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Integrated tools to evaluate environmental conditions in estuarine streams of Northeastern Brazil

Ferramentas integradas para avaliação da qualidade ambiental em córregos estuarinos no Nordeste do Brasil

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Abstract: Aim: This work proposes the application and development of environmental quality indexes for the evaluation of tropical estuarine streams in different spatial scales. The main goal was to understand the biological responses of the ichthyofauna in relation to different spatial indices in each group of streams, according to their predominant land use. Our hypothesis is that the impact on the stream riparian zones and in the land use in adjacent areas to the stream interfere in the structure of the fish assembly. **Methods:** The Physical Habitat Integrity Index (PHI) on the local scale (80.0 m) and the Microbasin Integrity Index (MII) on catchment scale (1.6 km radius) was applied in all streams. In parallel, fish collections with electric fishing equipment were carried out in the 80.0 m reach. With the data from the PHI, MII and ecological estimators (species richness and percentage of *Poecilia reticulata*), the Kruskal-Wallis non-parametric test and Dunn's post hoc test were carried out to verify the differences between the groups of land use, followed by a linear and polynomial regression analysis with trend line to show a relationship among indexes used and the biological responses. **Results:** We observed that all streams' groups presented a high positive correlation among PHI and MII. However, ecological estimators did not respond to changes in land use linearly, but in the form of a parable in a polynomial regression. **Conclusions:** Our main conclusion is that the use of indexes and estimators as tools for environmental assessment is an efficient way to assess the health of the streams. The results also show that the integration of local and spatial indexes reduces the distortions observed in the indexes in isolation.

Keywords: stream habitat quality; spatial evaluation; tropical estuary; estuarine fishes.

Resumo: Objetivo: Este trabalho propõe a aplicação e o desenvolvimento de índices de qualidade ambiental para a avaliação de riachos estuarinos tropicais em diferentes escalas espaciais. O objetivo foi compreender as respostas biológicas da ictiofauna em relação a diferentes índices de perturbação para cada grupo de riachos, segundo o uso de terra predominante. Nossa hipótese é que o impacto na zona ripária do riacho pelo uso do solo em áreas adjacentes aos riachos interfere na estruturação da assembleia de peixes. **Métodos:** Os Índices de Integridade Física do Habitat (IFH), em escala local (80,0 m), e o Índice de Integridade da Microbacia (IIM), em um raio de 1,6 km, foram aplicados em todos os riachos. Paralelamente, foram realizadas coletas de peixes com equipamento de pesca elétrica em um trecho de 80,0 m. Com os dados dos estimadores IFH, IIM e biológicos (riqueza de espécies e porcentagem de *P. reticulata*), foram realizados os testes não paramétricos de Kruskal-Wallis e de Dunn post hoc para verificar as diferenças entre os grupos de uso do solo, acompanhados de uma análise de regressão linear e polinomial com linhas de tendências que mostram uma relação entre os índices utilizados e as respostas biológicas. **Resultados:** Observamos que todos os grupos de riachos apresentaram correlação positiva alta para os índices IIM e IFH. No entanto, os estimadores ecológicos não respondem às mudanças no uso da terra de forma linear, mas na forma de uma parábola com uma tendência polinomial. **Conclusões:** Nossa principal conclusão é que a utilização de índices e estimadores como ferramentas de avaliação ambiental é uma maneira eficiente de avaliar a saúde de riachos. Os resultados também mostram que a integração dos índices locais e de paisagem reduzem as distorções observadas nos índices isoladamente.

Palavras-chave: qualidade de habitat em riacho; avaliação espacial; estuário tropical; peixes estuarinos.

1. Introduction

The diversity and complexity of the ichthyofauna of neotropical inland waters is enormous, especially in South America, embracing approximately 10% of all species of living vertebrates on the planet (Castro & Polaz, 2020). Nevertheless, this biodiversity faces increasing pressures from human actions, including changes in land use, habitat degradation, habitat fragmentation, climate change, pollution associated with urbanization, mining, overfishing, competition, predation and the introduction of invasive allochthones species (Albert et al., 2020; Newbold et al., 2015). Human activities are dramatically altering the distribution and flow of surface, groundwater and atmospheric water on regional scales, undermining the resilience of aquatic, riverside and coastal ecosystems, especially neotropical freshwater (Albert et al., 2020). He et al. (2019) project a decline in the diversity of stream megafauna worldwide. Therefore, understanding the connections between tropical freshwater ecosystems, physical changes in riverscapes and related biological responses can contribute to the elaboration of strategies to improve the environmental quality of anthropized streams and their receiving water bodies.

Among attributes most important to determine the environmental quality of lotic ecosystems are the internal physical habitat components (i.e. tree fine roots, gravel and rocks, logs and trunks) and the marginal area, which are impaired mainly by vegetation suppression and modification of streams, resulting in higher light incidence, increased temperature, eutrophication, silting water courses and loss of microhabitat resources (Gregory et al., 1991; Naiman & Décamps, 1997; Hepp & Santos, 2009; Casatti et al., 2009).

