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Review

Landscape Ecological Concepts in Planning (LEP): Progress, Hotspots, and Prospects

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Abstract: As an interdisciplinary topic, landscape ecology has great potential in providing knowledge for landscape planning. However, previous studies have not been reviewed by multidisciplinary journals. There has not yet been a thorough analysis of these studies, and it is unclear how different points of view have evolved. In this study, CiteSpace software is used to analyze the evolution and current state of LEP research from several perspectives, which also identifies research hotspots and future research trends. The main findings are as follows: (i) There are three phases in LEP research: preparation, rising, and prosperity. LEP research is gradually shifting from concentrated ecological or environmental science to multidisciplinary fields, and there are significant opportunities for LEP research to build global collaborative networks. (ii) The focus of this research has gradually shifted from quantifying environmental impact to analyzing the internal process of the urban system. (iii) Future research will concentrate on a spatial model of landscape system analysis, landscape ecological resilience research, and LEP research in "urban agglomeration" with the hope of increasing the ability to realize sustainable space development.

Keywords: landscape ecology; landscape ecological planning; bibliometric analysis; ecological service; CiteSpace; research progress; research hotspots

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1. Introduction

The geographical distribution and spatial patterning of organisms has long been of interest to ecologists and natural historians. Rapid and widespread changes in landscapes throughout the globe have prompted the development of a new field called "landscape ecology", whose goal is to serve as a foundation for landscape management, design, and policy via the dissemination of relevant data [1]. The application of ecological concepts in landscape sustainability [2], landscape methods, landscape design [3], and regional and landscape planning [4] has a historical tradition. Landscape ecology is the result of the interdisciplinary combination of geography and ecology. It uses the landscape ecosystem as its target of study. Through the transformation and transmission of energy flow, material flow, species flow, and information flow in landscape structures [5], landscape ecology is commonly used to examine the spatial structure, ecological function, and the construction of spatial–temporal models in landscape ecosystems [6,7]. The concept and theoretical core of landscape ecology link natural science with social science, and treat the landscape as a stage where structural features and social structures are integrated [8]. Landscape planning, as a comprehensive collaborative practice within a regional scope, is prominent all over the world [9] and benefits from landscape ecology in many ways. It tends to center on rural areas or open landscapes, where tensions between urban growth and recreational landscape value, agricultural output and environmental safeguards, and renewable energy generation and aesthetics are most prominent [10].

The concept of landscape ecology has great potential in incorporating landscape ecological knowledge into landscape planning [11]. Landscape ecology is generally regarded as a useful and appropriate perspective for landscape planning and promoting urban sustainability [11,12]. Landscape ecology is explicitly concerned with spatial patterns. Specifically, landscape ecology takes the development and dynamics of spatial heterogeneity, spatio-temporal interactions and exchanges between heterogeneous landscapes, the effects of spatial heterogeneity on biotic and abiotic processes, and the management of spatial heterogeneity into account. The relationship between spatial patterns and ecological processors is not limited to a specific scale. Landscape ecology provides some crucial planning considerations. A fundamental aspect is that it emphasizes the spatial component of the ecological process, thus providing a consensus for stronger interaction between ecologists and planners. Additionally, it considers the relationship between mutual patterns and processes, provides theoretical and empirical evidence for understanding and comparing different spatial allocation of land cover [13], and even predicts the ecological consequences of planned spatial allocation. The second basic aspect is the focus of landscape ecology on human ecology and its direction in terms of planning and management, rather than the traditional biological-centered ecological method. Human activities are regarded as a part of the system, rather than a separate component. The third aspect employs landscapes as the main research unit. Combined with a systematic and holistic approach, this interdisciplinary science can comprehensively analyze complex man-made landscapes, which are rapidly becoming global hotspots. The research component no longer serves as the sole (and most valuable) purpose of acquiring (ecological) knowledge, but also provides better insights about human and natural systems to support planning for sustainable utilization.

In the past 30 years, landscape ecology has made great progress in theory and practice [14,15]. Some researchers have claimed that this field is mature [16]. Conceptual empirical research is used to discuss the significance of landscape ecology in researching management and planning information [17,18]. Few studies have examined the use of landscape ecology in landscape design [19,20]. Importantly, the field of landscape ecology is currently full of vigor and a drive for perfection. Nonetheless, it is evident that the fundamental issues of landscape ecology are still emerging and condensing. Therefore, landscape ecology is still undergoing fast maturation and growth.

In this context, researchers are interested in guiding the growth of landscape ecology research to provide increasingly precise forecasts of future trends. By summarizing the findings in landscape ecology research, we can identify the present research frontiers and hotspots, thus generating ideas and possibilities that can guide future research and policy. Some previous reviews have analyzed the status of current research in the field of landscape ecology and landscape planning, and they provided insights on the most advanced research in this field [21]; however, the representativeness of applied research deserves further study. In addition, landscape ecology is a multidisciplinary field that requires further consideration, including other journals (for example, landscape architecture and planning practice) or analysis of landscape projects. These studies do not provide a whole study (that is, using a single perspective instead of multiple perspectives) and do not reveal how this research developed or affected the environment, which limits the ability to systematically analyze landscape ecological concepts in planning by combining different research results. The purpose of this paper is to identify the concepts of landscape ecology that are present in the scientific literature, to analyze the universality of these concepts, and to understand how these concepts provide information for the different steps of the planning process (from goal establishment to measurement). CiteSpace, a document data visualization software, was used to gather a huge number of publications for this purpose. This technique reveals the history and distribution of publications, the accumulated body of knowledge, and the topical issues in LEP research. Using this methodology, this study reviews the current status and potential future developments of this field and provides a theoretical reference for future scholars and decision makers. On this premise, this study proposes the path of future research. The rest of this article is organized as follows:

- Section 2 explains the data sources and analysis methods used in this study. In this chapter, the advantages of CiteSpace are analyzed compared to other software, which is the purpose of this article.

- Section 3 describes the literature identified by this review and its characteristics, including the number of publications and research topics. In addition, the knowledge base of LEP research is analyzed, and the research topics and how they evolved are described.
- Sections 4 and 5 provide a synopsis of current trends and future research directions. It should be noted that this publication does not compare research results on this topic. Instead, the purpose is to present an overview of the current status of this field, how it is developing, and key areas for future research.

2. Materials and Methods

2.1. Data Sources

In the initial phase of this research, the selection of reference journal articles from WoS databases for unified analysis was determined. The WoS is a primary data source with authority and representativeness. For the WoS, core collection consists of SCI-E, SSCI, A&HCI, etc. This study limited the search by creating a search string and selecting "topic" as the search type to retrieve the title, abstract, author keywords, and keywords plus. Keywords plus are words and phrases that appear in the titles of references cited by the authors; thus, keywords plus can express the contents of the articles more succinctly [22]. The present paper dwells upon the ability of author-assigned keywords and keywords plus to highlight coverage of topics and subject areas. The second step was to choose journal articles using relevant keywords. As a result, "Landscape ecological (LE)", "Landscape ecological concept (LEC)", and "planning" were chosen over an indefinite period (1900 to the present). The date of the search was 20 October 2022 and the search results were narrowed and filtered, yielding 8121 initial relevant items.

2.2. Methods

Knowledge mapping, a cutting-edge technique of analysis in bibliometrics and scientometrics, visually represents the findings of a quantitative study of a research topic intuitively [23]. With such a vast number of articles, human data extraction would be prohibitively time-consuming, so this paper turned to automation instead. In addition, the chosen application must offer superior visualization features in order to match the research goal. Common visual analysis tools include HistCite [24], RefViz [25], VOSviewer [26], SATI [27], and CiteSpace [23]. Comparing the characteristics of these pieces of software revealed that SATI, VOSviewer, and CiteSpace provide identical features and can generate co-occurrence and co-citation maps. However, SATI is incapable of producing timeline maps, which would hinder our research into the development of this scientific area. While HistCite and RefViz are both user-friendly, HistCite relies on word frequency analysis, which precluded it from satisfying the requirement of finding cooperative networks and performing co-occurrence and co-citation studies; thus, it could not have revealed the links between the components that this paper evaluated (authors, terminology, references). RefViz, on the other hand, is often used primarily for keyword grouping and analysis, and thus does not provide a multidimensional evaluation of the LEP field. To provide a comprehensive analysis of the selected literature, CiteSpace 6.1 R2 was chosen as the primary tool in this work.

Before visual inspection, this paper utilized the remove duplicates command in CiteSpace 6.1 R2 to exclude 1093 duplicate articles, and 7028 articles were deemed to be useful research materials. This paper then used CiteSpace to investigate publications and networks of collaboration, the evolution of LEP research through time, and the distribution of cooperation among nations, research organizations, and authors. This paper accomplished this by configuring the CiteSpace software's node types to "country" and "institution". In addition, by setting the node types to "Category" and selecting Timeline View, this paper identified the development of research themes in this field. Using the co-occurrence of "Terms" and cluster analysis, this paper identified cutting-edge research and hotspots across the field's history. By taking the findings of all of these studies into consideration, the development patterns for LEP research can be described and future issues and breakthroughs that may need attention can be identified. Figure 1 describes the study's general framework.

