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Bibliometric review of research on phytoplankton in water quality assessment

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ABSTRACT

To understand the current state of utilizing phytoplankton to globally evaluate water quality and provide references for future studies, bibliometric methods were used to review the articles on phytoplankton and water quality monitoring published in the Web of Science database between 1996 and 2016. A total of 5850 articles were retrieved, and 93.66% of the retrieved literature comprised research papers. The annual quantity of the published literature increased with time, for instance, 516 papers were published in 2015 which was 3.51 times the number of papers published in 1996 (147 papers). During our study period, the top five literature-publishing countries were the United States, China, Germany, Canada, and France, which published 1477, 490, 471, 465, and 351 articles, with literature growth rates of 25.25, 8.38, 8.05, 7.95, and 6.00%, respectively. All 15,990 authors, including 510 core authors, came from 3851 institutions belonging to 126 countries. The Chinese Academy of Sciences, which published 202 research papers accounting for 3.45% of the total literature published during the study period, was the first institute to publish the largest number of research papers. The total citation frequency of the articles was 130,865. The number of articles with citation frequency more than 100 and between 50 and 99 were 208 and 434, respectively. The average citation frequency of these papers was 22.37, and the H-index was 127. The annual citation of articles was found to be significantly increased, with citation only 33 times in 1996, but 18,127 times in 2015. The top five authors whose papers showed the highest citation frequency were from Germany, the United States, the United States, Australia and Canada, with the citation frequencies of 1203, 875, 698, 653, and 615, respectively. However, 693 articles had not been cited even once. All 5850 papers were published in 983 journals, mainly in the English journals, such as Hydrobiologia, Estuarine Coastal and Shelf Science, and Freshwater Biology, including 83 research subjects and mainly focused on the research fields such as marine freshwater biology, environmental science ecology. A total of 10,182 keywords were extracted from these papers, and 113 keywords appeared more than 20 times. Subsequently, 39 high-frequency effective keywords and 9 core high-frequency keywords were further extracted. The nine core high-frequency keywords, which appeared more than 100 times, were phytoplankton, algae, nutrients, eutrophication, toxicity, microalgae, estuary, phosphorus, and nitrogen, and their appearance frequencies were 442, 289, 196, 192, 137, 135, 134, 114, and 101, respectively. Analysis of the co-occurrence relationship of the high-frequency keywords showed that the keywords algae and nutrients, water eutrophication and nitrogen, phosphorus, and salt co-occurred 120 times; algae and taxonomy, biological diversity, and various groups co-occurred 82 times, algae and primary production, biomass, photosynthesis, chlorophyll, food web and bioenrichment co-occurred 57 times; algae and estuary and lake co-occurred 48 times, algae and water quality, organic matter, bacteria, toxins, and copper co-occurred 40 times; and algae and temperature and climate change co-occurred 28 times. These co-occurrence relationships showed that the relative studies concentrated on the water eutrophication, biodiversity of algae, ecology of phytoplankton, and influence of environmental factors on the phytoplankton community. Water areas of estuaries and lakes were mainly concerned. These results indicated that the amount and citation frequency of the research papers on utilizing phytoplankton to evaluate water quality were rapidly growing, and the developed countries in Europe and America contributed most to the research in this field. The number of papers published by the Chinese researchers ranked second, but there is still a huge gap between China and the developed countries because of the lack of researchers and papers with high impact power in this field of research.

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1. Introduction

As a primary producer in aquatic ecosystem, phytoplankton is the basis of the material circulation and energy flow [1], whose growth is limited by more than one resource, explaining the continuously changing stoichiometry of the ocean and the global nutrient cycle related phytoplankton nutrients [2]. Phytoplankton plays an extremely important role in aquatic ecosystems. When water quality is deteriorated and turbidity increases, the aquatic ecosystem will dramatically changes and leads to a decreased biodiversity [3]. The rapid increase of the number of phytoplankton (e.g. cyanobacteria) will cause severe problems in water ecosystems and public health. Meanwhile, phytoplankton is small, structurally simple, and sensitive to the change of habitat, which is easily affected by various environmental factors in a relative short period, and can reflect the change of water ecosystem on time [4]. Therefore, analyzing the species, quantity and community structure of phytoplankton in water is usually used for water quality assessment [5–6]. The growth and movement of phytoplankton is characteristics of vertical distribution cooperated with different resource gradients and confluence conditions in aquatic environment [7]. Suspended sediment, salinity and temperature have significant effects on phytoplankton community in shallow lakes [8]. Since 2000, under the "Water Framework Directive" EU countries have conducted river ecological health assessment research and protection according to the river type. Borics et al. [9] proposed the idea and method of using phytoplankton to evaluate the eutrophication status of the river. During the same period, many scholars tried to use phytoplankton to evaluate the ecological status and water quality of river and studied the effect of water eutrophication and climate changes on algae [10–12]. It is found that the biomass and its species composition of phytoplankton are very effective in assessing the eutrophication status of large rivers [13–15] and can be used as an important bioindicator for water quality monitoring [16]. Their community characteristics and response to their habitat changes are extremely important for water ecosystem protection, water ecosystem health assessment and biological monitoring of the formation of aquatic ecosystems [16–17]. The research of phytoplankton on water quality monitoring has become a worldwide hot topic, and a lot of research literatures have been published, which provide fundamental resources for the bibliometric analysis in this field.

