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Bibliometric Trends in Diatom Research: Emphasis on Lakes and Oxbow Lakes Ecosystems

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Abstract: Diatoms are unicellular microalgae that play a critical role as bioindicators of freshwater environmental conditions. This paper delivers a literature review and bibliometric analysis of diatom composition and distribution in lakes, with a particular focus on oxbow lakes. We compiled bibliometric data from Scopus and analyzed them using R with the Bibliometrix package to characterize publication trends, thematic emphases, and scholarly influence. The analysis reveals a persistent growth in diatom-related research over the last two decades, driven by themes such as climate change, habitat degradation, and environmental monitoring. The Journal of Paleolimnology emerges as a leading venue, with its impact shaped by key contributors who have significantly advanced publication volume and scientific influence in the field. Despite the ecological importance of oxbow lakes, their representation in the diatom literature remains limited, suggesting notable gaps and opportunities for future investigation. The findings underscore the value of interdisciplinary approaches to advance understanding and inform the conservation and sustainable management of freshwater ecosystems.

Keywords: Diatom, Bioindicator, Oxbow Lake, Bibliometric, Climate Change

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1. Introduction

Diatoms are a category of microalgae characterized by varied silica compositions that significantly contribute to aquatic ecosystems and have been extensively employed as bioindicators for evaluating water quality and conducting environmental monitoring. Diatom ecological sensitivity, swift reactions to environmental alterations, and considerable species variety render them exceptionally suitable for comprehending historical and contemporary ecosystem dynamics (Smol &

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Stoermer, 2010). Despite significant advancements in global research on diatom applications, a thorough bibliometric analysis of diatom studies, particularly in distinctive aquatic systems such as oxbow lakes, remains scarce, particularly concerning freshwater ecosystems in Indonesia.

Oxbow lakes are U-shaped lentic water bodies formed when a meandering river becomes separated from its main channel through natural processes or anthropogenic activities (Delhomme et al., 2013; Saha et al., 2022). These lakes play a significant role in regulating alluvial processes within flood plains (Constantine et al., 2010). Due to their distinct hydrological characteristics, oxbow lakes are dynamic, biologically diverse, yet highly fragile ecosystems. In addition to supporting diverse micro-floral and faunal communities in river basins and major fluvial systems, these lake types also serve as vital habitats for feeding, breeding, and providing refuge during extreme flood events, emphasizing their importance for conservation (Dembowska & Kubiak-Wojcicka, 2017; Naus & Reid Adams, 2018).

The present study applies Bibliometric, an R-based package for comprehensive bibliometric analysis, to delineate and evaluate global and national trends in diatom research, with a particular emphasis on its application in oxbow lakes. Bibliometric analysis is crucial for developing a comprehensive understanding of the current state and future directions of research within a specific scientific field (Khudzari et al., 2018). This study enables the application of diverse mathematical, statistical, and graphical techniques to scrutinize scholarly papers comprehensively (Han et al., 2020). Through this approach, we can examine research trends, the contributions of countries, journals, and institutions, as well as the flow of scientific knowledge within a specific topic area (Bezak et al., 2021; Ubando et al., 2021). Furthermore, co-occurrence analysis of keywords enables the identification of historical trends, contemporary themes, and emerging research frontiers (Ilmasari et al., 2022).

Previous studies have applied bibliometric approaches to diatom-related topics in various scientific contexts. For instance, Sahabudin et al. (2024) conducted a bibliometric analysis of diatoms to elucidate research trends related to fatty acids and their potential for biofuel production. Wu et al. (2024) employed bibliometric network analysis to gain insights into research modelling in the aquatic domain from 1962 to 2022. Falah et al. (2024) explored the potential of environmental DNA using a paleolimnological technique via bibliometric mapping.

The primary objective of this study is to identify and analyze current research patterns, future trends, and potential research gaps in diatom studies, specifically those focused on biomonitoring in lake ecosystems. The search process transitioned from general exploration to a more specific investigation of research topics. Oxbow Lake was not a popular research theme, with diatoms as the primary topic; we compared "lake" and "oxbow lake" to analyze the opportunities and threats for improving this research. Consequently, the relevant keywords for each topic were incorporated into the search string. We also analyzed the methodological and contextual challenges of studying oxbow lakes via diatoms, highlighting the emerging opportunities for interdisciplinary research and community engagement.

2. Materials and Methods

2.1. Data Collection

Bibliometric data were collected from the Scopus database on April 22, 2025. Scopus was selected as the data source to achieve the study's objective due to its extensive coverage and analytical capabilities. The Scopus database also integrates all MEDLINE journals and supports detailed citation analysis, enabling accurate mapping of scholarly influence and collaboration networks (Falagas et al., 2008; Kulkarni et al., 2009). Moreover, Scopus provides multiple operational features that facilitate bibliometric evaluations, including metadata on journal titles, document types, publication years, authors and affiliations, citation counts, and h-index metrics (Hirsch, 2005; Agarwal et al., 2016). These functions make Scopus particularly suitable for conducting comprehensive and reproducible bibliometric studies.

This study's central focus is research articles concerning diatoms as bioindicators in lake ecosystems. A comprehensive bibliometric analysis was performed using bibliographic

data related to diatom research retrieved from the Scopus database. The search strategy compared the keywords "diatom" AND "lake" AND "bioindicator" AND "climate change" for the years 2000 to 2025 with the keywords "diatom" AND "oxbow lake" AND "bioindicator" AND "climate change" from 2001 to 2021. Only peer-reviewed journal articles, conference papers, and English-language review articles were included. The data were exported in BibTeX format, compatible with Bibliometrix, an R package for bibliometric analysis (Aria & Cuccurullo, 2017). The search for the "diatom" AND "lake" AND "bioindicator" AND "climate change" keyword yielded 36 articles, while the "diatom" AND "oxbow lake" AND "bioindicator" AND "climate change" keyword produced 24 articles. However, when additional fields were included in the search scope, the results for "oxbow lake" decreased to a single article, indicating that diatom research within oxbow lake ecosystems remains underrepresented in the scientific literature.

2.2. Data Analysis

The data processing and analysis were conducted using RStudio v2024.12.1+563. The bibliometric analysis was performed using the bibliometrix package in R. The installation process began by typing "install.packages('bibliometrix')" in the console tab to install the bibliometric package. During the installation, a CRAN mirror was selected to ensure a stable and secure connection for downloading. In this study, the CRAN mirror "Indonesia (Banda Aceh) [https]" was chosen because it provided a reliable and regionally optimized source. After the installation was completed, the package was loaded by typing "library(bibliometrix)" and press enter. Subsequently, the command "biblioshiny()" was executed in the console tab to launch biblioshiny, the web-based interface used for conducting the bibliometric analysis (Machmud et al., 2023).

3. Results and Discussion

3.1. Main Information

A bibliometric analysis of the composition and distribution of diatoms in lakes as freshwater bioindicators was conducted using a single screening. The initial literature screening used the keywords "diatom," "oxbow lake," "bioindicator," and "climate change" for 2001 to 2021 and identified 24 documents published across 19 sources. The annual growth rate of publications was 0% (stable output over the period). The documents have a mean age of 12.8 years and a mean of 23 citations per article (552 total), equivalent to about 1.8 citations per article per year. There are 364 Keywords Plus and 106 author-provided keywords, reflecting diverse research topics. In total, 96 authors contributed; only two documents were single-authored and an average of 4.25 co-authors per document, reflecting a collaborative research environment. International collaboration is evident in 20.83% of the publications. Most documents are journal articles (23), with only one conference paper (Table 1).

Table 1. Main Information using the keywords "diatom," "oxbow lake," "bioindicator," and "climate change".

Main Information About Data	
Timespan	2001 to 2021
Sources (Journal, Books, etc)	19
Documents	24
Annual Growth Rate %	0
Document Average Age	12.8
Average citations per doc	23
References	0
Document Contents	
Keywords Plus (ID)	364
Author's Keywords (DE)	106
Authors	
Authors	96
Authors of single-authored	2
Authors Collaboration	
Single-authored docs	2
Co-Authors per Doc	4.25
International co-authorship %	20.83
Document Types	
Article	23
Conference paper	1

A bibliometric analysis from 2000 to 2025 identified 36 documents published across 21 sources. The annual growth rate remains 0%, while the average document age is 9.03 years, reflecting more recent publications. The average citations per document is 19.39, slightly lower than the previous dataset.

Table 2. Main Information using the keywords "diatom," "lake," "bioindicator," and "climate change".

Main Information About Data	
Timespan	2000 to 2025
Sources (Journal, Books, etc)	21
Documents	36
Annual Growth Rate %	0
Document Average Age	9.03
Average citations per doc	19.39
References	0
Document Contents	
Keywords Plus (ID)	576
Author's Keywords (DE)	150
Authors	
Authors	175
Authors of single-authored	0
Authors Collaboration	
Single-authored	0
Co-Authors per Doc	5.11
International co-authorship %	44.44
Document Types	
Article	34
Conference paper	2

This dataset features 576 Keywords Plus terms and 150 author-provided keywords, indicating an even broader thematic scope. In total, 175 authors contributed, with no single-authored documents and an average of 5.11 co-authors per document, highlighting increased collaboration. International co-authorship rises to 44.44%, demonstrating stronger global research cooperation. The document types include 34 articles and 2 reviews, indicating a slight diversifying in publication formats (Table 2).

Overall, both tables illustrate the evolution of diatom research in lakes, with increasing collaboration, expanding thematic diversity, and a growing trend toward international partnerships in recent years. These patterns reflect the research's dynamic and interdisciplinary nature on diatoms as bioindicators in freshwater ecosystems.

3.2. Classification of Leading Journals, Authors, Affiliations, Countries, and Documents

3.2.1. Leading Journals

The analysis of most relevant sources reveals a substantial disparity in scholarly focus between lake and oxbow lake. Research on lake ecosystems is considerably more prevalent, with the Journal of Paleolimnology emerging as the dominant outlet publishing nine articles. Other articles with notable representation in lake studies include Holocene (three articles), and Water (Switzerland), Science of The Total Environment, Journal of Great Lakes Research and Water, Air, and Soil Pollution (two articles each). Meanwhile, research on diatoms in oxbow lake environments is significantly less represented. While the Journal of Paleolimnology still leads the oxbow lake category with four articles, other contributors like Hydrobiologia and Quaternary science reviews published only two articles. The remaining oxbow lake publications are scattered, often represented by only one article, highlighting the limited research output and fragmented scholarly attention dedicated to these unique aquatic ecosystems (Figure 1).

