Review

Mapping the Research Trends of City Biodiversity from 1995-2021: A Bibliometric Analysis

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Review

Mapping the Research Trends of City Biodiversity from1995-2021: A Bibliometric Analysis

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Abstract: The biodiversity loss in urban areas has attracted public concern, which is one of the urgent global environmental issues. This study used bibliometric methods to analyze 3351 publications from 1995-2021 that retrieved from the Web of Science and visually represented the state-of-the-art of researches in city biodiversity field. The prolific authors, journals(sources), institutions, and countries are clearly identified. The most cited and influential paper proposed a conceptual framework of associations between urban green space, and ecosystem and human health, and then concluded that green infrastructure could physically and psychologically benefits people by ecosystem services it provides, and make a better socio-economic benefit. The theme hotspots are urbanization, urban ecology, ecosystem services, urban planning, green infrastructure, urban forest and urban park et al. Ingo Kowarik is the most productive author in terms of number of publications. Michael L. McKinney is the most cited authors by the publications in analyzed corpus, who identified how urbanization harms native ecosystems, however, a well ecologically educated population could greatly enhance species richness in all ecosystems. Urban park, garden, fragmented green spaces and green corridor networks could help enhance city biodiversity. In general, the city biodiversity research presents a trend that involves intensive global cooperation, and become more comprehensive.

Keywords: city biodiversity; bibliometric analysis; bibliometrix; research development; research trend; science mapping

1. Introduction

The biodiversity issues in urban areas have attracted public concern, which is one of the urgent global environmental issues [1]. Biodiversity loss is associated with urbanization [2–5], and has influenced ecosystem function, ecosystem services, socioeconomic, human health [6–8]. With the megatrend of urbanization and urban land expansion, by 2030, 60% of global population is project to live in urban area [9], the biodiversity issue is expected to be a more critical challenge for sustainable development in future. In China, extremely rapid urbanization is undergone, and resulted in natural habitat loss, which threats biodiversity [5]. As stated in *Sustainable Development Goals*, by 2020 ecosystem and biodiversity values should be integrated into national and local planning, development processes, poverty reduction strategies and accounts; Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species [10]. UN Biodiversity Conference (COP 15) will be hosted in Kunming, Yunnan Province, China, and looks to achieve a new set of goals for nature over the next decade [11].

Biodiversity is the basis of ecosystem functioning and plays a positive role in provision of ecosystem services with benefit to human well-being [12]. The impact of biodiversity on human society is multifaceted. Genetic richness plays a fundamental role for crop development and food security. Traditional medicine plays an essential role in health care, which is used by 60% of global population [13]. Furthermore, biomedical research on wildlife anatomy, physiology, and biochemistry

could benefits development of human health care [14]. Protecting biodiversity could help adapt to climate change sby enhancing resilience of ecosystem [15]. Biodiversity and healthy ecosystems could help on natural disaster reduction[16]. Biodiversity has social, cultural and spiritual importance [14].

Cities could contribute to biodiversity conservation [17,18], although urbanization and urban expansion is associated with biodiversity loss. J.A Pupppim de Oliveira discussed proper housing and infrastructure policies in urban planning to promote biodiversity conservation [19]. In practice, the size of habitat patches should be greater than 50 ha to preserve species richness [20], and the corridors networks among habitat patches are important for biodiversity conservation in urban [21]. Private garden is an effective tool for city biodiversity conservation [22], and gardens sit around urban park can increase species richness in corresponding park [23]. A careful start point is required for achieving success biodiversity conservation. Firstly, we should find what are the motivations for public involvement. The possible answer is fulfilling ethical obligations[24], preserve local biodiversity, creating stepping stones to nonurban habitat, understand and facilitate species' responses to environmental changes, conducting environmental education, providing ecosystem services, and improving human well- being [25].

The literature in city biodiversity field is rapidly increasing, and it increased unfeasible to synthesize with the frontier of past research findings. Voluminous and fragmented research are obstacles for knowledge accumulation [26]. Therefore, bibliometric analysis is applied on researches to synthesize previous research findings and provide evidence-based insights into the practice of exercising and sustaining professional judgement and expertise [27]. Several studies applied bibliometric analysis on specific topics. Shoukai Sun et al. analyzed the research on Ecological Infrastructure (EI) from 1990-2018 [28]. Dagmer Haase et al. focused on urban ecosystem service assesments. Barbara Clucas et al. analyzed relationship between urban agriculture and biodiversity [29]. However, few scholars had contributed to bibliometric analysis on biodiversity research and present a comprehensive insight. This study is design to achieve following objectives:

1. Identify the most prolific authors, journals, institutions, and countries in city biodiversity field.
2. Identify the collaboration among authors, institutions, and countries.
3. Identify the most influential publications, then their finding and implications, and how they involved over the time.
4. Identify conceptual structure and its evolution over time, and hot themes for future research.

By filling the gaps of bibliometric analysis on city biodiversity, this research could provide a comprehensive insight in to city biodiversity field, and help scholars quickly identify exist research structure and find topics that worth to explore.

2. Methods and Data

2.1. Methods

This study is based on the standard science mapping workflow [30,31], which consists of five stages:

- Research design;
- Data collection;
- Data analysis;
- Data visualization;
- Interpretation;

The purpose of this study is mapping the researches in city biodiversity field and to present a insight into the development of city biodiversity filed by using bibliometric methods. Thus, "city biodiversity" is selected as the search keyword. Several science databases are available for article data retrieval, such as Clarivate Analytic Web of Science (WoS), Scopus, Google Scholar et al.

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Scopus only has citation information from 1996 onward [32]. Google Scholar is lack of competence on citation indexing [32]. The WoS has the longest coverage with more detailed of both bibliographic and citation data from 1900 onward [32,33]. Therefore, our publication data is retrieved from the WoS.

After data retrieval process, bibliometric methods are applied: descriptive statistic analysis [34], co-citation analysis [35], co-author analysis [34,36,37], co-word analysis [38], collaborating networks analysis [39], and thematic analysis [40]. Finally, the results are interpreted and discussed.

So far, scholars have developed many software tools for bibliographic analysis, such as the Science of Science (Sci2) [41], Loet [42], SciMAT [43], VOSviewer [44], Bibexcel [45], CiteSpace [46], CiteNetExplorer [47], and ScientoText (R package) [48]. However, none of these software supports the entire workflow of science mapping [30]. Therefore, the Bibliometrix 3.1 [49], a R package developed by Aria and Curulo [30], is used to apply bibliographic analysis. Rstudio desktop 1.4 [50] is used as the platform to serve the Bibliometrix.

2.2. Data

Corpus data is obtained from Core Collection of the WoS. The aims of this research is to insight into research field of city biodiversity by using bibliometric analysis. Thus, "city biodiversity" is identified as the saerch keyword. The timespan is limited to no later than 31, August of 2021, and language is limited to English only. The following search strategy was conducted in September, 7, 2021:

TOPIC: city biodiversity
AND Language: English
Database: Web of Science Core Collection
Timespan: no later than 2021-08-31

A total of 3351 articles were obtained from the WoS. All data are exported and saved into "bibtex" format with full record and cited references. Each of record in corpur has following fields: author, journal, year, abstract, address, type, language, times-cited, affiliation, keywords, keywords-plus, research-areas, web-of-science-categories, cited-references.

3. Results and Discussion

3.1. Overview and Trend of Research Development on City Biodiversity

Figure 1 and Table 1 shows the general trend of research on city biodiversity from 1995 to 2021, and no publication is found before 1995. A total of 3351 documents are analyzed, and involving 10604 authors and 755 journals. This indicates city biodiversity attracts a broad interests from diverse journals and scholars. Before 2008, the number of articles was growing mildly, since then, growing steeply, the annual growth rate was 26.60%. The general trend indicates city biodiversity research is in expansion and keep attracting interests from scholars.