With significant advantages such as objective, quantitative, and being a model, bibliometric is widely used in many disciplines to analyze scientific research output, and help researchers quickly and accurately understand the progress of research and the future trends [18–20], for instance, the metrological analysis was used in application of global stem cell research trends [21], global remote sensing scientific research [22], global aquatic ecosystem research [23], biogeography [24], research progress on Melosira [25], nitrogen fertilizer agronomic effects and environmental effects of international research and development trends [26], and others.

To reveal the current status and trends of the research on the application of phytoplankton in water quality evaluation, this paper analyzed the global research literature in this field from 1996 to February 2016 in the Web of Science (WOS) database, providing important references for researchers in this field to carry out further studies.

2. Materials and methods

2.1. Data source and retrieval method

Data were retrieved from the Thomson Reuters Web of Science™ core collection, including Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) and Arts & Humanities Citation Index (A & HCI) and others. The searching period was 1996–2016, and the completion date of searching was February 21, 2016.

2.2. Searching method

Bibliometric method was used to analyze the global SCI literatures of utilizing phytoplankton to assess the freshwater quality from WOS database. To obtain all literature information for analysis, the searching was conducted with key words such as "Freshwater plankton algae" OR "freshwater algae" OR "freshwater phytoplankton" OR "freshwater floating alga" AND "water quality assessment".

2.3. Analytical method

TDA (Thomson data analyzer), literature review tools, Excel 2010 and other software were used to complete the data extraction, statistical and visual analysis. Priced formula was used to determine the core author: $M = 0.749\ (N_{pmax})^{1/2}$, N_{pmax} represented the number of paper generated by the author with the highest yield. The author with number M of papers was the core author [20].

3. Results

3.1. Trend analysis of the number of published papers

From 1996 to 2016, 5850 published papers of using phytoplankton to assess freshwater quality were retrieved from Web of Science core collection. The number of annually published papers increased year by year, with the largest number in 2015 (516 papers), which was 3.51 times as many as the number of papers published in 1996 (147 papers) (Fig. 1). Multiple regression analysis was used to analyze the trends in

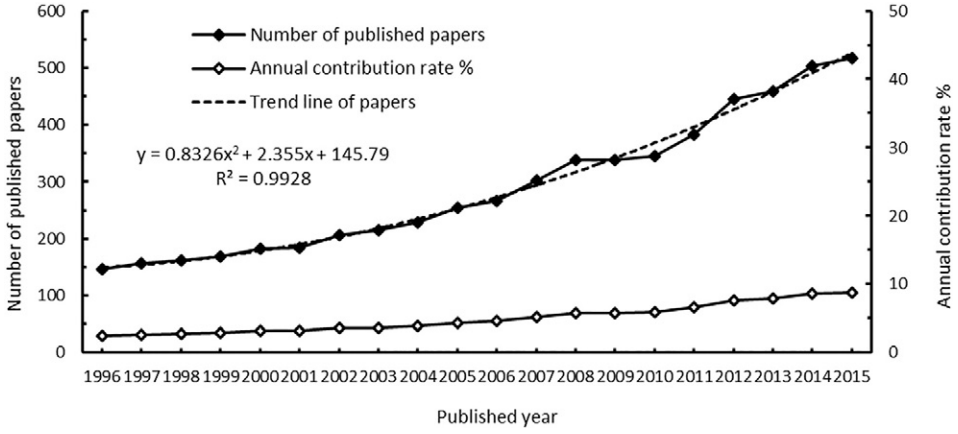

Fig. 1. Amount of literature worldwide between 1996 and 2015.

