Bioindicators for Forest Area Condition: A Systematic Literature Review

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Bioindicators for Forest Area Condition: A Systematic Literature Review

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Abstract

Flora and fauna are essential components of ecosystems, playing a vital role in maintaining environmental balance. They also serve as bioindicators for assessing forest health. As a result, many researchers have focused their studies on bioindicators, as evidenced by the extensive literature published in journals. The objective of this Systematic Literature Review (SLR) is to systematically identify, study, evaluate, and interpret data from relevant journal articles. We conducted a search in the Scopus database using the keyword "Bioindicator Forest," which yielded a total of 248 articles. After applying our criteria, we narrowed our research to only 49 articles. To conduct our inclusion and exclusion process, we utilized PRISMA guidelines. Analyzing the publication trend on the topic of forest bioindicators, we observed a decline from 2021 to 2023. However, in 2020, we noted a peak with nine articles published. Regarding the research approach, forest bioindicator studies employ quantitative, qualitative, and mixed methods. Notably, the most prominent authors in this field are F. Helbing, J. Litavsky, S Stasiov, Dominguez, and De Deyn. The dominant keyword used in these studies is biodiversity, often related to forestry botany. The authors of these articles originate from 29 different countries, with Europe contributing the majority at 62.07%. Collaboration-wise, a significant number of articles were published through both national and international collaborations. Furthermore, 47 articles received support or sponsorship from external parties. In our discussion, we explore the various techniques, instruments, and data analyses employed in these studies. Overall, this SLR serves as a comprehensive reference for researchers investigating forest bioindicators. Its findings contribute to the diversification of subjects and the enrichment of alternative bioindicators for forest ecosystems.

Keywords: Bioindicator; Biology; Forest; Systematic literature review

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INTRODUCTION

Biodiversity is essential for supporting life as it encompasses a wide variety of flora and fauna. It also encompasses the abundance of species and intricate ecosystems, which in turn have a profound impact on the organism community, ecosystem stability, and development (Heinen, 1993; Sandifer et al., 2015; Schulze et al., 2019). Living organisms have emerged as valuable tools for environmental monitoring and assessment, serving as sensitive indicators of ecological health and the quality of the surrounding environment (Beale et al., 2022; Chowdhury et al., 2023; Fraisl et al., 2022; Gibb et al., 2019; Li et al., 2020; Manisalidis et al., 2020; Sures et al., 2017). Moreover, the condition of a forest can be deemed healthy if it effectively fulfills its main functions of production, protection, and conservation. From an ecological standpoint, a healthy forest manifests a harmonious interplay among all its components. Bioindicators are capable of detecting signals across various temporal and spatial scales, providing comprehensive assessments of the environmental impacts resulting from ecosystem stress (Abas, 2023; Gunawan et al., 2022). Past studies pertaining to forest bioindicators, such as insects (Chowdhury et al., 2023; Y.-P. Wang et al., 2008), as well as diverse flora and fauna (Fares et al., 2020; Litavský et al., 2021; Neto et al., 2017; Pinilla-Cortés & Moreno-Gutiérrez, 2019), have been conducted.

In recent years, numerous studies have been conducted to identify and assess various species as bioindicators. In a search within Scopus for article titles, abstracts, and keywords, a total of 19,503 documents on bioindicators were found, while a search based solely on article titles yielded 1,227 results. However, the Scopus search results identified only three review articles related to bioindicators. These articles covered topics such as the use of green mussels as bioindicators for heavy metal pollution (Saleh et al., 2021), potential bioindicators for analyzing the toxicity of waterborne microplastics (Huang et al., 2023), and bioindicator species for measuring EROD activity (Gagnon & Rawson, 2017).

According to the search results in the September 2023 Scopus database, which represents the largest reputable journal database globally, a total of 248 publications included the term "forest bioindicator." However, upon thorough investigation, only 49 articles met the inclusion criteria. These publications were then subjected to an in-depth analysis to identify forms or models of bioindicator plant transformation and examine publication trends. This analysis encompassed the distribution of articles across different years, research types/methodologies, authorship and keyword patterns, author nationalities and international collaborations, as well as funding sponsors. The technique employed to conduct this analysis was a Systematic Literature Review (SLR). Such SLRs can yield significant contributions by identifying diverse methods and types of bioindicators and proposing novel frameworks for evaluating forest bioindicators. This Systematic Literature Review (SLR) aims to critically evaluate published research articles in journals about forest bioindicators. The aim is to contribute to the advancement of studies in this field and provide a reference for both researchers and readers on the subject of using specific plant and animal species as indicators of forest conditions. The scope of this review is limited to research/original articles, thereby offering an overview of researchers' focus and alignment regarding this particular topic.

The significance of an SLR in forest bioindicator studies lies in its ability to provide a comprehensive framework for systematically gathering, evaluating, and synthesizing existing scientific evidence. In the context of forest biological indicators, which seek to understand how certain species or ecological processes can serve as indicators of environmental conditions, an SLR assists in identifying common patterns, trends, and research gaps. This, in turn, enables researchers to consolidate knowledge about the effectiveness of various bioindicators in monitoring and assessing the health of forest ecosystems, the impacts of human intervention, and climate change.

