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Bibliometric Analysis of Silviculture and Climate Change: Trends, Patterns, and Research Hotspots

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Abstract: This research presents a bibliometric analysis of scientific studies addressing the intersection between silviculture and climate change. Analyzing 478 studies published between 1993 and 2023, this analysis reveals research trends, international collaboration networks, and the geographical distribution of scientific production on the topic. In recent years, especially after 2010, interest in the role of silviculture in adapting to and mitigating climate change has grown rapidly. The analysis of collaborative networks highlights the central role of the United States in this field, with countries such as Germany, Canada, and Spain also making important contributions through cross-border research partnerships. The United States and Europe are at the forefront of scientific production, revealing a growing awareness of the relationship between forest management practices and climate change. The research shows that key concepts such as 'forest management,' 'carbon sequestration,' and 'resilience' are becoming increasingly prominent, and research is focusing on sustainability and climate change adaptation strategies. In conclusion, this study highlights the importance of increased global collaboration and multidisciplinary approaches in research on climate change and silviculture and provides trends that will contribute to the development of sustainable forest management policies.

Keywords: Bibliometric, Biblioshiny, Climate change, Rstudio, Silviculture

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1. INTRODUCTION

Climate change is widely recognized as one of the biggest environmental problems of today (Pachauri et al., 2014). It will not be surprising that forest ecosystems also have their share of this environmental problem (Moore and Allard, 2006; Anderegg et al., 2022). Indeed, many studies have provided evidence that climate change is triggering tree mortality by increasing the severity of drought (Bigler et al., 2006; Senf et al., 2020). In addition, there are insights that climate change could increase damage from insect outbreaks and increase the amount of combustible material, leading to changes in fire regimes (Battisti et al., 2005; Pureswaran et al., 2015; Piqué and Domènech, 2018; Abram et al., 2021).

This scenario highlights the growing significance of implementing efficient solutions for forest management. Silviculture, the science and practice of controlling the establishment, growth, composition, and quality of forests, is at the forefront of efforts to manage and mitigate the impacts of climate change on forested landscapes (Saatçioğlu, 1971; Genç, 2013). Traditionally, silvicultural practices have focused on optimizing forest productivity, increasing timber yields, and maintaining forest health (Saatçioğlu, 1971; Genç, 2013). Nevertheless, as the impacts of climate change become more pronounced, the objectives of silviculture are changing (Achim et al., 2022). Today, there is increasing emphasis on developing adaptive management strategies that increase forest resilience to climate-induced stressors such as rising temperatures, prolonged droughts, pest outbreaks, and more frequent and intense wildfires (Sohn et al., 2016; Manrique-Alba et al., 2020; Achim et al., 2022; Moreau et al., 2022).

The intersection of silviculture and climate change is of great importance not only for the sustainable management of forests but also for the broader goals of climate change mitigation and adaptation (Achim et al., 2022). Effective silvicultural practices can contribute to carbon sequestration (Ameray et al., 2021), reduce the vulnerability of forests to climate impacts (Manrique-Alba et al., 2020), and support biodiversity conservation (Latterini et al., 2023). In contrast, the rapidly changing climate requires rethinking traditional silvicultural approaches to ensure they remain effective under new and challenging environmental conditions (Achim et al., 2022).

Given the critical nature of this relationship, it is crucial to understand the current state of research at the intersection of silviculture and climate change (Achim et al., 2022). Bibliometric analysis provides a systematic and quantitative approach to mapping the scientific literature, revealing trends, key research themes, influential institutions, and collaborative networks (Yardibi et al., 2024). Using this approach, many studies have been conducted in different fields (Donthu et al., 2021; Beram, 2024; Berk et al., 2024; Tekin and Akar, 2024). Such an analysis is invaluable for identifying research gaps, informing future work, and guiding policy development in the context of climate-smart forestry. This study aims to provide a comprehensive overview of the research landscape, offering insights into the evolution of silvicultural practices in response to climate change and highlighting global efforts to address this pressing environmental challenge.

2. MATERIAL AND METHOD

In this research, we conducted a bibliometric analysis of academic studies on “Silviculture” and “Climate Change” in the Web of Science Core Collection (WOSCC) database. WOSCC has more than 21,000 peer-reviewed journals and is one of the most frequently used and trusted global citation databases for academic article analysis (Yeung, 2023). We scanned the studies on climate change-silviculture relations between 1991-2023 through the WOSCC database. The oldest publication year on the subject in the database was determined as 1991. We downloaded all data on the same day to avoid deviations caused by database updates. Before downloading the data, we filtered the year, document type, and study language, respectively. While filtering the words, we searched for studies that included both climate change and silviculture as topics.

For bibliometric analyses, we used the Biblioshiny web-based interface running with the “bibliometrix” package in the R programming language (Aria and Cuccurullo, 2017; R Core Team, 2021). In order to perform the analyses by connecting to the web interface via R, the package required for bibliometric analysis was first

installed using the following commands: install.packages("devtools"), devtools::install_github (massimoaria/bibliometrix). Then we activated the package's library with the "*library(bibliometrix)*" command. Finally, we accessed the database using the *biblioshiny()* code. We selected WOS as the file type in the biblioshiny database and imported the prepared text file into the program. We then analyzed key statistics, journals, keywords, authors, institutions, countries, and studies.

