Review

Trends and Hotspots in Riparian Restoration Research: A Global Bibliometric Analysis during 1990–2022

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Abstract: Human activities and climate change have increased damage to riparian forest and their functions, stimulating interest in riparian restoration research and resulting in a surge of related publications. However, a comprehensive bibliometric analysis of riparian restoration research has been lacking until recently. To understand trends and hotspots in riparian restoration research, we performed a literature search of riparian restoration publications from 1990 to 2022 based on the Web of Science database. We found 2121 peer-reviewed articles, and then each paper was bibliometrically researched, analyzing authors, institutions, countries, citations, journals, publication years, and keywords. The results showed a growing number of annual articles during 1990–2022, but declining average citations. Environmental science, ecology, biodiversity conservation, engineering, and forestry were popular fields in riparian restoration. Publications on the riparian restoration field were widely dispersed in different journals, but *Restoration Ecology* and *Ecological Engineering* have higher influence and more publications and citations than other journals. Lorenz A. W., Nilsson C., and Kondolf G. M. were the most competitive authors because of their high number of publications and citations. The USA had the greatest research output and the most citations. American scientists preferred national collaboration, while Switzerland scientists engaged more in international collaborations. Research focus shifted from ecosystems and rivers before the 21st century to management topics after 2001 and biodiversity and conservation after 2011. This study provides valuable insights into the progress of riparian restoration research globally.

Keywords: bibliometric analysis; riparian ecosystems; riparian restoration; floodplain forests; Web of Science

1. Introduction

The riparian zone is the ecological interface between land and a river or stream [1,2] and provides critical habitat and ecosystem functions that are particularly threatened by human activities [3,4]. Although the riparian zone occupies a small area of the landscape [5,6], it plays a key role in protecting river water quality, maintaining biodiversity, storing carbon, and maintaining ecosystem integrity [7,8]. Furthermore, riparian areas are the last ecological barrier to the entry of sediment and organic pollutants into the river from the surrounding area [9,10]. Floodplain forests, as an important component of riparian ecosystems, are crucial for maintaining these functions and services of the ecosystem [3,8]. However, riparian ecosystem functions and their services have suffered significant negative impacts with the damming of rivers on a global scale [11,12]. Beyond this threat, riparian areas are currently threatened by agricultural practices, industrialization, changes in river flows, climate change, pollution, and biological invasions [10,13]. The degradation of riparian ecosystems is a global rather than a local problem [14]. Therefore, restoration of floodplain forests and riparian zones is critical to maintaining the ecological health and sustainability

of the planet [15]. Numerous studies have confirmed that the implementation of restorative measures is poised to abbreviate the recovery timeline and expedite the achievement of a robust natural reference condition [15–17]. Within this context, commencing from the 1980s, practical activities and research on the restoration of degraded riparian ecosystems have emerged globally to contain or mitigate the negative impacts of dams and other anthropogenic activities [13,18]. As a result, riparian restoration has emerged as a realm of profound scientific interest and noble endeavor, resulting in a surge of related publications.

Bibliometric analysis is a scientific method that explores advances in a specific scientific field by quantitatively analyzing relevant knowledge carriers using modern techniques including computer engineering and statistics [19,20]. This approach identifies areas of research that are rapidly growing or declining in popularity by analyzing patterns of publication and citations [21]. In addition, the bibliometric analysis provides assessments of different journals, institutions, countries, and authors, and enables unbiased and quantitative assessments of research themes and collaboration trends [21,22]. Therefore, bibliometric analysis is an invaluable tool for identifying current research gaps and potential research areas, which is crucial for new researchers to understand the research status and potential research trends on a given topic [21,23]. The bibliometric analysis has been extensively used in the disciplines of science, engineering, social sciences, and humanities to reveal research hotspots and trends in specific areas [24,25]. However, it has never been used before to quantitatively assess publications in riparian restoration research, which may indicate that more effort is needed to systematically review and synthesize the existing literature on the topic.

Hence, we searched the Web of Science Core Collection (WOSCC) database and conducted the bibliometric analysis using the r-based Bibliometrix [26] for an overview of trends and hotspots in riparian restoration research. Specifically, we aim to (1) reveal the publication and citation characteristics of riparian restoration research; (2) identify the contributions of different authors, journals, institutions, and countries to riparian restoration research; and (3) reveal the major topics and trends in riparian restoration research and reveal the topics that should be focused on in the future.

2. Materials and Methods

2.1. Data Collection and Processing

The Web of Science collects the most important and influential research outputs from around the globe and is the most widely used data source for researchers in bibliometric analysis [27,28]. To establish a bibliometric database in riparian restoration research, a literature search based on the WOSCC database was conducted on 24 June 2023 according to the following search criteria. The strings used in the subject type were "(riparian*) and (resto* OR rester* OR recreate* OR rehabilitation* OR recover* OR revegetation* OR planting* OR reforest*)". We then set the search language to English and excluded literature types such as reviews, books, letters, conference abstracts, editorials, briefs, and news. Only peer-reviewed published research articles are retained. Finally, our results indicated that there were 2121 relevant articles published before 31 December 2022, and we term these 2121 articles as "riparian restoration database" in this study.

2.2. Data Analyses and Visualization

In the riparian restoration database, we used the Bibliometrix (version 4.1.3) R package [29] to extract and analyze the information on authors, institutions, countries, citations, publication years, and journals. It is currently the most popular bibliometric tool and was used for all analyses in this study. To reveal publication and citation patterns in the field of riparian restoration, we analyzed the number of annual publications, the increasing trends in major subject categories, major journals, and countries, and the overall and average citation scores of articles per year.

