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Review

A bibliometric review of nitrogen research in eutrophic lakes and reservoirs

Xiaolong Yao[1,2], Yunlin Zhang[1,*], Lu Zhang[1], Yongqiang Zhou[1]

1. Taihu Laboratory for Lake Ecosystem Research, State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China. E-mail: qhuyxl@163.com
2. University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

The global application of nitrogen is far greater than phosphorus, and it is widely involved in the eutrophication of lakes and reservoirs. We used a bibliometric method to quantitatively and qualitatively evaluate nitrogen research in eutrophic lakes and reservoirs to reveal research developments, current research hotspots and emerging trends in this area. A total of 2695 articles in the past 25 years from the online database of the Scientific Citation Index Expended (SCI-Expanded) were analyzed for publication output, authors, institutions, countries, journals and keywords. Articles in this area increased exponentially from 1991 to 2015. Although the USA was the most productive country over the past 25 years, China achieved the top position in terms of yearly publications after 2010. The most active keywords related to *nitrogen* in the past 25 years included *phosphorus*, *nutrients*, *sediment*, *chlorophyll-a*, *carbon*, *phytoplankton*, *cyanobacteria*, *water quality*, *modeling*, and *stable isotopes*, based on analysis within 5-year intervals from 1991 to 2015 as well as the entire past 25 years. In addition, researchers have drawn increasing attention to *denitrification*, *climate change*, and *internal loading*. Future trends in this area should focus on: (1) nutrient amounts, ratios, and major nitrogen sources leading to eutrophication; (2) nitrogen transformation and the bioavailability of different nitrogen forms; (3) nitrogen budget, mass balance model, control, and management; (4) ecosystem responses to nitrogen enrichment and reduction, as well as the relationships between these responses; and (5) interactions between nitrogen and other stressors (*e.g.*, light intensity, carbon, phosphorus, toxic contaminants, climate change, and hydrological variations) in terms of eutrophication.

Contents

* *Corresponding author*. E-mail: ylzhang@niglas.ac.cn (Yunlin Zhang).

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Introduction

Both nitrogen and phosphorus are required to support aquatic plant growth and are the key limiting nutrients in most aquatic and terrestrial ecosystems (Conley et al., 2009; Glibert et al., 2005; Ma et al., 2015). However, nitrogen has received far more attention because it limits primary production and its global application (form synthetic fertilizers) is far greater than phosphorus (Glibert et al., 2005). The anthropogenic addition of reactive nitrogen to aquatic systems from fertilizer use, crop nitrogen fixation, urban and agricultural nitrogen wastes, atmospheric nitrogen deposition, fossil fuel combustion and other sources has increased in recent decades (Finlay et al., 2013; Galloway et al., 2004; Liu et al., 2011; Mulholland et al., 2008; Paerl et al., 2014a). The excessive input of nitrogen into aquatic systems may fuel excessive rates of plant growth and lead to eutrophication, which refers to the nutrient enrichment of water (Seitzinger, 2008). The most common effects of nutrient enrichment in aquatic systems are manifested as increases in the abundance of algae and aquatic plants (Smith et al., 1999). However, the effects of nutrient enrichment are more serious and complex. Many studies have shown that eutrophication was one of most important factors contributing to the expansion of some harmful algal blooms (HABs), especially cyanobacterial blooms (Anderson et al., 2002; Paerl and Huisman, 2009). Some cyanobacterial species form massive surface growths that produce toxins, cause oxygen depletion, alter food webs, and lead to deteriorated water quality (Paerl and Huisman, 2009; Smith, 1998; Smith et al., 1999; Ye et al., 2011). The consequences of cyanobacterial blooms may pose a major threat to the drinking and irrigation water supply (Paerl and Huisman, 2009). For example, the drinking water crisis in Wuxi City in May 2007 was caused by massive cyanobacterial blooms around the drinking water source, which caused 2 million local residents to be without water for a week (Liu et al., 2011; Qin et al., 2010; Yang et al., 2008; X. Zhang et al., 2010).

Several reviews have discussed the relationships between the nitrogen dynamics (enrichment, sources, composition, transformation) and eutrophication, especially harmful cyanobacterial blooms (Anderson et al., 2002; Conley et al., 2009; Glibert et al., 2005; Smith et al., 1999). Due to the limited literature, it is still difficult to gain a comprehensive understanding of the research hotspots of the past and the emerging trends of nitrogen research in eutrophic lakes or reservoirs. Bibliometrics, first introduced by Pritchard (1969), utilizes quantitative analysis and statistical methods to describe the characteristics of articles (*e.g.*, yearly publication, title, authors, institutions, and keywords) within a given topic or field (Fu et al., 2013). These methods have been widely used to analyze research development, current research hotspots, and future trends in specific fields, such as particulate matter and health (Feifei et al., 2016; Jia et al., 2013), climate change (Li et al., 2011), drinking water (Fu et al., 2013; Hu et al., 2010), carbon cycling (Zhi et al., 2015), estuary pollution (Sun et al., 2012), aquatic ecosystems (Liao and Huang, 2013), and remote sensing (Zhuang et al., 2012). Yi and Jie (2011) conducted a bibliometric analysis related to eutrophication, and they mainly focused on general eutrophic issues, in which the role of nitrogen was not thoroughly analyzed. Gao et al. (2015) examined a research trend related to phosphorus research in eutrophic lakes. Although they found that publications about phosphorus were significantly correlated with publications about nitrogen in various countries, the total publications and research focuses differed from nitrogen to phosphorus. Fundamental differences exist between nitrogen cycling and phosphorus biogeochemical processes. For example, transformations between different nitrogen forms were more complex than those of phosphorus, including nitrogen fixation, nitrification, denitrification, anammox, among others. Because of the increased nitrogen input (mainly anthropogenic) to lakes and reservoirs over the past decades, the eutrophication issue may become more difficult to resolve. It is important to investigate the development, current research hotspots, and future tendencies of nitrogen relevant to eutrophication of lakes and reservoirs to provide a better understanding of the global research status.

In this study, we conducted a bibliometric analysis and historical review of nitrogen research in eutrophic lakes and reservoirs. The aims of this study were to 1) quantitatively and qualitatively summarize the characteristics of yearly publication output, subject categories, mainstream journals, leading countries and institutions, 2) reveal the current hotspots related to nitrogen research, and 3) discuss research tendencies to provide a potential guide for nitrogen research.

1. Data and methodology

1.1. Data

The data used in this study were based on the online database of the Scientific Citation Index Expanded (SCI-Expanded) of the Web of Science from Thomson Reuters on March 2, 2016.

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