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Fishes from tributaries of the Itacaiúnas river

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Keywords: Stream; diversity; monitoring.

ABSTRACT – Anthropogenic activities in the Amazon region have an impact on the aquatic environment and, consequently, on the organisms that live there. The lack of knowledge about the ecological relationships of the fish community in the region, as well as their relationship with the environmental variables that determine their survival and distribution, leads to a loss of data for ecological studies and biomonitoring. The objective of our study was to evaluate how environmental variables influence the richness and abundance of fish species in tributaries of the Itacaiúnas river, Pará, Brazil. Therefore, we tested the hypothesis that the richness and abundance of these communities vary according to the variation of physical and chemical parameters in these streams. The study was carried out in 16 streams in the Carajás National Forest, with collections of the fish community, measurements of physical and chemical variables in the water and channel morphology. To synthesize the environmental variables, we used a Principal Components Analysis. We related environmental variables to species richness and individual abundance using forward selection regression with Poisson distribution. The results show that environmental variables influence the richness and abundance of the fish community as they are related to *habitat* availability, food, life cycle, trophic relationships and water quality. These results highlight the importance of water quality, particularly turbidity, which had the greatest influence on the condition of these aquatic communities, providing valuable information for future conservation and monitoring strategies.

 Instituto Chico Mendes de Conservação da Biodiversidade

Peixes dos igarapés tributários do rio Itacaiúnas

Palavras-chave: Igarapé; diversidade; monitoramento.

RESUMO – As atividades antrópicas na região Amazônica geram impactos ao ambiente aquático e, por consequência, aos organismos que vivem nesses locais. O pouco conhecimento sobre as relações ecológicas da comunidade de peixes na região, assim como sua relação com as variáveis ambientais determinando sua sobrevivência e distribuição, geram essas perdas de dados para estudos ecológicos e biomonitoramento. O objetivo do nosso estudo foi avaliar como as variáveis ambientais influenciam na riqueza e abundância de espécies de peixes de igarapés de afluentes do rio Itacaiúnas, Pará, Brasil. Por tanto, testamos a hipótese de que a riqueza e a abundância dessas comunidades se alteram de acordo com a variação dos parâmetros físico e químicos nesses igarapés. O estudo foi realizado em 16 igarapés da Floresta Nacional de Carajás, com coletas da comunidade de peixes, mensuração de variáveis físico e químico da água e de morfologia do canal. Para sintetizar as variáveis ambientais usamos uma Análise de Componentes Principais. Relacionamos as variáveis ambientais usando uma *forward selection* de regressão com distribuição de Poisson com a riqueza de espécies e abundância de indivíduos. Os resultados mostram que as variáveis ambientais influenciaram na riqueza e abundância da comunidade de peixes, pois estão relacionadas à disponibilidade de *habitat*, de alimentos, no ciclo de vida, nas relações tróficas e nas condições da água. Esses achados ressaltam a importância da qualidade da água, particularmente a turbidez, que foi a que mais influenciou o estado das comunidades aquáticas, fornecendo informações valiosas para futuras estratégias de conservação e monitoramento.

Peces de afluentes del río Itacaiúnas

Palabras clave: Arroyo; diversidad; control biológico.

RESUMEN – Las actividades antropogénicas en la Amazonia tienen un impacto en el medio acuático y, por ende, en los organismos que lo habitan. El desconocimiento de las relaciones ecológicas de la comunidad de peces de la región, así como su relación con las variables ambientales que determinan su supervivencia y distribución, supone una pérdida de datos para estudios ecológicos y de biomonitorización. El objetivo de nuestro estudio fue evaluar la influencia de las variables ambientales en la riqueza y abundancia de especies de peces en arroyos tributarios del río Itacaiúnas, en Pará (Brasil). Por lo tanto, pusimos a prueba la hipótesis de que la riqueza y abundancia de estas comunidades cambian de acuerdo con la variación de los parámetros físicos y químicos en dichos arroyos. El estudio se realizó en dieciséis arroyos de la Floresta Nacional de Carajás, y consistió en la colecta de la comunidad de peces, la medición de variables físicas y químicas del agua y la morfología del canal. Para sintetizar las variables ambientales, utilizamos un análisis de componentes principales. Relacionamos las variables ambientales mediante una regresión de selección hacia delante con una distribución de Poisson para analizar la riqueza de especies y la abundancia de individuos. Los resultados muestran que las variables ambientales influyen en la riqueza y la abundancia de la comunidad de peces, ya que están relacionadas con la disponibilidad de *habitat*, el alimento, el ciclo vital, las relaciones tróficas y las condiciones del agua. Estos resultados subrayan la importancia de la calidad del agua, en particular de la turbidez, que fue la que más influyó en el estado de estas comunidades acuáticas, y proporcionan información valiosa para futuras estrategias de conservación y control.

