







## Influence of different types of margins in the fish assemblage from an urban river

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### ABSTRACT

The presence or absence of a fish species may be associated with the physical and chemical characteristics of the water, in addition to the state of preservation of the riparian zone. This study examined whether the taxonomic fish composition in an urban river varies along three riparian zone preservation conditions: preserved, intermediate preservation and degraded. Six urban stretches of the Sorocaba/São Paulo River were selected for this study, with monthly sampling being carried out from June 2019 to February 2020. The samplings were carried out with the aid of a sieve, dip net, and trawl. Regarding the types of margins and environmental variables, the Principal Component Analysis explained 97.49% of the data variation, axis 1, which explained 91.85% of the total variation, was formed by the variables conductivity and total dissolved solids. Axis 2, which explained 5.64% of the variation, was formed by Sun Rays% and Siltation%, being inversely proportional to Riparian Forest%. For the ichthyofauna, the samples consisted in 50,983 fish distributed in 5 orders, 8 families, and 12 species. Cyprinodontiformes had the highest abundance, with 96.96% of the total number of individuals, followed by Siluriformes (2.39%), and the sum of the other orders did not reach 1% of the total collected. According to each type of margin, it was possible to register 11,592 individuals for the Margin A – preserved, with S=8 species, being 2 exclusive (*Corydoras flaveolus* and *Hoplosternum littorale*) and 3 exotic (*Coptodon rendalli*, *Pterygoplichthys ambrosettii*, and *Poecilia reticulata*), the latter was dominant in all types of margins. For Margin B – intermediate preservation, 19,645 individuals were sampled, with S=5 species, no exclusive species, only exotic and more tolerant native species such as *Hoplias malabaricus* and *Hypostomus ancistroides*. For Margin C – degraded, 19,746 individuals were recorded, the largest number of species (S=10), 3 were exclusive to this type of margin (*Psalidodon fasciatus*, *Rhamdia quelen*, and *Geophagus brasiliensis*). The pairwise comparison (similarity percentage) showed that the assemblage structure was different for the types of margins. The Canonical Correspondence Analysis explained 92.46% of the total data variation, showing the relationship of species to environmental data. It is evident the importance of preservation of micro-habitats still present in the locals sampled, since different anthropic pressures cause great loss of diversity, especially for native and more sensitive species.

**Keywords:** taxonomic composition, spatial distribution, diversity, habitat integrity; urban river syndrome.

### Influência de diferentes tipos de margens na assembleia de peixes de um rio urbano

### RESUMO

A presença ou ausência de uma espécie de peixe que vive em rios urbanos pode estar associada às características físicas e químicas da água, além do estado de preservação da zona ripária. O presente estudo verificou se a composição taxonômica de peixes de um rio urbano varia em três condições de preservação da zona ripária: preservada, preservação intermediária e degradada. Seis trechos urbanos do rio Sorocaba, localizado no estado de São Paulo, foram selecionados para este estudo, com coletas mensais de junho de 2019 a fevereiro de 2020 com auxílio de peneira, puçá e rede de arrasto. Com relação aos tipos de margens e às variáveis ambientais, a análise de componentes principais explicou 97,49% da variação dos dados. O eixo 1, que explicou 91,85% da variação total, foi formado pelas variáveis condutividade e total de sólidos dissolvidos. O eixo 2, que explicou 5,64% da variação, foi formado pelo percentual das variáveis raios solares e assoreamento, revelando-se inversamente proporcional ao de mata ripária. Para a ictiofauna, foram amostrados 50.983 indivíduos compreendidos em cinco ordens, oito famílias e 12 espécies. *Cyprinodontiformes* apresentou maior abundância, com 96,96% do total de indivíduos, seguida de siluriformes (2,39%); a soma das demais ordens não atingiu 1% do total coletado. De acordo com cada tipo de margem, foi possível registrar 11.592 indivíduos para a margem A preservada, com a s=8 espécies, das quais duas foram exclusivas (*C. flaveolus* e *H. littorale*) e três exóticas (*C. rendalli*, *P. ambrosettii* e *P. reticulata*), sendo esta última dominante em todos os tipos de margens. Para a margem B intermediária, foram amostrados 19.645 indivíduos, com S=5 espécies, dos quais nenhum representante de espécie exclusiva, apenas espécies exóticas e nativas mais tolerantes, como *H. malabaricus* e *H. ancistroides*. Já para margem C degradada, foram registrados 19.746 exemplares, maior número de espécies (s=10), três delas exclusivas desse tipo de margem (*P. fasciatus*, *R. quelen* e *G. brasiliensis*). A comparação par a par (porcentagem similar) mostrou que a estrutura da assembleia se apresentou distinta para os tipos de margens. A análise de correspondência canônica explicou 92,46% da variação total dos dados, evidenciando a relação das espécies com os dados ambientais. Torna-se evidente a importância da preservação dos micro-habitats ainda presentes nas margens amostradas, visto que diferentes pressões antrópicas causam grande perda de diversidade, sobretudo para espécies nativas e espécies mais sensíveis a essas alterações.

**Palavras-chave:** composição taxonômica; distribuição espacial; diversidade; integridade do habitat; síndrome do rio urbano.

## INTRODUCTION

Historically, many cities developed on the margins of rivers, but over time, the water bodies have been altered by interventions and engineering works, such as plumbing, busbars, rectifications, de-silting, soil waterproofing, among others (Dictoro and Hanai, 2016). Thus, the river is undoubtedly a key element of the urban landscape, initially shaping the organization and development of cities; however, with the advance of engineering, it ended up being disfigured in most of the urban centres where they are located (Pompêo, 2000).

Urbanization processes reconfigure the margins of an urban river, resulting in changes in both water quality and aquatic communities, especially fish (Oliveira and Mello, 2016). These changes come mainly from the absence of riparian vegetation and consequently silting up, in addition to clandestine sewers and engineering works on the margins or in the river channel. The silting observed in the rivers has different causes, but the most important are the absence of vegetation cover (Smith et al., 2018) and by the movement of earth for engineering works. Many urban rivers, which crossing cities, suffer from environmental impacts from anthropic actions; these rivers face the “urban river syndrome”, a concept described by Walsh et al. (2005) as the degradation and ecological changes in bodies of water that are inserted in urban areas.

The comprehension of ecological relationships is an important factor to verify the implications on the fish assemblage (Ribeiro et al., 2016), with changes in fish habitats being one of the most severe, causing changes in the community structure (Teresa et al., 2016). Knowing the fish community and the factors that influence it is relevant to its conservation and can be useful to understand and predict the impacts of any anthropogenic disturbances to these environments (Almeida and Cetra, 2016).

