Article

A scientometric study of the limnological societies: inferences of research collaboration and core topics based on publication networks

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Abstract

Scientometric analysis of limnological societies and related publications revealed complex relationships among research topics and research collaborations. We applied scientometric analysis, word networks, bibliographic coupling, and author networks analysis, to 34777 publications related to limnology and monsoon research. We analyzed usage frequencies of limnology-related words in a Google corpus and found that usage frequencies of most limnological terms peaked during the 1980s. Social interest in the term "limnology" showed a gradually decreasing trend after the late 1990s. Monsoon research was focused in the Asian–Indian region but not in the European, African, and American regions. Word networks of limnological studies related to monsoons were mainly grouped into 3 clusters (Indian monsoons, East Asian monsoons, and monsoon assessment clusters). In the citation network of limnology journals, water quality, plankton, and invertebrate research groups generally showed strong internal citation networks. An author connection map of the limnological societies revealed strong modulators in the international societies, whereas research collaboration was rather limited to small groups within the entire network. This retrospective analysis will provide meaningful information to further develop and enhance international collaboration within limnological studies.

Key words: centrality, citation network, limnology, monsoon, ngram, text mining

Introduction

Limnology covers broad types of inland waters; it addresses emerging environmental issues and has developed briskly over the last 100 years. Diverse academic societies related to limnology have focused on and contributed to interaction among biological, hydrological, and geological components and ecological issues (Wetzel 2000). Timely reviews of these limnological achievements have organized scattered findings and provided summary information to the societies and researchers. Based on these benefits, extensive reviews have focused on specific limnological topics (Wetzel 2000, Jeppesen et al. 2010, Moss et al. 2013) because expert reviews generally require and largely rely on researchers who have broad knowledge and continued experience in an academic field.

Today, the number of publications is skyrocketing, and research themes are more complicated as increasing collaborations develop among different scientific fields (e.g., biology and information technology, molecular biology, and field ecology). This rapid progression of scientific publications may further constrain the single expert review with a wide mandate. Meanwhile, as many scientific societies have accumulated stacks of research papers and historical documents, we may consider other types of reviewing methods that can provide a quantitative evaluation by using collected publications.

Scientometrics is concerned with the quantitative features and characteristics of science and scientific research. Scientometrics also focuses on the analysis of publications to review core topics and the relationships among author networks. Applications of this type of quan-

Table 1. List of limnological journals used in the scientometric analysis.

Journal title	# of publications used	Time period	Internal citation links
Annales de Limnologie - International Journal of Limnology	739	1990–2015	380
Aquatic Ecology	613	2003–2015	207
Aquatic Sciences	920	1989–2015	588
Freshwater Biology	4777	1973–2015	15 948
Freshwater Science	1734	1988–2015	6548
Hydrobiologia	15 984	1971–2015	31 718
Inland Waters	134	2011–2015	54
Journal of Limnology	457	2007–2015	270
Limnologica	548	2002–2015	340
Limnology	353	2003–2015	137
Limnology and Oceanography	6730	1970–2015	23 421

titative measurement have benefited reviews of the historical development of research topics and confined how research collaborations were forged within diverse scientific fields. Several studies analyze bibliographies in social studies (Hood and Wilson 2001), yet scientometric reviews of limnology remain limited (Liao and Huang 2013, Alves et al. 2014, Gao et al. 2014).

Accordingly, we examined scientific publications to discover trends in limnological research and researcher networks. We analyzed the development of research topics, keywords, and author networks in limnological societies by using published papers in international limnology journals. We also analyzed relative interest in limnological terms using the Google Ngram. This study addressed the following research questions in limnological societies: (1) What were the most issuing topics? (2) Which study groups were closely related? (3) How have researchers cooperated on diverse topics? We expected to find a distinct composition of research topics and insightful implications into core research networks.

Methods

Text corpora

We analyzed relative interest in limnological terms and related issues by using the Google Ngram database, which includes 5 million books published from the 1800s to the 2000s (Michel et al. 2011, Roth 2014). Previous studies based on the ngram database found meaningful trends in public interest and social issues ranging across diverse issues (Acerbi et al. 2013). We compared public interest on ecological issues (climate change, water quality, land use, acid rain, biomanipulation), limnological concepts

(river continuum, flood pulse, serial discontinuity, and nutrient spiraling), and types of monsoon (Asian, East Asian, Indian, African, Australian, and North American). Usage frequency of the term was computed by dividing the number of instances of the ngram in a given year by the total number of words in the corpus in that year (Michel et al. 2011).

We also considered 32 989 scientific papers, published in the Annales de Limnologie - International Journal of Limnology (739 articles), Aquatic Ecology (613), Aquatic Sciences (920), Freshwater Biology (4777), Freshwater Science (1734), Hydrobiologia (15 984), Inland Waters (134), Journal of Limnology (457), Limnologica (548), Limnology (353), and Limnology and Oceanography (6730). This corpus was used for the topic analysis, author connection map analysis, and citation network analysis (Table 1). Only English language papers were included. Scientific papers in the international journals were collected manually by searching in the journal publication database and Web of Science academic databases.

Monsoon-related studies constituted one of the important issues in the limnological studies. For a broad interpretation of limnological studies related to monsoons, we collected scientific publications in the international journals by using academic web searches. We searched "monsoon" and "limnology" in Google Scholar (Harzing 2013) and Web of Science academic databases and collected 28 330 papers. Initial search results still contained many oceanographic studies; thus, we excluded those results by using specific search operators (i.e., -oceanography, -ocean, -sea). Finally, 1788 papers were selected for the topic analysis of monsoon research.