To assess the physical integrity of these attributes, several techniques are known, among them, rapid bioevaluation protocols are often used, because they do not demand logistical and equipment complexity and reduce environmental assessment costs, producing quick results for decision-making processes, taking into account the technical and scientific rigor (Krupek, 2010). The use of rapid protocols consists of direct observation of local physical habitat descriptors and environmental measurements, classifying water bodies on a scale of values and characterizing them at conservation or degradation levels (Hannaford et al., 1997). Thus, biotic elements contribute with information on how these environmental characteristics can affect the biological quality of ecosystems (Barbour et al., 1999).

One of the most used protocols for characterizing the structural parameters of lotic ecosystems is the Physical Habitat Index (PHI), which evaluates a set of physical descriptors of the water body and the composition of the marginal cover of the channel (Barbour et al., 1999). This protocol has been regionally adapted for use in lowland Brazilian streams by Casatti et al. (2006b). The index values reflect the physical quality of the habitat, allowing the water body to be categorized according to the quality of the habitat (i.e. good, fair, poor, very poor). In addition to the disturbances that act in the marginal portion, anthropic interference accelerates the process of modifying landscape elements in drainage networks (Ligeiro et al., 2013). The composition of the terrestrial landscapes includes the aquatic ecosystems and their drainage areas (Gregory et al., 1991; Naiman & Décamps, 1997; Lo et al., 2020). When the natural landscape is modified by human activities, the physical and biological relationships in streams are negatively affected (Dala-Corte et al., 2020; Mello et al., 2020).

To understand the condition of the landscape basins (area of drained land) simplified tools and measurements have been applied. The visual analysis of features of the landscape has become an important tool to detect problems at different scales, and shapes and textures configure the landscape attributes, defining quantitative values used in environmental quality studies (Rawer-Jost et al., 2004; Laudon et al., 2009; Ligeiro et al., 2013; Shen et al., 2015; Erős & Lowe, 2019).

From the ecological point of view, maintaining the integrity of physical attributes in the riparian vegetation is notably important for the biotic composition (Vannote et al., 1980; Ward, 1989; Pease et al., 2015). The structuring of fish communities and their relationship with abiotic attributes of the environment must be considered when developing strategies for environmental assessment, monitoring, recovery and conservation. Thus, low values in physical habitat assessments generally result in increase of populations of generalist species and reduction or disappearance of specialist taxa (Teresa & Casatti, 2010).

We understand that studying the relationship between local, catchment and biological attributes of tropical freshwater ecosystems can provide parameters to assess the anthropic impacts of land use and cover in the ichthyofauna, providing practical tools for environmental assessment and monitoring in tropical estuarine streams. In this study, we evaluated whether the quality of the habitat and landscape varied according to the environmental context in which streams are inserted, as well as the biological response of the ichthyofauna. We made the environmental characterization in two scales; local (80 m) and microbasin (1.6 km), applying indexes adapted for tropical estuarine streams.

2. Material and Methods

2.1. Study site

The "Mundaú Manguaba" Estuarine-lagunar complex - MMELC - has great biodiversity and ecosystem diversity (Brasil, 2006; Guimarães Júnior et al., 2017), and extensive occupation of urban, agricultural and industrial activities in the landscape (Cotovicz Junior et al., 2012; Menezes et al., 2012). It is located in the central portion of the coast of Alagoas states, Northeastern Brazil, covering areas in the municipalities of Maceió, Marechal Deodoro, Pilar, Rio Largo, Satuba, Santa Luzia do Norte and Coqueiro Seco. The study was carried out in the dry season of years 2017 (december, streams S1-S16) and 2018 (november and december, streams S17-S24) in 24 streams inserted in the MMELC drainage, chosen to contemplate the environmental heterogeneity of the region. Subsequently sampled streams were classified according to three land uses based on the highest landscape percentage within a radius of 1.6 km from sample stretch. Data of landscape use of streams were obtained with the aid of Google Earth and QGIS tools. Ten streams with predominance of tree vegetation in the riparian buffer were classified as Forest group; seven streams with shrub and grassy vegetation were classified as grassy group; and seven streams with predominance of urban occupation and exposed soil were categorized as urban group (Figure 1, Table 1).

Streams were selected following criteria of order of magnitude (orders 1 and 2), perennity, similarity between reaches, and feasibility of sampling procedures (maximum depth up to 1.3 m). Streams and land use and cover can be observed in Figures 2, 3, 4, 5, 6, 7.

2.2. Physical Habitat Index (PHI)

The protocol for assessing Physical Habitat Integrity (PHI) Barbour et al. (1999) and adapted for Brazil by Casatti et al. (2006b), was used for each sampling of each stream site (80 meters long). This index was applied based on direct observation of abiotic structural descriptors of the habitat and environmental measurement of sampled streams. In the protocol, the following lotic ecosystem components were evaluated: hydrological components (channel width, depth, well-rapids combinations, flow velocity); internal physical components (stability and substrate composition, deposition of sediments and residues at the bottom, thin or thick roots, presence of oils, foams or odors); ecotone physical components (channel changes, channeling and marginal soil, composition and stability of the riparian vegetation cover). Scores of PHI ranging from 0 to 180 are assigned to each site, classifying streams into four categories: Very Degraded (0-45), Degraded (46-90), Regular (91-135) and Preserved (136-180).

