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Review

A Bibliometric Analysis of the Impact of Ecological Restoration on Carbon Sequestration in Ecosystems

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Abstract: Ecological restoration, as a vital means of effectively enhancing the carbon sink function of ecosystems, is currently the subject of active research by scientists. Researchers are actively exploring how to scientifically assess the response mechanisms of ecosystem carbon reservoirs during the process of ecological restoration. In this study, CiteSpace 6.1.(R3 and R6) literature visualization software was employed to conduct data mining on 1566 research articles published from 1996 to 2022, focusing on the impact of ecological restoration on ecosystem carbon reservoirs, as recorded in the Web of Science core database. The analysis involved visualizing various aspects, including the countries involved, research institutions, publication output, research hotspots, and cutting-edge research areas. The research indicates that China holds significant influence in the study of the impact of ecological restoration on ecosystem carbon reservoirs. The literature covers a wide range of research directions and encompasses rich content on the subject matter. The current research focuses on ecological restoration, and its impact on the carbon sink function of ecosystems mainly revolves around four key themes: "the carbon sequestration potential of ecological restoration", "technological approaches to enhancing the carbon sink function of ecological restoration", "the importance of assessing carbon sink in terrestrial ecosystems", and "characteristics of carbon sources/sinks in terrestrial ecosystems". Currently, the development of research findings on the impact of ecological restoration on the carbon reservoirs of ecosystems is progressing rapidly. Novel research theories, methodologies, and scientific techniques are emerging, necessitating the continuous monitoring and investigation of scholarship in this field. It is crucial to integrate ongoing global environmental-change factors, ensuring the continuity of research and observations and, thus, furnishing robust data support for the assessment and computation of ecosystem carbon sinks.

Keywords: Web of Science; ecological restoration; ecosystem carbon pools; bibliometrics; visual analysis

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1. Introduction

Ecological restoration stands as one of the most efficacious approaches for reinstating the functional and holistic integrity of impaired ecological systems [1,2]. Relevant studies have shown that 56% of carbon sequestration in ecological restoration areas is attributed to ecological restoration projects [3]. Over the past three decades, human activities have led to the degradation and destruction of ecosystems globally, resulting in a decrease of 129 million hectares in global forest area and a sharp decline in global biodiversity [4–6]. Terrestrial ecosystems, as a major component of the global carbon pool, annually absorb a net amount of carbon ranging from 2.0 to 3.4 petagrams of carbon (PgC), playing a critical role in regulating global carbon cycling and mitigating climate change [7–10]. The transformation of land-use types can significantly impact the carbon storage capacity of terrestrial ecosystems. However, the implementation of ecological restoration techniques can promote a transition towards land-use practices that favor carbon sequestration in terrestrial ecosystems [11]. After several decades of advancement, the field of ecological restoration research has evolved into a vast realm of knowledge, presenting challenges to researchers in the realm of the exploration of the literature. This article provides a comprehensive review of the impact of ecological restoration on ecosystem carbon sinks from the perspective of bibliometrics. It explores the trends in research development over the past three decades. What are the interrelationships among the key terms? What is the distribution of the main research forces at present? These questions are crucial for researchers to better grasp the research field and enhance scientific research efficiency. This article employs bibliometric methods and uses CiteSpace visualization software to conduct a visual analysis of the impact of ecological restoration on the carbon pool of ecosystems based on research articles published from 1996 to 2022 in the Web of Science (WOS) core database. By examining country distribution, research institution distribution, publication output, disciplinary distribution, and key terms, this study provides a visualization analysis of the main countries, institutions, knowledge absorption and diffusion, and major research topics in the field of the impact of ecological restoration on the carbon pool of ecosystems, thereby providing reference for relevant researchers.

2. Materials and Methods

2.1. Materials

To better understand the trends, hotspots, and frontiers of research on the impact of ecological restoration on the carbon sink function of ecosystems, the Web of Science (WOS) Core Collection database was used as the data source. The journal search formula is as follows: TS = "(Ecological restoration and (Ecosystem OR Ecosystems) and (Carbon sink OR Carbon sequestration OR Carbon stock OR Carbon storage OR Carbon)) OR (Restoration ecology and (Ecosystem OR Ecosystems) and (Carbon sink OR Carbon sequestration OR Carbon stock OR Carbon storage OR Carbon))". The time span covered is from 1996 to 2022, and the publication dates range from 1 January 1996 to 21 December 2022. The literature type searched for is limited to articles, resulting in a total of 1566 papers. After utilizing CiteSpace's built-in filtering and de-duplication functions, a total of 1566 valid papers were obtained.

2.2. Methods

Typically, bibliometrics is employed as a systematic review method to conduct statistical analysis of the scientific literature [12]. "Research progress and hotspots on the impact of ecological restoration on the carbon storage of ecosystems" is an area that has mainly employed the method of "scientific knowledge mapping" to present its research progress and hotspots. By visualizing selected statistical analyses from different dimensions, such as the distribution of countries, scientific research institutions, and publication output; subject distribution; and emerging keywords, the field has made great use of visualization tools. The primary software used is CiteSpace, a literature analysis and visualization software created by Professor Chaomei Chen, written in the Java programming language [13].