3. RESULTS AND DISCUSSION

The words scanned from the WOSCC database and the number of studies obtained as a result of filtering are presented in Figure 1.

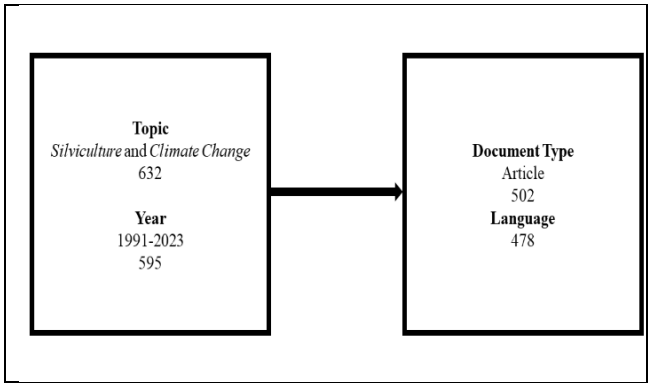

Figure 1. Database scanning and filtering algorithm

In the research, firstly, the studies in which the words "Silviculture" and "Climate Change" were mentioned together were searched, and 632 studies were identified. Then, the year (1991-2023), document type (Article), and language (English) options were filtered, respectively. As a result of the filtering, it was seen that the studies obtained covered the period between 1993 and 2023. There were 478 studies by 1911 authors; 38 of these studies were single-authored. The total number of references used was found to be 26545.

Looking at study production by year, in general, there was an increasing trend in the number of articles over the years (Figure 2). This probably indicates that the topic of interest has received more attention over time or that more relevant research resources have been published (Yardibi et al., 2024). It may also indicate a correlative increase.

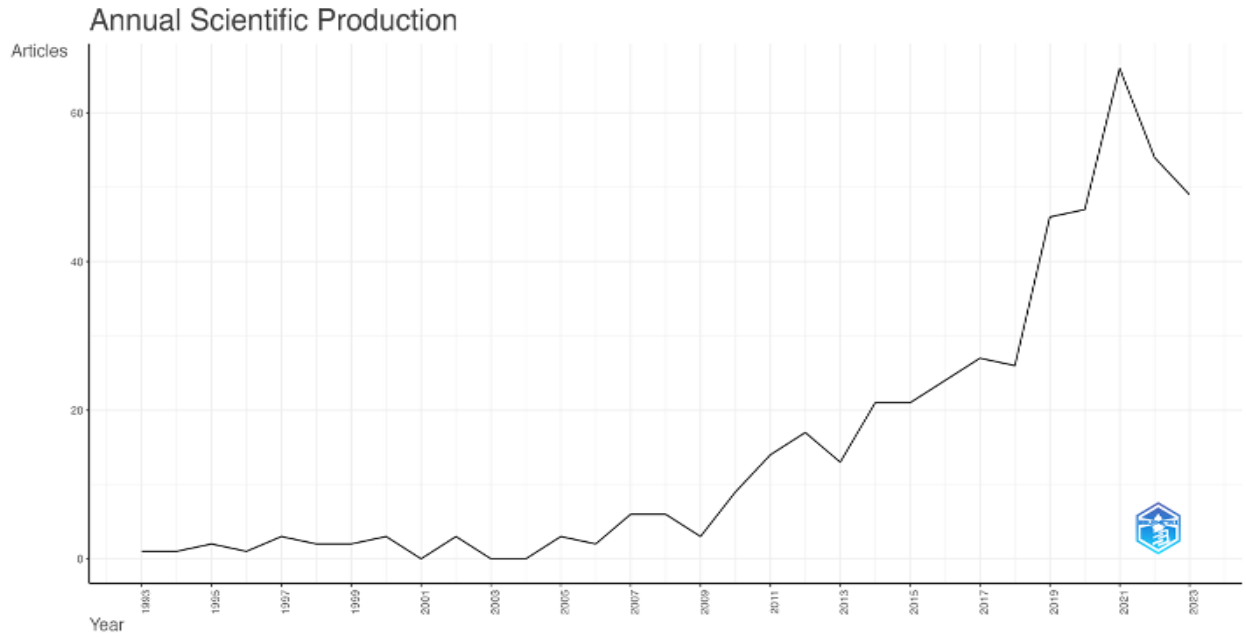

Figure 2. Scientific production of articles on related topics by year.

The journals that contributed the most to research on silviculture and climate change are given in Figure 3.

