MAPPING ECOLOGICAL TRENDS BY KEYWORDS IN THE LAST 30 YEARS

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Abstract. An effective bibliometric analysis based on the Science Citation Index (SCI) published by the Institute of Scientific Information (ISI) was carried out to identify the trend of ecological research between 1992 and 2022. This study put emphases on the high-frequency keywords and their relationships to reveal the hotspots and developing trends of ecological research fields. The results show that the hotpots of ecology has changed a lot during the last 30 years, but some topics occupied an important position in ecological research consistently. Especially, "Biodiversity" and "Climate change" have been obtained more and more attention, so their ranks also have been changed greatly. We also found that the most frequently used keywords are more varied than before and that keywords have become more closely related to each other. Another interesting and amazing result shows that the keywords related to anthropogenic increased sharply. Finally, keywords analysis was an effective approach for mapping ecological research. We guess that anthropogenic keywords may be a potential guide for future research.
Keywords: *bibliometric analysis, ecology journals, Web of Science, research trends, keywords*

Introduction

Ecology is an emerging science, often described as a dynamic science (Nathan et al., 2022; Carmel et al., 2013). Whereas ecology used to be primarily a descriptive and qualitative discipline, it has become more quantitative and experimental (Anderson et al., 2021). At the same time, the definition of ecology has changed, its theoretical foundations have become richer and its temporal and spatial scales have become broader (Carscadden et al., 2020). The study of ecology helps to deepen our understanding of biodiversity

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(Chase et al., 2020; Brown et al., 1989; Wiens, 1989). Various biological species in an ecosystem are interdependent and interact with each other, constituting a complex ecological network (Pielou, 1981). Through the study of biodiversity, we can reveal the relationship between different organisms, explore their impact on the stability and function of the ecosystem, and provide a scientific basis for the protection and restoration of biodiversity. Ecology is the study of the interrelationships between organisms and their environments, including both biotic and abiotic components, and involves life processes ranging from tiny bacteria to those spanning the entire planet (Begon et al., 2006). The discipline helps us to understand how different life forms interact with each other and how they influence and adapt to environmental change. Through the study of ecology, we can better understand the functioning and stability of ecosystems, predict the potential impacts of human activities and other factors on ecosystems, and provide a scientific basis for biodiversity conservation, environmental management and sustainable development. It is vital to humans because each species plays an important role in the ecosystem and has a significant impact on the environment in which humans live. An ecosystem is a complex biotic-abiotic system that contains a variety of living species and their interactions with the environment (Thuiller et al., 2005). By studying the structure, function and evolutionary patterns of ecosystems, we can understand how ecosystem stability is maintained and how resilient they are in the face of external disturbances. This helps us to predict and assess the impacts of climate change, natural disasters and other emergencies on ecosystems, and provides scientific support for the adoption of appropriate adaptation and regulatory measures. With population growth, industrialization and urbanization accelerating, human demand for and consumption of natural resources are also increasing, leading to the aggravation of environmental pollution, ecological damage and other problems. Through the study of ecology, we can deeply analyze the mechanism of the impact of human activities on the ecosystem, find out the root causes of environmental problems, and propose corresponding management and protection measures, so as to provide a scientific basis for sustainable development (Zalasiewicz et al., 2008).

With the development of society, today's ecology is closely related to global environmental change and globalization issues, such as climate change, land use, pollution and sustainable development. Almost every major ecosystem is affected by human activities (Cord et al., 2013). Geologists have recognized that such sweeping changes in the Earth's environment have made our present era a new geological era - the Anthropocene (Crowther et al., 2015). In addition, advanced scientific techniques have been frequently applied to ecological studies, such as remote sensing, lightweight unmanned aerial vehicles (UAVs) (Anderson et al., 2013), molecular methods and advanced modelling (Griffiths et al., 2012). Biophotometric analysis is an essential component of reference and research services, capable of providing a range of visualization and quantitative procedures that encapsulate patterns and dynamics in scientific publications. As a result, this approach has been increasingly adopted by researchers in science and engineering disciplines. For traditional bibliometric methods, which focus on publication output, research institutions, and citation analyses, it is difficult to reveal trends or future directions of a research area (Herbertz et al., 1995). Fortunately, the trend of keywords can be a good solution to this problem because keywords are considered as the basic elements to represent knowledge concepts and are commonly used to reveal the knowledge structure of a research field. Analyzed and identified through bibliometric methods, this helps to reveal current research trends and priorities in the field of ecology (Whittaker, 2014). High-frequency keywords are

