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Neglected area of meiobenthos: bibliometric analysis in the status of research on hyporheic meiofauna

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ABSTRACT

Studies on freshwater meiofauna are still enigmatic. This field of research is relatively neglected because this topic is not as increasing as the others, creating a gap in this area. The deficit of knowledge and surveys impose a barrier to new research and the increase of scientific interest in this area. This paper briefly reviews what exists in freshwater meiofauna worldwide, focusing on increasing knowledge on this topic and making this little-known area of meiofauna a common study field in science. The methodology involved a bibliographic survey from the Web of Science (WOS) bibliographic database. The search was performed by document title, keywords, and abstract, highlighting meiofauna (or meiobenthos) and hyporheic zone (or hyporheos). The results showed 28 documents on hyporheic meiofauna worldwide, mainly concentrated in Germany. The few articles highlighted that the lack of research on the hyporheic meiofauna community, its ecology, taxonomy, and biology is evident. It is hoped that this bibliometric review can be used as an alert about this area of meiofauna that is so important but at the same time is neglected, having a very exclusive group of authors and works, being of extreme importance different directions of research that involves hyporheic meiofauna to a better understanding of this fauna importance, ecosystemic services, and ecology.

Keywords: Bibliometrix, state of the art, ecology, meiofauna.

Introduction

Meiofauna (or meiobenthos) is a group of benthic, invertebrate, and cosmopolite organisms that occur in freshwater (rivers and lagoons), marine and oceanic environments, groundwater, glaciers, hot springs, rocks, plants, and algae roots, and in other cryptic habitats (Eisendle & Hilberg, 2015). Meiofauna can be defined as small-sized organisms (<1 mm) which are withheld in a geological sieve of mesh <45 mm (Giere, 2009). The microscopic size reflects an evolutionary benefit of dwelling and living in interstitial environments (Schratzberger & Ingels, 2018). The meiofaunistic community is mainly represented by Nematoda, Polychaeta, Oligochaeta, Platyhelminthes, Mollusks, and Crustaceans (Giere, 2009).

Meiofauna includes a variety of taxonomic groups, the most remarkable being nematodes, rotifers, tardigrades, and microcrustaceans. This group ranges from small, cylindrical worms to hardy organisms that can survive extreme conditions (Giere, 2009). Meiofaunistic organisms perform several essential roles in ecological functioning and balance in freshwater ecosystems, including nutrient cycling, working to decompose organic matter, and releasing nutrients into the aquatic environment (Bianchelli & Danovaro,

2020). Furthermore, these organisms are responsible for bioturbation, in which they excavate the sediment, promoting their mixing. The composition and health can be used as bioindicators of water quality in aquatic environments, where the rapid response of the meiofauna community can reflect environmental disturbances and pollution (Santos et al., 2021; Freitas et al., 2022). Moreover, meiofauna represents an important part of the food web, serving as a source of food for higher and bigger organisms, being the transition of energy between small and large organisms. Despite its ecological importance, freshwater meiofauna continues to be understudied compared to other components of aquatic ecosystems. However, with the joint increase of the importance recognition of these organisms and analysis techniques improvement, there will probably be an increase in research aiming to better understand the meiofaunistic community structure and its role in freshwater ecosystems.

It is well-known that the conservation of an environment, community, or even a species requires vast knowledge about the topic of interest (Ricklefs & Relyea, 2019). Some authors, such as Liu et al. (2017), highlight the importance of meiofauna in freshwater environments. Although hyporheic meiofauna has not been widely studied yet, it is known that these organisms undoubtedly play a fundamental role in improving water quality (Santos et al., 2020; Freitas et al., 2021). Their biological activity allows them to filter pollutants, remineralize organic matter, and oxygenate and dissolve minerals in water (Veras et al., 2018). An efficient way to conserve water resources is by unveiling unexplored areas, such as the hyporheic meiofauna organisms, and their unheard-of contributions and services to the hyporheic zone ecosystem. The hyporheic zone (HZ) is an ecotone between the surface and underground environments, situated just below a water body, such as a river, lake, or groundwater reservoir. This zone is fully composed of sediments and is characterized by the presence of water that flows through the pores and spaces between the particles (Veras, 2018). This hyporheic zone plays a role in the river-aquifer interaction, acting as a regulator of the water flow and also as a natural filter for contaminants (Santos et al., 2021), contributing to water purification and its biogeochemical processes, retaining nutrients and organic matter for aquatic organisms. Biologically, this environment provides an important habitat for an array of aquatic organisms, such as insects, crustaceans, and other invertebrates, which have adapted to live in this subsurface environment (Freitas, 2019).

