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Global distribution of expertise on soil micro- and mesofauna biodiversity evaluated by data science tools

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Abstract

Soils harbor a complex and diverse set of organisms able to regulate numerous environmental processes and affect the provision of various ecosystem services. However, these organisms are threatened by soil degradation, so we must expand knowledge and governance on these organisms and their multiple functionalities. The Global Soil Biodiversity Observatory (GLOSOB) was launched by the Convention on Biological Diversity in 2022 to assess and monitor soil biodiversity worldwide and fill this knowledge gap. As a basis for the establishment of GLOSOB, bibliographic analyses were conducted to map expertise in soil biodiversity, as well as the approaches and methods most used around the world. The present study focused on soil micro and mesofauna biodiversity, obtained by searching the Web of Science publications from January 2011 to February 2022 and subsequently applying a data science tool. The geographic distribution of the studies was highly skewed, with some nations like China, USA, several European countries, Brazil, the Russian Federation and Australia frequently appearing among the top 20 most productive and highlighting a stronger focus on soil micro and mesofauna research. The main gaps were in the African continent, the Middle East, Central and Southeast Asia and most of Latin America and the Caribbean, with few studies, heterogeneous and/or discontinuous scientific production on different aspects of micro and mesofauna. Most (65%) microfauna publications were on protists and 33% with nematodes. Microarthropods (Collembola and Acari) were the most studied groups of the mesofauna. For both soil micro and mesofauna, bioindicator approaches were the most used. In terms of methods for studying microfauna, DNA-related techniques were the most cited, while for mesofauna, extraction devices were the most frequently used. To establish soil micro and mesofauna biodiversity monitoring programs, there is a need for significant advances, both conceptually and in the standardization of methods for capacity building worldwide.

Keywords: soil biodiversity, soil invertebrates, bibliographic database, GLOSOB

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1. Introduction

The growing concern about global phenomena such as climate change effects, as well as social issues, like hunger and food insecurity, has placed soil at the center of scientific and political discussions (FAO 2015). At the same time, advances in knowledge about the importance of soil biodiversity in the delivery of ecosystem services, which directly and indirectly interfere with these global challenges, has led to the emergence of different initiatives to promote the conservation and awareness of soil biodiversity (FAO 2020).

Soil biota represent approximately 60% of all species on earth, although soil animals contribute to a smaller proportion (~25%) of this total (Anthony et al. 2023, Decaëns et al. 2006). However, the knowledge base on soil biodiversity is very unequal around the world (Guerra et al. 2020), and there are also variable levels of research effort on different taxa of soil biota (Cameron et al. 2018). Methodological advances and biotechnological developments with soil microbes have been unparalleled (Garg et al. 2024), while ecological knowledge on soil macrofauna has also greatly advanced in recent decades (Lavelle 2009, Lavelle et al. 2022). For some groups, such as Collembola, earthworms and macrofauna communities, the availability of a larger number of studies, both published and unpublished, have allowed for the construction of databases like the #GlobalCollembola database (Potapov et al. 2024), the global earthworm database (Phillips et al. 2021) and the global macrofauna database (Mathieu et al. 2022, 2025). Meta-analyses have also been an important tool for clarifying various issues, such as the composition of nematode functional groups on a global scale (van den Hoogen et al. 2019), the impacts of climate change (A'Bear et al. 2014), and the effects of land-use and global changes on soil fauna (Betancur-Corredor et al. 2022, Chiappero et al. 2024, Phillips et al. 2024). However, when we consider the accumulated knowledge about many soil fauna taxa, including representatives of the soil micro- and mesofauna, there are still many gaps in basic aspects related to their taxonomy, ecology and distribution (Guerra et al. 2020), as well as the development of new study methods and uses in various environmental and technological applications.

By definition, soil microfauna includes microscopic eukaryotic organisms (<0.1 mm in diameter), namely the nematodes, rotifers and tardigrades, and historically the protozoa (Swift et al. 1979). However, the latter are also frequently placed among the soil microbes (Caron & Countway 2009), and include parasitic, autotrophic (algae), heterotrophic (protozoa), and even fungi-like protists (Geisen et al. 2018). Protists predate bacteria and other protists and can be also plant pathogens, influencing the dynamics of microbial communities, nutrient turnover, and plant health (Xiong et al. 2020). The positive and negative impacts of microfauna on ecosystems and on human well-being have not been adequately investigated but are estimated to be on the order of billions of US dollars year^{1} for parasitic nematodes (Nicol et al. 2011).

Tardigrades are a group of organisms found both in aquatic and terrestrial ecosystems and are recognized as one of the most resistant to extreme environmental conditions. This is due to their ability to enter a cryptobiotic state (an extreme form of hibernation) at any stage of development. Terrestrial tardigrades live in mosses and lichens and feed on protozoa, rotifers and nematodes (Jefferey et al. 2010). In the soil, Rotifera live associated with the water film, and are microphages feeding on the bacterial film that grows on substrates, or on yeasts, algal cells or bacteria suspended in the soil water (Jefferey et al. 2010).

Soil mesofauna includes invertebrates whose body size varies from 100 µm to 2 mm, occurring in the soil in thousands of individuals per m^{-2} and hundreds of species per site (Bardgett et al. 2005). From an ecological point of view, they are fundamental elements of soil foodwebs, promoting decomposition and nutrient cycling, regulating microbial populations and serving as prey for important soil predators (FAO 2020). Collembola and Acari are among the most diverse, abundant and widely distributed terrestrial arthropods on the planet and interfere in multiple processes that occur in the soil, including plant development (Jernigan et al. 2023, Potapov et al. 2020). Although there is still much to be understood about their importance in ecosystem processes and services, experimental and empirical evidence has facilitated their use as bioindicators of soil pollution, management and conservation.

The Enchytraeidae, although much less abundant and diverse than springtails and mites, are small ecosystem engineers, altering the soil as a physical habitat and influencing the availability of food resources for other organisms (Conti & Mulder 2022). They are also widely used in ecotoxicological and soil quality studies (Didden & Rombke 2001, Römbke et al. 2017). As for Symphyla, a small group of myriapods, there is much less information available, but it is known that by feeding on decomposing organic plant matter and microorganisms, they contribute to the regulation of decomposition processes and nutrient cycling (Jefferey et al. 2010).

As a basis for the establishment of a Global Soil Biodiversity Observatory proposed by the Global Soil Partnership of the FAO (Parnell et al., Brown et al. this issue), it is important to identify research advances, but also to reveal knowledge gaps, in order to establish priorities for funding and training efforts, as well as awareness raising among governments and society overall (Brown et al, this issue). Hence, the present study aimed, through a bibliographic review, to identify the distribution of scientific knowledge regarding soil micro and mesofauna worldwide, as well as the main research themes addressed and the methods used, to reveal the potential gaps regarding research on these animals, hence contributing to the planning for a Global Soil Biodiversity Observatory.

2. Material and Methods

2.1 Publications on soil microfauna and mesofauna

A bibliographic survey was conducted to identify the global distribution of expertise in soil micro- and mesofauna studies, the methods used, and the main approaches of the studies. The search terms were selected based on the most widely studied soil micro and mesofauna taxa and their functions in soils. These taxa were used as proxies for the broader set of soil micro- and mesofauna groups. The research was carried out in March 2022, and included articles, books, book chapters, reviews, conference proceedings, notes, letters, editorials, data articles, and corrections, published between January 2011 and February 2022, extracted from one of the largest academic publication databases, Web of Science (WoS). No language selection was made, meaning that articles in languages other than English were included if they were listed in WoS. Terms made up of two words were enclosed in quotation marks to maintain their combined meaning, while asterisks were employed to account for plurals and different word endings for each taxon. For microfauna, searches were carried out using the following terms: “soil microfauna”, soil AND protozoa, “soil nematodes”, Rotifera, and Tardigrada. In the case of mesofauna, the terms used for searches in the WoS database were: “soil mesofauna”, Collembola, soil AND Collembol*, “soil mites”, soil AND Acari, Enchytraeidae, and Symphyla (Table 1).

2.2 Database construction and data analysis

Although there are software tools that perform bibliometric data extraction, they typically use information from the first author. Therefore, a customized database was created using PostgreSQL to access the data from the complete list of authors for each article obtained in the WoS search and to customize queries, combining groups of micro- and mesofauna with methods and applications of interest. PostgreSQL (EDB - Enterprisedb - PostgreSQL) is a free and open-source relational database management system (RDBMS), as outlined by Silva and Malaquias (2021). The database consists of entities (tables) that are interconnected, and detailed guidance on how to model a database, including data normalization rules and relational logic, can be found in Silberschatz et al. (1999).

Using this approach, queries executed on the data records (bibliographic information from WoS) were stored in the PostgreSQL database, focusing solely on the selected groups or topics of interest. Specific terms were used to identify relevant topics by searching within

Table 1. Topics and search terms used for the soil microfauna and mesofauna and the resulting number of publications retrieved from the Web of Science database, considering the period between January 2011 and February 2022.

Group name (Topics)	Search terms	No. publications
Microfauna	“soil microfauna”	41
Nematodes	“soil nematodes”	474
Protista	soil AND protozoa	907
Tardigrada	Tardigrada	40
Rotifera	Rotifera	26
Mesofauna	“soil mesofauna”	173
Collembola	Collembola	2,225
	Soil AND collembol*	1,525
Enchytraeidae	Enchytraeidae	215
Soil mites	soil mites	215
	"soil AND Acari"	1,644
Symphyla	Symphyla	51

the article title, abstract, author keywords and keywords plus. The resulting quantitative data were presented as the number of unique records (publications), with duplicates removed based on publication title. Only the queries with more than 80 percent match were validated for further analysis after removal of the unmatched records. This last step was conducted by checking manually the correspondence of publication contents (using the title and abstract) to the query keywords. The exceptions were biological control (78 percent), which was included due to its relevance for ecosystem service delivery.