The margins of rivers where disturbances are evident have particular complex effects on the ichthyofauna, due to the simplification of the habitat and the reduction of available resources (Brejão et al., 2021), affecting directly or indirectly the ichthyofauna, through the change in the availability of food resources, reproductive sites, species dominance (including an increase in exotic species), refuge sites, and among other changes that occur in the ichthyofauna, mainly those dependent on riparian vegetation (Marques and Cunico, 2021). There are four recognized and relevant habitat characteristics for fish, providing support for analysis of the effects of changes and/or changes in habitat (Smith et al., 2005): the depth and speed of the water, composition of the bed substrate, and vegetation cover (Becker, 2002).

This study started from the attempt to verify if the taxonomic fish composition in an urban river varies along three distinct conditions of preservation of the riparian zone, in order to compare the ichthyofauna that live in the riverside. For this, the following hypotheses were tested:

1. the taxonomic composition will be different between the different types of margins and

2. the fish assemblages will be composed of more tolerant species in the stretches with degraded margins.

Recognizing the influence of limnological characteristics on the structure of ichthyofauna, it is essential to understand which environmental variables are important locally, in order to develop efficient conservation strategies.

## MATERIAL AND METHODS

### Study area

The municipality of Sorocaba has an area of approximately 450 km<sup>2</sup> and is located in the interior of the State of São Paulo, with an estimated demographic population of 687.357 people according to updated data from the IBGE (2020). The land use is characterized by urbanized and industrialized areas, hortifruit-growing activities, reforestation, and natural and cultivated pastures in rural areas, and almost the entire municipality is considered urban. The region's climate is tropical, with hot, rainy summers and dry winters. The temporal variation throughout the hydrological year indicates the occurrence of a rainy period, between October and March, with monthly average rainfall above 100 mm, and a dry season, with the lowest average volume in August (Abreu and Tonello, 2017). The average annual temperature is 21.2°C, with the minimum recorded in June (17.1°C) and maximum in February (24.6°C) (Abreu and Tonello, 2017).

The stretch of the Sorocaba River, SP, Brazil, selected for the study is in the municipality of Sorocaba in its urban area and presents distinct characteristics on its margins, such as remnants of riparian vegetation; the presence of floodplain ecosystems; anthropic changes such as the rectification of the river, which currently has a more straight format in the urban section with fewer meanders; de-silting works; civil construction in inadequate areas; and punctual and diffuse pollution, in addition proximity to the main road city transit system (Smith et al., 2019). This river is widely used for various purposes, such as water catchment to supply municipalities located in its basin, fish consumption through recreational and sports fishing, and irrigation, in addition to the main tributary on the left margin of the Tietê River (Smith et al., 2014).

Six pre-selected stretches were sampled along part of this river in the urban area (Figure 1), and each stretch was characterized as to the preservation conditions of the riparian zone. Table 1 shows the condition of each type of margin for the sampled stretches.

### Environmental description

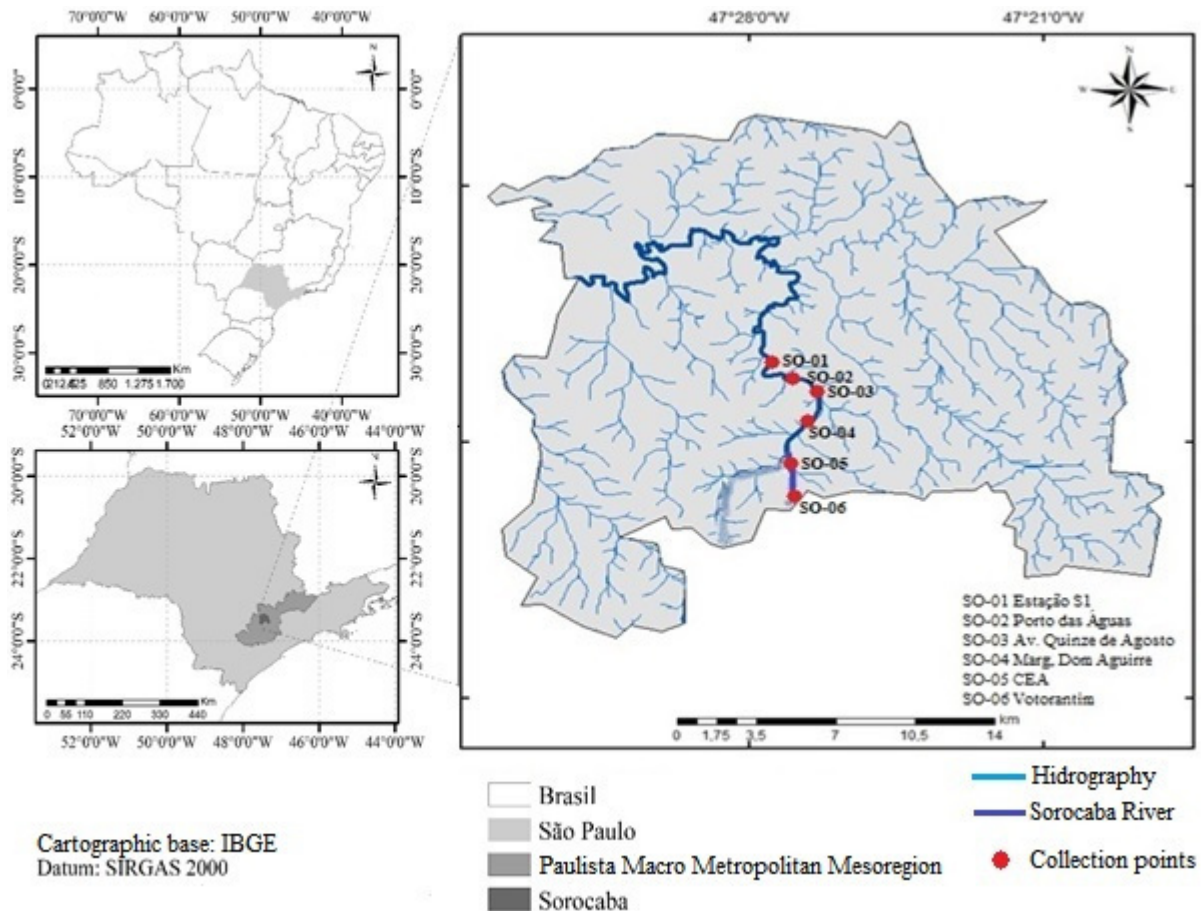
Prior to the collection at each stretch, the geographical coordinates were recorded using a GPS device, and at each margin of the selected stretches, measurements of the physical and

