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Carbon Dynamics of Tropical Forests and Their Role in Climate Change Mitigation: A Bibliometric Analysis (2000-2025)

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ABSTRACT

Tropical forests play a critical role in global carbon cycling and climate change mitigation; however, research in this field has expanded rapidly and remains fragmented across disciplines. This study conducted a bibliometric analysis of scientific publications on carbon dynamics in tropical forests from 2000 to 2025 using data from the OpenAlex database. A total of 5,517 articles were analyzed using the Bibliometrix package in R and Biblioshiny to examine publication trends, citation patterns, key authors, sources, collaboration networks and thematic evolution. Results indicate a steady increase in scientific output, with an annual growth rate of 6.76%, reflecting growing global attention to forest-based climate solutions. Highly cited studies emphasize the importance of biomass estimation, carbon mapping and remote sensing technologies. The field is characterized by strong collaboration, with an average of 6.15 co-authors per document and 45.22% international co-authorship. Core journals such as Forest Ecology and Management and Global Change Biology dominate publication output. Thematic analysis reveals a transition from traditional ecological studies to integrated approaches involving remote sensing and environmental science. Despite this progress, a core-periphery pattern persists in global collaboration, highlighting the need for greater inclusion of tropical regions in research.

Key words: Bibliometric analysis, Carbon, Climate change, Tropical forests.

Tropical forests play a critical role in the global carbon cycle and are widely recognized as one of the most important natural systems for climate change mitigation. These ecosystems store vast amounts of carbon in aboveground biomass, soils and vegetation, acting as significant carbon sinks that regulate atmospheric carbon dioxide concentrations (Pan *et al.,* 2011; Saatchi *et al.,* 2011; Sharma *et al.,* 2020). However, increasing pressures from deforestation, forest degradation and land-use change threaten their capacity to sequester carbon, thereby exacerbating global climate change (Hansen *et al.,* 2013; Lewis *et al.,* 2015). Understanding the dynamics of carbon storage, sequestration and emissions in tropical forests is therefore essential for developing effective mitigation strategies and informing international climate policies.

Over the past two decades, research on tropical forest carbon dynamics has expanded substantially, driven by advances in ecological monitoring, remote sensing technologies and global climate frameworks. Early studies primarily focused on field-based measurements of biomass and carbon stocks, often relying on permanent sample plots and allometric equations (Chave *et al.,* 2005; Phillips *et al.,* 2002). More recently, the integration of satellite-based observations and geospatial techniques has enabled large-scale assessments of forest carbon, improving both spatial coverage and temporal monitoring (Baccini *et al.,* 2012; Asner *et al.,* 2010). The integration of high-resolution remote sensing, GPS and GIS technologies has significantly improved environmental monitoring and resource characterization in recent decades (Sahu *et al.,* 2015). Likewise, recent advances in spatial analysis and geospatial technologies have improved ecosystem assessment and environmental monitoring, particularly in studies related to soil degradation and pollution assessment (Aswad *et al.,* 2025). This shift toward technology-driven approaches reflects the increasing need for accurate, scalable and policy-relevant carbon estimates, particularly in the context of mechanisms such as REDD+ (Reducing emissions from deforestation and forest degradation).

Despite the growing body of literature, the field remains highly interdisciplinary, encompassing forest ecology, environmental science, geography, climate science and remote sensing. As a result, research outputs are dispersed across numerous journals, authors and thematic areas. Previous studies have highlighted the importance of synthesizing scientific knowledge to better understand research trends, collaboration patterns and emerging topics in environmental sciences (Donthu *et al.,* 2021; Aria and Cuccurullo, 2017). Bibliometric analysis has emerged as a powerful tool for quantitatively evaluating

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scientific production, identifying influential contributors and mapping the intellectual structure of research fields.

In the context of tropical forest carbon dynamics, a comprehensive bibliometric assessment is particularly valuable for several reasons. First, it enables the identification of dominant research themes, such as biomass estimation, carbon sequestration and climate change mitigation, which are central to global sustainability agendas. Second, it reveals the evolution of research priorities over time, including the increasing prominence of remote sensing and geospatial technologies in carbon monitoring. Third, it provides insights into global collaboration networks, highlighting disparities between developed and tropical countries where forests are located. These insights are critical for addressing knowledge gaps and promoting more inclusive and regionally relevant research.

Furthermore, the rapid expansion of scientific output in this domain necessitates systematic evaluation to avoid fragmentation and duplication of research efforts. With thousands of publications produced over the last two decades, it is increasingly challenging to synthesize trends using traditional review approaches alone. Bibliometric methods allow for a structured and reproducible analysis of large datasets, offering a comprehensive overview of the field's development, key contributors and future directions.

Therefore, this study aims to conduct a bibliometric analysis of scientific publications on carbon dynamics in tropical forests and their role in climate change mitigation from 2000 to 2025. Specifically, this study seeks to: (1) examine the temporal trends in scientific production and citation patterns; (2) identify the most influential authors, journals and publications; (3) analyze global collaboration networks among countries; and (4) explore the conceptual structure and thematic evolution of the field. By providing a systematic and data-driven synthesis, this study contributes to a deeper understanding of the development and current state of research on tropical forest carbon dynamics and offers insights to guide future scientific and policy directions.