The scientific rejection of hyporheic meiofauna might be a kickoff to stimulate studies on this topic, including or sampling these organisms in freshwater biological or water quality assessments will result in better contributions and more robust research regarding contaminants clearance methodologies, environment conservation, and proper knowledge of the importance of hyporheic zone and their environmental services (Boon et al., 2016). Functional roles developed by the meiofauna in an environment are critical and, often, essential for well-functioning ecosystems (Hakenkamp et al., 2000; Benke & Hurry, 2010; Schratzberger & Ingels, 2018). By being responsible for transformations in ecosystems, the meiofauna has been an increasing research topic in the past decades by many authors in many environments, such as marine (and beach) and estuarine meiofauna, cryptic meiofauna, deep-sea meiofauna, and many others as it seen in Hoffmann & Gunkel (2011), Stubbington et al. (2012), Freitas (2018), and Schratzberger & Somerfield (2020). Hyporheic meiofauna, although, seems not to delight researchers' eyes, since publications about this group are not increasing as well as the other ones, some isolated research has been published in the past years (Guo et al. 2010), as Veras et al. (2017), Freitas (2015), Veras et al. (2018), Santos et al. (2020).

Bibliometric analysis is a tool that links bibliographic surveys and statistical analyses, measuring the state of the research status of any topic and whether it is widely or barely studied on a temporal or spatial scale. Therefore, this tool has increased exponentially in scientific publications in recent years as it gained massive popularity in sundry areas of science (Aria & Cuccurullo, 2017; Donthu et al., 2021; Khan et al., 2021). Meiofauna as the main target of a bibliometric analysis is not so common, although there are few publications with that approach (Lim et al., 2021; Liu, 2015; Guo et al., 2021), most of them focus on marine, estuarine, or terrestrial meiofauna, and the research status of hyporheic meiofauna is unknown until nowadays.

This bibliometric research aims to quantify the research, publications, and documents published about hyporheic meiofauna throughout the whole temporal span and worldwide, showing the few publications about hyporheic meiofauna and the lack in many areas of biological study on this topic. It is expected to increase the knowledge about this topic, make it a common publishing field

of science, and raise the research in that barely known meiofauna sub-area.

Material and Methods

In April 2022, a search was carried out on the electronic database Web of Science (WoS) to find and recognize the current state of scientific literature on freshwater meiofauna. The search was conducted using the fields "title", "keywords", and "abstract", covering the whole time span possible. The search was conducted using the fields "title", "keywords", and "abstract" and covered a time span from January 1979 (the first article published with freshwater meiofauna) and April 2021 (when this paper was written).

Only English-written documents were used (Table 1). A total of 28 publications were obtained, none of the documents was duplicated or could be excluded for any reason.

Table 1. Search and its combinations used in the bibliographic survey accomplished in the database Web of Science. Fonte: Santos et al. (2023).

Search: freshwater (or hyporheic); meiofauna (or meiobenthos)
Title= (“meiofaun*” OR “meiobent*) AND
Title = (“freshwater” OR “hyporheic”) OR
Keywords Plus = (“meiofaun*” OR “meiobent*) AND
Keywords Plus = (“freshwater” OR “hyporheic”)

All bibliometric analyses and graphics were performed in R language (R Core Team, 2021) in the IDE RStudio Software with the package "bibliometrix", which was created specifically to carry out bibliometric analyses (Aria & Cuccurullo, 2017). The total scientific production and citations over time with linear regression were fulfilled to estimate the importance of time in publication frequency trends. Most productive countries and the number of single countries and multiple countries publications show what countries publish by themselves or collaborate with others. Interaction analyses, such as country network, top author's production over time, history of authors’ interaction throughout time, and Multiple Correspondence Analyses (MCA) of keyword co-occurrence were performed as well.

Results

The total number of publications/scientific production about freshwater meiofauna was 28, divided into 25 articles, one editorial material, and two reviews (checklist). The documents span 42 years (1979 - 2021) with an annual percentage growth rate of 1.66% and average citations per year per document of 1.21. The maximum number of annual publications was four, and the minimum was zero (Figure 1A). The linear model showed a significant variation ($p<0.05$) in publications over the years but has shown a weak relation with time, which says publications are increasing over time but not continuously or rapidly (Figure 1A). For total citations, the maximum was four, and the minimum was zero (Figure 1B). Total citations did not increase significantly over time and showed a weak relationship in the model (Figure 1B).

