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Trends in Research on Forest Ecosystem Services in the Most Recent 20 Years: A Bibliometric Analysis

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Abstract: Forest resources and the flow of ecosystem services they provide play a key role in supporting national and regional economies, improving people's lives, protecting biodiversity, and mitigating the impacts of climate change. Based on the ISI (Institute of Scientific Information) Web of Science (WoS) database, we used a bibliometric approach to analyze the research status, evolution process, and hotspots of forest ecosystem services (FES) from a compilation of 8797 documents published between 1997 and 2019. The results indicated that: (1) research on forest ecosystem services has developed rapidly over the past 23 years. Institutions in the United States and other developed countries have significantly contributed to undertake research on the topic of ecosystem services. (2) The 11 hotpot key focus areas of completed research were payments for ecosystem services, biodiversity conservation, forest governance, ecosystem approaches, climate change, nitrogen, ecosystem management, pollination, cities, ecological restoration, and policy. (3) The trade-off relationships among ecosystem services, ecosystem resilience and stability have become the research frontier in this field. (4) Future research on FES will likely focus on the formation and evolution mechanism of ecosystem services; the interaction, feedback and intrinsic connections of ecosystem services at different scales; analysis of the trade-offs and synergies; unified evaluation standards, evaluation systems, model construction and scenario analyses; in-depth studies of the internal correlation mechanism between forest ecosystem services and human wellbeing; and realization of cross-disciplinary and multi-method integration in sustainable forest management and decision-making.

Keywords: ecosystem services; forest resources; bibliometric analysis; human disturbance

1. Introduction

Forests are an important component of the terrestrial ecosystem because of their rich biodiversity, which provides a variety of ecosystem services which serve as the foundation for human survival and development [1], such as wood supply, climate regulation, carbon sequestration and oxygen release, soil and water conservation, and habitat provision [2]. Research initiatives on forest ecosystem services (FES) have developed into various interdisciplinary approaches to effectively examine the relationships among ecology, society, and the economy. In recent years, the number of FES research projects/programs has grown exponentially [3]. To better understand the rapid development of the FES fields of research, it was necessary to conduct a comprehensive and systematic analysis of FES research and discuss its evaluation processes and trends.

Bibliometrics is a statistical technique for quantitative analysis of scientific publications such as books, citations, patent documents, and reports [4]. This technology can quickly and comprehensively summarize the development of a specific research field [5] or a discipline [6], and display the current status and developing trends of knowledge through visual network mapping. This method can break the scientific boundaries between countries and regions [7] and provide an innovative perspective for researching the development of scientific knowledge in a field [8,9]. At present, the characteristics and research topics regarding various fields of ecology have been discussed by using bibliometrics in a number of studies [5,9–15]. Aznar-Sánchez analyzed the global dynamics of FES from 1998 to 2017 [8]; however, little was known about qualitative analysis of the contents of the studies. Yu conducted a survey on the evaluation of FES functions in China based only on the CNKI database. In terms of the development of FES [7], there has been a lack of systematic and comprehensive understanding of the research status and hotspots in FES. Therefore, this study fills this gap by using bibliometric methods to identify the developing status of FES from both quantitative and qualitative aspects.

In this study, we identified, compiled, and analyzed the publications related to FES from 1997 to 2019 with bibliometrics, aiming to: (1) have an overview of FES in terms of authors, institutions, countries, journals, references, and keywords; (2) reveal the evolution of the knowledge structure and networks in this field from three aspects of highly cited articles, frequent keywords, and bursting keywords; (3) discuss the research status and hotspots in FEMS of FES; and (4) point out trends in forest ecosystem services in the future.

2. Methods

2.1. Data Sources

ISI's Web of Science (WoS) is the world's largest comprehensive and multidisciplinary academic retrieval platform and is one of the main reliable sources of citation data [16]. WoS includes the Science Citation Index Expanded (SCI), the Social Science Citation Index (SSCI), the Art and Humanities Citation Index (A&HCI), the Conference Proceedings Citation Index—Science (CPCI-S), and the Conference Proceedings Citation Index—Social Science and Humanities (CPCI-SSH). We used the SCI database to search for relevant publications by title, abstract, and keywords under the theme of "forest ecosystem services". The search terms were "forest-* -ecosystem-*-service*" (including "forest ecosystem service", "forest ecosystem services", etc.), "forest*", and "ecosystem-*-service*" (including "forest", "forests", "ecosystem service", "ecosystem services", etc.). The document type options were set to articles and reviews because they represent most studies with complete research results [17]. The language was set to English. Since the concept of ecosystem services was proposed by Daily in 1997, it has attracted attention in various research fields. Therefore, the time span of the research data was from 1997 to 2019. After merging and deduplication, 8865 publications were collected on 31 December 2019. Next, publications outside the research time scope were excluded, and 8797 publications were finally obtained.

2.2. Data Analysis

CiteSpace software (version 5.6) takes a set of bibliographic records as input and models the basic intellectual structure of a field according to a time series network formed by annual publications [18]. CiteSpace supports several types of bibliometric research, including collaboration network analysis, co-word analysis, author co-citation analysis, co-citation analysis, and textual and geospatial visualizations [18]. We filtered and deleted duplicated publications via CiteSpace 5.6.1R, and subsequently extracted information including the authors, institutions, countries, keywords, cited references, citing articles, and their relationship matrices, then drew network maps using Gephi (https://gephi.org/) accessed on 5 May 2022.

The parameters of CiteSpace were set as follows: the time span was 1997–2019, while the time slice was 1 year, 3 years, or 5 years as needed. According to the research content, a collaboration network analysis of authors, institutions, and countries; a co-citation analysis of authors, journals, and references; and a co-words analysis were selected separately. The merged network was pruned using the "Pruning the merged network" tool of Pathfinder. Log-likelihood ratio (LLR) was chosen for clustering analysis of co-words. Other parameters were based on the system's default settings.