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usually used to analyze hotspots and trends in the research field. By extracting and analyzing keywords in a large number of literatures, the current research hotspots and focuses of attention in the field of ecology can be identified (Allen et al., 2009). Commonly used methods include keyword co-occurrence network analysis, keyword frequency analysis and so on. By analyzing the citation relationships among the literature, research results and cutting-edge topics with significant influence can be revealed. Citation network analysis can help to identify current research hotspots and academic key nodes in the field of ecology (Zhang et al., 2010). Topic modelling is a text mining technique that can help identify the hidden topic structure in the literature. By analyzing the topic model, current research hotspots and emerging areas in the field of ecology can be identified to provide reference and inspiration for researchers (Ding et al., 2014). By analyzing the collaborative network between authors, the current research team and collaborative network structure in the field of ecology can be understood (Yoon et al., 2010). Collaboration network analysis can reveal influential research teams and institutions and help identify research hotspots and frontier directions (Su et al., 2014).

What are the dominant research topics in ecological research this year and where is ecological research likely to go next year? We can find the answers by looking at the most commonly used keywords in ecology papers published this year. Ecology is a very prolific field of research, with more than 360 active journals dedicated to publishing thousands of research articles each year (data from Web of Science). It is impossible for ecologists to read all of the published literature, so it is extremely important to summarize these papers as it can provide us with a good perspective or potential future research directions. In this study, we conducted a bibliometric analysis of ecological studies with keywords published between 1992 and 2022 with the aim of mapping trends in ecological research, especially the changes in hotspots over time. In addition, the results of this study will help researchers to understand the breadth of ecological research and provide an alternative way of presenting research progress, thus providing potential guidance for future research.

Data and methods

Journal selection

The trend analysis is based on five core ecological journals, covering a time period of 25 years (1992-2022), excluding Ecology letters because it was established in 1998. To reduce the biases of consequence resulting from journal selection, all journals are comparative broad. Three of the selected five journals provide general ecological orientation: Ecology, Journal of Ecology and Ecology Letters. We also selected two applied ecological journals: Ecological Applications and Journal of Applied Ecology (*Table 1*).

Data sources

Literature records (keywords) from 1992 to 2022 were derived from the Web of Science, an online academic citation index database provided by Thomson Reuters. This database is the most important and frequently used source for a broad review of scientific accomplishment in all field (Ugolini et al., 2015). First, we selected the target ecological journal and set the time interval (1992-2022). Second, we exported the full

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records from the Web of Science to text files, including title, author, keywords, abstract, organization, country and language. A total number of 64 text files were created, because the Web of Science limits each export to 500 records. From 1992 to 2002, the records of keywords were derived from JSTOR (Journal Storage). We searched title of paper, and then manually recorded the keywords, because the records of keywords in web of science were not complete before 1996. And then, we combine the text files into one for each journal. In every text files, "author keywords" were marked by "DE".

Table 1. *Introduction to core ecology journals for research*

Journal	Starting year	# of print/year	# of papers
Ecological Applications	1992	6	3879
Journal of Applied Ecology	1992	6	3137
Ecology	1992	12	7259
Journal of Ecology	1992	6	2749
Ecology Letters	1998	12	2469

Data process

Due to the fact that some keywords have similar meaning but different spellings, the keywords in the original paper are not all exactly the same as they appear in the word clouds and co-occurrence networks. For example, phylogeograph, phylogeographic, phylogeographical are merged into phylogeography. Similarly, land-use, climate-change and bio-diversity are considered as land use, climate change and biodiversity, respectively. The data from each txt file were extracted and analyzed with Bibexel (Persson et al., 2009), and the wordcloud was performed using 'wordcloud' package in R (R Core Team, 2016; Resende et al., 2021). Co-occurrence keywords networks were plotted for different period with Ucinet (Chung et al., 2013).