chemical variables were taken: electrical conductivity ( $\mu\text{S}\cdot\text{cm}^{-1}$ ), pH, total dissolved solids (TDS) ( $\text{mg}\cdot\text{L}^{-1}$ ) and water temperature ( $^{\circ}\text{C}$ ), obtained with the aid of a multiparameter probe model OAKTON PCD 150. The structural variables were obtained through the application of the Rapid Assessment Protocol (RAP), adapted from Callisto et al. (2001), in order to ascertain the changes in the surroundings of the studied stretches, evaluate the state of conservation of the river, and verify the influence of the adopted measures in the silting of some stretches of the river. The measured variables corresponded to the current, incidence of sunlight (%) and transparency (cm) of the water obtained through the Secchi disk. The substrate was characterized in relation to the type of bottom: rocky, sandy, and muddy (through visual estimation), the degree of silting (%) and the presence of riparian vegetation (%). Photographic records were also made to accompany the various moments of the interventions over time. Measurements of width and depth were obtained at each sampled stretch using a metric measuring tape, and the measurements were carried out in each sampled stretch on both the right and left margins; however, due to variations in the volume of water due to seasonality, an average was performed by margin, with each sampled stretch comprising a stretch of 100 m.

## Ichthyofauna sampling

The sampling effort was carried out monthly between June 2019 and February 2020 in nine campaigns over the sampling stretches including the right and left margins, sieve with 2 mm mesh with a diameter of 51 cm, used in the backwater areas and close to the vegetation, as well as the rectangular dip net with measurements of  $100\text{ cm}\times 70\text{ cm}$  and 1.0 cm mesh that was also used in these areas and the trawl 4 m long $\times$ 1.5 m high and 10 mm mesh that provided the collection in the potions and backwater areas. On each bank, these methodologies were carried out for a period of 40 min.

The fish caught were individually measured at their standard length (SL-cm) and weighed (g). Regarding the individuals collected, after euthanized with the benzocaine anaesthetic, these were fixed in 10% formaldehyde, preserved in 70% alcohol, identified, and separated in labeled glasses with information on date and place. In this way, the species were identified using identification keys and experts in the area, and all the collected vouchers were deposited in the fish collection at the Laboratory of Functional and Structural Ecology of Ecosystems at Universidade Paulista, Sorocaba Campus, São Paulo, Brazil (catalogue number LEEF 0176-0187). All collections were carried out with the authorization of the SISBIO license (24151-2).



**Figure 1.** Location of sampling points, on the right and left margins of the Sorocaba River (urban stretch). Source: Smith et al. (2005). Adapted by the authors.

**Table 1.** Description of sampling points in stretches of the Sorocaba River.

| Photographic register   | Coordinates                 | Surrounding stretch   |
|---|-----------------------------|---|
|    | 23°28'11.76"S 47°27'25.65"W | SO-01: A more preserved stretch of the Sorocaba River, with riparian vegetation present and residential areas further away from the water body. Note the presence of a Sewage Treatment Station near the right margin of the river. |
|    | 23°28'06.1"S 47°26'47.1"W   | SO-02: A stretch of river with the presence of some trees, shrubs, and grasses, located near an area intended for the population's leisure.   |
|   | 23°28'28.5"S 47°26'33.0"W   | SO-03: A stretch of river with the presence of some trees, shrubs, and grasses, located near the city's main access road, it shows signs of degradation. Residential areas close to the water body.                                 |
|  | 23°29'25.4"S 47°26'25.3"W   | SO-04: A stretch of river with no riparian vegetation and a predominance of grasses, located near the city's main access road.  |
|  | 23°30'22.2"S 47°27'04.3"W   | SO-05: A stretch of river with no riparian vegetation and a predominance of grasses, it shows signs of degradation, located near the city's main access road. Residential areas close to the water body.                            |
|  | 23°31'40.5"S 47°26'54.5"W   | SO-06: A more preserved stretch of the Sorocaba River, with riparian vegetation present and residential areas further away from the water body. Waterfall stretch.  |

SO: Sorocaba. Source: Authors.

## Analysis of data

To organize the margins according to the similarity between the limnological variables, Principal Component Analysis (PCA) was used (Krebs, 1989). The significance of the axes was tested at a significance level of 0.05; this analysis was obtained from the Program Past version 3.0. In addition, a descriptive analysis was carried out with the data collected, evaluating whether there were changes during the campaigns in the environmental characterization, being important to explain the association between the environment and the fish assemblages.

The ichthyofauna was evaluated for the general composition of the species (i.e., abundance, richness, diversity, and equitability) in each stretch sampled for both margins, obtained in the Program Past version 3.0. For statistical analysis, campaign data were grouped. The richness was obtained by the number of species captured; the absolute abundance was given by the total number of individuals collected in each species. Species diversity ( $H'$ ) for each sampled point was calculated using the Shannon-Wiener index (Magurran, 2004), with the formula  $H' = -\sum (p_i \cdot \log_2 p_i)$ , where  $p_i$  is the proportion of individuals found in each species. The Pielou Equitability Index is derived from the Shannon Diversity Index and allows representing the uniformity of distribution of individuals among existing species (Pielou, 1969). Its value ranges from 0 (minimum uniformity) to 1 (maximum uniformity).

To verify the existence of significant differences ( $p < 0.05$ ) in the composition of the ichthyofauna between the types of margins, a Permutation Multivariate Analysis of Variance (PERMANOVA) was applied, which allows testing the hypothesis of community variations due to environmental factors. In addition, based on the statistical difference between the types of margins, the Similarity Percentage (SIMPER) was used to identify the species that most contributed to each point (Clarke, 1993). As three groups were selected, all samples were pooled to perform a single overall SIMPER, all possible pairs of samples were compared using the Bray-Curtis similarity measure. These two analyses were performed using the PAST version 4.0 program. To find these differences in the composition of the ichthyofauna, the specie *Poecilia reticulata* was not considered for this analysis due to a large discrepancy in the data, which could interfere with the results.

To verify how the environmental variables determined the distribution of the species and how the ichthyofauna is related to these variables, the Canonical Correspondence Analysis (CCA) was used, with the significance of the axes tested through an ANOVA for the two axes at a level of significance of  $p < 0.05$  (Oksanen, 2012). To verify the significance at a level of  $\alpha = 0.05$ , 1,000 permutations were performed, which is considered the minimum statistically acceptable (Anderson, 2001). This analysis was performed using the software R environment for statistical computing (R CORE TEAM VERSION 3.6.2, 2019).

