Topics of limnological research in Mexico

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This book is dedicated to
Dr. Singaraju Sri Subrahmanya Sarma,
in gratitude for all his teachings in the world of limnology.

Index

Exploring Zooplankton-Macrophytes Interaction Research in Mexico: Bibliometric Analysis

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Abstract

This study conducted a bibliometric review of the Mexican scientific literature on the interactions between macrophytes and zooplankton. The findings suggest that comprehending the role and dynamics of each group is crucial for understanding the overall function of water bodies. Given the richness and distribution of both groups of organisms, Mexico presents a potential for further exploration of fundamental research questions and applications in ecology. The study highlights the need for more research on the impact of macrophyte removal on zooplankton communities, the role of macrophytes in mitigating anthropogenic stressors, the description of food webs, and different ecological interactions including allelopathy between primary and second producers. This work delves into discussing effective strategies for selecting editorial content and fostering collaborative efforts across different topics, all while considering the bibliometric results.

Keywords

Aquatic plants, rotifer, cladocerans, bibliometric analysis, citation.

Introduction

Importance of Zooplankton

Epicontinental aquatic systems such as lakes, reservoirs, and rivers harbor a vast array of biological diversity (Moss, 2018). An essential biological component of freshwater ecosystems is zooplankton which is of utmost importance as it serves as a building block for the sustenance of various trophic levels (Pace & Orcutt, 1981; Sommer, 2012; Kuczyńska-Kippen & Joniak, 2015). Zooplankton is a group of microscopic aquatic animals composed of invertebrates and heterotrophic (consumers) organisms, among which the following stand out for their frequency, species diversity, and biomass: rotifers, cladocerans, and copepods, among other groups such as protozoa and ostracods (Canfield & Jones, 1996; Sommer, 2012; García-Chicote et al., 2018). A great diversity of zooplankton species is recognized, including 850 species of cladocerans, 2,000 rotifers, and 2,800 freshwater copepod species (Boxshall & Defaye, 2007; Wallace et al. 2019).

Rotifers, together with microcrustaceans such as cladocerans and copepods, with sizes from 200 to 6,000 µm, have different feeding habits, most of them are consumers of algae, bacteria, and detritus; however, it is possible to find predators in these groups (Dumont & Negrea, 2002). These organisms have a central position in the aquatic trophic food web as primary consumers and, in addition, as a food resource for secondary consumers. Hence, they actively participate in various biotic interactions, which is why they have a great diversity of adaptations for optimal grazing (Lampert, 1997), predation avoidance, and intra and interspecific competition (DeMott, 1989; Diel et al., 2020); this has allowed the development of several areas of basic and applied research. Cladocerans, for example, have been used as an algal control tool to restore aquatic systems, mainly in temperate regions (Peretyatko et al., 2009). On the other hand, cladocerans and copepods have been used for live feed production in aquaculture (Piasecki et al., 2004; Pearson & Duggan, 2018).

Zooplankton has generated significant interest in scientific research, mainly in their use as indicators of water health status (Jeppesen et al., 2011; Chandel et al., 2023), this is due to their high sensitivity to natural and anthropogenic environmental changes and perturbations reflected in changes in their specific richness, densities, life history traits, and even morphological effects (Sarma & Nandini, 2006; Alvarado-Flores et al., 2022). Ecological indicators provide information for biodiversity conservation as well as to ensure the sustainable use of resources and ecosystem services associated with these systems (Jeppesen et al., 2011; Berta et al., 2018). Likewise, the sensitivity and short life cycles of zooplankton have led some rotifers and cladocerans species to be the focus of both descriptive and experimental ecotoxicological studies in the field (Peither et al., 1996; Friberg-Jensen et al., 2003) and laboratory (Rico-Martínez et al., 2016; Pérez-Morales et al., 2020; Guo et al., 2023).

In aquatic systems, zooplankton are widely distributed in the littoral, pelagic, and benthic zones (Wallace et al., 2019). However, it is possible to find a more significant number of species in the littoral zone, where the presence of macrophytes considerably plays an important role in mediating food web dynamics (Perrow et al., 1999; Duggan et al., 2001; Geraldes, 2004).

