Trends in global research in seed dispersal: A bibliometric analysis

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Abstract

In this study, data were sampled from the Science Citation Index Expanded (SCI-E) and Social Science Citation Index (SSCI) databases of the Web of Science Core Collection (WoSCC). With the help of CiteSpace visualization software, a systematic analysis was carried out on 1,939 publications from various countries in the field of seed dispersal. The activity index (AI) and attractive index (AAI) were used to evaluate the research effort and academic impact of different countries/territories in this field, and the global research progress and dynamic changes in research on seed dispersal were discussed. The results showed that (1) the number of publications on seed dispersal has increased rapidly, and research on seed dispersal is in a growth stage and has great potential. Ecology was the journal with the highest impact in this field, and ecology was the most popular subject category among the studies analysed. (2) The most productive authors in the field of seed dispersal are from Spain, and the most productive institution is in the USA. The research effort and academic impact of the USA were higher than the global average level in most years; the research effort and academic impact of Brazil, China and Japan were lower than the global average level in most years, but in recent years, the academic impact of these countries has been continuously increasing. (3) Keyword burst analysis showed that the new research hotspots or frontiers were mainly concentrated on seed conservation and the spatial patterns of seed dispersal. In-depth analysis of seed dispersal research indicated that the increasing development of mathematical models related to seed dispersal creates an opportunity to study the processes of seed dispersal and their consequences.

1. Introduction

The emergence of seed plants was a major breakthrough in the evolution of plant life history (Rutishauser 1993). Seed dispersal, as an important part of the life history of seed plants, has often been the focus of attention from and research by biologists. Seed dispersal depends mainly on movement by wind, water and birds or mammals (Proctor and V. 1968, Howe 1986, Tackenberg et al. 2003, Kowarik and Sumel 2008). There are approximately 260,000 kinds of seed plants in the world, and they all have unique morphological structures to ensure their successful dispersal. Since 1970, seed dispersal has become one of the research hotspots in the field of ecology (Butler et al. 2010). Seed dispersal is not only related to the co-evolution of plants and animals but also associated closely with environmental issues such as biodiversity conservation, forest and grassland degradation, habitat fragmentation, and the invasion of alien species (Byrne and Levey 1993, Campos-Arceiz and Blake 2011). Therefore, monitoring the international research progress and academic trends in the field of seed dispersal, tracking the influence of countries in related research fields and analysing the characteristics of knowledge evolution in related fields are of great significance to future research in the field of seed dispersal. Moreover, understanding the state of research on seed dispersal can provide scientific guidance for related research.

Although there are many related studies on seed dispersal, there are still few studies focused on the following issues: (1) Which subject category is the most popular in the field of seed dispersal? (2) Which journal most represents research on seed dispersal? (3) Which country and institution are the most active contributors to seed dispersal research? What are the differences in research progress between countries? (4) Which author is most represented in seed dispersal research? (5) Which articles played a key role in the evolution of knowledge about seed dispersal? (6) What are the research hotspots in related fields, and how have they developed and evolved? Addressing these questions is important for advancing research on seed dispersal; the answers will provide comprehensive insight into existing seed dispersal research and help scholars discover important unsolved scientific problems and determine which problems they should focus their research on. Although many scholars have published empirical and qualitative articles in the field of seed dispersal, these scope of these articles is still somewhat limited, for example, by subject category or region (Fuzessya et al. 2018, Camargo et al. 2019, Li et al. 2021). Although many reviews have shown development trends in specific aspects of seed dispersal-related research fields, they have not provided a comprehensive quantitative analysis of the current status of seed dispersal-related research and emerging fields. Thus, bibliometric analysis of seed dispersal research is needed.

Bibliometric analysis, an important quantitative analysis method, can effectively describe the overall trend of the development of a discipline or research field and has been widely used to measure the performance of various research fields (Wang et al. 2018, Liu et al. 2019). Moreover, knowledge graphs can combine information visualization technology with traditional bibliometric analysis to generate different types of knowledge graphs through data mining, information processing, scientific measurement, and graph drawing to provide researchers with more intuitive data displays (Boyack 2004).

Therefore, we conducted a bibliometric analysis of the scientific literature on seed dispersal for the period 1985-2020. The main objectives of this research include (1) determining the basic characteristics of the literature, such as the number of articles and citations, categories of research topics and representative journals; (2) determining the research power in the field of seed dispersal, such as the countries, institutions and authors represented in the literature; (3) recognizing the knowledge base of the research field; (4) discovering the research hotspots and trends of research hotspots over time; and (5) determining future research opportunities.

2. Materials and methodology

2.1 Data collection

Web of Science is an internationally recognized database that reflects the level of scientific research in a field. Among the resources included in Web of Science are the Science Citation Index Expanded (SCI-E), Social Science Citation Index (SSCI) and other citation index databases, such as Journal Citation Reports (JCR) and Essential Science Indicators (ESI), which are well known in the global technology and education fields. In this study, we used the SCI-E and SSCI databases from the Web of Science core collection (WoSCC) as the object database and set TI=((“Seed dispersal” OR “Wind dispersal” OR “Dispersal by birds and mammals” OR “Myrmecochory*” OR “Water and ballistic dispersal” OR “Evolution of dispersal” OR “Secondary dispersal” OR “Indirect seed dispersal” OR “Two-phase dispersal” OR “Two-stage dispersal” OR “Multi-phase dispersal”) OR (“Seed dispersal” AND Diploendozoochory*)) as the retrieval condition, with a time span of 1985-2020, to search for related results about seed dispersal. The WoSCC is one of the main databases for bibliometric analysis (Mongeon and Paul-Hus 2016). The retrieved records were downloaded and saved as a plain text file in the ”Full Record and Cited References” format and used as a sample of the data analysed in this study.

