Biomonitoring In Limnic Environments: A Scientometric Approach

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ABSTRACT

In the face of increasing human impacts, biomonitoring emerges as an approach to evaluate the status of these ecosystems. Our purpose was to evaluate the publications on biomonitoring in limnic environments and to answer the following questions: (i) What are the tendencies and subjects in biomonitoring studies around the world? (ii) Are the countries' human development index (HDI) and the available water volume capable to influence publications on biomonitoring? (iii) How are distributed biomonitoring publications by biological groups (e.g., fish, plants, phytoplankton, zooplankton, periphyton, insects) and by environments (lotic and lentic)? To access the publications about biomonitoring in limnic environments, we performed a search in the Web of Science database, restricted between 1991 and 2016. The scientific interest in biomonitoring in limnic environments showed an increasing trend over the years. Furthermore, the countries that presented the highest number of biomonitoring publications had also high HDI values, which reflected high investments in research and development or specific legislation for water quality monitoring. Despite the significant relationship, the water volume was not a major factor influencing the research development. Our study revealed that fish, macroinvertebrates, and lotic environments were the most used for biological monitoring purposes.

Key-Words: biological monitoring, HDI, water resources, bioindicators.

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D ue to severe habitat loss, fragmentation, pollutant emissions, and world population growth, the extinction tendency is higher than what has already been estimated in various geological epochs (Ceballos et al. 2015; Isbell et al. 2017). The increase in the incidence of anthropogenic stressors to natural processes with excessive nitrogen and phosphorus inputs, improper use of the freshwater available and the industry growth put in doubt the real land boundaries, considering that changes of local anthropic origin can generate effects on a global scale. Therefore, it was created create the possibility of a new geologic epoch, named "Anthropocene"(Corlett 2015).

Human activities such as irrigation, riverine transpositions, navigation, industrial waste discharges, and agricultural inputs, among others, may negatively affect the quality and availability of freshwater in continental environments, also called limnic environments (Peters & Meybeck 2000). Such activities, when carried out without planning, may generate significant impacts in the structuring and functioning of global freshwater ecosystems (Steffen et al. 2015; Isbell et al. 2017). This is of concern because, even though it represents only 0.8% of the planet's surface, the limnic environment is the habitat of around 06% of all number of species described (Peters & Meybeck 2000).

The human population growth on earth increased the demand for natural resources and, consequently, expanded the anthropic impacts on natural environments (Crist et al. 2017). Therefore, actions from public entities to measure and control these impacts have become necessary, like the use of organisms as monitoring instruments of anthropic impacts in natural environments (biomonitoring) (Isbell et al. 2017). Biomonitoring is an approach to evaluate the conservation status of these ecosystems in which species richness, diversity, biomass, population size, presence of chemical compounds or metal bioaccumulation in organisms, among others, may be used as biological variables (Oertel & Salánki 2003, Zhou et al. 2008). The use of such variables is considered relevant to complement physical and chemical assessments because organisms respond to changes in environments throughout their lives (Oertel & Salánki 2003); some respond faster (e.g., zooplankton and phytoplankton) (Reynolds 1980; Vieira et al. 2011) and others need more time (e.g., fish) (Karr 1981; Flotemersch et al. 2006), usually according to their life cycle. So, the biomonitoring covers a temporal assessment beyond the sampling moment (Dziock et al. 2006). On the other hand, environmental variables (e.g., chemical and physical variables) represent the environmental conditions of the sampling moment.

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Several countries, generally those that are environmental resources abundant, have been negligent in their policies for biodiversity conservation in a way that the legislation became incompatible with the maintenance of a rich biological diversity (Pelicice et al. 2017). On the other hand, other regions with less abundance in water resources, such as the European Union, faced with a social demand, implemented the "Water Framework Directive" in 2000 to promote the improvement of water quality through environmental and biological monitoring (WFD 2000). Such legislation highlighted the importance of social pressure as one of the main factors for the implementation of public policies.

