BOLETIM DO INSTITUTO DE PESCA
Scientific Article

Fish assemblage distribution along a stretch of neotropical urban river

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ABSTRACT

The objectives of this study were to evaluate some descriptors of fish assemblages in different stretches of a Neotropical urban river, located in the municipality of Sorocaba, São Paulo, Brazil, and to evaluate possible differences between them and the influence of seasonality. Collections were carried out between June/2019 and February/2020. The results obtained in relation to the physical and chemical variables of the water indicate that this is a river with the urban river syndrome and that seasonality has a relevant influence. The fish assemblage showed homogeneity in relation to richness and differences regarding diversity, dominance, and abundance in the stretches of the river studied. The multivariate ANOSIM analysis confirmed that the dry and rainy months are not similar to each other in terms of fish composition. The canonical correlation analysis explained 85.58% of the total data variation, indicating that water temperature and rainfall are important factors that influence species composition. It was concluded that the descriptors of the fish community in the studied stretches (richness, abundance, diversity, and dominance) undergo changes due to seasonal variations, which in urban rivers can be amplified, due to the consequences of the loss of vegetation cover, increased soil impermeability, reduction in the water infiltration rate, surface runoff, and maximum flows.

Keywords: Diversity; Ichthyofauna; River integrity; Urban river syndrome.

Distribuição da assembleia de peixes ao longo de um trecho de rio urbano neotropical

RESUMO

Os objetivos deste estudo foram avaliar alguns descritores das assembleias de peixes em diferentes trechos de um rio urbano neotropical localizado no município de Sorocaba, São Paulo, Brasil, e avaliar possíveis diferenças entre eles e a influência da sazonalidade. As coletas foram realizadas entre junho/2019 e fevereiro/2020. Os resultados obtidos em relação às variáveis físicas e químicas da água indicam que o rio analisado tem a síndrome do rio urbano e que a sazonalidade exerce influência relevante. A assembleia de peixes apresentou homogeneidade com relação à riqueza e diferenças quanto à diversidade, dominância e abundância nos trechos do rio estudado. A análise multivariada ANOSIM confirmou que os meses de seca e chuva não são similares entre si quanto à composição íctica. A análise de correlação canônica explicou 85,58% do total de variação de dados, indicando que a temperatura da água e a pluviosidade são fatores importantes e que influenciam na composição de espécies. Concluiu-se que os descritores da comunidade de peixes (riqueza, abundância, diversidade e dominância) nos trechos estudados sofrem alterações em razão das variações sazonais, o que em rios urbanos pode ser ampliado, por causa das consequências da perda da cobertura vegetal, aumento da impermeabilização do solo, redução da taxa de infiltração de água, escoamento superficial e vazões máximas.

Palavras-chave: Diversidade; Ictiofauna; Integridade dos rios; Síndrome do rio urbano.

Received: April 12, 2024 | **Approved:** January 20, 2025
Section editor: Raniere Garcez Costa Sousa

INTRODUCTION

The development of urban centers in neotropical countries has markedly affected rivers, causing serious environmental problems, such as the fragmentation and pollution of these important ecosystems (Damame et al., 2019). The urban rivers that are part of the landscape of many Brazilian cities have, in addition to their landscape importance, environmental and ecological importance for the maintenance of the local biodiversity (Gutiérrez-Rial et al., 2023).

Urban rivers have a fundamental ecological role, transporting water between regions, processing natural materials and nutrients, and being an important source of social and cultural heritage in the basins, in addition to representing habitats for a potentially diverse and productive biota (Walsh et al., 2005). These environments, however, are vulnerable, especially when associated with changes in land cover and other anthropogenic impacts (Azevedo-Santos et al., 2023).

In response to the increasing expansion of urban areas over natural remnants, the alteration of the landscape is evident and causes changes in ecological patterns and processes, resulting in a predominantly urban ecosystem whose interactions between populations and the environment determine the functioning and dynamics of the areas affected (Marques & Cunico, 2021; Oliveira & Bennemann, 2005). In this sense, the number of studies related to the effects of urban ecology is increasing, considering the impacts of urbanization on the physical, chemical, and biological characteristics of ecosystems, especially aquatic ones (Lisi et al., 2018).