2.2 Methodology

2.2.1 Bibliometric analysis methods

Bibliometrics is a form of mathematical statistics used to analyse academic literature quantitatively (Nakagawa 2004). CiteSpace software is currently one of the analysis tools applied most often in the field of bibliometric analysis (Huang 2019). It is an application program for literature analysis and visualization and was developed by Dr Chen (Chen 2006). The 5.7 R2 version of CiteSpace for 64-bit Windows with Java 8 was used. In this study, we focused on the assessment of three quantitative characteristics of the bibliometric data with (1) co-occurrence analysis, (2) collaboration networks, and (3) co-citation analysis. Details of the analysis process in this study are shown in Fig. 1.

2.2.2 Activity index (AI) and attractive index (AAI)

On the basis of existing research (Schubert and Braun 1986, Chen and Guan 2011, Shen et al. 2018), we employed two indicators in this study, the activity index (AI) and the attractive index (AAI), to assess changes in the research effort and academic impact of different countries in the field of seed dispersal over time.

The AI can measure the degree of relative effort of a country in a research field; it can be calculated with the following formula:

$\mathrm{AI}_i^t = \frac{P_i^t / \sum P}{\mathrm{TP}^t / \sum \mathrm{TP}}$(1)

The AAI can evaluate the impact of a country on a research field through the number of citations of publications. This index can be calculated with the following formula:

$\mathrm{AAI}_i^t = \frac{C_i^t / \sum C}{\mathrm{TC}^t / \sum \mathrm{TC}}$(2)

In the formulas, AI_i^t and AAI_i^trepresent the AI and the AAI of country i in year t, respectively;P_i^t and C_i^t represent the number of articles and citations of publications on seed dispersal from country i in year t; and $\sum P$ and $\sum C$ represent the total number of articles and the sum of citations to publications related to seed dispersal from country i during a period of time. Furthermore,TP^t and TC^t represent the global number of articles and citations of publications in year t;$\sum \mathrm{TP}$ and $\sum \mathrm{TC}$ represent the total number of articles and the sum of citations globally during the same period as that of $\sum P$ and $\sum C$, respectively.

In these formulas, when $\mathrm{AI}_i^t = 1$ and$\mathrm{AAI}_i^t = 1$, the research effort and academic impact, respectively, of country i in year t are equal to the global average. In addition, when $\mathrm{AI}_i^t > 1$ or $\mathrm{AI}_i^t < 1$, the research effort of country i in year t is higher or lower than the global average, and when $\mathrm{AAI}_i^t > 1$ or$\mathrm{AAI}_i^t < 1$, the number of citations of publications from country i in year t is more or less, respectively, than the global average level of citations.

3. Result

3.1 Basic characteristics of the literature

3.1.1 Quantity of articles and citations

From 1985 to 2020, the number of articles published in the field of seed dispersal worldwide increased, indicating that this field has received extensive attention from scholars and has strong developmental potential (Fig. 2). From the perspective of the number of articles, there were two turning points in the publication of seed dispersal research. One turning point was in 1993, when the number of articles published exceeded 31 for the first time; prior to 1993, the number of articles published annually grew very slowly. The other turning point was in 2002, when the number of articles published exceeded 47 for the first time. Since 2002, the number of articles published has increased steadily every year. From 2002 to 2020, an average of 123.33 articles were published each year, with an average annual growth rate of 4.21%. This result indicates that research on seed dispersal is in the growth stage and that this field has very large research potential. During the period from 1985-2020, the total number of citations was 72,460; the number of citations per article in this period was 37.49. The average number of citations was highest in 2000, reaching 146.63. Subsequently, the average number of citations showed a downward trend.

3.1.2 Analysis of subject categories

The 10 most frequent subject categories according to our research are shown in Table 1; these subjects include ecology (1,199 articles, accounting for 61.84% of the total), plant science (424 articles, 21.87%), evolutionary biology (204 articles, 10.52%), forestry (168 articles, 8.66%), biodiversity conservation (159 articles, 8.20%), zoology (141 articles, 7.27%), biology (101 articles, 5.21%), multidisciplinary sciences (99 articles, 5.11%), environmental sciences (89 articles, 4.59%), and genetics and heredity (86 articles, 4.44%). The number of publications in each category reflects the trends of seed dispersal research in different domains. As shown in Table 1, we found that the number of publications in the fields of ecology and plant science accounted for the vast majority of the literature included in this analysis.

Fig. 3 displays a co-occurring subject category network that includes 62 nodes and 227 links. Through the subject category network, we found that seed dispersal research is a discipline that involves various subjects, such as ecology, plant science, forestry, zoology and biology. Fig. 3 shows that the 3 most frequent categories in seed dispersal research are ecology, environmental science and plant science. Environmental science has high centrality because it connects many different subject categories, including atmospheric sciences, ecology, environmental chemistry and geoscience. Ecology also connected many subject categories, including environmental science, plant science, forestry and biodiversity conservation.

3.1.3 Journal analysis

The 1,939 articles on seed dispersal analysed in this study appeared in 371 journals. Table 2 lists the 10 journals with the highest numbers of publications on seed dispersal. The number of articles published by these 10 journals in the field of seed dispersal encompassed 27.7% of all the analysed publications. Biotropica was the most popular journal (88), followed by Oecologia (66), Journal of Tropical Ecology (65), Journal of Ecology (62) and Ecology (61). The number of total citations of a journal (TC) and the average number of citations per paper of a journal (TC/P) reflect the impact of that journal (Ji et al. 2014). The impact factor (IF) and H-index can also measure journal impact. As shown in Table 2, among the literature included in this study, Biotropica, Oecologia, Journal of Tropical Ecology, Journal of Ecology and Ecology each published more than 60 articles about seed dispersal. Ecology had the highest impact in the field of seed dispersal, with the highest H-index (41), TC (5614) and TC/P (92.03).

