Benthenic macroinvertebrates as bioindicators of water quality in a climate change scenario: a systematic review

# Macroinvertebrados bentônicos como bioindicadores de qualidade da água em um cenário de mudanças climáticas: uma revisão sistemática

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**Abstract:** The increasing anthropogenic changes in the terrestrial environment reflect significant impacts on freshwater ecosystems. One of the most efficient ways to carry out a diagnosis of the "health" of a given water body is through the use of water quality bioindicators, which we call benthic macroinvertebrates. These organisms quickly and accurately reflect minimal changes to aquatic environments due to their sensitivity to various types of pollutants and physical disturbances, in addition to being an essential component for the functioning and balance of aquatic ecosystems, acting in ecological processes of energy transfer and nutrient cycling. The present study aimed to carry out a systematic review of scientific works published on the Scopus platform in the last 10 years, evaluating the use of benthic macroinvertebrates as a biomonitoring tool for monitoring water quality, in the context of climate change. Of the 254 works sampled, only four were related to the study proposal, demonstrating an important knowledge gap to be explored in the coming years.

**Keywords:** biomonitoring, benthic communities, global changes.

**Resumo:** As crescentes alterações antrópicas no ambiente terrestre, refletem impactos significativos aos ecossistemas aquáticos. E uma das formas mais eficientes para se realizar um diagnóstico da "saúde" de um determinado corpo hídrico, é através da utilização de bioindicadores de qualidade das águas dos quais denominamos como macroinvertebrados bentônicos. Esses organismos refletem de forma rápida e precisa, alterações mínimas aos ambientes aquáticos devido a sua sensibilidade a vários tipos de poluentes e distúrbios físicos. Além de serem um componente essencial para o perfeito funcionamento e equilíbrio dos ecossistemas aquáticos, atuando em processos ecológicos de transferência de energia e de ciclagem de nutrientes. O presente estudo teve como objetivo, realizar uma revisão sistemática de trabalhos científicos publicados na plataforma Scopus nos últimos 10 anos, avaliando a utilização dos macroinvertebrados bentônicos como ferramenta de biomonitoramento para o monitoramento da qualidade das águas, relacionando-os em um contexto de mudanças climáticas. Dos 254 trabalhamos coletados, apenas 4 apresentaram relação com a proposta do estudo,

demonstrando uma lacuna de conhecimento a ser explorada nos próximos anos.

**Palavras-chave:** biomonitoramento, comunidades bentônicas, mudanças globais.

## 1. Introduction

The deterioration of the environmental health of continental freshwater ecosystems is a process on a global scale, whose consequences are reflected in several aspects in the biosphere and human societies (Brasil, 2019). It is known that one of the main factors that culminate in the degradation of these ecosystems are human activities (Heller et al., 2010). Climate change stands out among the consequences of human actions due to its effects on a global scale, such as increased temperatures, increased frequency of extreme hydrological events and species extinction events and ultimately biodiversity losses (Salmaso et al., 2021).

Climate change affects all ecosystems on a global scale, especially aquatic ecosystems, making it urgent to act more effectively in controls to mitigate impacts (Daneshvar et al., 2017). Alterations in air quality, atmospheric temperature and precipitation patterns, result in changes in water temperature, cycles and degree-days (Čiamporová-Zaťovičová et al., 2010). These changes, in turn, affect aquatic ecosystems, whose responses can be observed through changes in composition, community structure and reproductive cycles (U.S. EPA, 2008).

Changes in thermal regimes affect the reproduction and life cycle of organisms, compromising the entire production chain of ecosystem goods and services, resulting in the loss of biodiversity (Isaak et al., 2012; Beniston e Stoffel, 2014). These events especially affect taxa that are associated with this type of environment, such as the benthic organisms that include the orders Ephemeroptera, Plecoptera and Trichoptera, classified as sensitive taxa and bioindicators of climatic conditions and pollution in freshwater ecosystems (Domisch et al., 2013).

Biomonitoring programs are one of the most used tools in order to assess the ecological integrity of freshwater ecosystems (Callisto et al., 2019). In Brazil, legislation provides for the implementation of biomonitoring programs using water quality bioindicators, which aim to provide a situational diagnosis of the aquatic environment (Brasil, 2008). Benthic macroinvertebrates stand out as the most used in the assessment of effects and anthropic impacts in aquatic environments, as they constitute a very diverse group, being sensitive to various types of pollutants and physical disturbances (eg. erosion and silting processes) (CETESB, 2012).