## RESULTS

### Environmental characterization

Three types of margins were identified:

1. margins with the presence of riparian vegetation (P1 and P6), considered preserved;
2. margins with less riparian vegetation, presence of shrubs and predominance of grass (P2 and P3), considered with intermediate degree of preservation; and
3. margins with no riparian vegetation and predominance of undergrowth with grasses (P4 and P5), considered degraded.

The determination of the physical and chemical characteristics of the sampled stretches indicated greater variation in the values of conductivity and TDS. The average pH values showed less variation between the stretches. The water temperature ranged from a minimum of 20.5°C to a maximum of 25.3°C, with the stretches with no riparian vegetation on their margins or with less riparian vegetation, which had the highest sampled temperature and lesser degree of shading. The water transparency varied between the stretches, with a lower degree of transparency in the period of intense rainfall, which in this study occurred in the December, January, and February campaigns, in the same way for the largest values of width and depth that showed greater variation in these periods (Table 2).

Regarding the types of margins and environmental variables, the two main axes of the PCA explained 97.49% of the variation between the samples obtained with the means of the nine collections ((Table 3, Figure 2). Axis 1, which explained 91.85% of the total variation, was formed by the conductivity and TDS variables. Axis 2, which explained 5.64% of the variation, was formed by Sun rays% and Silting%, being inversely proportional to Riparian Forest%. The ordering of the samples (Figure 2), in general, showed the relationship of Margin A with the Riparian Forest%, with 3 points being very similar to each other. Margin B did not present variables that were significant to explain this type of margin. Margin C showed the influence of exposed margins, with a greater presence of TDS, due to the presence of sand banks, silting of the margins, and erosion. The result of the significance test indicated a significant value of  $p = 0.0004$ .

### Ichthyofauna

Overall, 50,983 individuals were collected and distributed in 5 orders, 8 families, and 12 species (Table 4). The order Cyprinodontiformes had the highest abundance, with 96.96% of the total number of individuals collected, which comprises 49,437 individuals, followed by Siluriformes (2.39%) with 1,219 individuals; and the sum of the other orders did not reach 1% of the total collected, being 311 individuals for Cichliformes, 16 individuals for Characiformes, and 2 individuals for Gymnotiformes. The ichthyofauna was composed of six species of the order Siluriformes (50%), two

**Table 2.** Average of environmental variables obtained in each sample stretch of both the right (R) and left (L) margins during the nine campaigns.

| Margins | Cond.  | pH   | TDS    | Temp  | Width | Depth | Current. | Transp. | Rocky Bottom | Sandy Bottom | Muddy Bottom | Sun Rays% | Silt% | Rip. Forest% |
|---------|--------|------|--------|-------|-------|-------|----------|---------|--------------|--------------|--------------|-----------|-------|--------------|
| P1-R    | 134.03 | 6.67 | 73.81  | 22.24 | 8.35  | 1.64  | 0.5      | 0.44    | 0            | 1            | 1            | 55        | 50    | 50           |
| P1-L    | 154.5  | 6.74 | 85.37  | 22.35 | 8.35  | 1.49  | 0.5      | 0.5     | 0            | 1            | 1            | 50        | 50    | 75           |
| P2-R    | 130.75 | 6.82 | 71.49  | 22.36 | 9.5   | 1.3   | 0.5      | 0.25    | 0            | 1            | 1            | 100       | 100   | 25           |
| P2-L    | 178.4  | 6.5  | 97.44  | 23    | 9.5   | 1.2   | 0.5      | 0.25    | 0            | 1            | 1            | 100       | 100   | 25           |
| P3-R    | 131.51 | 7.07 | 72.26  | 24.12 | 8     | 1.58  | 0.5      | 0.5     | 0            | 1            | 1            | 50        | 100   | 25           |
| P3-L    | 166.1  | 7.32 | 90.71  | 25.3  | 8.2   | 1.6   | 0.5      | 0.5     | 0            | 1            | 1            | 50        | 100   | 25           |
| P4-R    | 256.41 | 7.46 | 132.38 | 24.62 | 9.15  | 1.55  | 0.5      | 0.5     | 0            | 1            | 1            | 100       | 75    | 0            |
| P4-L    | 417.7  | 6.13 | 228.2  | 23.5  | 8.5   | 1.5   | 0.5      | 0.5     | 0            | 1            | 1            | 100       | 75    | 0            |
| P5-R    | 202.82 | 6.85 | 115.12 | 22.35 | 9.16  | 1.56  | 0.5      | 0.5     | 0            | 1            | 1            | 100       | 75    | 0            |
| P5-L    | 402.35 | 6.6  | 187.65 | 23.4  | 8.8   | 1.2   | 0.5      | 0.5     | 0            | 1            | 1            | 100       | 75    | 0            |
| P6-R    | 134.56 | 6.87 | 73.56  | 20.91 | 10.77 | 0.56  | 1        | 1       | 1            | 1            | 0            | 50        | 50    | 50           |
| P6-L    | 138    | 7.03 | 75.38  | 20.5  | 10    | 1.15  | 1        | 1       | 1            | 1            | 0            | 50        | 50    | 50           |

Cond: Conductivity; ph: Hydrogen potential; TDS: total dissolved solids; water temp.: water temperature; transp.: transparency; silt.: silting; rip. Forest: Riparian Forest. (width, depth, current, rocky bottom, sandy bottom, muddy bottom, sun rays).

**Table 3.** Values obtained from the Principal Component Analysis for each variable: conductivity, pH, total dissolved solids, water temperature, width, depth, current, transparency, rocky bottom, sandy bottom, muddy bottom, sun rays, silting and Riparian Forest, explained by Axis 1 and Axis 2 of the PCA.

|                                   | PCA 1      | PCA 2      |
|-----------------------------------|------------|------------|
| Conductivity                      | 0.87862    | -0.15676   |
| pH                                | -0.00142   | 0.00235    |
| TDS                               | 0.43007    | -0.06365   |
| Water temperature                 | 0.00424    | 0.02135    |
| Width                             | -0.00145   | -0.00042   |
| Depth                             | 0.00030    | 0.00239    |
| Current                           | -0.00053   | -0.00311   |
| Transparency                      | -0.00034   | -0.00506   |
| Rocky bottom                      | -0.00107   | -0.00622   |
| Sandy bottom                      | 3.9839E-55 | 2,8417E-43 |
| Muddy bottom                      | 0.00107    | 0.00622    |
| Sun Rays (%)                      | 0.1418     | 0.53349    |
| Silting (%)                       | 0.01415    | 0.6341     |
| Riparian Forest (%)               | -0.1508    | -0.53301   |
| Eigenvalue                        | 13736.4    | 844.719    |
| Proportion of variance (%)        | 91.85      | 5.64       |
| Significance of the axes (p<0.05) | 0,0004*    | –          |