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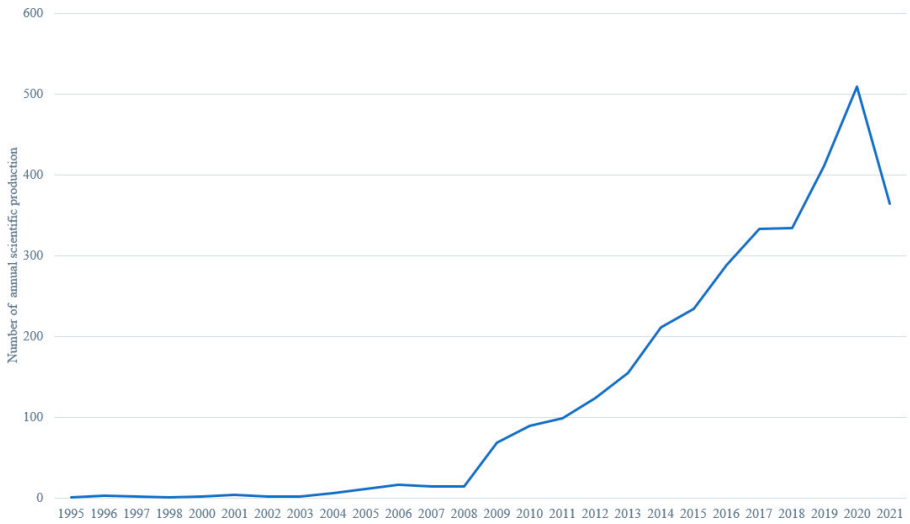

Figure 1. Number of annual publications on city biodiversity based on Web of Science core collection data from 1995-2021.

Table 1. Main Information of analyzed publications on city biodiversity from 1995-2021.

Timespan	1995:2021
Sources (Journals)	755
Documents	3351
Average citations per documents	23.18
Average citations per year per doc	3.54
Author's Keywords	8878
Authors	10604
Authors of single-authored documents	221

As regards document types, the majority were article (n=3128, 93.35%), followed by review (n=179, 5.34%) and editorial materials (n=31, 0.93%), other document types such as data papers, letters, book chapters et.al. counts less than 10 publications.

Table 2 shows the research areas on city biodiversity. "*Environmental sciences ecology*" was the highest frequent (n= 2291, 68.368%), following were "*Urban studies*" (n=741, 22.113%) and "*Biodiversity conservation*" (n=626, 18.681%). Top-12 research ares were the exceeded 100 publications, others were less common with less than 100 publications.

Table 2. Top 20 research areas of city biodiversity from 1995-2021.

Rank	Research Areas	Record Count	% of 3,351
1	Environmental Sciences Ecology	2291	68.368
2	Urban Studies	741	22.113
3	Biodiversity Conservation	626	18.681
4	Science Technology Other Topics	372	11.101
5	Plant Sciences	344	10.266
6	Geography	326	9.728
7	Physical Geography	309	9.221
8	Forestry	301	8.982
9	Public Administration	283	8.445
10	Zoology	156	4.655
11	Geology	108	3.223
12	Engineering	102	3.044
13	Entomology	94	2.805
14	Marine Freshwater Biology	87	2.596
15	Agriculture	84	2.507
16	Water Resources	82	2.447
17	Life Sciences Biomedicine Other Topics	78	2.328

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18	Evolutionary Biology	75	2.238
19	Remote Sensing	51	1.522
20	Business Economics	46	1.373

In addition, more than half of analyzed publications are open access, 1459 publications are all open access and 793 publications are gold access. Scholars focusing on city biodiversity are more likely to prefer open access to make their science production have a high visibility.

3.2. Country and Institution Performance

This section analyzes the performance of countries and institutions, including production, citation, collaboration. 3351 analyzed documents originate from 92 countries. Figure 2 shows the 10 most productive countries in terms of number of publications. United States was the most prolific countries by far (501 publications), followed by China (447 publications) and Germany (217 publications), these countries with Australia were the only four countries which exceeded 200 publications. There were 4 countries contributed between 100 and 200 publications, namely, in descending order, United Kingdom, Brazil, Italy and France. China has the highest number of multiple country publications.

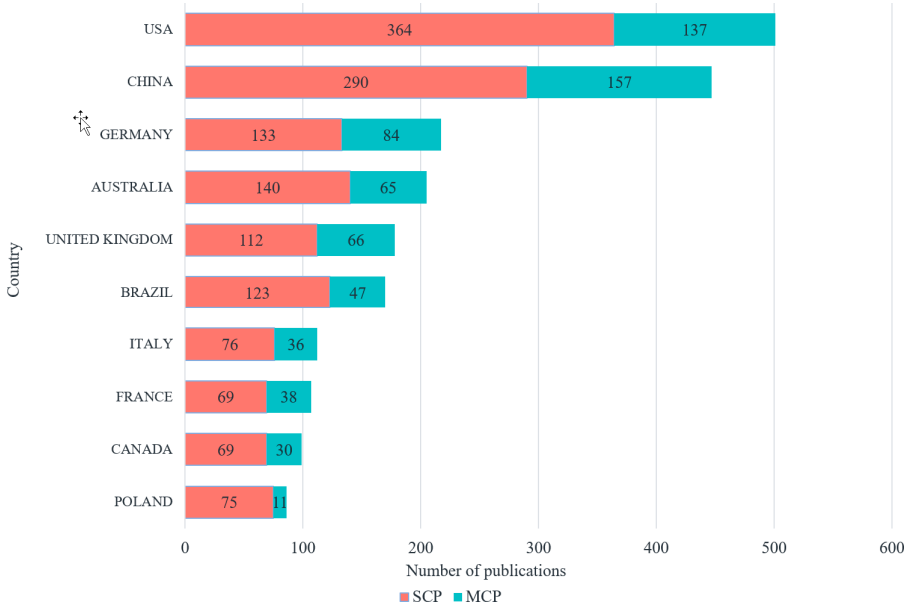

Figure 2. Number of country publication on city biodiversity from 1995-2021, grouped by multiple country publications (MCP) and single country publications (SCP). .

In terms of citations, Table 3 lists the top 10 most cited countries. The USA was dominant with more than 17571 citations, which was nearly double that of the United Kingdom (2nd in ranking). Australia ranks the third with 7534 citations. In terms of average article citations, Sweden ranks the first (49.646 citations per article), followed by United Kingdom (47.663 citations per article) and Australia (36.751 citations per article).

Table 3. The top 10 most cited countries on ciy biodiversity from 1995-2021.

Rank	Country	Number of Publications	Total Citations	Average Article Citations
1	USA	501	17571	35.072
2	United Kingdom	178	8484	47.663
3	Australia	205	7534	36.751
4	Germany	217	6737	31.046
5	China	447	6058	13.553
6	Sweden	79	3922	49.646
7	Italy	112	2411	21.527
8	Canada	99	2128	21.495
9	France	107	1885	17.617

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10	Brazil	170	1760	10.353

County collaboration networks demonstrates how countries work with each other in city biodiversity research. As shown in Figure 3, three collaborating groups are identified. Nodes denotes countries and links are cooperation between countries. The larger the node size, the more cooperation that corresponding country has, and the thicker the line, the closer cooperative relationship between tow linked countries. The color highlights different clusters. The countries within cluster are more likely to be associated in cooperation. United States is the most cooperative countries. China, United Kingdom and Australis are major patterner of United States. In addition, United States has intensive cross cluster cooperation with Germany and South Africa (in blue cluster), and Brazil (in green cluster). In general, we found that country collaboration is geographically correlated, the same as found in other research areas [51]. However, the global cooperation in cite biodiversity presents a intensive trend all around the world (Figure 4). The cooperation between countries facilitates research development by combing multi-disciplinary scholars, which positively affects the research in city biodiversity.