This introduction summarizes the key findings from a systematic literature review on bioindicators and forest structure and function sustainability. It emphasizes the valuable contributions and insights gained from this body of research.

METHOD

Research Framework

The study employs a Systematic Literature Review (SLR), which is a rigorous approach to identifying, evaluating, and elucidating all relevant research pertaining to a specific research question, topic area, or phenomenon of interest (Bramer et al., 2018; Jahan et al., 2016; Pati & Lorusso, 2017; Paul & Barari, 2022; Tawfik et al., 2019).

Research Question (RQ)

Determining research questions is essential for defining the scope and developing a clear focus for the study. The following research question (RQ) has been formulated based on the identified needs: "What are the publication trends related to the theme of 'forest bioindicator' in journals indexed by Scopus?"

Search Article and Inclusion Criteria

We utilized the term "forest bioindicator" in the search menu within the Scopus database. The data retrieved was saved in CSV and RIS format and subsequently synchronized into Reference Manager (Mendeley). To present the information in a more effective and engaging manner, we employed VOS-viewer software for data visualization. The search history on Scopus is as follows: "TITLE("plants+bioindicators+forest") AND (LIMIT-TO(PUBYEAR, 2012) AND LIMIT-TO(PUBYEAR, 2024) AND (LIMIT-TO(DOCTYPE,"ar")) AND (LIMIT-TO(LANGUAGE,"English")) AND (LIMIT-TO(OA,"all")) AND(LIMIT-TO(SUBJAREA,"AGRI") OR LIMIT-TO(SUBJAREA,"ENVI"))). Utilizing these keywords and search criteria, we were able to identify 248 articles. We applied the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) model for inclusion and exclusion, following the guidance of Moher et al. (2009), Page et al. (2021), and Shamseer et al. (2015). This approach has also been adopted by previous researchers in the field of environmental science (Husamah et al., 2022a, 2022b, 2023; Nurwidodo et al., 2023). The process of inclusion and exclusion is presented in Figure 1.

Figure 1 illustrates that the initial search yielded a total of 248 articles. From these, we selected only research articles/original articles, resulting in 208 articles meeting the criteria, while 40 articles were excluded. Subsequently, we applied the criterion for English-language articles. In Systematic Literature Reviews, researchers often prioritize English articles for practicality and efficiency reasons. English serves as the lingua franca in scientific communication, facilitating access to literature on international databases and simplifying data analysis and synthesis. This decision also considers resource limitations, such as time and cost constraints associated with translation, as well as the perception that English-language publications uphold higher standards of quality and international relevance. Nevertheless, we acknowledge that this approach may restrict diverse perspectives and exclude significant findings published in other languages, potentially leading to bias. This limitation arises from a lack of language skills among our research team and limited human resources and funding. Out of the 208 articles meeting the criteria, 18 articles were excluded based on language.

Next, we applied the criteria for Open Access articles. Under this criterion, we identified 60 articles that met the requirements, resulting in the exclusion of 180 articles. We then applied the inclusion criteria for the field of science or subject area, focusing on "agricultural and biological science and environmental science." We included 58 articles that fulfilled this criterion, while 2 articles were excluded. We excluded inappropriate subject areas such as decision science, earth and planetary science, biochemistry, genetics and molecular biology, pharmacology, toxicology and pharmaceutics, multidisciplinary, and medicine. Lastly, we selected articles published within the timeframe of 2013-2023. We identified 49 articles meeting this criterion, while 9 articles were excluded. Thus, we obtained a total of 49 articles that met the inclusion criteria.

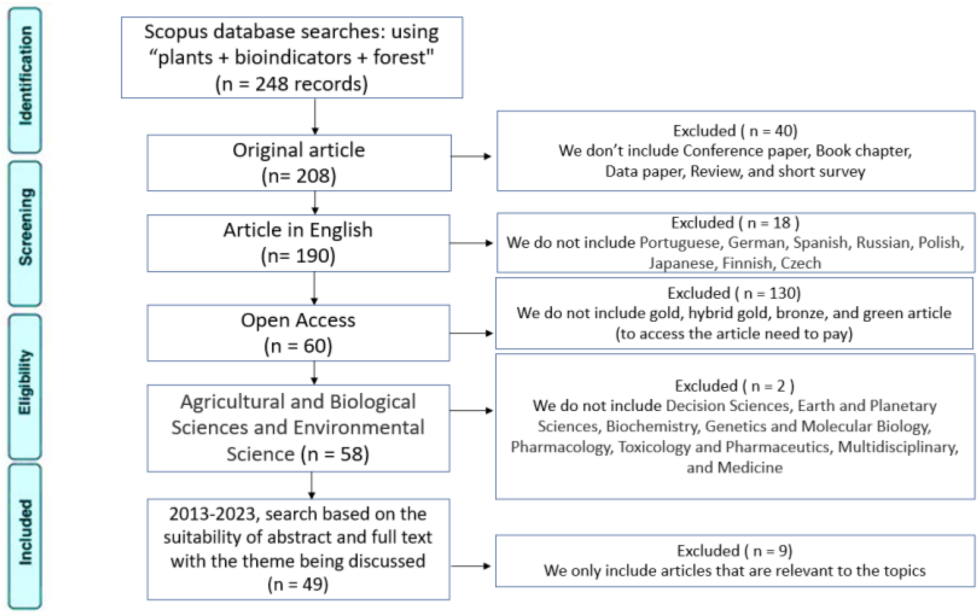

Figure 1. PRISMA flow diagram for SLR

RESULTS AND DISCUSSION

Distribution Year

Figure 2 illustrates the annual publication count from 2013 to 2023. According to the figure, the highest number of publications on the topic of "Types of plants that can be used as indicators of the condition of forest areas" was in 2020, with a total of 9 articles. In 2013, there were 3 articles published, which then decreased to 1 in 2014. The number of articles published increased to 4 in 2015, but remained at 3 per year from 2016 to 2018. In 2019, the number of articles published increased to 8, but decreased again to 6 in 2020. From 2022 to 2023, there will be 4 articles published each year.

