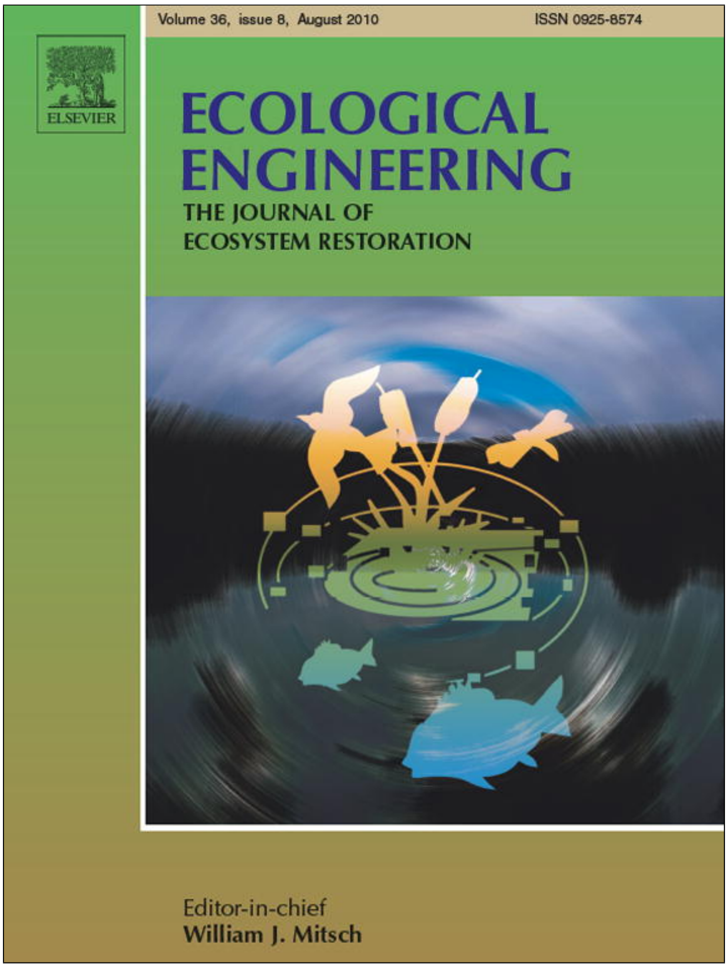
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A review of published wetland research, 1991–2008: Ecological engineering and ecosystem restoration

Liang Zhang[a], Ming-Huang Wang[b], Jie Hu[c], Yuh-Shan Ho[b,d,*]

[a] Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan 430077, People's Republic of China
[b] Department of Environmental Sciences, Peking University, Beijing, 100871, People's Republic of China
[c] Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands
[d] Trend Research Centre, Asia University, Taichung 41354, Taiwan

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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 wetland research between 1991 and 2008. The objective was to conduct a quantitative and qualitative analysis for global trends of wetland-related research. The characteristics related to publications were analyzed. The results showed the significant wetland research issues in the SCI database. From 1991 to 2008, the annual number of journal articles published and the number of articles cited to wetland research increased more than sixfold and ninefold respectively. The USA produced the most single-country articles and international collaborative articles, followed by Canada and UK. The results also showed the significant wetland research issues in SCI database. The most frequently used words were: "water" (or "water quality"), which ranked 3rd, 7th, and 3rd according to the word in article title, author keyword, and keyword plus analysis, respectively. Constructed wetland biodiversity became more active in wetland research. The keywords "constructed wetland" and "constructed wetlands" ranked 58th and 12th in 1991–1996, while they ranked 5th and 4th in 2003–2008; the author keyword "biodiversity" ranked 45th in 1991–1996, while it ranked 23rd in 1997–2002, and 14th in 2003–2008; and keyword plus "diversity" ranked 93rd in 1991–1996, while it ranked 20th in 1997–2002, and 17th in 2003–2008. Moreover, it was proved that article title, author keyword, and keyword plus analysis methods were effective approaches for mapping wetland research. Popular wetland research issues and wetland research changes were also identified by statistical analysis.

1. Introduction

Wetlands are of two basic types: natural and constructed wetlands. Wetland research mainly focuses on ecological engineering and ecosystem restoration (Mitsch and Jorgensen, 2003; Mitsch and Gosselink, 2007). Natural wetlands are natural areas where water covers the soil, including swamps, marshes, fens, sloughs, and bogs. Constructed wetlands are ecosystems similar to natural wetlands, combining physical, chemical and biological processes (USEPA, 2000; Mitsch and Gosselink, 2007). As a sustainable and energy-efficient method for wastewater treatment, many constructed wetlands have been commissioned to treat various types of wastewaters such as urban and agricultural runoff (Scholz et al., 2007; Mitsch et al., 2008; Zhang et al., 2008), municipal and industrial wastewaters (USEPA, 2000), and acid mine drainage (Weber et al., 2008; Nyquist and Greger, 2009). Wetlands, which generally consist of water, soil, vegetation and microorganism systems, are important for maintaining aquatic ecosystem biodiversity (Mitsch and Gosselink, 2007). The global researches of wetlands mainly focus on ecology, biodiversity and conservation (Whitehouse et al., 2008), water quality improvement (USEPA, 2000), circulation of materials (biogeochemical cycle) (Raich and Schlesinger, 1992), and environmental restoration (Suding et al., 2004; Fink and Mitsch, 2007; Moreno et al., 2007). There were many publications based on those topics, and the trends of wetland research were also studied by the researchers all over the world (Brix, 1994; Lehner and Doll, 2004; Mitsch and Gosselink, 2007; Zhang et al., 2009). However, a comprehensive statistical review of the global wetland research was not provided.