3.2 Research power of seed dispersal

3.2.1 Analysis of countries and institutions

(1) Quantity of articles and citations

The papers included in this study came from 82 countries around the world. The 10 most productive countries are listed in Table 3. As shown in Table 3, the USA had the largest number of publications (555 articles) and total citations (26,942 citations). Spain had the second highest number of publications (214 articles), followed by Brazil (156 articles), Germany (149 articles), Australia (109 articles) and China (96 articles). Fig. 4 shows the distribution of countries/territories and the relationships of international cooperation with impact on seed dispersal research. The USA had the earliest publication on seed dispersal and was the most productive country during the study period. The USA had the highest degree of centrality (0.60), followed by France (0.21), Germany (0.20) and Australia (0.16); these countries play an important role in collaboration networks. The analysis revealed that there was strong international cooperation between North America and Europe; however, China's international cooperation was weak.

(2) Collaboration network

Table 4 lists the 10 most productive institutions in terms of relevant articles. Consejo Superior de Investigaciones Científicas (CSIC) was the most productive institution, followed by the Chinese Academy of Sciences, Universidad Nacional Autonoma de Mexico, the University of Florida and Kyoto University. Fig. 5 shows the network of academic collaboration on seed dispersal research between institutions. The strongest collaborations were identified between CSIC and the University of Oviedo. Kyoto University collaborated with the Forestry & Forest Product Research Institute. The University of Oviedo had the highest centrality (0.16) and cooperated closely with other institutions, such as CSIC and the University of Sao Paulo.

(3) The development of seed dispersal research in selected countries

To evaluate the changes in the academic impact of the 10 abovementioned countries in terms of seed dispersal research, the AI and the AAI were used. It should be noted that because there is usually a lag between the publication time and the citation time of an article(Glänzel and Persson 2003, Qiu and Chen 2009), the time range of the AAI was set 2 years behind that of the AI in this study.

Quadrant diagrams of the changes in the two indexes are shown in Fig. 2, with quadrants I to IV representing 4 different situations. The points in quadrant I represent the years in which the country's AI and AAI indexes were both higher than the global average levels; the points in quadrant II represent the years in which the country's AAI and AI indexes were higher and lower than the global average levels, respectively; the points in quadrant III represent the years in which the country's AI and AAI indexes were both lower than the global average levels; and the points in quadrant IV represent the years in which the country's AI and AAI indexes were higher and lower than the global average levels, respectively.

In general, with the exception of Australia, the AI and AAI indexes of the 10 selected countries showed an upward trend during the study period. As shown in Fig. 2, the research power and academic impact of the USA in most years were higher than the global average level; in contrast, although Spain had a relatively large number of published and cited articles, its academic impact was lower than the global average level in most years. The research power and academic impacts of Brazil, China and Japan were lower than the global average level in most years, but in recent years, their academic impact was higher than the global average level, indicating that the impact of these countries on seed dispersal research is continuously increasing.

3.2.2 Author analysis

(1) Author collaboration network

Table 5 lists the 10 most productive authors according to the publications included in this study. As shown in Table 5, A Traveset, M Nogales and P Jordano had the highest numbers of publications. These authors were followed by XF Yi (19 articles), M Galetti (19 articles), D Garcia (18 articles), R Nathan (17 articles), SB Vander Wall (15 articles), MA Pizo (15 articles) and MB Soons (13 articles). The 10 most productive authors all came from different research institutions (Table 5); 4 of these authors were in Spain, and the remaining 6 were in different countries.

Fig. 7 is the collaboration network map of the authors of seed dispersal research. Five author groups were identified. (1) A team consisting of A Traveset, P Jordano and M Nogales (circle A) focused their research on long-distance seed dispersal (Nogales et al. 2012, Traveset et al. 2014, Pedro and Jordano 2017). (2) A group of authors led by XF Yi (circle B) focused on animal-seed interactions (Steele and Yi 2020, Xianfeng et al. 2020). (3) M Huynen and A Albert formed a core team (circle C), and much of their research focused on the analysis of feeding ecology and seed dispersal of pigtail macaques (*Macaca nemestrina*) (Latinne et al. 2008, Aurelie et al. 2013). (4) A team consisting of R Heleno and S Timoteo (circle D) studied ecological networks (such as food webs and pollinator networks) (Timóteo et al. 2018, Heleno et al. 2020). (5) A group of authors led by M Schleuning (circle E) focused on plant-animal interactions and ecological networks (Schleuning et al. 2015, Schleuning et al. 2016).

(2) Author co-citation network

The results of the author collaboration analysis can reflect an author's contributions to the field of seed dispersal and the cooperative relationship between authors, but it cannot reflect an author's impact on seed dispersal research. Therefore, we used author co-citation analysis to provide further information. We selected the 10 most cited project themes from each topic to ensure that we targeted the most prominent authors.

On the basis of the author co-citation network analysis results, the authors with high citation frequency and their countries of origin were determined. As shown in Table 6, the author with the highest citation frequency is R Nathan (3,612 citations, Israel), followed by P Jordano (2798 citations, Spain), DJ Levey (1273 citations, USA), A Traveset (1055 citations, Spain), M Galetti (976 citations, Italy), MB Soons (933 citations, Netherlands), SB Vander Wall (853 citations, USA), D Garcia (832 citations, Spain), M Nogales (637 citations, Spain) and PR Guimaraes (634 citations, Brazil). Four of these authors are from Spain, two are from the USA, and the others are from Israel, Italy and the Netherlands.

By comparing Table 6 and Table 5, we determined that there is a strong relationship between the 10 most cited authors and the 10 most productive authors. Only DJ Levey, M Nogales and PR Guimaraes appear in only Table S2; the remaining authors appear in both tables.