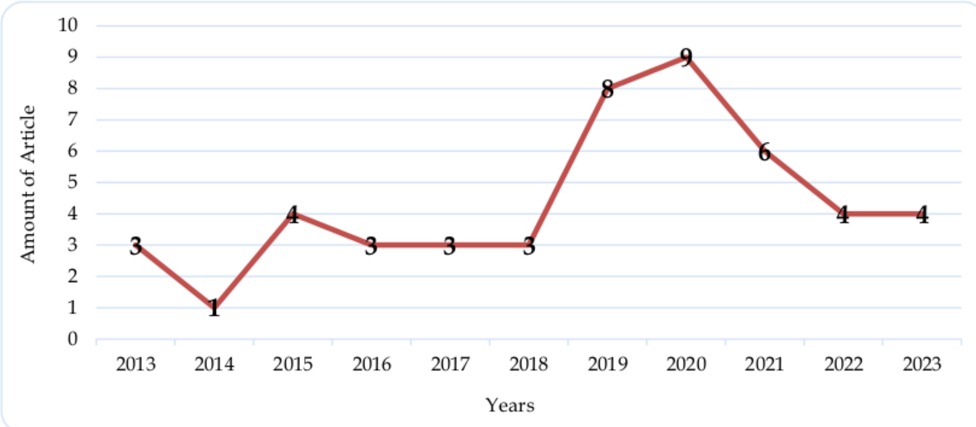

Figure 2. Distribution year of article

From 2018 to 2023, the highest production of articles related to plant types used as indicators of the condition of forest areas occurred in 2019-2020. This increase in production can be attributed to global forest destruction during that period, including the impact of the COVID-19 pandemic (Brancalion et al., 2020b, 2020a; Céspedes et al., 2023; Rahman et al., 2021; Saxena et al., 2021). In the first month after the implementation of lockdown policies to control the spread of COVID-19, Global Land Analysis & Discovery (GLAD) detected 9,583 km2 of deforestation alerts in global tropical regions, nearly double the number in 2019 (4732 km2) (Benson et al., 2011; Nirmal & Jacob, 2022; UNEP, 2022). The COVID-19 pandemic has negatively affected forest conditions due to various factors, including the impact on the global economy, conservation efforts, and environmental crimes such as illegal timber extraction and poaching (Beckmann-Wübbelt et al., 2023; Kuzman et al., 2022; D. Zhang, 2022). Forest management activities and fire prevention measures have also been disrupted, while the forest products industry has experienced disruptions in raw material availability, supply chains, and increased prices and transportation costs. Moreover, the demand for forest recreation during the pandemic has conflicted with climate change adaptation measures, creating challenges for stakeholders. Overall, the COVID-19 pandemic has placed negative pressure on forest conditions due to economic hardships, environmental crimes, disruptions in forest management, and conflicts between recreation and adaptation measures (Hlaváčková et al., 2024; Maraseni et al., 2022; Stanturf & Mansuy, 2021; Zahraee et al., 2022).

The increase in articles in 2019 reflects the heightened attention from researchers on environmental issues such as climate change, loss of biodiversity, and ecosystem degradation, including forests. This increased attention has motivated researchers to focus more and seek innovative solutions (Adla et al., 2022; Kumar et al., 2021; Malhi et al., 2020; Y.-J. Shin et al., 2022; Shivanna, 2022).

Research types/Method

Based on Figure 3, it is evident that a significant number of the reviewed articles employ quantitative methods, specifically 27 articles. Conversely, there are only seven articles in journals that utilize qualitative methods, and 13 articles employ mixed methods, combining both qualitative and quantitative approaches. Furthermore, there are two articles that do not specify the research methods employed.