Scientometric analysis

We merged the titles, authors, abstracts, and keyword information of each article into a single text corpus and prepared the text dataset for the various text-mining techniques. To find the major terms and issues in the publications, we used word frequency counts, word network analysis, citation networks, and author network analyses. The word frequency count analyzed unigrams and bigrams to discover the research terms in the dataset. Meaningless combinations of prepositions (e.g., "of the," "for a") were excluded in the word frequency count.

A term map based on collected text corpora was created for network visualization. A term map (or word network) locates terms so that the distance between 2 terms provides an indication of the number of co-occurrences of the terms. Closely located terms with smaller distances represent more co-occurrences of the terms. We used VOSviewer

1.6.1 (Leiden University, Netherland) and Gephi 0.8.2 (The Gephi Consortium, France) with binary counting methods to visualize the network and density map of the collected terms (Waltman et al. 2010). Synonyms were merged into a single term before the analysis. Research networks can also be inferred from citation patterns in the scientific literature. We analyzed citation networks in the international limnology journals with CitNetExplorer 1.0.0 (Leiden University, Netherland; van Eck and Waltman 2014). Non-matching cited references were not included in the network because we focused more on the internal network in the limnological societies than on the entire relationship with other disciplines. For a quantitative understanding of the network components (i.e., terms, organizations, authors), eigenvector centralities were calculated to characterize the global prominence of a vertex in the network (Bonacich 2007). We used this network index to estimate relative influence of organizations or authors in the network.
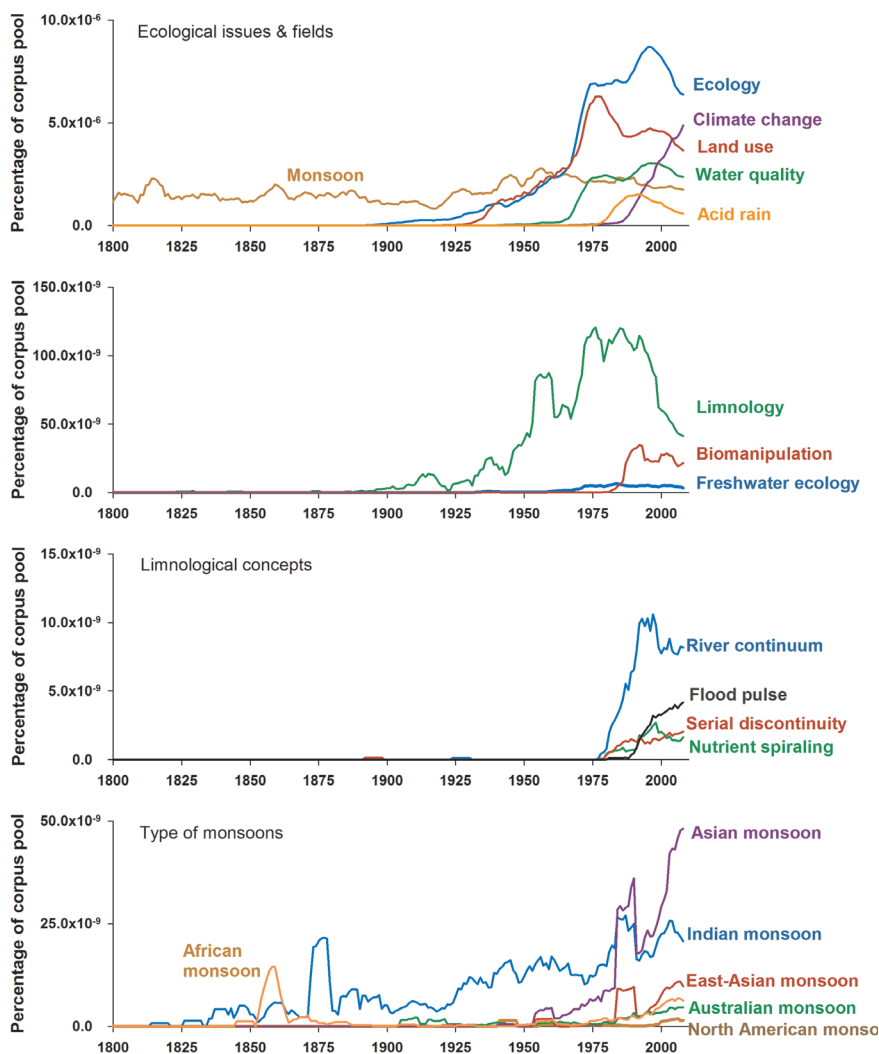

Fig. 1. Usage frequencies of words related with limnology in the Google Ngram (1800–2008).

Table 2. Frequency rank of bigram for publication titles (total $n = 32\,989$ publications) from 1970 to 2015.

Frequency rank	1970s (term number = 2495)	1980s (term number = 5197)	1990s (term number = 8449)	2000s (term number = 9935)	2010s (term number = 6062)
1	organic matter (3.8*)	fresh water (14.4)	fresh water (7.8)	organic matter (11.8)	shallow lake (11.0)
2	primary production (3.5)	life history (3.5)	organic matter (6.4)	dissolved organic (9.8)	organic matter (8.3)
3	organic carbon (2.8)	community structure (3.0)	new species (4.5)	organic carbon (6.6)	food web (8.2)
4	dissolved organic (2.8)	primary production (2.8)	eutrophic lake (4.3)	shallow lake (6.4)	long term (7.7)
5	nitrogen fixation (2.7)	population dynamics (2.8)	community structure (4.0)	community structure (6.2)	water quality (6.4)
6	primary productivity (2.5)	organic matter (2.7)	long term (3.7)	water quality (6.0)	dissolved organic (6.4)
7	new species (2.3)	water quality (2.4)	life history (3.5)	life history (5.9)	community structure (5.8)
8	blue green (2.3)	lake sediment (2.4)	dissolved organic (3.5)	long term (5.8)	life history (4.9)
9	vertical distribution (2.2)	heavy metal (2.4)	water quality (3.0)	headwater stream (5.5)	climate change (4.8)
10	lake sediment (2.2)	eutrophic lake (2.1)	food web (2.9)	food web (5.3)	organic carbon (4.7)
11	population dynamics (2.0)	life cycle (2.0)	organic carbon (2.4)	new species (5.2)	eutrophic lake (4.7)
12	vertical migration (1.8)	aquatic macrophytes (1.8)	population dynamics (2.1)	macroinvertebrate communities (4.0)	stable isotope (4.2)
13	spatial distribution (1.8)	dissolved organic (1.8)	primary production (2.0)	stable isotope (3.7)	land use (4.0)
14	fresh water (1.8)	new species (1.7)	seasonal variation (1.9)	global diversity (3.6)	freshwater (4.0)
15	water chemistry (1.7)	organic carbon (1.6)	mountain stream (1.8)	leaf litter (3.4)	river basin (3.6)
Total phrase #	602	1417	1664	1539	1896

