










## SCIENTOMETRIC ANALYSIS OF *Hoplias malabaricus* RESEARCH: TRENDS, GAPS, AND DISTRIBUTION

### Análise cientométrica da pesquisa de *Hoplias malabaricus*: tendências, lacunas e distribuição

### Análisis cientométrico de la investigación sobre *Hoplias malabaricus*: tendencias, lagunas y distribución

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## ABSTRACT

The study utilized scientometrics to analyze the scientific production on the *Hoplias malabaricus* group, employing quantitative methods to identify research trends, main areas, and knowledge gaps. The analysis was conducted through indexed search engines, focusing on taxonomy and biogeography studies, aiming to understand the evolution of research in these fields. Databases such as Elsevier, Clarivate, PubMed, SciELO, and Google Scholar were used to collect bibliometric data, with keywords combined using Boolean operators. The analysis revealed an irregular distribution of scientific production, with a predominance of researchers from Brazil and the United States, and a significant emphasis on taxonomy over biogeography. The results indicate a peak in publications over the last decade followed by a decline, suggesting the need for more studies on the biogeography of *H. malabaricus* to complement existing knowledge and improve the understanding of its geographical distribution.

**Key words:** Brazil, United States, scientometric studies, geographic distribution, taxonomy.

## RESUMO

O estudo utilizou a cientometria para analisar a produção científica sobre o grupo *Hoplias malabaricus*, empregando métodos quantitativos para identificar tendências de pesquisa, áreas principais e lacunas de conhecimento. A análise foi conduzida através de buscadores indexados, com foco em estudos de taxonomia e biogeografia, visando compreender a evolução da pesquisa nesses campos. Foram usadas bases de dados como Elsevier, Clarivate, PubMed, SciELO e Google Scholar para coletar dados bibliométricos, com palavras-chave combinadas por operadores booleanos. A análise revelou uma distribuição irregular da produção científica, com predominância de pesquisadores do Brasil e dos Estados Unidos, e uma ênfase significativa em taxonomia em detrimento da biogeografia. Os resultados indicam um pico de publicações na última década seguido de um declínio, sugerindo a necessidade de mais estudos sobre a biogeografia do *H. malabaricus* para complementar o conhecimento existente e melhorar a compreensão de sua distribuição geográfica.

**Palavras-chave:** Brasil, Estados Unidos, estudos cientométricos, distribuição geográfica, taxonomia.

## RESUMEN

En este estudio se utilizó la cienciometría para analizar la producción científica sobre el grupo *Hoplias malabaricus*, empleando métodos cuantitativos para identificar tendencias de investigación, áreas clave y lagunas de conocimiento. El análisis se realizó a través de motores de búsqueda indexados, centrándose en estudios de taxonomía y biogeografía, con el fin de comprender la evolución de la investigación en estos campos. Se utilizaron bases de datos como Elsevier, Clarivate, PubMed, SciELO y Google Scholar para recopilar datos bibliométricos, con palabras clave combinadas mediante operadores booleanos. El análisis reveló una distribución desigual de la producción científica, con predominio de investigadores de Brasil y Estados Unidos, y un énfasis significativo en la taxonomía en detrimento de la biogeografía. Los resultados indican un pico de publicaciones en la última década seguido de un declive, lo que sugiere la necesidad de realizar más estudios sobre la biogeografía de *H. malabaricus* para complementar los conocimientos existentes y mejorar la comprensión de su distribución geográfica.

**Palabras clave:** Brasil, Estados Unidos, estudios cuantitativos, distribución geográfica, taxonomía.

## INTRODUCTION

These fishes, commonly found in freshwater environments in South America, belong to the genus *Hoplias* and are included in the family Erythrinidae, popularly known as trahiras. They stand out for their extensive territorial manifestation and presence in various ecological and taxonomic studies (Guimarães et al., 2022). Within this group, the species *Hoplias malabaricus* is noteworthy for being widely distributed in the inland waters of Central and South America, playing an important role in aquatic ecosystems due to its position as a predator (Guimarães et al., 2021). Thus, the growing attention to *H. malabaricus* can be attributed in part to the wide variety of habitats occupied and its presence in many non-intercommunicating river basins (Ferreira et al., 2021).

In taxonomic studies, the malabaricus complex has proven to be a promising and dynamic field, with several reviews and descriptions dedicated to the classification of new species over the years (Auzier Guimarães et al., 2021). However, specifically on the biogeography of the group, it is still incipient, despite the apparent interest from the scientific community. Considering its wide distribution and diversity of habitats, there are still gaps in knowledge (Pires et al., 2020). Furthermore, studies on the geographical distribution and genetic structure of *H. malabaricus* populations have been occurring more consistently, often presenting new classificatory propositions for the group (Ibangón et al., 2020).

Many studies have significantly contributed to understanding the taxonomy of the genus *Hoplias* by detailing the morphological and genetic variations of these species in different South American river basins (Sassi et al., 2021). These works highlight the complexity of the *malabaricus* group, suggesting the existence of an intricate set instead of a single species (Bitencourt et al., 2023). Like what happened and still occurs for *H. lacerdae*, researchers have been using geometric morphometry techniques and mitochondrial RNA and DNA analysis to identify subtle differences between populations (Escobar Camacho et al., 2024), revealing biogeographical patterns that indicate historical events of isolation and reconnection between basins (Müller, 2023). This integrative approach proves pioneering, establishing a solid foundation for subsequent studies and emphasizing the need for continuous taxonomic reviews (Vieira-Guimarães et al., 2023).