2.3. Microbasin Integrity Index (MII)

We measured the lateral dimension following the Riverscape's approach developed by Allan (2004). The Microbasin Integrity Index (MII) allows assessing the landscape influences on the sampled streams and gives us a good indicator of integrity showing a gradient based on the complexity of the vegetation. At the study area Atlantic forest specially in northeastern Brazil is an ombrophile and dense

Table 1. Description of sampled streams.

Stream	Compartment in MMELC	Predominant land use	Latitude S (WGS84)	Longitude O (WGS84)	Altitude (m)	Magnitude order	Depth mean (m)
S1	Manguaba lagoon	Tree vegetation	9°44'24.40"	35°56'57.90"	21	1st	0.15
S2	Manguaba lagoon	Tree vegetation	9°40'31.93"	35°56'59.81"	52	1st	0.11
S3	Manguaba lagoon	Tree vegetation	9°41'28.30"	35°55'44.90"	32	2nd	0.28
S4	Connector channels	Tree vegetation	9°42'11.63"	35°50'0.30"	10	1st	0.32
S5	Mundaú lagoon	Tree vegetation	9°35'57.9"	35°45'52.3"	35	1st	0.12
S6	Mundaú lagoon	Tree vegetation	9°33'53.50"	35°48'0.50"	23	1st	0.21
S7	Manguaba lagoon	Tree vegetation	9°39'25.20"	35°52'25.60"	14	1st	0.44
S8	Manguaba lagoon	Tree vegetation	9°39'30.30"	35°52'45.00"	16	2nd	0.25
S09	Manguaba lagoon	Grassy vegetation	9°39'47.89"	35°56'1.49"	17	1st	0.35
S10	Manguaba lagoon	Grassy vegetation	9°40'48.30"	35°55'19.00"	30	1st	0.48
S11	Manguaba lagoon	Grassy vegetation	9°42'49.29"	35°54'26.84"	20	1st	0.40
S12	Mundaú lagoon	Grassy vegetation	9°35'32.60"	35°49'21.10"	11	2nd	0.38
S13	Manguaba lagoon	Grassy vegetation	9°36'23.80"	35°56'23.70"	7	1st	0.64
S14	Mundaú lagoon	Native tree	9°33'58.50"	35°48'31.40"	52	2nd	0.20
S15	Manguaba lagoon	Grassy vegetation	9°43'41.50"	35°55'54.40"	16	1st	0.14
S16	Mundaú lagoon	Grassy vegetation	9°36'22.66"	35°49'27.14"	23	1st	0.19
S17	Manguaba lagoon	Urbanized	9°42'51.5"	35°53'34.6"	3	1st	0.18
S18	Manguaba lagoon	Urbanized	9°36'38.3"	35°57'17.4"	8	1st	0.12
S19	Mundaú lagoon	Urbanized	9°3916.0"	35°44'30.8"	4	1st	0.06
S20	Mundaú lagoon	Urbanized	9°32'45.7"	35°44'40.5"	3	1st	0.06
S21	Mundaú lagoon	Urbanized	9°39'41.8"	35°44'47.8"	6	1st	0.11
S22	Mundaú lagoon	Urbanized	9°39'34.4"	35°45'49,5"	3	2nd	0.09
S23	Mundaú lagoon	Urbanized	9°36'40.5"	35°49'10.8"	3	1st	0.19
S24	Mundaú lagoon	Tree vegetation	9°34'20,3"	35°49'14,4"	8	1st	0.20