Bibliometrics, which was described as the application of mathematical and statistical methods to books and other media of communication, was introduced in 1969 (Pritchard, 1969). It pri-

* Corresponding author at: Trend Research Centre, Asia University, No. 500, Lioufeng Road, Wufeng, Taichung County 41354, Taiwan.
Tel.: +866 4 2332 3456x1797; fax: +866 4 2330 5834.
E-mail address: ysho@asia.edu.tw (Y.-S. Ho).

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marily referred to the research methodology employed in library and information sciences for citation analysis and content analysis. Conventional bibliometric methods have been widely applied in various fields to assess the research trends by investigating the publication characteristics, such as countries, institutes, journals, research fields, and citation habits (Rodríguez and Moreiro, 1996; Chen et al., 2005; Chiu and Ho, 2007). A bibliometric analysis of biological invasions-related publications from 1991 to 2007 was conducted on the basis of 3323 articles, which were published by 7261 authors from 1905 institutions of 100 countries (Qiu and Chen, 2009). Soteriades and Falagas (2006) performed a bibliometric analysis in the field of preventive medicine, occupational/environmental medicine, epidemiology and public health to map the research production around the world, the results indicated that USA researchers maintained a leadership position in the production of scientific articles, and less developed regions would need to support their researchers in the above fields. In 2000, a bibliometric analysis was applied to assess the research performance of chemists at Seoul National University, the most prestigious university in Korea, by using the numbers of articles appearing in journals and the numbers of citations received by those articles covered by Science Citation Index (SCI) CD-ROM, 1992–1998 (Kim and Kim, 2000). Bibliometric analysis was also carried out by Buznik et al. (2004) for the Journal of Structural Chemistry (JSC) published since 1960 by the Siberian Branch of the Russian Academy of Sciences, in their research, topics, authors, affiliations, and other criteria were analyzed, moreover, JSC authors and publications with the largest numbers of citations were also identified. However, the change in the quantities of citations or publication counts of countries and organizations alone may not be adequate to indicate the development trend or future orientation of the research field completely (Chiu and Ho, 2007). More information, based on the content of studies, such as article titles, author keywords, keyword plus should be introduced in research-trend studies (Qin, 2000; Tian et al., 2008). Analysis of word distribution in the paper titles, author keywords, keywords plus, and abstracts in different periods were recently used to evaluate research trends (Xie et al., 2008; Li et al., 2009; Zhang et al., 2010).

In this study, bibliometric method was used to quantitatively and qualitatively investigate the global research trends of wetland-related research during the period of 1991–2008. The results could provide a basis for better understanding the global development situation of wetland research, and a potential guide for novice researchers.

2. Data sources and methodology

The data were based on the online version of SCI, Web of Science. SCI are multidisciplinary database of the Institute for Scientific Information (ISI), Philadelphia, USA. According to Journal Citation Reports (JCR), it indexes 6620 major journals with citation references across 173 scientific disciplines in 2008. The online version of SCI was searched under the keywords “wetland” and “wetlands” to compile a bibliography of all papers related on wetland research. Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK). Articles from Hong Kong were not included in China. Besides, the reported impact factor (IF) of each journal was obtained from the 2008 JCR. Contributions of different institutes and countries were estimated by the affiliation of at least one author to the publications. Collaboration type was determined by the addresses of the authors, where the term “single country publication” was assigned if the researchers' addresses were from the same country. The term “internationally collaborative publication” was designated to those articles that were coauthored by researchers from multiple countries. The term “single institute publication” was assigned if the researchers' addresses were from the same institute. The term “inter-institutionally collaborative publication” was assigned if authors were from different institutes.

All the articles referring to wetland during 1991–2008 were assessed by the following aspects: document type and language of publications, characteristics of publication outputs, distribution of output in subject categories and journals; publication outputs of country, institute, and author; and word in article title, author keyword, and keyword plus.

3. Results and discussion

3.1. Document type and language of publication

The distribution of the document type identified by ISI was analyzed. From this study, 16 document types were found in the total 16,871 publications during the 18-year study period. Article (13,727) was the most-frequently used document type comprising 81% of the total production, followed by proceedings paper (1928; 11%), review (546; 3.2%), editorial material (247; 1.5%), meeting abstract (149; 0.88%), and news item (107; 0.63%). The others showing less significance were note (60), letter (44), correction (35), book review (14), reprint (5), correction, addition (3), discussion (3), and one for software review, item about an individual, and biographical-item respectively. As journal articles represented the majority of document types that were also peer-reviewed within this field. Only 13,727 original articles were used subsequently for further analysis as relevant citable items in this study, while all others were discarded.