*numbers in parentheses indicate relative percentage (%) of frequency against total phase number in each decade.

Results and discussion

Trends of limnological issues

Usage of limnological terms in the Google Ngram showed diverse seasonal patterns, and we could identify a general trend of interest in ecological topics (Fig. 1). The frequency of limnological terms (broadly related with ecology) was the highest for "ecology" (3.56×10^{-4}% of total corpora), followed by "monsoon" (3.50×10^{-4}%), "land use" (2.53×10^{-4}%), "water quality" (1.02×10^{-4}%), "climate change" (5.97×10^{-5}%), and "acid rain" (3.12×10^{-5}%). Use of the term "ecology" rapidly increased after the 1950s and peaked during the 1990s. Frequency of the term "monsoon" has been consistent since the 1800s and seems to have sustained interest, although it may be used as a meaning of seasonal rainfall (Ramage 1971) related to agricultural practices. "Climate change" appeared in the 1970s, and its frequency is sharply increasing as a strong response to the relative influence of social interest on related science (Pienitz and Vincent 2000).

The frequency of "limnology" showed a similar pattern to "ecology," although the use of limnology rapidly declined after 1992, possibly representing a relative reduction in pure limnological study, so the limnological societies may need to consciously consider a change of research framework and topical themes. Public awareness programs on river and lake research can be considered a means of widely spreading information from limnological publications. Use of "freshwater ecology" also decreased after 2000. The total frequency was highest for "limnology" (5.5×10^{-6}%), "biomanipulation" (6.02×10^{-7}%), and "freshwater ecology" (2.14×10^{-7}%).

The total frequency of limnological concepts was highest for the river continuum concept (2.04×10^{-7}%), flood pulse concept (5.57×10^{-8}%), serial discontinuity concept (4.06×10^{-8}%), and nutrient spiraling concept (3.85×10^{-8}%). Most major concepts were widely used over time. This consistent increase indicates the development and broad application of conceptual models.

We also compared the appearance of major monsoon types. The total frequency was highest for the Indian monsoon (1.87×10^{-6}%), followed by the Asian monsoon (9.28×10^{-7}%), African monsoon (2.78×10^{-7}%), East Asian monsoon (2.07×10^{-7}%), Australian monsoon (1.42×10^{-7}%), and North American monsoon (3.39×10^{-8}%). Consequently, monsoon appeared often in the Asian and Indian regions but not in the Europe, African, and American regions. Rapid increase in the use of the term "Asian monsoon" after the 1980s was notable among regional monsoons.