3. Results and Discussion

3.1. Overall Status of FES

The results from our analysis show that from 1997 to 2019, the number of publications in the field of FES was 8797. Between 1997 and 2005, the number of publications grew slowly and then increased exponentially. This was due to the United Nations Millennium Ecosystem Assessment (MEA) issued in 2005, which provided scientists a framework for conducting extensive and in-depth research on forest ecosystem services. Therefore, the number of publications between 2006 and 2019 grew rapidly and accounted for about 96% of the total FES publications in the study period (Figure 1). The rapid growth indicated that FES research has significantly grown in importance globally.

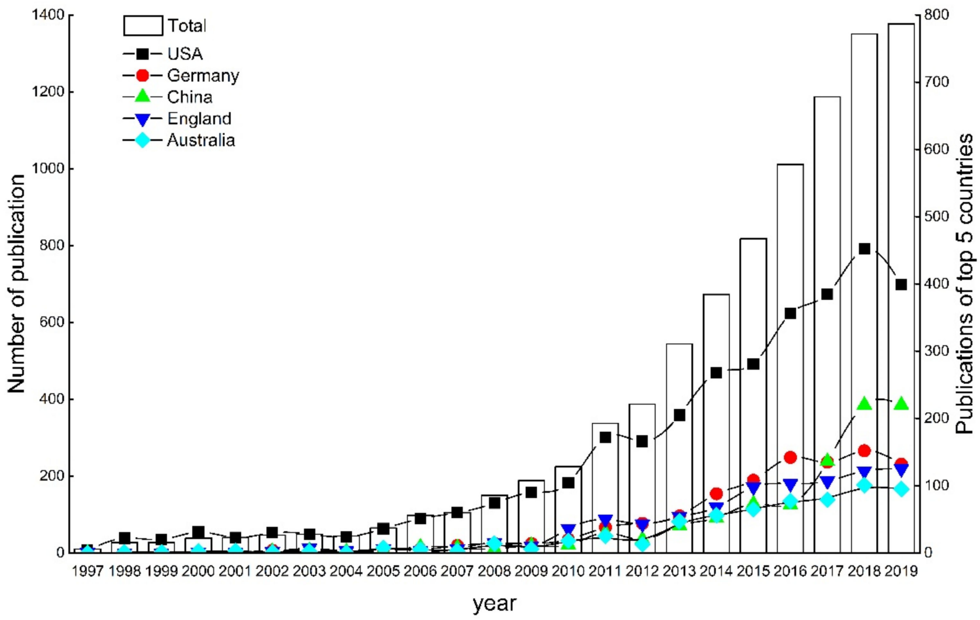

Figure 1. Number of FES publications by year from 1997 to 2019.

The USA and the UK initially produced the greatest number of FES publications, as scientists, academicians, and practitioners in the USA have been leading the initiatives for FES research since 1998 (Figure 1). Although China appeared to have started only in the early 1980s, its number of FES research publications has increased rapidly in recent years. In 2018 and 2019, China became the second country in terms of the number of annual publications, following only the USA, and was also the third country for total publications in the world.

3.1.1. Co-Citation Analysis of Authors

As shown in Table 1, the cited frequency of R. Costanza's study was the highest. The most cited study was "The value of the world's ecosystem services and natural capital" published in *Nature* in 1997. This article estimated the economic value of 17 ecosystem services of 16 biomes and emphasized the huge contribution of natural resources and the ecosystem services they provided to human wellbeing. The second most cited author was G.C. Daily. Her most cited publication was the book entitled *Nature's Services: Societal Dependence on*

Natural Ecosystems, published in 1997. This book made a preliminary assessment of the economic value of ecosystem services by explaining how people derive benefit from the flow of services that nature provides. It also described the extent to which humans depend on ecosystem services and how this concept enhances our understanding of the value of our natural systems, which lays the foundation for further research on sustaining the provision of ecosystem services. The third most cited author is R.S. De Groot. His most cited article is "A typology for the classification, description and valuation of ecosystem functions, goods and services" published in *Ecological Economics* in 2002. This study proposed a conceptual prototype for describing, classifying, and evaluating ecosystem functions, goods, and services. Some other authors were interested in the following research topics: the relationship between land use, climate change and ecosystem services, and their impact on humans; management and decision-making regarding natural resources and ecological systems; and multidisciplinary interactive integration.

Analysis of the co-citations of the authors showed that interim working teams or international organizations also contributed to research on ecosystem services. The international organizations or teams with very high citation rates include the R Development Core Team, Millennium Ecosystem Assessment, FAO, and IPCC, which achieved high citation rates. Since the R Development Core Team was cited for the first time in 2007, the number of its citations increased over the past 10 years, indicating that the R language has become the main tool for statistical analysis. The Millennium Ecosystem Assessment (MEA) systematically and comprehensively revealed the status and changes, future trends, and strategies of various ecosystems at a global scale for the first time in 2005. MEA highlights the importance of ecological conservation and its connection to the economy and society, thereby encouraging decision-makers to sustain and enhance natural capital and the flow of ecosystem services for current and future generations. The cited frequency of this report has increased exponentially since its publication in 2005, thereby guiding the thinking of academicians, researchers, and practitioners around the world in sustainable resource management. Consequently, some authors began to cite the report of FAO in 1997, and the number of citations has been increasing significantly since 2007.

3.1.2. Co-Occurrence Analysis of Journals

In the period of 1997–2019, the 10 journals with the greatest number of FES publications were *Forest Ecology and Management* (342), *Ecosystem Services* (273), *Forests* (240), *PLoS One* (223), *Ecological Indicators* (196), *Land Use Policy* (186), *Ecological Economics* (181), *Sustainablity* (175), *Forest Policy and Economics* (173), and *Science of the Total Environment* (158).

The top 10 journals with most cited frequency on FES were *Science*, *Forest and Ecology Management*, *Nature*, *Proceedings of the National Academy Sciences of the United States of America*, *Ecological Economics*, *Biological Conservation*, *Conservation Biology*, *Ecological Applications*, *BioScience*, and *Ecology*. These journals are an important source of knowledge in the FES field (Table 2).

Table 1. The top 10 most cited authors.