Introduction

The Amazon is a region characterized by its great diversity of fauna and flora, as well as its large rivers, which originate from small streams, known as igarapés, in the region. An igarapé is a first- to third-order stream with shallow depth, located within forests in the Amazon region [1] These watercourses are home to a vast and unparalleled variety of fish and other aquatic organisms compared to other regions of the planet [2].The negative impacts on aquatic ecosystems are predominant in this region and are major factors contributing to the significant loss of biodiversity among these organisms [3].

The Carajás National Forest (FLONATA), located in Pará, is a sustainable-use conservation unit that allows the direct utilization of natural resources and is part of the Carajás mosaic [4]. He area surrounding this forest is also composed of degraded lands, primarily due to livestock farming and mining activities [5]. Numerous studies indicate that these activities affect the aquatic fauna in this region, particularly fish, altering the ecological relationships of these organisms [6][7].

It is important to note that fish fauna respond in various ways to environmental changes, as alterations in growth rates and sexual maturation occur rapidly. Moreover, declines in the abundance, richness, and diversity of these animals indicate stress factors in the aquatic environment [8][9]. Fish communities can offer several advantages for assessing the biological integrity of an environment. These include their mobility, life cycle information, and diverse lifestyles. Additionally, they occupy various trophic levels, feeding on both aquatic and terrestrial food sources. Furthermore, top predators among fish provide an integrated view of the aquatic environment and are relatively easy to collect and identify [10]. As a result, these organisms serve as excellent bioindicators of water quality [11].

Studies indicate that the abundance and diversity of fish fauna are in decline, in parallel with the growth of human populations and anthropogenic activities. These characteristics have been the focus of considerable research, especially since anthropogenic impacts are leading to the extinction of fish species that have yet to be described by science. In light of this, the preservation of fish fauna has emerged as a rapidly growing field of study [12][13].

This study aimed to assess how environmental variables influence the diversity and richness of fish communities in streams that are tributaries of the Itacaiúnas river, Pará, Brazil. We tested the hypothesis that the richness and abundance of these communities vary according to the fluctuation of physicochemical parameters in these streams.

Material and Methods

The Carajás National Forest (FLONATA) is located in the southeastern portion of Pará state, between the geographical coordinates of 5°35’ and 6°00’ south latitude and 50°24’ and 51°06’ west longitude (Figure 1). From a geological perspective, FLONATA is part of the Carajás Mineral Province, which is situated on the Amazon Platform. Its average altitude is around 700 meters, with flat residual hilltops that have been intensely shaped by deep valleys [14]. According to Köppen’s climate classification, the predominant climate in the region is classified as AWi, characterized as tropical and rainy. Annual precipitation ranges from 2,000 to 2,400 mm, while temperatures fluctuate between 24.3°C and 28.3°C. The rainfall regime is well-defined, with two distinct seasons: dry (June to November) and rainy (December to May) [15].

