Düzce University Faculty of Forestry Journal of Forestry
Düzce Üniversitesi Orman Fakültesi Ormancılık Dergisi

22 (1), 2026, 12-28.
https://doi.org/10.58816/duzceod.1795776

ISSN: 2148-7871 e-ISSN: 2148-7855
https://dergipark.org.tr/en/pub/duzceod

Research Article

Science Mapping the Literature on Forest Production, Timber Extraction, and Transport (1980–2025)

Kamber Can Alkiş[1], Remzi Eker[2*]

[1] Independent Researcher, İzmir, Türkiye.

[2] İzmir Kâtip Çelebi Üniversitesi, Orman Fakültesi, Orman Mühendisliği Bölümü, İzmir, Türkiye.
ror.org/024nx4843

*Corresponding author:
remzi.eker@ikc.edu.tr

Received: 02.10.2025
Revision: 01.02.2026
Accepted: 27.02.2026
Online: 18.06.2026

Abstract: This study science-mapped the literature on forest production, timber extraction, and transport through a comprehensive bibliometric analysis of SCIE-indexed articles published between 1980 and 2025. Bibliometric records were retrieved from the Web of Science (WoS) Core Collection and analyzed in RStudio using the Bibliometrix package via its Biblioshiny web interface. Publication dynamics and the field's intellectual structure were characterized using annual publication trends, prolific authors and sources, keyword co-occurrence networks, and international collaboration patterns. The results indicated sustained growth in research output, with annual publications rising from 104 in 2000 to 564 in 2024 (+442.3%, ≈4.42×). The most productive countries were the United States, China, Brazil, and Canada. Overall, the analysis mapped the knowledge base, major thematic clusters, and evolving research fronts across the production–extraction–transport chain. The findings can help researchers working in forest production, timber extraction, and transport to better identify core themes and emerging directions and to position future studies more clearly within the field.

Keywords: *Bibliometric analysis, Forest production, Science mapping, Timber extraction, Transport*

I. INTRODUCTION

The growing demand for forest products from both society and industry-driven by population growth and heightened environmental awareness-has accelerated the turn toward renewable resources. Yet the diversification of human needs continues to place pressure on forest ecosystems, posing a significant threat to the sustainable supply of wood-based goods (Taş et al., 2024). To meet the needs of present and future generations, forests must be managed with an emphasis on sustainability and operational efficiency (Akay et al., 2010). Addressing the demand for forest products and services, therefore, requires not only an understanding of forest ecosystem dynamics but also a clear grasp of production processes and forest operations that deliver primary and secondary products. According to Erdaş et al. (2014), the production process encompasses all stages required to deliver a product to consumers and is guided by plans and principles designed to meet demand. Because timber cannot always be processed at the stump, it must be extracted from forest stands efficiently and with minimal loss or damage. In recent years, rising environmental consciousness has widened attention from the quantity of forest products to the ecological impacts of their production, prompting closer scrutiny of how timber harvesting and extraction techniques affect the internal balance of forest ecosystems (Acar & Ünver-Okan, 2015). This shift has elevated research and development on design and environmental impacts of forest production, timber extraction, and transport systems as a priority topic.

Historically, prior to the 19th century, timber extraction relied on human labor, animal power, gravity, or water energy (Johann, 2021). Techniques evolved with technological advances and local conditions. The expansion of forest road networks in the 19th century marked a turning point, gradually replacing traditional transport methods with carts and, eventually, mechanical cable systems (Erdaş et al., 2014). Today, timber extraction systems—including skidding, forwarding, cable logging, and tethered/winch-assisted systems on steep terrain—are selected and integrated according to principles of sustainability, site conditions, safety, and productivity. As Bont et al. (2022) argue, careful selection and integration of appropriate timber extraction techniques can enhance economic efficiency while reducing residual stand damage and workplace accidents, thereby contributing to sustainable production. Consequently, timber extraction operations have become a core focus within forest engineering, and bibliometric analysis offers a systematic approach to evaluate the evolution and structure of this field.

In recent years, bibliometric studies in forestry have proven valuable for identifying research trends, assessing scientific productivity, and revealing knowledge gaps. Examples include national or topical assessments (Aleixandre-Benavent et al., 2018; Fioravanti et al., 2018; Uribe-Toril et al., 2019), studies on fire management and remote sensing (Santos et al., 2021), innovations in the forest bioeconomy (Jankovský et al., 2021), regional trends (Fazeli-Varzaneh et al., 2021), and thematic syntheses across ecosystem services, big data, carbon neutrality, and the Sustainable

This is an open access paper distributed under the terms and conditions of the Creative Commons Attribution-NonCommercial 4.0 International License.

Development Goals (Chen et al., 2022; Gao et al., 2022; Huang et al., 2022; Ma et al., 2022; Zhang et al., 2022). Additional contributions span national publishing patterns, soil-related applications, micro-scale processes, biomass monitoring, climate-driven fire risk, unmanned aerial systems, pandemic impacts, machine-learning-based trend analysis, species-specific syntheses, and emerging spaceborne LiDAR applications (Aguilar et al., 2024; Bao et al., 2024; Chen et al., 2023; Santillán-Fernández et al., 2023; Shi et al., 2024; Silva et al., 2024; Jayasundara et al., 2024; Kumar & Pandey, 2024; Xie et al., 2023; Zhao et al., 2024). This expanding literature underscores both the breadth of forestry research and the methodological potential of science mapping. This study addresses that gap by conducting a bibliometric analysis of academic research on forest production, timber extraction, and transport systems published between 1980 and 2025, using the Bibliometrix methodology in RStudio. Our objective was to identify prevailing trends, collaborative networks, and thematic gaps, providing a structured overview of how research on forest production, timber extraction, and transport systems has evolved and establishing a foundation for future studies in forest operations and engineering.

II. MATERIALS AND METHODS

A. Data Collection

This study conducts a bibliometric analysis focused on "forest production, timber extraction, and transport systems (PTET)", based on academic publications in forestry over the past 45 years. The research follows a systematic workflow (Figure 1) that spans literature review, query design, data collection, data cleaning, data harmonization, analysis, and interpretation. As noted by Aria and Cuccurullo (2017), such end-to-end processes are demanding and require careful planning.

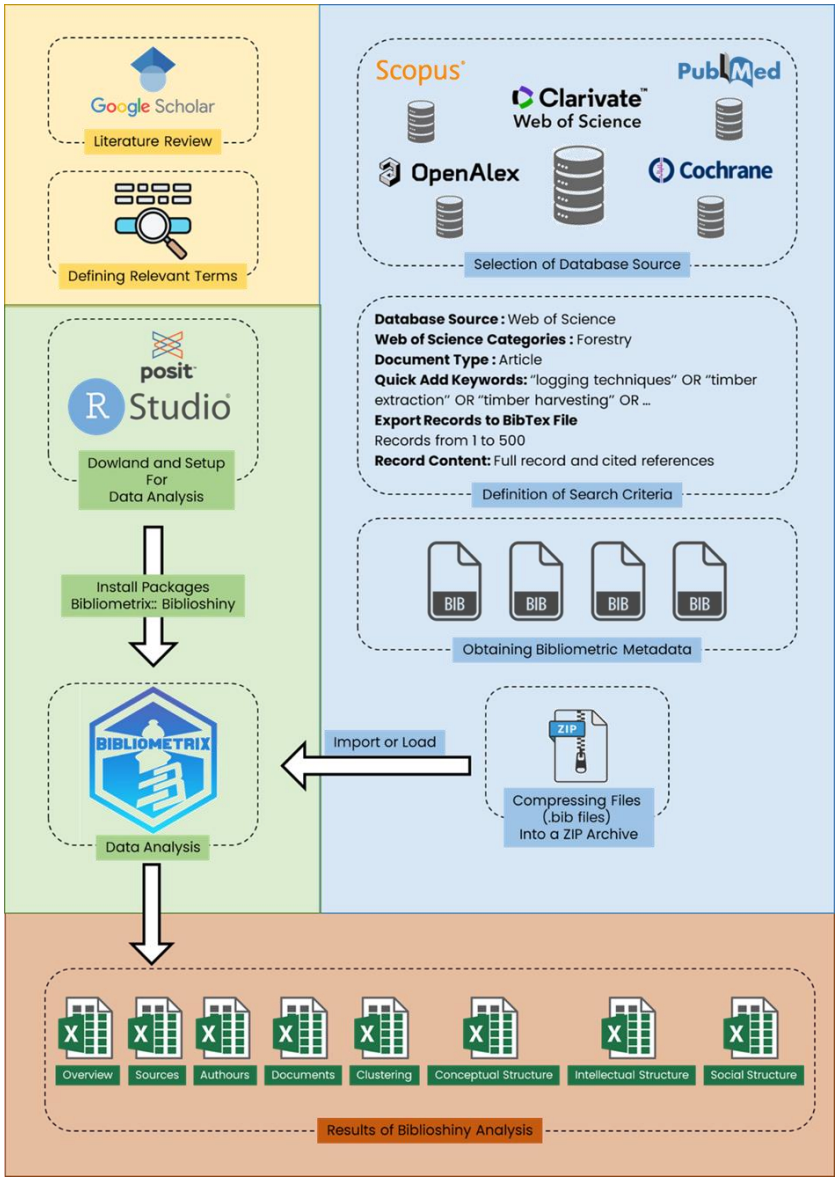


Figure 1. Workflow diagram.

In the initial stage, an exploratory keyword scan was carried out using Google Scholar (http://scholar.google.com) to identify discipline-specific terms commonly used in studies on forest production, timber extraction, and transport systems. Data gathered at this step were used solely to surface and refine terminology and were not included in the bibliometric dataset. Selecting the bibliographic data source presented a methodological challenge. Citation indexes such as Web of Science (WoS) and Scopus differ in disciplinary coverage and document types, whereas full-text platforms like ScienceDirect primarily serve as publisher repositories rather than neutral citation indexes. These differences can introduce corpus bias and complicate the goal of building a comprehensive yet focused dataset (Aria & Cuccurullo, 2017).