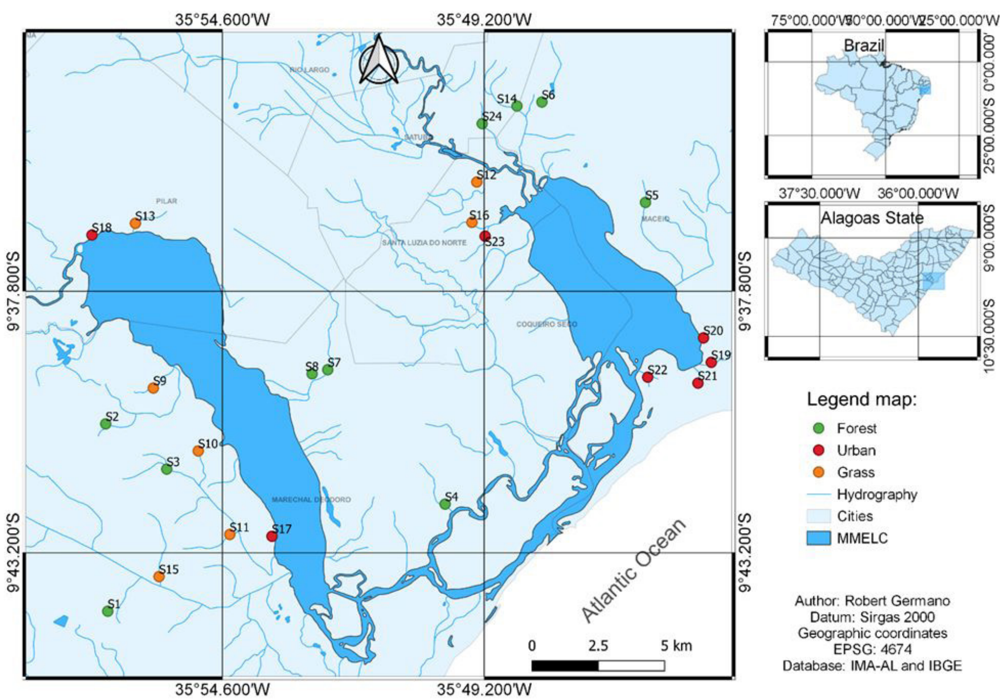

Figure 1. Location of stretches sampled at the "Mundaú Manguaba" Estuarine-lagunar Complex - MMELC.

ecosystem, with tall trees and ferns tied up by vines and bromeliads (Silva et al., 2014). Furthermore all this ecosystem is facing a severe fragmentation process, and the land use is being altered mainly by replacing natural vegetation cover by grass, for bovine pasture; and shrubs, for sugarcane crops

Figure 2. Sampled stream stretches showing their riparian cover vegetation. (Photo: Maria Angélica Pérez-Mayorga).

Figure 3. Streams sampled stretches showing their riparian cover vegetation. (Photo: Maria Angélica Pérez-Mayorga).

(Ribeiro et al., 2009). So we could expect that this conversion in vegetation reflects the values obtained with the index.

We estimated the land use and occupation for the microbasin of each sampled stream using the Google Earth Pro 7.3 and Qgis 3.4 software. First, a circular area of 1.6 km of radius from the sampling site was delimited, following Roth et al. (1996). Using the Google Earth Pro 7.3 software, manual vectorization of land use and occupation

Figure 4. Streams sampled stretches showing their riparian cover vegetation. (Photo: Maria Angélica Pérez-Mayorga).

Figure 5. Streams sampled stretches showing their riparian cover vegetation. (Photo: Maria Angélica Pérez-Mayorga).

was performed, based on categorization performed by Roth et al. (1996) with adaptations to include new categories, totaling five forms of land use and cover: urbanized (exposed soil), agriculture (sugar cane), pasture (grass vegetation), shrubs, and forest vegetation. After vectorization, a file in *kml* format with polygons representing land use and cover was created, which was loaded into the

Figure 6. Streams sampled stretches showing their riparian cover vegetation. (Photo: Robert Germano Alves da Silva).

Figure 7. Streams sampled stretches showing their riparian cover vegetation. (Photo: Robert Germano Alves da Silva).

QGis 3.4 Madeira software. Then the percentage area occupied by each type of land use and cover was calculated for each microbasin. Weights were assigned to the five categories, representing the potential of each land use for impairing the ichthyofauna (Ligeiro et al., 2013), as follows: urban and exposed soil (0x); agriculture (1x); pasture (2x); grasses and shrubs (3x); forest vegetation (4x).

The MII index being calculated as follows (Equation 1: Formula for calculating to Microbasin Integrity Index – MII):

$$MII = \frac{\left(\begin{array}{c}\%urban \times 0 + \%agriculture \times 1 + \\ \%pasture \times 2 + \%shrub \times 3 + \%forest \times 4\end{array}\right)}{4} \quad (1)$$

The proposed index ranges from 0 to 400, with value 0 being the most impacted scenario with 100% of land occupied by urbanization. Value 400 is attributed to the most preserved with drainages without impacts and area 100% occupied by forest vegetation. Intermediate values represent a combination of different land uses.

2.4. Integrated Habitat Quality Index (IHQI)

PHI and MII indexes were integrated using methodology described in Ligeiro et al. (2013), with the necessary changes according to the indexes we used, and the Pythagorean theorem was used to calculate the composite index to obtain an index (Integrated Habitat Quality Index - IHQI) that responded to both assessment scales (local and catchment) (Equation 2: Formula for calculating to Integrated Habitat Quality Index – IQIH):

$$IQIH = \sqrt[2]{\left[\left(\frac{PHI}{180}\right)^2 + \left(\frac{MII}{400}\right)^2\right]} \quad (2)$$

Thus, the IHQI reflects the "integrity" of the land cover, based on the assumption that the natural tree cover characteristic of the Atlantic forest of "dense broad shoulder" vegetation is expected for the region, which provides expected micro and macro habitats for the native species pool of this biome and its associated ecosystems. The index values ranged from 0 to 1.4 and reflected the local assessment of streams and their catchments, allowing the classification of streams into three categories: habitats with low environmental integrity (0-0.46), with moderate integrity (0.47-0.92) and with high environmental integrity (0.93-1.4).