The distribution related to the language of articles was analyzed. Ninety-nine percent of all these journal articles were published in English (13,580). Several other languages also appeared, containing French (48), Spanish (42), Portuguese (24), German (14), Japanese (5), Czech (4), Russian (3), Italian (2), Chinese (2), and one for each of Polish, Dutch, and Turkish respectively. English remained the dominant language in wetland research as it was the main language in many fields (Hsieh et al., 2004; Chen et al., 2005). A higher percentage of English would be used because more journals listed in ISI were published in English (Chiu and Ho, 2007).

3.2. Characteristics of publication outputs

The total amounts of SCI articles including searching keywords in titles only during the last 50 years were counted and are displayed in Fig. 1. Along with the development of SCI, wetland research continually grew in this long period, started to go up significantly in the year of 1975, and rocketed in the past 18 years. The Convention on Wetlands of International Importance especially as Waterfowl Habitat (known as the Ramsar Convention), which was established in February 1971 and then entered into force in December 1975, provided the frame work for international cooperation for the conservation of wetland habitats and aroused worldwide concern for the wetland research. At the beginning of the 1990s, several regulations of wetlands raised this issue more forcefully than any other actions related to the environment (Committee on Characterization of Wetlands, National Research Council, 1995). Built upon many breakthroughs in the study period during 1991–2008, wetland research has become one of the most important and dynamic fields of environmental research (Koerselman and Meuleman, 1996; Richardson, 1994; Zhang et al., 2008).

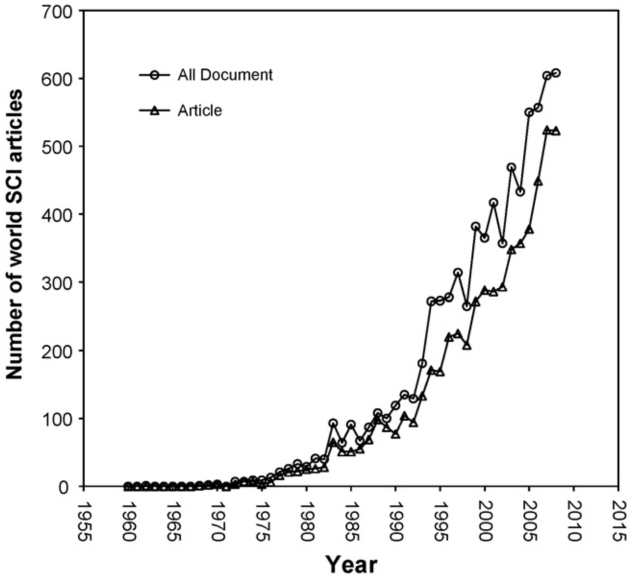

Fig. 1. Number of SCI publications referring to "wetland" and "wetlands" in the title during the last 50 years.

Several publication output characteristics of current wetland research during the time span of 1991 through 2008 were summarized in Table 1. The annual number of articles, the average number of authors, and the annual number of cited references increased significantly. Merely 255 articles were published in 1991, while the number of articles rose to 1577 in 2008. The annual number of journal articles published and the number of articles cited to wetland research increased more than sixfold and ninefold, respectively. There was an average of 2.5 authors per wetland-related article in the year 1991, while the number steadily increased to 3.8 in 2008. The progressive increases in the number of publication outputs and the references indicated the stable growth and communication in the field of wetland-related research during the past years (Table 1).

3.3. *Distribution of output in subject categories and journals*

In 2008, JCR of the ISI contained 6620 major journals with citation references across 173 scientific disciplines in SCI. The distributions of the subject categories are shown in Table 2. It indicates that environmental sciences (5376; 39%), ecology (4025; 29%), and marine and freshwater biology (1498; 11%) were the top 3 popular subject categories. The annual article outputs in the top five subject categories, containing 1300 above wetland-related articles, are statistically analyzed in Fig. 2. There were large publication increases in the five subject categories. The result indicates that wetland research had been steadily developed in various categories. As the use of statistics in any scientific discipline can be considered a key element in evaluating its degree of maturity, the statistical analysis result could provide a current view of the inter-

Table 2
Distributions of the subject categories.

SCI subject category in 2008	TP	%
Environmental sciences	5376	39
Ecology	4025	29
Marine and freshwater biology	1498	11
Water resources	1395	10
Multidisciplinary geosciences	1352	10
Plant sciences	1205	8.8
Environmental engineering	1064	7.8
Soil science	685	5.0
Biodiversity conservation	667	4.9
Zoology	661	4.8
Limnology	645	4.7
Meteorology and atmospheric sciences	531	3.9
Physical geography	488	3.6
Forestry	416	3.0
Ornithology	406	3.0
Oceanography	369	2.7
Civil engineering	315	2.3
Toxicology	277	2.0
Agronomy	251	1.8
Fisheries	241	1.8
Remote sensing	232	1.7
Entomology	227	1.7
Microbiology	207	1.5
Biotechnology and applied microbiology	200	1.5
Imaging science and photographic technology	186	1.4
Multidisciplinary sciences	145	1.1
Agricultural engineering	132	1.0
Geochemistry and geophysics	127	0.93
Multidisciplinary agriculture	125	0.91
Biology	122	0.89

TP, number of publications.

