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Hydrological alterations as the major driver on environmental change in a floodplain Lake Poyang (China): Evidence from monitoring and sediment records

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ABSTRACT

Due to the lack of long-term records on shallow lake environmental change, knowledge of the processes and mechanisms behind the limnological response of many shallow floodplain lakes to hydrological alterations and nutrient loading is often limited. We examined seasonal monitoring data and a dated sediment core from Lake Poyang, a large floodplain lake located on the Yangtze floodplain in the SE China. Multivariate analysis based on contemporary data (diatoms and water quality) revealed that the seasonal changes in the diatom assemblage of the lake were correlated with water temperature and Secchi depth (SD), although the weak spatial effect was not negligible. During the dry winter season, low water temperature, low SD, and high nutrient levels, were accompanied by high abundances of planktonic *Aulacoseira* species along with *Stephanodiscus hantzschii*, a species well adapted to cold and eutrophic waters. During the summer wet season, however, when water temperature and SD were high and nutrient levels low, benthic and epiphytic diatoms, such as the genus *Achnanthes*, dominated. Sediment records of diatoms and geochemistry were used to estimate long-term variation in the ecological condition of the lake. During the past ~60 years, the lake has shifted from a natural hydrologically connected, oligotrophic lake dominated by benthic and epiphytic diatoms to a poorly hydrologically connected, eutrophic state driven by nutrient-tolerant planktonic and eutrophic diatoms. Furthermore, our results indicate that the proposed Poyang dam may severely affect the water quality and ecosystem of the lake by altering its seasonal hydrology.

Introduction

Floodplain lakes are naturally dynamic ecosystems that provide various ecosystem services such as fresh water, food, biological resources, and flood control to the local human population, both historically and today (Dearing et al., 2012). Some of these lakes are large and thus have large catchments with many rivers as inlets and outlets, and constitute complex river-lake-floodplain systems. In addition to the general characteristics of shallow lakes, the ecosystems of floodplain lakes respond to the spatial and temporal variability of river discharge and flooding, and this affects their ecological stability and the rates of biogeochemical cycling (Junk, 2005; Wiklund et al., 2010). Floodplain ecosystems are therefore particularly vulnerable to hydrological alterations and other stressors associated with human occupancy and use of catchment resources (Tockner et al., 2008). Numerous studies have suggested that the degree of hydrological connectivity between rivers and floodplain lakes is a key factor influencing the physical, chemical, and biological properties of floodplain lakes, as seen in the Danube floodplain, the South American Amazon floodplain, the Murray Darling river basin in Australia, and the Tonle Sap river basin in Cambodia (Heiler et al., 1995; Hay et al., 2000; Gell et al., 2005; Wolfe et al., 2006; Reid and Ogden, 2009; McGowan et al., 2011; Holtgrieve et al., 2013; Siev et al., 2016). For example, in Batata Lake in the Amazon floodplain, Bozelli et al. (2009) found that floods dilute the concentration of inorganic suspended solids (SS) in the water and promote species exchange between rivers and lakes, which in turn contributes to increased lake biodiversity. In contrast, in the ultra-oligotrophic Okavango delta, Davidson et al. (2012) found that more infrequently flooded sites were the most species rich in diatom and invertebrate taxon due to the higher nutrient availability. In recent years, global climate change and human activities (such as damming, land reclamation

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and canalization) have continuously modified both basin hydrology and the nutrient state of many lakes worldwide, resulting in fundamental changes in lake hydro-ecological conditions, a situation that has been receiving increasing international attention by managers and scientists (Junk, 2005; Wolfe et al., 2006; Bhattacharya et al., 2016).

The Yangtze River floodplain (southeast China) is one of the world's largest floodplains and, historically hundreds of oxbow or riverine lakes had open hydraulic connections with the Yangtze River (Yang et al., 2000). Since 1950, most lakes have been disconnected from the Yangtze River by dams or sluice gates, leaving only two Yangtze-connected lakes in the region, Lake Poyang and Lake Dongting. The dams or gates not only form physical barriers between the river and its floodplain lakes, but they also reduce or eliminate the hydrological connectivity of the floodplain ecosystem (Wang and Wang, 2009). For example, the world's largest hydropower project to date, the Three Gorges Dam (TGD), has altered the sedimentary, erosional, and hydrological processes in the Yangtze river–lake–floodplain ecosystems since its completion in 2003 (Lai et al., 2014). Construction of Lake Poyang Dam (Fig. 1), which would alter the seasonality of the outflow from the lake, has long been debated (Liu et al., 2015b). There are growing concerns about the potential effects of the dam on the lake biota and environment. Accordingly, investigations on the ecological response to the natural and human modifications of the hydrological regimes in these shallow floodplain lakes are needed in order to identify the underlying processes and forcing mechanisms. However, due to the lack of regular monitoring efforts, current as well as background information on the ecology of Yangtze floodplain lakes is scarce (Liu et al., 2012).