Importance of Aquatic Plants

The Neotropics are the regions with the most remarkable diversity of aquatic macrophytes (Murphy et al., 2019). Different types of macrophytes, such as submerged, floating, and emergent macrophytes, play an important ecological role associated with the physical, chemical, and biological characteristics of the water. Macrophyte-zooplankton interactions have been shown to be fundamental to the structure of aquatic communities as they influence higher trophic levels, which in turn are closely related to water quality (Perrow et al., 1999; Declerck et al., 2011).

Furthermore, they play an important role in cycling nutrients, providing habitats, purifying water, controlling diseases, and preserving cultural services (Thomaz, 2021). Applied approaches include controlling eutrophication caused by excessive loading of nutrients (Phosphorus and Nitrogen), the remotion of contaminants, and as food source for humans and livestock (Jeppesen et al., 2012; Singh et al., 2023). On the other hand, macrophytes could be of economic importance in cases such as species invasion, affecting navigation and excessive evapotranspiration, for example water hyacinth (*Eichhornia crassipes*) (Lugo et al., 1998).

Macrophyte diversity impacts invertebrate density and diversity, especially when considering plant structure. Morphologically complex macrophytes significantly affect animal populations and communities, for instance, in temperate zones, it has been observed that richer communities of larger-bodied organisms with higher densities of plant-associated cladocerans are present. In contrast, smaller-bodied zooplankton are typically found in subtropical water bodies (Merhoof et al., 2007; Thomaz & Cunha, 2010). The presence of macrophytes creates a rich substrate and abundant physical area through their leaves and roots, resulting in an increase of epiphytic algae and organic matter. This, in turn, attracts invertebrates for grazing and predators, leading to a higher diversity and abundance of animals in littoral zones (Dibble et al., 1996; Taniguchi et al., 2003).

In order to conserve biodiversity, it is essential to explore biological invasions. There is a global dispersion and introduction of macrophytes mainly for ornamental purposes (Lobato-de Magalhães et al., 2022; Bora & Padial, 2023). In certain ecosystems, invasive aquatic macrophytes have the ability to modify the complexity of habitats, which can lead to a reduction in water quality and availability (Thomaz & Cunha, 2010). This highlights the importance of monitoring and managing invasive species to prevent them from negatively impacting aquatic ecosystems. Mexico is no exception and the problem is that, for example, the water hyacinth has been affecting a large number of aquatic ecosystems, as well as 10 other species throughout the country, although there are few studies that investigate, in depth, its effect on the ecological dynamics between species, the availability and use of water, as well as solutions and alternatives for the restoration, management, and conservation of these systems (Gutiérrez et al., 1996; Lugo et al., 1998; Martínez-Jiménez & Balandra, 2022).

Interaction Between Macrophytes and Zooplankton

It is common practice to use macrophytes and invertebrates as bio-indicators of water quality due to the varying sensitivity of these organisms to pollution in their environments (Habib & Yousuf, 2014). The interaction between these two groups is crucial for several reasons. Macrophytes serve as a source of carbon and other nutrients that are taken up by heterotrophic bacteria, which in turn are consumed by the various zooplankton groups (Szabó-Tugyi & Tóth, 2020). This indirect source of food for zooplankton can be tapped during plant growth and even during their decomposition (Habib & Yousuf, 2014). In addition, the surface of macrophytes is exploited by periphyton for growth, which constitutes a food source for some members of zooplankton (Rautino & Warwick 2006).

The role of macrophytes in providing protection against predation for zooplankton has been questioned, as they seem to offer greater protection in temperate zones compared to tropical regions. In tropical areas, factors such as depth and behaviors like vertical or horizontal migration contribute to zooplankton survival. However, while it has been observed that zooplankton evade macrophytes, it has also been noted that macrophytes can serve as a habitat or refuge for cladocerans (Stansfield et al., 1997; Perrow et al., 1999; Montiel-Martínez et al., 2015; Arcifa et al., 2016). Moreover, macrophytes can influence the functional group richness and diversity of the invertebrate community, which in turn affects the abundance and distribution of zooplankton (Su et al., 2021; Wang et al., 2023). Some of the findings reveal an interesting chemical interaction in the food chain, macrophytes infochemicals trigger changes in demography growth of both phytoplankton and zooplankton; this can have a positive or negative effect depending on the species of macrophyte, finding species of rotifers, and cladocerans that grow particularly due to the presence of these (Duggan et al. 2001; Kuczyńska-Kippen & Nagengast, 2006; Espinosa-Rodríguez et al., 2016), however, is not clear and is missing empirical and experimental data for a better understanding.

