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Polychaete research in Brazil: a bibliometric analysis

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ABSTRACT

This article shows a comprehensive bibliometric analysis of the literature on polychaetes from Brazil, with a focus on the growth of the field, publication venues, citation patterns, the collaboration among the Brazilian community and foreign researchers, and the main research topics over time. The analysis was based on a corpus of 568 articles published in 144 journals, covering a period from 1966 to 2022. The results reveal significant growth in the field, with a surge in publications particularly in the last decade. The top journals for publishing include Zootaxa, JMBA, and Zoologia. However, despite this growth, the overall impact of the research output remains somewhat limited, with most articles receiving relatively low numbers of citations, and those with more citations have broader research questions. This research community directed its efforts especially to taxonomy and phylogenetics research, community ecology, and physiology (ecotoxicology). These topics formed a common ground for more specialized themes. International collaboration was driven by research specialization, better infrastructure, and funding of developed countries. However, seeking collaborations with countries from the global south can also enrich the research conducted by the Brazilian community and stimulate new scientific inquiries. Embracing greater creativity and audacity as well as pursuing common goals, should yet enhance the quality of scientific research and sustain the remarkable growth and consolidation of this renowned research community.

Keywords: Annelida, Scientometrics, Collaboration networks, Scientific production

INTRODUCTION

The Brazilian coastline spans more than 8,000 km, encompassing a wide range of oceanographic and environmental features, as well as five biogeographic sub-provinces (Cord et al., 2022; Spalding et al., 2007). Despite the diversity of marine benthic fauna, their study has long been constrained to scattered samples, especially before the mid-20th century and particularly along the southern coast. Among invertebrates, polychaetes annelids were among the last to be extensively surveyed, despite great expeditions that visited Brazil and provided records from the coast (e.g., Kinberg, 1858; Hansen, 1882). Although the first "local" work with Brazilian polychaetes was carried out by Müller (1858) on the southern coast, only after the mid-20th century the works of Edmundo Ferraz Nonato (e.g., Nonato, 1958, 1963, 1965) marked a turning point with a new level of local detail on polychaetes studies off the Brazilian coast.

Like other countries, the Brazilian studies on polychaetes emerged from the need for bulk identification of oceanographic surveys (Fauchald,

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1977). In fact, Edmundo Nonato and his first generation of students conducted their studies in the 1970s and 1980s at the Oceanographic Institute of the University of São Paulo. Consequently, the research community foundation was based on benthic ecologists and generalist taxonomists but was in line with the prevailing taxonomic approach at that time. Subsequently, a new era emerged characterized by efforts to diversify the approaches towards polychaetes research, with a rising number of family-level specialists, as is more common nowadays, beyond the benthic ecology based only in species incidence. More detailed information about this raising and diversification of Brazilian polychaetes studies is provided by Lana et al. (2017).

We performed a bibliometric analysis of the scientific production on polychaetes from Brazilian institutions and researchers to answer questions from biological to social perspectives: performance, production, and interpersonal relationships. The main questions addressed were: 1) How was the growth of the field in Brazil? 2) Where are the articles being published? 3) Are these articles being cited? 4) Is there collaboration between Brazilian polychaetologists and those from abroad? 5) Is there collaboration within the Brazilian community? 6) What are the main research topics of such production through time?

METHODS

The data used herein was compiled only from indexed journals retrieved from three websites Thomson-Reuters Web of Knowledge, Scopus, and SciELO. It focuses on the scientific production published between 1945 and 2022. Articles were searched for the presence of the terms "Annelid*," *OR* "Polychaet*," *OR* "Poliqueta*" in their title, abstract, or keywords, and filter for "Brazil." Studies on earthworms were not considered. SciELO articles lack some of the required information to answer all the questions and were used only to address questions 1, 2, and 6. The databases are included in the supplementary materials.

To consider an article as part of the Brazilian scientific production on polychaetes, we elected and analyzed the literature that met at least two of the following criteria: i) Brazilian authors who had at least part of their training in Brazil, ii) research institutions from Brazil, iii) funding granted by an agency, and institutions from Brazil, and iv) taxonomic resolution from, at least, family rank. The combination of these criteria allows the identification of the scientific production without neglecting the formation and training of human resources, which sometimes occurs in collaborations with researchers from foreign countries. For each article selected, different types of information were retrieved, including the name and affiliations of the author(s), title, keywords, journals, publication year, and number of citations for each article. When these pieces of information were not apparent from the title or abstract, the article was examined in detail.

To assess the growth of the scientific production through time we adjusted linear models considering four different periods: 1990 to 1999, 2000 to 2009, 2010 to 2019, and 2010 to 2022, to account for the contribution of the last three years, marked by the limitations of the pandemics. To examine collaboration within Brazilian community, a collaboration network was built with the function *biblioNetwork* from the "bibliometrix" package (Aria and Cuccurullo, 2017). In the network, the nodes represent the authors, and the size of the nodes is the number of co-authorships among them (edges connecting the nodes). To understand the network we have to analyze the *size* – the same number of authors, *density* – the proportion of existing connections concerning the number of all possible connections given the number of authors, *transitivity* – the probability of two nodes connected to a third node also being connected, *diameter* – the greatest distance between any two nodes, *degree of centralization* – how centralized are the network nodes considering the most central node, and the *mean path length* – the mean distance among all pairs of nodes in the network.

To assess the main research topics explored in the published articles, we calculated the frequency of the total keywords on published articles per year of publication. Those frequencies were used to create word clouds showing the relative usage of keywords (considering the same four periods above), that were interpreted visually to infer

preferences and changes in research themes over the years. We also used keywords frequency per year to calculate keywords "richness" (i.e., the total number of different keywords in a year) and "diversity" (using the inverse Simpson diversity index, considering each keyword as a species).

To assess the main conceptual structure of the field: the research topics addressed by the community, we performed a multivariate correspondence analysis (MCA), using the co-occurrence of the authors' keywords (a matrix of articles vs. attributes). The analysis is similar to a non-metric multidimensional scaling (nMDS) – the greater the number of articles in which two terms co-occur, the more related they are, and k-means clustering was used to identify clusters of documents that resemble common concepts. The analysis was performed with the function *conceptualStructure* from the "bibliometrix" package, using only terms with at least three occurrences.

All analyses were performed using the R environment (R Core Team, 2021), with the following packages: "vegan" (Oksanen et al., 2013), "tidyverse" (Wickham et al., 2019), "rworldmap" (South, 2011), "tm" (Feinerer et al., 2008), "wordcloud" (Fellows, 2018), "ggwordcloud" (Le Pennec, 2019), and "bibliometrix" (Aria and Cuccurullo, 2017).

RESULTS

How was the growth of the field in Brazil?