In the second stage, the WoS Core Collection was chosen as the primary data source for bibliometric analysis. An advanced search query using logical operators (OR/AND) was constructed to capture the breadth of terminology associated with timber harvesting and extraction. The final search expression employed in this study was: PTET = ("forest transportation systems" OR "felling works" OR "log skidding" OR "log production" OR "logging" OR "logging techniques" OR "logging damages" OR "logging operations" OR "logging planning" OR "timber harvesting" OR "timber extraction" OR "hauling" OR "harvesting operations" OR "skyline" OR "skidding" OR "wood extraction techniques" OR "wood transport" OR "extraction" OR "extraction activities" OR "forest transport plan" OR "wood extraction activities" OR "forest harvesting operations" OR "forestry operations" OR "transport techniques" OR "mechanized harvesting systems").

This comprehensive query was designed to encompass the full range of terminology used in the literature, thereby enabling a thorough and accurate bibliometric assessment of forest production, timber extraction, and transport systems within the forestry domain.

In the third phase of the study, a topic-specific corpus was retrieved from the WoS Core Collection by applying filters on WoS Categories, Document Types, an advanced search expression, and related criteria (see Table 1). The resulting records were exported in BibTeX format, which is natively supported by the Biblioshiny interface in RStudio Desktop (Version: 2025.05.1+513) for subsequent bibliometric analysis (Posit, 2025).

Table 1. Search criteria for bibliometrix analysis.

Criterion type	**Explanation**
Database Source	WoS Core Collection
Categories	Forestry
Document Type/WOS Index	Article/Scientific Citation Index Expanded
Language of Keywords	English
Time Slicing	1980 – 2025
Search Date	3 May 2025

The WoS platform, provided by Clarivate Analytics, offers advanced keyword-based retrieval and reliable access to bibliographic metadata for scholarly publications, enabling the systematic execution of large-scale bibliometric workflows (Dirik et al., 2024). According to Bao et al. (2024), the WoS Core Collection is a globally recognized academic database distinguished by rigorous curation standards and extensive coverage of scientific and technical literature.

On May 3, 2025, the filtering procedure was executed within WoS to identify publications related to forest production, timber extraction, and transport systems. When the resulting corpus contained fewer than 500 records, it was exported as a single BibTeX file; when it exceeded 500 records, it was exported in multiple BibTeX batches to comply with platform constraints, after which the files were combined for analysis.

In the fourth phase of the study, the multiple BibTeX files exported from the search were packaged into a single ZIP archive to preserve file integrity and simplify handling. This created a single, version-controlled artifact that can be uploaded for analysis without tracking numerous individual files.

In the fifth phase, the bibliometrix package—purpose-built for bibliometric analysis—was installed in the RStudio environment, and the Biblioshiny module was launched to provide a user-friendly web interface.

In the sixth phase, the ZIP archive containing the BibTeX files was uploaded to the Biblioshiny interface (alternatively, the individual ".bib" files can be imported directly). Once the data were loaded, the bibliometric workflow was executed.

In the seventh phase, the outputs produced by Biblioshiny were organized under the principal analytical views—Overview, Sources, Authors, Documents, Clustering, Conceptual Structure, Intellectual Structure, and Social Structure—and the corresponding tables/figures were exported in Excel (.xlsx) format for further examination.

Finally, in the last phase, the bibliometric results were synthesized. The results delineated the current state of

research on forest production, timber extraction, and transport systems and highlighted thematic gaps and future research opportunities for the field.

B. Data Analysis

In this study, academic publications on forest production, timber extraction, and transport systems indexed in the WoS between 1980 and 2025 were analyzed using standard indicators: temporal publication trends; country, institution, and author distributions; citation-based measures; keyword structures (including word clouds and co-occurrence patterns); and co-authorship/collaboration networks. The increasing availability of specialized software, the growth of interdisciplinary practices, and advances in large-scale data processing have collectively amplified scholarly interest in bibliometric approaches (Dinca et al., 2025).

Widely used tools for visualization and analysis include CiteSpace, VOSviewer, HistCite, BibExcel, and the R-based bibliometrix package (Zhang et al., 2022). In the present study, the analysis is conducted via Biblioshiny (Figure 2) —a web-based, open-source interface developed by Massimo Aria (Napoli Federico II University, Italy) that is accessible online and integrated within the RStudio environment (Shi et al., 2024). As a component of the Bibliometrix toolkit, Biblioshiny provides a comprehensive framework for science mapping and is noted for its open-source accessibility and user-friendly interface (Zhang et al., 2022).



Figure 2. Graphical user interface of "Biblioshiny: the shiny app for bibliometrix".

III. RESULTS AND DISCUSSIONS

A. Overview of the Bibliometric Dataset

This study examined the academic literature on forest production, timber extraction, and transport systems through a bibliometric lens over a 45-year period (1980–2025), enabling a comprehensive view of the field's historical development. The dataset comprised 8,985 SCIE-indexed articles drawn from 169 distinct scholarly sources. Across the period, the average annual growth rate in publication volume was 4.24%, indicating a steady rise in research activity. Descriptive metadata for the corpus—covering document types, source categories, and citation indicators—were summarized in Figure 3 (Bibliometrix/Biblioshiny metadata overview), which outlines the dataset's structural composition and analytical potential.

Metadata	Description	Missing Counts	Missing %	Status
AU	Author	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
C1	Affiliation	66	0.73	Good
RP	Corresponding Author	66	0.73	Good
AB	Abstract	173	1.93	Good
CR	Cited References	180	2.00	Good
DI	DOI	1201	13.37	Acceptable
DE	Keywords	1205	13.41	Acceptable
ID	Keywords Plus	1606	17.87	Acceptable
WC	Science Categories	8985	100.00	Completely missing

Figure 3. Features of Bibliometric-Biblioshiny metadata.

Among the 28,223 contributing authors, only 578 documents were single-authored (≈6.43% of the corpus), underscoring the field's predominantly collaborative character. Accordingly, the average number of authors per document is 4.36, and the international co-authorship rate is 26.13%. The presence of 21,166 distinct keywords across the publications highlights the domain's conceptual breadth and multidimensional structure. Within the literature set, which contains 260,482 total citations, the average citations per document equals 18.33, while the average document age (at the time of analysis) is 11.5 years. Figure 4 charts annual publication counts on forest production, timber extraction, and transport systems (1980–2025).

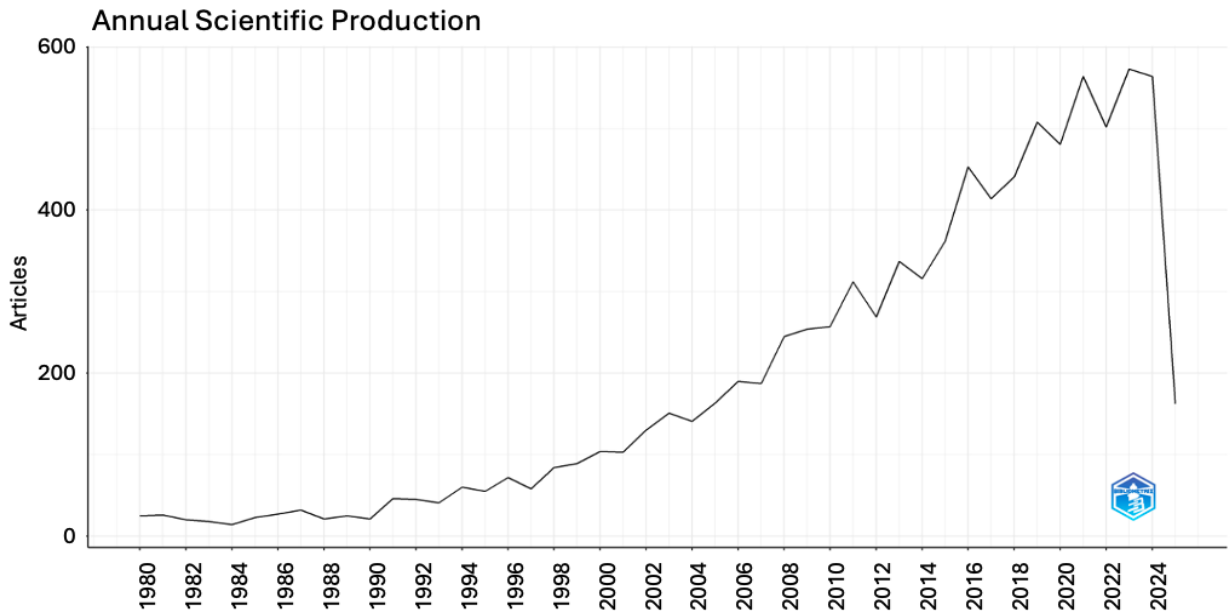


Figure 4. Annual scientific production.

The overall pattern shows steady—albeit nonlinear—growth. After an initial phase (1980–2000), a marked upswing begins around 2016, with yearly outputs reaching ~500 publications at the peak. The apparent downturn in 2025 reflects incomplete indexing for the ongoing year rather than a substantive decline in research activity.

The Three-Field Plot (Figure 5)—linking countries (AU_CO), author keywords (DE), and institutions (AU_UN)—highlights the geographic and institutional structure of the forest production, timber extraction, and transport systems literature. The strongest flows indicate that contributions from leading countries are closely associated with a core set of recurring themes, including logging, forest management, timber harvesting, disturbance, productivity, and forestry. In the plot, edge thickness reflects the intensity of co-occurrence across these three fields, showing which country–keyword–institution combinations appear most frequently in the dataset. These connections therefore represent patterns of thematic emphasis and publication linkage within the corpus rather than causal relationships or definitive rankings of expertise (Figure 5).