It is essential to understand the directions of studies involving biomonitoring. The scientometric method is a viable approach to understand the interest of the scientific community in a particular topic, as well as the factors that may determine this interest in order to point out gaps and questions for future studies (Vaz et al. 2015). In this way, our purpose was to evaluate the publications on biomonitoring in limnic environments, and to answer the following questions: (i) What are the tendencies and subjects in biomonitoring studies around the world? (ii) Are the countries' human development index (HDI) and the available water volume capable to influence publications on biomonitoring? (iii) How are distributed biomonitoring publications by biological groups (e.g., fish, plants, phytoplankton, zooplankton, periphyton, insects) and by environments (e.g., lotic and lentic, estuary, general and laboratory)?

Our expectations were that (i) as a reflection of a greater concern of the global population about water quality and availability of water resources, there would be an increasing temporal trend in the number of publications on the biomonitoring of limnic environments; (ii) countries with greater availability of water resources are more concerned with the preservation of their resources. As well, countries with higher HDI values, as they also reflect higher levels of education, have greater environmental concerns, which would reflect in greater studies on the biomonitoring of aquatic environments; (iii) that studies on larger organisms (e.g., fish) were more representative, as well as the lotic environments were representative of a larger number of publications;

METHODS

Data sampling

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To access the publications related to biomonitoring in limnic environments, we conducted an advanced search in the main database of Web of Science™, named Web of Science Core Collection. We restricted the search for the period of 1991 to 2016 and we used the following keywords (and sometimes variations of these, shown below) to limit the search to limnic environments: river, stream, lagoon, lake, floodplain, dam and freshwater, and also estuary when it was not used to evaluate sea water.

We used the Boolean vectors "AND" to select publications with all the words specified; "OR" to select publications with one or other word; or "NOT" to exclude articles with certain words. We also used the codes TI and TS to restrict the search to words found only in title or topics (topics = title, abstract, and keywords), respectively. Following this description, we inserted exactly the following expression in the advanced search of Web of Science™: TI= (biomonitor* OR (biologic* AND monitor*) OR (biologic* AND indicat*) OR bioindicator* OR (ecologic* AND indicat*) OR (index AND biologic* AND integrit*) OR (index AND biotic* AND integrit*)) AND TS=(water OR river* OR stream OR lagoon OR lake OR floodplain OR estuar* OR limnolog* OR freshwater OR dam OR hydroelectric) NOT TS=(sea OR ocean OR marine).

Additionally, we performed another search in order to add only the articles related to marine environments and estuary together, because in the previous search we realized that removing marine environments we automatically removed most articles related to estuary that did biomonitoring in limnic environments but mentioned marine environments in their abstracts. So, for this new search, we inserted exactly the following expression: TI= (biomonitor* OR (biologic* AND monitor*) OR (biologic* AND indicat*) OR bioindicator* OR (ecologic* AND indicat*) OR (index AND biologic* AND integrit*) OR (index AND biotic* AND integrit*)) AND TS=(water OR river* OR stream OR lagoon OR lake OR floodplain OR estuar* OR limnolog* OR freshwater OR dam OR hydroelectric) AND TS=(sea OR ocean OR marine) AND TS=estuar*.

Then, both results were combined into Web of Science™ to unify and to avoid duplication. We performed all searches until November 10, 2017. Then, we imported the data set from Web of Science TM to 26 spreadsheets, each one corresponding to one year evaluated. All article titles and abstracts were analyzed by one reviewer to ensure that all the articles were related to the purpose of this study.

We identified 1828 publications through search terms in the Web of Science Core Collection. After checking that there were no duplicate publications, we investigated whether the publications dealt with biomonitoring in limnic environments and, in this stage, we excluded 487 publications that were

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not related to the aim of this study. We used 1341 publications for the descriptive analyses. Then, we randomized 20% of these publications (n = 269) and selected for the evaluation of environments, organisms, and organisms by the environment.

After the selection of the articles, we analyzed each spreadsheet in the HistCite™ software to be possible to access the following results: number of articles per year, principal authors, number of publications by journal and number of publications by country.

Data analysis

First, whether there is a temporal trend in the number of publications and the number of publications that have researched on the subject over the past few years, we performed a linear regression between years and the number of publications by year. Then we estimated the annual diversity index of journals using the Shannon-Wiener diversity index (H') (Magurran 1988), and we provided the number of publications as abundance and the number of journals as richness, by year.

