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Original Articles

Spatial variability and temporal dynamics of HABs in Northeast China

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ABSTRACT

The increasing severity and intensity of harmful algal blooms (HABs) are of great concern to public health and a threat to ecosystems and have become a global problem in recent decades. Most of the related studies in China have been focused on low-latitude areas, such as Lake Taihu, Chaohu, and Dianchi. However, little attention has been devoted to algal blooms in Northeast China. As a significant Chinese commodity grain production base, the non-point source pollution deteriorated along with the grain production increasing year by year. In fact, the HABs in the little researched Northeast China were exceedingly serious. From 1982 to 2016, there was a total of 271 out of 2186 feasible Landsat images found HABs. The annual total frequencies of the detected HABs increased in fluctuation from 0 in 1982 to 11 times in 2016, and the highest frequency was observed twice, in 2010 and 2014, and was 29 times in both years. The number of lakes and reservoirs detected HABs and the annual sum of normalized HABs area also increased obviously. The tendency was almost coherent with the rising temperature, reduced wind speed, and declining atmospheric pressure. The R^2 and *p-value* between the annual frequency and the three meteorological indices were (0.274, < 0.005), (0.553, < 0.0001), and (0.073, 0.126), respectively. Besides, as anthropogenic influence indicators in this paper, we selected fertilizer application amount, industrial wastewater and municipal sewage discharge amount, land use type in 1986, 2000, and 2010. We comprehensively considered lacustrine morphologies and hydrological hydrodynamics and analyzed the driving factors of the spatiotemporal distribution pattern of HABs in Northeast China.

1. Introduction

Harmful algal blooms (HABs) occur when phytoplankton species increases in abundance without control and causes adverse impacts on the environment (Smayda, 1997). In this process, toxic species can release toxins which are fatal to fish, shellfish, mammals, and humans, while non-toxic phytoplankton species can accumulate to a higher biomass and result in hypoxia or anoxia (Stumpf and Tomlinson, 2005; Wells et al., 2015). In recent decades, both severity and intensity of HABs in lakes, reservoirs, rivers, and marine systems have increased as a consequence of climate change and anthropogenic disturbance (Masó and Garcés, 2006; Duan et al., 2009;Fu et al., 2012; Wells et al., 2015; Whitehouse and Lapointe, 2015). Nonetheless, the exact mechanism for the HABs is still not fully understood (Wells et al., 2015).

Nutrients, meteorological factors, and water heterogeneity have been generally accepted as the triggers of HABs. Nutrients are the material basis of eutrophication and algal blooms in the water body (Yang et al., 2015). *M. aeruginosa* exposed to nutrients and zinc was observed to experience a rapid growth and an increase in microcystin concentration (Polyak et al., 2013). The response of algal blooms to elevated nutrient concentrations was reported in the Sodus Bay (Perri et al., 2015), the Lake Winnipeg (Wassenaar and Rao, 2012), and specifically the diatom bloom to the levels of phosphates and silicates (Zhou et al., 2017).

Meteorological factors such as temperature, precipitation, wind, and light exert both direct and indirect effects on HABs. Shi et al. (2015) proposed that temperature, wind, and light conditions probably affected the temporal and spatial distribution of microcystins in Lake Taihu. Precipitation supplies nutrients via runoff to water bodies, which, for example, was described by Oliver et al. (2014) as erosion of P-rich sediments into the water. Wynne et al. (2010) indicated that high wind stress could mix HABs through the water column. In most regions of North America, the majority of HABs were caused by nutrient-enriched runoff from intense rain events, warm temperatures, low flushing, water-column stability and prolonged ice-free growing seasons (Watson et al., 2016). Wicks and Thiel (1990) proposed the

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environmental conditions that favor the formation of cyanobacterial (blue-green algal) blooms were moderate-to-high levels of nutrients, water temperatures between 15 °C and 30 °C, and a pH value of 6–9 or higher.

However, the sensitivity of cyanobacterial dynamics to climatic conditions was found to vary from region to region (Shi et al., 2017), depending on hydrodynamics, morphology, and some chemical parameters. A low to moderate hydrodynamic disturbance facilitates the release of nutrients from the bottom sediment of lakes with shallow depths and high contents of nutrients (Huang et al., 2016). Water depth and surface area were found to interactively affect Chl-*a* concentrations in smaller lakes (Huang et al., 2014b). In another study, external pollution loading coupled with hydrodynamic force affected the concentrations of nutrients, which, along with the underwater light intensity, consequently influenced phytoplankton evolution (Li et al., 2012).