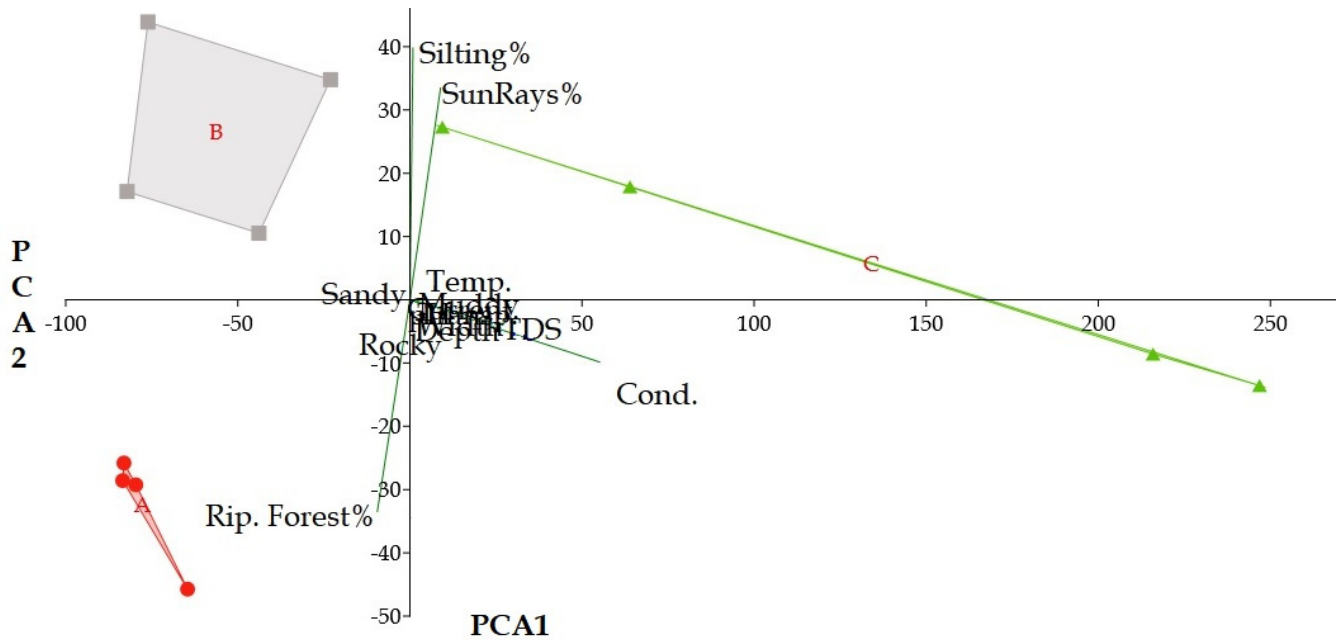
PCA: Principal Component Analysis; TDS: total dissolved solids. \*Refers to significance, because for principal component analysis the significance of the axes was tested at a significance level of 0.05. So values smaller than this indicate that the result was significant.

species of Characiformes (16.66%), two species of Cichliformes (16.66%), one species of Gymnotiformes (8.33%), and one species of Cyprinodontiformes (8.33%). There was no record of species threatened with extinction; according to the ICMBio Red Book of Endangered Brazilian Fauna (2018), the species fall under the low level of concern (LC).

According to each type of local, it was possible to register 11,592 individuals for Margin A, with the occurrence of eight species, two exclusives of this type of margin (*Corydoras flaveolus* and *Hoplosternum littorale*) and three exotic (*Coptodon rendalli*, *Pterygoplichthys ambrosettii*, and *P. reticulata*), the latter being dominant in all types of margins. For Margin B, 19,645 individuals were sampled, with a richness of five species, with no exclusive species of this type of margin, only the same exotic species from Margin A and more tolerant native species such as *Hoplias malabaricus* and *Hypostomus ancistroides*. For Margin C, 19,746 individuals were registered, with the greatest abundance for this type of local, with consequent greater richness, occurring 10 species, three exclusives to this type of bank (*Psalidodon fasciatus*, *Rhamdia quelen*, and *Geophagus brasiliensis*).

The predominance of *P. reticulata*, for all types of margins was high; consequently, the values of diversity were relatively low. Equitability was also low for all stretches due to the dominance of the species, so in general, the sampled stretches showed low values of uniformity (Table 5).

The PERMANOVA indicated significant differences in the structure of the assemblages between the types of margins (p=0.037), indicating variations in the sampled stretches; in addition, this analysis allowed us to confirm the presence of divergent groups. The pairwise comparison (SIMPER) showed that the assemblage structure was different for the types of



PCA: Principal Component Analysis

**Figure 2.** Ordering by Principal Component Analysis of the types of margins sampled from the Sorocaba River using data from physical, chemical, and structural variables. Margin A: stretches 1 and 6, Margin B: stretches 2 and 3, and Margin C: stretches 4 and 5. The variables used in the analysis are identified in Table 3.

**Table 4.** List of species sampled in Margin A, Margin B, and Margin C.

| Táxon                               | Common name | Margin A | Margin B | Margin C |
|-------------------------------------|-------------|----------|----------|----------|
| Characiformes                       |             |          |          |          |
| Characidae                          |             |          |          |          |
| <i>Psalidodon fasciatus</i>         | Lambari     |          |          | 2        |
| Erythrinidae                        |             |          |          |          |
| <i>Hoplias malabaricus</i>          | Traíra      |          | 5        | 9        |
| Siluriformes                        |             |          |          |          |
| Callichthyidae                      |             |          |          |          |
| <i>Corydoras flaveolus</i>          | Coridora    | 2        |          |          |
| <i>Hoplosternum littorale</i>       | Caborja     | 1        |          |          |
| Heptapteridae                       |             |          |          |          |
| <i>Rhamdia quelen</i>               | Jundiá      |          |          | 1        |
| Loricariidae                        |             |          |          |          |
| <i>Hypostomus ancistroides</i>      | Cascudo     | 153      | 450      | 592      |
| <i>Hisonotus depressicauda</i>      | Bagre       | 7        |          | 4        |
| <i>Pterygoplichthys ambrosettii</i> | Cascudo*    | 6        | 1        | 2        |
| Cyprinodontiformes                  |             |          |          |          |
| Poeciliidae                         |             |          |          |          |
| <i>Poecilia reticulata</i>          | Guarú*      | 11,384   | 19,161   | 18,892   |
| Cichliformes                        |             |          |          |          |
| Cichlidae                           |             |          |          |          |
| <i>Geophagus brasiliensis</i>       | Cará        |          |          | 4        |
| <i>Coptodon rendalli</i>            | Tilápia*    | 38       | 30       | 239      |
| Gymnotiformes                       |             |          |          |          |
| Gymnotidae                          |             |          |          |          |
| <i>Gymnotus carapo</i>              | Tuvira      | 1        |          | 1        |