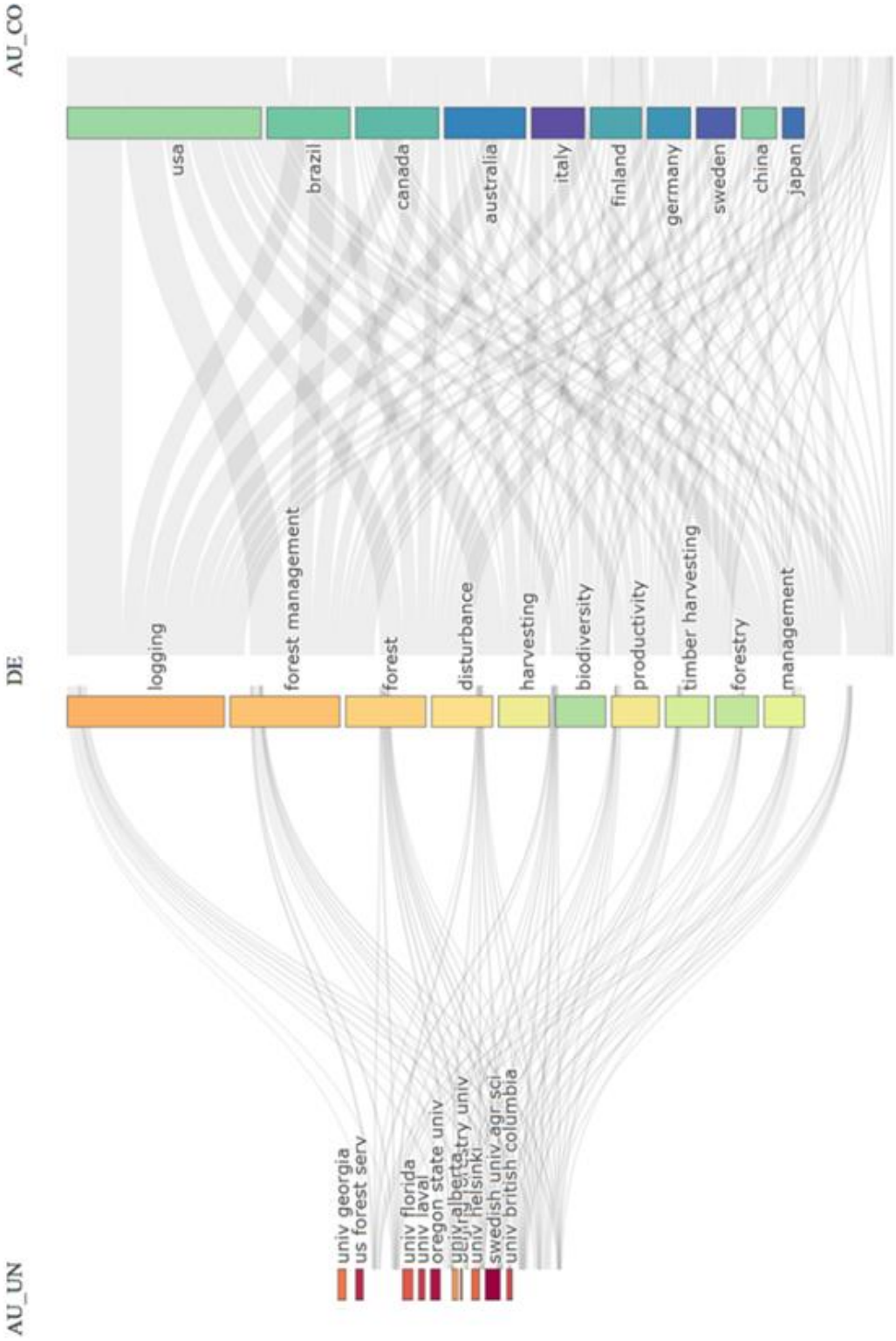


Figure 5. Three-field plot.

Within this corpus, the terms "logging" and "forest management" are most frequently associated with research originating from the United States, Brazil, and Canada. By contrast, Italy, Germany, and Sweden exhibit a stronger emphasis on operations-focused keywords such as "productivity," "harvesting," and "timber harvesting." Prominent contributing institutions include the University of Georgia, the U.S. Forest Service (USDA Forest Service), the University of Florida, Oregon State University, the University of Alberta, the University of Helsinki, the Swedish University of Agricultural Sciences, and the University of British Columbia. In the present dataset, these institutions most commonly co-occur with concepts such as "logging," "forest management," "disturbance," "harvesting," and "biodiversity." Although timber-extraction research is globally distributed, denser country–institution–keyword clusters emerge for specific nodes, indicating focused lines of inquiry and established collaborations. The United States retains a central role in overall scientific output, showing the highest concentration of institutional and keyword associations in this field in this dataset.

B. Source Analysis: Core Journals and Publication Outlets

In this dataset, the three most prolific sources on forest production, timber extraction, and transport systems are Forest Ecology and Management, Forests, and the Canadian Journal of Forest Research (Table 2).

Table 2. Source analysis for forest production, timber extraction, and transport systems.

Journal Name	Number of Publications	Local Citation Count	Local Impact (H Index)
Forest Ecology and Management	1751	24698	104
Forests	987	868	39
Canadian Journal of Forest Research	316	9346	53

Among them, Forest Ecology and Management not only leads in publication volume but also ranks first by citation impact within the field. The high level of local citations—i.e., citations received from documents inside this corpus—indicates that these journals sit at the center of knowledge production and dissemination on forest production, timber extraction, and transport systems. Accordingly, for researchers working in this area, these outlets function as foundational reference points and primary venues for scholarly communication (see Table 2 for source-level productivity and citation indicators).

The shaded Core Sources zone in Supplementary Figure 1 represents the small set of journals that account for the highest share of articles in this corpus—i.e., the Bradford core, which functions as the central hub of knowledge production. In our PTET dataset, Forest Ecology and Management, Forests, and the Canadian Journal of Forest Research are identified as core sources. These outlets serve as primary venues for scholarly output and concentrate many of the field's most influential, highly cited studies. Within the 8,985-document corpus, local impact is assessed using local citations and the local h-index. On that basis, Forest Ecology and Management stands out as the most impactful journal, with the highest local citation volume and a local h-index of 104, underscoring its central role in shaping scholarly discourse on forest production, timber extraction, and transport systems.

C. Author Productivity and Collaboration Patterns

This section examines author productivity and collaboration in the corpus, highlighting the most prolific and influential contributors and the patterns of co-authorship that shape research on forest production, timber extraction, and transport. In this corpus, Raffaele Spinelli ranks first by publication count, local citations, and local h-index, marking him as the field's most prominent contributor on forest production, timber extraction, and transport systems. His output has been sustained since 2009, with notably high volume and impact in 2023 and 2025 (see Supplementary Figure 2). As shown in Table 3, Natascia Magagnotti and Rodolfo Picchio follow Spinelli. Beyond sheer productivity, authors such as Spinelli and Magagnotti exhibit enduring influence—high, steady output coupled with strong citation performance—positioning them as key reference points for both established scholars and early-career researchers in this domain.

Table 3. Author productivity for forest production, timber extraction, and transport systems.

Author Name	Number of Publications	Local Citation Count	Local Impact (H Index)
Spinelli Raffaele	86	470	23
Magagnotti Natascia	57	350	21
Picchio Rodolfo	36	198	18

In this dataset, author productivity is visualized with the number of documents per author on the x-axis and the percentage of authors on the y-axis (see Supplementary Figure 3). The plot shows that over 80% of authors have contributed only one or two publications, indicating a long-tailed distribution in which a small minority accounts for a disproportionate share of output. The close alignment between the solid line (observed distribution) and the dashed line (Lotka's theoretical curve) suggests that the empirical pattern is consistent with Lotka's Law, which posits that the number of authors publishing n papers is roughly proportional to $1/n^2$—i.e., most authors publish infrequently, while a few are highly prolific.

D. Document-Level Impact and Citation Analysis

This section evaluates document-level impact in corpus of forest production, timber extraction, and transport systems by examining highly cited papers and the most influential sources, emphasizing local citation counts within the dataset. Within the topic-specific corpus of forest production, timber extraction, and transport systems, the most impactful document by local citations is Spinelli & Magagnotti (2012), "Wood extraction with farm tractor and sulky: Estimating productivity, cost and energy consumption" (Small-scale Forestry), which serves as a key reference for mechanized wood extraction. Consistently contributing outlets to this operations-focused literature include Small-scale Forestry, Silva Fennica, and the Croatian Journal of Forest Engineering, which play an important role in disseminating both theoretical and applied research on forest production, timber extraction, and transport systems.

E. Clustering Analysis of Keywords and Topics

A keyword frequency analysis was conducted to identify high-salience and thematically prominent terms in the corpus of forest production, timber extraction, and transport systems. The most frequent term is forest management (772 occurrences), followed by extraction (436) at a moderate level and conservation (376) at a lower level. Figure 6 presents a word cloud in which font size encodes relative frequency; terms such as logging, forest management, harvesting, and productivity appear largest, underscoring their centrality to the field. The presence of additional terms—e.g., silviculture, soil, and remote sensing—indicates a multilayered, interdisciplinary discourse around forest production, timber extraction, and transport systems.



Figure 6. Word cloud.

Beyond the Word Cloud and Most Relevant Words views, keyword prominence can also be visualized with a Tree Map (Figure 7), where each term is shown as a box whose area scales with its relative frequency in the corpus.