After conducting a thorough search and applying the filters, we identified a substantial corpus of 568 articles from a diverse range of 144 journals, spanning an impressive array of 1,274 unique keywords. These articles were published across various formats, including regular journal issues, conference and symposia proceedings (29), letters (4), and reviews (22). In total, 989 authors made significant contributions to this body of work, with 13 authors publishing 21 articles as sole authors.

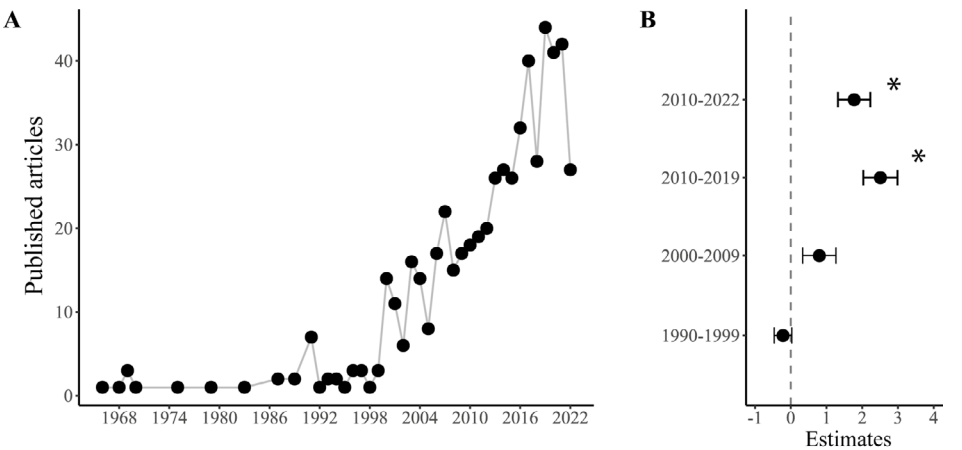

Figure 1. Distribution of published indexed articles from 1966 to 2022. A, the number of articles published per year, showcasing a steady upward trend over time; B, linear model estimates highlighting the annual growth rates observed across different decades, with asterisks (*) indicating statistically significant growth (*$p < 0.05$). The comparison 2010 – 2022 was made only to evidence the impact of the limitations from the three pandemic years. Data from WOS, Scopus, and SciELO.

Analyzing the temporal progression of indexed scientific production, the first article emerged in 1966 (Figure 1A). From 1966 to 1989, production displayed irregular patterns and accounted for only 2.30% of the total production (Figure 1A). Starting in 1991, the field's publication trajectory showed uninterrupted growth, with 4.10% of the articles being published by 1999 (Figure 1A). Subsequently, a substantial surge in publications occurred in the 2000s, with 140 articles published between 2000 and 2009, constituting 24.7% of the total output (Figure 1A). The following decade, from 2010 to 2019, had the publication of 280 articles, representing 49.4% of the total

(Figure 1A). In the most recent three-year span, from 2020 to 2022, 110 articles were published, encompassing 19.5% of the overall corpus (Figure 1A).

We also calculated the annual growth of the field, focusing on the period from 1991 onwards to exclude the initial irregular years of production. Between 1991 and 1999, the number of articles showed no significant increase, and a similar trend persisted from 2000 to 2009 (Figure 1B). A noteworthy shift occurred from 2010 to 2019, with production growing about 2.5 articles per year during this period (Figure 1B). Note that when considering the three years of the pandemics – between 2010 and 2022 – the growth rate declined to 1.7 articles per year (Figure 1B), with only 27 articles at 2022, reverting to the levels observed in 2018 (Figure 1A).

Where are the articles being published?

Based on our comprehensive analysis, we identified the top 20 journals utilized to disseminate this scientific production. Notably, *Zootaxa* emerged as the leading journal, with an impressive publication count of 77 articles. *The Journal of the Marine Biological Association of UK* (J. MAR. BIOL. ASSOC. U.K.) followed closely behind with 44 articles. The third position was occupied by the renowned Brazilian journal, *Zoologia*, which published 21 articles. Additionally, the *Bulletin of Marine Science* (Bull. Mar. Sci.) featured prominently with 15 articles. Note that *Zoologia*, formerly known as the *Brazilian Journal of Zoology*, is the highest-ranking Brazilian journal among the top 20, followed by the *Brazilian Journal of Oceanography* (now known as *Ocean and Coastal Research*) with 12 citations. Lastly, *Papeis Avulsos de Zoologia* (Pap. Avulsos Zool.) secured nine articles (Figure 2).

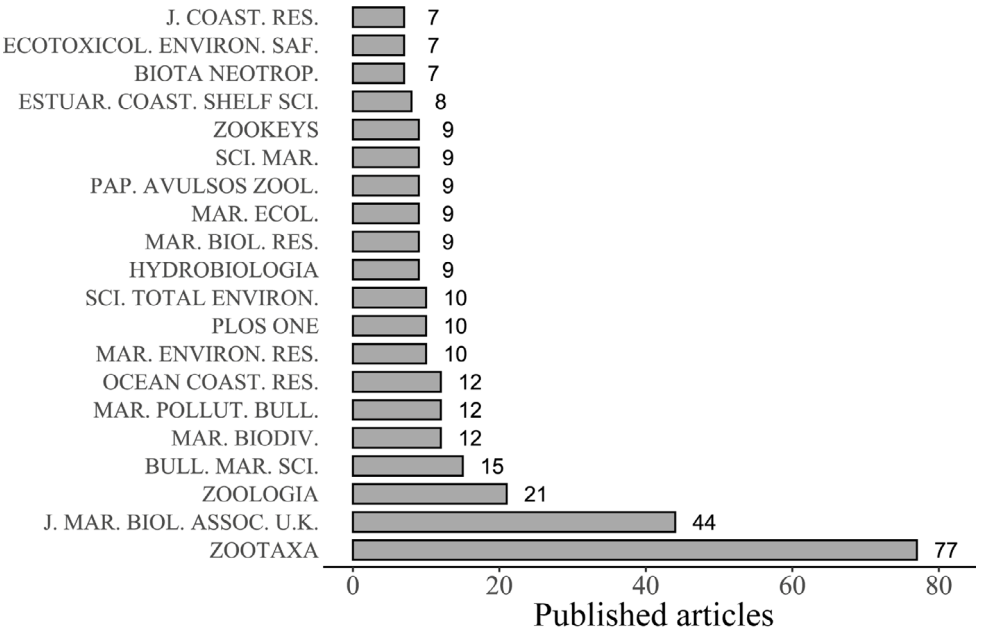

Figure 2. Distribution of published articles among the top 20 indexed journals for dissemination of scientific production. The exact number of published articles for a given journal is after its bar. Data from WOS, Scopus, and SciELO.