Source Local Impact (H-index) between studies on lake and Oxbow Lake revealing a distinct asymmetry in research visibility and influence. Journal of Paleolimnology shows the highest local impact across all sources with H-index of 9 for lake and 4 for oxbow lake. Other articles with moderate impact in lake studies include Holocene (H=3), Science of the total environment, water (Switzerland), Journal of Great Lakes Research, and Diatom Research (each with H = 2). In contrast, studies focusing on oxbow lake environments display lower and more fragmented research impact. The highest H-index for oxbow lake articles (H=4) is also attributed to the Journal of Paleolimnology, followed by Quaternary Science Reviews and Hydrobiologia (H=2). Most other sources, including Geomicrobiology Journal, Enviromental Science and Pollution Research, and Canadian water resources journal, record only minimal impact (H=1). This limited citation performance suggests that studies in oxbow lake ecosystems are still in their development stage, characterized by sparse publication frequency and lower research visibility (Figure 2).

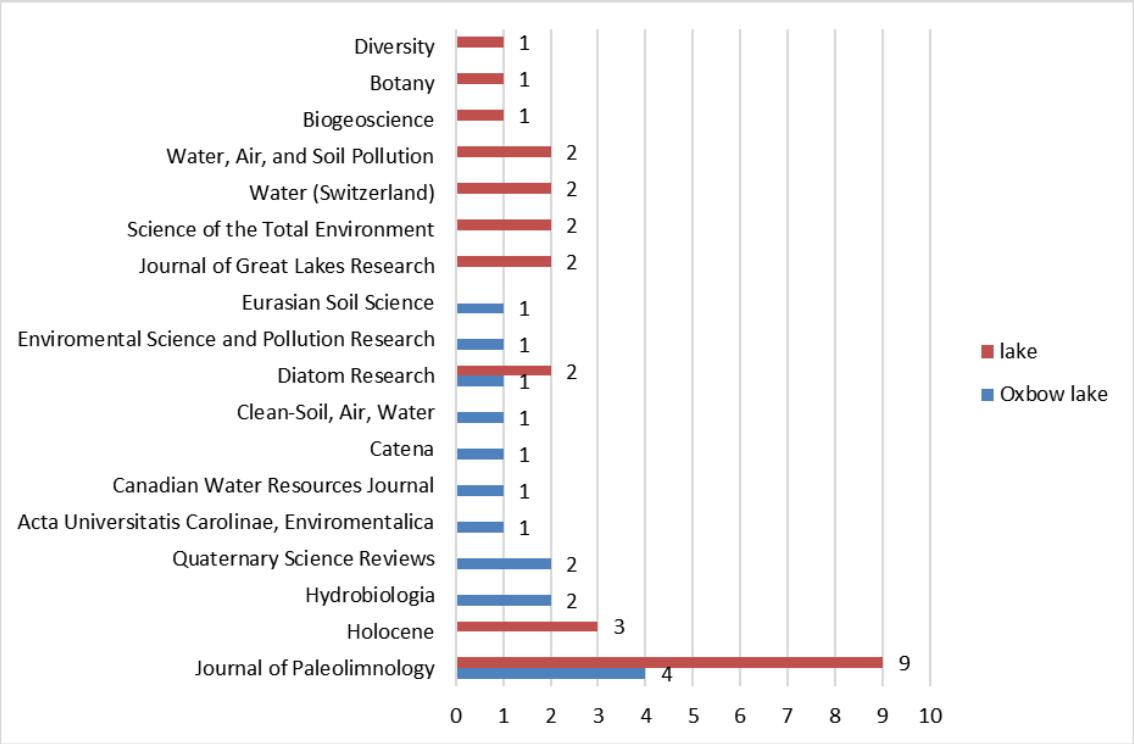

Figure 1. Most Relevant Sources between lake and oxbow lake

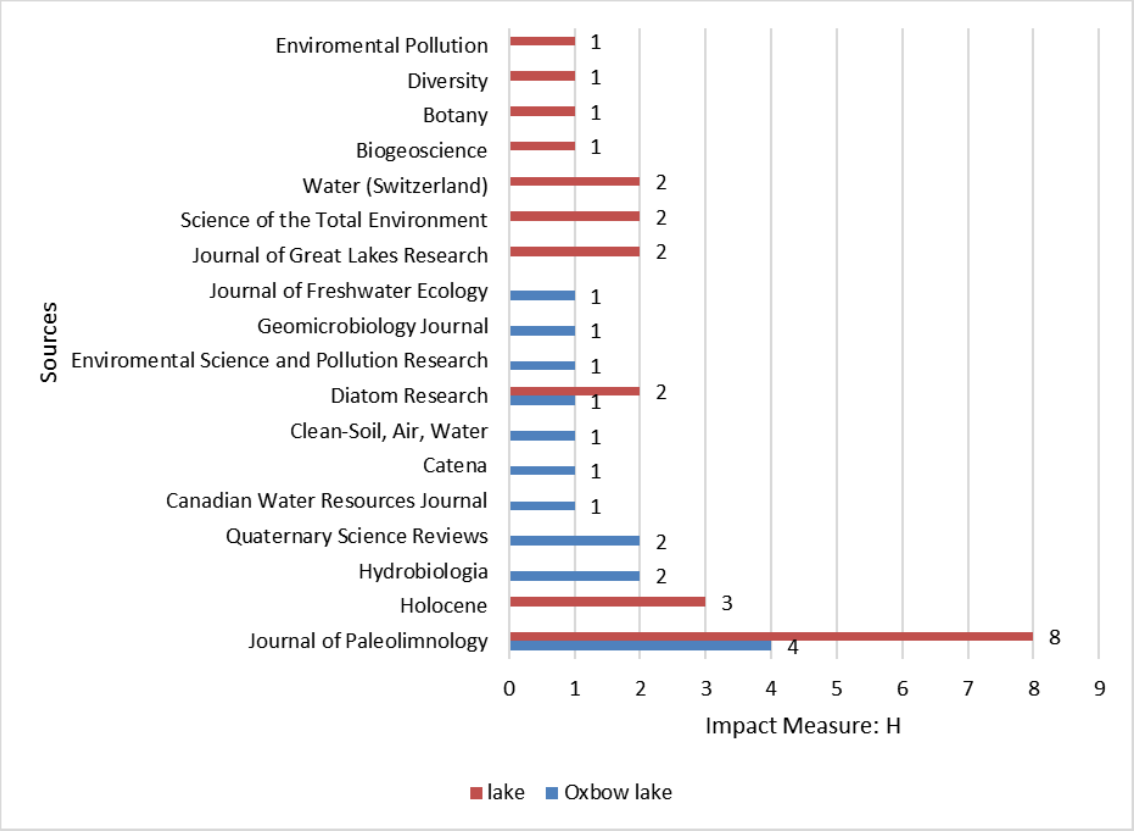

Figure 2. Source Local Impact between lake and oxbow lake

3.2.2. Authors

The production of articles on diatoms and oxbow lakes over time included 10 authors. Hall Roland I and Wolfe Brent B have a relatively higher number of publications than other authors, as indicated by the larger circle sizes around 2010. In addition, Dembowska Ewa A also demonstrated notable publication activity around 2018. Authors such as Espinosa Marcela A, Fayó Rocío, and Pan Jerónimo appear to have become active in publishing scientific works between 2018 and 2020, with relatively balanced productivity. Meanwhile, several other authors, including Abonyi András, Achimo Mussa, Afonso María dos Santos, and Armitage Derek, are recorded as having only one publication during earlier periods, approximately between 2004 and 2014, with lower citation counts (Table 3).

Table 3. Top Author Production Over Time for Diatom and Oxbow Lake

Author	Year	Freq	TC	TCpY
ABONYI A	2010	1	43	2.688
ACHIMO M	2015	1	27	2.455
AFONSO MDS	2004	1	54	2.455
ARMITAGE D	2010	1	16	1
DEMBOWSKA EA	2015	2	37	3.364
ESPINOSA MA	2018	1	18	2.25
ESPINOSA MA	2020	1	5	0.833
FAYÓ R	2018	1	18	2.25
FAYÓ R	2020	1	5	0.833
HALL RI	2010	2	65	4.063
PAN J	2018	1	18	2.25
PAN J	2020	1	5	0.833
WOLFE BB	2010	2	65	4.063

The results of the bibliometric analysis showed that the scientific production of authors focusing on the research theme of diatoms and lakes over time involved a total of 10 authors. As shown in Table 4, Reavie Euan D and Smol John P are two authors with more extended periods of productivity, each with more articles than others, as indicated by the larger circle sizes. Their publication activities were particularly significant from 2017 to 2020. Meanwhile, authors such as Barinova Sophia, Gabychev Viktor, and Genkal Sergey display more recent article production, specifically for 2023. Other authors like Wang Rong, Ahlborn Marieke, and Alexson Elizabeth E were also active during specific periods. However, the number of articles and citation levels they achieved were smaller compared to the two primary authors (Table 4).

Table 4. Top Author Production Over Time for Diatom and Lake

Author	Year	Freq	TC	TCpY
AHLBORN M	2021	1	4	0.800
ALEXSON EE	2018	1	5	0.625
BARINOVA S	2023	2	14	4.667
GABYSHEV V	2023	2	14	4.667
GENKAL S	2023	2	14	4.667
REAVIE ED	2018	3	32	4.000
SCHWALB A	2010	1	22	1.375
SCHWALB A	2021	1	4	0.800
SGRO GV	2018	2	27	3.375
SMOL JP	2017	1	20	2.222
SMOL JP	2021	2	24	4.800
SMOL JP	2024	1	0	0
WANG R	2011	1	36	2.400
WANG R	2019	1	35	5.000

Figures 3 presents the distribution of the most relevant authors contributing between lake and oxbow lake. In lake studies, Reavie Euan D and Smol John P emerge as the most prolific authors, each contributing three articles. In contrast, research on diatoms in oxbow lake demonstrates a more evenly distributed but comparatively lower level of author productivity. Authors such as Dembowska Ewa A, Espinosa Marcela A, Fayó Rocío, Hall Roland I, Pan Jerónimo, and Wolfe Brent B. Each authors contribute two articles, reflecting emerging but still limited scholarly engagement in this subfield. The absence of highly prolific authors and the presence of smaller publication counts suggest that oxbow lake studies are still developing as a distinct research niche, likely constrained by the limited availability of long-term datasets and region-specific investigations.

