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Soil macrofauna in Brazil: a bibliometric review and state of the art

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Abstract: Macrofauna individuals' knowledge and their environmental functions is essential to seek more conservationist forest management practices. Understanding how the publications are being distributed in Brazil, and what knowledge need to be discussed to direct future research. The purpose of this review was to compile and analyze all publications on soil macrofauna in Brazil until 2019, conducting a bibliometric and state of the art review. 60 documents were evaluated, it was analyzing institutions and authors, citations networks and terms used, forest sciences areas that encompass the most explored biomes, crop systems or natural environmental and the most studied soil macrofauna individuals. Since 2002, every year, publications on the topic indexed in the Scopus database. The Atlantic Forest was the most studied biome and although the North region has the largest number of states that have not yet developed works on the subject, the Amazon forest is in second place in terms of publications, together with Savannah/Cerrado. The largest gap in studies and areas of natural fields is found in the Brazilian North. The macrofauna individuals studied, the highlights are from the orders Coleoptera, Hymenoptera, Blattodea, Araneae and Hemiptera. Vegetation type was carried out predominantly in native forests, followed by pasture.
Keywords: Bioindicators of soil quality; Brazilian soils; Edaphic macrofauna; Forest ecology; Soil

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Introduction

The soil fauna is composed of invertebrate individuals who live, spend part of their life cycle or seek resources in an edaphic environment, varying according to size, body diameter and eating habits, exercising different ecological functions in the soil system (Borges *et al.* 2019). These organisms participate in the degradation process of organic material introduced to ecosystems, contributing to the stability of environments and nutrient cycling, in

addition to restoring soil fertility, which makes their study fundamental to understand some changes in the site.

The heterotrophic fraction of the soil plays a propelling role in the fragmentation of organic material, increasing the contact surface. Its movement creates galleries that are important for the system, since the decomposing material is taken to the innermost layers and the soil from the innermost layers to the surface, which gives these organisms the title of "soil engineers" (Anderson 1988). These invertebrates also establish relationships with microorganisms, increasing the system's productivity and actively contributing to nutrient cycling (Decaëns et al. 2006).

The macrofauna comprises individuals with a diameter varying between 2 mm and 20 mm, so that their classification is related to size, mobility, type of food they consume and their function, with diameter and body length being the most used criteria (Lavelle et al. 2006). Due to their size and mobility, the individuals that make up the macrofauna are able to interfere in the edaphic structure in search of food. Several factors can affect the abundance and distribution of soil zoology, including the management and occupation of the area by anthropic activities, mainly by reducing organic matter and causing disturbances in the environment (Huerta & Van Der Wal 2012). However, other factors must be considered, such as vegetation, food availability, climate, topography, area history, temperature and soil type (Machado et al. 2015, Borges et al. 2019, Coq et al. 2020, Wang et al. 2020).

In recent years, several studies have studied the edaphic macrofauna as a bioindicator of soil quality, since they are more sensitive to environmental changes (Paudel et al. 2012, Rousseau et al. 2013, Pereira et al. 2017, Araujo et al. 2018, Morais Sobrinho et al. 2019, Schubert et al. 2019, Velasquez & Lavelle 2019, Valani et al. 2020). The purpose of these studies is to understand how these individuals are affected and what their environmental functions are, in order to seek more conservationist forest management practices. Thus, it is necessary to understand how these works are being developed and distributed in Brazil, and what gaps in knowledge need to be addressed, in order to direct future research.

One of the ways to gather information referring to a given theme is to achieve the state of the art, by reviewing the literature of pre-existing scientific documents, compiling and interpreting the data. This exam can be developed through a bibliometric analysis, with quantitative classification of the information. To search the database, keywords related to the theme are used and applied in a search base, such as Scopus, Web of Science, Science Direct, among others. From then on, bibliometric indicators are used to develop statistics and generate graphs, according to what is intended to be evaluated.

In this context, the aim of this study was to compile and analyze all publications on soil macrofauna in Brazil until 2019, indexed in the Scopus database. Then, carry out a bibliometric review and state of the art of this topic, discussing the pre-established criteria.

Methods
Bibliometric review

The data used in this study were obtained from the Scopus database, made available by the Relx Group (2018). For this, publications that address the theme were selected, using the terms "soil macrofauna", or "edaphic macrofauna", or "*macrofauna do solo*", or "*macrofauna edáfica*" and "Brazil" or "*Brasil*" in titles, abstracts and keywords, ensuring that the researched literature is fully in accordance with the theme, whose research sequence was: TITLE-ABS-KEY ("soil macrofauna" OR "edaphic macrofauna" OR "macrofauna do solo" OR "macrofauna edáfica") AND ALL ("brasil" OR "brazil"). The terms were applied in English and Portuguese, as they are the languages that most publish on the topic in Brazil, and due to the fact that all documents have titles, abstracts and keywords in English. In this review, all the works carried out until 2019 were evaluated.

114 publications were found, being accessed, read and selected those that actually dealt with the theme "soil macrofauna in Brazil". The inclusion criteria were: 1) works carried out in Brazilian phytogeographic domains; 2) study area located in the Brazilian territory; and 3) identified or used species classified as edaphic macrofauna. Only the works that met the three requirements were selected for the next screening.

After this first classification, the following were observed: 1) year of publication; 2) identification, affiliation institution and nationality of the authors; 3) agencies and institutions that finance the work; 4) publications journals; 5) type of publication; 6) areas of science related to the works; and 7) areas of forest sciences in which the works were inserted. The examination of the data and preparation of the graphs were performed using Microsoft Office Excel 365 Home. In addition, the network of interconnection clusters between the authors and between the main words present in the titles of the works was produced and analyzed, both using the software VOSviewer version 1.6.1.