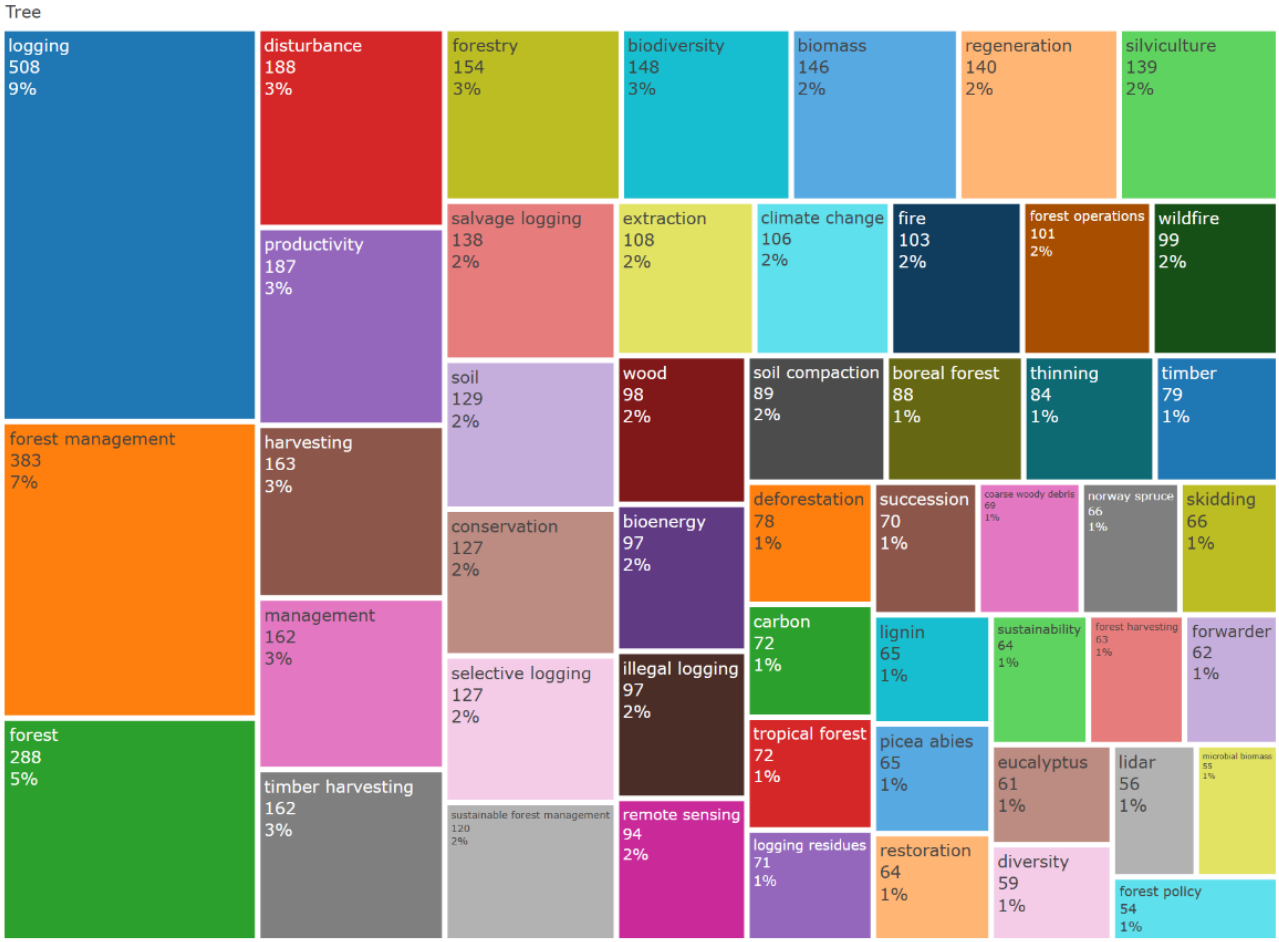


Figure 7. Tree map.

This representation offers a compact, structural overview of the field's conceptual makeup. In our dataset, logging, forest management, and forest dominate the visualization, indicating that research on forest production, timber extraction, and transport systems extends beyond harvesting methods to encompass sustainable forest management policies and practices.

Figure 8 plots cumulative frequencies for the ten most common keywords in forest production, timber extraction, and transport systems–related publications (1987–2025).

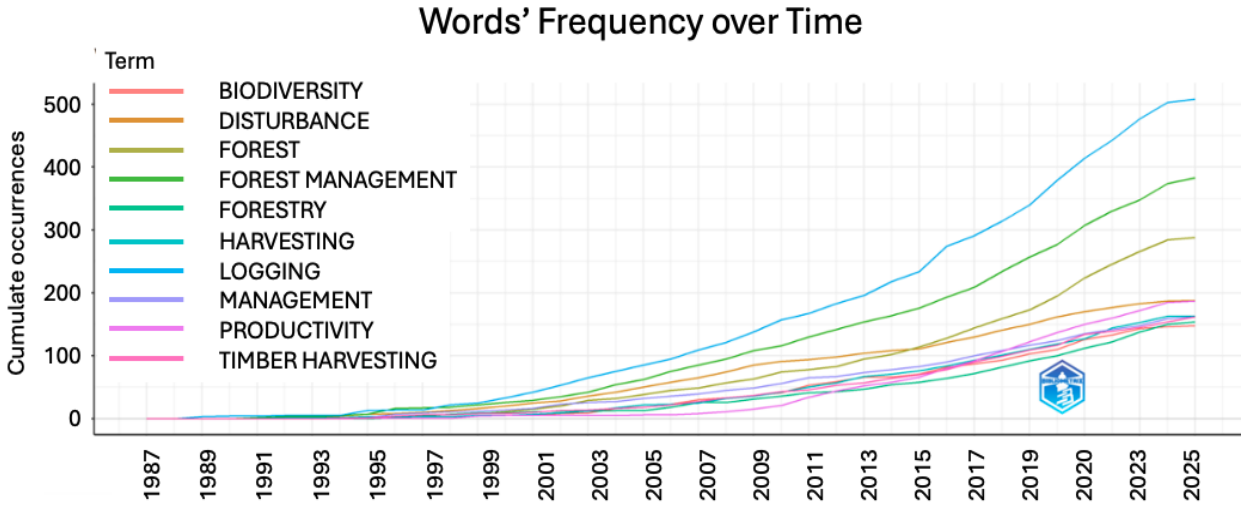


Figure 8. Word frequency over time.

Each color-coded curve traces cumulative occurrences; steeper slopes indicate faster contemporaneous growth and rising salience. The turquoise "logging" curve accelerates from the early 2000s, signaling intensifying interest in

production-oriented forest operations. Subsequently, “forest management” gains prominence, consistent with an increasing tendency to frame timber production within ecosystem-based planning and sustainable management contexts.

Supplementary Figure 4 presents a Trend Topics chart generated in the Biblioshiny (RStudio), which summarizes when keywords are most prevalent and their relative weight over time. In the early 2000s, harvest scheduling appeared frequently. After 2015, terms such as forest management, logging, forest operations, productivity, remote sensing, climate change, timber harvesting, and sustainability gain prominence; their relative influence then tapers as the vocabulary diversifies and newer methods emerge, rather than disappearing entirely. Since ~2020, computational and sensing terms—deep learning, machine learning, object detection, feature extraction, and LiDAR—have become increasingly salient, reflecting a shift toward multidisciplinary, data-intensive approaches spanning forestry, ecology, economics, artificial intelligence, and remote sensing. Taken together, these trajectories suggest that AI-enabled remote sensing will continue to expand its role in timber-extraction research.

Figure 9 displays a cluster map derived from document coupling, positioned by centrality on the x-axis and density on the y-axis.

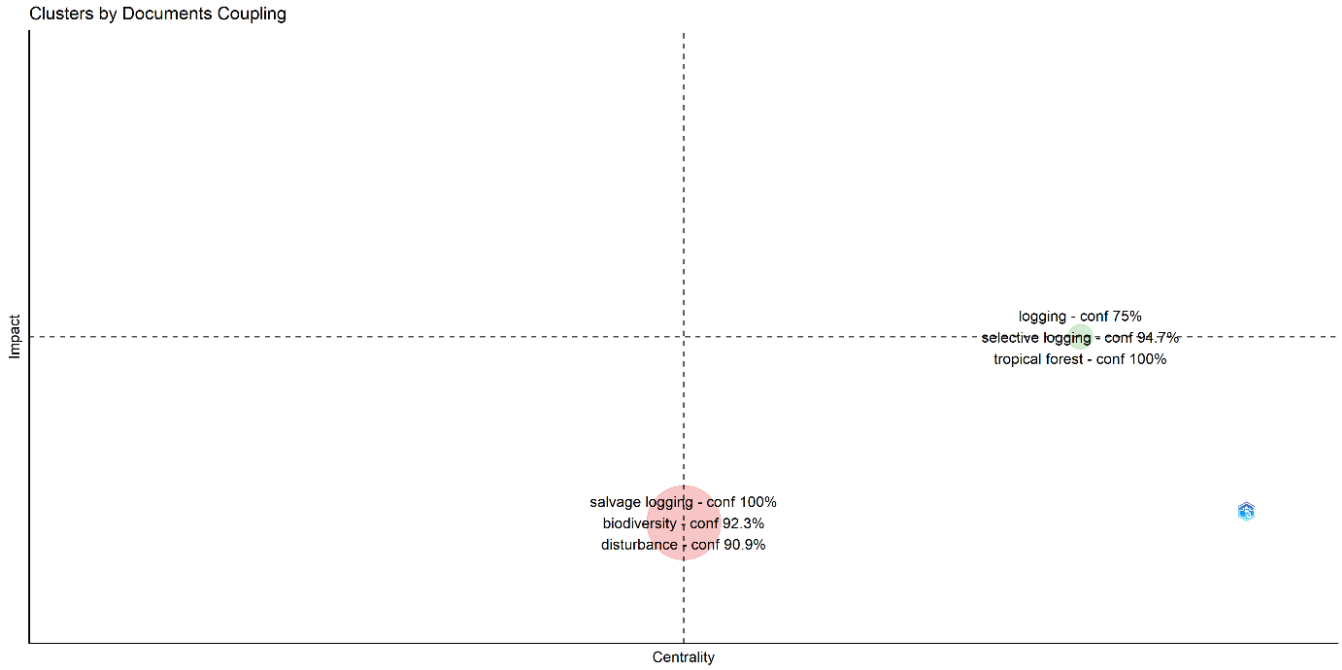


Figure 9. Plot of clusters by documents coupling.