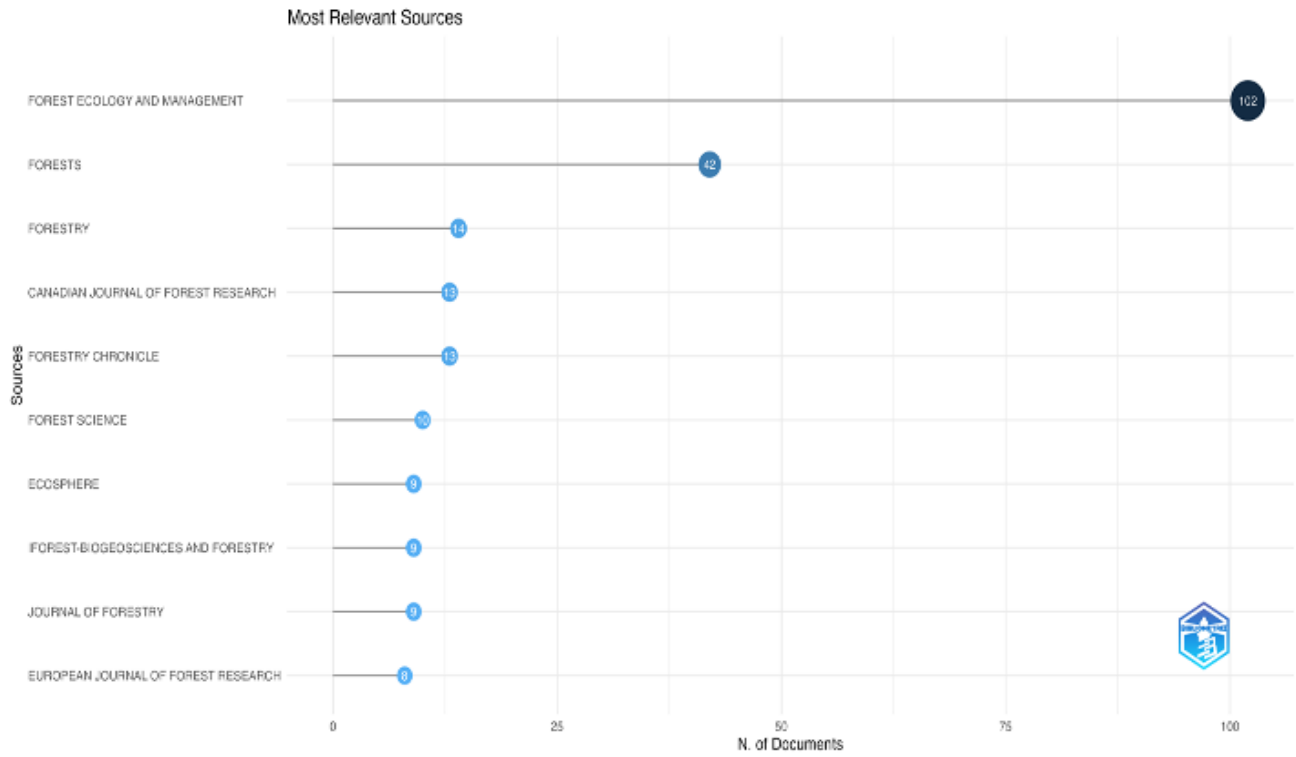

Figure 3. The top 10 journals that published the most studies on the subject.

The journal that published the greatest number of publications on these topics was “Forest Ecology and Management.” With a grand total of 102 articles, it outperformed other journals by a significant margin. The journal's primary emphasis on the intersection of silviculture and climate change positions it as a prominent journal for endeavors aimed at mitigating or adapting to climate change. “Forests” ranked second with a total of 42 articles. Nevertheless, this constituted around 50% of the total publications published in “Forest Ecology and Management.” The other journals that made contributions were “Forestry,” “Canadian Journal of Forest Research,” and “Forestry Chronicle.” The quantity of articles published in these journals was very comparable. Each journal had a specific emphasis on silviculture and climate change, and each of them produced a total of 13 to 14 pieces. Additionally, the journals included other journals such as “Forest Science,” “Ecosphere,” “iForest-Biogeosciences and Forestry,” and “Journal of Forestry,” with 9 to 10 articles published in each journal. In 10th place was the “European Journal of Forest Research” with eight articles. These results indicate a wide-ranging curiosity and investigation into how forest management techniques might adjust to a shifting environment (Achim et al., 2022).

The authors who contributed the most to research on silviculture and climate change are given in Figure 3.

