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Article

A Scientometric Analysis of the Use of Indices for Water Quality Biomonitoring

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ABSTRACT

Water resources are supplied under strong anthropic pressures and result in several problems of water contamination in the world, which necessitates the use of methodologies for their evaluation. Thus, this research aimed to identify the biomonitoring indices based on macroinvertebrates in the evaluation of the quality of the water used and to identify its application trends. The study was developed through a scientometric review over a 20-year period (2000–2020). The search consisted of articles indexed in the Scielo, ScienceDirect, and Scopus databases, based on the keywords "biotic index" * OR "aquatic macroinvertebrates" * OR "benthic macroinvertebrates" * OR "Biomonitoring" * AND "water quality." Selection, such as inclusion and exclusion, was applied in the Start program (State of the Art through Systematic Review-Start). The results showed that the EPT index (Ephemeroptera, Plecoptera, and Trichoptera) was the most used among all researched databases (20%), and among the Ecological Indicators journals from which the largest number of publications were obtained (11%). Regarding the indices used in biomonitoring research, the ASPT index (average score per taxon) was the only one with a tendency to increase in use over the years ($R^2 = 0.29$; $p < 0.05$). Although the biomonitoring indices are commonly used worldwide denoting that it is still an alternative tool, this literature review showed that among the indices only one has a trend of use, which must be considered for further research.
Keywords: macroinvertebrates, water resources, ecological indicators, review.

RESUMO

Os recursos hídricos são abastecidos sob forte pressão antrópica e dão origem a diversos problemas de poluição hídrica no mundo, que exigem o uso de metodologias para sua avaliação. Assim, esta pesquisa teve como objetivo identificar índices de biomonitoramento baseados em macroinvertebrados na avaliação da qualidade da água utilizada e identificar suas tendências de aplicação. O estudo foi desenvolvido através de uma revisão cienciométrica durante um período de 20 anos (2000-2020). A busca consiste em artigos indexados nas bases de dados Scielo, ScienceDirect e Scopus, com base nas palavras-chave "índice biótico" * OR "macroinvertebrados aquáticos" * OR "macroinvertebrados bentônicos" * OR "Biomonitoring" * AND "qualidade da água". A seleção, assim como a inclusão e a exclusão, foi aplicada no programa Start (estado da arte por meio de revisão sistemática-start). Os resultados mostraram que o índice EPT (Ephemeroptera, Plecoptera e Trichoptera) foi o mais utilizado entre todas as bases investigadas (20%) e entre os periódicos, obteve-se o maior número de Indicadores Ecológicos (11%). Em relação aos índices utilizados nas pesquisas de biomonitoramento, o índice ASPT (pontuação média por táxon) foi o único com tendência a aumentar sua utilização ao longo dos anos ($R^2 = 0,29$; $p < 0,05$). Embora os índices de biomonitoramento sejam comumente usados em todo o mundo, indicando que ainda é uma ferramenta alternativa, esta revisão de literatura mostra que dentre os índices apenas um apresenta tendência de uso, o que deve ser considerado para pesquisas futuras.
Palavras-chave: macroinvertebrados, recursos hídricos, indicadores ecológicos, revisão.

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Introducction

The human population has increased in association with the urbanization process in the last decades, negatively impacting water resources, with the emergence of problem of contamination of aquatic ecosystems in the world (Arslan et al. 2016; Wang et al. 2020). The intensified and indiscriminate use of water resources generated the need to establish guidelines for resource management and monitoring and protection programs for the sustainable use of water, as a measure to ensure safety and availability for all, as recommended by the Goals for the Millennium and the Sustainable Development Goals (World Program For United Nations Water Assessment Of Water Resources – WWAP, 2018).

Biological parameters, such as biomonitoring, gained space in the assessment of water quality as they are relatively simple, low-cost, and efficient tools, as well as informative to the public (De Queiroz et al. 2018). Biomonitoring can be defined as the systematic use of living organisms to assess the environmental changes arising from anthropic action (Johnson et al. 1993), which can be expressed through different indices that are used in different environments and groups of organisms (Kilgour et al. 2004; Li et al. 2010; Mao et al. 2019).

Germany was one of the pioneering countries in assessing water quality using biodiversity (Kolkwitz & Marsson 1909). In this country, at the beginning of the 20th century, the saprobity index was developed based on the use of bacteria, fungi, and protozoa as the first biological indicators. Subsequently, some European countries have used methods based on the same idea, but they call them biotic indices (Junqueira et al. 2010; Li et al. 2010).

The saprobity index is the basis for the creation of several other biotic indices, with the use of several organisms as biological indicators, including benthic macroinvertebrates (Metcalfe 1989; Steyn et al. 2019), which offer precise answers regarding the degree of pollution of the aquatic environment due to its wide distribution, prolonged life in the sediment, and low mobility, among other favorable characteristics (Callisto et al. 2006). Because they are tolerant or sensitive to specific environmental factors, the absence or presence of these organisms can be used as an indication of the state of the environment in a short evaluation period (Buss et al. 2003; Barbola et al. 2011).

A vast majority of biomonitoring indices originated in Great Britain, generated according to existing taxa; for use in other regions, they are tested and adapted according to the specificity of each location, such as the Biological Monitoring Working Party (BMWP). This index was created and tested in 1976 in the United Kingdom and uses benthic macroinvertebrates as organisms for the evaluation of water quality with identification at the family level (Gonçalves & Menezes 2011; Paisley et al. 2014).