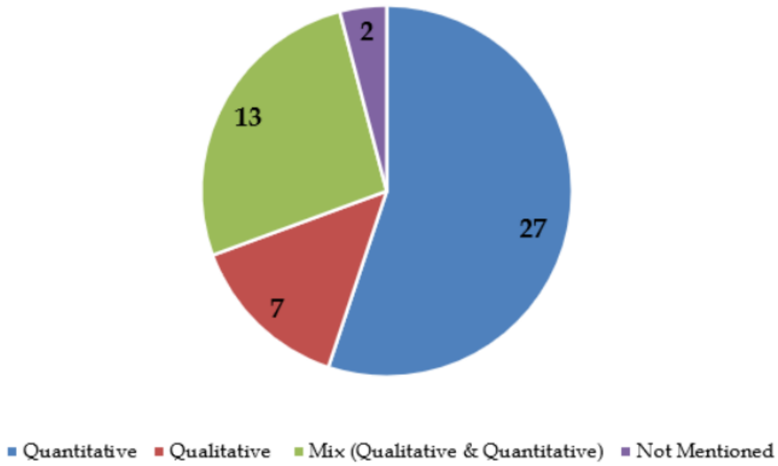

Figure 3. Research types/Method

This demonstrates that the investigation of plant types as indicators of forest area conditions can be approached through quantitative or qualitative methods, indicating a growing interest in utilizing mixed methods. Research on the topic of bioindicators in forest areas typically employs a balanced combination of qualitative and quantitative approaches. It is crucial for research studies to raise awareness among the general public about bioindicators in forest areas. Based on the reviewed articles, it is evident that both quantitative methods and a mix of quantitative and qualitative methods are commonly used to address the issues related to types of bioindicators in forest areas.

Researchers tend to have a preference for either quantitative, qualitative, or a combination of both approaches due to differences in epistemological, ontological, and methodological perspectives. Those who prioritize objectivity, generalization, and numerical measurement in data collection tend to adopt quantitative approaches, whereas researchers who value in-depth understanding, context, and subjective interpretation are more inclined towards qualitative approaches (Daniel, 2016; Haq, 2023; Makri & Neely, 2021; Nyein et al., 2020). By combining both approaches through mixed methods, researchers can leverage the strengths of each approach, leading to a more comprehensive and profound understanding of the phenomenon being studied. Additionally, a mixed approach can aid in validating findings, enhancing understanding, and providing robust triangulation support for research results (Dawadi et al., 2021; Fielding, 2012; Johnson & Onwuegbuzie, 2004).

Author

Based on Figure 4, it is evident that the authors with the highest number of references are F. Helbing, J. Litavsky, S. Stasiov, Dominguez, and De Deyn. Figure 4 also indicates that VOSViewer's results display the names of two authors, J. Litavsky and S. Stasiov, who link or connect other authors. It can be inferred that several of these authors are closely related and collaborate or cite each other, with J. Litavsky and S. Stasiov serving as the primary references. Additionally, F. Helbing has a close association with the authors Dominguez and De Deyn.

Figure 4. Dominant author and relationships between authors

The researchers who have received significant attention in bioindicator studies in forest areas are S. Stasiov and J. Litavsky, who specialize in bioindicators in forest areas and are frequently referenced by other researchers. Slavomir Stasiov is a professor at the Technical University in Zvolen, specializing in the Department of Biology and General Ecology. Results from a search on Researchgate reveal that he has published 31 scientific articles between 2003 and 2005, with 240 citations and 7,934 reads. Google Scholar data shows that Slavomir Stasiov has published 7 articles as the first author. Juraj Litavsky is a researcher at Comenius University in Bratislava, Slovakia. Researchgate search results indicate that he has published 22 journal articles and has been cited 46 times between 2015 and 2023. His publications often revolve around topics such as entomology, ecological monitoring, nature protection, biodiversity, community ecology, bioindication, and conservation ecology. Google Scholar data reveals that Juraj Litavsky has published 4 articles as the first author.

Keywords

Figure 5 illustrates the dominant keywords and their interrelationships. Based on our review of several articles, it is evident that biodiversity plays a crucial role in community ecology and ecosystem conservation, as indicated by its frequent use and current trend. Monitoring and evaluating ecosystem health can be achieved through the utilization of bioindicators, such as forestry botany. Forest botany contributes to maintaining ecosystem balance and safeguarding biodiversity.

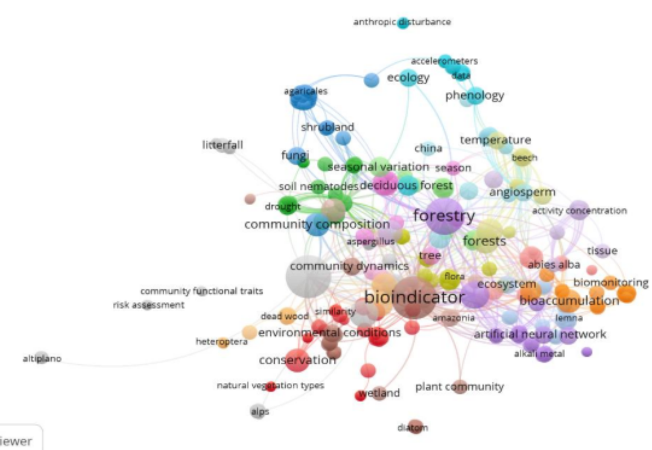

Figure 5. VOSviewer display for keywords

Additionally, it is essential to consider bioaccumulation in ecosystem conservation, as it refers to the accumulation of harmful substances in living organisms, posing a threat to ecosystem health. By comprehending the connections between bioindicators, forest botany, ecosystem conservation, community ecology, biodiversity, and bioaccumulation, we can effectively preserve and sustain ecosystems, in line with our chosen title.