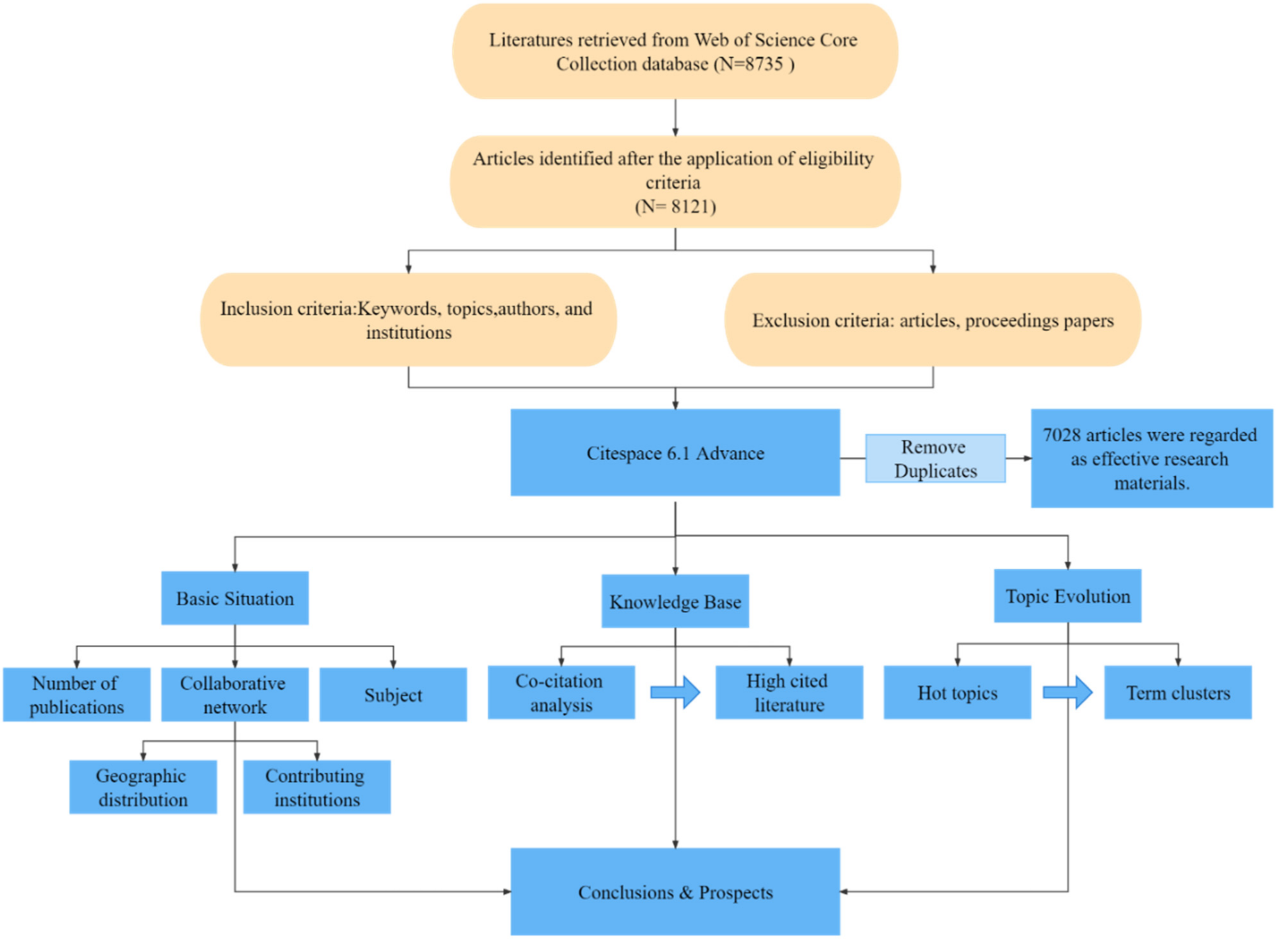

Figure 1. Overall research process framework.

3. Results

3.1. Basic Situation Analysis

3.1.1. Trends in Publication

Changes in the number of publications are a crucial sign that reveal the development of research fields. Utilizing CiteSpace, this article eliminated duplicate articles. This paper acquired a total of 7028 papers related to the LEP subject, as well as the distribution of the number of articles published per year. The data revealed three stages of LEP research between 1986 and 2022 (Figure 2).

- From 1986 to 1990, the number of publications increased slowly. The number of publications during the four years from 1986 to 1990 only accounted for 0.3% of the total, with 22 papers. In 1986, R. Forman and M. Godron used the principles and methods of ecology in their book to systematically study spatial structures, landscape dynamics, and the principle of landscape heterogeneity in landscape research [28], which laid the whole research framework for landscape ecology. In 1989, I.S. Zonneveld and R. Forman et al. co-edited a book. This book is a collective work of several of the major landscape ecologists in the world in the late 1980s, which reflects the deep development of landscape ecology research [29]. Although the research at this stage was not rich, the concept of landscape ecology and its definition and study methodologies provide a theoretical basis for further research. Therefore, these years represent the "preparation" stage of the landscape ecology concept mentioned in this paper.

- During the period from 1991 to 2008, the number of papers published on concepts related to landscape ecology increased exponentially and, by the end of this period, had increased to 34 times that of 1990, accounting for 17.1% of publications. It is the "rising" stage. In 1991, the World Congress of Landscape Ecology was held at Carleton University in Ottawa, Canada. More than 400 representatives from 40 countries attended the conference and put forward key research themes and shared major advancements regarding international landscape ecology development in the 1990s, which laid the foundation for LEP research. At this stage, international scholars conducted case studies on many LEP projects across the world, and the main research fields were landscape heterogeneity research [30] and landscape system analysis [31,32].
- In 2008, the United Nations Environment Program launched the international "Economics of Ecosystem Services and Biodiversity" initiative, which helps all society sectors to understand its importance by estimating the value of ecosystems and biodiversity. Thus, research on LEP has reached a "prosperous" level, with over one hundred publications published annually. This era accounts for 82.6% of the total number of publications, indicating that LEP research has become an active field for many researchers. In addition, LEP case studies, including ecological evaluations, data models, and landscape measurements, emerged at this stage [33,34]. At the same time, many research models and methods appeared [35,36], indicating the vigorous development of this field.

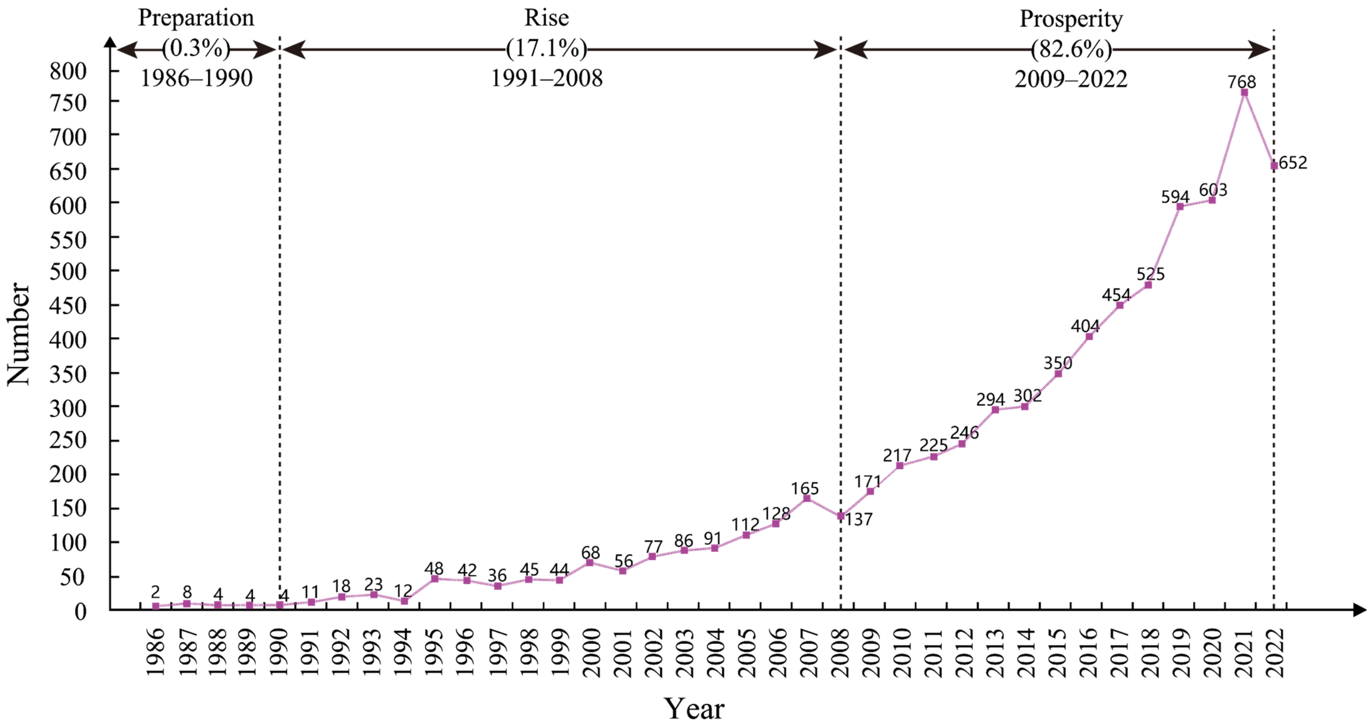

Figure 2. Number of publications per year in the LEP research field.

With increased global concern regarding climate change, the field of LEP has garnered greater scientific attention from worldwide researchers, and more stringent requirements have been proposed for the development of the LEP field. This area will quickly develop into a mature field.

3.1.2. Geographic Distribution

By evaluating the international collaboration network, it is possible to determine the nations and areas that have published the largest number of publications and those that have had the most effect on the field of LEP, as well as their cooperative relationships. The node type was set to country, the time slice was set to one year, and the data were sorted to produce a knowledge map in this field (Figure 3).

