CASTALDELLI, G. Exotic species invasions undermine regional functional diversity of freshwater fish. **Scientific Reports**, v. 9, n. 1, p. 17921, 2019.

MILARDI, M.; IEMMA, A.; WAITE, I. R.; GAVIOLI, A.; SOANA, E.; CASTALDELLI, G. Natural and anthropogenic factors drive large-scale freshwater fish invasions. **Scientific Reports**, v. 12, n. 1, p. 10465, 2022.

MOIA, D. A; ALVES, D. C.; FIGUEIREDO, B. R. S.; ANTIQUEIRA, P. A. P.; MELLO, F. T.; JEPPESE, E.; ROMERO, G. Q.; MORMULA, R. P.; BONECKER, C. C. Non-native fishes homogenize native fish communities and reduce ecosystem multifunctionality in tropical lakes over 16 years. **Science of the Total Environment**, v. 769, p. 144524, 2021.

MONDAL, R.; BHAT, A. Temporal and environmental drivers of fish-community structure in tropical streams from two contrasting regions in India. **PloS one**, v. 15, n. 4, p. e0227354, 2020.

MUNIZ, C. M.; GARCÍA-BERTHOU, E.; GANASSIN, M. J. M.; AGOSTINHO, A. A.; GOMES, L. C. Alien fish in Neotropical reservoirs: Assessing multiple hypotheses in invasion biology. **Ecological Indicators**, v. 121, p. 107034, 2021.

NÓBREGA, M. T.; COLLISCHONN, W.; TUCCI, C. E. M.; PAZ, A. R. D. Uncertainty in climate change impacts on water resources in the Rio Grande Basin, Brazil. **Hydrology and Earth System Sciences**, v. 15, n. 2, p. 585-595, 2011.

ORTEGA, J. C.; BACANI, I.; DORADO-RODRIGUES, T. F.; STRÜSSMANN, C.; FERNANDES, I. M.; MORALES, J.; MATEUS, L.; SILVA, H. P.; PENHA, J. Effects of urbanization and environmental heterogeneity on fish assemblages in small streams. **Neotropical Ichthyology**, v. 19, n. 03, p. e210050, 2021.

OTA, R. R.; DEPRÁ, G. D. C.; GRAÇA, W. J. D.; PAVANELLI, C. S. Peixes da planície de inundação do alto rio Paraná e áreas adjacentes: revised, annotated and updated. **Neotropical Ichthyology**, v. 16, p. e170094, 2018.

PAILLEX, A.; CASTELLA, E.; ZU ERMGASSEN, P.; GALLARDO, B.; ALDRIDGE, D. C. Large river floodplain as a natural laboratory: non-native macroinvertebrates benefit from elevated temperatures. **Ecosphere**, v. 8, n. 10, p. e01972, 2017.

PINI, S. F.; ABELHA, M. C.; KASHIWAQUI, E. A.; DELARIVA, R. L.; MAKRAKIS, S.; MAKRAKIS, M. C. Food resource partitioning among species of *Astyanax* (Characiformes: Characidae) in the Lower Iguaçu River and tributaries, Brazil. **Neotropical Ichthyology**, v. 17, p. e190028, 2019.

R DEVELOPMENT CORE TEAM. **R:** A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. 2021. Available at: https://www.r-project.org/. Last acess: 09 July 2024.

RIBEIRO, D. C.; CHAGAS, J. M. A.; THEREZA, M. R.; LANGEANI, F. Checklist and key for the identification of fish fauna of the Uberaba River, Upper Paraná River system, Brazil. **ZooKeys**, v. 875, p. 129-155, 2019.

RODRIGUES-FILHO, C. A. D. S.; GURGEL-LOURENÇO, R. C.; BEZERRA, L. A. V.; OLIVEIRA, E. F.; LEITÃO, R. P.; GARCEZ, D. S.; SANCHEZ-BOTERO, J. I. How are local fish communities structured in Brazilian semiarid headwater streams?. **Hydrobiologia**, v. 819, p. 93-108, 2018.