Benthic macroinvertebrates play important roles in maintaining ecological processes in streams (Linares et al., 2018). They actively participate in the degradation of organic matter that accumulate in watercourses, playing a fundamentally important role in nutrient cycling and in aquatic trophic chains (Callisto et al., 2019). Thus, the study of the composition and structure of benthic communities allows the evaluation of the integrity of freshwater ecosystems as a whole (Stoddard et al., 2006). It is for this reason that understanding biological and ecological responses to climate change, as well

as the interactions between the effects of climate change and other stressors, is important for the ongoing operation of biomonitoring programs and interpretation of bioassessment results (U.S. EPA, 2008).

The aim of his study is to discuss the use of benthic macroinvertebrates as a biomonitoring tool for monitoring water quality in the context of climate change, through a systematic review.

## 2. Material and methods

To carry out this study, a systematic literature review (RBS) was used, through searches in the "Scopus" database using the terms "Biomonitoring" and "benthic" and "macroinvertebrate". This search was carried out from May 13 to 16, 2023 using the protocol described in the book "Manual de Produção Científica" (Koller et al., 2014) for the standardization of data collection in this systematic review, and resulted in 257 results. A set of Boolean operators was used: AND and "" in order to inform the search system how to combine the search terms and restrict the search field (Koller et al., 2014). The flowchart of the systematic review can be seen in Figure 1.

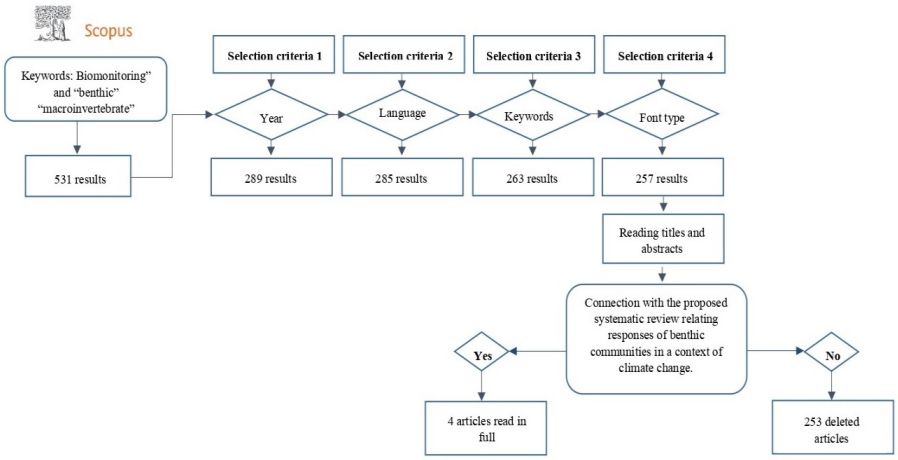


Figura 1. Fluxogram of the sistematic review.
Source: Authors.

With the purpose of refining our search results, we applied exclusion criteria to the works following the methodology of Koller et al. (2014). The selection of the most relevant scientific studies related to our objective was determined using the following criteria: (i) Using studies published in the last ten years (from 2013 to 2023); (ii) Studies published only in English, Spanish and Portuguese; (iii) Studies that have the following keywords: Biomonitoring, macroinvertebrates, macroinvertebrates, benthos, Benthic macroinvertebrates, benthic fauna, Macroinvertebrates, Trichoptera, Chironomidae, Community of macroinvertebrates, Plecoptera, bioindicators, bioindicator, Bivalve, Oligochaeta; (iv) Accept scientific papers only, excluding conference proceedings and book chapetrs; (v) Direct analysis of the sorted studies. The graphic representation of these data was produced using Microsoft Office Excel and the map that shows the areas studied was prepared using GIS software QGIS 3.28.

## 3. Results and discussion

Evaluating the 257 articles found in Scopus, it was observed that 113 papers had no connection with the proposed theme of this review, leaving 140 titles in which the abstracts were analyzed. Of these, only 4 articles were related to the specific objective of this study, which aimed to evaluate the use of benthic macroinvertebrates as a biomonitoring tool for monitoring water quality, relating them in a context of climate change (Table 1).