2.5. Biological data collection

To collect fish specimens, electric fishing equipment (220 V AC current, 50-60 Hz, 3.4-4.1 A, 1000 W) was used for 45 minutes in a delimited stretch of 80 meters in length, and each reach was sampled only once. Collected specimens were anesthetized with eugenol (Brasil, 2018) fixed in 10% formalin, and after 48 hours, preserved in 70% ethanol.

Fish identifications were checked by specialists, and all individuals were counted to record species abundance and richness, being later deposited in the Fish Collection of the São Paulo State University, campus of São José do Rio Preto (DZSJRP 21208-21315; 22719- 22721). Fish collection and transport were authorized by IBAMA-SISBIO (licenses No. 60910-1, 26 / oct / 2017).

To understand the response of ichthyofauna to land use and cover categories, data on species richness (S) were used as predictor of good environmental condition and species abundance as predictor of environmental degradation. The species richness is considered by Magurran (2013) as the simplest and intuitively most satisfactory, being defined as the number of taxa in a given assemblage. According to Casatti et al. (2006a), *Poecilia reticulata* abundance greater than 50% of the total assemblage abundance in streams indicates impaired conditions.

2.6. Statistical analyses

To verify whether there was a difference between the values of each index (Physical Habitat Index, Microbasin Integrity Index, Integrated Habitat Quality Index, Species richness estimator and *P. reticulata* abundance percentage) according to the land use (Forest, Grass and Urban), the Kruskal-Wallis non-parametric test was performed, followed by Dunn's post hoc test ($p = 0.05$). Kruskal-Wallis test assesses differences between medians of three or more groups independently sampled in a single continuous variable not normally distributed (McKight & Najab, 2010). Dunn's post hoc test allows assessing whether there are significant differences between pairs of groups regarding a variable, with $p < 0.05$ being considered significantly different (Dittrich et al., 2013). To understand the relationship between environmental characterization scales, the values of local and microbasin indexes were submitted to linear regression analysis. To correlate physical indexes with biological data, polynomial regression models were used. Analyses were performed using the Past software (Hammer et al., 2001).

3. Results

The results of local (PHI) and microbasin (MII) indexes showed that all streams presented some level of disturbance within the 1.6 km radius analyzed. Even streams inserted in the forest group (high PHI and MII values) were affected by small urbanization spots or agricultural activity, causing ecological disturbances in the drainage, which are not necessarily reflected in index cutoff values. The calculation of the integrated index (IHQI) incorporates local and landscape descriptors and reflects species richness and exotic species dominance, as percentage of abundance of *P. reticulata* (Table 2).

With the PHI index, it was possible to differentiate the three types of land use and occupation by the structure of the local habitat; however, in this descriptor, streams S14 and S24 presented low values when compared to the others of the forest group, presenting values closer to groups of grasses and urban, respectively (Table 2). The PHI results showed significant differences between land use groups (p = 0.0006); however, only the streams inserted in the forest were different from the urban group (p = 0.0001) (Figure 8a, Table 3).

In the analysis of the landscape using the Microbasin Integrity Index (MII), the highest values were obtained in reaches with tree vegetation at the stream riparian buffer; however, stream S14 showed value similar to points classified by use and occupation as grasses. The group classified as urban presented results that express a high degree of environmental disturbance, except for stream S23, which presented intermediate results.

The MII results showed significant differences between groups (p = 0.0002); however, forest and

Table 2. Comparison of results of Physical Habitat Index (PHI), Microbasin Integrity Index (MII), and Integrated Habitat Quality Index (IHQI) per sampled stream.

Stream	PHI	MII	IHQI	Stream	PHI	MII	IHQI
S1	156	391.82	1.30	**S13**	59	253.44	0.71
S2	136	241.69	0.96	**S14**	85	184.87	0.66
S3	136	260.43	0.99	**S15**	54	275.93	0.75
S4	141	344.71	1.16	**S16**	63	254.29	0.72
S5	114	326.55	1.03	**S17**	35	79.00	0.27
S6	147	329.65	1.16	**S18**	35	56.43	0.24
S7	128	361.27	1.14	**S19**	33	0.00	0.18
S8	119	354.84	1.10	**S20**	27	56.60	0.20
S9	77	212.46	0.68	**S21**	14	5.98	0.07
S10	47	112.78	0.38	**S22**	24	26.52	0.14
S11	44	141.25	0.42	**S23**	34	164.18	0.45
S12	41	171.35	0.48	**S24**	22	231.47	0.59