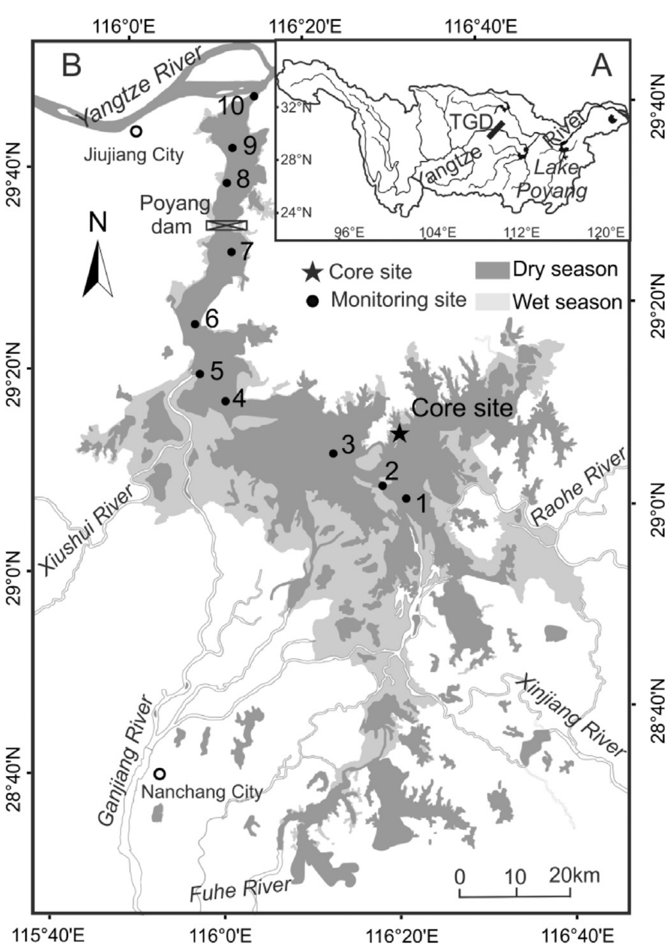

Fig. 1. A. Location of Lake Poyang in the Yangtze River catchment. TGD, Three Gorges Dam. B. Distribution of monitoring sites (1−10), core site, and the proposed Poyang dam (near monitoring site 7). The surface water areas in dry and wet season are shown.

Palaeolimnology allows the reconstruction of historical environmental changes in floodplain ecosystems, which is particularly useful where long-term historical records are absent (Gell et al., 2005; McGowan et al., 2005; Wolfe et al., 2008; Zalat and Vildary, 2007; Liu et al., 2012). Lacustrine sediments preserve a long-term record of abiotic and biotic conditions in aquatic ecosystems (Smol, 2008). For example, sedimentary grain size is a proxy for past hydrodynamic conditions (Molinaroli et al., 2009). Sedimentary elemental composition can be used for tracking past human activities and hydrological conditions (Hambright et al., 2008; Berner et al., 2012). Diatom assemblages are diverse and sensitive to a range of environmental factors, including water quality, hydrological conditions, and trophic state, and have been used to estimate past ecological conditions in many floodplain lakes (Grundell et al., 2012; Liu et al., 2012; Bhattacharya et al., 2016; Wu et al., 2017). Therefore, multi-proxy analyses based on lake sediment stratigraphy are increasingly used to elucidate environmental and ecological conditions in lakes (Bennion et al., 2015), including many floodplain lakes (Gell et al., 2005; Liu et al., 2012; Chen et al., 2015; Bhattacharya et al., 2016). In addition, contemporary aquatic ecology can provide a fuller consideration, particularly habitat preferences, seasonality and interactions of organisms (Sayer et al., 2010). Thus, the combination of contemporary ecology and palaeolimnology can be a powerful means to gain a fuller understanding ecological change in shallow lakes on multiple timescales (Sayer et al., 2010).

Of the two freshwater lakes that currently maintain free connection with the Yangtze River, Lake Poyang is the largest freshwater lake in China and it has a particularly complex hydrological regime and topography (Cheng and Li, 2006; Liu et al., 2013; Wu and Liu, 2014). Moreover, its hydrological connectivity has been heavily affected by water level controls from damming upstream and by the establishment of the Three Gorges Dam (TGD) (Zhou et al., 2016). Lake Poyang is therefore an ideal study lake for assessing hydro-ecological effects on the ecosystem. We hypothesized that hydrological alterations play a more important role than nutrients in driving the ecological change in Lake Poyang. To address this hypothesis, first, contemporary limnological records of diatoms and physicochemical variables were used to ascertain seasonal patterns in the response to hydrological alterations and nutrient loading in the lake. Second, stratigraphic records of sedimentary diatom assemblages, median grain size, and geochemistry were used in combination with long-term monitoring data to investigate environmental changes in response to hydrological alterations and anthropogenic nutrient loading in the lake. Considering the relatively high resolution (the core analyzed in this study with an average sedimentation rate 1.66 cm year^{-1}) and higher availability of historical literature in the past 60 years, only sediment samples spanning the last 60 years (the uppermost 76 cm in the core) was used (see below).

Study site

Lake Poyang (115°49′–116°46′E, 28°24′–29°46′N) is situated on the south bank of the middle Yangtze River, Jiangxi Province (central China), in a subtropical wet climate zone characterized by an annual mean precipitation of 1680 mm and an annual mean temperature of 17.5 °C. The lake mainly receives freshwater inflow from five tributary rivers: Ganjiang, Fuhe, Xinjiang, Raohe, and Xiushui, and discharges to the Yangtze River at Hukou. The watershed area is 162,000 km^2, covering 9% of the Yangtze River Basin and nearly 97% of the land mass of the Jiangxi Province (Gao et al., 2014). It exhibits major seasonal changes in both area and volume created by complex hydrological conditions (Fig. 1). The lake area fluctuates between the wet and dry seasons from 4000 km^2 to <3000 km^2, while the water level decreases seasonally from maximum 19.4 m in August to 7.9 m a.s.l. in January (Liu et al., 2015b). Because of these major seasonal water level fluctuations, the lake exhibits the characteristics of a river during the dry season and those of a lake during the wet season. As a proverb says: 'There is a big sheet with flood whereas a line with low water' (Cheng and Li, 2006).