3. Results and Discussion

3.1. Research Force Analysis

3.1.1. National and Regional Analysis

The number of papers published by a country reflects the degree of importance that country places on the relevant research field. Figure 1 depicts a macrolevel network map of national/regional cooperation in the English literature on the impact of ecological restoration on ecosystem carbon stocks. Among the 1566 papers analyzed, it can be seen from Figure 1 that the People's Republic of China, the USA, Australia, England, Germany, Spain, France, and Switzerland have higher intermediary centrality, indicating that these countries have cooperated with other countries in research and have shown highly intersecting and blending features. Some research topics involve a wide range, high complexity, or strong comprehensiveness, leading to cooperation between countries in the field of ecological restoration research. The top five countries in terms of publication volume are the People's Republic of China, the USA, Australia, England, and Canada (Table 1). Among them, the Peoples Republic of China has the highest number of publications (735 papers), and the USA ranks second (439 papers). Combined with Figure 1, it can be found that China is far ahead of any other country in terms of the number of researchers and publications in this field, reflecting its significant position in the research on the impact of ecological restoration on ecosystem carbon stocks. Compared with other countries, China has greater focus on protecting the natural ecological environment and has been implementing multiple major ecological restoration projects, such as returning farmland to forests, protecting natural forest resources, and so on, to solve serious ecological environmental problems caused by rapid economic development, urbanization, and industrialization. Therefore, when there is rapid population and economic growth and the process of urbanization and industrialization begins, there are many natural habitats available, making significant contributions to regional and global ecological restoration efforts [14–17].

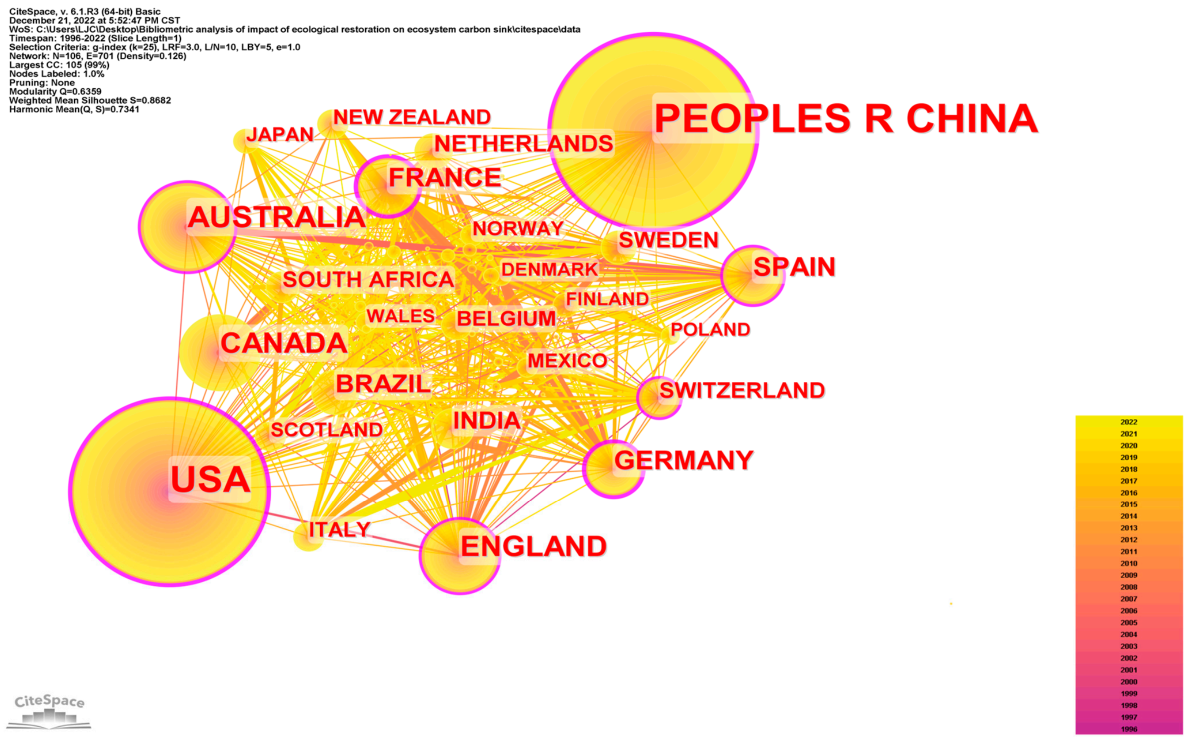

Figure 1. Collaboration network map of countries/regions.

Table 1. Top 10 countries/regions by the number of publications.

Ranking	Country	Article Quantities	Betweenness Centrality
1	China	735	0.2
2	USA	439	0.26
3	Australia	133	0.14
4	England	101	0.19
5	Canada	91	0.05
6	Germany	70	0.22
7	Spain	63	0.18
8	France	61	0.25
9	Brazil	56	0.01
10	India	47	0.01

3.1.2. Analysis of Research Institutions

Using the institution analysis function in CiteSpace, a cooperative network diagram (Figure 2) and a ranking table of the top 10 institutions in terms of published papers were drawn. Figure 2 contains a total of N = 548 nodes and E = 1278 edges, with a network density of Density = 0.0085. This indicates that 548 research institutions have studied the impact of ecological restoration on carbon pools in ecosystems, and the high number of edges compared to nodes and the high network density suggest that researchers have established extensive cooperation on this topic, primarily through multilateral collaboration, which facilitates resource sharing among research institutions. Combining Table 2 and Figure 2, it can be concluded that while numerous research institutions around the world are engaged in studying the impact of ecological restoration on carbon pools in ecosystems, China has made a significant contribution to the development of this field. Among the top 10 institutions in terms of published papers, China accounts for 6, with the Chinese Acad Sci (CAS), Univ Chinese Acad Sci (UCAS), and Northwest A&F Univ being the top 3. Figure 2 reveals that CAS has good cooperation with other research institutions and is at the center of the cooperation network, showing a radiating pattern of collaboration with different institutions. These results demonstrate that Chinese research institutions have achieved the most significant research output on the impact of ecological restoration on carbon pools in ecosystems.