Study design

This study employed a bibliometric research design to systematically analyze scientific publications on carbon dynamics in tropical forests and their role in climate change mitigation. Bibliometric analysis is a quantitative approach used to evaluate patterns in scientific literature, including publication trends, citation structures, authorship patterns and conceptual development within a research field (Aria and Cuccurullo, 2017; Donthu *et al.,* 2021). This approach enables a comprehensive understanding of the intellectual structure, evolution and global collaboration dynamics of the field.

The overall workflow of the study is illustrated in Fig 1, which summarizes the steps involved from data retrieval to bibliometric visualization and interpretation.

Data sources

The bibliographic data used in this study were obtained from the OpenAlex database, an open and comprehensive scholarly database that indexes academic publications, citations, authors and institutions across multiple scientific disciplines. OpenAlex provides structured metadata including authors, titles, publication years, journals, affiliations, keywords and citation counts, making it suitable for bibliometric research.

The database was selected because it offers large-scale coverage of scholarly literature and open accessibility, enabling systematic retrieval and reproducibility of bibliometric datasets.

Data search and extraction

A systematic search strategy was employed to retrieve relevant publications related to carbon dynamics in tropical forests and their role in climate change mitigation. The search was conducted using combinations of keywords associated with tropical forests.

The search query included terms such as:

("Tropical forest*" or rainforest* or "Humid tropics").

and

("Carbon stock*" or "Carbon sequestration" or "Carbon storage".

or "Carbon dynamic*" or "forest carbon".

or "Aboveground biomass" or biomass or "Carbon sink*").

The search was limited to publications within the period 2000-2025 to capture the evolution of research over the past two decades. Only journal articles were included to ensure the quality and consistency of the bibliometric dataset with available abstracts and written in English. The initial search yielded a total of 5,559 records, which were subsequently exported for further processing and analysis.

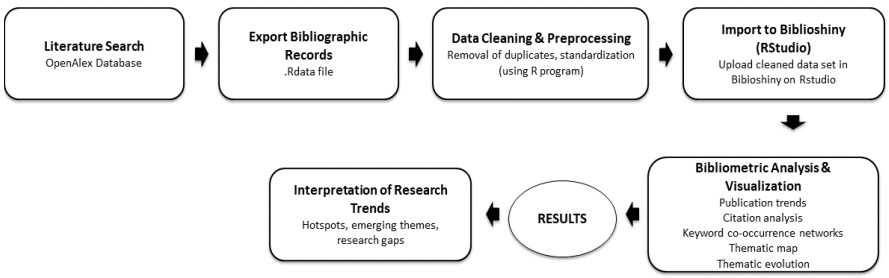


Fig 1: Workflow of the bibliometric analysis showing the process from literature retrieval in the OpenAlex database, data preprocessing, bibliometric analysis using the Bibliometrix package in R, to interpretation of research trends.

Data pre-processing or data cleaning

The retrieved dataset was processed and cleaned using the R programming environment, following established bibliometric data preparation procedures (Aria and Cuccurullo, 2017; Donthu *et al.,* 2021). The dataset was first imported in. *RData* format and filtered to retain only relevant records, specifically peer-reviewed journal articles written in English.

To enhance data quality and ensure reliability, duplicate records were removed using a two-step procedure. Initially, duplicates were identified and eliminated based on digital object identifiers (DOIs), which serve as unique identifiers for scientific publications, while records lacking DOIs were retained for further evaluation. Subsequently, for records without DOIs, a title-based comparison was performed by standardizing article titles through conversion to lowercase and removal of extraneous spaces, allowing for the identification and removal of duplicate entries. Following this cleaning process, the dataset was reduced from 5,559 to 5,517 unique records.

To ensure consistency in conceptual analysis, keyword fields, including author keywords and Keywords Plus, were examined and standardized by removing formatting inconsistencies such as extra spaces. The occurrence of missing keyword values was assessed and found to be minimal, indicating that the dataset was sufficiently robust for subsequent co-occurrence and thematic analyses.

Data analysis

The bibliometric analysis was conducted using the Bibliometrix package in R (Aria and Cuccurullo, 2017) and its graphical interface Biblioshiny. Bibliometrix provides comprehensive tools for quantitative analysis and visualization of bibliographic data.

The analysis included the following components:

- **Descriptive bibliometric analysis:** Main information about the dataset, annual scientific production, most productive authors and core journals based on Bradford's law.
- **Citation analysis:** Average citations per year and most globally cited documents.
- **Network analysis:** Keyword co-occurrence network, author collaboration networks and country collaboration map.
- **Thematic analysis:** Thematic map, thematic evolution and trend topics.

These analyses enabled the identification of research trends, influential publications, collaboration patterns and emerging thematic areas within the field.

Institutional affiliation and research period

This bibliometric study was conducted at the Office of Research, Innovation and Extension of Northwest Samar State University-San Jorge Campus. Data collection, processing, bibliometric analysis and manuscript preparation were carried out from January 2026 to April 2026.