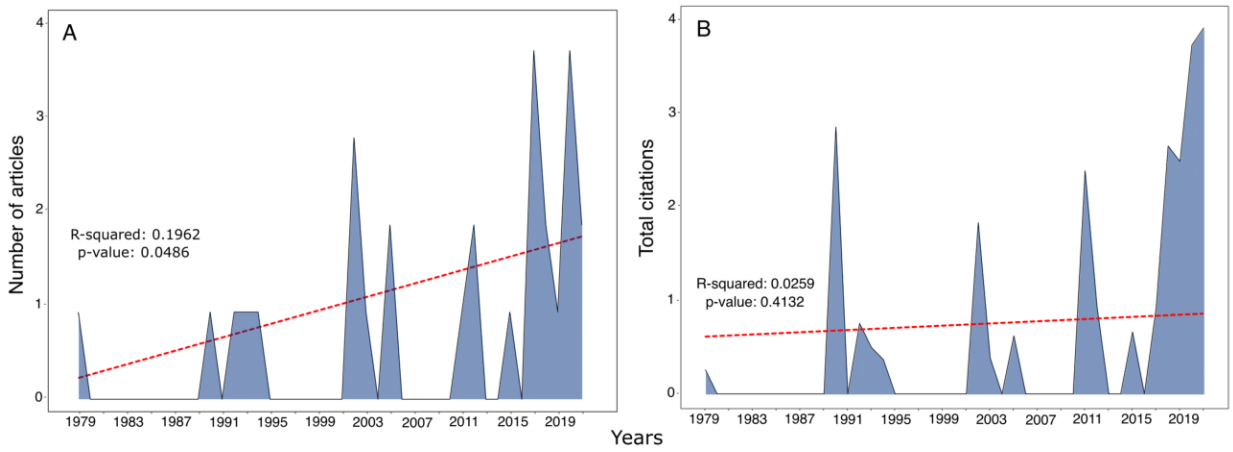

Figure 1. A. Scientific production over the year; B. Total citations over the years and their respective linear models of publications and citations by time. Font: Santos et al. (2023).

Countries network (Figures 2 and 3) shows that Germany has the most publications, and other countries, like Croatia and Spain, have isolated publications. The collaboration was among countries explicit that most countries interact with publishing and researching the hyporheic meiofauna, mainly countries with a high publication number (Germany and the United Kingdom). Otherwise, the United States and Brazil

publish relatively a lot but interact with no other country, being interactively isolated (Figure 3).

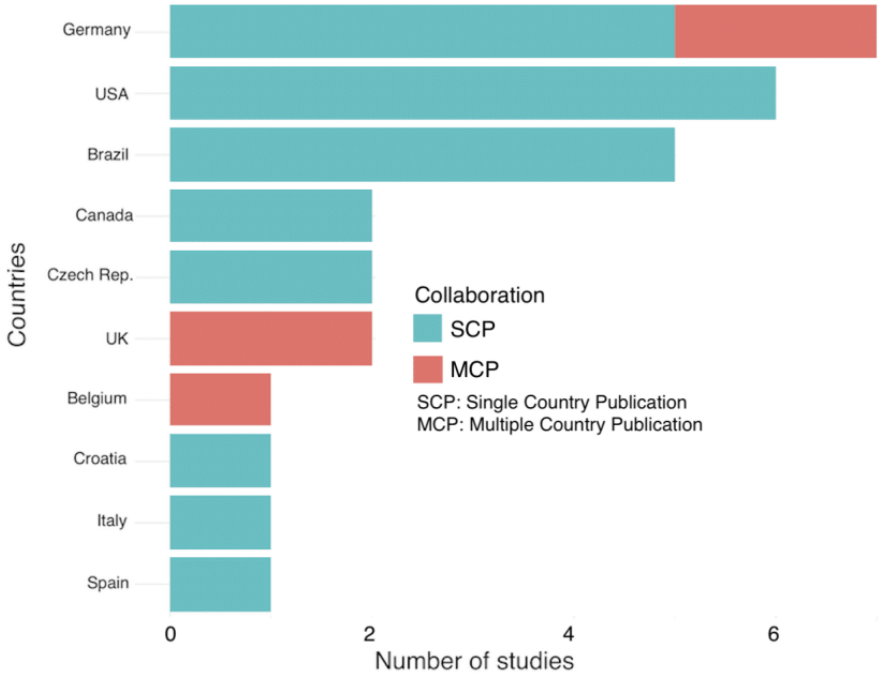

Figure 2. Most productive countries and their division in single country or multiple countries publications. Fonte: Santos et al. (2023).