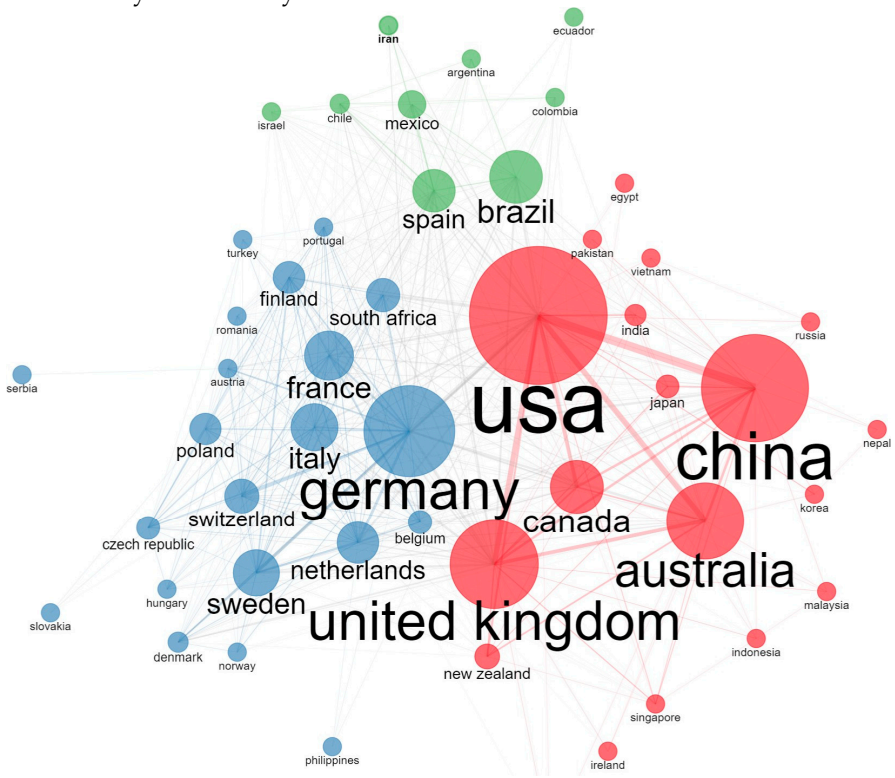

Figure 3. Country collaboration network based on co-authorship in city biodiversity from 1995-2021.

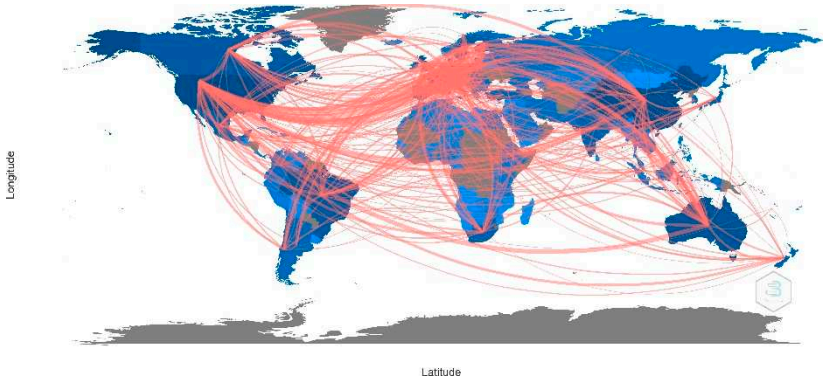

Figure 4. Country collaboration world map of city biodiversity research from 1995-2021.

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A total of 3518 institutions were identified in our corpus data, 45.96% (1617 institutions) of which published only one article. Table 4 shows the top-10 most productive institutions on city biodiversity. The Melbourne University was the most active institution, following were Technical University of Berlin, and Arizona States University. Institution collaboration presents a pattern that similar to country collaboration, United States institutions had more collaboration with institutions from China, United Kingdom and Australia. The institutions collaboration also is geographically correlated.

Table 4. The top 10 most productive institutions in city biodiversity field from 1995-2021.

Ranks	Institutions	Number of articles
1	UNIV MELBOURNE	162
2	ARIZONA STATE UNIV	117
3	UNIV NACL AUTONOMA MEXICO	107
4	TECH UNIV BERLIN	101
5	BEIJING NORMAL UNIV	97
6	UNIV HELSINKI	94
7	SWEDISH UNIV AGR SCI	86
8	CHINESE ACAD SCI	84
9	UNIV SHEFFIELD	83
10	UFZ HELMHOLTZ CTR ENVIRONM RES	81

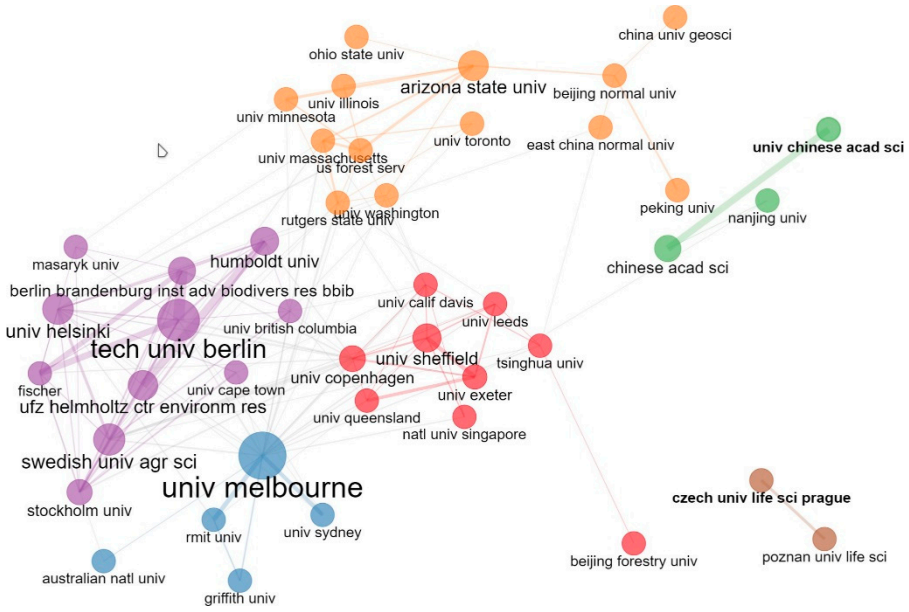

Figure 5. Collaboration network of institution based on co-authorship in city biodiversity fieldfrom 1995-2021.

3.3. Journal Performance

The analyzed 3351 articles were published on 675 journals, 55.11% (372 journals) of which have published only one article, and 49 journals(7.26%) have published 10 or more articles. Table 5 lists the top-10 most productive journals, on which 1036 articles were published, account for 30.91%. Landscape and Urban Planning (231 articles), and Urban ecosystems (212 articles) were the only two journals that published more than 200 articles, and rank the first and second, respectively. Following were Urban Forestry & Urban Greening, and Sustainability. It should be noticed that Landscape and Urban Planning published the first article on city biodiversity in 1997 in our corpus data, further more, it received highest citations, 9687 citations, which was nearly four times of second journal. The top-4 journals, as shown in Figure 6, are popular journals, the number of articles of which grows faster than others. In general, all top-10 journals are highs quartile and IF values.

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Table 5. The top 10 most productive journals on city biodiversity from 1995-2021.

