VOLUME 2 ISSUE 1 2022

INTERNATIONAL JOURNAL OF BIOLOGICAL AND ENVIRONMENTAL INVESTIGATIONS

Forum for Biological and Environmental Sciences

Published by Saran Publications, India

International Journal of Biological and Environmental Investigations Vol. 2, No. 1, 01-18 (2022)

International Journal of Biological and Environmental Investigations
Contents available at Journals Home Page: www.ijbei.net
Editor-in-Chief: Prof. Ajai Kumar Srivastav
Managing Editors: Dr. Abhishek Kumar & Dr. Abhai K. Srivastava
Published by: Saran Publications, Gorakhpur, India

ISSN: 2583-1690

Environmental Assessment Through the Biotic Integrity Index of Guaíba Lake, Rio Grande do Sul, Brazil

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Received: 2nd January, 2022; **Accepted:** 18th January, 2022; **Published online:** 2nd February, 2022

https://doi.org/10.33745/ijbei.2022.v02i01.001

Abstract: This work aimed to test an adaptation of the Biotic Integrity Index (BII) of in fish assemblages in the environmental monitoring. The fish samplings were standardized and performed seasonally during two years, using seine nets in eleven points of the hidrographic basin of Guaíba lake, Brazil. The results showed that the analyzed points were rated as regular or poor in terms of quality. The scores obtained by BII for the points Gasômetro and B. Ribeiro contradict the results obtained by main components analysis with physico-chemical parameters of the water. The parameters that most influenced the BII results for the points to be rated as fair in terms of quality were the species richness, the number of individuals, the percentage of individuals infected with black spot disease and the percentage of individuals with morphologic alterations. This paper discusses the fragility of the calculation method used to establish the categories of best, medium and low quality. These data demonstrate that other factors may be contributing to the water quality decrease. This study indicated the need to use more than one methodology as an instrument of the environmental quality evaluation.

Keywords: Environmental monitoring, Fish, Biotic Integrity Index, Physico-chemical parameters

Citation: Fábio Flores-Lopes and Ana Cristina Shilling: Environmental assessment through the Biotic Integrity Index of Guaíba Lake, Rio Grande do Sul, Brazil. Intern. J. Biol. Environ. Invest. 2(1): 01-18, 2022.
https://doi.org/10.33745/ijbei.2022.v02i01.001

Introduction

Environmental monitoring programs, to understand the causes of pollution, quantify the trends in the level of contaminants and how they enter the atmosphere and in aquatic and terrestrial habitats (Pearce and Despres-Patanjo, 1988). Araújo (1998a) pointed out that human activities lead to a decrease in water quality, a decrease in the diversity of biological communities and a deterioration of the environment, which has led to the need to develop methods for assessing environmental quality.

Biotic Integrity represents the ability of biological systems to function, maintain and develop in the face of anthropogenic disturbances (Lyons *et al.*, 1995). Biotic Integrity Index (BII) has been considered an interesting quantitative tool for environmental analysis (Lyons *et al.*, 1995). According to Karr (1981), the Biotic Integrity

Index is ecologically based multimetric index for assessing the biological quality of surface waters using biotic attributes that vary from individual health to properties at the ecosystem level. The index represents the capacity of maintenance and support of biological communities preserving their composition, diversity functional structure comparable to the natural characteristics of the region, or minimally disturbed by human actions (Karr, 1981).

According to Machado *et al*. (2011), the Biotic Integrity Index has been applied in many regions of the world-- USA (Karr, 1981), Europe (Oberdorff and Hughes, 1992), India (Ganasan and Hugges, 1998), Africa (Toham and Teugeks, 1999), Central America (Lyons *et al*., 1995), South America (Rodríguez-Olarte *et al*., 2006), and New Zealand (Joy and Death, 2004), as a way to analyze the environmental impacts in aquatic communities and the objective of assessing the biological quality of surface waters using biological attributes ranging from individual health to properties at the ecosystem level.

The use of multimetric indices with the objective of monitoring the biological condition of reservoirs, according to Terra and Araujo (2011), is an approach little applied, reflecting the difficulty of applying such indices in artificial systems related to rivers.

Huglhes and Oberdorff (1998) pointed out that the index is based on the structure of the fish assembly and has been used worldwide to assess the condition of the fish assembly. Cetra and Ferreira (2016) demonstrated the relationship between the environmental quality of streams and the biological integrity of fish assemblages. These authors commented that several aspects of biological integrity are changed, but there are environments that can be used as a biological reference. Bozzetti and Schulz (2004) pointed out the feasibility and usefulness of BII adaptations in tropical or subtropical regions.

Biotic integrity was defined by Karr and Dudley (1981) as the ability of the environment to sustain and maintain a balanced community of organisms, integrated and adjusted, with a species composition, diversity and functional organization comparable to that of the region's natural habitat. Karr *et al*. (1986) pointed out that the great advantage of using the Biotic Integrity Index is the ability to integrate several ecological attributes, avoiding the selection of a certain isolated criterion that can result in less reliable diagnoses than the set of measures. The index was considered adequate by Karr and Dudley (1981) in order to identify the capacity of an environment to resist and maintain a diverse community with a functional organization comparable to that of a natural regional habitat. Cooper *et al*. (2018) demonstrated that biotic indicators are useful for assessing ecosystem health because the structure of resident communities generally reflects abiotic conditions integrated over time. According to Ruaro and Gubiani (2013) and Simon and Evans (2017), the index emerged as an effective tool to monitor the health of the aquatic ecosystem.

According to Karr and Dudley (1981), the Index of Biotic Integrity was prepared using parameters (such as taxonomic wealth, habitat guilds and trophic guilds) that encompass structural and functional characteristics of organisms or fish communities in small streams in the north-central United States. The indices offer more comprehensive assessments than other biotic indicators based only on species richness, diversity indices, indicator species or multivariate analyzes (Verdonschot, *et al*. 2000), and are widely accepted as monitoring tools.

The way of assessing the integrity of environments, according to Hughes (1995), has used multimetric parameters, which aim to combine attributes that represent the wide ecological diversity existing at different levels of biological organization, always having the characteristic of comparing them with a condition of reference. The metrics were designed primarily for the purpose of detecting, rather than diagnosing, human impacts. Biotic integrity indexes measure the difference between the conditions observed and those expected in natural conditions (Costa and Schulz, 2010). For these authors, the use of specific metrics prevents the application of a common BII in different regions of Brazil and decreases the comparability of results. Gonino *et al*. (2020) stated that multimetric indices are considered a fast and low cost means of assessing ecological integrity in streams. Bozzetti and Schulz (2004), Costa and Schulz (2010), Cetra and Ferreira (2016) and Andrade *et al*. (2019), pointed out that changes were made to the metrics of the Biotic Integrity Index used in order to assess the structure of the fish community and the environment.