Similarly, researchers explore the biogeography of the *H. malabaricus* group through extensive surveys recorded in literature and biological collections (Dagosta et al., 2024). Mapping the presence of the species in various aquatic systems, from the Pantanal to the Amazon, analyzing how environmental and historical factors shaped its distribution (Melo et al., 2022). Using spatial analysis tools and ecological niche models, they predict potential occurrence areas, contributing to understanding how climate changes and habitat alterations may impact the species' distribution (Monteiro et al., 2020).

On the other hand, we can also highlight the occurrence of studies focused on feeding ecology, covering its diet in different environments and seasons (Lujan et al., 2020). This approach helps understand feeding strategies and allows verifying certain discrepancies in taxonomic classification (Salazar-Camacho et al., 2021). In this context, they point out that *H. malabaricus* is a potentially opportunistic predator, with a varied diet including fish, crustaceans, insects, amphibians, and even small birds and mammals, reflecting its adaptability to different environmental conditions (Dopazo et al., 2023). Including morphological adjustments, adding difficulty to the taxonomic classification of this group (Simões et al., 2022).

However, more in-depth studies on the population genetics of this group are emerging, using molecular markers to assess genetic variability between different populations (Cardoso et al., 2021). Revealing a high

diversity within and between populations, suggesting that the species has a complex evolutionary history, with multiple colonization, isolation, and regrouping events (Koerber et al., 2022). Emphasizing the importance of connectivity between aquatic habitats for maintaining genetic diversity and species adaptability (Albert et al., 2020). These regroupings expand population reconnections and increase the difficulty of identifying taxonomic entities (Brito et al., 2020).

Despite significant efforts by the scientific community to investigate and validate knowledge about all behavioral and physiological aspects, there are indications that the trahiras can adapt to environmental variations in their habitat (Chuctaya et al., 2020). Considering them as predators or evaluating them as bioindicators, it is possible to perceive that their distribution amplitude is a predominant factor for a assertive choice. However, the taxonomic gaps of the group are prohibitive, as the physiological peculiarities of each taxonomic entity can negatively interfere with the immune responses of organisms and consequently with the proposed analyses (Bánó et al., 2024).

Evaluating the negative interventions of genetic connectivity of these species within the *H. malabaricus* group and different river basins, this gene flow between populations or the morphological and genetic similarities are impediments to the effective taxonomic determination of organisms (Maiztegui et al., 2022).

In this context, scientometrics proves to be a powerful tool for analyzing scientific production on the *H. malabaricus* group. Involving the use of quantitative methods to measure and analyze developed studies, allowing the identification of research trends, main study areas, and knowledge gaps. Therefore, a thorough analysis of scientific production was sought through indexed search engines, focusing on taxonomy and biogeography studies, aiming to understand the evolution of research in these fields.

## MATERIAL AND METHODS

A scientometric analysis was used to analyze studies on *Hoplias malabaricus*. Databases such as Elsevier, Clarivate, PubMed, SciELO, and Google Scholar were used to collect bibliometric data from articles. Keywords were combined using Boolean operators, and results were analyzed using VOSviewer and Bibliometrix to identify patterns in scientific literature.

### INDICATOR DESCRIPTION

The selected keywords were "*Hoplias*," "taxonomy," "biogeography," and "*Hoplias malabaricus*," aiming to maximize the research coverage in predominantly English academic databases. Their synonyms in English were also used. The search strategy included using Boolean operators to refine the results, excluding irrelevant terminologies and studies. Data collection was performed on specific platforms, selecting relevant studies addressing taxonomic, biogeographic, and specific characteristics of *Hoplias malabaricus*.

For data collection, after defining keywords with Boolean operators ("AND" and "OR"), a refined search was conducted to find studies corresponding to the topic of interest.

### INDEXED DATA

Like this, the methodology employed for this scientometric analysis was a careful process from data collection to statistical analysis and result visualization. After defining the research terms, the databases Elsevier Science Direct (Scopus), Clarivate (Web of Science), MEDLINE (PubMed), Scientific Electronic Library Online (SciELO), and Google Scholar (Scholar Google) were selected for their coverage and relevance in the scientific field investigated. These databases were accessed with the aid of the CAFE platform hosted on the CAPES website. However, for effective analysis, only Web of Science and Scopus were relevant as they offer a combination of factors such as bibliometric data accuracy and the possibility of cumulative data export in a single file.

Therefore, the keywords and Boolean operators were combined to provide the necessary research data. Subsequently, the results were exported in CSV, XLSX, TXT, and BIB formats, compatible with Mendeley (Mendeley Reference Manager), VOSviewer, and the Bibliometrix [bibliometrix::biblioshiny()] application linked to R Studio (2024.04.2 Build 764 - Posit Software, PBC), used for scientometric analysis.