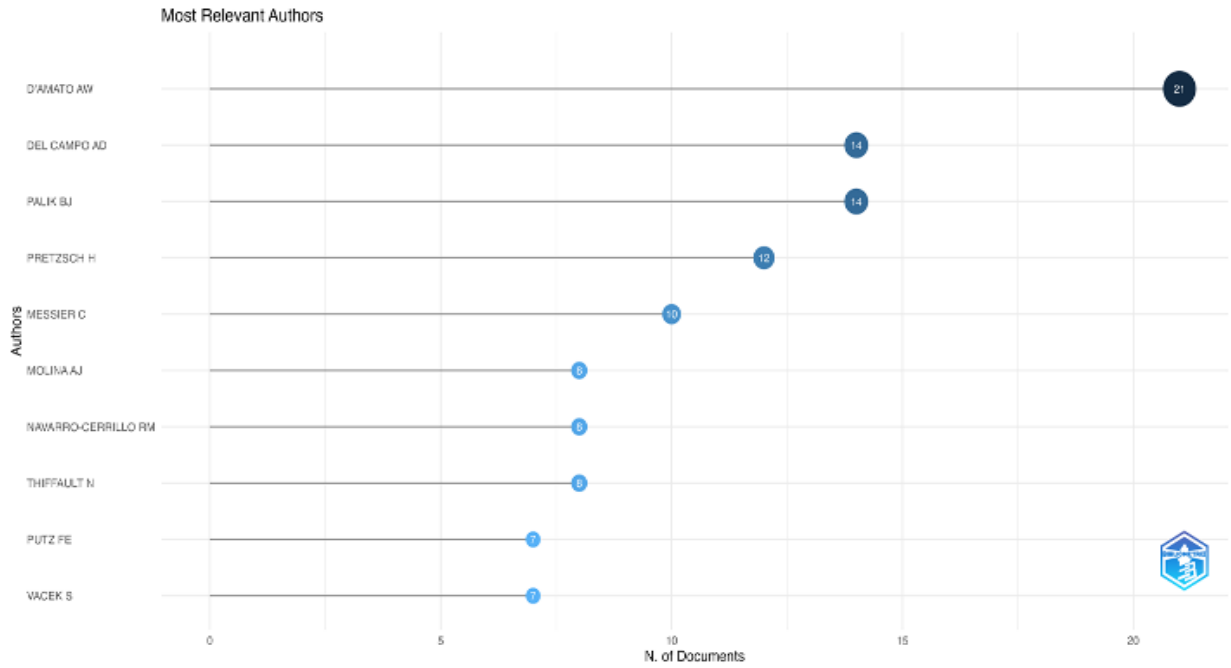

Figure 4. Top 10 authors who published the most studies on the topic.

"D'Amato AW" emerged as the most prolific author in this discipline, having produced the greatest number of publications. This author has emerged as a leading figure in the field, with 21 published articles on silviculture and climate change. This showcases the author's profound expertise and notable accomplishments in this specific domain, emphasizing his work as a crucial source of reference for researchers investigating this subject matter. "Del Campo AD" and "Palik BJ" were other authors who made important contributions, publishing 14 documents each. "Pretzsch H" (12 articles) and "Messier C" (10 articles) also made important contributions in this field, but they were slightly behind the first three authors. "Molina AJ," "Navarro-Cerrillo RM," "Thiffault N," "Putz Fe," and "Vacek S" were also on the list with 7-8 articles each. The works of these authors can be sources that should be taken into consideration in the research on the subject. Researchers can direct their own studies by examining the works of these authors.

In publications in silviculture and climate change, the countries of the authors responsible for the correspondence and how these countries are distributed between single country publications (SCP - Single Country Publications) and multiple country publications (MCP - Multiple Country Publications) are given in Figure 5.

