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Ecosystem Services Research in Green Sustainable Science and Technology Field: Trends, Issues, and Future Directions

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Abstract: Ecosystem services (ES) has an important place in sustainability science research as a powerful bridge between society and nature. Based on 513 papers correlated with ES in the field of green sustainable science and technology (GSST) indexed in ISI Web of Science database, we employ the bibliometric methods to analyze the disciplinary co-occurrence, keyword co-occurrence, partnerships, publication characteristics, co-citation, research themes, and transformative potential of these papers. The results show that innovation in research themes of the ES research in the GSST field is increasing rapidly in 2015–2018, while innovation in research themes is decreasing in 2018–2021. Moreover, keyword co-occurrence analysis indicates that the hot topics of previous research with respect to "environmental service", "capacity", "perception", "landscape", "forest management", "carbon sequestration", "contingent valuation", and "sustainable development". Recent hotspots include "blue carbon", "environmental impact", "coastal", "ecosystem services mapping", and "use/land cover change". Finally, the cluster analysis of co-cited references abstract thirteen largest clusters. The top six clusters are "mapping ecosystem service", "spatial gradient difference", "ecosystem service value", "water-related ecosystem service", "linking forest landscape model", and "culture ecosystem service". Moreover, the integration of spatial, value, environmental, and sociocultural dimensions may help to develop supportive policies, which is a future direction of ES research in the GSST field.

Keywords: ecosystem services; green sustainable science technology; CiteSpace; bibliometric analysis; knowledge mapping

Citation: Tang, J.; Fang, Y.; Tian, Z.; Gong, Y.; Yuan, L. Ecosystem Services Research in Green Sustainable Science and Technology Field: Trends, Issues, and Future Directions. *Sustainability* **2023**, *15*, 658. https://doi.org/10.3390/su15010658

Academic Editor: Antonio Boggia

Received: 21 October 2022
Revised: 17 December 2022
Accepted: 20 December 2022
Published: 30 December 2022

1. Introduction

As climate change and global pollution levels continue to intensify, there is a growing interest in sustainable science. Ecosystem services (ES) has become an important issue in sustainability science, acting as a bridge between society and nature [1,2]. Specifically, with the globalization of the economy and the increasing urbanization of countries, there is a widespread conflict between people and land and the degradation of the ecological environment, causing serious damage to ecosystems in the process of economic development, and thus the value of ecosystem services is decreasing. Ecosystems are irreplaceable natural assets for human survival and development, and the value of their services reflects the extent to which the life support products and services they provide meet human needs, and is the basis for measuring the function of regional ecosystems. The effective provision of ecosystem services is linked to the well-being of all people and the sustainable development of society and nature.

There is an increasing number of scholars who have centered on ES issues in the last decades [3], and articles on ES research have proliferated, while the sheer number of papers makes it hard to explore the core of the study, thus creating a significant risk of neglecting fundamental issues and research improvement fields. There are some questions that need further analysis; for example, what are the research subjects and development trends? Who are the famous scholars on the ES research in Green Sustainable Science Technology (GSST) field? Which countries and institutions have close exchanges? For solving these problems, scientometric software, such as bibliometric studies that have the ability to offer new knowledge situations and directions in a specific field, performs an increasingly significant role [4–7].

For the past few years, with the advent of visualization tools such as VOSviewer, VantagePoint, Bibexcel, CiteSpace, Sci2, etc., it has enabled the relevant fields to use these analysis techniques (keyword co-occurrence, literature co-citation) for quantitative and objective analysis [8]. For example: Aznar-Sánchez et al. (2018) analyzed numerous studies with respect to forest ES on a global scale between 1998 and 2017 using VOSviewer [9]. To survey temporal developments, scientific collaboration, research hotspots, and emerging trends on agroecosystem services between 2008 and 2017, Liu et al. (2019) explored the relevant scientific literature using Bibexcel on a global scale [10]; Chen et al. (2020) used a combination of BibExcel, social network analysis (SNA), and Gephi to explore the scientific literature on ES for the period 1997 to 2016 [11]; Wang et al. (2021) analyzed data from 1992 to 2018 to study these questions using CiteSpace [2]. However, we found that there are few papers exploring the scientific literature of ES in the field of GSST globally by combing through the previous literature. Therefore, this paper visualizes the knowledge structure and growing trend of ES research in the field of GSST via bibliometric analysis. On the one hand, it enables scholars to grasp more clearly and intuitively the current situation and problems of the ES research in the field of GSST, and on the other hand, it helps them to understand the future trends. Moreover, it helps to stimulate the interest of scholars and practitioners in ES research, guide them discover emerging topics, and deepen their comprehension and assessments of ES.

The remainder of the paper is structured as follows. Section 2 presents the main research materials and methods. Section 3 introduces the research findings and discussions. Section 4 summarizes the relevant conclusions.

2. Materials and Methods

2.1. Data Acquisition

Since the acquisition of data in CiteSpace is mainly from the Web of Science (WoS), this paper retrieved the number of publications and citations of the reference on ecosystem services in the Web of Science and obtained Figure 1. According to Figure 1, it can be seen that the first scientific literature on ES in the field of GSST appeared in 1997. After that, there was no significant change in growth from 1997 to 2014. However, the number of publications and citations have increased significantly since 2015. Based on this, this paper selected the data for the time period from 1 January 2015 to 7 September 2021. The data was indexed with the following settings: title = (ecosystem services), time span = 1 January 2015 to 7 September 2021, literature type = (article), Web of Science category = (green sustainable science and technology), index = (SCI-EXPANDED, SSCI and ESCI).

2.2. Bibliometric Analysis

Bibliometrics is a multi-discipline that integrates mathematics, statistics, and bibliography for quantitative analysis of academic literatures with data derived from the WoS database. The common analysis methods used for bibliometric analysis are: statistical analysis, partnership analysis, keyword co-occurrence analysis, and co-citation analysis [12]. However, different emphasis on different analysis methods.

The statistical analysis is a method of visual statistical analysis of authors, journals, countries, and institutions using an online analysis platform or Excel software 2021, which can quickly catch the basic information and trends of literature in a specific field [10].

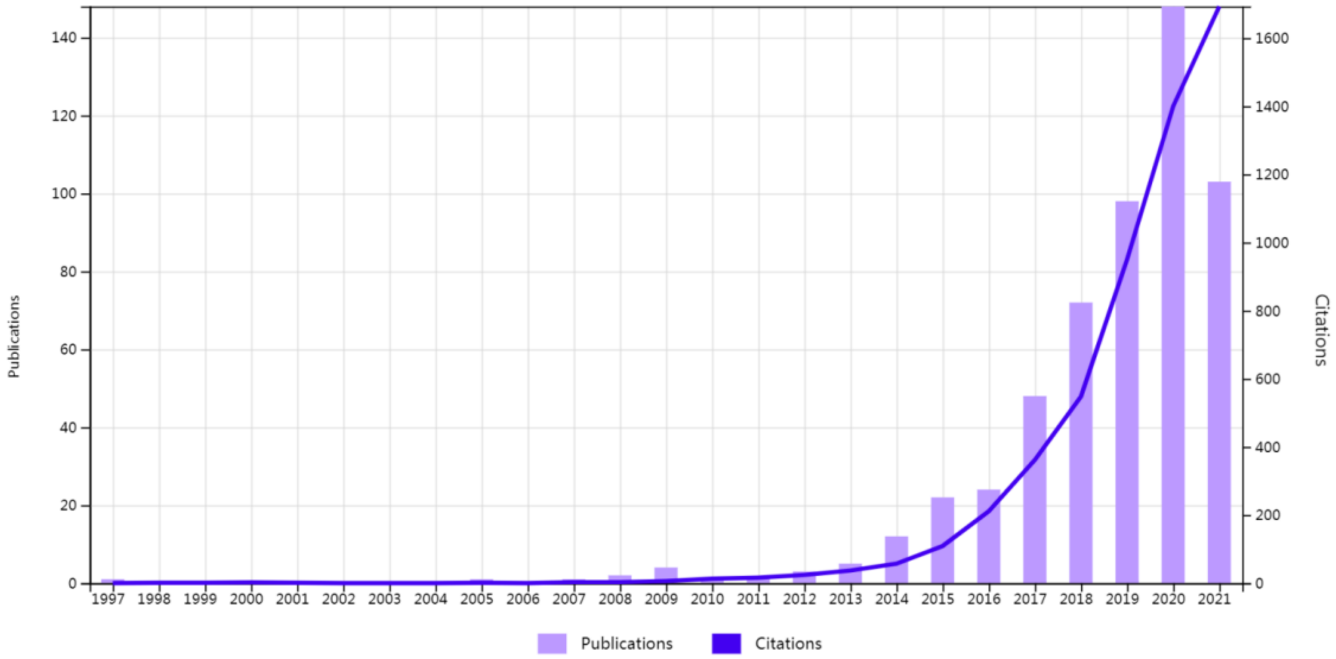

Figure 1. Number of publications and citations of papers from 1997 to 2021.