### DATA ANALYSIS

Thus, using Mendeley and Bibliometrix, the downloaded data was grouped and filtered. Later in VOSviewer, the files were imported and configured to create a keyword co-occurrence map. This map visualized the interactions between terms and revealed emerging patterns in the examined scientific literature. Before the final analysis, the data was refined in Excel to eliminate irrelevant terms and ensure result accuracy.

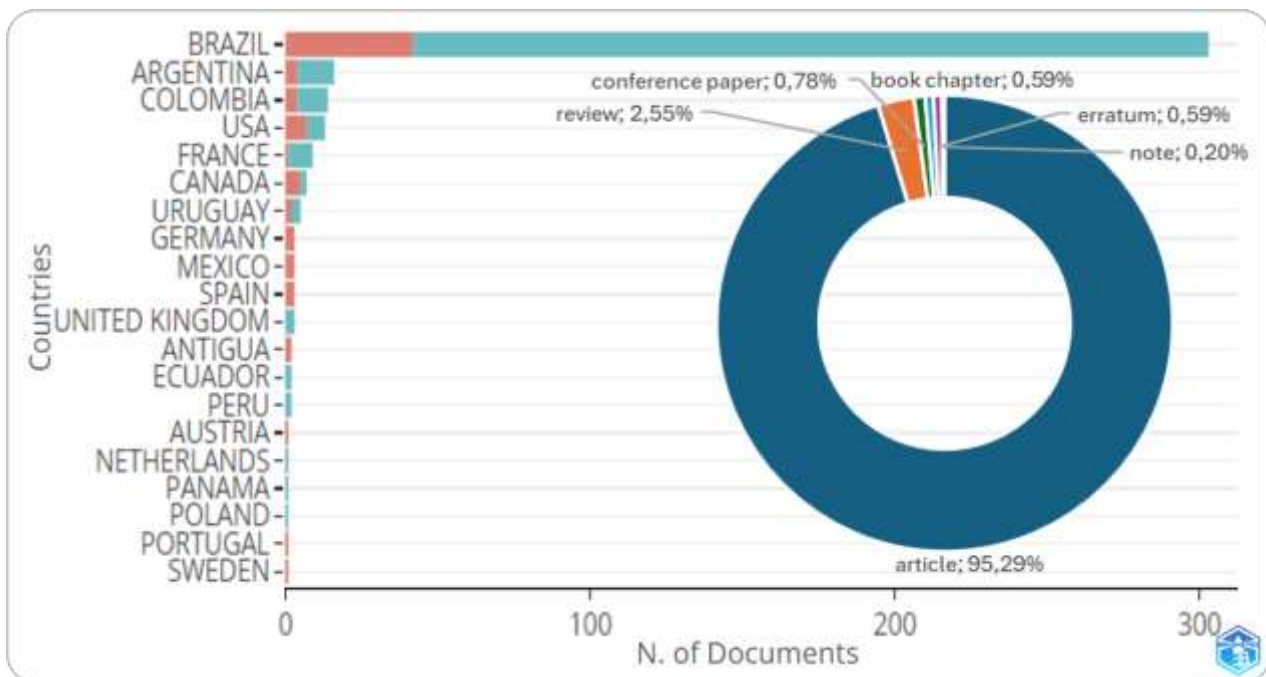
Consequently, we meticulously examined how the researched terms relate, examining their connections and differences. Additionally, we examined the citations and origins of the authors of each study to understand the impact and context of the scientific contributions. Simultaneously, we identified the origin of the biological material used and the institutions responsible for conducting the studies, providing a comprehensive overview of the analyzed database and the period in which the events occurred.

## RESULTS

Accordingly, an uneven distribution of research on the species *H. malabaricus* was found, with a predominance of researchers from Brazil and the United States. A significant focus on taxonomy was evident, with less attention to biogeography, indicating a gap in the literature. The studied scientific production showed a sampling peak for the last decade, followed by a decline.

### COLLECTED DATA

Hence, these results reveal an irregular distribution of scientific documents on the species *Hoplias malabaricus* among different countries. The explored bibliographic material included 376 listed bibliographies. Of this amount, 95.29% are indexed articles in the consulted databases. Additionally, 59.4% of all gathered data comes from Brazil. All acquired data first underwent scrutiny by the platform where it was hosted for our subsequent acquisition (Figure 1).



