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Global panorama of studies about freshwater oligochaetes: main trends and gaps

Luciana Falci Theza Rodrigues[1,2] & Roberto da Gama Alves[1,3]

[1] Universidade Federal de Juiz de Fora (UFJF), Instituto de Ciências Biológicas (ICB), Departamento de Zoologia (DEPZOO), Laboratório de Invertebrados Bentônicos (LIB). Juiz de Fora, MG, Brasil.
[2] ORCID: 0000-0002-7610-870X. E-mail: biofalci@hotmail.com (corresponding author)
[3] ORCID: 0000-0001-8392-2091. E-mail: gama.alves@ufjf.edu.br

Abstract. Freshwater oligochaetes have been studied over the years in a wide range of habitats around the world. To analyse the data published about freshwater oligochaetes in the 31 year period between 1985 and 2015, we searched for documents in the ISI Web of Science, Scopus and SciELO databases. A total of 979 works were evaluated from 184 periodicals. The United States is the country with the most publications about aquatic oligochaetes, followed by France, Germany and Italy. Works related to the ecology and ecotoxicology of these organisms are most abundant. Studies carried out in the laboratory are most frequent, consisting of investigations involving bioassays, morphology, genetics and molecular biology. The results also show that spring, cave water bodies and swamps have been studied less than any other aquatic habitat and that countries of the Southern Hemisphere are under-represented in the studies of aquatic oligochaetes. Hence, there is a need for increased efforts to fill in gaps in the knowledge about these oligochaetes.

Key-Words. Database; Literature review; Scientific production; Oligochaeta.

INTRODUCTION

Oligochaetes in freshwater ecosystems are composed of over 1,100 known species (Martin *et al.,* 2008). Despite their high richness and representation in various aquatic habitats (streams, rivers, lakes, reservoirs), the oligochaetes have not received proper attention in hydrobiology studies (Sambugar, 2007). Their identification in the majority of publications is at a relatively unrefined taxonomic level, such as class or family, causing a gap in knowledge about the species level. Their small body size, absence of peculiar morphological structures (Sambugar, 2007) and "poor" appearance, described by Righi (1984) as "lack of beauty and eye-catching behaviors", are factors contributing to the relative lack of interest of researchers.

Studies of freshwater oligochaetes in the Neotropical realm started in the nineteenth century, carried out by vanguard researchers like Michaelsen, Stephenson, Beddard, Cognetti de Martiis and Cernosvitov, among others (Gavrilov, 1981). In Brazil, knowledge about limnic oligochaetes was pioneered by the taxonomic studies of the husband-wife team Eveline Du Bois-Reymond Marcus and Ernest Marcus starting in 1934, and by Gilberto Righi at the end of the 1960s. Subsequently (as of 2000), works about ecology such as Alves & Lucca (2000), Alves *et al.* (2006, 2008), Gorni & Alves (2006, 2008a,b, 2012, 2014), Behrend *et al.* (2009, 2012), Martins & Alves (2008, 2010), Ragonha & Takeda (2014), Ragonha *et al.* (2014), Gorni *et al.* (2015), Oda *et al.* (2015), Petsch *et al.* (2015) and Rodrigues *et al.* (2013, 2015, 2016), and on aspects of the reproductive biology by Lobo & Alves (2011a,b), have contributed to the knowledge of these invertebrates in Brazil.

In other biogeographic regions, such as the Nearctic (Wetzel *et al.,* 2006, 2007) and the Australasian (Pinder *et al.,* 2006), information about worms is plentiful (Martin *et al.,* 2008). Although more studies about aquatic oligochaetes have been performed in these regions, not all habitats have been equally investigated. For example, little is known about the diversity of oligochaetes in groundwater (Giani *et al.,* 2001) and springs (Dumnicka, 2006).

In this context, the objective of this work was to analyze the publications on freshwater oligochaetes over time and in different geopolitical regions of the world, and based on the results to verify trends and provide information to help guide efforts to fill in the main knowledge gaps identified.