3.3 Intellectual base

The number of citations of an article represents the degree of recognition it received in a particular research field or its academic impact (Ebrahim et al. 2013, Yoshikane et al. 2013). The 10 most highly cited references are listed in Table 7. The most highly cited reference was published by R Nathan, with a citation count of 1,343. Through this review, the author shows that with the growing interest in spatial ecology, new methods for researching seed dispersal, which is one of the key processes in determining the spatial structure of plant populations, are emerging. Seed dispersal methods vary among plant species, populations and individuals; with distance from the parent plant; and by microsites and times. The development and improvement of mathematical models is expected to produce a deeper and more mechanical understanding of the seed dispersal process and its consequences. The remaining documents with a high citation rate were published in the 21st century, mostly between 2000 and 2011. The content of these papers shows that the intellectual base focuses on long-distance seed dispersal and dispersal patterns in different habitat conditions. These publications have laid a good foundation for future research directions.

3.4 Research hotpots

3.4.1 Keyword co-occurrence

Keywords reflect an author's intention and interests and summarize the main contents of an article. People can obtain useful information, such as research goals, methods, and important opinions, from the keywords of an article (Xu et al. 2018). Therefore, keyword frequency analysis and period change analysis are essential to discussing research hotspots and development changes within a research field (Wang et al. 2018).

We use the keyword co-occurrence analysis in CiteSpace software to create a keyword co-occurrence network diagram of the seed dispersal research analysed and identify the main research hotspots in this field (Fig. 8). Each node in the graph represents a keyword; larger nodes indicate keywords that appear more frequently. Similarly, the width of the links indicates the frequency of keywords appearing together; a thicker link indicates that the two connected keywords appear together more frequently. A total of 624 keywords were obtained, among which 14 appeared more than 100 times. There is no doubt that "seed dispersal", the main keyword of this article, is the largest node in the Fig. 8; this keyword appears 324 times and is closely related to "pattern" (245 times), "plant" (165 times), "frugivory" (160 times), "recruitment" (160 times), "ecology" (152 times) and "forest" (152 times). Other keywords, such as "germination" (136 times), "bird" (122 times), "predation" (136 times), "rainforest" (101 times) and "distance" (100 times), also had high frequencies.

3.4.2 Keyword burst analysis

Keywords burst analysis identifies those keywords with a sharp increase in frequency. Burst detection is a useful analytical method for finding keywords that are of particular interest to the relevant scientific community over a given period of time (B et al. 2018). Therefore, bursting keywords can be used as indicators of research frontiers and to forecast research trends. Fig. 9 shows the 20 keywords with the strongest citation bursts from 1985 to 2020. In this figure, the strength of the burst represents the intensity of focus on a given topic. In the field of seed dispersal research, wind dispersal has been a research hotspot since 1989, with the focus subsequently diversifying to include "selection" (strength: 4.55), "bird" (strength: 5.56), "dispersal" (strength: 5.26), "environment" (strength: 5.21), "tropical rainforest" (strength: 8.2) and "dynamics" (strength: 5.01). We found that in the last ten years (2010-2020), studies related to "conservation" and "spatial pattern" were emerging active topics (Fig. 9).

3.4.1 Keywords in different countries

Due to differences in climate, geographical features, and historical and economic conditions, the development of research in a certain field in different countries or regions may not be balanced. Fig. 10 shows the high-frequency keywords, main research types and regional distribution of relevant research in the 10 countries with the highest numbers of publications. The results showed that in the field of seed dispersal, the differences between countries or territories are not very large and that the study of the relationship between "seed dispersal" and "frugivorous animal" received the most attention. For example, from 1985 to 2020, the most frequently used keywords in the USA were "seed dispersal" (162 times) and "frugivory" (75 times); the most frequently used keywords in Spain during this period were "seed dispersal" (41 times) and "frugivory" (26 times).

4. Conclusions

In this study, the SCI-E and SSCI databases of the WoSCC were used as sample data and CiteSpace software was applied to visualize information about seed dispersal research. Based on the bibliometric analysis method, we systematically analysed the basic characteristics, main research institutions and research hotspots of literature in the field of seed dispersal. Furthermore, we used the AI and the AAI to assess the research efficiency and academic impact of major countries. The following conclusions were drawn from the results:

(1) The number of publications on seed dispersal research globally increased significantly over time. The number of citations per publication peaked in 2000. The 10 most productive journals accounted for 27.7% of all publications in the field of seed dispersal, and Ecology had the highest impact in this field. Researchers in the field of seed dispersal are mostly from the USA and European countries, and a collaboration network centred on the USA, Spain, Germany, Australia, Britain and France gradually formed.

(2) On the basis of the AI and the AAI, we determined that different countries/territories have different research abilities in the field of seed dispersal. The research effort and academic impact of the USA were higher than the global average level in most years. Although the research effort and academic impact of Brazil, China and Japan were lower than the global average level in most years, their academic impact has continuously increased in recent years. We also found that seed dispersal research was performed by five author groups with outstanding research records.

(3) The burst analysis showed that wind dispersal is a hotspot in the field of seed dispersal research, and new research hotspots or research frontiers have mainly concentrated on seed conservation and the spatial patterns of seed dispersal.

(4) Currently, many studies are limited to only the number of seeds and distance of seed dispersal and cannot systematically study every process of the seed renewal stage (seed production, seed dispersal, seed germination, seedling settlement, seedling establishment, etc.). Because the monitoring of seed germination and seedling growth in the later stages of seed dispersal is time-consuming and labour-intensive, relevant research is still lacking. In addition, too much attention has been paid to the negative impacts of human interference on the spreading of seeds by animals, and the beneficial aspects of human interference in the process of seed dispersal have been ignored. Finally, the development of mathematical models related to seed dispersal has created an opportunity to study the processes of seed dispersal and its potential consequences.