According to the above, several authors have described worrying effects of urbanization on these ecosystems, culminating in the so-called urban river syndrome. These rivers typically present high concentrations of nutrients and contaminants, changes in channel morphology and stability, reduced biotic richness and greater dominance of tolerant species, which may also depend on a reduction in base flow or an increase in suspended solids (Booth et al., 2005; Walsh et al., 2005).

The urbanization, to which rivers are subjected, causes serious disturbances in the structure of aquatic communities, especially in the ichthyofauna (Damame et al., 2019; Smith et al., 2019). Fish communities are influenced by a variety of biotic and abiotic factors that might alter their structure and diversity over time (Copatti & Copatti, 2011; Lima et al., 2021). Furthermore, fish assemblages in urban rivers are susceptible to sharp fluctuations in the hydrological water level during rainy seasons, because of soil sealing. In rivers with the syndrome described above, the urban disturbance regime is decisive, as this represents the change in the frequency, magnitude, and duration of hydrological disturbances induced in the channels and in the ecosystem, which implies geomorphological and ecological degradation (Hawley & Vietz, 2016).

Changes in water level can increase the productivity of fish fauna at the expense of increasing resources, in addition to adding complexity and longitudinal compartmentation in rivers (Isaac et al., 2016; Nobile et al., 2019). The duration of the flood regime is a factor that is positively linked to the abundance and richness of species, as the fish community is constantly affected by disturbances, such as drought and flood climatic events, controlling the availability of food and resources (Agostinho et al., 2007; Fernandes et al., 2009).

The disturbances that these rivers are subjected to affect their integrity and conservation status, and most notably where rivers are directly affected through urban and peri-urban centers, (Meyer et al., 2005). The Sorocaba River, the focus of this study, brings together numerous symptoms described in urban river syndrome. When crossing the municipality of Sorocaba, SP, Brazil, it appears rectified, with erosion processes and accentuated sediment deposition, in addition to its permanent preservation area occupied and altered by avenues and exotic plant species. Regarding ichthyofauna, Soinski et al. (2022) reported the occurrence of tolerant, exotic-invading species with high plasticity in the use of available resources.

Understanding how ichthyofauna responds to urban river syndrome (Walsh et al., 2005) supports new research and management and conservation actions not only for the present ichthyofauna, but also for urbanized neotropical water bodies (Morsch et al., 2017). Furthermore, Marques and Cunico (2021) show that there are many gaps in knowledge about the fish ecology in urban streams, which can be extended to rivers. In this context, the objectives of this study were to identify patterns of specific composition and diversity in the structure of fish assemblies in a neotropical urban river, located in the municipality of Sorocaba, and to evaluate the relationship between these patterns and their varying environments and seasons.

MATERIAL AND METHODS

This study was carried out in the Sorocaba River, Sorocaba River basin, Hydrographic Unit of the State of São Paulo, with extension of 227 km (Smith, 2003). It originates in the municipality of Ibiúna, by the junction of the rivers Sorocamirim, Sorocabuçu, and Una, crossing numerous municipalities, including Votorantim, Sorocaba, Iperó, Boituva, Tatuí, Cerquilho, and Laranjal Paulista, where it flows into the Tietê River, being its main tributary on the left bank (Smith, 2003; Smith et al., 2003). Sampling was performed in six urban stretches along the river:

- Stretch 1: 23°31'57.50"S, 47°26'56.27"W;
- Stretch 2: 23°30'23.50"S, 47°27'4.29"O;
- Stretch 3: - 23°29'24.68"S, 47°26'24.11"O;
- Stretch 4: 23°28'31.89"S, 47.26'33.11"O;
- Stretch 5: 23°28'5.28"S, 47°26'45.47"O;
- Stretch 6: 23°28'10.01"S, 47°27'22.76"O (Fig. 1).