Angermeier and Davideanu (2004) stated that the fish community is an excellent indicator of ecosystem health and that water is commonly used to assess the quality of rivers. Galuch (2007) highlighted the importance of emphasizing that fish are present both conserved and polluted ecosystems. Berge and Dahl-Hansen (2005) pointed out that fish are considered as the main elements of biological quality to be used to assess the ecological status of a river. Ichthyofauna, according to Ferreira (2010), has a high species richness, low dominance, absence of exotic species and a high contribution of alien items (seeds, fruits and terrestrial arthropods) in the diet of their fish. The fish community, according to Karr *et al*. (1986), has as an advantage, a high position in the trophic chain, its populations are relatively stable, has the potential to integrate various aspects of the habitat at multiple scales and allows a temporal assessment of the conditions of the stream.

Andrade *et al*. (2019) pointed out that Lake Guaíba is located in the metropolitan region of Porto Alegre, being the main source of water supply in the state capital. It is a navigable connection channel between the interior of the state and the sea, as it connects the rivers (to the north) to Laguna dos Patos (to the south). According to Morandi and Bringhenti (1997), it receives a large amount of pollutants from animal husbandry, rice cultivation systems and domestic and industrial wastes through its tributaries.

Terra and Gonçalves (2013) and Andrade and Giroldo (2014), pointed out that the waters presented variations in quality, with greater damage in marginal areas, where less dispersion of pollutants occur. According to them, several studies in the Guaíba Lake Basin point to changes in the concentrations of macronutrients (mainly phosphorus) and metals, reflecting in the reduction of dissolved oxygen and in the increase of environmental toxicity.

Londe *et al*. (2014) stated that pollution and degradation of water resources are recurrent realities of accelerated demographic growth, especially in metropolitan regions, directly and indirectly affecting populations. These authors further stated that the degradation process was a consequence of the intense population growth in Porto Alegre and cities in the region. Figueiredo *et al*. (2010) demonstrated that "the most important problem is that the population that lives in the rio dos Sinos Basin recognizes industrial development as the only way to visualize progress". Andrade *et al*. (2019) pointed out that despite the great importance of Lake Guaíba, there is a history of contempt for its quality. Several studies addressing the environmental issues were carried out in this environment, and none of the monitoring works on Lake Guaíba used the Biotic Integrity Index (BII) as an assessment tool.

This work aimed to-- (a) use an updated version of the multimetric Biotic Integrity Index (BII), adapted to the environmental reality of the Guaíba Lake basin; (b) evaluate its importance as an environmental assessment tool; (c) compare its results with the environmental quality data to verify any influence; and (d) to verify the occurrence of probable alterations due to the modification of the water quality.

Materials and Methods

Lake Guaíba is one of the most important water body in the state of Rio Grande do Sul, Brazil, supplying the city of Porto Alegre and neighboring municipalities, reaching 2,000,000 inhabitants. The Guaíba Lake basin has an area of 85,950 km^2, which means 30% of the Rio Grande do Sul area (Fepam, 1992), with 80% of GDP and 70% of the state's population (Emater, 1991). The lake receives a large amount of domestic and industrial waste from different sources, either directly or through its main tributaries (Gravataí, Sinos and Caí rivers).

Samples were collected in four seasons from December 2002 to October 2004 at eleven sampling points (Fig. 1). According to the location, six points were on Lake Guaíba [Pt.1 - Gasômetro, municipality of Porto Alegre (30° 02\` 06.3 ”S and 51° 14\` 29.3” W); Pt.2 - Saco da Alemoa, Eldorado do Sul municipality (29° 59\` 15.6 ”S and 51° 14\` 24.1” W); Pt.3 - Foz do Celupa, Guaíba municipality (30° 06\` 10 ”S and 51° 18\` 42.4 ”W); Pt.4 - Praia da Alegria, municipality of Guaíba (30° 08\` 28.7” S and 51° 18\` 53.4 ”W); Pt.5 - Barra do Ribeiro , municipality of Barra do Ribeiro (30° 17\` 11.4 ”S and 51° 18\` 01” W), and Pt.6 – Praia de Ipanema, Porto Alegre municipality (30° 08\` 03 ”S and 51° 14\` 07” W)] and five locations on three tributary rivers. Of these five locations, two were on the Caí river [(Pt.7 - near the BR 386 bridge (29° 49\` 22.6 ”S and 51° 21\` 00” W); and Pt.8 - Morretes, near at the mouth of the Jacuí river (29° 55\` 43.9 ”S and 51° 17\` 13.8” W), both in the municipality of Nova Santa Rita], one on the Sinos river [Pt.9 - next to the bridge of BR 386 (29° 52\` 36.5 ”S and 51° 14\` 35.4” W)], two on the Gravatí river [Pt.10 - Gravatí RS 118 (29° 57\` 43.7 ”S and 51° 00\` 09 ”W), and Pt.11 - Passo das Canoas (29° 57\` 25.7” S and 51° 00\` 23.2 ”W), both in the municipality of Gravataí] (Fig. 1).

Fish specimens were collected using a trawl (15 m long x 1.5 m wide; 0.5 cm mesh) (Malabarba and Reis, 1987). At each site, a 15 meter long and 4 meter wide siege was used 4 times near the coast. The collected specimens were preserved in 10% formalin. In the laboratory, the material was screened, identified at the species level according to Malabarba (1989) and preserved in 70% alcohol. Some specimens were sent to specialists at the Zoology Museum of the Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS) for identification. Part of the analyzed material was deposited in the scientific collection of the Universidade Federal do Rio Grande do Sul (UFRGS). Due to the fact that it is very difficult to observe a sample point without any environmental change, the choice of the reference site followed Pinto and Araújo (2007), who used the least environmentally disturbed point as a landmark.

Candidate metrics:

Seventeen metrics were tested-- (1) number of native species; (2) species richness; (3) number of individuals of intolerant species; (4) number of individuals of tolerant species; (5) percentage of territorial species; (6) percentage of scraper bottom; (7) percentage of species with parental care; (8) number of species of Characiformes; (9) number of Siluriform species; (10) number of individuals; (11) percentage of carnivores; (12) percentage of omnivores; (13) percentage of invertivores; (14) nektonic; (15) benthic; (16) percentage of individuals with black spot disease and (17) proportion of individuals with disease or anomaly. The data obtained by the test allowed to verify that the adaptation of the metrics was necessary due to the differences in the composition of the fish communities found in the two environments, since changes were observed in the item used in the initial BII, such as the occurrence of some species and the absence of others. The choice of metrics was based on the fact that they have low variability between samples, which avoids redundancy of information and allows better responses to environmental variations.