Although this research provides scientific guidance for future research directions in related fields, it still has some limitations. First, we strictly limited the scope of publications in the literature search to avoid obtaining search results that are inconsistent with the research goals. Second, although we identified main research hotspots and future research directions, deeper analysis of research hotspots, such as the methods applied to identify them and theoretical background, is still needed. Finally, CiteSpace software itself has certain limitations, although much research has been conducted using this software. For example, in the process of this research, we found that the software cannot distinguish the first author of a paper from the corresponding author, and the distinction between some areas is not very accurate. Nevertheless, the conclusions of this study are based on objective data, which are accurate and reliable. In short, the results of this study were not affected by anecdotal evidence.

Data Accessibility

activity index (AI) and the attractive index (AAI) file:Dryad doi: 10.5061/dryad.ttdz08kzq

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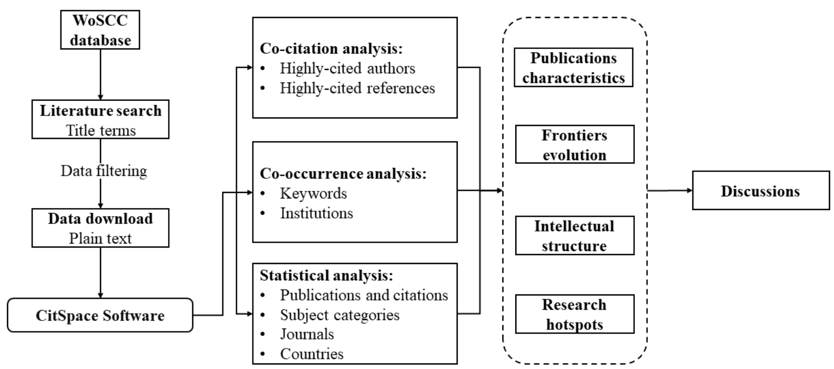

Fig. 1 Outline of research design.

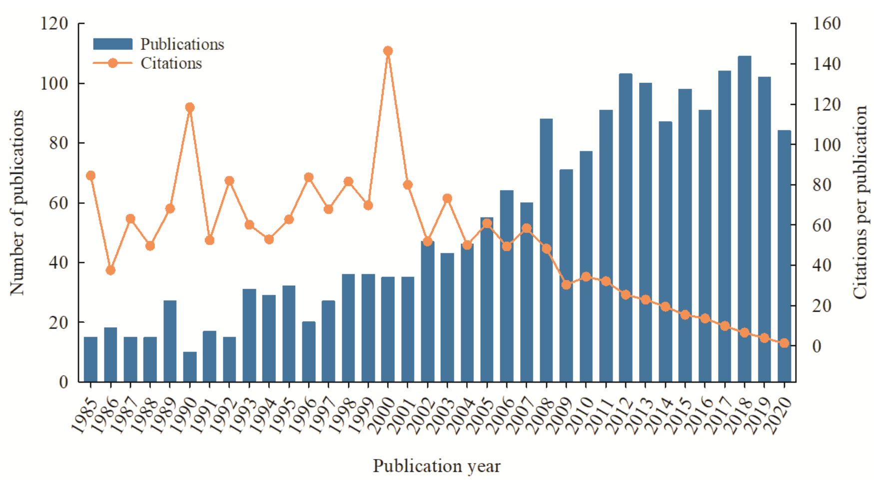

Fig. 2 Trends in the quantity of articles and average number of citations identified by Web of Science (WOS) that are related to seed dispersal from 1985 to 2020.

Table 1 The article output of the top 10 subject categories of seed dispersal research.

Subject category	1985-2020	% / 1939	Subject category	1985-2020	% / 1939
Ecology	1199	61.84	Zoology	141	7.27
Plant Sciences	424	21.87	Biology	101	5.21
Evolutionary Biology	204	10.52	Multidisciplinary Sciences	99	5.11
Forestry	168	8.66	Environmental Sciences	89	4.59
Biodiversity Conservation	159	8.2	Genetics Heredity	86	4.44

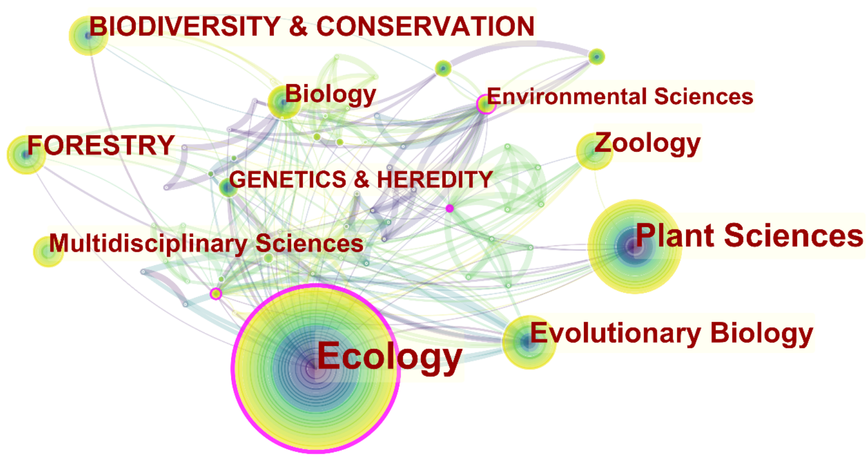

Fig. 3 A visualization of the co-occurring subject categories network. Nodes represent subject categories. The size of a node's proportional to the literature number of the subject category. The links represent the co-occurring relationship between different subject categories. The color of the rings and links corresponds to the year. The purple rings indicate high centrality.

Table 2 Top 10 productive journals in terms of related studies.

