Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Environmental and ichthyofaunistic characteristics of Amazonian streams with and without fish farm

Características ambientais e ictiofaunísticas de riachos amazônicos com e sem viveiros de peixes

S. M. Santos[a], A. T. Oliveira[a*], P. H. R. Aride[b], A. R. S. Liebl[b], F. P. Mendonça[c], J. Zuanon[d] and J. Pantoja-Lima[c]

[a]Instituto Federal de Educação, Ciência e Tecnologia do Amazonas – IFAM, Campus Manaus Zona Leste, Manaus, AM, Brasil
[b]Instituto Federal de Educação, Ciência e Tecnologia do Amazonas – IFAM, Campus Manaus Centro, Manaus, AM, Brasil
[c]Instituto Federal de Educação, Ciência e Tecnologia do Amazonas – IFAM, Campus Presidente Figueiredo, Presidente Figueiredo, AM, Brasil
[d]Instituto Nacional de Pesquisas da Amazônia – INPA, Manaus, AM, Brasil

Abstract

The environmental impacts caused by fish farming can lead to changes in aquatic ecosystems, especially in fish communities. In this study, we investigated possible changes in water quality, in the number of species and individuals of the same species caused by the construction of fish nurseries in dammed Amazonian streams. For this purpose, four streams located in the municipalities of Novo Airão and Presidente Figueiredo were selected. Samples were collected in streams without fish farming and in streams with stretches used for fish farming, where collections took place both downstream and upstream. The fish were captured, identified, quantified and the water was collected for physical and chemical analyses, in addition to the environmental characterization that was carried out. Comparisons were made using fish richness and abundance indices between the sampled points and correspondence analysis of the species identified at the collection sites, using the Mantel test and principal component analysis (PCA) for the environmental characteristics of the water and variables physical and chemical, and permutational multivariate analysis of variance (PERMANOVA) to verify the possible effects of species composition on the sampled conditions and on the analyzed environmental variables. In total, 2,302 fish belonging to 53 species, 15 families and six orders were found. We conclude that the Amazonian streams dammed for fish farming, under the analyzed conditions, can be characterized as environments with different and specific levels of richness and abundance, however, the data set analyzed in this study did not show that these characteristics are directly related to productive activity. We recommend that further studies be carried out following the current research.

Keywords: species abundance, species wealth, stream flow, fish farming, water quality.

Resumo

Os impactos ambientais causados pela piscicultura podem levar a alterações nos ecossistemas aquáticos, principalmente nas comunidades de peixes, na qualidade da água e na estrutura do meio. Neste estudo, nós investigamos possíveis mudanças na qualidade da água, na quantidade de espécies e de indivíduos de uma mesma espécie causadas pela construção de viveiros de peixes em riachos amazônicos represados. Para tanto, quatro riachos localizados nos municípios de Novo Airão e Presidente Figueiredo foram selecionados. Foram coletadas amostras nos riachos sem piscicultura e nos riachos com trechos utilizados para piscicultura, onde as coletas aconteceram tanto a jusante quanto a montante. Os peixes foram capturados, identificados, quantificados, e a água foram coletadas para realização de análises físicas e químicas, além da caracterização ambiental que foi realizada. As comparações foram feitas por meio dos índices de riqueza e abundância de peixes entre os pontos amostrados e análise de correspondência das espécies identificadas nos locais de coleta, utilizando teste de Mantel e análises de componentes principais (PCA) para as características ambientais da água e variáveis físicas e químicas, e análise de variância multivariada permutacional (PERMANOVA) para verificar os possíveis efeitos da composição das espécies nas condições amostradas e nas variáveis ambientais analisadas. No total, foram capturados 2.302 peixes pertencentes a 53 espécies, 15 famílias e seis ordens. Concluímos que os riachos amazônicos represados para piscicultura, nas condições analisadas, podem ser caracterizados como ambientes com diferentes e específicos níveis de riqueza e abundância, no entanto, o conjunto de dados analisados neste estudo não mostraram que estas características estão diretamente relacionadas a atividade produtiva. Nós recomendamos que mais estudos sejam realizados dando sequência a atual pesquisa.

Palavras-chave: abundância de espécies, riqueza de espécies, fluxo do riacho, piscicultura, qualidade da água.

*e-mail: adriano.oliveira@ifam.edu.br
Received: March 4, 2023 – Accepted: September 11, 2023

This is an Open Access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

1. Introduction

The interference in the natural environment provided by the production of aquatic organisms can impact the quality of water, soil and fish communities, in addition to negatively influencing human health (Stabili et al., 2022). In the Brazilian Amazon region, a fish production system can be found that occurs within streams, damming their water (Benini et al., 2014; Freitas et al., 2022).

This productive model tends to have different impacts on water quality and on the species that live upstream and downstream of the dams in the streams, in addition to being potentiated as a pollutant because the effluents from the nurseries are released into the environment (Benini et al., 2014). The activity also changes the morphology of the stream channel with the possibility of effects on the structure and trophic categories of the fish assemblages, since, in the construction of the nurseries, it is necessary to remove part of the riparian forest and its substrates (Honji et al., 2017). However, based on the raceway system, this production system has good acceptance and easy adaptation, and is seen as an alternative to keep fish farming in the field, reducing the rural exodus in the region (Santos et al., 2020).

Pantoja-Lima et al. (2015), state that although structured fish farming in streams is regulated by federal law, little is known about its impacts on natural fish communities along streams (from upstream to downstream) in Central Amazonia. However, it is known that conservation aspects, such as forest maintenance, are of great importance for fish communities, whether on a local scale (Lo et al., 2020) or multiscale (Yirigui et al., 2019). In addition, changes in riparian forests and in the environmental characteristics of streams, such as the soil, can cause a reduction in the biodiversity of native species (Paula et al., 2022).

Freitas et al. (2022) spatially analyzed small-scale dams that are used for fish production and hydroelectric power in the Amazon and found them to be highly concentrated in the region. The researchers attribute to these dams on the streams the probable cause of major impacts on the local aquatic environment and recommend increasing the number of protected areas and making licensing more difficult, aiming at better control of these activities, which would favor the conservation of many species of fish.

About 31% of the world's freshwater fish species, which includes tropical fish, are listed by the IUCN as endangered, which makes them more sensitive to environmental degradation (Tagliacollo et al., 2021). The number of species, or richness, and the number of individuals of the same species, or abundance, necessary to establish populations in a location depends on the intrinsic characteristics of the environment and the species (Duarte et al., 2022).

Thus, the current study aims to characterize the environment in terms of water quality and identify and quantify the ichthyofauna (in terms of richness and abundance) of streams that have dammed sections (nursery) for fish production. During the study, data from streams without fish nurseries are compared with data from streams with ponds, in addition to being evaluated both downstream and upstream. The main question is whether the perceived alterations can be related to the productive activity.

2. Materials and Methods

2.1. Study area

The investigated locations are located in the North region of Brazil in the Amazon biome. The Amazon region is characterized by dense forest, a vast water system, hot and humid equatorial climate with temperatures ranging from 24 to 38° C. The selected areas were the municipalities of Presidente Figueiredo (PF; left bank of the Negro River; Figure 1A) and Novo Airão (NA; right bank of the Negro River; Figure 1B), both located in the state of Amazonas, Brazil (CPRM, 1998). Sampling took place between October 2016 and November 2017. The investigated locations are located in the Metropolitan region of Manaus (capital of the state of Amazonas). Presidente Figueiredo is a municipality located approximately 100 km from the capital, while Novo Airão is about 200 km from the capital.