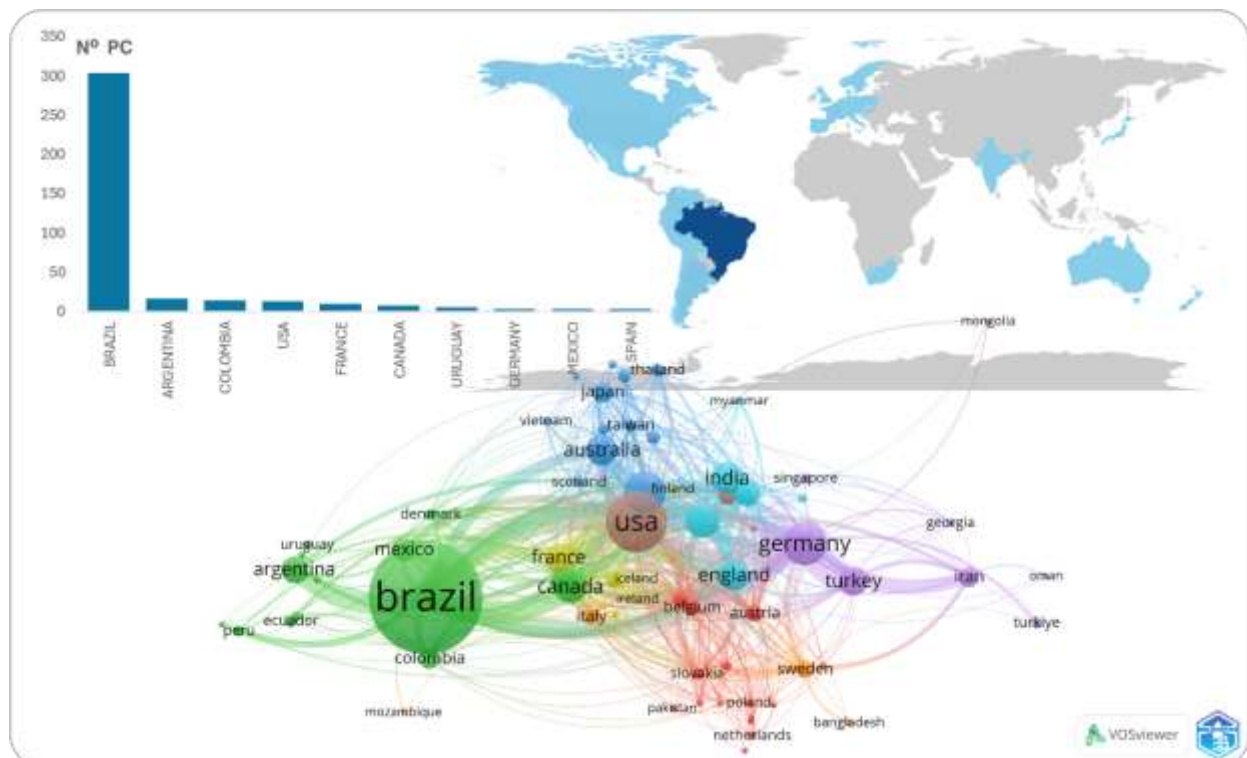
**Figure 1.** Amount of published material by the most prominent countries on this topic and percentage of articles on other publication forms used in this research (Source: Bibliometrix).

Table 1 analysis shows a predominance of researchers from countries like Brazil and the United States, while other countries contributed less significantly to this species' research. This analysis used counting methods that included co-authors and their respective countries, selecting at least three related documents from a universe of 121 countries, with 71 correlated. For each of these 71 countries, the total strength of co-authorship links with other countries was calculated. Thus, countries with the highest total correlation strength were selected (Figure 2).

**Table 1.** Distribution of values for the representativeness of the nine countries with the most publications on *Hoplias malabaricus*. SCP (Subjected to Critical Peer-review).

Country	Articles	Articles %	SCP
Brazil	303	59,4	261
Argentina	16	3,1	12
Colombia	14	2,7	10
USA	13	2,5	6
France	9	1,8	8
Canada	7	1,4	2
Uruguay	5	1	3
Germany	3	0,6	0
Mexico	3	0,6	0
Spain	3	0,6	0

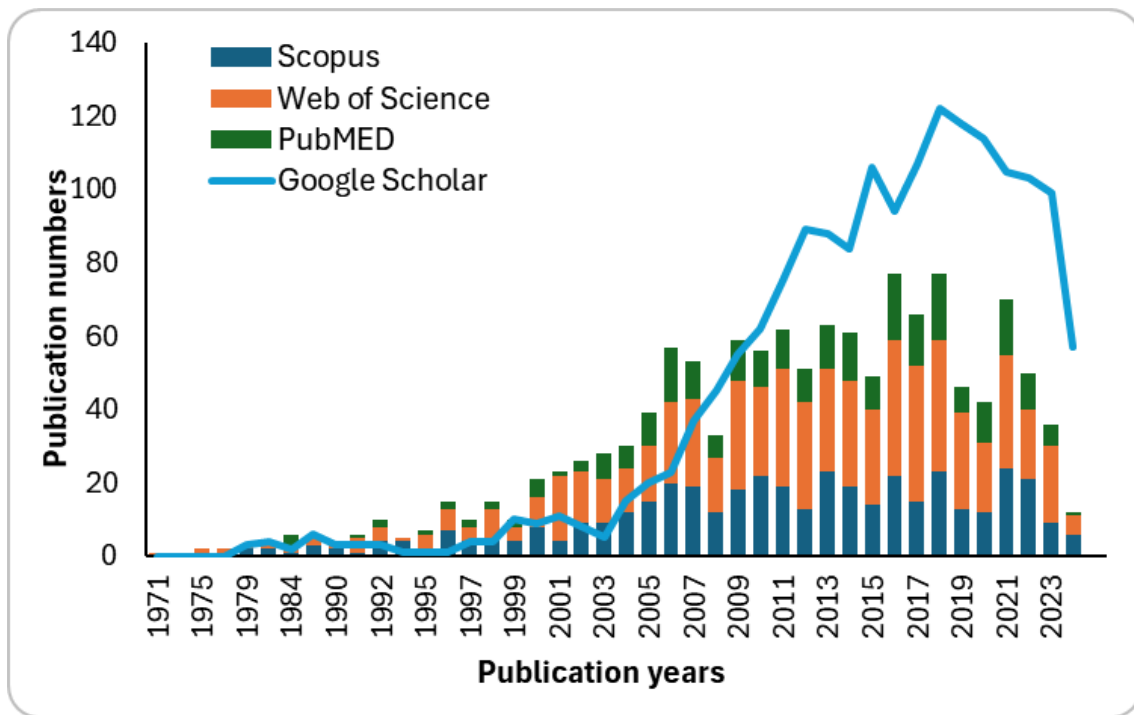
(Source: Bibliometrix)