The BMWP is still widely used in several countries because it is well adapted to the macrofauna present in several regions, and because its results accurately provide the degree of conservation of local water resources (Tafur et al. 2008). However, results obtained from the BMWP show that the use of this index for assessing water quality is highly dependent on the seasonal period and characteristics such as topography of each region, as well as reference degrees, which must be considered for adaptation of the index to the characteristics of the macroinvertebrate community in each ecosystem (Blijswijk et al. 2004; Fierro et al. 2012). This index scores families with values between 1 and 10, from organisms less tolerant to pollution (scores close to 10), such as ephemerals, to more tolerant ones such as chironomids (scores close to 1) (Hilsenhoff 1988).

Other biomonitoring indices that use benthic macroinvertebrates have been created, but they configure different scores for families found in a given ecosystem or that are calculated from the BMWP. The Family Benthic Index (IBF) also assigns a score for each family that ranges from 0 to 10, but with different scores for families when comparing the scores of the BMWP. The average score per taxon (ASPT) index is based on the results of the BMWP in order to make it more efficient, and is used to calculate the average of the values of

each family found in the BMWP index (Chutter 1972; Barbour et al. 1999; Gutiérrez-Fonseca & Ramírez 2016; Waydzik et al. 2018). The EPT index (Ephemeroptera, Plecoptera, and Trichoptera) is used to assess water quality based only on the percentage of identified organisms of the orders Ephemeroptera, Plecoptera, and Trichoptera in relation to the other taxonomic groups (Barbosa et al. 2020), which are quite sensitive to environmental changes or pollution.

The different adaptations of biomonitoring indices suggest that these methods have been considered important tools for the evaluation of water quality, and because of their relative ease in the collection, analysis, and interpretation of results, they are used worldwide. Therefore, knowing the use of biotic indices in environmental monitoring in several countries around the world allows the popularization of the state of the art for the scientific community. In this work, we aim to carry out a bibliographic survey of articles through a scientometric analysis to identify the biomonitoring indices with the use of macroinvertebrates in the evaluation of water quality. To this end, a diagnosis was made of (1) most used indices on a 20-year time scale (2000 to 2020), (2) journals that publish articles relating water quality to biomonitoring, and (3) trends in the use of biomonitoring indices in environmental assessment. Moreover, we also identified the researchers that uses biomonitoring indices to evaluate the water quality as a source for future researchers.

Methodology

This study was made through a scientometric review on biomonitoring indices of water quality from 2000 to 2020 (until March 2020), using StArt (*State Of The Art Through Systematic Review-Start*), version 2.3. 4.2, (2016). The period for data collection was based on the Millennium Goals, which foresees measures and improvements for water resources within the same period.

The search consisted of exploring articles indices to the Scopus, ScienceDirect, and Scielo databases based on the keywords, using the asterisk (*) after each term to contemplate words in the singular, plural, and their varied forms. The Boolean operators AND and OR were used in the databases; the AND operator served to combine two or more terms, and OR was used to group two or more terms that contained the words benthic macroinvertebrates, aquatic macroinvertebrates, biotic index, biomonitoring, and water quality.

The search string was organized in the following order: Biotic index * OR aquatic macroinvertebrates * OR benthic macroinvertebrates * OR Biomonitoring * AND water quality for the three databases mentioned above. Then, we filtered the material, containing some limitations for the time interval from 2000 to 2020, type of document (articles only), languages, English, Spanish, and Portuguese. After consulting the databases, the articles were exported in BibTex format to the Start program. To apply the selection criteria as "inclusion", publications containing the terms about the use of macroinvertebrates to assess water quality using biotic indices were considered.

The exclusion criterion in the research was considered for articles that did not address biomonitoring indices and benthic macroinvertebrates, articles that included only the water quality index and diversity indices, and studies that used macroinvertebrates correlated with other aquatic species.

The data were analyzed statistically using linear regression and polynomial regression of two orders to verify the trends in the use of biotic indices. The Kruskal-Wallis test was used to compare the contributions of publications from different continents. For all analyses, a value of $p < 0.05$ was considered significant, and the maps in the networks were created using VOSviewer version 1.6.16, demonstrating the main authors and keywords of the articles accepted for this research.

Results

Of the 518 publications found by the applied methodology 150 were rejected for not meeting the established criteria 49 did not include the files available in the online format, and 5 publications were duplicated in the databases, and 314 were accepted because they met the inclusion criteria of the research. Among the three databases searched, Scopus was the one with the largest number of publications, containing 92% of the total articles found, followed by Science Direct (5%) and Scielo (3%).

The EPT index was the most used index among all the researched databases (Figure 1). The time series under analysis in this research showed that the EPT and BMWP indices are significantly more used compared to the other indices (Kruskal-Wallis; $X^2 = 39.01$; $p < 0.01$), demonstrating that these indices are the most used in publications in recent years.