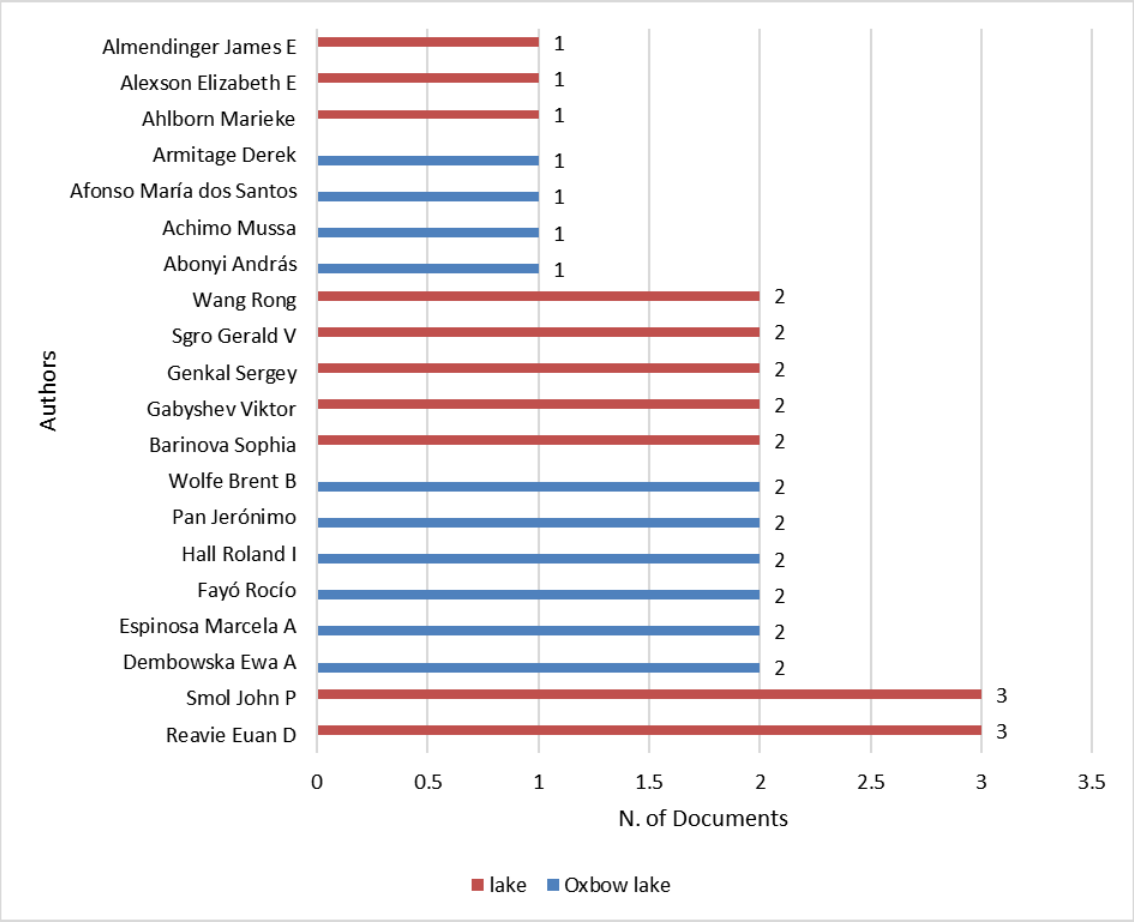

Figure 3. Most Relevant Authors between lake and oxbow lake

The results presented in Figure 4 indicate the local author impact (H-index) for researchers contributing to diatom studies in lake and oxbow lake ecosystems. The pattern reveals that lake exhibit a generally higher and more consistent impact compared to oxbow lake research. Reavie Euan D and Smol John P emerge as the most nfluential authors, both with an H-indeks of 3. Their sustained scholarly visibility reflects not only high publication productivity (as shown in Figure 4) but also strong citation performance, indicating that their works serve as key references in lacustrine diatom research. Several other authors like Barinova Sophia, Gabyshev Viktor, Genkal Sergey, Sgro Gerald V, and Wang Rong maintain moderate influence (H=2), suggesting active participation and recognition within the scientific cimmunity studying lake diatoms. The author impact for oxbow lake studies appears more evenly distributed but lower in magnitude. Dembowska Ewa A, Espinosa Marcela A, Fayó Rocío, Hall Roland I, Pan Jerónimo, and Wolfe Brent B record an H-index of 2, indicating moderate local recognition but limited citations accumulation compared to their counterparts working on lake systems (Figure 4).

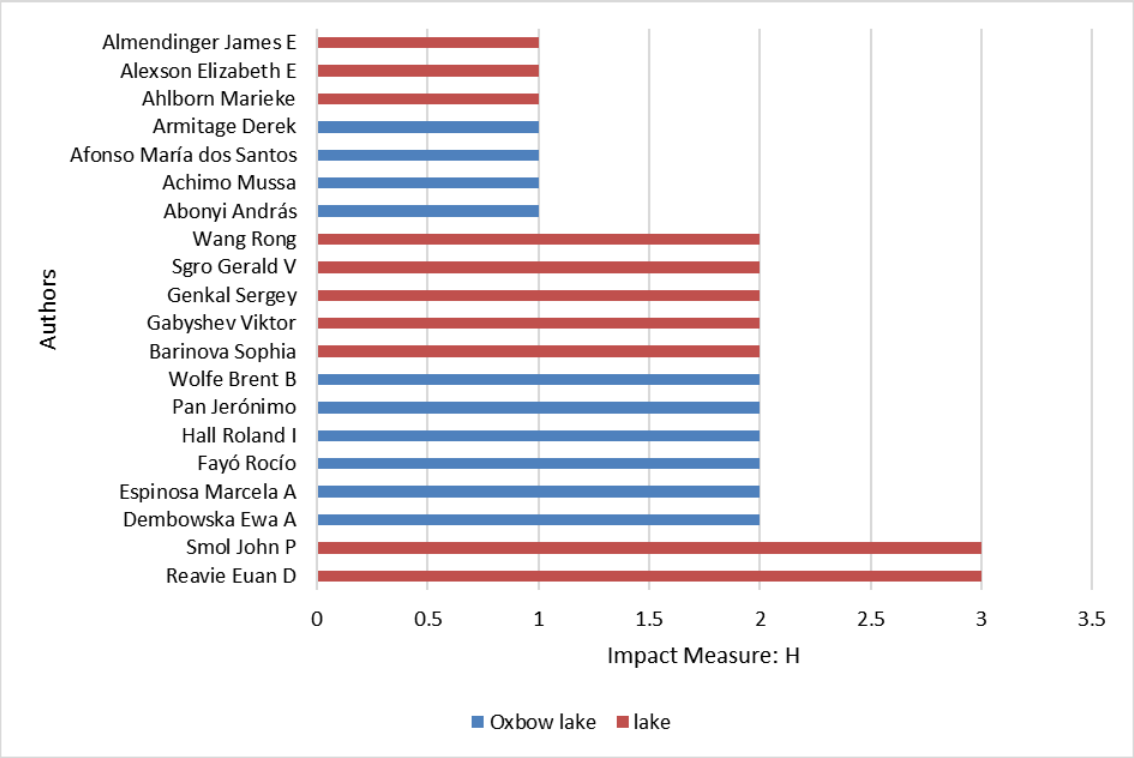

Figure 4. Author Local Impact between lake and oxbow lake

3.2.3. Affiliations

Figure 5 shows a comparison of institutions most relevant to lake and oxbow lake research. The findings reveal a distinct pattern in the distribution of research outputs across various institutions. General lake research seems to be more widespread, with several institutions, including the University of Minnesota Duluth and Queen's University, producing the highest number of outputs (n=3) among a variety of affiliations. Most other institutions involved in lake research have lower but steady levels of contributions. In contrast, oxbow lake research is more concentrated at a few key institutions. Stockholm University stands out as the top institution, with four research outputs. The University of Waterloo and Universidad de Buenos Aires follow, each contributing three outputs. This pattern indicates that while lake studies attract broader participation from various institutions, oxbow lake research relies primarily on a smaller group of specialised centres that are more active (Figure 5).

3.2.4. Co-occurrence Network

The network visualization reveals two distinct yet interconnected thematic clusters (Figure 6). The red cluster focuses on diatoms and related bioindicator topics, with large nodes such as diatom and Bacillariophyta indicating a high concentration of research activity around diatoms as indicators of aquatic health. The size and proximity of these nodes suggest strong research intensity and a central role for diatoms in assessing lake ecosystems. The blue-green cluster centers on climate change and freshwater ecosystem variables, including lake, lakes, water quality, and environmental monitoring. This cluster displays a dense network of connections among climate-related terms and hydrological factors, reflecting broad interdisciplinary work linking climate dynamics to lake ecology. Connections between the clusters show ongoing integration between climate and environment-based research and diatom bioindication. Overall, the visualization demonstrates a growing emphasis on diatoms as primary bioindicators within lake studies while maintaining significant attention to environmental monitoring, climate change, and comprehensive ecological assessment

