

Review

A Bibliometric Analysis on the Effects of Land Use Change on Ecosystem Services: Current Status, Progress, and Future Directions

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Abstract: Land use changes cause significant alterations in the land surface structure and significantly impact ecosystem services. Research on land use change (LUC) and ecosystem services has become one of the hotspots of interdisciplinary research in ecology and geography. Based on 1860 publications collected from the Web of Science Core CollectionTM (WoS), the top authors, top organizations, top journals, and subject categories were discussed in detail. For the number of published articles, *Sustainability* ranks first with 86 publications, providing significant contributions in domain. The keywords could be classified into six categories: land use/land cover change, conservation, biodiversity, policies and programmers, environmental change, and agriculture. Citations and reference co-citations were analyzed, and popular literature and co-cited literature in the field were identified. In the discussion, we focus on four important issues, including land use area changes, land use pattern changes, land use spatial pattern changes, and land use changes at different scales. The research framework in the field and the shortcomings of existing research are discussed as well. The main aim of the paper is to assist researchers in identifying potential gaps in the research that should be addressed in future research.

Keywords: land use change; ecosystem services; bibliometric analysis



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1. Introduction

The structure, process, and functions of ecosystems directly and indirectly provide the products and services that support human existence, which are called ecosystem services [1]. Hence, ecosystems are fundamental to human existence and are intimately linked to benefits that are pertinent to human life. The 1970s witnessed the beginning of the use of “ecosystem services” as a scientific term [2], and the use of this term began to increase in the 1990s. Many scholars have paid attention to the economic value of forest, grassland, wetland, agricultural land, and urban ecosystem services at different scales [3]. Costanza et al. quantified the economic worth of benefits provided by the global ecosystem by employing the utility value theory and the equilibrium value theory in “the value of the world’s ecosystem services and natural capital”, which was published in *Nature* [4]. In the same year, Daily’s landmark research “Nature’s Services: Societal Dependence on Natural Ecosystems” described an evaluative outline of ecosystem services value in detail [5]. These two studies promoted ecosystem services from the conceptual research stage to a new stage of systematic, comprehensive, and applied research, clarifying and increasing the comprehensiveness of the theories and methodologies needed to evaluate the worth of ecosystem services from the perspective of science. A worldwide upsurge in assessing the worth of ecosystem services has been observed, and this has increased scientific interest in the subject. At present, researchers in this field are focusing on the following aspects: (1) ecosystem services in important ecological areas such as river basins [6–8], nature reserves [9,10], and forests [11–13]; (2) the multiple perspectives of cultivated

land protection [14–16], contraction scenarios [17,18], and landscape heterogeneity [19,20]; (3) reviews of the trade-off and coordination between connect ecosystem services [21–23], as well as the relationship between supply and demand [24,25]; (4) comprehensive assessments [26–28], practical applications and frontier exploration of ecosystem services [29–31]; and (5) detailed categorization of ecosystem service supply—for instance, research progress on the topic of cultural services [32,33].

Land use, which is closely linked to human ventures, is defined as the maintenance and transformation of land by human beings over the long term or over a period of time in accordance with the intrinsic features of the land for socio-economic aims [34,35]. Land use change (LUC), which represents the concentrated embodiment of how human activities and natural ecological environment interplay with each other, is defined by alterations in land use mode, cover, and use degree that change the land characteristics and engendered by the change in individual or group human actions [36,37]. Land use change (LUC) has not only resulted in considerable land use type changes but has also affected the regional climate, water resources, soil physicochemical properties, biodiversity, and the global material cycle [38,39], thus affecting the structure and function of the whole ecosystem and thereby becoming one of the main causes of global environmental change [40,41]. In the process of economic and social development, human activities affect the structures and processes of local and global ecosystems through changes in land use patterns, land use intensities, and land use structures, thus affecting the ability of ecosystems at all levels to provide products and services to human beings [42]. Therefore, the eco-environmental effects of land use change and its impact on ecosystem services have gradually become one of the core aspects of research into land use change [43]. Under different land use patterns, the analysis of the interdependence, trade-offs, and relationships between ecosystem services such as primary productivity, carbon fixation, soil and water conservation, and biodiversity maintenance can provide scientific theoretical basis and data support for land and space planning, land decision making, and ecological protection in terms of ecosystem services [44].

Because a close relationship exists between land use changes and ecosystem services, studying the relationship between land use changes and ecosystem services is essential to promoting the sustainable development of a regional economy and the ecological environment. However, given the huge amount of the literature, it is time-consuming to analyze the evolutionary path and development trend by abstracting and summarizing the problems, leading to a few scholars identifying the development trends, hotspots, and frontiers in this important area of research. Therefore, with the help of bibliometric analysis, quantitative literature analysis is a helpful tool that can be used to quickly extract the frontier hotspots and to identify the future research gaps. Accordingly, as shown in Table 1, our aim in this study is to answer four research questions.

Table 1. Research questions and purpose.

No.	Research Questions	Purpose	Answer
1	What is the contemporary status of the field?	Analyzing publishing trends, key authors, top institutions, top journals, and subject areas.	Section 3.1
2	What is the evolution route of research in this field?	Analyzing the characteristics of keywords in each time period.	Section 3.2
3	What is the research framework in this field?	Identifying the key components and the relationship between them.	Sections 3.3 and 4.1
4	What are the potential research opportunities?	Analyzing the current problems, and provide reference for follow-up research.	Section 4.2

2. Materials and Methods

2.1. Methods and Workflow

Bibliometrics is a subject that studies the distribution structure, quantitative relationship, change law, and quantitative management of literature information, and then discusses the structures, characteristics, and laws of science and technology using mathematical and statistical methods [45]. As the literature contains large amounts of potential knowledge, bibliometrics can provide readers with a new method of application toward understanding the world of knowledge [46]. As shown in Figure 1, basic analysis methods include publishing trends, key authors, key institutions, key journals, and subject categories in the literature, as well as burst analysis [47], keyword co-occurrence network analysis [48], citation analysis [45], PageRank [49], and literature co-citation analysis [46,50]. To address these four questions, we used a bibliometric method to analyze the knowledge layout and to provide a comprehensive overview for scholars, with the intention of helping them to understand the research status and identify any research gaps in the analyzed field.

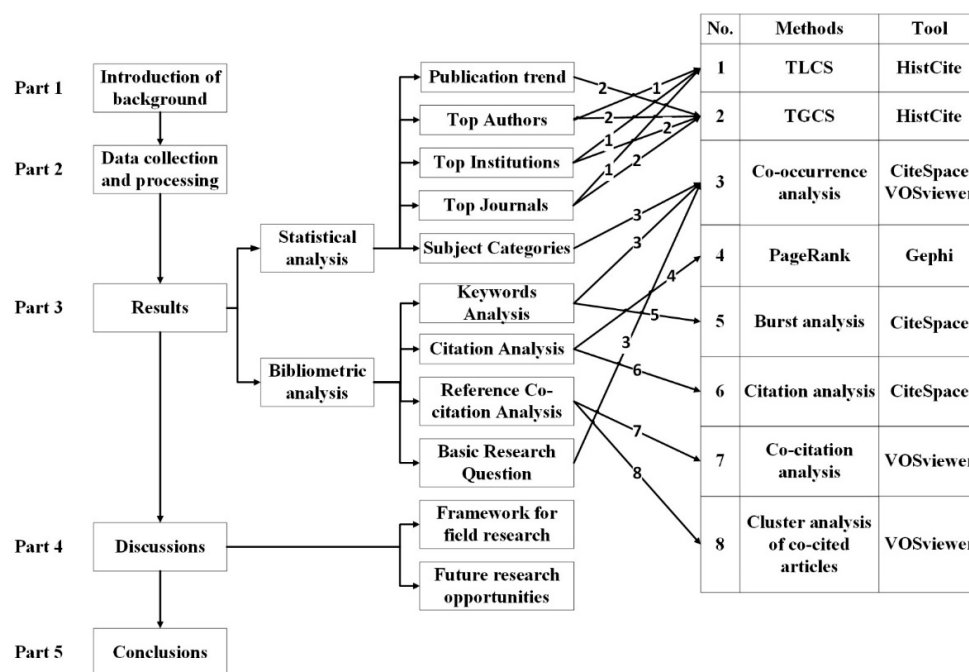


Figure 1. Workflow and methods.

