A stream multimetric fish index in a large-sized city in south-eastern Brazil

Índice multimétrico de peixes de riachos em uma cidade de grande porte no Sudeste do Brasil

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Abstract: Aim: Our study was carried out to develop a multimetric index suitable for urban wadeable streams in Sorocaba, a large-sized city from the Atlantic rainforest in south-eastern Brazil. **Methods:** Twenty-seven stream stretches were selected for environmental and fish evaluation. Twenty ecological metrics were tested over an environmental gradient between the reference and degraded stretches. Candidate metrics were screened for range, responsiveness, and redundancy. We calculated a multimetric fish index (MFI) subdivided into five quality classes: reference ≥ 0.8, 0.6 ≤ good < 0.8, 0.4 ≤ moderate < 0.6, 0.2 ≤ poor < 0.4, and bad < 0.2. **Results:** Four metrics were adequate for discriminating higher biotic quality from degraded stretches. Five stream stretches (18%) were classified as a reference or good, and 16 (60%) were poor or bad. Three reference stretches could be used for a hydromorphological restoration programme. **Conclusion:** Our results indicated that biological integrity was altered, which was indicative of severe environmental degradation. Our study results may be useful for a management and restoration project of the Sorocaba/Médio Tietê hydrographic basin.

Keywords: urban streams; habitat quality; Index of Biotic Integrity.

Resumo: Objetivo: Nosso estudo foi realizado para desenvolver um índice multimétrico adequado para riachos urbanos em Sorocaba, uma cidade de grande porte inserida na Mata Atlântica do sudeste do Brasil. **Métodos:** Vinte e sete trechos de riachos foram selecionados para avaliação ambiental e de peixes. Vinte métricas ecológicas foram testadas em um gradiente ambiental entre os trechos de referência e degradados. As métricas candidatas foram selecionadas quanto à amplitude, capacidade de resposta e redundância. Calculamos um índice multimétrico de peixes (MFI) subdividido em cinco classes de qualidade: referência ≥ 0,8, 0,6 ≤ bom <0,8, 0,4 ≤ moderado < 0,6, 0,2 ≤ pobre < 0,4 e ruim < 0,2. **Resultados:** Quatro métricas se mostraram adequadas para discriminar trechos com maior qualidade biótica daqueles degradados. Cinco trechos de riacho (18%) foram classificados como referência ou bom e 16 (60%) como pobre ou ruim. Três trechos de referência podem ser usados para um programa de restauração hidromorfológica. **Conclusões:** Esses resultados indicaram que muitos aspectos da integridade biológica foram alterados, indicativo de severa degradação. Nossos resultados podem ser úteis para um projeto de gestão e restauração da bacia hidrográfica do Sorocaba/Médio Tietê.

Palavras-chave: riachos urbanos; qualidade do habitat; Índice de Integridade Biótica.

1. Introduction

Stressors can be considered as any physical, chemical or biological parameters or entities that directly or indirectly result in biotic responses of concern (USEPA, 2017). Urbanization can cause perturbations to a system through sewage effluent, channelization, and riparian vegetation reduction. These multiple stressors can make it difficult to determine individual stressor relative importance (Paul & Meyer, 2001; Walsh et al., 2005).

Urbanization-induced changes in water quality and or hydrologic regimes are referred to as urban stream syndrome (Sheldon et al., 2019). The loss of breeding, feeding, and resting habitat can modify the fish community. These mechanistic pathways are not well studied in urban streams (Wenger et al., 2009). The fish assemblage similarity of urban with reference streams, species richness and diversity, proportions of lithophilic spawners fish, and sensitive species decreased with increasing urbanization (Helms et al., 2005; Wang et al., 2001; Morgan & Cushman, 2005). On the other hand, tolerant species, fish with eroded fins, lesions, tumours increased with urbanization (Helms et al., 2005; Morgan & Cushman, 2005). The amount of connected impervious surface may have harsh effects on fish assemblages in the river basin scale, including low fish density, species richness, diversity, and index of biotic integrity (IBI) score (Wang et al. 2001). On the other hand, historical species pool and stream characteristics can shape fish communities, with urbanization playing a rather individual role (Czeglédi et al., 2020).