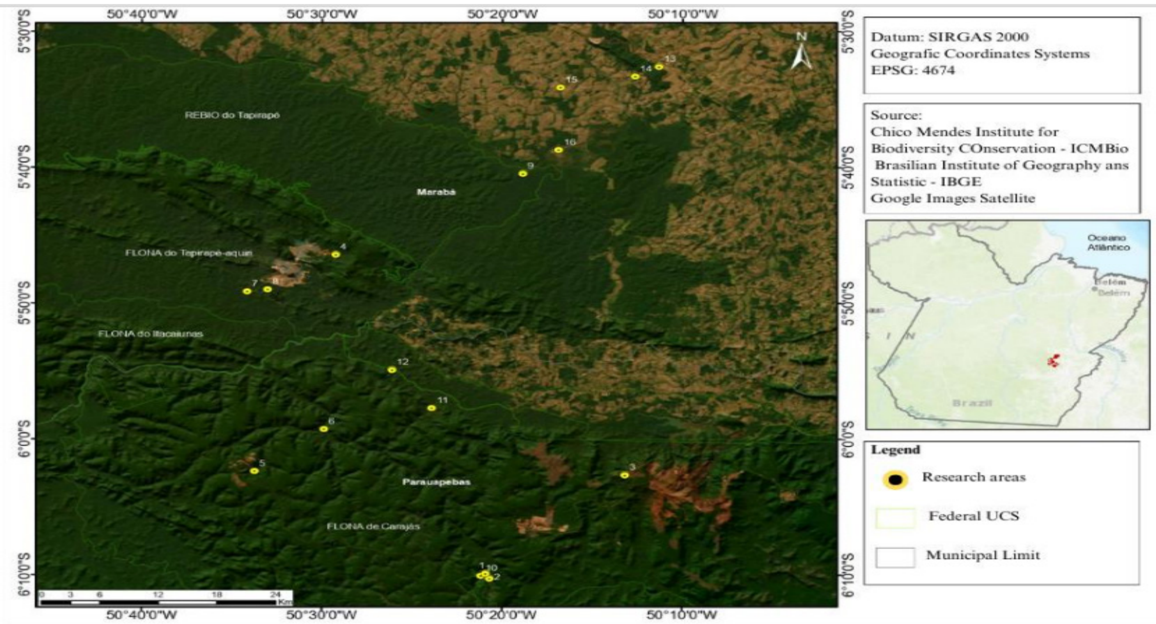

Figure 1 – Distribution of the 16 sampling sites on the river Itacaiúnas Basin in Tapirapé-Aquiri National Forest, Brazil. The sampling events occurred in June and July 2023.

We sampled 16 streams in the Itacaiúnas river basin, which exhibited varying degrees of impact and land use. The collections were conducted between June and July 2023. A 20-meter segment of each stream was selected for sampling, with nets placed upstream and downstream to block the area. Fish were collected using hand nets by sweeping the stream. The individuals were anesthetized with eugenol, euthanized, and preserved in 10% formalin for later identification in the laboratory to the lowest possible taxonomic level, following standard references [16][17].

Physical and chemical variables were obtained using a multi-parameter field probe that measured dissolved oxygen, pH, electrical conductivity, total dissolved solids, turbidity, and temperature. Each variable was evaluated at three different points in the stream and an average was estimated for a more accurate representation of the environment. We used a metric tape to estimate the deep of stream channel and wet with (the distance between the limits of water at the margin) to defined the stream morphology.

In order to visualize the ordination of the sample units we used a principal component analysis (PCA) with the environmental variables. We standardized the environmental variables - as they have different units of measurement - for the construction of the correlation matrix to linearize any relationships. To verified the effect of environmental variables to the fish communities we used the multiple regression with Poisson distribution. We used a forward selection to determine which environmental variables were retained in the analyses (Figure 2). We repeated the regression analysis for richness of species and the number of individuals (abundance). For the analyses we used R [18] with packages *vegan* [19] and *car* [20].