Table 1
Characteristics by year of publication outputs from 1991 to 2008.

Year	TP	AU	AU/TP	PG	PG/TP	NR	NR/TP
1991	255	632	2.5	2927	11	6965	27
1992	276	672	2.4	2996	11	7046	26
1993	324	804	2.5	3650	11	8397	26
1994	403	1081	2.7	4670	12	10,907	27
1995	413	1090	2.6	4504	11	13,019	32
1996	493	1411	2.9	5417	11	17,842	36
1997	564	1573	2.8	6274	11	20,003	35
1998	616	1850	3.0	7212	12	22,349	36
1999	703	2080	3.0	7817	11	26,198	37
2000	723	2223	3.1	8570	12	27,742	38
2001	780	2431	3.1	9183	12	30,132	39
2002	809	2627	3.2	9624	12	31,619	39
2003	950	3097	3.3	11,190	12	37,545	40
2004	1009	3376	3.3	11,623	12	40,971	41
2005	1103	3844	3.5	12,998	12	44,318	40
2006	1307	4681	3.6	14,578	11	53,146	41
2007	1422	5203	3.7	15,684	11	57,527	40
2008	1577	5961	3.8	17,294	11	67,450	43
Total	13,727	44,636		156,211		523,176	
Average			3.3		11		38

TP, number of publications; AU, number of authors; PG, page count; NR, cited reference count; AU/TP, PG/TP, and NR/TP, average of authors, pages, and references in a paper.

national wetland research emphases of this topic (Palmer et al., 2005).

Table 3 shows the top 21 productive journals including the impact factor (IF), the SCI category of the journal, the position of the journal in its category, the number of articles, and the percentage of total articles. These journals included at least 100 published articles related to wetland research during 1991–2008. Above 30% of the total wetland-related articles are from these 21 core journals. *Wetlands*, a quarterly journal published by the Society of Wetland Scientists, ranked first with 850 (6.2%) published articles; *Ecological Engineering* ranked second with 358 (2.6%) articles; *Hydrobiologia*, *Journal of Environmental Quality*, *Journal of Wildlife Management* ranked 3rd, 4th, and 5th, respectively. The IF is usually used to evaluate a journal's relative importance, especially when compared to others in the same field (Benavent et al., 2004). Nevertheless, when used to indicate the quality of an article, the journal IF will upgrade the bad ones and downgrade the good ones (Gisvold, 1999). Sometimes, higher journal impact factor can hardly decide the power of a journal on certain issues; for example, for the most active journal, *Wetlands*, the impact factor is 1.117, which is a relatively low value if compared to other journals in the wetland research field.

3.4. Distribution of country and institute publications

The contribution of different countries/territories was estimated by the location of the affiliation of at least one author of the published papers. The top 30 countries/territories were ranked by number of total articles, including the number and percentage of single country articles and internationally collaborative articles, as well as first author and corresponding author articles (Table 4). The number of countries participated in wet-

Table 3
The top 21 most active journals with the number of articles, impact factor, ISI subject category of journals, and the position of the journal in its category during the period of 1991–2008.

Journal title	TP (%)	IF	Subject category	Position
Wetlands	850 (6.2)	1.117	Ecology Environmental sciences	83/124 101/163
Ecological Engineering	358 (2.6)	1.836	Ecology Environmental engineering Environmental sciences	56/124 10/38 64/163
Hydrobiologia	269 (2.0)	1.449	Marine and freshwater biology	36/87
Journal of Environmental Quality	206 (1.5)	2.098	Environmental sciences	49/163
Journal of Wildlife Management	192 (1.4)	1.323	Ecology Zoology	71/124 45/125
Aquatic Botany	189 (1.4)	1.129	Plant sciences Marine and freshwater biology	78/156 50/87
Environmental Management	176 (1.3)	1.109	Environmental sciences	104/163
Water Research	173 (1.3)	3.587	Environmental engineering Environmental sciences Water resources	3/38 13/163 1/60
Biological Conservation	163 (1.2)	3.566	Biodiversity conservation Ecology Environmental sciences	5/28 24/124 14/163
Journal of Hydrology	156 (1.1)	2.305	Civil engineering Multidisciplinary geosciences Water resources	3/91 27/144 3/60
Environmental Science and Technology	153 (1.1)	4.458	Environmental engineering Environmental sciences	2/38 7/163
Biogeochemistry	149 (1.1)	2.961	Environmental sciences Multidisciplinary geosciences	26/163 16/144
Science of the Total Environment	145 (1.1)	2.579	Environmental sciences	33/163
Ecological Applications	143 (1.0)	3.628	Ecology Environmental sciences	23/124 11/163
Soil Science Society of America Journal	126 (0.92)	2.207	Soil science	5/31
Journal of Geophysical Research-Atmospheres	126 (0.92)	3.147	Multidisciplinary geosciences	11/144
Journal of Coastal Research	117 (0.85)	0.517	Environmental sciences Physical geography Multidisciplinary geosciences	153/163 30/31 126/144
Chemosphere	112 (0.82)	3.054	Environmental sciences	23/163
Water Resources Research	102 (0.74)	2.398	Environmental sciences Limnology Water resources	37/163 2/19 2/60
Water Air and Soil Pollution	102 (0.74)	1.398	Environmental sciences Meteorology and atmospheric sciences Water resources	84/163 34/52 15/60
Freshwater Biology	100 (0.73)	2.704	Marine and freshwater biology	9/87