Table 1. Articles that showed the use of benthic macroinvertebrates as a biomonitoring tool in a context of climate change.

| Authors | Title | Year | Journal |
|---|---|---|---|
| Krajenbrink H.J., White J.C., Dunbar M.J., Wood P.J. | Macroinvertebrate and diatom community responses to thermal alterations below water supply reservoirs | 2022 | River Research and Applications |
| Haubrock P.J., Pilotto F., Haase P. | Do changes in temperature affect EU Water Framework Directive compliant assessment results of central European streams? | 2020 | Environmental Sciences Europe |
| Daneshvar F., Nejadhashemi A.P., Herman M.R., Abouali M. | Response of benthic macroinvertebrate communities to climate change | 2017 | Ecohydrology and Hydrobiology |
| Phillips I.D., Pollock M.S., Bowman M.F., McMaster D.G., Chivers D.P. | Thermal alteration and macroinvertebrate response below a large Northern Great Plains reservoir | 2015 | Journal of Great Lakes Research |

Source: Authors.

The selected papers were published in journals from the following countries: England, Germany, United States and Canada, however, there are differences regarding the country of publication of the article and the location of the study area. Most authors (n=3) published their studies in the same country as their study area, only one article was published in the United States and its study area was located in China (Figure 2).

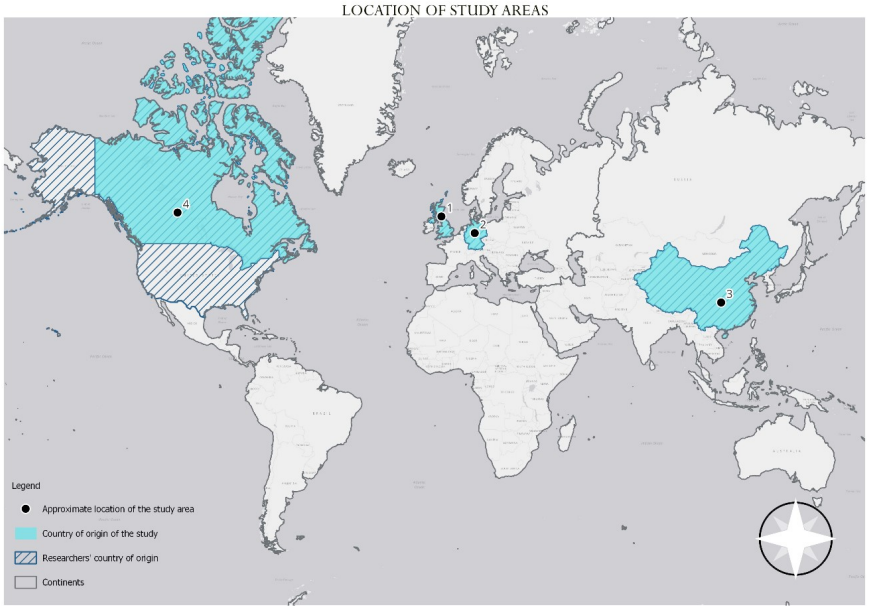


Figure 2. Selected papers' location.
Source: Authors.

After employing the sorting criteria for selecting and reading the titles and abstracts, it was identified that the keyword "Macroinvertebrates" combined with the keyword "Climate Change", are the ones that best represents a qualified search on the central theme proposed in this review (Figure 3).