Biological monitoring can be an essential tool for properly managing water resources, reflecting physical, chemical and biological stream structures (Karr, 1991). The multimetric approach (Karr, 1981) attempts to provide an integrated analysis of the biological community (e.g., species richness, diversity indices, and feeding type composition) into a unitless measure, which can be used to assess an overall site condition (Hering et al., 2006). There is no universal multimetric index (Davis and Simon, 1995). One must consider the intrinsic regional characteristics to select a set of biological variables used to categorize local environmental changes (Omernik, 1995).

Several studies have adapted a multimetric index based on neotropical fish assemblages (Bozzetti & Schulz, 2004; Marciano et al., 2004; Ferreira & Casatti, 2006; Casatti et al., 2009; Esteves & Alexandre, 2011; Casatti et al., 2012; Terra et al., 2013; Santos & Esteves, 2015; Cetra & Ferreira, 2016; Gonino et al., 2020).

The relationships between the fish community and environmental perturbations can be obtained using a multimetric biotic index and physical habitat structure assessment. The structure of the surrounding physical habitat (e.g., canopy cover, riparian vegetation structure complexity, and a measure of disturbance) that influences the quality of the water resource (e.g., substratum mean diameter and stability, large woody debris and proportion of reach composed of pools and riffles) compound the physical habitat structure assessment (Barbour et al., 1999).

Our objective was to develop a multimetric index suitable for urban wadeable streams in the Atlantic rainforest of south-eastern Brazil. We selected fish richness, abundance, trophic structure, and habitat use metrics. We understand how physical habitat disturbances influence different aspects of the fish communities, i.e., which species and or which metrics are correlated with disturbance gradients. By these analyses, we aim to develop a tool to diagnose the urban streams state. The methods used in our study may be helpful in a management and restoration hydrographic basin programme.

2. Materials and Methods

2.1. Study area

This study was conducted in the City of Sorocaba (23°20' – 23°35'S;47°17' – 47°34'W) in the south-east of Brazil, in São Paulo state. The Sorocaba river basin presents intense urban, industrial, and agricultural activity. In the middle of the 17th century, Sorocaba municipality developed along the Sorocaba River. In the second half of the 18th century, several districts already existed. From the 1950s, the river was rectified, and between 1960 and 1990, the pollution from industrial activities was intense. The worst fish mortality occurred in 1978, in which tons of fish perished over a large stretch of the river. Sewage treatment starts at the beginning of the 21st century and gradually recovered the Sorocaba River limnological characteristics (Smith, 2003).

The city of Sorocaba has a total area of 450.4 km², including 355 km² of urbanization. The Sorocaba River passes through the town. Sorocaba is the 32nd largest city in Brazil (5570 counties) and 9th in São Paulo (645 counties) in terms of population size, with an estimated total population of 586,625 (population density 1,304.18 km⁻²) (IBGE, 2010). Sorocaba City has a matrix of forest

patches within the anthropic landscape. Forest covers 17% of the city area, and 60% of the forest patches comprise <1 ha (Mello et al., 2016). The average yearly rainfall within the basin is around 1300 mm, with the most massive fall in the summer. The amount of precipitation and its intensity varies considerably on a seasonal basis, with a drier season occurring from April to August (12 to 22 °C) and a wetter period in September to March (16 to 27 °C). The region is characterized by transitional vegetation between the Atlantic Forest and the Cerrado (Mello et al., 2016).

2.2. Sampling sites

Twenty-seven wadeable stream stretches were investigated during the dry season in 2016 (Figures 1 and 2). Twenty-three stretches were in Sorocaba City and four on the edge of the Floresta Nacional de Ipanema (FLONA-Ipanema), which is without the direct influence of urbanization and are our reference stream stretches. This design created a disturbance gradient that is important in developing a multimetric index (Hughes et al., 1998). The stream stretches measured 3.4 ±1.7 m in width and 26.7 ±21.0 cm in depth (mean ± S.D.).

2.3. Stream stretches classification

To characterize the stream stretches, we used a physical habitat index (PHI) (Barbour et al., 1999). We evaluated the stretches with nine habitat parameters: epifaunal substratum available cover, velocity/depth regime, sediment deposition, channel flow status, channel alteration, frequency of riffles, bank stability, vegetative protection, and riparian vegetative zone width (Table 1). The PHI range classification was: 0 to 45 (poor), 46 to 90 (marginal), 91 to 135 (suboptimal) and 136 to 180 (optimal).