The interaction between macrophytes and zooplankton is crucial for maintaining aquatic ecosystem balance and functioning, as it affects nutrient cycling, energy transfer, and overall ecosystem health (Mulderij et al., 2007). By conducting a bibliometric analysis based on the search of Mexican literature, this study aimed to describe the publication trends on the scientific research in recent years, as recorded in indexed journal databases. This analysis allowed us to identify the journals with the highest publication frequency, the leading institutions, and the primary topic addressed. Additionally, it highlights the most cited works, thematic trends, and reference patterns in the publications, along with the collaboration networks among authors. These findings, along with a discussion on the concepts, their importance, and the understanding of the macrophyte-zooplankton interactions, will be elaborated upon of this work.

Bibliometric Analysis

The study relied on bibliometric techniques to analyze the scientific output data obtained from the core collection of Web of Science© (WoS). The search method involved the utilization of the following keywords: “macrophyte* OR aquatic plant*”, which were subsequently refined by the term “zooplankton” and sorted by country (Mexico). This initial set of results was then subjected to a second logical operation, which was then applied using “zooplankton” filtered by “macrophyte* OR aquatic plant*”, followed by a final filter for the country. The results were from 1997 to 2023. The data from the documents obtained were exported as follows: the export selection was selected in the main WoS web page, then *Tab delimited file* was chosen, an emergent window asks for the records selection and it was marked *Full Record and Cited References* which includes the metadata of each document, finally, the text file was analyzed on R-language software using the Bibliometrix package (Aria & Cuccurullo, 2017). The package incorporates an interactive web interface (Biblioshiny) that permits an automatization of analysis, this involved the extraction and analysis of quantitative data related to the frequency and the impact of scientific publications. A three-field plot, including keywords, affiliation and source (journal) was obtained; a list of the most cited articles; a list of the topic tendencies during the last years; an occurrence network for dominant topics, and a network of collaboration within this two fields of study. A limitation of this package is the use of indexed databases, so those articles published under a different index database are omitted, and both the results and conclusions will be limited.

Discussion

In the period from 1997 to 2023 (26 years), a set of 30 documents were compiled. According to the bibliometric analysis (Table 1), there was no annual growth rate (0 %) in the topics related to macrophytes and zooplankton interactions. However, an average of approximately 10 citations per document was found, which could benefit the academic community in the dissemination of knowledge, for example, articles such as van Donk and van de Bund (2002), from 2002 to 2024 have a total of 435 citations, this article contributes to the impact of macrophytes on the plankton food web, showing a considerable gap in the scientific production and its impact worldwide. There has been a discussion (Leimu & Koricheva, 2005) on how different factors, such as the researcher's age, gender, the country where the research was conducted, the type and length of the article, the methodological strategies used, and the hypotheses proposed, can impact the citations of articles in the field of ecology.

Table 1. Main Information Data of Literature for Bibliometric Analysis.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1997:2023
Documents	30
Annual Growth Rate %	0
Document Average Age	8.17
Average Citations per Doc	10.23
References	1453
DOCUMENT CONTENTS	
Keywords Plus (ID)	173
Author's Keywords (DE)	125
AUTHORS	
Authors	77
Authors of Single-authored Docs	0
AUTHORS COLLABORATION	
Co-Authors per Doc	3.73
International Co-authorships %	20
DOCUMENT TYPES	
Article	26
Article; Proceedings Paper	3
Review	1

In the three-dimensional analysis of the interrelationships between the keywords of scientific articles, university affiliations, and publication journals (Fig. 1), the central role of the National Autonomous University of Mexico (UNAM) stands out. Currently, UNAM is recognized as a foremost actor in scientific research, covering a variety of research topics and consolidating its role as a leader in the generation of scientific knowledge, followed by the National Polytechnic Institute (IPN). These and other institutions contribute to knowledge on topics of interest in the present work. Although Mexico has about 20,825 km^2 of hydrophytic cover including coastal systems, the information generated is still limited (Palacio-Prieto et al., 2000). Similarly, the diversity of zooplankton is high, and there is still a tendency to increase the study of zooplankton in freshwater systems of Mexico (Elías-Gutiérrez et al., 1997; Gómez & Morales-Serna, 2014; Sarma et al., 2021). This is why academics, researchers, and their students could utilize these topics in their future research projects and, as a consequence, publish information on them. Aside from the above, the information generated would also provide insight into problems arising from anthropogenic activities, such as the increase in eutrophication, xenobiotic contamination, and plant invasion, topics of great interest nowadays.