Cited Frequency	Author	Research Institute	Representative Article	Rearch Topic
1185	Costanza R Robert Costanza	Crawford School of Public Policy, Australian National University, Australia	The value of the world's ecosystem services and natural capital	transdisciplinary integration, systems ecology, ecological economics, landscape ecology, ecological modeling, ecological design, energy analysis, environmental policy, social traps, incentive structures and institutions
737	Daily GC Gretchen C. Daily	Department of Biology, Stanford University, Stanford, CA	Ecosystem services in decision making: time to deliver	ecosystem services valuation, countryside biogeography, biodiversity change and conservation, agriculture development, policy and financial analysis for integrating conservation and human development
731	De Groot R Rudolf de Groot	Environmental Systems Analysis Group, Wageningen University, The Netherlands	A typology for the classification, description and valuation of ecosystem functions, goods and services	sustainable development; natural resource management; environmental impact assessment; biodiversity; ecology
542	Foley JA Jonathan A. Foley	Institute on the Environment, University of Minnesota, St. Paul, Minnesota, United States	Global consequences of land use	complex relationship between global environmental systems and human civilization, land use changes, model analyze, ecosystems and resources changes
530	Wunder S Sven Wunder	Center for International Forestry Research, Lima, Peru	Taking stock: a comparative analysis of payments for environmental services programs in developed and developing countries	environmental science, climate change, forest management, forest conservation, natural resource management
495	Tilman D David Tilman	Department of Ecology, Evolution, and Behavior, University of Minnesota, USA; Bren School of the Environment Science and Management, University of California, USA	Diversity–stability relationships: statistical inevitability or ecological consequence	ecosystem services valuation, species invasions, the evolution and maintenance of biodiversity, population ecology, theory of community dynamics and biodiversity, resource competition, biodiversity and ecosystem functioning
476	Myers N Norman Myers	21st Century School, Oxford University, United Kingdom	Biodiversity hotspots for conservation priorities	
470	Chazdon RL Robin L. Chazdon	Department of Ecology and Evolutionary Biology, University of Connecticut, USA	Beyond Deforestation: Restoring Forests and Ecosystem Services on Degraded Lands	Tropical forest restoration is a global, high-value opportunity
446	Kremen C Claire Kremen	IRES and Biodiversity Research Centre, University of British Columbia, Canada	Managing ecosystem services: What do we need to know about their ecology?	Biodiversity, agricultural production, ecosystem service, agroecosystem
432	Laurance WF William F. Laurance	Centre for Tropical Environmental and Sustainability Science and College of Science and Engineering, James Cook University, Australia	Ecosystem Decay of Amazonian Forest Fragments: A 22-Year Investigation	habitat fragmentation, climate change, soil biology, surface fires, environmental protection policy, nature reserve design

Table 2. Top 10 cited journals in terms of the number of publications on FES-related topics.

Journal	TC	Impact Factor (2018)	h-Index
Science	5099	41.037	1058
Forest and Ecology Management	4146	3.126	152
Nature	4079	43.07	1096
Proceedings of the National Academy Sciences of the United States of America	4075	9.58	699
Ecological Economics	3232	4.281	174
Biological Conservation	3211	4.451	173
Conservation Biology	3198	6.194	201
Ecological Applications	3170	4.378	193
BioScience	2828	6.591	189
Ecology	2820	4.285	262

Note: Impact factors are taken from journal citation reports published in 2018 (JCR). TC: total citations of journal.

3.1.3. Collaboration Network Analysis of Countries and Institutions

Cooperation and exchange contribute to improve the research level and academic influence of countries and institutions. From 1997 to 2019, 109 countries published studies related to FES, as shown in Figure 2. The top 10 countries with the highest number of FES publications were the USA (3281), Germany (968), China (924), the UK (861), Australia (622), Brazil (617), Canada (600), Spain (498), France (473), and Italy (444). The United States cooperated with 15 countries, the countries most frequently cooperated with being China (243 times), the United Kingdom (236 times), Brazil (198 times), and Canada (192 times). However, its centrality is less than 0.1, indicating weak international communication and cooperation. The UK and France have high centrality, indicating that they occupy an important position in international cooperation and play a crucial role in promoting exchanges between other countries. Although China is the third country for total publications, there are only seven connections between China and other countries, so China should strengthen international exchanges and cooperation in this field.

In the institutional collaboration network, the top 10 institutions with the highest number of publications are the United States Department of Agriculture Forest Service, the Chinese Academy of Science, the Swedish University of Agricultural Sciences, Stanford University, the University of Wisconsin, the University of Sao Paulo, the University of Queensland, Universidad Nacional Autónoma de México, the University of Copenhagen, and the University of Florida. These 10 institutions and other institutions work closely together. Among them, Stanford University occupies an important position in cooperating with other institutions (its centrality is 0.11). The number of studies published by the Chinese Academy of Sciences ranks second. However, its centrality is relatively small (0.05), which also indicates that its international cooperation and exchanges are relatively weak and need to be strengthened still further (Table 3).

Table 3. Top 10 institutions in terms of the number of publications on FES-related topics.

Institutions	Freq	Burst	Degree	Centrality	Sigma
United States Department of Agriculture Forest Service	464	22.09	52	0.07	4.08
Chinese Academy of Science	403		28	0.05	1.00
Swedish University of Agricultural Sciences	160		41	0.05	1.00
Stanford University	138	7.02	65	0.11	2.10
University of Wisconsin	137		49	0.04	1.00
University of Sao Paulo	132		40	0.03	1.00
University of Queensland	129		44	0.05	1.00
Universidad Nacional Autónoma de México	127		36	0.02	1.00
University of Copenhagen	127	4.13	40	0.04	1.17
University of Florida	125		52	0.04	1.00