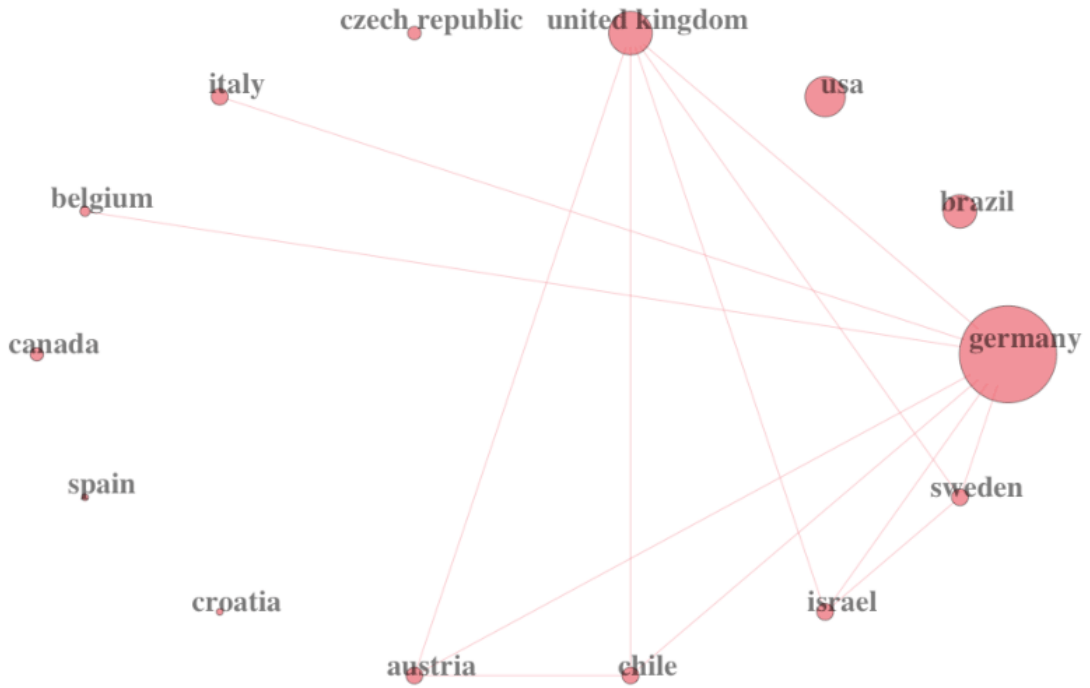

Figure 3. Countries' interactions and respective publications by circle size. Max publications by country: six; min publications by country: one. Fonte: Santos et al. (2023).

The author's production and citations started to grow a lot since 2010-2012 (Figure 4) when the hyporheic environment, its processes, and organisms began to concern researchers. Freshwater meiofauna research has gained more attention in recent years and has begun to concern researchers due to a growing wave of environmental issues and concerns, thus contributing to the increased interest in freshwater meiofauna in recent years that led to an increase in the number of studies. Increased environmental awareness (Braz et al., 2022) and interest in the study of biodiversity and conservation have most likely contributed to the concern of research on

meiofauna. As problems related to pollution and degradation of aquatic ecosystems increase, meiofauna which is known as a sensitive bioindicator begun to be studied as a proxy of water quality (Gambi et al., 2020) and sediment sorting (Schenk et al., 2020) given that small changes can foment significant shift in meiofaunistic community structure. Therefore, researchers are aware of the pattern of meiofauna responses to these changes and how these variations can influence the resilience of ecosystems. This progress is expected to continue, with different authors recognizing the relevance of these studies to aquatic ecosystems' long-term health.