IF, impact factor; TP, total publications.

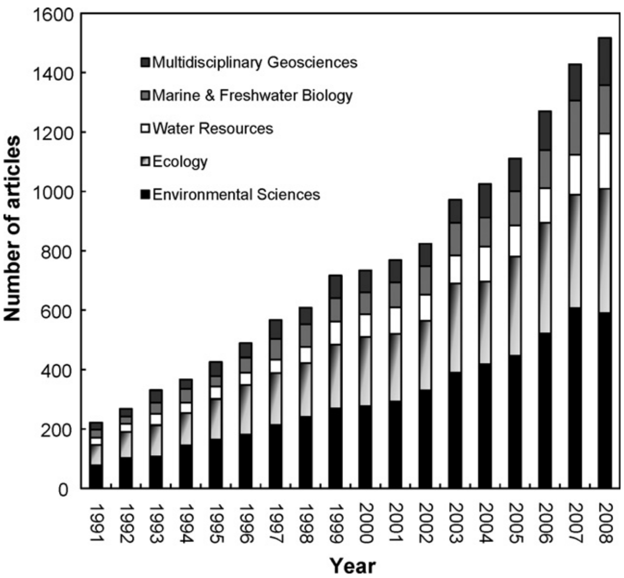

Fig. 2. Comparison the growth trends of the top five subject categories wetland-related articles during 1991–2008.

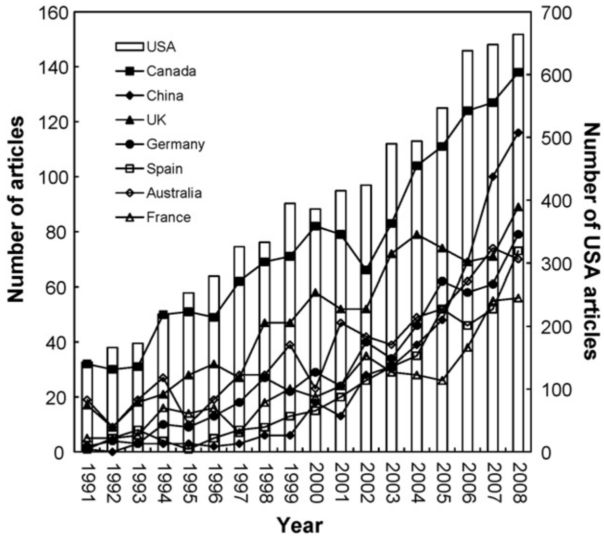

Fig. 3. Comparison the growth trends of the top eight productive countries during 1991–2008.

land research increased fast. Five American countries, 17 European countries, 5 Asian countries/territories, 1 African country, and 2 Oceania countries were ranked in the top 30 productive countries of articles. Most articles were from two North American countries: USA (6993; 51%) and Canada (1359; 10%). The USA produced the most single-country articles and international collaborative articles, followed by Canada and UK (Mitsch and Gosselink, 2007). The 7 major industrial countries (G7: Canada, France, Germany, Italy, Japan, the UK, and the USA) were all ranked in the top 15 of articles. The result demonstrated that the developed countries, North American and European countries, played the important roles in wetland research. Moreover, some developing countries, such as BRIC (China, India, Brazil, and Russia) were also listed as productive countries.

The time-trend analysis among the top 8 productive countries is displayed in Fig. 3. The USA has exhibited its predominant in wetland research since 1991. An obvious rise can also been seen in the number of articles related to wetland research of all 8 countries. There is no doubt that a series of positive regulations and

Table 4
Top 30 most productive countries/territories of articles during 1991–2008.