Core research topics in limnological publications

The frequency rank in the ngram for publication titles revealed that "organic matter" was the most dominant research term during the last 45 years (Table 2). Pollution or eutrophication-related terms were widely used in the 1970s–1980s. In the 1970s, high use of "nitrogen fixation" (2.7%), "blue green" (2.3%), "vertical distribution" (2.2%), and "vertical migration" (1.8%) was characteristic. Higher use of the term "heavy metal" (2.4%) reflects the many industrial pollutions and biological accumulation
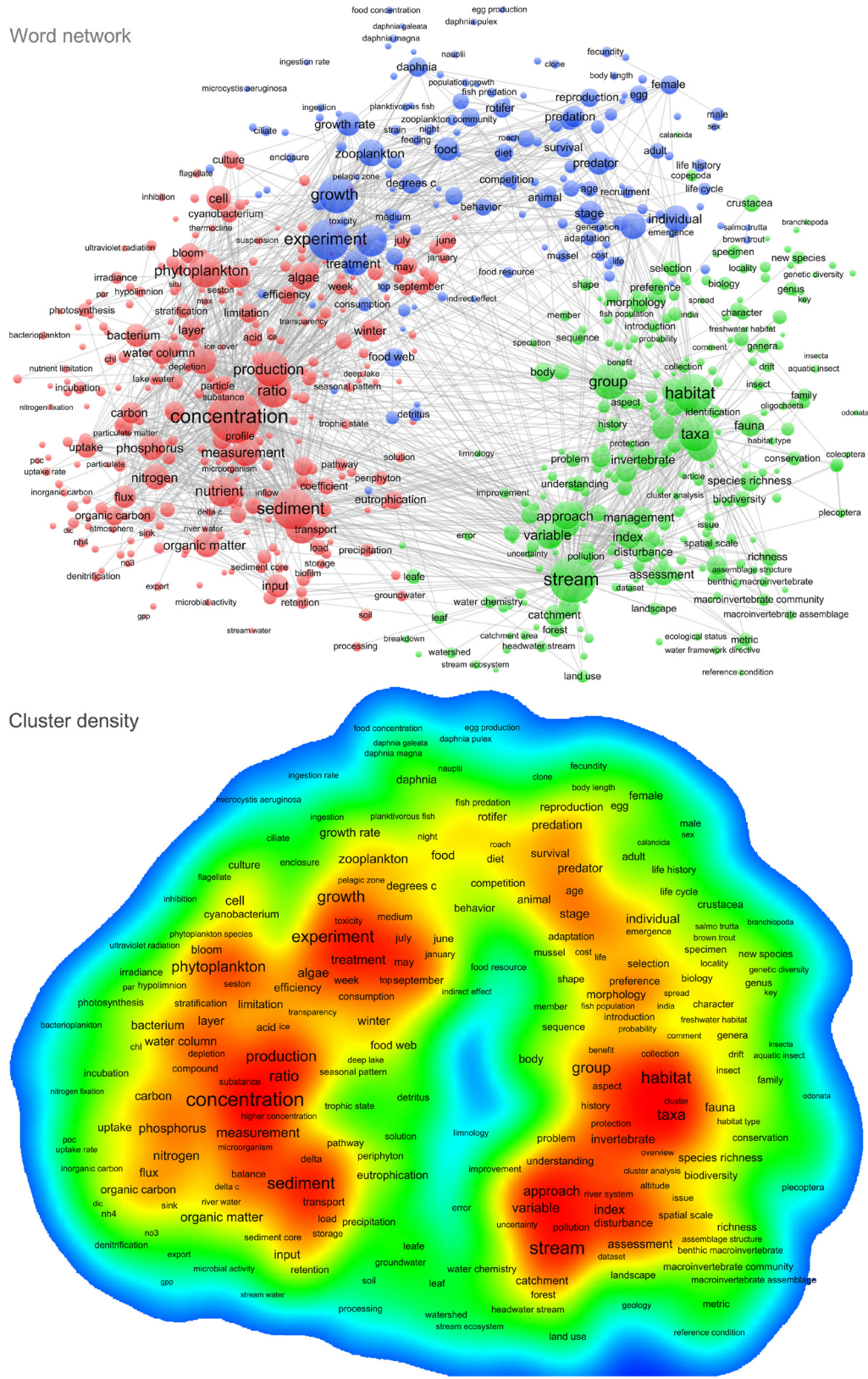
Fig. 2. Term maps for limnological publications from 1970 to 2015. Different colors in the word network represent conceptual clusters in the corpus. Node size is proportional to term frequency, and red in the cluster density map represents the position of highly connected node cluster.

studies conducted in the 1980s. After the 2000s, terms related with global issues such as "global diversity (3.6%) and "climate change" (4.8%) had emerged. Landscape-level studies seemed to increase during the 2010s, with related terms including "land use" (4.0%) and "river basin" (3.6%) emerging with higher frequency. Increased frequency of "shallow lake" (6.4% in the 2000s, 11.0% in the 2010s) and "food web" (2.9% in the 1990s, 5.3% in the 2000s, 8.2% in the 2010s) was also notable in the 2010s.

The relationship of research topics was more clearly represented in the term map (Fig. 2). Three clusters, including "lake research," "river and stream research," and "population dynamics and competition research" were identified in the word network of limnological publications. The word network of the limnological publications contained a lake research cluster (Fig. 2, red, left) reflected by terms such as "concentration" (4826 occurrences), "sediment" (3164), "production" (2513), "phytoplankton" (2329), "nutrient" (1904), and "chlorophyll" (1677). Research terms related with nutrient cycling and phytoplankton bloom were dominant in this cluster. Cluster density was high in "nutrient concentration," "sediment loading," and "phytoplankton experiment."

The river and stream research cluster (Fig. 2, green, right) included common terms such as "stream" (3781) and "habitat" (2914), with associated terms such as "taxa" (2493), "group" (2480), "diversity" (1995), "information" (1207), "assessment" (1154), "management" (1072), "disturbance" (985), and "macroinvertebrate" (920). The river and stream research cluster included biological index and habitat conservation related studies. Macroinvertebrates and fish were dominant biological taxon appearing in the river and stream research cluster. Density was high for "pollution," "index," and "habitat." The population dynamics and competition research cluster (blue, top) included common terms such as "experiment" (3148), "growth" (2693), "zooplankton" (1547), "treatment" (1406), "individual" (1471), "larvae" (1428), and "predation" (1004). Studies of zooplankton and aquatic insects were dominant in this cluster. Higher frequency of manipulated experiment was also notable compared with other clusters.

The citation network further revealed characteristic research groups within limnology journals (Fig. 3). The 100 most frequently cited publications were included in the final network. In the citation network analysis, publications of different ages should refer to the time delay issue; recent publications tend to have fewer citations than older publications because of differences in exposure time (van Eck and Waltman 2014). The integrated citation network composed of 32 989 limnological publications had 174 474 citation links. In addition, the citation cluster indicated relative strength of each research topic. Plankton

and fish studies have an extended citation network from the 1970s to 2000s, and the water quality cluster has a close relationship with the plankton and fish cluster. Invertebrate publications have a strong internal citation network but a relatively weak interaction with other research clusters.

Internal citation networks in each limnological journal showed their inherent focus and orientation (Appendix 1). Citation structures of recently organized journals (i.e., Aquatic Ecology, Inland Waters, Journal of Limnology, Limnology) were grouped into a single citation cluster because of the small number of publications. Moreover, this citation cluster has a weak citation network with other limnological topic clusters. Journals with a relatively long history (i.e., Freshwater Biology, Limnology and Oceanography) had large numbers of articles and showed a strong internal network in the journal citations. Most of the limnological components (e.g., physical environment and biological taxa) were interrelated with topic groups. A dense citation network could represent collaborative information sharing within a journal.