Regarding the diffusion of research publications, it is noteworthy that the academic journal Hydrobiologia (Impact Factor=2.6, Q1) has indicated a significant preference, followed by Allelopathy Journal (Impact Factor=0.96, Q3), and Ecohydrology & Hydrobiology (Impact Factor=2.6, Q2) in terms of publishing (Fig. 1). These results indicate the relevance of the journals as platforms for the publication of studies related to the topics of zooplankton and macrophytes suitable for members of the National System of Researchers of CONAHCYT who have the challenge of publishing their research (Silva Payró et al., 2016; Díaz-Martínez, 2020). This finding highlights the significant relevance of carefully selecting journals for disseminating scientific knowledge in the Mexican context. Each of these journals addresses diverse themes, which allows for a detailed understanding of the different fields of study that receive particular attention. These results contribute substantially to the understanding of the editorial dynamics in scientific research in Mexico and highlight the strategic importance of editorial decisions in the process of knowledge dissemination on topics of interest.

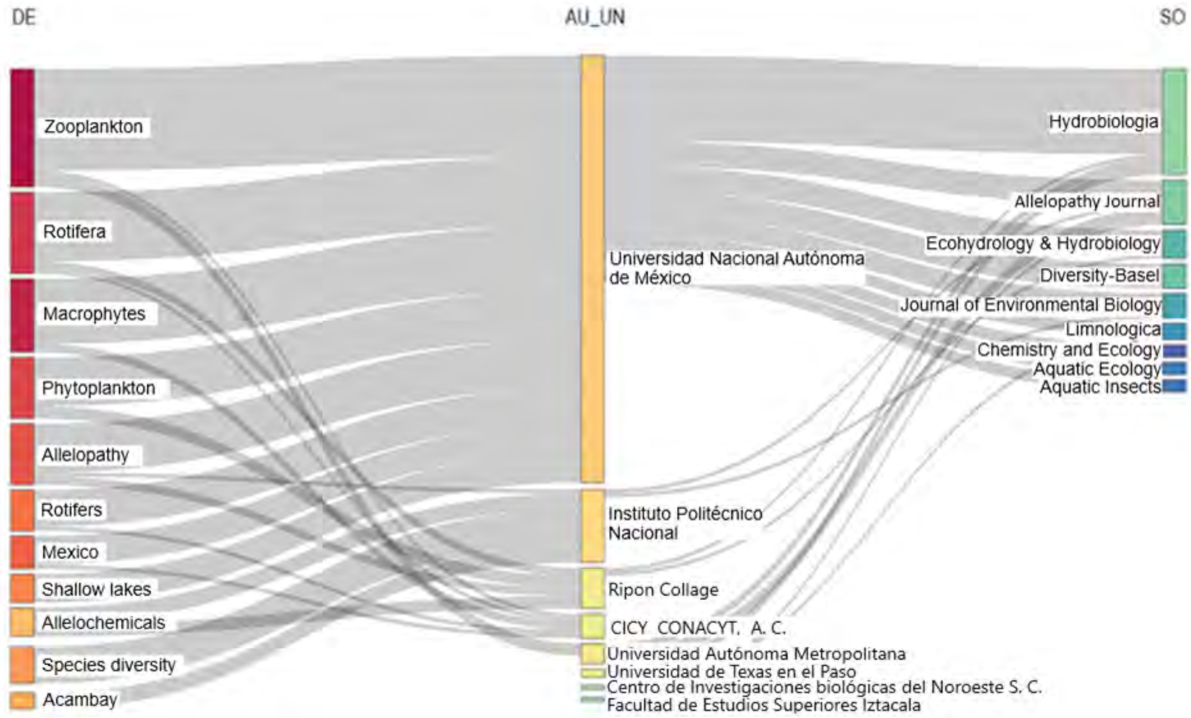

Figure 1. 3-field Graph, Showing the Interactions between DE: Keywords, AU_UN: Affiliation, SO: Source (Journal), Data from the Literature Indexed in WoS Related to Macrophytes and Zooplankton in Mexico.