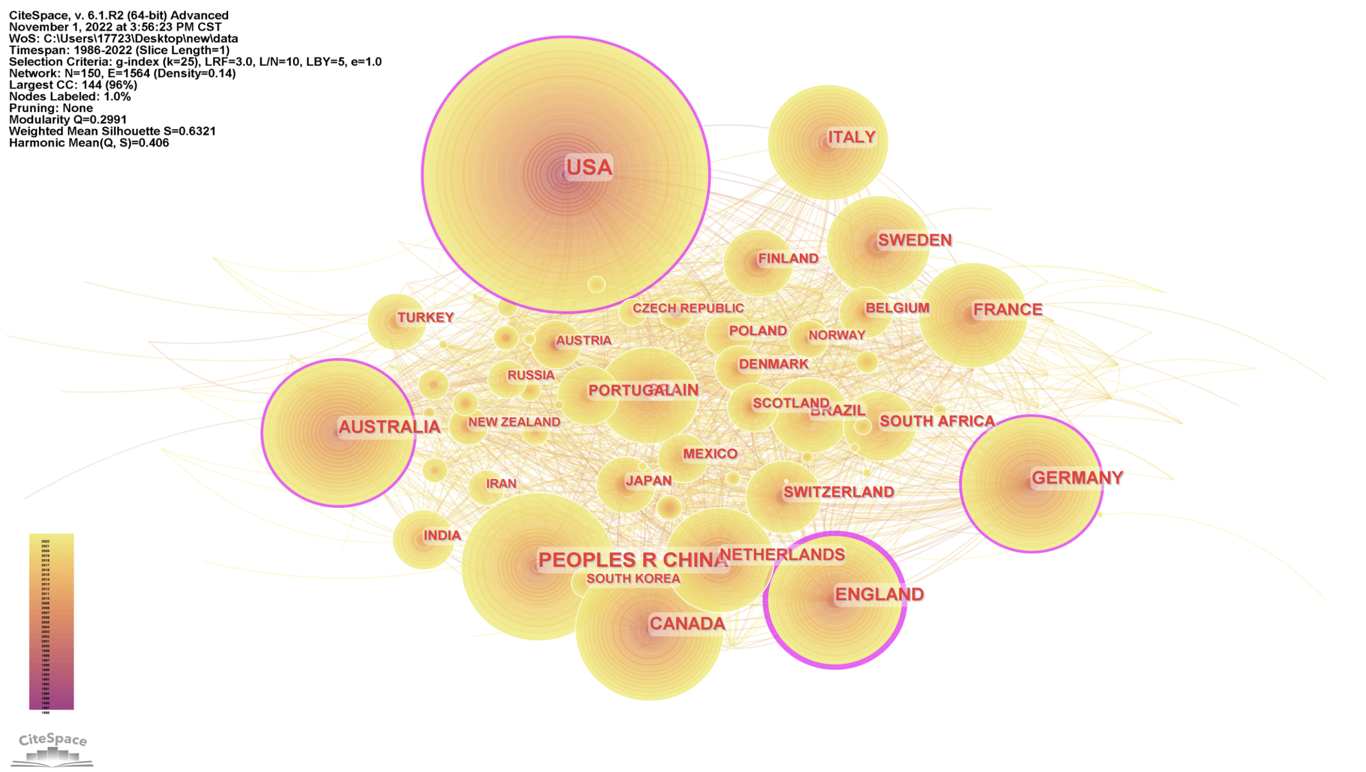

Figure 3. Knowledge map of cooperative countries and regions in LEP research (1986–2022).

A total of 150 nodes and 1564 data lines were obtained, representing 150 countries and regions that have conducted relevant research in this field and 1564 interrelations. From 1986 to 2022, 2056 articles were published by the USA, 1115 by China, and 591 by Australia. As seen in Figure 3, the United States is the top contributor to LEP research and has the greatest amount of collaboration and cross-citation with other nations (0.14 centrality) (Table 1). England has strong ties with Germany, China, Australia, France, Spain, and Italy, as well as other developed nations, indicating that there is tremendous potential for building international collaboration networks that can aid research into LEP as a global concern.

Table 1. Major countries and regions in the field of LEP (1986–2022).

Rank	Numbers of Articles	Centrality	Year of First Publication	Country
1	2056	0.14	1987	USA
2	1115	0.03	2000	China
3	591	0.12	1995	Australia
4	489	0.05	1993	Canada
5	464	0.2	1996	England
6	464	0.12	1995	German
7	370	0.09	2000	Italy
8	318	0.09	1990	France
9	317	0.09	1995	Spain
10	264	0.07	1991	Sweden

3.1.3. Distribution of Major Institutions

Analysis of the distribution of collaboration between research institutions pro-vided insights into academic support and recognition in this field [37]. Setting the node types to reference and the time slice to 1 year presented a knowledge graph containing 753 nodes and 2745 links, with a density of 0.0097 (Figure 4).

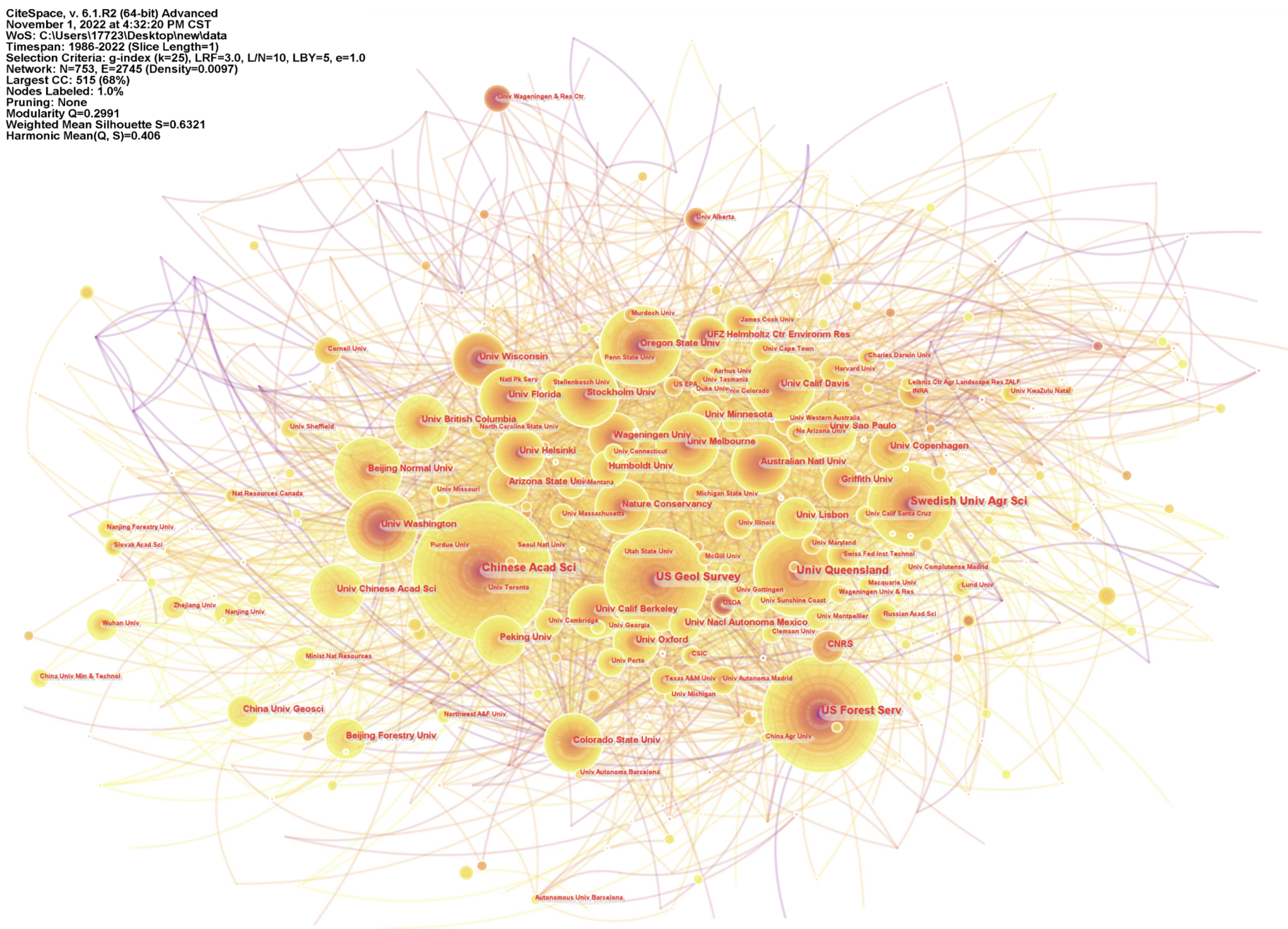

Figure 4. Distribution of main research institutions for LEP research (1986–2022).

Among the top 10 publishers from 1986 to 2022, the Chinese Academy of Science published the most publications (235), followed by the US Forest Service and the US Geological Survey (118). China and the United States were the leading countries, but their institutional distributions were vastly different. The United States is home to a greater number of LEP research institutions, such as the US Forest Service, US Geological Survey, Oregon State University, the University of California, Davis, Colorado State University, the University of Washington, etc. However, the number of papers published by each institution, except for the first two, was less than 100. In contrast, China's research achievements are mostly provided by a slightly larger group of prominent academic institutions, such as the Chinese Academy of Sciences, Beijing Normal University, the University of Chinese Academy Science, and Peking University (Figure 4). Among these, the Chinese Academy of Sciences is especially notable, producing 235 articles, which is higher than the second-ranked nation, the United States, which generated 160 publications. From the standpoint of a cooperative network, the degree of centrality is crucial. Centrality shows the strength of a node in the overall network based on its number of connections to other nodes; a node with high centrality has a significant impact on interactions within the network. The Chinese Academy of Sciences and the University of Queensland had the highest degree of centrality (0.07), followed by the University of California, Davis and the US Forest Service (0.06) (Table 2). These countries also cooperated closely with each other. In addition, these countries had close cooperation with Sweden, Germany, and other developed countries' institutions.

Table 2. Centrality and frequency ranking for the major research institutions.

Rank	Publications	Centrality	Year	Institution	Country
1	235	0.07	2000	Chinese Academy of Sciences	China
2	160	0.06	1997	US Forest Service	USA
3	118	0.04	2003	US Geological Survey	USA
4	110	0.05	2000	Swedish University of Agricultural Sciences	Sweden
5	93	0.07	2006	The University of Queensland	Australia
6	90	0.03	2007	Beijing Normal University	China
7	83	0.01	2015	University of Chinese Academy Science	China
8	78	0.03	1998	Oregon State University	USA
9	72	0.06	2006	University of California, Davis	USA
10	72	0.04	2005	The University of Melbourne	Australia

3.1.4. Research Themes

Setting the node type to category and the time slice to 1 year generated a co-occurrence mapping of subject categories, with 156 nodes and 523 connections obtained. According to publication time, ecology had its first relevant studies in 1986, followed by evolutionary biology, genetics and heredity, and physical geography and multidisciplinary geoscience (1987) (Figure 5). In general, LEP research has evolved from a field focused on environmental science and ecology to a multidisciplinary field.

As is known to all, the rapid increase in human activity has led to tremendous resource consumption and severe environmental contamination. Moreover, with the development of contemporary ecological ideas and approaches, environmental challenges have emerged as a central concern for many academics. Currently, based on frequency, environment and ecology (including ecology, environmental science, and environmental studies) are still the main subjects of LEP research and account for 60% of the most influential subjects as calculated by CiteSpace 6.1 R2 (Table 3). Since the 1960s, geographic studies (including geography, multidisciplinary geoscience, and geography and physics) have been closely linked to landscape ecology. The German, Soviet, and central European schools of landscape science have described the landscape as a complex geographic system [38]. Subsequently, since 1988, ecological concepts have attracted attention for their practicality in landscape planning, with some scholars utilizing these methodologies to tackle actual issues in engineering, environmental engineering, urban studies, regional and urban planning, and other domains.