Monsoon research

The word "network" in limnological studies related with monsoon was mainly grouped into 3 clusters (Fig. 4, Appendix 2) related to 2 dominant monsoon types. The Indian monsoon cluster (Fig. 4, green, right) was associated with terms such as "pond," "fish pond," "freshwater pond," "biodiversity," "fish," "production," "growth," and "zooplankton diversity." The related

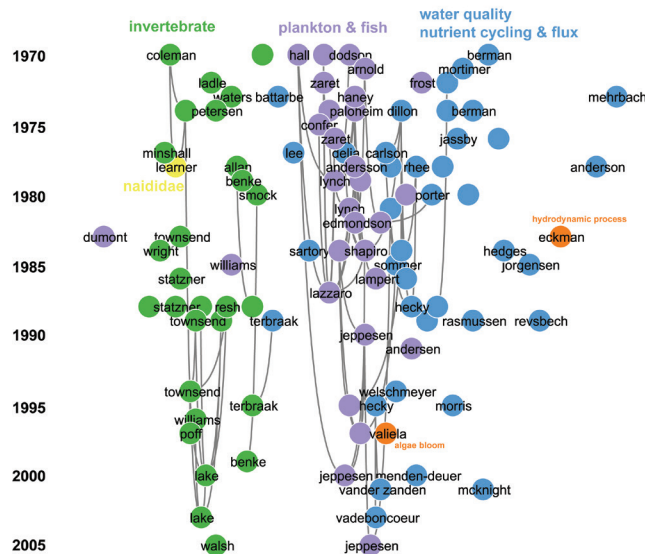**Intergrated citation network (n=32 989, links=174 474)**

Fig. 3. Citation network in international limnology journals. Only the top 100 publications based on citation numbers are presented. Core publications are located horizontally based on publication date.

appearance of Indian monsoon studies was concentrated in the South Asia region (i.e., India, Tibet, Southern China). Most cases in this cluster mentioned the influence of monsoons on water quality, although the statistical approaches for pathway or trends were rather limited. Fish and plankton were the major target taxa of the studies.

The East Asian monsoon cluster (Fig. 4, red, left) was associated with terms such as "precipitation" (rainfall), "drought," "flood," "water balance," "East Asia," "nutrient input," and "chlorophyll." Major research topics in the East Asian monsoon cluster were trends and patterns of monsoon (rainfall), responses of the biological community (plankton, plant, macroinvertebrate), and the modeling and simulation of its dynamics. Korea, China, Taiwan, Japan, and Ethiopia were frequent study sites in this cluster group. Because the oscillation of Indian and Asian monsoons is closely interconnected, limnological studies related to monsoons should also have proceeded with a consensus among the Asian–Indo countries. The evaluation and assessment cluster (Fig. 4, blue, bottom) represented many modeling approaches that evaluated the rate of climate change and the seasonal dynamics of climatic factors, including monsoons.

Research networks in limnology societies

The organization network, biographic coupling network, and author network in the limnological societies revealed a quantitative framework of academic collaboration (Fig. 5–9). We identified 8023 organizations and clustered them into 4 groups in the publication network. Organization clusters (Fig. 5a) showed a strong tendency for nationality

to influence collaboration. Cluster 1 (red, left) included many universities and governmental agencies in the United States; Cluster 2 (orange, right) included European and some Asian universities; Cluster 3 (blue, bottom) included organizations in Canada and Australia; and Cluster 4 (green, top) mainly included integrated organizations in France, Netherland, Spain, and others.

Centrality is a structural characteristic of how individuals fit within the network overall (Bonacich 1972, Nikolaev et al. 2015). Individuals with high centrality scores can be interpreted as leading nodes in a network. Average eigenvector centrality of these national clusters was significantly different ($F = 4.339$, $p = 0.006$; Fig. 5b), whereas their publication number was not significantly different ($F = 0.937$, $p = 0.425$; Fig. 5c). Cluster 1 had higher eigenvector centrality, reflecting their stronger influence on research cooperation at the organization level. Further, number of publication was not proportional to its relative influence in the network (Fig. 6). Relative importance of each publication is difficult to evaluate, yet we should consider how it would be beneficial to the interests of scientific communities.

The bibliographic coupling network (Fig. 7) also had a similar pattern to the organization network. Researchers tend to cite and share more references published from closely related organizations or nearby countries. Currently, many limnological studies and other related sciences are focusing on global issues for an in-depth understanding of ecological phenomenon (Condit et al. 2014, Hamilton et al. 2014, Zwart et al. 2015). International projects, including GLEON (The Global Lake Ecological Observatory Network) and ILTER (International Long-Term Ecological Research), are examples of
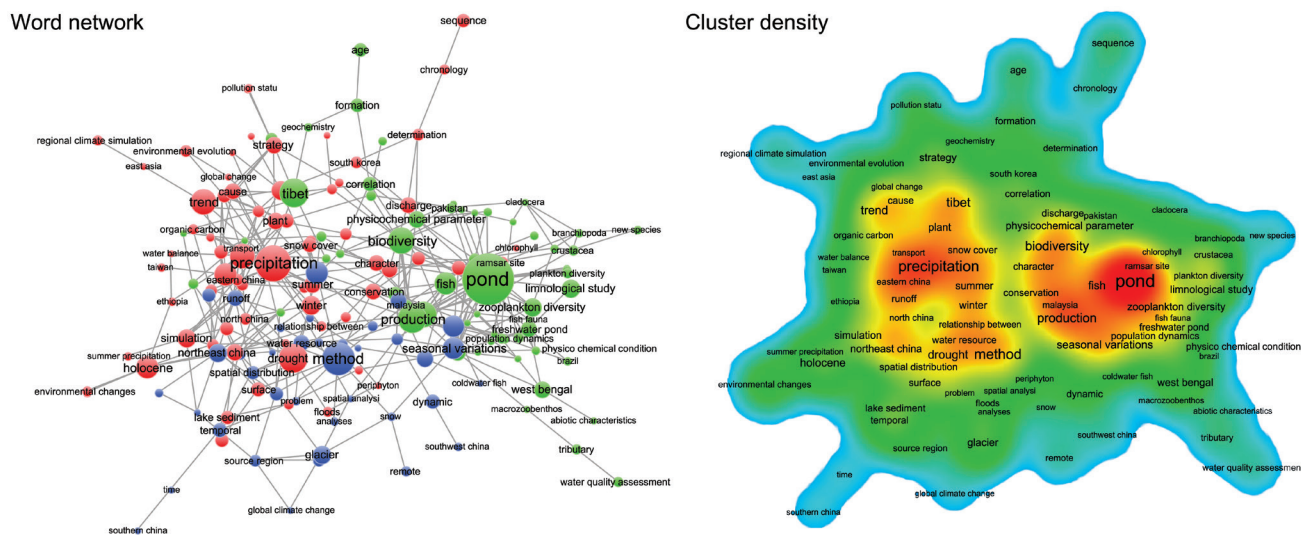