To identify key drivers in the field of riparian restoration, we used the number of publications, total local citation scores (TLCS), and total global citation scores (TGCS)

to quantify the contributions of authors, journals, institutions, and countries to riparian restoration research. TLCS and TGCS refer to the number of citations to other articles in the riparian restoration database and the WOSCC database, respectively. Furthermore, to reveal the intensity of cooperation between different countries, we created a network of relationships between the 30 most productive countries using the Biblionnetwork function in the Bibliometrix R package [29] and visualized it through the VOSviewer (version 1.6.15) software [30].

Keywords effectively summarize the core content of an article; thus, analyzing high-frequency keywords is an effective means of identifying key themes and trends in riparian restoration research [20]. To clarify the temporal trend of the hotspots of riparian zone restoration research during 1990–2022, we categorized the years 1990–2022 into three periods: 1990–2000, 2001–2011, and 2012–2022. We then used the tableTag function in the Bibliometrix package [29] to analyze the frequency of keywords at three different periods, thereby encapsulating prevalent topics and trends within riparian restoration research.

3. Results and Discussion

3.1. Publication Characteristics

The earliest study on riparian restoration in our database was published in 1977, and only three studies were published until 1990 (Figure 1). Therefore, in the subsequent analysis, we focus only on studies during 1990–2022, covering the last 33 years of publication. Our results showed that the number of annual articles related to riparian restoration research trended upward in general during this period. Specifically, the number of articles increased from 2 in 1990 to 169 in 2022, with an average annual growth rate of 14.39%. Over the past 33 years, the number of articles on riparian restoration has increased nearly 85 times.
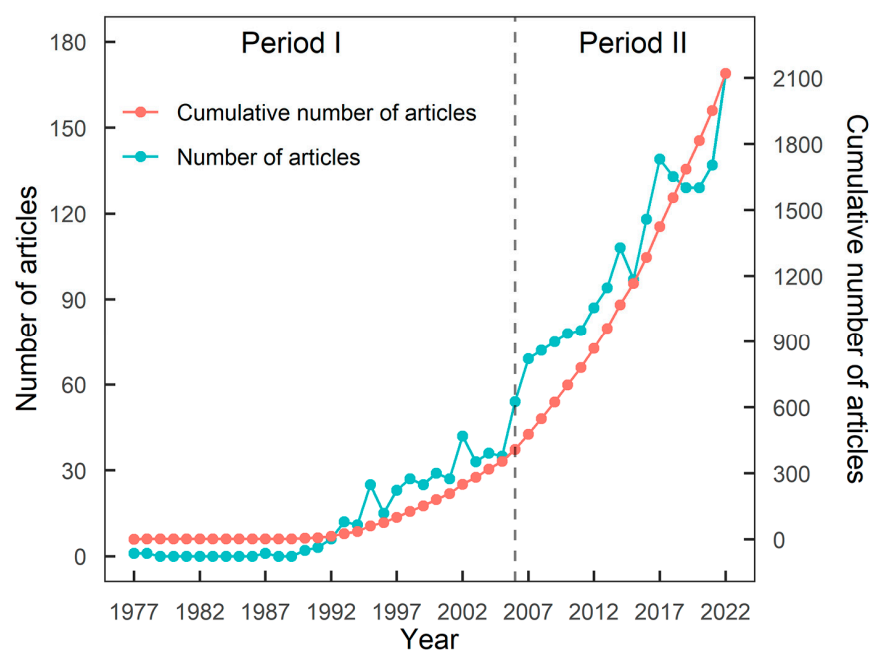

Figure 1. Trends in the number of publications for riparian restoration research.

During the period 1990–2005, the publication count demonstrated gradual growth, averaging around 22 articles annually and culminating in a total of 351 entries. However, the number of articles started to increase rapidly in 2006, accounting for approximately 83% of the articles spanning 2006 to 2022. Our findings align with other recently published studies that have analyzed the published characteristics of riparian zones or ecological restoration globally [26], with a significant increase in the number of articles related to these areas. Overall, the rapid accumulation of publications related to riparian restoration research

indicates that the field is receiving increasing attention and rapid development, which will contribute to the gradual refinement of riparian restoration theories and methods [31]. As a result, the impacts in the riparian restoration field will increase over time.

The increase in the number of articles on riparian restoration will promote the evolution of different subjects. Based on "Web of Science research areas", we found that the number of articles increased from 2 subjects in 1990 to 23 subjects in 2022, encompassing a total of 56 subject categories. Among them, the five subject categories with the highest publications are environmental science (616), ecology (507), biodiversity conservation (161), engineering (97), and forestry (97), accounting for approximately 70% of the total (Figure 2). Overall, these five subjects exhibited a fluctuating upward trend from 1990 to 2022, especially environmental sciences and ecology, which experienced remarkable increases during this period, with distinct differences compared to the other subjects. Thus, environmental science and ecology are the core subjects in the field of riparian restoration, and these two subjects are likely to become more prominent in the future (Figure 2). Forestry is a major subject category for riparian restoration and contributes significantly to flood control, water quality improvement, biodiversity conservation, and climate regulation. Floodplain forests, serving as crucial carbon reservoirs, play a vital role in greenhouse gas emission reduction, with their importance expected to grow over time. Notably, riparian restoration also covers other important fields, such as soil science, agronomy, plant science, geography, water resources, fisheries, and sustainable development.
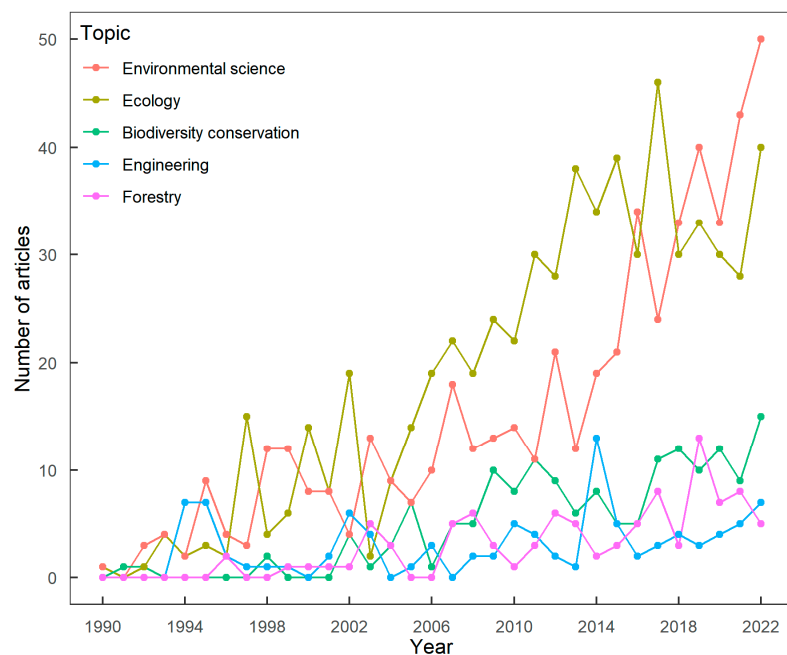