**Figure 2.** Relations between researchers and their countries of origin and the number of works on *Hoplias malabaricus* published (Source: Bibliometrix vs VOSviewer).

Specifically, the search highlighted the prevalence of the term "taxonomy" compared to the other sought-after aspect "biogeography," underscoring a substantial gap in specialized literature. Emphasizing that more attention is needed in studies addressing less explored aspects, such as the species' biogeography, to complement and enrich existing knowledge in this scientific field and improve understanding of its geographical distribution.

Moreover, quantitative data reveals that Brazil, and the United States led in terms of co-authorship in scientific production on this species, with a significantly higher number of collaborators. This pattern reflects not only academic and scientific interest in these regions but also may indicate disparities in available research resources and funding capacity dedicated to this specific topic.

Another relevant aspect observed is the temporal distribution of publications on the species. The analysis indicates that most studies were published between 2009 and 2019, with a declining trend in subsequent years. This pattern suggests a possible decrease in interest or research capacity on the species after the last decade (Figure 3).



**Figure 3.** Relationship of the number of publications per year tracked in the databases, on the species *Hoplias malabaricus* (Source: Created by the author).

There seems to be a notable disparity between publication trends in stringent databases and Google Scholar in recent years. These databases, which generally have strict criteria for article inclusion, showed stabilization in the number of productions on the specific terms analyzed. In contrast, Google Scholar searches revealed a significant increase in the same period.

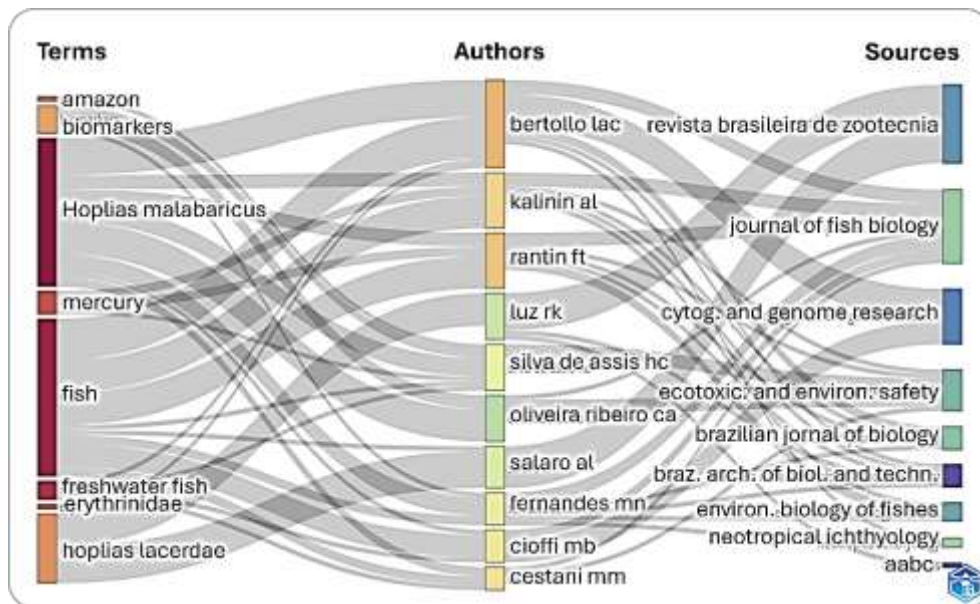
However, a general observation is that all sources, regardless of their rigor, indicated a sharp reduction in the number of publications after 2021. This can be attributed to various factors, such as changes in editorial policies, impacts from the pandemic, or even shifts in research priorities.