MATERIAL AND METHODS

To analyze the theme "freshwater oligochaetes", we used the bibliographic production from 1985 to 2015. The search for data was performed using the following databases: ISI Web of Science (Thomson Reuters), Scopus (Elsevier) and SciELO (Scientific

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Electronic Library Online). We used these three bases due to the different scopes regarding the number and quality of the scientific periodicals indexed. The keywords were: "aquatic oligochaet*" or "*water oligochaet*" or clitellat* or tubificid* or naidid* or lumbriculid* or lumbriculus* or tubifex*. Because the group is paraphyletic, many researchers avoid using the name "oligochaete" or "Oligochaeta" and instead use the term "clitellate" or "Clitellata". For this reason, we included this as a keyword. Furthermore, in many documents only the family names are given, not "oligochaete", so we also included the main families of freshwater oligochaetes, as well as some of their genera.

We selected the "Title" option for advance search, to filter only specific works about the theme of interest. We only considered articles, reviews, notes, books and book chapters. Proceedings papers, meeting abstracts and editorial pieces were excluded from the analysis. Often these types of writings wind up being redundant, such as when the results presented in proceeding abstracts are later included in scientific articles. All the documents found were analyzed individually and those found not to be related to the theme were removed. The databases were searched in August 2016.

The elements tallied in each article were: (i) year of publication; (ii) number of publications per country/continent (where the study was conducted); (iii) area of knowledge (genetics, taxonomy, ecology, morphology, among others); and (iv) type of habitat where the study was performed (river, stream, lake, reservoir, spring, laboratory, among others).

RESULTS

We found 2,325 results for publications containing the keywords in their titles. Of this number, 1,240 (53.33%) specifically investigated freshwater oligochaetes (the rest were related to terrestrial, marine, estuarine forms or clitellate other than oligochaetes, such as Hirudinea and Branchiobdellida). Of all the publications found referring to freshwater oligochaetes, 33 came from consulting SciELO, 621 from Scopus and 586 from Web of Science (Fig. 1). However, some of these works were found in more than one of the databases, so the final total was 979 publications analyzed analyzed (see Supporting Information).

The works analyzed were mainly scientific articles (97.34%). The others were reviews (1.63%), notes (0.82%) and book chapters (0.20%). These works were published in 184 different periodicals, but most of them (about 73%) contained fewer than five works. The most frequent periodicals were Hydrobiologia (24.56%), Environmental Toxicology and Chemistry (7.63%) and Annales de Limnologie-International Journal of Limnology (3.66%).

The number of publications on freshwater oligochaetes fluctuated during the years studied, without showing a gradual growth trend. The two years with the largest numbers (Fig. 2A) were 1987 (55 works) and 1999 (54 works). On the other hand, there was a rising trend in the sum of the articles in the 10-year periods (Fig. 2B).

Studies related to ecology, ecotoxicology and taxonomy were most abundant. "Others" in the topic category included works related to oligochaetes as food for fish and use in activated sludge reduction (Fig. 3A). The interest in ecotoxicology increased in the three decades, as did studies involving taxonomy and genetics/phylogeny (Fig. 3B). Among the oligochaetes species most cited and analyzed are *Tubifex tubifex* (Müller, 1774), *Lumbriculus variegatus* (Müller, 1774), *Branchiura sowerbyi* Beddard, 1892, *Limnodrilus hoffmeisteri* Claparède, 1862 and *Chaetogaster limnaei* Von Baer, 1827, (not necessarily in

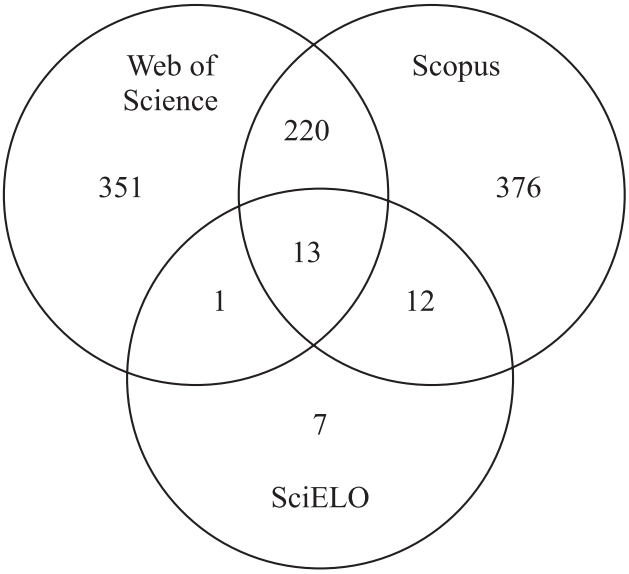

Figure 1. Total number of exclusive and shared publications on oligochaetes in freshwater habitats found in each database entre 1985 e 2015.