The queries validated for soil microfauna included: bioindicator OR indicator OR monitoring OR pollution, soil health OR soil quality OR soil fertility, taxonomy OR inventory, biological control, and DNA OR sequencing OR metabarcoding OR barcoding OR molecular technique. For soil mesofauna the queries validated used the following search terms: bioindicator OR indicator OR monitoring OR pollution, soil health OR soil quality OR soil fertility, taxonomy OR inventory, biological control, funnel OR Berlese OR Tullgren OR Kempson, Pitfall OR Provid OR trap, and ecotoxicology OR toxicology.

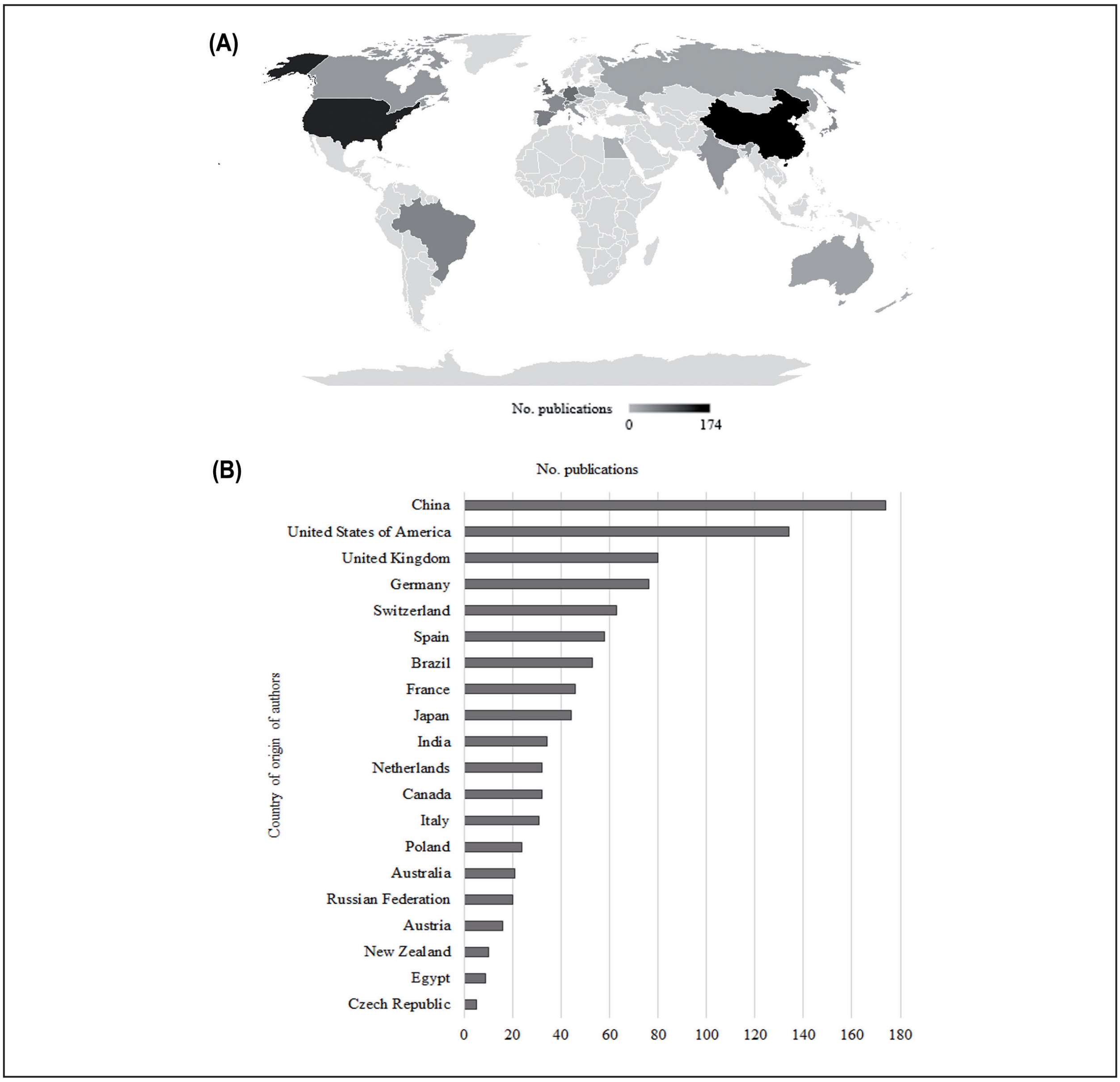

Figure 1. Geographic distribution of publications with the soil microfauna groups (A) and top 20 countries with highest number of publications (B) during the period from January 2011 to February 2022. The frequency of publications is based on the authors' country of origin according to the WoS author's address. In the map, the intensity of the black/grey color represents an increasing number of publications in each country. Countries not among the top twenty are displayed in light grey color.

A frequency analysis of the queries was conducted using the statistical software R (R Core Team 2021). The scientific database and statistical tools used in the analysis provided an approximate overview of global research on soil micro- and mesofauna, considering the top 20 publishing countries for each query that combined organisms with applications or methods. The countries were classified according to the FAO list (https://www.fao.org/countryprofiles/en/). Microsoft Excel 2019 was then used to generate tables, graphs, and maps.

3. Results

3.1 Soil microfauna

3.1.1 Publications by country and taxa

The 20 countries with the highest number of publications on microfauna and its two main taxa (protists and nematodes) included only one country in Latin America and the Caribbean (Brazil), several European (mostly Western) and Asian countries (particularly China), as well as Australia and New Zealand in the Pacific region (Figure 1A). China and the USA stood out with the highest number of publications (> 100) (Figure 1B). Although publications were obtained with authors from 66 countries, only 13 countries from the African continent appear on the list with less than 10 publications each (Table S1).

The search term Protista represented 61% of the total of 1,488 publications for microfauna, followed by Nematodes, with 32% (Table 1). On the other hand, the term soil microfauna itself resulted in only 41 publications, revealing that authors working with these taxa do not necessarily refer to these organisms as members of the soil microfauna. China, USA and the UK were the leading countries in the number of publications for Protista and Nematodes (Figure 2A, 2B).

Only 40 articles were found for Tardigrada, mainly focused on taxonomy and occurrence in natural environments. Most of the work was done by researchers from Poland, in association with scientists from other countries. Other countries with at least 5 articles mentioning tardigrades were: Australia, USA, Czech Republic, Germany, and Italy (Figure 2 C).

The number of articles published on Rotifera was even lower than for Tardigrada (26 publications). But, excluding those dealing with zooplankton rotifers, only 15 articles remained for Rotifera associated with soil/terrestrial environments. Poland was again the country with the highest number of articles (5), followed by Australia (4), USA and Czech Republic (3), and Italy (2), while the remaining countries had only 1 publication (Figure 2D).

3.1.2 Main uses and applications and their geographical distribution

Regarding the main uses and applications of soil microfauna, China stood out in first place with publications in the following areas: bioindicators, soil health and DNA-based studies. The United Kingdom and the China had the highest number of publications focused on taxonomy. Although there were few publications focused on biological control, Brazil, France, India and Turkey each had two publications, followed by other countries with only one publication (Figure 3).

Regarding the specific groups of soil microfauna, publications including uses were more numerous for Protists, followed by Nematodes, being almost non-existent for the search term “soil microfauna”. The most prominent uses were for bioindicators, soil health, taxonomy and DNA. The term microfauna included only publications on bioindicators, soil health and DNA (Figure 4).

3.2 Soil mesofauna

3.2.1 Publications by country and taxa

The number of publications on “soil mesofauna”, and on the main mesofauna groups (Collembola, soil mites, Enchytraeidae and Symphyla), was very heterogeneous across the world. The top 20 countries with the highest number of publications were in the Americas, Europe, part of Asia and Oceania. A low number of studies indicated a gap in knowledge on mesofauna in the African continent, the Middle East, Central Asia, part of Southeast Asia and a major part of Latin America and the Caribbean (Figure 5).

Although 65 countries had authors publishing on mesofauna or specific groups, the top 20 with the highest number of publications accounted for 82 percent of the total production. USA led the ranking with 174 publications (ca. 10%), followed by Brazil, China, Spain, Germany, France, Italy, Poland, Australia and the United Kingdom (Figure 6A). A complete list of the publications from the 65 countries is available in the supplementary files (Table S1). Of the top 20, half were from European countries, three from North America and Asia, and one each from