Figure 2. The number of annual articles in the top five subjects on riparian restoration research.

Our results showed that the number of publications has increased annually over the past 33 years, whereas the average number of citations per paper showed the opposite trend (Figure 3a). The total number of citations for annual total publications had a hump shape, with 2010 having the highest number of citations (3728) (Figure 3b). The connection between the number of published papers and the frequency of citations is commonly denoted as the "publication-citation relationship". Typically, these two variables exhibit a positive correlation. However, anomalies do arise where a substantial volume of papers is published, yet they receive comparatively fewer citations, or conversely, where a limited number of papers attract a disproportionately high number of citations [20]. One explanation is that earlier publications are the basis for subsequent riparian restoration research, and they may obtain a large number of citations due to the widespread interest in riparian restoration [20]. By comparison, the newer articles take a long enough time to obtain a high number of

citations. Therefore, the number of citations for later publications may be lower, which implies that the total number of citations per year does not increase throughout the period even if the number of publications per year increases. Thus, citation timing differences may be an important factor contributing to changes in citation patterns of this study.
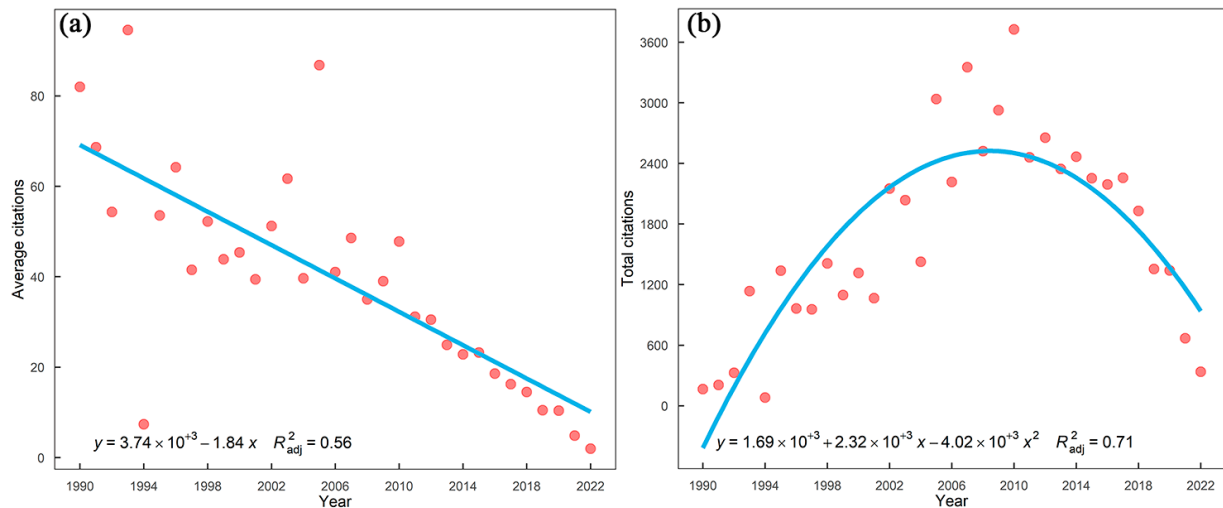

Figure 3. Change in the number of average citations (**a**) and total citations (**b**) per year on riparian restoration research.