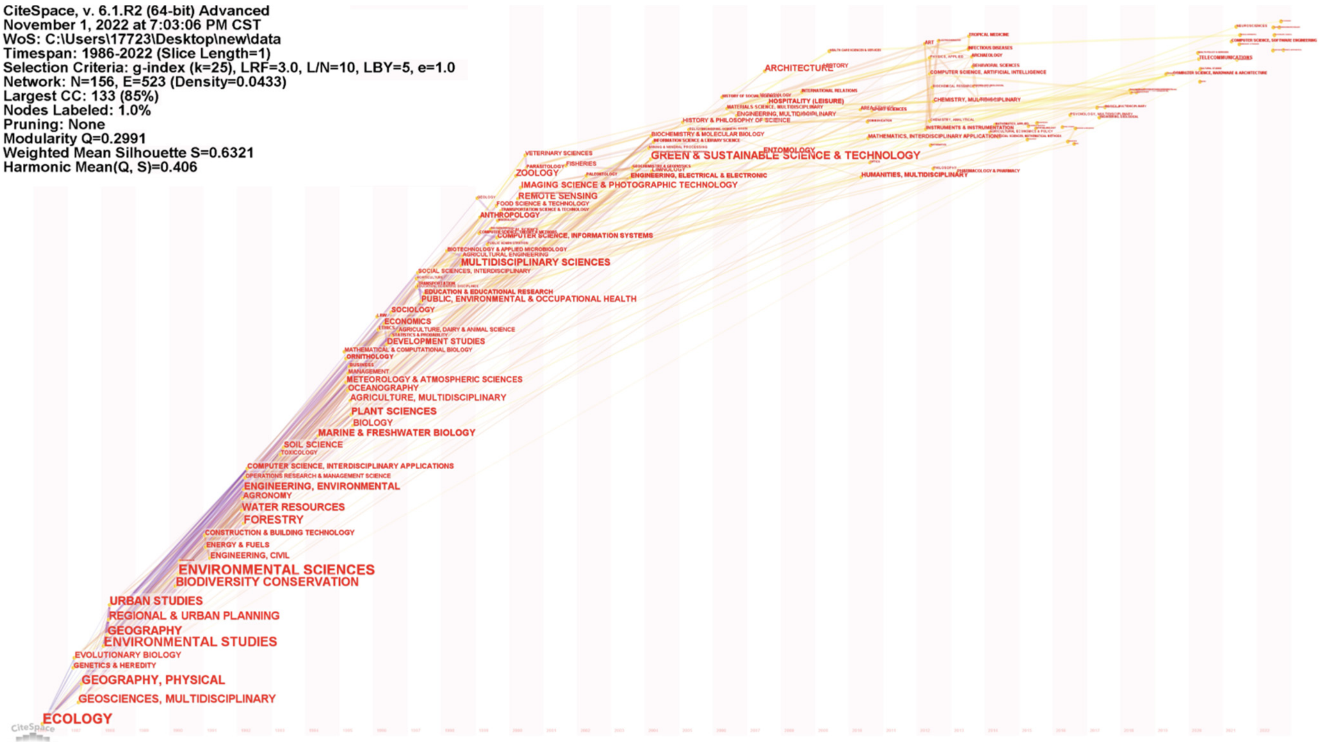

Figure 5. Time zone view of research subjects.

Table 3. List of main research themes.

Rank	Freq	Centrality	Year	WoS Categories
1	2453	0.22	1986	Ecology
2	2375	0.27	1990	Environment science
3	1382	0.25	1988	Environment studies
4	943	0.04	1990	Biodiversity conversation
5	702	0.09	1987	Geography, physical
6	644	0.13	1988	Geography
7	575	0.03	1988	Urban studies
8	515	0.01	1992	Forestry
9	472	0.13	1987	Geoscience multidisciplinary
10	472	0.01	1988	Regional and urban planning

In addition, the research areas are divided into three main directions, as shown in Figure 6: (1) ecology research, (2) urban and geography studies, and (3) environment research (which links these two directions, indicating that this is a core discipline in this field of study). Environmental science has a centrality of 0.27, which is the most substantial citation explosion and thus indicates its importance. It is worth noting that LEP research has developed a remarkable multidisciplinary focus, with LEP research emerging in a range of natural science or social disciplines including resources (forestry, water resources, biodiversity conservation), civil engineering and construction (green and sustainable science and technology, civil engineering, architecture), and agronomy and economics. In addition, the development of computer science and remote sensing technologies have broken the limits of research techniques and are closely linked to LEP studies.

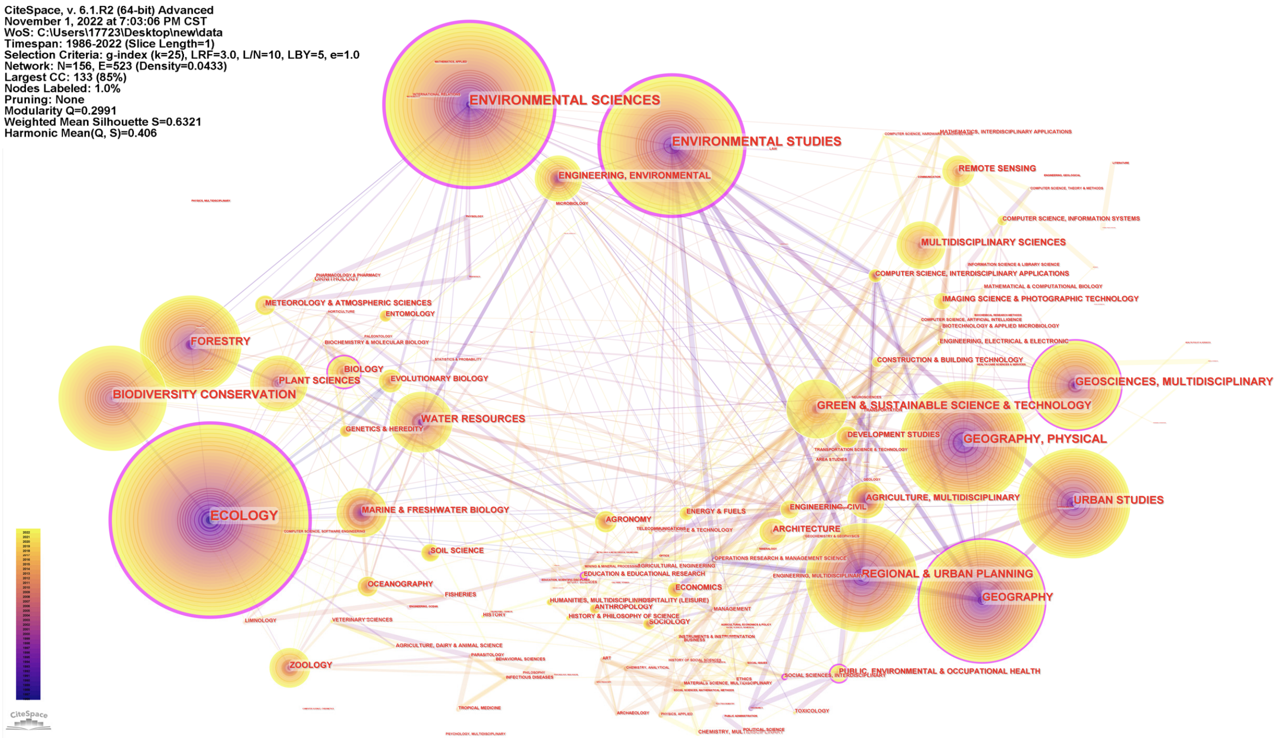

Figure 6. Co-occurrence network of research subjects.

3.2. Knowledge Base Analysis

3.2.1. Co-citation Clustering

Co-citation analysis can identify which publications in landscape ecological study have been reviewed and cited [39]. The co-citation network was constructed by extracting the top 25 papers each year (1986 to 2022). This paper clustered the map according to the LLR algorithm in CiteSpace and named the clustering labels by extracting keywords [40]. Setting the node types to reference and the time slice to 1 year generated a co-citation mapping with a total of 2399 nodes and 8036 connections. By clustering the cited publications, this review detected 16 main clusters that reflect the LEP knowledge base (Figure 7).

Even though related articles were published in 1986, there were not enough publications to form clusters until 1987. The term "fractal" first appeared as early as 1987. Fractal theory and fractal methodologies have been extensively used in soil science, geography, and, especially, landscape ecology. The majority of the referenced works concentrate on research into and quantitative description of landscape patterns and utilize terms such as landscape patterns, disturbance propagation, cross-scale morphology, and so on. These concepts are often used in landscape design and landscape structure analysis, particularly landscape evolution modeling. "Ecosystem services", a keyword that occurred in 2010–2022, created the biggest cluster. This cluster contained the most cited literature and spanned the longest period of time (12 years), reflecting the importance of this field's study theme. Ecosystem Service (ES) constitutes the link between ecosystems (their biodiversity and functioning) and human society [41]. In this cluster, the majority of ecosystems offer a variety of functions, including food supplies, climate and water quality management, and aesthetic and recreational benefits. Global, continental, and regional spatial assessments of ES are required immediately for policy, management, and land planning. The "Graph Theory" group lasted for 12 years (from 2004 to 2016), focusing on the level of research methods. Graph theory is a commonly used visualization technique in landscape ecology, showing a clear geographical distribution. Graph theory is used as an initial, heuristic framework for management and is driven iteratively and exploratively with minimum data needs, making it applicable for landscape ecological evaluations, planning, and design. The "succession" cluster started in 2002 and lasted until 2010. It is the second cluster that emerged in this analysis. To some extent, it reflects the current continuous concern of landscape ecology research, and succession offers more ecosystem-specific lessons. The topics in this group include carrying capacity, landscape ecological revitalization, and the habitat model, thus providing a knowledge base for studying and constructing a succession model that can be used to evaluate ecological changes in wetland landscapes. "Nature conservation" also formed a cluster with a long duration (1995–2004), probably because the rise of landscape ecological research in the later period increased the attention given to natural ecosystems. Under this cluster, biosphere landscapes, conservation, and ecosystem functions become the most important knowledge base. Among the other ten clusters, "floods" had a long duration but contained fewer cited publications. The other nine clusters had a shorter duration (maximum duration of five years), which indicates that landscape ecological research has reduced its attention to a single influencing factor in the development process.