Bibliometric review

Descriptive characteristics of the dataset

Table 1 summarizes the main characteristics of the dataset on tropical forest carbon dynamics from 2000 to 2025. A total of 5,517 documents were published across 1,255 sources, indicating a highly multidisciplinary research field spanning ecology, climate science and remote sensing. The annual growth rate of 6.76% reflects a steady increase in scientific output, consistent with the growing global focus on forests as critical carbon sinks for climate change mitigation (Pan *et al.,* 2011).

The dataset shows an average document age of 9.67 years and a relatively high average citation rate of 51.36 per document, suggesting strong scientific influence and sustained relevance of publications in this field (Saatchi *et al.,* 2011). In terms of authorship, a total of 18,227 authors contributed to the dataset, with only 600 single-authored documents, indicating a strong dominance of collaborative research. This is further supported by an average of 6.15 co-authors per document and an international co-authorship rate of 45.22%, highlighting the global and interdisciplinary nature of tropical forest carbon research (Wuchty *et al.,* 2007).

Additionally, the large number of references (121,983) and diverse keywords (2,869 author keywords and 1,973 Keywords Plus) reflect a well-established and conceptually diverse knowledge base. These findings indicate that the field is rapidly expanding, highly collaborative and scientifically impactful, emphasizing its importance in addressing global climate challenges.

Annual scientific production

The annual scientific production on tropical forest carbon dynamics demonstrates a clear and sustained upward trend from 2000 to 2025 (Fig 2). In the early period (2000-2008), publication output remained relatively low and

Table 1: Descriptive statistics of the bibliometric dataset (2000-2025).

Description	Value
Timespan	2000-2025
Sources (Journals, books, *etc*.)	1,255
Documents	5,517
Annual growth rate	6.76%
Average document age	9.67 years
Average citations per document	51.36
References	121,983
Author's keywords	2,869
Keywords plus	1,973
Authors	18,227
Authors of single-authored documents	532
Single-authored documents	600
Co-authors per document	6.15
International co-authorship	45.22%

fluctuating, generally below 110 articles per year. A noticeable increase began around 2009, followed by a steady growth phase between 2010 and 2015. From 2016 onwards, the field experienced a rapid expansion, with annual publications exceeding 300 articles and reaching nearly 400 by 2024-2025.

This growth pattern reflects the increasing global emphasis on climate change mitigation and the critical role of tropical forests as carbon sinks (Pan *et al.,* 2011). The surge in publications after 2015 may also be associated with heightened research interest following international climate agreements and advances in remote sensing technologies for carbon monitoring. Although minor fluctuations are observed in recent years, the overall trajectory indicates that research on tropical forest carbon dynamics has evolved into a rapidly expanding and highly active scientific domain.

Average citations per year

The trend in average citations per year shows a generally declining pattern over time, with notable fluctuations in the early and middle periods (Fig 3). Higher citation rates are observed in the early 2000s, peaking at around 2002, followed by intermittent increases around 2008 and 2011. From 2012 onwards, citation rates stabilize at approximately 4-5 citations per year before declining sharply in the most recent years (2023-2025).

This pattern reflects the citation accumulation effect, where older publications have had more time to receive citations compared to more recent studies (Wang and Barabasi, 2013). The decline in recent years should therefore not be interpreted as reduced research quality, but rather as a temporal limitation in citation accrual. Additionally, the rapid increase in publication output may contribute to citation dispersion, where citations are distributed across a larger number of articles. Despite the observed decline, the relatively stable citation rates during the mid-period indicate sustained scientific relevance and continued influence of research in tropical forest carbon dynamics.

Top most cited publications in the field of carbon dynamics in tropical forests

Table 2 presents the top 10 most cited publications in the field of tropical forest carbon dynamics between 2000 and 2025. The most highly cited work is by Huete *et al*. (2002), with 9,389 citations, which focuses on the performance of MODIS vegetation indices, highlighting the foundational

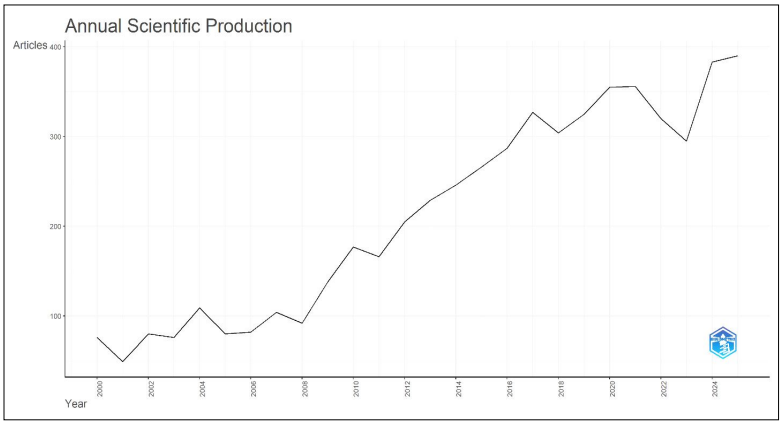


Fig 2: Annual scientific production.