Are these articles being cited?

The mean number of citations per document was 13.03 ± 23.05 (sd) (Figure 3). The distribution of citations is asymmetrical and non-normal, with most articles receiving a relatively low number of citations, with a peak in the lower range, thus the mean is not a good descriptor of the trend (Figure 3). The median and maximum number of citations were seven, and 386, respectively. The number of citations by quantiles shows that 90% of the production has 29.5 citations or less, whereas 50%, half of the publications have only seven or fewer citations (Figure 3).

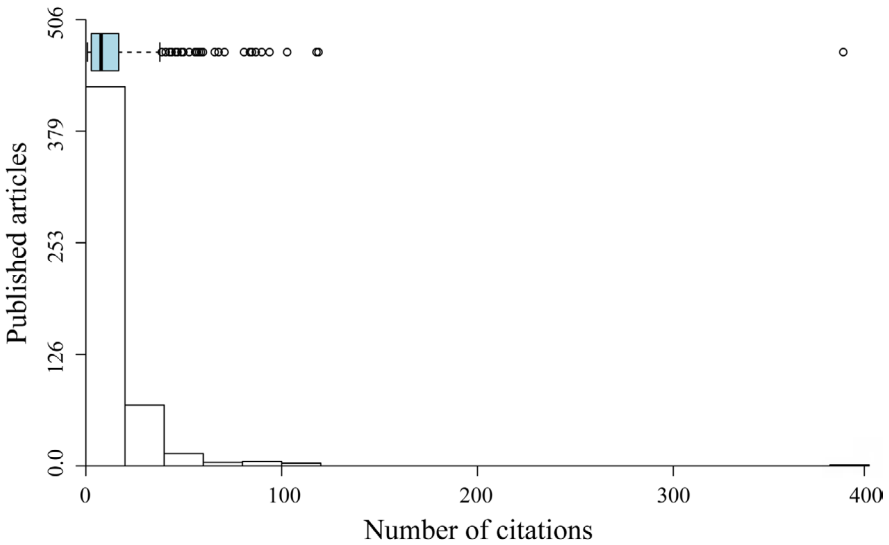

Figure 3. Distribution of the number of citations received by indexed articles published. Data from WOS and Scopus.

Among the top 10 most cited articles, seven were authored solely by researchers affiliated with Brazilian institutions, whereas three were the result of international collaborations (Table 1). These relatively highly cited articles span various research topics, including physiology and ecotoxicology – using polychaetes as model organism –, phylogenomics, and community ecology, with a focus on environmental impact assessment and the utilization of morphology in functional approaches (Table 1). Interestingly, no traditional taxonomic or morphological articles appeared among the top 10 most cited articles (Table 1). The oldest article among the top 10 dates back to 1991, whereas five articles were published in the 2000s and four in the 2010s (Table 1).

Table 1. The ten most cited articles published by the field of Brazilian polychaetology between 1966 and 2022. Based on Scopus and Web of Science bibliometric data. Data from WOS and Scopus.

Title	Countries	Citations	Year	Type of the study
Pollution biomarkers in estuarine animals: Critical review and new perspectives	Brazil	386	2007	Ecotoxicology
Determination of lipid peroxides in invertebrates tissues using the Fe(III) xylenol orange complex formation	Brazil	118	2003	Physiology
Articulating archiannelids phylogenomics and annelid relationships with emphasis on meiofaunal taxa	Brazil; USA; UK; Denmark; Sweden;	117	2015	Phylogenomics
Oxidative stress responses in two populations of *Laeonereis acuta* (Polychaeta: Nereididae) after acute and chronic exposure to copper	Brazil	102	2004	Ecotoxicology
Eurythoe complanata (Polychaeta: Amphinomidae) the cosmopolitan fireworm consists of at least three cryptic species	Brazil	93	2010	Phylogeography
Macrofaunal succession in sediments around kelp and wood falls in the deep NE pacific and community overlap with other reducing habitats	Brazil; USA	89	2010	Community ecology

continued

Title	Countries	Citations	Year	Type of the study
Influence of *Spartina alterniflora* on structure and temporal variability of macrobenthic associations in a tidal flat of Paranaguá Bay Southeastern Brazil	Brazil	86	1991	Community ecology
Functional diversity of macrobenthic assemblages decreases in response to sewage discharges	Brazil; The Netherlands	84	2016	Community ecology
Polycyclic aromatic hydrocarbons and changes in the trophic structure of polychaete assemblages in sediments of Todos os Santos Bay Northeastern Brazil	Brazil	83	2004	Community ecology
Another diet of worms: the applicability of polychaete feeding guilds as a useful conceptual framework and biological variable	Brazil	80	2005	Community ecology and Functional morphology

Is there collaboration between Brazilian polychaetologists and those from abroad?

A corpus of 398 articles were published with Brazil as corresponding author's country; this represents about 76% of the total production (Figure 4). Almost a quarter of the scientific production was done in collaboration with researchers affiliated from other countries, especially from the global north: the USA, and European countries, such as Portugal, France, Spain, and more moderately with Russia and Australia (Figure 4). Collaborations with countries in the global south are less prominent, with some emphasis on Mexico, Argentina (Figure 4).

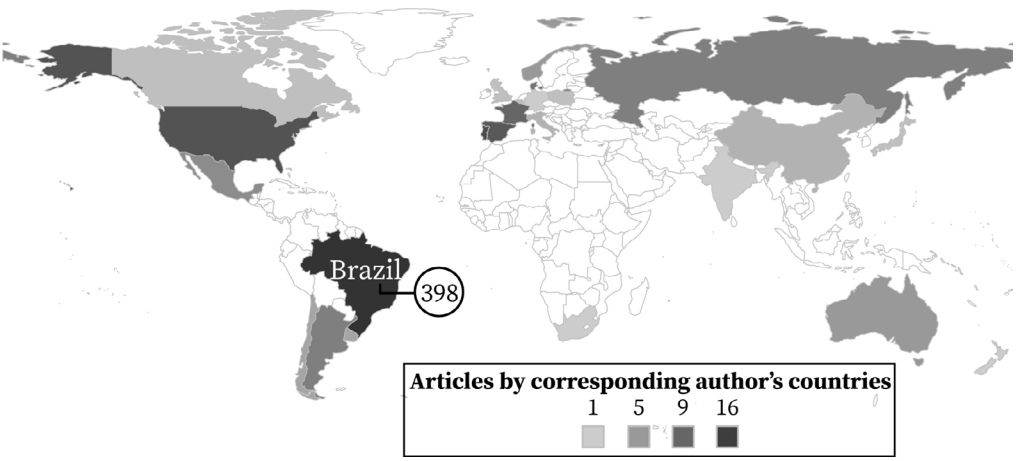

Figure 4. Scientific production from Brazilian researchers and their collaborations around the world. Based on Scopus and Web of Science bibliometric data. Data from WOS and Scopus.