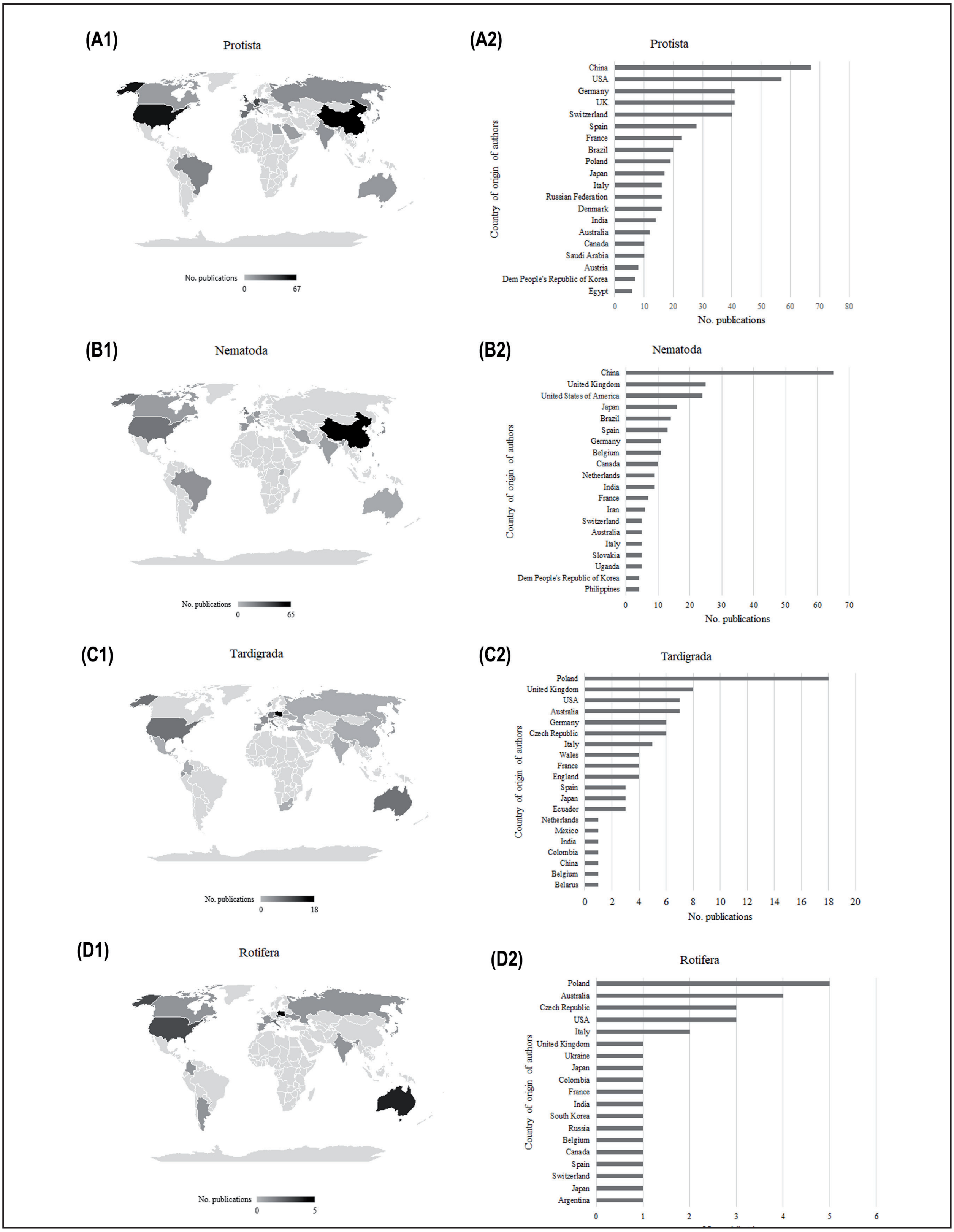

Figure 2. Top twenty countries with the highest number of publications per group of soil microfauna in the world between January 2011 and February 2022. Frequency of publications is based on the country of origin of authors according to WoS. (A1,2) Protista; (B1,2) Nematodes; (C1,2) Tardigrada (D1,2) Rotifera. In the maps, black/grey color intensity represents the number of publication records in each country. Countries not among the top twenty are displayed in light grey color.

Oceania, South America and the Middle East. This clearly highlights a concentration of knowledge on soil mesofauna in the northern hemisphere and in temperate vs. tropical regions.

Furthermore, one must consider that some of the countries included in the top 20 have large territorial extensions, such as the USA, Brazil, China, Australia, the Russian Federation and Canada, with surfaces ranging from almost 8 million to over 17 million km^2. When we relate the number of articles to the size of the country (Figure 6B), the Netherlands stands out with almost 100 articles per 100,000 km^2, and of the top 20 countries using this classification, 17 were in the European continent, showing the clear bias of knowledge and concentrated research in these countries compared to the rest of the world. Regarding countries with large territories, the ratio of the number of publications per 100,000 km^2 was two for the USA and Brazil, one for China and Australia and less than one for the Russian Federation and Canada. Therefore, even in countries with large territorial extensions and a relatively large number of publications, there is a small level of knowledge in relation to the surface area. Hence, a greater number of publications on soil mesofauna does not necessarily mean that there is sufficient knowledge on the biodiversity of these organisms in the country.

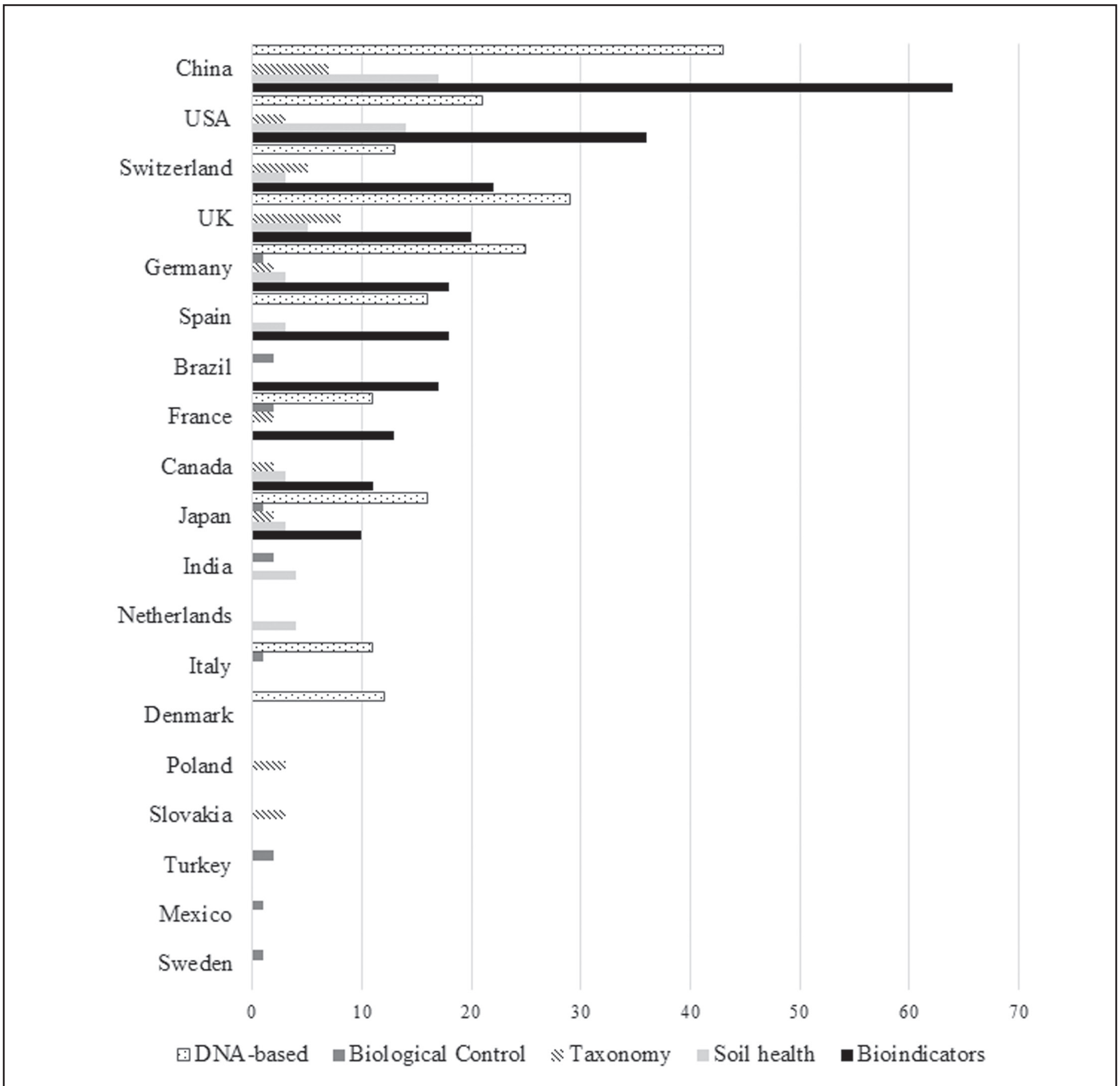

Figure 3. Countries with highest number of publications on the uses of soil microfauna (including the subgroups) as DNA-based, biological control, taxonomy, soil health and bioindicators.

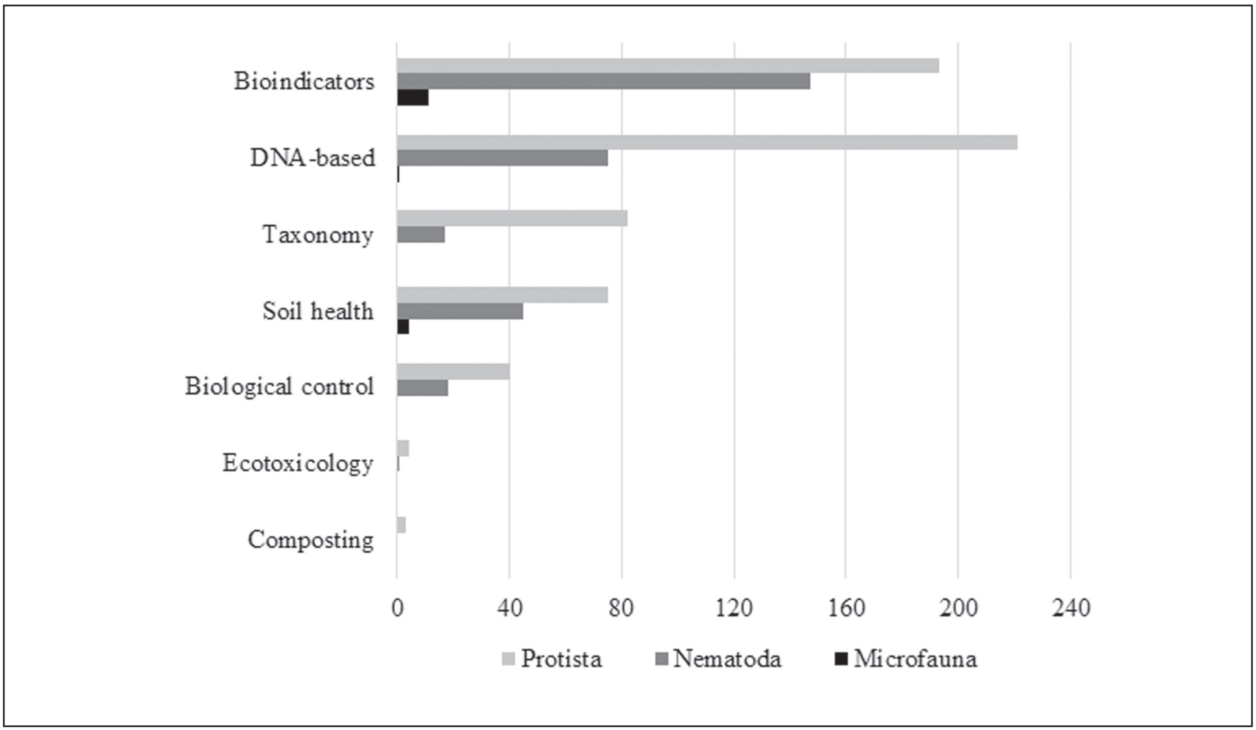

Figure 4. Number of publications per main groups of soil microfauna (including the subgroups Protista and Nematodes), related to their uses as bioindicators, in DNA-related studies, in taxonomic studies, for soil health-related topics, for biological control, for ecotoxicology and for composting