Samplings were carried out monthly between June/2019 to February/2020. Air temperature and rainfall were obtained at the National Institute of Meteorology. An environmental characterization was carried out in all campaigns and all sections, obtaining the depth and width through a measuring tape and with the aid of a multi-parameter probe, model Oakton PCD 650, the following physical and chemical water descriptors were obtained *in situ*: pH, electrical conductivity (uS/cm), temperature (°C), and total dissolved solids (ppm).

Aiming to capture fish and collect species of different sizes and habits, different methodologies were carried out. The gear used was a waiting net (grill), trawl, and sieve. The standby network batteries had different mesh sizes (3 to 12 cm between opposite nodes) and ranged from 10 to 30 m in length and 1.5 m in height, being always installed in the late afternoon and removed the following day by the morning. For the capture of small-sized species or fingerlings that preferentially inhabit the margins of water bodies, active-type capture methodologies were used (sieve and trawl), and both were applied with a sampling effort of approximately 30 minutes at each location. The drag measures approximately 2 m long by 60 cm wide.

The captured species were identified at the lowest possible taxonomic level with the help of specialized literature and identification keys, for all individuals, and data on weight (grams) and standard length (centimeters) were obtained. They were anesthetized with benzocaine and then fixed in 10% formalin and preserved in 70% alcohol. All collected specimens were deposited in the fish collection at the Laboratory of Functional and Structural Ecology of Ecosystems, Universidade Paulista, Sorocaba *campus* (catalog code LEEF 0176-0187). The collections were carried out under the authorization of the permanent license for the collection of zoological material SISBIO no. 24151-2 and the Ethics Committee issued by Universidade Paulista, for the use of animals.

For each sampling point during the nine campaigns, Shannon-Wiener abundance, richness, dominance, and diversity data were obtained, and the differences between the data sets were verified with the Shapiro-Wilk's statistical tests (normality test), one-way analysis of variance (ANOVA) (univariate) and Tukey's test. ANOSIM similarity analysis (multivariate) was performed to compare the fish composition as a whole and check for differences between the months of collection and the sampling