State of the art

After the second screening, documents that were fully related to the topic were selected. From these, the state of the art was carried out, through a systematic review, to observe: 1) the individuals collected in order and class levels; 2) biomes of the study area; 3) type of vegetation of the study area; 4) comparison between different forms of cultivation; and 5) collection environment, whether soil or litter.

Results and discussion
Bibliometric review

After the two screenings, 60 papers were selected, which fully met the pre-established criteria.

Analyzing the type of publication, it was observed that 93.3% are from scientific articles, the rest being represented by literature reviews, book chapters and conference papers (Figure 1). Scientific articles were considered to those who had publications with declared authorship, who present and discuss ideas, methods, techniques and results in the various areas of knowledge (ABNT 2018). As for review, those that discuss topics covered in other types of articles, chapters as pairs of works or collections and conference papers with the works presented in scientific meetings.

The first work found on the subject, in Brazil, was published in 2002. Although there are works prior to 2002, they are indexed in other databases, so they were not computed in this study. According to the distribution of publications over time, there are greater records in the years 2008 and 2019, with six publications each, showing considerable variations in the other years (Figure 2). Despite the years 2002, 2003 and 2010 having presented only one research on the subject, there was no year without publication registration, which demonstrates that the interest on the subject is of continuous flow.

As for the most used terms in the title of the publications (Figure 3), it was observed that 32 words stood out over the others, being divided into four research segments, according to: 1) the environment of the place searched, whose main words used were **pasture**, **crop**, **tillage** and **Amazonian pasture**, in addition to biomes such as *Cerrado* and *Amazônia*, including **central Amazonia** and **eastern Amazonia**, and **soil** being the main highlight for the macrofauna habitat; 2) the place where the studies were carried out, mainly because they were carried out in the country, highlighting the words **Brazil** and its correspondent in Portuguese ***Brasil***, and **southeastern Brazil**; 3) the type of fauna evaluated, as observed by the words **macrofauna**, **soil macrofauna**, **soil macrofauna community** and **edaphic macrofauna**; and 4) the characterization of the macrofauna and its implications for the environment, whose main words are **system** and its corresponding in Portuguese ***sistema***, ***uso***, **influence**, **diversity**, **abundance**, **land use change**, **effect** and **brazil characterization**. This evaluation was carried out with words in English and Portuguese, languages chosen for research of the works. 154 authors were registered, 31.2% female and 68.8% male. Among the authors and co-authors, 23 were responsible for the largest number of publications, with three or more published works, concentrating 39.7% of the publications about the edaphic macrofauna (Figure 4).
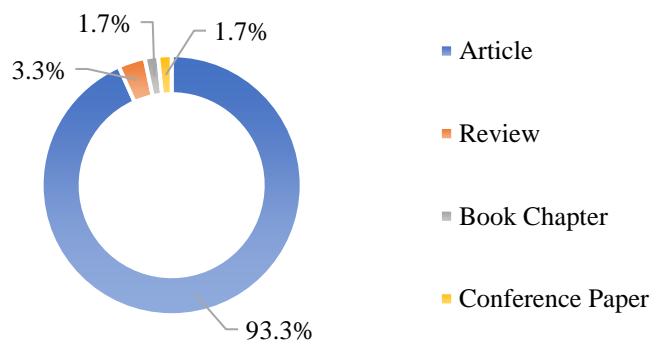

Figure 1. Number of publications on soil macrofauna in Brazil, by type of documents, until 2019.

Figure 2. Number of publications on soil macrofauna in Brazil per year.
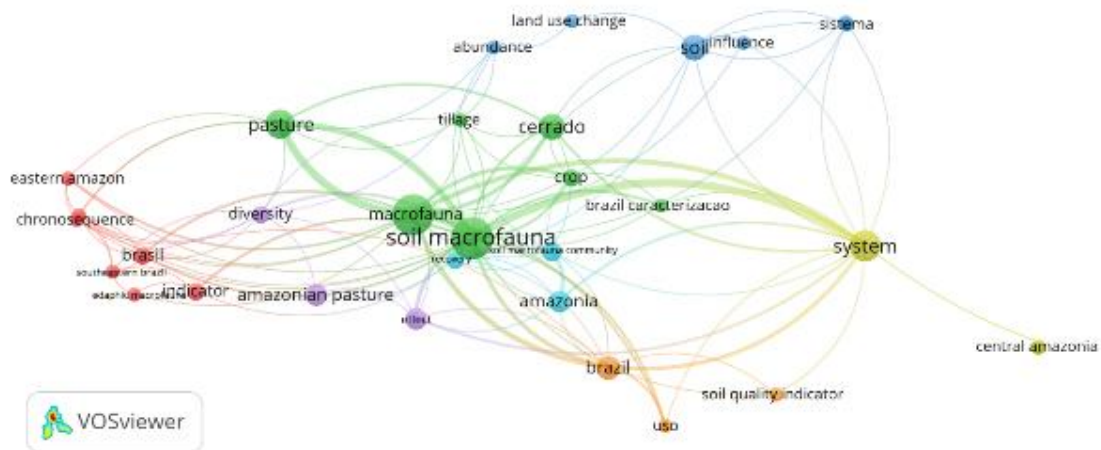
Figure 3. Interconnection network between the most used terms in the titles of soil macrofauna publications in Brazil, until 2019.
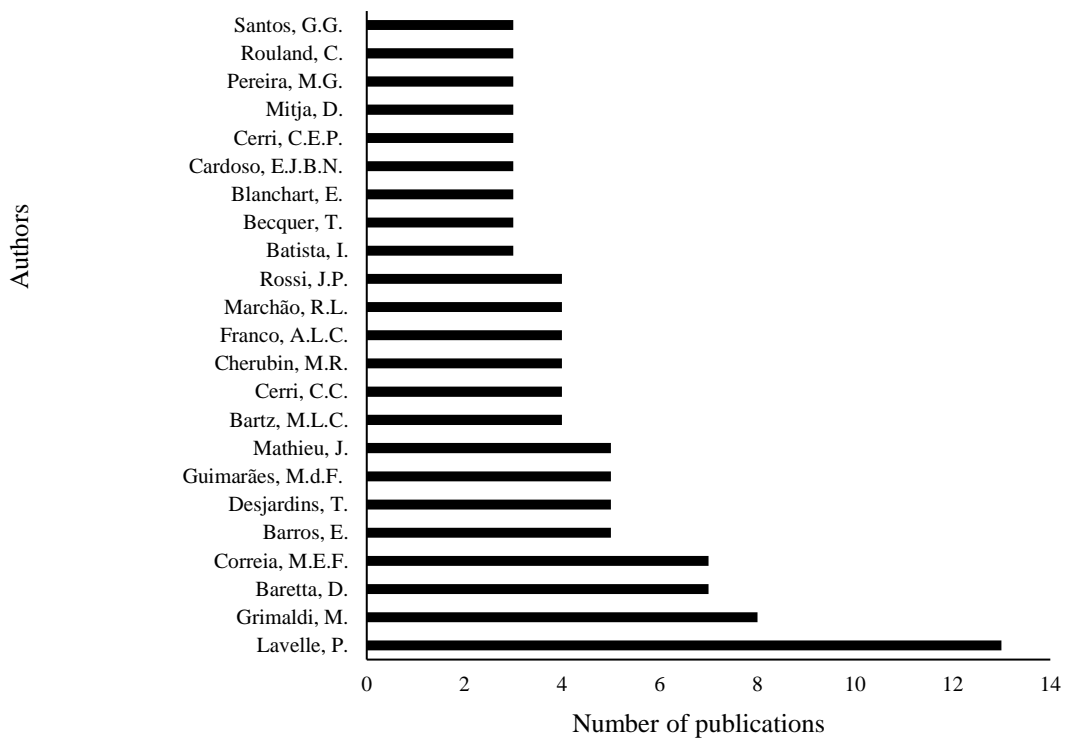