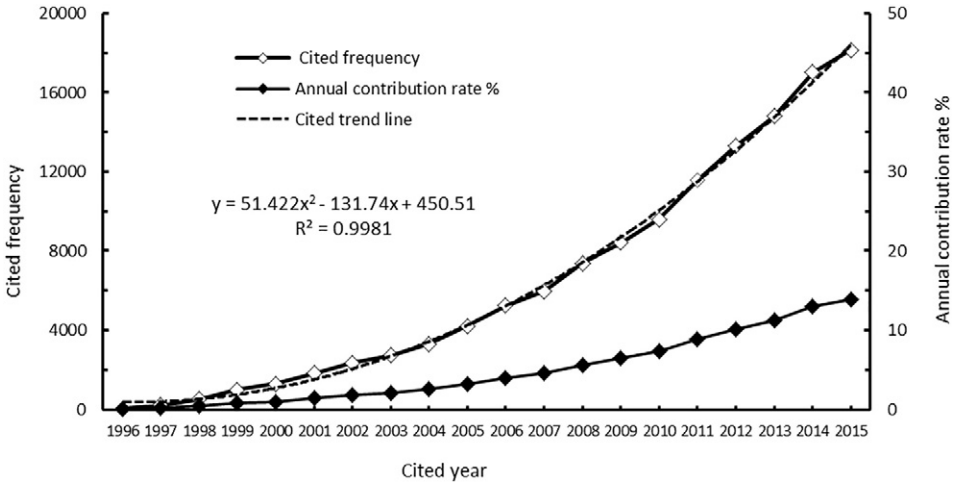

Fig. 2. Citation frequency of literature worldwide between 1996 and 2015.

the period from 1996 to 2015, indicating the increasing trends. Polynomial regression analysis showed the highest value, with $R^2 = 0.9928$.

Of all 5850 articles, the total citation frequency was up to 130,863 times, with average citation frequency of 22.37 times and H-index of 127. Through the citation frequency analysis, the citation frequency of global papers of utilizing phytoplankton to assess freshwater quality was rapidly increasing, from 33 times in 1996 and 226 times in 1997, to 17,020 times in 2014 and 18,127 times in 2015, indicating a significantly increasing trend (Fig. 2). Multiple regression analysis was used to analyze the trends in the period from 1996 to 2016, indicating the increasing trends. Polynomial regression analysis showed the highest value, with $R^2 = 0.9981$.

Based on the types of paper, all literatures were classified into 10 types, which ranked by the number of papers in descending order: article, proceedings paper, review, meeting abstract, editorial material, book chapter, correction, news item, biographical item, letter. Of all records, 5479 were articles, accounting for 93.66% of all literatures; 293 were proceedings papers, accounting for 5.01%; 292 were reviews, accounting for 4.99%; 84 were the other 7 types, accounting for only 1.44%. Article was the absolutely primary type of literatures in this field. Based on the language, a total of 11 languages were used. Of all, 5775 were in English, accounting for 98.72%. There were 24 literatures in Spanish, 11 in Portuguese, and the remaining 35 were in French, Russian, Japanese, Polish, German, Chinese, Korean, Czech.

3.2. The distribution of issuing countries, institutions and their cooperation

All literatures were published by 3851 institutions from 126 countries. The top five countries with the highest number of published papers were: the United States, China, Germany, Canada and France, with the number of published papers of 1477, 490, 471, 465 and 351, respectively, which accounted for 25.25%, 8.38%, 8.05%, 7.95% and 6.00% of all papers published, respectively. With its absolute advantage of published papers, the United States was the top first country on the list. China was the second country with 490 papers published in this field, only accounting for 33.18% of the number of the United States, and it was not significantly different from that of the following three countries. Top 20 countries of published papers on assessment of freshwater quality using phytoplankton as biological indicator worldwide between 1996 and 2016 are shown in Fig. 3.

Of all 3851 institutions, the top 5 most-frequently-publishing-SCI institutions were Chinese Academy of Sciences (Chinese Acad Sci), Russian Academy of Sciences (Russian Acav Sci), United States University of Maryland, United States Geological Survey (US Geol Survey), and University du Québec in Canada. Of the top 20 most-frequently-publishing-SCI institutions, 9 were from the United States (accounting for 45%), which had the most high-level research institutions in world's algae research and water quality assessment research field. China, Canada, Denmark and France had two institutions each. Russia, Belgium and