Journals	Ps	% / 1939	TC[a]	TC/P[b]	h-index[c]	IF[d]	Initial year
Biotropica	88	4.54%	3341	37.97	32	2.090	1985
Oecologia	66	3.40%	3975	60.23	37	2.654	1985
Journal of Tropical Ecology	65	3.35%	2246	34.55	27	1.163	1988
Journal of Ecology	62	3.20%	3647	58.82	35	5.762	1986
Ecology	61	3.15%	5614	92.03	41	4.700	1985
Oikos	46	2.37%	2253	48.98	27	3.370	1988
Plant Ecology	43	2.22%	939	21.84	19	1.509	1997
Acta Oecologica-International Journal of Ecology	36	1.86%	1044	29.00	19	1.220	1992
Plos One	36	1.86%	852	23.67	15	2.740	2008
American Journal of Botany	34	1.75%	1664	48.94	19	3.038	1985

Note: TC[a] : the total citations for a journal. TC/P[b] : average number of citations per paper for a journal. h-index[c] o: according to Hirsch in 2005(Hirsch 2005): A scientist has index H if H of his/her Np papers have at least H citations each, and the other Np-H pappers have no more than H citations each, in which Np is the number of articles published during n years. A high H-index indicates greater academic impact. IF[d] : 5-year impact factor, impact factors data from the 2020 edition of Journal Citation Reports in Web of Science.

Table 3 Top 10 most productive countries in terms of relevant ariticles.

Country	Ps	TC^a	TC/P^b	h-index
USA	555	26942	48.54	90
Spain	214	5995	28.01	53
Brazil	156	2924	18.74	37
Germany	149	4183	28.07	43
Australia	109	3269	29.99	35
China	96	1217	12.68	20
France	92	3107	33.77	40
England	91	4508	49.54	38
Japan	86	1325	15.41	23
Canada	80	2378	29.73	31

Note: TC^a : the total citations for a country. TC/P^b : average number of citations per paper for a country.

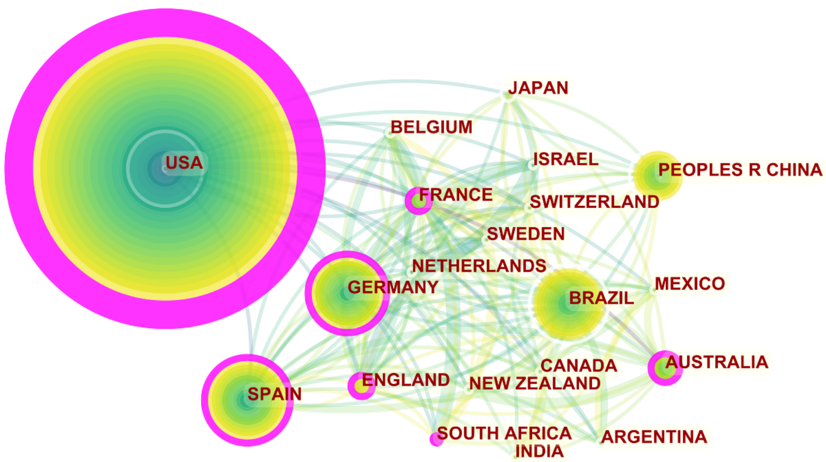

Fig. 4 The collaboration network of countries. Nodes represent countries. The size of a node is proportional to the amount of papers produced by the country. The links represent the collaborative relationship between different countries. The color of the rings and links corresponds to the year. The purple rings indicate high centrality.

Table 4 Top 10 most productive institutions in terms of relevant articles.

Institution	Country	PS	TC^a	TC/P^b	h-index
Consejo Superior de Investigaciones Científicas	Spain	148	6994	47.26	44
Chinese Academy of Sciences	China	55	622	11.31	15
Universidad Nacional Autonoma de Mexico	Mexico	42	1408	33.52	19
University of Florida	USA	41	3221	78.56	28
Kyoto University	Japan	37	485	13.11	15
University of Sao Paulo	USA	37	964	26.05	18
Duke University	USA	30	1838	61.27	20
University of California, Davis	USA	30	1744	58.13	17
Smithsonian Tropical Research Institute	Panama	29	2729	94.10	20
Universidade Estadual Paulista	Brazil	26	1311	50.42	17

Note: TC[a] : the total citations for an institution. TC/P[b] : average number of citations per paper for an institution.

Fig. 5 The collaboration network of institutions. Nodes represent institutions. The size of a node is proportional to the amount of papers produced by the institution. The links represent the collaborative relationship between different institutions. The color of the rings and links corresponds to the year.