The results show that one of the 12 papers published in 1993 was cited more than 600 times, which significantly boosted the number of citations that year (Figure 4). However, the 11 papers published in 1994 with the highest number of citations were only 14. Furthermore, two papers in the list of the top ten most influential papers were published in 2010, and they were cited 1022 and 449 times, respectively. This characteristic was an important factor contributing to the highest total number of citations in 2010. Therefore, in addition to the number of papers and citation timing differences, the change in the number of citations may also be related to the number of high-impact publications each year. High-quality studies are usually more likely to be cited, while low-quality studies may be less likely to be cited, even if there is a large number of publications.
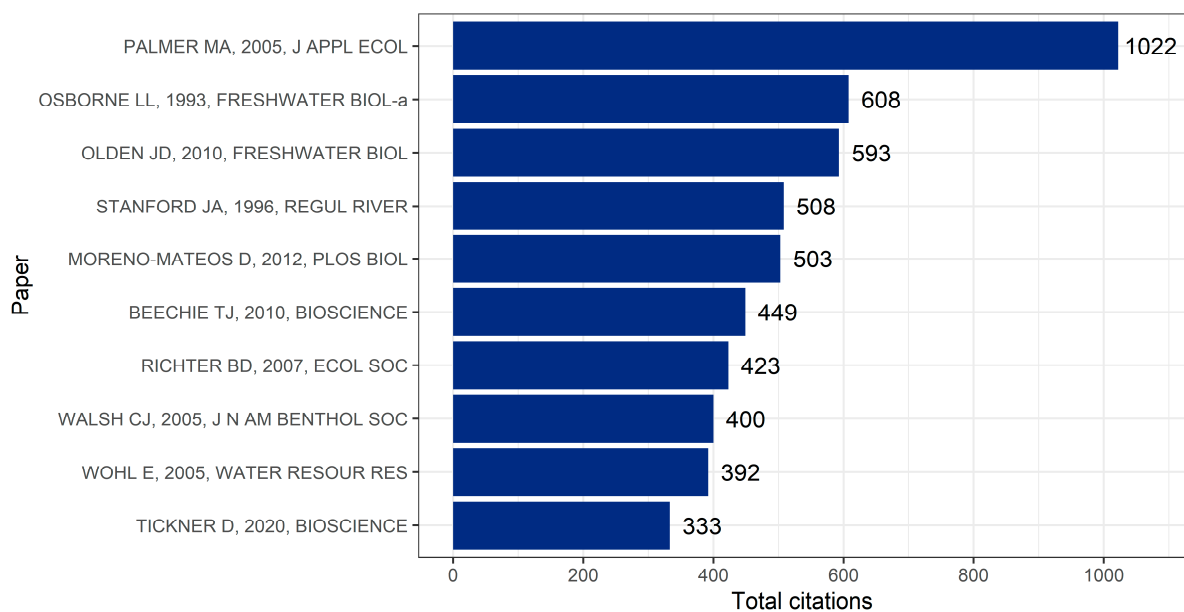

Figure 4. Top 10 most cited articles [32–41] on riparian restoration research during 1990–2022.

3.2. Publication Contributions

Articles on riparian restoration research were published in 483 journals. Of these, 274 (56.73%) journals have published only one paper, 59 (12.22%) journals have published two papers and 39 (8.07%) journals have published three papers. A total of 414 journals (85.71%) had no more than five publications. These findings suggested that articles in the field of riparian restoration are highly dispersed across different journals, with only a few journals publishing a large number of articles. As shown in Figure 5, *Restoration Ecology*, *Ecological Engineering*, *River Research and Applications*, *Environmental Management*, *Science of the Total Environment*, *Hydrobiologia*, *Journal of Applied Ecology*, *Freshwater Biology*, *Wetlands*, *Journal of Environmental Management*, and *Ecological Applications* are the 11 journals with the most publications in riparian restoration research. These journals, particularly *Ecological Restoration* and *Ecological Engineering*, are the most influential, and the number of articles has increased significantly in recent years (Figure 5).
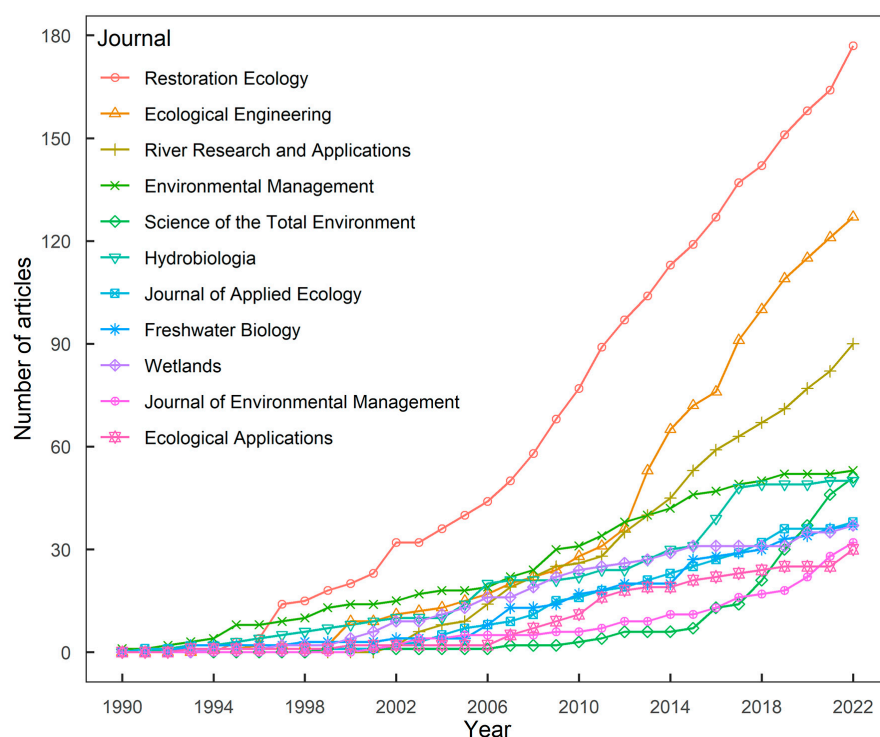

Figure 5. Temporal trends in the top 10 most published journals in riparian restoration research.

Table 1 shows the number of publications, TLCS, and TGCS of the 11 most influential journals during the period 1990–2022 in the field of riparian restoration. Each of these journals had no fewer than 30 publications, and together they published 722 of the 2121 papers (30.04%). *Restoration Ecology* was the most influential journal contributing to the field of riparian restoration, with 8.35% of the overall number of publications. *Restoration Ecology* was also the most contributing journal in both TGCS and TLCS. *Restoration Ecology* is a core forum focusing on all areas of ecological restoration, and it is also the top journal in the field of ecological restoration worldwide. In addition, *Ecological Engineering* had the second largest contribution with 6% of the papers published. This journal included specific topics such as habitat rehabilitation, ecological technologies, biological engineering, restoration ecology, ecological conservations, ecosystem restoration, river restoration, and reclamation ecology. Overall, journals with a higher number of publications had higher TLCS and TGCS. These results indicated that the number of publications plays an essential role in the TLCS and TGCS scores of the journals, which is highly meaningful in improving the competitiveness of journals.