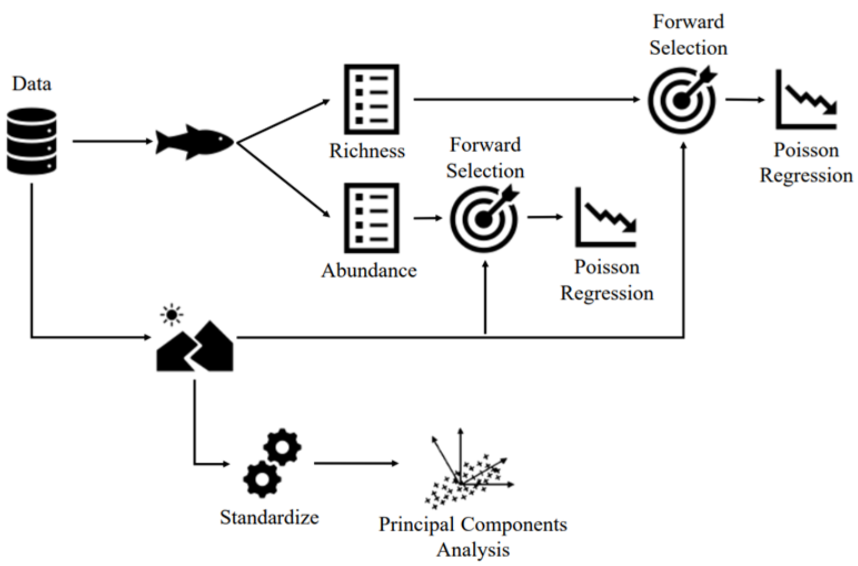

Figure 2 – Diagram representing the methological design of statistical analyses used in this study.

Results

Despite the sampling effort, no fish were found in *igarapés* 3 and 4. In the others, the sampling resulted in 510 individuals, divided into six orders (Characiformes, Cichliformes, Siluriformes, Gymnotiformes, Myliobatiformes, and Cyprinodontiformes), 16 families, 45 genera, and 71 species. Among these, the most abundant order was Characiformes (436 individuals), with the family Characidae (352), the genus *Moenkhausia* (119), and the species *Moenkhausia cf. pankilopteryx* (42), along with the genus *Astyanax* (85) and the species *Astyanax cf. anterior* (76).

The lowest values of electrical conductivity, TDS, and water deep was observed at Ig03. The Ig07 and Ig15 showed the highest values for environmental variables (Table 1). The first two axis of the PCA retained 43% of the variation of environmental variables (PC1 25%, and PC2 18%). The first axes were related with electrical conductivity, TDA, and temperature (only positive relationship); and the second axis were related with dissolved oxygen, water deep (positive), and pH (negative) (Table 2 and Figure 3).

Table 1 – Environmental variables measured in 16 streams on the river Itacaiúnas Basin in Tapirapé-Aquiri National Forest, Brazil. The sampling events occurred in June and July 2023.

Igarapé	pH	Cond	TDS	Turb	DO	Temp	Deep	W. with
Ig01	7.83	20.66	10.33	2.97	3.19	20.49	19.07	4.58
Ig02	7.76	25.66	12.33	2.12	3.16	20.65	10.92	2.82
Ig03	7.63	8	4	1.49	2.88	24.38	5.01	1.88
Ig04	7.29	19.33	9.67	3.94	3.06	23.19	16.88	1.83
Ig05	6.98	28.67	14.33	7.50	2.97	23.66	15.79	2.31
Ig06	6.82	213.67	90.67	2.29	2.86	27.44	12.67	2.80
Ig07	6.42	127.67	63.67	2.25	4.02	24.27	25.46	2.94
Ig08	6.61	45.67	23.00	18.25	3.07	23.25	20.63	2.56
Ig09	6.59	19.00	9.33	0.26	3.14	21.02	14.58	3.13
Ig10	6.64	30.00	15.00	0.68	3.12	22.42	33.58	5.22
Ig11	6.56	29.67	15.00	10.21	2.95	25.35	9.13	2.08
Ig12	7.32	111.00	56.00	5.13	3.04	23.84	14.98	1.38
Ig13	7.25	143.67	72.00	18.41	2.98	25.02	24.46	1.73
Ig14	6.37	64.67	32.67	19.77	3.07	23.54	67.75	1.78
Ig15	7.33	38.00	19.00	16.52	3.12	22.70	19.96	3.32

Cond = Electrical conductivity ($\mu S.cm^{-2}$), TDS = Total dissolved solids (ppm), Turb = Turbidity (NTU), DO = Dissolved oxygen (ppm), Temp = Temperature (°C), Deep = Water deep (cm), W. with = Wet with (meter).

Table 2 – Correlation between the principal components analysis axes and environmental variables measured in streams on the river Itacaiúnas Basin in Tapirapé-Aquiri National Forest, Brazil.

