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Spatial heterogeneity of lake eutrophication caused by physiogeographic conditions: An analysis of 143 lakes in China

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ABSTRACT

In order to identify the effect of geographic characteristics on the variations of nutrient concentrations and the utilization efficiency of nutrients by phytoplankton, data from 143 lakes, from 2008 to 2010, including three very different types of topography, *i.e.*, the first topography ladder (FTL), second topography ladder (STL), and third topography ladder (TTL), were statistically analyzed. Lakes in the FTL and STL, located at high elevation (above 1000 m) and low longitudes (lower than 105° E), were sporadically oligotrophic, whereas lakes in the TTL were almost all mesotrophic and eutrophic. The trophic level index (TLI) became higher with the rise of longitude. Two turning points (5 and 15°C) on the curve of TLI as function of the average annual temperature (AAT) corresponded with the AAT in different lake regions in the STL and TTL. Because the responses of TLI to AAT differ significantly, there were variations of nutrient and algal biomass concentrations in different lake regions in the same type of topography ladder. According to the differences in utilization efficiency of total nitrogen or total phosphorus by phytoplankton, China could be partitioned into six lake regions. Scientific nutrient criteria for each lake region shall be established considering these differences in China.

Introduction

Lake eutrophication is affected not only by anthropogenic factors (Müller et al., 1998; Hall et al., 1999; Taranu and Gregory-Eaves, 2008) but also by natural factors, such as geographic location (Nõges, 2009; Liu et al., 2010), bedrock (Portielje and Van der Molen, 1998; Hamilton et al., 2001), lake morphology (Fee, 1979; Nõges, 2009), and climate (Tibby and Tiller, 2007; Brown et al., 2011). Rawson (1939) demonstrated that geographic location was the essential one among the natural factors affecting the trophic status of lakes. Human activities and natural factors that may affect the trophic status of lakes, including geology, topography, and latitude, are all dominated by geographic location. The effects of land use, point-source pollution, water management, and socio-economic development on eutrophication parameters are frequently researched around the world (Galbraith and Burns, 2007; Fraterrigo and Downing, 2008). In contrast, the correlations between natural factors and eutrophication parameters were not given much emphasis by previous studies (Nõges et al., 2003; Nõges, 2009; Liu et al., 2010), especially at large scales (Thierfelder, 1998; Liu et al., 2010).

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At present, there are 2573 natural lakes with an individual area >1.0 km^2 (Ma et al., 2011) in China. These lakes are located along a longitudinal gradient (from 73°40′ E to 135°2′ 30″ E), which includes three very different types of topography (Fig. 1a), namely, the first topography ladder (FTL), the second topography ladder (STL), and the third topography ladder (TTL). The FTL is located at the highest elevation (higher than 4000 m), and mainly comprises the Qinghai–Tibetan Plateau and the Qaidam Basin. The STL descends from approximately 2000 m to 500 m and mainly comprises the Inner Mongolia Plateau, Loess Plateau, Yunnan–Guizhou Plateau, Junggar Basin, Tarim Basin, and Sichuan Basin. The TTL is located at the lowest elevation (lower than 500 m), and mainly contains Daxinganling, Xiaoxinganling, Shandong Hills, the southeast hills, northeast plain, North China plain, and the plain of the Yangtze River. The chemical characteristics, meteorology, and morphology of the lakes located in these three types of topography are quite different, leading to regional variations in nutrient concentrations, trophic status, and the utilization efficiency of nutrients by phytoplankton. Thus, expectations will not be the same in different parts of the country where geographic phenomena, such as soils, vegetation, climate, and geology, cause different nutrient concentrations. Partitioning land into regions based on the combinations of geographic phenomena associated with regional differences in lake nutrient concentrations can be a powerful classification tool for nutrient criteria development (Rohm et al., 2002).