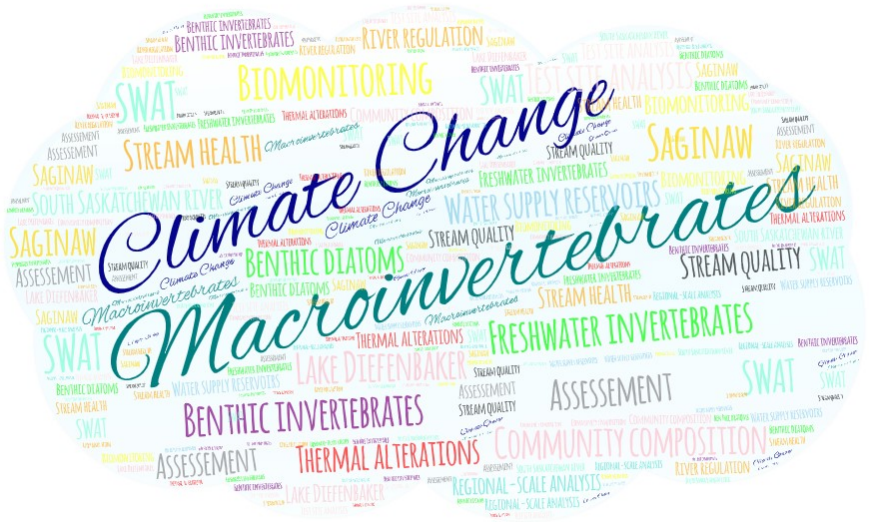


Figura 3. Word cloud in the presente review.
Source: Authors

Our results show that information associated with the responses of benthic communities in a context of climate change is still incipient. According to Daneshvar et al. (2017), benthic communities of aquatic ecosystems are affected by climate change, however, this knowledge is still embryonic and deserves attention and further studies. These changes affect ecosystems, whose responses can result in changes in community composition, reproductive cycles, evolutionary adaptations and genetic selection (U.S. EPA, 2008). The question

is, as temperatures continue to rise and the number of extreme hydrological events, i.e. droughts and floods, tend to increase and the entire surrounding environment becomes inhospitable, competitive and resource-limited, lead to species extinction (Zhu et al., 2014).

According to Couvet and Jiguet (2008) and Devictor et al. (2012), in recent decades, high rates of temperature variations have resulted in changes in the composition in both terrestrial and freshwater communities (Post et al., 2009). Increasing water temperature reduces dissolved oxygen concentrations, which in turn affects most benthic invertebrate species, as most of them maintain species-specific preferences for certain dissolved oxygen levels (Bÿrziÿš & Pejler, 1989). Other authors such as Lavoie et al. (2010) report that higher temperatures promote primary production, favoring the creation of biofilm through algae growth, causing various impacts on the production and food chain of aquatic communities. Such changes reflect in the trophic chains affecting the feeding functional groups (e.g. variations in growth rates, body size, respiratory system, etc.) of benthic invertebrate communities.

In the study carried out by Daufresne et al. (2003), evidence was documented that species shifts, changes in distribution, and overall changes in the composition of fish and macroinvertebrate communities in France were associated with increased water temperature due to global warming. A study carried out in Wales on the increase in temperatures, showed a decrease in the abundance of macroinvertebrates in spring over 25 years, with an estimated average of 21% reduction in the abundance of these organisms (U.S. EPA, 2008). If future effects are consistent with these observed trends, the progressive increase in temperature may remove some more sensitive taxa, compromising stream ecosystems' structure and functioning (Durance and Ormerod, 2007).

There is also evidence that projected increases in $CO^2$ will reduce the nutritional quality of litter to detritivorous macroinvertebrates. Reduced litter quality would result in slower assimilation and growth of organisms (Tuchman et al., 2002). Although they appear to be a secondary effect of climate change, changes in these processes can have food chain implications: primary and secondary productivity that impacts fish and other consumers (U.S. EPA, 2008).

Research carried out in the US great plains shows that climate change is already resulting in the extinction of local endemic species, such as certain populations of fish that tolerate a specific range of temperature (Covich et al., 1997). Biological effects can manifest as changes in the relative abundance of communities, species losses (local extinctions) and reduced diversity (U.S. EPA, 2008). Evolutionary changes may play a small role in species responses to climate change through adaptation (Parmesan, 2006; Berteaux et al., 2004). Extinctions are still expected to be a likely consequence of directional climate change, even with evolutionary changes: in part because average phenotypes lag behind ideal phenotypes, and rates of change may exceed estimated maximum sustainable rates of evolution (Parmesan, 2006).

## 4. Conclusion

In this systematic review, only four studies were found that addressed the use of benthic macroinvertebrates as bioindicators of water quality in a scenario of

climate change. Although the scarcity of studies is a limiting point, these studies have provided valuable insights into the role of benthic macroinvertebrates as biological indicators to assess water quality in the face of the challenges posed by climate change. The results of these studies suggest that climate change can have significant effects on the benthic macroinvertebrate community. Variations in water temperature, oxygen availability, rainfall and increase in extreme events can affect the distribution and abundance of these organisms, leading to changes in the composition and structure of communities.

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