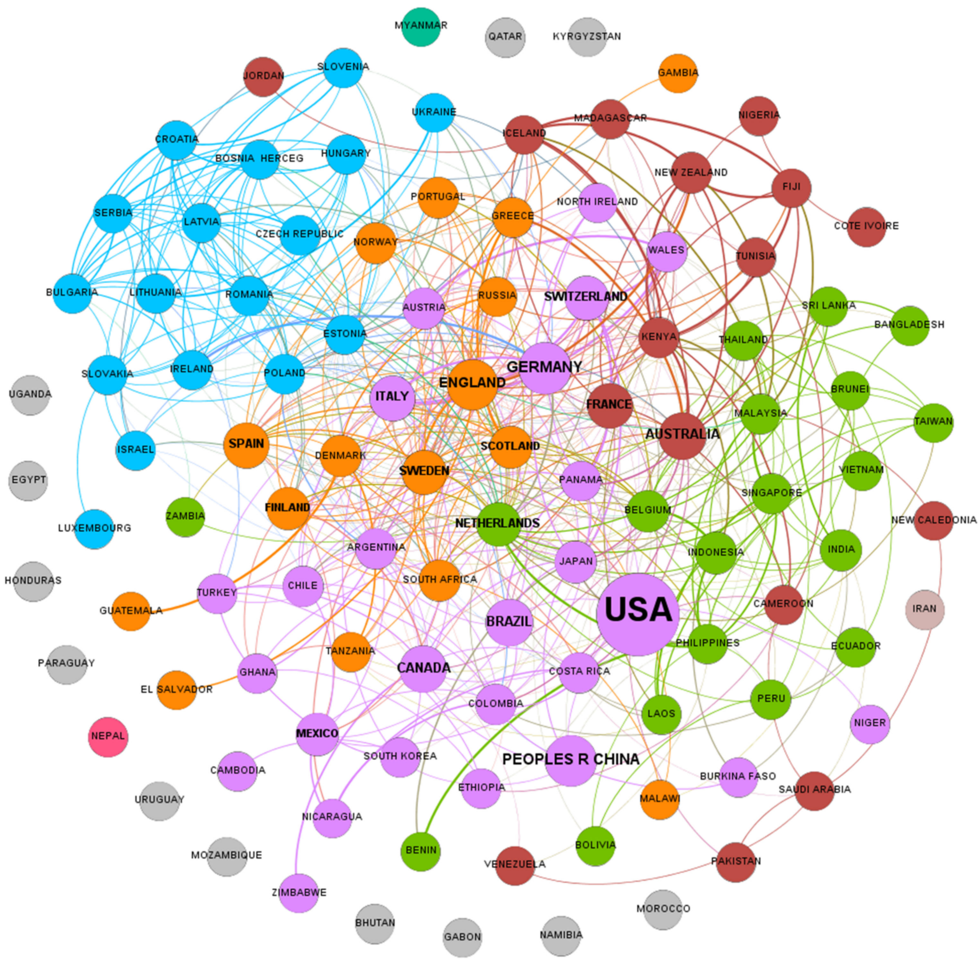

Figure 2. Institutional cooperation in research and publications on FES-related topics among countries. The size of each country (node) in the network is directly proportional to its number of occurrences in the documents analyzed. Colors indicate the clusters to which country is unequivocally assigned on the basis of their reciprocal relatedness (gray represents individuals).

3.1.4. Co-Citation Analysis of Publications

Higher citation frequency usually indicates the greater influence of the publication. Table 4 lists the 10 most cited publications in the field of FES from 1997 to 2019. The most highly cited is "High-resolution global maps of 21st-century forest cover change" published in *Science* by Hansen [19]. This study describes the application of spatial analysis of global forest losses between 2000 and 2012, and the corresponding impacts on the provision forest ecosystem services, using satellite data of the Earth. The article provided a good visualization and quantification of global forest change. The second most cited publication is titled "Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making", which was published in the *Ecological Complex* by de Groot [20]. This study incorporated the concepts of ecosystem services and evaluation methods into planning, management, and decision-making frameworks of the landscape. It highlighted that investing in conservation, restoration, and sustainable utilization of the ecosystem can lead to "win–win" prospects for the environment and economic development. The third most cited article is "Changes in the global value of ecosystem services" published in *Global Environmental Change* by Costanza [21]. This article estimated the impacts of land use change on the value of ecosystem services between 1997 and 2011. Other very frequently cited articles focused on describing, classifying and evaluating ecosystem services [22]; the trade-offs and synergies among ecosystem services at different landscape scales [23,24]; the impacts of biodiversity on ecosystem services and human wellbeing [25]; the impacts of land use change on ecosystem services [26]; and payments for ecosystem services and ecosystem management [27,28].

3.2. Research Hotspots

Keywords are high-level summary of a publication's research theme. The frequency of keywords reflects the research hotspots of a given field, while the bursting keywords represents the emerging trends in this field. We merged similar keywords such as "ecosystem services" and "ecosystem service"; "land use change" and "land-use change"; "biodiversity", "diversity", "biological diversity", "species diversity", and "plant diversity"; "economic value" and "economic valuation"; "Amazon" and "Brazilian Amazon"; "CO_2" and "carbon dioxide"; and "USA" and "United States". Finally, a knowledge graph of keyword co-occurrence with 229 nodes and 1163 connections was constructed. According to the occurrence frequency, the top 20 keywords of publications in FES field from 1997 to 2019 were determined (Table 5). Furthermore, these keywords were classified into 11 categories to represent research hotspots through cluster analysis (Figure 3).