HistCite™ (v2.1, Thomson Reuters, Toronto, and Canada) is a software that was developed by Garfield et al. [51] that can be applied to obtain domain information (e.g., subject categories, journals, number of publications, authors, and institutions). The Total Local Citation Score (TLCS) was used to represent the total frequency of citations in the current literature list, which can also be understood as the frequency in the research field to which it belongs [52]. The Total Global Citation Score (TGCS) represents the total frequency of citations in the WoS database, and “Records” represents the number of papers published [52]. CiteSpace is a bibliometric program that is based on the Java object-oriented programming language developed by Chen [53] that is widely used in bibliometric analysis to determine and reveal emerging developments regarding the trends and dynamics of a certain field. In this study, CiteSpace was used to detect and demonstrate the distribution features of the discipline’s categories, the explosive index of keywords, and the co-occurrence analysis of keywords. VOSviewer is a free bibliometric analysis program that was developed by Waltman et al. [54], and it was employed here to analyze the mapping of keywords. In addition, in order to present both popular and prestigious references, Gephi was applied to obtain the PageRank value of each reference in a cited network.

2.2. Data Sources

Literature data sources are a key part of bibliometric research. Table 2 illustrates the literature search strategy, including the keywords, language, article type and time period. The search form “Topic = ‘Land use change’ and ‘Ecosystem services’” was used to acquire the greatest amount of data possible. The document type was selected as “all document types”. Due to restrictions of Central China Normal University’s remote access to the Web of Science database, this study only obtained articles published from 2005 to 2020 (15 years in total). By implementing specific search settings, 1878 publications were obtained. Book chapters were not considered a document type in this study. There were no references in the data exported from the Web of Science database, so it was impossible to conduct keyword co-occurrence analysis, citation analysis, and co-citation analysis for these data. After removing book chapters (14), corrections (1), and letters (3), 1860 publications were selected from the Web of Science Core Collection™ on 5 January, 2021. Figure 2b shows that these 1860 publications are academic articles, including literature reviews, which only summarize existing data and that would therefore most certainly affect the research data and the accuracy of the analysis.

Table 2. Literature search strategy.

Criteria	Details
TS	‘Land use change’ and ‘Ecosystem services’
Languages	‘All language’
Document types	‘All document types’
Period	2005–2020
Database	‘Web of Science Core Collection™’

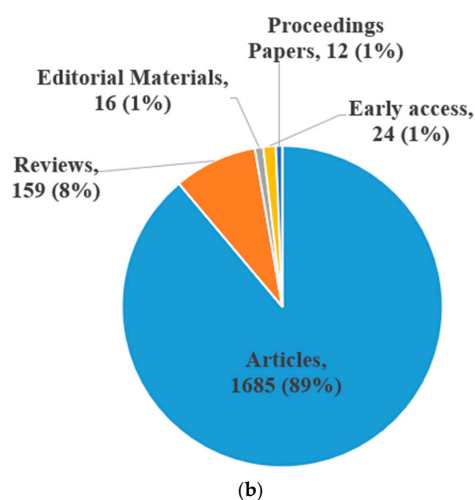
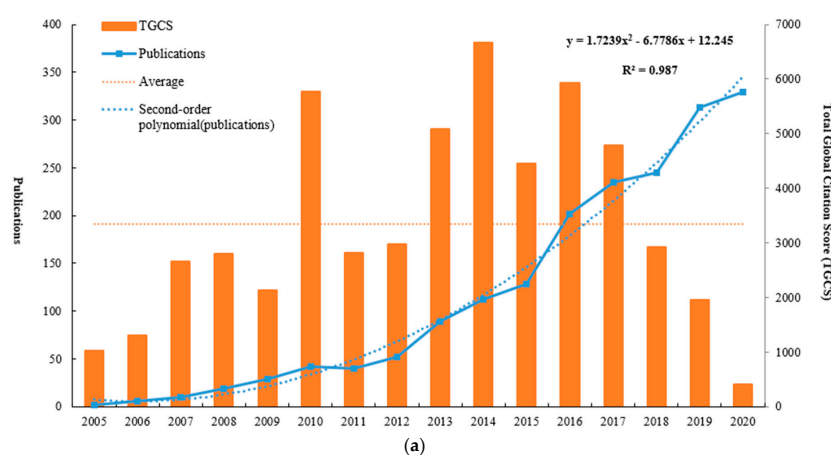


Figure 2. (a) Number of publications and citations from 2005 to 2020; (b) publication types.

3. Results

3.1. Basic Information of Field Research

3.1.1. Publishing Trends and Types of Publications

Figure 2a shows a clear increase in the number of publications and citations from 2005 to 2020. The number of publications per year shows a growth trend ($y = 1.7239x^2 - 6.7786x + 12.245$; $R^2 = 0.987$). According to the annual number of publications, the development process can be mainly divided into three main phases: initiation, development, and increase. During initiation phase (2005–2011), the annual publication volume was less than 50 articles, which is relatively low. In the development phase (2012–2015), although the annual publication volume of carbon footprint research increased, it was still below 200. Since 2016, the annual publication volume has increased rapidly, indicating that research on land use changes and ecosystem services has begun to enter a stage of growth (2008–2019). The rapid increase in attention and research on land use changes and ecosystem services also provide a research basis for bibliometric analysis. One of the main purposes of this study was to present the development path, main nodes, and cluster distribution of land use changes and ecosystem services research in different stages.

Figure 2b shows that the 1860 publications that were included in the analysis can be divided into six types: reviews, early access, editorial material, proceeding papers, and articles. Articles comprise 89% of the publications, and the other types only account for 11% of the total. From Figure 2a, not many years are above the TGCS average. Since 2016, the TGCS declined year by year because the newly published papers have not yet been cited by many researchers.

3.1.2. Top Authors

It is not necessarily effective to determine the contribution of authors solely by analyzing an author's number of publications [52]. Based on Price's law [55], the total number of papers published by scientists who have published more than $0.749N_{max}^{0.5}$ papers is equal to half of the total number of papers. By implementing Price's law, the threshold number of publications can be obtained, and the formula is provided below:

$$TP_n = 0.749\sqrt{N_{max}} \quad (1)$$

where N_{max} represents the number of publications created by the most productive author, and TP_n is the threshold number of the core author.

The role of Price's law is to macroscopically and comprehensively describe the relative relationship between authors and papers in order to guide us to estimate the scale of high-yield authors and their writing ability [45]. The following portion of the paper identifies the key researchers who, apart from having a significant number of achievements, have also contributed the most to the development of the discipline, which will help us to better understand this field [56]. After analyzing the data, 7677 authors were found to have published articles. As shown in Table 3, the most prolific author is Peter H. Verburg, who has authored 30 publications. Therefore, the critical standard for a core author is 4.10, so 152 authors can be treated as core authors. Collectively with Peter H. Verburg (30), Brett A. Bryan (20), Stephen Polasky (17), Sandra Lavorel (15), and Catharina J. E. Schulp (13) represent the top five prolific authors in the field.

3.1.3. Top Institutions

According to the number of publications, the organizations were extracted by HistCiteTM v2.1. As shown in Table 4, the top three organizations are located in China. The Chinese Academy of Sciences occupied the top spot with the most published articles, amounting to 178 publications, followed by the University of Chinese Academy of Sciences, Beijing Normal University, Vrije Univ Amsterdam, and the University of Wisconsin rounding out the top five. Based on the comprehensive perspective of countries and institutions, China, the United States and European countries have outstanding performance in this

research field and are among the best in terms of the number and influence of publications, indicating that they have fruitful scientific research achievements and high academic level. The dominance of the United States and China in the number of publications shows that these countries attach great importance to this field and encourage extensive research.

Table 3. Top 20 influential authors based on records.