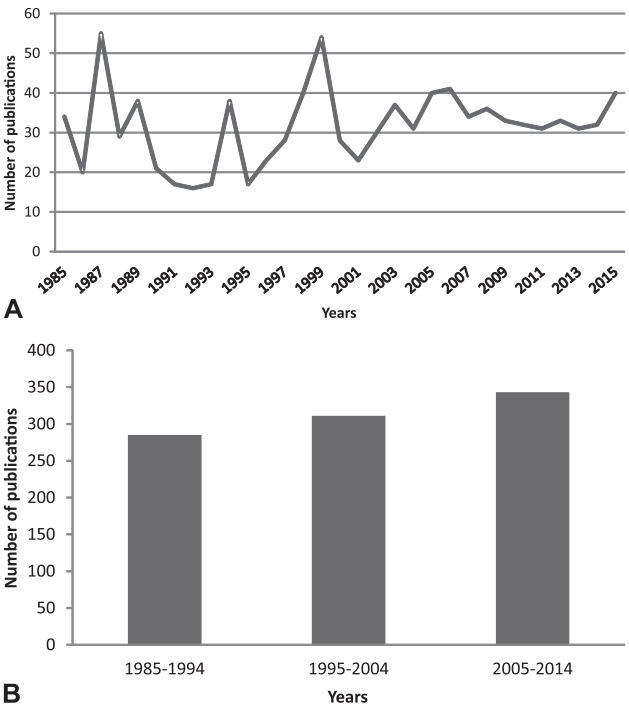

Figure 2. Number of works on freshwater oligochaetes published between 1985 and 2015 (A) and 10-year totals (B).

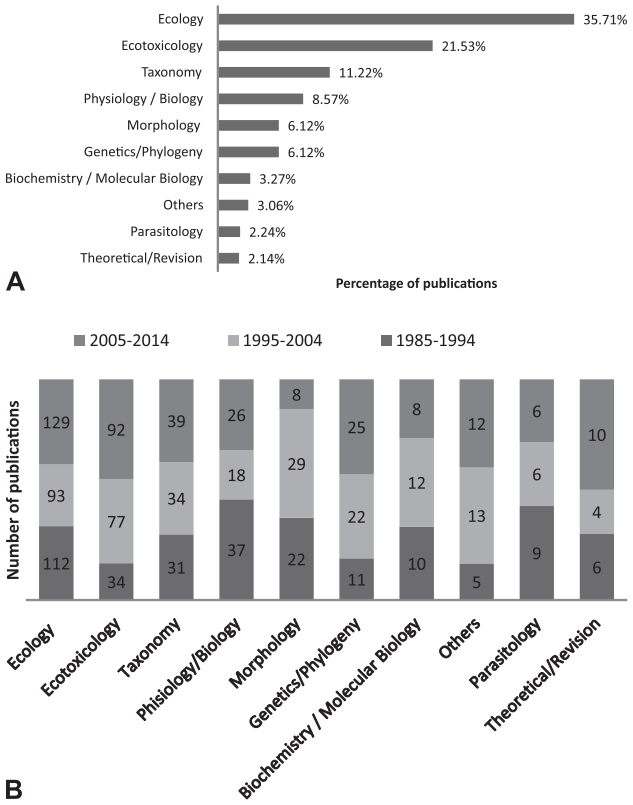

Figure 3. Percentage of works on freshwater oligochaetes published between 1985 and 2015 by area of knowledge (A) and 10-year totals (B). The "Others" category contains works related to oligochaetes as food for fish and used in reduction of activated sludge.

this order), mainly in investigations related to toxicity, organic pollution and parasitism.

We found works on oligochaetes in various aquatic environments, such as groundwater, swamps, caves, springs, rivers, streams, lakes and reservoirs. In many cases the studies analyzed the interaction of these worms with other organisms (bryophytes, macrophytes, bromeliads, sponges, snails, insects, anurans and fish). We also found experimental laboratory studies (the latter being most frequent, accounting for about 50% of the total publications). Besides empirical studies in these various aquatic environments, we also found studies only using bibliographic data as primary source. Springs, cave water bodies and swamps were the least studied habitat in the past 31 years, representing under 2.5% of the published works (Fig. 4).