#### DATA ANALYSIS

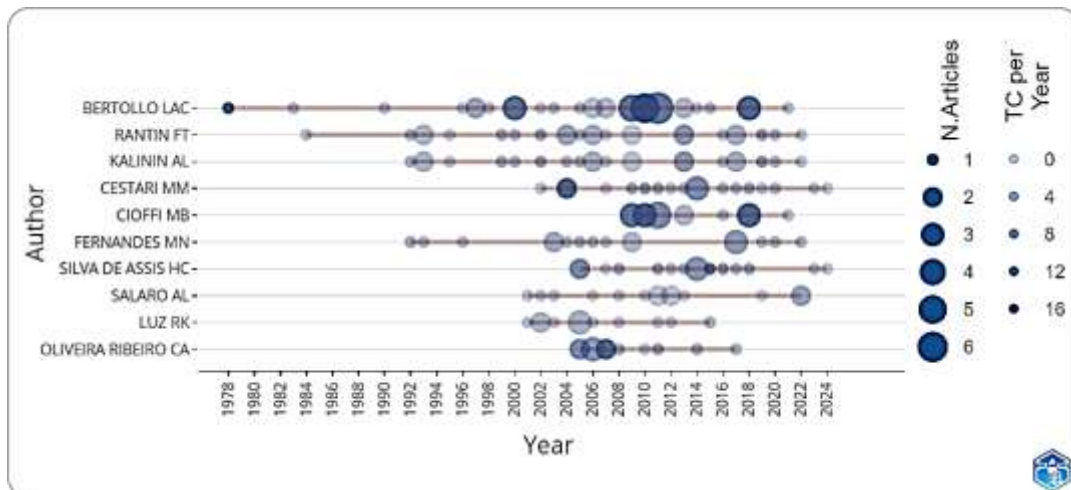
From the data compiled for the cited databases, the analysis was conducted meticulously, using a scientometric methodology process (research; analysis; refinement, and final analyzes). This process allowed mapping using algorithms employed to track works with a similar focus in their research areas through keyword co-occurrence. This variable was graphically represented, allowing the identification of links between terms and the frequency with which they are repeated. Being fundamental and decisive for inferring the impact of each term in the study, as well as identifying the main keywords, prominent authors, and the most sought-after journals for publishing these works (Figure 4).

In the first analysis, the general data of the found terms were examined. Based on the keywords that originated this study, we filtered the data to obtain the most recent and relevant contributions on the topic, categorizing them by type of publication, including articles, reviews, research articles, and book chapters. Highlighting the researchers who contributed most to the topic and their contribution over time. Where it was possible to identify that Bertoldo is the author with the longest career and the highest number of publications per year. However, others do not count as ancillary researchers but have visible contributions to scientific research on *Hoplias malabaricus* (Figure 5).

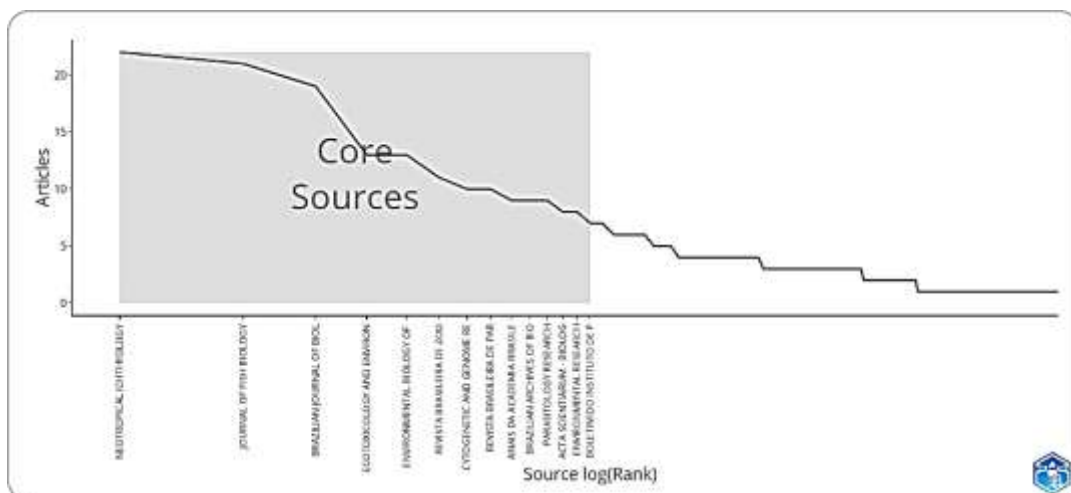
Similarly, we can observe that according to Bradford's theory diagram, considering that most works (about 50%) are restricted to fewer than 15 researchers. Still pondering that only one of these has 28 publications on the topic (Figure 6).



**Figure 4.** Relationship of the main keywords (terms) used, the most prominent authors in the area, and the most sought-after journals for publication (Source: Bibliometrix).