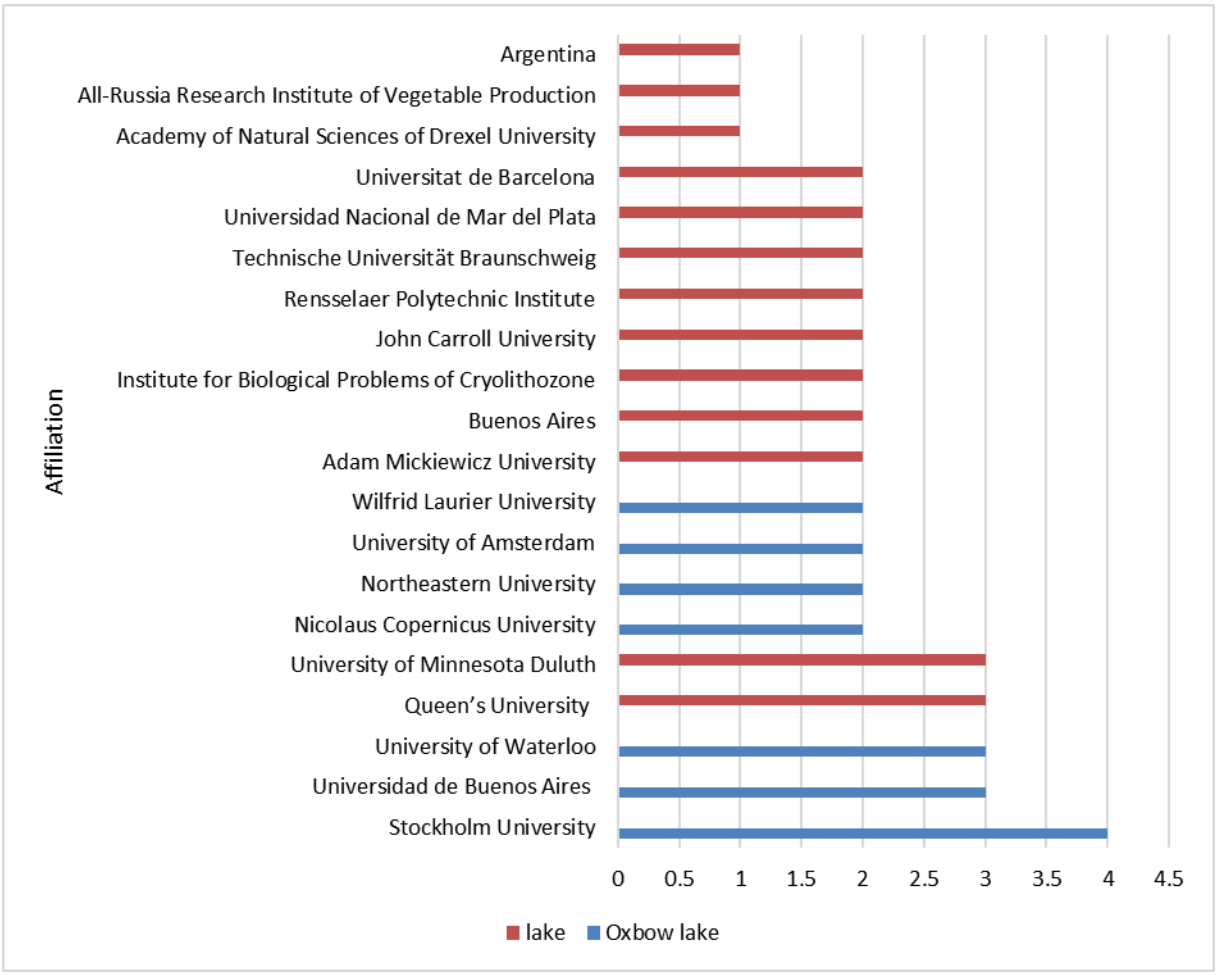

Figure 5. Most Relevant Affiliations between lake and oxbow lake

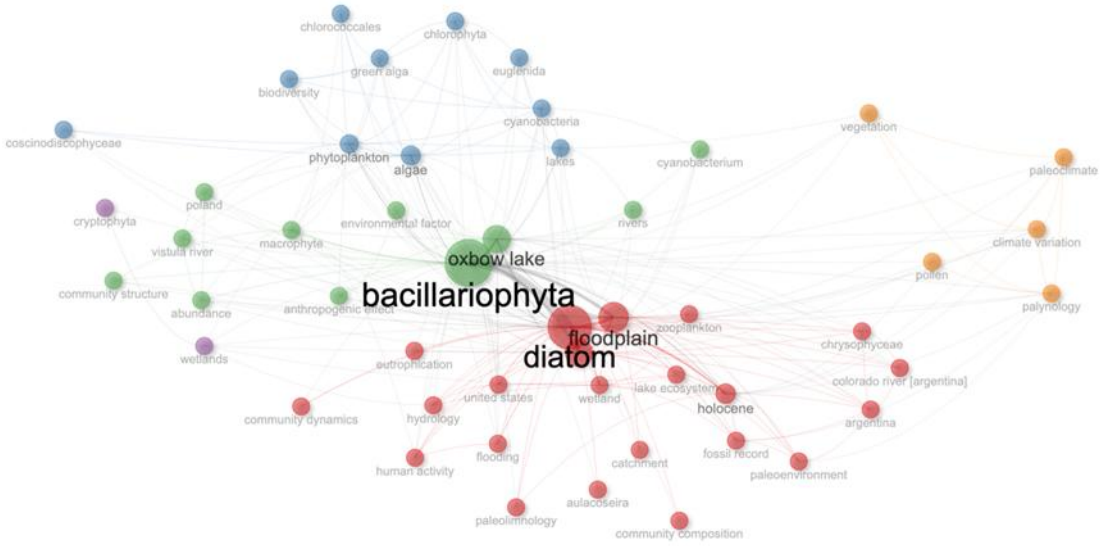

Figure 6. Co-occurrence Network for diatom and oxbow lake

The literature network visualization reveals two distinct thematic clusters (Figure 7). The blue cluster is centered on the concept of climate change and is closely associated with freshwater ecosystem variables, such as lakes, lake water, water quality, environmental monitoring, and related environmental factors. This cluster displays relatively uniform node

sizes, indicating a broad thematic interconnection and varied depth of focus across those topics. In contrast, the red cluster focuses on bioindicator concepts, with pronounced attention on diatom indicators and related terms, including Bacillariophyta, paleoenvironments, global change, and aspects of paleoecology. The larger node sizes in the red cluster suggest higher research intensity on diatoms as bioindicators for assessing the health of aquatic environments. The visualization also highlights substantial interconnectivity between clusters, especially along research pathways linking climate variables and aquatic biogeochemistry with bioindicator concepts. This pattern demonstrates that research in this domain remains strongly interdisciplinary, merging climate dynamics, water quality assessment, and biotic community responses. Overall, the network structure points to a growing research emphasis on diatoms as primary bioindicators within lake studies, while also confirming the persistent relevance of environmental monitoring, climate change, and integrated ecological assessments. These findings share consistency with existing literature, emphasizing the increasingly central role of diatoms for evaluating the ecological effects of climate change on freshwater ecosystems and the necessity for synthesizing chemical, physical, and biological parameters in comprehensive environmental evaluations.

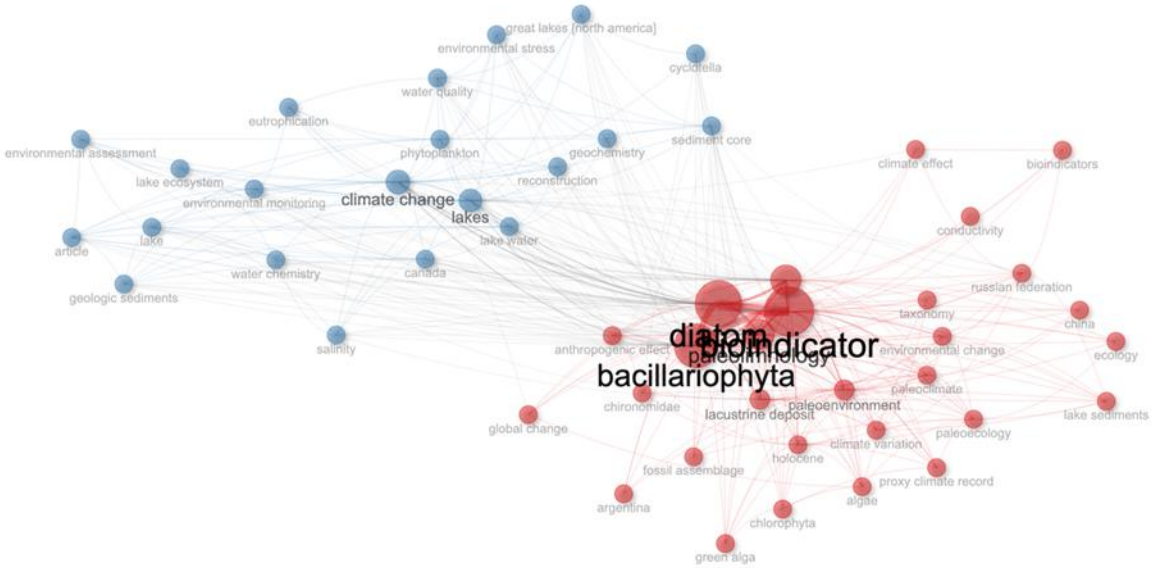

Figure 7. Co-occurance Network for diatom and lake

The analysis presented in Figure 8 demonstrates that research on lake and oxbow lake is highly concentrated within a select group of countries. Canada stands out as the most frequently cited with registering 119 citations. United States and chine surpassing both 108 citations. Argentina (61 citations), United Kingdom (66 citations) and Germany (78 citations) also feature prominently among the top contributors to lake citations. In contrast, citations related to oxbow lake are comparatively lower. The United States (59 citations), Argentina (52 citations), and Canada (49 citations) remain leading contributors, while European and Asian countries such as Hungary (43 citations), Australia (45 citations), India (29 citations), and Poland (21 citations) also exhibit growing scholarly engagement (Figure 6). This trend reflects the increasing recognition of oxbow lakes as important yet understudied components of fluvial ecosystems, particularly in relation to biodiversity conversation and hydrological dynamics.

3.2.5. Articles

Figure 9 illustrates the annual scientific production from 2000 to 2021. Overall, the number of published articles has exhibited noticeable year-to-year fluctuations. The most significant increase in scientific output occurred in 2010, with a peak of four articles, marking the highest publication rate during the observation period. Additional production spikes were observed in 2015 and 2018, with three published articles.

Conversely, several years recorded extremely low publication activities, including no articles in 2002, 2006, 2008, 2009, 2013, 2017, and 2019. This pattern reflects an inconsistency in publication trends, potentially influenced by various factors, such as research funding dynamics, shifts in academic policy, or variability in research activities across institutions and researchers.