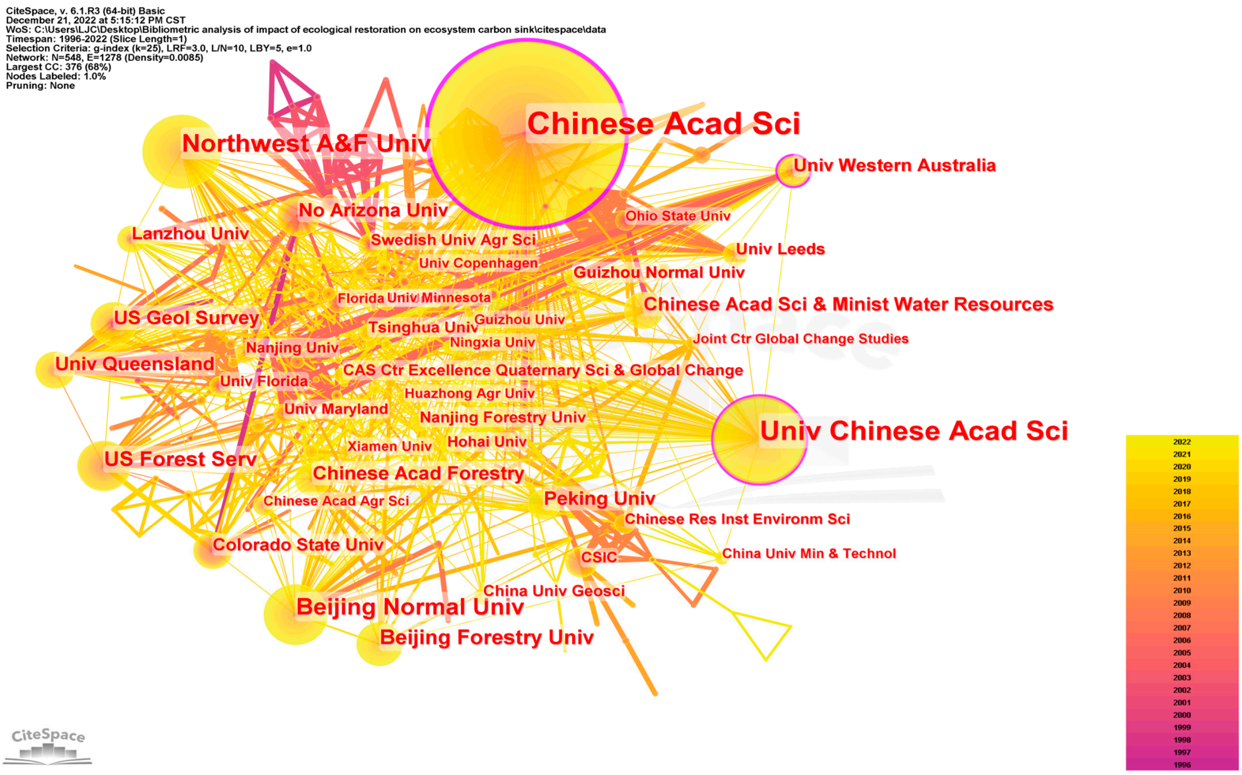

Figure 2. Collaboration network map of the institutions.

In addition, the US Forest Service is dedicated to studying how to efficiently and rapidly restore forest ecosystems after wildfires, restore ecosystems in areas damaged by floods, and research different seed and planting techniques to restore damaged forests and grasslands. The University of Queensland focuses on how to better utilize local plants for ecological restoration, as well as on evaluating and monitoring the impact of plants on ecosystems, how to better manage soil and water resources to promote ecosystem recovery to the greatest extent possible, how to better protect endangered species and ecosystems, and how to evaluate and monitor changes in biodiversity.

Table 2. Top 10 institutions in terms of the number of published papers.

Ranking	Institution	Article Quantities	Betweenness Centrality
1	Chinese Acad Sci	299	0.47
2	Univ Chinese Acad Sci	131	0.13
3	Northwest A&F Univ	85	0.06
4	Beijing Normal Univ	64	0.04
5	Beijing Forestry Univ	35	0.01
6	US Forest Serv	34	0.08
7	Chinese Acad Forestry	27	0.05
8	Univ Queensland	26	0.08
9	Northern Arizona Univ	26	0.03
10	US Geol Survey	24	0.03

3.1.3. Analysis of the Number of Posts

In recent years, the impact of ecological restoration on carbon sequestration in ecosystems has increasingly attracted the attention of domestic and foreign experts and scholars. Especially since 2016, the research in this field has shown an overall exponential growth trend (Figure 3). In terms of the number of publications, the exploration and development of the impact of ecological restoration on carbon sequestration in ecosystems has gone through three stages of development: (1) In the nascent stage (1996–2009), research on the impact of ecological restoration on the carbon pool of ecosystems was in its infancy. The number of journal articles was limited, and research focused on the mechanisms of ecological restoration and the impact of biodiversity on the carbon pool of ecosystems. (2) In the preliminary exploration phase (2009–2016), the number of core journal articles increased slowly. Qualitative research was the main focus, which highlighted the impact of ecological restoration and sustainable development on the carbon pool of ecosystems. Additionally, research was characterized by team-oriented development. (3) In the rapid development phase (2016–present), this field has shown a rapid growth trend. In the years 2020, 2021, and 2022, the number of related papers reached 192, 264, and 271, respectively. Research has been strengthened in all aspects, and the mechanisms and mechanisms of ecological restoration, sustainable development, and biodiversity continue to be the focus of research. The number of academic papers on the impact of ecological restoration on the carbon pool of ecosystems has been increasing each year, and the goodness of fit of the annual publication curve is as high as 98%. This exponential growth trend indicates that the impact of ecological restoration on the carbon pool of ecosystems remains a hot research topic internationally, and the study of this topic is expected to develop rapidly in the future. Moreover, new research theories, methods, and technologies are likely to emerge continuously. These findings underscore the need for scholars in related fields to continuously monitor the latest developments in this area. The growth of the research on the impact of ecological restoration on the carbon pool of ecosystems is primarily due to three factors. Firstly, the gradual improvement in the theoretical understanding of the carbon pools of ecosystems has helped researchers to more deeply appreciate the crucial role that ecological restoration plays in increasing the carbon pool. Secondly, an increasing number of studies on the response of the carbon pool to ecological restoration in different regions worldwide have provided researchers with more data and technical support for further relevant studies. Finally, more experiments simulating ecological restoration have been conducted, providing theoretical support revealing the mechanism of the impact of ecological restoration on the carbon pools of ecosystems by combining model calculations with simulation experiment fittings.