Country/territory	TP	TP R (%)	SP R (%)	CP R (%)	FA R (%)	RP R (%)
USA	6993	1 (51)	1 (52)	1 (46)	1 (48)	1 (47)
Canada	1359	2 (10)	2 (8)	2 (19)	2 (8.1)	2 (7.9)
UK	862	3 (6.3)	3 (4.3)	3 (16)	3 (4.9)	3 (5.0)
Australia	656	4 (4.8)	4 (4.3)	8 (7.0)	4 (4.2)	4 (4.1)
Germany	541	5 (4.0)	8 (1.9)	4 (14)	7 (2.5)	7 (2.5)
China	489	6 (3.6)	5 (2.6)	6 (8.2)	5 (3.0)	5 (3.1)
France	421	7 (3.1)	7 (1.9)	5 (8.6)	8 (2.4)	8 (2.4)
Spain	404	8 (3.0)	6 (2.3)	9 (6.0)	6 (2.5)	6 (2.5)
Netherlands	398	9 (2.9)	10 (1.9)	7 (7.8)	9 (2.1)	9 (2.2)
Sweden	302	10 (2.2)	11 (1.7)	11 (4.8)	10 (1.8)	10 (1.9)
Japan	275	11 (2.0)	12 (1.4)	10 (5.0)	12 (1.6)	11 (1.7)
India	262	12 (1.9)	9 (1.9)	25 (2.0)	11 (1.7)	12 (1.7)
Italy	206	13 (1.5)	16 (0.86)	13 (4.6)	13 (1.1)	14 (1.1)
Brazil	202	14 (1.5)	14 (1.1)	15 (3.5)	14 (1.1)	15 (1.1)
New Zealand	194	15 (1.4)	13 (1.1)	17 (3.1)	15 (1.1)	13 (1.2)
South Africa	165	16 (1.2)	15 (0.87)	20 (2.8)	16 (1.0)	16 (1.0)
Switzerland	164	17 (1.2)	24 (0.44)	11 (4.8)	20 (0.71)	20 (0.75)
Finland	137	18 (1.0)	18 (0.74)	22 (2.2)	18 (0.77)	19 (0.78)
Denmark	136	19 (1.0)	26 (0.43)	14 (3.7)	22 (0.60)	22 (0.61)
Greece	128	20 (0.94)	19 (0.72)	24 (2.0)	19 (0.75)	18 (0.79)
Argentina	125	21 (0.92)	17 (0.80)	29 (1.5)	17 (0.83)	17 (0.86)
Belgium	120	22 (0.88)	24 (0.44)	18 (3.0)	21 (0.63)	21 (0.63)
Mexico	115	23 (0.84)	28 (0.36)	16 (3.1)	27 (0.43)	26 (0.50)
Czech Republic	101	24 (0.74)	22 (0.47)	23 (2.0)	23 (0.56)	23 (0.58)
Russia	99	25 (0.73)	32 (0.27)	19 (2.9)	31 (0.33)	30 (0.35)
South Korea	92	26 (0.67)	29 (0.32)	21 (2.4)	27 (0.43)	27 (0.48)
Poland	91	27 (0.67)	21 (0.53)	31 (1.3)	24 (0.53)	24 (0.57)
Turkey	77	28 (0.56)	20 (0.56)	45 (0.59)	25 (0.52)	25 (0.52)
Hong Kong	71	29 (0.52)	32 (0.27)	26 (1.7)	29 (0.38)	29 (0.38)
Austria	70	30 (0.51)	31 (0.27)	28 (1.7)	34 (0.32)	34 (0.31)

TP, total publications; SP, single country publication; CP, internationally collaborative publication; FP, publication with first author; RP, publication with corresponding author; %, share in publication; R, Rank.

Table 5
Most productive institutions in wetland-related research fields from 1991 to 2008.

Institute	TP	TP R (%)	SP R (%)	CP R (%)	FP R (%)	RP (%)
U.S. Geological Survey, USA	549	1 (4.0)	1 (2.5)	1 (5.3)	1 (2.3)	1 (2.5)
Louisiana State University, USA	355	2 (2.6)	2 (2.3)	2 (2.9)	2 (1.9)	2 (1.5)
University of Florida, USA	330	3 (2.4)	3 (1.9)	2 (2.9)	3 (1.7)	3 (1.5)
Chinese Academy of Sciences, China	241	4 (1.8)	4 (1.3)	4 (2.2)	4 (1.2)	4 (1.2)
University of Wisconsin, USA	220	5 (1.6)	6 (1.1)	5 (2.0)	5 (1.1)	5 (1.0)
University of Minnesota, USA	209	6 (1.5)	5 (1.1)	6 (1.9)	6 (0.86)	6 (0.84)
University of Georgia, USA	185	7 (1.4)	8 (0.81)	8 (1.8)	8 (0.84)	9 (0.74)
U.S. Fish and Wildlife Service, USA	175	8 (1.3)	9 (0.80)	10 (1.7)	17 (0.52)	11 (0.69)
University of California, Davis, USA	173	9 (1.3)	16 (0.59)	7 (1.8)	10 (0.74)	10 (0.71)
United States Environmental Protection Agency (US EPA), USA	171	10 (1.3)	10 (0.72)	9 (1.7)	11 (0.73)	8 (0.78)
United States Department of Agriculture, Agricultural Research Service (USDA ARS), USA	163	11 (1.2)	14 (0.68)	11 (1.6)	9 (0.78)	7 (0.79)
Ohio State University, USA	142	12 (1.0)	7 (0.94)	18 (1.1)	7 (0.84)	12 (0.64)
Environment Canada, Canada	140	13 (1.0)	21 (0.49)	12 (1.5)	21 (0.48)	13 (0.55)
Cornell University, USA	134	14 (1.0)	13 (0.7)	16 (1.2)	12 (0.65)	14 (0.54)
McGill University, Canada	123	15 (0.90)	26 (0.46)	14 (1.3)	20 (0.50)	19 (0.48)
Florida International University, USA	121	16 (0.89)	26 (0.46)	15 (1.2)	14 (0.56)	17 (0.50)
South Florida Water Management District, USA	120	17 (0.88)	10 (0.72)	21 (1.0)	17 (0.52)	16 (0.51)
University of Maryland, USA	115	18 (0.84)	32 (0.39)	16 (1.2)	25 (0.43)	17 (0.50)
US Forest Service, USA	112	19 (0.82)	61 (0.26)	13 (1.3)	41 (0.31)	30 (0.34)
Texas A&M University, USA	110	20 (0.81)	10 (0.72)	29 (0.88)	13 (0.57)	15 (0.54)