2.2. Environmental characterization in streams with and without nurseries

Under authorization from the Chico Mendes Institute for Nature Conservation through approvals SISBIO/ICMBIO nº 51874-1 and nº 55949-1, the geographic coordinates were registered with Garmin Etrex® GPS equipment under the Datum WGS84 system. In each study area, 12 streams were sampled, 8 SWON - stream without nurseries and 4 SWN - stream with nurseries. The sampling points consisted of the demarcation of stretches of 50 meters, with measurements and collections (water and fish) carried out to characterize the studied environments.

Sampling was done at one point, for streams without nurseries, and at two points, for streams with nurseries (50m; one upstream and the other downstream). At each collection point, the structure was sampled by measuring:

a) Average channel width (W): calculated in meters from the average of four equidistant measurements along the stretch;
b) Average flow ($m^3.s^{-1}$): obtained by relating average velocity, width, and depth, using the formula Q = A.Vm, where Q = flow rate, Vm = mean speed of the current, A = mean transactional area in the cross-section of the watercourse;
c) Types of substrates: classified into nine categories; sand, pebbles, stones, clay, tree trunks (wood greater than 10 cm in diameter), litter (composed of leaves and small twigs), fine litter (delicate particulate matter), roots (tangles of roots, primarily delicate, from marginal vegetation) and macrophytes (aquatic vegetation). The general substrate composition of each stream was characterized by the frequency of occurrence (%) of each substrate type.

The selected nurseries were built with materials such as plastic screens and wood, both on the sides and the water inlet and outlet, without professional support. All nurseries were populated with an average density of 20-80 $fish^{-1}.m^3$. For the current study, the data were standardized (Guedes et al., 2012).

2.2.1. Physical and chemical variables of water

Following the Standard Method for Examining Water and Sewage (APHA, 2012), the following physical and

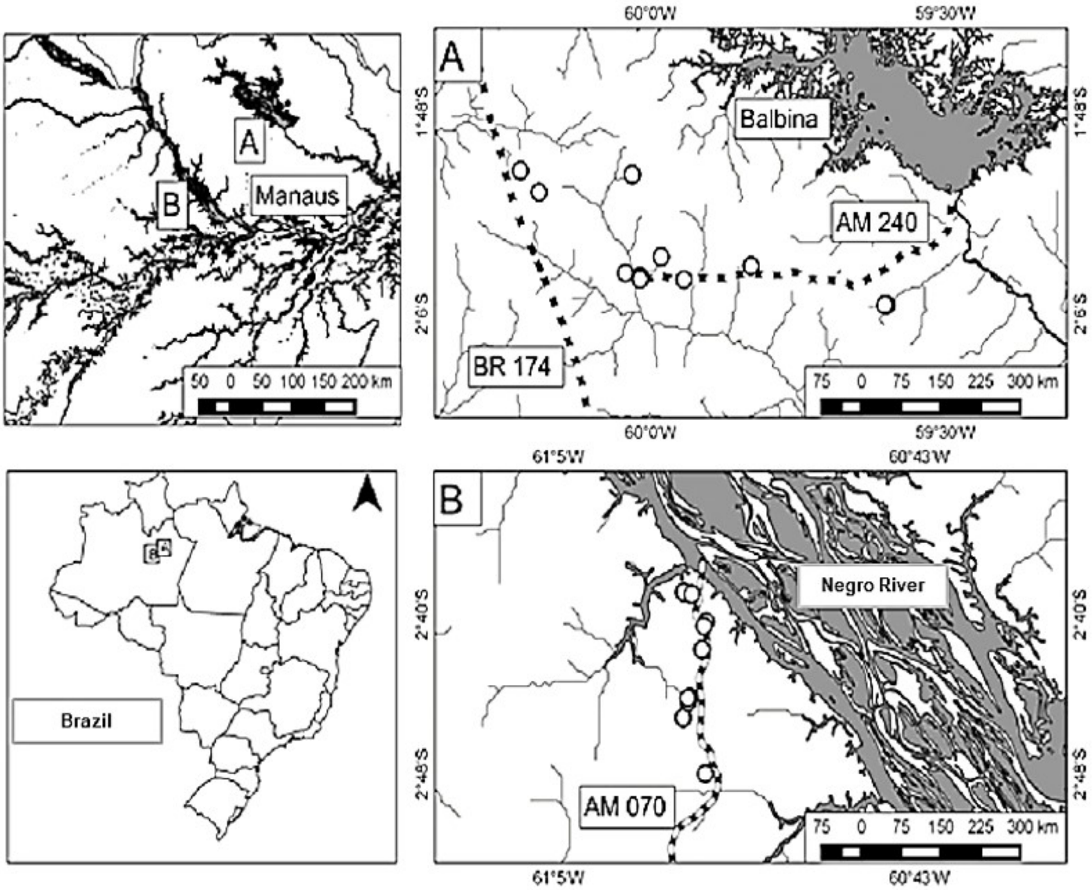

Figure 1. Map of sampling sites in the Brazilian Amazon. (A) Municipality of Presidente Figueiredo (PF), Amazonas, Brazil; sampling points in PF; (B) Municipality of Novo Airão, Amazonas, Brazil; sampling points.

chemical variables were evaluated: pH (Alfakit®, model AT-315), temperature (ºC), dissolved oxygen ($mg.L^{-1}$) (Alfakit®, model AT-150), ammonia ($mg.L^{-1}$), nitrite ($mg.L^{-1}$), nitrate ($mg.L^{-1}$), orthophosphate ($mg.L^{-1}$), total phosphorus ($mg.L^{-1}$) and total solids ($mg.L^{-1}$). In addition, the average and maximum average depths (Zn) were measured, calculated (m) from nine equidistant probes in four transversals along the stretch, and the average current velocity, determined from the average between four points arranged in the center from the channel.

Water samples were collected in the center of the stream and the middle of the water column using an amber-colored bottle (500 mL), which was stored in a thermal box with ice. All measurements and collections were carried out during the day (9 am – 2 pm) and before the experimental fishing activities.

2.3. Ichthyofaunistic characterization: collection of fish in the downstream and upstream streams with and without nurseries

The sampling of fish in streams was carried out according to the methodology described by Mendonça et al. (2005), with adaptations. In all collection sites, fence and hand nets were used with standardized fishing effort – four collectors for 90 minutes of collection in the same stretch (50 meters of stream).

The specimens were euthanized with eugenol anesthetic, fixed in 10% formalin, and stored in 70% alcohol. First, the taxonomic identification was carried out using dichotomous keys, specialized literature, and the help of specialized researchers.

2.4. Statistical analysis

For the ichthyofauna, values of richness and abundance were evaluated. Correspondence analysis (CA) was performed, with sample points being objects and species. The Jaccard coefficient was calculated, ranging from 0 (=different) to 1 (total similarity), according to Mendonça (2010), and these values were used in the permutational multivariate analysis of variance (PERMANOVA; Anderson and Walsh, 2013).

According to Guedes et al. (2012), data were standardized for environmental and water quality variables. In addition, the Mantel Test and principal component analysis (PCA) of the streams were applied, comparing the conditions SWN-U (streams with nurseries with upstream sampling) and SWN-D (streams with nurseries with downstream sampling) on SWON. The statistical programs used were the PAST 3.0 software.