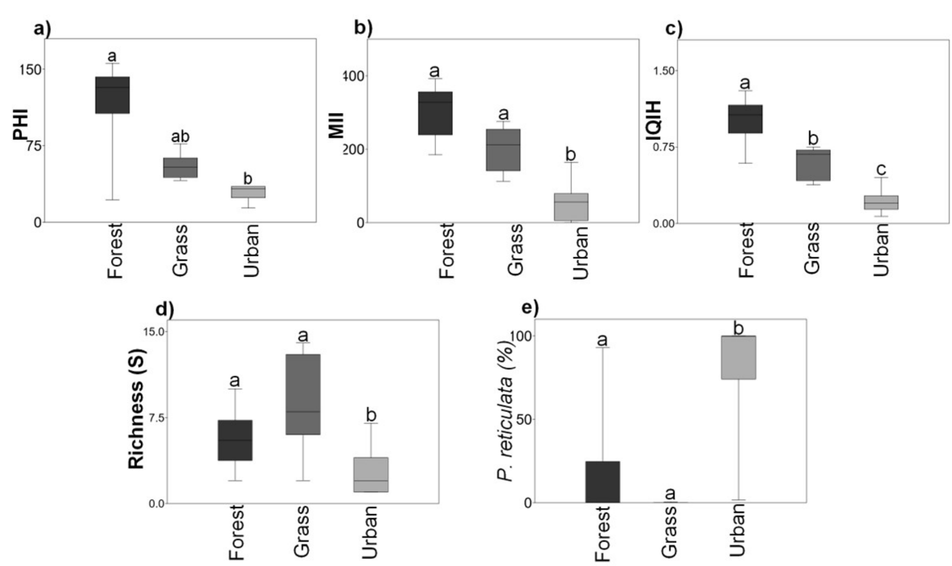

Figure 8. *B*oxplot according to land use. Averages followed by the same letter do not differ significantly by the Dunn's post hoc test. a) Physical Habitat Index (PHI) boxplot; b) Microbasin Integrity Index (MII) boxplot; c) Integrated Habitat Quality Index (IHQI) boxplot; d) Species richness estimator (S) boxplot; e) *P. reticulata* abundance percentage boxplot.

grass were equal and significantly different from urban (p = 0.00005 and p = 0.03) (Figure 8b, Table 3).

The Integrated Habitat Quality Index (IHQI) was used to integrate the two scales, local and catchment. We found that all forested streams were classified as good integrity, except stretches S14 and S24 which have been classified as moderate integrity; all streams with grasses and shrubs were classified as moderate disturbance; all urban streams presented values showing high environmental disturbance. The IHQI results showed significant differences between groups (p = 0.0001), and all groups were significantly different from each other (p = 0.04, p = 0.00003 and p = 0.04) (Figure 8c, Table 3).

Species richness data differed significantly among land use groups (p = 0.0008); however, forest and grass vegetation groups were equal to each other, but significantly different from the urban group (p = 0.04 and p = 0.002, respectively) in group to group comparisons, according to the Dunn test (Figure 8d, Table 3).

The biological indicator used for environmental degradation, *P. reticulata* abundance percentage, showed sensitivity to urban land uses. In this group, six of the streams had *P. reticulata* abundance greater than 50%. In the group with forest vegetation, stream S5 had high *P. reticulata* abundance (97%), characterizing high environmental disturbance level. Although the physical characterization does not point to degradation, the stretch is inserted in a municipal protected area that received urban effluents in the microbasin.

P. reticulata percentage abundance showed significant difference among land uses (p = 0.0006), with forest and grass vegetation equal to each other and different from the urban group (p = 0.002 and p = 0.002) (Figure 8e, Table 3).

The linear regression result explains the improvement trend of PHI when MII increases; therefore, in streams influenced by urban structures, sites were plotted below the trend line, showing that these environments are strongly related to environmental disturbances (r^2 = 0.75) (Figure 9a).

Considering the biological responses, data reflected polynomial graphical models responding to a trend line in the form of a parabola over the gradient, with preserved environments presenting high richness and moderate impact, with the addition of new species, increasing the richness values and with degraded environment, species richness is considerably reduced, keeping only tolerant taxa. This trend can be observed in polynomial regression graphs of PHI (r^2 = 0.32) and MII (r^2 = 0.39) indexes; the curve trend is even more evident when analyzed with the integrated IHQI index (r^2 = 0.45) (Figure 9b, 9c and 9d).

4. Discussion

Data obtained from land use and occupation classification are fundamental for environmental monitoring, considering that human activities in tropical lotic environments can have important effects on aquatic biota. It was observed that the habitat quality represented by physical indexes acts in the biotic structuring of streams. The results obtained allowed characterizing the physical impact of land use caused by the urbanization process, and it could be detected by some ichthyofauna indicators (i.e. species richness and guppy abundance). This pattern was confirmed in our study, where low values of the indexes PHI, MII and IHQI in urban and exposed soil were related to fish species richness and *P. reticulata* dominance (more than 50%).

The concern with water resources comes from their close connection with environmental impacts associated with land occupation, removal of riparian forests, indiscriminate use of water, sedimentation, construction of dams, among other factors that have contributed to the disappearance of rivers and lakes (Araújo et al., 2009).

The results show the importance of vegetation cover in the channel margin and in the riparian

Table 3. Results of the Kruskal-Wallis test and Dunn's post hoc multiple comparison test among land use groups for each variable.