Table 1. Number of publications and citations in the 11 most influential journals in riparian restoration research. TLCS and TGCS are the total number of citations in the riparian restoration database and the Web of Science database, respectively.

Journal	Number of Articles	TLCS	TGCS
Restoration Ecology	177	711	4500
Ecological Engineering	127	436	3042
River Research and Applications	90	339	2928
Environmental Management	53	321	2520
Science of the Total Environment	51	247	2494
Hydrobiologia	50	217	1784
Journal of Applied Ecology	38	215	1624
Freshwater Biology	37	202	1608
Wetlands	37	130	1479
Journal of Environmental Management	32	98	1329
Ecological Applications	30	97	1193

Our results show that there are 6781 authors in the Riparian Restoration Research Database, of which 5642 (83.2%) authors have published only one paper, and 675 (9.95%) authors have published only two papers (Table 2). The 10 most productive authors have published at least 10 papers, totaling 127 papers, approximately 6% of the total. These authors are also in the top 10 for TGCS and TLCS, making them the most influential authors. Lorenz A. W. and Nilsson C. are two of the most prominent authors with 17 and 16 publications in the field of riparian restoration, respectively. Kondolf G.M. is the third most prominent author with 11 publications. Notably, Kondolf G.M. was the first of these authors to publish a study on riparian restoration and was ranked first in the TGCS and TLCS.

Table 2. Number of publications and citations of the 10 most influential authors in riparian restoration research.

Author	Number of Articles	TGCS	Rank of TGCS	TLCS	Rank of TLCS	Start of Publication
Lorenz A. W.	17	767	4	165	3	2009 [42]
Nilsson C.	16	554	9	125	5	2001 [43]
Kondolf G. M.	15	2274	1	384	1	1995 [44]
Hering D.	13	590	6	125	4	2005 [45]
Piegay H.	13	549	10	92	10	2009 [46]
Tockner K.	11	1512	2	124	6	1997 [47]
Beechie T. J.	11	625	5	106	7	2004 [48]
Kaushal S. S.	11	586	7	97	8	2008 [49]
Lake P. S.	10	1494	3	232	2	2003 [50]
Mayer P. M.	10	568	8	94	9	2008 [49]

Globally, there are 1930 institutions dedicated to research in the field of riparian restoration. The 10 most productive institutions contributed 457 papers or 21.55% of the total (Table 3). Among these 10 institutions, the University of California Davis is the most productive institution, but its TGCS and TLCS are not in the top 10 list. The University of Maryland has the highest number of citations (TGCS and TGCS). The University of Maryland and the University of California, Berkeley are in the top 10 in terms of publications, TGCS, and TLCS. Although Oregon State University and the University of Illinois are highly productive institutions, neither of them ranked in the top 10 in TGCS and TLCS. It is noteworthy that the 10 most productive institutions, except for the University of Duisburg-Essen, are all located in the United States, indicating that the United States has been placing considerable emphasis on riparian restoration research.

Table 3. Number of publications and citations of the 10 most influential institutions in riparian restoration research.

Institute	Number of Articles	Rank of Articles	TGCS	Rank of TGCS	TLCS	Rank of TLCS
University of California Davis	63	1	1149	13	145	14
United States Forest Service	58	2	1517	8	157	13
Colorado State University	51	3	1387	9	166	11
Oregon State University	49	4	1121	16	99	19
University of Illinois	47	5	1081	17	78	25
University of Maryland	41	6	2749	1	411	1
Utah State University	39	7	1140	14	188	10
University of California, Berkeley	38	8	1795	6	218	7
University of Washington	37	9	2486	2	145	15
University of Duisburg-Essen	34	10	1136	15	235	5

The number of publications in a country to some extent reflects the importance it attaches to the relevant field of research. Although riparian restoration research has been carried out in 58 countries globally, 12 (20.69%) countries have published only 1 article, 8 (13.79%) countries have published 2 articles, and 34 (58.62%) countries have published no more than 10 articles. These results indicate that articles in the field of riparian restoration are highly dispersed across different countries. As shown in Table 4, the 10 most productive countries published 1725 (81.33%) articles. Compared to other countries, the United States is the largest contributor to riparian restoration research, contributing 41.49%, with the most significant leadership in publications, TGCS, and TLCS. The country with the second highest contribution is Brazil with 7.21%. Since Brazil and the United States account for about 20% of the global forested land area (12% and 8%, respectively), it can be expected that both countries are particularly interested in riparian zone restoration, especially Brazil, which has suffered from a high rate of deforestation in the last decades [18].

Table 4. Number of publications and citations of the 10 most influential countries in riparian restoration research.

Country	Number of Articles	Rank of Publications	TGCS	Rank of TGCS	TLCS	Rank of TLCS
USA	880	1	28718	1	2729	1
Brazil	153	2	1898	11	129	10
Australia	143	3	6788	2	589	2
China	136	4	2299	9	113	14
Germany	109	5	4628	3	554	3
United Kingdom	78	6	4542	4	347	6
Canada	65	7	2790	7	99	16
France	63	8	3328	6	421	4
Netherlands	58	9	3623	5	358	5
Switzerland	40	10	2690	8	322	7