The attribute number of native species, originally proposed by Karr (1981), was not used in this study, because the knowledge of freshwater species in Rio Grande do Sul is still incomplete. According to Becker *et al.* (2012), Rio Grande do Sul has 262 described species of freshwater fish, and that in addition to this number, there are still just over 60 known species to be described (Reis

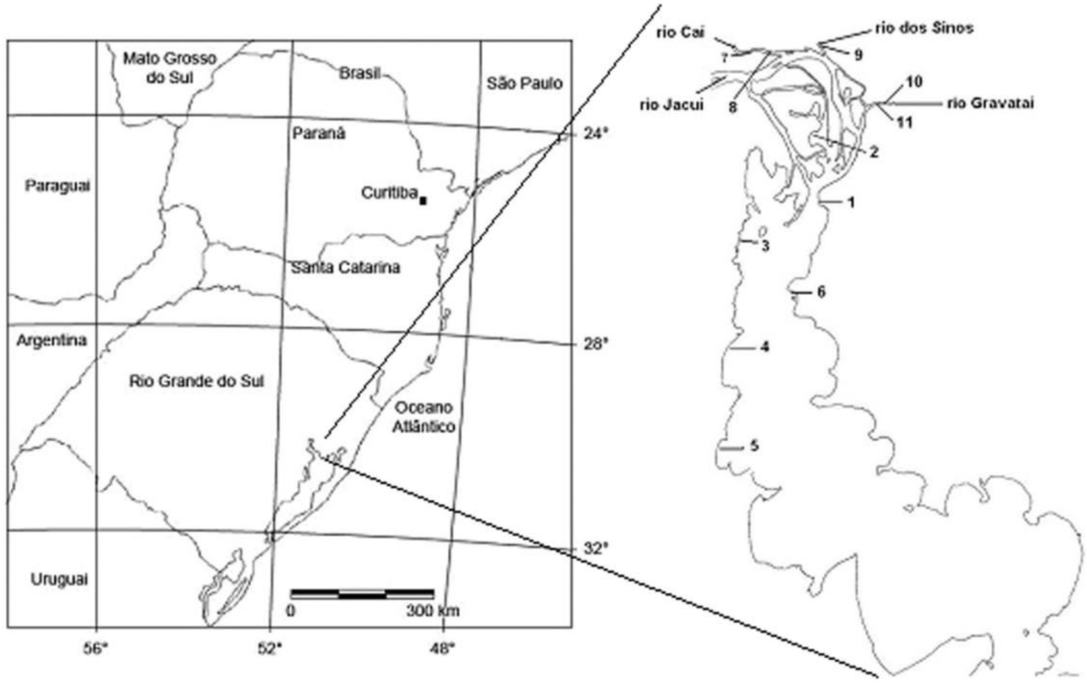

Fig. 1: Map of the State of Rio Grande do Sul (Brazil) and, in detail, the Guaíba lake basin showing the flowing rivers and sampling sites. (1) Gasômetro, (2) Saco da Alemoa, (3) Foz do Celupa, (4) Praia da Alegria, (5) Barra do Ribeiro, (6) Praia de Ipanema, (7) Caí, (8) Caí-Jacuí, (9) Sinos, (10) GravataíRS118 and (11) GravataíPC (Flores-Lopes and Thomaz, 2011).

et al., 2003). The metric "Number of intolerant sps", although very important, was not used due to the lack of available knowledge about the species in the Lago Guaíba Basin.

In a study on the Laguna dos Patos System, Malabarba (1989) presented a historical review and a list of 106 species of native freshwater fish. Since then, several species have been described for the region (Malabarba and Weitzman, 2003), reaching 121 species currently known for this environment (Reis *et al*., 2003). According to Becker *et al*. (2012) this number does not include occasional visitors and seasonal species that are part of their life cycle in a marine or estuarine environment. For these authors, the occurrence of exotic species is considered very rare in the Guaíba Lake watershed.

The metric "Species richness" was used without modifications, being considered important due to the assumption that a healthier environment has a greater number of species and a greater diversity index than a degraded environment (Bruschi Jr. *et al*., 2000; Flores-Lopes *et al*., 2010). The metric "The number of individuals of intolerant and tolerant species" was not used, since the knowledge about the tolerance of neotropical species to different environmental factors that may influence environmental conditions is still insufficient.

The metric "Percentage of species with parental care" was used based on the fact that in better quality environments it is possible to observe a higher occurrence of species with this type of behavior than in lower quality environments. Although this resource is not used as a metric at BII, Irz *et al*. (2008) and Winemiller and Rose (1992) suggest that it is an important feature of life history strategies and may show responses to anthropic disorders. The "number of species" was the metric selected due to the fact that these groups comprise most of the species present in the ichthyofauna of rivers and streams in South America, their importance and meaning, behavior, function, etc. and a wide variety of life forms and habits (Reis *et al*., 2003, Menezes *et al*., 2007).

The metric "Number of Individuals" was used assuming that in most of the preserved environments, a smaller number of individuals is observed than in the impacted environments (Bruschi, Jr. *et al*., 2000; Flores-Lopes *et al*., 2010). Bruschi Jr. *et al*. (2000) stressed that the most impacted environments, a larger number of individuals of generalist species is normally observed in relation to the others. The metrics "percentage of carnivores", "percentage of omnivores", "percentage of invertivores" were used because the dominance of these species presumably grows as a result of degradation in the food base, especially invertebrates. As a result, their opportunistic foraging ecology makes them more successful compared to more specialized foragers (Karr, 1981). The presence of native carnivores is an indication of a healthy lotic environment, since these fish depend on a complex trophic structure. With the decrease in water quality in the system, native carnivorous species tend to decrease or even disappear. The classification of eating habits of species occurring in Lake Guaíba for this study followed the data available in the literature and on the site fishbase.com.

The "nektonic" and "benthic" metrics were not used, as there was no in-depth knowledge including fish species in this group and with these characteristics. It was also considered that some species of Characiformes and Siluriformes are benthic and that some species can travel to the surface to feed, which could cause misinformation for the calculation of the BII. The metric "Percentage of individuals with black spot disease" was used according to Marcogliese and Cone (1997), in which parasites can be important for verifying environmental quality based on the assumption that they need a healthy environment to perform their development generally within more than one intermediate host, as in degraded environments they cannot complete their life cycle because they do not have these hosts or even the final host (Overstreet, 1997). The data observed by Flores-Lopes and Thomas (2011a) were used to calculate the BII.

The percentage of individuals with anomalies and diseases was used with adaptation of the BII since the occurrence of individual changes in diseases is associated with the presence of a stressor in the water (Flores-Lopes *et al*., 2001, 2002, 2019, 2020; Flores-Lopes and Reuss-Strenzel, 2011; Paulo *et al*., 2012, 2020). The metrics were divided into five categories: composition and species richness, abundance, trophic guilds, position in the water column and health.

Metric scoring and index construction:

According to Karr *et al*. (1986), Ganasan and Hughes (1998), Bozzetti and Schulz (2004) and Terra and Araújo (2011), the metric scoring criteria for the BII were based on the highest or lowest scores observed in our samples, since not minimally disturbed, the data was available on the reference site.