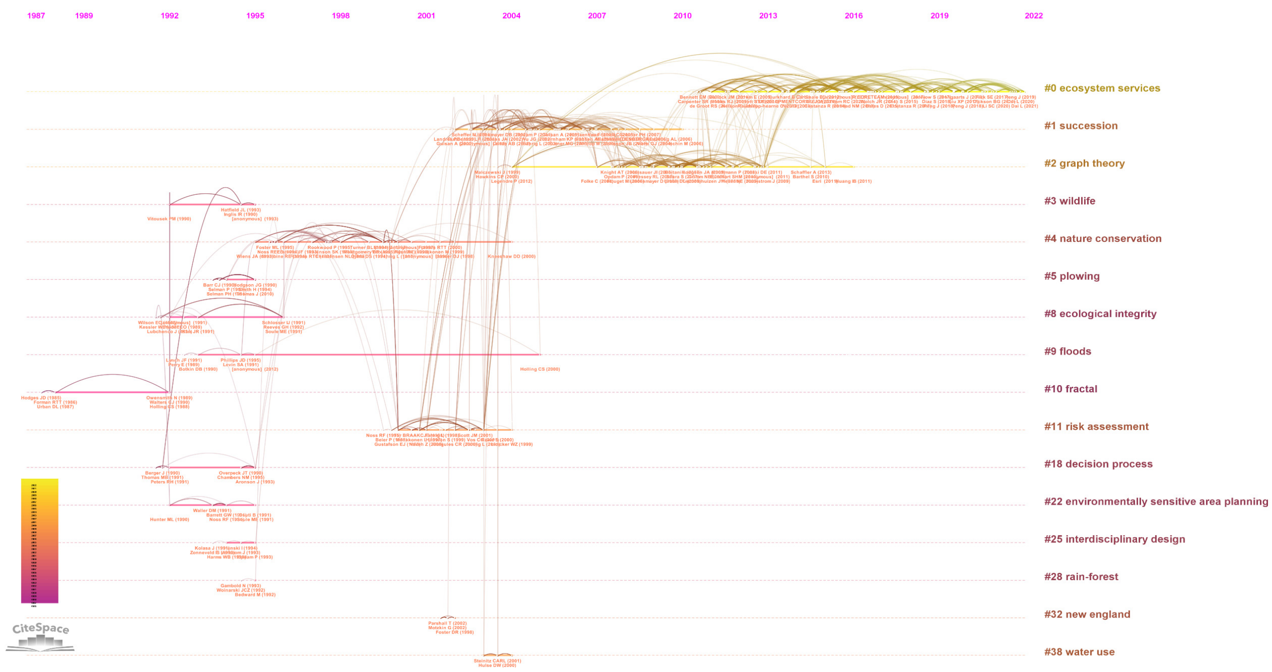

Figure 7. Co-citation cluster analysis diagram.

3.2.2. Highly Cited Literature

According to citation frequency, landmark references were extracted. The co-citation map reveals that 20 articles have been mentioned more than 25 times (excluding three narratives about R language, with only one cited document with relevant content kept) (Figure 8), and this map illustrates the evolution of the field in detail, the main norms utilized in research, multidisciplinary interactions, and creative models and methodologies, all of which contribute to the accumulation of LEP knowledge.

In total, 55% of the 20 most-cited publications are journal papers that provide literature reviews or opinions or viewpoints (the total of the percentages in this section does not equal 100% since some studies are grouped into several categories, e.g., a viewpoint may be supported by a case study that demonstrates the outcomes of that viewpoint) (Table 4). Additionally, this paper discovered a monograph. Bastian et al. conducted comprehensive analysis and research on the development and status of landscape ecology [42]. This publication fully supported research into the development of landscape ecology structure and evaluation methods. Robert Costanza published a review in the journal "*Ecosystem Services*". He reviewed the history leading up to two publications on ecosystem services, which concluded that the fundamental change in economic theory and practice required to achieve a societal revolution toward a sustainable and attractive future should be based on the enormous contributions of ecosystem services to the sustained well-being of humans and the rest of nature [43]. Consequently, it has become the most-cited publication (cited 59 times). Similarly, R.S. De Groot et al., Diaz, S. et al., and other experts comprehensively analyzed the fundamental topics of ecosystem services and proposed development measures or future opportunities for the issues and deficiencies in this area [44–46]. The participation of spatial analysis, dynamic modeling tools, and stakeholders have become an important part of the knowledge base for researchers to learn from. For example, Invest [47] and the conceptual framework of IPBES [48] were cited 34 times and 31 times, respectively. Wu, J.G. also discussed the core issues and themes of landscape ecology. In addition, he also summarized the latest progress in this field, such as landscape connectivity and fragmentation, spatial analysis and landscape modeling, and land use and land cover changes [49]. These concepts were widely discussed and even appeared in other literature reviews, such as reviews focusing on the impact of habitat fragmentation on biodiversity [50] and the use of spatial analysis and dynamic modeling tools in quantifying and evaluating ecosystem services [44]. It is worth noting that Meerow, S. et al. and Wu, J.G. paid attention to the development status of urban landscape ecology [51,52]. The performance of landscape ecology in enhancing urban resilience and ecosystem services has attracted the attention of researchers.

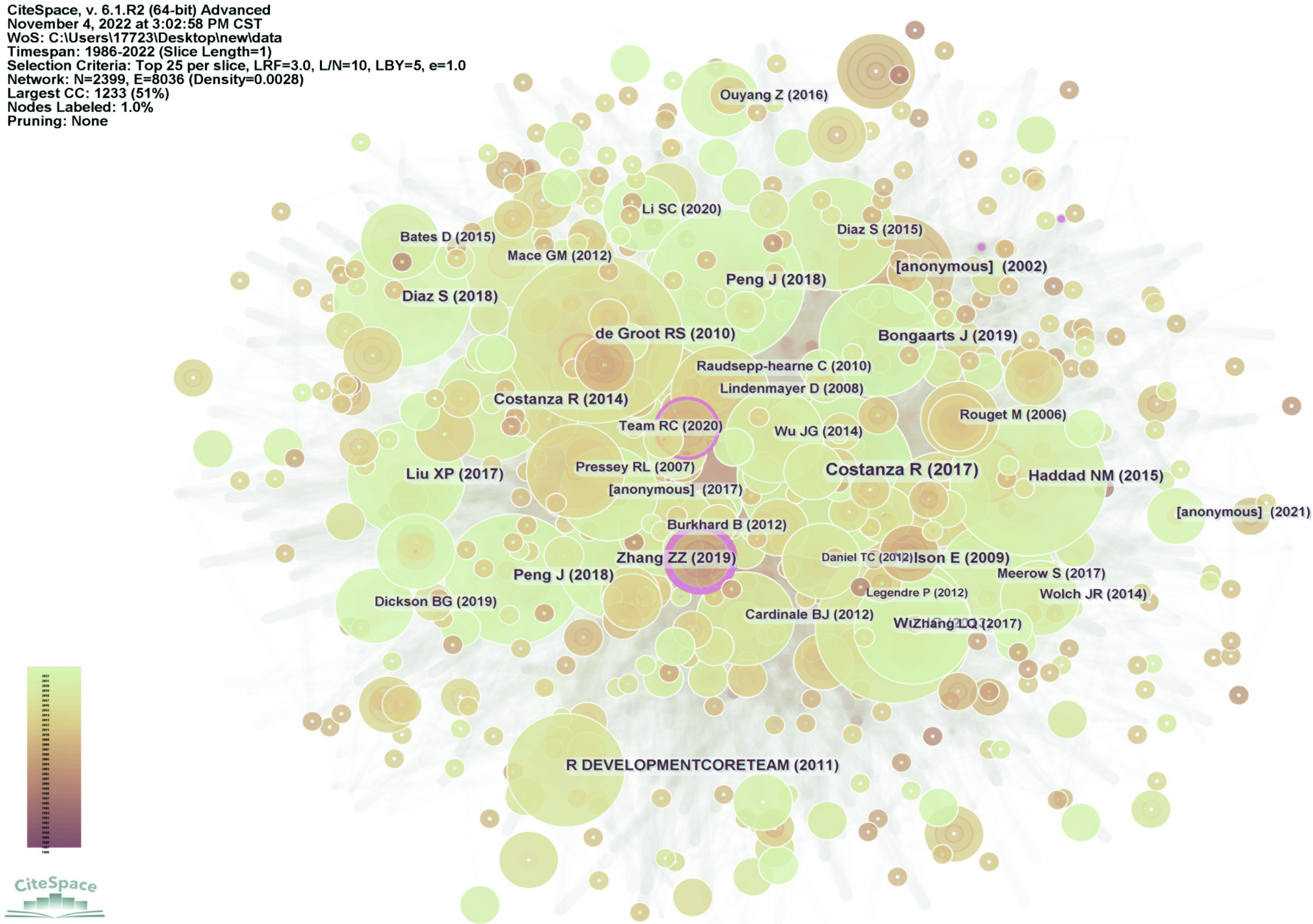

Figure 8. Highly cited references in the LEP field are often cited 25 times or more.

Table 4. Highly cited references in the field of LEP.