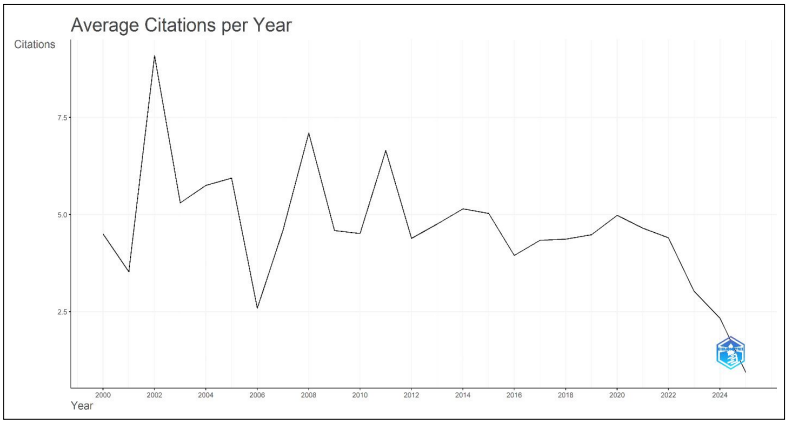


Fig 3: Average citations per year.

Table 2: Top 10 most cited publications on carbon dynamics in tropical forests (2000-2025).

Authors	Year	Title	Journal	Citations	DOI
Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X. and Ferreira, L.G.	2002	Overview of the radiometric and biophysical performance of the MODIS vegetation indices.	Remote sensing of environment	9389	10.1016/s0034-4257(02)00096-2
Fargione, J., Hill, J., Tilman, D., Polasky, S. and Hawthorne, P.	2008	Land clearing and the biofuel carbon debt	Science	3862	10.1126/science.1152747
Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D. and Yamakura, T.	2005	Tree allometry and improved estimation of carbon stocks and balance in tropical forests	Oecologia	3476	10.1007/s00442-005-0100-x
Donato, D.C., Kauffman, J.B., Murdiyarso, D., Kurnianto, S., Stidham, M. and Kanninen, M.	2011	Mangroves among the most carbon-rich forests in the tropics	Nature geoscience	3168	10.1038/ngeo1123
Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T., Salas, W. and Morel, A.	2011	Benchmark map of forest carbon stocks in tropical regions across three continents	Proceedings of the national academy of sciences	2354	10.1073/pnas.1019576108
Baccini, A.G.S.J., Goetz, S.J., Walker, W.S., Laporte, N.T., Sun, M., Sulla-Menashe, D. and Houghton, R.	2012	Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps	Nature climate change	1815	10.1038/nclimate1354
Gibbs, H.K., Brown, S., Niles, J.O. and Foley, J.A.	2007	Monitoring and estimating tropical forest carbon stocks: Making REDD a reality	Environmental research letters	1643	10.1088/1748-9326/2/4/045023
Janssens, I.A., Dieleman, W., Luyssaert, S., Subke, J.A., Reichstein, M., Ceulemans, R. and Law, B.E.	2010	Reduction of forest soil respiration in response to nitrogen deposition	Nature geoscience	1586	10.1038/ngeo844
Ahlström, A., Raupach, M.R., Schurgers, G., Smith, B., Arneth, A., Jung, M. and Zeng, N.	2015	The dominant role of semi-arid ecosystems in the trend and variability of the land CO_2 sink	Science	1444	10.1126/science.aaa1668
Poulter, B., Frank, D., Ciais, P., Myneni, R.B., Andela, N., Bi, J. and van der Werf, G.R.	2014	Contribution of semi-arid ecosystems to interannual variability of the global carbon cycle	Nature	1444	10.1038/nature13376

role of remote sensing in monitoring vegetation and carbon dynamics. This is followed by Fargione *et al*. (2008), which addresses the concept of carbon debt associated with land-use change, reflecting the strong linkage between bioenergy development and carbon emissions.

Several highly cited studies emphasize methodological advancements in estimating forest carbon stocks. For instance, Chave *et al*. (2005) introduced improved allometric equations for biomass estimation, which remain widely used in tropical forest research. Similarly, Saatchi *et al*. (2011) and Baccini *et al*. (2012) contributed significantly to large-scale mapping of tropical forest carbon stocks using remote sensing technologies. These studies underscore the increasing importance of integrating field data with satellite observations for accurate carbon assessment.

In addition, ecosystem-specific studies such as Donato *et al*. (2011) highlight the exceptional carbon storage capacity of mangrove forests, while broader global analyses, including Ahlström *et al*. (2015) and Poulter *et al*. (2014), demonstrate the role of different ecosystems in regulating the global carbon cycle. The presence of studies addressing policy-relevant themes, such as REDD+ (Gibbs *et al.,* 2007), further indicates the strong connection between scientific research and climate change mitigation strategies.

The most cited publications reveal that the field is shaped by three major research directions: (1) methodological innovations in carbon estimation, (2) application of remote sensing technologies and (3) ecosystem and global-scale carbon cycle analyses. The high citation counts of these studies indicate their foundational role in advancing knowledge and guiding subsequent research in tropical forest carbon dynamics.

Most relevant authors

Fig 4 presents the most productive authors in the field of tropical forest carbon dynamics from 2000 to 2025. Among them, Phillips, O.L. and Malhi, Y. emerge as the most prolific contributors, with 90 and 89 publications, respectively. Their extensive body of work has significantly advanced understanding of tropical forest carbon storage, biomass dynamics and ecosystem responses to climate change. These authors are widely recognized for long-term forest monitoring and large-scale carbon assessments, which have become foundational in the field.