Partnership analysis focuses on the analysis of inter-author relationships, inter-institutional relationships, and inter-country relationships. In this paper, VOSviewer is commonly used to analyze inter-author partnerships with the following settings: "Minimum number of literature for one author = 1", "Minimum number of citations for one author = 2", and "Number of authors to be selected = 1551"; while CiteSpace is often used to analyze inter-institutional partnership networks with the time span, year per slice, node type, and scale factor parameters set as follows: " 2015 to 2021", "year per slice = 1", "node type = institution", and "scale factor k = 15"; finally, the relationships on inter-country were often analyzed on the online bibliometric analysis platform (https://bibliometric.com/, accessed date: 2021-11-25).

The keyword co-occurrence analysis also uses CiteSpace. The difference with partnership analysis, which focuses on analyzing inter-institutional collaboration networks, is mainly that the former focuses on detecting high-profile issues and frontiers in a given research area over time [13]. Both are the same in terms of time span, year per slice, and scale factor parameter settings, except that the node type in partnership analysis is set to "node type = institution", while the node type in keyword co-occurrence analysis is set to "node type = keyword".

The co-citation analysis uses CiteSpace to find the main research areas and construct journal overlay graphs and analyzes the dynamics of knowledge structure and co-citation clusters through co-citation analysis, respectively, with the same main parameter settings as partnership analysis for analyzing inter-institutional collaboration networks [4]. It has long been widely used to study the characteristics of academic communities and the knowledge structure of academic fields [14].

In addition, in order to make it easier for scholars to grasp research hotspots, frontiers, and trends in a subject area, this study applies a knowledge-mapping approach to visualize the development process and structural relationships of the subject area [15].

The bibliometric analysis process of this research is shown in Figure 2.

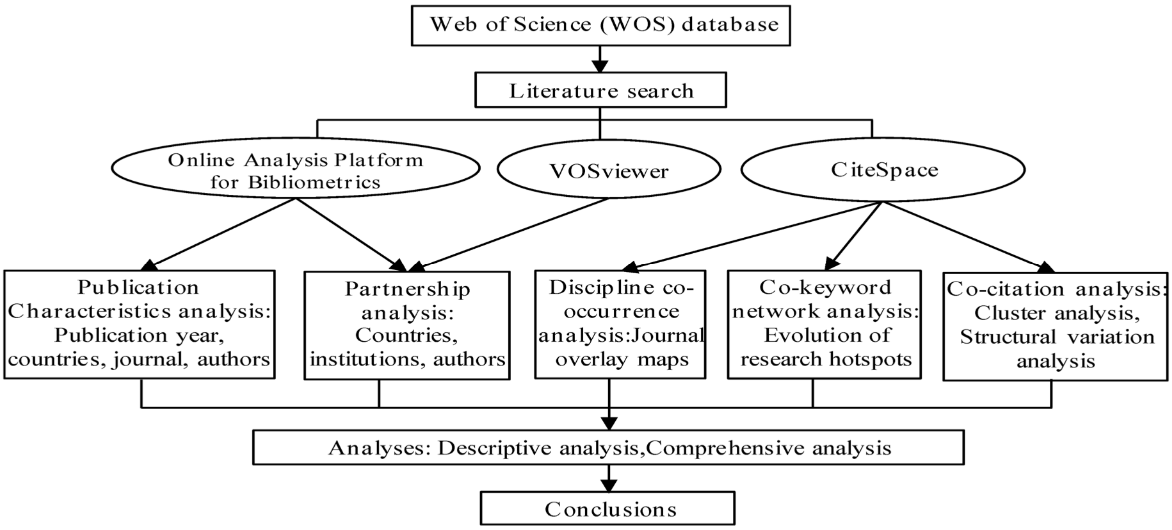

Figure 2. Bibliometric analysis process.

3. Discussion and Results

3.1. Discipline Co-Occurrence Analysis

We use the dual-map overlay function of CiteSpace to map the disciplinary co-occurrence network in Figure 3. According to Figure 3, mass journals with more than 10,000 titles in WoS are divided into various disciplines by various colors. These disciplines are distributed in various positions in the source and reference regions, or rather, in the left or right regions. For instance, the lake blue color in the graph represents the discipline "ECONOMICS, ECONOMIC, POLITICAL", which is ranked 10th in the source region on the left and 12th in the reference region on the right [16]. After that, a colored link between the source and reference areas was formed by adding a layer containing 513 ES bibliographic records to the GSST domain. Based on this, this paper finds that ES in the GSST field is relatively widespread.

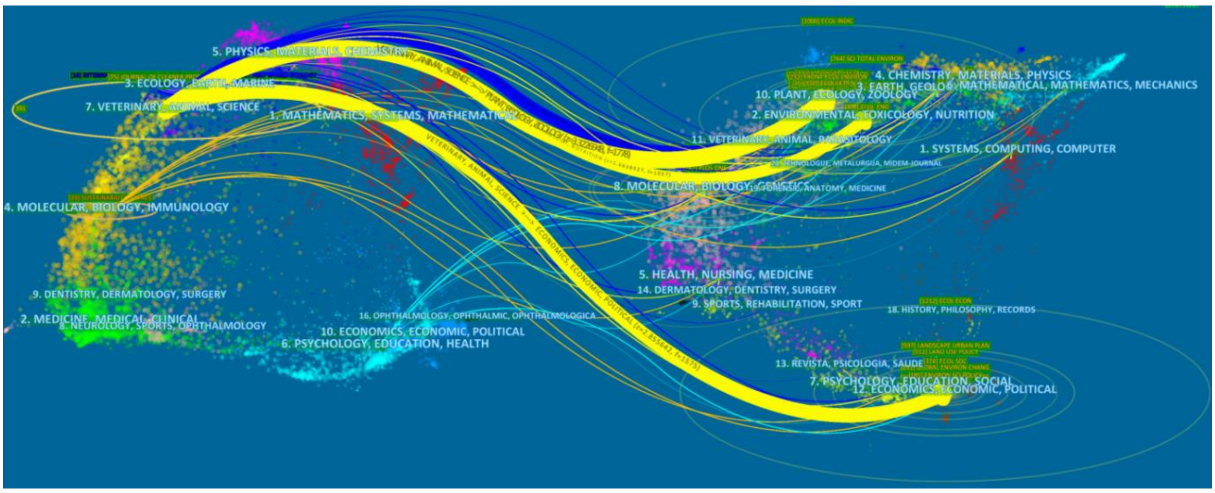

Figure 3. A dual-map overlay of literature on ES in GSST field.

3.2. Publication Characteristics Analysis

Based on the online bibliometric analysis platform, this paper employs statistical analysis to implement visualization of global publishing trend, top 10 journals and authors with publication volume, and top 10 cited papers. The trend in the annual publishing volume between 2015 and 2021 is shown in Figure 4. Based on this, we can know that their numbers present a roughly increasing trend. CHINA issued a total of 214 articles, accounting for 41.72%; USA issued a total of 63 articles, accounting for 12.28%; ITALY issued a total of 52 articles, accounting for 10.14%; GERMANY issued a total of 44 articles, accounting for 8.58%.

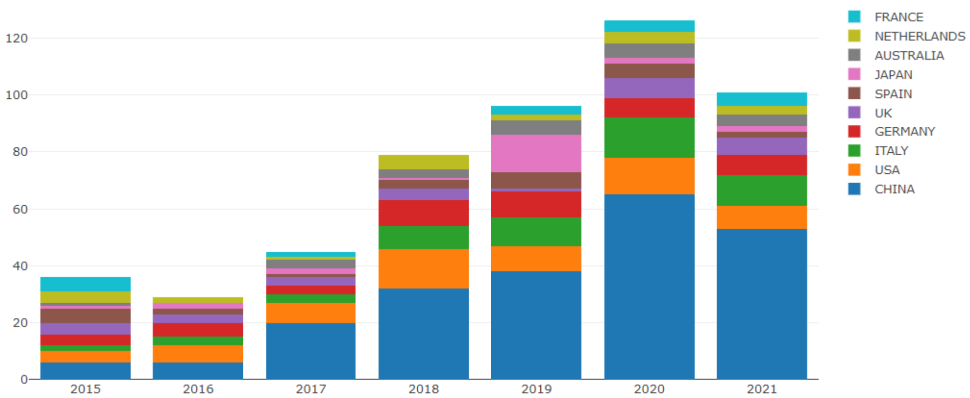

Figure 4. Annual publication volume between 2015 and 2021.