\*Exotic species.

margins, and it is possible to visualize in Table 6 the contribution (%) of each species in the formation of the groups. *H. ancistroides* was the species that most contributed to the formation of the groups, occurring in the three types of margins, however, in greater abundance in Margin B and Margin C. *C. rendalli* was the second species with the greatest contribution, also appearing in the three groups, however, with significant abundance in Margin C. *G. brasiliensis*, *P. fasciatus*, and *R. quelen* were exclusive to Margin C; *H. littorale* and *C. flaveolus* were exclusive to Margin A and there was no exclusivity for Margin B. The other species contributed less to separate the groups.

The CCA explained 92.46% of the variation in the data (Figure 3) the correlation of the environmental variables with the species data. Axis 1, which explained 68.61% of the total variation, was formed by the current, transparency, rocky bottom and Riparian Forest% variables associated with the species *H. littorale*, *C. flaveolus*, *P. ambrosettii*, and *H. depressicauda* that are part of Margin A. Axis 2, which explained 23.85% of the variation, was formed by the conductivity, TDS, muddy bottom, and Sun Rays% variables, associated with the species *R. quelen*, *P. fasciatus*, *G. brasiliensis*, *C. rendalli*, *H. ancistroides*, *H. malabaricus*, and *P. reticulata* that are part of

Margin C. The ordering of the other variables was associated with Margin B, and the species that occurred in this type of margin were exotic and native species that also occurred in the other stretches in greater abundance; thus, they were not important to explain the association of environmental variables with species. The result of the ANOVA significance test indicated a significant value of  $p=0.016$ .

## DISCUSSION

In the environmental characterization, the results showed changes mainly in the surroundings, which reflected directly in the margins, with three conditions of preservation of the riparian zone: preserved (PRE), intermediate preservation (INT) and degraded (DEG). These changes are related to the silting activity in some stretches of the Sorocaba River, carried out in 2019 in addition to the maintenance that is done by the city in the high grass of the margins, deconstructing important habitats for local fauna, especially fish, in addition to the interventions that this river has already suffered, such as the rectification of the canal for the construction of the main access avenue of the municipality.

A relevant detail to be considered when activities related to silting are carried out is that the rivers, in most cases, are not dead, as they present biodiversity, a comprehensive richness of fauna, so that the carrying out of interventions to remove banks sand or dredging has irreversible consequences for countless species, destroying specialized habitats as well as making the environment more homogeneous (Smith et al., 2019). The increase of sand banks formed in the river, with a strong presence of silting, and in most margins, there is less to no vegetation in the surroundings, directly reflects the entry of fine sediments that are carried from other places into the river, thus increasing siltation and erosion rates (Fialho et al., 2008).

**Table 5.** Values of richness (S), abundance (N), species diversity (H') and equitability (J) considering the total value obtained in the nine sampling campaigns.

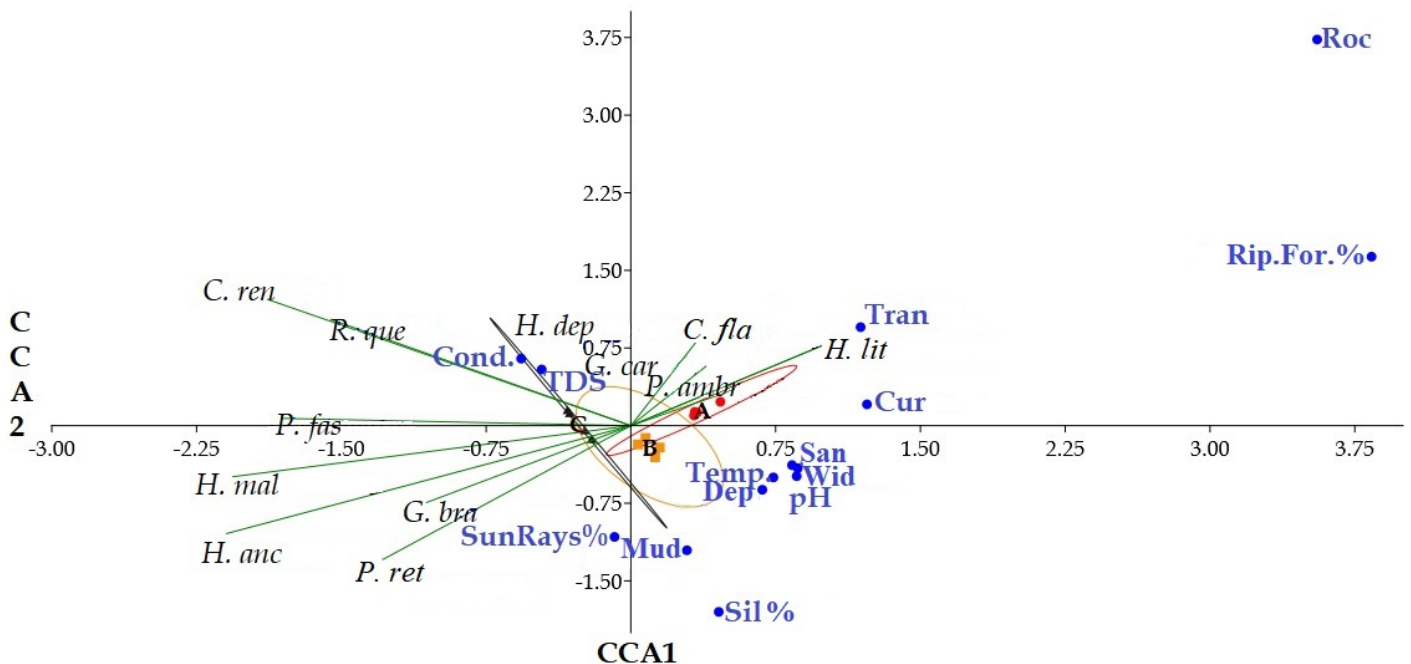
| Points   | Richness (S) | Abundance (N) | Diversity (H') | Equitability (J) |
|----------|--------------|---------------|----------------|------------------|
| Margin A | 8            | 11.592        | 0.1052         | 0.0505           |
| Margin B | 5            | 19.645        | 0.1234         | 0.0767           |
| Margin C | 10           | 19.746        | 0.2107         | 0.0915           |

S: richness; N: abundance; H': species diversity; J: equitability.