Furthermore, the keyword analysis reveals that bioindicators, forestry, and community composition dominate the literature. Bioindicators serve as ecological indicators for organisms that are susceptible to environmental changes caused by human activities and natural disturbances. The presence of bioindicators can demonstrate the relationship between biotic and abiotic factors in an environment (Bhaduri et al., 2022; Pinilla-Cortés & Moreno-Gutiérrez, 2019; Russo et al., 2021). Forestry is vital for supporting life and serving as a resource for living organisms. Understanding various plant species that contribute to forest quality is increasingly crucial. Forestry also plays a key role in promoting environmental sustainability, providing sustainable resources, and safeguarding biodiversity (Aju et al., 2015; Chu & Karr, 2017; Karjalainen et al., 2010). The condition of a forest area is closely linked to the composition of its community, which serves as a fundamental measure of diversity. The presence of diverse tree species and other plants signifies ecosystem stability, shapes forest structure, and influences the ecological functioning of the forest (Ali, 2019; Bugmann & Seidl, 2022; Ikbal et al., 2023; Latt & Park, 2022; Nugroho et al., 2022; Pan et al., 2018; Y. Wang et al., 2023).

Author’s Nationality and Collaboration

The distribution of authors' nationalities in research related to "forest bioindicator" themes is presented in Table 1. According to Table 1, there are 29 countries represented by the authors. The top five countries with the highest number of publications on plant bioindicators are Brazil (11 articles), Poland (7 articles), Spain (5 articles), Germany (4 articles), and China (4 articles). In terms of continents, Europe has the highest contribution to authors publishing on plant bioindicators (62.07%), followed by America at 24.14% and Asia at 10.34%. Australia only accounts for 3.45% of the publications. It is interesting to note that authors from various continents contribute to articles on plant bioindicators, indicating a global interest and concern in this theme.

Table 1. Author’s nationality and continental

No	Country	Continental	Amount
1	Brazil	America	11
2	Poland	Europe	7
3	Spain	Europe	5
4	Germany	Europe	4
5	China	Asia	4
6	Mexico	America	3
7	Czech Republic	Europe	3
8	Slovakia	Europe	3
9	Argentina	America	3
10	Guatemala	America	3
11	Chile	America	2
12	France	Europe	2

No	Country	Continental	Amount
13	Switzerland	Europe	2
14	United States	America	2
15	Belgium	Europe	1
16	Iran	Asia	1
17	Netherlands	Europe	1
18	Romania	Europe	1
19	Slovenia	Europe	1
20	Australia	Australia	1
21	Croatia	Europe	1
22	Ecuador	America	1
23	Finland	Europe	1
24	Lithuania	Europe	1
25	Portugal	Europe	1
26	Russian Federatic	Europe	1
27	Serbia	Europe	1
28	Thailand	Asia	1
29	Turkey	Europe	1

There are 29 countries represented by authors contributing to the articles, with Europe being the dominant region. However, Brazil, from the Americas, has the highest number of publications. European and Brazilian researchers show a greater interest in the bioindicator and forest theme, as these regions possess abundant biological richness and diverse forest ecosystems. The forests in Europe and Brazil not only host remarkable biodiversity but also play a crucial role in maintaining global environmental balance. This condition motivates researchers in these regions to delve deeper into bioindicators, which provide valuable information about the health of forest ecosystems and the impacts of environmental changes. Such knowledge can support conservation and sustainable management efforts (Berglund et al., 2021; J. S. H. Lee et al., 2011; Storch et al., 2023).

Figure 6 illustrates the collaboration in article publication among authors, including cross-country collaboration, collaboration between universities within a country, and non-collaborative publications. Based on the figure, the results indicate that there are more articles published through collaboration, either within a country or internationally, compared to those with no collaboration. Specifically, there are 18 articles published through collaboration within a country or internationally, while there are 13 articles without collaboration.

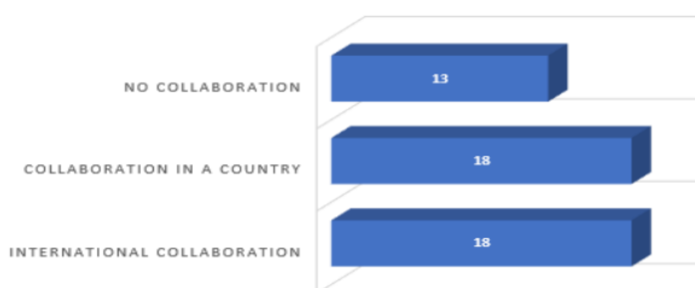

Figure 6. Author collaboration in writing articles

Collaborative research and publications, whether conducted domestically or internationally, are crucial for advancing understanding, innovation, and solutions to global challenges. Collaboration facilitates the exchange of knowledge, resources, and technology among researchers from diverse backgrounds, resulting in a more comprehensive understanding and more effective solutions to complex problems. Both local and international collaborative efforts expand the scope of research, enhance the accuracy and reliability of discoveries, and increase the accessibility of knowledge for the global population. By incorporating perspectives and expertise from various scientific disciplines and cultures, such collaborations have the potential to accelerate advancements in a wide range of fields, including science, technology, social development, and economic growth (Alamah et al., 2023; Mcclunie-Trust et al., 2022; Nyangulu, 2023; H. Shin et al., 2022; van Rijnsoever & Hessels, 2021).

Figure 7 illustrates that the majority of journal articles have five or more authors. This can be observed from the curve representing 24 articles with five or more authors. Additionally, there is one article with two authors, six articles with three authors, and ten articles with four authors. Therefore, it can be concluded that multiple authors contribute to the findings of plant-type bioindicators to determine forest quality and maximize it.