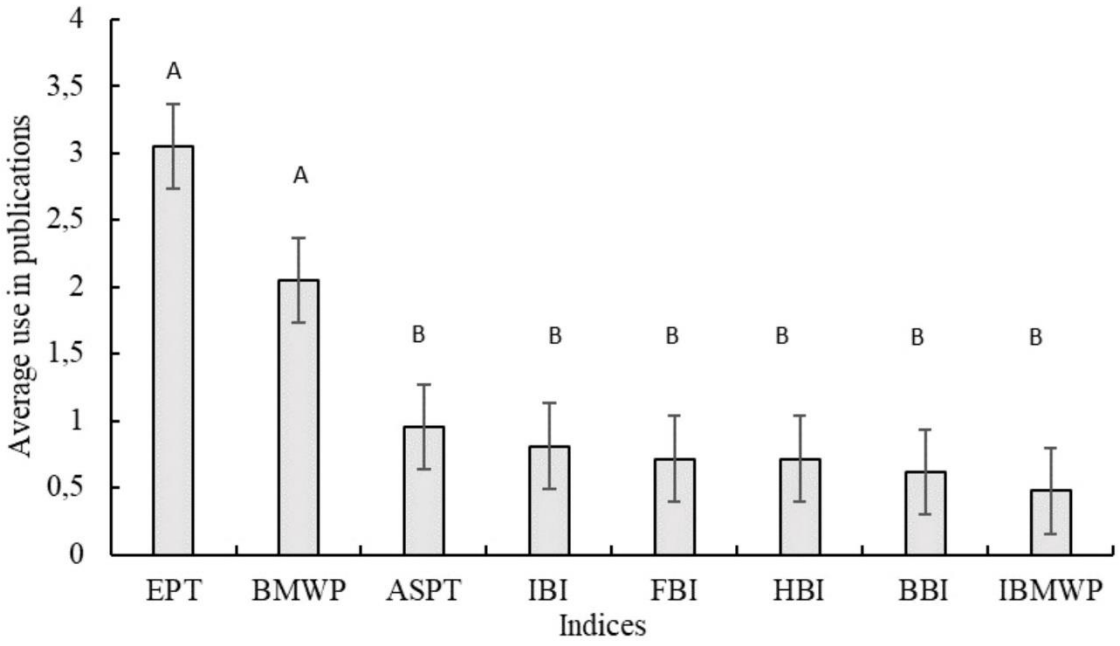

Figure 1 Biomonitoring indices most used in scientific publications between 2000 and 2020 in at least 10 publications. Vertical bars denote the standard deviation (Kruskal-Wallis; $X^2 = 39.01$; $p < 0.01$). EPT (Ephemeroptera, Plecoptera and Tricoptera), BMWP (Biological Monitoring Working Group), ASPT (Average Tax Score), IBI (Biotic Integrity Index), FBI (Benthic Family Index), HBI (Hilsenhoff Biotic Index), BBI (Belgian Biotic Index), IBMWP (Iberian Bio-Monitoring Working Party). Letters (A and B) denote differences.

Between 2000 and 2020, 141 scientific journals published articles on the use of macroinvertebrates to assess water quality. Among them, the Ecological Indicators magazine was the one with the largest number of articles, representing 11% of the total, followed by Environmental Monitoring and Assessment (5%), Hydrobiology (4%), and Limnetica (3%; Figure 2).