2.4. Fish collection

Seasonal fluctuation of the water level is one of the most important factors influencing the structure of fish assemblages (Rodríguez & Lewis Junior, 1997). The sampling period for the ichthyofauna was the dry season. During this period, connections between the structure of the fish assemblage and the habitat structure are more robust, the effect of temporal variation can be controlled, and sampling is more efficient due to the smaller volume of water and the consequent increase in fish density (Willis et al., 2005; Pease et al., 2012).

We used data from single-pass electric fishing catches (Fame Consortium, 2004) performed using an LR-24 Smith Root backpack between 0800 and 1700 hours without stop nets at the upper and lower stream stretches limits (License no 13352-1 SISBIO/IBAMA/MMA). The ichthyofauna was collected from 70 m stretches representing the range of available mesohabitats, i.e., a repeating sequence of a riffle, pool and run.

Vouchers of the species collected were deposited in the collection of Laboratório de Ictiologia de
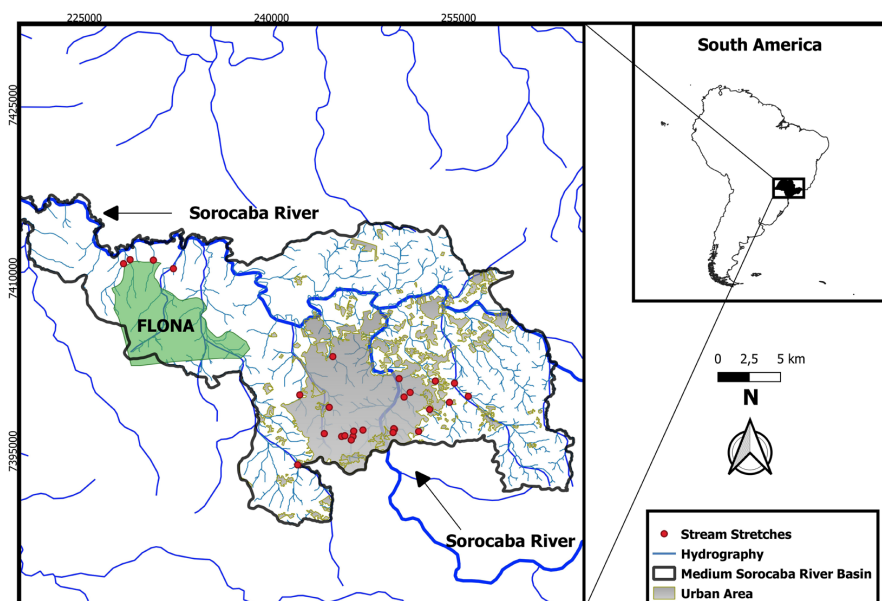

Figure 1. State of São Paulo, Medium Sorocaba River Basin and stream stretches sampled in Sorocaba City and FLONA-Ipanema (Datum SAD 69, UTM 23S).

Figure 2. Representative stream stretches sampled from Sorocaba City.

Sorocaba (LISO-UFSCar-Sorocaba). The specimens were identified by Prof. Dr. George Mendes Taliaferro Mattox (UFSCar-Sorocaba).

2.5. Data analysis

Species were categorized into a trophic group and position in the water column (Casatti et al., 2012) (Table 2). Twenty metrics were considered (Table 3). The metrics were grouped into richness and origin, abundance, trophic structure, and habitat use. The assumption underpinning the species richness and origin category is that environmental degradation will change communities containing many species to simple assemblages dominated by a few species (Barbour et al., 1999). The proportion of exotic species measures the extent to which introduced species have invaded the fish assemblage. The presence of exotic species reflects biological pollution, and generally, these species are more tolerant of degradation of habitat and water quality than the native species and thus may indicate degraded conditions (Barbour et al., 1999). A healthy and stable assemblage will be relatively consistent in its proportional representation. The relative contribution of the populations (*e.g.*, Cyprinodontiformes) to the total fauna is a simple measure of redundancy, and a high level of redundancy is equated with the dominance of a pollution tolerant organism and a lowered diversity.

Trophic structure measures provide information on the balance of feeding strategies. Without relatively stable food dynamics, an imbalance in functional feeding groups will result, reflecting stressed conditions. Insectivores are the dominant trophic guild of most tropical streams (Winemiller et al., 2018). As the invertebrate food source decreases in abundance and diversity due to habitat degradation by urbanization, there is a shift from insectivorous to omnivorous fish species (Barbour et al., 1999). The habitat use category metrics were used to make the index sensitive to stream geomorphology changes resulting from the effects of channelization and dams on habitats required by benthic riffle and water column species.