To evaluate the different main subjects and tendencies of the articles, we created a map of words using the software *VOSviewer*. This software creates maps based on similarity association strength matrices, so the words that are closer in the map tend to be more associated with each other, as well as more distant words are less associated. The program also creates a clustering of similarity, in which words that belong to the same group have the same color, and the size of the words are related to the number of citations in publications (van Eck & Waltman 2010). To perform this analysis, we imported the file from Web of Science™, inserted it into the program VOSviewer, and created the map based on text files (titles and abstracts). Then we selected the binary counting method in order to count only one occurrence of the given term for each publication. To create the word map, we required that words must occur in at least fifty publications, thus avoiding words with small occurrence.

We obtained the water volume availability and the HDI in each country in the page of the Food and Agriculture Organization of the United Nations (FAO, 2019) related to the year 2014 and the values were given in km³. We performed a correlation of Spearman to evaluate the relation between factors – water availability volume and HDI – and the number of publications and also between years and number of articles published in each country in order to evaluate the interest and tendency on biological monitoring by countries over the years. Then, we performed a descriptive analysis to evaluate

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the number of publications by biological groups and environments studied. In these analyzes, we considered the entire set of publications found.

Finally, we divided the environments into four categories to classify the sampled studies: lotic, lentic, lotic/lentic (when it was related to both), estuary, general (when it was related to continental aquatic environments in a general form) and laboratory (studies conducted in laboratory or mesocosms directly related to limnic environments). The organisms were categorized as: macroinvertebrates (annelids, arthropods, molluscs, among others), fish, plants (trees, mosses, macrophytes), bivalves, phytoplankton, crustaceans, bacteria, zooplankton, periphyton, amphibians, human (as bioindicators), and others with less representation in number of publications (foraminifera, birds, porifera, mammals, parasites and fungi). In these analyzes, we evaluated 20% of publications (269 articles).

RESULTS

The 1341 publications on biomonitoring of limnic environments were increasingly distributed between 1991 and 2016 (Figure 01.a). Furthermore, we detected an expressive increase in diversity of journals that had published studies on this subject over the years (Figure 01.b).

Figure 01 (a): Total number of publications per year and (b) index of Shannon-Wiener diversity applied to journals that published on the biomonitoring in limnic environments between 1991 and 2016
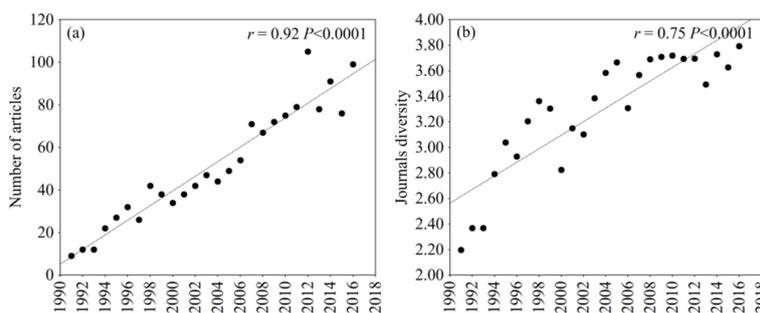

The United States presented the highest number of publications (Figure 02). As second-placed France and Canada. On the other hand, African countries showed the fewest studies related to this topic.

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Figure 02: Worldwide distribution of publications related to biomonitoring in limnic environments between 1991 and 2016
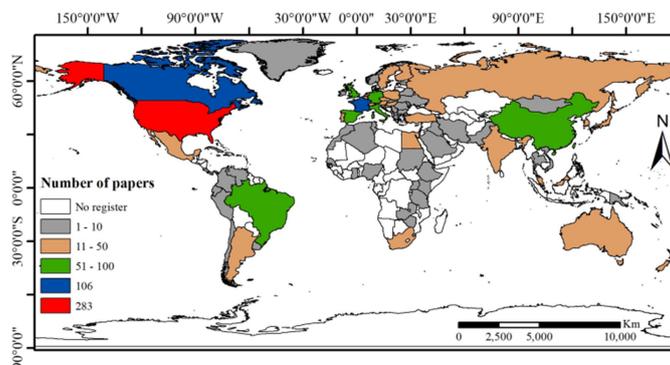
Brazil, Russia and the United States had the highest volume of available limnic water resources, but the countries that presented the highest number of articles on this subject were the United States, France, and Canada (Figure 03.a). Brazil and Russia each had fewer publications than France. Furthermore, other European countries had also been distinguished with a higher number of publications, even though these countries have less territory area and water volume, like Spain, the United Kingdom, Italy, and Germany. However, these European countries showed the highest values of the human development index (HDI) (Figure 03.b) among the countries that published on the topic. Besides that, HDI was a more relevant variable than the total volume of water resources.