Figure 4. Number of publications by the 23 authors with more publications on soil macrofauna in Brazil, until 2019.

Analyzing Lavelle's publications, it is possible to verify that the focus of the studies is the Amazon, with a predominance of the TSBF (Tropical Soil Biology and Fertility) soil collection method, described by Anderson & Ingram (1993). For all collections, the dimensions of the jigs were 25.0 cm x 15.0 cm, with different depths. As for the collection environment, 69.23% of their research evaluated the soil and litter simultaneously, while 23.07% only the soil, and 7.70% did not inform which environment was evaluated. Regarding the type of vegetation, 38.10% of the results were related to pasture, 33.33% to natural forest, 14.29% in agroforestry systems, and the rest are distributed equally in soy plantations, planted forests, or not have been informed.

Grimaldi's works are focused on the Amazon region, specifically in the states of Pará (87.5%) and Amazonas (12.5%). The type of vegetation studied was predominantly pasture (62.5%), followed by the comparison between native and planted forest (25%) and only native vegetation (12.5%). Regarding the collection environment, most of them were carried out in both soil and litter (87.5%), and only one of the

surveys was carried out only in the soil (12.5%). In all of the author's works, the methodology used was TSBF, with square jigs measuring 25 cm × 25 cm.

The researches carried out by the author Correia was carried out in Rio de Janeiro (42.86%), Mato Grosso do Sul (42.86%) and Espírito Santo (14.28%), covering the phytogeographic domains of the Cerrado and Atlantic Forest. As for the studied vegetation, most of the works were carried out on native vegetation (42.86%), followed by agroforestry systems (28.57%) and comparison between native vegetation and soybean and pasture planting, both with equivalent representation (14.28%). Regarding the methodology used, the vast majority of collections were also performed using TSBF, with jigs measuring 25 cm × 25 cm. The study environments were also soil (42.86%) or soil and litter (57.14%).

Baretta publications were developed in the state of Santa Catarina (42.86%), followed by São Paulo (28.57%), Espírito Santo (14.28%) and simultaneously in Goiás and São Paulo (14.28%). The phytogeographic domains studied were the Cerrado and the Atlantic Forest, and the types of vegetation were forest plantations compared to agricultural crops (42.86%), native forests (28.57%) and the comparison between native forests and forest plantations (28.57%). The studied environments coincided with the previous authors, being soil (42.86%) or soil and litter (57.14%), with no studies with litter alone. The collection methods used also followed the TSBF, with jigs measuring 25 cm × 25 cm, and only one of the surveys collected soil with a 17 cm diameter circular tube.

Figure 5a shows the networks of authorship and co-authorship of publications on soil macrofauna in Brazil. The main network of authors has five of the eight authors with the largest number of publications (Figure 5b), being composed by Lavelle, Grimaldi, Barros, Mathieu and Desjardins. Despite the large amount of research, Correia and Baretta appear in secondary publication networks.

From the data of the authors, it was identified that they are affiliated with 92 institutions, 26 of which have three or more publications. Of these institutions, 15 are brazilians and 11 from other countries, which concentrate about 62.20% of the works indexed in the Scopus base about soil macrofauna in Brazil. Embrapa is the institution with the largest scientific contribution, with 27 publications, followed by the IRD Center d'Ile-de-France and the University of São Paulo with 14 and 12 publications, respectively (Figure 6).

Evaluating affiliation institutions according to their location in Brazil or in other countries (Figure 7), the Brazilian Southeast and South region stand out, mainly linked to research in the Atlantic Forest and the Cerrado. The international contribution was also relevant, since it represents almost half of the surveys.

No indexed studies were found in the Scopus database on the topic in the following Brazilian states: Acre, Alagoas, Amapá, Mato Grosso, Paraíba, Rio Grande do Norte, Rondônia, Roraima and Tocantins (Figure 8), areas that can be considered as potential for developing research and filling gaps. The places with the highest number of publications were Paraná, Rio de Janeiro and São Paulo, with 12 or more works.