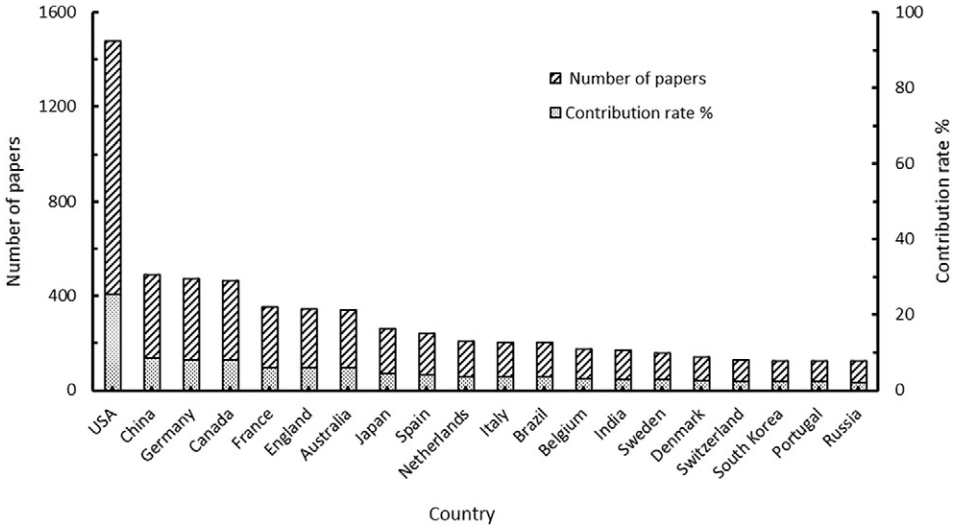

Fig. 3. Top 20 countries of published papers worldwide between 1996 and 2016.

Table 1
Top 20 institutions of literature worldwide between 1996 and 2016.

Rank	Institute	Country	Amount of literature	Contribution rate %
1	Chinese Academy of Sciences	China	202	3.45
2	Russian Academy of Sciences	Russia	76	1.30
3	University of Maryland	USA	63	1.08
4	United States Geological Survey	USA	61	1.04
5	University du Québec	Canada	55	0.94
6	University of Wisconsin	USA	54	0.92
7	University of Copenhagen	Denmark	53	0.91
8	France National Academy of Sciences	France	53	0.91
9	China Shipbuilding Industry Corporation	China	52	0.89
10	Ghent University	Belgium	47	0.80
11	Cornell University	USA	46	0.79
12	University of Washington	USA	45	0.77
13	University of North Carolina	USA	45	0.77
14	US Environmental Protection Agency	USA	44	0.75
15	Florida International University	USA	44	0.75
16	Environment Canada	Canada	43	0.74
17	University Paris 06	France	42	0.72
18	University of Aveiro	Portugal	42	0.72
19	Aarhus University	Denmark	42	0.72
20	The Ohio State University at Columbus	USA	40	0.68

Portugal had one institution each. Detailed information is shown in Table 1.

In order to explore the cooperative relationship among the issuing institutions, we built the whole matrix of the top 20 institutions, conducted the co-word analysis and visualization, through extracting the information of issuing institutions and summarizing the frequency. The larger the node area in the view, the higher the frequency of the institutions, the larger the number of paper issued (Fig. 4). The line connected the two institutions meant the cooperative relationship. The number on the line represented co-occurrence frequency. The larger the number, the stronger cooperation. As shown in Fig. 4, except for Russian Academy of Sciences, there were cooperative relationships among the other institutions. The most stronger cooperative relationship was France National Academy of Sciences (CNRS) and University of Paris 06, with co-occurrence of 15 times, followed by University of Copenhagen and Aarhus University, with co-occurrence of 6 times. Chinese Academy of Sciences had the highest frequency of cooperation, which had cooperated with University of North Carolina, University of Quebec, Ghent University, University of Paris 06, and had a strong cooperative relationship with University of North Carolina, with co-occurrence of 3 times (Fig. 4).

3.3. Core author and citation frequency analysis

The 5850 papers were published by 15,990 authors. Of the top 20 authors of published papers, Belgian authors were the most (5 authors), followed by American authors (4 authors). There were two authors from Denmark, Brazil, Switzerland and Canada, respectively, and one author from Netherlands, Hong Kong and Australia, respectively. Vis ML from the United States published the most papers, 36 papers. Using Priced formula, $M = 4.476$, meant that the authors with 5 or more papers published was core authors, the highly-productive active authors. There were 510 core authors identified in this study. The number of papers generated by core authors accounted for 43.6% of total number of published papers, indicating that there was a stable core author group formed in this field of using phytoplankton for water quality evaluation. The details of the top 20 authors are shown in Table 2.