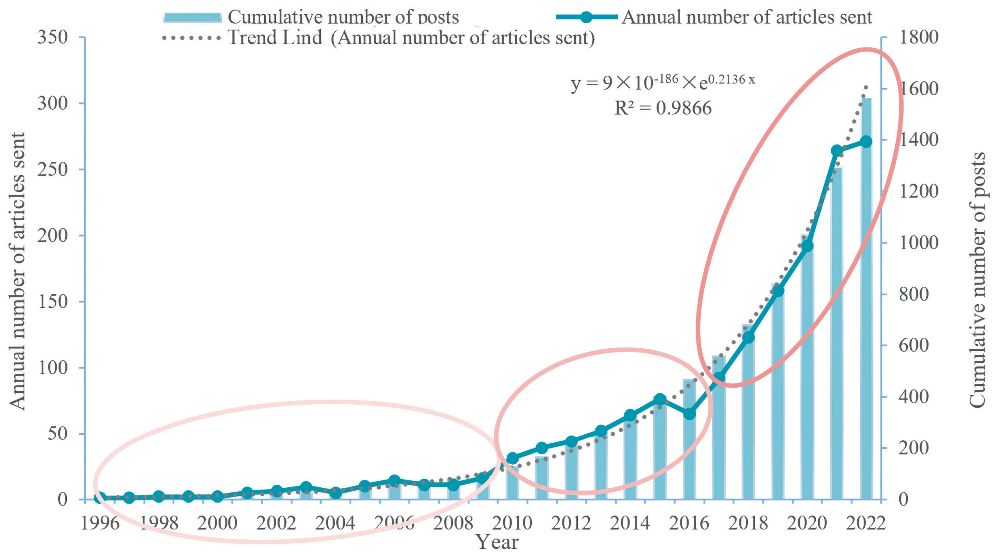

Figure 3. Annual distribution of papers on the impact of ecological restoration on ecosystem carbon sinks in WOS from 1996 to 2022.

3.2. Analysis of Research Hotspots

The keywords of a literature review are part of a highly summarized core vocabulary extracted from the article to represent its main themes. Moreover, keyword clustering can reflect the main direction of the research field and the key themes of that direction [18]. To elucidate the research hotspots in the field of the impact of ecological restoration on ecosystem carbon sequestration, an analysis can be conducted using a keyword clustering map (Figure 4) and a timeline graph (Figure 5).

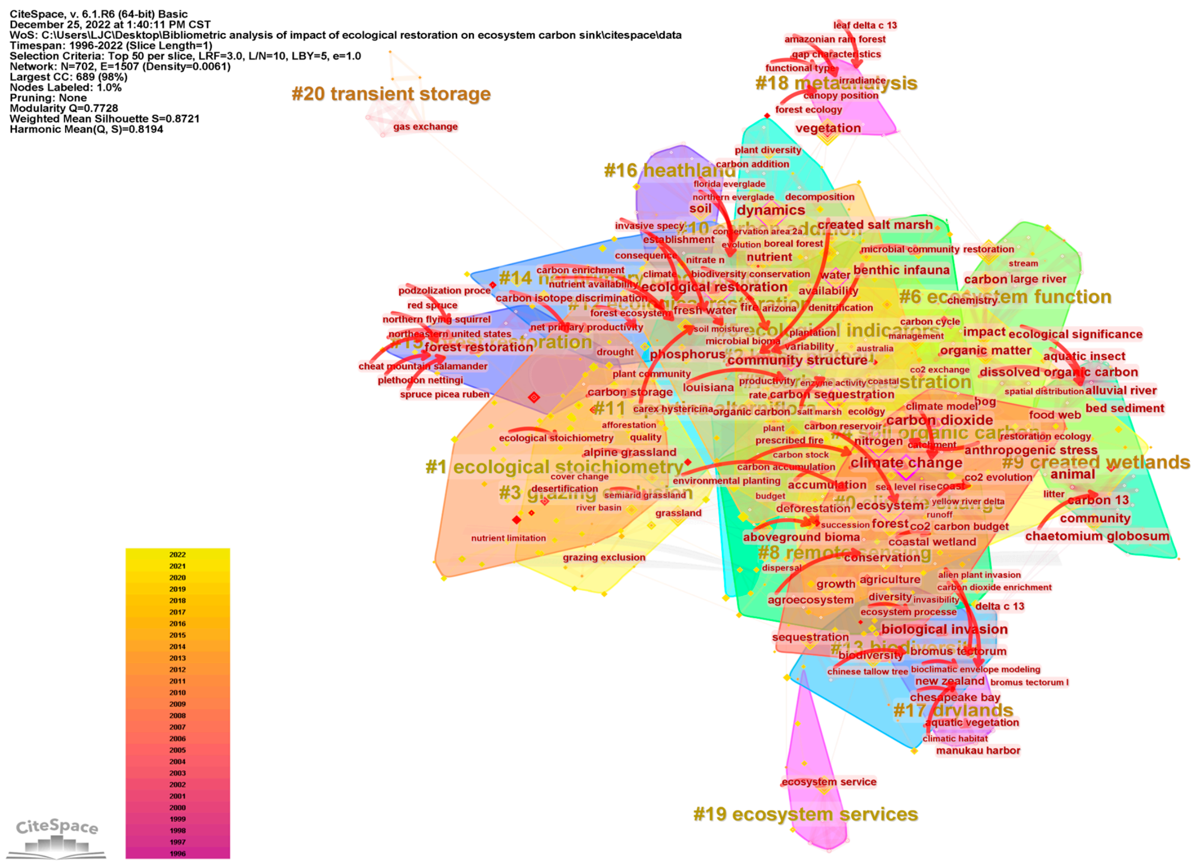

Figure 4. Study on the effect of ecological restoration on ecosystem carbon sequestration.