Figure 6 illustrates the temporal evolution of publications across the 10 most productive countries. The publication count in the United States exhibited a wavelike pattern from 1990 to 2022, with pronounced increases notably observed since 2006. Post-2006, a consistent upward trend in annual article output emerged among the nine remaining countries (excluding the United States). Particularly noteworthy were China and Brazil, which displayed a substantial surge in research output within the realm of riparian restoration (Figure 6). Both China and Brazil are categorized as developing nations. The Chinese government has notably introduced a pivotal policy, the "Overall Plan for Major Projects for the Protection and Restoration of National Important Ecosystems (2021–2035)", to tackle ecological and environmental challenges arising from rapid economic development, urbanization, and industrialization. This strategic framework underscores China's commitment to the systematic safeguarding, holistic restoration, and comprehensive management of diverse ecosystems. Conversely, Brazil has been a trailblazer in shaping environmental policies and advancing forest conservation and ecological restoration efforts in the past decades [18]. It is crucial to emphasize that our analysis was limited to English-language peer-reviewed publications. This approach may inadvertently underestimate the total number of studies available, as it does not account for potential contributions published in languages other than English or within non-peer-reviewed journals.
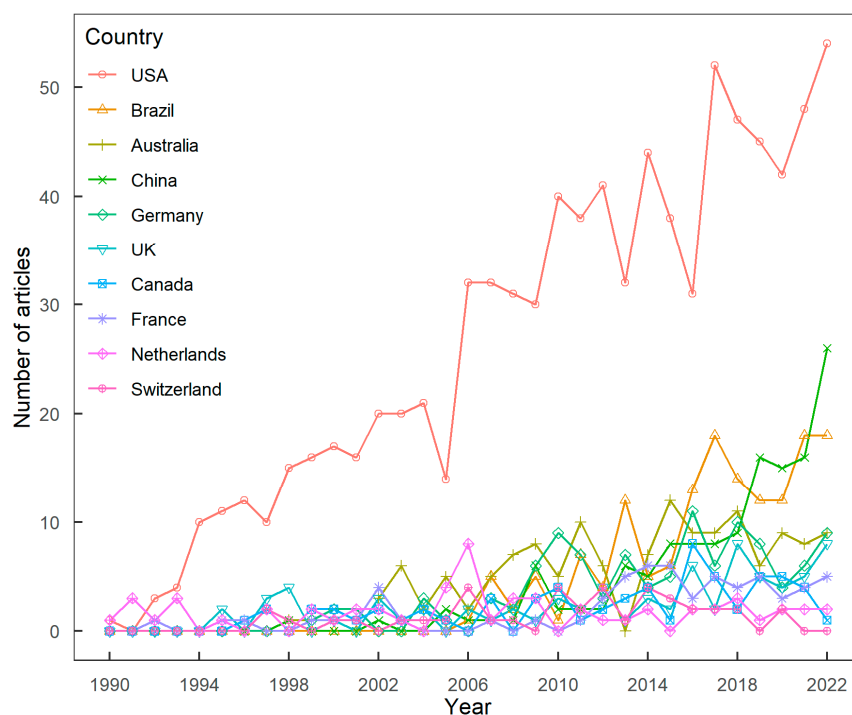

Figure 6. Temporal evolution of publications in the 10 most productive countries in riparian restoration research.

In addition, the tally of single-country publications (SCP) and multiple-country publications (MCP) can serve as a gauge of a nation's research capacity and the collaborative ties fostered among various countries. During the period 1990–2022, the proportion of SCP and MCP in the United States stood at 91.93% and 8.07%, respectively (Figure 7). This distribution implies a prevalent inclination of American researchers toward autonomous investigations. Among the top 10 countries contributing extensively to riparian restoration research, all of them conducted independent research to a large extent, except for Switzerland. Switzerland exhibited the highest MCP ratio at 62.5%, suggesting that Switzerland scientists are more involved in international collaborations. Scientific collaboration is deemed imperative as it enables knowledge and resource amalgamation, fostering a comprehensive approach. Cross-border collaboration enhances efficiency and quality through

shared experiences and best practices. Moreover, given the transnational nature of many riparian zones, cooperation becomes indispensable for addressing boundary-agnostic issues, including water quality, wildlife preservation, and flood control. Thus, as riparian zone restoration research receives more and more attention from scientists, cooperation among countries and institutions in different regions will become a trend in riparian zone restoration research.
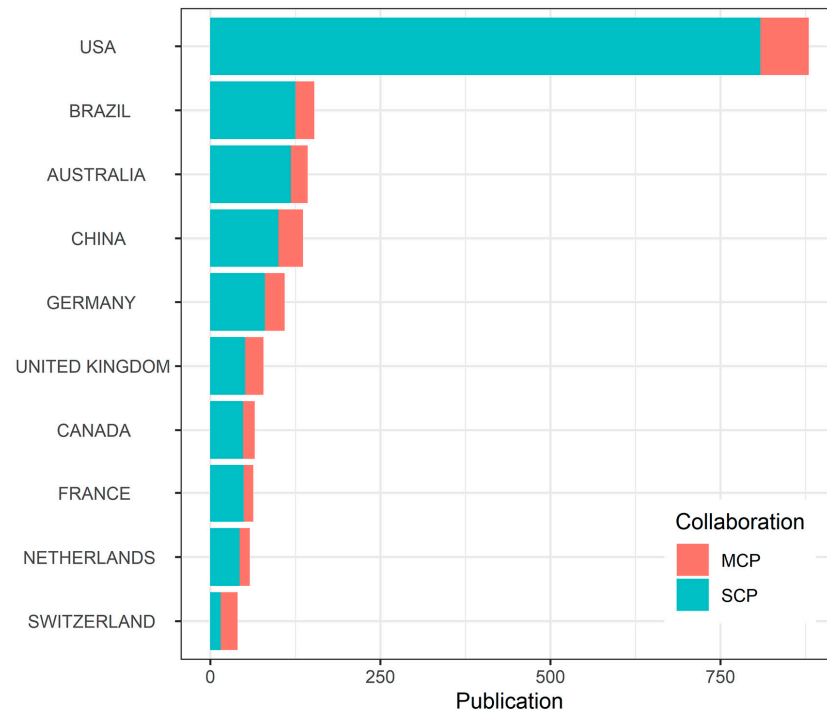

Figure 7. Collaborative publications from the 10 most productive countries in riparian restoration research. SCP and MCP refer to single-country and multi-country publications, respectively.