To a certain extent, the citation frequency of a literature reflects the degree of concerning of the research field, the roles and status in academic communication. Thus, the citation frequency is an important measurement of a paper. The total citation frequency of the 5850 literatures was 130,865 times, with an average of 22.37 times. There were

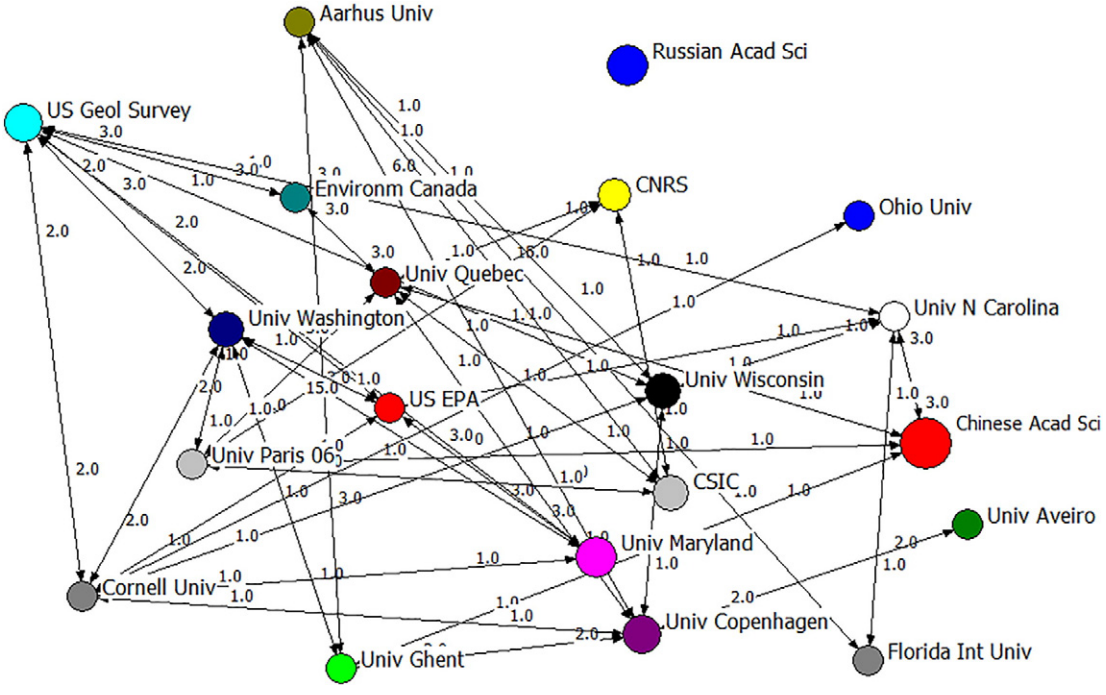

Fig. 4. Co-operation relationship of top 20 institutions worldwide* *:US Geol Survey: United States Geological Survey; Aarhus Univ: Aarhus University; Russian Acad Sci: Russian Academy of Sciences; Environm Canada: Environment Canada; CNRS: France National Academy of Sciences; Ohio Univ: The Ohio State University at Columbus; Univ Quebec: University du Québec; Univ Washington: University of Washington; Univ N Carolina: University of North Carolina; US EPA: United States Environmental Protection Agency; Univ Wisconsin: University of Wisconsin; Chinese Acad Sci: Chinese Academy of Sciences; Univ Paris o6: University Paris 06; CSIC: China Shipbuilding Industry Corporation; Univ Maryland: University of Maryland; Univ Aveiro: University of Aveiro; Cornell Univ: Cornell University; Univ Ghent: Ghent University; Univ Copenhagen: University of Copenhagen; Florida Int Univ: Florida International University.

Table 2
Top 20 authors of amount of literature worldwide between 1996 and 2016.

Rank	Author	Amount of literature	Contribution rate %	Institute	Country
1	Vis ML	36	0.62	Ohio University	USA
2	Paerl HW	31	0.53	University of North Carolina	USA
3	Van Donk E	25	0.43	Utrecht University	Netherlands
4	Vyverman W	24	0.41	Ghent University	Belgium
5	Muylaert K	23	0.39	Laboratory Aquatic Biology	Belgium
6	Vieira AAH	20	0.34	Universidade Federal de São Carlos	Brazil
7	De NYS R	20	0.34	The Technical University of Denmark	Denmark
8	Wang WX	19	0.33	The Hong Kong University of Science and Technology	Hongkong, China
9	Vincent WF	19	0.33	Université Laval, Québec	Canada
10	Stauber JL	19	0.33	Commonwealth Scientific and Industrial Research Organization	Australia
11	Maberly SC	19	0.33	University of Aarhus	Denmark
12	Janssen CR	19	0.33	State University of Ghent	Belgium
13	Descy JP	19	0.33	University of Namur	Belgium
14	Sherwood AR	18	0.31	University of Hawaii	USA
15	Behra R	18	0.31	Swiss Federal Institute of Aquatic Science and Technology	Switzerland
16	Necchi O	17	0.29	Sa˜o Paulo State University	Brazil
17	Sigg L	16	0.27	Swiss Federal Institute for Environmental Science and Technology	Switzerland
18	Sabbe K	16	0.27	Ghent University	Belgium
19	Litchman E	16	0.27	Michigan State University	USA
20	Campbell PGC	16	0.27	University du Québec	Canada