Twenty institutions and agencies responsible for financing the research that generated these publications were identified, with the occurrence of 33 funded studies in this review. Among these institutions, 11 are Brazilian and nine from other countries, and the national ones, in addition to being the majority, are responsible for 72.7% of the research about soil macrofauna in Brazil (Figure 9).

The Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) was the biggest contributor, followed by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), with eight, five and three publications, respectively, representing together almost half of the funded publications. These agencies play a fundamental role in national research, since they are sponsors of undergraduate and graduate research.

In addition, 31 journals were identified in which the documents were published, 12 of them with two or more publications, representing 66.7% of the works. The most relevant journal in quantitative terms is the Revista Brasileira de Ciência do Solo, with eight publications, followed by Pesquisa Agropecuária Brasileira with six, both national and with a scope focused on soil science (Figure 10).

Scopus classified publications within six areas of science (Figure 11). Among the areas, the one that presented the largest number of studies was the Agricultural and Biological Sciences, with 72.50% of the studies, which is justified by the fact that it is the base area for studies of soil macrofauna. Most works seek to explain how edaphic individuals are affected according to the change in land use and occupation for the most varied purposes, especially in the removal of forests from natural environments to introduce planted forests, agriculture and/or pasture.

Framing these publications in the areas of Forest Sciences (Figure 12), most works focused on the Nature Conservation area, followed by Forest Management, addressing aspects such as change in use and occupation, as well as soil management. The works mainly assess the impacts generated by human activities, as well as the consequences for soil communities.
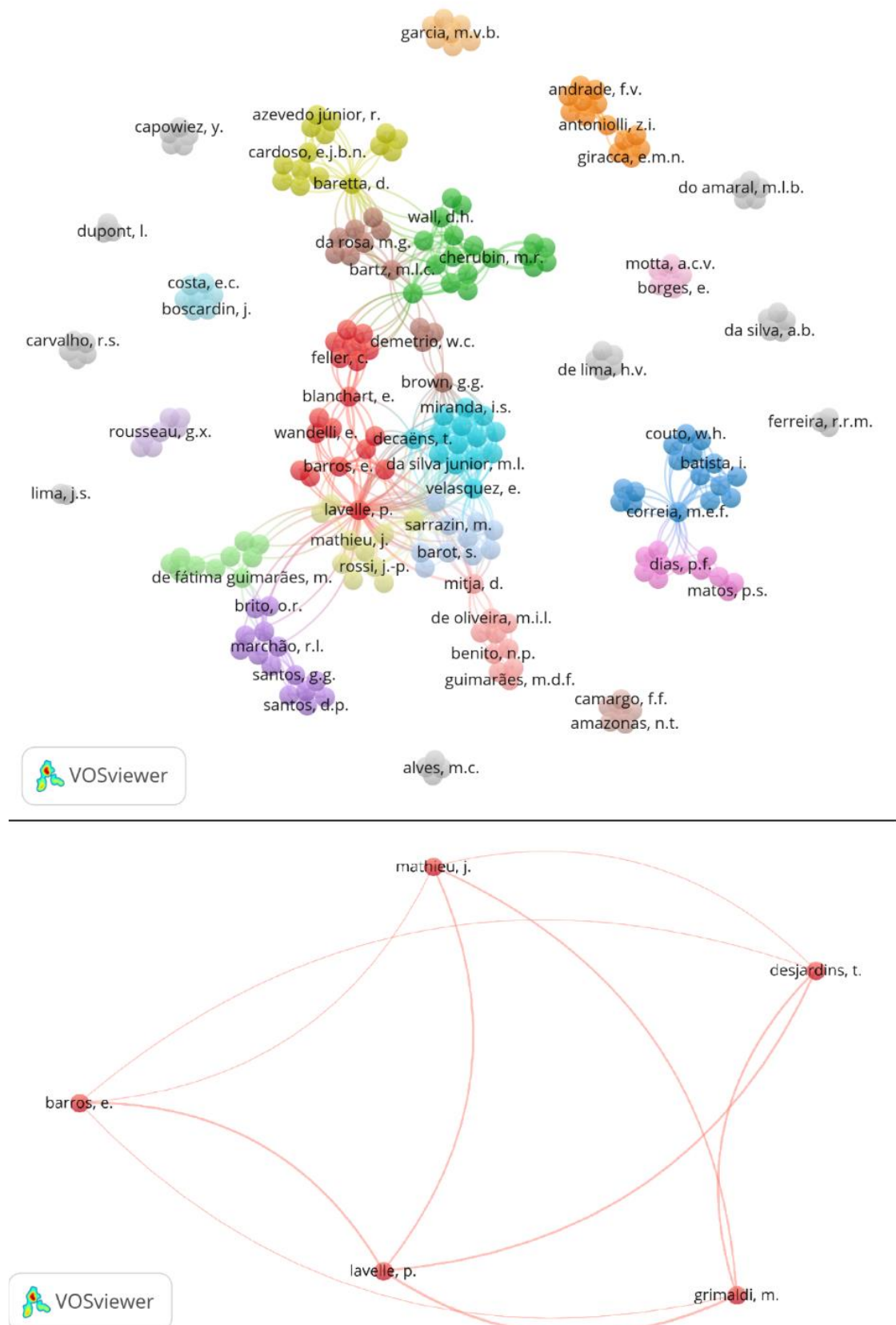
Figure 5. Interconnection clusters between all authors (a) and cluster of main authors (b) of publications on soil macrofauna in Brazil, until 2019.
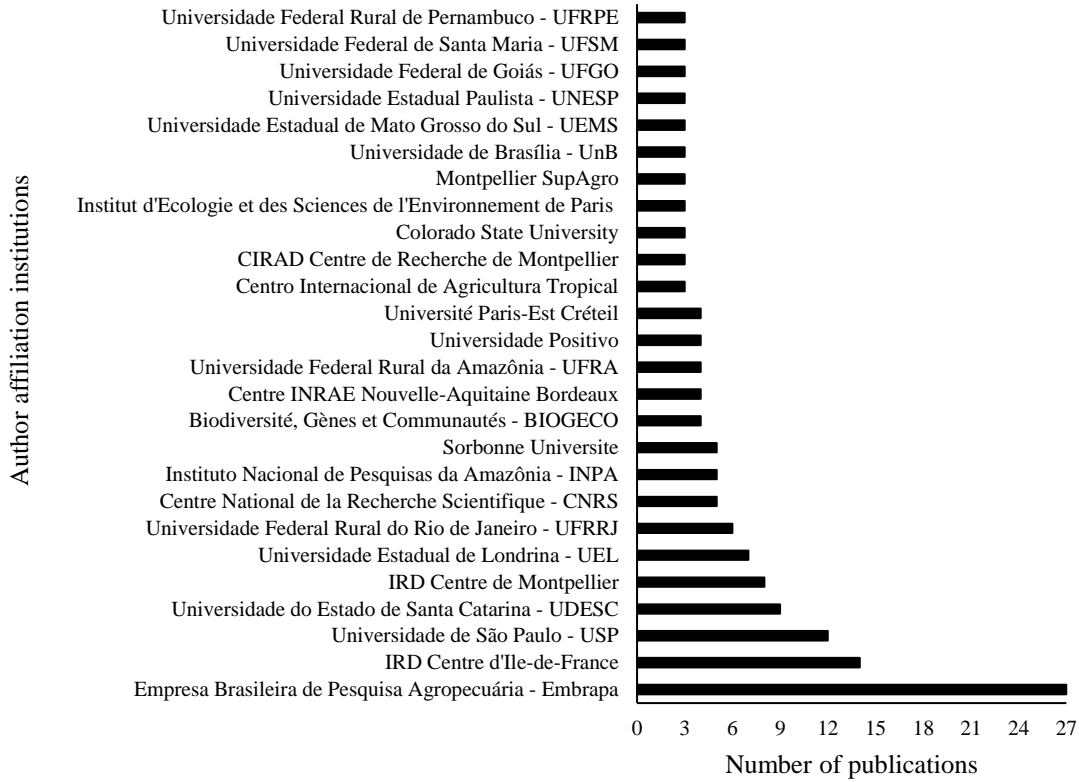
Figure 6. Affiliation institutions of prominent authors in publications on edaphic macrofauna in Brazil, until 2019
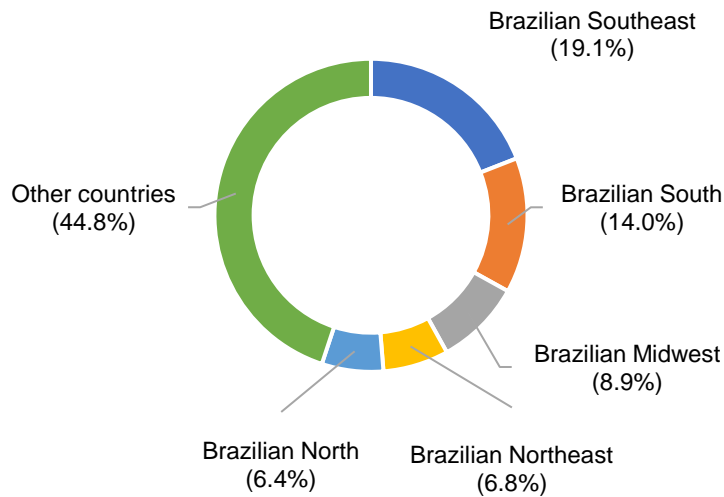