Other key contributors include Lewis *et al*. (2015) who have also produced substantial numbers of publications. Their work largely focuses on forest structure, biomass estimation and carbon fluxes, particularly through the development of allometric models and global forest datasets. Similarly, authors such as Saatchi *et al*. (2011) have contributed to advancing remote sensing applications for mapping forest carbon stocks, highlighting the increasing integration of geospatial technologies in ecological research.

The distribution of publications among these leading authors indicates a relatively concentrated authorship structure, where a small group of highly productive researchers drives much of the scientific output. This pattern is typical in mature research fields, where influential scholars shape research directions and contribute to the development of dominant methodologies and frameworks (Lotka, 1926; Price, 1963).

The prominence of these authors reflects the interdisciplinary nature of the field, combining ecology, remote sensing and climate science to better understand the role of tropical forests in global carbon cycling and climate change mitigation.

Most relevant sources (journals)

Fig 5 shows the most productive journals contributing to research on carbon dynamics in tropical forests from 2000 to 2025. Among these, forest ecology and management is the leading source, with 237 publications, followed by global change biology (122) and Remote Sensing (106). This distribution highlights the dominance of journals focusing on forest ecology, global environmental change and geospatial technologies.

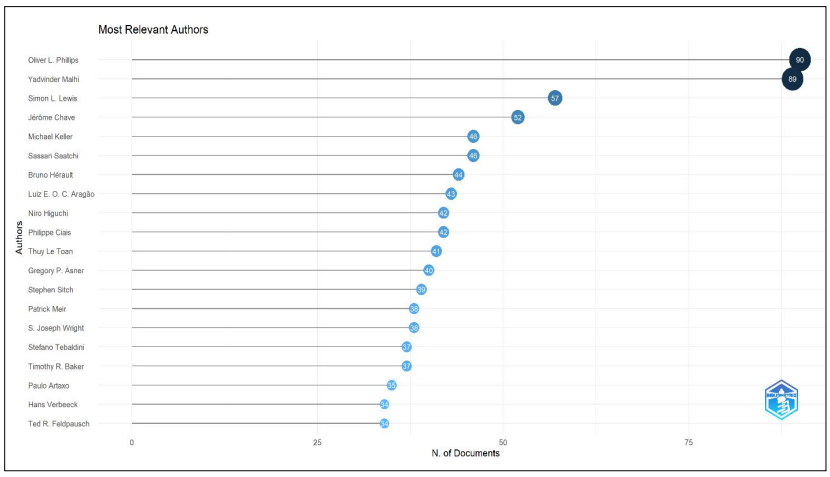


Fig 4: Most relevant authors.

Other prominent journals include forests, biotropica and remote sensing of environment, which collectively emphasize the interdisciplinary nature of the field, integrating ecological processes with remote sensing and climate science. The presence of high-impact journals such as Global Change Biology and Environmental Research Letters further indicates the strong linkage between tropical forest carbon studies and broader climate change discourse.

The concentration of publications in a relatively small number of journals suggests a core-periphery structure consistent with Bradford's Law, where a limited set of core sources accounts for a large proportion of scientific output (Bradford, 1976). These core journals serve as primary platforms for disseminating key findings and advancing methodological innovations in carbon monitoring and ecosystem assessment.

The identified sources reflect the evolution of the field toward increasingly interdisciplinary research, combining forest ecology, biogeochemistry and remote sensing to address global carbon cycle dynamics and climate mitigation strategies.

Core sources (Bradford's law)

Fig 6 illustrates the distribution of scientific publications across journals based on bradford's law. The results show a highly skewed distribution, where a small group of core journals contributes a disproportionately large share of the total publications, followed by a long tail of less productive sources.

The core zone, highlighted in the figure, includes leading journals such as forest ecology and management, global change biology and remote sensing, which collectively account for a substantial portion of the literature on tropical forest carbon dynamics. These journals serve as primary outlets for high-impact studies and methodological advancements in forest carbon assessment, remote sensing applications and climate change research.

Beyond the core, the number of journals increases rapidly while the number of publications per journal declines sharply. This pattern reflects the classical Bradford distribution, where knowledge dissemination becomes more scattered across peripheral sources as the subject area expands (Bradford, 1976). The presence of numerous

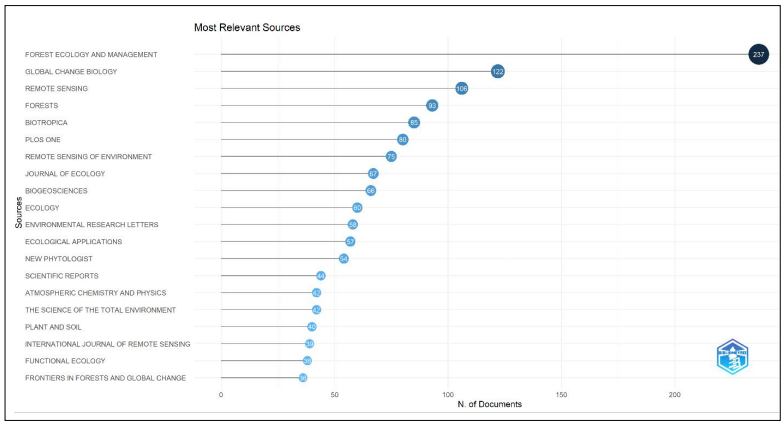


Fig 5: Most relevant sources.