208 literatures with citation frequency more than 100 times, 434 literatures with citation frequency between 50 and 99 times, 3498 literatures with citation frequency between 4 and 49 times, 282 literatures with citation frequency of 3 times, 319 literatures with citation frequency of 2 times, and 416 literatures with citation frequency of 1 time. 693 literatures had not been cited even once. The top 5 authors whose paper showed the highest citation frequency of a single paper were from Germany, the United States, the United States, Australia and Canada. Of the top 20 authors with the highest citation frequency of a single paper, 8 were from the United States, 3 were from Australia, 2 were from the United Kingdom and German respectively, and 1 from Canada, Spain, Japan, Switzerland and Denmark respectively. A paper reported by Hillebrand H. from Germany has the highest citation frequency, up to 1203 times, followed by a paper generated by Else James J. from the United States, with 875 times. The United States is a country with high output of published papers and high citation frequency, indicating that the United States and Germany had strong influence in this field beyond other countries. Top 20 authors of cited literature on assessment of freshwater quality using phytoplankton as biological indicator worldwide between 1996 and 2016 are shown in Table 3.

3.4. Top 20 publication sources and research direction

The 5850 literatures were from 983 publications. There were 6 publications issued more than 100 literatures, including Hydrobiologia from Netherlands (245 literatures, accounting for 4.19%), Estuarine Coastal and Shelf Science (151 literatures, accounting for 2.58%), Freshwater Biology (144 literatures, accounting for 2.46%), Limnology and Oceanography (123 literatures, accounting for 2.10%), Journal of Phycology (113 literatures, accounting for 1.93%), and Environmental Toxicology and Chemistry (100 literatures, accounting for 1.71%). The top 20 publications had issued 1876 literatures, accounting for 32.07% of all published literatures, of which, 6 publications were from the United States and the UK, respectively, 5 publications were from Netherlands, 2 from Germany, 1 from Japan (Table 4). According to the impact factor (IF) of those journals (2015 JCR), the IF were generally low, and the most majority were non-top journals.

The 5850 literatures covered 83 disciplines, indicating phytoplankton was widely used in assessing the freshwater quality research. The top 5 disciplines were: marine freshwater biology with 2268 literatures, environmental sciences ecology with 2039 literatures, oceanography

Table 3
Top 20 authors of cited literature worldwide between 1996 and 2016.

Rank	First author	Publication year	Total/Average annual citation frequency	Institute	Country
1	Hillebrand, H	1999	1203/66.83	Institute of Oceanography	Germany
2	Elser, James J	2007	875/87.5	Arizona State University	USA
3	Meyers, PA	1997	698/34.9	University of Michigan	USA
4	Schenk, Peer M	2008	653/72.56	University of Queensland	Australia
5	Solomon, KR	1996	615/29.29	University of Guelph	Canada
6	Reynolds, CS	2002	603/40.2	CEH algal modelling unit	UK
7	Nishiyama, Y	2003	562/40.14	University of Tokyo.	Japan
8	Elser, JJ	2000	546/32.12	Arizona State University	USA
9	Volkman, JK	1998	539/28.37	Commonwealth Scientific and Industrial Research Organization	Australia
10	Franklin, Natasha M	2007	502/50.2	Commonwealth Scientific and Industrial Research Organization	Australia
11	Landsberg, JH	2002	473/31.53	Florida Marine Research Institute	USA
12	Smith, VH	2003	449/32.07	University of Kansas	USA
13	delGiorgio, PA	1997	448/22.4	Institute of Ecosystem Studies	USA
14	Ratte, HT	1999	446/24.78	Aachen University of Technology	Germany
15	Rabalais, NN	1996	416/19.81	Louisiana Universities Marine Consortium	USA
16	Filella, M	2002	409/27.27	University of Geneva	Switzerland
17	Camargo, Julio A	2006	403/36.64	University of Alcala	Spain
18	Brett, MT	1997	386/19.3	University of California	USA
19	Jeppesen, E	1997	371/18.55	National Environmental Research Institute	Denmark
20	Handy, Richard D	2008	330/36.67	University of Plymouth	UK

Table 4
Top 20 Source publications worldwide between 1996 and 2016.