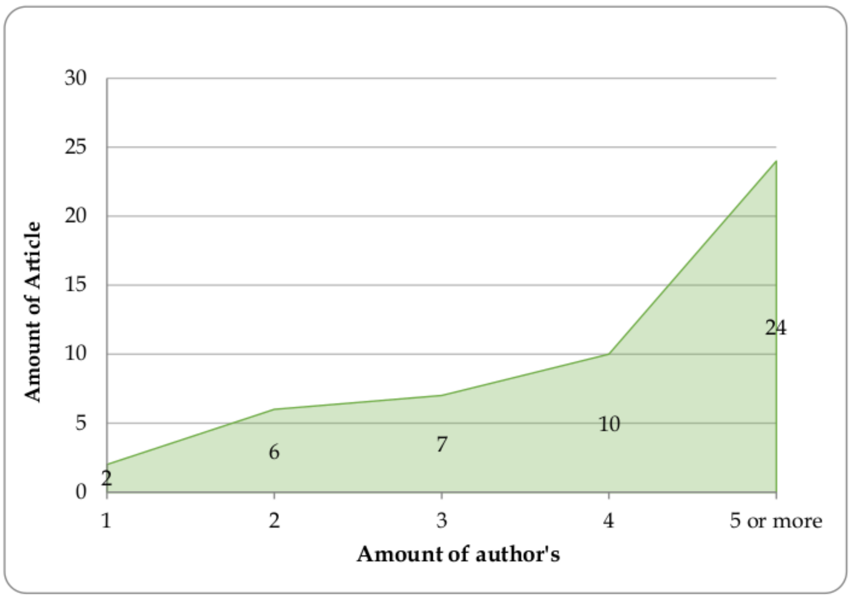

Figure 7. Distribution of scientist collaboration

An effectively crafted article that is published should ideally be authored by multiple individuals. This collaborative approach facilitates the integration of diverse skills, perspectives, and experiences from various authors. Involving multiple contributors allows for a wider range of viewpoints to be encompassed in the article, leading to more comprehensive arguments and more holistic research findings. Additionally, collaborative writing endeavors enable the division of tasks, a more rigorous peer review process, and meticulous validation and verification of discoveries. These factors collectively enhance the quality and credibility of the published outcomes (Borer et al., 2023; Delias et al., 2024; Lingard, 2021; Mcclunie-Trust et al., 2022; Singhal & Kalra, 2021).

Funding Sponsor

Figure 8 illustrates that out of the total 49 articles reviewed, 47 articles received support or sponsorship from external parties. This indicates the presence of financial involvement or external backing in the conducted research. It is crucial to consider the potential influence of sponsors or interests on the objectivity and integrity of the research findings. Transparency and honest disclosure of funding sources and potential conflicts of interest are essential for ensuring the integrity and credibility of research. With support and involvement from external parties, this can serve as a benchmark and foster a strong motivation for authors to produce high-quality research. Financial support from various funding sources, such as government agencies, research foundations, or private companies, enables researchers to access necessary resources like equipment, chemicals, or research personnel (Baur et al., 2019; DeAngelis et al., 2001; Edsall, 2017).

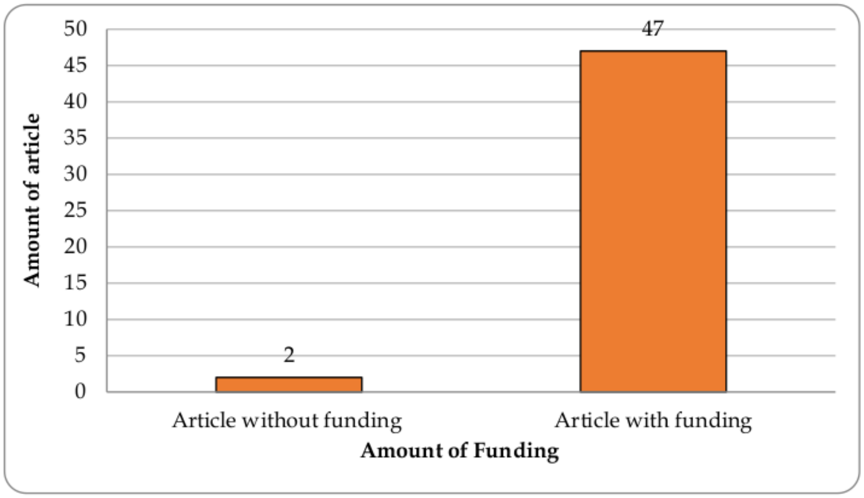

Figure 8. Funding sponsor

The primary impact of this funding is the expansion of research scope. Sufficient financial support allows researchers to engage in larger and more comprehensive studies. Research funding can be viewed as one of the most crucial resources in the science reward system. It enables researchers to collect more data, conduct larger trials, or involve a greater number of participants in their research. This facilitates a deeper and more accurate understanding of the research topic under investigation (Aagaard et al., 2021; Grove, 2018; Neema & Chandrashekar, 2021).