Rank	Journal	h_Index	Total Citations	NP	IF	Quartile	Category	Year
1	Landscape and Urban Planning	54	9687	231	6.142	Q1	Ecology	1997
2	Urban Ecosystems	25	2748	212	3.005	Q2	Ecology	2011
3	Urban Forestry & Urban Greening	35	2821	183	4.537	Q2	Forestry	2009
4	Sustainability	17	933	111	3.251	Q2	Environmental Sciences	2011
5	PLOS ONE	25	3169	78	3.24	Q2	Multidisciplinary Sciences	2009
6	Ecological Indicators	24	1698	65	4.958	Q2	Environmental Sciences	2011
7	Science Of The Total Environment	16	993	51	7.963	Q1	Environmental Sciences	2009
8	Biological Conservation	21	1641	40	5.99	Q1	Biodiversity Conservation	2006
9	Land Use Policy	14	725	34	5.398	Q1	Environmental Studies	2004
10	Ecology and Society	20	1614	31	4.403	Q1	Ecology	2006

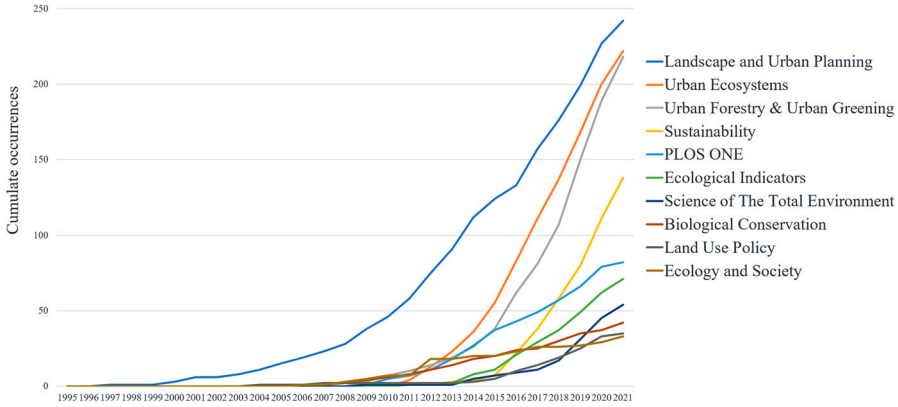

Figure 6. Journal growth on city biodiversity from 1995-2021.

3.4. Author Performance

A total of 10604 authors are identified in analyzed corpus. 8788 (82.87%) authors published only 1 article, 1647 (15.53%) authors published 2-5 articles, 123 (1.16%) authors published 6-10 articles. 46 (0.43%) authors published more than 10 articles.

Table 6 lists the top 10 most productive authors. Igno Kowarik from Technische Universität Berlin (Germany) is dominant in this rank, with 35 articles (h-index: 30, total citation: 1469), following are Kevin J.Gaston from University of Sheffield (United Kingdom) with 32 articles (h-index: 26, total citation: 3789), and C.Y Jim from The University of Hongkong (China) with 25 articles (h-index: 14, total citation: 638). There are three authors from Technische Universität Berlin. Two authors are from University of Melbourne.

Figure 7 shows the top 20 authors' publication over time from 1995-2021. The node size represents the number of publications, and the saturation represents the total citation per year. C.Y Jim published the first article, *Green-space preservation and allocation for sustainable greening of compact cities*, in 2004 on *Cities* [52], in addition, C.Y Jim is activate in the entire investigated time, and has publications in 2021. Ingo Kowarik and Kevin J. Gaston are, who are most prolific authors, have started to publish articles in 2011 and 2005, respectively. Ingo Kowarik's last paper is publishedin 2021, and Kevin J Gaston's recent paper is in 2018. Nicholas S. G. Williams, who active from 2009 to 2021, are as a co-author published the highest cited article in 2014. This article investigated more than 100 cites over the world to explore the urbanization's impact on bird and plant diversity [53], and received 569 citations. In general, majority top-20 authors are active during1995-2021, six authors have started publish before or in 2009.

As regard to author collaboration, as shown in Figure 8, 6 author groups are identified, which are highlighted in different color. The authors were represented as nodes, size of which indicates the

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number of articles published by given author and the lines represented the cooperation relationships between authors, thickness of which represented the intensity. of cooperation. Strong links are presented among Ingo Kowarik, Leonie K. Fischer, and M. Von Der Lippe, they barely have cooperation with authors from other groups. Two Chinese author groups have many authors involved, but, comparatively, less cooperation among them. In addition, a few cross-group collaboration between these two groups are detected. The blue color group centering on Nicholas S. G. Williams has more authors and intensive cooperation.

Table 6. The top 10 most productive authors on city biodiversity from 1995-2021.

Rank	Authors	N. of Article	h_index	Total citation	Year of first publication	Affiliation
1	Ingo Kowarik	35	19	1469	2011	Technische Universität Berlin (Germany)
2	Kevin J.Gaston	32	26	3789	2005	University of Sheffield (UK)
3	C.Y Jim	25	14	638	2004	The University of Hong Kong (China)
4	Dagmar Haase	23	16	1904	2008	Humboldt Universität zu Berlin (Germany)
5	IanMacGregor-Fors	22	11	420	2009	Universidad Nacional Autónoma de México
6	Nicholas S. G. Williams	21	16	2144	2009	The University of Melbourne (Australia)
7	Marco Moretti	19	11	464	2010	Swiss Federal Research Institute WSL (Swiss)
8	Leonie K. Fischer	18	11	421	2013	Technische Universität Berlin(Germany)
9	Erik Andersson	17	17	1569	2006	Stockholm University (Sweden)
10	Amy K. Hahs	16	11	1021	2009	University of Melbourne (Australia)

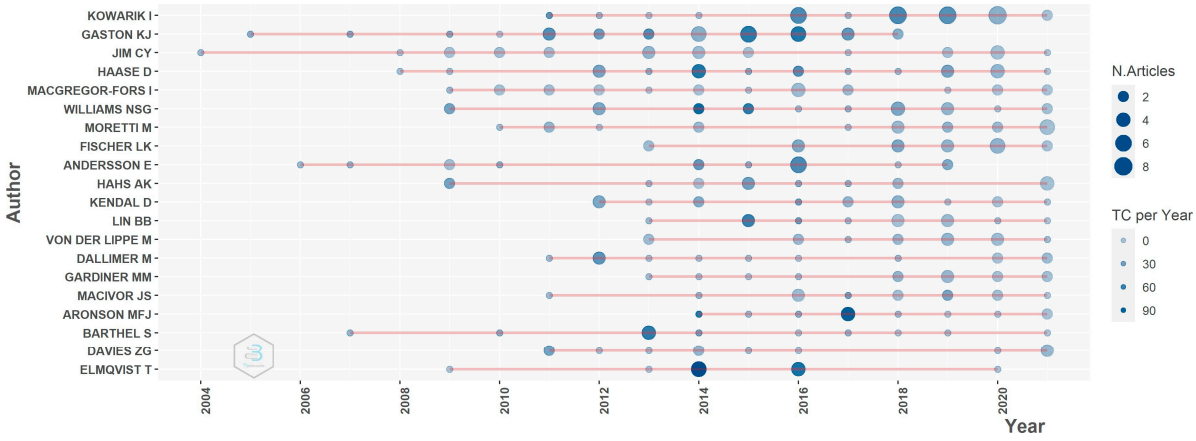

Figure 7. The top-authors publications over time from 1995-2021.