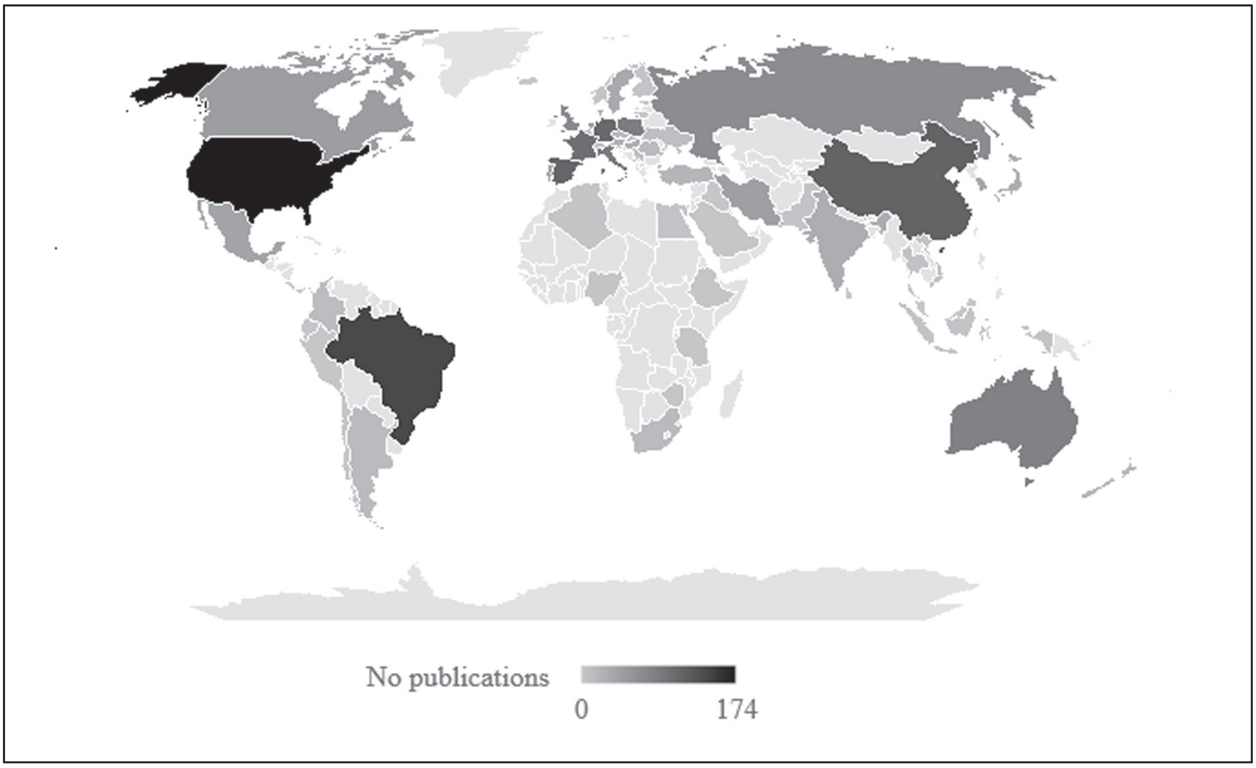

Figure 5. Top twenty countries with the highest number of publications on mesofauna groups between January 2011 and February 2022. Frequency of publications is based on the country of origin of authors according to WoS. In the map, black/grey color intensity represents the increasing number of publication records in each country. Countries not among the top twenty are displayed in light grey color.

The most investigated soil mesofauna groups were Collembola and soil Acari, with 3,750 and 1,859 records respectively, considering all the search terms used for each group (Table 1). The number of publications on Enchytraeidae represented around 6 percent of those on Collembola. In the literature search, a very small number of publications on Symphyla was found, with only 51 records retrieved, though this number does not necessarily represent the totality of articles on Symphyla, as they can often be referenced by names at lower (species) or higher (Myriapoda) taxonomic levels.

Regarding Collembola, 49 countries had at least one publication, and China led the tally with 85 publications, followed by the USA, Germany, France, Brazil, Australia, Spain, United Kingdom, Poland, and Italy. The countries with no publications were mainly in the African continent, the Middle East and Central Asia (Figure 7A1, 7A2). Enchytraeidae studies were restricted to 27 countries, with the highest number of affiliated authors in Sweeden (14 publications), followed by Germany, France, Hungary, Italy, Brazil, Spain, Portugal and Russian Federation. Of these 10 countries, eight are from the European continent, and only one from South America and Asia (Figure 7B1, 7B2).

Considering the soil mites, one of the traditionally most studied groups of soil mesofauna, the authors' geographic distribution was similar to that for Collembola, with 53 countries represented. Among those with the highest number of publications, the USA appeared with 89 articles, followed by Brazil (49), and Spain, Iran, Poland, Russian Federation, Italy, Germany, Republic of Korea and Turkey, with number of publications varying from 36 to 18. The geographic knowledge gaps were similar to those for Collembola, including the African continent and the countries of Central Asia (Figure 7C1, 7C2). The number of publications on Symphyla was very low, with only nine countries listed: Italy, Portugal, Finland, Brazil, Canada, Australia, USA, Austria, and Hungary (Figure 7D1, 7D2).

3.2.2 Main uses and applications and their geographical distribution

The predominant use related to mesofauna was as bioindicators in a broad sense, and most publications on this topic were with Collembola (214) and Acari (193), while Enchytraeidae, "Soil mesofauna" and Symphyla had fewer publications (Figure 8). The term "soil quality", which in a way is a refinement of the term "bioindicator", had a similar profile in terms of publications per group, with more on Collembola (61) and Acari (32) as well. The geographical distribution of studies on these topics was similar to that of mesofauna research as a whole, with Poland, Brazil, China, Italy, France and Spain among the top 10 countries with the highest number of publications (Figure 9).

In terms of taxonomic research, a higher effort was seen for Collembola than for the soil Acari and Enchytraeidae, while on the other hand, biological control research was mostly with Acari (104 publications) rather than Collembola (Figure 8).

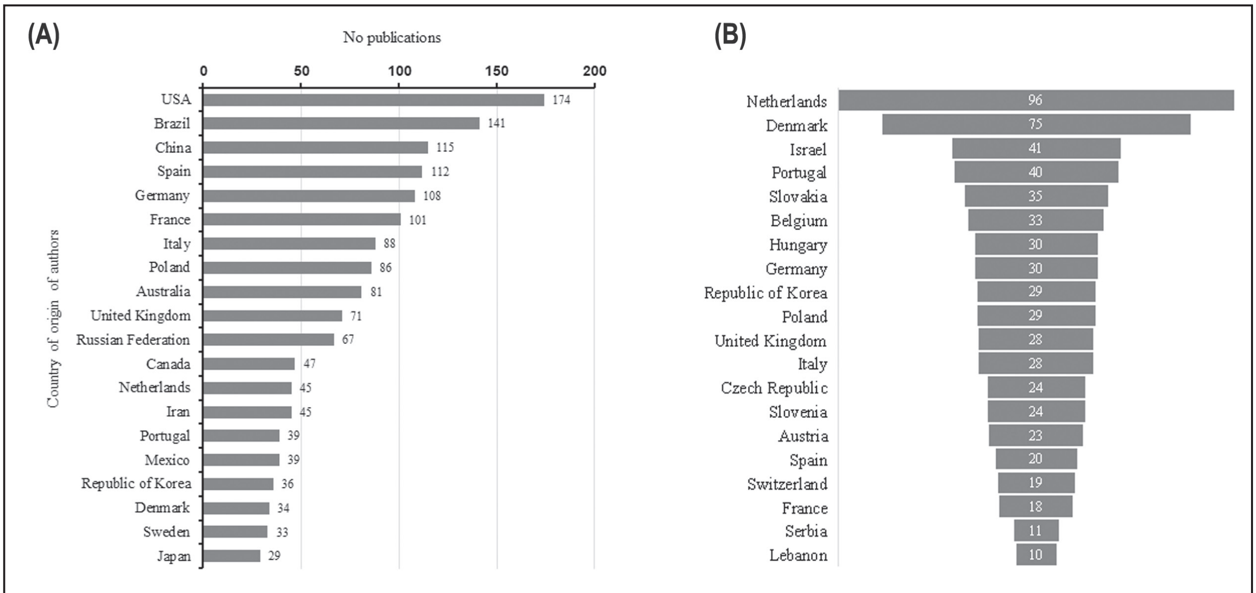

Figure 6. Top twenty countries with the number of publications on mesofauna between 2011 and February, 2022. Frequency of publications is based on the country of origin of authors according to WoS (A), and top 20 countries with highest relative number of publications per 100.000 km^2 of surface area (B).