Variables	(p)	Forest – Grass	Forest – Urban	Grass – Urban
PHI	0.000635	0.07508	0.000128*	0.05867
MII	0.000273	0.07932	0.00005113*	0.03429*
IQIH	0.000184	0.04951*	0.00003513*	0.04511*
S	0.008749	0.2099	0.04077*	0.002348*
P. reticulata	0.000642	0.3296	0.002904*	0.000268*

*There is a significant difference between sample medians

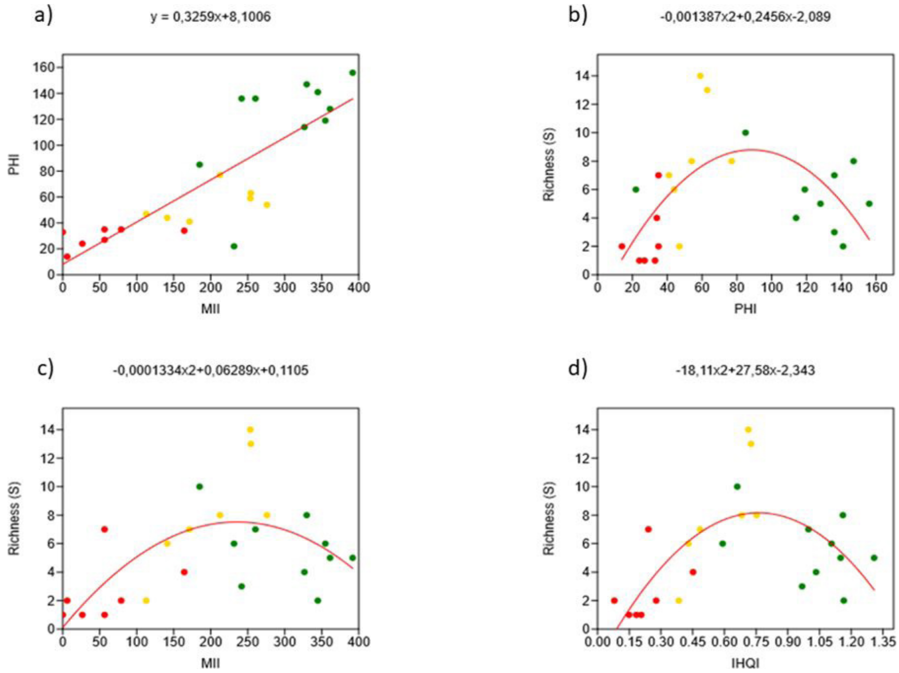

Figure 9. Regression graphs. a) Linear regression graph with PHI and MII index; b) Polynomial regression graph of species richness and PHI variables; c) Polynomial regression graph of species richness and MII variables; d) Polynomial regression graph of species richness and IHQI variables. S = species richness; PHI = Physical Habitat Index; MII = Microbasin Integrity Index; IHQI = Integrated Habitat Quality Index; red dots = urban; yellow dots = grass vegetation; green dots = forest vegetation.

buffer for the environmental quality of tropical streams, since the best PHI, MII, IHQI and species richness results were observed in streams that maintained vegetation in the landscape scale (forest and grasses). Within these two groups, only one stream showed *P. reticulata* abundance greater than 50%. Studies predict that land use change and consequent habitat degradation by human activities will have the greatest impact on biodiversity decline and consequent species extinction for the next 100 years (Sala et al., 2000). The native biota maintains a balanced biological system, but human beings modify landscapes and streams, compromising biological integrity with the degradation of physical habitats, with consequent decline in fish diversity (Karr, 1998). Recent estimates in Brazil point to species loss from 5.4% to 7.6% with the suppression of native vegetation for riparian buffers of up to 100 m (Dala-Corte et al., 2020).

The importance of riparian vegetation for maintaining environmental health of several habitats and, consequently the conservation of species, including fish, is well known. In this sense, Marchetti & Moyle (2001) and Casatti et al. (2009) affirm that the maintenance of this cover is an important environmental factor that contributes to environmental quality, promoting habitat diversification and structuring of fish assemblages in streams. In this study, environments with riparian vegetation have high PHI values when compared to the grass group, and even higher than urban landscapes. These results are also found in other studies in different biomes and regions, climate, geography and plant formation contexts (Callisto et al., 2001; Casatti et al., 2006b; Krupek, 2010), reinforcing the usefulness and validating this indicator as a tool for monitoring and handling tropical estuarine streams, such as those that compose MMELC, minimizing biotic losses caused by habitat degradation.

With the PHI protocol, it is not capable of identifying impacts outside its scale that act on the quality of streams and biotic structuring, then MII was proposed and applied for landscape assessment. Evaluation on this scale favors comparisons between locations and highlights the role of land occupation (Taddeo & Dronova, 2020). The landscape evaluation values obtained by the application of MII corroborate the biotic results. In Ligeiro et al. (2013), the catchment disturbance index (CDI) and the local disturbance index (LDI) were not able to explain the biological responses in all portions of studied basins. Reinforcing the need to use the integration of indices from different scales to obtain more accurate results. In addition, it was possible, with the application of MII, to infer that anthropic changes in the natural landscape produce negative ecological responses in streams with good riparian evaluation provided by PHI, as observed in S4 and S5. The first is inserted downstream of a recreational resort that makes water dams to supply its pools. Studies have shown that fish assemblages are sensitive to river flow barriers and the interruption of hydrological connectivity causes fauna homogenization (Li et al., 2013), the obstruction acts as a biogeographic barrier that fragments the habitat, preventing recolonization and causing species loss (Franssen, 2011). Therefore, even with good environmental conditions, the low species richness in the stretch can be attributed to the stream dam, which prevents downstream colonization. The second is geographically located in a valley that receives a high load of urban effluents with changes in water quality, and dominance of *P. reticulata*. The guppy dominance is commonly associated with urban impacts in streams, since the species exhibits generalist, opportunistic and high tolerance to conditions of intense habitat degradation (Casatti et al., 2006a; Cruz & Pompeu, 2020; Ganassin et al., 2020). According to Gomes-Silva et al. (2020), *P. reticulata* abundance increases proportionally to the level of water pollution, so, it could be concluded that the stretch is affected by the discharge of urban effluents.