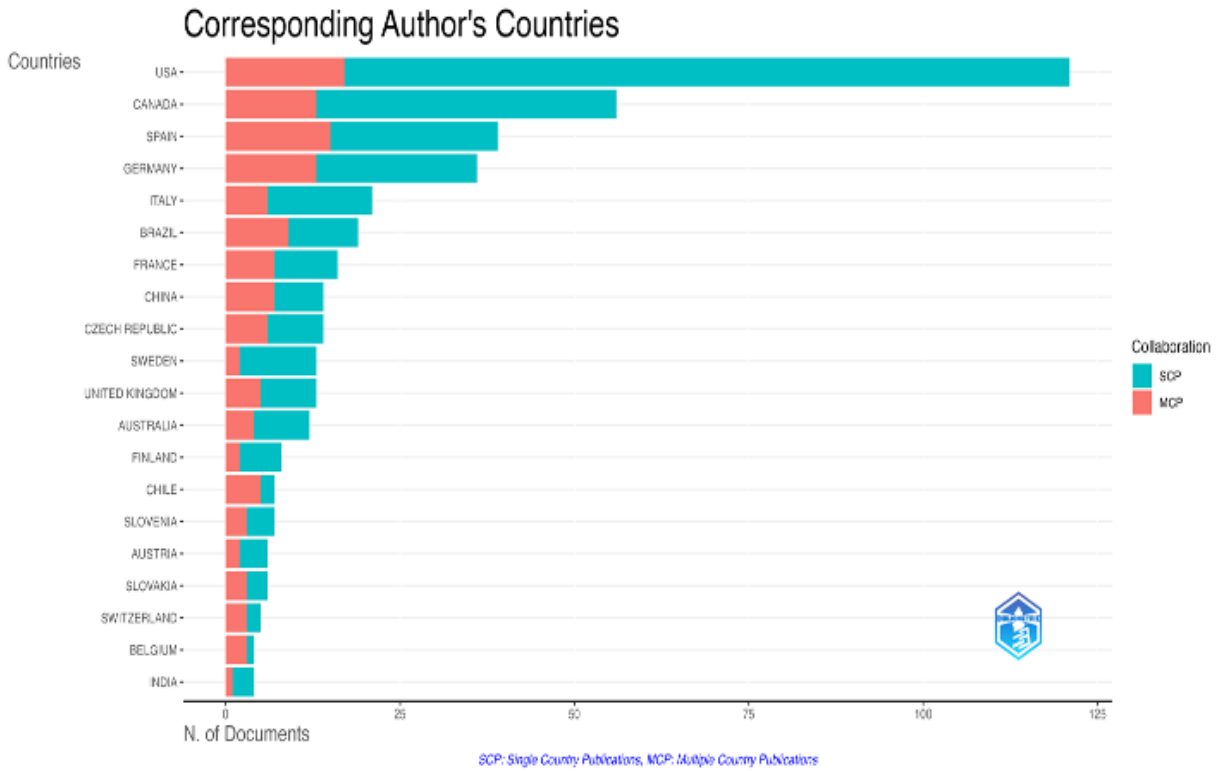

Figure 5. Countries of corresponding authors

The United States of America (USA) had by far the largest number of publications in this field. Authors in the USA were the leaders not only in single-country contributions, but also in multi-country collaborations. The vast majority of publications from the USA were single-country contributions. These show that the USA plays a leading role in research in this field and has a wide network of international collaborations. Following the USA, Canada and Spain also had a significant number of publications in this field. While Canada focused more on single-country broadcasts, Spain played a more active role in international cooperation. This reveals that both countries make significant contributions to research in this field, but follow different strategies in terms of cooperation. Germany and Italy also had a considerable number of publications in this field. Both countries had a significant number of publications in both SCP and MCP, indicating that they are active in both national and international research. Brazil, France, and China were more prominent in multi-country publications (MCP), which emphasizes the importance they attach to international collaborations. These countries seem to be integrated into international scientific networks and make global contributions in this field. Countries such as the Czech Republic, Sweden, the United Kingdom, Australia and Finland were in the middle of the list of major contributors in this area. Chile, Slovenia, Austria, Slovakia, Slovakia, Switzerland, Belgium and India were the only other contributors in the bottom 20. In conclusion, the USA, Canada and Western European countries are the leaders in this field and seem to be very open to international collaboration. This may give an idea about which countries researchers can find more studies and collaborations in this field. Especially for researchers who want to take part in international projects, countries with high MCP rates are important in terms of collaboration opportunities (Waham et al., 2023).

The treemap showing the importance and frequency of keywords used in research on silviculture and climate change is given in Figure 6.

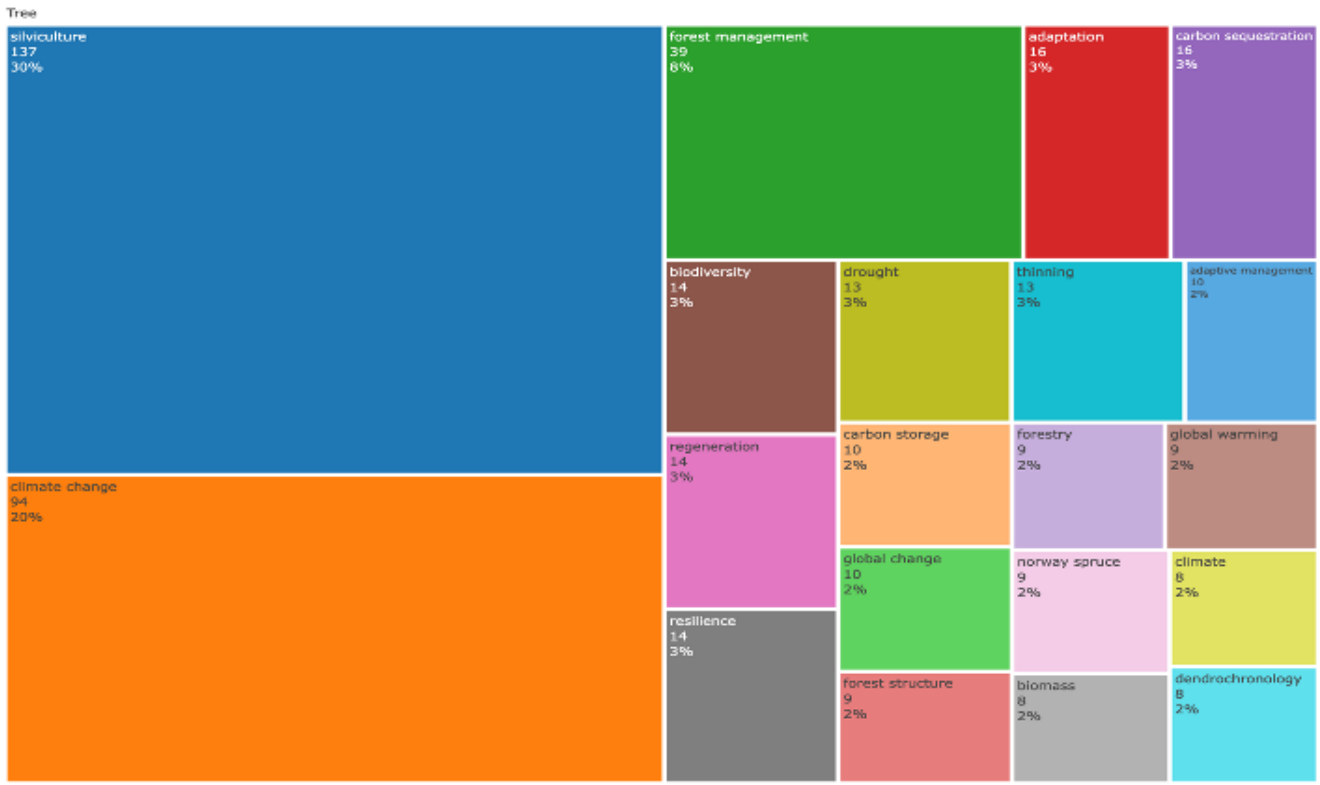

Figure 6. Treemap for the top 20 keywords.