Is there collaboration within the Brazilian community?

The collaboration network among authors in the field is characterized by 989 nodes, representing individual researchers. The network exhibits a low density of connections, with a value of 0.008. The transitivity of the network, which measures the extent to which authors tend to form clusters or groups, is intermediate with a value of 0.495. The network's diameter is 8, meaning the maximum intermediary connections required to connect any two authors within the network. The mean pathway length is 4.003, indicating the number of steps to connect any pair of authors within the network.

The analysis of the collaboration network displaying only the 20 most productive authors

revealed interesting patterns (Figure 5). One notable finding is a physiology/ecotoxicology group represented by Gerassintano L and Montserrat J, depicted in purple (Figure 5). This group shows exclusive intra-group collaborations and remains disconnected from all other nodes in this network (at least considering the top 20). Furthermore, the network highlights a diverse collaboration pattern involving different generations of researchers, including taxonomists and benthic ecologists, leading to more interdisciplinary collaborations. Among these coauthors, three, namely Amaral A, Lana P, and Paiva P belong to the first-generation students under Nonato EF, and their connections are depicted in red (Figure 5). The complexity of the red network representing Nonato's first generation indicates a higher degree of centrality for the Nonato EF first-generation authors. The intense co-authorship connections observed between certain pairs, such as Lana P/Garrafonni A, Nogueira J/Fukuda M, Nogueira J/Carrerette O, and Paiva P/Barroso R, reflect the strong supervisor-student relationships established during their academic journey. Note that other connections within the network are a result of post-student collaborations and the transfer of supervision, leading to a more complex network structure (Figure 5).

In this network, note the participation of authors like Hutchings P from Australia, Worsaae K, and Martínez A from Denmark (Figure 5). Although they are not Brazilian nationals or residents, their inclusion in the network is due to their extensive and diverse collaborations with Brazilian researchers, especially in the field of Terebelliformia taxonomy (for Hutchings), and taxonomy, phylogeny, and community ecology of meiofaunal polychaetes (Worsaae, and Martínez).

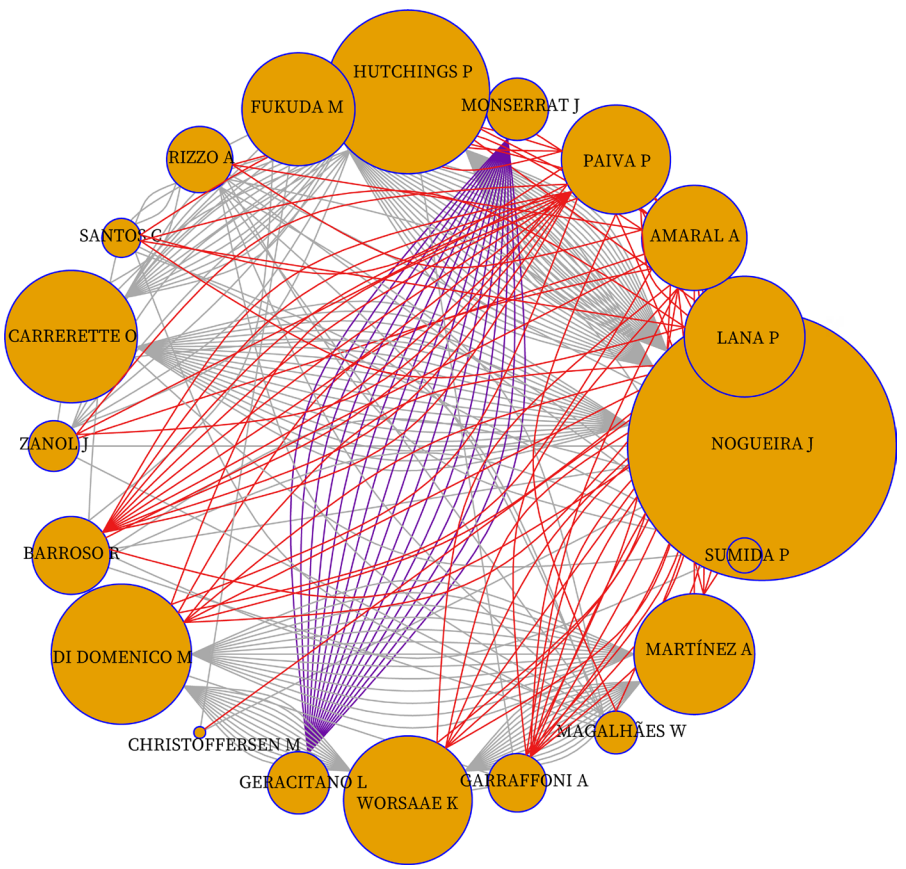

Figure 5. Collaboration network for the 20 most productive authors. Node size is relative to the number of edges (co-authorships). The red connections are from Nonato's first research generation, and the purple ones are from the physiology/ecotoxicology group. Based on Scopus and Web of Science bibliometric data. Data from WOS and Scopus.

What are the main research topics of such production through time?

We observed a slow and gradual shift in research keywords over time (Figure 6). The keyword "Taxonomy" consistently emerged as the dominant theme in Brazilian polychaetes research throughout all periods examined (Figure 6A-C). Before 1999, when keyword diversity was relatively low (Figure 6D), "Morphology" and "New Species" were the main topics following "Taxonomy" (Figure 6A, D). From 2000 to 2009, as keyword diversity and richness began to increase, topics related to physiology and benthic ecology notably emerged. Additionally, family names started to appear more frequently, indicating a shift towards studies encompassing multiple species within specific families rather than isolated new species descriptions (Figure 6B, D). The period from 2010 to 2022 exhibited a significant increase in keyword richness, although keyword diversity did not expand as much (Figure 6D). Notably, the keyword "Phylogeny" became increasingly prominent, indicating a growing focus on evolutionary relationships within the field. Furthermore, there was a renewed surge in interest in "New Species," "Deep Sea," and "Cryptic Species," as well as the emergence of keywords such as "Functional Diversity," "Northeaster Brazil," "New Record," and "Meiofauna," which gained considerable attention (Figure 6C).