Fig. 4. Term maps for limnological studies related to monsoon from 1956 to 2015 ($n = 1788$). Different colors in the word network represent conceptual clusters in the corpus. Node size is proportional to term frequency, and red in the cluster density map represents the position of highly connected node cluster.
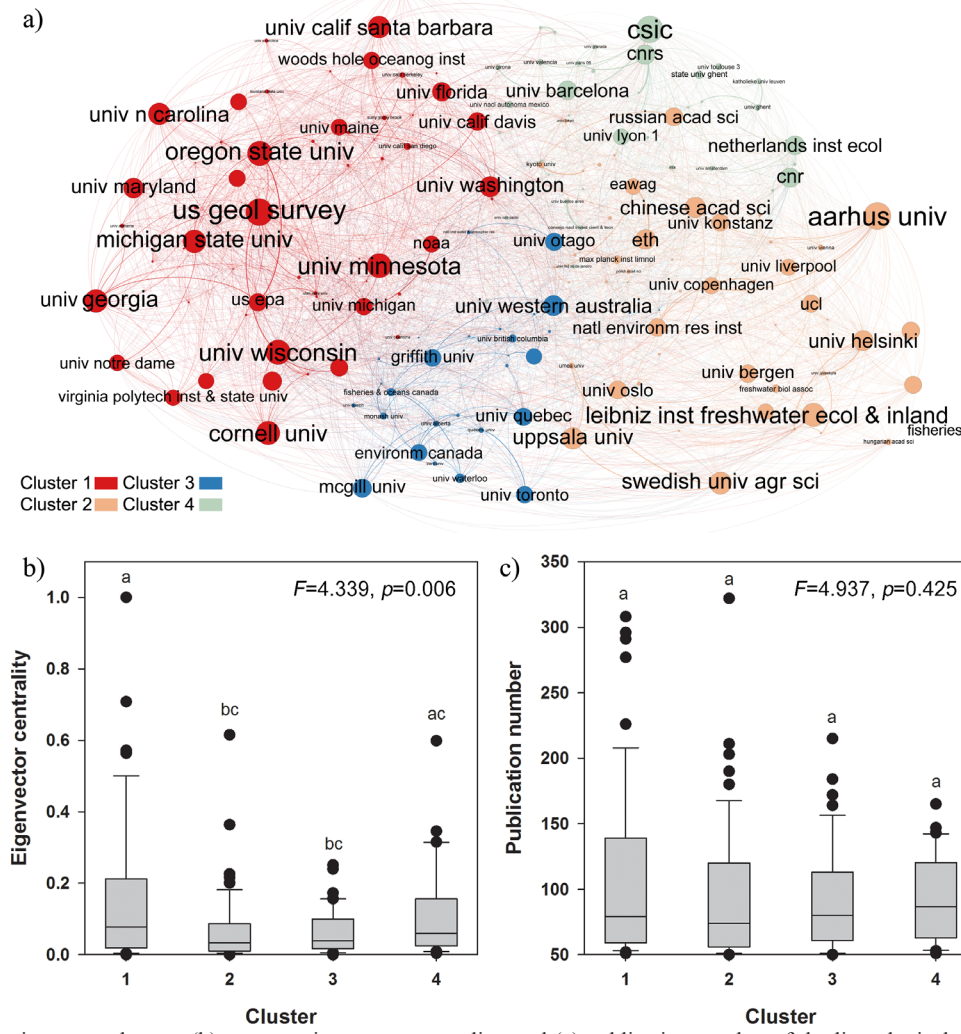
Fig. 5. (a) Organization network map, (b) average eigenvector centrality, and (c) publication number of the limnological societies. Different colors in the network represent different clusters. Node size is proportional to the number of publications.
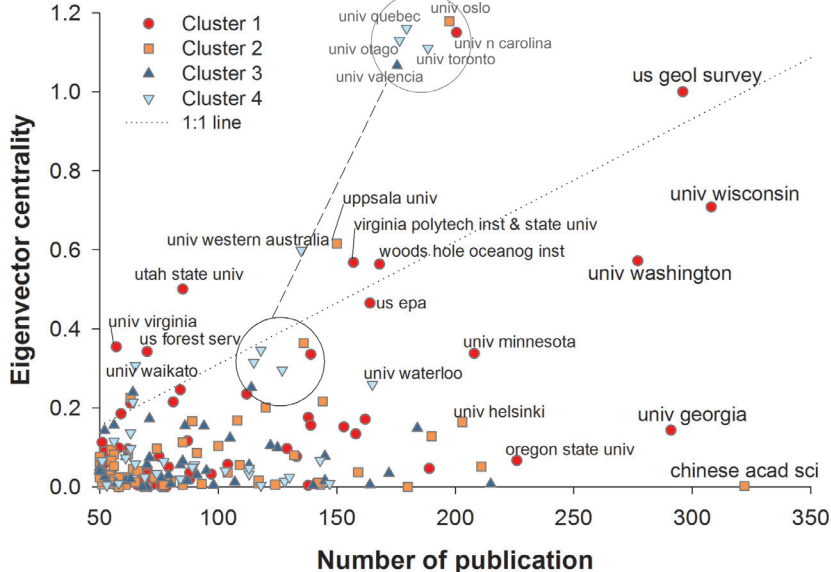