With respect to global distribution, studies of freshwater oligochaetes occurred in 51 countries, the five leading ones being the United States (n = 157), France (n = 72), Germany (n = 60), Italy (n = 59) and Canada (n = 52). Brazil and Argentina are the only Latin American countries with more than 30 published studies and appearing among the 15 leading countries (Fig. 5A). In the continental breakdown, Europe showed the highest percentage, with about 50% of the total, while Oceania and Africa each accounted for under 1%. Approximately 2.5% of the papers analyzed did not mention the place where the study was conducted, so they are included in the "Undefined" category (Fig. 5B).

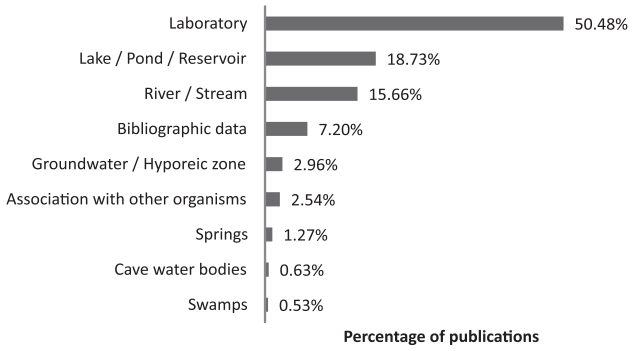

Figure 4. Percentage of works on freshwater oligochaetes published between 1985 and 2015 by habitat/ecosystem where the study was conducted.

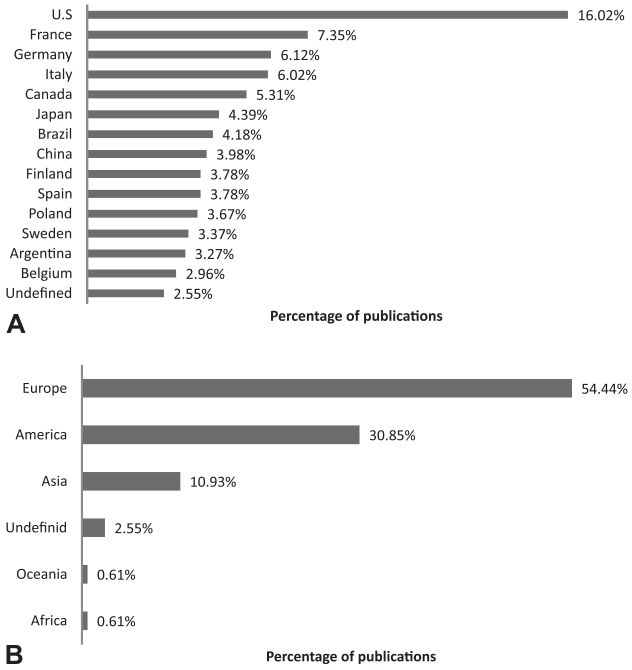

Figure 5. Percentage of works on freshwater oligochaetes published between 1985 and 2015 by continent (A) and by countries (15 leading ones in number of publications) (B).

DISCUSSION

Freshwater oligochaetes have been the target of studies involving biodiversity of aquatic habitats in preserved areas, biomonitoring, water quality analysis and toxicity monitoring in many countries. Therefore, researchers have published their findings in periodicals with different scopes, both widely distributed and limited, such as regional or local periodicals. This is shown by the survey of the three databases chosen here.

SciELO is a narrower database, because it only includes periodicals from countries in Latin America, along with South Africa, Spain and Portugal. For this reason, substantially fewer publications were found in this database. In contrast, Web of Science (WoS) and Scopus have global scope and presented a larger number of publications. The WoS database indexes more than 12,700 periodicals, in a wide range of scientific fields, and the majority of its titles are in English (Lopes *et al.,* 2012). Only about 2.5%

of the titles are from Latin American countries, explaining the small overlap of articles with SciELO. On the other hand, the Scopus base contains about 18,000 titles and has more European content than WoS, as well as including more languages besides English (about 60% of the coverage is countries other than the U.S.) (Lopes *et al.,* 2012). Many periodicals not indexed in WoS are indexed in Scopus, explaining the larger coverages of articles in the latter database and the greater overlap with SciELO.