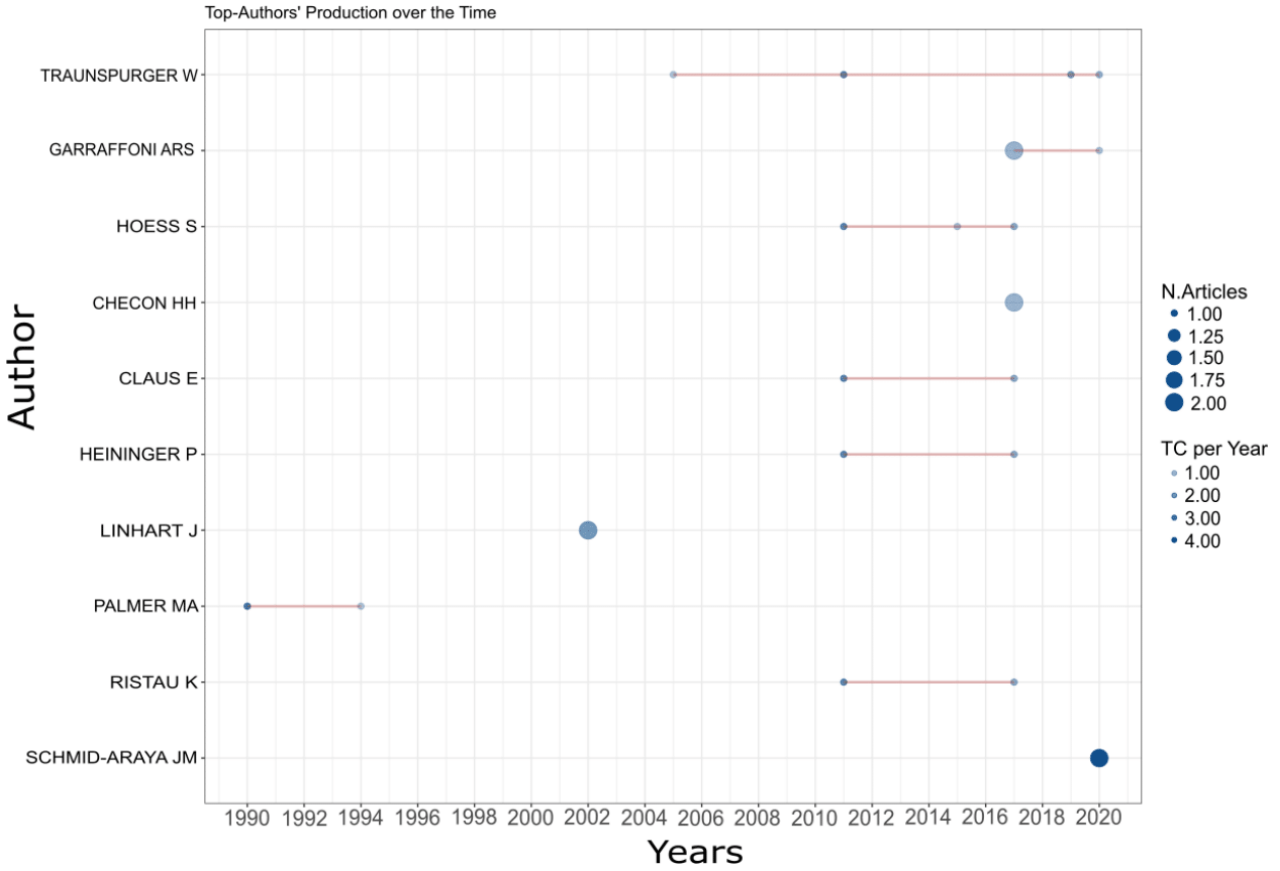

Figure 4. Top authors' occurrence, their number of articles, and total citations per year. Fonte: Santos et al. (2023).

Figure 4 shows that 2011 was a remarkable year for the hyporheos. Brinke et al. (2011) was a particularly important paper because most of the co-authors kept publishing in the subsequent years in hyporheic meiofauna. The network of citations among authors (Figure 5) shows that there are few research clusters, in which the studies are mostly related to the first surveys on hyporheic meiofauna (purple cluster). The three reminiscent groups have few articles that do not directly cite any other cluster, this fact expresses that irrespective of the small number of articles, there is a lack of connectivity among researchers in this area.

Most publishers in the search topic in 2011 have studied meiofauna before but in other environments. Citations started to increase from articles in 2011, as it is a very exclusive group of authors whose network citations are too close (Figure 5).

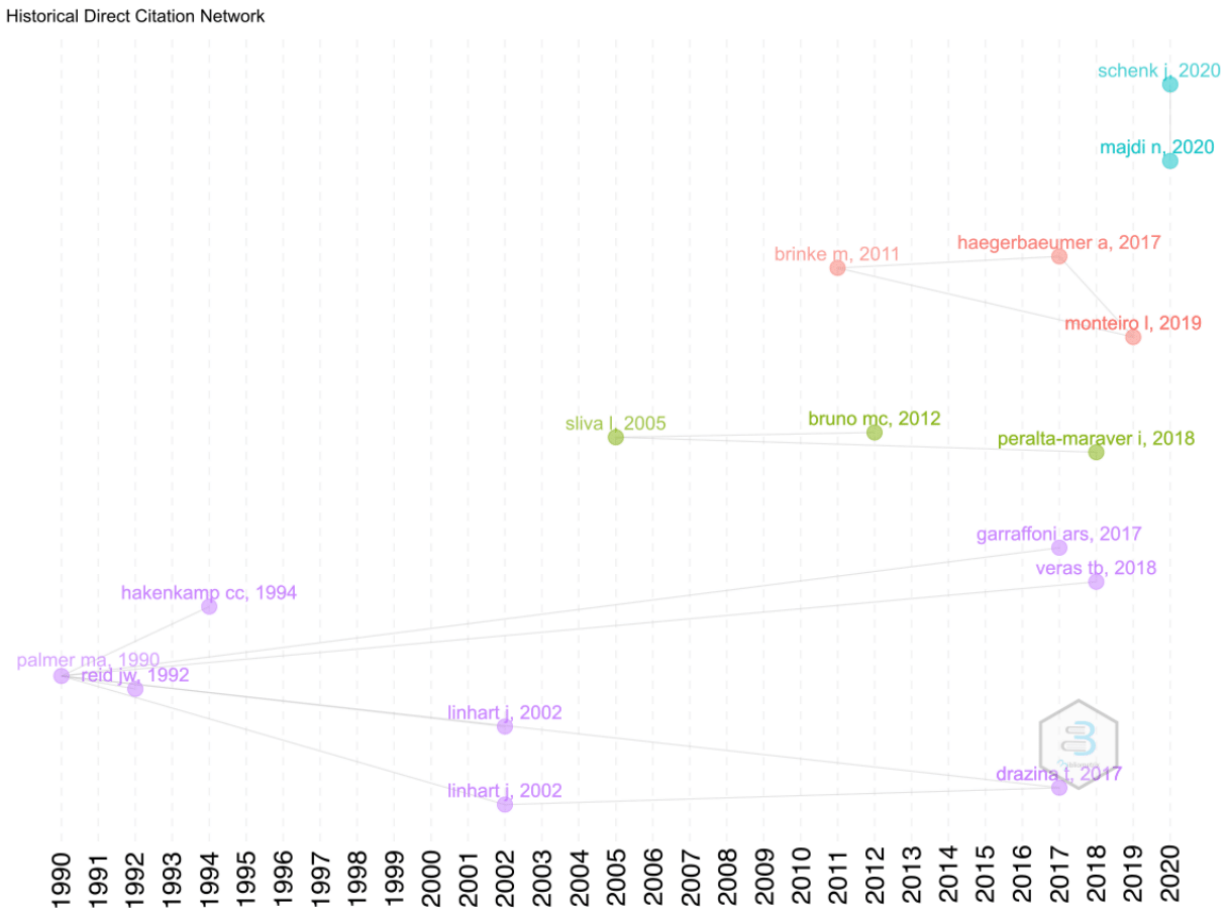

Figure 5. Authors' direct citations network throughout time. Fonte: Santos et al. (2023).