"Silviculture" had a 30% share, and 'climate change' had a 20% share in the keywords. This shows that these two terms are the most commonly used keywords in the research literature and that the relationship between silviculture and climate change is the most focused topic in the studies. The terms "forest management" and "adaptation" were also important. This suggests that developing forest management strategies to adapt to climate change is an important theme in research (Achim et al., 2022). Terms such as "biodiversity" and "drought" were again keywords frequently used in studies examining the impacts of climate change on ecosystems. This suggests that researchers are exploring ways to protect biodiversity and cope with drought under climate change. The terms "carbon sequestration" and "global warming" are important components of research focusing on efforts to mitigate climate change. This highlights the direct link between carbon management and climate change (Ameray et al., 2021).

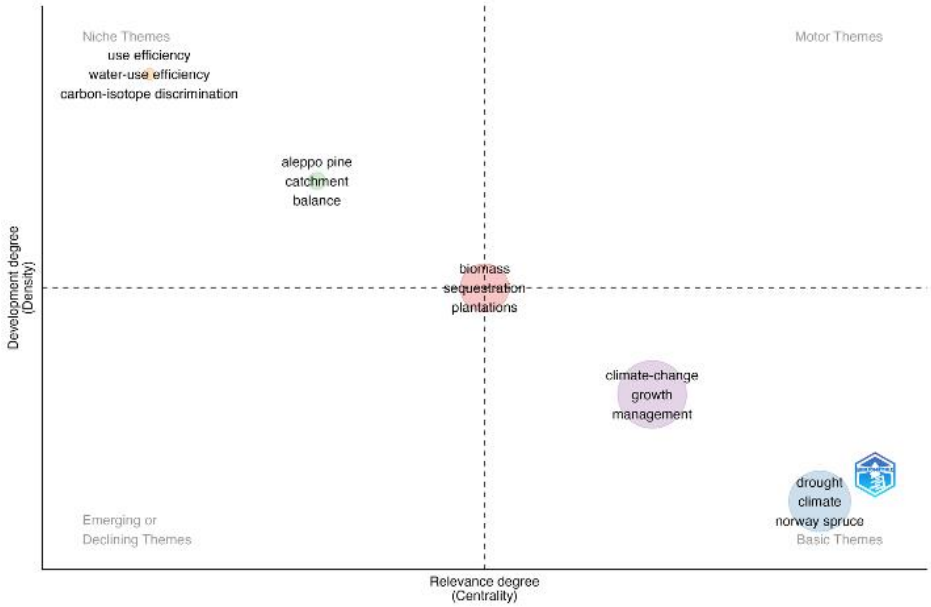

Figure 7. Thematic map.

The thematic map showed that the keywords used in research on silviculture and climate change fall into four main groups (Figure 7). Motor Themes (Top right corner): Includes central and well-developed themes (Kaiser and Kuckertz, 2023; Madsen et al., 2023). These themes are very important for the relevant research area and are well-established in the literature. However, in this way, this region is empty, i.e., there was no group identified as a motor theme in this research area. In the Niche Themes section in the top left corner, terms such as "use efficiency", "water-use efficiency" and "carbon-isotope discrimination" are topics with high density but low centrality. This result indicates that these themes belong to a specific area of expertise and do not yet play a central role in the broader research field (Kaiser and Kuckertz, 2023; Madsen et al., 2023). The bottom left section, emerging or declining themes, contains themes with low intensity and low centrality (Kaiser and Kuckertz, 2023; Madsen et al., 2023). These themes may be either emerging or declining in importance in the research field. On the map, this area appears empty, which may indicate that such themes have not yet crystallized or are not present. The Basic Themes in the bottom right corner include terms such as "drought", "climate" and "Norway spruce". These themes have high centrality but low intensity, meaning that these topics are considered a central part of the research, but have not yet been developed in detail (Kaiser and Kuckertz, 2023; Madsen et al., 2023). There are no themes in the Motor Themes section. Motor themes generally have high centrality and high intensity and represent topics that are critical to moving the research area forward. The absence of such themes in this map may indicate that there are important themes in this area that are still to be developed or have not yet become evident. Overall, this thematic map shows which topics are central to silviculture and climate change research, which are niche or emerging, and which are basic but not elaborated (Kaiser and Kuckertz, 2023; Madsen et al., 2023). This type of analysis can help researchers understand which areas need more focus.

A thematic evolution map showing how research topics in the field of silviculture and climate change have evolved over time by setting the publication dates of IPCC reports as thresholds is given in Figure 8.