TP, total publications; SP, single institute publication; CP, inter-institutional collaborative publication; FP, publication with first author; RP, publication with corresponding author; %, share in publication; R, Rank.

environmental events motivate the rapid development of the wetland research in the world. It could be also seen in Fig. 3 that the rapid development of wetland research in the last 18 years was partly driven by these countries' contribution. China had a high growth pace in recent 10 years, and finally ranked 3rd in 2008, behind two North American countries: USA and Canada. Since the rapid urbanization and industrialization, and highly accelerated economic development in China resulted in serious environmental problems; increased wetland-related studies were promoted correspondingly (Ma et al., 1993; Ding et al., 2004; Zhang et al., 2009).

The most productive institutions in wetland-related research fields from 1991 to 2008 are displayed in Table 5. USA, Canada, UK, Australia, Germany, China, France, and Spain were the top 8 most productive countries. However, no institution in the UK, Australia, Germany, France, and Spain can be found among the top 20 institutes. There are 17 USA, 1 China and 2 Canada research institutions ranking in the top 20 research institutions. The US Geological Survey (549), Louisiana State University (355), and University of Florida (330) are the top 3 research institutions. Furthermore, the Chinese Academy of Sciences (CAS), with 241 published articles, ranks 4th. Environment Canada and McGill University are the most productive institutes related to wetland research in Canada. A bias would appear because the Chinese Academy of Sciences has branches in many cities. In the present study, the articles of these institutes were pooled under one heading, dividing the articles among the branches would have given different rankings (Li et al., 2009).

3.5. Distribution of words in article title, author keywords, and keywords plus analysis

The dissertation title analysis was primarily applied to assess the growth and development of a research by Rodríguez and Moreiro (1996). The title of an article, which would be seen by all the readers at first, always includes the information of the whole paper. Author keyword analysis, which could offer the information of research trends concerned by researchers, is another effective method. Bibliometric method using keyword analysis could be found in recently years (Chiu and Ho, 2007), whereas using the author keyword analysis to assess the trend of a research was also presented (Ho, 2007). Keywords plus provide search terms extracted from the titles of papers cited in each new article in the database in ISI (Garfield, 1990). Compared to the keyword analysis methods mentioned previously, the keyword plus analysis as an independent supplement, reveals the articles contents with more details.

In this study, all the single words in the article title, author keywords, and keywords plus of wetland-related articles were statistically analyzed. Some prepositions were used frequently, but had no useful meaning for the analysis of research trend. Therefore, all these empty words were discarded in analysis. According to the distribution of word in article title, author keyword, and keyword plus analysis, popular wetland research issues could be roughly found by the statistically analysis. Except for "wetland" and "wetlands," which were searching keywords in this study, the most frequently used word was "water" (or "water quality"). As a basic environmental element of wetland, "water" (or "water quality") ranked 3rd, 7th, and 3rd according to the word in article title, author keyword, and keyword plus analysis respectively. Water (or water quality) was the most important issue in wetland research fields from 1991 to 2008 (Osborne and Kovacic, 1993; Carpenter et al., 1998; Mitsch and Gosselink, 2007; Mitsch et al., 2008; Zhang et al., 2008). Other basic environmental elements of wetland were soil, vegetation (or plant), and microorganism. The word "soil" ranked 11th and 8th, while "soils" ranked 26th and 18th in the article title and keyword plus analysis respectively. The keyword "vegetation" ranked 8th, 25th, and 2nd in the article title, author keyword, and keyword plus analysis, respectively, while "plant" ranked 12th in the article title analysis and "plants" ranked 11th in the keyword plus analysis. Nevertheless, another important element "microorganism" did not appear in the top 30 most frequency keywords of all three analyses. Conrad (1996) studied the processes in soils contributed to the global cycles of many trace gases that were relevant for atmospheric chemistry and climate; the results indicated that soil microorganisms played an important role controlling those processes.