In this study, the method proposed by Karr (1981) was adopted to obtain the results of the BII, which uses scores 5 (best quality), 3 (medium quality) and 1 (low quality). The scores were obtained by subtracting the maximum and minimum values obtained for each parameter. The result was divided by three to establish the categories (Karr *et al*., 1986; Araujo, 1998a, b). For the attributes that indicate better environmental quality, the highest values correspond to 5, the intermediate ones correspond to 3 and the lowest ones to 1. For the attributes that indicate worst environmental quality, the lowest values correspond to 5, the intermediate values to 3 and the highest to 1. One result was published for each metric and through the sum of all published data the final BII result was obtained. This score produces a BII ranging from 0 to 55. In this study, the following integrity classes were established, based on those used by Araújo (1998a)-- excellent (50-55), good (41-49), fair (36-40), poor (25-35), very poor (<24) and no fish (0).

BII validation:

In order to evaluate the BII, Flores-Lopes and Reuss-Strenzel (2011) compared the results obtained and the data from the Integrated Quality Index (IQI) and the physical-chemical analysis of the water used in the same points. These authors obtained results for the parameters of temperature, pH, BOD_5, O_2 and thermotolerant coliforms, and the Integrated Quality Index was not performed. The data were compared to perform an assessment of the spatial and temporal behavior of the data.

Data analysis:

Non-metric multidimensional scaling (NMDS) based on Bray-Curtis distance was used to verify the presence of structure in the data as a function of species composition. This technique allows visualizing the relationships between the fish communities by generating a two-dimensional graph that shows the relationships between the sampling points. Principal Component Analysis (PCA) was used to detect metrics with a low variance.

Results

53,408 specimens of fish were captured, 24,020 in Guaíba Lake and 29,388 in the three tributaries (Caí, Sinos and Gravataí rivers), resulting in a total of 66 species belonging to 8 families and 22 orders (Table I). Of the identified species, 52 were observed in Guaíba Lake and 58 in the tributaries. The analysis of the ichthyofauna composition showed that the most abundant orders were Characiformes (43%), Siluriformes (30%) and Perciformes (14%). The most abundant families were Characidae (29%), Loricariidae and Cichlidae (12%) and the most abundant species were *Cheirodon ibicuhiensis* Eigenmann, 1915 (21.7%), *Astyanax* aff. *fasciatus* (Cuvier, 1819) (20.5%), *Hyphessobrycon luetkenii* (Boulenger, 1887) (15.5%) and *Corydoras paleatus* (Jenyns, 1842) (11%). The points with the highest percentage of individuals were Gravataí PC (31%), Gasômetro (23%), Gravataí RS118 (11%) and S. Alemoa (10%).

The results showed that the Praia da Alegria and Praia de Ipanema points were considered to be of poor quality because they have lower BII averages and the Gravataí PC point was considered to be of good quality because they had a higher average. Below-average values were observed between the Gasômetro and P. Ipanema points, ranging from 30.6 at the Saco da Alemoa point and 22 at point P. Ipanema, resulting in a poor rating on all of these points. Among the points Caí-Jacuí and Gravataí PC, higher values were found for the BII average, which ranged from 32 at the Sinos point to 42 at the GravataíPC point (Table 2; Fig. 2). When the BII values were related to seasonality, similar results were observed in all seasons, and in some places there was little variation. At the Gasometer and Caí-Jacuí points, the highest values were observed in the spring and summer, respectively, and at the Sinos and Gravataí RS118 points, the lowest values were observed in the winter and autumn, respectively.

The NMDS analysis showed the formation of three distinct groups, which showed greater similarity in the points. One of the groups was formed by the Foz do Celupa, Praia da Alegria, Barra do Ribeiro, Ipanema and Sinos points; and the Foz do Celupa and Praia da Alegria points were the points with the highest stress values (Fig. 3). The Praia da Alegria and Praia de Ipanema points were classified as very bad and the others were classified as bad by BII. A second group was formed by the points Gasômetro, Saco da Alemoa, Caí-Jacuí and Caí, all classified as bad by BII, and a third group was formed by the points Gravatai RS118 and Gravataí PC, the latter being classified as reasonable.

When the BII results were compared with the results of the Principal Component Analysis (PCA) for the physical and chemical parameters of the water, it was found that most of the points could be classified as good or reasonable during the study period, confirming the results obtained by BII. The results showed two significant axes and showed an accumulated percentage of 67.21% in the variation between the sampling points, with

Table 1: List of families and species observed and ecological aspects of each species. P.C.= Parental Care; T.G.=Trophic Guilds; T= Territorial; P. W. C.= Position in the water column.

