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Diatom taxa and assemblages for establishing nutrient criteria of lakes with anthropogenic hydrologic alteration



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ABSTRACT

Stressor-response models offer guidance for concentration-based nutrient criteria in lakes under human intervention. Diatom-based statistics from biological responses were incorporated to derive taxon-specific and community-level change points (thresholds) of phosphorous and nitrogen in 77 Yangtze floodplain lakes. Diatom metrics relating with conductivity were adopted as response variables, since conductivity explained the maximum variation (38.1%) in diatom assemblages via Bootstrapped regression trees. Nonparametric change-point analysis and Threshold Indicator Taxa ANalysis showed threshold responses of diatom community structure at 0.05–0.08 mg TP/L in connected lakes and 0.02–0.04 mg TP/L in isolated lakes. Distinct community change points of sensitive diatoms occurred at 0.96–1.63 mg TN/L in connected lakes and 0.52–0.63 mg TN/L in isolated lakes. Diatom community structures of tolerant taxa were substantially altered beyond 0.22–0.23 mg/L in connected lakes and 0.52–0.69 mg NO_x/L in isolated lakes. Hydrological river-lake connectivity differed significantly in ecological nutrient criteria with more TN/TP criteria and less NO_x criteria in connected lakes. Given the ecological significance and biological integrity, diatom-based statistics can provide more reliable change points (thresholds) for nutrient criteria than Chl *a*-nutrient relationships.

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1. Introduction

Elevated nutrients are the major factors contributing to the poor lake ecosystem, highlighting the need for nutrient criteria that can aid management efforts to protect or restore the water quality from eutrophication. Prevailing approaches to deriving TN or TP criteria include percentile analysis and stressor-response analysis. Percentile analysis focus on identifying reference conditions by using the 75th percentile of reference lakes or the 25th percentile of all lakes, while stressor-response analysis related nutrients to ecological or biological changes when lake ecosystem suffer severe anthropogenic impacts and thus reference lakes cannot be identified. The stressor-response analyses including linear and non-linear relationships are conducted to determine whether change points (thresholds) exist, aiding in nutrient criteria establishment. Linear stressor-response relationships between nutrients

and chlorophyll *a* (Chl *a*) are often shown in numerous waterbodies, since Chl *a* is a surrogate for algal biomass and strongly affected by nutrient concentrations (Huo et al., 2013a, 2014). However, non-linear statistical methods that define ecological change points have become prevalent for deriving nutrient criteria, since the biological responses to environmental stressor are always non-linear, non-normal, and heterogeneous (King and Richardson, 2003; King and Baker, 2010). Moreover, non-linear statistics are useful for visually facilitating interpretation, revealing data structures, and displaying interactions.

Biological response elements, such as macroinvertebrate species, macrophytes, diatoms, and zooplankton, have been used to identify nutrient change points (thresholds), which represent as the meaningful criteria of nutrient concentrations and impairment level (Lougheed et al., 2007). Diatoms are well-suited for aquatic ecosystem assessment around the world, since they can integrate stressor effects over time and describe the complexity, stability, and functioning of ecosystem (Stevenson et al., 2008a). However, aquatic macrophytes and large zooplankton usually dominate the clear-water state of lakes. There is only limited evidence for

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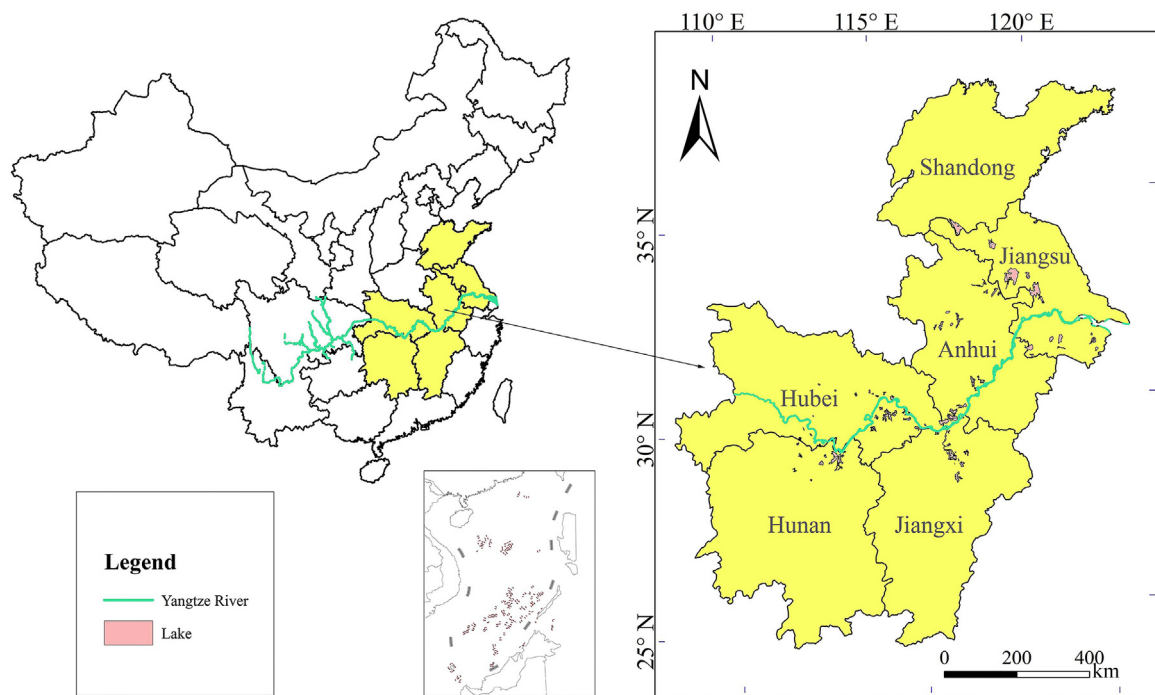