Rank	Source publication	Number of papers	Country of publication	Impact factor	Contribution rate %
1	Hydrobiologia	245	Netherlands	2.051	4.19
2	Estuarine Coastal and Shelf Science	151	UK	2.335	2.58
3	Freshwater Biology	144	UK	2.933	2.46
4	Limnology and Oceanography	123	USA	3.660	2.10
5	Journal of Phycology	113	USA	2.536	1.93
6	Environmental Toxicology and Chemistry	100	USA	2.763	1.71
7	Phycologia	89	Japan	1.628	1.52
8	Journal of Plankton Research	88	UK	2.150	1.50
9	Environmental Science & Technology	85	USA	5.393	1.45
10	Aquatic Toxicology	84	Netherlands	3.557	1.44
11	Aquatic Microbial Ecology	84	Germany	2.109	1.44
12	PLoS ONE	81	USA	3.057	1.39
13	Marine Ecology Progress Series	75	Germany	2.361	1.28
14	Chemosphere	73	UK	3.698	1.25
15	Estuaries and Coasts	60	USA	2.659	1.03
16	Journal of Applied Phycology	59	Netherlands	2.372	1.01
17	Ecotoxicology and Environmental Safety	57	UK	3.130	0.97
18	Bioresource Technology	56	Netherlands	4.917	0.96
19	Science of the Total Environment	55	Netherlands	3.976	0.94
20	Water Research	54	UK	5.991	0.92

with 764 literatures, plant sciences with 626 literatures, toxicology with 456 literatures. The top 2 disciplines included 4307 literatures, accounting for 73.62% of all literatures. The top 20 research branches are shown in Table 5.

3.5. The summary of global funding supporting the research

The funding supporting the research indicated the concerning degree of government, enterprises and funding institution paying attention on a certain research area. Based on the funding information of the retrieved literatures, there were a total of 3900 records of funding (the same funding but with different translated names was treated as different funding). The top 20 funding included 21 categories, supporting 879 published literatures. The National Science Foundation funded the publication of 208 papers, accounting for 23.66% of all papers funded by the top 20 funds. The National Natural Science Foundation of China funded the publication of 183 papers, accounting for 20.82% of all papers funded by the top 20 funds. Of the top 20 funds, 5 funds supporting the research in this field were from China, accounting for 23.83%, which supported the publication of 279 papers, accounting for 31.74% of all papers supported by the top 20 funds. 2 funds from the United States supported the publication of 222 papers, accounting for 25.26% of all papers supported by the top 20 funds. 3 funds from Brazil supported the publication of 58 papers. Germany, Canada and Europe also have two types of funds each to support the research in this field (Table 6).

Table 5
Top 20 research branches worldwide between 1996 and 2016.

Rank	Research branch	Amount of literature	Contribution rate %
1	Marine Freshwater Biology	2268	38.77
2	Environmental Sciences Ecology	2039	34.86
3	Oceanography	764	13.06
4	Plant Sciences	626	10.70
5	Toxicology	456	7.80
6	Microbiology	352	6.02
7	Geology	340	5.81
8	Biotechnology Applied Microbiology	328	5.61
9	Engineering	306	5.23
10	Chemistry	243	4.15
11	Water Resources	231	3.95
12	Fisheries	195	3.33
13	Biochemistry Molecular Biology	191	3.27
14	Science Technology Other Topics	182	3.11
15	Energy Fuels	119	2.03
16	Biodiversity Conservation	115	1.97
17	Life Sciences Biomedicine Other Topics	111	1.90
18	Agriculture	108	1.85
19	Geochemistry Geophysics	92	1.57
20	Physical Geography	87	1.49
20	Paleontology	87	1.49

3.6. Co-occurrence of key words and the research hotspot

10,182 key words were extracted by using SATI software in this study, of which, 113 key words appeared more than 20 times. Defined the top frequent 50 key words as the high-frequency key words. After removing the redundancy of high-frequency key words and manually cleaning, we got 39 effective high-frequency key words. Defined the key words with frequency of occurrence more than 100 times as the high-frequency core key words, and we got 9 high-frequency core key words: phytoplankton, algae, nutrients, eutrophication, toxicity, Microalgae, estuary, phosphorus and Nitrogen, with frequency of occurrence of 442, 289, 196, 192, 137, 135, 134, 114 and 101 times, respectively.