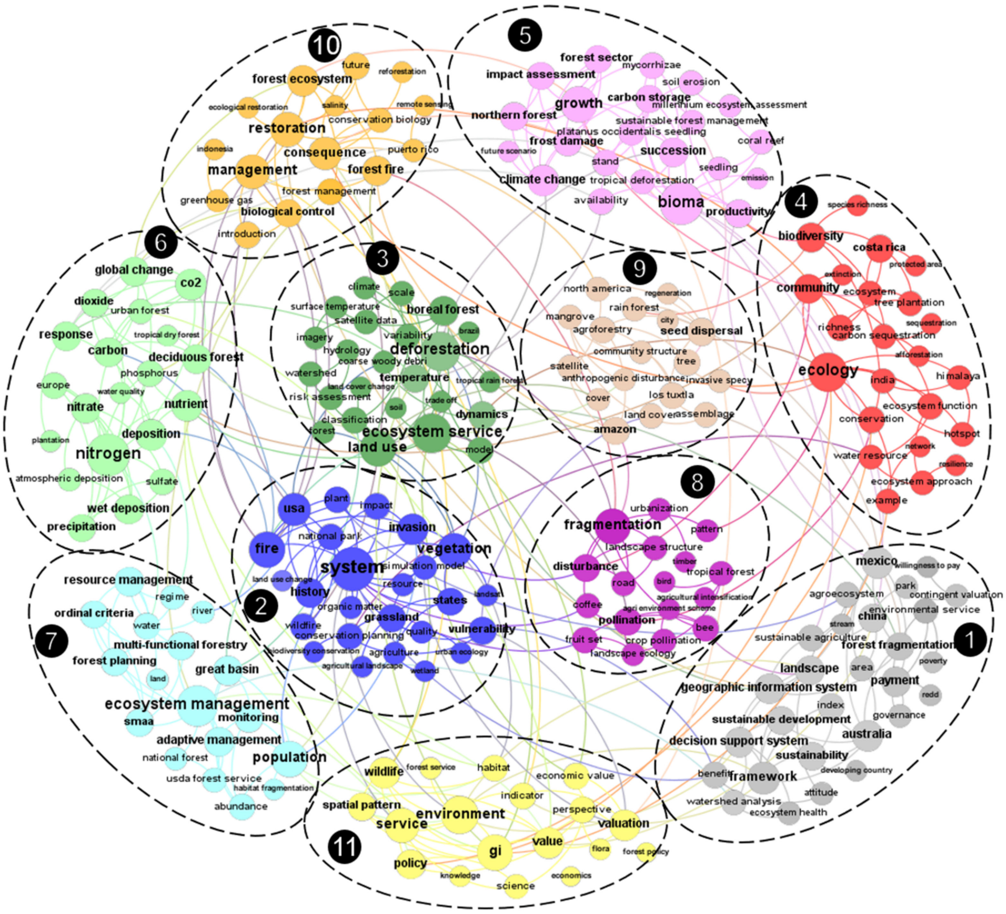

Figure 3. General diagram of keyword clustering of published articles on FES-related topics from 1997 to 2019. Note: ① payments for ecosystem services; ② biodiversity conservation; ③ forest governance; ④ ecosystem approach; ⑤ climate change; ⑥ nitrogen; ⑦ ecosystem management; ⑧ pollination; ⑨ city; ⑩ ecological restoration; ⑪ policy.

Table 4. Top 10 most cited articles.

Articles	Author	Year	Source	DOI
High-Resolution Global Maps of 21st-Century Forest Cover Change	Hansen MC et al.	2013	*Science*	10.1126/science.1244693
Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making	de Groot RS et al.	2010	*Ecological Complex*	10.1016/j.ecocom.2009.10.006
Changes in the global value of ecosystem services	Costanza R et al.	2014	*Global Environmental Change*	10.1016/j.gloenvcha.2014.04.002
Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales	Nelson E et al.	2009	*Frontiers in Ecology and the Environment*	10.1890/080023
Biodiversity loss and its impact on humanity	Cardinale BJ et al.	2012	*Nature*	10.1038/nature11148
Defining and classifying ecosystem services for decision making	Fisher B et al.	2009	*Ecological Economics*	10.1016/j.ecolecon.2008.09.014
A Large and Persistent Carbon Sink in the World's Forests	Pan YD et al.	2011	*Science*	10.1126/science.1201609
Ecosystem service bundles for analyzing tradeoffs in diverse landscapes	Raudsepp-Hearne C et al.	2010	*Proceedings of the National Academy of Sciences of the United States of America*	10.1073/pnas.0907284107
Designing payments for environmental services in theory and practice: An overview of the issues	Engel S et al.	2008	*Ecological Economics*	10.1016/j.ecolecon.2008.03.011
Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment	Carpenter SR et al.	2009	*Proceedings of the National Academy of Sciences of the United States of America*	10.1073/pnas.0808772106

Table 5. Top 20 keywords used in published articles on FES-related topics from 1997 to 2019.

Ranking	Frequency	Keyword	Ranking	Frequency	Keyword
1	3621	Ecosystem service	11	566	Dynamics
2	2509	Biodiversity	12	533	Vegetation
3	1664	Forest	13	458	Ecosystem
4	1628	Conservation	14	454	Land use change
5	1397	Management	15	443	biodiversity conservation
6	1281	Climate change	16	420	Carbon
7	925	Land use	17	419	Community
8	810	Impact	18	400	Tropical forest
9	663	Landscape	19	396	Pattern
10	642	Deforestation	20	394	Model

(1) Payments for ecosystem services

Cluster 1 mainly includes keywords such as landscape, environmental service(s), sustainability, framework, payment(s), benefit, etc. This category contains the most keywords. Payments for ecosystem services (PES) are an effective method of protecting ecosystem services based on market mechanisms. As an incentive policy tool, PES has attracted widespread attention worldwide [29]. For avoiding deforestation and forest degradation, the goal of PES is to sustain and enhance forest conservation initiatives and additional forest conservation by raising the returns to forested land [30]. The research content of PES mainly includes determination of the compensation's scope, standards, and methods and its impact on the benefits of PES programs; the cost of ecosystem service supply; the relationship between ecosystem services and land use; the relationship between ecosystem services and the welfare of users; evaluations of PES programs, etc. PES programs have become governments' intermediary between the stakeholders and ecosystem protectors [9], and aim to enhance the supply of agricultural ecosystem services and reduce the deforestation caused by agricultural production [31,32]. In addition, in response to deforestation and climate change, the United Nations proposed the Reducing Emissions from Deforestation and forest Degradation (REDD) program, while China also put forward the Grain-for-Green Program. These programs are dedicated to restoring forest landscapes and developing agroforestry [9].

(2) Biodiversity conservation

Cluster 2 includes related keywords such as impact, vegetation, land use change, biodiversity conservation, etc. Forests provide habitats for plants, animals, and microorganisms. Correspondingly, biodiversity helps forests to provide various ecosystem services [33]. For example, forest ecosystems have higher carbon storage than grassland and farmland ecosystems [34]; soil microorganisms have the functions of improving the soil structure, promoting nutrient circulation, and decomposing organic matter [35]; and biodiversity promotes and guarantees the multifunctionality and stability of forest ecosystems [36–38]. Forest destruction and degradation caused by climate change, land use change, and human economic activities are the main reasons for forest biodiversity loss, which poses a serious threat to human survival and development. These factors contributed to biodiversity conservation and the sustainable development of forestry gaining increasing attention over the past few decades.