Candidate metrics were screened for range, responsiveness, and redundancy. First, a principal component analysis (PCA) was used to detect the metrics with low variance. We used a broken-stick model to decide which axes were important and representative. Metrics with a factor loading > 0.6 were rejected. Secondly, a Pearson correlation coefficient (r) significance ($\alpha < 0.10$) was used to examine the responsiveness of the remaining candidate metrics discriminating the minimally and the most disturbing sites based on the PHI. Thirdly, r was used to test redundancy. Pairs of the metrics with strong positive correlations (r > 0.75) were considered redundant. The metrics were then

Table 1. Habitat parameters, condition categories and scores of the sampled streams from Sorocaba City (adapted from Barbour et al., 1999).

Habitat parameter	Condition category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
Epifaunal substratum/ available cover	Greater than 70% of substratum favourable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at a stage to allow full colonization potential (*i.e.*, logs and snags that are not new fall nor transient).	40-70% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substratum in the form of new-fall, but not yet prepared for colonization (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substratum frequently disturbed or removed.	Less than 20% stable habitat; lack of habitat is obvious; substratum unstable or lacking.
Score	20　　19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Velocity/depth regime	All four velocity: depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (Slow is < 0.3 ms^{-1}, deep is > 0.5 m).	Only three of the four regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only two of the four habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by one velocity/depth regime (usually slow-deep).
Score	20　　19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Sediment deposition	Little or no enlargement of islands or point bars and < 5% of the bottom affected by sediment deposition	Some new increase in bar formation, mostly from gravel, sand, or fine sediment; 5-30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand, or fine sediment on old and new bars; 30-50% of the bottom affected; sediment deposits at obstructions, constrictions and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; > 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
Score	20　　19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Channel flow status	Water reaches base of both lower banks, and minimal amount of channel substratum is exposed.	Water fills >75% of the available channel; or <25% of channel substratum is exposed.	Water fills 25-75% of the available channel, and/or riffle substrata are mostly exposed.	Very little water in channel and mostly present as standing pools.
Score	20　　19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Channel alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, *i.e.*, dredging, (greater than past 20 years) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.

Table 1. Continued...

Habitat parameter	Condition category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Frequency of riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally, all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Bank stability (score each bank)	Bank stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; 'raw' areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
Score — Left bank	10 9	8 7 6	5 4 3	2 1 0
Score — Right bank	10 9	8 7 6	5 4 3	2 1 0
Vegetative protection (score each bank)	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs or non-woody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 cm or less in average stubble height
Score — Left bank	10 9	8 7 6	5 4 3	2 1 0
Score — Right bank	10 9	8 7 6	5 4 3	2 1 0
Riparian vegetative zone width (score each bank riparian zone)	Width of riparian zone >18 m; human activities (*i.e.*, parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 m; human activities have impacted zone only minimally.	Width of riparian zone 6- 12 m; human activities have impacted zone a great deal.	Width of riparian zone <6 m: little or no riparian vegetation due to human activities.
Score — Left bank	10 9	8 7 6	5 4 3	2 1 0
Score — Right bank	10 9	8 7 6	5 4 3	2 1 0

selected based on their responsiveness and the applicability to the study area (Casatti et al., 2009; Jia et al., 2013). Proportional variables were arcsine-square root-transformed, whereas other variables were natural log-transformed before analysis.

The core metrics selected varied between different ranges of values. We normalized the core metrics *via* transformation to unitless scores to combine these individual measures into an integrated multimetric index. Each metric result was translated into a value

Table 2. Classification of sampled species according to attributes related to trophic group (alg, algivores; aquins, insectivores with predominance of aquatic forms; car, carnivores; det, detritivores; oni, omnivores; terins, insectivores with predominance of terrestrial forms), position in the water column (ben, benthic; ben/rif, benthic associated with riffles; nek, nekton; nek/bank, nekton associated with stream banks; sur, close to the surface of the water) and origin in the Upper Paraná River system (nat, natives; exo, exotics).