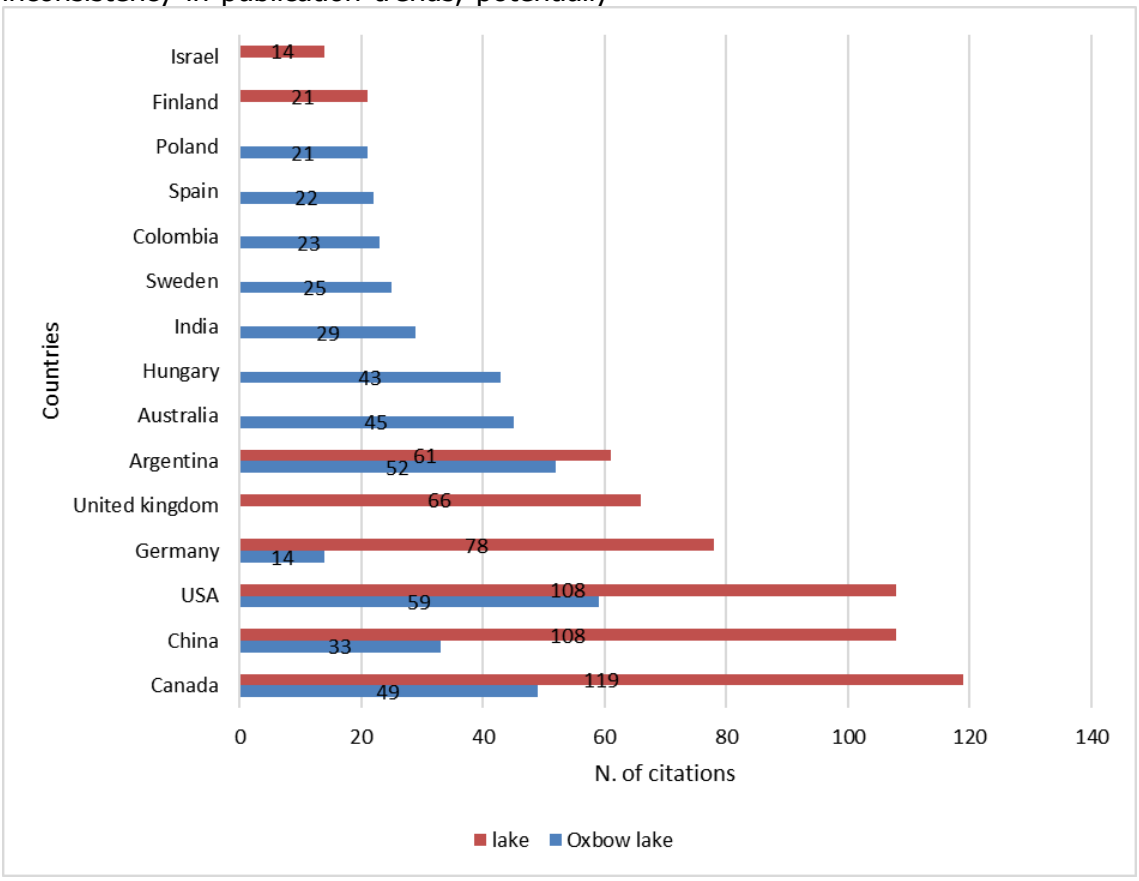

Figure 8. Most Cited Countries between lake and oxbow lake

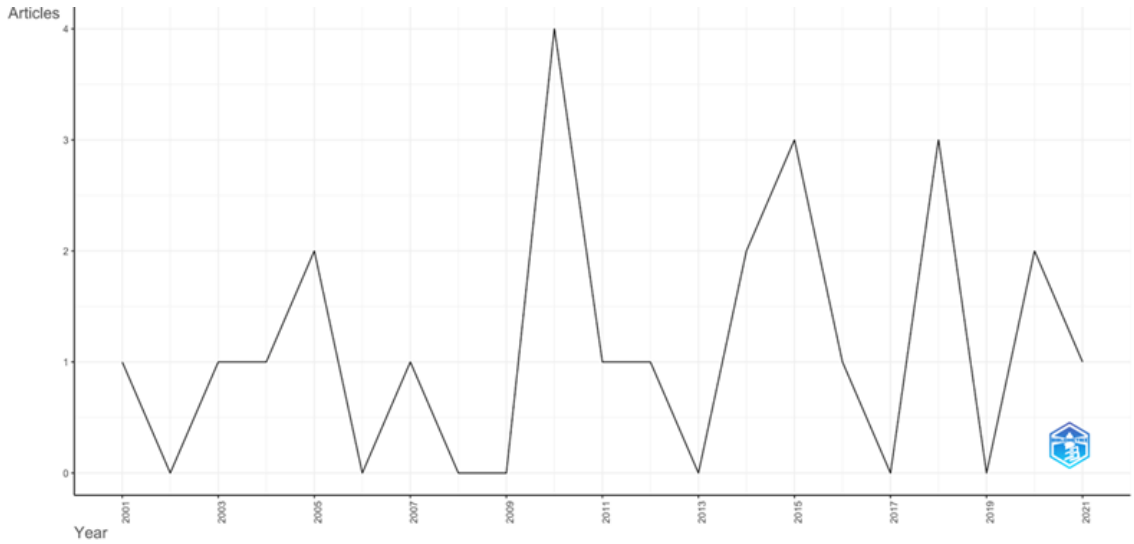

Figure 9. Line Chart of Annual Scientific Production for Diatom and Oxbow Lake

Figure 10 illustrates the annual scientific production trend from 2000 to 2025. In the early 2000s, the number of published articles remained very low, with no publications recorded in several years, such as 2001, 2002, and 2004 to 2008. A noticeable increase began

in 2010, with three articles published; the peak occurred in 2012 and 2017, each reaching four articles. The period between 2015 and 2020 reflects a relative stability phase, maintaining a steady output of three articles per year. However, a sharp decline followed after 2021, with no articles published in 2022, a modest recovery to 2 articles in 2023, and only 1 article published in 2024 and 2025. Overall, the scientific production trend revealed a period of growth post-2010, stabilization during the mid-2010s, and a decline in the early 2020s.

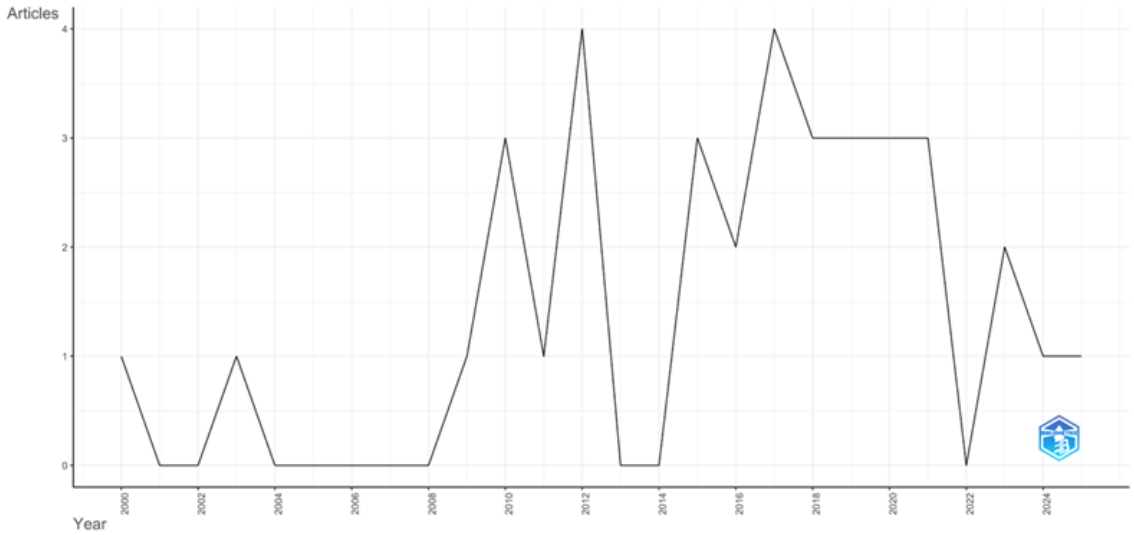

Figure 10. Line Chart of Annual Scientific Production for Diatom and Lake

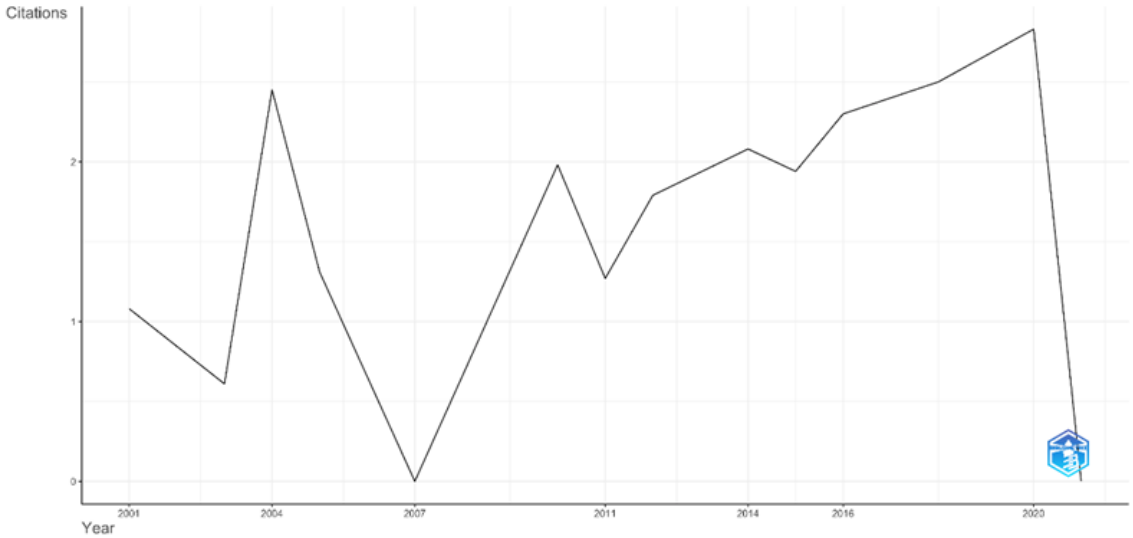

Figure 11. Average Citations per Year for Diatom and Oxbow Lake

In the early 2000s, the average citations per article remained low, fluctuating slightly between 1 and 2. A sharp increase occurred in 2004, reaching a temporary peak at approximately 2.5 citations per article. After a steep decline in 2007, the trend began to rise consistently from 2009 with minor fluctuations. From 2012 to 2020, the average number of citations per year increased steadily, indicating the growing visibility and impact of scientific publications. The highest average was recorded in 2020, approaching 3 citations per article. However, a significant drop was observed following this peak, with citation averages falling to nearly zero by 2022 and 2023 (Figure 11).

The chart in Figure 12 illustrates the trend of the average citations per year from 2000 to 2025. During the early period (2000–2009), citation levels remained stable, averaging

between 1 and 1.5 citations per article, reflecting an initial phase of scientific output with moderate visibility. Starting in 2010, a noticeable increase in average citations began, reaching its first peak in 2012–2013, with values ranging between 2.5 and nearly three citations per article. From 2014 to 2018, the trend showed minor fluctuations, with a slight decline, yet remained above 1.5 citations. Another peak occurred in 2019, which was followed by a subsequent decline. After 2022, the graph displays a sharp drop, approaching zero citations in 2024–2025. This is most likely due to the recency of publications in those years, meaning that they have not yet had time to accumulate citations.