The green cluster—including Logging (75%), Selective logging (94.7%), and Tropical Forest (100%)—sits far right with mid-level y, indicating high centrality and moderate density. In thematic-map terms, this corresponds to basic, field-structuring topics that are widely connected across the literature. By contrast, the red cluster—Salvage logging (100%), Biodiversity (92.3%), Disturbance (90.9%)—is centrally placed on the x-axis but low on the y-axis, i.e., lower density despite strong internal links, suggesting transversal or under-developed themes during the study window. Such clusters often include areas that are either previously saturated (with slower recent development) or emerging fronts awaiting consolidation. Overall, this clustering provides a practical lens for separating established, field-defining themes from nascent or under-developed lines of inquiry, helping to pinpoint actionable research gaps in forest production, timber extraction, and transport systems.

F. Conceptual Structure: Thematic Mapping of Research

This section presents a thematic mapping of the field based on keyword co-occurrence networks, highlighting the core topic clusters, their linkages, and the themes that sit at the center versus the periphery of the literature. The co-occurrence network in Figure 10 maps how frequently paired keywords cluster into themes. Three clusters are evident.

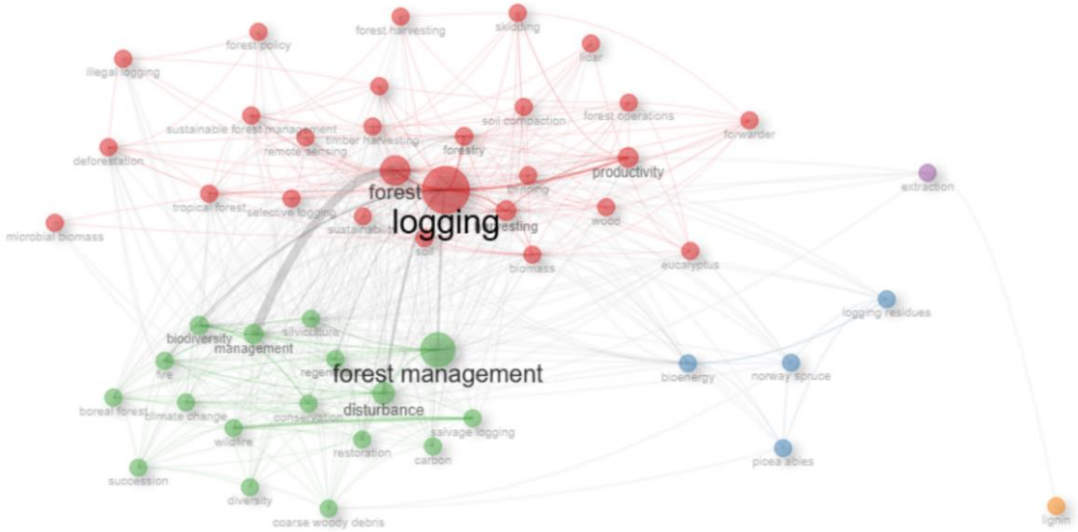


Figure 10. Co-occurrence network.

The red cluster is centered on "logging," while the green cluster is anchored by "forest management." Together, these poles reflect the field's dual emphasis: operations/technique (logging) and management/policy (forest management). A third, blue cluster includes "bioenergy" and "logging residues," indicating growing lines of inquiry related to by-product utilization and supply-chain topics. Node size reflects term frequency and edge thickness reflects co-occurrence strength; colors denote algorithmic community detection. These patterns characterize topical structure within this corpus rather than causal relationships.

Figure 11 classifies keywords by centrality (x-axis; connectedness to the overall field) and density (y-axis; internal development), partitioning them into four quadrants—basic (high centrality, low density), motor (high–high), niche (low centrality, high density), and emerging/declining (low–low).

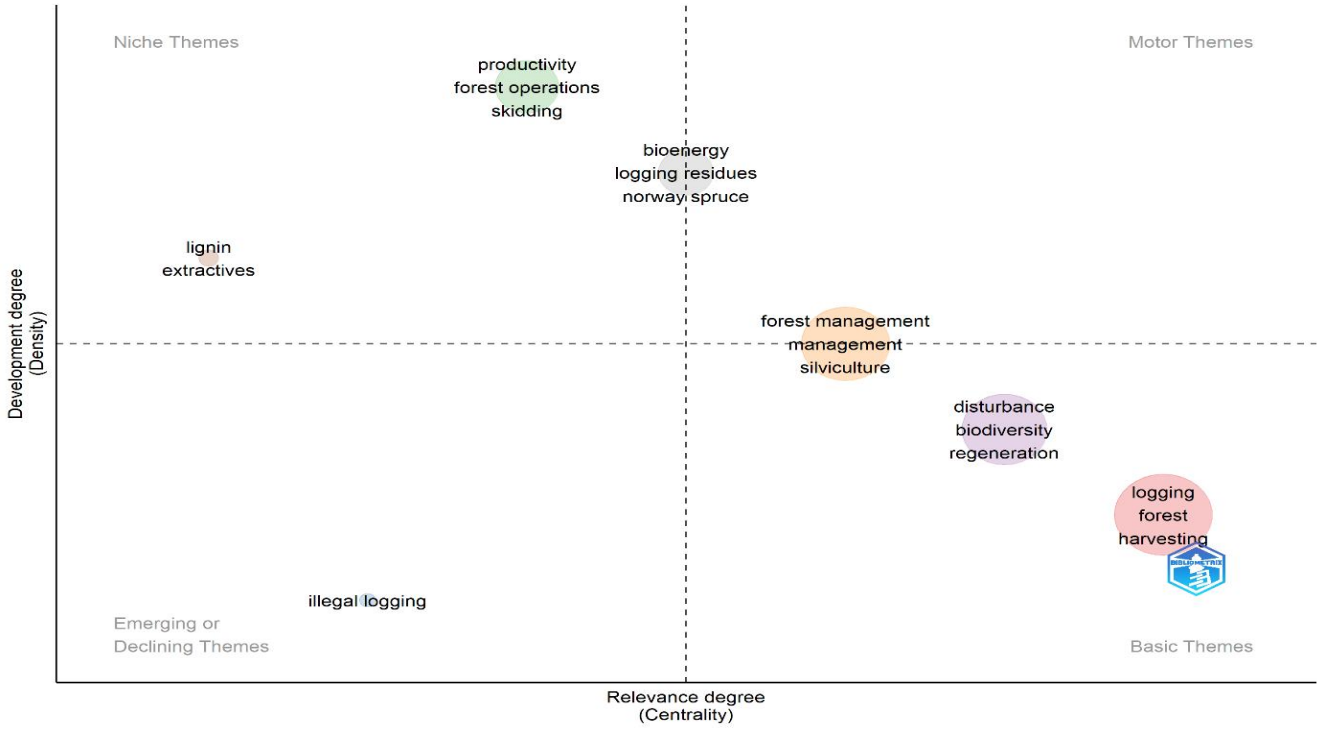


Figure 11. Thematic map of the study field (1980–2025).

In our corpus, "logging," "forest," and "harvesting" occupy the basic themes quadrant, confirming their foundational role and continued relevance. "Bioenergy" and "logging residues," positioned near the central axis, show potential to mature into motor themes, aligning with their rising prominence in the co-occurrence network. Within niche themes, terms such as "productivity," "forest operations," and "skidding" appear under-developed yet promising, suggesting

focused opportunities for future inquiry. By contrast, "illegal logging" resides in the emerging/declining quadrant—indicative either of waning momentum after a prior peak or of a topic constrained by policy-centric framing. Overall, the map delineates the field's established pillars while signaling trajectories likely to shape forthcoming research on forest production, timber extraction, and transport systems.

Our findings align with prior forestry bibliometrics that document a post-2010 acceleration and growing interdisciplinarity (e.g., ecosystem services, bioeconomy). Where we extend the literature is in the operations center: we show that timber-extraction topics cohere around logging/harvesting/skidding (basic themes) while data-intensive fronts (LiDAR, ML/DL, object detection) increasingly intersect with operations after ~2020, bridging ecological assessment and engineering optimization. This bridge is also visible in the co-citation map, where Forest Ecology and Management and the Canadian Journal of Forest Research function as cross-community hubs.

G. Intellectual Structure: Co-citation and Bibliographic Coupling

The Web of Science–based analysis delineates the intellectual base of forest production, timber extraction, and transport systems via the Cited References output, which surfaces the works most frequently referenced within this corpus. Broadly, the field rests on two intertwined pillars: (i) ecosystem-based environmental impact assessment and (ii) forest engineering/operations optimization (mechanization, productivity, and damage control). Exemplary contributions include Putz et al. (2008) and Cambi et al. (2015), which respectively illustrate the ecological evaluation and technical refinement strands. As shown in Supplementary Figure 5, the distribution of cited references by publication year rises gradually from the 1950s, accelerates sharply from the 1980s through the 2010s, and then remains elevated until ~2020. The subsequent dip is expected and likely reflects citation accrual lag for newer publications rather than a substantive decline. The red curve peaks between 1990–2000, indicating a "golden era" in which a concentration of highly influential works—frequently reused as methodological and conceptual anchors—entered the literature and continues to structure current research trajectories. Figure 12 maps frequently co-cited journals into two main clusters.