Order/species	Trophic	Position	Origin[a]
Characiformes			
Astyanax lacustris (Lütken, 1875)	oni	nek	nat
Psalidodon bockmanni (Vari & Castro 2007)	oni	nek	nat
Psalidodon fasciatus (Cuvier, 1819)	terins	nek	nat
Deuterodon intermedius (Eigenmann 1908)	terins[b]	nek	nat
Bryconamericus sp.	terins[c]	nek	nat
Hyphessobrycon bifasciatus Ellis, 1911	terins	nek	nat
Serrapinnus notomelas (Eigenmann, 1915)	alg	sur	nat
Prochilodus lineatus (Valenciennes, 1837)	det[d]	ben	nat
Cyphocharax modestus (Fernández-Yépez, 1948)	det	ben	nat
Characidium zebra Eigenmann, 1909	aquins	ben/rif	nat
Hoplias malabaricus (Bloch, 1794)	car	nek/ban	nat
Siluriformes			
Callichthys callichthys (Linnaeus, 1758)	oni	ben	nat
Corydoras aeneus (Gill, 1858)	aquins	ben	nat
Hoplosternum littorale (Hancock, 1828)	oni	ben	nat
Imparfinis mirini Haseman, 1911	aquins	ben/rif	nat
Pimelodella avanhandavae Eigenmann, 1917	aquins	ben	nat
Rhamdia quelen (Quoy & Gaimard, 1824)	aquins	ben	nat
Hypostomus ancistroides (Ihering, 1911)	det	ben	nat
Gymnotiformes			
Gymnotus sylvius Albert & Fernandes-Matioli, 1999	aquins	nek/ban	nat
Cyprinodontiformes			
Phalloceros harpagos Lucinda, 2008	oni	sur	nat
Poecilia reticulata Peters, 1859	det	sur	exo
Synbranchiformes			
Synbranchus marmoratus Bloch, 1795	car	nek/ban	nat
Perciformes			
Australoheros facetus (Jenyns, 1842)	aquins[e]	nek/ban	nat
Crenicichla britskii Kullander, 1982	aquins	nek/ban	nat
Geophagus brasiliensis (Quoy & Gaimard, 1824)	oni	ben	nat
Oreochromis niloticus (Linnaeus, 1758)	oni	ben	exo

[a] Langeani et al. (2007); [b] Abilhoa (2007), [c] Brandão-Gonçalves et al. (2010); [d] Moraes et al. (1997); [e] Fernández et al. (2012).

between 0 and 1 (ecological quality ratio, EQR). The EQR represents the relationship between the values of the biological variables observed for a given stream stretch and the values for these variables under the reference conditions applicable to that stream stretch. The ratio is expressed as a numerical value between zero and one: high ecological status is represented by values close to one and low ecological status by values close to zero (Hering et al., 2006).

We used the 'general approach' to calculate the multimetric index (Hering et al., 2006). In the 'general approach', the metrics results are individually compared to the respective metric values under reference conditions. From this comparison, we scored each metric. The multimetric index was a combination of these scores. The same number of metrics has been selected for each metric category and the final multimetric fish index (MFI) was the mean of the 0–1 digit scores of all core metrics (Böhmer et al., 2004). This range was subdivided into five quality classes using the setting class boundaries (Hering et al., 2006): reference ≥ 0.8, good ≥ 0.6 < 0.8, moderate ≥ 0.4 < 0.6, poor ≥ 0.2 < 0.4, and bad < 0.2.

3. Results

All habitat parameters varied from poor to optimal. Fifty to sixty per cent of the stream stretches had an epifaunal substratum/available cover, velocity/depth regime, riparian vegetative

Table 3. Candidate metrics for the index of biotic integrity and the expected response to an increase in environmental degradation.

Category/candidate metric	Response to environmental degradation
Richness and origin	
Species richness (S)	reduces
Simpson effective number of species (1/D)	reduces
Shannon effective number of species (e^H)	reduces
Proportion of exotic species (Psexot)	increases
Abundance	
Total abundance (*N*)	reduces
Proportion of exotic species abundance (Pnexot)	increases
Proportion of Cyprinodontiformes abundance (PCyp)	increases
Trophic structure	
Trophic categories (Stroph)	reduces
Proportion of insectivores species with predominance of aquatic forms (PSaquins)	reduces
Proportion of insectivores individuals with predominance of aquatic forms (PNaquins)	reduces
Proportion of detritivores species (PSdet)	increases
Proportion of detritivores individuals (PNdet)	increases
Proportion of onivores species (PSoni)	increases
Proportion of onivores individuals (PNoni)	increases
Proportion of insectivores species with predominance of terrestrial forms (PSterins)	reduces
Proportion of insectivores individuals with predominance of aquatic forms (PNterins)	reduces
Habitat use	
Proportion of benthic species (PSben)	reduces
Proportion of benthic individuals (PNben)	reduces
Proportion of nekthonic species (PSnek)	reduces
Proportion of nekthonic individuals (PNnek)	reduces