In China, the main standard for environmental management is the surface water quality standard (GB3838-2002). However, nutrient criteria and standards for lake eutrophication control have been lacking, especially in regional applications (Huo et al., 2009). In the beginning of the 21st century, the United States established a nutrient criteria technical guidance manual for lakes and reservoirs (US EPA, 2000), in which the lakes were divided into several eco-regions. Nutrient criteria in each eco-region were separately established according to the variations of nutrient concentrations caused by geographic parameters. However, limited reports were presented about the spatial variations of eutrophication-related parameters and the utilization efficiency of nutrients by phytoplankton at large scale, which hindered the establishment of regional nutrient criteria in China. The primary objective of the study is to clarify differences among or within the three types of topography according to the variations of nutrient concentrations and the utilization efficiency. Our research can help to promote the scientific partitioning of nutrient eco-regions and the establishment of regional nutrient criteria in China.

1. Materials and methods

1.1. Data collection

In this study, water-quality parameters from 143 representative lakes were selected based on the lakes' locations and areas, and the accessibility of data (Fig. 1b). The lakes' selection was endorsed later by the expert panel in Mega-projects of Science Research for Water Environment Improvement (2009ZX07106-001) in China.

Five water-quality parameters from 143 lakes during the period of 2008–2010 were selected to assess the trophic status and spatial heterogeneity according to the former research results (Jin, 1995; Wang et al., 2002). These parameters included Secchi disk depth (SD), chemical oxygen demand (COD_{Mn}) (using the potassium permanganate oxidation method), total nitrogen (TN), total phosphorus (TP), and chlorophyll *a* (Chl-*a*). The monthly data of water-quality parameters in 2008 were collected from several local monitoring institutions. The data of 2009–2010 were gathered seasonally from several research groups, which were parts of the Mega-projects of Science Research for Water

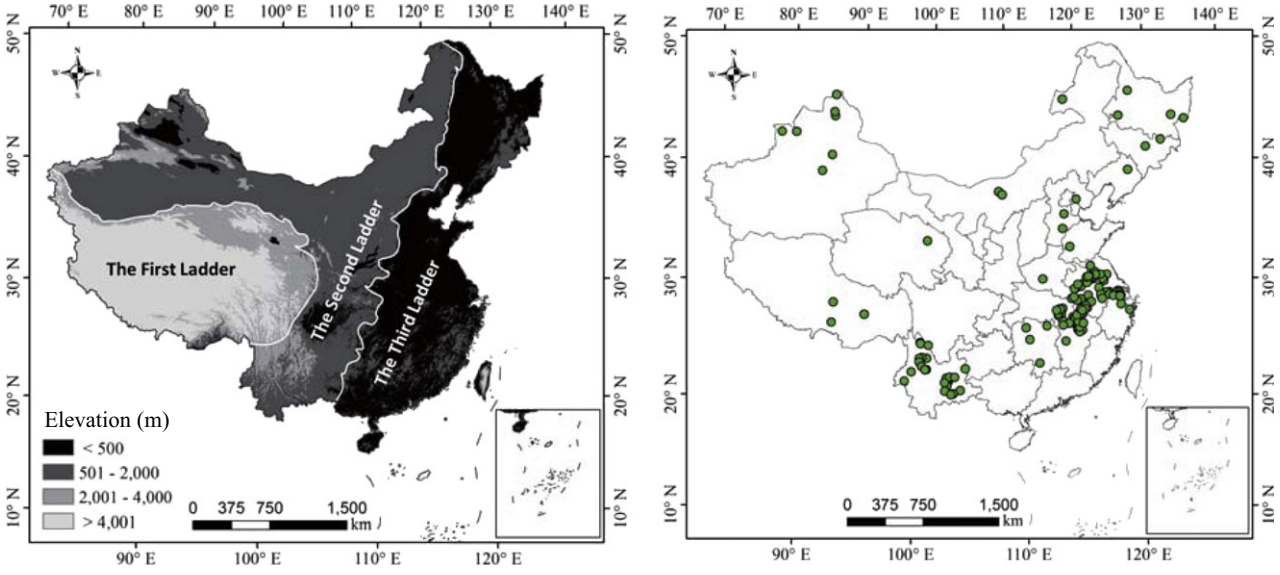

Fig. 1 – Topography of China (a) and locations of the 143 Chinese lakes (b) mentioned in the present study, the background map shows the provincial boundaries of China (GS (2015)9).