Figure 5 shows the top 10 journals with publication volume. Among them, "SUSTAINABILITY" accounted for 57.90%; "JOURNAL OF CLEANER PRODUCTION" accounted for 14.62%; "FOREST POLICY AND ECONOMICS" accounted for 4.48%.

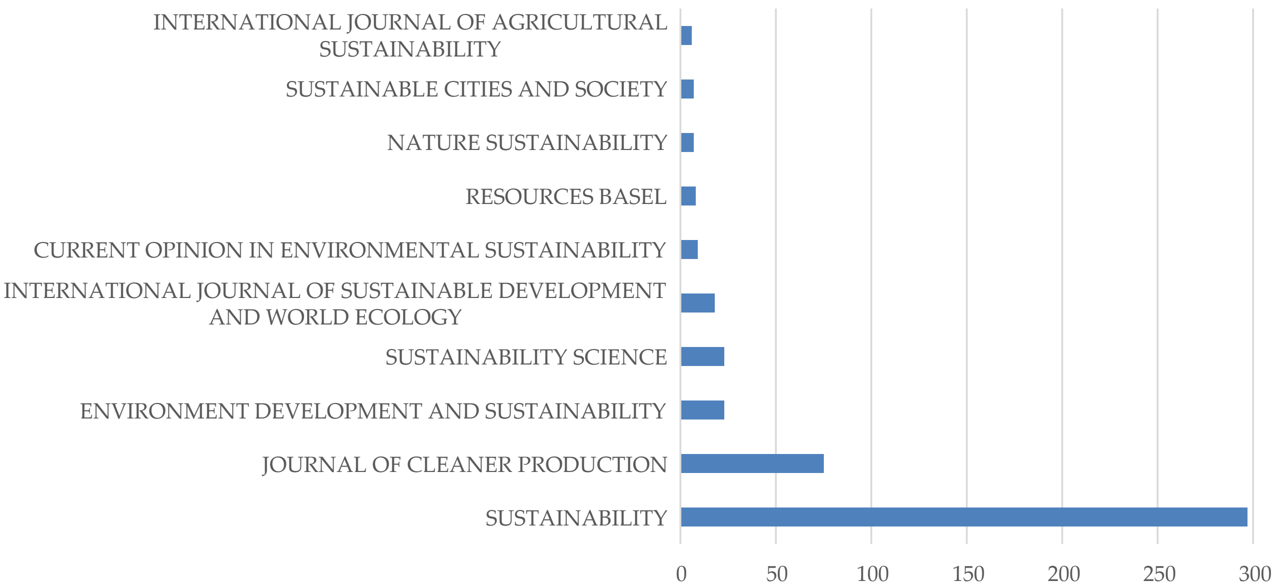

Figure 5. Top 10 journals with publication volume.

Figure 6 shows the top 10 authors with publication volume. Among them, the author who has published eight articles is Li C, and the authors who have published seven articles are Hashimoto S, Li J, Saito O, and Xiao Y.

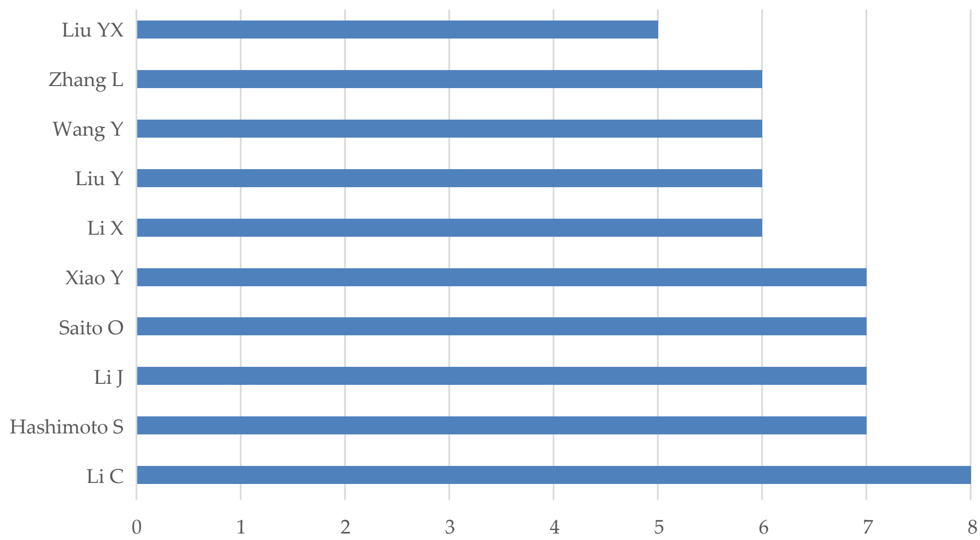

Figure 6. Top 10 authors with publication volume.

The top ten cited papers are shown in Table 1. Among them, six papers originated from the journal "Current Opinion in Environmental Sustainability". These six papers researched ES at the global scale, in urban areas, and in the tropics at the level of the regional scope of the study, and combined ES with biodiversity, landscape management, social rights relations, and agroecology at the level of the relationship between ES and other subject areas. The highest number of citations was 341. In addition, two papers originated from the journal "Journal of Cleaner Production". These two papers focus on WRESs and urban ecological infrastructure. Finally, the papers of Salzman and Garbach examined ES in terms of payments and crop yields, respectively.

Table 1. Top 10 cited papers.

Serial Number	The Name of the Paper	Author	Published Journals	Publication Time	Citation per Year since Publication	Number of Citations
1	Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability	Bennett E M, et al. [17]	Current Opinion in Environmental Sustainability	2015	5, 28, 48, 54, 83, 69, 54	341
2	Benefits of restoring ecosystem services in urban areas	Elmqvist T, et al. [18]	Current Opinion in Environmental Sustainability	2015	1, 10, 23, 34, 66, 65, 55	254
3	The global status and trends of Payments for Ecosystem Services	Salzman J, et al. [19]	Nature Sustainability	2018	8, 37, 52, 59	156
4	The role of cultural ecosystem services in landscape management and planning	Plieninger T, et al. [20]	Current Opinion in Environmental Sustainability	2015	1, 16, 17, 20, 30, 22, 22	128
5	Towards an ecosystem services approach that addresses social power relations	Berbes-Blazquez M, et al. [21]	Current Opinion in Environmental Sustainability	2016	4, 21, 21, 34, 24, 15	119
6	A social-ecological approach to managing multiple agro-ecosystem services	Lescourret F, et al. [22]	Current Opinion in Environmental Sustainability	2015	3, 8, 11, 15, 20, 11, 12	80

Table 1. *Cont.*

Serial Number	The Name of the Paper	Author	Published Journals	Publication Time	Citation per Year since Publication	Number of Citations
7	The impact of land-use change on water-related ecosystem services: a study of the Guishui River Basin, Beijing, China	Gao J, et al. [23]	Journal of Cleaner Production	2017	1, 7, 18, 23, 29	78
8	Urban ecological infrastructure: an integrated network for ecosystem services and sustainable urban systems	Li F, et al. [24]	Journal of Cleaner Production	2017	3, 9, 14, 26, 14	66
9	Examining multi-functionality for crop yield and ecosystem services in five systems of agroecological intensification	Garbach K, et al. [25]	International Journal of Agricultural Sustainability	2017	1, 7, 14, 12, 22, 10	66
10	Payments for ecosystem services in the tropics: a closer look at effectiveness and equity	Calvet-Mir L, et al. [26]	Current Opinion in Environmental Sustainability	2015	2, 4, 10, 13, 16, 10, 11	66

3.3. Partnership Analysis

We employ the online bibliometric analysis platform to explore the relationships on inter-country. Figure 7 shows the partnership between countries. According to the graph, it can be seen that authors from CHINA, USA, GERMANY, and UK have more cooperation with authors from other countries.

This paper uses CiteSpace to analyze inter-institutional partnership networks with the time span, year per slice, node type and scale factor parameters set as follows: "2015 to 2021", "year per slice = 1", "node type = institution", and "scale factor k = 15". Figure 8 shows the cooperation between institutions. As shown in the Figure, the center of the institutional cooperation network mainly includes Chinese Acad Sci, Univ Chinese Acad Sci, Beijing Normal Univ, Beijing Forestry Univ. The organizations that cooperate with core organizations mainly include Univ Tokyo, China Agr Univ, Arizona State Univ, Peking Univ, Eurac Res, CIRAD, East China Normal Univ, Osaka Univ, United Nat Univ, Wageningen Univ and Res, etc.

We use the VOSviewer to analyze inter-author partnerships with the following settings: "Minimum number of literature for one author = 1", "Minimum number of citations for one author = 2", and "Number of authors to be selected = 1551". Figure 9 shows the partnership between authors. According to the graph, it can be seen that Ouyan Zhiyun, Pereira Paulo, Liu Yanxu, Wang Lei, Li Cong, Jiang Wei, Fu Bojie, etc. played crucial roles in the primary author collaboration network.