Figure 03: Scatter plot relating the (a) total volume of available water resources and (b) HDI of the countries to the number of publications
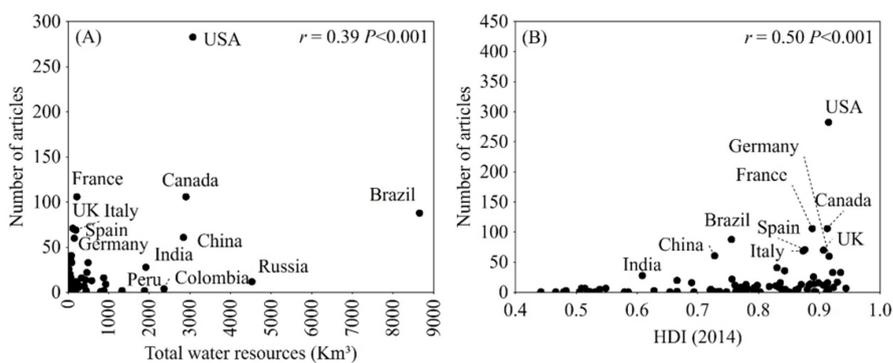
We identified two groups with different tendencies related to the words in publications title and abstract (Figure 04): (i) "metal concentration in organisms and exposure to pollution and contamination", with the following words more related to this group: concentration, metal, activity,

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exposure; and (ii) "ecological responses of biological organisms", with the words/expressions index, metric, taxa, biotic integrity, abundance and diversity more related to this group.

Fishes, macroinvertebrates, and plants received considerable attention from the scientific community over the years, in the same way that lotic environments were highly representative in biomonitoring publications, representing more than twice as many publications as lentic environments (Table 01). Fish were the most representative organisms in laboratory studies, followed by bivalve organisms (Table 01).

Figure 04: Map based on title and abstract words. Words closer and with the same colors indicate similarity and the size is related to the number of publications
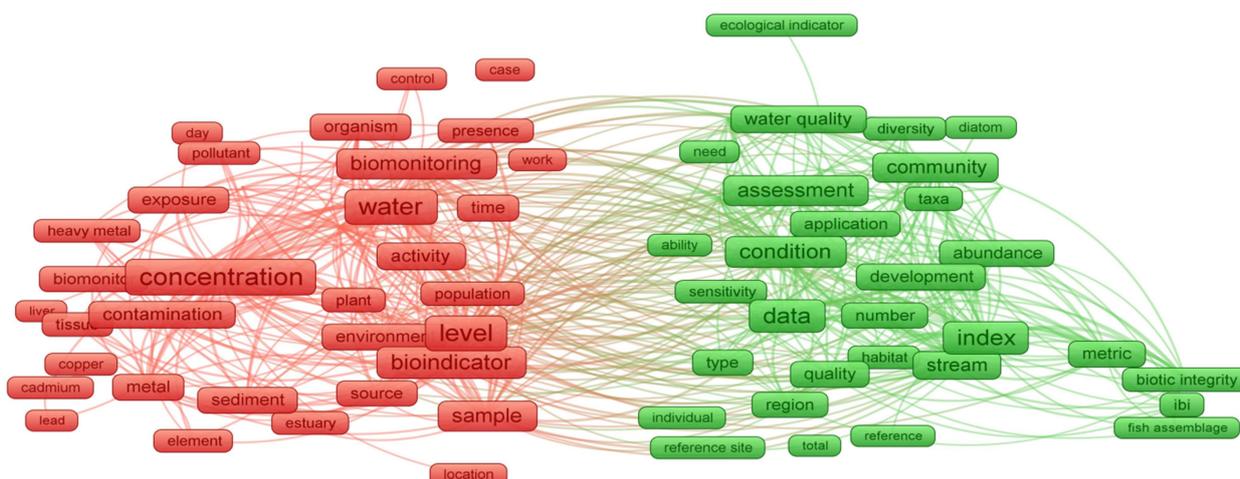
Table 01. Number of publications from the screened articles per group and environment