There was a total of 159 keywords and the top five most used ones were "Community", used 10 times, "Nematoda", nine times, "Invertebrates", six times, "Ecology", six times, and "Patterns", six times (Table 2). The centrality (intercluster keyword co-occurrence) was greater for "Community", which shows that this keyword co-occurred 10 times with other keywords from other clusters. The least centrality was seen in the "Invertebrates" keyword, which occurs when interacting with other intracluster keywords or from another close cluster.

Table 2. Most frequent five keywords and their respective centrality tendency (meiofauna, hyporheic zone, and freshwater omitted). Fonte: Santos et al. (2023).

Keywords	Occurrences	Centrality (degree)
Community	10	0.412
Nematoda	9	0.228
Invertebrates	6	0.184
Ecology	6	0.215
Patterns	6	0.241

The five most used keywords' cumulative occurrence over time (Figure 6) shows that from 1992 to 2010 (18 years), all the keywords were almost or in 50% of their cumulative, and then increased by the other half in less than 10 years (Figure 6), what is explained by the 1.66% increase trend seen in Figure 1A. There is a slight increase in keywords and publications regarding the hyporheic meiofauna community, Nematoda, invertebrates, ecology, and patterns.

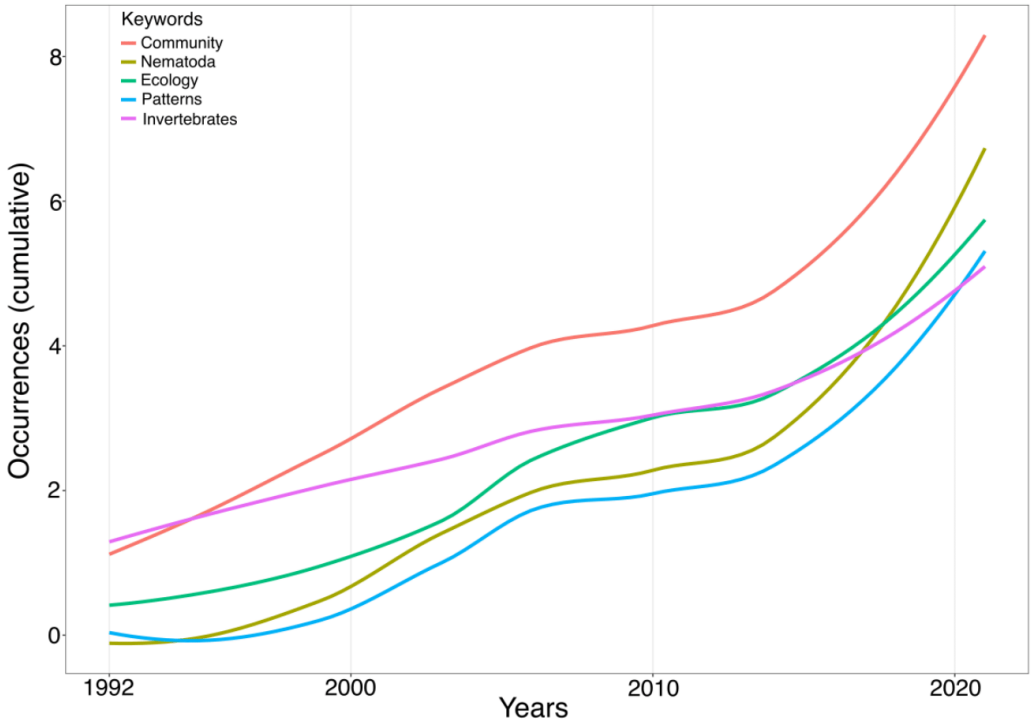

Figure 6. Cumulative occurrences of the top five most used keywords over time (meiofauna, hyporheic zone, and freshwater omitted). Fonte: Santos et al. (2023).

The Multiple Correspondence Analyses (MCA) showed a pattern of 4 (four) clusters in which there was overlapping in none of them despite there being a lot of interaction of keywords co-occurrences (Figure 7). The four clusters differ in their main topic: the first cluster (green) has a topic more related to freshwater meiofauna community; the second (purple) turned to ecotoxicity and pollutants; the third (red) to diversity and ecological Patterns; and the fourth (blue) to hyporheic and freshwater by itself, like lotic habitats and hyporheic zones.