Figure 8 illustrates the collaborative network of 30 countries that have published at least five papers. The United States has the most prominent networks with other countries in terms of the length and breadth of their collaborations. China's network is primarily connected to the United States. Many European countries collaborate well with each other due to their geographic location and close interconnections. Remarkably, the vast majority of the line widths in the national cooperation networks are very thin (Figure 8), which is mainly because most of the studies are conducted independently by only a single country (Figure 7). Moreover, developing nations with limited expertise and antiquated technology can leverage the extensive experience and advanced technological capabilities of developed nations to engage in ecological restoration through international collaboration. Therefore, the cooperation network of different countries is strengthened to ensure that each country may benefit from more frequent cooperation with other countries, thus achieving an integrated understanding of the ecological and environmental effects of riparian restoration.

3.3. Trends of Research Topics

Keywords highly summarize the research focus of an article and can reflect the hot issues and trends in riparian restoration research [28]. In 1990–2000, the research on riparian restoration was in its initial stage, with only 20 keywords appearing at least five times (Table 5). During this period, "vegetation" and "ecosystems" were the most popular keywords, which highlighted the close relationship between riparian and riparian vegetation, and the adjacent aquatic and terrestrial ecosystems. The vegetation is the foundation for maintaining a healthy riparian ecosystem function, and the design of a

successful riparian revegetation project can affect the success or failure of the entire project. In addition, other high-frequency keywords related to river ecosystems (i.e., river, stream, quality, and water), highlighted the importance of riparian restoration to river ecosystems. The United States and California were mentioned five and eight times during this period, indicating that the United States is frequent in riparian restoration research and plays a pioneering role as a basis for subsequent research.
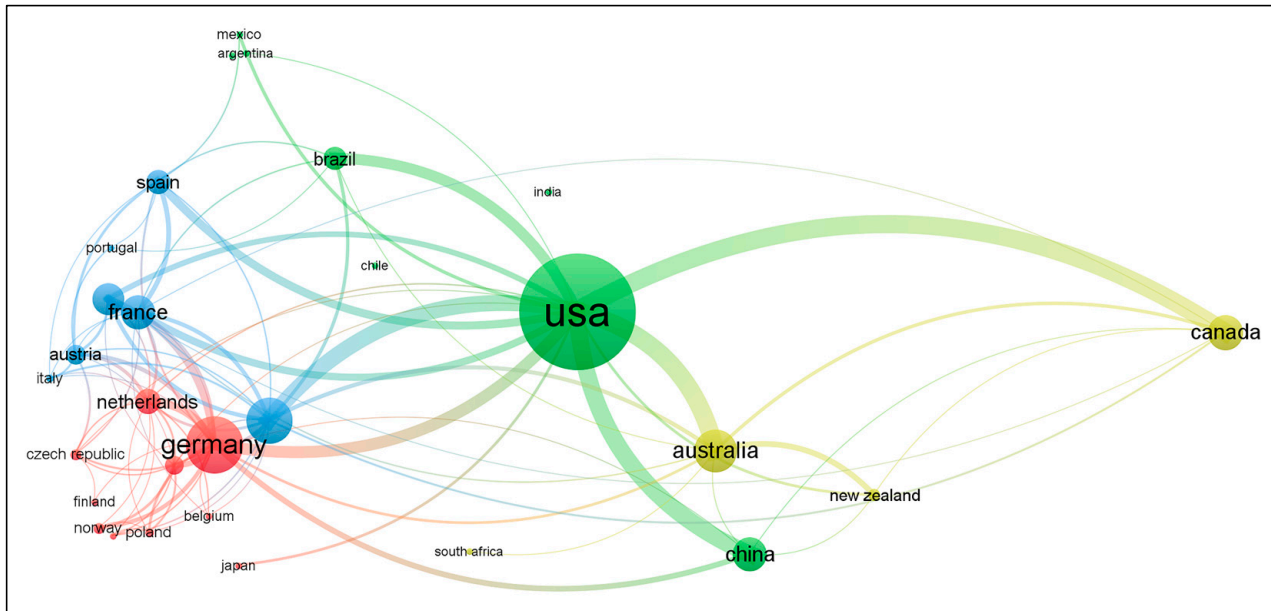

Figure 8. Visualization of the cooperation network between regions/countries in the field of riparian restoration research. Node size and line width are positively correlated with the number of country publications and the frequency of country cooperation, respectively. The distance between two nodes is negatively correlated with the intensity of country cooperation.

Table 5. High-frequency keywords associated with riparian restoration per 11 years during 1990–2022.

1990–2000		2001–2011		2012–2022		1990–2022	
Keywords	Frequency	Keywords	Frequency	Keywords	Frequency	Keywords	Frequency
vegetation	17	vegetation	80	vegetation	174	vegetation	271
ecosystems	14	management	75	management	165	management	251
river	13	river	63	biodiversity	130	river	186
dynamics	12	dynamics	45	conservation	124	dynamics	171
perspective	12	ecosystems	42	diversity	114	biodiversity	170
management	11	water	42	dynamics	114	conservation	158
stream	11	biodiversity	40	river	110	diversity	152
communities	10	growth	40	habitat	94	habitat	142
riparian	10	habitat	39	river restoration	85	ecosystems	137
disturbance	9	patterns	39	ecosystems	81	water	128
habitat	9	communities	38	water	81	patterns	120
California	8	diversity	37	ecology	80	ecology	117
patterns	7	ecology	35	forest	75	communities	114
quality	7	conservation	32	patterns	74	forest	110
classification	6	disturbance	32	land use	69	growth	106
flows	6	forest	30	communities	66	river restoration	101
forest	5	land use	29	impacts	65	riparian vegetation	99
phytoplankton	5	riparian	26	growth	64	land use	98
USA	5	establishment	25	ecosystem services	62	impacts	88
water	5	floodplain	23	climate change	56	stream	79