(3) Forest governance

Cluster 3 includes related keywords such as ecosystem service(s), forest(s), land use, deforestation, dynamics, model(s), trade-off, etc. Forests play an important role in mitigating climate change and providing various products and services. The conflicts between people's ecological, economic, environmental, and cultural demands provided by forests exacerbates the difficulty of forest management. Forest governance includes the application of social science, which focuses on forest-related decision-making and its implementation process and outcome effects in a given institutional environment [39]. The main constituents of forest governance include governments, various formal and informal organizations, public and private organizations, markets, communities, etc. Due to the variation in terms of scale (e.g., regional, district, country, global), there is no one governance solution that applies to all levels. Thus, forest governance should consider the scale, the preferences of the stakeholders, and the complexity of the situation. Therefore, forest governance is multi-level, various, and comprehensive. Extensive research on forest governance involves a wide range of problems which lead to unsound forest governance systems and mechanisms. However, it has been realized that the interdisciplinarity and mutual assistance of social science and natural science is needed to solve this problem. The lack of scientificity and practicality makes the development of forestry governance frameworks very challenging.

(4) Ecosystem approach

Cluster 4 mainly includes related keywords such as biodiversity, conservation, ecosystem, community, carbon sequestration, ecology, etc. The ecosystem approach (EA) is an interdisciplinary strategy that integrates various methods in the fields of ecology, society, and the economy for ecosystem management. The Convention on Biological Diversity defines the EA as "an integrated management strategy for promoting conservation and sustainable utilization of land, water and biological resources in an equitable manner" [40]. In order to balance the three objectives of the Convention on Biological Diversity, namely biodiversity conservation, sustainable utilization of biodiversity, and equitable utilization of the benefits provided by biodiversity, the EA was specified as the main framework for action [41]. Biodiversity conservation and the sustainable utilization of forests have always been a concern of international high-level policy processes [42]. For forest management, sustainable forest management and the EA are two different concepts, but have a common goal [43].

(5) Climate change

FES can play an important role in mitigating the impacts of extreme weather events such as flood mitigation, drought mitigation, water flow regulation, and storm water mitigation. Using FES to deal with climate change has become a low-cost, sustainable, and effective approach recognized by the international community. Cluster 5 includes related keywords such as climate change, biomass, growth, productivity, carbon storage, emission(s), etc. Climate change has a direct effect on forests' structure, composition, distribution, productivity, carbon stocks, biodiversity, and ecosystem services, etc. Climate change places higher and newer demands on forests. Forest carbon stocks and carbon sinks may conflict with other FES [44]. The impacts of climate change on forest feedback vary because different types of forest ecosystems respond differently to climate change [45]. Tropical forests have a certain mitigating effect on climate warming; however, there is still a lot of uncertainty about the feedback of temperate and boreal forests on climate warming. Climate change, deforestation, carbon storage, and biodiversity are closely related [46]. Deforestation directly causes global warming, and climate change will be the main driver for species extinction in the future [47], and will further lead to a reduction in forest carbon storage [48] On the other hand, increased biodiversity may relieve the negative effects of climate change by providing ecosystem resilience [49,50]. Therefore, in order to manage forests, understanding the integrated effects of climate change and management measures on forest dynamics and ecosystem services is absolutely essential.

(6) Nitrogen

Cluster 6 includes related keywords such as carbon, response, nitrogen, deciduous forest(s), nutrient(s), etc. Nitrogen is a necessary mineral element for tree growth. In forest ecosystems, soil with the greatest nitrogen storage is the most active carrier for storing nitrogen. The migration and transformation of nitrogen in the soil not only affects the nitrogen supply capacity of the soil, but also is closely related to environmental pollution. In addition, nitrogen also restricts the carbon cycle of terrestrial ecosystems [51,52]. The interaction between the two cycles affects the productivity of forest ecosystems and decides the impact of forest ecosystems on the global climate. Consequently, understanding the process and mechanism of forest ecosystems' nitrogen cycle is of great significance to reveal the forests' nutrient cycling process, the formation of ecosystem services, and the sustainable management of forests.

(7) Ecosystem management

Cluster 7 includes related keywords such as water, ecosystem management, land, habitat fragmentation, population, abundance, national forest, regime, etc. Ecosystem management is a strategic and collaborative process that combines the relationships among economic, social, and ecological values, and their limiting factors to provide the resources and services needed for future generations while maintaining biodiversity and the integrity of ecosystem processes and functions at multiple scales [53]. The main tasks of ecosystem management include establishing and implementing ecosystem constraints and principles; maintaining and restoring the diversity, health and productivity of ecosystem; formulating and adopting interdisciplinary policies, planning, and management methods; incorporating adaptive management procedures; and adapting to human use and occupancy while maintaining ecosystem integrity [54]. Forest ecosystem management provides a system of approaches to achieve a balanced development between sustainable utilization of forest resources and ecosystem health and activity. One of the most important aspects of forest ecosystem management is to maintain and promote biodiversity. The complexity and diversity of the forest structure not only directly affect ecosystem processes, but also provide a habitat for organisms that maintain important ecosystem processes. The goals of forest management are changing from the exploitation and utilization of natural resources to sustainable forest management that balances various ecosystem services. Forest managers need to consider the interactions between the forest's composition and structure, and ecosystem services at multiple scales based on disturbance conditions, development patterns, forest structures, and potential trajectories of the forest stand [53]. Forest management systems also need to be flexible enough to adapt to various sources of risks and uncertainties such as climate change [55].