No.	Author	Records	TLCS	TGCS	Institution
1	Peter H. Verburg	30	129	1602	Vrije Universiteit Amsterdam
2	Brett A. Bryan	20	153	706	Deakin University
3	Stephen Polasky	17	273	1591	University of Minnesota
4	Sandra Lavorel	15	213	3598	Université Grenoble Alpes
5	Catharina J.E. Schulp	13	66	459	Vrije Universiteit Amsterdam
6	Ulrike Tappeiner	13	69	439	University of Innsbruck,
7	Lang Zhang	13	10	238	Shanghai Academy of Landscape Architecture Science and Planning
8	Bojie Fu	12	102	430	Beijing Normal University
9	Feng Li	12	105	393	Chinese Academy of Sciences
10	Yuanxin Liu	12	42	277	Capital Normal University
11	Tobias Kuemmerle	11	56	719	Humboldt University
12	Wei Song	11	66	302	Chinese Academy of Sciences
13	Jeffery D. Connor	10	77	261	University of South Australia
14	Adrienne Grêt-Regamey	10	22	421	ETH Zurich
15	Felix Kienast	10	47	476	Swiss Federal Institute for Forest, Snow and Landscape Research
16	Jing Li	10	36	177	Chongqing Geomatics Center
17	Yue Liu	10	54	198	Guizhou Institute of Technology
18	Erik Nelson	10	247	1136	Stanford University
19	Tobias Plieninger	10	34	932	University of Copenhagen
20	Erich Tasser	10	59	377	EURAC Research

Table 4. Top 10 influential institution based on records.

No.	Institution	Records	TLCS	TGCS	Country
1	Chinese Academy of Sciences	178	500	2771	China
2	University of Chinese Academy of Sciences	73	102	596	China
3	Beijing Normal University	56	215	1309	China
4	Vrije Univ Amsterdam	44	247	3094	Netherlands
5	University of Wisconsin	36	214	2057	United States
6	Stanford University	35	199	1946	United States
7	Humboldt State University	34	104	1890	United States
8	University of Minnesota	34	344	2776	United States
9	Wageningen University	33	288	5295	Netherlands
10	US Geological Survey	28	64	903	United States

3.1.4. Top Journals

Based on the collected data, 413 journals produced publications in this field. The top 10 journals are listed in Table 5. The outcome indicates that about 29% of the publications were issued in these top 10 journals. This means that about 29% of the publications are available in the top 3% of the journals. We also calculated the average number of citations in each journal; that is, the data in the TLCS column are divided by the data in the records column to obtain A_TLCS and by dividing the data in the TGCS column by the data in the records column to obtain A_TGCS. In addition, the top five ranked journals, accounting for more than 20% of the total publications, were *Sustainability*, *Land Use Policy*, *Science of The Total Environment*, *Ecological Indicators*, and *Ecosystem Services*. *Sustainability* published 86 articles, which is the highest number of articles, but this journal has the lowest TLCS and TGCS values. Five journals, namely *Land Use Policy*, *Science of The Total Environment*, *Ecological Indicators*, *Ecosystem Services*, and *Agriculture Ecosystems & Environment*, have TGCS

sores of over 1000. These results show that the publications, including those published in the five journals with high TGCS scores, have good communication and integration with other fields. According to the number of publications, *Land Use Policy* and *Agriculture Ecosystems & Environment* are ranked second and eighth, respectively, while according to A_TGCS, they rank second and first, respectively, indicating that scholars pay attention to authoritative journals and high-level journals in this field.

Table 5. Top 10 journals based on records.

No.	Journal	Records	TLCS	TGCS	A_TLCS	A_TGCS
1	<i>Sustainability</i>	86	3	345	0.03	4.01
2	<i>Land Use Policy</i>	79	197	2251	2.49	28.49
3	<i>Science of The Total Environment</i>	79	203	1511	2.57	19.13
4	<i>Ecological Indicators</i>	72	242	1612	3.36	22.39
5	<i>Ecosystem Services</i>	58	186	1094	3.21	18.86
6	<i>Plos One</i>	37	0	669	0	18.08
7	<i>Landscape Ecology</i>	35	131	874	3.74	24.97
8	<i>Agriculture Ecosystems & Environment</i>	33	259	1421	7.85	43.06
9	<i>Regional Environmental Change</i>	31	64	529	2.06	17.06
10	<i>Journal of Environmental Management</i>	30	63	671	2.10	22.37

3.1.5. Subject Category

Through the co-occurrence analysis of subject categorization in CiteSpace, disciplines that are associated with a specific knowledge field can be found effectively, and the five top-ranked classes are environmental sciences and ecology, environmental sciences, ecology, environmental studies, biodiversity conservation, and agriculture. As shown in Figure 3, the diameter of the circle represents the proportion of the classification. The larger the circle, the higher the proportion. The lines between the circles represent the relationships between the categories: the thicker the lines, the closer the relationship. These results indicate that the research domain is an interdisciplinary research field that is mainly conducted from the perspective of environmental sciences and ecology, ecology, and environmental studies. However, it can also be combined with some other research topics with considerable development potential, such as geology and engineering, to be considered for research.

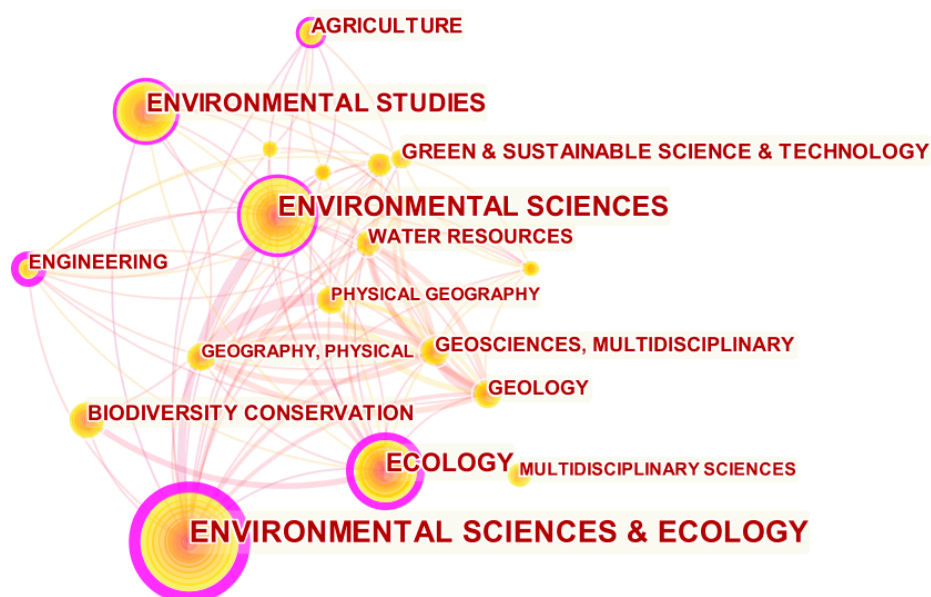


Figure 3. Subject categories of research and their relationships.

With the acceleration in agricultural intensification and urbanization, forest changes are showing reduction and degradation trends in some areas [61] due to complex reasons such as drought [62] and poverty [63].

The third group contains keywords about the types of diversity (e.g., “species diversity”, “plant diversity”, and “species richness”) and pollination (e.g., “pollination services”, “pollinators” and “crop pollination”). In recent years, the significance of diversity in agroecosystems and other ecosystems has been widely acknowledged. For instance, pollinators play a significant role in agricultural production and help in controlling pests. The factors that also affect agroecosystem growth include pollination services and crop pollination [64]. Consequently, scholars have focused on the inter-relations connecting biodiversity and ecosystem services.