Family	Species	P. C.	T. G.	T.	P. W. C.
Anablepidae	*Jenynsia lineata*(Jenyns, 1842)	No	Invertivorous	No	Nektonic
Anostomidae	*Leporinus obtusidens* (Valenciennes, 1836)	No	Herbivorous	No	Nektonic
	Schizodon jacuiensis Bergman, 1988	No	Herbivorous	No	Nektonic
Aspredinidae	*Bunocephalus doriae* Boulenger, 1902	No	Omnivorous	No	Benthic
	Pseudobunocephalus iheringii (Boulenger, 1891)	No	Omnivorous	No	Benthic
Atherinopsidae	*Odontesthes* aff. *perugiae* Evermann & Kendall, 1906	No	Carnivorous	No	Nektonic
Callichthyidae	*Corydoras paleatus* (Jenyns, 1842)	No	Omnivorous	No	Benthic
	Corydoras undulatus Regan, 1912	No	Omnivorous	No	Benthic
	Hoplosternum littorale (Hancock, 1828)	No	Omnivorous	No	Benthic
Characidae	*Aphyocharax anisitsi* Eigenmann & Kennedy, 1903	No	Invertivorous	No	Nektonic
	Astyanax eigenmanniorum (Cope, 1894)	No	Invertivorous	No	Nektonic
	Astyanax aff. *fasciatus* (Cuvier, 1819)	No	Invertivorous	No	Nektonic
	Astyanax jacuhiensis Cope, 1894	No	Invertivorous	No	Nektonic
	Astyanax sp. 1	No	Invertivorous	No	Nektonic
	Astyanax sp. 2	No	Invertivorous	No	Nektonic
	Bryconamericus iheringii (Boulenger, 1887)	No	Invertivorous	No	Nektonic
	Characidium rachovii Regan, 1913	No	Invertivorous	No	Benthic
	Characidium tenue (Cope, 1894)	No	Invertivorous	No	Benthic
	Characidium zebra Eigenmann, 1909	No	Invertivorous	No	Benthic
	Charax stenopterus (Cope, 1894)	No	Invertivorous	No	Nektonic
	Cheirodon ibicuhiensis Eigenmann, 1915	No	Herbivorous	No	Nektonic
	Cheirodon interruptus (Jenyns, 1842)	No	Herbivorous	No	Nektonic
	Diapoma alburnus (Hensel, 1870)	No	Invertivorous	No	Nektonic
	Diapoma speculiferum Cope, 1894	No	Invertivorous	No	Nektonic
	Hyphessobrycon igneus Miquelarena, Menni, López & Casciotta, 1980	No	Invertivorous	No	Nektonic
	Hyphessobrycon luetkenii (Boulenger, 1887)	No	Invertivorous	No	Nektonic
	Hyphessobrycon meridionalis Ringuelet, Miquelarena & Menni, 1978	No	Invertivorous	No	Nektonic
	Hyphessobrycon sp.	No	Invertivorous	No	Nektonic
	Oligosarcus jenynsii (Günther, 1864)	No	Carnivorous	No	Nektonic
	Oligosarcus robustus Menezes, 1969	No	Carnivorous	No	Nektonic
	Pseudocorynopoma doriae Perugia, 1891	No	Invertivorous	Yes	Nektonic
	Serrapinnus calliurus (Boulenger, 1900)	No	Herbivorous	No	Nektonic
Cichlidae	*Cichlasoma portalegrense* (Hensel, 1870)	Yes	Omnivorous	Yes	Nektonic
	Crenicichla lepidota Heckel, 1840	Yes	Carnivorous	Yes	Nektonic
	*Crenicichla punctata*Hensel, 1870	Yes	Carnivorous	Yes	Nektonic
	Geophagus brasiliensis (Quoy & Gaimard, 1824)	Yes	Omnivorous	Yes	Nektonic
	Gymnogeophagus gymnogenys (Hensel, 1870)	Yes	Omnivorous	Yes	Nektonic
	Gymnogeophagus labiatus (Hensel, 1870)	Yes	Omnivorous	Yes	Nektonic
	Gymnogeophagus rhabdotus (Hensel, 1870)	Yes	Omnivorous	Yes	Nektonic
	*Tilapiarendalli*Boulenger, (1876)	Yes	Omnivorous	Yes	Nektonic
Clupeidae	*Platanichthys platana* (Regan, 1917)	No	Invertivorous	No	Nektonic
Curimatidae	*Cyphocharax spilotus* (Vari, 1987)	No	Detritivorous	No	Nektonic
	Cyphocharax voga (Hensel, 1870)	No	Detritivorous	No	Nektonic
Engraulidae	*Lycengraulis grossidens* (Spix & Agassiz, 1829)	No	Invertivorous	No	Nektonic
Erythrinidae	*Hoplias malabaricus* (Bloch, 1794)	No	Carnivorous	No	Nektonic
Gymnotidae	*Gymnotus carapo* (Linnaeus, 1758)	Yes	Carnivorous	Yes	Nektonic
Heptapteridae	*Pimelodella australis* Eigenmann, 1917	No	Omnivorous	No	Benthic
	Rhamdia aff. quelen (Quoy & Gaimard, 1824)	No	Omnivorous	No	Benthic
Loricariidae	*Ancistrus brevipinnis* (Regan, 1904)	Yes	Scraper	Yes	Benthic
	Hisonotus sp.	No	Scraper	No	Benthic
	Hypostomus aspilogaster (Cope, 1894)	Yes	Scraper	No	Benthic
	Hypostomus commersoni Valenciennes, 1836	Yes	Scraper	No	Benthic
	Loricariichthys anus (Valenciennes, 1836)	Yes	Detritivorous	No	Benthic
	Otocinclus flexilis Cope, 1894	No	Scraper	No	Benthic

	Rineloricaria cadeae (Hensel, 1868)	Yes	Scraper	Yes	Benthic
	Rineloricaria sp.	Yes	Scraper	Yes	Benthic
	Rineloricaria strigilata (Hensel, 1868)	Yes	Scraper	Yes	Benthic
Pimelodidae	*Parapimelodus nigribarbis* (Boulenger, 1889)	No	Invertivorous	No	Benthic
	Pimelodus pintado Azpelicueta, Lundberg & Loureiro 2008	No	Omniorvorous	No	Benthic
Poecilidae	*Phallocerus caudimaculatus* (Hensel, 1868)	No	Invertivorous	No	Nektonic
Prochilodontidae	*Prochilodus lineatus* (Valenciennes, 1836)	No	Scraper	No	Nektonic
Pseudopimelodidae	*Microglanis cottoides* (Boulenger, 1891)	No	Omnivorous	No	Nektonic
Rivulidae	*Cynopoecilus nigrovittatus*Costa, 2002	No	Invertivorous	Yes	Nektonic
	Cynopoecilus melanotaenia(Regan, 1912)	No	Invertivorous	Yes	Nektonic
Sciaenidae	*Pachyurus bonariensis* Steindachner, 1879	No	Omnivorous	No	Nektonic
Trichomycteridae	*Homodiaetus anisitisi*Eigenmann & Ward, 1907	No	Carnivorous	No	Benthic

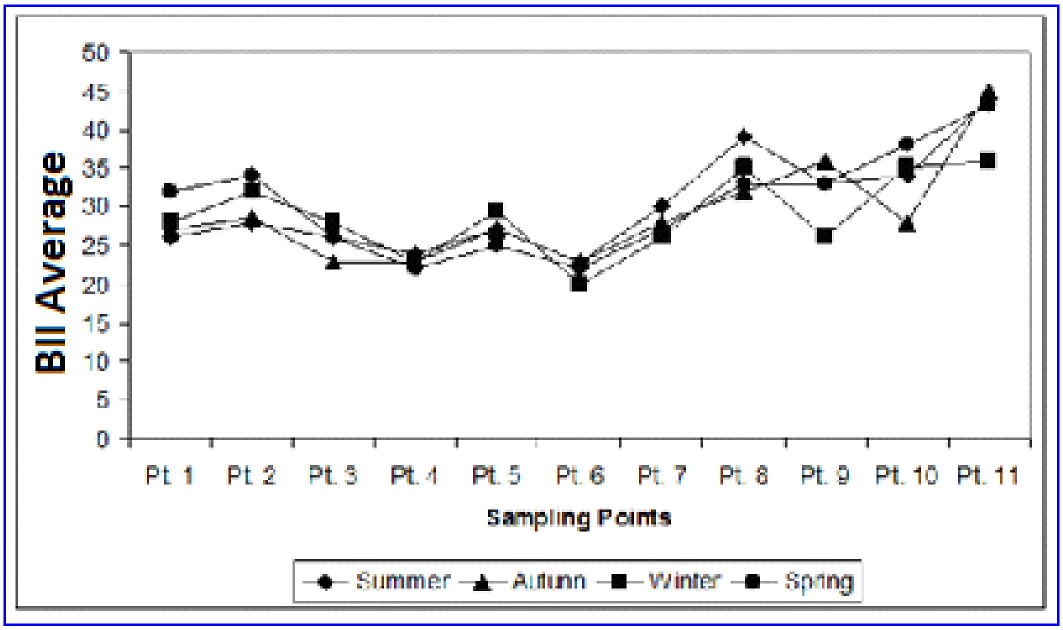

Fig. 2: Change in average of BII for each sampled point in the period sampled.

point B. Ribeiro presenting the best water quality in the entire hydrographic basin due to its higher O_2 average, and its lowest average for thermotolerant coliforms and BOD_5.

The results of the water quality analysis showed that the localities S. Alemoa, F. Celupa, P. Alegria and P. Ipanema presented water quality lower than B. Ribeiro, varying from good to reasonable during the sampling period. The points Gasômetro, river Caí, Morretes and river Sinos presented the worst quality, due to their lower averages of O_2 and higher averages of thermotolerant coliforms and BOD_5. The Gasômetro point can be considered of poorer quality due to the high average of thermotolerant coliforms and BOD_5 and low average of O_2 throughout the sampling period (Table 3).