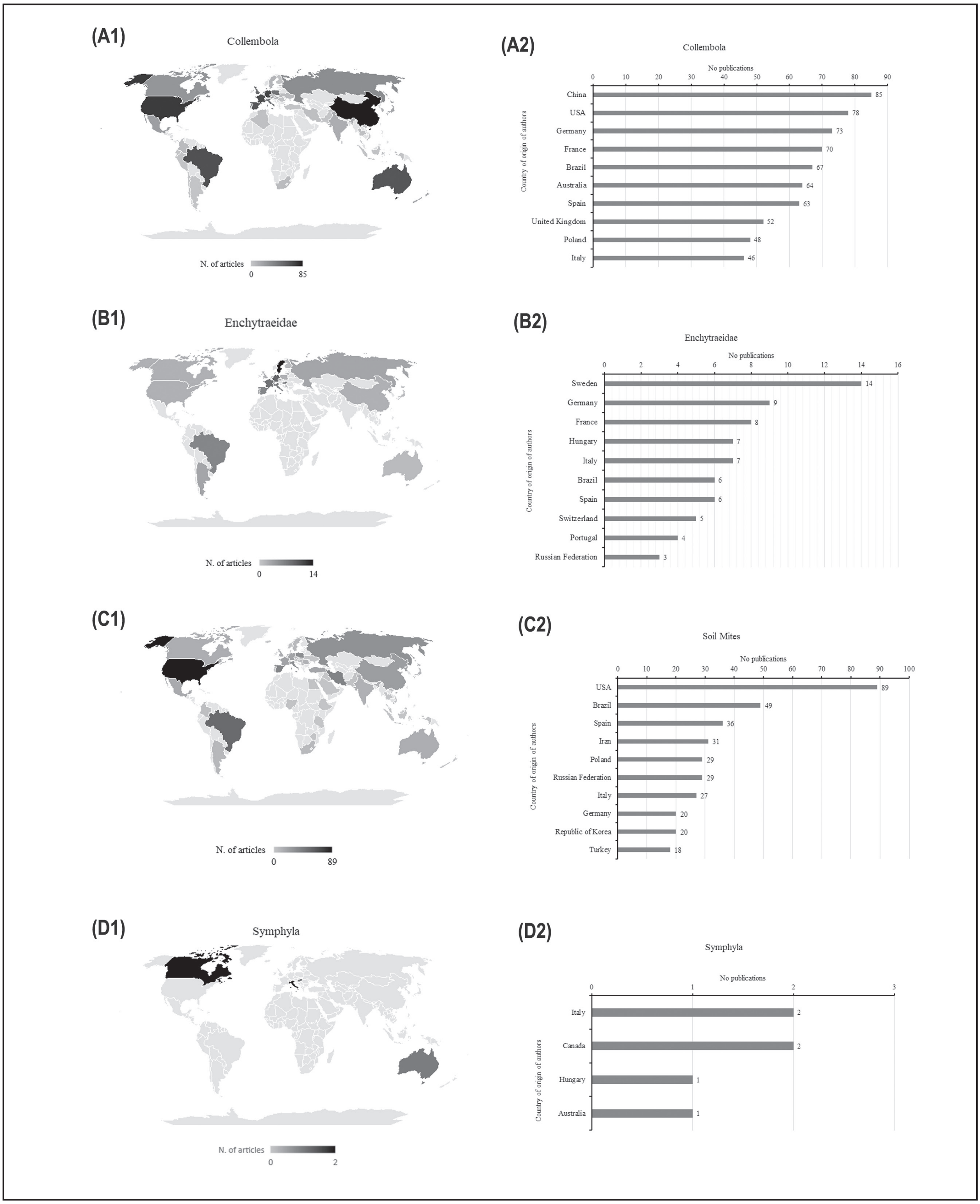

Figure 7. Top twenty countries with the highest number of publications in the world (on the left) between January 2011 and February 2022 on Collembola (**A1**, **A2**), Enchytraeidae (**B1**, **B2**), Soil Mites (**C1**, **C2**) and Symphyla (**D1**, **D2**). Number of publication records of the top 10 countries of each group of invertebrates is shown on the right. Frequency of publications is based on the country of origin of authors according to WoS. In the maps, black/grey color intensity represents the number of publication records in each country. Countries not among the top twenty are displayed in light grey color.

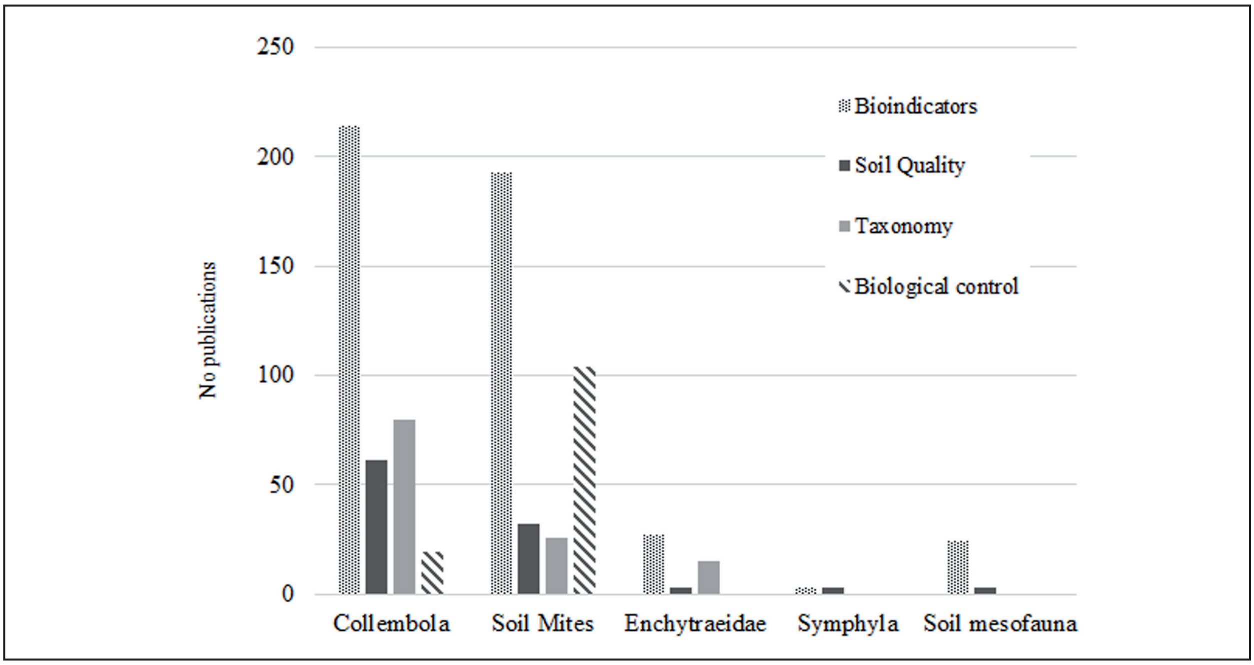

Figure 8. Number of publications on the main groups of soil mesofauna relating to their uses as bioindicators, soil quality, taxonomic studies and biological control.

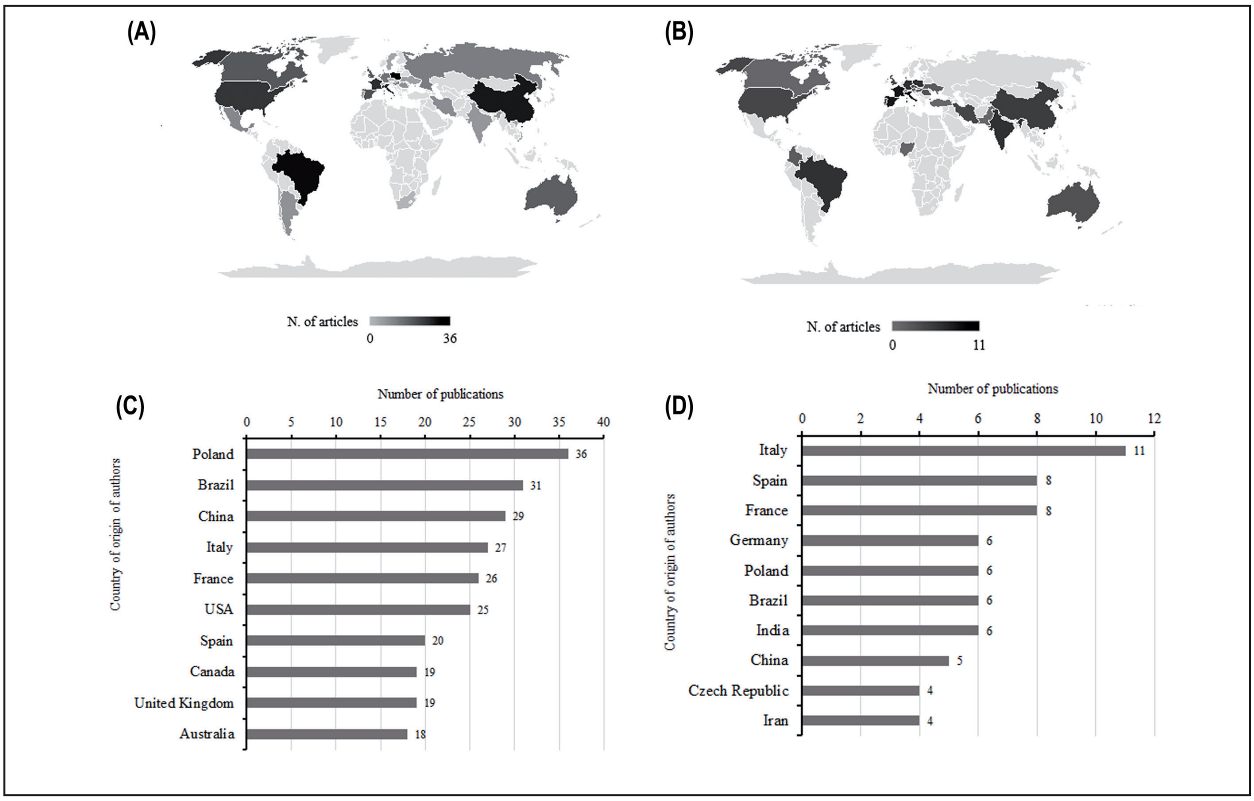

Figure 9. Geographic distribution of the top twenty (**A**, **B**) and listing of the top ten countries (**C**, **D**) with the highest number of publications using soil mesofauna as a bioindicator (**A**, **C**) and associated with soil quality (**B**, **D**). In the maps, black/grey color intensity represents an increasing number of publications in each country. Countries not among the top twenty are displayed in light grey color.