A classification of the most cited scientific articles in the bibliometric analysis (Fig. 2) indicates that in 10 articles, the number of citations varies from 12 to 43 in accordance with WoS, reflecting the breadth and relevance of the Mexican contribution to the global scientific community, for example in a study related to citation of marine and freshwater articles and average of citation of 19.4 in a range of 1 to 373 (Nash et al., 2017) was found. Mexican literature has made significant contributions in several areas, involving field and laboratory research. Studies have been carried out on the taxonomic description of species using traditional approaches (Elías-Gutiérrez et al., 1997). The use of isotopes has been added, for the study of biotic communities and their interaction with abiotic factors related to water quality (Zambrano et al., 2010; Muñoz-Colmenares et al., 2017). Research has been conducted on allochthonous fish and macrophyte species (Rocha-Ramírez et al., 2006). The potential impact of heavy metals on aquatic ecosystems can occur through several pathways, including the uptake of these metals by macrophytes. This may lead to their consumption by other aquatic organisms and aggravate the adverse effects of heavy metals on the ecosystem (De La Vega Salazar et al., 1997). Certain research gaps exist in the intriguing topic of fish-zooplankton predation mediated by macrophytes. Nonetheless, recent studies have addressed these gaps, revealing that free-floating macrophytes, such as water hyacinth, can serve as habitats for *Chydorus brevilabris* or refuges for *Simocephalus vetulus* (Montiel-Martínez et al., 2015).

It is worth noting that recent research has demonstrated the significant contribution of macrophytes to the diversity of invertebrates in aquatic ecosystems. In comparison to open water areas, macrophytes have been found to foster a greater taxonomical and functional diversity of invertebrates (Enríquez-García et al., 2009; González-Gutiérrez et al., 2016; Jiménez-Santos et al., 2019; Espinosa-Rodríguez et al., 2021). These findings highlight the importance of macrophytes in promoting biodiversity and the need to consider their presence when assessing the health and ecological dynamics of aquatic environments.

Despite being a common practice in lake management in Europe and North America, the impact of the introduction and even removal of macrophytes on the taxonomic and functional groups of zooplankton has been little studied in Mexico. Recent research has shown that macrophyte removal has a significant influence on organisms over time, highlighting the need to better understand its effects (Espinosa-Rodríguez et al., 2021). The allelopathic effects of macrophytes in primary producers and their consumers is a topic that has been gaining attention currently. These effects can range from stimulating growth in *Simocephalus* spp. to interrupting growth in phytoplankton (*Scenedesmus acutus*) through interaction with *Egeria densa* (Espinosa-Rodríguez et al., 2016). The aforementioned contributions have provided valuable insights on diverse subjects, contributing significantly to the expansion of our knowledge at a regional as well as a global level.

Figure 2. Documents with the Highest Number of Citations in the Area of Macrophytes and Zooplankton.

Figure 3 represents the Trend Topics through time and their temporal changes, 15 keywords with a high frequency of use and interest, mainly between 2010 and 2022. It is evident that certain topics were the subject of a more frequent study between 2010 and 2016 (“abundances” and “fish”), indicating a notable interest during that interval (articles from those years and the topics they address). Other topics, for their part, show an increase in their frequency of study between 2016 and 2018, suggesting a change in focus in research and an increase in the study and interest in the main topics of zooplankton and macrophytes (“*Daphnia*”, “submerged macrophytes”, “trophic state”). Additionally, a set of topics is identified that attracted notable attention between 2018 and 2022 (“diversity”, “population growth”, “zooplankton”, “communities”), showing the progress in research where the interest in understanding natural phenomena passes through autoecology to the ecology of communities, suggesting interest in a holistic approach, not just a descriptive one. This temporal representation offers insight into research trends and changing focus on different topics across these observed periods.