Discussion

When assessing the stream fish community, Cetra and Ferreira (2016) applied the Biotic Integrity Index (BII), applying four metrics, whichsatisfactorily reflected the environmental gradient. Several studies have demonstrated a relationship between environmental quality of streams and biological integrity of fish assemblages and can be used as an indicator for

Table 2: Seasonal variation of BII values and total BII per point. Scoring criteria used for classification

Points	Samples								Total BII	Scoring Criteria		
	1	2	3	4	5	6	7	8		5	3	1
pt 1	23	29	29	37	27	31	29	29	29,3	>13,66	7,33 - 13,66	<7,33
pt 2	27	27	34	35	33	32	31	33	31,5	> 10,66	5,33 - 10,66	< 5,33
pt 3	27	25	29	31	29	27	33	25	28,3	> 13,32	6,66 - 13,32	< 6,66
pt 4	21	21	27	27	27	27	21	21	24,0	> 670,66	336,3 - 670,66	< 336,3
pt 5	27	29	33	27	29	25	27	25	27,8	> 8	4 - 8	< 4
pt 6	23	25	21	25	23	23	21	19	22,5	> 6	3 - 6	< 3
pt 7	35	29	23	31	21	27	29	30	28,1	> 5,54	2,77 - 5,54	< 2,77
pt 8	43	39	31	39	35	25	39	31	35,3	< 4,09	4,09 - 8,18	> 8,18
pt 9	37	25	25	33	35	41	33	31	32,5	> 13,91	8,54 - 13,91	< 8,54
pt 10	31	33	33	37	39	25	39	37	34,3	< 1,24	1,24 - 2,48	> 2,48
pt 11	45	47	37	39	45	43	39	45	42,5	< 1,22	1,22 - 2,44	> 2,44

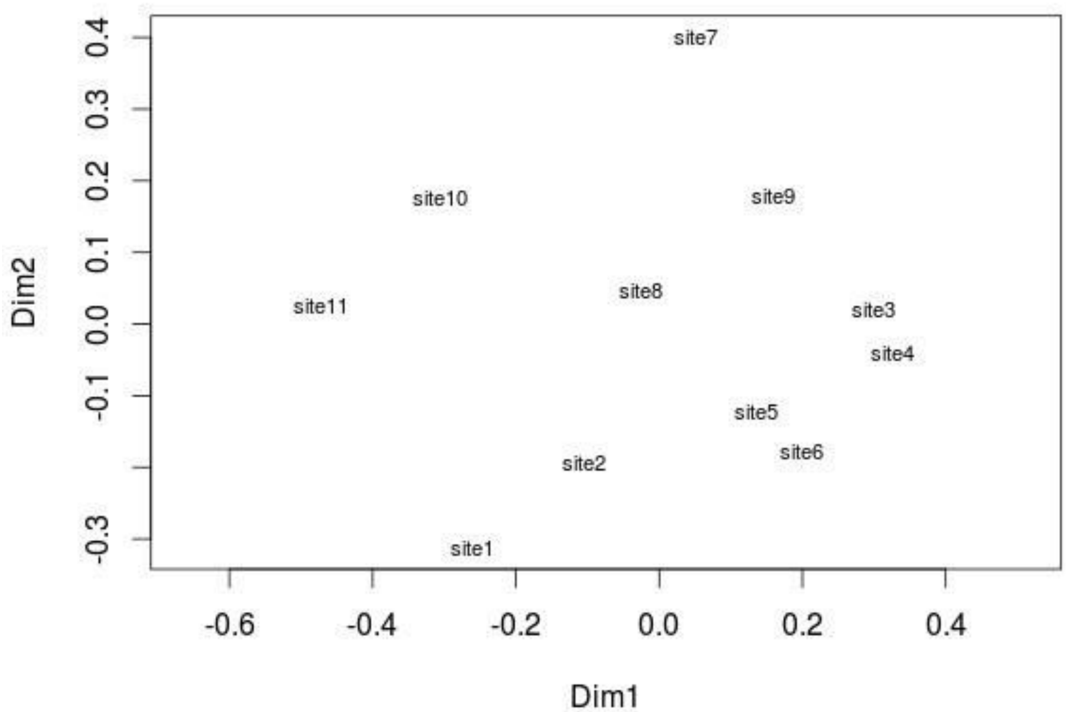

Fig. 3: NMDS analysis performed with the BII average for each of the sampling points. Non-metric multidimensional scaling ordination based on Bray-Curtis similarity, performed with species composition in the sampling points.

Table 3: Values of the average physico-chemical parameters analyzed for each sampling point throughout the study period in the hydrographic basin of Guaíba lake. pH = Potential Hydrogen; O_2 = Dissolved oxygen (mg L^{-1} O_2), BOD_5 = Biochemical Oxygen Demand (mg L^{-1} O_2); Therm. Col.= thermotolerant coliforms (units per 100 milliliters); Temp= temperature (C)

Local	pH	O_2	DBO_5	Therm. Col.	Temp.
Gasômetro	6.9 (±0.21)	5.7 (±1.46)	2.2 (±1.3)	17375 (±13935)	20 (±3.78)
S. Alemoa	7.1 (±0.21)	7.7 (±0.86)	0.5 (±0.27)	171.6 (±160)	20.2 (±4.1)
F. Celupa	7.6 (±0.4)	7.2 (±0.84)	1.4 (±0.77)	13.1 (±471)	21.2 (±4.03)
P. Alegria	7 (±0.18)	7.7 (±0.95)	0.7 (±0.22)	1063.3 (±2111)	21.3 (±4.9)
B. Ribeiro	7.4 (±0.38)	8.2 (±0.99)	0.8 (±0.37)	12.5 (±15.61)	23 (±5.37)
P. Ipanema	7.1 (±0.23)	6.9 (±1.1)	1.6 (±0.74)	9982.5 (±12767)	24.2 (±6.43)
Caí	7.0 (±0.07)	2.7 (±0.7)	2 (±1.68)	18122.5 (±30612)	20 (±4.41)
Caí-Jacuí	6.9 (±0.07)	2.7 (±0.7)	2 (±1.68)	18122.5 (±30612)	20.2 (4.03)
Sinos	7.1 (±0.12)	3.1 (±0.97)	1.8 (±0.83)	910 (±1046)	20.2 (±3.77)
GravataíRS118	6.4 (±0.65)	5.3 (±1.11)	1.2 (±0.52)	993.3 (±1261)	20.8 (±3.4)
GravataíPC	7.3 (±0.13)	5.3 (±1.11)	1.2 (±0.52)	993.3 (±1261)	21.1 (±3.23)

assessing and monitoring the quality of water bodies. Araujo (1998b) stated that a great advantage of the Biotic Integrity Index is its ability to integrate several ecological attributes, avoiding the selection of a certain isolated criterion that can result in less reliable diagnoses than the set of measures.