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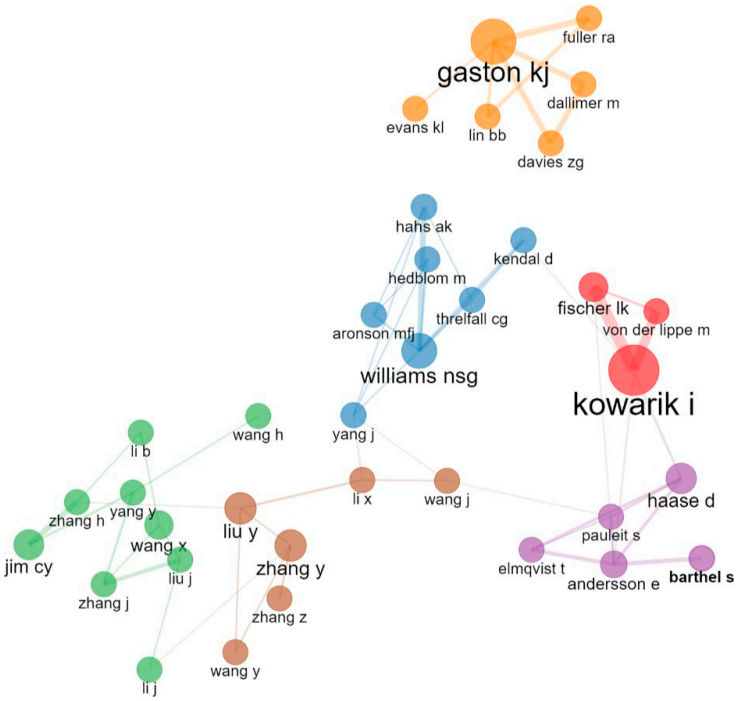

Figure 8. Collaboration network of authors.

3.5. Citation Analysis

The top 10 most cited documents in analyzed corpus were listed in Table 7. A frequently cited article in the research field, indicating it has been critically reviewed by scholars, which provide a profound basis for a theme or proposed an attracting direction for further researches. Analysis of frequently cited articles can help identify influential documents of city biodiversity.

The article *Promoting Ecosystem and Human Health in Urban Areas Using Green Infrastructure: A Literature Review*, published on Landscape and Urban planning by Konstantinos Tzoulas et al. [8] in 2007, has received the highest citations with 1239 total citations. Based on a synthesis of the literature, this paper proposed a conceptual framework of associations between urban green space, and ecosystem and human health, and then concluded that green infrastructure could physically and psychologically benefits people by ecosystem services it provides, in addition, make a better socio-0economic benefit [8].

Table 7. The top 10 most cited document in analyzed corpus from 1995-2021.

Rank	Authors	Title	Source	The First Author's Institution	Year	Total Citations
1	Konstantinos Tzoulas et.al. [8]	Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review	Landscape and Urban Planning	The University of Salford	2007	1239
2	Karen C. Seto et.al. [54]	A Meta-Analysis of Global Urban Land Expansion	PLOS ONE	Yale University	2011	1019
3	Mark A. Goddard et.al. [22]	Scaling up from gardens: biodiversity conservation in urban environments	Trends in Ecology & Evolution	University of Leeds	2009	739
4	James R. Miller [58]	Biodiversity conservation and the extinction of experience	Trends in Ecology & Evolution	Iowa State University,	2005	611
5	Myla F.J. Aronson [53]	A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers	Proceedings of the Royal Society B: Biological Sciences	The State University of New Jersey	2014	569
6	Marina Alberti [56]	The Effects of Urban Patterns on Ecosystem Function	International Regional Science Review	University of Washington	2005	543
7	S.T.A. Pickett et.al. [55]	Urban ecological systems: Scientific foundations and a decade of progress	Journal of Environmental Management	Cary Institute of Ecosystem Studies	2011	524
8	Jean-Pierre L Savard et.al. [59]	Biodiversity concepts and urban ecosystems	Landscape and Urban Planning	Canadian Wildlife Service	2000	485
9	Ingo Kowarik [57]	Novel urban ecosystems, biodiversity, and conservation	Environmental Pollution	Technische Universität Berlin	2011	485
10	Lucas N. Joppa et.al. [60]	High and Far: Biases in the Location of Protected Areas	PLOS ONE	Duke University	2008	473

Near half of frequently cited articles focus on urban land expansion [54], urbanization [53,55,56] impacts on biodiversity and ecosystem, and identified some urgent research directions. Another half of frequently cited articles are dedicated to biodiversity conservation from perspectives of managerial, principle and practical. urbanization caused homogenization of certain ecosystem function [55], the private gardens in urban area and novel urban ecosystems are value resources for enhancing biodiversity [22,57], conservation scientists should have partnership with public to convey conservation principles that make people work together to conserve biodiversity [58].

To further identify the articles the have made important contribution in city biodiversity field, most local citation is introduced to measure document impact. local citation measures the number of citations a document has received from documents included in the analyzed data collection. The top 10 most local cited articles are listed in Table 8, all of 10 most local cited articles have a higher number of global citation, indicating that these researches attract attention not only from specific research field of city biodiversity, but also more interests from a wide range of scholars who are with diverse academic backgrounds. In another side, this represents city biodiversity is a public concern urgent issue. Joscha Beninde et al. conducted the first meta-analysis on biodiversity variation of 75 cities worldwide, and concluded that the size of habitat patches and corridors networks are important for maintaining biodiversity in urban [20]. Donald C. Dearborn et al. explored seven possible motivations for biodiversity conservation in urban, and argued that to common challenges in urban environment must be faced [25].

Table 8. The top 10 most local cited documents in analyzed corpus from 1995-2021.

Rank	Authors	Title	Source	The First Author's Institution	Year	Local Citations	Global Citations
1	Mark A. Goddard et.al. [22]	Scaling up from gardens: biodiversity conservation in urban environments	Trends in Ecology & Evolution	University of Leeds	2010	288	739
2	Ingo Kowarik[57]	Novel urban ecosystems, biodiversity, and conservation	Environmental Pollution	Technische Universität Berlin	2011	221	485
3	Joscha Beninde et.al. [20]	Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation	Ecology Letters	Trier University	2015	181	324
4	Donald C. Dearborn et al. [25]	Motivations for Conserving Urban Biodiversity	Conservation Biology	Bucknell University	2010	143	318
5	Myla F.J Aronson [61]	Biodiversity in the city: key challenges for urban green space management	Frontiers in Ecology and the Environment	The State University of New Jersey	2017	141	261
6	James R. Miller[58]	Biodiversity conservation and the extinction of experience	Trends in Ecology & Evolution	Iowa State University	2005	129	611
7	Robert I. Mcdonald et.al. [62]	The implications of current and future urbanization for global protected areas and biodiversity conservation	Biological Conservation	Harvard University	2008	114	432
8	Kevin J. Gaston et.al [63]	Urban Domestic Gardens (IV): The Extent of the Resource and its Associated Features	Biodiversity & Conservation	University of Sheffield	2005	113	355
9	Stanley H. Faeth et.al [64]	Urban biodiversity: patterns and mechanisms.	Annals of the New York Academy of Sciences	University of North Carolina Greensboro	2010	104	213
10	Nicholas S.G. Williams et.al [65]	A conceptual framework for predicting the effects of urban environments on floras	Journal of Ecology	University of Melbourne	2008	103	232

After analysis of most global cited articles and most local cited articles, we identified the references cited the most by the analyzed 3551 articles in our corpus. Table 9 lists the 10 most cited references by ducments in analyzed corpur. These researches may offer either theory basis, models or solid empirical study cases to later scholar to build on further research. *Urbanization, Biodiversity, and Conservation* published by Michael L. McKinney in 2002 is the most cited refrence by the publications in analyzed corpus. Another two papers from Michael L. McKinney have also received frequent citations. These three papers with papers from other authors provides evidences that how urbanization harms native ecosystems, however, a well ecologically educated population could greatly enhance species richness in all ecosystems [17,53,66–69].

Table 9. The 10 most cited references in analyzed corpurs from 1995-2021.