In an attempt to integration of results of the two scales (local and landscape), the IHQI was applied, reflecting divergences of biological responses that occur when indexes are applied separately (i.e. abundance of alien species in good integrity local stream), which significantly reflect on the structuring of fish communities in a polynomial model with graphic curve in the form of a parabola for species richness, which follows the gradient from conserved to degraded. A predictable structure would cause a linear ecological pattern over the course of the gradient. The parabola pattern in the species richness behavior follows the hypothesis of intermediate disturbance (Connell, 1978), that is, in the transition environment from conservation to degradation, where there is increase in species in the middle of the curve, for later reduction and homogenization. In this situation, the environment tends to present greater diversity, leading to a flawed interpretation of good environmental conditions, from which it could be inferred that the increase in richness in the intermediate gradient of this study does not necessarily mean good environmental conditions.

Thus, local and landscape descriptors enable the construction of a robust integrated index IHQI. It index permits statistically discriminate significant differences between land use groups and provide more adequate subsidies for the understanding of biotic structures, which was not possible with PHI and MII indexes individually. According to Martines & Toppa (2018), the combined use of local and landscape scales in environmental monitoring is essential for conservation, especially in the Atlantic Forest region, where there is wide variety of land uses and occupations. Therefore, it could be inferred that this integrated scale approach helps equalizing assessments in the complex's drainage network. Thus, the proposal of integration of local (PHI) and landscape (MII) scales showed relevant results to equalize the individual distortions of each land use and occupation. Levin (1992) states that integrating descriptors that act in different scales is important to solve problems of increasingly complicated distortions, involving wide ranges of ecosystem scales, explaining environmental impacts.

With data obtained, it was possible to conclude that the ecological conditions in MMELC streams are strongly linked to land use. It pattern was corroborated by Hepp & Santos (2009), who affirm that anthropic changes in watersheds cause geological and chemical alterations in the water body that reach the associated biota. In MMELC, several changes in the landscape are evident which, according to Souza et al. (2004), alter the ecological balance, causing environmental disturbances such as reduction in species richness. In the interpretation of results, it is clear that environments with riparian vegetation cover (forest or grasses) have greater species richness and environments with influence of urban effluents have high *P. reticulata* percentage. Floyd et al. (2013) observed that environments with more complex habitats reflect an increase in species richness, compared to degraded environments and Casatti et al. (2006a) associates *P. reticulata* species to degradation conditions. These biological estimators do not show changes in the taxonomic composition, as they do not focus on species that compose the community. Species richness observes the number of different taxa in the community; however, greater diversity is related to better ecological conditions.

In order to improve the biological results at MMELC, it is essential to restore forest fragments and protect water bodies that operate in this hydrographic unit. Vegetation cover in the watershed causes structural and functional changes in the drainage condition, acting in the ecosystem recovery (Dyste & Valett, 2019) and environmental restoration of streams positively influences the fish community (Floyd et al., 22013). In addition, the presence of riparian vegetation decreases the runoff speed, stabilizes soil and maintains water quality, which positive effects do not depend only on natural formations, but, in deforested areas, they can be recovered by environmental restoration processes (Monteiro et al., 2016).

5. Conclusions

Data from riparian (PHI), microbasin (MII) and integrated index (IHQI) were related to biological indicators. Streams with vegetation cover have better biological results compared to environments with human occupation. For environments with tree and grassy vegetation cover, biological results did not indicate any difference in statistical tests, reinforcing the effect of the riparian vegetation on the maintenance of the stream physical habitat integrity and the fish indicators.

Physical characterization data of streams inserted in different types of land uses in the MMELC landscape confirm the growing concern with the monitoring of the environmental quality of estuarine lotic environments (streams and rivers). Thus, the MII tool is a proposal for assessing the quality of microbasins of streams and a promising instrument applicable to environmental monitoring, given that its application does not require hardware and software complexity and presents satisfactory results, which are consistent with literature. In the integration of scales, the IHQI calculation as a proposal of applied protocols showed sensitivity to distinguish the different land uses and occupations, which could be used as a tool to define environmental gradients. Furthermore, only with scientific based studies society could pressure the public environmental agencies to make their responsibility to monitor and evaluate the quality of these essential natural resources.

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