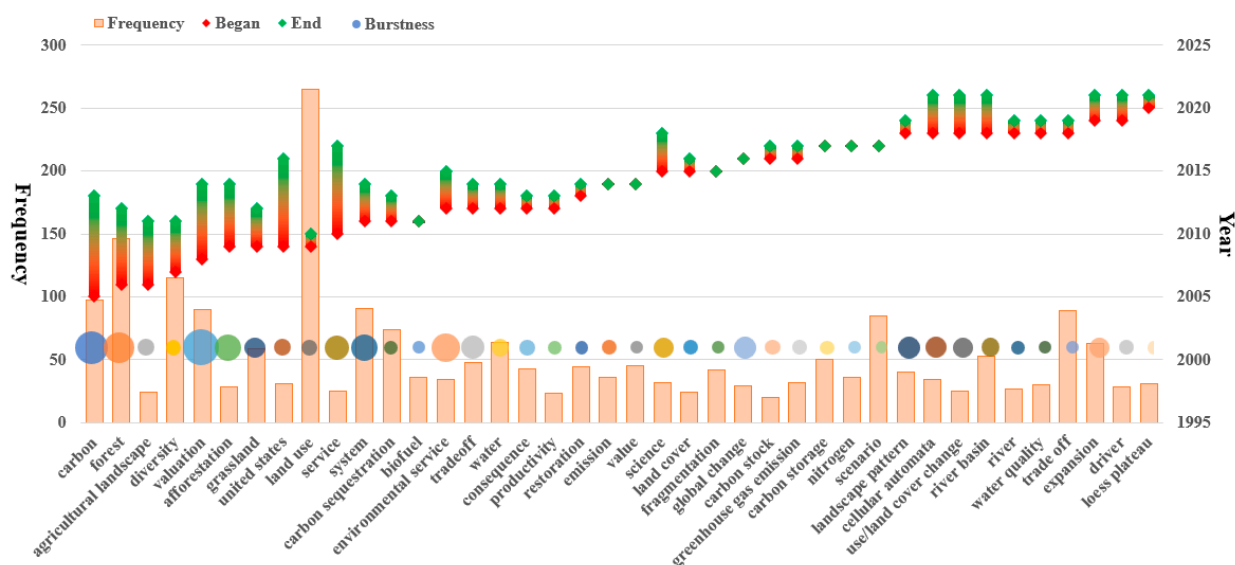
The fourth group contains keywords about the key management issues (e.g., “food security”, “agricultural abandonment”, and “agricultural intensification”) and management philosophy (e.g., “sustainability” and “adaptation”). It was found that disordered land use change leads to rapid urban expansion, resulting in the continuous reduction in cultivated land quantity and quality, which will eventually threaten food security [65]. Unlike other ecosystems, the main concern of agroecosystems is food production. Hence, there is an urgent necessity to simultaneously safeguard the growth in food production and agroecosystem functions. A sustainable development strategy is a recognized solution to this critical issue [66].

The fifth group contains keywords regarding the uncertainty of impacts (e.g., “uncertainty” and “variability”), affected objects (e.g., “net primary productivity” and “forest”), and results (e.g., “desertification” and “precipitation”). The interplay between two factors, land use and climate change, is complicated. Climatic change has an ever-increasing impact on ecosystems and their services [67,68]. Agriculture is considered among the most delicate area in terms of the risk of being impacted by climate change. The effects of global environmental change are so uncertain that any extent of climate change will significantly impact the agricultural yield and its associated functions.

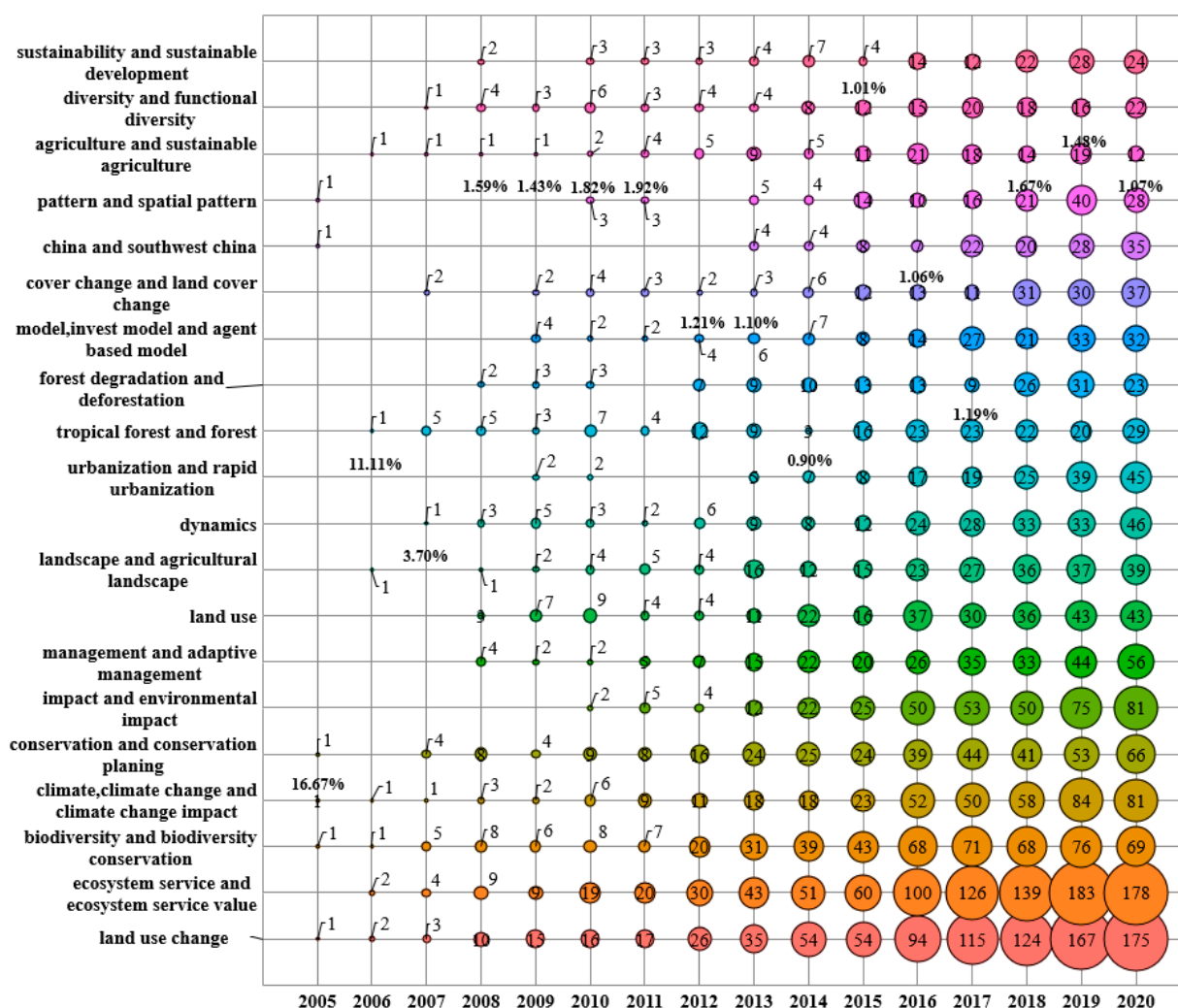
The sixth group contains keywords about the soil material (e.g., “soil carbon”, “organic matter” and “phosphorus”), the evaluation of agriculture (e.g., “Life cycle assessment” and “eutrophication”), and agricultural practices (e.g., “cropping systems”, “stocks”, and “pasture”). In the process of agricultural production, the characteristics of the soil and fertility indicators have been a research focus. To meet the demands of the increasing needs of the population for food and to protect the environment, modern agricultural practices, on the basis of not respecting the objective situation, such as blindly pursuing food production and abusing chemical fertilizers and pesticides, have had many negative climatic and social impacts [69,70]. Therefore, to minimize disservices, cultivators are guided by employing Life Cycle Assessment (LCA) and other concepts to decrease the use of chemical fertilizers and insecticides in order to alter how land is used and to employ farming strategies that are consistent with natural ecological processes.

3.2.2. Evolution of Research Hotspots

By analyzing the keywords with CiteSpace’s burstiness detection feature, 68 keywords with an explosive degree were obtained. The results obtained after removing the keywords with a total frequency of less than five, are shown in Figure 5a. The keywords are sorted according to the initial year of the outbreak in the horizontal direction. The left ordinate is the word frequency of the keywords and corresponds to the height of the histogram. The high and low stock market charts correspond to the right ordinate, indicating the length of the outbreak cycle. The diameter of the circle where the keywords are located indicates the height of its burst index, which is used to identify research topics that have grown significantly or that rapidly decreased over a short period of time [71].



(a)



(b)

Figure 5. Keywords analysis (a) Keywords with explosive characteristics; (b) Temporal changes in hot topic keywords.