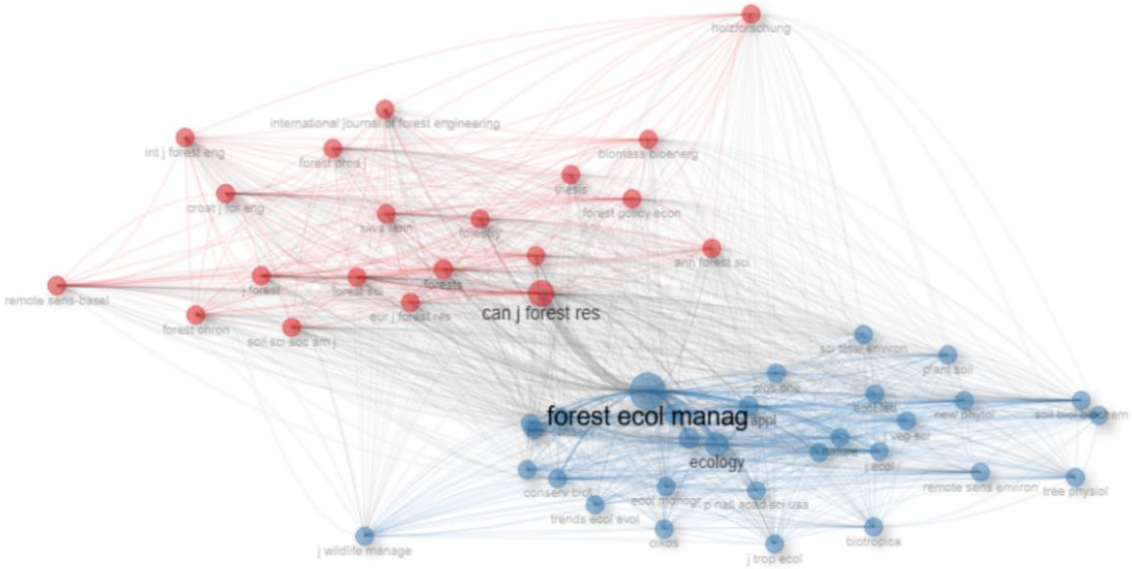


Figure 12. Co-citation network.

The blue cluster, centered on Forest Ecology and Management, groups outlets such as Ecology, Conservation Biology, Trends in Ecology & Evolution, Journal of Tropical Ecology, Remote Sensing of Environment, and Soil Biology and Biochemistry—i.e., ecology/management–oriented sources with strong environmental assessment linkages. The red cluster, anchored by the Canadian Journal of Forest Research, includes International Journal of Forest Engineering, Forest Products Journal, Croatian Journal of Forest Engineering, Silva Fennica, and Forest Policy and Economics, reflecting an operations/engineering and policy–economy axis. At the interface of these communities, Forest Ecology and Management and the Canadian Journal of Forest Research emerge as bridging nodes, indicating central roles in the field's intellectual connectivity via frequent co-citation.

H. Social Structure: Collaboration Networks and Country-Level Analysis

Based on WoS records in this dataset, leading affiliations in forest production, timber extraction, and transport systems include the Swedish University of Agricultural Sciences (SLU; 416 articles), Oregon State University (337), the U.S. Forest Service (295), Université Laval (249), and the University of British Columbia (UBC; 244). These institutions are located in countries with long-standing forestry research traditions and policy frameworks.

Figure 13 plots annual outputs for these affiliations from 1980 to 2025 (x-axis: year; y-axis: publication count), with each colored line representing one institution. The chart offers a 45-year view of institutional research activity. Notably, SLU's trajectory rises sharply after 2010, indicating sustained growth, whereas Oregon State University and UBC exhibit a recent softening in slope. Because 2025 is a partial indexing year, apparent late-period declines should be interpreted cautiously. All counts reflect publications within this corpus as indexed in WoS.

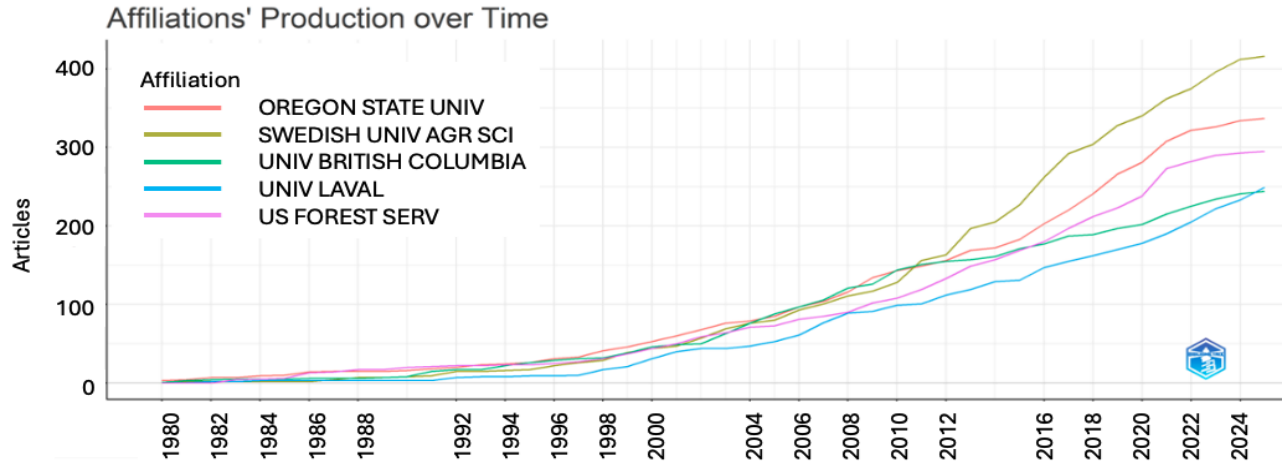


Figure 13. Affiliations' production over time.

Figure 14 shows the distribution of publications by the corresponding author's country. The United States, Canada, China, and Brazil are the leading contributors to research on forest production, timber extraction, and transport systems in this corpus, whereas Türkiye does not appear among the major contributors. The United States ranks first in both single-country publications (SCP)—all authors from the same country—and multi-country publications (MCP)—co-authorship spanning two or more countries—indicating strength in both domestically led and internationally collaborative output.

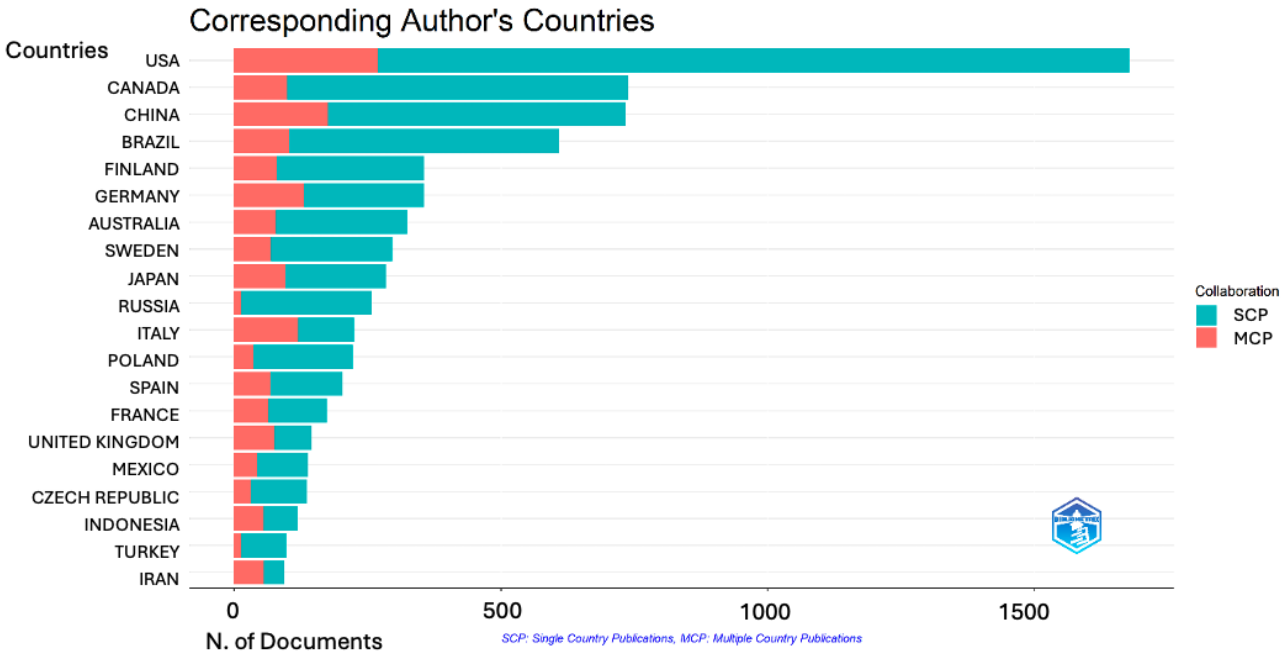


Figure 14. Corresponding author's countries.

Figure 15 visualizes country contributions using a blue choropleth: darker shades denote higher publication counts, lighter shades denote lower output, and gray indicates no/insufficient data in this corpus. The United States is the dominant contributor, appearing in the darkest blue. Within the Middle East, Iran and Türkiye show limited participation, while most other countries appear in grey. Note: Map intensity reflects counts in this WoS-derived corpus and may be influenced by coverage and indexing conventions.

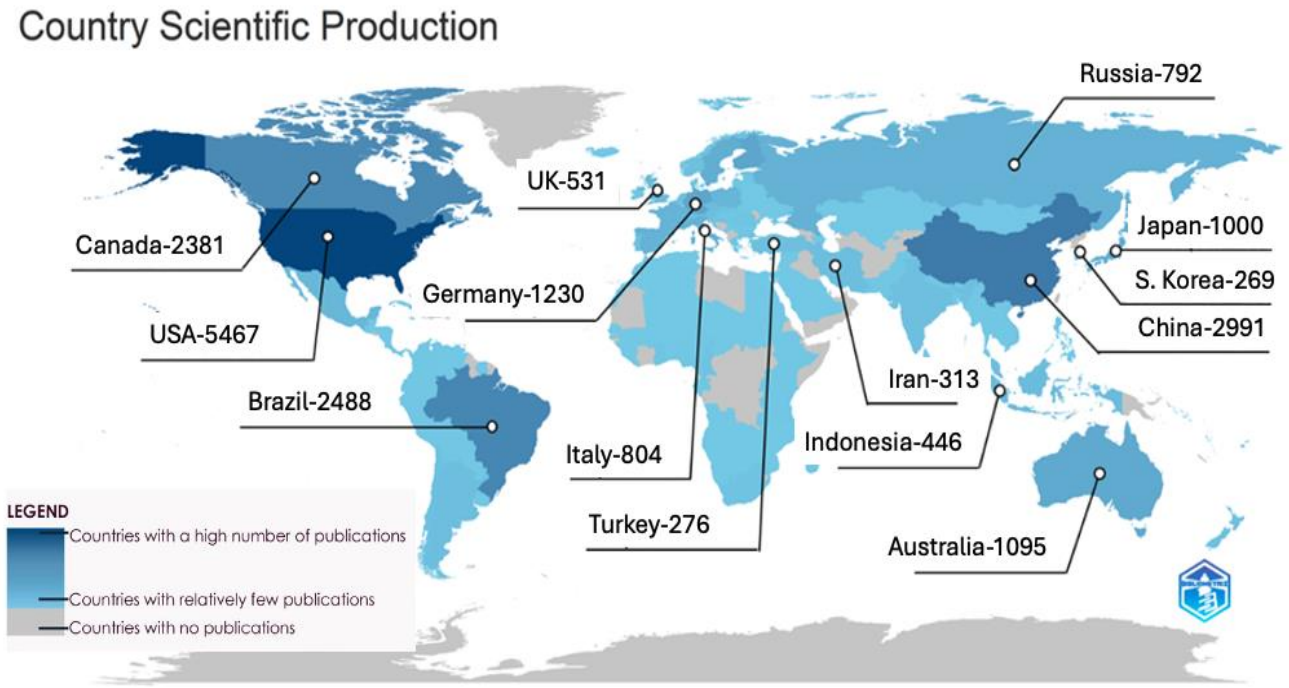


Figure 15. Country specific production.