3.4. Keyword Co-Occurrence Analysis

We use CiteSpace to perform the keyword co-occurrence analysis. Hot topics can often be obtained by the mapping knowledge domain analysis of keyword co-occurrence [4]. Figure 10 constructed the keyword co-occurrence network for the period 2015 to 2021. Each circle in Figure 10 represents a keyword, and the position (year) of the keyword in Figure 10 is the year of its first occurrence in the analyzed dataset. Once a keyword appears, it will be fixed in the year of first occurrence, and although it will still appear in the literature afterwards, it will not be shown again in Figure 10, but only in the year of first occurrence.

If the keyword appears again in later years, the frequency of the keyword will be increased by 1 at the position of the first occurrence; the frequency will be increased for several subsequent occurrences of the keyword. For example, why do the keywords "biodiversity conservation" and "assessment biodiversity" have such large circles in 2015 when the volume of literature is small? This is because the keywords "biodiversity conservation" and "assessment biodiversity" that appeared in the papers afterwards were added up in 2015. Only topics that are different from previous research will appear in the new year. This explains why the keyword co-occurrence network seems to be shrinking. In turn, we can point out that innovation in research themes in the ES field is increasing rapidly in 2015–2018, while innovation in research themes is decreasing in 2018–2021.

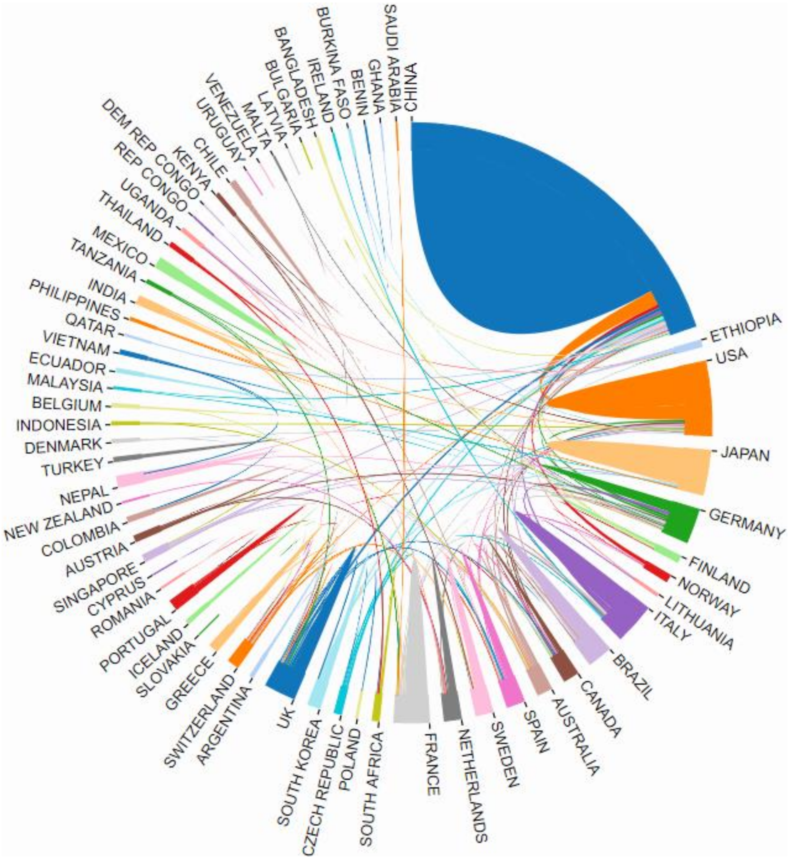

Figure 7. Partnership between countries.

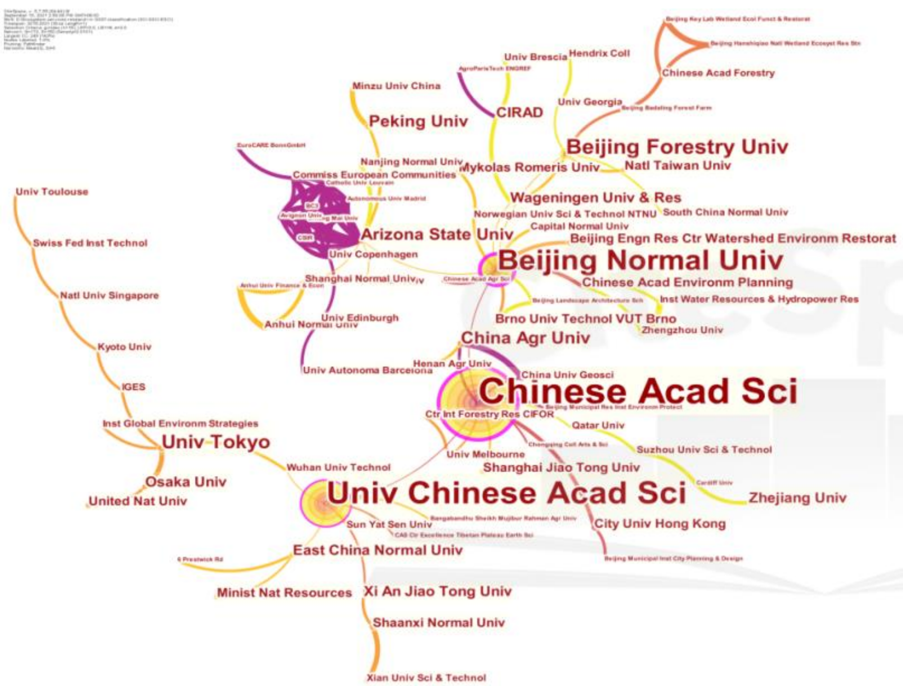

Figure 8. Partnership between institutions.

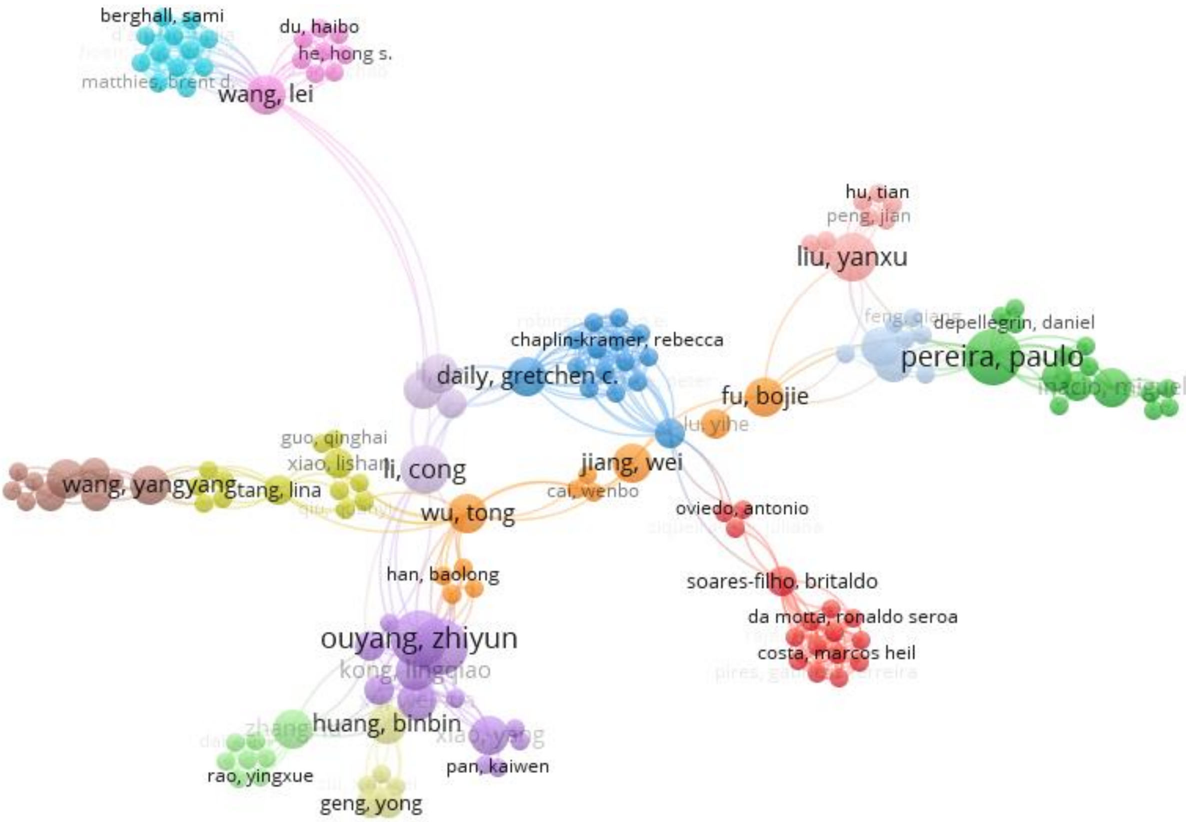

Figure 9. Collaboration between authors.