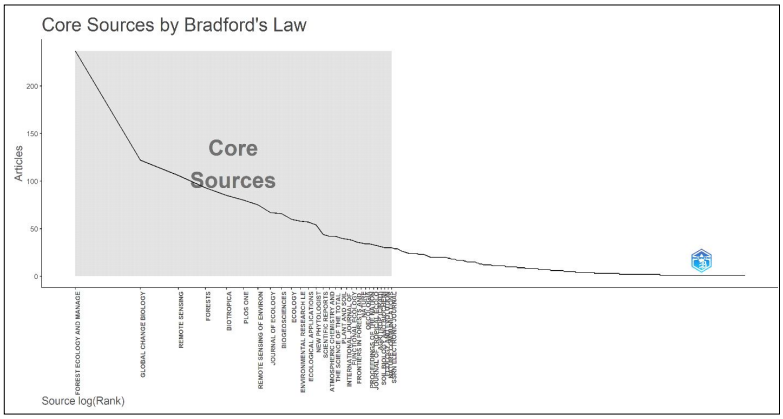


Fig 6: Core sources (Bradford's law).

secondary and tertiary journals indicates the interdisciplinary reach of the field, spanning ecology, environmental science, geosciences and atmospheric research.

The observed distribution confirms that research on tropical forest carbon dynamics is concentrated within a relatively small set of influential journals, while also demonstrating a broad diffusion of knowledge across diverse scientific domains.

Thematic evolution

Fig 7 illustrates the thematic evolution of research on tropical forest carbon dynamics from 2000 to 2025. The results reveal a clear progression of research themes across five time periods, reflecting the increasing complexity and interdisciplinarity of the field.

During the early period (2000-2005), research was primarily centered on foundational topics such as carbon sequestration, ecology and environmental science, indicating an initial focus on understanding the role of forests as carbon sinks. In the subsequent period (2006-2010), these themes expanded to include agroforestry and ecosystem, highlighting growing interest in land-use systems and ecosystem-level processes.

Between 2011 and 2015, the field began to incorporate more quantitative and methodological approaches, as reflected by the emergence of tree allometry, alongside continued emphasis on ecology and environmental science. This shift suggests increasing efforts to improve biomass estimation and carbon accounting techniques.

In the period 2016-2020, research themes became more integrated with global environmental concerns, with climate change and ecosystem gaining prominence. This reflects the alignment of tropical forest research with international climate agendas and policy frameworks.

In the most recent period (2021-2025), the thematic structure shows further diversification, with the emergence of atmospheric sciences, geology and soil water, alongside the continued dominance of environmental science and ecology. This indicates a transition toward more holistic and system-based approaches, integrating biophysical, atmospheric and hydrological processes in understanding carbon dynamics.

Hence, the thematic evolution demonstrates a shift from foundational ecological concepts to advanced, interdisciplinary and climate-oriented research, highlighting the growing role of tropical forests in global climate change mitigation and Earth system science.

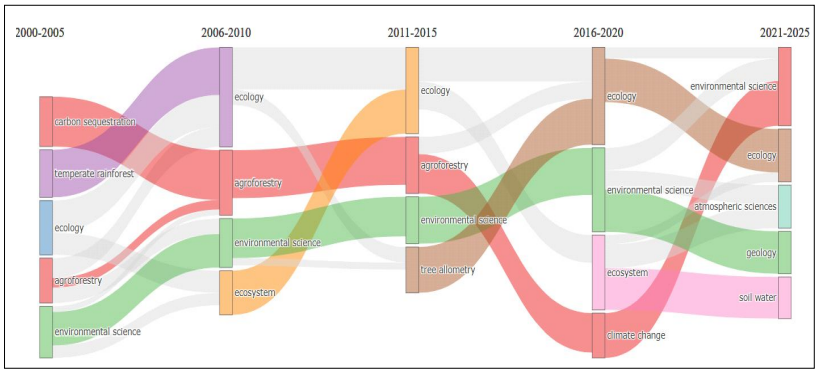


Fig 7: Thematic evolution.

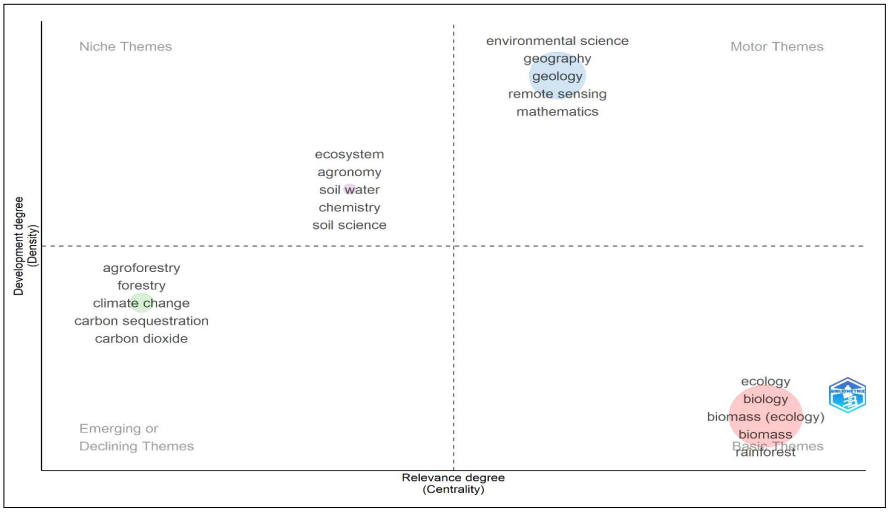


Fig 8: Thematic map.