3. Results

3.1. Environmental characterization of streams with and without nurseries and physical and chemical water variables

The physical, chemical, and environmental variables of the Novo Airão stream SWON and SWN-U (Supplementary Material Figure 1S A-B) indicate that the most significant contributions in the first axis (PC 1) were from temperature (TEMP), average width (LM), average depth (PF) and maximum (pm), surface velocity (Vs) and average flow (vz). For the second axis (PC 2), those that contributed to the variation were pH, electrical conductivity (COND), nitrate (nitra), total phosphorus (Ft), and total suspended solids (sts). For SWON and SWN-D, the greatest indications of contributions occurred in the PC 1 variation regarding nitrite (Nitri), orthophosphate (Ortho), total suspended solids (sts), average width (lm), average depth (pf) and maximum depth (pm). There were no variations between the sampling points (upstream, downstream and controls) for pH, temperature, electrical conductivity and dissolved oxygen for the two study areas (Supplementary Material Figure 2S A-B). There were oscillations in the speed of surface water and the average flow of streams, but these are related to the characteristics of each environment sampled.

The physical and chemical variables of water and other environmental variables of the Presidente Figueiredo SWON and SWN-U streams (Supplementary Material Table 1S) showed that the greatest contributions to the variation of the first axis (PC 1) were temperature (TEMP), electrical conductivity (COND), nitrate (nitra), nitrite (nitri), total phosphorus (ft) and orthophosphate (Ortho). For the second axis (PC 2), those that contributed to the variance were: pH, average width (lm), average depth (pf) and maximum depth (pm). For Presidente Figueiredo SWON and SWN-D streams, the variance contribution of the first axis (PC 1) came from nitrate (nitra), total phosphorus (ft), orthophosphate (Ortho), average width (lm), average depth (pf) and of the maximum depth (pm).

Regarding the types of substrates sampled, sand, litter and roots were present (Supplementary Material Table 2S). Novo Airão presented three types and Presidente Figueiredo, five types. During sampling, the presence of substrates such as trunks, aquatic macrophytes and gravel was not detected in Novo Airão.

3.2. Ichthyofaunistic characterization: fish collected in the downstream and upstream streams with and without nurseries

In Novo Airão, 793 fish were captured, comprising 33 species distributed in 5 orders and 11 families. Characiformes was the most representative order with 86.1%, while Siluriformes and Synbranchiformes had less than 5% each.

In the control streams (SWON – streams without nurseries), 636 fish of species belonging to 26 species, four orders and nine families (Table 1) were captured. The Characiformes was the most representative, with 89.3% of the fish captured; this was followed by Cichiliformes and Cyprinodontiformes with about 5% each, but with the lowest richness with only one species for each order. Finally, Siluriformes accounted for less than 1%, with one species.

In streams with nurseries and upstream sampling (SWN-U), 74 fish from 14 species, three orders and six families (Table 1). The most representative order was Characiformes, with ten species, followed by Cichiliformes, with three species (8.1%), and Synbranchiformes, with one species (2.7%).

In streams with nurseries and downstream sampling (SWN-D), 83 fish were captured, belonging to 14 species, three orders and seven families (Table 1). Characiformes remained the most representative, with nine species (49 fish), which represents 59% of the collected fish, followed by Cichiliformes with 38.5% (47.5 g) and Siluriformes with only two specimens (one species).

In Presidente Figueiredo, 1509 fish were captured, belonging to 30 species, in five orders and 13 families. Characiformes represented 93.4% of the total number of fish, followed by Cichiliformes with 5.6% and Cyprinodontiformes, Gymnotiformes, and Siluriformes with less than 1% each. Only the species *Hyphessobrycon melasonatus* (Durbin, 1908), *Pyrrhulina* gr. *brevis* and *Aequidens pallidus* (Heckel, 1840) had specimens captured at all collection points and in both study areas. Only five species had an abundance more significant than 8% of the total found in the two basins: *Hyphessobrycon* cf. *needle* (22.07%), *Pyrrhulina* gr. *brevis* (13.35%), *H. melasonatus* (12.66%), *Copella nigrofasciata* (Meinken, 1952) (8.77%) and *Bryconops giacopinni* (Fernández-Yépez, 1950) (8.12%).

In the SWON, 650 fish belonging to 20 species, four orders and nine families (Table 1) were collected. Characiformes accounted for 89.5% of the fish captured, followed by Cichiliformes with almost 10%, Siluriformes, and Gymnotiformes with less than 1%. In streams with nursery and upstream sampling (SWN-U), 151 fish were captured, belonging to 14 species, five orders and seven families (Table 1). Characiformes showed the highest richness (eight species). Cichiliformes had only two species, followed by Gymnotiformes (2 species), Siluriformes, and Cyprinodontiformes with only one species each.

In streams with nurseries and sampling downstream (SWN-D), 708 fish of 12 species, three orders and five families (Table 1). Characiformes had the highest richness (nine species), followed by Cichiliformes with two species, while Siluriformes had only one.

In Novo Airão (Figure 2A), some species were related to a single sampling point. In common, in the three sampling points (upstream, downstream, and a control site), the following eight species were grouped: *Gnathocharax steindachneri* (Fowler, 1913) (Gste), *Iguanodectes geisleri* (Géry, 1970) (Igei), *H. melasonatus* (Hmel), *Crenuchus spirulus* (Günther, 1863) (Cspi), *Erythrinus erythrinus* (Bloch & Schneider, 1801) (Eery), *C. nigrofasciata* (Cnig), *Pyrrhulina gr brevis* (Pbre) and *A. pallidus* (Apal). The other sampled points that had species in common were the control site (SWON) and the upstream site (SWN-U) with *Bryconops humerais* (Machado-Allison, Chernoff & Buckup, 1996) (Bhum), *Nannostomus marginatus* (Eigenmann, 1909) (Nmar), and the species *Bryconops inpai* (Knöppel, Junk & Géry, 1968) (Binp), *Crenicichla inpa* (Ploeg, 1991) (Cinp), which

Table 1. Composition of fish species captured in Novo Airão and Presidente Figueiredo.