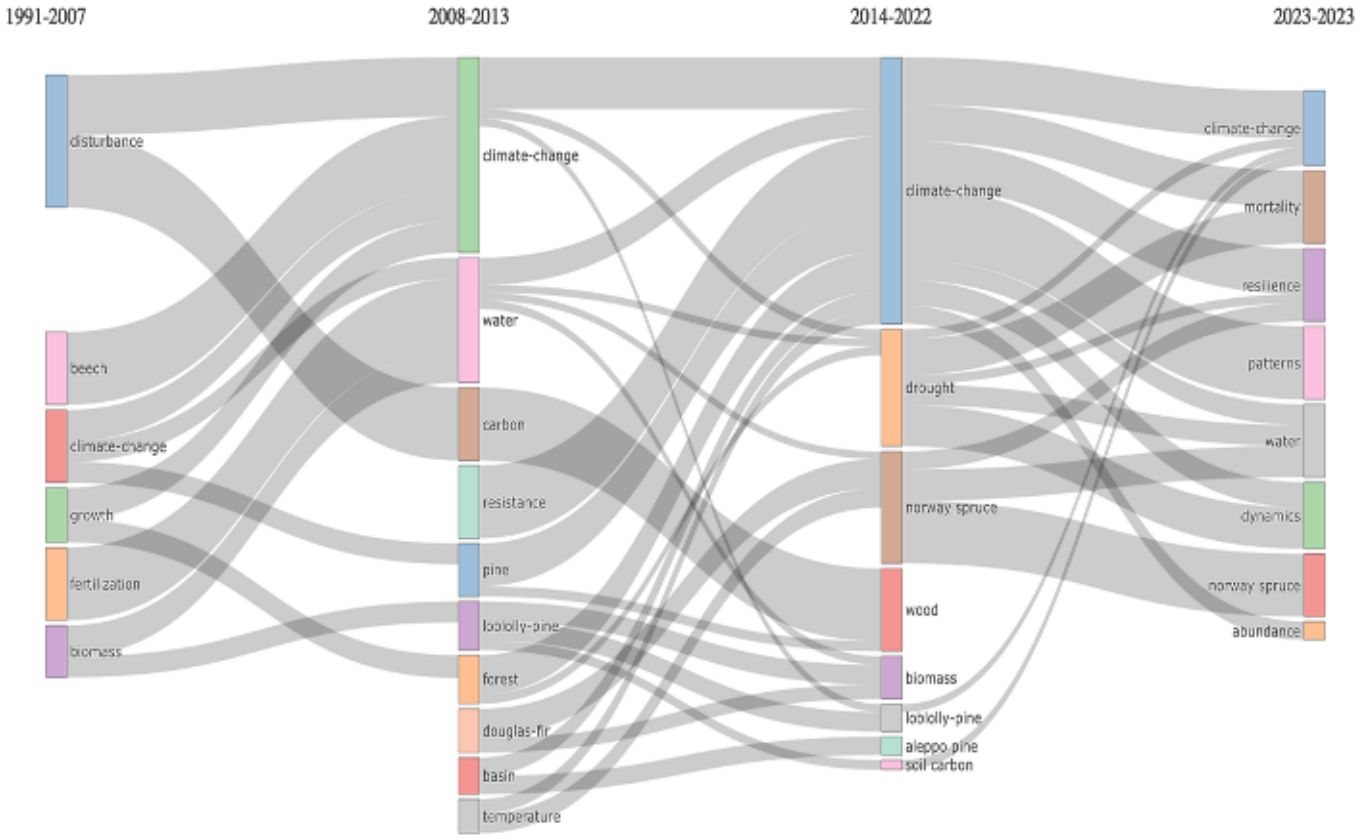

Figure 8. Thematic evolution of keywords by years.

In the period 1991-2007, the themes “disturbance”, “beech”, “climate-change”, “growth”, “fertilization”, and “biomass” were prominent. These themes seem to mean that the work is focusing on the responses of forest ecosystems to changing environmental conditions and how tree species grow under these conditions. In the period 2008-2013, the theme “Climate Change” was still central, with the addition of the themes “water” and “carbon”. This shows a growing interest in issues such as the impacts of climate change on the water cycle and carbon sequestration strategies. Themes such as “resistance” and “pine” also gained importance during this period, indicating that the resilience of specific species to climate change was being explored. In the 2014-2022 period, “climate-change” remained a dominant theme, but specific topics such as “drought” and “Norway spruce” emerged. Studies on drought and specific tree species show growing interest in the specific impacts of climate change. Recently, the theme of “climate-change” has again remained at the forefront, but in addition, themes such as “mortality”, “resilience”, and “patterns” have gained importance. These themes seem to represent studies that investigate how forest ecosystems survive and change in the face of climate change. Overall, this map shows how silviculture and climate change research has evolved in parallel with the publication dates of the IPCC reports and how their focus has changed (Zhang et al., 2022). Each period has developed new themes, expanding or deepening the research topics of the previous period, reflecting how strategies to adapt to and mitigate climate change have evolved over time (Zhang et al., 2022).

The network of scientific cooperation between countries is given in Figure 9. This visual shows which countries cooperate most intensively in research on silviculture and climate change and how these collaborations are shaped (Segura-Robles et al., 2020). The lines in the image show the intensity of cooperation between countries (Segura-Robles et al., 2020). The multiplicity and diversity of these lines reveals that research in the field of silviculture and climate change has a very international structure and that many countries share information and resources in this field.