Results

Using the above-mentioned searching strategy, totally 19,493 publications were collected in 5 core journals during 1992-2022. There are only 374 publications in 1992. But it sharply increased to 916 in 2012, and then smoothly increased to 981 publications in 2022 (*Fig. 1*). In general, the number of publications of each core journal also shows an increasing trend, in which Ecology ranked first with 7259 publications, accounting for 37.2% of total publications, followed by Ecological Applications (3879; 13.3%), Journal of Applied Ecology (3137; 16.1%), Journal of Ecology (2749; 14.1%) and Ecology Letters (2469; 12.7%) (*Fig. 1*; *Table 1*).

Ecology has changed greatly in the last 30 years, although some topics or themes consistently obtained more attention. For example, "Competition", "Conservation", "Biodiversity" and "Climate change" occupied an important position in ecological research, but their ranks have changed slightly besides "Climate change" in different time periods (*Fig. 2*; *Table 2*). The most frequently used keywords were "Competition" and "Herbivory" in 1992-2002, while "Biodiversity" and "Climate change" were the most used keywords in the last two periods, respectively (*Fig. 2*). However, a consistent and evident trend in keyword use was emerged. Most generally, the diversity of keywords increased over three study periods while the evenness decreased.

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We selected top 30 keywords in ecology journals, finding that in terms of rank, the trend of the keywords related to anthropogenic increased sharply (*Fig. 3*). For instance, the rank of "Invasive species" increased from 792 in 1992-2002 to 8 in 2013-2022. At the same time, some of others showed a dramatic decrease, such as the rank of "Succession", which decreased from 15 in 1992-2002 to 46 in 2013-2022. The results of four selected keywords that are closely related to human activities, show that each increased dramatically during the past 30 years.

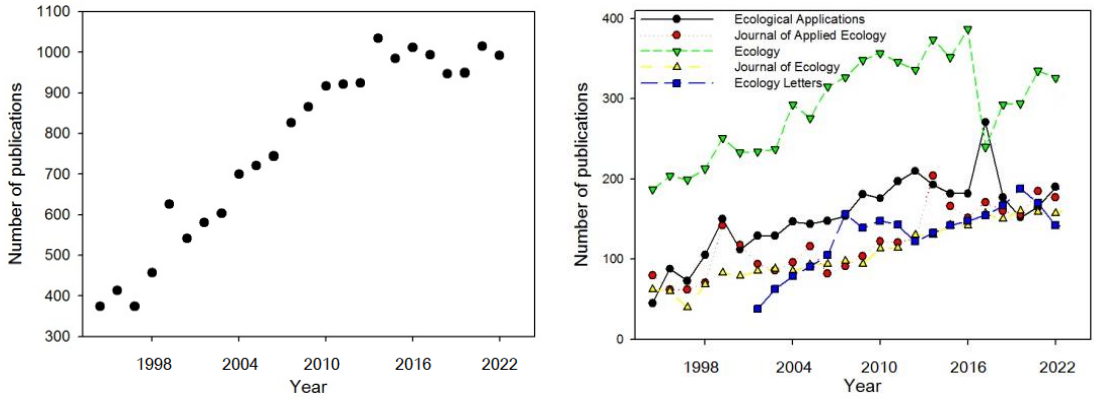

Figure 1. *Temporal changes of number of papers in selected journals (left), and changes of all journals (right) in recent 30 years*