**Table 6.** Percentage Similarity Analysis between the types of margins of the fish assemblage of the Sorocaba/São Paulo River.

| Táxon                               | Contribution (%) | Cumulative (%) | Mean Margin A | Mean Margin B | Mean Margin C |
|-------------------------------------|------------------|----------------|---------------|---------------|---------------|
| <i>Hypostomus ancistroides</i>      | 70.44            | 70.44          | 38.3          | 113           | 148           |
| <i>Coptodon rendalli</i>            | 23.45            | 93.89          | 9.5           | 0.75          | 59.8          |
| <i>Hisonotus depressicauda</i>      | 1.57             | 95.46          | 1.75          | 0             | 1             |
| <i>Hoplias malabaricus</i>          | 1.49             | 96.95          | 0             | 0.75          | 2.25          |
| <i>Pterygoplichthys ambrosettii</i> | 1.22             | 98.17          | 1.5           | 0.25          | 0.5           |
| <i>Geophagus brasiliensis</i>       | 0.70             | 98.87          | 0             | 0             | 1             |
| <i>Corydoras flaveolus</i>          | 0.35             | 99.22          | 0.5           | 0             | 0             |
| <i>Psalidodon fasciatus</i>         | 0.25             | 99.48          | 0             | 0             | 0.5           |
| <i>Gymnotus carapo</i>              | 0.24             | 99.42          | 0.25          | 0             | 0.25          |
| <i>Hoplosternum littorale</i>       | 0.17             | 99.9           | 0.25          | 0             | 0             |
| <i>Rhamdia quelen</i>               | 0.10             | 100            | 0             | 0             | 0.25          |





**Figure 3.** Canonical Correspondence Analysis (CCA) carried out between the fish assemblages and the environmental variables together with the sampled types of margins (i.e., Margin A, Margin B, and Margin C), showing the species and environmental variables. The variables used in the analysis are conductivity (cond.), pH, TDS, water temperature (temp.), width (wid.), depth (dep.), current (cur.), transparency (tran.), rocky bottom (roc.), sandy bottom (san.), muddy bottom (mud.), Sun Rays, silting (sil.) and Riparian Forest (Rip. For.), and the species used in the analysis are *Corydoras flaveolus* (*C. fla*), *Hoplosternum littorale* (*H. lit*), *Pterygoplichthys ambrosettii* (*P. ambr*), *Gymnotus carapo* (*G. car*), *Hisonotus depressicauda* (*H. dep*), *Rhamdia quelen* (*R. que*), *Coptodon rendalli* (*C. ren*), *Hoplias malabaricus* (*H. mal*), *Psalidodon fasciatus* (*P. fas*), *Hypostomus ancistroides* (*H. anc*), *Poecilia reticulata* (*P. ret*) and *Geophagus brasiliensis* (*G. bra*).

The pH values remained close to neutrality, with most continental aquatic environments having pH values ranging between 6 and 8 (Libânio, 2010). The high TDS values can be interpreted as evidence of environmental degradation (Gordon et al., 2004), since these environments are highly anthropized. The variations in the concentration of TDS can also be related to the presence of sandbanks for some stretches, in addition to erosion processes. In addition, it can have natural causes such as high rainfall, which carries material from the margins into the water body, such as causing the recirculation of the previously stratified water column and promoting the uplift of particles from the bottom to the more superficial layers (Gastaldini and Mendonça, 2001; Leite, 2012).

The high conductivity values may be associated with the absence of riparian vegetation, with a predominance of undergrowth, waterproofing of the soil and the presence of residences and industries in the areas adjacent to the river, causing an increase in nutrients and concentration of suspended solids from the leaching of the basin, which in periods of rain causes greater erosion and sediment input into the water body (Venturieri et al., 2005; Smith et al., 2018).

The water temperature was more associated with seasonality and in relation to the presence of riparian vegetation, with the highest values obtained for the stretches that had no vegetation. Therefore, the presence or absence of riparian forest directly interferes with the temperature of the aquatic environment, causing several consequences for water resources, making the margins susceptible to erosion, a process that results in silting of the water body and exposes it to solar radiation, with consequent temperature rise (Bastos et al., 2004). Its changes are responses to anthropic and natural activities such as insolation (amount of radiation from the Sun that falls on the surface of the water column) and climate (Libânio, 2010).

Studies of fish-environment interaction in Neotropical regions show that local (physical and chemical) and anthropogenic environmental variables influence aquatic biota, as they control the dynamics and structure of environments by changing the habitat available to the organisms found in it (Tejerina-Garro and Mérona, 2001; Brejão et al., 2021). Regarding environmental variables, those that are among the most affected by anthropic changes include pH, turbidity, water temperature, conductivity, suspended matter and riparian vegetation (Tundisi and Tundisi,

2008; Melo et al., 2009). The locals studied in this work presented distinct limnological variables, which may be probably due to the conditions of the margins, the different types of vegetation and mainly to the use and occupation of the soil in the areas adjacent to the river.

The replacement of riparian forests by shrubs or grasses creates environmental conditions that favour the occurrence of tolerant species (e.g., *H. ancistroides*, *H. malabaricus*, *P. reticulata*), the establishment of exotic species (*P. reticulata*, *C. rendalli*), but still harbours a residual fauna of native and even more sensitive species (e.g., *H. depressicauda*, *C. flaveolus*, *Psalidodon* sp.). This indicates that changes in the fish community can follow a degradation gradient, as observed in the different types of margins in this study, and for several species, the stretches with intermediate preservation represent the limit for their distribution and occurrence. On the other hand, habitat degradation favours other species, with more generalist and tolerant eating habits, capable of exploiting resources and conditions that become abundant in degraded environments (Casatti et al., 2012; Marques and Cunico, 2021).

The most abundant species, i.e. *P. reticulata*, *H. ancistroides*, and *C. rendalli*, are considered tolerant, have greater environmental plasticity, live well in altered environments and have greater homogenization of resources, as was the case of most of the sampled margins. The exotic species found at locals in this work, i.e. *P. reticulata*, *C. rendalli*, and *P. ambrosettii*, can pose serious problems for native ichthyofauna, since the introduction of these species through recreational fishing or aquaculture and aquarium can cause the so-called “anthropogenic homogenization”, making with the species becoming more and more similar and causing the decrease in native species and consequently loss of biodiversity (Souza et al., 2009; Reid et al., 2019), as has been happening in the study section.