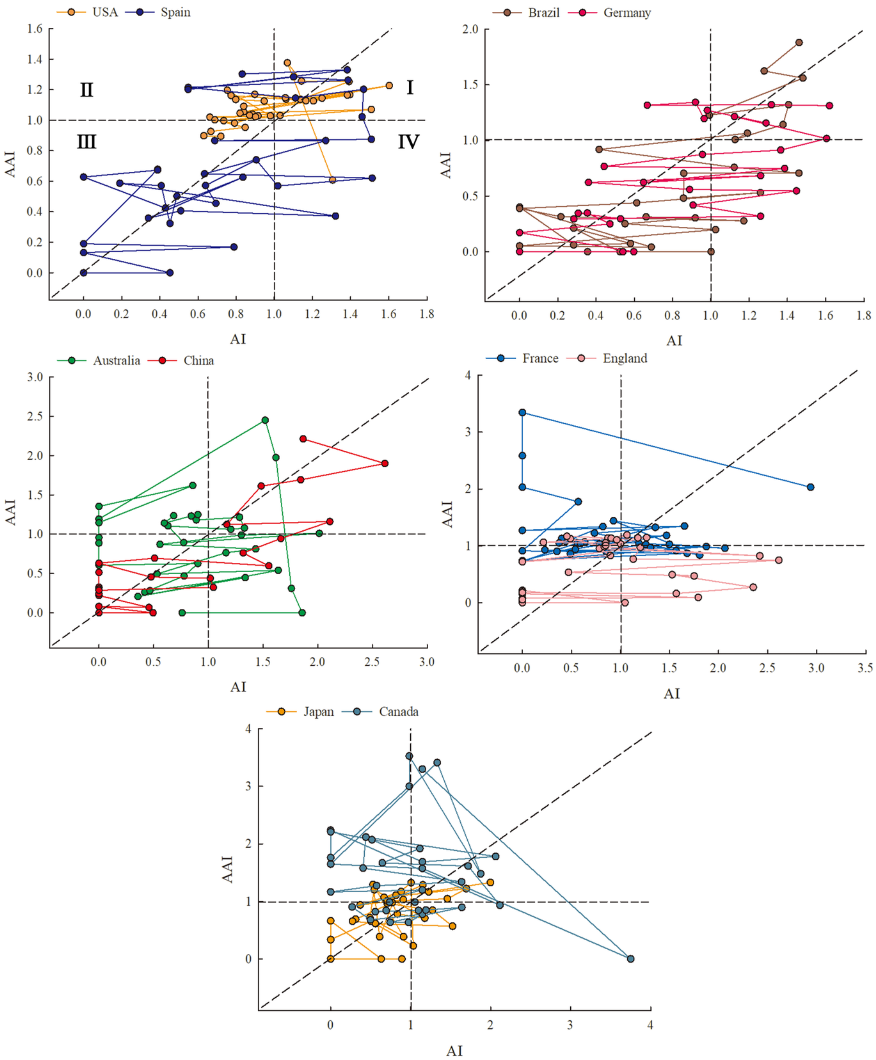

Fig. 6 Relational chart of AI and AAI for 10 countries: USA, Spain, Brazil, Germany, Australia, China, France, England, Japan and Canada. The reference line x=y represents a balance AI and AAI of seed dispersal research in a given country.

Table 5 Top 10 most productive authors based on publications.

Author	Ps	Institution	country
Traveset A	24	University of Barcelona	Spain
Nogales M	21	Instituto de Productos Naturales y Agrobiología	Spain
Jordano P	21	Consejo Superior de Investigaciones Cientificas	Spain
Yi XF	19	Chinese Academy of Sciences	China
Galetti M	19	University of Parma	Italy
Garcia D	18	University of Oviedo	Spain
Nathan R	17	Hebrew University of Jerusalem	Israel
Vander wall SB	15	University of Nevada Reno	USA
Pizo MA	15	Universidade Estadual Paulista	Brazil
Soons MB	13	Utrecht University	Netherlands

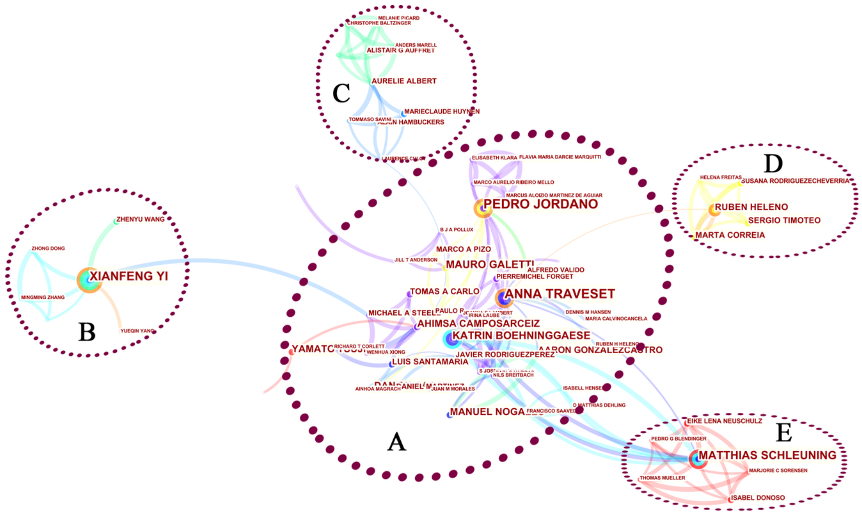

Fig. 7 Collaboration network of authors. Nodes represent authors. The size of node is proportional to amount of papers published by the author. The color of the rings and links corresponds to the year.

Table 6 Top 10 most productive authors based on total citations.

Author	Tc	Institution	country
Nathan R	3612	Hebrew University of Jerusalem	Israel
Jordano P	2798	Consejo Superior de Investigaciones Cientificas	Spain
Levey DJ	1273	University of Florida	USA
Traveset A	1055	University of Barcelona	Spain
Galetti M	976	University of Parma	Italy
Soons MB	933	Utrecht University	Netherlands
Vander wall SB	853	University of Nevada Reno	USA
Garcia D	832	University of Oviedo	Spain
Nogales M	637	Instituto de Productos Naturales y Agrobiología	Spain
Guimaraes PR	634	Universidade de Sao Paulo	Brazil

Table 7 Top 10 highly-cited reference.