Classifying and statistically analyzing the co-occurrence of high-frequency key words showed that, the keywords algae and nutrients, water eutrophication and nitrogen, phosphorus, and salt co-occurred 120 times; algae and taxonomy, biological diversity, and various groups co-occurred 82 times, algae and primary production, biomass, photosynthesis, chlorophyll, food web and bioenrichment co-occurred 57 times; algae and estuary and lake co-occurred 48 times, algae and water quality, organic matter, bacteria, toxins, and copper co-occurred 40 times; and algae and temperature and climate change co-occurred 28 times, indicating relative close relationship among those subjects. Those studies mainly focused on 4 aspects: 1, Studies on water eutrophication: mainly focused on key issues such as phytoplankton and eutrophication, water nutrient composition. 2, Studies on biodiversity of algae: mainly focused on the population structure, biodiversity and taxology of phytoplankton such as cyanobacteria, green algae, microalgae, diatoms, and others. 3, Studies on ecology of phytoplankton: mainly focused on biomass, food network relationships and material transfer and conversion. 4, Influence of environmental factors on the phytoplankton community: mainly focused on the effects of climate factors such as climate change, nitrogen, phosphorus and temperature on the phytoplankton community. Water areas of estuaries and lakes were mainly concerned. Using phytoplankton to assess eutrophication and other water quality problem, and studying the influence of climate change on phytoplankton are still important directions for future phytoplankton research [4,27].

Table 6
Top 20 funding supporting the research worldwide between 1996 and 2016.

Rank	Fund or funding sources	Amount of literature	Contribution rate %	Country
1	US National Science Foundation	208	3.56	USA
2	National Natural Science Foundation of China	183	3.13	China
3	Natural Sciences and Engineering Research Council of Canada	84	1.44	Canada
4	European Union	49	0.84	EU
5	National Basic Research Program of China	39	0.67	China
6	Australian Research Council	31	0.53	Australia
7	National Council for Scientific and Technological Development of Brazil, CNPQ	28	0.48	Brazil
8	Chinese Academy of Sciences	26	0.44	China
9	Swiss National Science Foundation	23	0.39	Switzerland
10	German Research Foundation	21	0.36	Germany
11	Deutsche Forschungsgemeinschaft	33	0.56	Germany
12	Canada Research Chair Program	18	0.31	Canada
13	Academy of Finland	17	0.29	Finland
14	Fundamental Research Funds for the Central Universities	16	0.27	China
15	CAPES Foundation, Ministry of Education of Brazil	16	0.27	Brazil
16	Russian Foundation for Basic Research	15	0.26	Russia
17	Natural Science Foundation Of Jiangsu Province	15	0.26	China
18	European Commission	15	0.26	EC
19	National Oceanic and Atomspheric Administration, NOAA	14	0.24	USA
20	The Fundação para a Ciência e a Tecnologia, FCT	14	0.24	Portuguesa
20	A Fundação de Amparo à Pesquisa do Estado de São Paulo, FAPESP	14	0.24	Brazil

4. Conclusions and discussion

Bibliometrics can be used to analyze the worldwide research progress of using phytoplankton to assess water quality, to keep abreast of the latest international research trends in this field, and to provide a theoretical approach and support for promoting the water quality monitoring and pollution controlling in China. Based on the bibliometrics analysis using SCI published in the last 20 years (1996–2015), a lot of researchers utilized phytoplankton to assess water quality, and formed a core author group. The number of published papers was increasing year by year, and the citation frequency increased rapidly. Developed countries such as European countries and the United States contributed a lot. Lacking of leading scientists, our Chinese researchers in this field fell behind with those from developed countries, regardless of the number of published papers or the influence of papers.

Published paper is an important type of scientific research yields. Occasional assessment of research quality in different disciplines had an important impact in British universities [28], but the research quality assessing was very complicated, which was determined by many factors such as the importance, originality, rigor, conciseness, accuracy, and scientific influence. There was no mathematical formulas can directly calculate the research quality, thus, a series of citation-based measurements were used for assessing the paper quality in bibliometircs [29–30]. The number of published papers and the citation were not only used to measure and compare the activity and influence of research between different countries and regions, but also served as a main parameter to quantitatively evaluate the scientific power of each research institutions, which can reflect the characteristics of development of science and technology as well as its advantages and disadvantages. For instance, using the frequency of core key words to summarize the characteristics, patterns, basic information of research in this field can conclude the emphasis and trends of research in this field [18–20]. The high-frequency core key words can be more objective to reflect the research hotspot. Analyzing the number of papers, citation frequency, countries and regions, publications, and research direction showed that the application of phytoplankton in water quality evaluation has been widely concerned and valued by researchers in this field, possessing a wide range of research groups and basis. Developed countries and regions such as American had the most high-level research papers and institutions in the field of worldwide algae research and water quality evaluation. In this field, the number of SCI published by Chinese researchers ranked the second, but only accounting for 33.86% of that published by American researchers which ranked the first. Only 2 research institutions from China were include in the top 20 institutes list, only 1 author from Hong Kong of China was included in the top 20 authors list. No author was included in the top 20 citation list. However, based on the funding institutes, sources, and the quantities, the China government (mainly the National Natural Science Foundation of China and the 973 National Basic Research Project) had provided relatively adequate funding for the research of this field.

Competing interest

The authors declare that they have no competing interests.

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