Thematic map

Fig 8 presents the thematic map of research on tropical forest carbon dynamics, classified according to centrality (relevance) and density (development). The map is divided into four quadrants: motor themes, niche themes, emerging or declining themes and basic themes.

The motor themes (upper-right quadrant) include environmental science, geography, geology, remote sensing and mathematics. These themes exhibit both high centrality and high density, indicating that they are well-developed and play a crucial role in structuring the research field. Their prominence highlights the increasing importance of geospatial technologies and quantitative approaches in advancing carbon monitoring and analysis.

The basic themes (lower-right quadrant), such as ecology, biology, biomass and rainforest, are highly central but less developed. These represent the foundational concepts of the field, serving as the core knowledge base upon which more specialized and advanced research is built.

In the niche themes (upper-left quadrant), topics such as ecosystem, agronomy, soil water, chemistry and soil science are well-developed but relatively isolated. These areas reflect specialized research directions that contribute depth to the field but are less interconnected with the broader research structure.

Finally, the emerging or declining themes (lower-left quadrant) include agroforestry, forestry, climate change and carbon sequestration. These themes show lower centrality and density, suggesting either emerging areas of interest or topics that are becoming less prominent over time. However, given their continued relevance to climate mitigation, these themes may represent evolving research directions rather than decline.

The thematic map indicates a field that is both methodologically advancing and conceptually expanding, with strong integration of environmental science and remote sensing, while maintaining its ecological foundations.

Keyword co-occurrence network

Fig 9 presents the keyword co-occurrence network, revealing the conceptual structure of research on tropical forest carbon dynamics. The network is organized into distinct clusters, indicating major thematic areas within the field.

The red cluster, dominated by ecology, biology and biomass, represents the core ecological foundation of the research. These keywords are highly interconnected, reflecting strong emphasis on forest structure, species composition and biomass estimation as central components of carbon dynamics. The prominence of biomass (ecology) highlights its critical role as a proxy for carbon storage in tropical forests.

The blue cluster, centered on environmental science, geography and remote sensing, indicates a major methodological and interdisciplinary domain. This cluster reflects the increasing application of geospatial technologies and Earth observation data in quantifying forest carbon stocks and monitoring environmental changes. The strong linkage between this cluster and the ecological core suggests the integration of field-based and remote sensing approaches (Saatchi *et al.,* 2011; Baccini *et al.,* 2012).

The green cluster focuses on climate change, carbon sequestration, carbon cycle and land use, representing the broader environmental and policy-oriented dimension of the field. These themes highlight the role of tropical forests in global carbon regulation and climate mitigation strategies, including land-use change and greenhouse gas dynamics.

Overall, the network demonstrates a highly interconnected research landscape, where ecological, technological and climate-related themes converge. This integration underscores the evolution of the field toward a more holistic understanding of tropical forest carbon dynamics, combining biophysical processes, remote sensing tools and climate policy frameworks.

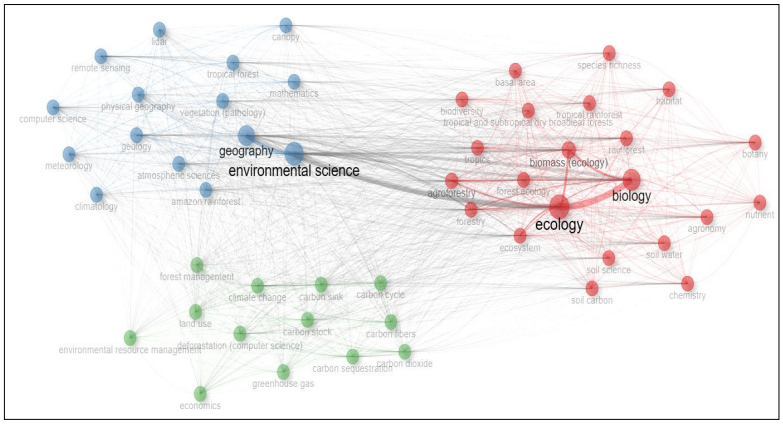


Fig 9: Keyword co-occurrence network.

Country collaboration network

Fig 10 presents the global collaboration network in research on tropical forest carbon dynamics. The network reveals a highly interconnected structure, with several dominant countries acting as central hubs of international collaboration.

The United States emerges as the most influential node, exhibiting the highest number of collaborations and the strongest linkages with countries such as Brazil, the United Kingdom and China. This highlights its leading role in advancing research through extensive international partnerships. Brazil, representing a key tropical forest region, also plays a significant role, reflecting the importance of geographically relevant research locations in carbon dynamics studies.