Groups	Environments						Total
	Lotic	Lentic	Lotic/Lentic	Estuary	General	Laboratorial	
Amphibians	2	0	1	0	0	0	3
Birds	0	1	0	0	1	0	2
Bacteria	1	0	2	1	3	1	8
Bivalves	3	6	4	3	2	8	26
Crustaceans	7	3	2	4	1	3	20
Fishes	46	15	2	6	3	9	81
Foraminiferans	0	0	0	2	0	0	2
Fungi	0	0	1	0	0	0	1
Humans	0	0	0	1	2	0	3

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Macroinvertebrates	42	10	6	5	5	4	72
Periphyton	1	2	0	0	1	0	4
Phytoplankton	11	8	5	2	1	1	28
Plants	18	10	3	3	0	3	37
Zooplankton	1	4	0	0	1	1	7
Others	4	2	3	3	11	0	23
No registry	1	0	1	0	0	0	2
Total	137	61	30	30	31	30	319

Source: Author

DISCUSSION

In this study, it was possible to detect the growing interest of the scientific community in studies related to limnic environments, given the increasing number of publications and diversity of journals that have published articles on the subject over the years. Science has shown an increasing trend in the number of publications and research related to biomonitoring in limnic environments over the years. It is important to note that several European countries that had publications on this subject (including France which placed second in the ranking) have a low volume of water resources. The interest in these countries on monitoring limnic environments may be associated with their high HDI values.

The HDI takes into consideration income, education and health (PNUD 2018) and the practice of aquatic environments monitoring may be directly reflected on the health of the population (Lee et al. 2017; Gifford et al. 2018). Also, European countries share several river basins, so one country that misuses the water may be responsible for the impairment of water quality or supply cut (Mylopoulos & Kolokytha 2008) in other countries. Therefore, there is a cycle of environmental awareness, the effectiveness of biological monitoring programs, and population health that are visible in some European countries. Such factor justifies the implementation of the "Water Framework Directive" (WFD 2000) in the European Union, which emerged to improve the environmental status of the surface waters, in addition to the long-term of environmental and biological monitoring of these hydric bodies. It may explain the large number of European publications related to biomonitoring in limnic environments.

On the other hand, the African continent presented the highest number of countries without records of research on biomonitoring in limnic environments. Such results show the necessity for higher investments in environmental and public policies directed to the biomonitoring of water resources in this continent. The African continent, with an emphasis on sub-Saharan Africa, suffers

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severe political and social conflicts, so the population is affected in education, health and safety, which is mainly due to the arbitrary distribution of historically distinct ethnic groups within the same territorial limits (Easterly & Levine 1997). Besides that, this region has high biological diversity, and it is of concern the high population density (Balmford 2001).

As shown in our cluster analysis, the scientific community is studying the availability of metal concentrations in freshwater (Morina et al. 2016, Velez et al. 2016). The increasing anthropogenic activities caused increasing input of heavy metals, pesticides, and polycyclic aromatic hydrocarbons directly into aquatic environments or indirectly by the leaching of terrestrial environmental contamination, bringing several consequences for the balance of these ecosystems (Prosi 1981; Tao et al. 2012). The effects of organisms exposition to pollution and contamination have caused by pesticides and polycyclic aromatic hydrocarbons have a strong mutagenic potential and its availability in the environment is anthropically related (e.g., industrial, motor diesel) and natural sources (e.g., volcanic eruptions and fires) (Khalili et al. 1995; Manoli & Samara 1999). In the same way as heavy metals, the organic pollutants have several effects on the environment, including the extinction of species. This is promoted by vectors of contamination that are diluted in water and easily distributed among aquatic organisms that may be directly or indirectly affected by such factors, as bioaccumulation (Krcmar et al. 2018). In addition, there are many approaches to ecological indicators (e.g., biotic integrity indexes), in fact, ecological indicators have been shown to be effective in detecting changes at different spatial and temporal scales. In addition, they are associated with several forms of application (e.g. genetic variations, populations, communities and landscape patterns) (Niemi & McDonald 2004).