The analysis of keyword co-occurrence using MCA revealed the presence of four distinct clusters (Figure 7). Cluster I (red) primarily consists of taxonomic articles, with a particular emphasis on Terebellomorpha, and highlights the strong collaboration between the Nogueira J group and the Hutchings P group from Australia (depicted in Figure 5). Cluster II (red) is the largest and encompasses a wide range of topics, with scientific research combining taxonomy, benthic ecology, beach and deep-sea ecosystems, pollution studies, and even antioxidant research (Figure 7). Cluster III (green) is focused on the investigation of benthic ecology in estuarine systems, exploring both biological and functional traits and addressing aspects related to pollution impacts on polychaetes communities (Figure 7). Group IV (blue) represents the previously mentioned physiology/ ecotoxicology group from the state of Rio Grande do Sul, and mostly used estuarine Nereididae species as model organism to research oxidative stress, biomarkers, and antioxidant responses (Figure 7).

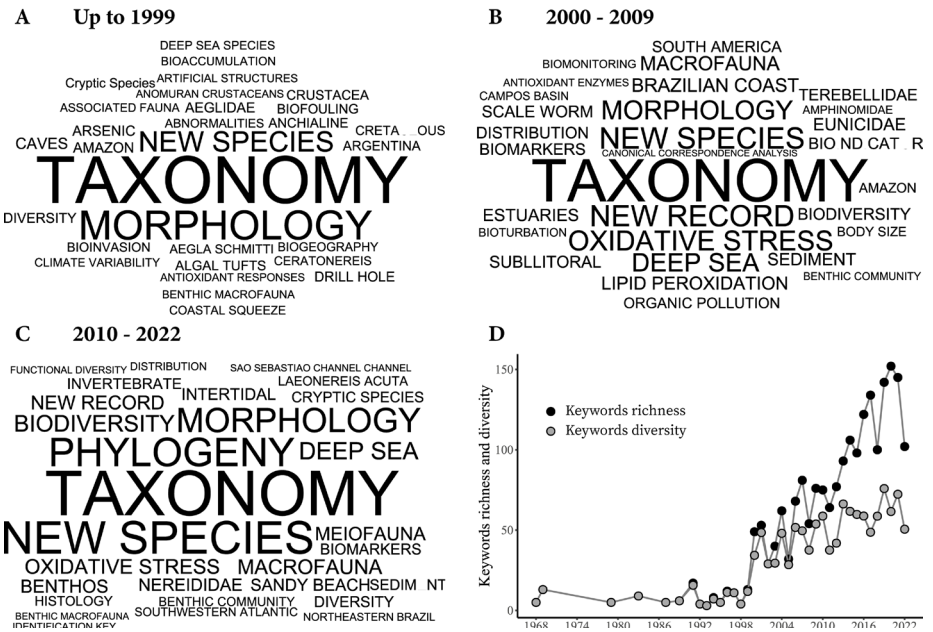

Figure 6. Word clouds based on the articles informed keywords. A, B, and C are word clouds for periods up to 1999, 2000 – 2009, and 2010 – 2022, respectively; D is the distribution of keywords richness and diversity (as inverted Simpon diversity) through time. Data from WOS, Scopus, and SciELO.

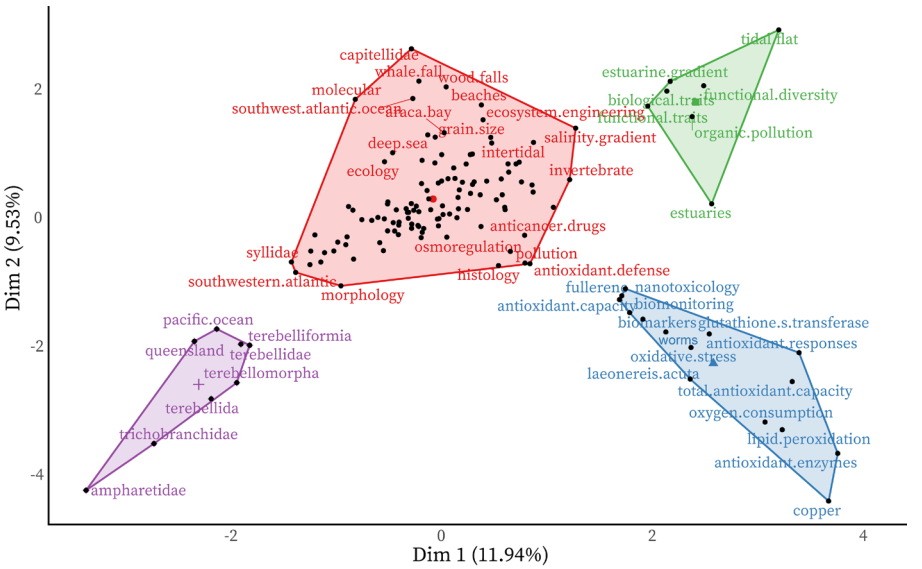

Figure 7. Conceptual structure produced by the Brazilian researchers over time. The MCA analysis was performed using the authors' keywords. Cluster I (purple), cluster II (red), Cluster III (green), and cluster IV (blue). Data from WOS and Scopus.

DISCUSSION

The results presented herein point to a very sharp growth in the scientific production, and the consolidation of a renowned corpus of researchers and institutions. These major advances highlight the importance of the fixation and establishment of a dedicated institution for advancing polychaetes science in Brazil. The Founder-effect was initiated at the Oceanographic Institute of the University of São Paulo with the efforts of Edmundo Ferraz Nonato. Over his extensive career, Nonato mentored some students who subsequently dispersed across the Southeastern Brazil.

The analysis of the collaboration network revealed interesting dynamics. Although the high number of authors could indicate a more collaborative pattern, the network displayed a low density, suggesting that collaborations are relatively sparse and only a small proportion of all possible connections between authors are realized. On the other hand, intermediate transitivity indicates the presence of cohesive groups or communities. Once researchers engage in a research group, the probability of co-authorship increases by almost 50%, particularly among authors with a higher degree of centrality, such as the Nonato EF first-generation. The diameter and mean pathway length of the network reflect a moderate tendency for authors to collaborate within distinct groups. However, unconnected groups evidently still exist. Among the 20 most productive authors, we have observed both specialized collaborations within specific research topics and intergenerational collaboration patterns that have shaped the network in this field. There is still much potential for further collaborations, and we believe that they will develop over time, since these groups share common features such as sampling habitats, model organisms, and research topics.

The dynamics of scientific production have changed over time, leading to an exponential increase in the number of published articles. This growth can be attributed to various socio-economic factors, both globally and locally. These factors encompass the growing diversity in the field of science, including greater participation of women (Handelsman et al., 2005), improved access to publishing platforms and journals for disseminating research findings, as well as the overall economic development of countries, as measured by indicators such as the Gross Domestic Product (GDP) and Human Development Index (HDI) (Stocks et al., 2008). Public investment in science and technology is also recognized as a driving force for a country's scientific production growth (Wagner et al., 2015). All these factors

contribute to understanding the growth pattern observed herein, for instance, investments in science in Brazil increased by 142% between 2000 and 2020 (MCTI, 2022).