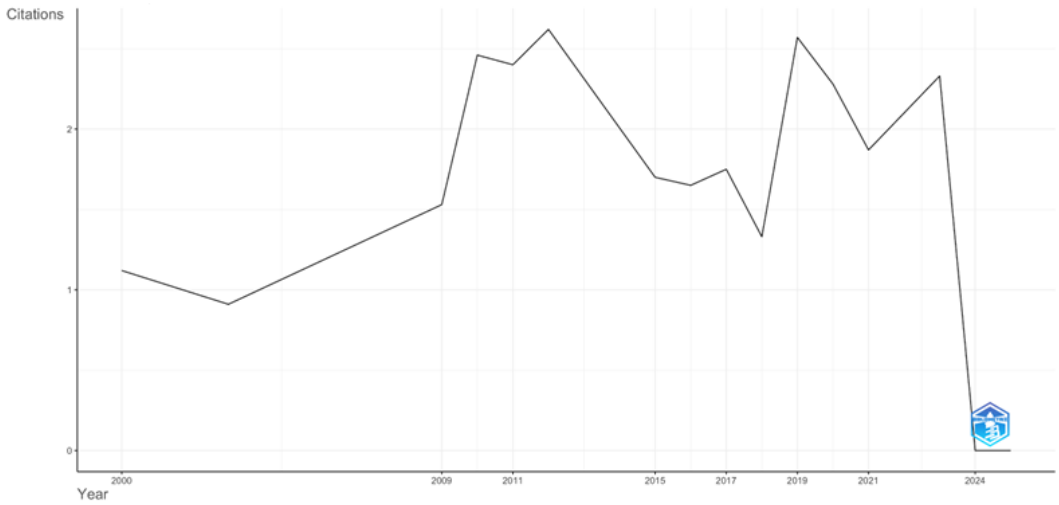

Figure 12. Average Citations per Year for Diatom and Lake

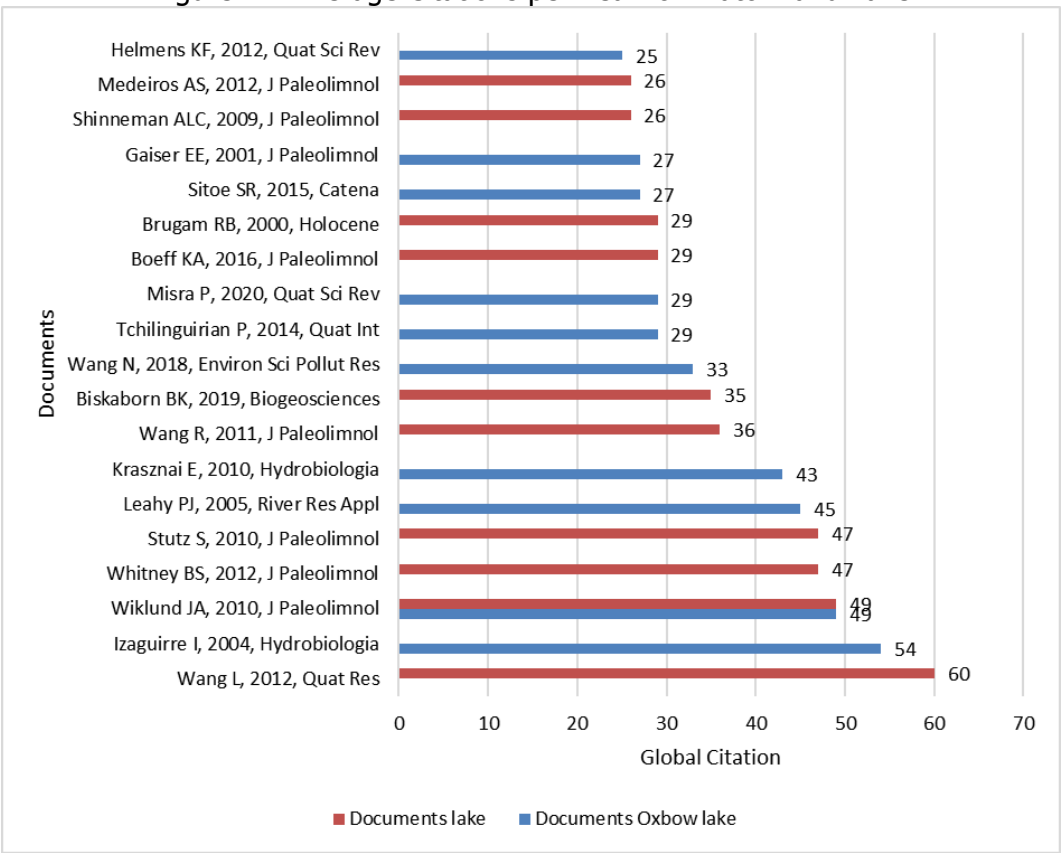

Figure 13. Most Globally Cited Documents between lake and oxbow lake

The bibliometric assessment illustrated in Figure 13 compares the global citation counts of the 20 most-cited documents related to diatom studies in both lake and oxbow lake ecosystems. Citation frequencies range between 25 and 60, reflecting the significant influence of these foundational publications within the field. The most influential contribution is Wang L (2012) published in Quaternary Research, which centers on lake system and has accumulated 60 citations, representing the highest level of global recognition. Similarly, Izaguirre I (2004) in Hydrobiologia (54 citations) reinforces the substantial impact of oxbow lake studies at the upper end of the citation spectrum. Following Overall, citation dominance by studies in the Journal of Paleolimnology, Hydrobiologia, and Quaternary Science Reviews highlights their role as key publication outlets for diatom-based paleoenvironmental research.

3.3. Topic Trend

An analysis of research topic trends revealed that several terms experienced increased usage during specific periods. "algae" emerged as early as 2004 and remained a central focus until around 2010. Terms such as "lakes" and "cyanobacteria" appeared more frequently in 2010. The term "holocene" peaked in usage in 2012. Between 2010 and 2014, there was a notable rise in the use of the terms "bacillariophyta" and "diatom", which showed high frequency and reflected a strong interest in diatom studies and other phytoplankton groups. During the same period, "cyanobacteria" appeared more often, albeit at a lower frequency. In the following years, terms such as "phytoplankton" and "wetland", became increasingly common, followed by "oxbow lake" and "floodplain". These data indicate an evolving research landscape, transitioning from aquatic ecology and environmental change to themes centered on conservation and biodiversity over the past decade (Table 5).

Table 5. Topic Trends for Diatom and Oxbow Lake

Term	Fre-quency	Year (Q1)	Year (Med)	Year (Q3)
algae	7	2004	2010	2012
cyanobacteria	5	2010	2010	2018
lakes	5	2010	2010	2016
holocene	8	2005	2012	2016
bacillariophyta	23	2010	2014	2017
diatom	21	2010	2014	2018
phytoplankton	6	2011	2014	2016
wetland	5	2010	2015	2016
diatoms	12	2010	2016	2018
floodplain	12	2013	2016	2018
oxbow lake	11	2012	2016	2019

The analysis of the research topic trends in Table 6 illustrates the evolving focus of scholarly studies from 2010 to 2021. In the early years of this period, terms such as "paleoclimate", "Holocene", and "paleoenvironment" dominated scientific discourse, reflecting a growing interest in past climate reconstruction. Over time, the focus shifted toward themes such as "climate variation", "paleolimnology", and "lacustrine deposit" around 2015–2016, indicating increased attention to the interactions between ancient climates and environments. In subsequent years, new terms such as "bacillariophyta", "bioindicator", and "diatom" appeared with high frequency, signaling a transition in research toward the use of biological indicators for environmental and climate change analysis. From 2017 to 2019, the focus further shifted to contemporary issues, including "climate change", "lakes", "climate change", and "Anhtropogenic-effect". Between 2019 and 2022, topics such as "phytoplankton", "environmental-monitoring", and "Russian federation", became increasingly prominent, reflecting a growing interest in environmental monitoring and regional biodiversity studies, particularly in the Russian Federation. This shift demonstrates that research in paleolimnology and aquatic ecology has increasingly incorporated climate change and conservation issues into analytical frameworks.

Table 6. Topic Trends for Diatom and Lake

Term	Freq-uency	Year (Q1)	Year (Med)	Year (Q3)
paleoclimate	8	2011	2012	2015
holocene	8	2010	2014	2018
paleoenvironment	11	2012	2015	2017
climate variation	6	2013	2015	2016
paleolimnology	16	2012	2016	2018
lacustrine deposit	10	2015	2016	2018
paleoecology	7	2014	2016	2017
bioindicator	35	2012	2017	2020
diatom	33	2010	2017	2020
bacillariophyta	29	2012	2017	2019
climate change	14	2017	2018	2021
lakes	11	2016	2018	2020
Anthropogenic-effect	6	2016	2018	2019
phytoplankton	6	2018	2019	2022
russian federation	6	2018	2019	2022
Environmental-monitoring	6	2018	2020	2021
lake	5	2017	2020	2021

3.4. Keyword

Figure 14 illustrates the distribution of the most frequent or relevant keywords found in studies of lake and oxbow lake, comparing their occurrence for each category. Diatom, bioindicator, and bacillariophyta stand out as the most commonly used keywords for lakes, with exceptionally high counts, while their frequency is noticeably lower yet still prominent for oxbow lakes. Other keywords, such as climate change, paleolimnology, and floodplain, appear frequently in both contexts, although their values are generally higher in the lake category. Keywords such as biodiversity, the United States, and cyanobacteria are mentioned less often across both categories. The data suggest that research on lakes is more strongly associated with terms linked to biological indicators and paleoenvironments compared to oxbow lakes, where these terms appear but with less frequency.