Table 4. Number of stream stretches by physical habitat index (PHI) parameter classification.

Habitat parameter	Classification			
	Optimal	Suboptimal	Marginal	Poor
Epifaunal substratum/available cover	4	6	12	5
Velocity/depth regime	2	8	6	11
Channel flow status	6	9	10	2
Sediment deposition	9	6	10	2
Frequency of riffles	4	2	15	6
Channel alteration	1	15	11	0
Vegetative protection	6	0	10	11
Riparian vegetative zone width	7	3	6	11
Bank stability	9	4	9	5
PHI	5	6	12	4

zone width and bank stability classified as marginal or poor. Around 75% had a frequency of riffles and vegetative protection classified as poor and marginal. The PHI ranged from 31 (poor) to 170 (optimal). About 60% of the stream stretches were classified as marginal and poor (Table 4).

We collected 2492 individuals. Five stream stretches have no species (Table 5). The total abundance (N) metric was removed because of the low factor loading on PC1, PC2 and PC3. These axes were selected to analyse the range of metrics because they accounted for 76.82% of the total variation (33.09, 31.13 and 12.60%, respectively), higher than the broken-stick model and most metrics had the highest values on these axes. In PC3, the metrics had a load factor> 0.6, so this axis was not analysed. Seven metrics were retained because of the responsiveness test (Table 6).

The proportion of insectivore species with a predominance of aquatic forms (PSaquins) and

Table 5. Species richness and fishes from 27 stream stretches in the Sorocaba City (S) and FLONA-Ipanema (F) of the Medium Sorocaba River basin.

species	S1	S2	S3	S4	S5	S06	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	F23	F24	F25	F26	S27
Astyanax lacustris	X	-	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-	X	-	X	-	X	X	X
Australoheros facetus	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bryconamenricus sp	X	-	-	-	-	-	-	-	X	-	-	-	-	X	-	-	-	-	-	-	X	-	X	-	-	-	X
Callichthys callichthys	-	-	-	-	-	-	-	X	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
Characidium zebra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-
Corydoras aeneus	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Crenicichla britskii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-
Cyphocharax modestus	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Deuterodon intermedius	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-	-	X	X	-	-	-	-	-	X
Geophagus brasiliensis	-	-	X	-	X	-	-	X	X	X	X	-	-	X	-	-	-	-	-	-	X	X	-	-	-	X	X
Gymnotus sylvius	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	X	-	-	X
Hoplias malabaricus	-	-	-	-	-	-	-	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	X	X
Hoplosternum littorale	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Hyphessobrycon bifasciatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
Hypostomus ancistroides	-	-	-	-	X	-	-	X	X	X	-	-	-	X	-	-	-	-	-	-	X	-	X	-	-	X	X
Imparfinis mirini	-	-	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-
Oreochromis niloticus	-	-	-	-	-	-	X	X	-	-	-	-	-	X	-	-	X	-	-	-	-	-	X	-	-	-	-
Phalloceros harpagos	-	X	-	X	X	-	X	X	X	X	X	X	-	X	-	-	X	-	X	-	X	-	X	X	X	-	X
Pimelodella avanhandavae	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-
Poecilia reticulata	-	X	-	-	X	-	-	X	X	X	X	X	X	-	X	-	-	X	-	X	-	X	-	-	X	-	X
Prochilodus lineatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Psalidodon bockmanni	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	X	-	-
Psalidodon fasciatus	-	-	X	-	X	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	-
Rhamdia quelen	-	-	-	-	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-
Serrapinnus notomelas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-
Synbranchus marmoratus	-	-	-	-	-	-	-	X	X	-	X	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-	-
Species richness	3	2	2	1	7	0	1	7	10	13	5	4	0	11	0	0	4	0	3	2	6	6	15	5	2	8	9

proportion of benthic species (PSben) was considered redundant with species richness (S). The proportion of insectivore individuals with a predominance of aquatic forms (PNaquins) was considered redundant with the proportion of benthic individuals (PNben).