The series tracks annual outputs for Brazil, Canada, China, Finland, and the United States (Figure 16). The U.S. maintains a consistent lead throughout, with a pronounced acceleration from the early 2000s; by 2025, its cumulative output approaches ~5,000 publications, far exceeding the other countries. China overtakes Finland after 2018 and surpasses Canada and Brazil by 2022. In total citations, the United States leads with 39,964, followed by Canada with 7,769; other influential contributors include China, Finland, Sweden, Australia, Brazil, Germany, Spain, and the United Kingdom.

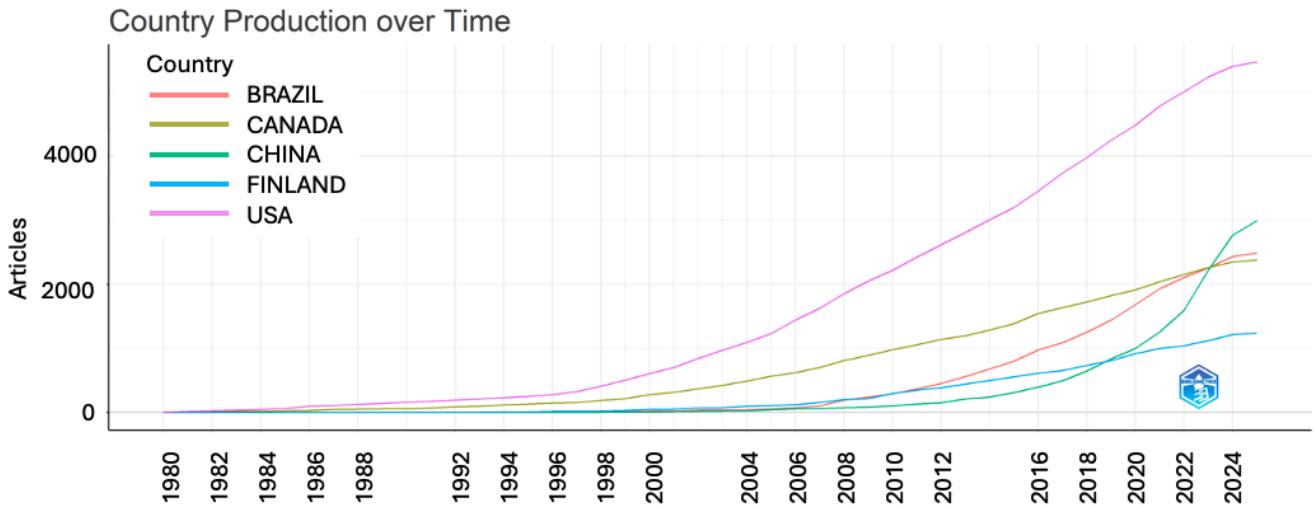


Figure 16. Country production over time.

Each node in Figure 17 represents an author and each edge a co-authored publication; node size scales with collaboration intensity/centrality (within this corpus), edge thickness reflects the strength of collaborative ties, and colors denote community clusters. The network positions Raffaele Spinelli as the most central and influential author, followed by Rodolfo Picchio and Han-Sup Han. At the country level, the United States, Germany, China, the United Kingdom, Australia, and Canada exhibit strong international co-authorship patterns. The accompanying Country Collaboration Map corroborates that research of forest production, timber extraction, and transport systems is shaped not only by nationally led efforts but also by extensive multinational collaboration.

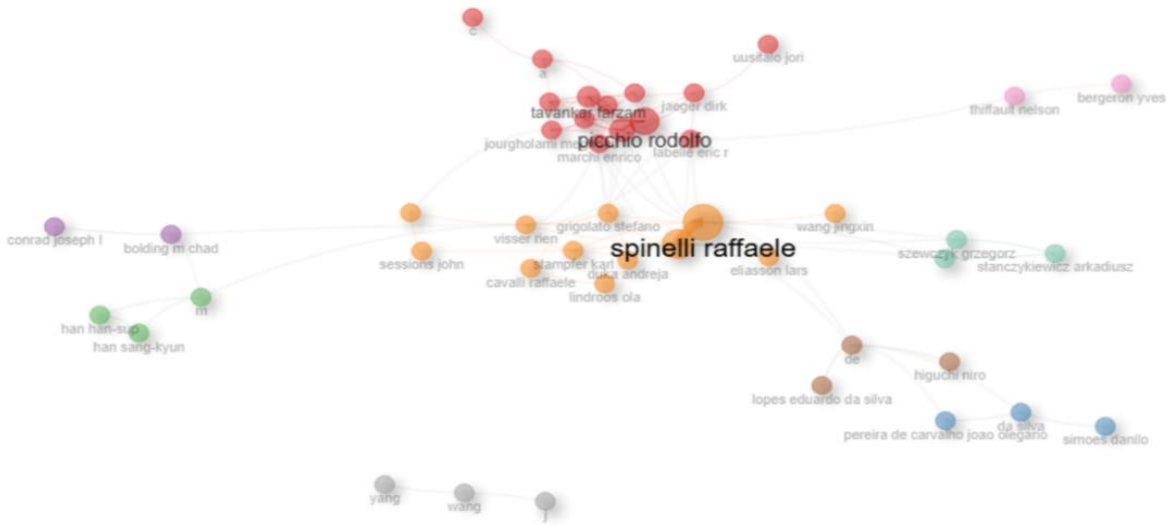


Figure 17. Collaboration network.

Practically, the shift toward AI-assisted remote sensing and geospatial analytics enables finer planning on steep terrain, improved safety for tethered/winch-assisted systems, and better prediction of productivity and residual stand damage. We suggest (i) standardized reporting of operational variables (slope class, stand structure, machine type), (ii) shared open datasets for productivity/safety modelling, and (iii) life-cycle and cost-effectiveness analyses to support procurement and policy decisions.

This study has several limitations that inform the interpretation of results. First, relying on the WoS Core Collection—while advantageous for citation-quality consistency—may under-represent outlets indexed in engineering and operations venues beyond the Forestry category. Second, generic tokens (e.g., "extraction") can inflate topic heterogeneity; our sensitivity checks with a tighter, forestry-bound query reduce this risk but may lower recall. Third, 2025 is a partial indexing year; hence, apparent late-period declines are likely artefacts. To mitigate age bias, we recommend reporting citations per year and, for country/affiliation analyses, fractional counting based on author addresses. These robustness steps do not overturn the main patterns (dual technical/managerial axes, U.S. centrality, and the rise of AI-enabled sensing), but they nuance their magnitudes.

IV. CONCLUSIONS AND FUTURE IMPLICATIONS

This study provides a comprehensive bibliometric mapping of academic research on forest production, timber extraction, and transport systems over 1980–2025, using the WoS Core Collection and the Bibliometrix methodology via Biblioshiny. The workflow enabled a structured assessment of the field's evolution, structure, and dynamics. The choice of WoS (over Scopus) is methodologically defensible here, given the consistency and completeness of citation metadata required for co-citation and intellectual-structure analyses within this corpus.

The results show a steady expansion of the literature, with a marked acceleration after 2010 and a peak in 2024. The domain exhibits strong international collaboration, with the United States, China, Brazil, and Canada leading in productivity and citation influence. At the institutional level, actors such as the Swedish University of Agricultural Sciences and Oregon State University have been pivotal in shaping outputs and agenda setting.

Conceptually, the field is organized around two dominant axes:

i. technical operations (e.g., logging, harvesting, skidding) and
ii. managerial frameworks (e.g., forest management, sustainability).

Keyword clustering and thematic mapping indicate that foundational terms like "logging" and "forest management" remain central, while "bioenergy," "remote sensing," and "machine learning" have gained salience—signaling a transition toward interdisciplinary, data-intensive approaches.

The intellectual base combines ecosystem-based impact assessment with engineering/operations optimization, exemplified by Putz et al. (2008) and Cambi et al. (2015). Journal co-citation networks highlight the bridging roles of Forest Ecology and Management and the Canadian Journal of Forest Research, which connect ecological and operations/engineering clusters.

Looking ahead, several avenues appear especially promising:

- deeper integration of AI, LiDAR, and geospatial analytics to improve precision in planning and monitoring;
- systematic development of underexplored niche clusters—notably productivity, forest operations, and skidding—to translate methods into operational gains;
- broader, cross-disciplinary collaborations that incorporate ecology, engineering, economics, and policy;
- expanded evaluative frameworks (e.g., altmetrics, open-access dynamics) and clearer reporting of reproducibility (search expressions, cleaning/disambiguation steps, and code).

Pursuing these directions can help advance a more resilient, data-informed, and ecologically responsible forestry sector—one that aligns operational efficiency with long-term sustainability.

DECLARATIONS

Acknowledgements: The authors would like to thank the anonymous reviewers for their valuable comments and suggestions that helped improve the quality of this manuscript.