Funding also contributes to the development of technology and innovation. Financial support grants researchers access to the latest technology, facilitates the development of more efficient research methods, and encourages the adoption of new research approaches. This expedites scientific progress and enables new discoveries that can have a positive impact on society. Research and publication funding involves obtaining grants to conduct research and publish scientific articles through a competitive process (J. Lee & Cho, 2023; Schot & Steinmueller, 2018; Zhao et al., 2022).

Furthermore, funding plays a vital role in the publication and dissemination of research findings. Financial support can be utilized to attend scientific conferences, publish articles in reputable journals, and disseminate research results to the public through relevant media and platforms. This allows researchers to share their knowledge and findings with the scientific community and society as a whole, thereby generating a broader and more sustainable impact. Overall, research funding has a significant influence in expanding the scope of research, fostering innovation, and facilitating the dissemination of research results. This financial support plays a critical role in advancing science and providing societal benefits (Beck et al., 2019; Clores & Clores, 2021; McCray et al., 2018; McElfish et al., 2018).

Sample, Method, and Data Analysis

Table 2 presents sample, method, and data analysis data from the 49 articles examined. Based on Table 2, the data analysis employed is a combination of quantitative and qualitative analysis, a common approach used by various authors in their research. Research on bioindicators primarily relies on observation. It is evident that studies related to the topic, specifically the identification of flora and fauna that can serve as bioindicators for forest conditions, necessitate the observation of factors that influence forest health. This is crucial for determining the quality and preservation of the forest and its floral diversity (Markert et al., 2012; Markert & Wünschmann, 2011; Parmar et al., 2016). Various other tools and techniques employed in this research include statistical analysis, indicator value, laboratory analysis, biomonitoring statistics, stainless steel secateurs for collecting plant samples, plant associations, temperature sensors, ICP-MS, Li-6400, and SOFMs. It is worth noting that two journals do not specify the instruments used.

Table 2. Sample, method, and Data analysis

No.	Authors	Sample	Method	Data analysis, technique, and instrument
1	(Almeida et al., 2020)	Animal (nematoda)	Qualitative & quantitative	Data analysis (ANOVA)
2	(Barbosa et al., 2016)	Fungi (aspergillus & penicilant)	Qualitative & Quantitative	Analyzed in the physics and soil fertility
3	(Bernardes Júnior et al., 2020)	Ant	Qualitative & Quantitative	Analysis statistic with the jackknife 1 estimator software
4	(Bini et al., 2013)	Plant (Eucalyptus grandis and Acacia mangium)	Quantitative	Quantitative analysis
5	(Cardoso et al., 2021)	Plant (*Enterolobium contortisiliquum* (Fabaceae))	Qualitative & Quantitative	Fluctuating asymetry
6	(Carron et al., 2020)	Fungi	Qualitative & Quantitative	Quantitative and qualitative analysis
7	(Castro & Espinosa, 2015)	Animal (butterflies)	Qualitative	Qualitative analysis
8	(Cerqueira et al., 2023)	Microbiology	Qualitative & Quantitative	Qualitative analysis

No.	Authors	Sample	Method	Data analysis, technique, and instrument
9	(Gong et al., 2022)	plant (*Populus tomentosa* and *Ficus virens*).	Quantitative	Observation
10	(de Azcárate & Costilla, 2015)	Vegetation	Qualitative	Observation
11	(de Sousa et al., 2019)	Animal (Butterflies)	Qualitative	Qualitative analysis & Observation
12	(Domínguez-Begines et al., 2019)	Animal (nematoda)	Qualitative & Quantitative	Experiment
13	(Fares et al., 2020)	Macrophyte	Quantitative	Observation & Quantitative analysis
14	(Fernández et al., 2018)	Fungal community associated with N pumilio seeds	Qualitative	Observation
15	(Fu et al., 2019)	*Fagus sylvatic* and horse	Quantitative	Quantitative analysis
16	(Gheoca et al., 2021)	Snail	Quantitative	Observation & Quantitative analysis
17	(Helbing et al., 2023)	Vascular plant and insect	Quantitative	Observation
18	(Heydari et al., 2020)	*Quercus brantii, Acer monspessulanum L., Pistacia atlantica Desf, Crataegus puntica C. Koch., Amygdalus scoparia Spach,* and *Lonicera nummularifoli*a	Quantitative	Quantitative analysis
19	(Molina et al., 2016)	Plant	Quantitative	Observation & Quantitative analysis
20	(Kohyt & Skubała, 2013)	Comunities miter (Acari)	Quantitative	Observation and Quantitative analysis
21	(Litavský et al., 2021)	ground beetles	Quantitative	observation & Quantitative analysis
22	(Liu et al., 2022)	nematoda community and soil	Quantitative	Quantitative analysis
23	(Mallmann et al., 2019)	*Dicksonia sellowiana*	Quantitative	Observation & Quantitative analysis
24	(Kohyt & Skubała, 2020)	792 plants	Quantitative	Analysis of environmental variables
25	(Lencinas et al., 2015)	Animal (Pseudoscorpion)	Quantitative	Data Analysis (ANOVA)
26	(Neto et al., 2017)	Floristic, landside sector & lanside strata	Quantitative	Indicator Value & Quantitative analysis
27	(O'Leary et al., 2021)	Plant (Pittosporaceae), Bird	Quantitative	Observation & Quantitative analysis