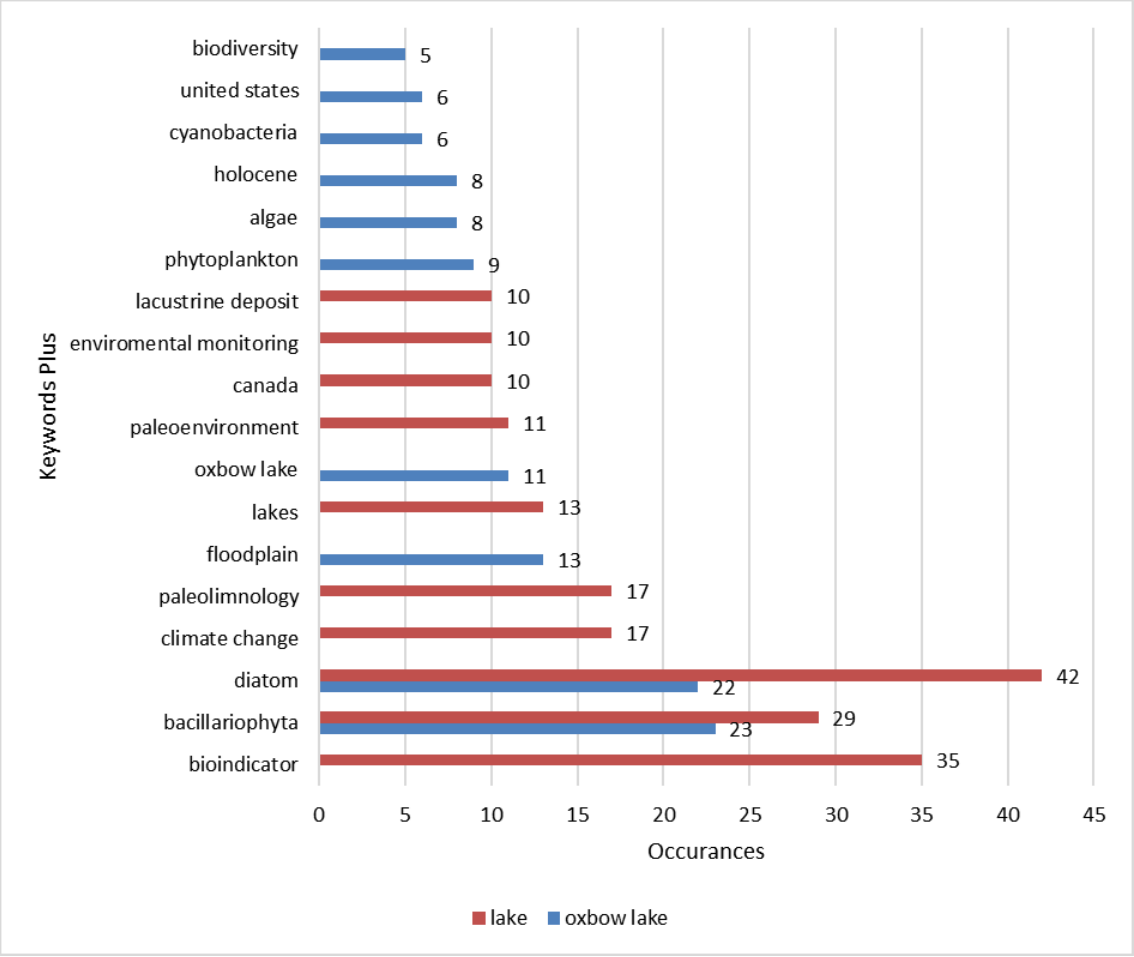

Figure 14. Most Frequent/Relevant Words for lake and oxbow lake

Figure 15. Treemap visualizing the frequency of major terms and topics within diatom research in lacustrine environments, as determined from bibliometric analysis of publications indexed in Scopus. Each box represents a distinct term or topic, with size proportional to the number of publications referencing that term. The largest categories, such as bacillariophyta, diatom, floodplain, oxbow lake, and phytoplankton, reflect dominant research areas in the field. Notably, 'oxbow lake' appears less frequently than broader categories, highlighting a relative gap in focused research on these ecosystems. Colors group related research themes, including taxonomy, ecology, and geography, with percentage values shown for each tile. This treemap allows quick assessment of research priorities and underrepresented areas, supporting the conclusion that, although oxbow lakes are ecologically important, studies specific to these systems remain comparatively limited within the diatom literature. The visualization emphasizes the need for broader research efforts directed toward underexplored habitats such as oxbow lakes.

The treemap in Figure 16 visually depicts the distribution of key research themes and terminology within diatom studies conducted in lacustrine environments, based on a comprehensive bibliometric analysis of articles indexed in the Scopus database. Each rectangle on the treemap corresponds to a specific term or category, with its size proportional to the number of publications in which the term appears, thereby reflecting the prominence of each research focus within the field. Predominant categories, such as diatom, bacillariophyta, and bioindicator, are represented by larger segments, indicating their central significance and extensive discussion in the scholarly literature. Other substantial categories, including climate change, paleolimnology, lakes, and environmental monitoring, highlight continuing research attention to environmental processes and lake ecosystem dynamics. The comparatively smaller segment devoted to oxbow lakes underscores a relative lack of focus on this habitat, suggesting that these ecosystems remain underrepresented in diatom research despite their ecological importance. The use of color serves to separate and clarify different thematic groupings, enabling readers to discern patterns of emphasis and gaps within the research landscape. Collectively, this visualization provides a succinct overview of how scholarly attention has been allocated in diatom-related studies, illustrating established priorities while also evidencing the need for further research devoted to less-studied habitats, like oxbow lakes, within the broader field of freshwater science.

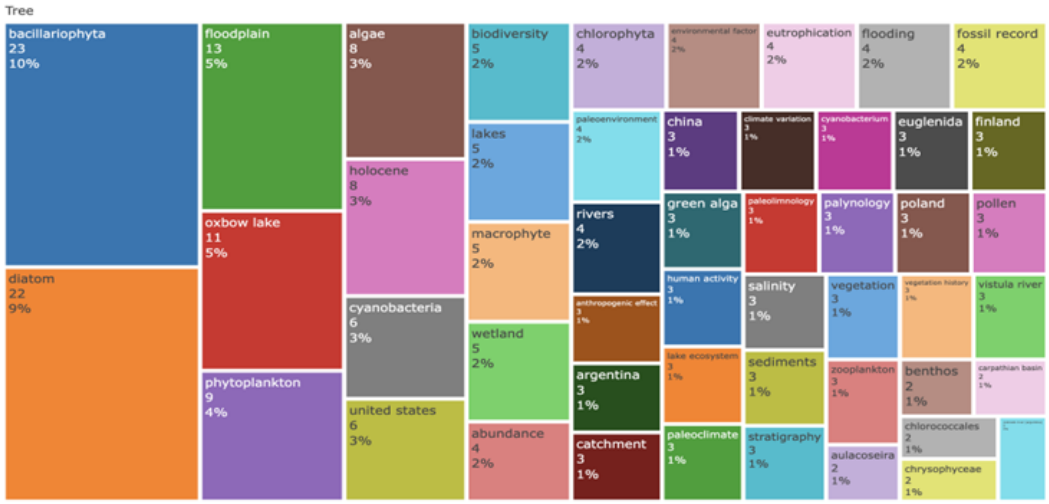

Figure 15. Tree Map for Diatom and Oxbow Lake

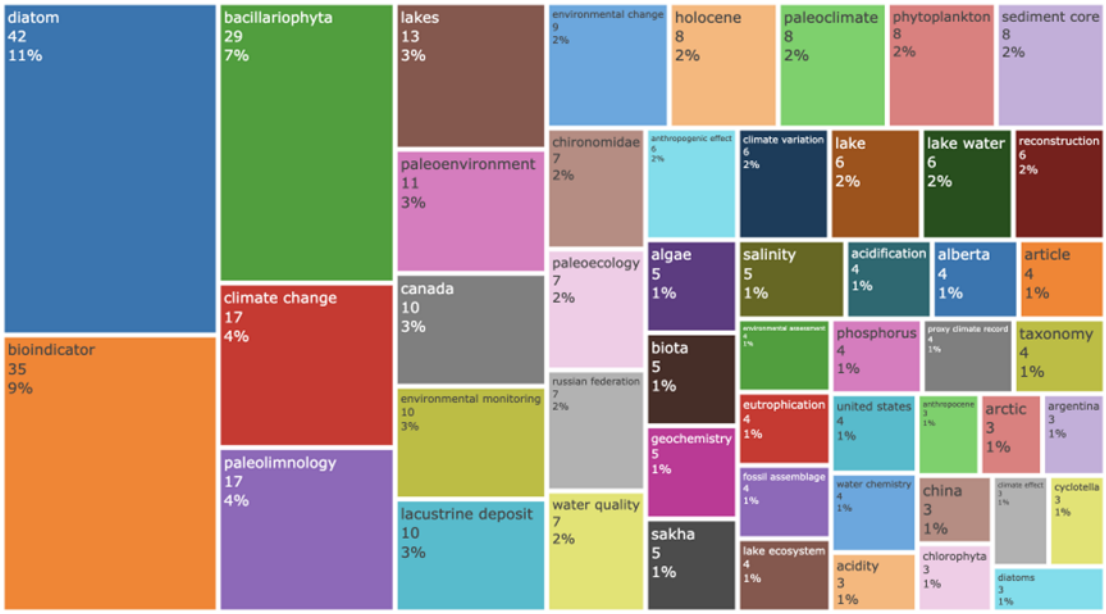

Figure 16. Tree Map for Diatom and Lake

3.5. Future research opportunities on diatom-related topics in lakes and oxbow lakes

Figure 17 presents a thematic map illustrating the position and relationships among the research themes based on their level of development (density) and relevance (centrality). Themes such as "bacillariophyta", "diatom", and "floodplain" occupy the Motor Themes quadrant, indicating that these topics are both significant and well-developed, serving as central pillars in the field. Themes such as "climate variation", "paleoclimate", and "palynology" are located in the lower right quadrant as Basic Themes, suggesting that although they are crucial, they are still undergoing further development. Meanwhile, themes such as "anthropogenic effect", "catchment", and "floods" are situated in the lower left quadrant, categorized as Emerging or Declining Themes, indicating they are underdeveloped and currently play a limited role within the research network. Lastly, themes like "chlorococcales" and "embryophyte" in the extreme lower left quadrant represent specialized topics that are less integrated into the mainstream research flow. This mapping provides a clear overview of the dynamics and priorities of the development of research within the field.

The thematic map in Figure 18 illustrates the distribution of the research themes based on their degree of development (density) and relevance (centrality). Themes such as "climate change", "lakes", and "Canada" are positioned in the Motor Themes quadrant, indicating that these topics are highly relevant and well-developed, serving as primary drivers within this research field. Meanwhile, themes like "bioindicator", "diatom", and "bacillariophyta" are located at the center of the map, reflecting that they are critical general topics but are still undergoing further development. Themes such as "Sakha", "climate effect", and "spatial distribution" appeared in the lower-left quadrant as Emerging or Declining Themes, suggesting that these topics are less central and less developed in the current literature. Overall, the map highlights a primary research focus on the impact of climate change on lakes in the Canadian region, supported by the use of diatoms as environmental bioindicators.