Table 2. *The rank of top 30 keywords in ecology journals*

Keyword	1992-2002		2003-2012		2013-2022		Change in rank
	Frequency	Rank	Frequency	Rank	Frequency	Rank	
Biodiversity	102	4	514	1	377	2	←
Climate change	63	9	246	6	490	1	↑(8)
Competition	132	1	358	2	249	3	↓(-2)
Herbivory	123	2	278	4	208	5	↓(-3)
Conservation	83	8	261	5	247	4	↑(4)
Disturbance	91	6	241	7	180	7	←
Species richness	45	16	281	3	160	9	←
Dispersal	57	11	224	8	188	6	↑(5)
Population dynamics	110	3	218	9	128	15	↓(-12)
Fragmentation	56	12	218	9	158	10	←
Predation	97	5	198	11	102	24	↓(-19)
Nitrogen	87	7	143	15	125	16	↓(-9)
Invasive species	4	792	152	13	173	8	↑(684)
Density dependence	42	20	148	14	120	17	←
Facilitation	18	90	135	16	117	18	←
Demography	45	16	122	18	93	30	↓(-14)
Life history	42	20	124	17	76	44	←
Succession	52	15	111	23	74	46	↓(-31)
Restoration	30	39	93	37	106	22	↑(17)
Community structure	222	55	14	120	18	47	←

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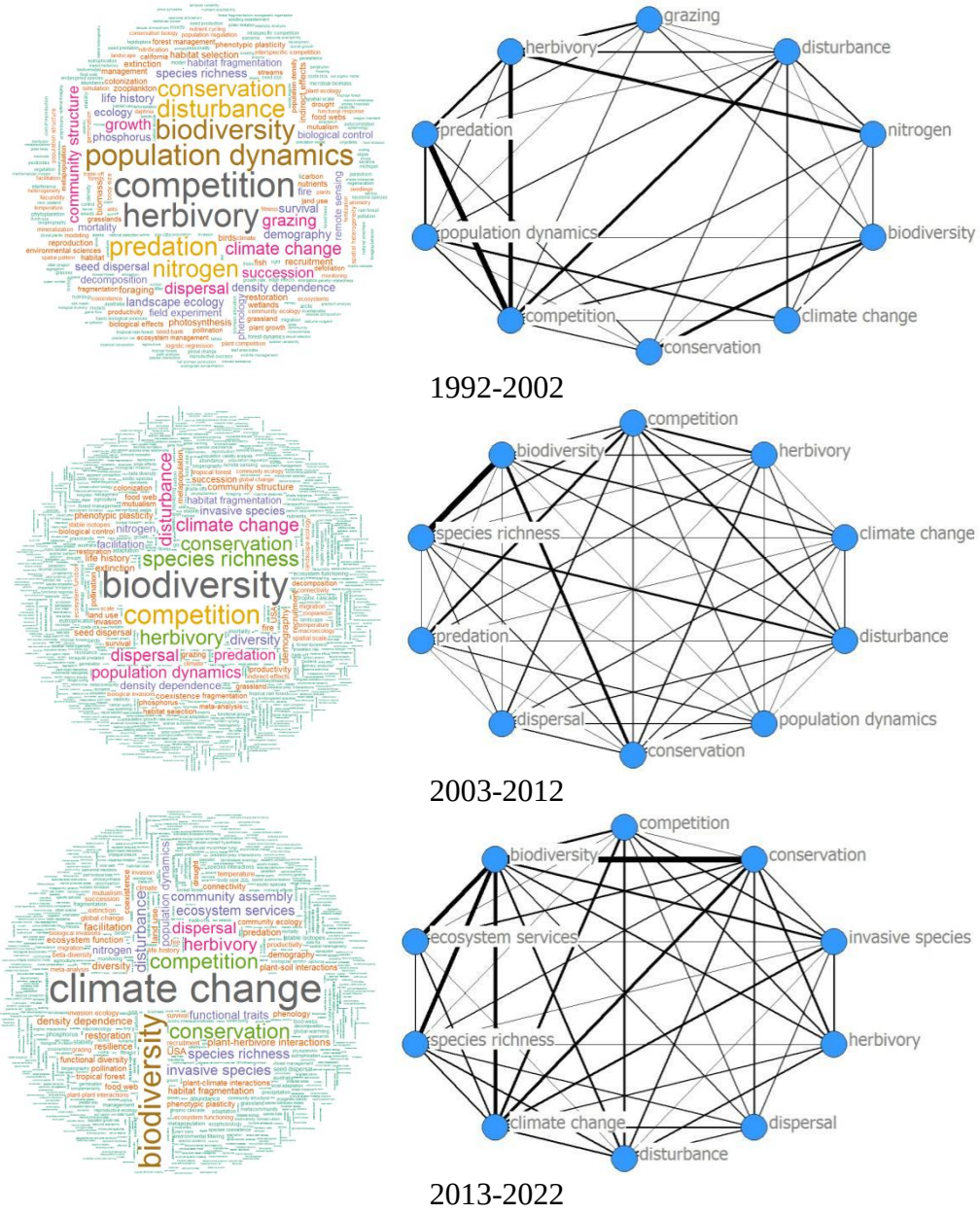