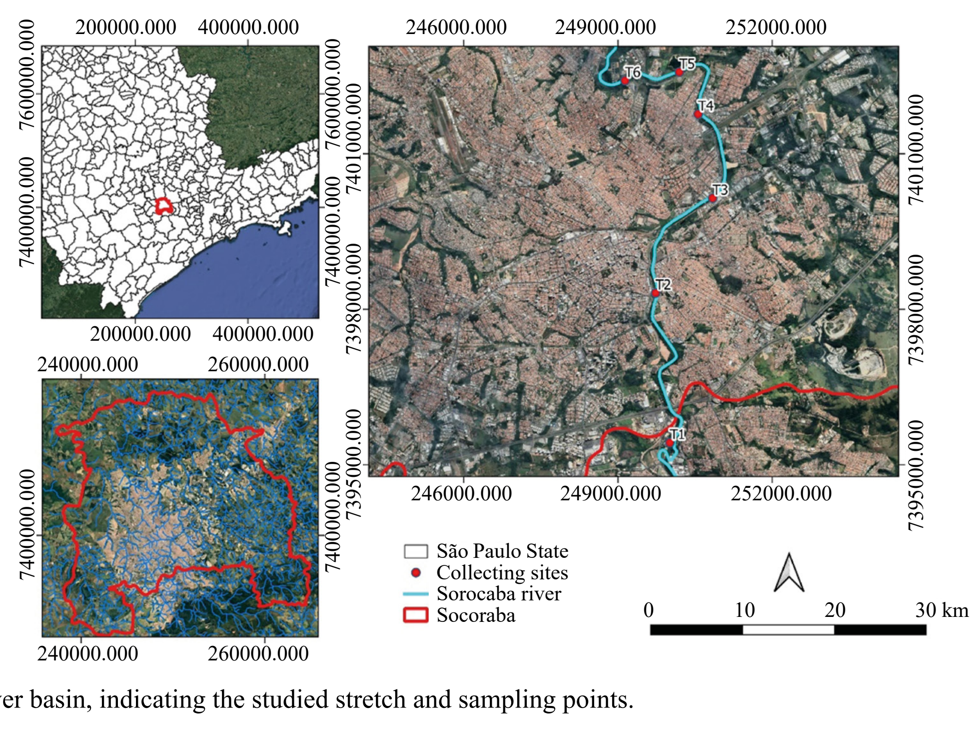


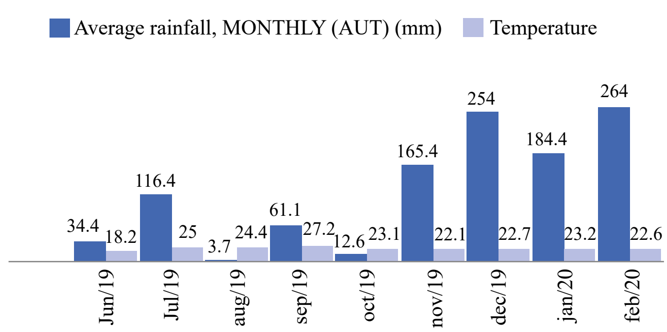
Figure 1. Sorocaba river basin, indicating the studied stretch and sampling points.

points. To explain the environmental data concerning the dry and rainy periods, a boxplot of environmental variables between the sampling points that may have interfered with the species composition was first plotted, and the same variables were correlated using a principal component analysis. To correlate the environmental data, the months of collection, and the occurrence of the species, a canonical correlation analysis was performed; the species whose abundance was less than 10 individuals were excluded from the analysis for a better interpretation of the data. All analyses were run in the Past version 4.03 program (https://past.en.lo4d.com/windows).

RESULTS

Environmental variables

Air temperature and rainfall were obtained at the National Institute of Meteorology, indicating that at the rainy season (summer) temperature attained 27°C and at the dry season the minimum of 18°C. The months of November, December, January, and February were the ones with the highest rainfall levels recorded, reaching values between 165.4 and 264.0 mm (Fig. 2).



Source: INMET (2020).

Figure 2. Monthly rainfall and temperature from June 2019 to February 2020.

Regarding physical environmental and physical-chemical water variables, all six sampled stretches had similar characteristics (Fig. 3). The width varied between 8.0 and 10.7 m and the depth between 1.1 and 1.8 m. The electrical conductivity varied over the months, with the highest value recorded for the dry months, as it was verified for total dissolved solids. The similarity in the dispersion of values between both was evident, with the highest value registered for the two variables in the month of July, when it is possible to interpret an outlier.