Fig. 6. Network characteristics of organizations in the limnological societies. Different color symbols represent organization clusters in Fig. 5.
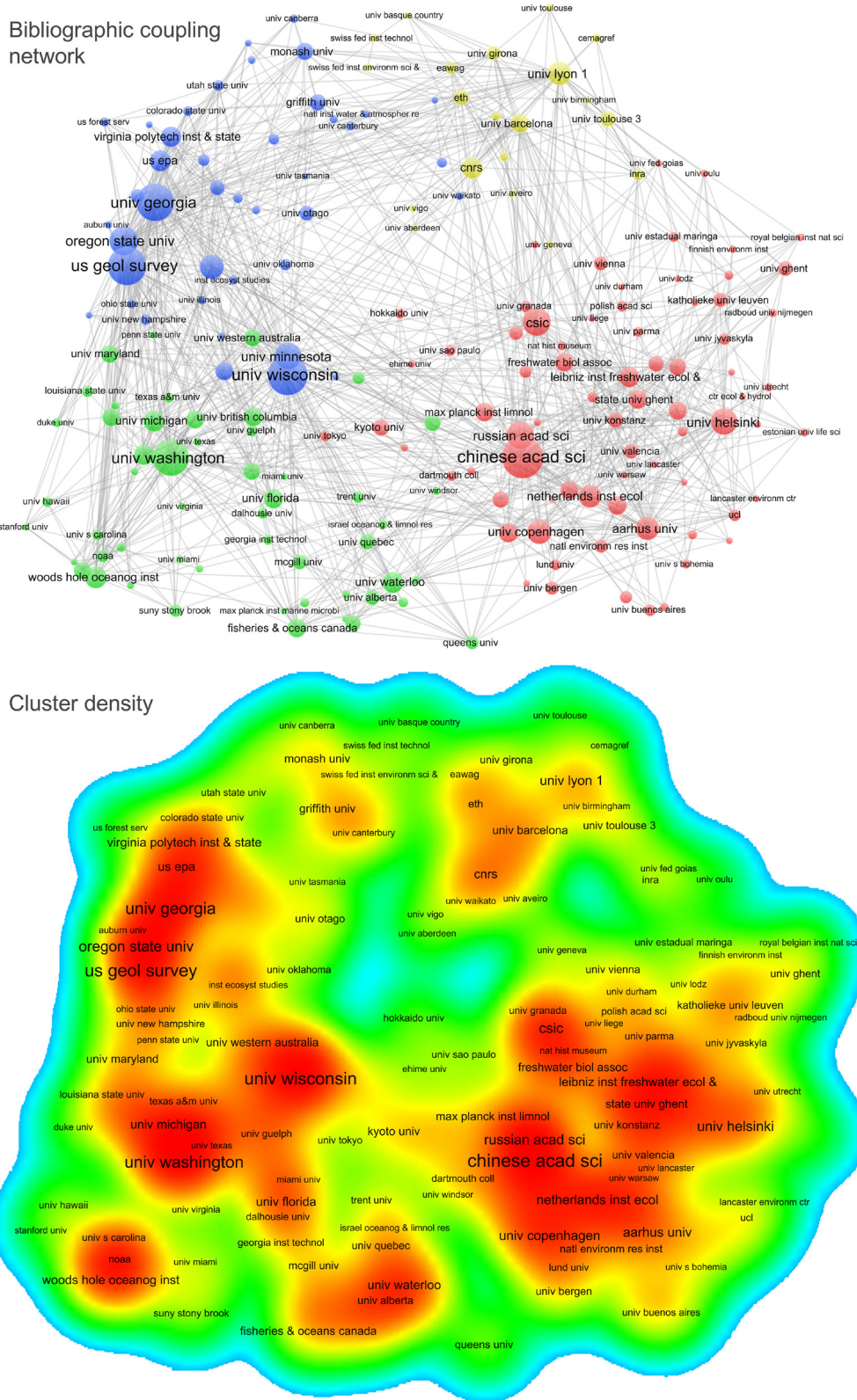
Fig. 7. Bibliographic coupling network for limnological publications from 1970 to 2015. Different colors represent conceptual clusters in the network. Node size is proportional to number of publications, and red in the cluster density map represents the position of highly connected node cluster.
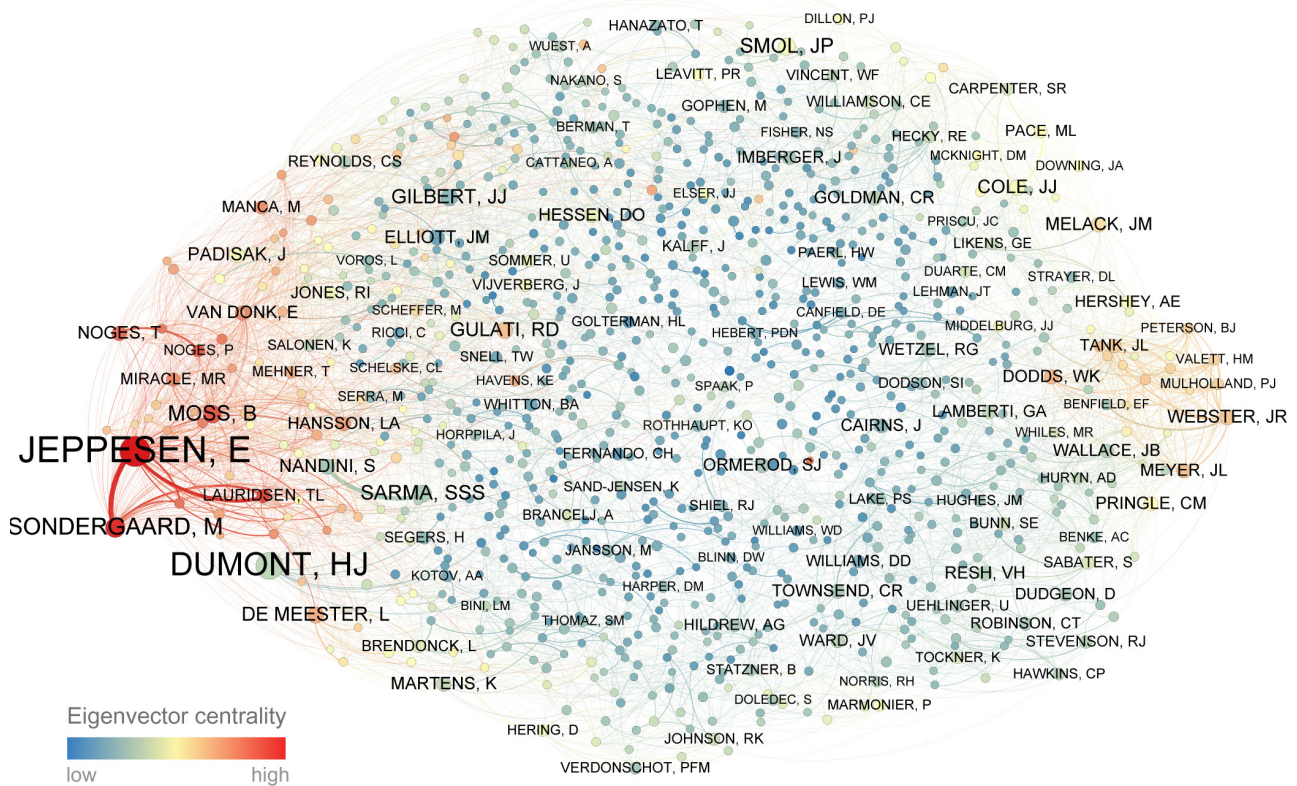
Fig. 8. Author connection map of the limnology journals (total 32 989 publications with 42 381 authors, average clustering coefficient: 0.37). Author names are presented as surname, followed by initials of first name(s). Labels are only presented on nodes with high publication number (publication number >50).
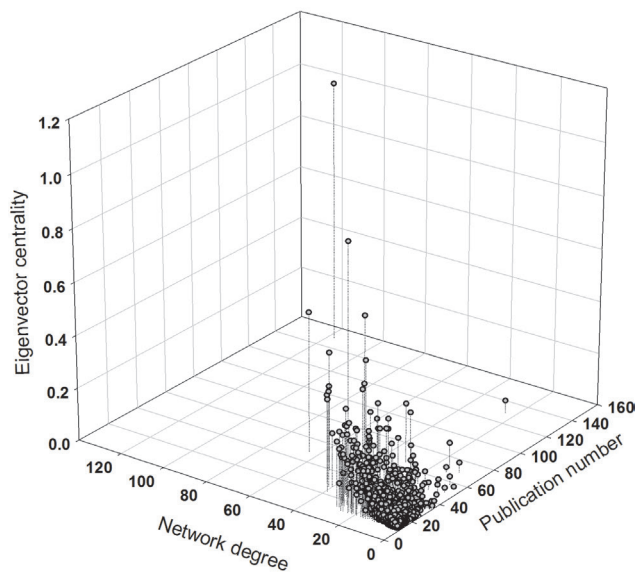