Figure 7. Location of affiliation institutions of authors of publications about soil macrofauna in Brazil, until 2019.
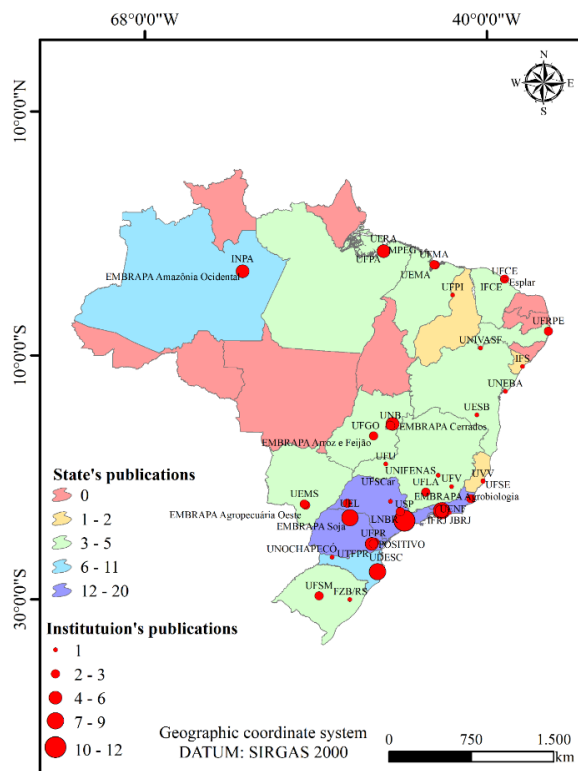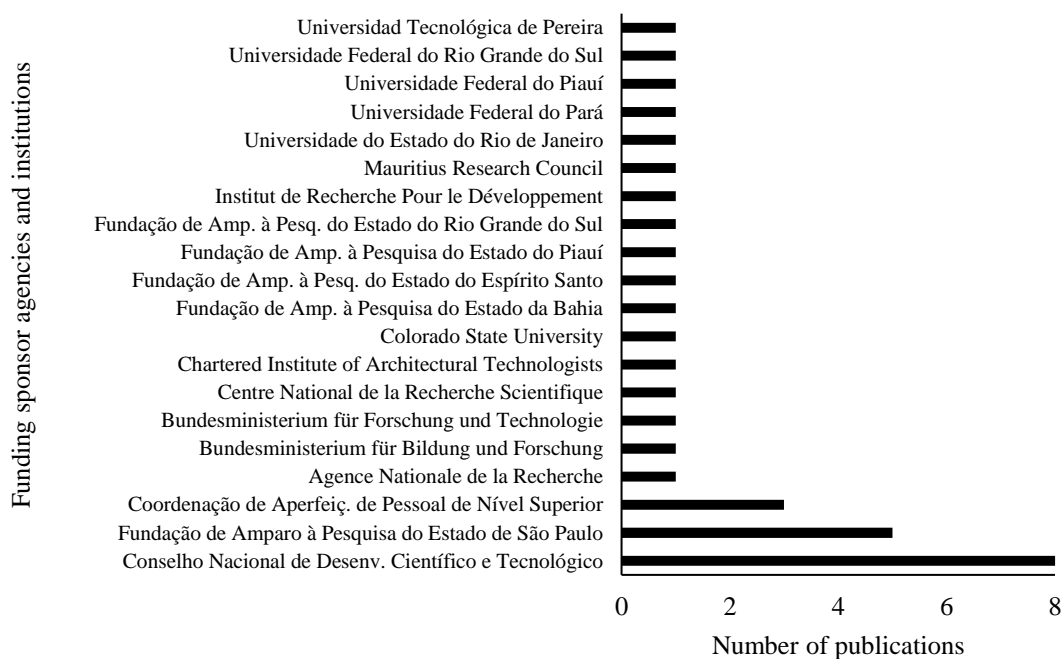
Figure 8. Brazilian affiliation institutions of prominent authors in publications about soil macrofauna in Brazil, until 2019.