Fish captured	Localization					
	NOVO AIRÃO			PRESIDENTE FIGUEIREDO		
(Species, order, and family)	SWON	SWN-U	SWN-D	SWON	SWN-U	SWN-D
Characiformes						
Acestrorhynchidae						
Acestrorhynchus falcatus (Bloch, 1794)	0	0	0	1	0	0
Anastomidae						
Pseudanos varii (Birindelli, Lima & Britski, 2012)	1	0	0	0	0	0
Characidae						
Gnathocharax steindachneri (Fowler, 1913)	1	3	1	0	0	0
Hemigrammus analis (Durbin, 1909)	8	0	0	0	0	0
Hemigrammus bellottii (Steindachner, 1882)	45	0	0	17	22	0
Hemigrammus coeruleus (Durbin, 1908)	1	0	0	0	0	0
Hemigrammus cf. pretoensis (Géry, 1965)	0	0	0	5	0	0
Hemigrammus vorderwinkleri (Géry, 1963)	4	0	0	0	0	0
Hyphessobrycon cf. agulha (Fowler, 1913)	1	0	0	0	0	510
Hyphessobrycon aff. melazonatus (Durbin in Eigenmann, 1908)	10	2	1	232	47	1
Iguanodectidae						
Bryconops cf. caudomaculatus (Günther, 1864)	0	0	0	45	0	0
Bryconops giacopinii (Fernández-Yépez, 1950)	7	0	0	127	3	51
Bryconops humeralis (Machado-Allison, Chernoff & Buckup, 1996)	33	2	0	0	0	0
Bryconops inpai (Knöppel, Junk &Géry, 1968)	0	3	2	58	18	14
Iguanodectes geisleri (Géry, 1970)	6	1	2	0	0	0
Iguanodectes variatus (Géry, 1993)	0	0	0	46	0	0
Characidae						
Hyphessobrycon sp	0	0	0	0	10	0
Moenkhausia comma (Eigenmann, 1908)	0	0	0	0	0	1
Moenkhausia copei (Steindachner, 1882)	0	0	0	22	0	24
Chenuchidae						
Crenuchus spilurus (Günther, 1863)	10	36	24	1	0	0
Odontocharacidium aphanes (Weitzman & Kanazawa, 1977)	0	0	1	0	0	0
Elachocharax pulcher (Myers, 1927)	1	0	0	0	0	0
*Microcharacidium weitzmani (*Buckup, 1993)	8	0	0	0	0	0
Erythrinidae						
Erythrinus erythrinus (Bloch & Schneider, 1801)	2	1	1	0	0	0
Hoplerythrinus unitaeniatus (Spix & Agassiz, 1829)	0	0	0	0	0	1
Lebiasinidae						
Copella nattereri (Steindachner, 1876)	44	0	0	0	0	0
Copella nigrofasciata (Meinken, 1952)	191	1	11	0	0	0
Nanostomus eques (Steindachner, 1876)	1	0	0	0	0	0
Nanostomus marginatus (Eigenmann, 1909)	1	1	0	0	19	15
Pyrrulina aff. brevis (Steindachner, 1876)	192	16	6	4	20	70
Pyrrulina semifasciata (Steindachner, 1876)	1	0	0	24	1	0

SWON: streams or without nurseries; SWN-U: streams with nurseries with upstream sampling; SWN-D: streams with nurseries with downstream sampling.

Table 1. Continued...

Fish captured	Localization					
	NOVO AIRÃO			PRESIDENTE FIGUEIREDO		
(Species, order, and family)	SWON	SWN-U	SWN-D	SWON	SWN-U	SWN-D
Cyprinodontiformes						
Rivulidae						
Laimosemion cf. romeri (Costa, 2003)	33	0	0	0	0	0
Rivulus micropus (Steindachner, 1863)	0	0	0	0	2	0
Gymnotiformes						
Gymnotidae						
Gymnotus coropinae (Hoedeman, 1962)	0	0	0	1	0	0
Hypopomidae						
Microsternarchus cf. bilineatus (Fernández-Yépez, 1968)	0	0	0	1	1	0
Sternopygidae						
Sternopygus macrurus (Bloch & Schneider, 1801)	0	0	0	0	1	0
Peciformes						
Cichlidae						
Acanonia nassa (Heckel, 1840)	0	1	0	0	0	0
Aequidens pallidus (Heckel, 1840)	31	4	23	57	5	19
Apistograma cf. regani (Kullander, 1980)	0	0	0	1	1	0
Apistogramma gephyra (Kullander, 1980)	0	0	1	0	0	0
Apistogramma hippolytae (Kullander, 1982)	0	0	0	0	0	1
Crenicichla alta (Eigenmann, 1912)	0	0	0	1	0	0
Crenicichla inpa (Ploeg, 1991)	0	1	1	0	0	0
Heros sp.	0	0	7	0	0	0
Siluriformes						
Cetopsidae						
Helogenes marmoratus (Günther, 1863)	0	0	0	0	1	0
Heptapteridae	0	0	0	0	0	0
Brachyglanis frenatus (Eigenmann, 1912)	0	0	0	4	0	0
Myoglanis koepckei (Chang, 1999)	0	0	0	0	0	1
Rhamdia sp.	1	0	0	0	0	0
Loricariidae						
Acestridium discus (Haseman, 1911)	2	0	2	0	0	
Acestridium gymnogaster (Reis & Lehmann A., 2009)	1		0	0	0	0
Ancistrus aff. hoplogenys (Günther, 1864)	0	0	0	2	0	0
Rineloricaria lanceolata (Günther, 1868)	0	0	0	1	0	0
Synbranchiformes						
Synbranchus sp.	0	2	0	0	0	0
Total	636	74	83	650	151	708
Number of species	26	14	14	20	14	12

SWON: streams or without nurseries; SWN-U: streams with nurseries with upstream sampling; SWN-D: streams with nurseries with downstream sampling.

were captured at upstream and downstream points and allowed the points to be clustered in the center of Figure 2A.

In Presidente Figueiredo, the species associated with the sampling sites (upstream, downstream, and control) are in

Figure 2B. PtoS1, PtoS2, and PtoS3 represent overlapping species collected at only one of the sites, PtoS1 being downstream, PtoS2 upstream, and PtoS3 control. Between upstream and downstream, only the species *N. marginatus* (Nmar) and *Pyrrhulina* gr. *brevis* (Pbre) are more related. The species present in the three sampling points (upstream, downstream, and control) were: *B. giacopinii* (Bgia), *B. inpai* (Binp), *H. melasonatus* (Hmel), *Pyrrhulina* gr. *brevis* (Pbre) and *A. pallidus* (Apal).

The SWN-D sampling points in Presidente Figueiredo showed a greater abundance of fish due to a large amount of *Hyphessobrycon* cf. *needle*, representing more than 70% of the specimens. *B. giacopinii*, *Pyrrhulina* gr. *brevis*, and *Hyphessobrycon needle*, accounted for nearly 90% of the fish caught at this point.

In all (streams with and without nurseries), 2,302 fish belonging to 53 species, six orders, and 15 families were captured. The ichthyofauna was composed of 31 species of the order Characiformes (58.5%), eight species of Cichiliformes (15.1%), eight species of Siluriformes (15.1%), three species of Gymnotiformes (5.65%), two species of Cyprinodontiformes (3.77%) and one species of Synbranchiformes (1.88%).

Within the fish production nurseries installed in the analyzed streams, the following species were found: matrinxã (*Brycon amazonicus*, Agassiz, 1829), tambaqui (*Colossoma macropomum*, Cuvier, 1818), pirapitinga (*Piaractus brachypomus*, Cuvier, 1818) and pirarucu (*Arapaima gigas*, Schinz, 1822). The fish under production were fed industrialized diets and fruits, however, there was no control over the diet and other aspects of production.