The number of high-frequency keywords is increasing steadily as more and more scientists with different professional backgrounds from different countries are exploring different research topics over time. The use of the word "vegetation" has increased from 17 times in 1990–2000 to 174 times in 2012–2022 (Table 5), reflecting the centrality of riparian vegetation to riparian restoration research. In addition, the use of the term "management" has increased from 11 times in 1990–2000 to 165 times in 2012–2022, indicating that enhanced management and protection of riparian ecosystems is critical for determining the success of riparian restoration efforts to a large extent. Riparian ecosystems are highly heterogeneous and subject to dynamic changes over time, as they are intertwined areas of materials cycling between aquatic and terrestrial ecosystems. As a result, the terms "river", "dynamics", "water", "habitat" and "diversity", which reflect riparian characteristics and relate to riparian restoration targets, are widely referred to in the field of riparian restoration. These results imply that scientists are attempting to increase the biodiversity of riparian or aquatic ecosystems and improve river water quality through vegetation restoration [51]. However, we must recognize that this is a very challenging task because riparian zones are under increasing pressure from anthropogenic activities and climate change. Studies have shown that over 58,000 large dams regulate more than half of the world's major rivers [52], altering the riparian ecosystem functions. Particularly in developing countries, dam-driven hydrologic changes will be exacerbated leading to flooding and degradation of riparian areas that are not currently inundated [53]. Therefore, successful restoration of dynamic riparian habitats requires consideration of inundation intensity, plant fitness, habitat conditions, and effective restoration approaches [6].

In addition, the term "biodiversity" has increased from 40 times in 2001–2011 to 130 times in 2012–2022 (Table 5), representing one of the most frequent keywords in riparian restoration research in the last decade. In recent decades, especially after the promulgation of the Convention on Biological Diversity (CBD) in 1992, the topic of biodiversity conservation has been widely mentioned worldwide. In the context of global biodiversity loss, especially after dam impoundments have caused severe losses in global wetland biodiversity [5], the conservation and management of riparian biodiversity has become a research priority for riparian ecosystems [15]. Given this, scientists have been working on how to enhance riparian biodiversity and protect treasured and endangered wildlife as well as aquatic organisms through ecological restoration approaches [14]. At the same time, the term "land use" has been mentioned about 100 times since 2001 in the field of riparian restoration due to the impact of human activities on riparian ecosystems. Human-driven land use change has resulted in widespread loss of ecosystem services globally [54]. How land use change affects biodiversity, stream water quality, soil nutrient cycling, and riparian function remains a topic of interest for us in the future.

During the period 1990–2022, the most frequent keywords include "vegetation", "management", "river", "dynamics", "biodiversity", "conservation", "diversity", "habitat", "ecosystems", and "water", which are among the most established and popular research topics among scientists in riparian restoration research. Vegetation restoration can improve habitat quality, promote biodiversity, and enhance ecosystem function, and is recognized as an effective method of protecting riparian ecosystems [54]. Riparian restoration involves many subjects and restoration objectives and can be categorized into many fields based on restoration objectives. In addition, the impact of future climate extremes on the effectiveness of riparian vegetation restoration needs to be taken into account [7], as well as the need for relevant governmental departments to adopt effective approaches to enhance the management and protection of riparian ecosystems [55].

4. Conclusions

In this study, we provided a comprehensive overview of the riparian restoration research based on bibliometric analysis. To our knowledge, this study is the first comprehensive assessment of the current status, progress, research gaps, and trends in the field of riparian restoration utilizing bibliometric methods. Our findings are important

to researchers and institutions concerned with riparian restoration because they provide valuable insights that will help researchers, policymakers, conservationists, and resource managers identify research priorities, rationalize funding allocation, and promote interdisciplinary collaboration [55].

Based on our analysis, it was possible to establish the following conclusions:

(1) The number of annual articles related to riparian restoration research trended upward in general over the past 33 years, primarily because the importance of vegetation restoration for the functioning and health of riparian ecosystems is being increasingly emphasized. The average number of citations for publications shows a continuous decreasing trend, which is mainly due to the limitation of citation peaks for newly published articles. Riparian restoration research encompasses a broad spectrum of research areas, but environmental science, ecology, biodiversity conservation, engineering, and forestry are dominant.

(2) Articles in the field of riparian restoration are highly dispersed across different journals. In terms of the number of publications and citations, *Restoration Ecology* was the most influential journal contributing to the field of riparian restoration. Lorenz A. W. and Nilsson C. have a higher number of papers and Kondolf G.M. has the highest number of total citations. The United States stands as the preeminent research nation in the domain of riparian restoration, closely pursued by Brazil, Australia, China, and Germany.

(3) Vegetation, management, river, dynamics, and biodiversity are the research topics that have received the most attention from scientists in riparian restoration research. Vegetation has received a lot of attention in the period 1990–2022 because it is the basis for ecological restoration. Before the 21st century, scientists focused mainly on ecosystems and rivers, after 2001 research focused on management topics, and after 2011 on biodiversity and conservation topics.

The results indicated that a substantial portion of the research output remains confined to non-internationally collaborative articles. Considering the increasing number of publications from these countries, inter-country cooperation should be strengthened in the future for their benefit in areas such as water quality, wildlife conservation, and flood control. Furthermore, the effectiveness of implemented management and conservation approaches largely determines the outcome of riparian restoration efforts [14]. To ensure the lasting success of restoration efforts in dynamic riparian habitats, future efforts must emphasize more efficient restoration techniques and improved biodiversity conservation and management. Although our research might be insufficiently covered due to the limited databases searched, it can help advance riparian restoration as an important effort to sustainably manage these important ecological areas. Bibliometric studies can identify thematic trends and knowledge gaps in a given field; novice researchers can use this approach to examine the trajectory of riparian restoration research and determine their expected contributions to the field.

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