Rank	Author	Title	Source	Year	Citation
1	Michael L. McKinney [66]	Urbanization, Biodiversity, and Conservation	BioScience	2002	429
2	Michael L. McKinney [67]	Urbanization as a major cause of biotic homogenization	Biological Conservation	2006	419
3	Grimm,N.B. et al. [68]	Global Change and the Ecology of Cities	Science	2008	394
4	Michael L. McKinney [17]	Effects of urbanization on species richness:A review of plants and animals	Urban Ecosystems	2008	348
5	Mark A. Goddard et al.[22]	Scaling up from gardens: biodiversity conservation in urban environments	Trends in Ecology & Evolution	2009	288
6	Karen C. Setoa et.al. [69]	Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools	Proceedings of the National Academy of Sciences	2012	257
7	Myla F. J. Aronson et al. [53]	A global analysis of the impacts	Proceedings of the Royal Society B: Biological Sciences	2014	235

		of urbanization on bird and plant diversity reveals key anthropogenic drivers			
8	Ingo Kowarik [57]	Novel urban ecosystems, biodiversity, and conservation	Environmental Pollution	2011	221
9	Per Bolund et al. [70]	Ecosystem services in urban areas	Ecosystem services in urban areas	1999	211
10	Richard A. Fuller et al. [71]	Psychological benefits of greenspace increase with biodiversity	Biology Letters	2007	198

At the end of the citation analysis, we represent historiography, which was proposed by Eugene Garfield [72] in 2004, to identify the most significant research of city biodiversity and trace its year-by-year historical development. As shown in Figure 9, over the time, the references historical development could be divided in to three periods. The first is before 2005, three important articles represent in this period; the second is 2005-2012, many important articles emerge; the third is after 2012.

The earliest research is *A habitat island approach to conserving birds in urban landscapes: case studies from southern and northern Europe* from Esteban Fernández-Juricic and Jukka Jokimäki, and published on Biodiversity & Conservation in 2001 [73]. This study reviews research methods on bird in urban landscape and highlights the significance of the habitat island ecological theory for the management and conservation of urban birds. Based on two projects in city park, this paper concludes that the enlargement of city park is difficult, enhancing resource availability is a effect way to increase bird diversity in urban area, and human activities should be controlled to minimize its negative impact on bird. Finally, a conceptual bird conservation model was drawn.

Tow important articles were published in 2005, each of which generates 4 citations. *Urban Domestic Gardens (IV): The Extent of the Resource and its Associated Features* published by Kevin J. Gaston et al [63]. This study investigated domestic garden by a telephone based surveys in Sheffield of United Kingdom. The result shows that domestic garden consists diverse features that are of potential significance for biodiversity conservation in urban area. *Biodiversity conservation and the extinction of experience* published by James R. Miller [58]. This paper argues that the place we live and work should be designed to offer meaningful interactions with the nature, restoring human connections with the natural world would get public support to conserve biodiversity in urban area.

The article *Scaling up from gardens: biodiversity conservation in urban environments* published by Mark A. Goddard et al., encourage "wildlife-friendly" management of collection of fragmented city green spaces [22]. Nicholas S.G. Willames et al. utilized mechanism-based frameworks to predict floristic change in urban area, and identified connections between floristic change factors to outcome. The resuluts benefits vegatation management and biodiversity conservation in urban [65].

3.6. Conceptual Structure Analysis

A total of 8878 author keywords are identified in analyzed corpus, 77.49% (6680 keywords) of which occurs only once. "city(cities)" and "biodiversity" should be ignored because it is included in our search keyword in article data retrieval process. "urbanization" and "urbanisation" merge into "urbanization". Plural form and singular form merge into singular form. The words has a broad concept associated with environmental study are excluded (as shown in Figure 11).

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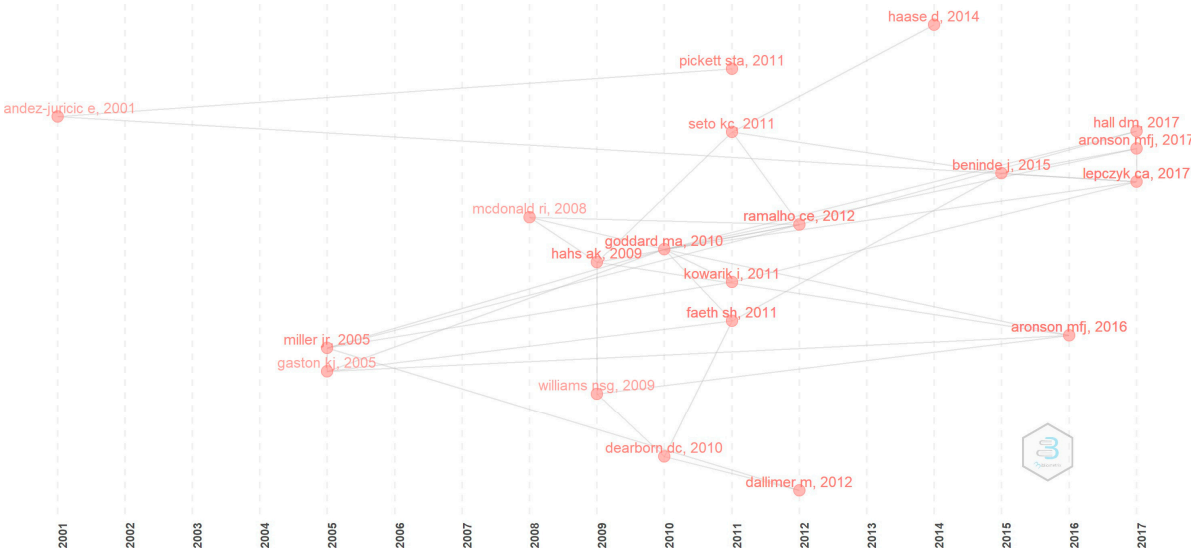

Figure 9. References histograph of analyzed corpus from 1995-2021.

The top 20 most frequent author keywords are listed in Table 10. The city biodiversity research has extended to urban ecology [74–76], urban planning [77–79], urban forest [80–82], urban agriculture [83], urban ecosystem [84–86], urban green space [87– 89], urban flora [90–92], urban park [93–95]. As a comparison, top 20 frequent keywords plus are listed in Table 12.

Table 10. The 20 most frequent author keywords of analyzed corpus from 1995-2021.

Rank	Word	Frequent	Rank	Word	Frequent
1	urbanization	392	11	urban forest	44
2	urban ecology	287	12	green space	42
3	ecosystem services	251	13	urban agriculture	39
4	urban biodiversity	131	14	urban ecosystem	58
5	urban planning	97	15	urban green space	67
6	green infrastructure	94	16	biotic homogenization	29
7	species richness	76	17	habitat fragmentation	27
8	climate change	62	18	urban flora	25
9	biodiversity conservation	61	19	urban greening	24
10	sustainability	61	20	urban park	24

Table 11. Excluded author keywords of analyzed corpus.