**Figure 5.** Scientific contribution by the number of works published per author over time (Source: Bibliometrix).



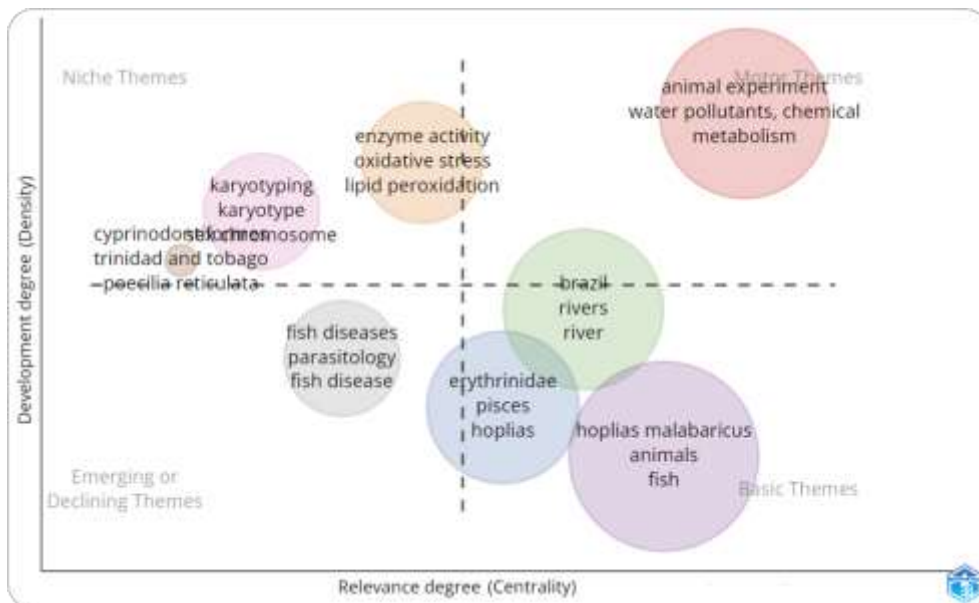
**Figure 6.** Bradford's theory diagram for the distribution of publications by authors (Source: Bibliometrix).

Therefore, the quantitative results highlighted the relevance of the researched terms in the context of the study. The keyword "*Hoplias malabaricus*" was found 421 times, indicating a significant interest in the species within the scientific literature. The term "taxonomy" appeared 13 times, reflecting the importance of these taxonomic studies related to this species but with less emphasis than other topics. Finally, "biogeography" was cited only eight times, emphasizing that this theme is still rarely mentioned and presents a gap to be explored. However, even using the cited Boolean operators, many other terms related to these chosen keywords were still found, such as "phylogeny" and "biodiversity," directly linked to this research's proposition (Figure 7).



**Figure 7.** Correlation between terms found in Scopus (Elsevier) and Web of Science (Clarivate) databases (Source: Bibliometrix).

For the second evaluation stage, the generated files were then processed via Mendeley (filtering) and R-Studio (consolidation). Using VOSviewer from the found terms, thematic correlations were made. The data filtering aimed to assess the most recent and relevant contributions on the topic, categorizing them by type, terminologies, authors, and study locations. This allowed us to identify that the correlation between the themes and the concentration of the authors is mainly concentrated on the *H. malabaricus* taxon itself and on topics related to animal health and welfare, physiology, among others (Figure 8).

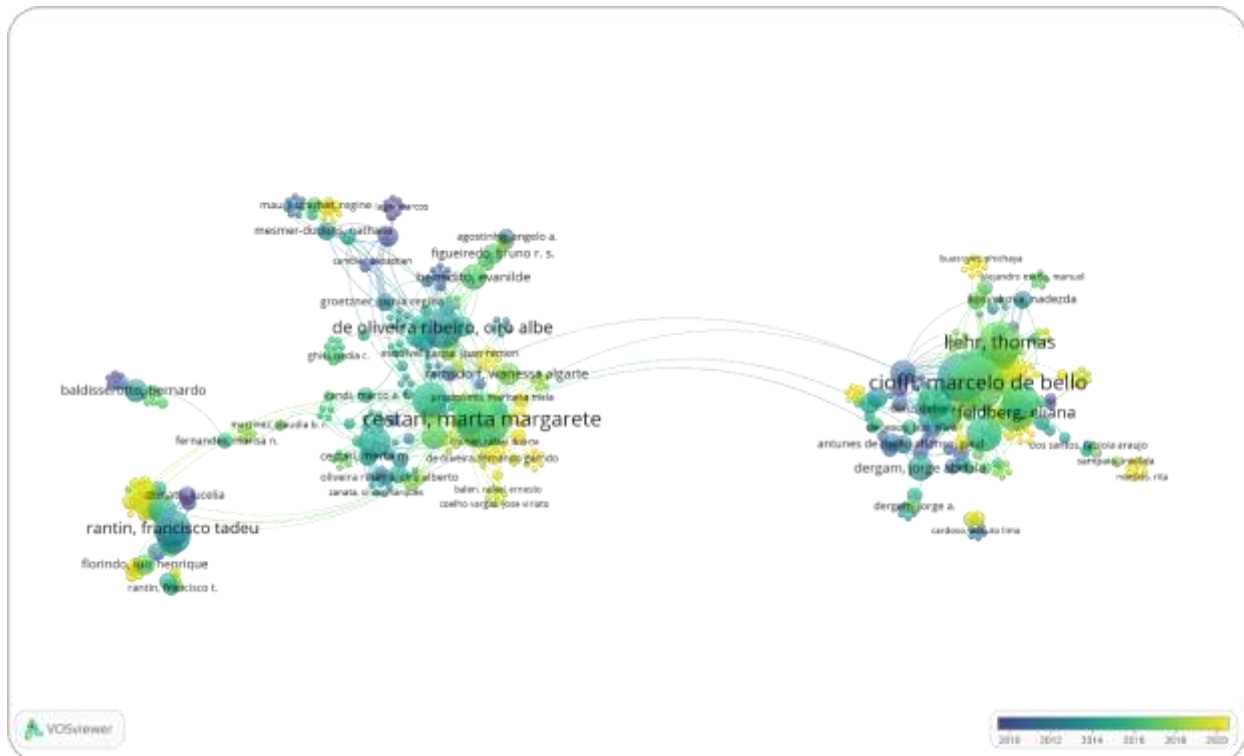


**Figure 8.** Diagram of the concentration of bibliographies generated for each set of most correlated themes (Source: Bibliometrix).