Fig. 9. Network characteristics of coauthors in the limnological societies. Each dot represents author in the network

establishing global networks to better understand key processes in ecosystems. For an integrated understanding of ecological process, research collaboration should be expanded to cover diverse biomes and different continents. This bibliographic coupling network may need further analysis by considering different research topics in each organizational group.

The author connection map of limnology journals revealed a strong modulator in international societies (Fig. 8 and 9). We identified 42 381 authors in the limnological societies, and of these, 15 097 (35.6% of total authors) published more than one paper. The average path length of the network was 4.11, which means that researchers in the limnological societies are closely connected within 4–5 colleagues. Collaboration between authors also showed similar pattern with the organization network (Fig. 8). Author groups were largely separated into European, American, Canada–Australian, and Asian research groups. Most authors had strong networks within domestic academic societies, whereas research collaboration between countries was limited to a few modulators (high between centrality). Limnological societies may consider broadening international collaboration for an effective framework on complex ecological issues. Eigen centrality

scores of the limnological network, which represent relative leading influence, showed a large gap in the rank distribution (Fig. 9) and a rapid drop after the first or second rank author. Furthermore, only 0.09% of overall researchers (40 people) had an eigen centrality higher than 0.2. No definite solution currently evaluates which network structure (i.e., leader-based or collaborative) would be effective for scientific collaboration. In the interim, the relationships in the network should be interpreted with broad understanding. Even in remote sites of an author network, some researchers may work on "minor" topics (based on the numbers in the research group, not the quality of research), which make an essential contribution to limnology.

Limnology is composed of diverse attributes including physical, chemical, and biological components. Studying complex processes requires collaborative networking from different research fields. Thus, limnological societies should strengthen researcher networks and collaborate to reveal complex interactions among different ecological components. Collective intelligence based on a global research network plays an essential role in developing limnological concept models and broadening our understanding of freshwater ecosystems.

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