Only the value of the PERMANOVA analysis (Table 2) by Presidente Figueiredo (PF) for the upstream sites and without nurseries shows variation between the variables

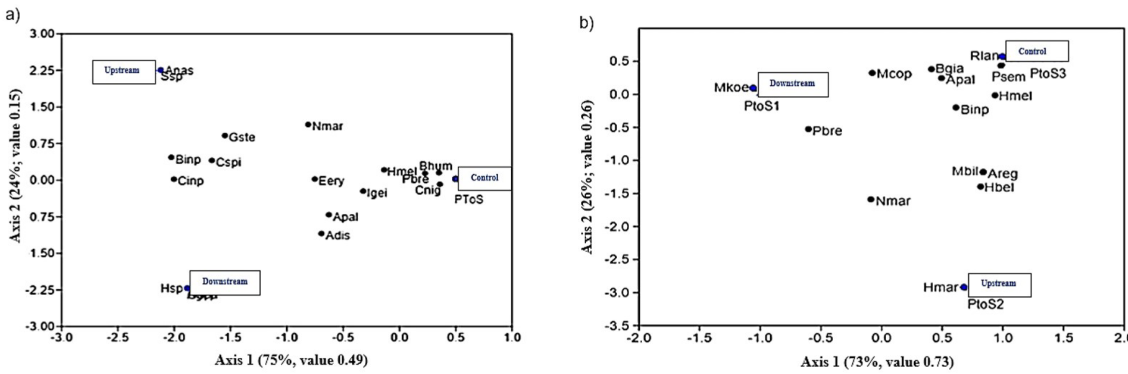

Figure 2. Correspondence analysis of sampled streams in Novo Airão and Presidente Figueiredo for upstream, downstream and control; grouping in PtoS (overlapping species). a) New Airão. PtoS: *Pseudanos varii* (Pvar); B*ryconops giacopinii* (Bgia); *Hemigrammus analis* (Hana); *Hemigrammus Belotti* (Hebel); *Hemigrammus coeruleus* (Hcoe); *Hemigrammus vonderwinkleri* (Hvon); *Hyphessobrycon* cf. *needle* (Hagu); *Elachocharax pulcher* (Epul); *Microcharacidium weitzmani* (Mwei); *Copella nattereri* (Cnat); *Nanostomus eques* (Nequ); *Pyrulina semifasciatus* (Psem), *Laimosemion* cf. *romeri* (Lrom) and *Rhamdia* sp. (Rsp). Other species; b) Presidente Figueiredo. PtoS1: *Hyphessobrycon* cf. *needle* (Hagu); *Moenkhausia* sp. (Mcom); *Hopleritrynus unitaeniatus* (Huni); *Myoglanis koepckei* (Mkoe). PtoS2: *Heros* sp. (Hsp); *Rivulus micropus* (Rimc); *Sternopygus macrurus* (Smac). PtoS3: *Acestrorhynchus falcatus* (Afal); *Briconops* cf. *caudomaculatus* (Bcau); *Iguanodectes variatus* (Ivar); *Hemigrammo* cf. *pretoensis* (Hpre); *Crenuchus spirulus* (Cspi); *Gymnotus coropinae* (Gcor); *Crenicichla alta* (Calt); and *Brachyglanis frenata* (Bfre). **Gste:** *Gnathocharax steindachneri;* **Igei:** *Iguanodectes geisleri;* **Hmel:** *Hyphessobrycon melasonatus;* **Cspi:** *Crenuchus spirulus;* **Eery:** *Erythrinus erythrinus;* **Cnig**: *Copella nigrofasciata;* **Pbre:** *Pyrrhulina* gr *brevis;* **Apal:** *Aequidens pallidus*; **Bhum:** *Bryconops humerais;* **Nmar:** *Nannostomus marginatus*; **Binp:** *Bryconops inpai;* **Cinp:** *Crenicichla inpa;* **Hmar:** *Helogenes marmoratus;* **Mkoe:** *Myoglanis koepckei;* **Hbel:** *Hemigrammus belotti;* **Areg:** *Apistograma* cf. *regani; **Mbil:*** *Microsternarchus* cf. *bilineatus;* **Psem:** *Pyrrhulina semifasciata;* **Mcop:** *Moenkhausia copei;* **Rlan:** *Rineloricaria lanceolata*.

Table 2. PERMANOVA analysis performed from the richness and diversity parameters and the most representative scores of physical and chemical variables and geoenvironmental characteristics.

	Condition	TSS	SSW	F	*p*
NA	SWN-U and SWON	1.066	0.986	0.807	0.485
	SWN-D and SWON	1.066	0.998	0.675	0.589
PF	SWN-U and SWON	1.122	0.713	5.735	**0.003**
	SWN-D and SWON	0.927	0.761	2.185	0.108

SWON: streams or without nurseries; SWN-U: streams with nurseries with upstream sampling; SWN-D: streams with nurseries with downstream sampling; TSS: total sum of squares; SSW: sum of the squares within; F: PERMANOVA value; p: probability value; NA: Novo Airão; PF: Presidente Figueiredo. Values in bold indicate statistical difference p<0.05.

and the fish community indices ($p<0.05$). However, the Mantel test did not show the existence of a correlation between the variables and the indices ($r= -0.41$, $p= 0.96$, from 9999 permutations) analyzed at the upstream (SWN-U) and in streams without nurseries (SWON), did not prove the effect of fish farms in the sampled streams.

4. Discussion

4.1. The ichthyofauna of Amazonian streams with and without nurseries

The richness and abundance of species found in Amazonian streams were like those found by Santos et al. (2015) who found 13 species in studies in Amazonian streams. However, other researchers, such as Mendonça et al. (2005) and Barros et al. (2013), found a more significant number of species per stream, reaching an average variation of 4 to 6 per stream.

When comparing the richness of the unaltered environments (without nurseries) with the altered ones (with nurseries), it can be seen that in the streams without nurseries, the richness was more significant both in Presidente Figueiredo and in Novo Airão. Despite this, it is not possible to state that the construction of nurseries can influence the composition of fish communities in the sampled locations since, according to Kemenes and Forsberg (2014), this difference in the composition may be associated with ecological limitations and tactical feeding of each species along the longitudinal gradient of the stream.

The species *A. pallidus*, *H. melazonatus*, and *P.* cf. *brevis* were present in all sampled streams. According to the study by Anjos (2007), their presence indicates that there is no pollution or that the anthropic impact is low. On the contrary, species belonging to Poeciliidae, Heptapteridae, and Loricariidae are indicators of pollution or urbanization of aquatic ecosystems, as they can tolerate environmental variations and impacts (Pini et al., 2021). Felipe and Suarez (2010) reported that streams with anthropic interference had reduced levels of richness and evenness, which indicates environmental disturbance, as there is a loss of some native species and an increase in tolerant species.

The *C. nigrofasciata, C. nattereri*, and *C. spirulus* were captured in greater abundance in places without nurseries and were few or absent in places with nurseries, which emphasizes the status of these species as indicators of the state and quality of conservation of streams. For species that occurred in only one of the sampling sites (*Gnathocharax steindachneri, Iguanodects variatus, Moenkhausia copei*), it is fair to assume that these differences may be natural, i.e., the advantage of species in exploiting the environment to maximize energy consumption and this characteristic can influence the dispersal process of the species, as well as the adaptation to environmental changes (Prado et al., 2020).

Siluriformes were few in the collections in the two study areas and Gymnotiformes, with four representatives in Novo Airão and no representative in Presidente Figueiredo. As in other studies on ichthyofauna in Amazonian streams, richness, abundance, and diversity seem to be associated with different factors such as collection methodology, sampling effort, the geological formation of the region (Alter do Chão formation), and seasonality (Espírito-Santo et al., 2017). According to Vieira and Shibatta (2007), other factors influencing diversity, richness, and abundance are streams with or without anthropic impacts. Sites with anthropic alterations can modify limnological variations and thus influence the presence or absence of species (Pereira et al., 2021). Even with the variations presented, it cannot be said that fish farming in stream channels influences fish communities or that these fish communities are causing these minor environmental disturbances. However, it is known that if there is an increase in fish farming activity without any control, such as an increase in the number of nurseries per stream and no effluent management, there may be changes in the structure of the communities of aquatic organisms and the natural courses of the streams along the stream. over time (Felipe and Súarez, 2010).