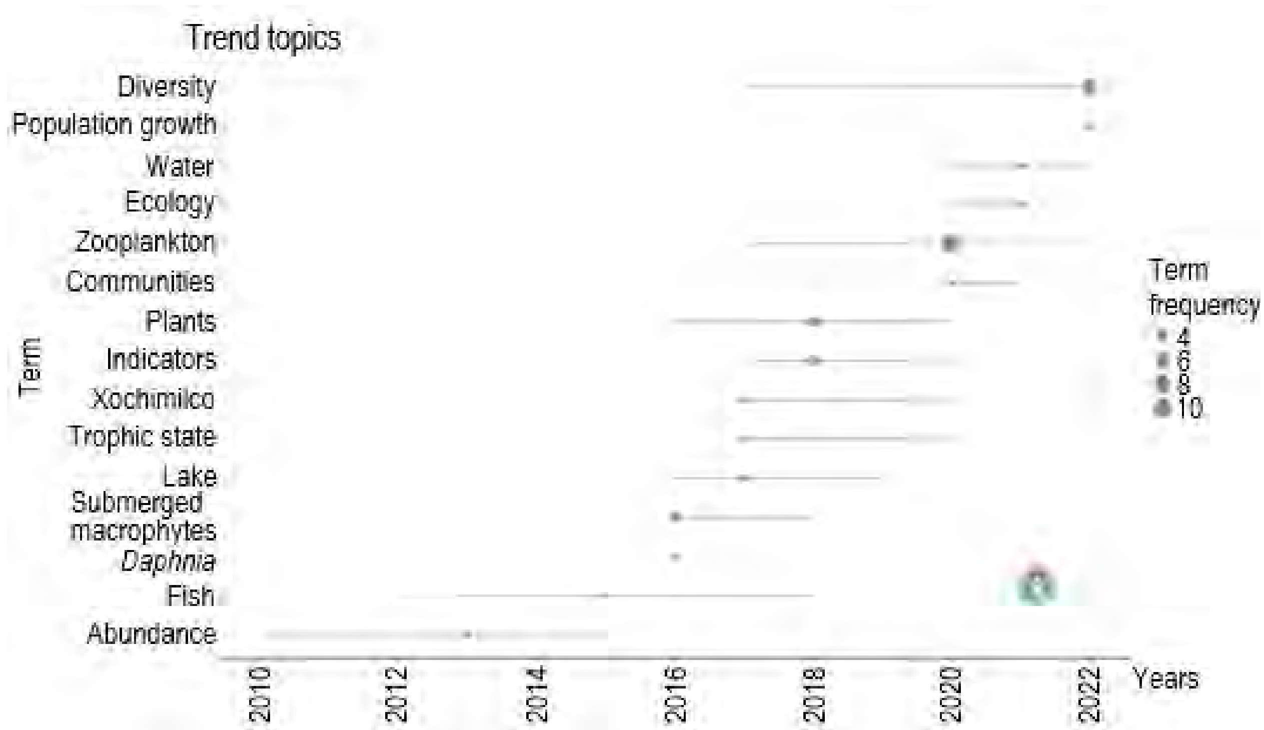

Figure 3. Topics and Their Trend in Relation to Publications Made in Mexico, Considering the Plus Keywords Provided in WoS Database.

The co-occurrence network analysis of the primary themes in Mexican literature related to zooplankton and macrophytes has revealed five distinct thematic groups (Fig. 4). The first group primarily focuses on zooplankton as a central theme. The second group highlights the interaction between fish and zooplankton evasion as relevant subtopics. In the third group, researchers address water diversity and quality, along with bioindicators, highlighting the link between these research areas. The fourth group mainly represents the predator-prey relationship in rotifers. Finally, the fifth group emphasizes the study of macrophyte coverage and geographic information systems, which is inclined towards technological approaches and integrated ecology. These findings provide a comprehensive understanding of the thematic interconnection in scientific research in conjunction with the above results, offering specific insights into biological dynamics in the aquatic environment.