Fig. 1. A spatial map with 77 Yangtze floodplain lakes in China.

macroinvertebrate diversity being imposed by nutrient pollution (Langford et al., 2009). Compared to other organisms, diatoms were commonly selected as the biological indicators for reference condition of lakes due to their direct responses to lakes and their great ability to assess ecological integrity. In fact, diatom-based index supports a good reference for nutrient criteria of streams (Lavoie et al., 2014).

Non-linear stressor-response models between diatoms and nutrients are useful tools in determining nutrient concentrations based on valued ecological attributes, since diatom species relative abundances often contain zero values. Threshold responses by diatoms to nutrients are well documented, especially in response to phosphorous (Smith and Tran, 2010; Dodds et al., 2010). Diatom taxon-specific and assemblage-level change points can be detected from Threshold Indicator Taxa Analysis (TITAN) by separating responses of negative and positive indicator taxa (Baker and King, 2010). On the other hand, diatom metrics relating changes in community structure to gradients of nutrient concentrations or other environmental conditions can be applied to identify change points in Nonparametric change-point analysis and regression trees. Sensitive/tolerance and bloom metrics have been elaborated based on quantitative and qualitative characteristics (Carvalho et al., 2013).

Floodplain lakes located in the Yangtze Basin of China are numerous, with a total lake surface area of 16,600 km². Most lakes are very shallow and suffered from serious eutrophication due to internal pollution sources and external loading sources. It highlights the need for nutrient criteria of Chinese lakes that can aid in the effective lake management strategies. Most floodplain lakes in the Yangtze basin were connected freely with the Yangtze River historically. However, owing to the protection of villages and cultivated land from flooding, dams and embankments were constructed during the 1950s–70s, which destroyed the longitudinal and lateral connectivity, and eventually induce most lakes isolating from the Yangtze River hydrologically. In recent years, only 3 lakes including Dongting Lake, Poyang Lake, and Shijiu Lake remain connected with the Yangtze River. Long-term presence of dams seriously affects waterbody characteristics and biological habitat availability (Walter and Merritts, 2008). Water velocity (current

flow) and hydrological connectivity are found to be the most important factors explaining the distribution of biological assemblages and positively influencing the regional diversity (Pan et al., 2011; Obolewski, 2011). There is so far less knowledge on nutrient criteria from diatoms in floodplain lakes differing hydrologic connectivity, although China has implemented the Regional Nutrient Criteria Research Plan to develop lake nutrient criteria since 2008. Since hydrological characteristics have been recognized as the major factors controlling the spatial distribution of benthic algae and lake nutrient dynamics, hydrological connectivity could regulate the relationships between nutrients and biological responses (Read et al., 2015). The responses of diatom assemblage to hydrologic connectivity differed from the algal biomass and water chemistry. Diatom community physiognomy and taxa sensitive to nutrients are influenced by hydrologic connectivity (Smucker et al., 2013). These patterns may lead to variability in appropriate nutrient criteria of lakes differing hydrologic connectivity.

Therefore, the main objectives of this study are: (1) to explore the variables explaining relative deviance of diatom assemblages via Boosted regression trees; (2) to estimate nutrient criteria of 77 floodplain lakes in Eastern China from diatom biomass and metrics by using Bootstrapped regression trees, Nonparametric change-point analysis and Threshold Indicator Taxa Analysis; (3) to elucidate the significant differences of nutrient criteria for type-specific lakes in different hydrologic connectivity.

2. Methods

2.1. Study sites and sampling

The present study was conducted in 77 shallow lakes along the middle and lower reaches of the Yangtze River located in Eastern China. A spatial map including 77 lakes is shown in Fig. 1 and the basic statistics regarding the information of 77 lakes are shown in Table 1. Hydrologic regime in middle and lower reaches of the Yangtze River mainly supported the flow volumes for the lakes of Eastern China (Huo et al., 2013b). The majority of lakes were formed by the migration of the Yangtze River during the

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