From the above, we divided the evolution of research hotspots into the three stages. In the first stage (2005–2010), many keywords had a high frequency, long outbreak period, and high outbreak degree, which indicated they were the focus by researchers during this period. After 2005, the keywords that appeared and that quickly became research hotspots include “carbon”, “forest”, “diversity”, and “agriculture landscape”, indicating that carbon, forests, and diversity attracted the attention of scholars during this period. “Land use” has the highest frequency, but the explosive index is not high, which shows that it was the focus of many scholars. In the second stage (2010–2015), some short-term but highly explosive keywords appeared, including “emission”, “value”, “fragmentation”, “tradeoff”, and “water” representing greenhouse gases, climate change, value measurement, trade-off, landscape fragmentation, and ecosystem management. In addition, during this stage, the scholars paid special attention to the theoretical research content of system elements and restoration, such as “system”, “science”, and “restoration”. In the third stage (from 2015 to 2020), the explosive words appearing in this stage are “global change”, “green gas emission”, and “scenario”, which are discussed from the global change perspective, global greenhouse gas emissions, and multiperspective situations. In addition, some key regions, especially river basins and Loess Plateaus, are becoming hot research areas because they will be facing many new challenges in terms of social, ecological, and economic development.

Figure 5b depicts the time series evolution diagram of hot topics. From 2005 to 2020, taking each year as a period, the top 35 high-frequency keywords were merged to obtain the time series changes of the 20 hot topics and the proportion of these topics in the same period. The percentage in the figure indicates the percentage of keywords with the lowest probability of occurrence in the same period. Compared to Figure 5a,b accounts for the change in word frequency caused by the growth in the overall literature volume and therefore focuses on the evolution of topic importance. As shown in Figure 5b, (1) the topics that have received continuous attention are “biodiversity and biodiversity conservation”, “diversity and functional diversity”, “sustainability and sustainable development”, “conservation and conservation planning”, etc.; (2) the themes of “agriculture and sustainable agriculture”, “pattern and spatial pattern”, and “forest degradation and degradation” are becoming increasingly mature, and the degree of attention is steadily decreasing; (3) for “landscape and agriculture landscape” and closely related keywords, such as “land use”, “management and adaptive management”, “urbanization and rapid urbanization”, etc., researcher attention has been relatively stable; (4) researchers have paid more attention to the impact mechanism and the repercussions of land use alterations. To provide an example, research on “impact and environmental impact” has increased rapidly since 2013. (5) “China and South West China” have been the subject of attention in recent years, showing that developing countries are paying attention to how land use change influences the environment while developing their economy.

3.2.3. Citation Analysis

The purpose of citation analysis is to measure the popularity of an academic publication according to the number of citations in the field, ignoring another main measurement standard and prestige, which is usually expressed as the number of times a publication is cited by another highly cited citation [72]. In Table 6, the top five papers in the field are listed based on their TGCS values. Among these publications, [73] has the highest TGCS value, which was published in *Ecological Complexity*. The PageRank algorithm was designed for sorting publications with higher reputations [74,75]. Table 6 shows that the top ten publications were unanimously selected by the PageRank score as calculated by Gephi. The TGCS values of [76] and [77] were only 20 and 65, respectively, indicating that these articles were cited by other scholars less frequently and cannot be regarded as highly cited articles in this field. However, according to their PageRank scores, they can rank within the top ten publications.

Table 6. Top ten publications based on PageRank value.

No.	Publication	PageRank	TLCS	TGCS	Journal
1	[78]	0.013822	20	73	<i>Ecosystem Services</i>
2	[73]	0.007735	0	1532	<i>Ecological Complexity</i>
3	[79]	0.007697	90	404	<i>Agriculture, Ecosystems & Environment</i>
4	[76]	0.006945	7	20	<i>Ecological Economics</i>
5	[80]	0.006163	81	999	<i>Science</i>
6	[81]	0.005856	10	38	<i>Ecosystem Services</i>
7	[82]	0.005853	0	9	<i>Sustainability</i>
8	[77]	0.005559	21	65	<i>Science of the Total Environment</i>
9	[83]	0.005503	70	879	<i>Philosophical Transactions of the Royal Society B: Biological Sciences</i>
10	[84]	0.005112	0	28	<i>Ecosystem Services</i>

3.2.4. Reference Co-Citation Analysis

Reference co-citation analysis helps researchers in the field to identify potential research gaps. Using VOSviewer to accomplish the fusion of mapping and clustering, the bibliometric network structure and five different colored clusters are acquired. Potential research opportunities can be analyzed from each cluster category. In Figure 6, it can be seen that 436 distinct references out of 90558 were simultaneously referred to upwards of ten times by academic research works. Reference [4] is the vastest node, meaning that it is the most frequently co-cited reference in the field up until now.

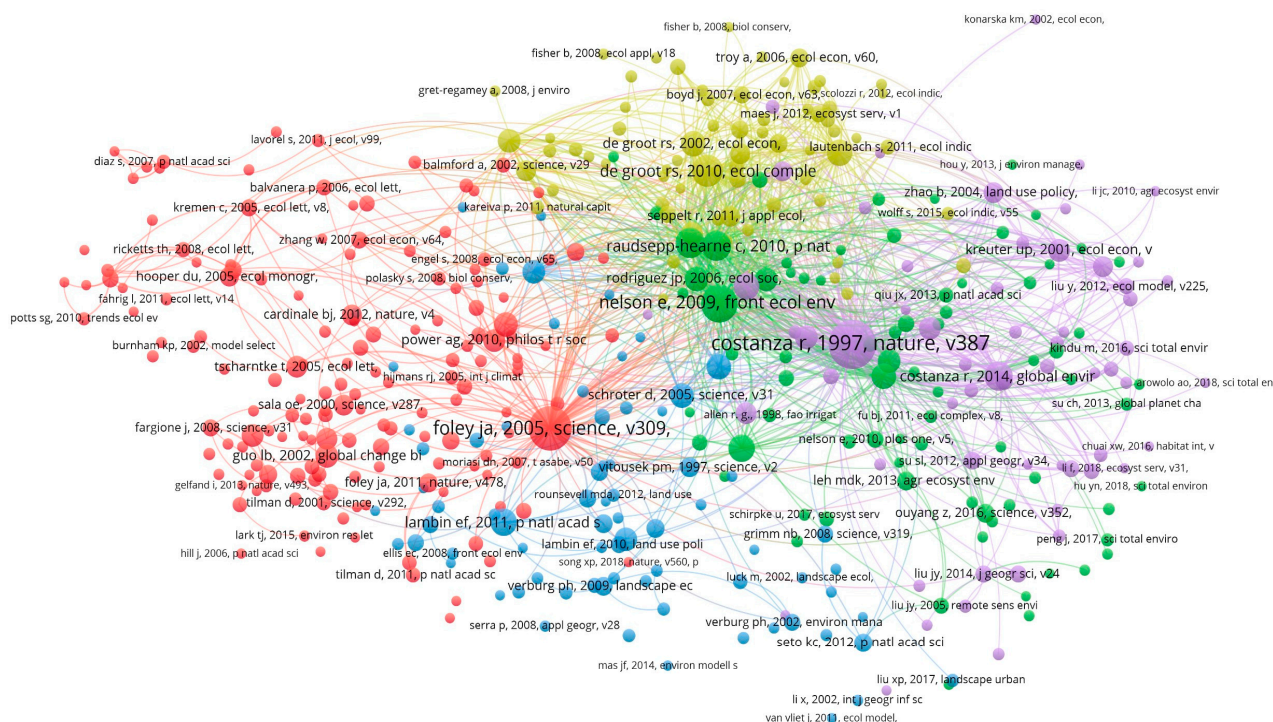


Figure 6. Network of the co-cited references.

In Figure 6, Cluster 1 emphasizes agroenvironment schemes to protect agroecosystems, which provide food, feed, bioenergy, and medicine for human beings and, most importantly, are essential for human well-being. Natural ecosystems provide various ecosystem services:

the maintenance of soil structure and fertility, pollination, nutrient cycling, hydrological services, and biological pest control. Agroecosystems depend on these ecosystem services. The academic research in Cluster 1 can be further expanded to accurately assess the current situation of agroecosystems and provide feasible suggestions for the protection of agroecosystems.

Landscape multifunctionality, the main focus of Cluster 2, refers to the landscapes characteristics that provide a variety of different functions and that interact with each other. High-quality landscape multifunction performance can effectively improve regional human well-being, resulting in the multifunction landscape being a common topic in human land coupling research. Different land use statuses and landscape versatility intensities lead to changes in the ecosystem services of complex landscapes.