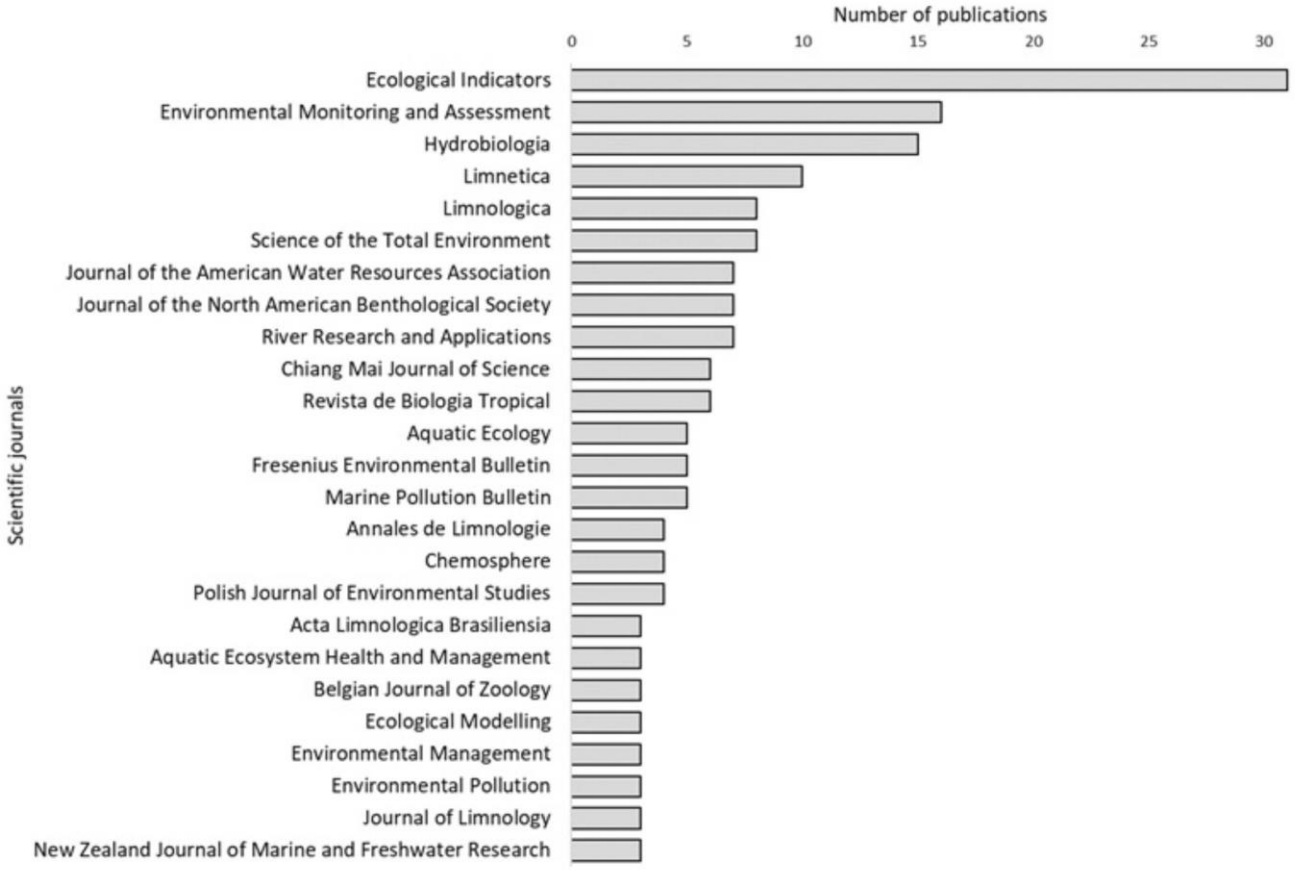

Figure 2 List of journals and the number of publications between 2000 and 2020 on the use of macroinvertebrates in assessing water quality. This figure presents only journals with at least three publications during the years surveyed (2000 - 2020).

The Ecological Indicators Journal, in addition to having the largest number of published articles, was the one with the highest number of biomonitoring indices, in which 35 indices appear to be used in the evaluation of water quality in this journal. Among them, the AMBI index (five publications) and EPT (four publications) were the most used.

According to the temporal analysis, the ASPT index was the only index with a tendency to increase the number of publications with its use (linear regression; $R^2 = 0.29$; $p < 0.05$; Figure 3). None of the other indices showed significant trends.

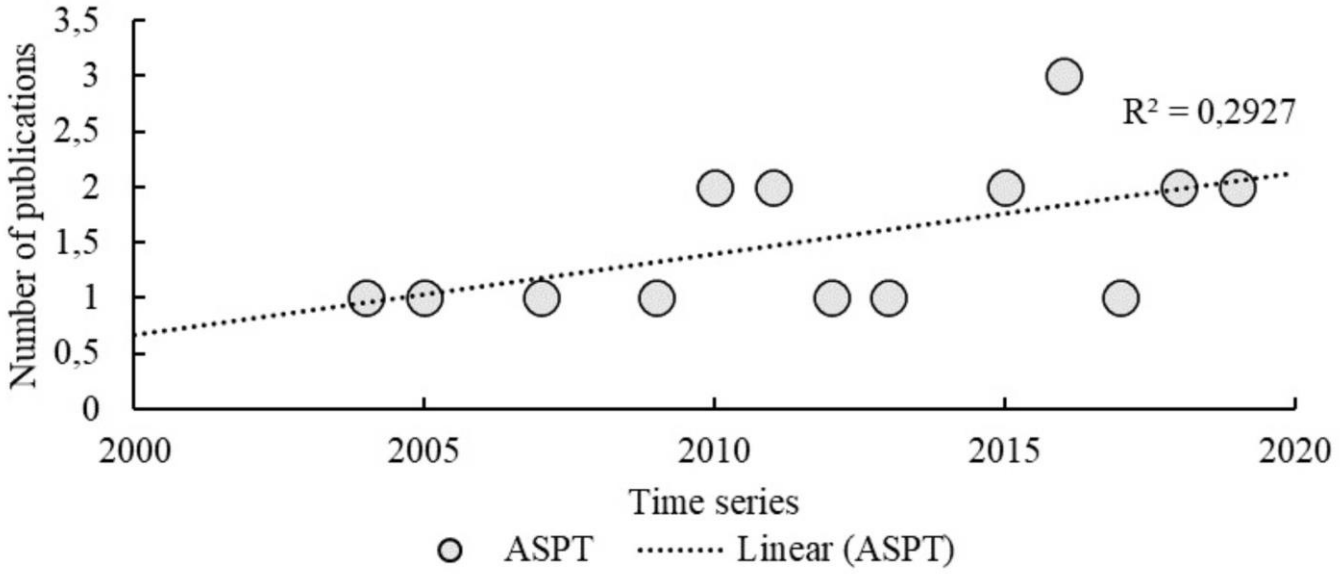

Figure 3 Relationship between the use of the ASPT index and the number of publications in the period 2000 and 2020 (Linear regression; $R^2 = 0.29$; $p < 0.05$). ASPT (Average Score Per Taxon).

Considering all the biomonitoring indices most used in the recent years or along the revised period, there was an increase in the number of articles published until the year 2012, with 27 publications during this year, contrasting a negative trend in the subsequent years until 2020, reducing to 15 publications in the year 2019 (polynomial regression of two orders: $R^2 = 0.71$; $F = 22.15$; $p < 0.01$; Figure 4).