No.	Frequency	Author and Date	Title	Categories
1	59	Costanza, R. et al., 2017 [43]	Twenty years of ecosystem services: how far have we come and how far do we still need to go?	Review
2	53	Haddad, N.M. et al., 2015 [50]	Habitat fragmentation and its lasting impact on Earth's ecosystems	Review
3	53	Peng, J. et al., 2018a [35]	Linking ecological degradation risk to identify ecological security patterns in a rapidly urbanizing landscape	Case study
4	51	R.S. de Groot et al., 2010 [44]	Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making	Review
5	50	Peng, J. et al., 2018b [53]	Linking ecosystem services and circuit theory to identify ecological security patterns	Case study
6	45	Diaz, S. et al., 2018 [45]	Assessing nature's contributions to people	Review
7	44	Wu, J.G. et al., 2013 [49]	Key concepts and research topics in landscape ecology revisited: 30 years after the Allerton Park workshop	Review
8	38	Liu, X.P. et al., 2017 [54]	An integrated model for simulating multiple land use scenarios by coupling human and natural effects	Case study
9	35	Costanza, R. et al., 2014 [55]	Changes in the global value of ecosystem services	Review
10	34	Bongaarts, J. et al., 2019 [46]	Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science	Review
11	34	Nelson, E. et al., 2009 [47]	Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales.	Case study
12	34	Zhang, Z.Z. et al., 2019 [56]	Enhancing landscape connectivity through multifunctional green infrastructure corridor modeling and design	Case study
13	34	O. Bastian et al., 2002 [42]	Landscape structures and processes in *Development and perspectives of landscape ecology*	Book chapter
14	33	Zhang, L.Q. et al., 2017 [57]	Coupling ecosystem services supply and human ecological demand to identify landscape ecological security pattern: A case study in Beijing–Tianjin–Hebei region, China	Case study
15	31	Diaz, S. et al., 2015 [48]	The IPBES Conceptual Framework—connecting nature and people	Case study
16	31	Meerow, S. et al., 2017 [51]	Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit	Case study
17	31	Team RC, 2020 [58]	R: A language and environment for statistical computing	Model and method
18	27	Bates, D. et al.,2015 [59]	Fitting Linear Mixed-Effects Models Using lme4	Model and method
19	26	Wu, J.G., 2014 [59]	Urban ecology and sustainability: The state-of-the-science and future directions	Review
20	25	Burkhard, B. et al., 2012 [36]	Mapping ecosystem service supply, demand and budgets	Case study

Case studies account for 35% of the published literature, and these results serve as a guide for techniques and content for subsequent research. Zhang, L.Q. (2017) proposed a more comprehensive method of coupling ecosystem service supply and human ecological requirements to build a safe ecological model in the Beijing–Tianjin–Hebei region [57]. This method combined ecosystem service importance assessment and landscape connectivity analysis with human ecological requirements to identify ecological sources, which added new insights to the method. Peng, J. (2018b) introduced a novel approach for identifying ecological corridors and major ecological nodes by measuring "resistance" or "flow" to simulate ecosystem processes in diverse environments [53]. Additionally, some studies respectively studied landscape ecology and practical planning, which included considerations of design methods, a quantitative framework for identifying urban expansion points, and appropriate quantification of the supply of and demand for ecosystem services in an urban environment [35,36,56]. Their research findings have been cited in several subsequent papers. In total, 35% of the widely referenced articles focused on models and techniques, indicating that researchers in this field recognized the significance of this research in the development of innovative modeling approaches. Among them, Zhang, Z.Z. (2019) combined social and ecological factors with site-scale multifunctional greenway designs to evaluate the landscape connection mode and determine the priority position of the green corridor. Functional connectivity habitat evaluation is based on graph theory, and Conefor software is highly dispersed in Detroit. Nelson, E. used a modeling tool with clear space, the integrated valuation of ecosystem services and trade-offs (InVEST), to predict changes in ecosystem services, biodiversity protection, and commodity production level, which provided a reference for follow-up research. In addition, some scholars have improved the green infrastructure spatial planning (GISP) model [51] and multi-index evaluation [47] and combined it with LEP research, which has received some attention and been used as a reference. Some interdisciplinary law summaries also provide a methodological basis for supporting research into landscape ecology. In this literature, the R language statistical method [58] and lme4 model [59] are widely cited in related research (citation frequency is 31 and 27, respectively). For example, an analysis of ecosystem service associations and bundle types was carried out using statistical software [60]. In addition to proving that the research on landscape ecology covers more than one field, these pieces of evidence demonstrate that the research issue is interdisciplinary.

3.3. Research Hotspots and Research Topics

3.3.1. Analysis of the Co-Occurrence Network of Terms

The term co-occurrence shows that two keywords exist simultaneously in numerous manuscripts. The examination of lexical co-occurrence represents frontiers and hot areas for various research eras throughout the evolution of landscape ecology research, demonstrating the fluctuating popularity of certain research subjects [37]. Co-occurrence frequency and the centrality of terms are estimated by using a software-based approach to term path computation, and the knowledge map of terms is thus constructed. The database spans from 1986 to 2022, with a one-year slice and terms used as network nodes. The first 50 cited terms in each time slice were selected and the frequency threshold was set to more than 100 to generate the co-occurrence spectrum of LEP research terms (Figure 9), which led to a total of 1209 nodes and 9787 links. According to the ranking statistics for word frequency in LEP research, terms such as ecosystem service, climate change, and conservation planning are the core topics of LEP research (Table 5). Urban area, climate change, and sustainable development show that the study of landscape ecology pays attention to urban landscape ecology in the context of a changing global climate, as well as to the sustainable development of landscape ecological planning.

Table 5. List of terms co-occurrence.

No.	Freq.	Centrality	Year	Term
1	691	0.02	2007	ecosystem service
2	422	0.02	2002	climate change
3	325	0.02	2000	conservation planning
4	316	0.07	1988	ecological process
5	289	0.01	1999	protected area
6	289	0.04	1990	biodiversity conservation
7	287	0.02	1993	sustainable development
8	275	0.02	2003	urban area
9	266	0.05	1988	landscape planning
10	256	0.09	1991	landscape ecology

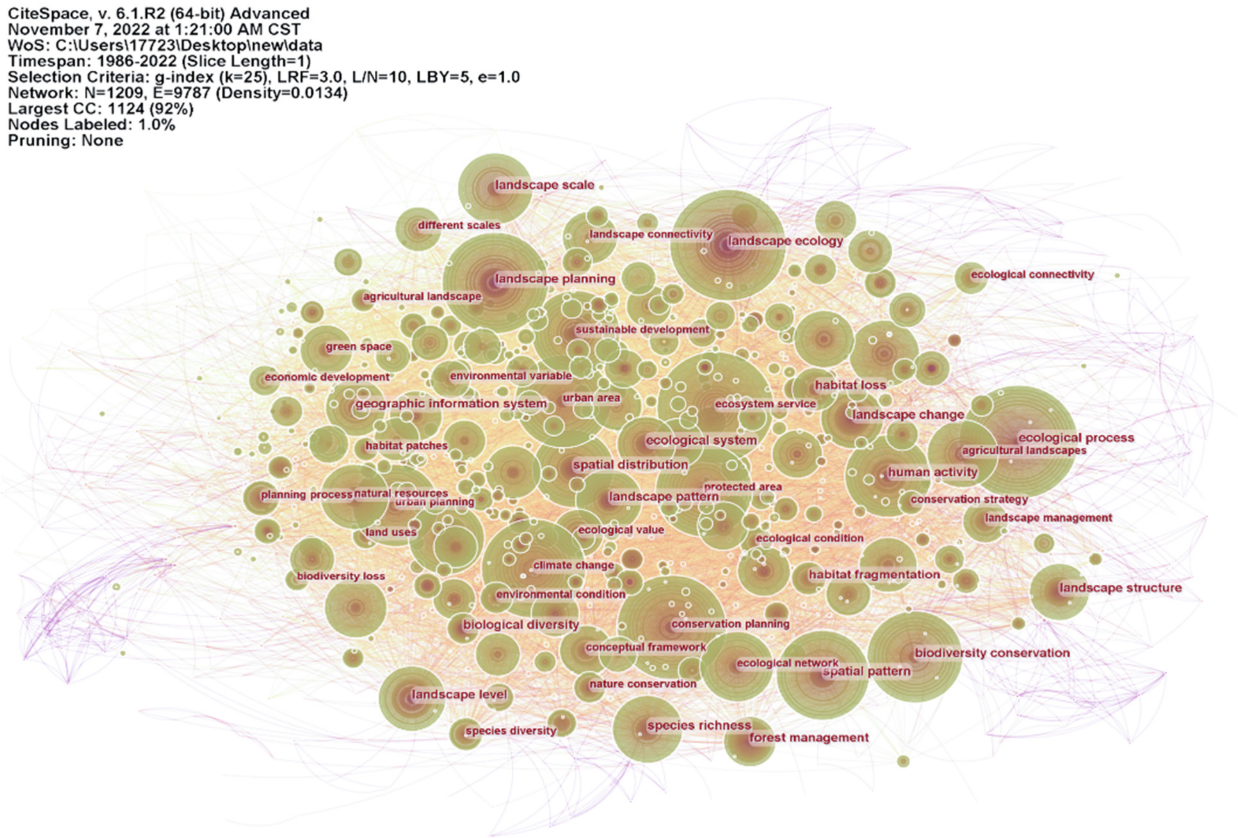

Figure 9. Co-occurrence network of terms in the field of LEP. Terms cited 100 or more times are tagged.

3.3.2. Hot Topics in Various Stages of Discipline Development

According to the term data gathered by CiteSpace, 97 study topics have occurred at least 50 times. This paper manually categorizes them as follows: subject (system or study area), content (what was investigated about this topic), method, factor, and purpose. The variations in co-occurrence throughout the three periods of domain development are shown in Figure 10. Due to the small number of publications during the preparation phase (1986–1990), the total quantity of terms was fairly low. While the number of publications rose from 1991 to 2008, the number of new terms also increased and accounted for 76.3% of the total. From 2008, more than half of the identified articles had been published, however, the number of new terms began to decrease, which is likely because most of the relevant terms had already been defined in previous phases and few new terms were required despite the increase in the number of studies.

The majority of terms emerging from 1986 to 1990 pertain to purpose (50%), followed by content (37.5%) and subject (12%); methods and factors received little consideration. Only terms pertaining to ecological systems are classed as "subject". The term ecological process occurs frequently (316 times throughout the whole research period, not just the preparation phase) and showed a high degree of centrality (0.07) in the "content" category (Table 6). It is the most significant node in the co-occurrence network of terms except for landscape level (0.08), which is another term in the "content" category. Landscape ecological research has created information regarding the link between landscape patterns and landscape processes, and landscape ecology has also made significant advancements regarding the characterization of landscape patterns and the comprehension of pattern–process relationships [3]. Biodiversity conservation was the most important "purpose" of this period. In addition, ecological planning (1986) was one of the earliest major objectives in this period, but it was not in the top 20% of all terms. This partly reflects that the principle of using ecology to realize harmony between man and nature has become a recurring theme in the field of planning; however, standardized and systematic research methods have not been widely used.