(8) Pollination

Cluster 8 includes related keywords such as tropical forest(s), pattern(s), disturbance, fragmentation, urbanization, crop pollination, bird(s), etc. The protection of forests is of great significance to the development of agriculture. Pollination services are important ecosystem services with great economic value [56]. About 35% of the global crops with food supply properties require animal-mediated pollination [57], especially by bees [58]. However, pollination faces increasing threats from anthropogenic disturbances, such as habitat loss and fragmentation [56,59] habitat isolation [60], agricultural intensification [61], herbicides and other chemical products [62], climate change [63], etc. Changes in ecosystems and the loss of pollinators has decreased the productivity of many crops. Agricultural productivity can be improved by increasing pollination in residual forests [64]. Tropical rainforests are potential reservoirs of insects that contribute to crop pollination [65] Orchards close to the forest receive more pollination services than those far from the forest [52].

(9) Cities

Cluster 9 includes related keywords such as rainforest(s), tree(s), cover, city, community structure, land cover, etc. Urbanization is a major reason for global land use change [66]. As urbanization continues, there has been a growing recognition of the necessity to understand and quantify the supply of urban ecosystem services, especially the role of urban forests in providing welfare and services to residents [67]. Urban forests are the key to urban sustainable development [68]. They adapt to climate change through rainwater absorption, carbon sequestration, erosion control, and atmosphere regulation [69], as well as improving health by filtering atmospheric pollutants. In addition, they also play an important social and cultural role in entertainment, spiritual experience, environmental education, and cultural heritage [67]. Regulating the ecosystem services of urban forests is of great significance for improving the quality of life and wellbeing of residents, and this field has also become an emerging research direction.

(10) Ecological restoration

This cluster includes related keywords such as management, restoration, forest management, ecological restoration, consensus, remote sensing, etc. Ecological restoration refers to restoring degraded ecosystems to their natural state or being more adaptable to a new environment through natural restoration and anthropogenic intervention [70]. Ecological restoration management methods mainly include afforestation, reforestation, natural regeneration, captive forests, returning farmland to forests, and reduced timber harvesting [71,72], etc. Ecological restoration methods and local degradation types (the intensity, extent, and duration of land use) are essential for forest protection and management due to their impact on the availability of ecosystem service restoration. Most implementations of ecological restoration have improved ecosystem services such as soil and water retention [73], flood mitigation [74], carbon sequestration [71], and biodiversity conservation [45], etc. Besides, some studies have also shown that restoration projects have a negative impact on certain ecological environments [75]. Therefore, the goals and strategies of ecological restoration should ensure the realization of various ecosystem functions and meet the demands of different stakeholders [76] to maintain biodiversity and ultimately the resilience and adaptability of ecosystems to environmental changes [77].

(11) Policy

Cluster 11 includes related keywords such as valuation service(s), policy, indicator(s), value, environment, etc. Global forest policies mainly refer to the attitudes and actions taken by international organizations and governments regarding forests, which are reflected in relevant forestry assistance programs and the cooperative projects of the United Nations and other international organizations [78]. According to the increase in the understanding of forests, the core of forest policies has been gradually transformed from forest exploitation to forest conservation and restoration. The failure of a policy often stems from the mismatch between ecosystems and human systems [79]. If the reasons and consequences of deforestation are not considered, limiting deforestation may have unexpected or unjustified effects. If ecological factors are not considered, policies in some regions will exacerbate environmental problems in other regions. Similarly, as a result of failing to understand how residents use forest resources, well-intentioned policies may accelerate deforestation. Public policies may not protect forest resources unless the scale of sustainable utilization of natural resources is addressed [80]. The important role of biodiversity in the restoration and management of terrestrial ecosystems such as forests, farmland, and agroforestry must be taken into account in any policy involving mitigation and adaptation. In addition, the application of ecological knowledge, science, and technology in various sectors such as forestry, agriculture, transportation, energy, and human health at the landscape scale should also be considered when formulating policies [81]. A crucial sound evaluation of the policies should not only cover the concept of ecosystem services, but also include the different views, knowledge, and preferences of stakeholders at different scales, which will strengthen the consistency between policies by revealing trade-offs and achieving synergies [82].

3.3. Research Frontiers and Trends

The burst in the frequency of some keywords indicates that the research field or direction indicated by these keywords is attracting the attention of scientists, and can be used to predict the emerging trends of this field. From 1997 to 2019, there were 68 keywords with high emergence intensity in the FES field (Table 5).

As shown in Figure 4, the evolution trend of research hotspots can be divided into three stages. The first is the period from 1997 to 2005, which was the initial stage of FES. The number of bursting keywords appearing at this stage accounts for more than half of the total, and most of them lasted for a long time. In addition, a large number of classic articles appeared in this stage, and the research topics that scientists are concerned about, such as ecosystem valuation assessments, ecosystem management, scale conversion, landscape fragmentation, and ecosystem function, have laid the foundation for the development of this field. The overall intensity of keywords appearing at the second stage from 2006 to

2012 was relatively weak, and the duration was short. The bursting word with the highest intensity was "REDD". A series of reports and agreements published by IPCC, UNFCCC, and other organizations prompted people to consider the impact of land use change, climate change, and human interference on ecosystem services, and their relationship with human wellbeing. Third, in the period from 2013 to 2019, "China" was the word with the strongest bursting intensity at this stage, and even for the whole study period from 1997 to 2019. It was shown that China has developed rapidly in the FES field in recent years (Figure 1). The research themes at this stage focus on ecosystem service trade-offs, and ecosystem resilience and stability, and put forward greater requirements for the sustainable development of humans and ecosystems.