Cluster 3 includes multiple vulnerability assessment methods. Terrestrial ecosystems provide many important facilities for human beings and society, which include food, fiber, biodiversity, water resources, and entertainment as well as carbon sequestration. Factors such as the features of the socio-economy, land use, atmospheric composition, biodiversity, and environmental change determine how well ecosystems can provide and facilitate the above-mentioned services. By affecting these factors, climate change will increase the vulnerability of the human-environment system.

Cluster 4 addresses the classification of ecosystem functions. According to the literature in Cluster 4, the main human activities that influence the environment involve land use and land cover changes. These alterations impact the efficacy of an ecosystem in facilitating human society with goods and services. If the sustainable use of the human-environment system and natural capital can achieve self-sustainability, nature will be able to cope with the needs of society by supplying the necessary goods and services, and ecosystem functions must be classified. For a description of their status and dynamics, suitable indicators and data are required for quantification, including quantitative and qualitative evaluation.

The works in Cluster 5 consider the value of ecosystem services. Landscapes produce a huge number of valuable services pertaining to the ecosystem, but the worth of these services is often ignored in land use decision making. Ecosystem services and the stock of natural capital that generates them are crucial for the system processes that support life on Earth. They are directly and indirectly crucial for the well-being of human beings. As land use conversion causes the loss of or a significant reduction in the various beneficial aspects of ecosystems, enhancing decision making and the performances of organizations that work to conserve biodiversity and to manage feasible ecosystems require better accounting of the public goods and services supplied by ecosystems.

3.3. Basic Research Questions in This Field

Wang et al. stated that to clearly define the impact of land use changes on ecosystem services, it is necessary to analyze them from their impact in terms of four aspects, namely land use area changes, land use pattern changes, land use spatial pattern changes, and land use scale changes, to answer the following four key questions [85]: (1) What impact will land use area changes have on ecosystem services? (2) How does the change in land use type affect ecosystem services? (3) How does the change in the spatial pattern of land use affect ecosystem services? and (4) What is the impact of land use changes at different scales on ecosystem services? Based on the results of the keyword co-occurrence analysis, the keywords were sorted according to their meaning, as shown in Figure 7.

3.3.1. What Impact Will Land Use Area Changes Have on Ecosystem Services?

The first question is directly related to the calculation of the worth of ecosystem services. Costanza et al. and Xie et al. proposed the average ecosystem service value coefficient of each kind of land use from the global and Chinese perspectives, respectively, to evaluate the total ecosystem service value of a region [86]. Most researchers adopted the above methods, that is, using different land use types to represent the ecosystem services worth, and then multiplying that value with the coefficient of the ecosystem

service value to obtain the total economic worth of regional ecosystem services. The total value of regional ecosystem services is closely related to the land use area, and the value of ecosystem services per unit area is intricately linked to environmental conditions such as land cover [87]. Because of ecosystem complexity and spatial heterogeneity, the value of ecosystem services per unit area of the same type of land varies with time and space [85].

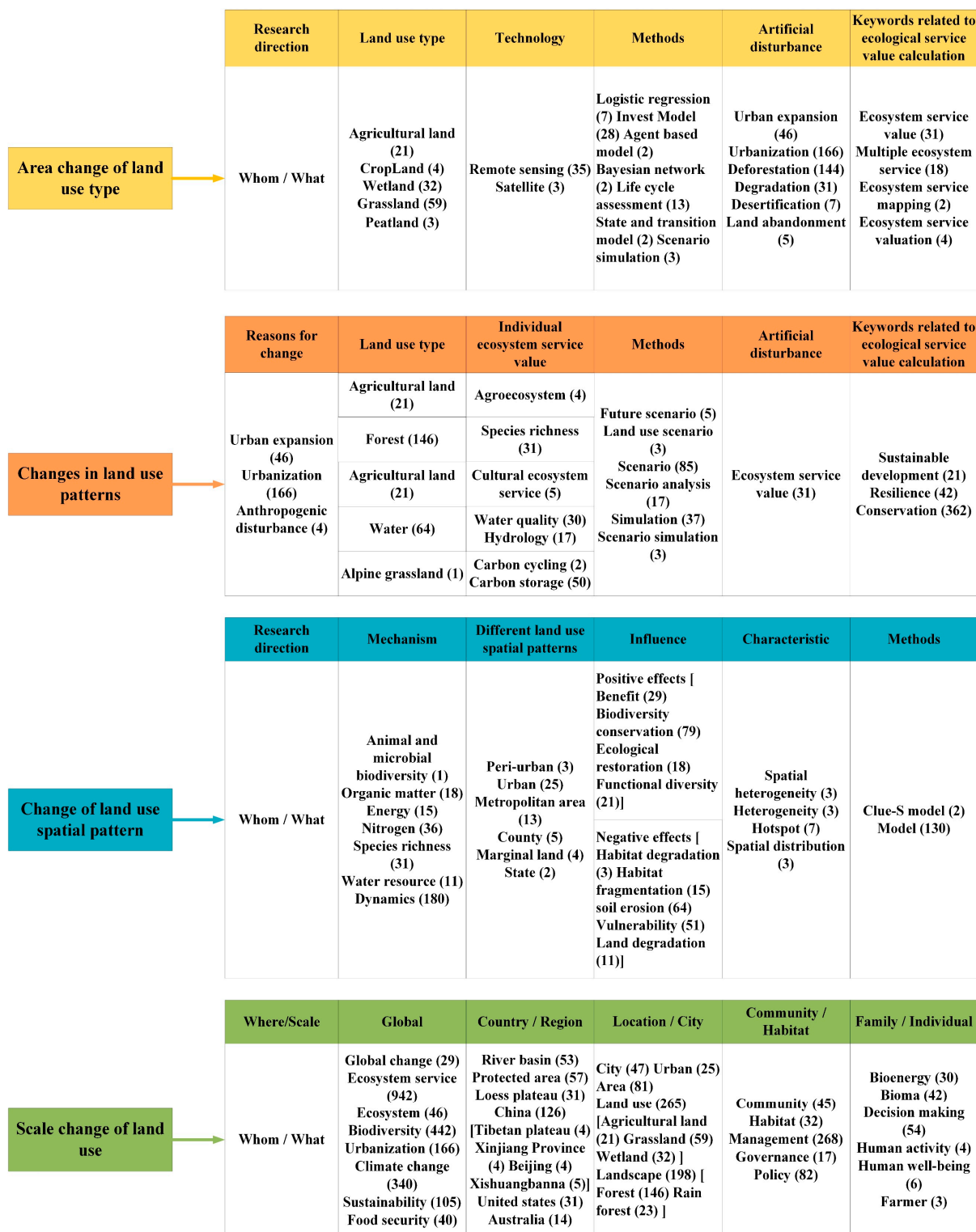


Figure 7. Keyword classification map based on four key problems.

Given the popularity of remote sensing (RS) and geographic information systems (GIS), the research on the dynamic assessment of ecosystem service value has been constantly expanding. Dynamic land use monitoring based on high-resolution multisource remote sensing images has provided data to support the determination of land use area changes. Different indexes, such as land use change rate [88], land use degree [89], etc., have been used together with spatial analysis models to quantitatively examine the interrelation amongst land use area change and the value of ecosystem services. A certain negative correlation between land use degree and the ecosystem service value was found [90]. The higher the land use degree, the lower the regional ecosystem service value. Because land use area directly affects the ecosystem service value in current assessment methods, it is particularly important to accurately assess ecosystem service value per unit area. Moreover, the accuracy of the average ecosystem service value coefficient based on global and national scales has also been questioned. In related studies, biomass [91], food production [92], ecological vulnerability [93], and ecological location [94], etc. have often been used to modify the average value coefficients according to region.

3.3.2. How Does the Change in Land Use Pattern Affect Ecosystem Services?

The close relationships connecting land use patterns with ecosystem services are generally indicated by the differences in individual ecosystem services with varying land use patterns [95]. For example, farmland ecosystems focus on food production services. Forest ecosystems maintain biodiversity, conserve soil, balance the climate and provide other services. Changes in agricultural production land use patterns will cause conflicts between regional ecosystem service value, such as grassland reclamation for arable land, which strengthens the product supply service value of the ecosystem but weakens its regulation and support service value in terms of the preservation of soil and water [96]. Alterations in land use patterns will alter the distribution of biological habitats and resources according to both spatial and temporal scales, which affects the operations and services of the ecosystem. Changes in the land use pattern lead to alterations in individual ecosystem service values affecting the total worth of ecosystem services.