4.2. Effects of inserting nurseries in Amazonian streams on physical and chemical water variables, environmental characteristics and local ichthyofauna

Stream fish communities are strongly related to geological and environmental variables (Samarkhanov et al., 2021). The results obtained by the principal component analysis carried out for Novo Airão and Presidente Figueiredo show that the most representative variables were temperature, conductivity, nitrate, phosphorus and compounds and total soluble solids. According to Toledo and Nicolella (2002), these variables may indicate changes in the aquatic ecosystem due to pollution from the disposal of domestic, industrial or agricultural waste. In this study, the collected water samples showed distinct aspects of clear water and poorly dissolved material, which shows that they were strongly influenced by geochemical processes and rainfall in the region (Lemke and Súarez, 2013).

Other verified factors that are inherent to the environmental characteristics were: average width and average and maximum depth. These factors act on the structure of fish communities in streams and, together with the most frequent substrates (sand, litter and roots), form a diversity of microhabitats (Barros et al., 2013). Such microhabitats are crucial for some fish families and constitute shelter and food for several aquatic animals (Taira et al., 2020). Mortati (2004) found higher rates of colonization in pools on riverbanks (70%) than on streambanks (~30%). This characterization emphasizes the importance of water flow and velocity in streams, essential factors for the heterogeneity of Amazonian aquatic environments.

Changes in limnological and environmental characteristics can directly affect communities of aquatic organisms in streams, especially fish (Carvalho and Tejerina-Garro, 2015). When approaching the water quality of Amazonian streams and their parameters, one must consider the geomorphological characteristics of the sites and the annual cycles that are important in the distribution of ions and dissolved gases in the water column (Queiroz et al., 2009). Added to this are factors linked to the increase in water volume during the Amazonian rainy season, which can increase the allochthonous material and nutrient load that feeds the entire Amazonian ecosystem and thus camouflage a possible change in the environment.

Although effluents from fish farming are released into the environment, which tends to cause large amounts of solids dissolved in the water and condition changes in the electrical conductivity variable, the values found were low, being 10 to 15 uS.cm^{-1}. In these streams, the release of soluble solids did not influence or change the natural characteristics of the places.

Water nitrogen groups are also worrying variables when talking about fish farming, and ammonia was present in all sites collected in this study, according to PCA analyses. However, the samples collected in Presidente Figueiredo showed values below the detection limit for the analyzes carried out in most streams (0.00 mg.L^{-1}), and only two streams (one upstream and the other downstream) showed values around 0.035 mg.L^{-1}. Although in Novo Airão the values were between 0.012 and 0.055 mg.L^{-1}, it is not possible to certify the environmental degradation, since the modifications and their possible origins along the gradient of the streams are unknown. Furthermore, when altered, the nitrogen groups can modify the dissolved oxygen density in the medium, and fish growth can be affected when ammonia levels are high (Lu et al., 2020).

According to the PCA, total phosphorus, high in the sampled sites, is a limiting variable and may be responsible for the eutrophication of ecosystems such as lakes and rivers (Tiwari and Pal, 2022). In nurseries, phosphorus can cause fish mortality and, together with orthophosphate, indicate excess food offered to fish (Elahi and Khalid, 2022). Given the above, the values found in this study tend to reflect the lack of control over the diet of fish kept in nurseries.

The dissolved oxygen values measured upstream were above the average limit of 5.0 mg.L^{-1}, as recommended by CONAMA Resolution nº 357 of 03/17/2005. However, this variable is directly linked to the current speed in the rapids and rapids of Presidente Figueiredo and results in good oxygenation throughout the year. As for temperature values, they were higher in downstream environments and streams without nurseries in Novo Airão, with means like those found by Arbeláez-Rojas et al. (2002). In art. the values are close to CONAMA Resolution nº 357 of 03/17/2005. However, 34 of the Conditions and Norms for Effluent Disposal establish that effluents must have temperatures below 40°C. Furthermore, these temperature values for all sampled points are below the study carried out near Manaus and in black water areas (Queiroz et al., 2009).

A worrying factor in the implementation of fish farming in a stream is the deforestation of riparian forests close to the streams. Riparian forests are necessary for the entire Amazonian biome and an essential component for fish communities, as fish depend on food supplies (plants, seeds and insects), in addition to increasing habitat availability (Marques et al., 2021). The absence of riparian forest can influence the trophic structure of local communities and, consequently, the structure and composition of local fish communities and, over time, can lead to a functional homogenization of the ichthyofauna (Carvalho and Tejerina-Garro, 2015). Leitão (2015) emphasized that the removal of riparian forests increases the submerged vegetation, and this can lead to a reduction in the functional regularity of the assemblages and changes in the structure of the beds and in the functional identity of the assemblages, in addition to the fragmentation of the forests, which can reduce the breadth of occupied niches and the functional homogenization of local assemblies.

Amirkolaie (2008) states that fish farming effluents, together with pollutants, can affect water quality, but do not cause significant effects and do not cause an impact on the aquatic ecosystem. However, water management and input management are critical factors in improving fish farms to become successful businesses (Bohnes et al., 2019).

5. Conclusion

The data, as presented in this study, allow us to characterize the Amazonian streams containing stretches with fish production as environments endowed with specific and differentiated levels of richness and abundance, considering the number of species and the number of individuals of the same species. However, these differences may be mostly associated with the natural conditions of the streams, since the environmental analyzes (physical and chemical characteristics of the water, and environmental) did not show alterations resulting from the construction of the nurseries.

Acknowledgements

We want to thank CNPq for the financial aid via the Universal call (Process 447035/2014-2), and to the Federal Institute of Education, Science and Technology of Amazonas, Presidente Figueiredo campus (IFAM CPRF) for support in the execution of the project; to the Federal University of Amazonas (UFAM) for support via the Laboratory of Limnology and Water Quality as well as entry into the post-graduate program; to the Pablo Garcia Dias, Manoel Pio and Rogério Paixão. AT Oliveira has a research fellowship from CNPq/Brazil (Process 315713/2020-8). We also thank CAPES for the Ph.D. internship for SMS. This work was carried out with the support of the Coordination for Improvement of Higher Level Personnel – Brazil (CAPES) – Finance Code 001. The FAPEAM (PDPG CAPES/FAPEAM, Call 018/2020).

References

AMERICAN PUBLIC HEALTH ASSOCIATION – APHA, 2012. *Standard methods for the examination of water and wastewater*. 22nd ed. Washington, DC: APHA/AWWA/WEF.

AMIRKOLAIE, A.K., 2008. Environmental impact of nutrients discharged by aquaculture wastewater on the Haraz River. *Journal of Fisheries and Aquatic Science*, vol. 3, no. 5, pp. 275-279. http://dx.doi.org/10.3923/jfas.2008.275.279.

ANDERSON, M.J. and WALSH, D.C.I., 2013. PERMANOVA, ANOSIM, and the Mantel test in the of heterogeneous dispersions: what null hypothesis are you testing? *Ecological Monographs*, vol. 83, no. 4, pp. 557-574. http://dx.doi.org/10.1890/12-2010.1.

ANJOS, H.D.B., 2007. *Efeitos da fragmentação florestal sobre as assembléias de peixes de igarapés da zona urbana de Manaus,* *Amazonas*. Manaus: Instituto Nacional de Pesquisas da Amazônia, Universidade Federal do Amazonas. 114 p. Dissertação de Mestrado.