European countries, particularly Germany, France and the Netherlands, form another prominent cluster characterized by strong intra-regional collaboration. These countries contribute substantially to methodological and interdisciplinary research, particularly in remote sensing and environmental science.

In addition, emerging contributions from countries in Southeast Asia and Latin America, including Malaysia, Thailand, Colombia and Peru, indicate increasing global participation. However, their relatively smaller node sizes suggest that research output and collaboration intensity remain concentrated in developed countries.

This network demonstrates a core-periphery structure, where a few highly connected countries dominate global knowledge production and collaboration, while many others participate at a more limited scale. This pattern is consistent with global scientific collaboration trends, where research capacity, funding availability and institutional networks shape international partnerships (Glänzel, 2001).

Global collaboration map

Fig 11 illustrates the global distribution and collaboration patterns in research on tropical forest carbon dynamics. The map highlights strong international linkages, with research activities concentrated in North America, Europe, South America and parts of Asia.

The United States stands out as the primary hub of global collaboration, exhibiting extensive connections with countries across all continents. Strong bilateral collaborations are evident between the United States and Brazil, reflecting the importance of tropical forest regions in carbon-related research. Similarly, collaborations with the United Kingdom, China and Australia indicate the global

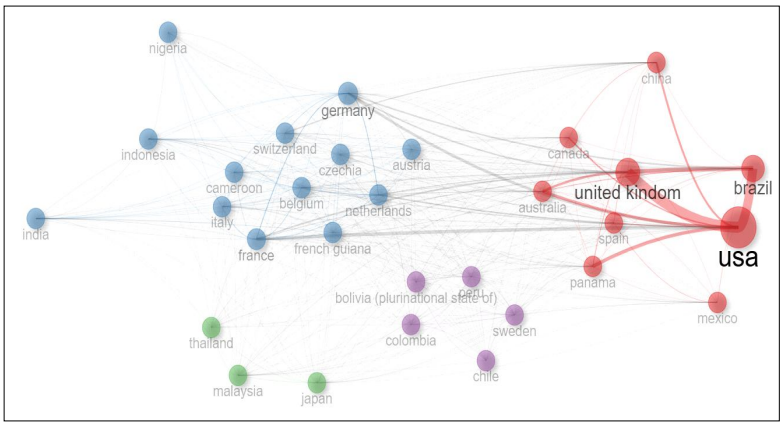


Fig 10: Collaboration network.

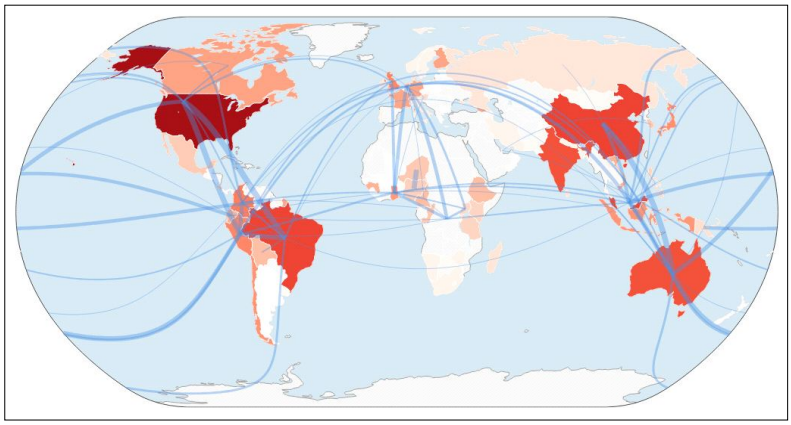


Fig 11: Country collaboration map.

nature of scientific efforts addressing climate change and forest carbon dynamics.

In Europe, countries such as Germany, France and the United Kingdom form an active network of collaboration, contributing significantly to methodological and interdisciplinary research. Meanwhile, countries in South America, particularly Brazil, play a crucial role due to their ecological relevance, serving as key sites for empirical studies on tropical forests.

Emerging participation from countries in Southeast Asia and Africa is also observed, although their collaboration intensity remains relatively lower. This pattern suggests disparities in research capacity and access to resources, which continue to influence global scientific collaboration.

The map reflects a globally connected but uneven research landscape, where developed countries dominate collaboration networks, while tropical countries contribute essential ecological data and field-based insights. This underscores the importance of strengthening international partnerships to enhance inclusive and regionally representative research on tropical forest carbon dynamics.

CONCLUSION

This bibliometric analysis of research on carbon dynamics in tropical forests (2000-2025) reveals a rapidly expanding and increasingly interdisciplinary field that plays a central role in climate change mitigation. The literature has evolved from traditional field-based studies to technology-driven approaches integrating remote sensing, geospatial analysis and earth system science. Core themes such as biomass estimation, carbon sequestration and ecosystem dynamics remain dominant, while global collaboration continues to increase despite the underrepresentation of many tropical countries. These findings highlight the need for more inclusive international partnerships and stronger interdisciplinary integration. Overall, tropical forests remain indispensable to global carbon regulation and this study provides a valuable roadmap for future research and policy development.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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