Regarding the methods most used to evaluate the different groups of soil mesofauna, extraction devices like Berlese funnels were more frequently used for soil mites, while pitfalls were more used for Collembola (Figure 10A). Extraction apparatuses were more used in Iran, Brazil, USA, Turkey, Mexico, Poland, Russian Federation, Republic of Korea, Spain, and India, while pitfall traps were more commonly used in the USA, followed by Brazil, Germany, Spain, Australia, Mexico, UK, China, Russian Federation, and New Zealand (Figure 10B).

Ecotoxicological research was more common with Collembola, than Acari and Enchytraeidae (Figure 10A), and mostly performed by authors in the Netherlands, Brazil, Portugal, Germany, Hungary, Denmark, China, Spain, Canada, and Nigeria (Figure 10B).

4. Discussion

4.1 Geographic distribution of knowledge on taxa, methods and functions

The present bibliographic analysis confirmed a highly skewed global knowledge on various aspects related to soil micro and mesofauna research, with a few countries like China, USA, several European nations, the Russian Federation, Brazil and Australia frequently appearing among the top 20 most productive, demonstrating a concentration of research in just a few hubs. This appears to be a recent trend, as there is a long tradition of soil biodiversity research in European and North American countries.

As an exercise to illustrate this change, a search in the WoS database from 1945 to December 2000 using the term "Collembola", retrieved 2,053 publications, with the 10 most productive nations being (in descending order): USA, France, Germany, England, Poland, Norway, Canada, Australia, Italy, and Denmark. China ranked 22nd. For the same search from January 2001 to December 2010, the top 10 most productive countries were: USA, Germany, England, France, Poland, China, the Netherlands, Denmark, Italy, and Australia. During the period of this study, from January 2011 to February 2022, the top 10 were: China, Germany, the USA, Brazil, France, Poland, Spain, Russia, the Netherlands, and Australia. Finally, for the period from March 2022 to November 2024, the ten countries with the most publications were: China, Germany, Brazil, France, the USA, Italy, Russia, Spain, the Netherlands, and Poland.

A greater number of published articles can be used as a proxy for the existence of consolidated research groups and greater investments in research on these topics. The most productive nations are also normally major agricultural players and/or large economies, with knowledge of the soil and associated biodiversity being an important factor for economic development. Nevertheless, when we related the number of published studies to the size of the country's territory, we found that this research effort was often not sufficient to address the potential diversity in nations with large areas (Culik & Filho 2003). This may be particularly important in countries with high degree of endemism, which is typical for several groups of the soil micro and mesofauna, related

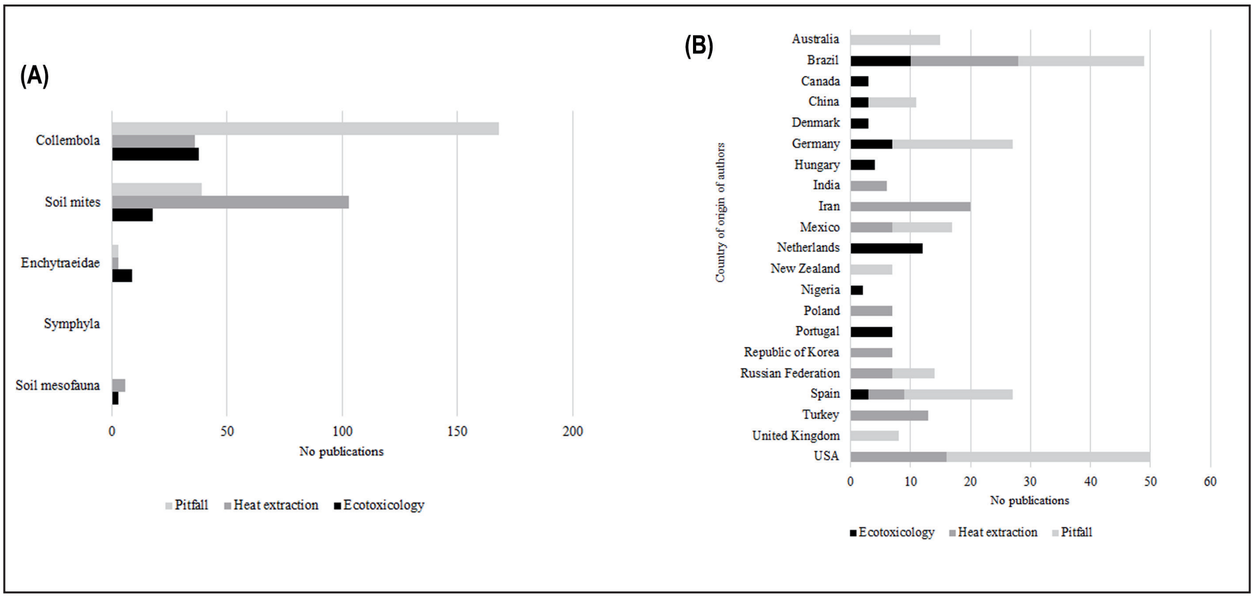

Figure 10. Number of publications using pitfall traps, heat extraction and ecotoxicological assays in relation to mesofauna groups (**A**) and the countries with highest number of publications using pitfalls, heat extractors and performing ecotoxicological research using mesofauna.

both to the limited dispersal ability of some species and to the environmental gradients found in soil (Arribas et al. 2021).

Knowledge gaps were evident and represent a pattern, regardless of the soil fauna group or study approach. The African continent, the Middle East, Central and Southeast Asia and much of Latin America and the Caribbean had low scientific output on many different aspects of micro and mesofauna research. This is particularly worrying considering the need for more precise estimates of existing biodiversity and the extent of its loss in the face of major threats (FAO 2020, Lindo et al., this issue). Many threats to biodiversity are global in scope, such as climate change (Tibbett et al. 2020), and certainly have an impact on soil biodiversity in these regions, reducing both species abundance and richness (Kevan 1985, Brown & Sautter 2009).

In relation to the most studied soil micro- and mesofauna groups, it is clear that in many cases, authors do not associate their research with this taxonomic group classification based on body size. Several authors have already argued the advantages and disadvantages of this classification, which still represents a commonly used strategy in soil ecology to deal with the enormous complexity and diversity of soil organisms (Briones 2018). Clearly, future efforts aiming to quantify scientific output of meso- and microfauna research need to take this into consideration, and include the use of taxonomically targeted key-words.

Among the microfauna taxa, although Protists (sometimes considered as microorganisms; Briones 2018) were the most studied, the number of publications on nematodes was not in accordance to the true importance and investment in research on these organisms. These common agricultural and plant parasites include around 4,000 species that cause important damages worldwide, resulting in economic losses of around US$173 billion per year[1] (Dutta & Phani 2023). The human-health related aspects of both protist and nematode research are also highly relevant (Wall et al. 2015) and in need of further attention.

In the case of mesofauna, the microarthropods Collembola and Acari were the most studied, being mainly used as bioindicators in a broad sense, confirming their well-known application for this purpose (Gergócs & Hufnagel 2009, Joimel et al. 2022). However, research related to the taxonomy of these organisms is still lacking, particularly for Acari that represent an enormous source of unclassified diversity worldwide (Walter & Proctor 2013, Lienhard & Krisper 2021), and major challenges for identification of both pest and biological control agents (e.g., Liao et al. 2023, Saccaggi & Ueckermann 2024). Considering their economic importance worldwide, and the major geographic gaps in research on these taxa worldwide, there is an urgent need to promote capacity building and further work on various aspects of the taxonomy, ecology and potential uses of these organisms. Although potworms (Enchytraeids) are widely used as bioindicators of soil quality and contamination (Rombke et al. 2017), their poor taxonomic knowledge in many countries and the small number of active taxonomists worldwide are an important limiting factor (Schmelz et al. 2013). On the other hand, their ease of culture provides ideal conditions for their more widespread use in ecotoxicological studies (Rombke et al. 2017), currently limited to only a few countries, mainly in Europe.

In relation to the study methods used for microfauna, DNA-related techniques were prevalent likely due to the high number of articles with Protista. These techniques are gaining popularity as the analytical costs fall, and as the taxonomic libraries expand, although the ability to perform this type of research is still limiting in many countries due to lack of appropriate infra-structure (technical and/or analytical).

For mesofauna, the widely used heat extraction methods and the easy to apply traps confirm the suitability of these for wider adoption, though they tend to be biased toward capturing more active fauna (Fioratti Junod et al. 2023), and capacity building for identification is necessary, as mentioned above. Furthermore, the numerous modifications and adaptations of this method make comparisons between studies with different apparatus difficult, so that standardized methods are important for future global studies.

4.2 Outlook on the methodological approach

In recent years, several studies have sought to understand the roles played by soil fauna, as well as the threats to this component of soil biodiversity through bibliometric studies, systematic reviews, and meta-analyses. In most studies, the WoS database has been used, either as the sole database (Guerra et al. 2020, Christel et al. 2021, Betancur-Corredor et al. 2023, Lang et al. 2023, Chen et al. 2024, Phillips et al. 2024) or in combination with other bibliographic databases (Krogh et al. 2020, Zhang et al. 2022, Szabó et al. 2023).