No.	Authors	Sample	Method	Data analysis, technique, and instrument
28	(Petrokas & Baliuckas, 2017)	Tidak disebutkan	Qualitative	Qualitative analysis
29	(Polechońska et al., 2022)	Water, leaves N. Lutea	Quantitative	The self-organizing feature maps (SOFMs) & Quantitative analysis
30	(Polechońska et al., 2019)	Plant (S. Natans) dan water	Quantitative	Shapiro-Wilk's W-test & homogeneity of variances by Levene's test
31	(Popijač, 2021)	Threes (rings of hole, growth rings, roots, needles, shoots, and soil)	Quantitative	Analysis laboratory & Quantitative analysis
32	(Quevedo et al., 2014)	Ant communites	Quantitative & Qualitative	Quantitative analysis / using pitfall traps
33	(Salemaa et al., 2020)	Water, snow, three, mosses	Quantitative & Qualitative	Quantitative & Qualitative analysis
34	(Scherrer et al., 2019)	Animal (bat)	Qualitative	Observation & combining acoustic recordings
35	(Şenel et al., 2023)	Phenological plant	Qualitative	NDVI & Surface reflectance data
36	(Silva et al., 2019)	Bryophyte, tree tunks, soil, rocks	Quantitative & Qualitative	Observation, Quantitative & Qualitative analysis
37	(Skrynetska et al., 2018)	The plant matetrials and Soil in the city of Sosnowicc	Quantitative	Analysis of varience
38	(Sliacka et al., 2013)	The Ensifera and Caelifera	Quantitative	Observation and Quantitative analysis
39	(Solomentseva, 2022)	Statistics and biometry	Quantitative & Qualitative	Observation and Quantitative & Qualitative analysis
40	(Sousa-Souto et al., 2016)	Ant	Quantitative	Observation and Quantitative analysis
41	(Stašiov et al., 2021)	Soil and leaf	Quantitative	Observation and Quantitative analysis
42	(Stojnić et al., 2019)	Leaves and branches of Quercus petraea (Matt.) Liebl. and Quercus robur	Quantitative & Qualitative	Analysis of varience and Descriptive statistic
43	(Suchara et al., 2015)	Moss, spruce bark, and forest floor humus	Quantitative & Qualitative	Chemical analyses of the samples and Biomonitoring campaigns
44	(Szwalec et al., 2018)	Shoots of herbaceous	Quantitative	Stainless steel secateurs for collectiSng plant samples, a soil sampler for collecting soil samples, a high-speed rotor mill for grinding plant samples, and an atomic flame absorption spectrometer (Unicam Solaar M6) for determining concentrations of cadmium, lead, zinc, and copper

No.	Authors	Sample	Method	Data analysis, technique, and instrument
45	(Taeprayoon et al., 2023)	Mae Tao River basin in Tak Province, Thailand	(not mentioned)	ICP-MS (Inductively Coupled Plasma-Mass Spectrometry)
46	(Fu et al., 2019)	Saplings of both beech and horse chestnut	Quantitative	Temperature sensors
47	(Testé et al., 2020)	Plant associations and phytolith assemblages.	Quantitative	Plant associations and phytolith assemblages.
48	(Wolski & Kruk, 2020)	Bryophyte	Quantitative	Quantitative analysis
49	(R. Zhang et al., 2017)	Moso bamboo tree	Quantitative	Li-6400 (Li-Cor, Lincoln, NE, USA.)

The complexity and diversity of challenges associated with comprehending and supervising environmental health are exemplified by the assortment of analytical methods, instruments, and techniques employed to evaluate bioindicators. This multifarious approach facilitates the exploration of various facets of bioindication, ranging from the use of living organisms as indicators to the chemical or physical analysis of their habitats. Biotic indices, statistical analysis, and the use of sensors or modern monitoring devices are among the analytical methods employed to understand changes in the environment and their impact on biodiversity. Overall, the diversity of methods employed signifies ongoing efforts to enhance our understanding of the intricate nature of ecosystems and the environmental obstacles they face, as well as to strengthen ongoing conservation and environmental restoration initiatives.

CONCLUSION

This systematic literature review (SLR) presents compelling findings. In the analysis of the publication trend on the topic of forest bioindicators, it was observed that there was a decline from 2021 to 2023, with the peak occurring in 2020 when a total of 9 articles were published. The issue of forest bioindicators can be approached through quantitative, qualitative, and mixed research methods. Notably, the authors who received the most attention in this field are F. Helbing, J. Litavsky, S. Stasiov, Dominguez, and De deyn. The dominant keyword used in the articles is biodiversity, closely related to forestry botany. The authors of these articles originate from 29 different countries, with Europe accounting for the majority at 62.07%. In terms of collaboration, it was observed that a significant number of articles were published through both national and international collaborations. Additionally, 47 articles received support or sponsorship from external entities. This SLR serves as a valuable reference for researchers interested in the topic of forest bioindicators, particularly those focused on diverse subjects such as flora and fauna, thus contributing to the enrichment of alternative forest bioindicators.

RECOMMENDATIONS

We highly recommend that future authors prioritize the study of bioindicator plants, bioindicator animals, agricultural land indicators, water indicators, and biomonitoring. Research focused on these areas has the potential to provide a more comprehensive understanding of the subject matter.

Author Contributions
All authors have sufficiently contributed to the study and agreed with the results and conclusions.

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