We observed that fish and macroinvertebrates are organisms that the global scientific community are most interested in, besides being organisms used worldwide in biomonitoring purposes. Macroinvertebrates are useful in detecting disturbances in aquatic environments, with emphasis on Ephemeroptera, Plecoptera, and Trichoptera, that are sensitive to environmental variations (Bonada et al. 2006; Li et al. 2010). Fish, on the other hand, have longer life cycles when compared to other limnic organisms and are capable of dispersing in face of unfavorable environmental conditions (Karr 1981; Li et al. 2010). Also, because they feed on other organisms, they are used to determine the bioaccumulation of many contaminants (Vinodhini & Narayanan 2008). On the other hand, bacteria, zooplankton, periphyton, amphibians, and humans had few articles. This fact is surprising, taking into account that these groups are usually pointed out as good bioindicators (Payne 2013; Pesce et al. 2013; Zhelev et al. 2016).

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Furthermore, there were few studies related to biomonitoring in lentic environments and estuaries, compared with lotic environments. Lentic environments occupy only a small area of continental territories, and most of these environments are small (Downing et al. 2006) which may justify the smaller number of publications on these environments. Despite lentic small water bodies have received little attention from the scientific community, some few studies highlighted their importance to the whole ecosystem functioning (Lorenz et al. 2017).

CONCLUSION

The scientific interest on biomonitoring in limnic environments showed an increasing trend over the years. Furthermore, the countries that presented the highest number of publications related to this subject had also high HDI indicators, high investments in research and development or specific legislation for water quality monitoring. Despite the significant relationship, national water volume was not a major factor influencing the research development.

Our study also revealed that fish and macroinvertebrates are the most studied groups of organisms with biological monitoring purposes, as well as lotic environments. On the other hand, there were few studies on lentic continental environments and estuary regions. There were also few studies evaluating the utility of bacteria, zooplankton, periphyton, amphibians, humans, foraminifera, birds, porifera, mammals, fungi and parasites on biomonitoring purposes.

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BIOMONITORAMENTO EM AMBIENTES LÍMNICOS: UMA ABORDAGEM CIENCIOMÉTRICA

RESUMO

Diante dos crescentes impactos humanos, o biomonitoramento surge como uma abordagem para avaliar o status desses ecossistemas. Nosso objetivo foi avaliar as publicações sobre biomonitoramento em ambientes límnicos e responder às seguintes questões: (i) Quais são as tendências e assuntos nos estudos de biomonitoramento em todo o mundo? (ii) O índice de desenvolvimento humano (IDH) e o volume de água disponível dos países são capazes de influenciar publicações sobre biomonitoramento? (iii) Como são distribuídas publicações de biomonitoramento por grupos biológicos (e.g., peixes, plantas, fitoplâncton, zooplâncton, perifíton, insetos) e por ambientes (lótico e lêntico)? Para acessar as publicações sobre biomonitoramento em ambientes límbicos, foi realizada uma busca na base de dados Web of Science, restrita entre 1991 e 2016. O interesse científico em biomonitoramento em ambientes limnicos mostrou uma tendência crescente ao longo dos anos. Além disso, os países que apresentaram o maior número de publicações em biomonitoramento também apresentaram altos valores de IDH, o que refletiu altos investimentos em pesquisa e desenvolvimento ou legislação específica para o monitoramento da qualidade da água. Apesar da relação significativa, o volume de água não foi um fator importante que influenciou o desenvolvimento da pesquisa. Nosso estudo revelou que peixes, macroinvertebrados e ambientes lóticos foram os mais utilizados para fins de monitoramento biológico.

Palavras-chave: monitoramento biológico, IDH, recursos hídricos, bioindicadores.