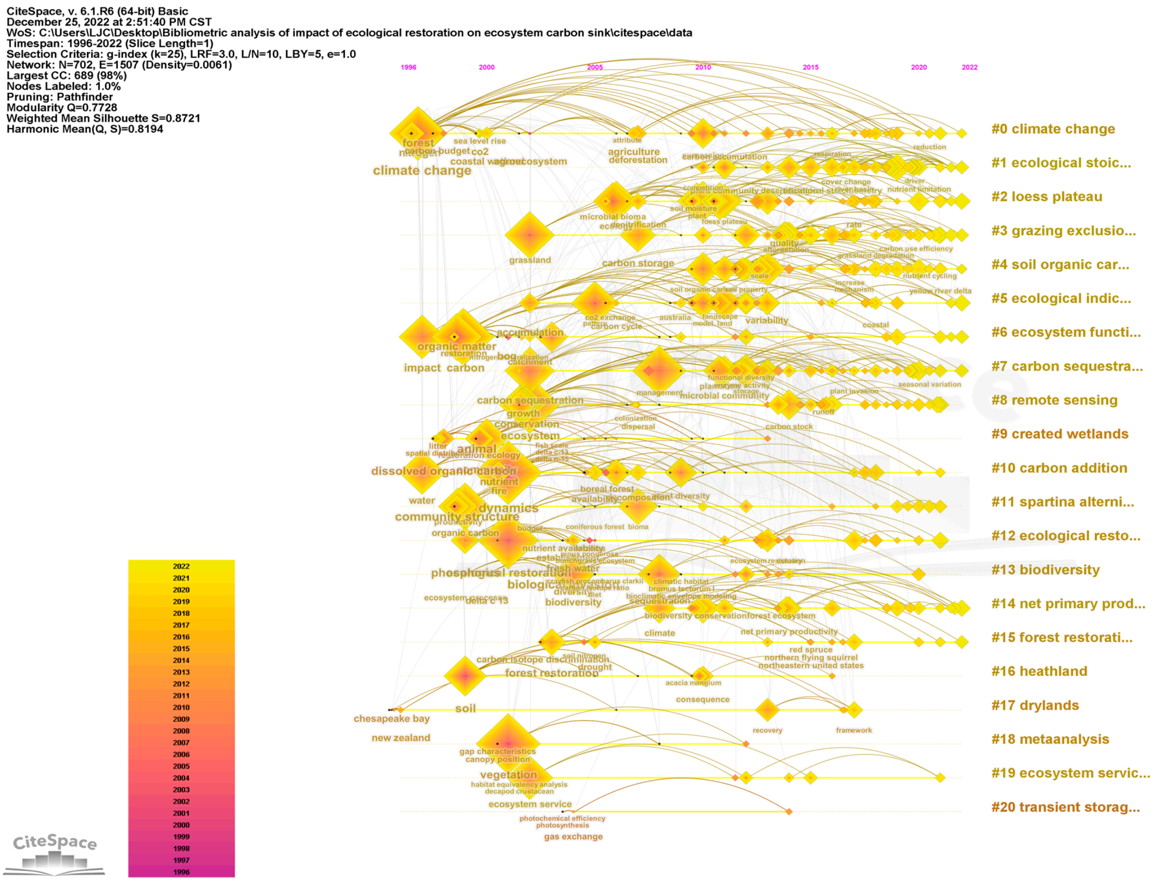

Figure 5. Study on the effect of ecological restoration on ecosystem carbon sequestration, keyword clustering timeline map.

CiteSpace 6.1.R6 was utilized to cluster keywords in order to analyze the research hotspots regarding the impact of ecological restoration on the carbon sequestration of ecosystems. The time span was set to 1996–2022, with a time slice of "1". The node type was set as "Keyword", and other parameters were kept as the default. The logarithmic likelihood ratio (LLR) method was adopted to cluster the keywords into 20 irregular areas (as shown in Figures 4 and 5), with a modular value of 0.7728, which is greater than 0.3, indicating a significant clustering structure. The average silhouette value of the clustering was 0.8721, which is greater than 0.7, indicating a convincing clustering result. In order to provide a clearer illustration of the keyword clustering results, Table 3 was generated to summarize the number of members, the silhouette value, and average year of each of the 20 clusters. Each cluster is composed of several closely related keywords, arranged in ascending order from #0 to #20, where a smaller number indicates a greater number of keywords contained in the cluster.

Table 3. Keyword clustering tag data table.