According to Brinkhurst (1999), the majority of publications on oligochaetes up to 1970 were taxonomic, containing descriptions of new species and re-descriptions of known ones. In the 31 years examined (1985-2015), studies with ecological focus stood out over the other areas of knowledge, although the number of taxonomic works also continued to rise in the those years. Besides this, there was a strong trend for increase of works related to toxicology (Rodriguez & Reynoldson, 2011). The increase in the number of publications in general with time and regarding determined academic fields, even if timid in some cases, is an indication of the increase in the number of researchers and/or interest in investigating certain themes. The increase in the total number of publications also indicates the scientific advances made, considering that the number of publications is one of the metrics most often used to quantify the evolution of science (Lima-Ribeiro *et al.,* 2007).

Bioassays and toxicity tests were largely responsible for the large number of laboratory studies found, and for the same reason, species such as *Tubifex tubifex, Branchiura sowerbyi* and *Lumbriculus variegatus* were frequently found in the titles. These species are typical models in ecotoxicological studies due to their high reproductive rate and eash cultivation (Lobo & Alves, 2011a). Works involving biology, morphology, genetics and molecular biology also accounted for a large number of publications about laboratory experiments.

Studies of oligochaetes in springs were less frequent, as were those focused on swamps and water bodies in caves. With respect to springs, for example Cantonati *et al.* (2012) also affirm that in general this type of habitat is less frequently studied than other aquatic ecosystems. Therefore, these three ecosystems deserve greater attention in future studies. This rarity of studies of oligochaetes in some aquatic environments makes it urgent to learn more about the fauna of these habitats, which are facing increasing degradation from human activity.

Nearly half of the works analyzed were European. The European continent has 61 countries, and of these, studies were found about freshwater oligochaetes in 30 of them, with a large number of overall publications. The American continent as a whole (North, Central and South America) was in second place, although the largest number of works were from the United States. Countries of Africa and Oceania were under-represented in studies of freshwater oligochaetes. This result indicates a need for efforts to fill in gaps in various areas of knowledge of these organisms, as well as the preservation of aquatic ecosystems in these regions. In particular, these regions contain many forests and aquatic ecosystems that under threat of human activity (Nicacio & Juen, 2015), accounting for nearly half (44%) of the global hotspots.

Among Latin American countries, considered emerging or developing, Brazil appeared in first place in the number of publications between 1985 and 2015. Most of these studies were performed in the states of São Paulo, Minas Gerais and Paraná. Many species of oligochaetes are endemic to tropical regions, mainly in South America (Christoffersen, 2010). Studies to take inventory of fauna and learn the ecological relations between species and the environment are very important to formulate policies to preserve biodiversity, especially in forest regions under strong threat such as the Atlantic Forest fragments in Brazil.

CONCLUSION

According to the literature review, some tendencies and gaps exist in knowledge about freshwater oligochaetes that deserve attention. First of all, although there was a good deal of yearly upward and downward fluctuation in the number of works published, the trend considering the totals in the three 10-year periods was increasing, albeit modestly. This increase in the general number of publications was accompanied by specific increases in certain areas of knowledge, such as ecotoxicology, genetics/phylogeny and taxonomy. Descriptions, redescriptions and reclassifications of species became more frequent, spurred by advances in molecular techniques, applied alone or in combination with morphological investigation, through interactive taxonomy, an important tool in various areas of biology. Nevertheless, despite the modest increase in the number of publications, studies of freshwater oligochaetes are still scarce. There are few specialists devoted to studying freshwater oligochaetes, leading to many gaps regarding geographic region and habitat focus. The Southern Hemisphere has been under-represented in studies of these organisms, mainly in countries of Africa and Oceania, while springs, caves and swamps are relatively neglected habitats. Therefore, more varied investigation is necessary to deepen understanding of freshwater oligochaetes and provide insights about their global diversity, and to guide efforts to protect their habitats.

In closing, if readers want to start studying or deepen their studies of aquatic oligochaetes, we suggest Reynolds & Wetzel (2018). The site is very comprehensive, containing updated references, nomenclature and species counts as well as news about events and related sites.

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SUPPLEMENTARY MATERIAL

Additional Supporting Information may be found in the online version of this article:

This list contains all the references consulted and utilized to obtain the data in the article "Global panorama of studies about freshwater oligochaetes: main trends and gaps".

— The list of SciELO contains references found only in this database (7 references).
— The list of Web of Science contains references found only in this database (351 references).
— The list of Scopus contains references found in this database and those that were common with the SciELO or Web of Science bases (621 references).

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