Both homogenization and biotic differentiation are processes in which communities are simplified or impoverished over time between different stretches of rivers or urban rivers, mainly due to the replacement of native species and the predominance of non-native species. During this process, native fish species, which are more sensitive, specialist or endemic, are generally replaced by non-native, widely distributed and generalist species, causing a reduction in native species richness and loss of ecosystem functions (Brito et al. 2020; Magalhaes et al., 2020).

The introduction of non-native species is currently one of the biggest problems responsible for the decline and/or even extinction of native species (Garcia et al., 2021). After going through some steps in the invasion process, introduced species can become invasive; if that happens, they are able to change the structure of communities, the functionality of ecosystems and interfere in ecological relationships, such as predation, competition, parasitism, and mutualism (Gallardo et al. 2016). Furthermore, they can hybridize with native species, transmit parasites or diseases, generate socioeconomic

impacts (Pelicice et al., 2017) and cause changes in diversity patterns (Brito et al. 2020).

Biological invasions are among the greatest threats to global biodiversity, and in Brazil, the introduction of non-native fish has become increasingly common. However, the factors related to these processes still lack information, a fact observed for the exotic fish species *P. ambrosettii*, considered one of the most abundant species in the floodplain of the upper Paraná River, its introduction is more widespread, and even thus, there are no studies on its biology and natural history (Nobile et. al., 2018).

It is common to find juveniles of medium and large species, indicating that the margins of a river are important as a place for the initial development of larger species (Súarez, 2008). This study presented a rate of wealth constituted by both small species, such as juveniles of medium and large fish; however in low occurrence, this may be causally related to the dominance of only one species *P. reticulata*, which is resistant to several changes in the environment for presenting greater environmental tolerance (Pinto and Melo, 2012).

Uniformity is a component of diversity that describes variability in species abundance (Magurran, 2004). The low values obtained in the different types of margins indicate a non-uniform distribution, with dominance of one species in question, being *P. reticulata*, making the environment more homogeneous and decreasing the occurrence of other native species. The taxonomic homogenization is evidenced by the greater similarity in the ichthyofauna composition, which (loss and gain of species) is not a random process and can be influenced by the functional traits of the species (McKinney and Lockwood, 1999). In this case, the replacement of more sensitive species by species tolerant to urbanization and environmental changes leads to functional homogenization (Clavel et al., 2011). For example, species of the Poeciliidae family are regularly found in urban rivers around the world (Strecker et al., 2011) in high abundance (Pereira et al., 2014).

The occurrence of species with low abundance or that appeared sporadically may be a combination of the existence of persistent or resident species that are common in different, altered or polluted habitats (Magurran and Henderson, 2003).

The CCA separated the species in relation to each type of margin, and the most important environmental variables for these species, that being said, Margin A, showed the occurrence of exclusive species of this type of habitat, being that *C. flaveolus* and *H. littorale* have preference for sandy and soft substrate to avoid injuries in the barbels of these species, as well as the preference to live close to the margins, under marginal vegetation, where they take refuge to shelter and feed (Reis et al., 2003). The greater occurrence of *H. depressicauda* and *P. ambrosettii* in this type of local can be explained by their preference for environments of running and highly oxygenated water, with rocky or gravel bottom; in addition, they also inhabit the banks of rivers and streams under the marginal vegetation (Reis et al., 2003; Nobile et. al., 2018).

For Margin B, there were exotic species and two tolerant natives being *H. malabaricus* and *H. ancistroides*, inhabiting areas of backwaters in rivers, with preference for the banks and by vegetated ravines, they are species that have great adaptation to the different habitats they inhabit (Smith, 2003; Oyakawa et al., 2006).

For Margin C, there was the greatest abundance and richness of species, considering that they are more resistant species and tolerant to anthropic changes, and three of these species were exclusive to this type of local, *P. fasciatus*, *G. brasiliensis*, and *R. quelen*, who have a sedentary habit and live on the margins, where water flows more slowly, are also generalist species in obtaining food, increasing their ability to survive in these environments (Reis et al., 2003). The other species such as *G. carapo*, *H. malabaricus*, *C. rendalli*, *H. ancistroides*, *P. ambrosettii*, *H. depressicauda*, and *P. reticulata* live well in silted environments, with muddy bottom, absence of riparian vegetation, predominance of grass, high conductivity, and higher incidence of sunlight, favouring these species with different eating habits (Smith et al., 2003; Oyakawa et al., 2006).

The occurrence of these species is caused by either or both: anthropic changes and sediment deposition in the channel bed; and the occurrence is explained by the similar life habit of these species. It should be noted that some species do not occur at the highest speed points, stream, and rock bottom (Súarez and Lima-Júnior, 2009). The result of the many characteristics of habitats, which influence the patterns of composition and diversity of fish communities, such as environmental filters, the availability of resources, and the complexity of habitats (Felipe and Suárez, 2010), are aspects that contribute to installation and development of fish species. Araújo and Tejerina-Garro (2009) and Matos et al. (2013) showed that the structuring and distribution of the fish community may be more associated with the physical and structural characteristics of the environment, favouring the occurrence of species; however, when these are destroyed or altered, more sensitive fish species can be removed locally, contributing to the installation of more tolerant species.

## CONCLUSIONS

We found severe problems related to silting, formation of sand banks and the lack of riparian vegetation, which end up interfering in the structure of the fish community. The three types of margins that occur in the Sorocaba River presented the occurrence of fish, however, with distinct taxonomic characteristics. The tested hypotheses were proven in this study. Finally, the changes identified during the research showed that works such as the desorption that the Sorocaba River went through, in an attempt to reduce the cases of flooding in the city, directly affected the assemblages of fish that live on the margins of that river; even though the Sorocaba River presents good levels of species diversity already mentioned in other studies carried out in the basin, the fish in this study proved to be more homogeneous and with dominance of more tolerant and

resistant species, in addition to the abundance of exotic species, which can compromise the diversity of the composition of fish that inhabit the margins of this river. The present study was conducted to generate information on the composition of species from different types of margins of an urban river, contributing with managers in decision-making to mitigate or avoid changes and impacts that affect the existing fish community. Therefore, more effective protection and recovery law enforcement is also necessary, in addition to environmental education for the population, paramount to the preservation of these environments.

## CONFLICTS OF INTEREST

Nothing to declare.

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## AUTHORS' CONTRIBUTIONS

Soinski, T.: Conceptualization, Data curation, Formal Analysis, Methodology, Project administration, Writing – original draft, Writing – review and editing. Cavallari, D.: Conceptualization, Data curation. Stefani, M.: Conceptualization, Methodology. Pinheiro, P.: Conceptualization, Investigation, Methodology. Smith, W.: Project administration, Supervision, Validation, Writing – review.

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