Cluster Number	Cluster Name	Cluster Size	Silhouette	Mean Year	Cluster Label (LLR)
0	Climate change	66	0.907	2007	Climate change; sea-level rise; temperature; carbon dioxide; soil enzymes
1	Ecological stoichiometry	54	0.867	2018	Ecological stoichiometry; scenario analysis; nutrient limitation; Tibetan Plateau; net primary production

Table 3. *Cont.*

Cluster Number	Cluster Name	Cluster Size	Silhouette	Mean Year	Cluster Label (LLR)
2	Loess Plateau	45	0.74	2013	Loess Plateau; vegetation restoration; soil moisture; land use; nature-based solutions
3	Grazing exclusion	43	0.795	2016	Grazing exclusion; alpine meadow; grassland degradation; carbon storage; grazing
4	Soil organic carbon	43	0.804	2016	Soil organic carbon; soil aggregate; soil properties; soil microbial community; organic carbon fraction
5	Ecological indicators	42	0.837	2012	Ecological indicators; alternate stable states; spatial variability; trees; carbon cycle
6	Ecosystem function	42	0.939	2005	Ecosystem function; restoration; natural capital; biosolids; retention
7	Carbon sequestration	42	0.795	2014	Carbon sequestration; sustainable development; bacterial community; microbial communities; enzyme activities
8	Remote sensing	41	0.856	2013	Remote sensing; carbon stock; aboveground biomass; species richness; conservation
9	Created wetlands	39	0.964	2000	Created wetlands; restoration ecology; food webs; allelopathy; food web
10	Carbon addition	36	0.886	2007	Carbon addition; plant diversity; tallgrass prairie; tree islands; Florida
11	Spartina alterniflora	29	0.897	2006	Spartina alterniflora; community structure; water quality; organic carbon; rhizosphere fungi
12	Ecological restoration	29	0.889	2009	Ecological restoration; ecosystem restoration; stoichiometry; tree diversity; Paris agreement
13	Biodiversity	27	0.97	2007	Biodiversity; earthworms; soil fauna; bibliometric analysis; soil microbiome
14	Net primary productivity	25	0.803	2015	Net primary productivity; water use efficiency; casa model; human activities; ecological restoration
15	Forest restoration	22	0.936	2012	Forest restoration; environmental monitoring; secondary forest; red spruce; soil nitrogen
16	Heathland	17	0.935	2006	Heathland; termites; root nodule; zonation; Southern China
17	Drylands	15	0.907	2002	Drylands; phytoplankton biome; fluvial deposit; fish production; sentinels
18	Meta-analysis	12	0.983	2003	Meta-analysis; forest ecology; climate change; vegetation; restoration treatment

Table 3. *Cont.*

Cluster Number	Cluster Name	Cluster Size	Silhouette	Mean Year	Cluster Label (LLR)
19	Ecosystem services	11	0.963	2007	Ecosystem services; valuation; ecosystem service; sediment; coastal management
20	Transient storage	9	1	2007	Transient storage; semi-arid sandland; quantum efficiency; sparse-elm grassland; stream daylighting

The study of the impact of ecological restoration on the carbon sink function of ecosystems is based on the restoration or improvement of the structure and function of existing ecosystems, thus optimizing the spatial layout of regional ecosystems and, thereby, realizing the carbon sequestration functions of forests, grasslands, wetlands, soils, and permafrost [19]. By analyzing the high-frequency keywords, the clustering co-occurrence map (Figure 4), and the timeline map (Figure 5) of the research on the impact of ecological restoration on carbon sinks, we can further summarize and analyze the research hotspots in this field. It can be observed that past research on the impact of ecological restoration on carbon sinks has focused on four main themes: "carbon sequestration potential of ecological restoration" (#4, #7, #10, #14, and #20), "technical approaches to enhancing the carbon sink function of ecological restoration" (#3, #9, #12, #15, and #19), "assessment methods for terrestrial ecosystem carbon sinks" (#0, #1, #5, #6, #8, #18, and #13), and "characteristics of terrestrial ecosystem carbon sources/sinks" (#2, #16, #17, and #11).

"The potential for carbon sequestration and storage through ecological restoration" (#4, #7, #10, #14, and #20) has become an indispensable part of ecological restoration in the context of current carbon neutrality efforts. Research indicates that soil organic carbon is the largest carbon reservoir in terrestrial ecosystems, accounting for over 1.55×1012 t of global carbon storage [20]. Increasing soil carbon content is an important pathway to carbon sequestration, with 40% of this sequestration being achieved through protecting existing soil carbon and 60% through restoring degraded ecosystems [21]. Ecological restoration projects contribute to 56% of the carbon sequestration in these areas [3]. In the face of increasingly severe climate and environmental issues, the conversion of farmland to forest and grassland is an effective method for carbon sequestration and ecological restoration. Soil organic carbon storage decreased by 3.64% within 5 years of converting farmland to forest, but it subsequently increased over the following 30 years, surpassing the original level of organic carbon storage in the farmland [22]. Therefore, comprehensive scientific methods of ecological restoration are necessary to improve soil properties, increase soil organic matter content, restore and enhance soil carbon sequestration potential, and reasonably increase soil carbon sequestration and storage potential.

"The technical approach to enhancing the carbon sequestration function of an ecosystem through ecological restoration" (#3, #9, #12, #15, and #19): Generally, the techniques for enhancing the carbon sequestration function of an ecosystem through ecological restoration include afforestation, reforestation, land reclamation and afforestation, and the protection of natural grasslands, all of which are green, low-carbon-emission, or sequestration measures [23]. Vegetation restoration is considered one of the important ways to increase and fix organic carbon. Different vegetation restoration patterns have positive effects on the accumulation of soil organic carbon [24]. The vegetation restoration can be used to increase soil organic carbon content, improve soil environment, and further improve the ecological benefits of restoration. However, the impact of different vegetation restoration patterns on soil organic carbon is more complex [25]. Soil macroaggregates contain more organic carbon after vegetation restoration [26]. Blindly planting forests or shrubs on a large scale in arid and semi-arid deserts not only has a limited carbon sequestration effect but also causes soil loss and carbon loss [27]. Three ecological restoration methods, namely the natural restoration of ecosystems, human-assisted restoration, and passive restoration of abandoned pastures, are all considered to produce carbon sequestration effects, which can alleviate global warming, but the time required and the resources invested are different [28].