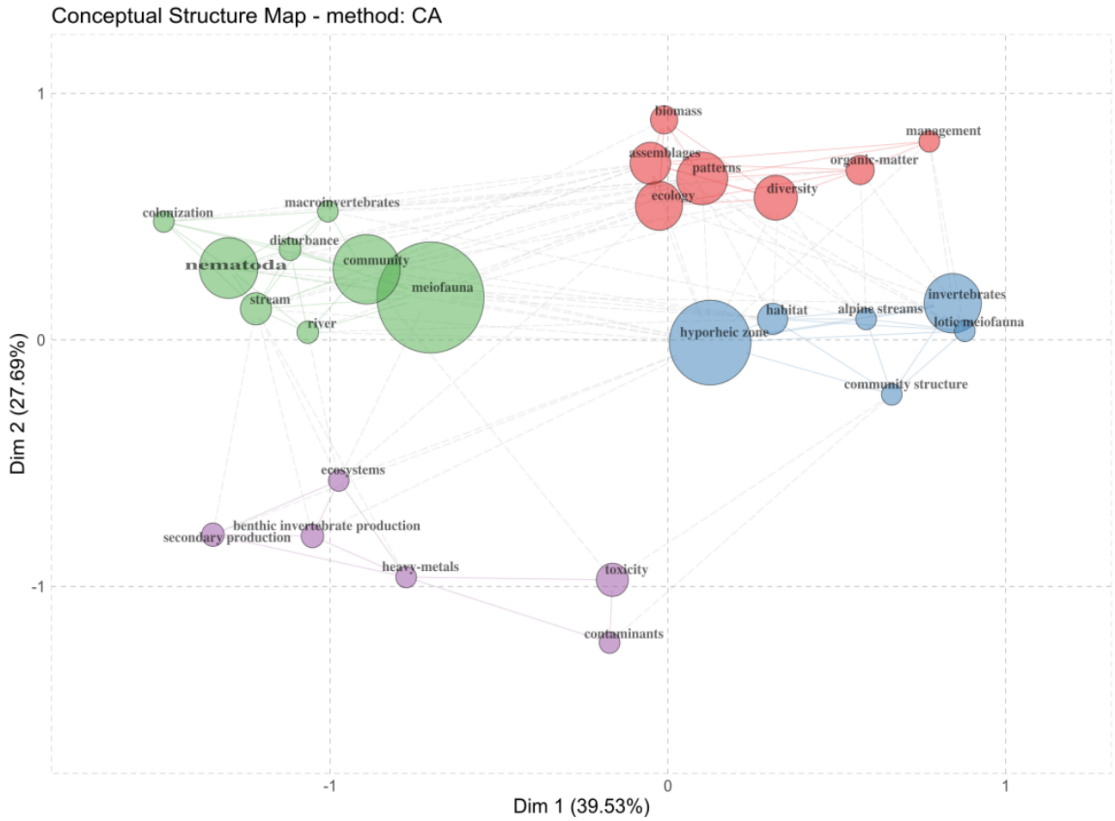

Figure 7. Multiple Correspondence Analyses (MCA) of the most used keywords and their co-occurrences network, their occurrences are discriminated by the circle size. Fonte: Santos et al. (2023).

Table 3. Journal titles, number of publications, Impact Factors, and subject categories. Fonte: Santos et al (2023).

Journal title	Nº of papers	IF	Subject categories
Hydrobiologia	5	2.694	Oceanography
Archiv für Hydrobiologie	2	-	Limnological Sciences
Marine and Freshwater Research	2	1.488	Oceanography
Environmental Toxicology and Chemistry	2	3.742	Environmental Sciences
Annales de Limnologie - International Journal of Limnology	1	0.887	Limnological Sciences
Ecotoxicology and Environmental Safety	1	6.291	Environmental Sciences
Ecological Indicators	1	4.958	Environmental Sciences
Limnology and Oceanography	1	4.745	Oceanography
Scientific Reports	1	4.379	Natural Sciences
Molecular Phylogenetics and Evolution	1	4.286	Biology
Freshwater Biology	1	3.809	Biology
River Research and Applications	1	2.443	Environmental Sciences
Journal of Sea Research	1	2.108	Oceanography
Limnologica	1	2.093	Oceanography
Water Environment Research	1	1.946	Environmental Sciences
Canadian Journal of Zoology	1	1.637	Biology
Limnology	1	1.576	Limnological Sciences
Vie et Milieu/Life & Environment	1	0.434	Ecology
The American Microscopical Society	1	-	Biology
Estuaries	1	-	Oceanography
Journal of the North American Benthological Society	1	-	Biology

Most of the 21 journals publishing at least one article about hyporheic meiofauna have a high impact factor. The most-publishing journal is Hydrobiologia, which holds five publications. Ecotoxicology and Environmental Safety are the top two, and their impact factor is 6.291; the last one is the French journal Vie et Milieu/Life & Environment (0.434). Three journals had no records of their impact factors, as seen in Table 3.

Discussion

In theory, there was a considerable increase in publications throughout the years for hyporheic meiofauna, however considering scientific production, four annual publications about a single topic are relatively minimal. Compared, only in Brazil, marine sandy beaches' meiofauna average publications per year is approximately nine (Maria et al., 2016), while the maximum number of publications in hyporheic meiofauna in a year is four. This fact shows that even growing significantly, hyporheic meiofauna is still a cryptic research field. The fact that the citation patterns do not increase significantly over time proves that the meiofaunal hyporheic community, ecology, taxonomy, biology, and populations remain quite unknown until today and need improvement in their scientific concernment.