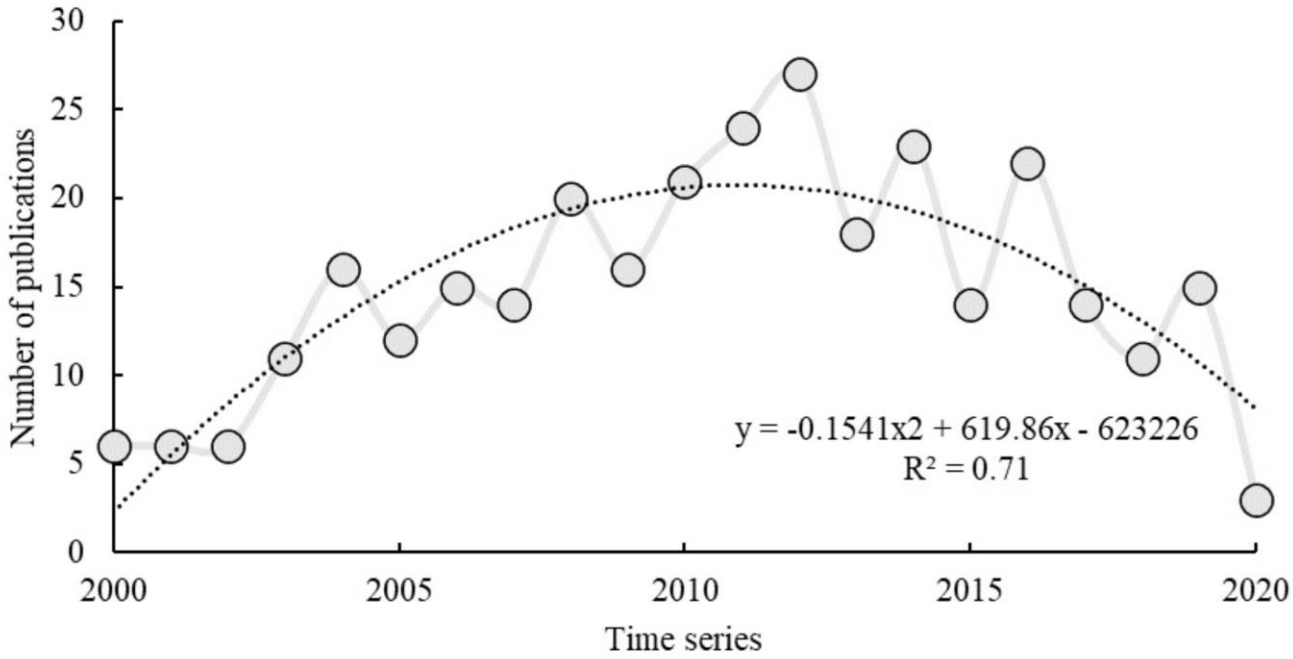

Figure 4 Evolution of the number of publications with biomonitoring indices with macroinvertebrates in the evaluation of water quality between the years 2000 and 2020. Two-order polynomial regression; ($R^2 = 0.70$; $p < 0.01$).

The published articles totaled 6,984 citations containing indices during the studied time series. The decade from 2000 to 2010 was the one with the highest number of citations of articles, with 2003 being the most representative (976%–14% of all citations), followed by 2007 (801%–11% of all citations). In the last decade, there has been a significant decline in the number of citations (polynomial regression of two orders: $R^2 = 0.50$; $F = 9.01$; $p < 0.01$).

Among the places of publication, the United States of America (USA) was the country with the largest number of publications on macroinvertebrates as tools for biomonitoring, representing 16% of all publications. Subsequently, Portugal and Italy accounted for 5% of the total number of publications. China, South Africa, and Brazil accounted for 4% of the total publications.

The USA was also the country with the largest number of publications carried out annually on average (2.5 ± 1.7), followed by Italy (0.85 ± 0.91) and Portugal (0.85 ± 1.55). The distribution of research carried out with macroinvertebrates in assessing water quality is concentrated mainly in the USA, followed by Europe and Asia. For example, a comparison between the continents showed that the American and European continents present similar number of studies, while America has four times more research performed than the African continent (Kruskal-Wallis; $X^2 = 48.14$; $p < 0.01$).

The articles indexed in the databases presented 1,655 keywords in the 20-year interval, among which the most used were macroinvertebrates (7%), followed by water quality (5%) and biotic index (3.93%). The analysis of networks considering at least the appearance of the keyword five times among the 314 accepted articles demonstrated the formation of six clusters, inspired by the words macroinvertebrates (red), water quality (green), benthic macroinvertebrates (blue), ecological status (yellow), diatoms (light blue), and water framework directive (purple) (Figure 5).