Words	Frequent	Words	Frequent	Words	Frequent
biodiversity	444	birds	42	infrastructure	30
urban	260	planning	41	china	29
conservation	136	ecosystem	39	brazil	26
cities	80	remote sensing	35	connectivity	25
diversity	67	restoration	35	disturbance	25
ecology	62	vegetation	35	nature-based solutions	25
species	62	habitat	34	sustainable development	25
landscape	58	gis	31	forest	24
management	55	invasive species	31	functional traits	24
land use	53	land use change	31	green	24
city	49	resilience	31	analysis	23
fragmentation	46	citizen science	30	beta diversity	23

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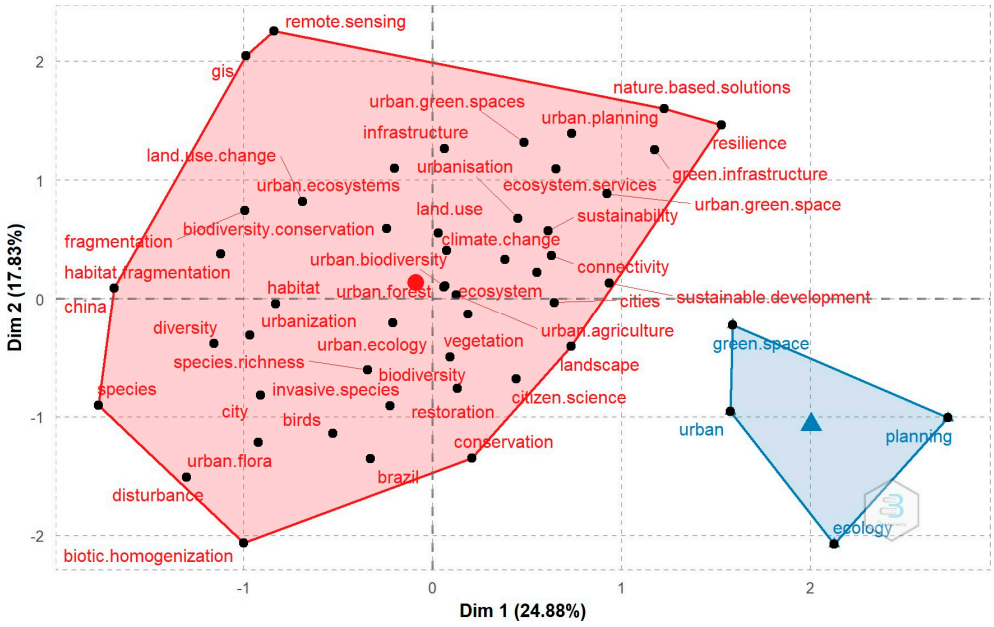

Figure 10. Clusters of the top 50 frequent author keywords on city biodiversity from 1995-2021.

Table 12. 20 Most frequent keyword plus of analyzed corpus from 1995-2021.

Rank	Keyword Plus	Occurrences	Rank	Keyword Plus	Occurrences
1	biodiversity	1524	11	management	298
2	urbanization	647	12	vegetation	255
3	conservation	626	13	landscape	252
4	diversity	548	14	urban	252
5	city	349	15	species richness	230
6	ecosystem services	340	16	communities	193
7	ecology	322	17	habitat	193
8	land-use	311	18	impacts	169
9	cities	308	19	areas	164
10	patterns	300	20	forest	154

3.7. Cluster of High Frequent Keywords

Keywords highlights the topic and research focus of one articles and help scholars quickly identify the research directions. The high frequent keyword cluster map is generated by multiple correspondence analysis [30]. The clusters of top 50 frequent author keywords are shown in Figure 10. The keywords are grouped into two groups. The centered red cluster includes majority of keywords, and is highly related to city biodiversity. urban forest, ecosystem, biodiversity conservation, urban agriculture is primary research subjects of this keywords cluster. Habitat fragmentation, species, biotic homogenization, green infrastructure, landscape and resilience locates at the periphery of this cluster, indicating these specific topics have received considerable interest from scholars. The blue cluster primarily focuses on urban green space, urban planning and urban ecology.

The Figure 11 shows the clusters of top 50 frequent keywords plus, which represent similar characters with author keywords clusters. The red centered clusters includes majority concepts, and focuses on biodiversity, forest, conservation, and ecosystem are primary research subjects of this cluster. The blue cluster focuses on green space and park in urban area, health benefits and challenges.

It is interesting that both author keywords and keywords plus include bird and flora. The bird [96–102] and flora [97,103–107] in urban might be an ideal research variable in city biodiversity field.

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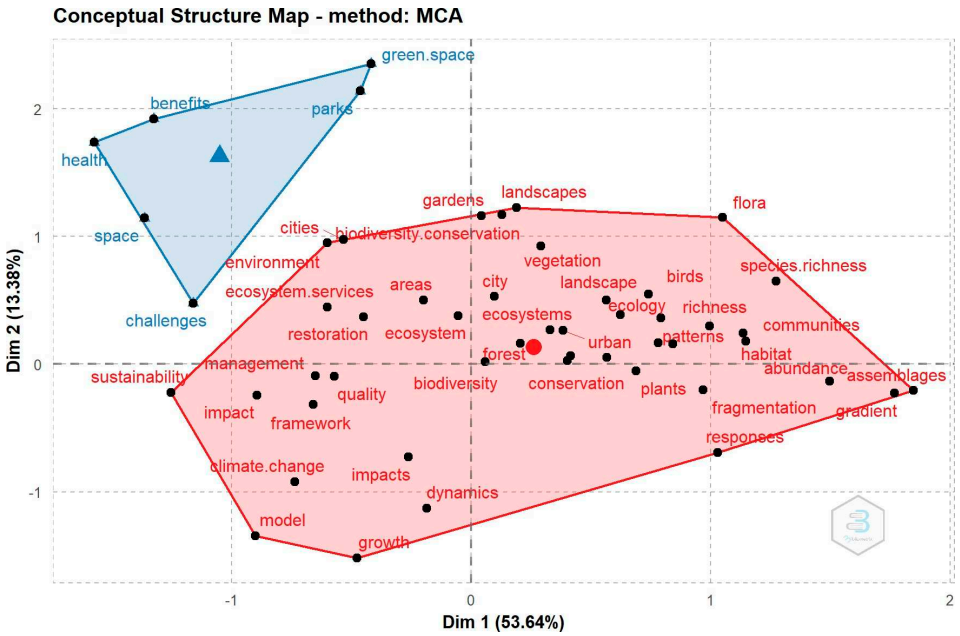

Figure 11. Cluster of the top 50 frequent keywords plus on city biodiversity from 1995-2021.

3.7.1. Thematic Analysis

This section represents thematic map and thematic evolution. Thematic evolution is generated based on co-word analysis, and highlight the theme flow over the time. As shown in Figure 12, the timespan of our analyzed corpus is divided into three slices whit cutting year 2008 and 2015. The nodes denote research theme, size of which represent the keywords frequent. The label indicates the core keyword of corresponding theme. The gray stream line demonstrates themes in adjacent timespan share the same keywords. In early timespan (1995-2008), the themes are some broad concept words, such as urban, land use, urban ecology, green space, and sustainability. In second slice, some specific theme emerge, such as species richness, biodiversity conservation. In the third slice, the thematic development trend is uniformity, but keywords are broad concept words, such as biodiversity, urbanization, and ecosystem services.

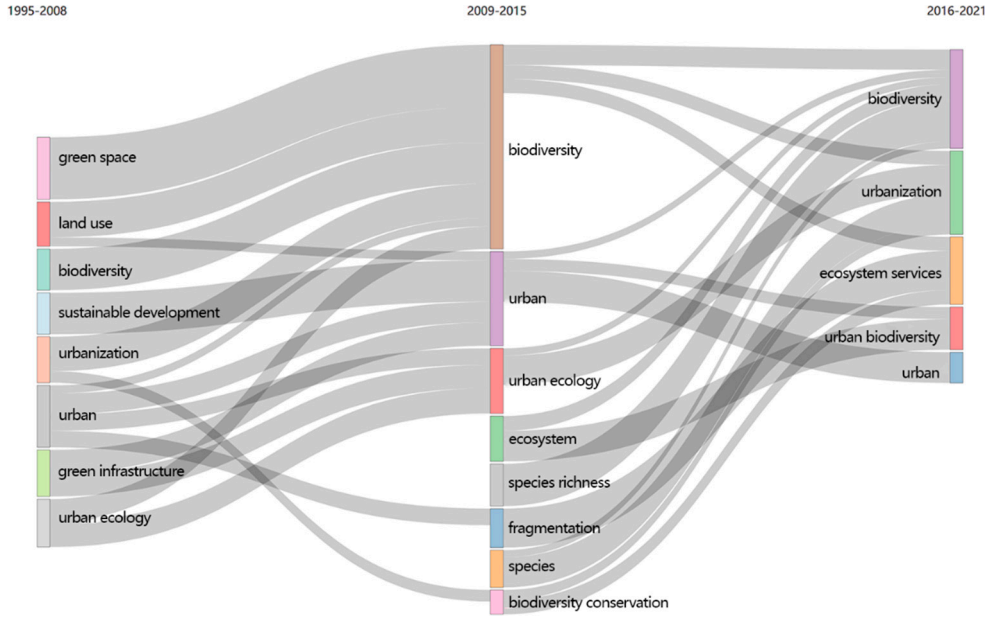

Figure 12. Thematice evolution of city biodiversity field from 1995-2021.