The establishment of research partnerships and collaborations, coupled with increased grants and financial support from Brazilian scientific research funding agencies, particularly between the early 2000s and 2015 (SNPG, 2021), has played a significant role in expanding the number of polychaetes researchers from Brazil. Notably, national agencies like CAPES and CNPq, as well as individual research funding agencies of each Brazilian state (e.g., FAPESP, FAPERJ, etc.), have provided crucial financial support to researchers and graduate programs. This support has encouraged researchers to pursue their studies and foster collaborations (Mugnaini et al., 2004; SNPG, 2021). Furthermore, institutional decisions such as the reorganization of undergraduate and graduate education systems have also contributed to consolidate this research community by facilitating the formation of a critical mass, necessary to sustain a growth pattern of scientific production as observed herein. This phenomenon can also be observed among other groups of Brazilian researchers dedicated to zoological groups with diverse requirements: habitats, life histories, and sampling strategies, since similar trends have been identified for sponges (Santos, 2021) and Odonata (Miguel et al., 2017).

The overall impact of the research output remains somewhat limited, which is not significantly different from other less-developed countries like Brazil, or even other Brazilian researchers' groups, such as those studying sponges and odonates (Santos, 2021; Miguel et al., 2017). This can be attributed to a citation bias that favors research from high-income countries (Harris et al., 2017). Furthermore, note that most published articles by the polychaetes researchers from Brazil are focused on taxonomy-related topics. Considering the intricacies and challenges associated with this type of fundamental scientific research, including issues related to recognition, funding, finding suitable publishing journals, as well as adhering to proper usage and citation practices (Wägele et al., 2011; Salvador et al., 2022), a low citation rate is not surprising.

Taking an integrative approach to polychaetes taxonomy that incorporates other aspects of polychaetes biology, ecology, physiology, reassessment of morphology using new technologies, and molecular biology, can open up new and more intriguing scientific inquiries. This approach appeals to a broader range of researchers and increases the likelihood of citations from various fields. The polychaetes researchers from Brazil have already embraced this approach, as demonstrated by their work (e.g., Barroso et al., 2010). This approach holds immense significance, given the considerable efforts devoted to describing approximately 20,200 valid annelid species, with an estimated 10,000 species yet to be documented (Magalhães et al., 2021).

The most cited articles are generally produced by international collaborative groups with access to good lab infrastructure and ample financial support (Leimu and Koricheva 2005). However, of the 10 most cited articles (Table 1), seven were produced without international collaboration, with relevant and up-to-date scientific questions. Note that no traditional taxonomic/morphological article appeared among the top 10, although they make up the bulk of the production. Physiological and community ecology articles were the most cited since they present a much wider audience of readers besides the polychaetes research community. Articles on physiology are expected to have high rates of citations and are cited for a longer time (Bennet et al., 2019). Nevertheless, we must recognize that these achievements would not have been possible without the foundational taxonomic and morphological work that characterized the initial periods (1968-89 and partially 1991-1999). For instance, studies in community ecology were made possible solely due to the groundwork laid by earlier taxonomic investigations (Bortolous, 2008). Similarly, species delimitation studies were essential for model species used for physiological and ecotoxicological research (Römbke et al., 2016) since wrong identification has great consequences not only for scientific knowledge but also for environmental stakeholders.

The relative contribution of international collaboration to polychaetes-themed research reveals that spatial and cultural proximity does not significantly impact collaborations. Notably, collaborations within the Global South are quite limited, with few articles with Argentina, Uruguay, Mexico, and Chile, whereas most collaborations were carried out with countries from the Global North (e.g., USA and Europe). Several factors appear to influence collaborations, including (a) the concentration of experts, particularly in taxonomic articles; this is evident in countries such as the USA (e.g. Magalhães and Bailey-Brock, 2013), and Australia (e.g. Nogueira et al., 2013), (b) a better working framework (e.g. collections) and financial support provided by foreign countries' collaborators, such as the USA (e.g. Zanol et al., 2007), and (c) collaborations with authors who have worked in Brazil, such as those from Russia (e.g. Radashevsky and Lana, 2009). International collaborations contribute to the professional development of researchers and facilitate the exchange of ideas, which can lead to enhanced productivity and increased research impact (Mugnaini et al., 2004). Indeed, that was fundamental to the collaboration patterns highlighted herein.

On the other hand, fostering more collaborations with researchers and institutions from countries in the Global South would bring a multitude of perspectives and expertise, thereby enriching the scope of research conducted by the Brazilian polychaetes research community. Engaging in research projects with countries in South and Central America, and Africa, which share similar geographical features and regional species pools, has the potential to stimulate the emergence of new scientific inquiries in areas such as biogeography, macroecology, evolution, and related areas. This approach would help explore untapped professional niches and attract a wider audience.

Overall, the evolving patterns in articles' keywords offer valuable insights into the shifting of research topics and interests within Brazilian polychaetes researchers. These patterns indicate an expansion of the scope beyond traditional taxonomy, encompassing a broader range of topics such as community ecology (e.g., functional ecology), and biogeographic patterns. Notably, the period from 2010 to 2022 exhibited a distinct pattern, with an increase in the richness of keywords surpassing the increase in diversity. This suggests a dominant focus on certain topics – incremental science. Curiously, a new increase of the "New Species" keyword from the last decade was evident. That can be attributed to a higher number of oceanographic surveys conducted in deep-sea environments, as well as sampling efforts in previously unexplored geographic areas (northeastern and eastern Brazilian coast) and habitats (reef systems), which have led to the discovery of new taxa. This trend reflects the formation of research clusters comprising highly collaborative authors with shared interests and expertise.

CONCLUSION

The analysis of bibliometric data from the Brazilian polychaetes researchers highlights its remarkable growth and consolidation as a renowned research community. This progress can be attributed to several factors, including increased diversity in the field of science, improved access to publishing platforms, financial support from Brazilian scientific research funding agencies, and the formation of a critical mass that sustains a consistent research pattern. However, despite this growth, the overall impact of the research output remains somewhat limited. Low citation levels do not solely result from low-impact taxonomic or polychaetes community ecology articles, but they also convey a message for the development of future research directions. Furthermore, the late Paulo da Cunha Lana emphasized, in various conferences, including the one referenced herein (Lana, 2021 and this issue), the need for a shift in scientific practices in Brazil. He advocated for embracing greater creativity and audacity to enhance the quality of our research and align it with international standards. As he aptly put it, "We are still doing the same science as before in an incremental way, thus we need to be more creative and audacious in order to do a better science in line with what is done abroad."

To enhance the research impact of the Brazilian polychaetes researchers, adopting an integrative approach that incorporates other aspects of taxonomy is essential. Additionally, research and supervision practices that encourage creativity and audacity should be supported, particularly by the senior researchers. Collaboration with countries in the global south can also enrich the research conducted by Brazilian researchers and stimulate new scientific inquiries.