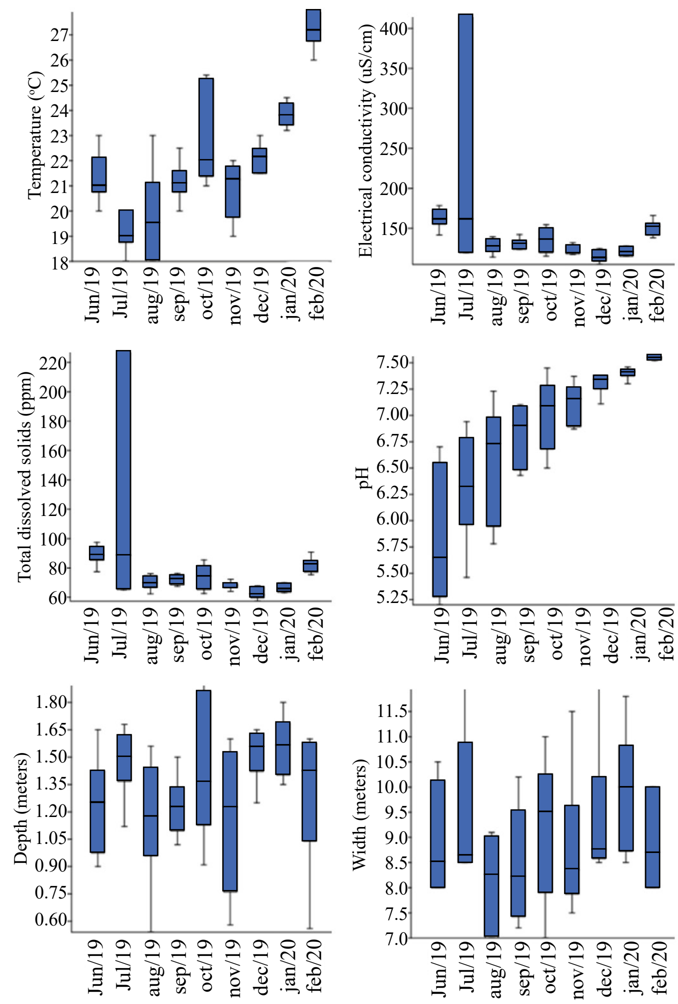


Figure 3. Boxplots of environmental and limnological variables: water temperature (°C), conductivity (uS/cm), total dissolved solids (ppm), pH, depth (meters), and width (meters), between the months of June/ 2019 to February/2020, Sorocaba River, Sorocaba, SP, Brazil.

The pH values increased over the nine months of collection, being higher in the hottest months, and considered rainy, as verified for the water temperature, which was higher between the months of September/2019 to February/2020.

The principal component analysis explained 85.58% of the total data variation considering the first two principal components. As observed in the boxplot, this analysis proved the influence of electrical conductivity and total dissolved solids for the month of July. The variables that most contributed to form axis 1 were electrical conductivity (positive values) and total dissolved solids (positive values), both for the month of July (dry), while water temperature (positive values) for the month of October (full) and air temperature (negative values) for the month of June (dry) were the factors that contributed to the formation of axis 2. We can observe that three of the hottest months, considered rainy (December, January, and February), were related to the variables rainfall, depth, and width. The pH was better related to the month of November, also rainy (Fig. 4).

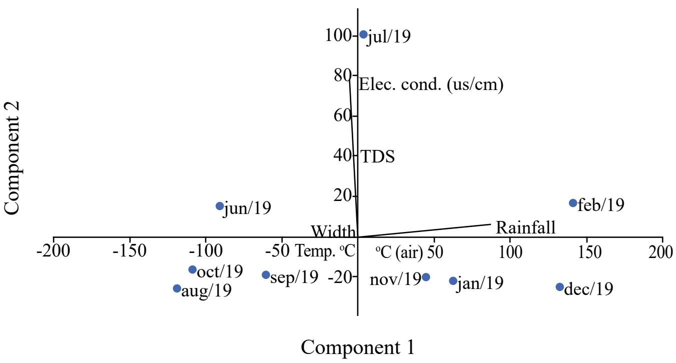


Figure 4. Principal component analysis biplot representing the results of the principal component analysis, considering the environmental and physical-chemical variables of the water in the six stretches sampled during the nine campaigns.

Ichthyofauna

Overall, 23 species of fish were identified, belonging to five orders and 12 families. The predominant orders were Characiformes, with nine species, followed by Siluriformes, with eight species. It was verified greater richness for the rainy months, with 23 species sampled, while for the drier months it was verified a richness of 17 species. The species *Schizodon nasutus*, *Psalidodon paranae*, *Cyphocharax modestus*, *Steindachnerina insculpta*, *Pimelodus maculatus*, and *Gymnotus carapo* occurred only in the rainy months, while the species *Corydoras aeneus* only occurred in dry months.

The Shannon-Wiener diversity values were higher in the months of November 2019 to February 2020, months that corresponded to the river's flood period, in which the richness values were also higher. The dominance values, as expected, behaved inversely to diversity, with the highest values recorded for the months of June 2019 to October 2019, months that corresponded to the dry period of the river and in which the highest values were recorded for abundance (Fig. 5).

Statistical tests were performed to check whether the difference in values between the months of collection in the six sampled stretches was significant. First, the Shapiro-Wilk's normality test was performed, showing that all data sets have a