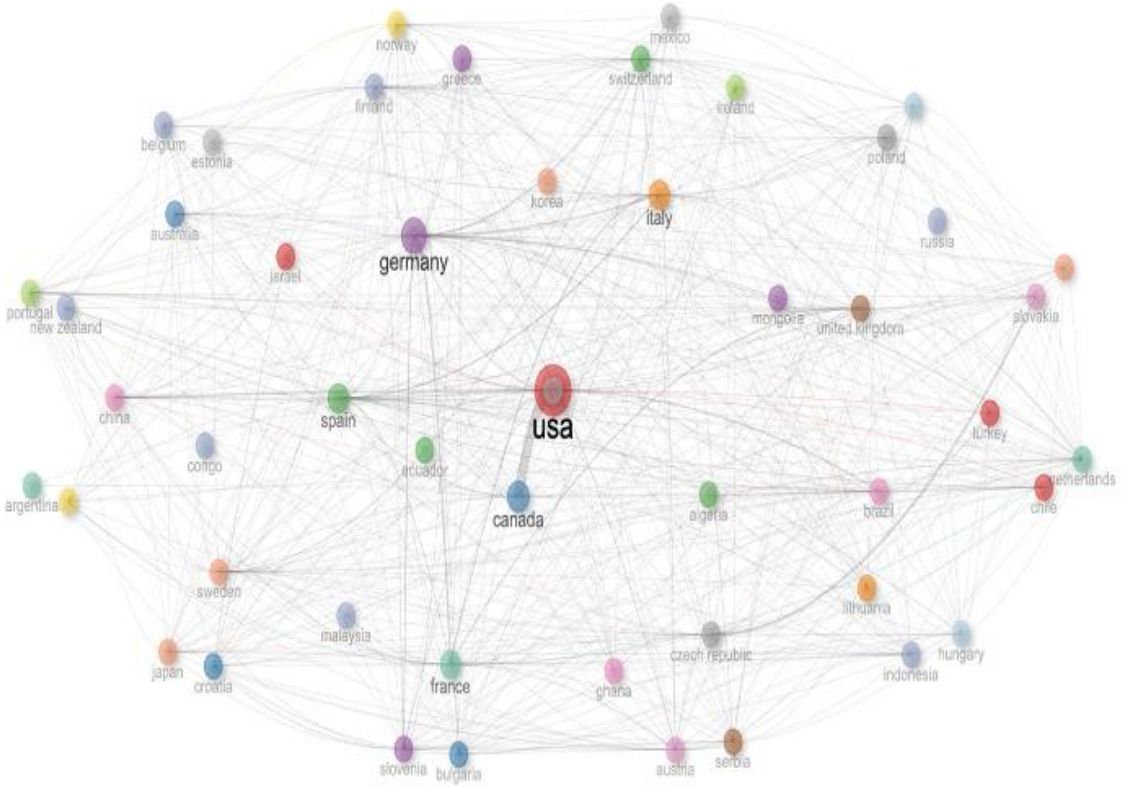

Figure 9. Collaboration networks of the countries.

The United States (US) was by far the largest node in the visual. This shows that the US is the country that cooperates the most in this area. The US has formal collaborations with many different countries and is a global leader in research in this area. Germany, Canada, and Spain were also important nodes. In addition to their intensive collaboration with the US, these countries had also established strong leadership among themselves. There were also summary collaborations with other countries in Europe and the Americas. Countries such as France, Italy, the United Kingdom, and the Netherlands stood out as important collaboration nodes in Europe. These countries seem to continue to cooperate with both other countries in Europe and leading research centres such as the US and Canada. Türkiye's Contribution: Although Türkiye is a smaller node, it was seen that it has established connections with many different countries. This shows that Türkiye has a contribution to research in this area and is involved in international collaborations.

5. CONCLUSIONS

In this study, a bibliometric analysis of scientific publications on silviculture and climate change was conducted. The results show that the relationship between these two important topics is increasingly becoming a global research focus.

The annual scientific production graph shows that there has been a significant increase in the number of articles published in this field since the 1990s. This increase accelerated, especially in the 2010s, indicating that the impacts of climate change on silviculture are being addressed more widely. In particular, the journal “Forest Ecology and Management” stands out as the journal that publishes the most in this field and seems to be a focal point in this field.

Keyword analysis and thematic maps show how the relationship between silviculture and climate change has evolved over time and which themes have become prominent. “Silviculture” and ‘climate change’ are among the most used keywords and these two concepts play a central role in research. In addition, topics such as forest management, adaptation, drought, and biodiversity are among other important themes that are frequently addressed. The thematic evolution map shows that in parallel with the publication periods of the IPCC reports, research focuses on increasingly more specific and in-depth topics. Early on, the focus was on more general topics, while over time there has been an increasing focus on more niche topics such as specific species, drought, and the dynamics of forest ecosystems.

Collaborative networks between countries reveal the global nature of the work on silviculture and climate change. While the US is a leader in this field, countries such as Germany, Canada and Spain are also engaged in important collaborations. European countries are making significant contributions to the development of research in this field by establishing strong scientific links with the USA and Canada. Türkiye, although a smaller node, plays an active role in this field by participating in international collaborations.

In conclusion, this bibliometric analysis shows that research in silviculture and climate change covers a wide range of topics and that knowledge in this field is enriched by international collaborations. Future research can help us better understand the impacts of climate change on forest ecosystems by focusing more on issues at the intersection of these two disciplines. Furthermore, further strengthening of international collaborations can encourage knowledge sharing and the development of innovative solutions in this field. The critical role of silviculture practices in adapting to and mitigating climate change is of great importance from both a scientific and practical perspective. Therefore, continued research is essential for sustainable forest management and global environmental health. In this framework, we believe that our article can guide future studies on these issues and open new horizons for researchers on the subject.

Ethics Committee Approval
N/A

Peer-review
Externally peer-reviewed.

Author Contributions
All process steps, such as conceptualization, research, analysis, visualization, methodology, and writing were carried out by Mahmut Çerçioğlu. The author has read and accepted the published version of the article.

Conflict of Interest
The author has no conflicts of interest to declare.

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