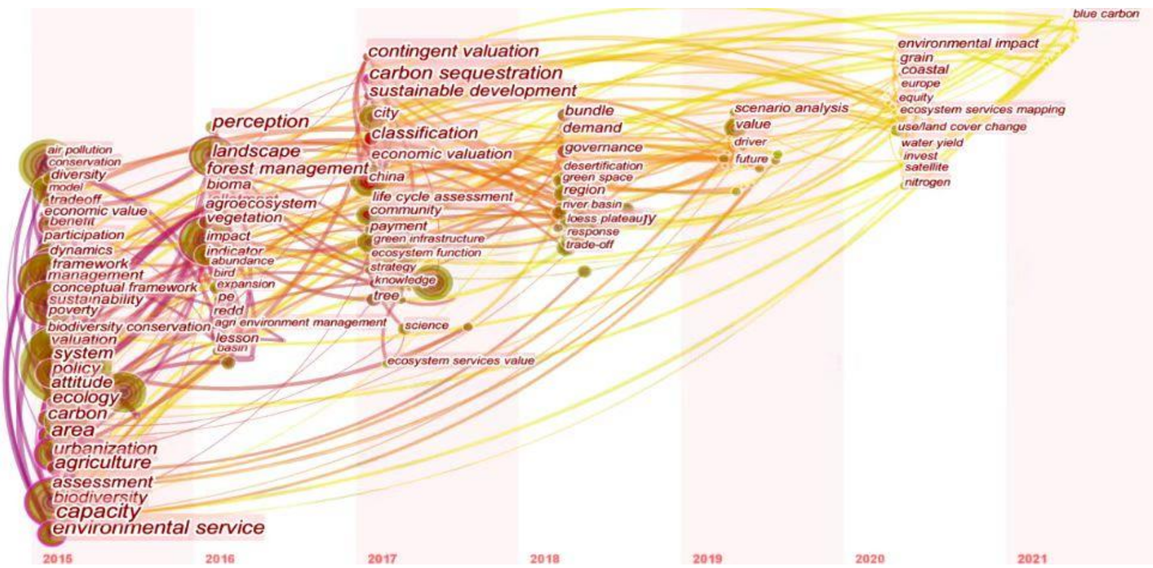

Figure 10. Keyword co-occurrence network.

3.5. Co-Citation Analysis

3.5.1. Landscape View

In bibliometrics, the analysis of references is one of the most significant indicators. The co-citation map of references estimated the scientific relevance of publications [27,28]. This paper employs the CiteSpace to conduct co-citation analysis.

The clustering analysis of literature co-citations can be explored in research patterns, emerging tendencies, and interconnections in ES research in the field of GSST. As can be seen from this cited reference map in Figure 11, there are 263 nodes and 422 links, with S = 0.9394 (average Silhouette) and Q = 0.7807 (Modularity). When Q > 0.7, it represents the network is sensibly classified into loosely coupled clusters. On this basis, in order to generate high-quality clusters, this section employs the LLR clustering technique in Figure 11 (Chu et al., 2009; Kim and Zhu, 2018) [29,30], which divides the network into 13 co-citation clusters.

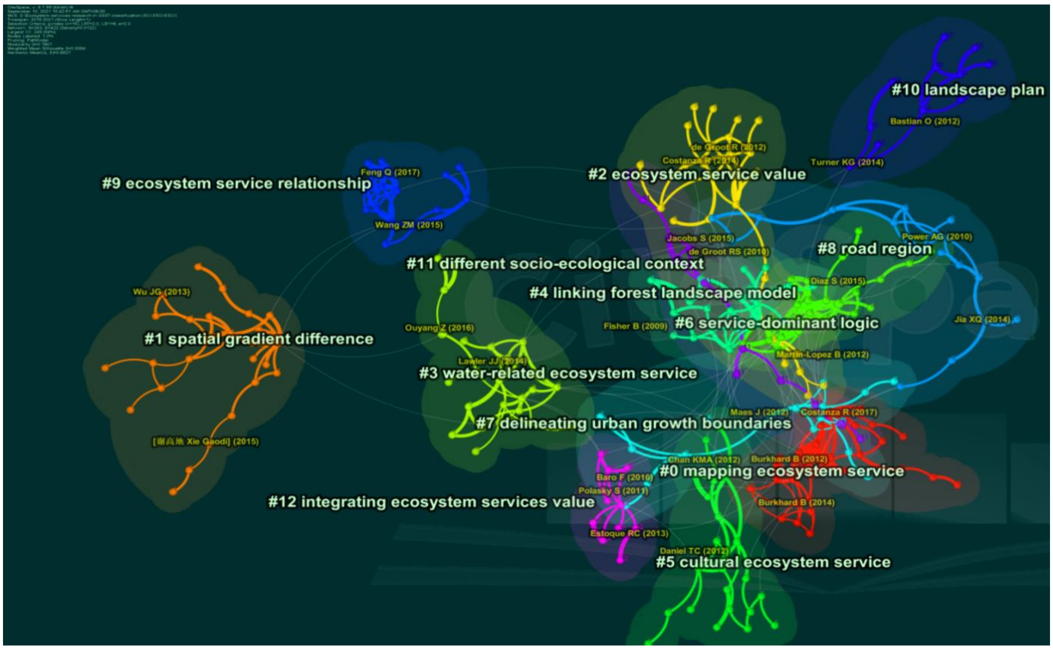

Figure 11. Reference co-citation map of publications on ES in GSST field from 2015 to 2021.

3.5.2. Timeline View

Figure 12 shows the clusters from left to right along a horizontal timeline via the timeline visualization in CiteSpace. The top of the view is the time of publication. Clusters are arranged vertically in decreasing order of their size. The largest cluster is displayed at the top of the view. Co-citation links increased in different color years are indicated by the corresponding colored curves. We need to pay more attention to nodes that are large in size or have a red tree diagram because some of these nodes may be highly cited, some may have citation bursts, or both. The three most cited references in a given year are shown below each timeline. The labels of the most cited references are shown at the lowest position in the figure. In this section, we focus on all clusters.

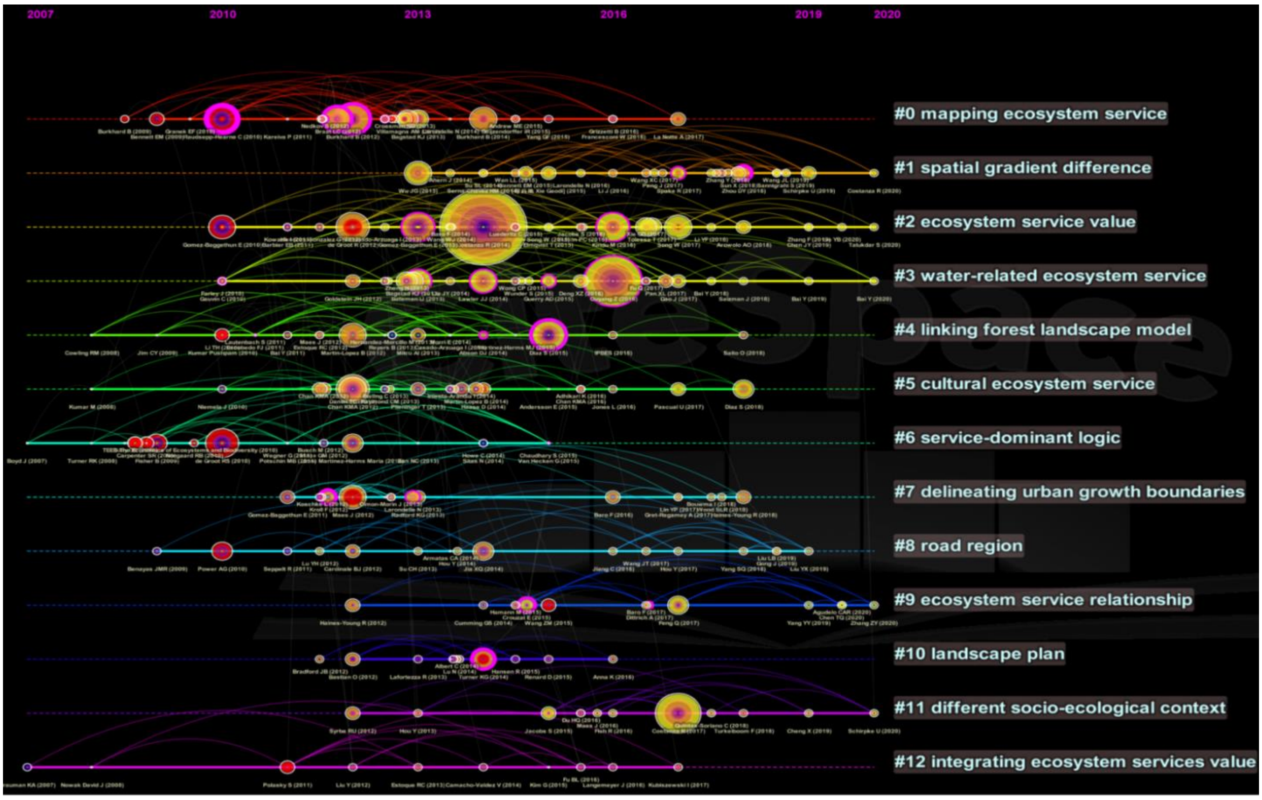

Figure 12. A timeline visualization of clusters.