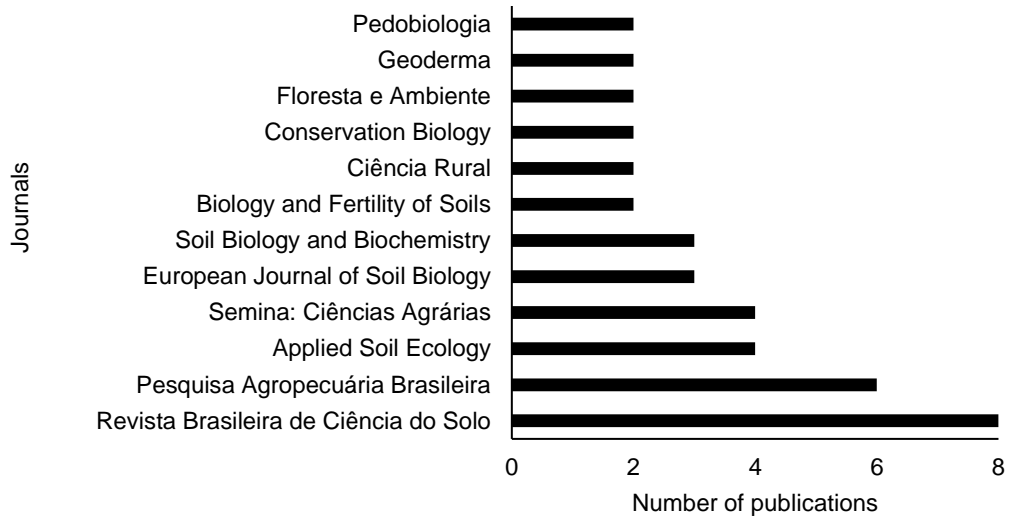Figure 9. Number of publications sponsored by agencies and institutions that promote research about soil macrofauna in Brazil, until 2019.

Figure 10. Journals of publishing documents about soil macrofauna in Brazil, until 2019.
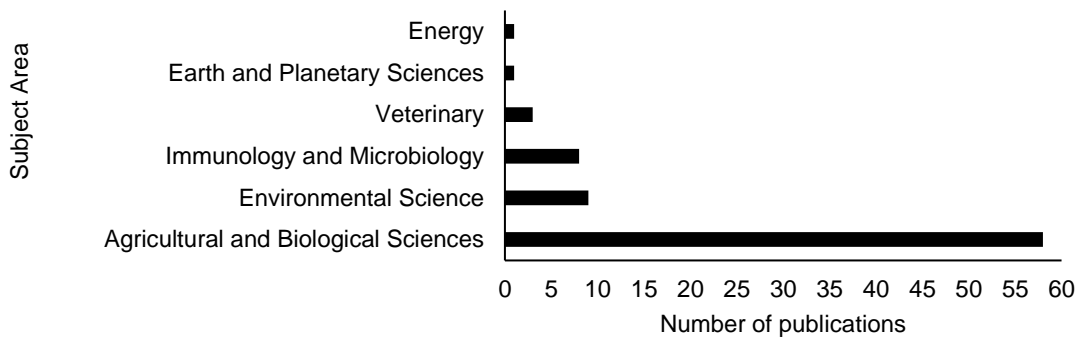

Figure 11. Publications about soil macrofauna in Brazil classified in areas of science according to Scopus, until 2019.
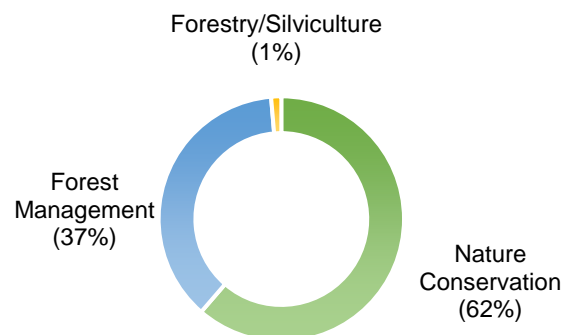

Figure 12. Publications about soil macrofauna in Brazil, until 2019, classified in areas of Forest Sciences.