Four metrics were finally included in the MFI. They belonged to the categories richness and origin (S), abundance (PCyp), trophic structure (Stroph) and habitat use (PNben) (Table 7). Five streams (18%) were classified as reference or good and 16 (60%) as poor or bad (Table 8).

Five candidate metrics were significantly correlated with the MFI: Simpson effective number of species (1/D, $r = 0.76$), Shannon effective number of species (e^H, $r = 0.82$), proportion of omnivore species and individuals (PSoni, $r = -0.48$ and PNoni, $r = -0.47$) and proportion of insectivores individuals with predominance of aquatic forms (PNaquins, $r = 0.70$).

4. Discussion

Urbanization altered many aspects of fish biological integrity. We found a low EQR (MFI) at 60% of the stretches. Three reference stretches can be used for a physical restoration proposal, such as epifaunal substratum/available cover, velocity/depth regime, riparian vegetative zone width, bank stability, frequency of riffles and vegetative protection. The MFI used four biological variables, and the low number of metrics contributes to a quick and easy biomonitoring process (Gonino et al., 2020). These variables allowed for a differentiation between sites with different impact levels in the urban area. The selected metrics are easy estimates to obtain and proved to be satisfactory for the adaptation of the MFI.

Species richness proved to be an important metric and can be used to infer urban streams biotic integrity. As it is a very intuitive variable (Magurran, 2004), species richness has been widely used to infer ecological systems quality (Roth et al., 2000). The distribution of the number of individuals per species, represented by dominance, was not correlated with environmental degradation despite being a helpful indicator of changes in the stream fish biotic integrity (Terra et al., 2013). On the

Table 6. Minimum (Min), maximum (Max), mean and coefficient of variation (CV) of the candidate metrics (see Table 3) for the multimetric fish index (MFI). Range and responsiveness significance: PCA metric loadings (PC1 and PC2) and Pearson correlation coefficient with PHI (PHIr).

	Min	Max	Mean	CV	PC 1	PC 2	PHIr
S	0	15	5.73	0.69	0.83	-	0.48
1/D	1	6.87	2.55	0.63	0.77	-	-
e^H	1	8.38	3.23	0.65	0.82	-	-
Psexot	0	50%	15%	1.14	-	0.79	-
N	4	977	113.27	1.92	-	-	-
Pnexot	0	33%	10%	1.22	-	0.76	-
PCyp	0	100%	46%	0.92	-0.66	0.70	-0.46
Stroph	1	6	3.27	0.42	0.84	-	0.36
PSaquins	0	38%	11%	1.23	0.78	-	0.51
PNaquins	0	70%	9%	2.15	0.61	-	0.44
PSdet	0	50%	20%	0.81	-	0.67	-
PNdet	0	31%	13%	0.88	-	0.67	-
PSoni	0	100%	44%	0.54	-0.67	-	-
PNoni	0	100%	51%	0.58	-0.65	-	-
PSterins	0	50%	18%	1.00	-	-0.66	-
Pnterins	0	94%	26%	1.24	-	-0.87	-
PSben	0	60%	26%	0.88	0.66	-	0.55
PNben	0	73%	17%	1.26	0.71	-	0.58
PSnek	0	100%	27%	1.06	-	-0.82	-
PNnek	0	100%	33%	1.13	-	-0.88	-

Table 7. Multimetric fish index (MFI) metrics (see Table 3) and class boundaries for Sorocaba City streams.

Metric	Reference	Good	Moderate	Poor	Bad
S	> 11	9 to 10	6 to 8	3 to 5	< 2
PCyp	< 10%	10 to 30%	30 to 45%	45% to 70%	>70%
STroph	> 5	4	3	2	1
Pben	> 70%	40 to 70%	30 to 40%	20 to 30%	< 20%

Table 8. Detailed descriptions of stream multimetric fish index (MFI) with ecological quality ratio (EQR) values and number of streams by category (n).