ARBELÁEZ-ROJAS, G.A., FRACALOSSI, D.M. and FIM, J.D.I., 2002. Composição corporal de tambaqui, *Colossoma macropomum*, e matrinxã, *Brycon cephalus*, em sistemas de cultivo intensivo, em igarapé, e semi-intensivo, em viveiros. *Revista Brasileira de Zootecnia*, vol. 31, no. 3, pp. 1059-1069. http://dx.doi.org/10.1590/S1516-35982002000500001.

BARROS, D.F., ALBERNAZ, A.L.M., ZUANON, J., ESPÍRITO SANTO, H.M.V., MENDONÇA, F.P. and GALUCH, A.V., 2013. Effects of isolation and environmental variables on fish community structure in the Brazilian Amazon Madeira-Purus interfluve. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 73, no. 3, pp. 491-499. http://dx.doi.org/10.1590/S1519-69842013000300005. PMid:24212688.

BENINI, S.M., DIAS, L.S. and BENINI, E.M., 2014. *Avaliações ambientais em bacias hidrográficas*. Tupã: ANAP, 146 p.

BOHNES, F.A., HAUSCHILD, M.Z., SCHLUNDT, J. and LAURENT, A., 2019. Life cycle assessments of aquaculture systems: a critical review of reported findings with recommendations for policy and system development. *Reviews in Aquaculture*, vol. 11, no. 4, pp. 1061-1079. http://dx.doi.org/10.1111/raq.12280.

CARVALHO, R.A. and TEJERINA-GARRO, F.L., 2015. The influence of environmental variables on the functional structure of headwater stream fish assemblages: a study of two tropical basins in Central Brazil. *Neotropical Ichthyology*, vol. 13, no. 2, pp. 349-360. http://dx.doi.org/10.1590/1982-0224-20130148.

COMPANHIA DE PESQUISA DE RECURSOS MINERAIS – CPRM, 1998. *Situação fundiária do município de Presidente Figueiredo – AM*. Presidente Figueiredo: Programa de Integração Mineral em Municípios da Amazônia/Primaz de Presidente Figueiredo, 26 p.

DUARTE, C., FARAGO, T.L.B., ANJOS, C.S., SANTOS, N.R., NASCIMENTO, L.M., CELLA-RIBEIRO, A. and DEUS, C.P., 2022. Spatial and seasonal variation of benthic fish assemblages in whitewater rivers of Central Amazon. *Biota Neotropica*, vol. 22, no. 4, p. e20211312. http://dx.doi.org/10.1590/1676-0611-bn-2021-1312.

ELAHI, E. and KHALID, Z., 2022. Estimating smart energy inputs packages using hybrid optimization technique to mitigate environmental emissions of commercial fish farms. *Applied Energy*, vol. 326, p. 119602. http://dx.doi.org/10.1016/j.apenergy.2022.119602.

ESPÍRITO-SANTO, H.M.V., RODRÍGUEZ, M.A. and ZUANON, J., 2017. Strategies to avoid the trap: stream fish use fine-scale hydrological cues to move between the stream channel and temporary pools. *Hydrobiologia*, vol. 792, no. 1, pp. 183-194. http://dx.doi.org/10.1007/s10750-016-3054-6.

FELIPE, T.R. and SÚAREZ, Y.R., 2010. Caracterização e influência dos fatores ambientais nas assembléias de peixes de riachos em duas microbacias urbanas, Alto Rio Paraná. *Biota Neotropica*, vol. 10, no. 2, pp. 143-151. http://dx.doi.org/10.1590/S1676-06032010000200018.

FREITAS, C.E.C., MEIRELES, M.A., PEREIRA, D., SIQUEIRA-SOUZA, F.K., HURD, L.E., JAMES, R., MORAES, G.R.P. and GARCEZ, R.S., 2022. Death by a thousand cuts: small local dams can produce large regional impacts in the Brazilian Legal Amazon. *Environmental Science & Policy*, vol. 136, pp. 447-452. http://dx.doi.org/10.1016/j.envsci.2022.07.013.

GUEDES, H.A.S., SILVA, D.D., ELESBON, A.A.A., RIBEIRO, C.B.M., MATOS, A.T. and SOARES, J.H.P., 2012. Aplicação da análise estatística multivariada no estudo da qualidade da água do Rio Pomba, MG. *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 16, no. 5, pp. 558-563. http://dx.doi.org/10.1590/S1415-43662012000500012.

HONJI, R.M., TOLUSSI, C.E., CANEPPELE, D., POLAZ, C.N.M., HILSDORF, A.W.S. and MOREIRA, R.G., 2017. Biodiversidade e conservação da ictiofauna ameaçada de extinção da bacia do rio Paraíba do Sul. *Revista da Biologia*, vol. 17, no. 2, pp. 18-30. http://dx.doi.org/10.7594/revbio.17.02.05.

KEMENES, A. and FORSBERG, B.R., 2014. Factors influencing the structure and spatial distribution of fishes in the headwater streams of the Jaú River in the Brazilian Amazon. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 74, no. 3, suppl. 1, pp. S023-S032. http://dx.doi.org/10.1590/1519-6984.06812. PMid:25627363.

LEITÃO, R.P., 2015. *Estrutura funcional e conservção de assembléias de peixes de riachos na Amazônia Brasileira*. Manaus: Instituto Nacional de Pesquisas da Amazônia, 164 p. Tese de Doutorado.

LEMKE, A.P. and SÚAREZ, Y.R., 2013. Influence of local and landscape characteristics on the distribution and diversity of fish assemblages of streams in the Ivinhema River basin, Upper Paraná River. *Acta Limnologica Brasiliensia*, vol. 25, no. 4, pp. 451-462. http://dx.doi.org/10.1590/S2179-975X2013000400010.

LO, M., REED, J., CASTELLO, L., STEEL, E.A., FRIMPONG, E.A. and ICKOWITZ, A., 2020. The influence of forests on freshwater fish in the tropics: a systematic review. *Bioscience*, vol. 70, no. 5, pp. 404-414. http://dx.doi.org/10.1093/biosci/biaa021. PMid:32440023.

LU, J., ZHANG, Y., WU, J. and WANG, J., 2020. Nitrogen removal in recirculating aquaculture water with high dissolved oxygen conditions using the simultaneous partial nitrification, anammox and denitrification system. *Bioresource Technology*, vol. 305, p. 123037. http://dx.doi.org/10.1016/j.biortech.2020.123037. PMid:32105846.

MARQUES, N.C., JANKOWSKI, K.J., MACEDO, M.N., JUEN, L., LUIZA-ANDRADE, A. and DEEGAN, L.A., 2021. Riparian forests buffer the negative effects of cropland on macroinvertebrate diversity in lowland Amazonian streams. *Hydrobiologia*, vol. 848, no. 15, pp. 3503-3520. http://dx.doi.org/10.1007/s10750-021-04604-y.

MENDONÇA, F.P., 2010. *Níveis de similaridade entre assembléias de peixes em riachos de terra-firme: padrões locais, coexistência em mesoescala e perspectivas macroregionais na Amazônia Brasileira*. Manaus: Instituto Nacional de Pesquisas da Amazônia, 155 p. Tese de Doutorado.

MENDONÇA, F.P., MAGNUSSON, W.E. and ZUANON, J., 2005. Relationships between habitat characteristics and fish assemblages in small streams of Central Amazonia. *Copeia*, vol. 2005, no. 4, pp. 751-764. http://dx.doi.org/10.1643/0045-8511(2005)005[0751:RBHCAF]2.0.CO;2.