It is important to clarify that bibliographic databases often have inherent limitations and biases related to discipline, publication type, language, and other factors (Aali & Shokraneh 2021). Some specific disadvantages of the WoS database include its high subscription costs, which can make access challenging for some institutions, limited coverage of books and conference proceedings, and inadequate mechanisms for differentiating authors with similar names (Wilder & Walters, 2021). However, the impact of these issues varies based on the time frame and field of interest, being particularly notable in the social sciences and for periods prior to 1998 (Pranckuté 2021, Keller et al. 2022). Among various fields, natural sciences are among the best represented in WoS, and since 2014, the database has expanded its sources to include more content from regions such as Latin America and the Caribbean, Russia, Korea, and Arabic-speaking countries (Pranckuté 2021).

According to Clarivate's Terms of Use and copyright restrictions, public redistribution of data directly extracted from WoS is prohibited without explicit permission. These policies are designed to protect the intellectual property and usage rights of Clarivate. Consequently, we were unable to publicly provide the bibliographic reference database generated during our research. This restriction means that the study cannot be exactly replicated, as a new search in WoS may yield a different list of articles due to the dynamic nature of its content, which changes as journals are added or removed based on inclusion criteria. Instead, we present our analyses, results, and conclusions derived from this data while adhering to the usage limitations set by Clarivate. An additional limitation of this study approach, beyond those associated with the WoS database, is that articles published prior to the study's time frame would be essential to more comprehensively map global expertise, including contributions from various countries and lesser-studied soil micro- and mesofauna groups.

Based on the data from all authors of each article in the affiliation field, we identified the countries where the institutions of the authors were located for each article. Therefore, a single article with authors from multiple countries was counted for all of them. It is important to clarify that fieldwork was not necessarily conducted in these countries; for example, the soil mesofauna of a tropical forest may have been extensively studied by teams from countries other than the one where the site is located. Since the objective of this study was to identify the countries with expertise, the counting was based on the affiliation field, without considering the target territory of each publication.

5. Conclusions

This study does not represent an exact portrait of all scientific production on soil micro and mesofauna worldwide in the period of 2011 to 2022, but it provides the best approximation given the information available in WoS. It mapped expertise on various research topics and taxa in countries and regions around the world, to facilitate the development of human resources in research on soil biodiversity. Significant differences were observed in the capacity to study the different taxa of soil micro- and mesofauna in different countries, based on author affiliations. Several groups showed an low level of scientific output indicating the lack of specialists and capacity to perform research on these animals (e.g., tardigrades, rotifers, symphylans, and enchytraeids). The establishment of the Global Soil Biodiversity Observatory should consider the gaps identified here, particularly the need for assessments and capacity building activities in the African continent, Latin America and the Caribbean, the Middle East and parts of Asia. The challenges to overcome this lack of knowledge and to implement an effective global observatory need special attention and assessment of infrastructural, human, conceptual and methodological limitations, some of which were evidenced here.

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Supplementary online material

Table S1, containing the number of publications by country, retrieved using the search terms associated with soil micro- and mesofauna groups, in the Web of Science database, from January 2011 to February 2022.

References

Aali, G., & Shokraneh, F. (2021). No limitations to language, date, publication type, and publication status in search step of systematic reviews. *Journal of Clinical Epidemiology, 133*. https://doi.org/10.1016/j.jclinepi.2021.02.002

A'Bear, A. D., Jones, T. H., & Boddy, L. (2014). Potential impacts of climate change on interactions among saprotrophic cord-forming fungal mycelia and grazing soil invertebrates. *Fungal Ecology, 10*, 34–43. https://doi.org/10.1016/j.funeco.2013.01.009

Anthony, M. A., Bender, S. F., & van der Heijden, M. G. A. (2023). Enumerating soil biodiversity. *Proceedings of the National Academy of Sciences of the USA, 120*, e2304663120. https://doi.org/10.1073/pnas.2304663120

Arribas, P., Andújar, C., Salces-Castellano, A., Emerson, B. C., & Vogler, A. P. (2021). The limited spatial scale of dispersal in soil arthropods revealed with whole-community haplotype-level metabarcoding. *Molecular Ecology, 30*(1), 48–61. https://doi.org/10.1111/mec.15591

Bardgett, R. D., Usher, M. B., & Hopkins, D. W. (2005). *Biological diversity and function in soils*. Cambridge University Press.

Betancur-Corredor, B., Lang, B., & Russell, D. J. (2022). Reducing tillage intensity benefits the soil micro- and mesofauna in a global meta-analysis. *European Journal of Soil Science, 73*(6), e13321. https://doi.org/10.1111/ejss.13321

Betancur-Corredor, B., Lang, B., & Russell, D. J. (2023). Organic nitrogen fertilization benefits selected soil fauna in global agroecosystems. *Biology and Fertility of Soils, 59*(1), 1–16. https://doi.org/10.1007/s00374-022-01677-2

Briones, M. J. I. (2018). The serendipitous value of soil fauna in ecosystem functioning: The unexplained explained. *Frontiers in Environmental Science, 6*, 149. https://doi.org/10.3389/fenvs.2018.00149

Brown, G. G., & Sautter, K. D. (2009). Biodiversity, conservation and sustainable management of soil animals: The XV International Colloquium on Soil Zoology and XII International Colloquium on Apterygota. *Pesquisa Agropecuária Brasileira, 44*, i–ix.

Brown, G. G., Ferreira, T., Correia, M. E. F., Niva, C., Jesus, E. C., Oliveira, M. I. L., Antunes, L. F. S., Parron, L. M., Coelho, M. R. R., Chaer, G. M., et al. (2025). Soil biodiversity knowledge and use worldwide: Results from a global survey. *Soil Organisms, 97*(SI), 7–31.

Brown, G. G., Parnell, J. J., Kobayashi, M., Ferreira, T., Parron, L. M., Correia, M. E. F., Jesus, E. C., Chaer, G. M., Coelho, M. R. R., Niva, C., et al. (2025a). Towards a Global Soil Biodiversity Observatory (GLOSOB): Science and policy backgrounds. *Soil Organisms, 97*(SI), 127–141.

Caron, D., & Countway, P. (2009). Hypotheses on the role of the protistan rare biosphere in a changing world. *Aquatic Microbial Ecology, 57*, 227–238. https://doi.org/10.3354/ame01352

Cameron, E. K., Martins, I. S., Lavelle, P., Mathieu, J., Tedersoo, L., Gottschall, F., Guerra, C. A., et al. (2018). Global gaps in soil biodiversity data. *Nature Ecology & Evolution, 2*(7), 1042–1043. https://doi.org/10.1038/s41559-018-0573-8

Chen, J., Zhao, J., Du, H., Xu, M., Lei, Y., Chen, W., & Chao, J. (2024). Earthworms' role in the management and regulation of croplands: Comparative research on field and laboratory studies revealed by bibliometric analysis. *Ecological Indicators, 163*, 112077. https://doi.org/10.1016/j.ecolind.2024.112077

Chiappero, M. F., Rossetti, M. R., Moreno, M. L., & Pérez-Harguindeguy, N. (2024). A global meta-analysis reveals a consistent reduction of soil fauna abundance and richness as a consequence of land use conversion. *Science of the Total Environment*, 173822. https://doi.org/10.1016/j.scitotenv.2024.173822

Christel, A., Maron, P. A., & Ranjard, L. (2021). Impact of farming systems on soil ecological quality: A meta-analysis. *Environmental Chemistry Letters, 19*(6). https://doi.org/10.1007/s10311-021-01302-y

Conti, E., & Mulder, C. (2022). Chemistry-driven Enchytraeidae assemblages acting as soil and ecosystem engineers in edaphic communities. *Ecological Indicators, 144*, 109529. https://doi.org/10.1016/j.ecolind.2022.109529

Culik, M. P., & Filho, D. Z. (2003). Diversity and distribution of Collembola (Arthropoda: Hexapoda) of Brazil. *Biodiversity and Conservation, 12*(6), 1119–1143. https://doi.org/10.1023/A:1023069912619

Decaëns, T., Jiménez, J. J., Gioia, C., Measey, G. J., & Lavelle, P. (2006). The values of soil animals for conservation biology. *European Journal of Soil Biology, 42*, S23–S38. https://doi.org/10.1016/j.ejsobi.2006.07.00

Didden, W., & Römbke, J. (2001). Enchytraeids as indicator organisms for chemical stress in terrestrial ecosystems. *Ecotoxicology and Environmental Safety, 50*, 25–43.

Dutta, T. K., & Phani, V. (2023). The pervasive impact of global climate change on plant-nematode interaction continuum. *Frontiers in Plant Science, 14*, 1143889. https://doi.org/10.3389/fpls.2023.1143889

FAO. (2015). *Status of the world's soil resources: Main report*. FAO & ITPS.