3.5.3. References with Strongest Citation Bursts

In Table 2, we can learn relevant information about the top 22 references with the strongest citation bursts during 2015–2021, such as year of publication, DOI, and strength. Most of the literature was published in top journals with high impact factors. The Sigma metric measures both citation explosion and structural centrality of the cited literature. Among them, the largest amount of literature focused on the concept and diversity of ecosystem services; for example, de Groot R S, Raudsepp-Hearne C (2010) and Turner K G (2014) conducted a spatial analysis of multiple ecosystem services in landscape planning; Fisher B (2009) and Hauck J (2013) theoretically and empirically analyzed the definition and classification of ecosystem services, respectively, from the level of environmental decision; Bennett E M (2009) proposed a typology of ecosystem services to analyze the relationship of multiple ecosystem services; Burkhard B (2009), Wang Z M (2015), Nelson E (2009), and Polasky S (2011) used the GIS and InVEST methods to analyze the change of multiple-ecosystem service through changes in land use/cover; Maes J (2012) covered water-related ecosystems based on land cover by mapping ecosystem services. Secondly, eight papers focused on the value of ecosystem services. Finally, Carpenter S R (2009), Power A G (2010), Haase D (2014), and Zhou D Y (2018) focused on studying social ecosystem services, agro-ecosystem services, and urban ecosystem services, respectively.

Table 2. Top 22 references with strongest citation bursts.

References	Year	Strength	Begin	End	2015–2021
de Groot R S, 2010, [31] ECOL COMPLEX, V7, P260, DOI 10.1016/j.ecocom.2009.10.006	2010	7.76	2015	2018	
Fisher B, 2009, [32] ECOL ECON, V68, P643, DOI 10.1016/j.ecolecon.2008.09.014	2009	6.84	2015	2017	
Raudsepp-Hearne C, 2010, [33] P NATL ACAD SCI USA, V107, P5242, DOI 10.1073/pnas.0907284107	2010	6.39	2015	2018	
Bennett E M, 2009, [34] ECOL LETT, V12, P1394, DOI 10.1111/j.1461-0248.2009.01387.x	2009	5.86	2015	2017	
Carpenter S R, 2009, [35] P NATL ACAD SCI USA, V106, P1305, DOI 10.1073/pnas.0808772106	2009	4.87	2015	2017	
Gómez-Baggethun E, 2010, [36] ECOL ECON, V69, P1209, DOI 10.1016/j.ecolecon.2009.11.007	2010	4.35	2015	2018	
Daily G C, 2009, [37] FRONT ECOL ENVIRON, V7, P21, DOI 10.1890/080025	2009	2.91	2015	2017	
Muradian R, 2010, [38] ECOL ECON, V69, P1202, DOI 10.1016/j.ecolecon.2009.11.006	2010	2.33	2015	2018	
Power A G, 2010, [39] PHILOS T R SOC B, V365, P2959, DOI 10.1098/rstb.2010.0143	2010	4.65	2016	2018	
Nelson E, 2009, [40] FRONT ECOL ENVIRON, V7, P4, DOI 10.1890/080023	2009	3.23	2016	2017	
Kumar Pushpam, 2010, [41] EC ECOSYSTEMS BIODIV, V0, P0, DOI 10.4324/9781849775489	2010	3.23	2016	2017	
Hauck J, 2013, [42] ENVIRON SCI POLICY, V25, P13, DOI 10.1016/j.envsci.2012.08.001	2013	2.69	2016	2017	
Burkhard B, 2009, [43] Landscape Online, V0, P0, DOI 10.3097/LO.200915	2009	2.69	2016	2017	
Norgaard R B, 2010, [44] ECOL ECON, V69, P1219, DOI 10.1016/j.ecolecon.2009.11.009	2010	2.69	2016	2017	
Villamagna A M, 2013, [45] ECOL COMPLEX, V15, P114, DOI 10.1016/j.ecocom.2013.07.004	2013	2.6	2016	2017	
Wang Z M, 2015, [46] SCI TOTAL ENVIRON, V514, P119, DOI 10.1016/j.scitotenv.2015.01.007	2015	3.01	2018	2019	
Maes J, 2012, [47] ECOSYST SERV, V1, P31, DOI 10.1016/j.ecoser.2012.06.004	2012	2.98	2018	2019	
Polasky S, 2011, [48] ENVIRON RESOUR ECON, V48, P219, DOI 10.1007/s10640-010-9407-0	2011	2.37	2018	2019	
Turner K G, 2014, [49] LANDSCAPE URBAN PLAN, V125, P89, DOI 10.1016/j.landurbplan.2014.02.007	2014	2.1	2018	2019	
de Groot R, 2012, [50] ECOSYST SERV, V1, P50, DOI 10.1016/j.ecoser.2012.07.005	2012	3.24	2019	2021	
Haase D, 2014, [51] AMBIO, V43, P407, DOI 10.1007/s13280-014-0503-1	2014	3.01	2019	2021	
Zhou D Y, 2018, [52] ECOL INDIC, V95, P152, DOI 10.1016/j.ecolind.2018.07.007	2018	2.25	2019	2021	

3.5.4. Cluster Analysis

Cluster #0—Mapping Ecosystem Service

The cluster has 27 members and a silhouette value of 0.895. The main research contents of the important papers citing this cluster are as follows: (1) Vollmer et al. (2016) applied the four-step spatial multi-criteria analysis (MCA) method that includes scenario development, quantification, and mapping of ecosystem services, preference weighting, and optimization to obtain spatially explicit information on ecosystem services as an important input factor for maximizing ecosystem services and minimizing costs in regional spatial planning [53]; (2) Depellegrin et al. (2016) raised a method of ES potential assessment; this method used a two-dimensional ES matrix and geospatial analysis based on GIS to confirm the urban and forest ES potential and forest of Lithuania, the spatial correlation of regulating, cultural, and provisioning ES, and to identify geospatial distribution factors [54]; (3) Vrbičanová et al. (2020) focused on the "hot-spots" of ecological socio-cultural value accumulation, linking land cover information obtained using ES matrices, GIS methods, and field survey data to compare and analyze the CES provisioning capacity in areas with higher and lower cultural values [55].

According to Figure 12, it can be seen that the cluster had a high level of activity during the period of 2009 to 2017. There were six original articles with outstanding contributions during this period [33,34,43,56–58].

Cluster #1—Spatial Gradient Difference

The cluster has 26 members and a silhouette value of 0.995. The main research contents of the important papers citing this cluster are as follows: (1) Shen et al. (2021) analyzed the spatial patterns and interrelationships of six ES provisioning in specific regions and found that different ESs and socio-ecological drivers at different scales interact with each other in terms of direction and depth [59]; (2) Li et al. (2020) revealed the spatial and temporal effects between ES and urbanization and emphasized the importance of CES by zoning and evaluating CES based on the urbanization levels [60]; (3) Xu et al. (2021) analyzed the spatial imbalance and differentiating features of ES supply and demand within and between cities in terms of regional ES supply functions, ES function types, and ES value changes [61].

According to Figure 12, it can be seen that the cluster had a high level of activity during the period of 2013 to 2020. There were three original articles with outstanding contributions during this period [52,62,63].

Cluster #2—Ecosystem Service Value

The cluster has 26 members and a silhouette value of 0.979. The main research contents of the important papers citing this cluster are as follows: (1) Xi et al. (2021) used the equivalence coefficient approach to evaluate the ESV of Zhoushan Islands in the context of changes on land use/cover and used the "Future Land Use Simulation Model" to simulate the ESV under various scenes in 2025 [64]; (2) Ma et al. (2021) incorporated an ecosystem service assessment that emphasizes representing the ecological benefits of land into a fuzzy multi-objective linear programming (FMLP) model, analyzed the cities with unbalanced land use structures, and pointed out that an optimizing land use construction is beneficial to realize the double-winning in terms of ESV and economic benefits [65]; (3) Castillo-Eguskitza et al. (2019) calculated the monetary and biophysical values of ESs in conjunction with land use changes in a time series, and revealed the importance of intermediate values as the core component with the highest degree of overlap between the two ecosystem service assessments [66]; (4) Jiang et al. (2020) adopted a combination of indicators and benefit transfers to analyze the impact of land use/cover change on ESV, and used elasticity as a measure of anomalous change between regions [67].