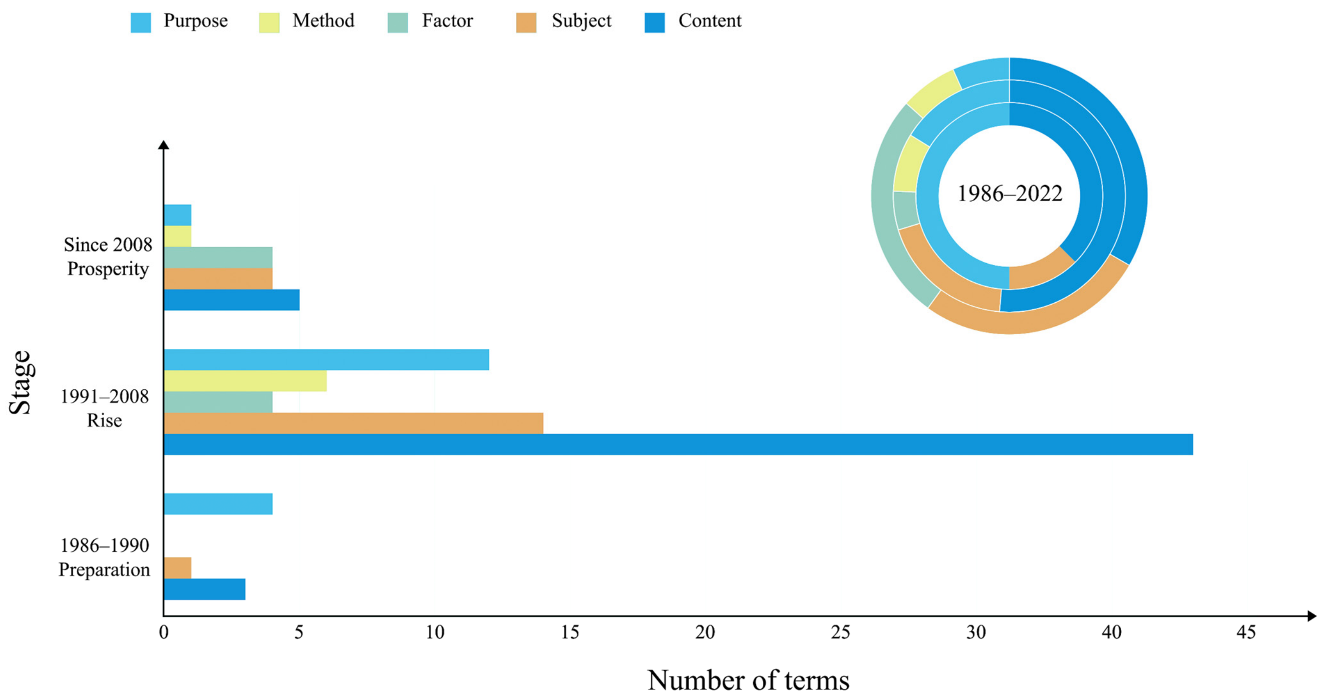

Figure 10. The proportion of various terms in each stage.

Table 6. Principal words used in LEP research (the top twenty percent of all terms based on frequency). The "Year" column indicates the date of the first publication to use the term.

No.	Freq.	Centrality	Year	Term	Category
Stage: Preparation (1986–1990)					
1	316	0.07	1988	ecological process	Content
2	289	0.04	1990	biodiversity conservation	Purpose
Stage: Rise (1991–2008)					
1	691	0.02	2007	ecosystem service	Content
2	422	0.02	2002	climate change	Factor
3	325	0.02	2000	conservation planning	Purpose
4	289	0.01	1999	protected area	Subject
5	287	0.02	1993	sustainable development	Methodology
6	275	0.02	2003	urban area	Subject
7	256	0.09	1991	landscape ecology	Subject
8	229	0.06	1996	human activity	Factor
9	219	0.01	2005	urban planning	Purpose
10	212	0.01	2002	ecological restoration	Purpose
11	198	0.05	1997	spatial pattern	Content
12	184	0.05	1995	spatial distribution	Content
13	174	0.04	1999	landscape scale	Subject
14	166	0.02	2000	ecological network	Content
15	164	0.02	1999	ecological function	Content
Stage: Prosperity (since 2018)					
1	151	0.01	2011	landscape connectivity	Content
2	117	0.01	2011	social–ecological system	Subject
3	113	0	2013	green infrastructure	Content

From 1991 to 2008, the number of papers and subjects explored by LEP researchers surged; 76.3% of new terms emerged during this period. "Content" was still the most focused upon category, accounting for 51.4% of new submissions. The "subject" category surged to second position, increasing from 12.5% in the preparation stage to 18.0%. The proportions of the other three topics were between 5% and 17%. Ecosystem service (691 times, centrality = 0.02) was the most prominent new term under the "content" category at this time, indicating that academics had begun to investigate ecosystem service values and rehabilitation in the planning stage, including ecosystem service planning in terms of conservation planning. In addition, ecosystems are heterogeneous in space, showing considerable complexity and variability in time and space [61]. Therefore, spatial pattern and spatial distribution became hot topics at this stage (centrality = 0.05), both of which can be used to analyze programs for quantifying landscape structures. Protected area (289) and urban area (275) became the two research topics with the highest frequency within the "subject" category, which represents the ongoing clarification of study subject boundaries and the continuous concern for urban landscape ecology. Human activities (second in centrality) and climate change (second in frequency) were two important factors in the early and late stages. As far as methodology is concerned, sustainable development became the mainstream method in this period. Several frequent terms under the "purpose" category are also associated with ecological sustainable development, which indicates that LEP research gradually tends to find ways to improve sustainable development in ecological environments in the process of economic growth [11], even for cities [62,63].

The majority of LEP articles were released after 2008. While additional terms were included, they represent a smaller percentage of the total than earlier iterations (15.5%). The most common term was landscape connectivity (151 times, centrality = 0.01), which belongs to the "content" category and can be regarded as the concrete embodiment of connecting landscape ecosystem services. Connectivity is usually regarded as the emergent attribute of a landscape [64]. The "content" category still possessed the most terms and accounted for 66.7% of new terms, although the terms under this category were less central than they were before. Social–ecological system had also been a key word in the "subject" category since 2011.

3.3.3. Evolution of Term Clusters

By clustering words, ten major clusters were discovered (Figure 11). The longest-lasting cluster was "biodiversity conservation," which was found in the majority of research periods since it is one of the field's most significant objectives. There are relatively few early terms in this group (only ecological approach and landscape level, which mainly focus on the impact of landscape ecology on biodiversity). In the medium term (rising period), specific issues such as spatial scale, ecological function, ecological factors, and ecological value theory gradually attracted attention.

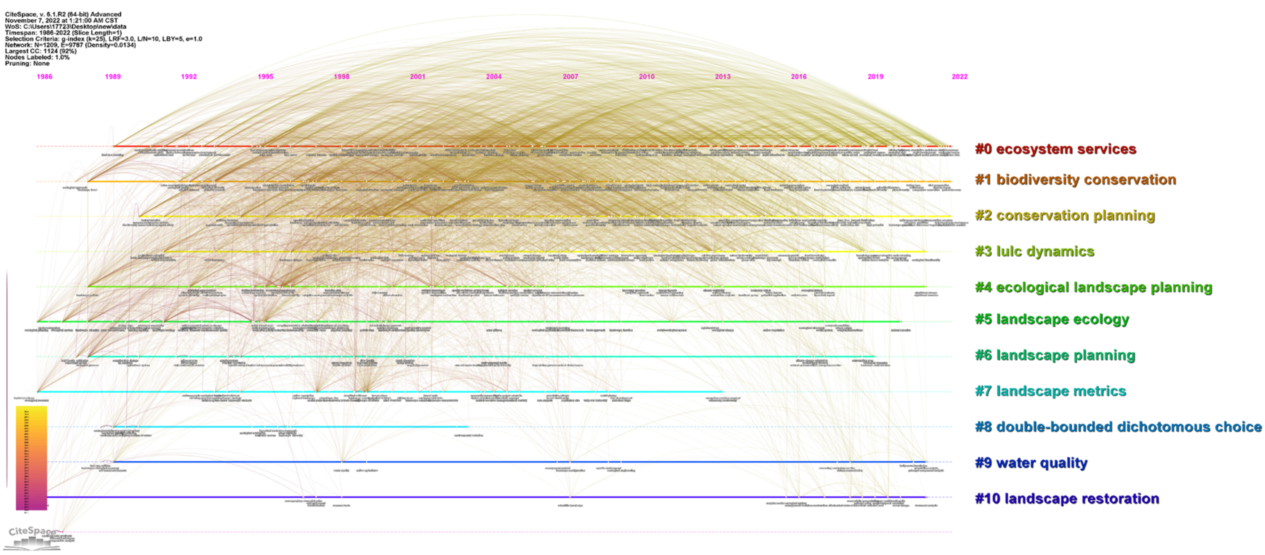

Figure 11. Clusters of LEP research based on terms.

"Ecosystem Service" (ES) is a term that was chosen to describe the largest cluster according to the research objectives and spans from 1989 to 2022. The early focus of this category was on integrating ES concepts into practical planning. With a thorough knowledge of ecosystem services, ecosystem and landscape services have risen to the forefront of research and policy [65]. It is also considered an important part of the emerging science of landscape sustainability [66], including land use planning, forest land sustainability, and agricultural land sustainability, and has been gradually transferred to topics such as ecological sustainability and urban landscape terminology. The purpose of research in this cluster is to apply ES concepts to existing (or new) planning tools and participatory planning processes [67].

"Conservation planning", "ecological landscapes planning", and "landscape planning" are three clusters that became important in the middle of the research period and remained important for a long time. Ecological landscape planning is a planning concept that incorporates an ecological direction. Its main content is to apply ecological landscape concepts and indicators to landscape planning in order to achieve sustainability. Ecological restoration, spatial distribution, and human activity are the main research topics of these clusters in the rising and prosperous stages. Among them, "conservation planning" is the newest of the three (since 1990) and also the largest cluster. Conservation planning is the process of locating, configuring, implementing, and maintaining a region [68]. Research on this topic was mainly prominent in the medium term (rising period) and the prosperity period. Conservation planning is a hot issue and a number of articles have highlighted landscape structure as a crucial concept for conservation planning, with a focus on enhancing landscape connectivity in protected areas. In the medium term, biodiversity conservation, species conservation, and habitat fragmentation became the themes of interest and involved biodiversity patterns. In addition, conservation planning is spatial in nature. Its underlying science has addressed significant geographical issues and increasingly affected practice. Forest area, natural area, and spatial scale have become important key terms. In the prosperous stage, conservation planning paid more attention to systematic ecological protection planning, and the research on landscape connectivity in conservation greatly increased. For habitat connectivity, landscape connectivity is the key term. At the later stage of this study, observations of global climate change and the potential impacts on species and ecosystems have been described by a large number of studies. In order to cope with the expected impact of climate change, conservation organizations have adopted an "adaptation strategy" for conservation planning so as to promote the adjustment of human society and ecosystems so they can match the climatic conditions of climate change. In addition to water protection and management, ecological restoration, monitoring, and planning became strategic terms in this cluster.