According to these results, FES research needs to make further efforts in the following areas: (1) Elucidating the quantitative transfer relationship between different levels in the cascade framework of ecosystem structure, processes, functions, services, and human well-being to deepen the formation mechanism, evolution mechanism, and main driving factors of ecosystem services. (2) The supply and demand of ecosystem services and their flow have different characteristics at different scales, while being affected by interference factors at different scales. Clarifying the spatial-temporal heterogeneity of ecosystem services, scale transformation, and the mutual feedback and intrinsic interactions between ecosystem services and climate change, and biodiversity at different scales are huge challenges in this field, and are also key issues that need to be resolved in the evolution of ecosystem services. (3) Analyses of trade-offs and synergies are a comprehensive and dialectical approach to understand the relationships among ecosystem services and their relationship with social and economic development [83]. Under the combined effect of human disturbance and climate change, dynamic changes in trade-offs and synergies and their influencing factors are more complex and have spatial-temporal differences, which promote deep consideration of ecological management and planning. Research on ecosystem service trade-offs can provide stakeholders and decision-makers with a basis for correct judgments and a plan to resolve social–ecological conflicts. (4) To establish a unified evaluation standard system and build a model and scenario analysis, assessments of FES need to be comprehensively quantified from a broader socio-ecological perspective [46]. In the assessment process, the use of standardized assessments and classification indicator systems and frameworks can enhance the comparability of research results and ensure the practicality of ecological protection and construction. With the enhancement of 3S technology, geospatial data information, and big data, the construction of models based on ecological processes and mechanisms is inevitable for quantitative research [83]. These models will not only be used for assessments of FES at different scales with related policies, but will also quantify the potential changes in ecosystem services under different environmental and socioeconomic scenarios. (5) The impact of FES on human wellbeing and the dependence of humans on ecosystem services are very complex. The intrinsic impact mechanism of land use change, climate change, and human activities on the relationship between ecosystem services and human wellbeing at different scales is a challenging research topic. Besides, it is beneficial for stakeholders to hold natural resources and realize sustainable development of ecosystems. (6) In the process of achieving scientific management and decision-making for the sustainable development of forest ecosystems, the interdisciplinary and deep integration of theories and methods of ecology, environmental protection, 3S technology, ecological economy, and regional sustainable development has become a trend. The increasing mutual cooperation between scientific research and government policy-making bodies will help to formulate adaptive management strategies under global change and enhance the supply capacity of FES.

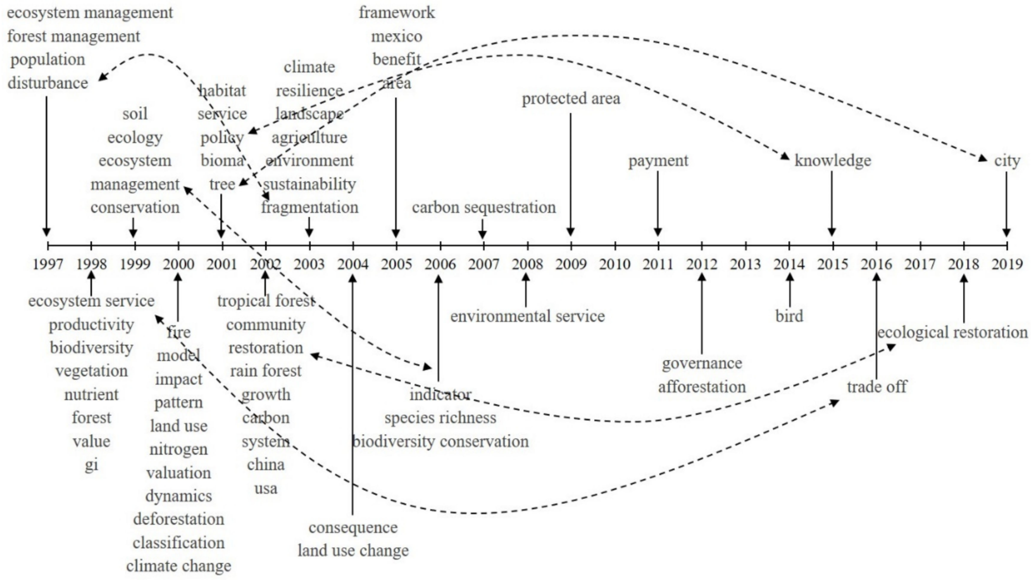

Figure 4. Graphical representation of time series of the top 20 keywords used in published articles on FES-related topics from 1997 to 2019.

4. Conclusions

The resources and the flow of services provided by forest ecosystems are essential to promote economic development, improve living standards, conserve biodiversity, and adapt to and mitigate the impacts of climate change. Research in the FES field has become a very important research undertaking for scientists and government departments. Based on the SCI database of the Web of Science indexing platform, we collected publications related to FES from 1997 to 2019, and provided a bibliometric analysis and visualization analysis of the knowledge structure, research hotspots, and emerging trends in the FES field by using CiteSpace. The conclusions drawn from this are as follows:

(1) Research on FES has developed rapidly over the past 23 years. Research institutions in developed countries are the main participants in this field. For example, the United States Department of Agriculture Forest Service is the main research institution, and the UK and France play an important role in promoting international cooperation, while Stanford University is a key institution for promoting and providing linkages across relevant institutions.

(2) The top three journals with the most articles are: *Forest Ecology and Management*, *Ecosystem Services*, and *Forests*. The top three most cited journals are: *Science*, *Forest and Ecology Management*, and *Nature*. The authors of the most frequently cited papers are R. Costanza, G.C. Daily, and R.S. De Groot, who are the most prominent scientists in the FES field according to this study.

(3) The 11 research hotpots in the FES field are payments for ecosystem services, biodiversity conservation, forest governance, the ecosystem approach, climate change, nitrogen, ecosystem management, pollination, cities, ecological restoration, and policy. During the evolution of each research hotspot, studies on ecosystem value assessments, ecosystem management, scale conversion (transformation), landscape fragmentation, and ecosystem functions have become the basis of this field. The effects of land use change, climate change, and human disturbance on ecosystem services and their relationship with human wellbeing have also been studied further; the trade-offs of ecosystem services, resilience, and the stability of ecosystem have become research frontiers.

(4) Last but not the least, it is recommended that future research on FES should more deeply and comprehensively examine the following: the generation mechanism and evolution mechanism of ecosystem services; the feedback mechanism and intrinsic interactions of ecosystem services with climate change and biodiversity at different scales; analyses of the trade-offs and synergies; a unified evaluation standard system (one of the

platforms that we can mention for this is the SEEA Ecosystem Accounting (2021) model construction and scenario analysis); studies of the correlative mechanism between FES and human wellbeing; and realization of cross-disciplinary and multi-method integration in sustainable forest management and decision-making.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13071087/s1, Table S1: Top 68 Keywords with the Strongest Citation Bursts.

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