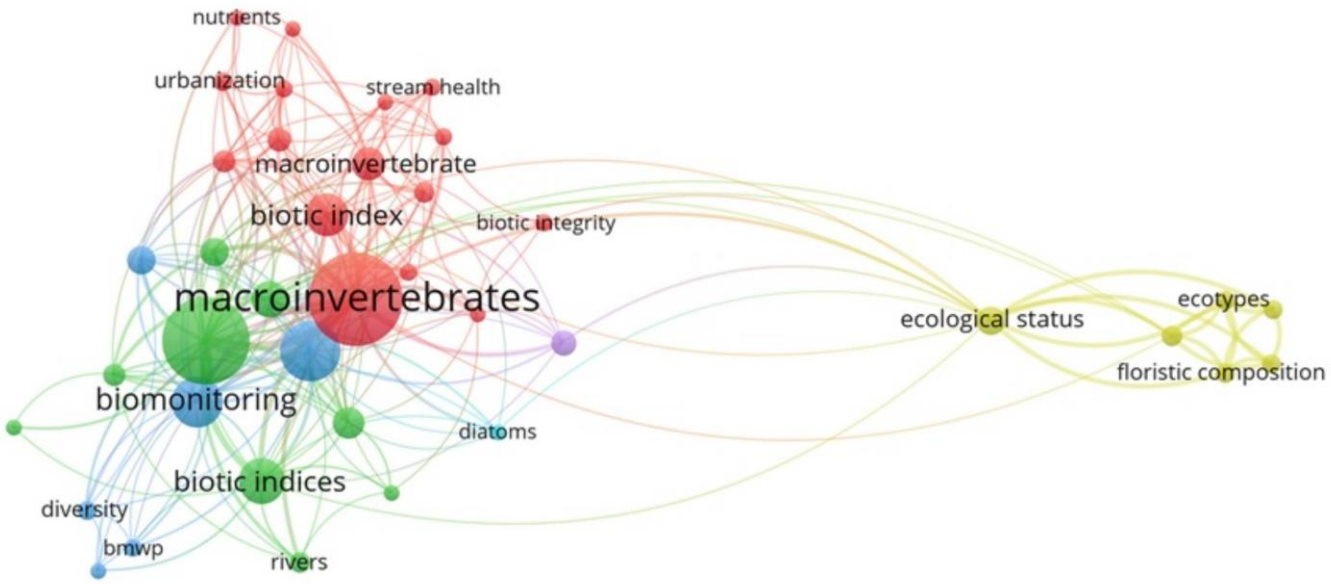

Figure 5 Keywords used in articles accepted for scientometric analysis published between 2000 and 2020.

Among the analyzed articles, the network formed highlighted six clusters with 44 authors (Figure 6), in which Goethals, Lock, Boets, De Pauw, Musonge, Dominguez-Granda, Mereta, and Nopens were highlighted as the main authors with the highest number of publications over the past 20 years.

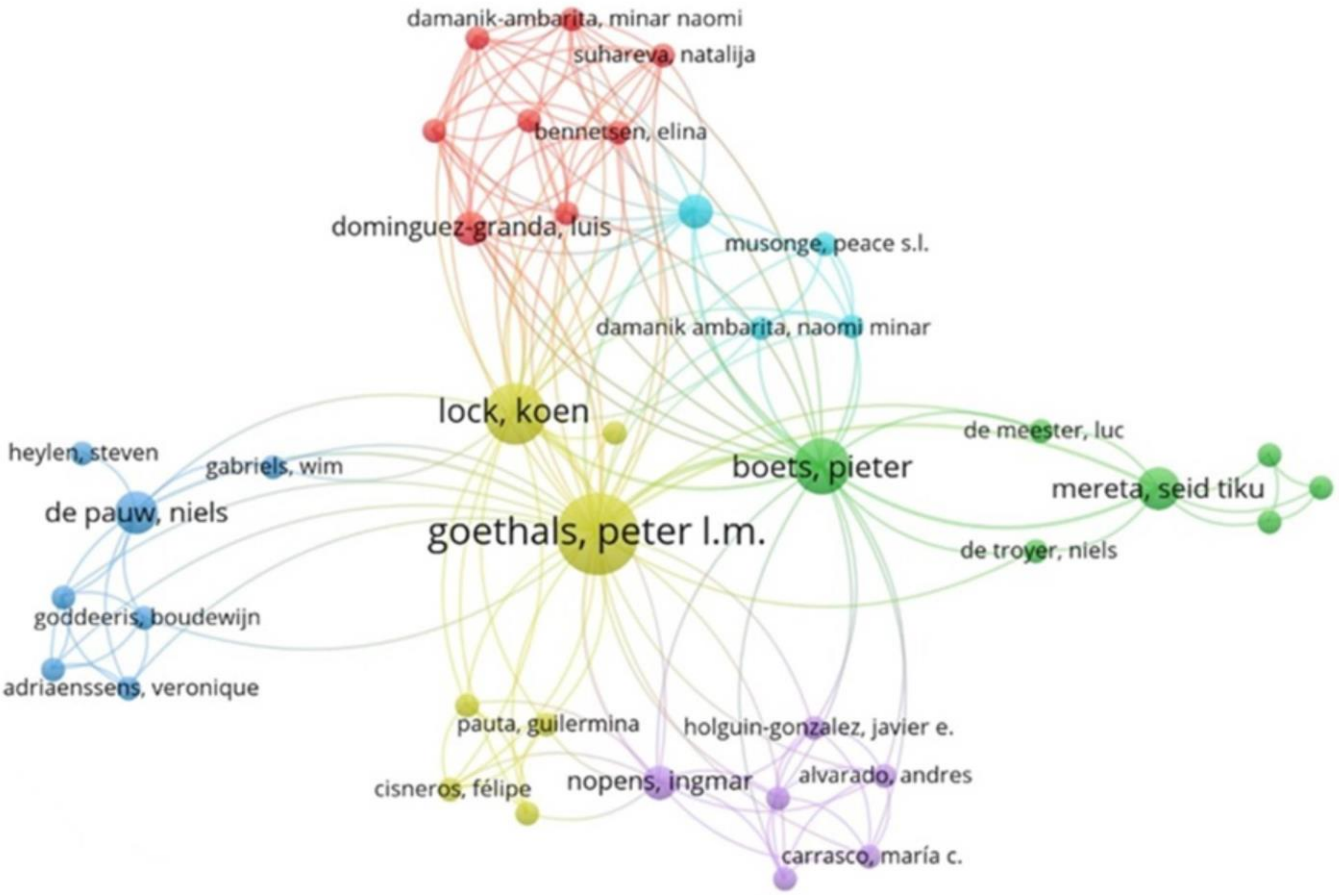

Figure 6 Main authors with scientific publications between the years 2000 and 2020 according to the accepted articles for scientometric analysis.