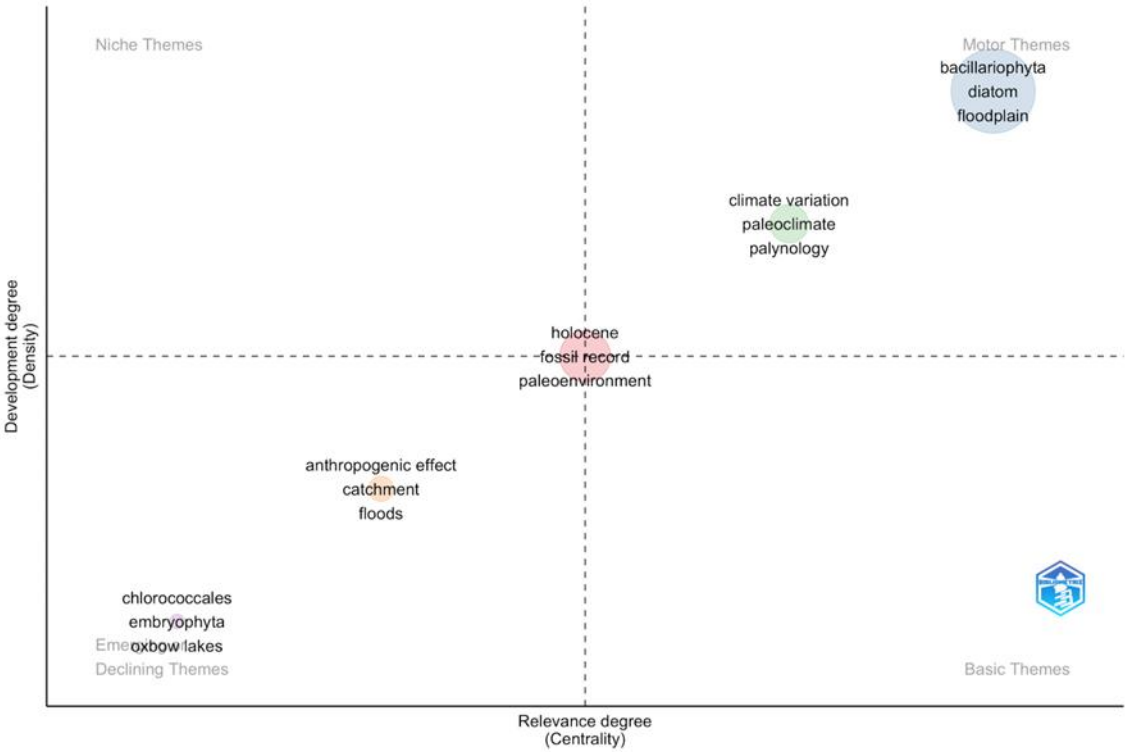

Figure 17. Thematic Map for Diatom and Oxbow Lake

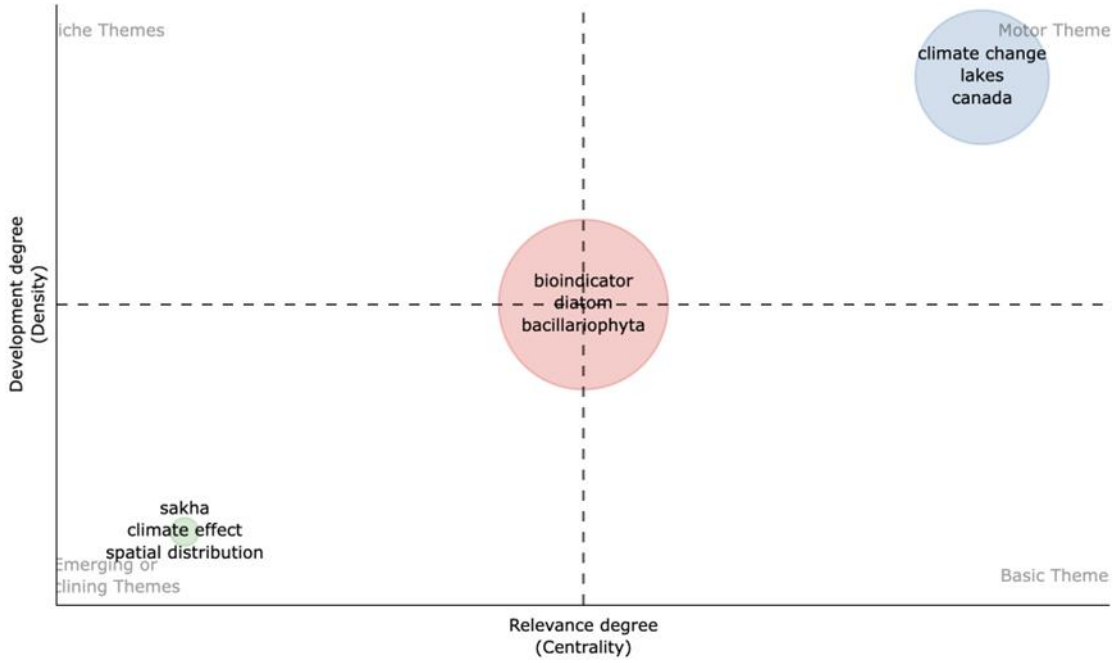

Figure 18. Thematic Map for Diatom and Lake

3.6. Collaboration in bibliometrics

The authors depicted in Figure 19, such as Hall Roland I and Espinosa Marcela A, emerge as central figures in the collaboration network, indicated by the larger node sizes and higher levels of connectivity, reflecting their dominant roles within the network. Other groups led by authors such as Black Jessica L, Deák Csaba, and Farooqui Anjum demonstrate smaller yet solid collaborations within their respective clusters. This visualization suggests the existence of several relatively independent scientific communities, with limited connections between clusters, reflecting the specialization

of research themes and more intensive collaboration within specific groups.

As shown in Figure 20, Reavie Euan D and Smol John P are central hubs within the research collaboration network, as reflected by the larger node sizes and extensive connections surrounding them. Researchers such as Genkal Sergey, Barinova Sophia, and Wang Rong also demonstrated significant roles within their respective collaborative clusters, albeit on a smaller scale. Each group formed relatively isolated collaboration clusters, indicating a specialization of research themes or geographical focus within the field. Additionally, several minor collaborative pairs operate with more limited interactions, such as Borel Cmarcela, Del Puerto Laura, Almedinger James E, and Edlund Mark B. This visualization illustrates a fragmented research community structure with minimal connections between clusters but high collaboration intensity within specific groups, reflecting a focused, expertise-driven collaboration pattern.

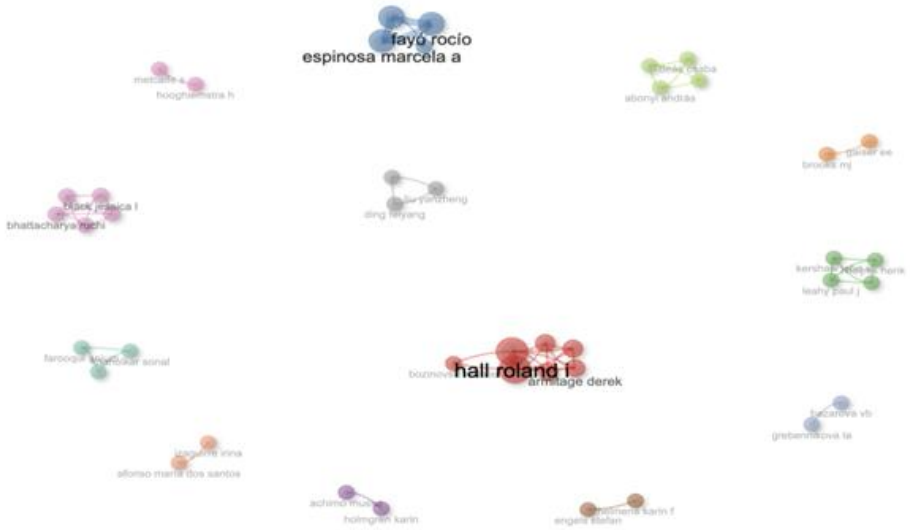

Figure 19. Collaboration Network for Diatom and Oxbow Lake

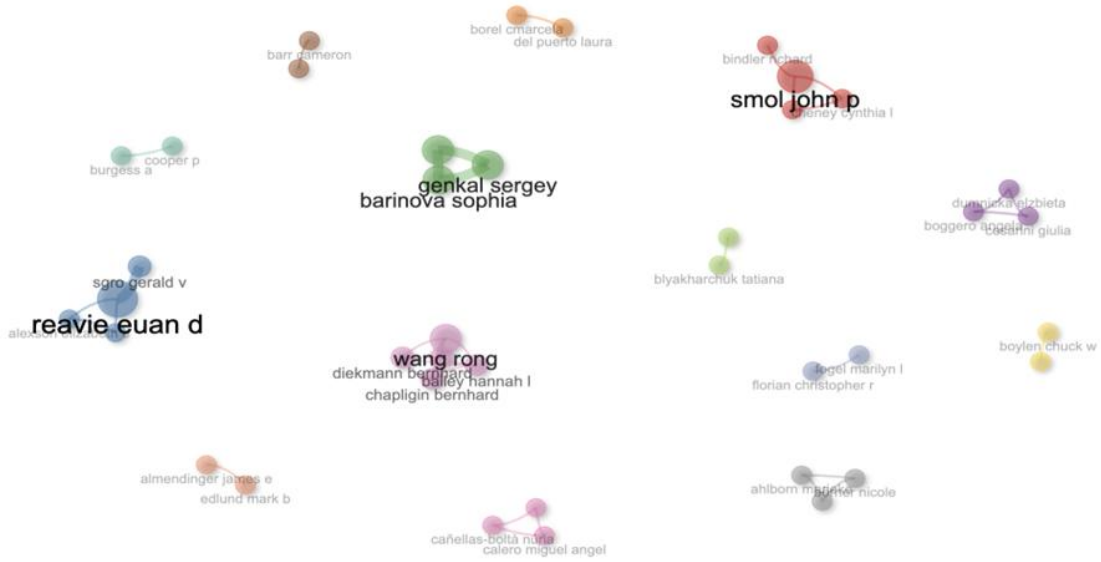

Figure 20. Collaboration Network for Diatom and Lake

Based on the bibliometric analysis, future directions in paleolimnology for lacustrine systems, including oxbow lakes, should emphasize the integration of high-resolution sediment-based records with multi-proxy approaches to illuminate long-term environmental change. Specifically, future work would benefit from collecting continuous sediment cores from oxbow lakes to reconstruct past hydroclimate variability, flood regimes, and land-use impacts over centennial to millennial timescales, and from pairing diatom assemblages with geochemical tracers, isotopic indicators, and sedimentary DNA to improve attribution of climatic versus anthropogenic forcing. Developing regionally calibrated transfer functions for diatoms will enhance quantitative reconstructions of past temperature, nutrient status, and hydrological connectivity in both temperate and tropical oxbow systems. Chronology improvements—through varve analysis, radiocarbon dating, lead-210, and tephrochronology—will enable detection of short-lived environmental episodes. Emphasis on underrepresented regions, particularly tropical and subtropical oxbow lakes, will fill critical knowledge gaps and improve global syntheses. Finally, fostering open data practices by building shared, metadata-standardized paleolimnology databases will facilitate cross-site comparisons, enhance reproducibility, and accelerate the translation of paleo-records into actionable conservation strategies for vulnerable freshwater ecosystems. This direction aligns with the growing recognition of paleolimnology as a powerful tool for understanding long-term ecological dynamics in lakes and for informing adaptive management in the face of ongoing climate and land-use change.

4. Conclusion

This literature review and bibliometric analysis confirm that diatoms play a critical role as bioindicators in freshwater lake ecosystems, especially in monitoring environmental changes, such as climate variability and anthropogenic disturbances. The study revealed a significant increase in scientific output on this topic over the past two decades, with dominant contributions from countries such as the USA, Canada, and Argentina. The analysis also shows that research activity is concentrated in several key publication venues and driven by influential contributors in the field. Research has transitioned from foundational studies on diatom taxonomy to more applied themes, including environmental monitoring and paleoenvironmental reconstructions. Despite their ecological importance, oxbow lakes remain underrepresented in diatom studies, highlighting the potential gap and opportunities for future research. Thematic analyses underscore the need for continued interdisciplinary approaches integrating taxonomy, paleolimnology, and environmental science to support freshwater conservation. This study contributes to a clearer understanding of global research patterns and offers strategic insights for advancing diatom-related studies, particularly within the Indonesian context.

Data availability statement

The data included and used in this study is not confidential and is available upon request.

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Conflict of interests

The authors declare that there are no conflicts of interest related to the submission of this manuscript.

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Author Contributions

SP conducted the investigation, data collection, formal analysis, bibliometric processing, and preparation of the manuscript. **TRS, LK, JJ, MHAF, YY, AA,** and **ŁK** were involved in the conceptualization of the study,

contributed to methodological refinement, and critically reviewed and edited the manuscript. All authors read and approved the final version of the manuscript.

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