Categories	MFI	Description	n
Reference	≥ 0.8	Above eight species, low proportion of Cyprinodontiformes, more than four trophic groups, and high abundance of benthic species	3
Good	≥ 0.6 < 0.8	Above eight species, low proportion of Cyprinodontiformes, more than four trophic groups, and moderate abundance of benthic species	2
Moderate	≥ 0.4 < 0.6	Species richness of six to eight species, moderate abundance of Cyprinodontiformes, up to three trophic groups, and presence of benthic species	6
Poor	≥ 0.2 < 0.4	Species richness around four species, moderate to high abundance of Cyprinodontiformes, up to two trophic groups, and low presence of benthic species	5
Bad	< 0.2	Species richness up to two species, high abundance of Cyprinodontiformes, one trophic group, low presence of benthic species or repeated samplings without catching any fishes	11

other hand, Bozzetti & Schulz (2004) and Esteves & Alexandre (2011) verified that low IBI scores and diversity indices reflected environmental degradation. The proportion of exotic species was not a good metric. It was not correlated with MFI, possibly due to the capture of only two species that may have caused a low gradient of values capable of indicating biotic integrity.

The proportion of Cyprinodontiformes abundance (PCyp) is relevant in the lower biotic integrity stream classification. In this order, we captured two species, a native *Phalloceros harpagos* Lucinda, 2008 and an exotic *Poecilia reticulata* Peters, 1859. *Poecilia reticulata* is characterized by its small size, wide geographical distribution, and large capacity to live in low environmental quality environments (Casatti et al., 2009; Cunico et al., 2006). Esteves and Alexandre (2011) selected the abundance of *Astyanax lacustris* as a metric to compose the IBI. This species was more

abundant in impaired urban sites than less degraded sites.

Trophic specialization is not a feature of tropical fishes (Abelha et al., 2001). We identified six types of eating habits. These six types of eating habit have allowed us to obtain a range that can detect reference and good or bad biotic integrity. Streams with many eating habits reflect the amplitude of food chain levels and trophic relationships (Uieda et al., 1997; Casatti et al., 2006). In developing an IBI based on fish communities to assess the effects of rural and urban land use on a Paraná River basin stream, Esteves & Alexandre (2011) selected richness of insectivore and detritivore-algivore species that increased with environmental quality.

The contribution of insectivores may reflect food availability and not food specialization (Abelha et al., 2001). The increase in proportional insectivores contribution that feeds predominantly on aquatic insects is related to greater biotic and environmental integrity environments (Cetra & Ferreira, 2016). Marciano et al. (2004) indicated some degree of degradation using the abundance of invertivores in third-order streams in the Sorocaba river basin using an IBI composed of richness, total abundance of the species, intolerance, and trophic guilds. On the other hand, omnivores representing more generalist species in the food chain were not part of the MFI. This group is not statistically correlated with physical stream integrity but is negatively correlated with biotic integrity. Therefore, high values of the proportion of omnivorous individuals and species represent low biotic integrity.

Ferreira & Casatti (2006) verified that habitat structure measured by a PHI index influenced the stream biotic integrity assessed by fish assemblages in the Upper Rio Paraná basin. The low physical integrity of urban streams caused by fine sediments entry gives rise to the loss of substratum-associated habitats complexity. This situation can reduce surface water and groundwater exchange and potentially decrease the hyporheic zone size and function (O'Driscoll et al., 2010). In this sense, the increase in the proportion of benthic individuals is a metric that indicates good biotic integrity. Casatti et al. (2012) recorded in streams with riparian zone preserved an ichthyofauna with specialized habits, notably benthic insectivores, intolerant, and rheophilics. Santos & Esteves (2015) verified that the IBI successfully detected the effects of different riparian conditions on stream fish fauna, suggesting the riparian zone was essential to maintaining ecosystem integrity in the intensively managed sugarcane areas.

Initial stream restoration records were collected in the 19th century in the U.S.A., Germany, and Norway with fishing records (Roni & Beechie, 2013). There are no physical stream restoration projects in urban areas in Brazil. Strategies for restoration in urban streams for many years have not solved problems related to excess sediment, loss of riparian vegetation and habitat diversity structures (Wenger et al., 2009). The catchment level restoration approach seems to be the most efficient as it has an ecosystem approach (Roni & Beechie, 2013). Therefore, we propose adopting this MFI as an indicator of the effect of a more holistic restoration, and we believe in the success of this approach as we have found streams around the city with good environmental and biotic quality (Gonino et al., 2020).

Acknowledgements

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