Discussion

In a period of 20 years, from 2000 to 2020, there was a significant increase in the number of publications that used biomonitoring indices with macroinvertebrates until 2012 (Figure 1). After this period, there was a tendency for publications to be reduced. Only the ASPT index showed a positive trend in its use during the survey period. Among the 60 indices found, EPT and BMWP are the most used in biomonitoring research. Variations of the BMWP have been found widely, such as the ASPT and the IBMWP. The indication and use of biomonitoring indices such as BMWP, ASPT, and EPT may be related to the type of the hydrographic basin of each region, since a vast majority of these indices have multiple origins and need to be adapted for the research regions. The ecological reference conditions of each region are different since the indices are tested and sometimes adapted to the structure of the organisms, integrity of the aquatic environment, as well as climatic and environmental situations of the place to be studied, and the methods of sampling (Ding et al. 2015; Eriksen et al. 2021).

A study carried out on the Pinto River in the state of Paraná with the application of several biotic indices (BMWP', BMWP-ASPT, EPT, and IBF), showed that these presented different results in relation to water quality, with less representation of the IBF (Gonçalves & Menezes 2011). Similar results were identified by Roche et al. (2010) using the BMWP and ASPT, and the ASPT was considered more advantageous for the analysis of water quality because it presents values that are consistent with the natural, seasonal situation of tropical streams. Researchers from Uganda found that the BMWP and its adaptations identified water quality

as poor or moderate, while ASPT classified the same water resource as moderate or very good quality (Ochieng et al. 2020). Moreover, the ASPT index was found to be relatively robust in a study to assess the water quality of rivers in the United Kingdom (Abbasi & Abbasi 2011).

Although Ochieng et al. (2020) did not find differences in the classification of water quality when comparing the BMWP proposed in United Kingdom for temperate environments, and BMWP-CR, adapted for Costa Rica, the scores of the families used are different, and may present different results when considering locality and seasonality (for instance Zamora-Muñoz et al. 1995). In addition to the adaptations, the biotic indices can be combined with other bioindication measures or decomposed to create an index to meet the local or regional water quality classification. Similar to Ruiz-Picos et al. (2017), who validated the BMWP index in Mexico by adapting the index to the specific environmental conditions and also analyzing physicochemical variables, thus creating the BMWP Water Quality index.

Studies carried out in Greece, using various indices such as the Iberian Biomonitoring Working Party (IBMWP), Average Score Per Rate (IASPT), and others, showed that the latter two were the most suitable for the region, as they indicate the inclusion of all registered families and the degree of pollution in each sampled location (Iliopoulou-Georgudaki et al. 2003), being widely employed for their effectiveness in various environments; however, used in isolation, these indices can have some shortcomings (Eriksen et al. 2021). Another factor considered an important variant for the results obtained in the biomonitoring indices is the use of different mesh networks in the collection of macroinvertebrates, which results in differences in the number of captured organisms, richness, and consequently in the application and comparison of the indices (Silva et al. 2005). In fact, the method used to sample macroinvertebrates reflect in different results. In a survey conducted in Costa Rica, using different collection methods, it was showed that the Surber sampler had higher scores for using the BMWP_CR index compared to the filter method. Gutiérrez-Fonseca e Lorion (2014) showed the importance of sampling effort and collection methods for better classification of water quality, as well as its limitations and disadvantages.

The EPT is the second most published index in the journal Ecological Indicators, the one with the largest number of publications containing biomonitoring indices and is preceded by the AMBI index. This fact demonstrates that there seems to be a consensus among the scientific community that the EPT is a robust index for assessing water quality and is one of the most acceptable when publishing scientific material. In research conducted in China, Li et al. (2018) demonstrated that EPT provides clearer results regarding the stressors that affect aquatic organisms. Another study carried out in Brazil also showed that this index was efficient in bioindicating water quality and that it can be used in biomonitoring in tropical regions (Valente-Neto et al. 2018).

The fact that the BMWP index is less used compared to EPT may be related to the fact that for each aquatic system, it is necessary to adapt indices according to the species found and the degree of pollution of the environment. EPT is a very simple index, as the percentage rate of these organisms is an easier measure to calculate compared to other indices. Studies carried out with the EPT revealed that the orders of these organisms point to a rapid assessment of water quality and have seasonality as an important factor for the disappearance of the most sensitive insects, such as the ephemeris (Duka et al. 2017).

Even though the EPT index is the most used globally, the ASPT index was the only one with a tendency to increase in use in recent years. This demonstrates that the ASPT index is well accepted for biomonitoring of aquatic environments in several countries, such as showed for Bulgary, Macedonia, Brazil and Turkey (Roche et al 2010; Arslan et al 2016; Biljana and Vidinova 2020). Moreover, in a study carried out in the Czech Republic

using several indices, the ASPT was a better representative of the evaluation of water quality because its result reflected stressors mainly to organic pollution (Brabec et al. 2004).

Our results also show that there was an increase in the number of articles published until 2012, with a greater number of publications during this year, and then a decrease in subsequent years, reducing from 27 publications in 2012 to 15 publications in 2019. This decrease in the number of publications in recent years may indicate that the water quality biomonitoring indices using macroinvertebrates are not widely used or published. It is worth remembering that the research was carried out at the beginning of the year 2020, which may be a reason for little publication during this year.