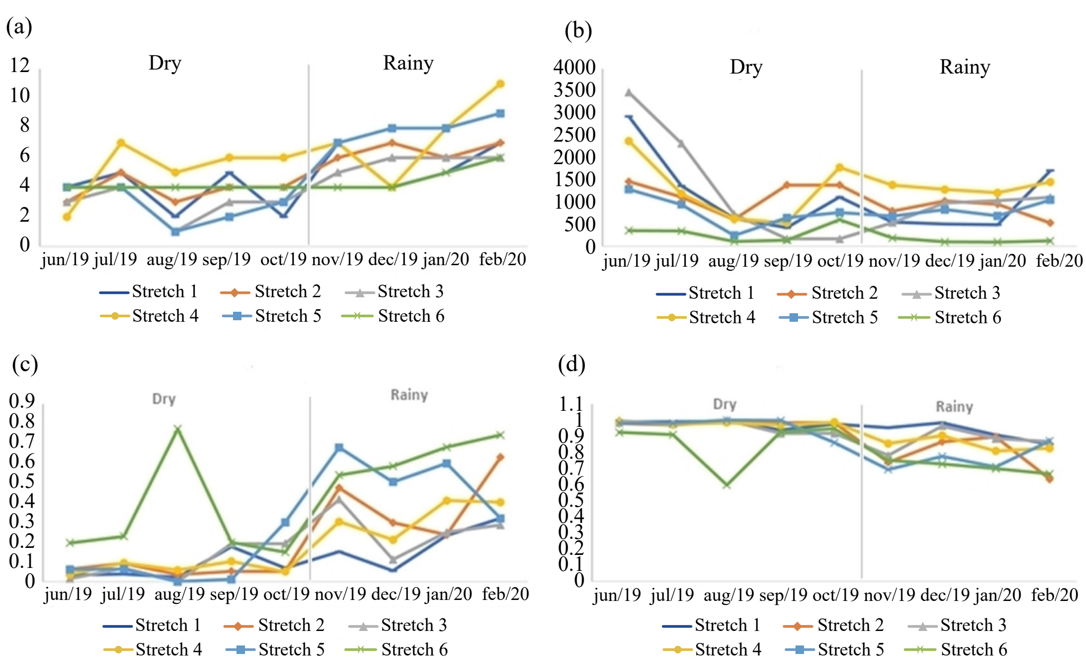


Figure 5. Descriptors of fish assemblages evaluated in each studied stretch. (a) Total richness; (b) total abundance; (c) diversity; and (d) dominance and seasonal variation (dry and wet) during the nine months of the campaign in the six sampled stretches, from June 2019 to February 2020.

normal distribution. The analysis of one-way ANOVA similarity revealed the following results: there was a significant difference between the nine campaigns in the six sampled stretches for diversity (significance level $p < 0.05$; $p = 0.0002956$); there was a significant difference between the nine campaigns in the six stretches sampled for dominance (level of significance $p < 0.05$; $p = 0.0004241$); considering richness, there was no relevant difference between the nine campaigns in the six sampled stretches (significance level $p < 0.05$; $p = 2.726$); considering abundance, there was a significant difference between the nine campaigns in the six sampled stretches (significance level $p < 0.05$; $p = 0.003385$). The Tukey's test, reinforcing that there are significant differences between the flood and dry months regarding diversity, dominance, and abundance, confirmed these results. Only for richness, it was tested that there were no significant differences. The similarity analysis (ANOSIM) confirmed the values obtained in the graphs considering the ichthyic composition, refuting the null hypothesis and confirming that the species composition was not similar between the dry and rainy months (r = 0.175; $p = 0.1565$); just as the sampling points were not similar to each other (r = 0.1193; $p = 0.0094$).

The canonical correspondence analysis explained 89.07% of the data variation, correlating the environmental variables with the occurrence of species for the stretches sampled during the nine campaigns. It was noted that most species were positively correlated with the variables depth, width, water temperature, and pH in the months of December/2019 to February/2020 (rainy). These were: *Hoplosternum littorale*, *Hypostomus ancistroides*, *Parodon nasus*, *Pterygoplichthys ambrosettii*, *Coptodon rendalli*, and *Poecilia reticulata*. The rainfall variable was also positively correlated with the occurrence of species in the month of November/2020 (rainy). They were: *Psalidodon fasciatus*, *Geophagus iporangensis*, *Hypostomus margaritifer*, *Hisonotus depressicauda*, *Prochilodus lineatus*, and *Hoplias malabaricus*. The variables total dissolved solids, electrical conductivity, and air temperature were not correlated with the occurrence of species for this study (Fig. 6).