"Assessment methods for terrestrial ecosystem carbon sinks" (#0, #1, #5, #6, #8, #18, and #13): As an important carbon sink, the carbon uptake of soil and vegetation in terrestrial ecosystems is a crucial means of reducing atmospheric CO_2 concentration [29]. Terrestrial ecosystems mainly regulate regional carbon cycling by absorbing CO_2 through photosynthesis and fixing it in vegetation and soil, thereby maintaining the global ecological balance [30]. Among global terrestrial ecosystems, forests cover an area of 4.06 billion hectares, accounting for one-third of the global land area. Forests are the largest carbon reservoir or carbon sink in terrestrial ecosystems, with their vegetation carbon pool accounting for 80% of the global vegetation carbon pool. Compared with other ecosystem types, such as grasslands, wetlands, and croplands, forests have stronger carbon sink functions and greater potential for carbon sequestration. Negative responses to global changes can lead to significant changes in atmospheric CO_2 concentrations, accelerating the process of global climate warming [31–33]. Therefore, forest carbon sinks, as the main component of terrestrial ecosystems, are considered an effective way to offset carbon emissions from fossil fuels [10,34,35]. Since the 1980s, remote-sensing technology has been widely used in studying the spatial patterns, interannual variations, and long-term trends of carbon dynamics in different scales of ecosystems [36–38]. The widespread use of remote-sensing technology can better estimate forest carbon stocks, especially aboveground biomass [39]. Accurately estimating the carbon storage and stability of terrestrial ecosystems under global change is of great significance for evaluating the carbon sink functions of specific regional ecosystems and predicting their responses to climate change [40].

"Characteristics of terrestrial ecosystem carbon sources/sinks" (#2, #16, #17, and #11): Before the 1970s, scholars believed that terrestrial ecosystems were absorbing more CO_2 than they were emitting, making them carbon sinks [41]. However, with the rapid development of global industrialization after the 1970s, vegetation and climate were impacted, and terrestrial ecosystems came to be considered as carbon sources [42]. Currently, the carbon sink function of terrestrial ecosystems is mainly concentrated in the high-latitude areas of the Northern Hemisphere, with a range of 2.0~3.4 Pg C yr^{-1} [43]. In tropical regions, however, they exhibit weak carbon sink functions or are weak carbon sources [44]. The increase in CO_2 concentration and nitrogen deposition has greatly contributed to the carbon sink function of terrestrial ecosystems, while land-use and land-cover change, climate change, and increased ozone concentration can cause them to become carbon sources [45]. The Loess Plateau, one of the regions with the greatest increase in vegetation coverage in China, is a typical area where major ecological projects such as returning farmland to forest and grassland, gully treatment and terracing, and sediment-trapping dam construction have been implemented [46,47]. Currently, with the rapid recovery of vegetation and the positive succession of plant communities on the Loess Plateau, the continuous accumulation and decomposition of litter has increased the amount of soil organic matter [48], which, in turn, promotes plant growth and community development [49] and has significant and far-reaching impacts on the carbon cycle and soil carbon sink function of terrestrial ecosystems [50,51].

3.3. Research Frontier Analysis

The emerging hotspot of "the impact of ecological restoration on carbon storage in ecosystems" is associated with the sharp increase in the frequency of keywords. The outbreak of keywords indicates the emergence of topics with developing potential or that are widely recognized among researchers at a specific time [52]. Therefore, sudden detection, as an indicator of highly active research areas, indicates emerging trends and hotspots in the research field by detecting nodes with a significant increase in citation frequency or co-occurrence frequency during a certain period [53]. The burst analysis of keywords was performed using CiteSpace software, and the resulting map (Figure 6) was obtained.

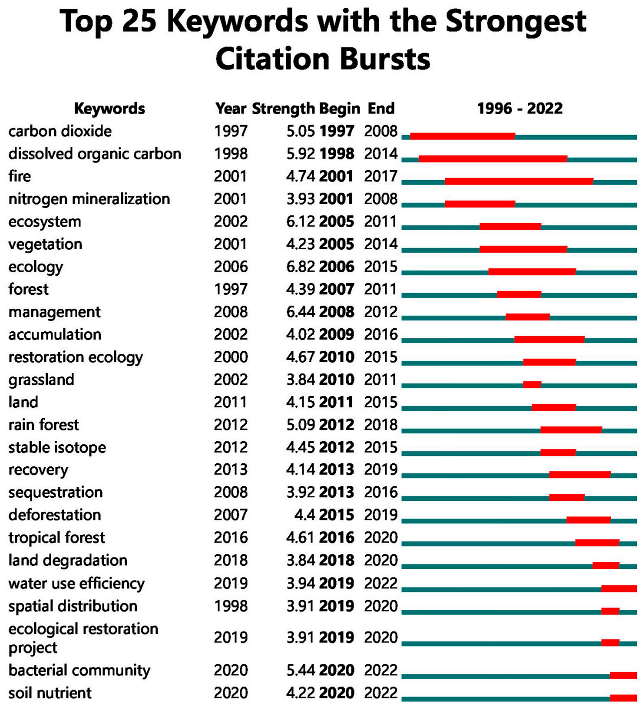

Figure 6. Study on the effect of ecological restoration on ecosystem carbon pool.