Goethel was the one with the largest number of publications in the last 20 years, with 10 articles published. Google Scholar demonstrates that this author has more than 5,000 citations in his articles, among which water analysis is one of the topics. The analysis of the authors of the publications is important for clarifying the interaction networks and highlighting their importance for science (Abramo & D'angelo 2015).

The network formed in our study demonstrates the possible contacts that other researchers can form, guaranteeing greater visibility for the main authors on the topic. These publications also denote the number of citations by this author, in which he was cited more than 200 times, according to our results, in articles in conjunction with Lock, Boets, De Pauw, Musonge, Dominguez-Granda, Mereta and Nopens, demonstrating the network formed by him.

In all, the largest number of articles were cited from 2000 to 2010, and among them, 2003 was the most representative, with 14% of all citations, followed by 2007 (11%). In contrast, there was a significant decline in subsequent years in relation to the number of citations. In fact, the work carried out in the first decade generates more citations than those carried out in the second decade. For example, the work of Borja e Tunberg (2011) presented only 84 citations, while the work of (Roy et al. 2003) presented 274 citations.

The keywords used in scientific articles demonstrate a network of interactions between the physical and chemical parameters of water with macroinvertebrates, and even with other aquatic organisms, such as diatoms. There is an intrinsic relationship between the word macroinvertebrates and terms such as ecological integrity, floristic composition, nutrients, and urbanization, which indicates that these organisms are used as tools in environmental assessment for different purposes. Several studies have been carried out to analyze the environmental restoration taking into account the composition of aquatic macroinvertebrates (**e.g.,** Nakano et al. 2008; Selvakumer et al. 2010).

In view of the results, it was possible to observe that in the last few years, there have been fewer citations regarding the use of macroinvertebrates as bioindicators of water quality, which, on the one hand, may reflect the shorter time available in the literature for citation, and on the other, that the quotes are more focused on the physical and chemical parameters of the water. In addition, new trends in organism analysis must be considered for the assessment of environmental quality, such as the meta barcoding method (Fernández et al. 2019). This method has been widely used in recent years in which a DNA demonstration analysis of organisms that have passed through it is able to classify water resources over time. The meta barcoding technique identifies more taxa than the morphology-based protocol, and in addition to the efficiency and reliability of the results, this method has a higher cost compared to other techniques; however, the process is faster (Fernández et al. 2019).

Among the places of publication and conducting research, the United States of America is the country with the largest number of articles published using macroinvertebrates as tools for biomonitoring, which represents 16% of the publications found during the 20 years. This concentration for this country, both in publications and in research, can probably be because the largest number of articles published is in English,

facilitating publication in this country. Another factor that can also be considered is that, according to the literature, the biotic indices originated in temperate environments, which can make their use in other countries difficult, since it is necessary to adapt according to the pollution and species present in each hydrographic basin (Gonçalves & Menezes 2011).

The results showed that the distribution of research carried out with macroinvertebrates in the evaluation of water quality are concentrated mainly in America, followed by Europe and Asia, and when comparing the continents, the American and the European present similar research numbers. A similar scientometric study was carried out in India, which shows that the United States of America is one of the main countries that contributes to the study of water quality (Nishy & Saroja 2018), which is corroborated by our results.

Since the beginning of the 20th century, in European countries, there has been a policy for the management of water resources (Borsoi 1997). According to the same researcher, in United Kingdom, since 1948, there was a legislation that administered river waters, and its regulation for monitoring water resources was given by the Water Law in 1974. In the United States of America, since 1972, the Clean Water Act existed for each American State to produce reports on the quality of the water to guarantee the preservation of aquatic biota. Some agencies, such as the United States Environmental Protection Agency (USEPA), use macroinvertebrates in biomonitoring to assess the environmental conditions of streams in order to ascertain what types of impacts pollution has on habitats.

This type of assessment is carried out by volunteers based on protocols developed by the USEPA region office and supervised by professional aquatic biologists. These volunteers were trained to conduct the work on the samples, use laboratories, and identify macroinvertebrates at the family level (Report by the United States Environmental Protection Agency (USEPA-EPA).

Since 1990, Australia has also developed the National Health Program for rivers and streams in the country, and part of the program involves governments and agencies with the aim of standardizing the rapid assessment of biological biomonitoring. This is based on national protocols and guidelines, with the purpose of evaluating water bodies on a large scale, and the results of the research are used to compose the database (Humphrey et al. 2008).

Conclusion

The efficiency of biotic indices with macroinvertebrates represents a low-cost and agile option for environmental monitoring aimed at water quality. The studied indices represent water monitoring options that, with adaptation, can be used in different climates and watersheds and must be taken into account in environmental biomonitoring, mainly to avoid expensive tools.

Among the indices most applied and accepted by the scientific community are the EPT and the BMWP, and the latter has several adaptations for the locations where it is employed. Even with greater application and publication with these indices, the only index that is expected to be applied increasingly in the future is the ASPT, which is also an index derived from the BMWP. Our analysis shows that the temporal trend in the use of indices using macroinvertebrates in biomonitoring has been declining in recent years; however, they are still robust tools for the assessment of water resources. It is true that new trends have shown promise, but the large number of articles produced worldwide, and the adaptation of the indices for the most varied regions shows that this tool is still an alternative for ecosystem assessment.

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