Considerable efforts have been made to describe and document the vast diversity of polychaetes, aiming to address the Linnean and Wallacean shortfalls. That needs to be reinforced. Moreover, we can pursue other important directions as common goals to benefit the community as a whole. These include: i) seeking a comprehensive phylogeny for key polychaetes groups, ii) building a public functional trait database, iii) supporting a distributional database like the NONATOBase (Pagliosa et al., 2014), and The Catalog of Annelida Polychaeta species from Brazil (Amaral et al., 2022), iv) sharing resources and fostering collaborations to build a molecular sequences database for the species occurring in the Brazilian waters, v) starting the investigation of freshwater polychaetes, and vi) promoting greater integration and circulation of results and ideas with regular congress and symposia. These directions should also promote insights into ecological, biogeographical, and evolutionary questions to understand the biology of polychaetes and the marine environment as well.

This piece analyzed only scientific production. We know that a research field may be analyzed in complementary ways, especially those related to social metrics and human resources. However, this is still about people more than anything else. As the late Paulo da Cunha Lana used to say: “I really like marine worms and other animals, but I like people much more.”

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R.L.N.: Conceptualization; Methodology, Investigation, Formal Analysis, Writing – Original draft, Writing – Review & Editing.

S. M.: Methodology, Investigation.

M.V.C.V.: Conceptualization, Methodology, Formal Analysis;

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REFERENCES

Amaral, A.C.Z., Nallin, S.A.H., Steiner, T.M., Forroni, T. O., Gomes-filho, D., Araújo, G. R., freitas, R., Costa, C.A.O., Ruta, C., Gomes, K.R.E. & Bonaldo, R.O. 2006-2022. *Catálogo das espécies de Annelida “Polychaeta” do Brasil*. Unicamp, Campinas, São Paulo.

Aria, M. & Cucurullo, C. 2017. *bibliometrix*: An R-tool for comprehensive science mapping analysis. *Journal of informetrics*, 11, 959-975. https://doi.org/10.1016/j.joi.2017.08.007

Barroso, R., Sole-Cava, A., Klautau, M. R. L. & Paiva, P. C. 2010. *Eurythoe complanata* (Polychaeta: Amphinomidae), the ‘cosmopolitan’ fireworm, consists of at least three cryptic species. *Marine Biology*, 157, 69-80. https://doi.org/10.1007/s00227-009-1296-9

Bennet, L., Eisner, D. A. & Gunn, A. J. 2019. Misleading with citation statistics? *The Journal of Physiology*, 597, 2593-2594. https://doi.org/10.1113/JP277847

Bortolous, A. 2008. Error Cascades in the Biological Sciences: The Unwanted Consequences of Using Bad Taxonomy in Ecology. *AMBIO: A Journal of the Human Environment*, 37, 114-118. https://doi.org/10.1579/0044-7447(2008)37[114:ECITBS]2.0.CO;2

Cord, I., Nunes, L. T., Barroso, C. X., Freire, A. S., Gadig, O. B. F., Gomes, P. B., Gurgel, C. F. D., Lindner, A., Mantelatto, F. L., Targino, A. K. G. & Floeter, S. L. 2022. Brazilian marine biogeography: a multi-taxa approach for outlining sectorization. *Marine biology*, 61. https://doi.org/10.1007/s00227-022-04045-8

Fauchald, K. 1977. *The polychaete worms. Definitions and keys to the orders, families and genera*. Los Angeles, Natural History Museum of Los Angeles County.

Feinerer, I., Hornik, K. & Meyer, D. 2008. Text Mining Infrastructure in R. *Journal of Statistical Software*, 25, 1-54. https://doi.org/10.18637/jss.v025.i05

Fellows, I. 2018. wordcloud: Word Clouds. R package version 2.6. Available at: https://cran.r-project.org/package=wordcloud. Accessed in 06/27/2023).

Handelsman, J., Cantor, N., Carnes, M., Denton, D., Fine, E., Grosz, B., Hinshaw, V., Marrett, C., Rosser, S., Shalala, D. & Sheridan, J. 2005. More women in science. *Science*, 309, 1190-1191.

Hansen, G. A. 1882. Recherches sur les annélides recueillies par M. le professeur E. Van Beneden pendant son voyage au Brésil e à La Plata. Académie Royale de Belgique. Classe des Sciences. *Mémoires*, 44, 1-29.

Harris, M., Marti, J., Watt, H., Bhatti, Y., Macinko, J. & Darzi, A. W. 2017. Explicit bias toward high-income-country research: A randomized, blinded, crossover experiment of English clinicians. *Health Affairs*, *36*, 1997-2004. https://doi.org/10.1377/hlthaff.2017.0773

Kinberg, J. G. H. 1858. Annulater Kongliga Svenska Fregatten Eugenies Resa omkring jorden under befal af C.A. Virgin aren 1851-1853. *Zoology*, 1, 1-32.

Lana, P. C., Pagliosa, P., Paiva, P. C., Carrerette, O., Paresque, K., Nogueira, J. M. M., Amaral, A. C. Z., Steiner, T. M., Christoffersen, M. L., Garraffoni, A. R. S., Di Domenico, M., Barroso, R., Rizzo, A. E. & Fukuda, M. V. 2017. Polychaetes in Brazil: people and places, past, present and future. *Boletín del Instituto Oceanográfico de Venezuela*, 24-50.

Lana, P. C. 2021. Ciência no Brasil: O que fazemos e o que precisaríamos fazer. Online, vídeo. Rio de Janeiro. https://www.youtube.com/watch?v=Y45JwR9_P9o&ab_channel=PPGZoologia-MuseuNacional (visited in 06/27/2023).

Le Pennec, E. & Slowikowski, K. 2019. *ggwordcloud: A Word Cloud Geom for 'ggplot2'*. R package version 0.5.0. Available at: https://cran.r-project.org/package=ggwordcloud acessed in 06/27/2023.

Leimu, R. & Koricheva, J. 2005. What determines the citation frequency of ecological papers? *Trends in Ecology and Evolution*, 20, 28-32. https://doi.org/10.1016/j.tree.2004.10.010

Magalhães, W., Hutchings, P., Oceguera-Figueroa, A., Martin, P., Schmelz, R., Wetzel, M., Wiklund, H., Maciolek, N., Kawauchi, G. & Williams, J. 2021. Segmented worms (Phylum Annelida): A celebration of twenty years of progress through Zootaxa and call for action on the taxonomic work that remains. *Zootaxa*, 4979, 190-211. https://doi.org/10.11646/zootaxa.4979.1.18

Magalhães, W. F. & Bailey-Brock, J. H. 2013. Bitentaculate Cirratulidae (Annelida: Polychaeta) from the northwestern Pacific Islands with description of nine new species. *Zootaxa*, 3630, 80-116.