According to Figure 12, it can be seen that the cluster had a high level of activity during the period of 2010 to 2020. There were five original articles with outstanding contributions during this period [36,50,68–70].

Cluster #3—Water-Related Ecosystem Service

The cluster has 24 members and a silhouette value of 0.986. The main research contents of the important papers citing this cluster are as follows: (1) Liu et al. (2021) used an integrated evaluation and trade-off of ecosystem services (InVEST) model that includes quantification and mapping of WRESs, scenario analysis, and the average ecological effect (AEE) indicator, pointed out that forest expansion and grassland shrinkage play a dominant role in WRES changes, and revealed that different scenarios show significantly different directions of influence on soil and water quality combined with the AEE indicator [71]; (2) Liang et al. (2021) estimated the magnitude of changes in water production, grain production, sediment export, and soil conservation between 1980 and 2015 under the WRESs trade-off assessment framework, constructed four land use scenarios to investigate the interaction of land use change and ESs in the Xiangjiang River Basin, and pointed out that the combined scenario is the optimal scenario [72]; (3) Yang et al. (2021) assessed the changes in grain production, arable land area, water production, soil conservation, and nitrogen and phosphorus export in the Songhua River Basin (SRB) during 2000–2015 in the temporal dimension and analyzed the relationship between the five in the spatial dimension. In addition, they concluded that grain production affects WESs through changing land use [73]; (4) Cai et al. (2020) examined WRESs from the standpoint of supply and demand budgets and flow analysis, based on the sub-regional examination of relation between supply and demand of core cities in the specific river basin, classified cities, and identified two types of intercity relationships, cooperative and non-cooperative based on six types of ecosystem service city definitions, which are important for promoting ecological integration in highly urbanized areas [74].

According to Figure 12, it can be seen that the cluster had a high level of activity during the period of 2010 to 2020. There were four original articles with outstanding contributions during this period [75–78].

Cluster #4—Linking Forest Landscape Model

The cluster has 23 members and a silhouette value of 0.919. The main research contents of the important papers citing this cluster are as follows: (1) Haga et al. (2019) presented a LANDIS-II model linking models and social scenarios, quantitatively analyzed the effects of population distribution and capital preference assumptions on natural capital and ES, respectively, examined the consequences of influencing natural capital and ES, and further analyzed their relationships with social drivers and ecological processes [79]; (2) Lhoest et al. (2020) adopted an integrated ES assessment method that quantifies the per capita ES use provided by tropical forests in a region, and examined the main factors affecting ES use. This method had important implications for the rational management and conservation of threatened tropical forests [80]; (3) Lorilla et al. (2018) quantified seven ESs of the Ionian Islands and then understood ES interactions in the spatio-temporal dimension by analyzing ES relationships, identifying ES bundles, and specifying the occurrence of ESs within bundles, which can be a guide for sustainable management of archipelagic ecosystems [81].

According to Figure 12, it can be seen that the cluster had a high level of activity during the period of 2008 to 2018. There were three original articles with outstanding contributions during this period [41,82,83].

Cluster #5—Culture Ecosystem Service

The cluster has 22 members and a silhouette value of 0.879. The main research contents of the important papers citing this cluster are as follows: (1) Johnson et al. (2019) quantified and incorporated park benefits into CES framework of the Millennium Ecosystem Assessment (MEA), sorted out three ways to stimulate CES in urban green spaces, and revealed the characteristics of CES categories in Prospect Park, Brooklyn [84]; (2) Müller et al. (2019) assessed the presence of CES in biosphere reserves and the relationship between CES and biodiversity by investigating visitors' use of the landscape, their perception and evaluation of CES, and the relationship with biodiversity [85]; (3) Giedych et al. (2017) used data from existing policies on the spatial planning and environment of Warsaw's parks to assess cultural ecosystem services in Warsaw's green spaces in ten ways, and thus to derive the actual impact, potential capacity, and category of all evaluated parks [86]; (4) In order to reduce the possibility of underestimation of ES with insufficient information, Canedoli et al. (2017) obtained spatially explicit data on the perception of cultural services in parks and messages from both matching or mismatching patterns by separately mapping and contrasting cultural ecosystem services (CES) of urban park users and park management [87].

According to Figure 12, it can be seen that the cluster had a high level of activity during the period of 2008 to 2018. There were three original articles with outstanding contributions during this period [51,88,89].

Cluster #9—Ecosystem Service Relationship

The cluster has 14 members and a silhouette value of 0.969. The main research contents of the important papers citing this cluster are as follows: (1) Xu et al. (2021) focused on the study of the coupling relationship between ESs and mapped the spatial and temporal dynamics of ESBs to more accurately understand the relationship between ESs at different scales [90]; (2) Yang et al. (2019) used the ES bundle approach at the county level to analyze ESs with similar dominance in rapid urbanization processes, analyzed seven important ESs and five different ES bundles to identify the main drivers, dominant services, and multiple functions that showcase the landscape, and formed the corresponding ecosystem service portfolio [91]; (3) Gou et al. (2021) integrated use of Pearson parametric correlation analysis, redundancy analysis, and k-means cluster analysis to analyze the spatial and temporal changes of ESBs and their socio-ecological driving factor in the Three Gorges Reservoir area from a historical dynamic perspective, and revealed the main drivers and their time dependence [92].

According to Figure 12, it can be seen that the cluster had a high level of activity during the period of 2012 to 2020. There were three original articles with outstanding contributions during this period [46,93,94].

Cluster #11—Different Socio-Ecological Context

The cluster has 12 members and a silhouette value of 0.970. The main research contents of the important papers citing this cluster are as follows: Costanza et al. (2017) comprehensively assessed main ESs in small mountain lakes, incorporated indicators from ethological, spatial, and socioeconomic data into a quantitative system of non-monetary ESs, and thus revealed the variability of ES levels in lakes [95].

According to Figure 12, it can be seen that the cluster had a high level of activity during the period of 2012 to 2020. There was one original article with outstanding contributions during this period [96].

3.6. Structural Variation Analysis (SVA)

Most of any citation-based metrics cannot avoid the dependence on citations accumulated for a long time. Therefore, based on the disadvantage that this measure tends to ignore newly published articles, we can use SVA as an alternative method to understand the effect of a newly published article on the conceptual structure of concerned intellectual field by searching for additional links that may change or have the potential to change the global structure [11,97]. This approach is useful to identify the potential of an article to create unusual or unexpected links between different clusters. Based on the theory of scientific discovery, numerous important contributions are generated by ideas that cross boundaries [7].

Based on this, we use SVA (the sliding window time span of six years was adopted) to examine the converted potential of recent studies. Table 3 enumerates the articles with high transformative potential, which were measured by the centrality divergence metric (one of the three structural variance metrics). All of the articles on the list were published in 2021. The first paper on the table has already been cited 25 times. It focused on the collaborations and trade-offs between ESs in relation to changes in spatial scale and pointed out that the reconfiguration of ecosystem service packages changes with spatial scale and that the degree of influence of socio-ecological drivers on ESs also varies with scale [59]. The second paper has already been cited 22 times and revealed the differential ring structure of ES by establishing a spatial gradient of ES supply and demand [61]. The third paper has been cited eight times. It quantified ESV using a direct benefit transfer program based on spatio-temporal LULC database generated from satellite imagery over the period 1988–2018 [98]. The last paper on the list has the same centrality divergence metric as the third article, which examined the relationship between household demographic factors, land use, ESs, and HWB by using data from 2007 to 2016 [99]. Interested readers may revisit this list regularly and surveillance whether the transformative potential is achieved.

Table 3. Potentially transformative papers published recently.

Δ Centrality	References	Journal	Title
0.05	Shen et al. (2021) [59]	J CLEAN PROD	Uncovering the relationships between ecosystem services and social-ecological drivers at different spatial scales in the Beijing-Tianjin-Hebei region
0.04	Xu et al. (2021) [61]	J CLEAN PROD	Spatial gradient differences of ecosystem services supply and demand in the Pearl River Delta region
0.02	Sharma et al. (2021) [98]	ENERGY ECOL ENVIRON	Longitudinal study of changes in ecosystem services in a city of lakes, Bhopal, India
0.02	Zhang et al. (2021) [99]	SUSTAINABILITY	Linking demographic factors, land use, ecosystem services, and human well-being: Insights from an sandy landscape, Uxin in Inner Mongolia, China

Figure 13 displays some information of a newly published paper. We focus on three structural change indicators. The centrality divergence indicator confirms that the paper has a high conversion potential. It also ranks relatively high on the modularity change indicator. The visualization shows the distribution of references cited in the paper across various clusters. The next question is whether these cross-cluster connections reveal an underlying boundary-spanning mechanism [11].