Classifying the individuals in order level, it was possible to observe a predominance of Coleoptera, Hymenoptera, Blattodea, Araneae and Hemiptera, representing 44.27% of the total (Figure 13). However, 25.11% of individuals were only identified at the phylum level, classes, or were simply classified as unidentified, making the classification in order unfeasible. It is worth mentioning that currently the order Isoptera was incorporated into Blattodea, being accounted for together (Inward & Beccaloni 2007, ESA 2018).

Grouping individuals into classes, 88.11% were classified as Insecta, Arachnida, Oligochaeta, Chilopoda or Diplopoda (Figure 14). However, it was not possible to identify 2.64% of individuals because they were classified by the phylum or as unidentified.

It was observed that most articles were carried out in the Atlantic Rainforest, followed by Amazon Rainforest, Savannah/Cerrado, Stepp Savannah/Caatinga, Pampas and Natural Fields (Figure 15). Of the publications evaluated, 9% did not inform the location or the type of vegetation that was studied, however, despite not specifying the study environment, they remain relevant works for understanding the soil macrofauna as a whole.

As for the type of vegetation in the studies, the surveys were carried out predominantly in native forests, followed by pasture, agricultural crops, planted forests and agroforestry systems, with about 1% of the studies not reporting (Figure 16). The great contribution of the work carried out in native forests is due to the fact that these are the reference environment, mainly for comparison with anthropized areas.

In Figure 16b, the interactions carried out in the studies can be observed, through which it is possible to perceive that nine out of the ten interactions carry out research in native forests. This fact confirms the idea that these are used as a reference environment in many situations, as it is a stable environment for natural observation of individuals, helping to understand how their behavior has changed in environments of change in land use and occupation.

Regarding the edaphic environment, most studied the soil (60%), and 38% the litter, and 2% of the surveys did not inform the study environment. A single survey studied only the litter, while 35 of them studied both the soil and the litter and 22 only the soil (Figure 17).
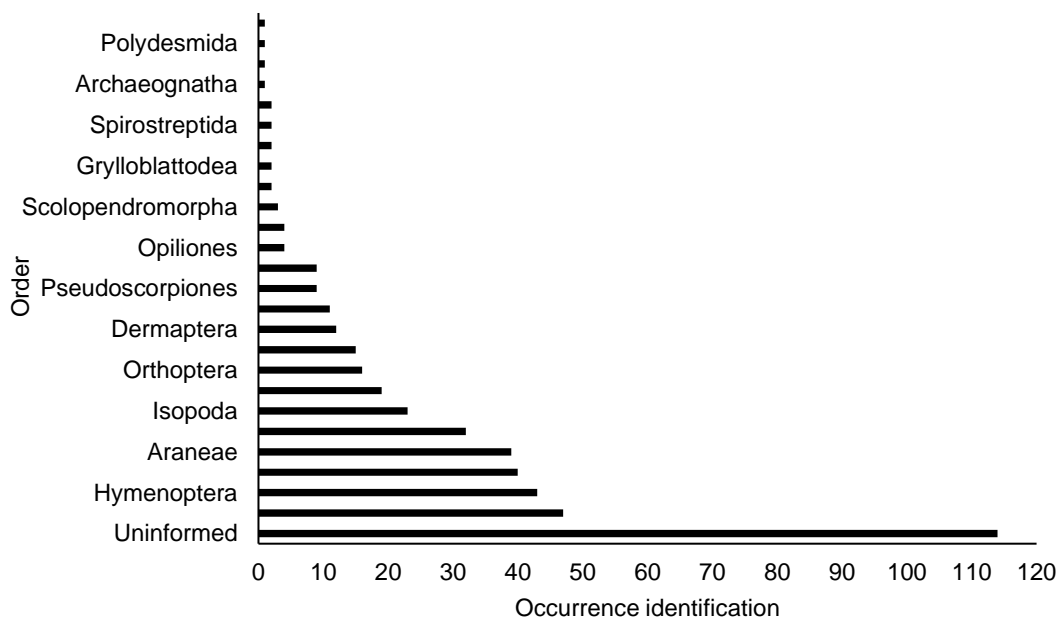