Human ecological restoration practices have a long history. Upon analyzing emergent terms, we can observe that early researchers primarily focused on fire and dissolved organic carbon (DOC). Relevant studies suggest that fire is a disaster and that forest, grassland, and pasture fires can damage the local ecological environment. To prevent or reduce the occurrence of fires, it is necessary to increase forest thinning. However, the real disaster is not the fire itself but the significant changes in the ecosystem structure and composition caused by a series of non-standard firefighting policies that follow the fire [54–56]. However, some studies have found that the use of fire can also promote ecosystem restoration; for example, burning can promote the development of soil microbial communities [57–59]. Therefore, the application of fire for ecological restoration is considered a useful but risky technique. With the intensification of global climate change, people are gradually paying attention to the impact of dissolved organic carbon (DOC) on global climate change. Each year, 0.45 Gt of organic carbon is transported from terrestrial ecosystems to marine ecosystems [60–62]. DOC can also affect gas-exchange processes between the atmosphere and the ocean, leading to an increase in atmospheric CO_2 concentration, which is important for global carbon cycling and climate change [63]. Further research has found that bacteria in aquatic ecosystems can use DOC as an important factor for growth and a source of nutrients, with approximately 13% of endogenous DOC supporting 30% to 65% of bacterial growth metabolism [64–66]. In recent years, research progress on dissolved organic carbon at a global level includes the role and regulation of organic carbon in aquatic ecosystems, the impact of heavy rainfall on the transport of organic carbon in rivers, the impact of biochar application on global organic carbon, and research on permafrost and carbon cycling on the Qinghai–Tibet Plateau [67–71].

In recent years, scholars have increasingly focused on the impact of ecological restoration on the carbon pool of ecosystems, with attention centered on soil nutrients, bacterial communities, water-use efficiency, spatial distribution, ecological restoration projects, and land degradation. Soil microorganisms, as the most active parts of the soil, play an important role in the function and stability of ecosystems, with bacterial diversity reflecting soil quality to some extent [72]. Bacteria are involved in almost all biochemical cycles of terrestrial ecosystems and play an important role in the stability of ecosystems [73]. Carbon fixation in soil can be achieved by suppressing the short-term carbon source consumption of soil microorganisms and increasing soil carbon sinks [74]. Studies have found that, in arid environments and areas with low carbon content, the diversity and biomass of soil microorganisms reach their peak, while the opposite is true in carbon-rich and cold environments [75]. Meanwhile, long-term straw cover significantly increases the content of organic carbon and residual microbial carbon in the topsoil [76,77]. Straw decomposition inputs a large amount of exogenous carbon into the soil, which changes the activity of bacterial taxa and improves their ability to utilize carbon sources [78]. Ecological restoration projects such as afforestation and reforestation can increase the soil carbon storage of terrestrial ecosystems and can enhance and improve the ecological function of fragile karst areas [79]. Currently, there is relatively little research comparing different ecological restoration technologies, so using locally suitable ecological restoration methods can significantly improve ecological restoration efficiency [80]. For example, in the Qinghai–Tibet Plateau ecosystem, the construction of artificial grasslands can significantly increase grass production and enhance the carbon and nitrogen storage of the current ecosystem [81]. With regard to tropical forest ecosystem restoration, research has involved three methods: natural recovery, human-assisted recovery, and passive recovery of abandoned pastures. Studies have shown that all three restoration methods can restore tropical forest ecosystems, produce carbon sinks, and alleviate global warming, but they require different time and resource investments [28]. In summary, as research on ecological restoration continues to deepen, there will be new insights into the changes in the carbon pool of ecosystems, and we will have a more comprehensive understanding of the impact of ecological restoration on the carbon pool function of ecosystems.

4. Conclusions

We conducted a bibliometric analysis of studies on the impact of ecological restoration on ecosystem carbon storage from 1996 to 2022 and explored the trends in the relevant literature. Based on our analysis, we drew the following conclusions:

(1) Through our analysis of the research output data, we found that China far surpasses other countries in terms of article production on the impact of ecological restoration on the carbon pool of ecosystems. In fact, China occupies six out of the top ten institutions in terms of publication output, with the top three institutions being the Chinese Academy of Sciences, the University of Chinese Academy of Sciences, and Northwest A&F University, in order. The close collaboration between these institutions reflects China's important position in research on the impact of ecological restoration on the carbon pool function of ecosystems.

(2) Based on the growth rate of the literature, the study on the impact of ecological restoration on ecosystem carbon storage can be roughly divided into three stages: the budding stage (1996–2009), the initial exploration stage (2009–2016), and the rapid development stage (2016 to present). The goodness of fit of the annual publication curve has reached 98%, indicating that the impact of ecological restoration on ecosystem carbon storage is still a hot research topic internationally. In the future, research on the impact of ecological restoration on ecosystem carbon storage will continue to rapidly develop, and new research theories, methods, and scientific and technological advancements will continue to emerge. Meanwhile, researchers in related fields will continue to track and study this topic for reference.

(3) The current research hotspot in "the impact of ecological restoration on the carbon pool of ecosystems" mainly revolves around four divergent themes: "the carbon sequestration potential of ecological restoration", "the technical approaches to enhancing the carbon sequestration function of ecological restoration in ecosystems", "assessment methods for land-based carbon sinks," and "characteristics of land-based carbon sources/sinks". These themes are predominantly explored through collaborative

research between different countries and exhibit a high degree of cross-disciplinary integration.

(4) Currently, researchers are focusing on several key aspects related to the impact of ecological restoration on carbon storage in ecosystems, including soil nutrient, bacterial community, water-use efficiency, spatial distribution, ecological restoration projects, and land degradation. The longest studied keywords are related to fire and dissolved organic carbon (DOC).

In light of the current research hotspots and deficiencies, the future research direction for "the impact of ecological restoration on the carbon pool of ecosystems" should be as follows:

(1) Future research directions on the impact of ecological restoration on ecosystem carbon storage should focus on strengthening the study of the response mechanisms of ecological restoration under different landforms, climates, and vegetation types. Additionally, it is essential to combine factors of current global environmental change and maintain the continuity of research and observation on the impact of ecological restoration on ecosystem carbon storage to provide robust data support.
(2) International cooperation and communication should be strengthened to establish a global network for ecological restoration research in order to explore the response mechanisms of different ecosystem carbon pools to ecological restoration on a global scale.

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