The keywords "phosphorus", "nitrogen", "nutrient", and "nutrients" have relatively high ranks. Nutrients, such as nitrogen and phosphorus, are considered to be the most important pollutants causing water pollution. But the removal efficiencies of wetlands for nitrogen and phosphorus are often low if compared to those of chemical oxygen demand and biochemical oxygen demand (USEPA, 2000; Vymazal, 2007). Nitrogen has an intricate biogeochemical cycle with various biotic and abiotic transformations. In wetlands, the main inorganic forms of nitrogen are ammonia–nitrogen (NH_4^+–N), nitrate–nitrogen (NO_3^-–N) and nitrite–nitrogen (NO_2^-–N) (Vymazal, 2007), while those of phosphorus are ortho-phosphate, condensed (pyro-, meta- and poly-) phosphates, and organically bound phosphate (USEPA, 2000). The transform processes for nitrogen and phosphorus in wetlands are highly complex, and include microbial, biological, physical and chemical processes that may occur sequentially or simultaneously (Hammer and Bastian, 1989; USEPA, 2000; Vymazal, 2007). Those processes are significant to the nutrient transformation for the wetland ecological systems (Mitsch and Gosselink, 2007).

Wetland research changes could be also found by statistical analysis. Constructed wetland research (according to keywords: "constructed", "constructed wetland", and "constructed wetlands"), which aimed at pollutants removal and retention, developed very well during 1991–2008 (Mander and Mitsch, 2009). For example, keywords "constructed wetland" and "constructed wetlands" ranked 58th and 12th in 1991–1996, while ranked 5th and 4th in 2003–2008. The percentage of articles with author keywords "constructed wetland" and "constructed wetlands" went up from 0.81% and 2.0% in 1991–1996 to 2.6% and 2.8% in 2003–2008; the results accorded highly, with great attention given to constructed wetland research in recent decades. Mitsch et al. (2008) assessed the overall performance of tropical wetlands for climate change research, water quality management and conservation education on a university campus in Costa Rica. A serious experiment was reported to assess the performance of constructed wetlands treating wastewater (Bezbaruah and Zhang, 2003, 2004, 2005). Free surface flow Integrated Constructed Wetlands are constructed to clean and manage farmyards runoff with that of integrating the wetland infrastructure into the landscape to enhance its biological diversity (Scholz et al., 2007). It could be predicted that the number of scientific publications based on constructed wetland research would still grow stably in the future.

Biodiversity (or diversity), which is significant for the nutrition, livelihoods, and survival of local people, is an important factor for the performance evaluation of wetlands (Moreno et al., 2007; Mitsch and Gosselink, 2007; Xiang et al., 2009). The research focused on wetland biodiversity (or diversity) developed considerably during 1991–2008, and was receiving more attention in recent years. There were some keywords related to biodiversity that became more active in wetland research. The author keyword "biodiversity" ranked 45th (0.90%) in 1991–1996, while it ranked 23rd (1.1%) in 1997–2002, and top 14th (1.5%) in 2003–2008. Moreover, keyword plus "diversity" ranked 93rd (0.93%) in 1991–1996, while it ranked 20th (2.5%) in 1997–2002, and top 17th (3.4%) in 2003–2008.

On the other hand, the percentage of words such as "methane", "northern", "waterfowl", "flooding", and "salt-marsh" obviously reduced respectively during 1991–2008. There were two possible explanations for these decreases. For one thing, some of them were the general words in wetland research which were replaced by another synonym or more specific single words in the articles. The keyword "methane", sometimes appeared as "CH_4", might belong to this case. Another possible explanation was that some keywords were gradually disregarded by researchers, or were retreated from the mainstream of wetland research relatively. For example, the author keyword "flooding" ranked 8th in 1991–1996, while ranked 29th in 2003–2008. The percentage of articles with it reduced from 2.2% and 1.1% in 1991–1996 to 2.6% and 2.8% in 2003–2008. The effect of flooding on wetlands was reported by many earlier wetland-related publications, but the number of publications based on this issue decreases gradually in recent years (Vandervalk, 1994; Baskin et al., 1996).

4. Conclusions

Significant wetland research points in SCI database were obtained by the bibliometric analysis. In total, 16 document types were found in the total 16,871 publications during the period from 1991–2008. English was the main language of wetland research, accounting for 99% of all SCI articles were published in English. With the development of SCI, wetland research continually grew and started to go up significantly in the year of 1975, and rocketed in the past 18 years. It could be predicted that the number of scientific publications based on wetland research would still grow quickly in the future. The results also indicated that "environmental sciences", "ecology", and "marine and freshwater biology" were top three popular subject categories in wetland research fields during 1991–2008. Above 30% of the total wetland-related publications resided in 21 core journals. The most active journal was *Wetlands*. The institutes in USA produced the most single-country and internationally collaborative articles. China had a high growth pace, and ranked 3rd by 2008. Article title, author keyword, and keyword plus analysis methods were effective approaches for mapping wetland research. Based on these statistical analyses, the popular wetland research issues and wetland research changes were roughly found. Constructed wetlands for the improvement of water quality, the nutrients transformation through water, soil and vegetation in wetlands were the most active research issues in the studied period. Furthermore, constructed wetland and wetland biodiversity researches might be the main issues in wetland research in the future.

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