In consequence, the generated chart emphasizing the connections between co-authors collaborating to study this topic, as well as the creation of systematic groupings among these researchers. Thus, we can observe the configurations in nine different convergence centers, all connected and always associated with one or more notable researchers as convergence or scientific production centers. Emphasizing a specific geographic concentration for subsequent research, ecological and agro-industrial demands, and the convergence of the most important river basins for this group of fish.

Therefore, we can highlight that most current publications, being a scientific-academic convergence center, are based on two main researchers. The most prominent, with a more branched network, is Prof. Dr. Marta Margarete Cestari, from the UFPR (Federal University of Paraná) in the Genetics Department, followed by Prof. Dr. Marcelo de Bello Cioffi from the Department of Genetics and Evolution at the Federal University of São Carlos (UFSCar). Both researchers are Brazilian and from national universities but have a vast contribution from many foreign researchers and partners. In various science areas, but with convergence towards genetics and evolution (Figure 9).



**Figure 9.** Distribution and correlation between co-authors of the researched bibliographies for the *Hoplias* genus (Source: VOSviewer).

## DISCUSSION

The scientometric analysis of scientific production on *H. malabaricus* reveals a dynamic field of study that has shown significant growth over the past decade, reflecting the biological and ecological complexity of this species complex (Santos et al., 2020). It highlights various aspects of biology, from taxonomy and biogeography to dietary ecology, population genetics, physiology, and responses to environmental impacts (Locatelli et al., 2023). Each study has uniquely contributed to the understanding of this taxonomic group, showcasing both the diversity of methodological approaches and the range of research questions in the field (Brito-Santos et al., 2021).

It is fundamentally important to assess the main points presented, their implications, and the gaps identified in this research. This involves addressing various aspects, from the geographic distribution of scientific production to the analysis of key terms most highlighted in databases, emphasizing the predominance of taxonomic studies and, conversely, the less emphasis placed on biogeography, as well as exploring the temporal aspects of these publications and the contribution of key researchers to the field (Pereira et al., 2020).

Thus, the unequal distribution among Brazil, the United States, and other countries reveals disparities not only in research resources and funding but also in academic interests and scientific capabilities (Sacco et al.,

2024). Continental freshwater fishes are categorized as the most diverse vertebrates, surpassing those from marine environments (Anaisce et al., 2023). This suggests a need for more research on *H. malabaricus*, as it is considered a transnational species, given recent discoveries regarding its geographic distribution, which still covers most of the South American Shield (Lima et al., 2021).

On the other hand, even with the emphasis on taxonomic studies compared to other terms, these serve as a foundation for many other studies, such as physiology, ecology, and others, with biogeography also depending on these classificatory studies (Azra et al., 2022). While taxonomy is crucial for the accurate classification and identification of species, biogeographic studies are essential for understanding the species' geographic distribution and the factors influencing it (Segaran et al., 2023). Once again, suggesting that the lack of in-depth studies in this area does not limit possibilities; rather, it opens up imperative scientific exploration opportunities for this group (Kaur et al., 2023).

From another perspective, the temporal analysis of publications indicates a peak in studies, followed by a potential decrease in subsequent years, suggesting changes in research priorities, funding availability, or other factors influencing scientific interest in the species (Bandara et al., 2023). Nevertheless, this trend suggests the need for continuous incentives for research and investments in updated studies on *H. malabaricus*, as there are still many classificatory discrepancies and few current studies on this group, which occurs in almost all South American basins (Miroğlu et al., 2020).

Thus, some researchers outline that scientometric studies offer a comprehensive view of the research, highlighting both advancements and gaps in scientific knowledge (Chanikya et al., 2023). These advancements promote further studies, encourage collaboration among authors, and integrate multidisciplinary approaches that encompass both basic ecology and conservation challenges (Ravichandran et al., 2022).

## CONCLUSION

Based on these analyses, it was possible to highlight the great complexity and diversity of research involving *Hoplias malabaricus*, emphasizing that there is a predominant focus on taxonomy, but with a notable gap in specifically biogeographic studies. Thus, there is still an unequal distribution of scientific production among research groups, indicating that scientific centers in Brazil and the United States show greater academic interest in this taxonomic group. Although it is currently part of a large number of publications, its complexity and taxonomic impediments hinder some scientific progress. Therefore, these inferences allow for the identification of the need to expand studies on the biogeography of the group, which is widely distributed in South and Central America but still poorly understood in terms of effective taxonomic classification. Despite the abundance of studies focused on taxonomy, a significant gap remains in the biological classification of the components of the *H. malabaricus* taxonomic group. Therefore, this study contributes not only to fundamental knowledge about the diversity and distribution of studies on this fish but also to guiding future research that could fill these gaps and provide a more robust basis for its conservation and management.

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