Author	Journal/Book	Title
Nathan R	Trends in Ecology&Evolution	Spatial patterns of seed dispersal, their determinants an
Cain ML	American journal of botany	Long-distance seed dispersal in plant populations
Johnson ML	Annual Review of Ecology Evolution&Systematics	Evolution of Dispersal: Theoretical Models and Empiric
Clark JS	Ecology	Seed dispersal near and far patterns across temperate a
Schupp EW	The New phytologist	Seed dispersal effectiveness revisited: a conceptual revie
Liljegren SJ	Nature	SHATTERPROOF MADS-box genes control seed dispe
Mcpeek MA	The American Naturalist	The evolution of dispersal in spatially and temporally v
Schupp EW	Vegetatio	Quantity, quality and the effectiveness of seed dispersal
Levin SA	Annual Review of Ecology Evolution&Systematics	The ecology and evolution of seed dispersal: A Theoreti
Bakker JP	Acta Botanica Neerlandica	Seed banks and seed dispersal: important topics in reste

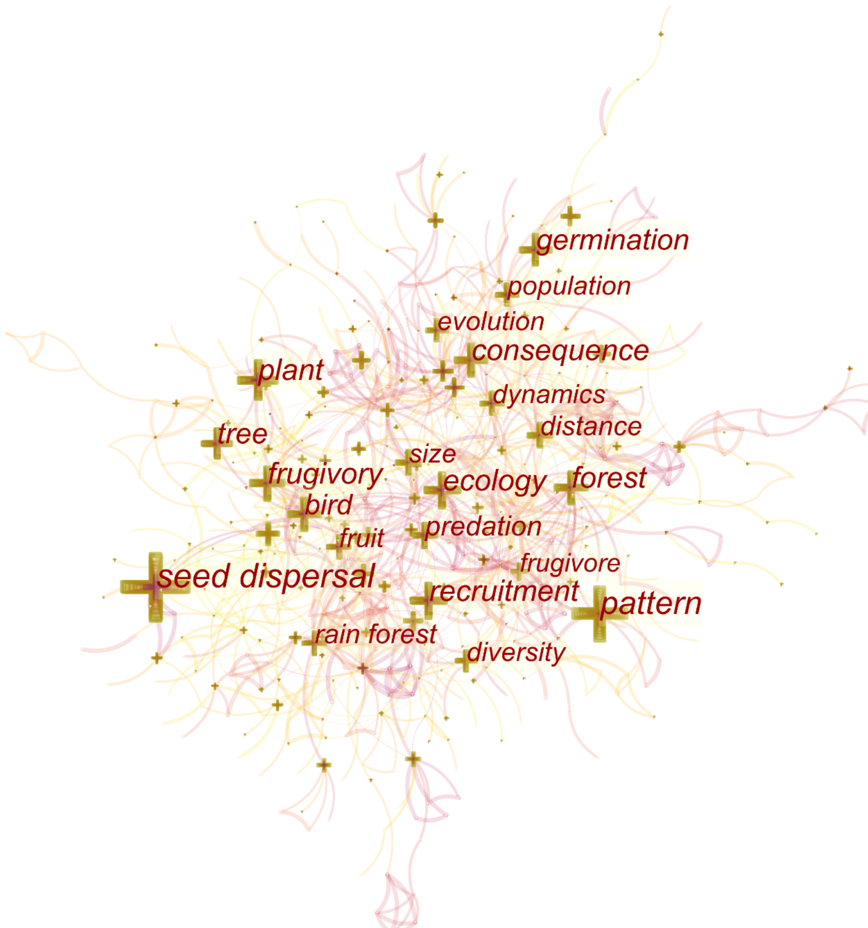

Fig. 8 Keyword co-occurrence network from 1985 to 2020.

Keywords	Year	Strength	Begin	End	1985 - 2020
wind dispersal	1985	5.08	**1989**	2020	
seed dispersal	1985	14	**1991**	2020	
plant	1985	4.55	**1992**	2020	
selection	1985	6.8	**1993**	2020	
bird	1985	5.56	**1993**	2020	
coevolution	1985	3.61	**1993**	2020	
dispersal	1985	5.26	**1994**	2020	
seed	1985	4.03	**1994**	2020	
ant	1985	4.22	**1996**	2020	
french guiana	1985	6.94	**1997**	2020	
environment	1985	5.21	**1997**	2020	
strategy	1985	4.59	**1997**	2020	
population dynamics	1985	3.67	**1997**	2020	
tropical rain forest	1985	8.2	**1998**	2020	
dynamics	1985	5.01	**1999**	2020	
rain forest	1985	4.05	**2000**	2020	
predation	1985	3.67	**2000**	2020	
metapopulation	1985	4.12	**2001**	2020	
conservation	1985	3.84	**2010**	2020	
spatial pattern	1985	5.52	**2012**	2020	

Fig. 9 Top 20 keywords with the strongest citation bursts from 1985 to 2020.

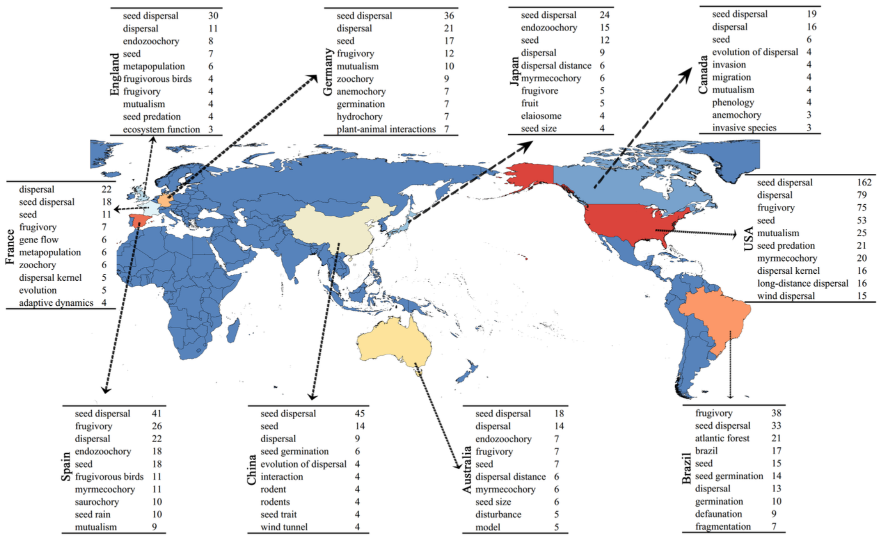

Fig. 10 The most frequently used keywords in the 10 most influential.

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