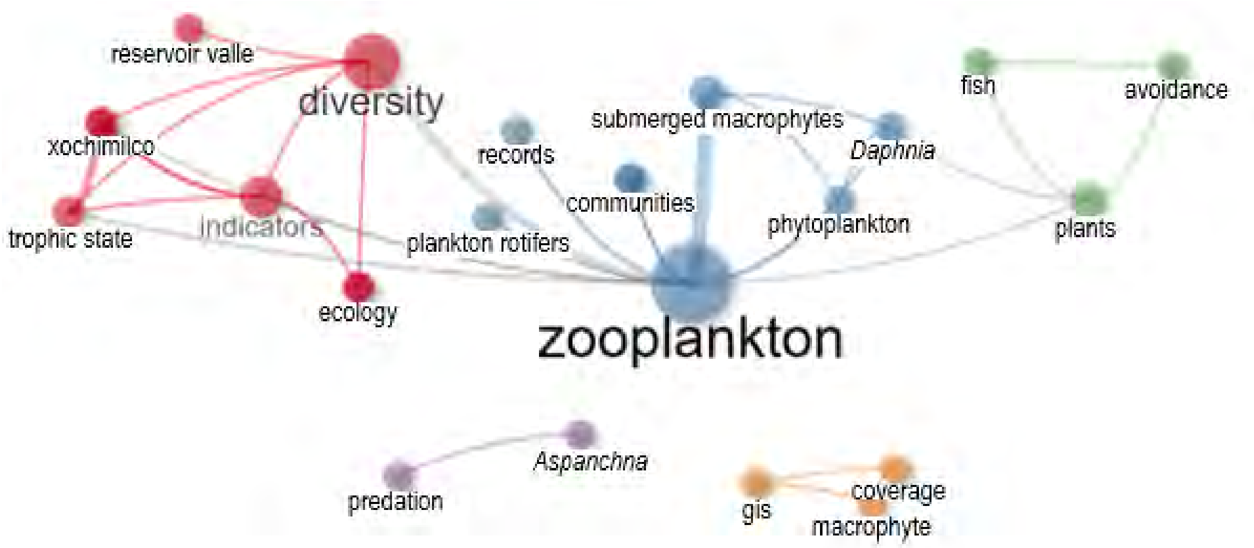

Figure 4. Network of Co-occurrence between the Dominant Themes of Focus in the Literature of Mexico.

The research on zooplankton and macrophytes in Mexican scientific literature shows a positive environment for collaboration, as evidenced by an average of 3.73 co-authors per document and 20 % of collaborations involving international co-authors (Table 1, Fig. 5). The collaboration network analysis reveals the presence of isolated clusters that reflect specialized scientific communities, varying in size from binary collaborations to groups with up to fifteen participants. Collaboration is crucial in scientific work, as well as in freshwater ecology, as it facilitates the convergence of diverse perspectives and skills, leading to the advancement of knowledge (Cullen et al., 1999). Identifying key actors and research producers in these groups enhances collaboration opportunities and promotes valuable synergy that contributes to the continuous progress of the scientific field. Collaboration among researchers establishes a breeding ground for exchange of ideas, access to funding, learning new skills, this promotes quality of results, which would be of great importance for this particular field of research conducted (Bansal et al. 2019).

Figure 5. Network Analysis of the Studies Distribution According to Authors in Mexican Literature in the Area of Macrophytes and Zooplankton.

Conclusion

This bibliometric work focused on the description of the ecological importance and scientific productivity related to the interaction of zooplankton and aquatic plants in Mexico, showing slow progress with limited diffusion of publication through the last decades with a limited finding due to indexation of articles. We found a current interest in research going from the autoecology and description approach to understanding the ecological interaction mechanisms at a community level in remarkable topics of diversity, water quality, predation, food webs, seasonal variation, allelopathy, and ecotoxicology with some opportunities in remote sensing, genomics, biogeochemical, climate change, biomanipulation, and conservation as challenges for future studies. The interaction between macrophytes and zooplankton has been observed to yield interesting and noteworthy phenomena. However, the current state of research and publication in this area needs collaborative and participative initiatives that can provide funding support. Such efforts will facilitate knowledge development, as well as the restoration and conservation of natural habitats. By enhancing our understanding of this phenomenon, we can better protect and conserve the environment.

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Authors' Contributions

JSMA conceptualization; JSMA drafting the initial manuscript; JSMA and FSMA methodology and data research; JSMA and FSMA data interpretation; JSMA and FSMA writing and editing the final manuscript.

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This book takes a significant step in showcasing the relevance of limnology to our survival. Freshwater habitats, though they cover less than 1 % of the Earth's surface, are home to a substantial portion of the world's biodiversity—at least 10 % of all known species. Freshwater habitats and the biodiversity they support are under threat. Moreover, our survival depends on access to high-quality freshwater. This book not only highlights the beauty of limnology and the scientific methods used to study it, but it also draws attention to the major causes of biodiversity loss in freshwater ecosystems. It shows all readers what it means to deal with inland waters as a scientist interested in understanding ecosystems and protecting them.

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