MORTATI, A.F., 2004. *Colonização por peixes no folhiços submerso: implicações das mudanças na cobertura florestal sobre a dinâmica da ictiofauna de igarapés na Amazônia Central*. Manaus: Instituto Nacional de Pesquisas da Amazônia/Universidade Federal do Amazonas. Dissertação de Mestrado.

PANTOJA-LIMA, J., SANTOS, S.M., OLIVEIRA, A.T., ARAÚJO, R.L., SILVA-JUNIOR, J.A.L., BERNARDINO, G., ALVES, R.R.S., FERRAZ-FILHO, A., GOMES, A.L. and ARIDE, P.H.R., 2015. Pesquisa e transferência de tecnologia aliadas para desenvolvimento da aquicultura no Estado do Amazonas. In: M.T. DIAS and W.S. MARIANO, orgs. *Aquicultura no Brasil: novas perspectivas*. 2nd ed. São Carlos: Pedro & João, vol. 2, pp. 313-332.

PAULA, F.R., LEAL, C.G., LEITÃO, R.P., FERRAZ, S.F.D.B., POMPEU, P.S., ZUANON, J.A.S. and HUGHES, R.M., 2022. The role of secondary riparian forests for conserving fish assemblages in eastern Amazon streams. *Hydrobiologia*, vol. 849, no. 20, pp. 4529-4546. http://dx.doi.org/10.1007/s10750-020-04507-4.

PEREIRA, L.M., DUNCK, B. and BENEDITO, E., 2021. Human impacts alter the distribution of fish functional diversity in Neotropical stream system. *Biotropica*, vol. 53, no. 2, pp. 536-547. http://dx.doi.org/10.1111/btp.12896.

PINI, S.F.R., MAKRAKIS, M.C., NEVES, M.P., MAKRAKIS, S., SHIBATTA, O.A. and KASHIWAQUI, E.A.L., 2021. Ichthyofauna in the last free-flowing river of the Lower Iguaçu basin: the importance of tributaries for conservation of endemic species. *ZooKeys*, vol. 1041, pp. 183-203. http://dx.doi.org/10.3897/zookeys.1041.63884. PMid:34163285.

PRADO, M.R.D., CARVALHO, D.R.D., ALVES, C.B.M., MOREIRA, M.Z. and POMPEU, P.S., 2020. Convergent responses of fish belonging to different feeding guilds to sewage pollution. *Neotropical Ichthyology*, vol. 18, no. 1, p. e190045. http://dx.doi.org/10.1590/1982-0224-2019-0045.

QUEIROZ, M.M., HORBE, A.M.C., SEYLER, P. and MOURA, C.A.V., 2009. Hidroquímica do rio Solimões na região entre Manacapuru e Alvarães – Amazonas – Brasil. *Acta Amazonica*, vol. 39, no. 4, pp. 943-952. http://dx.doi.org/10.1590/S0044-59672009000400022.

SAMARKHANOV, T.N., MYRZAGALIYEVA, A.B., CHLACHULA, J., KUSHNIKOVA, L.B., CZERNIAWSKA, J. and NIGMETZHANOV, S.B., 2021. Geoenvironmental implications and biocenosis of freshwater lakes in the arid zone of East Kazakhstan. *Sustainability*, vol. 13, no. 10, p. 5756. http://dx.doi.org/10.3390/su13105756.

SANTOS, S.M., LIMA, J.P., OLIVEIRA, A.T., ARIDE, P.H.R., BARBOSA, R.P. and FREITAS, C.E.C., 2015. Interações tróficas entre as comunidades de peixes e a floreta ripária de igarapés de terra firme (Presidente Figueiredo – Amazonas – Brasil). *Revista Colombiana de Ciência Animal*, vol. 7, no. 1, pp. 35-43. http://dx.doi.org/10.24188/recia.v7.n1.2015.420.

SANTOS, S.M., ZUANON, J.A.S., MENDONÇA, F.P., OLIVEIRA, A.T., ARIDE, P.H.R. and PANTOJA-LIMA, J., 2020. Influência da piscicultura de pequena escala em canais de igarapés sobre as categorias tróficas da ictiofauna Amazônica. *Revista Ibero-Americana de Ciências Ambientais*, vol. 11, no. 5, pp. 210-226. http://dx.doi.org/10.6008/CBPC2179-6858.2020.005.0021.

STABILI, L., DI SALVO, M., ALIFANO, P. and TALÀ, A., 2022. An integrative, multiparametric approach for the comprehensive assessment of microbial quality and pollution in aquaculture systems. *Microbial Ecology*, vol. 83, no. 2, pp. 271-283. http://dx.doi.org/10.1007/s00248-021-01731-w. PMid:33948706.

TAGLIACOLLO, V.A., DAGOSTA, F.C.P., PINNA, M.D., REIS, R.E. and ALBERT, J.S., 2021. Assessing extinction risk from geographic distribution data in Neotropical freshwater fishes. *Neotropical Ichthyology*, vol. 19, no. 3, p. e210079. http://dx.doi.org/10.1590/1982-0224-2021-0079.

TAIRA, D., HEERY, E.C., LOKE, L.H., TEO, A., BAUMAN, A.G. and TODD, P.A., 2020. Ecological engineering across organismal scales: trophic-mediated positive effects of microhabitat enhancement on fishes. *Marine Ecology Progress Series*, vol. 656, pp. 181-192. http://dx.doi.org/10.3354/meps13462.

TIWARI, A.K. and PAL, D.B., 2022. Nutrients contamination and eutrophication in the river ecosystem. In: S. MADHAV, S. KANHAIYA, A. SRIVASTAV and V. SINGH, eds. *Ecological significance of river ecosystems: challenges and management strategies*. Amsterdam: Elsevier, pp. 203-216. http://dx.doi.org/10.1016/B978-0-323-85045-2.00001-7.

TOLEDO, L.G. and NICOLELLA, G., 2002. Índice de qualidade de água em microbacia sob uso agrícola e urbano. *Scientia Agrícola*, vol. 59, no. 1, pp. 181-186. http://dx.doi.org/10.1590/S0103-90162002000100026.

VIEIRA, D.B. and SHIBATTA, O.A., 2007. Peixes como indicadores da qualidade ambiental do ribeirão Esperança, município de Londrina, Paraná, Brasil. *Biota Neotropica*, vol. 7, no. 1, pp. 57-65. http://dx.doi.org/10.1590/S1676-06032007000100008.

YIRIGUI, Y., LEE, S.W. and NEJADHASHEMI, A.P., 2019. Multi-scale assessment of relationships between fragmentation of riparian forests and biological conditions in streams. *Sustainability*, vol. 11, no. 18, p. 5060. http://dx.doi.org/10.3390/su11185060.

Supplementary Material

Supplementary material accompanies this paper.

Figure 1S A-B. Principal component analysis of the physical, chemical and geoenvironmental variables sampled in Novo Airão.

Figure 2S A-B. Principal component analysis of the physical, chemical and geoenvironmental variables sampled in Presidente Figueiredo.

Table 1S. Principal component analysis of the first two axes calculated for the physical and chemical variables and environmental characteristics of the streams of the study areas.

Table 2S. Mean values and percentages of the physical and chemical variables and environmental characteristics and type of substrates of the study areas and in the sampled sites.

This material is available as part of the online article from https://doi.org/10.1590/1519-6984.272623