MCTI (Ministério da Ciência e Tecnologia) 2022. *Indicadores Nacionais de Ciência, Tecnologia e Inovação*. Available at: https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/indicadores/paginas/publicacoes/arquivos/indicadores_cti_2022.pdf. Acessed in 10/02/2023.

Miguel, T. B., Calvão, L. B., Vital, M. V. C. & Juen, L. 2017. A scientometric study of the order Odonata with special attention to Brazil. International *Journal of Odonatology*, 20, 27-42. http://dx.doi.org/10.1080/13887890.2017.1286267

Mugnaini, R., Jannuzzi, P. M. & Quoniam, L. 2004. Indicadores bibliométricos da produção científica brasileira: uma análise a partir da base Pascal. *Ciência da Informação*, 33, 123–131. https://doi.org/10.18225/ci.inf.v33i2.1054

Müller, F. 1858. Einiges uber die Anneliden Fauna der Insel Santa Catarina an der Brasilianischen Kuste. Arch. *Für Naturgeschichte*, 24, 211-220.

Nogueira, J. M. M, Fitzhugh, K. B & Hutchings, P. C. 2013. The continuing challenge of phylogenetic relationships in Terebelliformia (Annelida: Polychaeta). *Invertebrate Systematics*, 27, 186-238. https://doi.org/10.1071/IS12062

Nonato, E. F. 1958. Sobre duas arenicolas da costa brasileira (Annelida, Polychaeta). *Oceanografia Biológica*, 3, 1-7.

Nonato, E. F. 1963. *Poecilochaetus australis* sp. nova. (Annelida, Polychaeta). *Neotropica*, 9, 17-26.

Nonato, E. F. 1965. *Eunice sebastiani* sp. nova. (Annelida, Polychaeta). *Boletim do Instituto Oceanográfico*, 14, 133-139.

Oksanen, J., Simpson, G., Blanchet, F., Kindt, R., Legendre, P., Minchin P., O'hara, R., Solymos, P., Stevens, M., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Carvalho, G., Chirico, M., De Caceres, M., Durand, S., Evangelista, H., Fitzjohn, R., Friendly, M., Furneaux, B., Hannigan, G., Hill, M., Lahti, L., Mcglinn, D., Ouellette, M., Ribeiro, C. E, Smith, T., Stier, A., Ter Braak, C. & Weedon, J. 2022. *vegan: Community Ecology Package*. R package version 2.6.4. Available at: https://CRAN.R-project.org/package=vegan Acessed in: 06/27/2023.

Pagliosa, P. R., Doria, J.G., Misturini, D., Oegui, M. B., Oortman, M. S., Weis, W. A., Faroni-Perez, L., Alves, A. P., Camargo, M. G., Amaral A. C., Marques, A. C. & Lana, P. C. 2014. NONATObase: a database for Polychaeta (Annelida) from the Southwestern Atlantic Ocean. *Database (Oxford)*, 2014. https://doi.org/10.1093/database/bau002

Radashevsky, V. I. & Lana, P. C. 2009. *Laonice* (Annelida: Spionidae) from South and Central America. *Zoosymposia*, 2, 265-295. https://doi.org/10.11646/zoosymposia.2.1.19

R Core Team. 2021. *R: A language and environment for statistical computing*. Austria: R Foundation for Statistical Computing.

Römbke, J., Aira, M., Backeljau, T., Breugelmans, K., Domínguez, J., Funke, E., Graf, N., Hajibabaei, M., Pérez-Losada, M., Porto, P. G., Schmelz, R. M., Vierna, J., Vizcaíno, A. & Pfenninger, M. 2016. DNA barcoding of earthworms (Eisenia fetida/andrei complex) from 28 ecotoxicological test laboratories. *Applied Soil Ecology*, 104, 3-11. https://doi.org/10.1016/j.apsoil.2015.02.010

Salvador, R. B., Cavallari, D. C., Rands, D. & Tomotani, B. M. 2022. Publication practice in Taxonomy: Global inequalities and potential bias against negative results. *PLOS ONE*, 17, e0269246. https://doi.org/10.1371/journal.pone.0269246

Santos, H. S. 2021. *Evolução do estudo de poríferos no Brasil: uma análise cienciométrica* [Trabalho de Conclusão de Curso]. Maceió: Universidade Federal de Alagoas. Available at: http://www.repositorio.ufal.br/jspui/handle/123456789/10332 Acessed in: 06/30/2023

SNPG (Sistema Nacional de Pós-Graduação) 2021. *EVOLUÇÃO DO SNPG NO DECÊNIO DO PNPG 2011-2020*. Brasília, DF: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior. Available at: https://www.gov.br/capes/pt-br/centrais-de-conteudo/07032022_EvolucaodoSNPGnodeceniodoPNPG20112020_ISBNWeb.pdf Acessed in: 06/30/2023).

South, A. 2011. rworldmap: A New R package for Mapping Global Data. *The R Journal*, *3*, 35-43.

Spalding, M. D., Fox, H. E., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M., Halpern, B. S., Jorge, M. A., Al Lombana, Lourie S. A., Martin, K. D., Mcmanus, E., Molnar, J., Recchia, C. A. & Robertson, J. 2007. Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas. *BioScience*, 57, 573-583. https://doi.org/10.1641/B570707

Stocks, G., Seales, L., Paniagua, F., Maehr, E. & Bruna, E. M. 2008. The geographical and institutional distribution of ecological research in the tropics. *Biotropica*, 40, 397-404.

Wagner, C. S., Park, H. W. & Leydesdorff, L. 2015. The continuing growth of global cooperation networks in research: A conundrum for national governments. *PLOS ONE*, 10, e0131816. https://doi.org/10.1371/journal.pone.0131816

Wägele, H., Klussmann-Kolb, A., Kuhlmann, M., Haszprunar, G., Lindberg, D., Koch, A. & Wägele, J. W. 2011. The taxonomist - an endangered race. A practical proposal for its survival. *Frontiers in Zoology*, 8, 25. https://doi.org/10.1186/1742-9994-8-25

Wickham, H., Averick, M., Bryan, J., Chang, W., Mcgowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K. & Yutani, H. 2019. Welcome to the tidyverse. *Journal of Open Source Software*, 4, 1686. https://doi.org/10.21105/joss.01686

Zanol, J., Fauchald, K. & Paiva, P. C. 2007. A phylogenetic analysis of the genus *Eunice* (Eunicidae, polychaete, Annelida). *Zoological Journal of the Linnean Society*, 150, 413-434.