RUARO, R.; MORMUL, R. P.; GUBIANI, É. A.; PIANA, P. A.; CUNICO, A. M., GRAÇA, W. J. Non-native fish species are related to the loss of ecological integrity in Neotropical streams: a multimetric approach. **Hydrobiologia**, v, 817, p. 413-430, 2018.

SANCHES, B. O.; HUGHES, R. M.; MACEDO, D. R.; CALLISTO, M.; SANTOS, G. B. Spatial variations in fish assemblage structure in a southeastern Brazilian reservoir. **Brazilian Journal of Biology**, v. 76, p. 185-193, 2016.

SANCHES, B., O.; BECKER, B.; HUGHES, R. M.; PETESSE, M. L.; RIBEIRO, J. R.; SANTOS, G. B. Fish-based multimetric index for evaluating land use effects on large neotropical reservoirs. **Journal of Applied Ichthyology**, v. 35, n. 5, p. 1129-1140, 2019.

SHAO, X.; FANG, Y.; JAWITZ, J. W.; YAN, J.; CUI, B. River network connectivity and fish diversity. **Science of the Total Environment**, v. 689, p. 21-30, 2019.

SILVA, A. C.; VAN DEN BERG, E.; HIGUCHI, P.; OLIVEIRA-FILHO, A. T.; MARQUES, J. J. G. S. M.; APPOLINÁRIO, V.; PIFANO, D. S.; OGUSUKU, L. M.; NUNES, M. H. Florística e estrutura da comunidade arbórea em fragmentos de floresta aluvial em São Sebastião da Bela Vista, Minas Gerais, Brasil. **Brazilian Journal of Botany**, v. 32, p. 283-297, 2009.

SILVA, L. C. D.; LEONE, I. C.; SANTOS-WISNIEWSKI, M. J. D.; PERET, A. C.; ROCHA, O. Invasion of the dinoflagellate *Ceratium furcoides* (Levander) Langhans 1925 at tropical reservoir and its relation to environmental variables. **Biota Neotropica**, v. 12, p. 93-100, 2012.

SILVA-SENE, A. M.; LOURES, R. C.; ANDRADE NETO, F. R.; POMPEU, P. S. Fish assemblage distribution along free-flowing rivers entering a reservoir cascade. **Environmental Biology of Fishes**, v. 105, n. 11, 1535-1547, 2022.

SOUZA JR., C. M.; SHIMBO, J. Z.; ROSA, M. R.; PARENTE, L. L.; ALENCAR, A. A. RUDORFF, B. F. T.; HASENACK, H.; MATSUMOTO, M.; FERREIRA, L. G.; SOUZA FILHO, P. W. M.; OLIVEIRA, S. W.; ROCHA, W. F.; FONSECA, A. V.; MARQUES, C. B.; DINIZ, C. G.; COSTA, D.; MONTEIRO, D.; ROSA, E. R.; VÉLEZ-MARTIN, E.; WEBER, E. J.; LENTI, F. E. B.; PATERNOST, F. F.; PAREYN, F. G. C.; SIQUEIRA, J. V.; VIEIRA, J. L.; NETO, L. C. F.; SARAIVA. M. M.; SALES, M. H.; SALGADO, M. P. G.; VASCONCELOS, R.; GALANO, S.; MESQUITA, V. V.; AZEVEDO, T. Reconstructing three decades of land use and land cover changes in brazilian biomes with landsat archive and earth engine. **Remote Sensing**, v. 12, n. 17, p. 2735, 2020.

SULZBACHER, R.; SALVADOR, G. N.; ALVES, C. B. N.; FORMAGIO, P. S.; HUGHES, R. M.; POMPEU, P. S. The longitudinal gradient prevails over local characteristics in shaping the fish distribution in a large neotropical reservoir. **Water Biology and Security**. In press.

TERRA, B. D. F.; HUGHES, R. M.; ARAÚJO, F. G. Fish assemblages in Atlantic Forest streams: the relative influence of local and catchment environments on taxonomic and functional species. **Ecology of Freshwater Fish**, v. 25, n. 4, p. 527-544, 2016.

THEREZA, M. R.; LANGEANI, F. **Bagres e cascudos do rio Grande, alto rio Paraná**. Curitiba: Editora CRV, 2019.