Figure 13. Individuals collected and identified at the order level in publications about soil macrofauna in Brazil, until 2019.
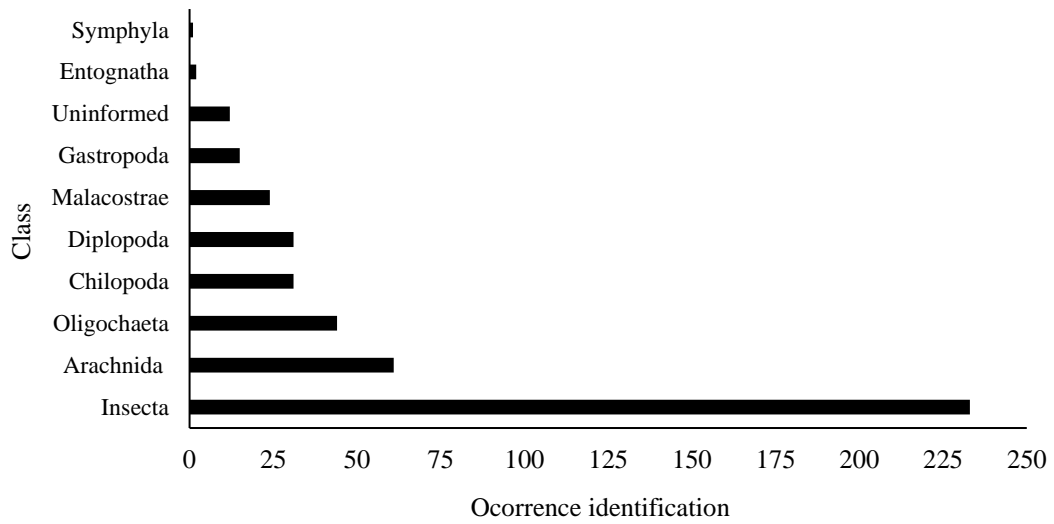
Figure 14. Individuals collected and identified at the class level in publications about soil macrofauna in Brazil, until 2019.
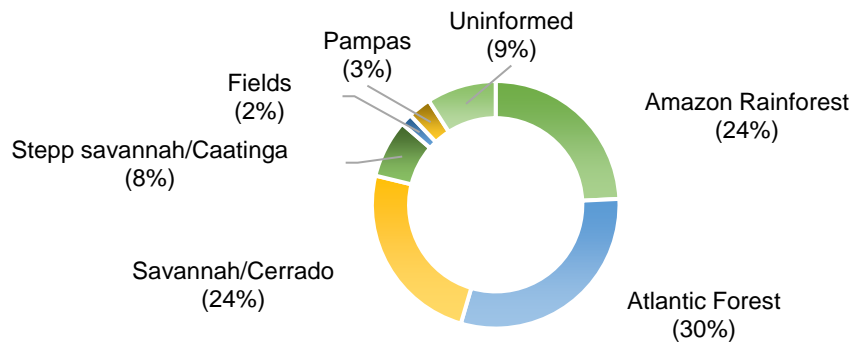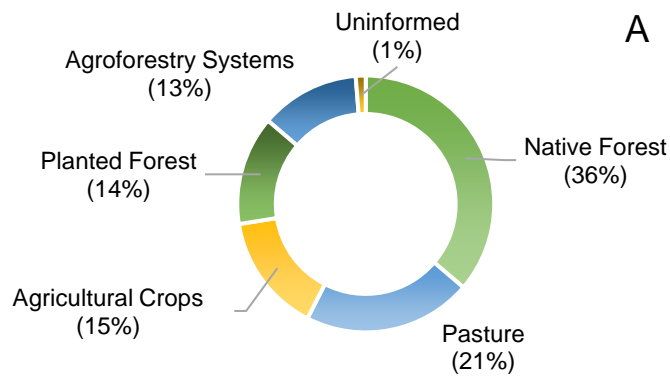

Figure 15. Publications about soil macrofauna made in Brazil, until 2019, classified by phytogeographic domain.
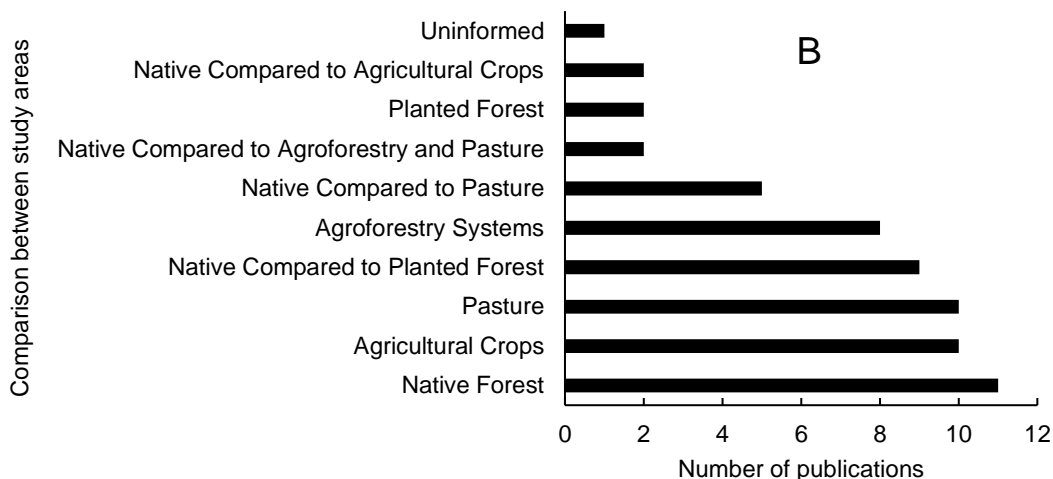
Figure 16. Publications about soil macrofauna made in Brazil, until 2019, classified by type of vegetation (a) and comparison between crops made by the authors (b).
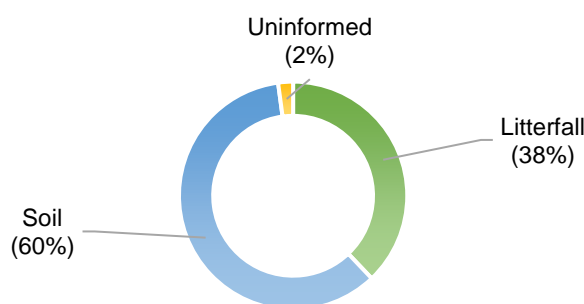

Figure 17. Publications about soil macrofauna made in Brazil, until 2019, classified by collection environment.

Final considerations

The results showed that since 2002, every year, publications on the topic have been indexed in the Scopus database, concentrated in the area of Agricultural and Biological Sciences. The Atlantic Forest was the most studied biome and although the North region has the largest number of states that have not yet developed works on the subject, the Amazon forest is in second place in terms of publications, together with Savannah/Cerrado. Thus, it is possible to observe that the largest gap in studies is found in the North of the country, and in biomes the largest gap occurs in the areas of natural fields. This information can assist in the redistribution of future research.

As for the macrofauna individuals studied, the highlights are from the orders Coleoptera, Hymenoptera, Blattodea, Araneae and Hemiptera. When classified into classes, Insecta, Arachnida, Oligochaeta, Chilopoda or Diplopoda stand out. Regarding the type of vegetation in the studies, the research was carried out predominantly in native forests, followed by pasture.

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