Variable	PC1	PC2
pH	-0.28	-0.47
Cond	0.52	-0.07
TDS	0.53	-0.03
Turb	0.23	0.15
DO	0.03	0.47
Temp	0.48	-0.21
Deep	0.12	0.60
Wet_wid	-0.28	0.35
Variation explained	0.25	0.18

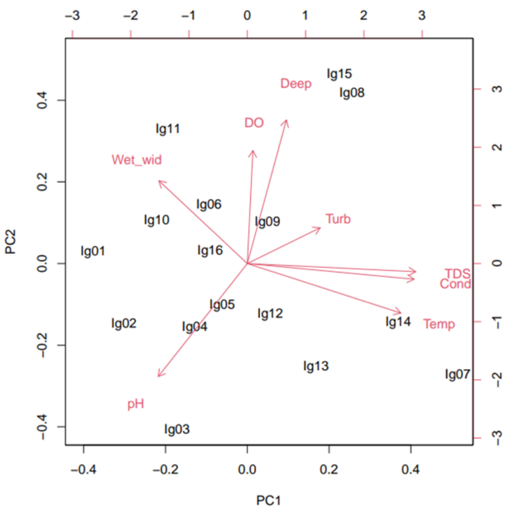

Figure 3 – Principal components analysis (PCA) ordination of environmental variables measured in streams on the river Itacaiúnas Basin in Tapirapé-Aquiri National Forest, Brazil.

The richness of species was related with the environmental variables (Table 3 and Figure 4). The model was good fitness (R^2 = 0.80), and highlighted the turbidity, wed with, electrical conductivity, and TDS as the principal variables of the relationship. For abundance, the model showed the variables turbidity, wed with, electrical conductivity, deep, temperature and pH as relevant for the number of individuals (Table 4 and Figure 5).

Table 3 – Effects of environmental variables at a Poisson regression for richness of fish species in 16 streams on the river Itacaiúnas Basin in Tapirapé-Aquiri National Forest, Brazil.

Variable	Coefficient	Standard deviation	Z value
Intercept	-0.27	0.57	-0.47
Turbidity	0.11	0.02	6.35
Wet with	0.37	0.13	2.82
Elec. Conductivity	0.05	0.02	2.50
TDS	-0.09	0.04	-2.29

R^2 =0.80. In the model all environmental variables (except the intercept) had P<0.05.

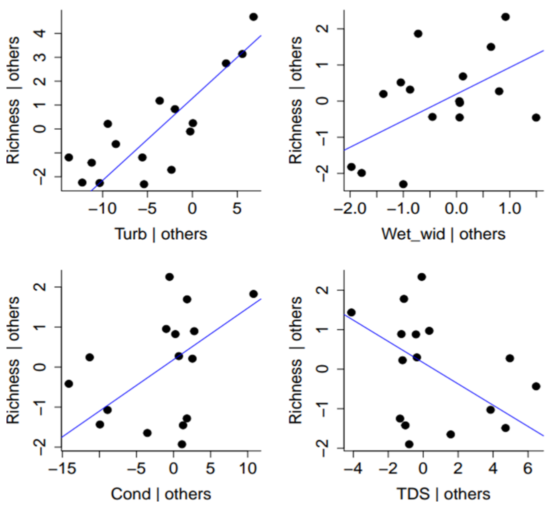

Figure 4 – Residual plots of the Poisson regression for the relationship of environmental variables with richness species of fish. The blue line is the predicted of the model.

Table 4 – Effects of environmental variables at a Poisson regression for abundance of fish species in 16 streams on the river Itacaiúnas Basin in Tapirapé-Aquiri National Forest, Brazil.

Variable	Coefficient	Standard deviation	Z value
Intercept	14.73	2.05	7.20
Turbidity	0.17	0.01	20.66
Wet with	0.50	0.07	7.15
Water deep	-0.03	0.01	-7.40
Temperature	-0.44	0.07	-6.82
Elec. conductivity	0.01	0.01	5.40
pH	-0.57	0.13	-4.37

R^2 = 0.76. In the model all environmental variables had P<0.05.