Generally, for land use types experiencing moderate human perturbation, the supply service value is higher, while the regulation and support service value is lower; for natural ecosystems where the disturbance is lower, the supply service value is lower, but the regulation and support service value is higher [97]. The unreasonable use of land results in serious ecological and environmental problems, such as air quality decline, land desertification, land pollution, water shortages, nonpoint source pollution, and biodiversity reduction, which all considerably affect the creation, expression, and transmission of ecosystem services [98]. Changes in the land use patterns have been observed to be strongly correlated with the ecosystem service value. Changes in the land use scheme that take place due to human activities, such as agricultural development and urbanization, often cause the decline in regional ecosystem service values, indicating that we should consider its eco-environmental effect, formulate a reasonable plan and layout, adjust land use patterns and structures, and build a reasonable total value structure of ecosystem services in order to realize the goal of ensuring that the land use efficacy and the benefits provided by ecosystem services are as high as possible.

3.3.3. How Does the Change in Land Use Spatial Pattern Affect Ecosystem Services?

The land use scheme that is applied to the spatial scale affects the movement of energy, matter, and organisms in the landscape space, and inevitably affects or restricts ecosystem processes such as species movement, water and nutrient migration, nonpoint source pollution formation, population dynamics, and biodiversity in the landscape [99]. The diversity of ecosystems and of environmental conditions determine spatial variation in the types and intensity of services provided by ecosystem, whether from the macro or micro spatial scale. The ecosystem service function and value per unit area depend not only on biomass but also on spatial location. The reasonable spatial allocation of land

use can significantly promote improvements in the regional ecological environment and ecosystem service value; otherwise, it will cause a vicious cycle in the regional ecological environment, resulting in ecological effects such as habitat degradation, deterioration in the environmental functions of soil and water, decreased biodiversity, and the simplification of ecosystem components [100,101].

Using the landscape pattern index to quantitatively study the influence of spatial land use pattern alterations on service values pertaining to ecosystems, Farley et al. and De et al. found that the area of ecological land as well as its spatial structure, such as connectivity impacted ecosystem service value [102]. Zhang et al. used correlation analysis and multiple regression analysis to study karst areas in China [103]. The results showed that the patch-type areas, the maximum patch index, spread index, aggregation index, effective network area, and neighborhood percentage are positively correlated with ecosystem service value. With increasing proportions of key landscape types and connectivity, the value of ecosystem services increases. The separation index, partition index, and patch richness index negatively correspond with the service value pertaining to ecosystems. With the increases in fragmentation and the separation of patches and the decrease in the proportion of key patch types, ecosystem services decrease in worth.

The above studies show the influence of alterations in the spatial land use pattern on the services provided by ecosystems from different aspects. Due to the limitations of ecosystem complexity, spatial heterogeneity, and assessment methods, a theoretical system has not yet formed for current research. Therefore, this will be one of the important research directions in the future: scientifically and systematically applying ecological theory to ecosystem service assessment toward truly reflecting the impact of the ecological environment in terms of how the alterations in the spatial land use pattern affect the service function and value of the regional ecosystem.

3.3.4. What Is the Impact of Land Use Changes on Ecosystem Services at Different Scales?

The ecosystem structure and its processes in time and space define the services provided by the ecosystem. Different scales determine the perspective and content of the research [104]. For example, on the small scale, the focus of the research has usually been the impact of changes in ecosystem services due to land use changes on the productivity [105,106]. On the medium scale, research has focused on the evaluation of the mechanisms and spatial and temporal patterns of the main ecosystem services changes caused by land use and their impact on human welfare. On the macro scale, the main focus has been the alterations in the world environment and the coupled inter-relation between ecosystem services changes and social economy driven by urbanization and land use change [107,108]. Different research methods are used for different scales. For example, on the macro scale, the dynamic evaluation model of ecosystem services is often used for simulation research [109–111]. At the small and medium scales, observation and experimental methods are often used. The selection of methods that are appropriate for the scale is important, as they have the ability to fully mirror the changing trends in land use alternation characteristics and ecosystem services.

With large-scale studies, local pattern features or special phenomena tend to disappear, especially for ecological processes with threshold and nonlinear characteristics. Small- and medium- scale research (such as urban, watershed, agricultural, and forest ecosystem, etc.) is more conducive to the exploration of specific problems to provide a reliable basis for land use decision making [112,113]. Therefore, the perspective of related research is constantly shifting from the regional and global scale to smaller scale and typical regions, including some typical regions with a fragile ecological environment. Hence, research on the alterations in the influence of how land is used on services provided by ecosystem at different scales, as well as the scale conversion, scale correlation, and interaction mechanism between ecosystems at different scales is required to understand the dynamic function of alterations in land use on the services provided by ecosystems and its significance for the welfare of humankind.

4. Discussion

4.1. Framework for Field Research

As shown in Figure 8, the DPSIR framework (driving factors, pressure, status, influence, and response) can be used in the human environment interaction system, integrating complex factors, connections, and relationships into causal pathways [114,115]. The two main reasons for land use change are biophysical and socio-economic drivers [116]. The biophysical drivers comprise features such as environmental changes, landforms, topography, geomorphic processes, volcanic eruptions, plant succession, soil types and processes, and drainage patterns [117]. The socio-economic drivers are population, industry, technology, policies and rules, values, and community organization [118]. Due to natural and human-driven factors, changes occur in terms of the land use area, land use patterns, spatial land use patterns, and land use changes will manifest at different scales. Land use activities, in line with the laws of nature, should result in the harmonious coexistence of humans and nature [119]. Merely satisfying the interests of humankind and neglecting ecological protection places tremendous pressure on the ecosystem in a specific area, thereby changing the ecosystem status, including biophysical structure and processes, ecosystem functions, and ecological security. The influences of human and natural systems may cause alterations in ecosystem goods and services, which will impact the welfare of human beings [120]. Only after society and governments recognize these complex interactions can they implement measures to diminish the detrimental effects on the human–environmental system [121]. This framework explains the mechanism between land use changes with ecosystem services, including the impact on the response components or drivers and the upcoming demands as well as effects. This specific framework focuses on the relationship among the benefits provided by services, human welfare, values pertaining to society and economics, management, and policy [122]. In addition to the present content, a topic worthy of discussion in future research is the connection between these components.

4.2. Future Research Opportunities

In recent years, scholars have conducted numerous explorations into the impact of land use changes on ecosystem services, and many meaningful results have been acquired, but the following shortcomings can be noted:

(1) The methods for dynamically assessing ecosystem services need to be improved. The accurate assessment of ecosystem services is fundamental for studying the impact of land use changes on ecosystem services, but a complete set of ecosystem service evaluation theories and an index system have not yet been established [29]. Different assessment methods vary in terms of the calculation model, parameter determination, and ecosystem classification, and their assessment results are often quite different. Even for the same ecosystem, the assessment results may vary widely. In addition, the global average ecosystem service value coefficient, which is widely used in current research, is also considered as containing considerable uncertainty [3,35]. Some studies have suggested that due to the dependency relationship and substitution effect between ecosystem services, simply adding the value pertaining to services provided by an ecosystem may lead to problems related to double calculation, resulting in an excessively high valuation [31,123].

(2) Understanding of the mechanisms that are responsible for ecosystem service changes at different scales is insufficient. At present, many statistical analyses are based on quantity, which reveal the correlation between land use changes and ecosystem services, but correlation does not imply causation, and the implied ecological significance needs to be further explored [100]. The changes in land use area, pattern, and spatial pattern (such as habitat area change, landscape fragmentation, etc.) first affect the ecological processes (such as hydrological processes, soil erosion, biological movement, etc.) and then affect ecosystem service functions and values. In addition, ecosystem processes and services can only fully express their leading role and effects on a specific spatial–temporal scale. In other words, ecosystem processes and services often have a characteristic scale. Therefore, the mechanisms of ecosystem service expression at different scales vary, and the lack of

research regarding these mechanisms will inevitably restrict the conversion and deduction of the results of the effects of land use change on ecosystem services at different scales [124].