BII offers more comprehensive assessments than other biotic indicators, based only on species richness, diversity indices, indicator species or multivariate analyzes (Verdonschot, 2000). Although widely accepted as monitoring tools, Pinto *et al*. (2006) commented that BIIs are also useful to relate the responses of the fish assembly to the degradation of riverside areas and landscapes. The results of these authors confirmed expectations that the large urban and industrial complex of Volta Redonda was strongly associated with environmental changes along the middle Paraíba do Sul River. Lower water levels reduced the volume and diversity of the habitat and provided less dilution of organic and industrial pollutants, which are associated with a worse environmental quality in the dry season. Bozzetti and Schulz (2004), commented that the choice of less disturbed sites located at the headwaters is problematic due to the natural longitudinal changes in the ichthyofauna that is impossible in regions like Brazil, where historical information on the distribution and abundance of smaller fish is completely absent.

The results obtained for Lake Guaíba showed that the Gravataí PC point was classified as regular, the Praia da Alegria and P. Ipanema points were classified as terrible and the other points were classified as bad. These results were different from those observed by Flores-Lopes and Reuss-Strenzel (2011), who used the Principal Component Analysis (PCA) for physical and chemical parameters, and revealed that the point P. Ipanema had reasonable water quality, varying from good to regular during the sampling period. The B. Ribeiro point was the one with the best water quality in the entire basin, and the S. Alemoa, F. Celupa, P. Alegria points showed lower water quality, varying from good to reasonable during the sampling period. The Gasômetro, Caí, Caí-Jacuí and Sinos points presented the worst quality waters.

The study showed that the parameters that most influenced the Gravataí PC point to be classified as regular in terms of quality were "Species wealth", "Number of individuals", "Percentage of individuals infected with the black spot" and "Percentage of individuals with morphological disease". The occurrence of this type of change caused the highest value obtained by BII. This point received the best evaluations for these parameters in terms of offering great wealth and a low percentage of individuals infected with black spots and morphological changes. On the other hand, the parameters "Percentage of territorial", "Parental care", "Number of individuals", "Percentage of carnivores", "Omnivores" and "Invertivores" negatively influenced the result of the index, in which it was observed almost exclusively classifications 3 and 1. The low values obtained for these parameters contributed significantly to the verification of low BII values at points 4 and 6, which made them considered of low environmental quality.

According to the data of Flores-Lopes and Reuss-Strenzel (2011), the environments were classified as medium or high quality and this result is due to the fact that a low number of individuals were considered who were marked with a high frequency of a kind of abnormality at these points. Araújo (1998a, b) observed that a criterion that seems useful in the classification of an environment is the frequency of fish with tumors, lesions or deformities in the fins, presence of parasites (Flores-Lopes and Thomaz, 2011a) and other indicators of diseases or abnormalities. Flores-Lopes and Thomaz (2011b) and Flores-Lopes (2014) reported that several individuals had a high number of individuals infected with black spot disease. Author like Araújo (1998a) pointed out that the frequency of fish with tumors, fins or deformities, parasites and other indicators of diseases or anomalies can be an important criterion that seems to be useful in the classification of an environment. Karr *et al*. (1986) and Hughes and Gammon (1987) reported that this type of parameter has been an important indicator of degraded areas.

Araújo (1998a) observed that the proportion of omnivorous individuals was one of the parameters that negatively influenced the results of the BII, and in this study a local decline in quality was noticed when this parameter was increased and that among all points the Gasômetro was classified as low quality (bad), due to the appearance of a large number of omnivorous and generalist species. With regard to the parameters related to trophic guilds, a more in-depth knowledge about the diet of neotropical species is necessary, and the results obtained in this study, which found the predominance of invertivore species followed by omnivorous species (Table I), indicated that these points are classified as poor.

Karr (1981) established that samples with less than 20% omnivores are good, while those with more than 45% omnivores are seriously degraded. This factor is another important issue to be assessed when adapting the BII. Can the percentages used only be used according to the data obtained in the specific study or if the same percentages can be used in different types of habitat? In the same watershed there are sampling points with different characteristics and it is difficult to establish that samples with less than 20% omnivores mean that they are classified as samples of good quality and above 45% are considered degraded.

Among other points, the Gasômetro was classified as low quality (bad), due to the appearance of a large number of omnivorous and generalist species, and the high frequency of sick individuals, which corroborates the results obtained by Flores-Lopes and Thomas (2011a) and Flores-Lopes and Reuss-Strenzel (2011), who considered this point poor in terms of quality for having demonstrated a high frequency of moderate and severe changes in the gills of *Astyanax* aff. *fasciatus* (Cuvier, 1819) and *Diapoma alburnus* (Hensel, 1870), a high frequency of various types of morphological abnormalities and the lowest concentrations of dissolved O_2 and highest concentrations of thermotolerant coliforms.

In this study, the fact that most points are classified as poor or very poor in terms of quality was corroborated by Flores-Lopes *et al*. (2010) who observed that, except for points B. Ribeiro and P. Ipanema, there is a predominance of some species over others, such as *Astyanax* aff. *fasciatus*, *Astyanax jacuhiensis* Cope, 1894, *Diapoma alburnus* and *Hyphessobrycon luetkenii* (Boulenger, 1887), since these species were listed as generalists by Bruschi Jr. *et al*. (2000). On the other hand, Mason (1991) considers that the diversity indexes of the unpolluted environments show a large number of species, with none of them composing the majority of the community, unlike the polluted environments, which are characterized by the presence of few species, which predominate over others.

The results of the NMDS analysis showed that the Gravataí PC point, which presented reasonable quality by the BII, is totally different from the other points, which were classified as bad (Gasômetro, S. Alemoa, F. Celupa, B. Ribeiro, Caí, Caí-Jacuí, Sinos and Gravataí RS118) or very poor (P. Alegria and P. Ipanema). The results are similar to those reported by Flores-Lopes and Reuss-Strenzel (2011), who classified the Gasômetro, P. Alegria, B. Ribeiro, Gravataí RS118 and P. Canoas points as of low environmental quality because of lack of randomness in the frequency of morphological changes. Flores-Lopes *et al*. (2010) found that the points F. Celupa, S. Alemoa, Sinos and Gravataí PC had better environmental quality in this basin because these points had a greater diversity and at points B. Ribeiro and Gravataí PC more regular diversity was observed throughout study period. Flores-Lopes and Thomas (2011b) also found better environmental quality in the points F. Celupa, P. Alegria, B. Ribeiro and P. Ipanema due to the non-random occurrence of the parasite that causes the black spot (probably the Diplostomatidae family), one that needs a healthy environment to complete its life cycle.

Point B. Ribeiro was classified as bad in each period of one year and regular in the sampling throughout the study period. This result contradicts the results obtained by the Principal Component Analysis (PCA) for the physical-chemical parameters analyzed in this study and performed by Flores-Lopes and Reuss-Strenzel (2011), who verified that this point presented the highest concentrations of dissolved O_2 and lower concentrations of thermotolerant coliforms. Meador and Goldstein (2003) emphasized that the BII and the physical-chemical parameters are complementary and have been used to obtain a more holistic assessment of environmental quality, since it has been reported as an efficient tool for monitoring diffuse and integrates, through fish community metrics, the general health status of a lotic system compared to traditional physical-chemical parameters.