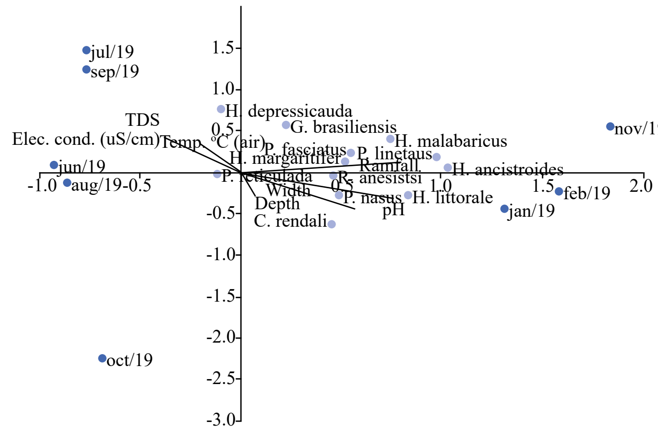


Figure 6. Canonical correspondence analysis biplot representing the results of the canonical correspondence analysis, considering the environmental and physical-chemical variables of the water and its correlation with the occurrence of species in the six stretches sampled during the nine campaigns.

DISCUSSION

Our evaluation indicated that, through the physical and chemical parameters evaluated, the studied river presents numerous characteristics that we can consider as the urban river syndrome. High values of conductivity and total dissolved solids in addition to the reduced depth are some of the indicators of such a situation. Smith et al. (2019) confirm this prognosis, describing that the Sorocaba River underwent interventions in the stretch studied, a situation that led it to have a more rectilinear shape and a smaller presence of meanders, a situation that affects changes in the flow speed of its waters and in the solid load transported. Furthermore, they cite the compromise of the ecological integrity of its marginal vegetation in addition to the influence of organic pollution, despite efforts in recent decades to treat effluents.

The highest pH values in the rainy season may be related to the carrying of sediment coming from the tributaries of the Sorocaba River or to the algae photosynthesis, more active on days with higher temperatures, and it removes carbon dioxide from the water during this process, being the main natural source of water acidity. So, as the amount of carbon dioxide decreases, the pH becomes more alkaline. We emphasize that, in the dry period, the situation of the above parameters worsens, which must be considered in the dynamics of the river and in the structure of the fish assemblage. Seasonal variations can alter the limnological characteristics of a body of water and may alter its physicochemical and microbiological composition.

The relationship between seasonality and the physical and chemical parameters analyzed is corroborated by Lima et al. (2021) and Silva et al. (2018), who evaluated the influence of seasonality on parameters such as conductivity and total dissolved solids and concluded that both undergo changes in the rainy season, in which they obtained the highest values, already expected, due to the increase in water volume at these times, and decrease in times of drought.

Regarding the fish assemblage, the absence of differences in fish species richness along the studied stretches can be attributed to environmental homogenization and the dominance of non-native species with high plasticity in resource use. Species richness is expected to be positively associated with channel size, water velocity, and riparian vegetation (Walrath et al., 2016), which explains the findings in the Sorocaba River, which has a similar channel size between stretches and degraded riparian vegetation. Cruz and Pompeu (2020) found greater biotic homogenization in urban streams in the Rio Grande basin, MG, Brazil. These same authors, in addition to Ortega et al. (2021), who studied 45 streams in the municipality of Cuiabá, MT, Brazil, state that environmental homogenization triggers an increase in the dominance of generalist and opportunistic species in the river and allows the invasion of non-native species, leading to the loss of native species.

The high abundance and occurrence of three non-native species (*Poecilia reticulata*, *Pterygoplichthys ambrosettii*, and *Coptodon rendalli*) demonstrates the response of the ichthyofauna to the urbanization of the studied river. This finding is consistent with the results of numerous studies, including in Brazil (Cunico et al., 2006; Daga et al., 2012). According to Cruz and Pompeu (2020), the dominance of *P. reticulata* in urban areas represents an important indicator of biotic homogenization. Marques and Cunico (2021) reinforce this idea, highlighting that the process of homogenization of fish fauna in urban streams has as an evident consequence the loss of distinction of populations and communities at the level of taxonomic. In contrast, the homogenization found for richness in the stretches studied was not obtained for beta diversity, dominance and abundance, which demonstrated differences between the stretches. This can be attributed to differences in water speed, as there are backwaters and waterfalls, which according to Vander Vorste et al. (2017) may result in the differences found.