Author Contributions: Conceptualization: KCA, RE; Data curation: KCA; Formal analysis: KCA; Investigation: KCA; Methodology: KCA; Resources: KCA; Software: KCA; Validation: KCA; Visualization: KCA; Writing – original draft: KCA, RE; Writing – review & editing: RE.

Conflict of Interest: The authors declare no conflict of interest.

Supporting Institutions: This study received no financial support.

Ethical Approval: This study does not involve human or animal participants. All procedures followed scientific and ethical principles, and all referenced studies are appropriately cited. The authors reviewed and approved the final manuscript and take full responsibility for the content. This work has not been previously presented or published. The data are provided within the manuscript.

Plagiarism Statement: This article has been evaluated for plagiarism and no instances of plagiarism were detected.

Use of AI Tools: Generative artificial intelligence tools (GPT-5.2) were used solely for language editing (grammar and readability).

REFERENCES

Acar, H. H., & Ünver-Okan, S. (2015, September 7–11). Evaluation of the using of monorail system in forestry in terms of precision forestry. In *XIV World Forestry Congress*, Durban, South Africa.

Aguilar, F. J., Rodríguez, F. A., Aguilar, M. A., Nemmaoui, A., & Álvarez-Taboada, F. (2024). Forestry applications of space-borne LiDAR sensors: A worldwide bibliometric analysis. *Sensors, 24*(4), Article 1106. https://doi.org/10.3390/s24041106

Akay, E. A., Sessions, J., Serin, H., Pak, M., & Yenilmez, N. (2010). Applying optimum bucking method in producing Taurus fir (Abies cilicica) logs in Mediterranean Region of Turkey. *Baltic Forestry, 16*(2), 273–279.

Aleixandre-Benavent, R., Aleixandre-Tudó, J. L., Castelló-Cogollos, L., & Aleixandre, J. L. (2018). Trends in global research in deforestation: A bibliometric analysis. *Land Use Policy, 72*, 293–302. https://doi.org/10.1016/j.landusepol.2017.12.060

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics, 11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Bao, M., Liu, J., Ren, H., Liu, S., Ren, C., Chen, C., & Liu, J. (2024). Research trends in wildland fire prediction amidst climate change: A comprehensive bibliometric analysis. *Forests, 15*(7), Article 1197. https://doi.org/10.3390/f15071197

Bont, L. G., Fraefel, M., Frutig, F., Holm, S., Ginzler, C., & Fischer, C. (2022). Improving forest management by implementing best suitable timber harvesting methods. *Journal of Environmental Management, 302*, Article 114099. https://doi.org/10.1016/j.jenvman.2021.114099

Cambi, M., Certini, G., Neri, F., & Marchi, E. (2015). The impact of heavy traffic on forest soils: A review. *Forest Ecology and Management, 338*, 124–138. https://doi.org/10.1016/j.foreco.2014.11.022

Chen, S., Chen, J., Jiang, C., Yao, R. T., Xue, J., Bai, Y., Wang, H., Jiang, C., Wang, S., Zhong, Y., Liu, E., Guo, L., Lv, S., & Wang, S. (2022). Trends in research on forest ecosystem services in the most recent 20 years: A bibliometric analysis. *Forests, 13*(7), Article 1087. https://doi.org/10.3390/f13071087

Chen, Z., Gao, Y., Chen, J., Yang, L., Zeng, S., Su, Y., Li, J., He, Q., & Qiu, Q. (2023). Global bibliometric analysis of research on the application of biochar in forest soils. *Forests, 14*(11), Article 2238. https://doi.org/10.3390/f14112238

Dinca, L., Constandache, C., Postolache, R., Murariu, G., & Tupu, E. (2025). Timber harvesting in mountainous regions: A comprehensive review. *Forests, 16*(3), Article 495. https://doi.org/10.3390/f16030495

Dirik, D., Erhan, T., & Eryılmaz, İ. (2024). A bibliometric analysis on potential trends in artificial intelligence and organization studies. *Bulletin of Economic Theory and Analysis, 9*(3), 669–698. https://doi.org/10.25229/beta.1487924

Erdaş, O., Acar, H. H., & Eker, M. (2014). *Forest products transportation techniques* (Publication No. 233/39). Karadeniz Technical University.

Fazeli-Varzaneh, M., Bettinger, P., Ghaderi-Azad, E., Kozak, M., Mafi-Gholami, D., & Jaafari, A. (2021). Forestry research in the Middle East: A bibliometric analysis. *Sustainability, 13*(15), Article 8261. https://doi.org/10.3390/su13158261

Fioravanti, M., Giannetti, F., Spinelli, S., & Marchetti, M. (2018). Bibliometric analysis of the scientific production in forestry-related scientific fields. *Forest@ – Journal of Silviculture and Forest Ecology, 15*, 65–70. https://doi.org/10.3832/efor2861-015

Gao, W., Qiu, Q., Yuan, C., Shen, X., Cao, F., Wang, G., & Wang, G. (2022). Forestry big data: A review and bibliometric analysis. *Forests, 13*(10), Article 1549. https://doi.org/10.3390/f13101549

Huang, L., Xia, Z., & Cao, Y. (2022). A bibliometric analysis of global fine roots research in forest ecosystems during 1992–2020. *Forests, 13*(1), Article 93. https://doi.org/10.3390/f13010093

Jankovský, M., García-Jácome, S. P., Dvořák, J., Nyarko, I., & Hájek, M. (2021). Innovations in forest bioeconomy: A bibliometric analysis. *Forests, 12*(10), Article 1392. https://doi.org/10.3390/f12101392

Jayasundara, M., Kadam, P., & Dwivedi, P. (2024). The impact of COVID-19 on the global forestry sector: A bibliometric analysis-based literature review. *Forest Policy and Economics, 158*, Article 103103. https://doi.org/10.1016/j.forpol.2023.103103

Johann, E. (2021). Transportation of wood out of the forest (along short distances). *International Journal of Wood Culture, 1*(1–3), 80–111. https://doi.org/10.1163/27723194-20210008

Kumar, A., & Pandey, A. (2024). A bibliometric analysis of 100 years of research on Himalayan cedar: Research trends, gaps, and future implications. *Frontiers in Forests and Global Change, 7*, Article 1485083. https://doi.org/10.3389/ffgc.2024.1485083

Ma, Z., Hu, C., Huang, J., Li, T., & Lei, J. (2022). Forests and forestry in support of sustainable development goals (SDGs): A bibliometric analysis. *Forests, 13*(11), Article 1960. https://doi.org/10.3390/f13111960

Posit. (2025). *RStudio Desktop* [Computer software]. https://posit.co/download/rstudio-desktop

Putz, F. E., Sist, P., Fredericksen, T., & Dykstra, D. (2008). Reduced-impact logging: Challenges and opportunities. *Forest Ecology and Management, 256(*7), 1427–1433. https://doi.org/10.1016/j.foreco.2008.03.036

Santillán-Fernández, A., Vásquez-Bautista, N., Pelcastre-Ruiz, L. M., Ortigoza-García, C. A., Padilla-Herrera, E., Tadeo-Noble, A. E., Carrillo-Ávila, E., Juárez-López, J. F., Vera-López, J. E., & Bautista-Ortega, J. (2023). Bibliometric analysis of forestry research in Mexico published by Mexican journals. *Forests, 14*(3), Article 648. https://doi.org/10.3390/f14030648

Santos, S. M. B. d., Bento-Gonçalves, A., & Vieira, A. (2021). Research on wildfires and remote sensing in the last three decades: A bibliometric analysis. *Forests, 12*(5), Article 604. https://doi.org/10.3390/f12050604

Shi, Y., Wang, Z., Zhang, G., Wei, X., Ma, W., & Yu, H. (2024). Evaluating the research status of the remote sensing-mediated monitoring of forest biomass: A bibliometric analysis of WOS. *Forests, 15*(3), Article 524. https://doi.org/10.3390/f15030524

Silva, B. R. F. d., Ucella-Filho, J. G. M., Bispo, P. d. C., Elera-Gonzales, D. G., Silva, E. A., & Ferreira, R. L. C. (2024). Using drones for dendrometric estimations in forests: A bibliometric analysis. *Forests, 15*(11), Article 1993. https://doi.org/10.3390/f15111993

Spinelli, R., & Magagnotti, N. (2012). Wood extraction with farm tractor and sulky: Estimating productivity, cost and energy consumption. *Small-scale Forestry, 11*, 73–85. https://doi.org/10.1007/s11842-011-9169-8

Taş, İ., Akay, A. E., Eker, M., Gümüş, S., Demir, M., Acar, H. H., & Özdemir, M. (2024). Assessment of optimum timber extraction methods using geographic information system-based multi-criteria decision support method. *Forestist, 74*(2), 113–128. https://doi.org/10.5152/forestist.2024.23069

Uribe-Toril, J., Ruiz-Real, J. L., Haba-Osca, J., & de Pablo Valenciano, J. (2019). Forests' first decade: A bibliometric analysis overview. *Forests, 10*(1), Article 72. https://doi.org/10.3390/f10010072

Xie, J., Zhang, G., Li, Y., Yan, X., Zang, L., Liu, Q., Chen, D., Sui, M., & He, Y. (2023). A bibliometric analysis of forest gap research during 1980–2021. *Sustainability, 15*(3), Article 1994. https://doi.org/10.3390/su15031994

Zhang, Y., Fei, X., Liu, F., Chen, J., You, X., Huang, S., Wang, M., & Dong, J. (2022). Advances in forest management research in the context of carbon neutrality: A bibliometric analysis. *Forests, 13*(11), Article 1810. https://doi.org/10.3390/f13111810

Zhao, J., Li, L., Liu, J., Yan, Y., Wang, Q., Newman, C., & Zhou, Y. (2024). A bibliometric analysis using machine learning to track paradigm shifts and analytical advances in forest ecology and forestry journal publications from 2010 to 2022. *Forest Ecosystems, 11*, Article 100233. https://doi.org/10.1016/j.fecs.2024.100233