The term "landscape ecology" has been picked as the term for the whole study area as it has existed since the early research eras. The potential use of early notions in planning was widely discussed. Since then, structure, function, and change have become the basic concepts of landscape ecology, and landscape analysis based on these ideas supports the planning and design of patterns, processes, and human–environment interactions. The appearance of "ecological system" (1987) in the early period indicates that researchers supported the wide acceptance of planning through the structured assessment of landscapes and ecosystems. By the middle stage (rising stage), researchers considered landscapes as a social ecosystem that could promote the development of comprehensive models. Social ecological systems and social systems became the main topics of research. These models conceptualized landscapes as a nested set of coevolutionary social and natural subsystems connected by feedback, time-lag, and cross-scale interactions [21]. The dynamic interdependence of the landscape's social and ecological components may be analyzed using these models [69].

Another cluster, "LULC (land use and land cover) dynamics", was a significant influencer on the study process as a whole. Changes in LULC have an immediate effect on landscape patterns, which are also the most intuitive representation of LULC change [70].

Changes in land and land use may not only produce some economic impacts, but also have a significant impact on soil and water quality. In order to better comprehend the land cover change process, fine-grained analysis must be undertaken throughout the study process. Thus, the majority of studies in this cluster are case studies. Meanwhile, models of land cover change must be constructed to anticipate the most probable future changes. These predictive data are crucial for formulating and executing effective and sustainable environmental policy [71].

"Landscape metrics" (1986–2013) is the term with the shortest duration in the whole cluster. The main content of "landscape metrics" involves collecting relevant information and evaluating and monitoring biodiversity. Landscape metrics are necessary to clarify the relationship between ecological processes and spatial patterns [72,73]. Therefore, measurement, analysis, and interpretation of ecological landscapes has received great attention in landscape ecology [74], and a large number of related terms appeared in the rising period of research. In this cluster, terms such as "digital analysis", "digital elevation", and "environmental data" reflect the data collection process for landscape indicators, and the ability of efficient calculation methods to quantify spatial patterns promotes the unprecedented development of landscape ecology theory and practice [75].

"Water quality" is one of the specific indicators of landscape metrics, and landscape structure is one of the important factors affecting nutrients and organic matter watershed runoff [73]. Therefore, the demand for indicators and methods is increasing. "Land options" and "aquatic environment" are the main topic terms of this cluster. These indicators and methods make it possible to evaluate landscape factors that affect water quality in freshwater management [76]. Some researchers have determined the quality of the relationship between land use/land cover structure and water, but most of them depended on composition landscape indicators to a great extent [77,78].

4. Discussion

In this study, we examined the major WoS data relating to LEP and used CiteSpace software to quantitatively and visually evaluate the academic achievements and advancements in this field. This resolves a core issue with previous research in this field, namely that previous studies analyzed the target landscape ecology from multiple viewpoints but did not reveal changes through time as a whole. By studying research fields, the evolution of research fields and research orientations can be tracked throughout the course of the development of LEP. From the growth in LEP hotspots, a co-occurrence network of terms and co-occurrence time division can be derived. This paper analyzes the whole developmental history of LEP research and provides support for more scientifically and precisely predicting future developments in LEP. Therefore, it also provides guidance to decision makers and offers in-depth insight into the field's future growth.

Landscape ecological planning is a significant aspect of landscape management, as well as a significant topic that focuses on the practicality of landscape ecology research. In planning, ecological principles and indicators can be integrated from both horizontal and vertical perspectives. The horizontal approach assesses the potential application of ecological knowledge to current planning issues, departments, and applications, such as water resources, protection, urban (and suburban) vegetation, wildlife, and forests. The vertical viewpoint relates to each phase of the planning process, and each planning principle is universal. They may be used to characterize and model the pattern–process connection [79], contribute to spatial conceptual design, assist in the selection of planning methods, form part of an integration tool for various natural resources [80,81], evaluate long-term planning strategies, and monitor the success and execution of management initiatives [82,83]. Currently, too few individuals recognize the significance of landscape ecological approaches in landscape design. Consequently, planning theories and techniques must be re-examined [84]. By integrating landscape ecology into landscape planning, the landscape design process is communicated via the idea of space, and the essential ecological model and subsequent functions are included. These are essential for assuring the ecological viability of the final design and the subsequent landscape.

In addition, the capacity to statistically define the structure of the landscape is a prerequisite for researching functions and changes in landscape. For this purpose, various indicators have appeared in landscape ecology [85,86]. Landscape indicators describe the spatial organization of the landscape. They also provide information on the composition of content, such as the proportion of each landscape type or categories found in the research area, as well as the form of elements of the landscape's components. They therefore form an important cluster in this research; however, the use of indicators to support landscape pattern changes is limited to scientific research and their application in planning so far is either limited or basically nonexistent. At present, there are hundreds of indicators that can measure landscape patterns in numerous applications, but their use is not censored. Part of the reason for this is the large number of available indicators and the resulting confusion about which indicators to use and how to interpret the results. In addition, scientists have debated the ecological significance of spatial patterns for decades, but they continue to have doubts about their ability to accurately quantify the function of the landscape [87]. Landscape indicators are applicable to structural aspects of a landscape and are not suitable for measuring all services [88]. As for complex programs or high precision assessments, landscape indicators may need to be combined with other indicators.

Lastly, existing research has proven that landscape ecology has made great contributions to urban research [89,90]. With the rising urbanization process, cities are formed and sustained by the most intensive form of human–nature interactions. The future of mankind will become more reliant on cities, and future research on landscape ecology will necessarily involve more urban studies.

4.1. Future Studies

Future studies on the evaluation of LEP should also focus on the following areas:

- As global urbanization enters a new phase, cities are not only expanding in size but also merging in several places to form "urban agglomerations". The acceleration of urban agglomeration will unquestionably have a greater impact on the ecology and sustainability of landscapes, regions, and the whole world. To achieve the sustainable development goals, these concerns must be addressed in the context of biodiversity, ecological function, ecosystem services, and human well-being. This is a new frontier in the field of landscape ecology and landscape sustainability.
- There is a strongly intertwined relationship between planning and ecological landscapes. Planning measures based on the concept of landscape resilience increase the likelihood of a rapid and efficient response to a range of repercussions, including extreme events and disasters. Due to global climate change, adaptive planning and design represent a necessary stage of interdisciplinary development among planners, designers, stakeholders, and decision makers when constructing unique methods and methodologies that address the most major development issues.
- System analysis often requires the use of various quantitative indicators when evaluating the landscape, classifying the landscape, and building relevant models (a large number of words concerning technology or models also appeared in this review, such as GIS, InVEST, etc.). With the continuous emergence of new methods and technical means, the research in this field has been deepened. New technologies such as fractal theory, GIS, and RS support the current development of landscape ecology and provide possibilities for its future development and application. As the theoretical foundation and practical examples of using fractal theory, GIS, and RS technology in the field of landscape ecological study have not yet been developed, more research is necessary. Future study will focus on how to better integrate geo-statistical approaches to create a spatial model that more accurately reflects landscape characteristics.

4.2. Restrictions

- Taking LE, LEC, and planning as keywords, a search for articles with LEP as the research topic was conducted. However, either the main themes of most index articles appeared to be land ecological network, landscape planning ecological functions, etc., or landscape appeared as a related word in the title together; thus, the scope of this research may be uncertain.
- The WoS core database serves as the research foundation in this work. Other databases such as Scopus and CNKI (an academic website servicing China) have not been considered; therefore, the data are slightly deficient in terms of depth.
- Meanwhile, CiteSpace software has weaknesses in terms of selecting relevant articles as the data source is based on relevance; therefore, the data obtained when calculating the cited papers are biased (for example, during a cursory check of Google Scholar, the number of citations for number 2 is considerably higher than number 1 in Table 4). Although this has less impact on our descriptive analysis, it is necessary to analyze this issue in conjunction with highly cited papers in the WoS Core Collection in future research.
- Increased interest in LEP research and the associated growth in the number of publications has necessitated that additional researchers follow this field and contribute to the body of knowledge.

In conclusion, LEP research requires constant and dynamic focus. LEP research in interdisciplinary fields should be regularly monitored in order to guarantee that the literature is exhaustive and to allow for the evolution of LEP research in general to be understood.

5. Conclusions

In this work, CiteSpace software was used to quantitatively and visually examine the academic accomplishments and advancements in this field by analyzing a vast number of papers from the inception of LEP research to the present. This has resolved a significant issue from earlier studies in this subject. Landscape ecology planning is rarely examined holistically from a variety of aspects, and this problem prevents how it has changed over time from being revealed. This study offers a more comprehensive analysis of the whole developmental history of LEP research and provides support for predicting the changes in LEP research more scientifically and accurately. As a result, it offers direction to those who make decisions and those who have a thorough understanding of how this sector will develop in the future.

This report reveals the current state of this area and traits relating to literature citations and research topics through a thorough review of the literature. Three phases in this field have been identified: preparation, rise, and prosperity. Regional cooperation between publications is distributed among countries, forming different groups and close cooperation among groups. The creation of transnational networks for collaboration has significant promise for the globalization of LEP research. LEP study has advanced from initially creating a theoretical framework for research in this topic to current practical applications and has also grown from a single discipline (ecology or environment) into a multidisciplinary field, likely due to it becoming a more pressing worldwide concern. In terms of research hotspots and the evolution of research topics, the LEP field has gradually begun to pay attention to the sustainable development of urban landscape ecology and landscape ecological planning, a shift from quantifying environmental impacts to analyzing the internal process of urban systems. In the preparation period, the impact on the ecological environment was mainly explored by introducing new topics and research results. In the rising period, the whole research field re-examined this concept, opened up new perspectives, and bridged the gap between science and practice. In the prosperous period, studies regarding the symbiosis of ecological and social mechanisms of sustainable landscape planning and development began to emerge. What is certain is that, with the expanding scope of applications of landscape ecology in development processes, landscape planning has also changed from a qualitative to quantitative approach and from traditional planning to ecological planning, and planning efforts in ecological planning have been continuously strengthened.

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