Northeast China is an old industrial base of China as well as the largest Chinese commodity grain base. In recent years, the intensified lacustrine eutrophication and the occurrence of HABs have been reported more frequently, which could be related or attributed to global warming, the economic development and the population growth resulting from the realization of the reform and the opening policies since 1978. Given that HABs are a good indicator of the ecological health of Northeast China, investigating HABs in freshwaters of this region is necessary for understanding environmental changes from basin to watershed scales and for constraining the processes that drive algal blooms (Ho et al., 2017).

Traditional studies were used to studying the HABs in a single lake or reservoir, different from them, this study regarded a whole region covering many lakes and reservoirs as an object. The present study focuses on investigating the spatial variability and temporal dynamics of HABs for lakes and reservoirs located in Northeast China, which necessitates determining the historical occurrence of HABs back to around 1978. To achieve the goal, satellite images obtained from Landsat (including Landsat/MSS/TM/ETM + /OLI) were analyzed. The specific objectives of this study were to determine the spatial pattern and temporal frequency of HABs in Northeast China, compare the spatial pattern and temporal frequency of HABs for lakes and reservoirs to be investigated, and understanding possible environmental factors that drive the spatial variability and temporal dynamics of HABs in Northeast China.

2. Materials and methods

2.1. Study area

Northeast China (115°E–135°E in longitude and 38°N–53°N in latitude) is a large administrative region with the total area of 1.24 million square kilometers and encompassing Heilongjiang Province, Jilin Province, Liaoning Province, and the eastern part of Inner Mongolia Autonomous Region. The water bodies account for approximately 12,757 km^2, including freshwater lakes, reservoirs, and ponds. The region is dominated by two types of climate: temperate continental and temperate grassy (Fig. 1). However, under the influence of human activities and climate change, nine of the Northeast China lakes and reservoirs have been reported for the presence of HABs at various degrees, and they are Erlongshan Reservior (ELSR), Xinlicheng Reservoir (XLCR), Shitoukoumen Reservior (STKMR), Hulun Lake (HLL), Xiaoxingkai Lake (XXKL), Hamatong Reservoir (HMTR), Nierji Reservoir (NEJR), Dalonghu Lake (DLHL), and Lianhua Reservoir (LHR). The

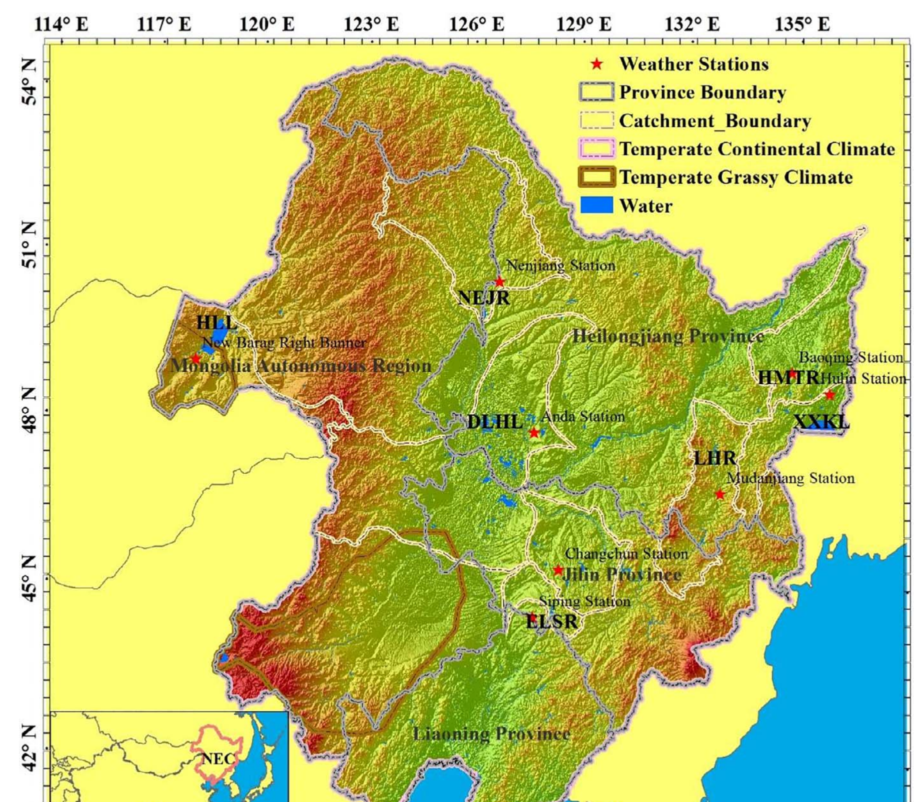

Fig. 1. Location, topography, climate zone distribution of lakes and reservoirs found algal blooms in this study as well as the meteorological stations nearest to the object lakes.