Figure 2. *Keyword clouds of 5 selected ecology journals in recent 30 years (left column), and network maps of keyword co-occurrence networks (right column). Networks include a subset of the 10 most frequently occurring keywords. The density of the connecting lines represents the number of keyword co-occurrences*

Discussion

Keyword analysis or trends of keywords used can offer information about research trends that concern researchers. However, few studies attempt to use this method to gather systematic data on ecological research. The growth of journal publications reflects various supply and demand as well as editorial policy changes. Nonetheless, it is worth recording the increase in the number of papers published in journals. Overall, these effects may result in a huge increase in volume and so I believe that it can promote a substantial growth in this period, especially in 1992 to 2012. However, the

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upward trend in the number of papers published is slowing down, which possibly because the content of papers is increasing through the online Supporting Information (Whittaker, 2014). As the development of ecological research, the diversity of keywords in our study increases over the three periods, but the evenness decreases. This suggests that although more aspects of ecology are being addressed, there are also an increase in the proportion of studies addressing some same core themes.

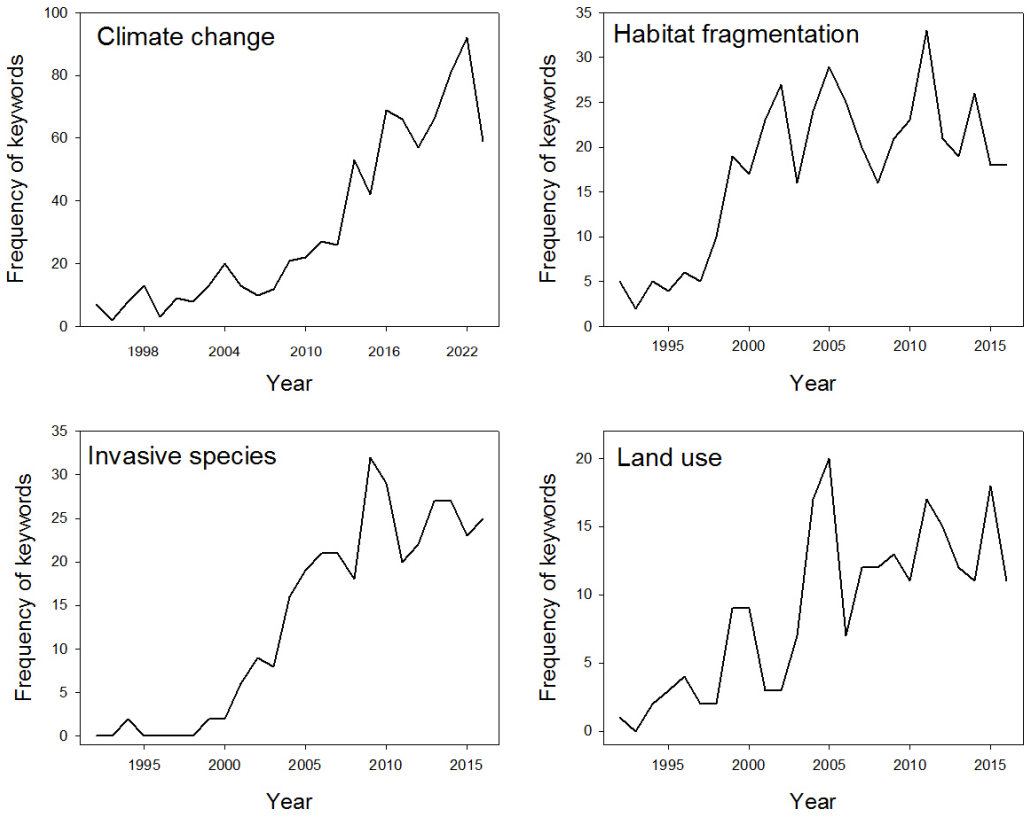

Figure 3. *Temporal changes of hot keywords during 1992-2022*

The word cloud patterns revealed that “Competition”, “Biodiversity” and “Climate change” were most frequently used and comparatively stable in the three periods, which reflected that the importance and popularity in ecological research. One of the central problems in ecology is how the large number of species on Earth can coexist, and what sets limits on diversity (Buttel et al., 2002), therefore, it is not surprising that “Competition” and “Biodiversity” are the most frequent keywords in different time period. In the past century, the global temperature and precipitation have changed spatially and temporally (Parry et al., 2007), so it has attracted more attention by publics and ecologists because changes in climate have affected species distribution, population sizes and composition, as well as increasing the frequency of pest and disease outbreaks (Walker, 1999), and this partly explained why “Climate change” and “Biodiversity” have become more and more closely related. Another explanation is that climate change is a major driver to species extinction, especially for species with small ranges (Pimm et al., 2014). Hoffmann et al. found that one quarter of the species assessed so far at risk of extinction, and the extinction rate is about 1000 times the background rates of extinction (Hoffmann et al., 2010; Barnosky et al., 2011). As