The greater diversity related to the months of greater precipitation and water temperature, which are the rainy months (November/2019 to February/2020), can be explained by the movement of fish at this time, making them more active and thus facilitating their capture, as evidenced by Copatti and Copatti (2011). We can add to this the improvement in water quality, which can contribute to the increase in diversity due to the movement of fish to these stretches with better conditions at this time and also reproduction, since during the flood period, fish are looking for places to spawn (Andrade & Braga, 2005; Ribeiro & Moreira, 2012). These aspects can contribute to the increase in diversity. In the stretches studied, fish assemblages respond positively to rainfall stimuli, whether these are more backwater or lotic environments (Fernandes et al., 2009).

Seasonal differences in the composition of the ichthyofauna were evidenced in this study, as it was also verified by Nascimento and Smith (2016) and Santos and Caramaschi (2011), who concluded in their studies that in tropical rivers the fish community changes due to the expansion of the water level (depth), which increases in the rainy season compared to the dry season. Thus, the fish community components change according to the time of year and the volume of water mainly, as well as for this study, in which 23 species were inventoried for the rainy months, while in the dry months 17 species were inventoried, showing that the seasonal period can directly influence the composition of the ichthyofauna. As presented by Santos and Caramaschi (2011), canonical correlation analysis is a multivariate technique that can describe how different species can correspond to each type of environmental variable, thus forming a set of ecological data. They correlated that small species are the least influenced by the hydrological regime, as shown in this study, whereas those that were more influenced by hydrological levels were the medium and large species.

The evaluation of the influence of seasonal variations on the occurrence of species and diversity in a river, such as the Sorocaba River, is extremely important to understand the behavior of species under different conditions of temperature and rainfall throughout the year. The rainy months were the ones with a greater diversity of fish, while the driest months had less diversity and a greater number of dominant species. Furthermore, in rivers with urban river syndrome, the rainy season can represent an improvement in water quality, while in the dry season it worsens, due to the reduction in volume and in the ability to dilute pollutants.

CONCLUSION

This study provides relevant information on fish assemblages in evaluated stretches of an important urban river, the main tributary of the left bank of the Tietê and the Upper Paraná basin. The study of the ichthyofauna of urban rivers deserves attention, because it still lacks in-depth information. Environmental homogenization, seasonality and non-native fish species are fundamental parameters that influence important descriptors of fish assemblages in urbanized rivers. Expanding knowledge on this topic is essential to support public conservation policies and restoration projects.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

All data relevant to the study are included in the article and as supporting information.

AUTHORS' CONTRIBUTIONS

Conceptualization: Cavallari, D.E., Smith, W.S.; **Data curation:** Cavallari, D.E., Soinski, T.A., Pinheiro, L.A.S., Smith, W.S.; **Investigation:** Soinski, T.A., Pinheiro, L.A.S., Smith, W.S; **Supervision:** Smith, W.S.; **Resources:** Smith, W.S.; **Formal Analysis:** Cavallari, D.E., Smith, W.S.; **Writing – original draft:** Cavallari, D.E., Soinski, T.A., Pinheiro, L.A.S., Smith, W.S.; **Writing – review & edition:** Cavallari, D.E., Soinski, T.A., Pinheiro, L.A.S., Smith, W.S.; **Final approval:** Smith, W.S.

FUNDING

Not applicable.

ACKNOWLEDGMENTS

The authors thank to the Universidade Paulista/Laboratory of Structural and Functional Ecosystem Ecology, to the Vice-rectory of Graduate and Research and Fisheries Institute, Postgraduate Program in Aquaculture and Fisheries, for logistical support. They are also grateful to the two anonymous reviewers for their contributions to improve the manuscript.

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