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The thematic map is also generated based on co-word analysis. Themes are measured by two parameters, namely centrality and density. The centrality indicates the importance of the theme, while density indicates development of theme [40]. The research themes were distributed according to their centrality and density which were denoted by X-axis and Y-axis, and were classified into four quadrants. The first quadrant (upper-right quadrant) was known as motor-theme, which means the themes were important and developed well. The second quadrant(upper- left quadrant) were well-developed but unimportant for studied field, and were marginal specialty. The third quadrant(lower-left quadrant) have low density and low centrality representing either emerging or disappearing, weakly developed and marginal themes. The fourth quadrant(lower-right quadrant) were low in centrality but high in density, representing the important but not well-developed themes. The specific themes represented by "ecosystem services", "urban planning", "green infrastructure", "urban" ecology, and "conservation" are basic theme, which indicates these themes are important but not fully developed and worth to explore in future research.

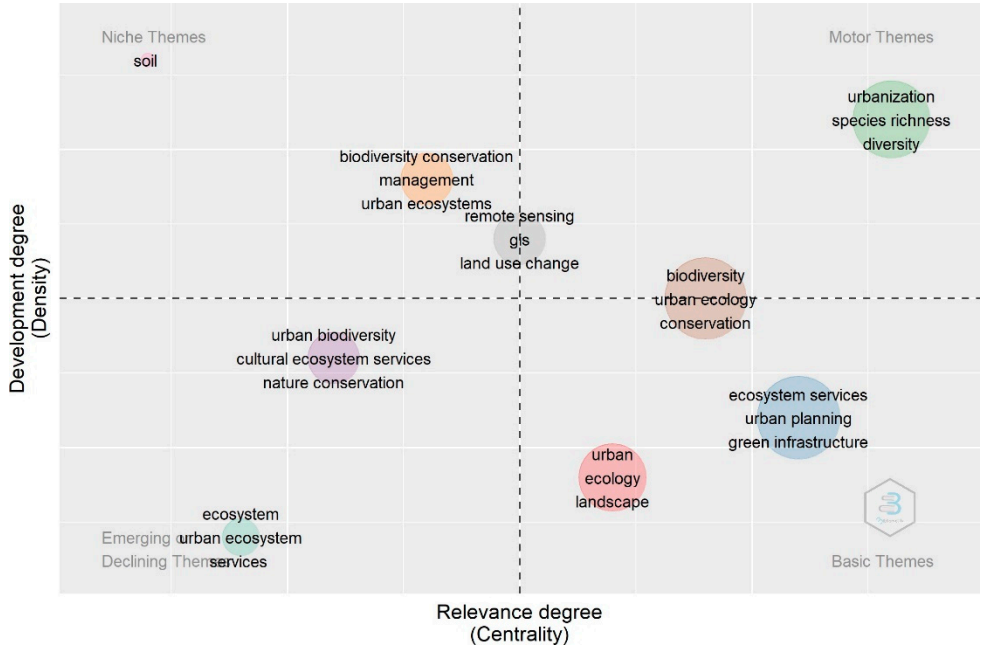

Figure 13. Thematic map of city biodiversity research from 1995-2021.

4. Conclusions

City biodiversity issues have attracted increasing public concern worldwide. Several studies have systematically reviewed sub-topics of city biodiversity field. However, this is still no bibliometric analysis on city biodiversity presented. Thus, this study utilized R language with the Bibliometrix package to applied bibliometric analysis on the 3351 publications that retrieved from the Web of Science.

The results shows that research in city biodiversity is rapidly growing. The steady increasing annual publication productions in city biodiversity field indicates this area is still under spotlight and in rapidly expansion. United States is the most productive country in terms of number of publications, and is the most cited country. This indicates that United States has considerable quality and quantity researches in city biodiversity field. China and Germany respectively rank in second and third in terms of number of publications. United Kingdom and Australia respectively hold second and third position in citation rank. Country collaboration analysis illustrates that China, United Kingdom, Canada, and Australia close patterner of United States. Moreover, China and USA are major patterner of each other. Germany and Brazil are more likely have cooperation with countries that locate in same continent. In general,

As regard to journal performance, *Landscape and Urban Planning* published the first paper in city biodiversity field, which ranks the first in h-index, total citations and number of publications.

Urban Ecosystems and *Urban Forestry & Urban Greening* respectively rank the second and third in terms of number of publications. *Landscape and Urban Planning*, *Urban Ecosystems*, *Urban Forestry & Urban Greening* and *Sustainability* are in favorite of scholars, as their growth in total number published articles is more faster than any other sources. In general, all most prolific journals are high quartile and impact factor values. In addition, more than half of analyzed publications are open access, the scholars in city biodiversity field prefer publish with open access to make their science productions have a high visibility.

Author performance analysis reveals that Ingo Kowarik is the most productive author in terms of number of articles, followed by Kevin J. Gaston and C.Y Jim. They are respectively associated with institution in Germany, United Kingdom and China. United States scholars are absent in this ranking, although Unite States is the most prolific country. In terms of total citation, Kevin J. Gaston received the highest citations. Scholars from Germany occupy three positions in this ranking. The majority top-20 authors are still active in 2021, and C.Y Jim has the longest active time, from 2004-2021.

Citation analysis helps identify the influential publications and research front [108]. *Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review* published by Konstantinos Tzoulas et al. in 2007, has received the highest citations. Based on a synthesis of the literature, this paper proposed a conceptual framework of associations between urban green space, and ecosystem and human health, and then concluded that green infrastructure could physically and psychologically benefits people by ecosystem services it provides, in addition, make a better socio-economic benefit [8]. *Urbanization, Biodiversity, and Conservation* published by Michael L. McKinney in 2002 is the most cited reference by the publications in analyzed corpus. This study identified how urbanization harms native ecosystems, however, a well ecologically educated population could greatly enhance species richness in all ecosystems [66].

Conceptual structure analysis helps identify hot research themes. The hot themes include urbanization, urban ecology, ecosystem services, urban planning, green infrastructure, urban forest and urban park et al. Then, two keyword clusters are identified and a thematic evolution map is generated. The thematic evolution shows the pattern of theme transfer over time. In the first stage, from 1995-2008, that the research themes are some broad concept words such as urban, land use, urban ecology, green space, and sustainability. More specific themes are developed in second stage, such as species richness, biodiversity conservation et al. In the last stage, the themes are more macro, such as biodiversity, urbanization, and ecosystem services. At the end, a thematic map is presented to demonstrates the importance and development of themes. Urbanization, species richness and diversity are classified as motor themes which are important and well developed. Ecosystem services, urban planning, green infrastructure, urban ecology and conservation are classified as basic theme, which indicates they are important but sufficiently developed and need further development.

This study provides a "big picture" of research development in city biodiversity from 1995-2021. The results may deliver values to help scholars have a comprehensive understand of current research and identify future directions of city biodiversity as well as implications for governors. For the governors and practitioner, the urbanization and urban expansion impacts on city biodiversity should be carefully evaluated. Urban park, garden, fragmented green space, and green corridors networks should be taken into considerations to enhancing species richness. The motivations for public involvement in biodiversity conservation should be carefully considered in policy.

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