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well as, we found that some keywords shown a decreased trend in three time period, such as “Succession” and “population dynamics”. Three possible explanations for these decrease are (a) some general keywords were replaced by more specific keywords, (b) some keywords were fell out of mainstream of ecological research and (c) the communication tools were changed, notably the internet, promoted international collaboration, and normalization and standardization of research themes and vocabulary (Marriner et al., 2010).

Conclusion

Interestingly, both word cloud and the rank of keyword frequency revealed that keywords related to anthropogenic sharply increased, which may be a potential guide for future research. Now, we had left the Holocene and had entered a new Epoch - the Anthropocene, because of the global environment effects from increased population and economic development (Zalasiewicz et al., 2008). To date, about half of the Earth’s ice-free terrestrial ecosystems have converted into cropland and pasture, it would result in the local loss of biodiversity (Pimm et al., 1995; Vitousek et al., 2008). Furthermore, other anthropogenic changes include fire suppression, habitat fragmentation, land use and climate warming, which likely affect many aspects of ecosystem or our living environment (Barnosky et al., 2011). Many of these alternations would lead to great changes in the biotic structure and composition of ecological communities, either from the loss of species or from the introduction of exotic species. Moreover, these changes may potentially affect ecosystem properties (Hooper et al., 2005). Human-driven environmental changes may simultaneously affect the biodiversity, productivity, and stability of Earth’s ecosystems, but there is no consensus on the causal relationships linking these variables (Hautier et al., 2015), partly because of the more complicated nature in a new era compared with before. There is a need to develop management and conservation applications from the emerging areas of ecological research and it requires more collaboration among ecologist, applied practitioners, industry, economists, and even social scientists.

Focusing on high-frequency keywords and their relationships, this study reveals hotspots and trends in the field of ecological research. The results show that the hotspots of ecology have changed significantly over the past 30 years, but certain topics such as “biodiversity” and “climate change” continue to be emphasized. In addition, there has been a dramatic increase in the number of keywords related to human activities, which may indicate potential directions for future research. This analysis provides the scientific community with a macro view of trends in ecological research, helping researchers to understand the breadth and depth of the research field and thus to select research objectives that are current and important.

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