The United States (in the 90s) and Germany (since 2002) have the leading role in meiofauna publications, being the pioneers on the topic and influencing the whole world of publishing in the field. The first hyporheic meiofaunal study was in the USA (Oden, 1979). In 2002, the first publication, after a five-year gap, came from Germany (Linhart et al., 2002), and it afterward increased the number of publications over the years, becoming the most productive and interactive country on this topic until nowadays. The addition/occurrence of many countries shows that despite the few publications, the topic is increasing geographically, and studies with hyporheic meiofauna are becoming a worldwide-known area.

Authors' productions over time show that the increase of interest and publication in hyporheic meiofauna started to emerge with novel authors after 2010. Most of these new authors only published twice; their articles were not cited many times, and then they seem to not publish about Hyporheic Zone again. This tendency might be explained by the difficulty of studying hyporheic meiofauna and identifying organisms at the species level due to the lack of publications and studies about hyporheic meiofauna species, taxonomy, and other subtopics. Freshwater meiofauna shelters organisms that live in environments such as rivers, lakes, and streams. Within this group, there is a variety of organisms, such as nematodes, rotifers, and microcrustaceans. Despite their diminutive size, these organisms play significant roles in freshwater ecosystems, including the decomposition of organic matter, nutrient cycling, and their role in the food web (Majdi et al., 2020). Unfortunately, these roles are often underestimated, rendering freshwater meiofauna unnoticed and neglected, frequently becoming less

visible and of lesser public interest, as reflected in the number of related research papers found (Schmid-Araya & Schmid, 2000). The scarcity of studies on freshwater meiofauna can be attributed to the difficulty of identification, as the majority of these organisms are indeed very small. This fact makes their study increasingly challenging and often necessitates complex techniques and analyses, as well as the involvement of specialists in the field. The shortage of experts in this area can also act as a limiting factor for their studies, in addition to the high complexity of lotic ecosystems (Swan & Palmer, 2000), making research even more challenging.

The few authors that constantly publish are divided into four clusters of citations. Clusters are separated by the paper citations network. These clusters show how new studies appeared throughout time, like community studies, biodiversity, DNA analysis, and ecological patterns, and most of these new subtopics started after 2000.

Keywords centralities show that studies on Community, Nematoda, and Patterns are the most published in sub-areas of hyporheic meiofauna, showing a trend and rapid growth since 2010. The five most used keywords explicitly are the main areas studied until now (2021), and "Community" issues are extensively explored in the published documents, followed by "Nematoda". The second one, "Nematoda", is widely researched due to its peculiarities and ease of study. Most articles are focused on ecological patterns, communities, and invertebrates. Studies using keywords like direct environmental impacts, importance, diversity, taxonomy, and resilience of hyporheic meiofauna are the least used, which shows how much this area is unexplored.

Multiple Correspondence Analyses (MCA) converge with the keywords' centrality and occurrences showing that they are firmly divided into four clusters (as the authors' network). Clusters approaching community and ecology are more studied, and ecotoxicology and pollution are less studied. Despite interactions, the clusters do not overlap, so the few articles published do not merge these areas, and the same happens with the authors. As can be seen, there is also no "taxonomy" keyword. This sub-area is neglected (despite being the study basis of any biological area), limiting barriers to studying hyporheic meiofauna.

More studies efforts approaching mainly taxonomy, functional roles, trophic ecology, and the entire hyporheic ecotone must be applied. The hyporheos strongly divided into clusters of different studies is not a good sign because this fact shows that there are no interactions among different approaches and authors, restricting the studies. Surveys on hyporheic meiofauna are essential to expanding the knowledge concerning this area and elaborating efficient conservation plans regarding groundwaters, riverine and freshwater quality, and health.

Freshwater meiofauna has been referred to as an agent that helps improve water quality and hyporheic ecosystem health provider, being even cited as a biological factor in the water filtration process (Hoffmann & Gunkel, 2011; Romero et al., 2014; Gillefalk et al., 2018; Veras et al., 2018; Santos et al., 2021; Freitas et al., 2022). The hyporheic meiofauna purification process is even used in engineering techniques, such as the Riverbank filtration (RBF), which is an alternative method for water treatment that is very efficient and low-cost and makes use of the hyporheic zone to attenuate contaminants and purify water (Veras et al., 2018; Santos et al., 2021; Freitas et al., 2022). Therefore, the influence of these organisms as auxiliary agents in the attenuation of contaminants is clear, making it necessary to conserve these environments.

Conclusion

Freshwater meiofauna is a neglected topic in a growing trend of publications, with a limited group of authors separated into four survey subgroups, which shows a good exploration of the area. However, a barrier is created in cluster knowledge due to a lack of interaction among subgroups, making it difficult to merge. Taxonomy is a basis in other areas, such as ecology, and communities, and diversity is little studied in freshwater meiofauna. It means that almost no publications are cataloging and identifying species in this area, generating publication limitations for many authors or researchers. Studies on the taxonomy of freshwater meiofauna need to increase, allowing a better description of the occurrence of species, limiting factors, and the distribution of species, assemblages, and communities, and in this way, the publication rate will increase worldwide.

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