FAO. (2020). *State of knowledge of soil biodiversity – Status, challenges and potentialities. Summary for policy makers*. FAO, ITPS, GSBI, SCBD & EC. https://policycommons.net/artifacts/1526136/state-of-knowledge-of-soil-biodiversity-status-challenges-and-potentialities/2214245/

Fioratti Junod, M., Reid, B. J., Sims, I., & Miller, A. J. (2023). Below-ground pitfall traps for standardised monitoring of soil mesofauna: Design and comparison to Berlese/Tullgren funnels. *Pedobiologia, 101*, 150911. https://doi.org/10.1016/j.pedobi.2023.150911

Garg, D., Patel, N., Rawat, A., & Rosado, A. S. (2024). Cutting edge tools in the field of soil microbiology. *Current Research in Microbial Sciences, 6*, 100226. https://doi.org/10.1016/j.crmicr.2024.100226

Geisen, S., Mitchell, E. A. D., Adl, S., Bonkowski, M., Dunthorn, M., Ekelund, F., Fernández, L. D., Jousset, A., Krashevska, V., Singer, D., Spiegel, F. W., Walochnik, J., & Lara, E. (2018). Soil protists: A fertile frontier in soil biology research. *FEMS Microbiology Reviews, 42*, 293–323. https://doi.org/10.1093/femsre/fuy006

Gergócs, V., & Hufnagel, L. (2009). Application of oribatid mites as indicators (review). *Applied Ecology and Environmental*

Research, 7(1), 79–98. https://doi.org/10.15666/aeer/0701_079098

Guerra, C. A., Heintz-Buschart, A., Sikorski, J., Chatzinotas, A., Guerrero-Ramírez, N., Cesarz, S., Beaumelle, L., et al. (2020). Blind spots in global soil biodiversity and ecosystem function research. *Nature Communications, 11*(1), 3870. https://doi.org/10.1038/s41467-020-17688-2

Jeffery, S., Giardi, C., Jones, A., Montanarella, L., Marmo, L., Miko, L., Ritz, K., Römbke, J., & van der Putten, W. H. (2010). *European atlas of soil biodiversity*. Publications Office of the European Union. https://data.europa.eu/doi/10.2788/94222

Jernigan, A., Kao-Kniffin, J., Pethybridge, S., & Wickings, K. (2023). Soil microarthropod effects on plant growth and development. *Plant and Soil, 483*(1–2), 27–45. https://doi.org/10.1007/s11104-022-05766-x

Joimel, S., Chassain, J., Artru, M., & Faburé, J. (2022). Collembola are among the most pesticide-sensitive soil fauna groups: A meta-analysis. *Environmental Toxicology and Chemistry, 41*(10), 2333–2341. https://doi.org/10.1002/etc.5428

Keller, C., Heck, T., & Rittberger, M. (2022). How many sources are needed? The effects of bibliographic databases on systematic review outcomes. In *The ACM/IEEE Joint Conference on Digital Libraries in 2022 (JCDL'22)* (June 20–24, Cologne, Germany). https://doi.org/10.1145/1234567890

Kevan, D. K. M. c. E. (1985). Soil zoology, then and now—mostly then. *Quaestiones Entomologicae, 21*, 371–472.

Krogh, P. H., Kostov, K., & Damgaard, C. F. (2020). The effect of Bt crops on soil invertebrates: A systematic review and quantitative meta-analysis. *Transgenic Research, 29*(5), 487–498. https://doi.org/10.1007/s11248-020-00213-y

Lang, B., Betancur-Corredor, B., & Russell, D. J. (2023). Soil mineral nitrogen content is increased by soil mesofauna and nematodes–A meta-analysis. *Soil Organisms, 95*(2), 117–128. https://doi.org/10.25674/so95iss2id310

Lavelle, P. (2009). Ecology and the challenge of a multifunctional use of soil. *Pesquisa Agropecuária Brasileira, 44*(8), 803–810.

Lavelle, P., Mathieu, J., Spain, A., Brown, G., Fragoso, C., Lapied, E., De Aquino, A., et al. (2022). Soil macroinvertebrate communities: A worldwide assessment. *Global Ecology and Biogeography, 31*(7), 1261–1276. https://doi.org/10.1111/geb.13492

Liao, J.-R., Ho, C.-C., & Ko, C.-C. (2023). Milestones and future directions in the taxonomy of Phytoseiid mites (Acari: Mesostigmata) in Taiwan. *Formosan Entomologist, 43*, 15–23. https://doi.org/10.6662/TESFE.202302_43(1).002

Lindo, Z., Battigelli, J., Parnell, J. J., de Ruiter, P., Brown, G. G., & Barreto, C. (2025). The threat-work: A network of potential threats to soil biodiversity. *Soil Organisms, 97*(SI), 31–46.

Lienhard, A., & Krisper, G. (2021). Hidden biodiversity in microarthropods (Acari, Oribatida, Eremaeoidea, Caleremaeus). *Scientific Reports, 11*, 23123. https://doi.org/10.1038/s41598-021-02602-7

Mathieu, J., Antunes, A. C., Barot, S., Bonato Asato, A. E., Bartz, M. L. C., Brown, G. G., Calderon-Sanou, I., Decaëns, T., Fonte, S. J., Ganault, P., et al. (2022). SOilFauna – A global synthesis effort on the drivers of soil macrofauna communities and functioning: Workshop report. *Soil Organisms, 94*(2), 111–126. https://doi.org/10.25674/so94iss2id282

Mathieu, J., Lavelle, P., Brown, G. G., Eisenhauer, N., & Cooper, M. (2025). *Global Soil Macrofauna*. http://www.globalsoilmacrofauna.com/

Nicol, J., Turner, S., Coyne, D., den Nijs, L., Sue, H., & Maafi, Z. (2011). Current nematode threats to world agriculture. In *Genomics and molecular genetics of plant-nematode interactions* (pp. 21–43). https://doi.org/10.1007/978-94-007-0434-3_2

Parnell, J. J., Brown, G. G., Guerra, C., Lindo, Z., Battigelli, J., de Ruiter, P., Wall, D. H., Montanarella, L., Malorgio, G., Bagnara, G. L., González, R., Vargas, R., Corona-Cuevas, R. & Eugenio, N. R. (2025). Global Soil Biodiversity Observatory. *Soil Organisms*, *97*(SI), 143–148.

Phillips, H. R. P., Bach, E. M., Bartz, M. L. C., et al. (2021). Global data on earthworm abundance, biomass, diversity and corresponding environmental properties. *Scientific Data, 8*, 136. https://doi.org/10.1038/s41597-021-00912-z

Phillips, H. R. P., Cameron, E. K., Eisenhauer, N., Burton, V. J., Ferlian, O., Jin, Y., Kanabar, S., Malladi, S., Murphy, R. E., Peter, A., et al. (2024). Global changes and their environmental stressors have a significant impact on soil biodiversity—A meta-analysis. *iScience, 27*(9), 110540. https://doi.org/10.1016/j.isci.2024.110540

Potapov, A., Bellini, B., Chown, S., Deharveng, L., Janssens, F., Kováč, Ľ., Kuznetsova, N., Ponge, J.-F., Potapov, M., et al. (2020). Towards a global synthesis of Collembola knowledge – Challenges and potential solutions. *Soil Organisms, 92*(3), 161–188. https://doi.org/10.25674/so92iss3pp161

Potapov, A. M., Chen, T. W., Striuchkova, A. V., Alatalo, J. M., Alexandre, D., Arbea, J., ... & Scheu, S. (2024). Global fine-resolution data on springtail abundance and community structure. *Scientific Data, 11*(1), 22. https://doi.org/10.1038/s41597-023-02784-x

Pranckutė, R. (2021). Web of Science (WoS) and Scopus: The titans of bibliographic information in today's academic world. *Publications, 9*(1), 12. https://doi.org/10.3390/publications9010012

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Römbke, J., Schmelz, R. M., & Pélosi, C. (2017). Effects of organic pesticides on enchytraeids (Oligochaeta) in agroecosystems: Laboratory and higher-tier tests. *Frontiers in Environmental Science, 5*, 20. https://doi.org/10.3389/fenvs.2017.00020

Saccaggi, D. L., & Ueckermann, E. A. (2024). The problem of taxonomic uncertainty in biosecurity: South African mite interceptions as an example. *Acarologia, 64*(2), 363–369. https://doi.org/10.24349/top1-r59v

Schmelz, R. M., Niva, C. C., Römbke, J., & Collado, R. (2013). Diversity of terrestrial Enchytraeidae (Oligochaeta) in Latin America: Current knowledge and future research potential. *Applied Soil Ecology, 69*, 13–20.

Silberschatz, A., Galvin, P. B., & Gagne, C. (1999). *Applied operating system concepts*. John Wiley & Sons, Inc.

Silva, O. D. D., & Malaquias, J. V. (2021). *Organização de dados de pesquisa no PostgreSQL e realização de análise estatística em ambiente R: abordagem prática*. Embrapa Cerrados, Documentos 370, 81p.

Swift, M. J., Heal, O. W., Anderson, J. M., & Anderson, J. M. (1979). *Decomposition in terrestrial ecosystems* (Vol. 5). Univ of California Press.

Szabó, B., Korányi, D., Gallé, R., Lövei, G. L., Bakonyi, G., & Batáry, P. (2023). Urbanization decreases species richness, and increases abundance in dry climates whereas decreases in wet climates: A global meta-analysis. *Science of the Total Environment, 859*, 160145. http://dx.doi.org/10.1016/j.scitotenv.2022.160145

Tibbett, M., Fraser, T. D., & Duddigan, S. (2020). Identifying potential threats to soil biodiversity. *PeerJ, 8*, e9271. https://doi.org/10.7717/peerj.9271

Van Den Hoogen, J., Geisen, S., Routh, D., Ferris, H., Traunspurger, W., Wardle, D. A., de Goede, R. G. M., Adams, B. J., Ahmad, W., Andriuzzi, W. S., et al. (2019). Soil nematode abundance and functional group composition at a global scale. *Nature, 572*(7768), 194–198. https://doi.org/10.1038/s41586-019-1418-6

Wall, D. H., Nielsen, U. N., & Six, J. (2015). Soil biodiversity and human health. *Nature, 528*(7580), 69–76. https://doi.org/10.1038/nature15744

Walter, D. E., & Proctor, H. C. (2013). *Mites–ecology, evolution and behaviour: Life at a microscale* (2nd ed.). Springer.

Wilder, E. I., & Walters, W. H. (2021). Using conventional bibliographic databases for social science research: Web of Science and Scopus are not the only options. *Scholarly Assessment Reports, 3*(1), 4, 1–17. https://doi.org/10.29024/sar.36

Xiong, W., Song, Y., Yang, K., Gu, Y., Wei, Z., Kowalchuk, G. A., Xu, Y., Jousset, A., Shen, Q., & Geisen, S. (2020). Rhizosphere protists are key determinants of plant health. *Microbiome, 8*, 27. https://doi.org/10.1186/s40168-020-00799-9

Zhang, Y., Peng, S., Chen, X., & Chen, H. Y. (2022). Plant diversity increases the abundance and diversity of soil fauna: A meta-analysis. *Geoderma, 411*, 115694. https://doi.org/10.1016/j.geoderma.2022.115694