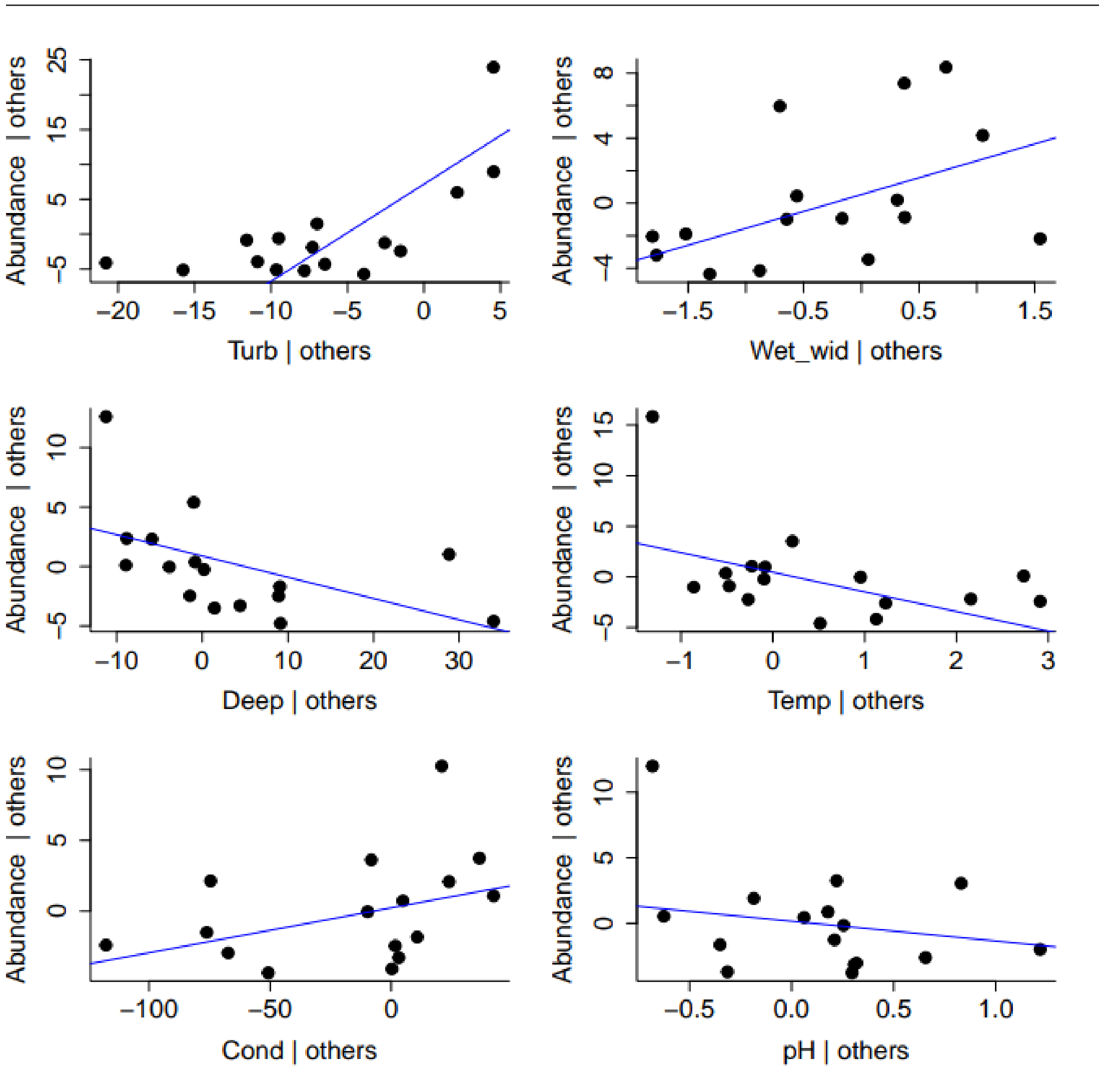

Figure 5 – Residual plots of the Poisson regression for the relationship of environmental variables with abundance of fish individuals. The blue line is the predicted of the model.

Discussion

Our study found that the richness and abundance of fish species in the tributaries of the Itacaiúnas river varied according to environmental variables, mainly physical and chemical. Species richness tended to increase with turbidity, wetted width and conductivity, and to decrease with increasing TDS. In turn, abundance increased with turbidity, wetted width and conductivity, and decreased with increasing depth, temperature and pH. The absence of fish in two streams (Ig3 and Ig4) can be explained by several factors, but is mainly influenced by the physical characteristics of these sites.