These parameters provide punctual and instant information on the water quality of a given location (Karr *et al*., 1986; Verdonschot *et al*. 2000), which was also verified by Angermeier and Davideanu (2004), who highlighted that the biological indicators they complement the traditional physical-chemical indicators and facilitate a more comprehensive and accurate assessment of the environment.

The results also differ from those obtained by Flores-Lopes and Thomas (2011a, b) and Flores-Lopes (2014) who observed slight abnormalities in the gills of *Astyanax* aff. *fasciatus* and *Diapoma alburnus*, and a high frequency of *Astyanax* aff. *fasciatus* infected by the parasite that causes black spot disease in this environment. These authors stated that high rate of infection associated with better water quality in this place makes it considered one of the most qualified places in the Guaíba lake basin. The BII results showed that, in addition to the parameters studied, other environmental factors that are not normally perceived by the physical-chemical and biological pattern may have contributed to the drop in water quality in the Guaíba lake basin. The results obtained were considered similar to those observed by Flores-Lopes *et al*. (2010) and Flores-Lopes and Thomas (2011a), who demonstrated, through the use of physical-chemical and biological aspects of fish species, that the water quality in most of the studied points varied from regular to poor.

A factor discovered in this study which must be taken into account is the establishment of limits in the intervals that correspond to scores from 1 to 5 in the elaboration of the biotic integrity index. This fact reveals the difficulty in establishing the criteria to determine whether the percentage of a given attribute corresponds to low, medium or high quality. In the literature, most authors, with some exceptions, tend not to mention how these intervals are established. This study used the criteria given by Araújo (1998a, b) and Karr *et al*. (1986), who established three categories by dividing the result of the highest value decline by the result of the lowest value.

Despite being considered a good mathematical solution, this system can have a number of limitations, as it has a biotic index that takes into account the sensitivity/tolerance of species or groups of species to pollution and assigns a value based on that, and the sum these values results in a pollution rate for a given location (Mason, 1991), which constitutes a major problem, since the tolerance or sensitivity of many species are not known, and, especially in countries like Brazil, even the species themselves are often unknown. Bendati *et al*. (1998) pointed out that high levels of diversity can show where the quality of the environment is poor.

The results of this study and the results obtained by Flores-Lopes *et al*. (2010) and Flores-Lopes and Thomas (2011a) revealed the need to use more than one methodology as a tool for assessing environmental quality. Depending on the complexity of the relationships between the physical, chemical and biological processes that make up the aquatic environment, a wider range of methodologies is indispensable for a diagnosis to be more consistent on the real conditions of the hydrographic basin under study. Eaton and Lydy (2000) demonstrated the importance of using several attempts to assess water quality. According to them, the use of only one method is a mitigation of the physical, chemical and biological relationships of water.

The biotic integrity index (BII), as one of these methodologies, showed some effectiveness in this study, but like any index, it must be analyzed with caution. Some items, such as "Percentage of territory", "Percentage of species with parental care", "Percentages of necrotics and benthic" as well as those related to trophic guilds should be reevaluated in other studies, in order to confirm their effectiveness and not the best or worst environmental quality to obtain a more accurate assessment of the environment. According to Karr *et al*. (1986), the great advantage of using BII is the fact that it has the ability to integrate several ecological attributes and avoid the use of a specific isolated criterion, which could result in a less reliable diagnosis than the use of a set of measures. Whittier *et al*. (2007) raised some questions about the use of the BII, such as “When and how should metrics be modified, replaced or eliminated in an existing BII?”, “How many metrics are needed in an BII?”, “How should the metrics be proposals, evaluated and chosen?”. Karr and Chu (2000) stated that the BII has been widely discussed and researchers have questioned about the proper use of the method and its evaluation.

Hugueny *et al*. (1996) reported that an advantage of BII is that it is potentially sensitive to a variety of disturbances: organic pollution or physical-chemical structure of habitat decline, etc. The relative sensitivity of the twelve attributes varies considering the geographical scale, type of degradation and region to region. Individually, each attribute is not a reliable indicator of decay, but, combined with the other parameters, they become strongly related to degradation (Angermeier and Karr, 1986). Individually, each parameter derives information about a particular characteristic of the sampling site, but combined, this information characterizes the biological integrity of the site (Karr *et al*., 1986).

According to Cooper *et al*. (2018), Esteves and Alexandre (2011), Terra and Araújo (2011), several types of modifications were made to the different metrics used, according to the environment to be studied, some of which were even eliminated, in order to allow the taking of ecosystem information. According to them, the adaptation of the metrics was necessary due to differences in the composition of the fish communities found in the two environments. These authors further stated that it is expected that different assessment methodologies will demonstrate specific responses to certain environmental factors, which could be observed in the studies cited, since each type of method presented a specific response to environmental changes. The use of such methodologies in the assessment of environmental quality generates several types of responses. They are an important source of information about the condition of the organisms in the environment in which they live, allowing the researcher to more safely infer about the nature and time of exposure of individuals to the stressor. The results of this study make it clear that the responses obtained from only one assessment methodology are not sufficient to make a more accurate diagnosis of the real situation of the ecosystem. In this study, several modifications were made to different metrics.

According to Marciano *et al*. (2004), it was observed that all areas of shock absorbers in the streams of the hydrographic basin were degraded or even destroyed to accommodate agriculture. Most of the tributaries underwent drastic structural interventions, such as plumbing and the removal of riverside vegetation. The decrease in BII scores in urban areas is mainly caused by the physical degradation of the aquatic environment (Costa and Schulz, 2010). The results observed by Esteves and Alexandre (2011), showed that the places within the agricultural areas where the cane fields were dominant supported biologically diverse fish communities, urban areas, especially in the dry season. The results of this study suggest that the integrity of the stream is decreasing, especially in urban locations, due to changes in habitat and/or deterioration in water quality.

The results of Cassati *et al*. (2012) indicate that the composition of the fish community reflects the progressive loss of vegetation quality in the riverside area. The study data showed that changes in species composition were also accompanied by changes in the functional composition of communities, represented by the dominance of tolerant and opportunist fish, to the detriment of the decrease/elimination of more sensitive and specialized species along the degradation gradient, riverside area. These results indicate that the stream ichthyofauna responds to the degradation gradient of riparian vegetation, through a change in its species composition and functional characteristics.

Acknowledgements

The authors wish to thank Fernando G. Becker and Fábio Vilella for their suggestions and discussions on the Biotic Integrity Index. FFL thanks his colleagues from the Laboratory of Ichthyology at UFRGS for field work support and Luiz Roberto Malabarba and Roberto Esser dos Reis for specimens identification. CNPq provided a fellowship to FFL (proc. 476821/2003-7).

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