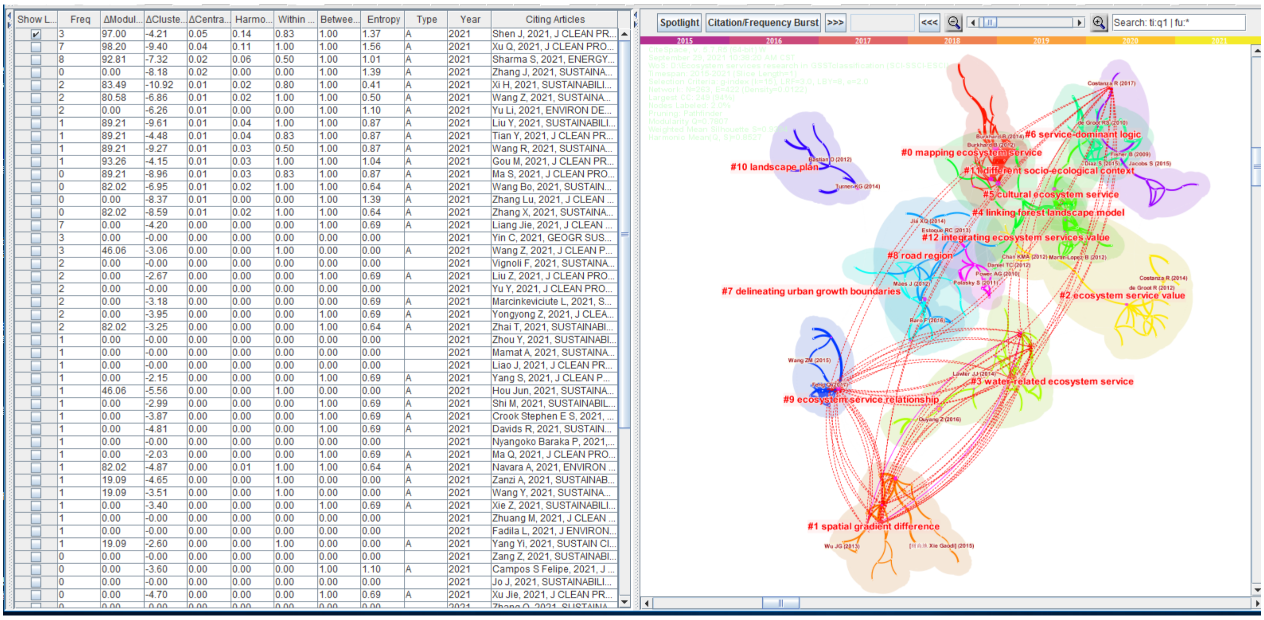

Figure 13. Articles identified by SVA with high transformative potential based on centrality divergence.

4. Conclusions and Policy Implications

This paper utilizes bibliometric methods to review the discipline co-occurrence, publication characteristics, partnership, keyword co-occurrence, co-citation, research themes, and the transformative potentials of recent papers in ES within the GSST field at the quantitative and qualitative levels, respectively. The use of interactive visualization considerably reduces the cognitive load of visual exploration of scientific literature.

Based on the WoS database, there were a total of 513 records related to ES research in the GSST field between 1 January 2015 and 7 September 2021. The annual publication volume showed a growing trend during this period. More source journals are located in "7. VETERINARY, ANIMAL, SCIENCE" and "3. ECOLOGY, EARTH, MARINE". The solid foundation of research on ES in the GSST field are located in "2. ENVIRONMENTAL, TOXICOLOGY, NUTRITION", "10. PLANT, ECOLOGY, ZOOLOGY" and "12. ECONOMICS, ECONOMIC, POLITICAL". From a global perspective, four countries have published more than 40 papers in this area, demonstrating a high degree of cooperativeness with other countries/regions. There are nine authors that have published more than six articles. There are six papers originated from the journal "Current Opinion in Environmental Sustainability" among the top ten cited papers. CHINA, USA, GERMANY, and UK perform an important role in the main country collaboration network. Chinese Acad Sci, Univ Chinese Acad Sci, and Beijing Normal Univ perform an important role in the main institution collaboration network. Ouyan Zhiyun, Pereira Paulo, Liu Yanxu, Wang Lei, Li Cong, Jiang Wei, and Fu Bojie performed an important role in the main author collaboration network.

Furthermore, a keyword co-occurrence analysis indicates that the hot topics of previous research were with respect to "environmental service", "capacity", "perception", "landscape", "forest management", "carbon sequestration", "contingent valuation", and "sustainable development". Recent hotspots include "blue carbon", "environmental impact", "coastal", "ecosystem services mapping", and "use/land cover change".

Finally, the cluster analysis of co-cited references abstract thirteen largest clusters. The top six clusters were "mapping ecosystem service", "spatial gradient difference", "ecosystem service value", "water-related ecosystem service", "linking forest landscape model", and "culture ecosystem service". The integration of spatial, value, environmental, and sociocultural dimensions may help to develop supportive policies, which is a future direction of ES research in the GSST field. The results of SVA analysis show that the cross-group citation of articles with high transformation potential was a good proof.

Given these findings and the associated implications, this paper yields several policy recommendations regarding ES in the field of GSST.

First, "blue carbon" is a recent hotspot of ES research in the GSST field such as addressing global climate change, biodiversity conservation, and sustainable development. Compared to terrestrial afforestation to increase green carbon sinks, the efficient carbon sequestration of blue carbon ecosystems is a very effective option to increase blue carbon sinks. An analysis of the classical literature reveals that the conservation and restoration of blue carbon is a key direction of blue carbon research, and there is an urgent need to avoid irreversible damage and further degradation of existing blue carbon resources through the development of effective monitoring and conservation plans. As blue carbon is an emerging field, research has not yet gained mature progress and does not intersect much with the cooperation and application of various disciplines, which is worthy of continued exploration by the industry and scholars.

Second, the recent hotspots also include coastal, which focuses on coastal zones and coastal wetlands. The coastal zone is the most frequent and concentrated area for the exchange of materials, energy, and information among the earth's sea, land, and air systems, and is the most sensitive and fragile zone for the ecological environment, as well as an area with a large population, rich resources, and a high degree of development, and the center of national economic construction and social development. Coastal wetlands are one of the most productive ecosystems, which not only provide resources such as rich land resources, biological resources, hydrocarbon resources, aquaculture resources, and salt resources, but also play an important role in maintaining biodiversity, optimizing the environment, purifying water, regulating climate, providing habitat, and cultural services. However, there are few studies on the changing landscape patterns of coastal zones and coastal wetlands, and the intersection with various resources such as cultural services and biology, which could continue to be studied in depth.

Third, use/land cover change is an important current research topic of the ES research in GSST field. Information on land use/cover dynamics reflects changes in regional land cover conditions under the influence of a combination of natural, economic, and human activities. The land use change is primarily linked to human activity, which is the main factor causing land use change. Land use/cover types, inter-type dynamics, and driving factors are the key directions of research, especially on land use/cover dynamics between forests, wetlands, croplands, grasslands, shrubs, watersheds, and built-up land, which can provide scientific data reference and basis for regional sustainable development strategies.

Last, the integration of spatial, value, environmental, and sociocultural dimensions is a future direction of ES research in the GSST field. As ESs cover all the services that humans can derive from ecosystems such as supply services to provide subsistence material, regulation services to control flood and disease, cultural services to meet spiritual needs, and support services to maintain the living environment. The resources needed for human survival and development are ultimately derived from natural ecosystems. Therefore, sustainable development strategies that meet all aspects of human needs while preserving the Earth's life-support systems should be developed along spatial, value, environmental, and sociocultural dimensions.

Author Contributions: J.T.: Conceptualization, Software, Writing—original draft, Writing—review and editing; Y.F.: Writing—original draft, Writing—review and editing; Z.T.: Data curation, Formal analysis; Y.G.: Formal analysis, Software, Funding acquisition, Writing—review and editing; L.Y.: Formal analysis, Project administration. All authors have read and agreed to the published version of the manuscript.

Funding: This study is supported by the National Social Science Foundation of China (20BGL201) and Hunan Provincial Natural Science Foundation of China (2021JJ30281).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All remaining errors are on our own.

Conflicts of Interest: The authors declare no conflict of interest.

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