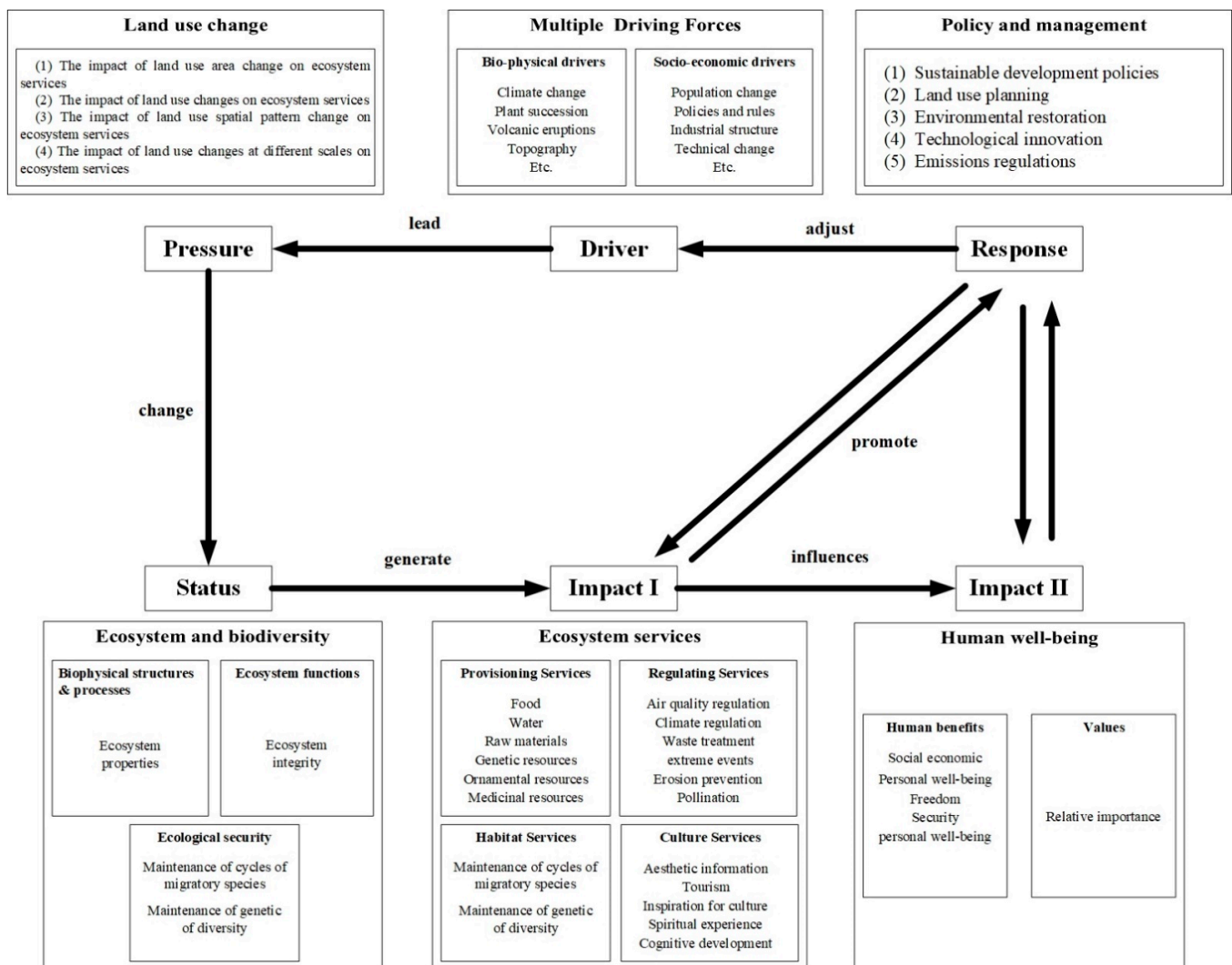


Figure 8. The DPSIR framework of land use changes and ecosystem services.

(3) Research on the integration and application of ecosystem services is lacking. Ecosystems can provide multiple services for human society. In ecosystem management, humans ignore the interdependence and inter-relationship between different ecosystem services and pay too much attention to the outputs of ecosystem services, mainly in terms of a supply function such as in the case of food and wood, which often leads to substantial declines in ecosystem support and other services [32]. Regarding land use practices, the practical significance of the research is reduced due to the lack of trade-off and integrated application research of ecosystem services under the changes in land use patterns.

(4) This paper only discusses the impact of land use changes on ecosystem services from beginning to end, while ignoring the impact of land cover change on ecosystem services. Land use and land cover change (LUCC) has two parts, including land use and land cover [125]. Land use refers to the long-term business activities of human beings on land according to certain economic and social purposes, such as agricultural land, industrial land, transportation land, residential land, etc. Land cover refers to the complex of surface elements formed naturally or covered by artificial buildings, such as vegetation, soil, glaciers, lakes, wetlands, buildings, roads, and so on. In general, LUCC refers to land cover changes caused by human changes in land use and management, so it refers

to the simultaneous change of land use and land cover, such as the transformation of forests into farmland. However, there are also situations where land use changes but land cover remains unchanged. For example, grassland land use can change from grazing to tourism leisure without changing the amount of land cover. Accordingly, there are also situations where land use remains unchanged but land cover changes, such as changing land cover due to land degradation caused by overgrazing when the use mode of grazing land remains unchanged.

5. Conclusions

The purpose of this study was to describe the state of current progress, research hotspots, and potential research directions based on the bibliometric method. Articles related to land use change and ecosystem services published between 2005 and 2020 were obtained from the Web of Science Core CollectionTM, and bibliometric software was employed to explore the data. The main findings of our work are as follows:

(1) Accordingly, as shown in Table 1, the aim of this study is to answer four research questions. The first question is answered in Section 3.1, which includes data on publishing trends, main authors, main institutions, main journals, and research fields. In terms of publication trends, the numbers of documents and citations are continually increasing, and articles present the main type of publication. Peter H. Verburg, Brett A. Bryan, Stephen Polasky, Sandra Lavorel, and Catharina J.E. Schulp are the top five prolific authors. The Chinese Academy of Sciences occupied the top ranking in terms of the most published articles. For the number of published articles, *Sustainability* ranks first with 86 publications, providing significant contributions in this domain.

(2) The main content in Section 3.2, which includes data for the co-occurrence analysis of keywords and the co-citation analysis of literature, is the answer to the second question. The keywords can be classified into six categories: land use/land cover change, conservation, biodiversity, policies and programmers, environmental change, and agriculture. The evolution of research hotspots can be divided into three stages: the expansion period, developmental period, and low-production exploration period. The top five co-cited references of each cluster were selected to precisely determine the key research areas of agroenvironment scheme, the characteristic of landscapes, vulnerability, ecosystem functions, and ecosystem services value.

(3) The answer of the third question is discussed in detail in Sections 3.3 and 4.1. The DPSIR framework can explain the mechanism between land use change and ecosystem services, including the impact on the response components or drivers, and the upcoming pressures and impacts. The analysis of the mechanisms between land use change and ecosystem services should focus on the following four aspects: land use area changes, land use pattern changes, land use spatial pattern changes, and land use changes at different scales.

(4) The answer to the fourth question is explained in Section 4.2. Several potential directions can be noted in terms of research opportunities, including developing methods for dynamically assessing ecosystem services, the ecological mechanism of ecosystem service change on varying scales, the integration and application case of ecosystem services, and the impact of land cover change on ecosystem services.

As with other research works, this study also has some limitations. One is the literature search paradigm. Although the search term settings should be as comprehensive as possible, some of the research scope may not have been covered. Moreover, although a rigorous and structured research process was adopted, the selection of articles only published in scientific journals may have led to the omission of relevant articles. In addition, although objective results in relevant research fields can be obtained based on bibliometric analysis, some of the root causes of these results need to be further explored. The discussion and analysis in this paper is expected to help decision makers establish a clearer framework and adopt more effective strategies to achieve sustainable environmental and human development. This paper can also help the research community to identify the existing gaps in research to be filled in, thus aiding in the development direction of disciplines in this field.

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