We observed that the Characidae family was predominantly present across all sampled sites, reflecting its high ecological plasticity and tolerance to a wide range of pH, conductivity, turbidity, and dissolved oxygen levels. This observation aligns with, who highlighted the versatility of this family in adapting to diverse environmental conditions and its frequent occurrence in ecosystems with high heterogeneity [21].

The occurrence of Erythinidae was limited to sites with high conductivity, elevated concentrations of dissolved solids, and low levels of dissolved oxygen. These findings reflect the ability of this family to thrive in *habitat* with reduced water renewal, often associated with increased organic loads and potential anthropogenic impacts [22].

In contrast, Siluriformes, particularly from the Loricariidae and Callichthyidae families, were recorded at only two sites. Their distribution was associated with *habitat* characterized by higher turbidity, variable depths, and moderate conductivity, conditions that promote the benthic and detritivorous behavior typical of this order, which relies heavily on organic matter-rich substrates for feeding and refuge [23].

The stream three was located very close to its source, with a wide wetted area and extremely shallow depth, creating an environment unsuitable for most fish species due to temperature extremes and low oxygen levels [24]. The stream four on the other hand, was adjacent to a gold extraction site, which releases sediments, potentially toxic trace elements, and other pollutants into the water, directly impacting the physical environment and causing toxic effects on the fish population, significantly altering their dynamics [25][26].

The streams exhibited high environmental heterogeneity, which is associated with variation in richness and abundance in these areas. Variations in environmental conditions determine community composition and life history strategy of fishes [27]. Wetted width is associated with larger environments that provide high *habitat* heterogeneity and conditions that favor organisms that have more sources of food and shelter [28]. Turbidity is a metric that is often associated in many studies with the consequences of anthropogenic impacts on these waters, resulting in negative effects on the organisms that inhabit these areas. However, this study shows that this variable has an incremental effect on species richness and abundance.

The relationship between these organisms and their environment is strong, with their morphology adapted to live under specific environmental conditions [8]. Turbidity can affect the food chain and the success of predation in some fish species [29], in on study involving *G. auratus*, turbidity helped the prey hide and made it harder for the predator to find them [30]. This can affect community richness by allowing dominant species to coexist with those controlled by predation, and abundance by providing favorable conditions for population growth [31]. High TDS levels in the water may indicate toxic substances, and high temperature and depth conditions act as environmental stressors on fish. Richness decreases as less tolerant species are excluded and more tolerant species are favored [32]. And adverse conditions reduce the survival of individuals, resulting in lower abundance [33].

Even though people said these factors were rich, we should still look at the limits of these factors. The intermediate disturbance hypothesis may be affecting these results. This hypothesis suggests that moderate changes in these metrics, especially turbidity, control competitor species. This allows coexistence with less competitive but more tolerant organisms, increasing richness in these areas [34]. More studies are needed to confirm this hypothesis. On the other hand, exceeding these limits could lead to higher levels of disturbance, generating negative effects that alter the structure and ecological relationships of these communities, as observed in other studies [35][36].

Studies highlight that fish species diversity may increase with the impact of agricultural and grazing activities, as these areas contribute to nutrient enrichment in water bodies, favoring the growth of aquatic plants. These plants provide food and shelter for fish, creating an environment conducive to biodiversity [37]. Mining activities reduce species richness in nearby areas. This is because sediments and toxic elements are released, which damages the *habitat* [38].

We must monitor these metrics in aquatic environments to understand how human activities affect fish communities, how tolerant these communities are, and to promote conservation This aims to prevent the loss of ecosystem services that affect the environment and society. However, to achieve robust data for monitoring, it is necessary to incorporate new metrics for *habitat* integrity assessment. Currently, physical-chemical evaluations alone do not provide comprehensive data for environmental analysis or management [39].

Conclusion

We conclude that the richness and abundance of fish species in the tributaries of the Itacaiúnas river are influenced by variations in the environmental characteristics of the water body. Our study provides important data for the assessment of water quality in maintaining the ecological processes of these aquatic communities. In addition, it contributes to a better understanding of the richness and abundance of fish species in this site, which is subject to constant human intervention, providing valuable information for future conservation and monitoring strategies. However, we emphasize the need to incorporate new *habitat* metrics, as we selected only physicochemical characteristics and two channel morphology variables to allow a more comprehensive and effective study of this environment.

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