Journal of Great Lakes Research xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

Effects of water level fluctuations on phytoplankton in a Changjiang River floodplain lake (Poyang Lake): Implications for dam operations

Xia Liu, Kuimei Qian, Yuwei Chen *

Poyang Lake Laboratory for Wetland Ecosystem Research, State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, PR China

ARTICLE INFO

Article history:
Received 29 October 2014
Accepted 23 June 2015
Available online xxxx

Communicated by Noel Urban

Index words:
Phytoplankton
Hydrology
Dam construction
Floodplain lake
Changjiang River basin

ABSTRACT

As one of the few remaining lakes that is freely connected with the Changjiang (Yangtze) River, Poyang Lake exhibits highly variable water level fluctuations. In this study, we examined the phytoplankton biomass and community including two hydrological and climatic variables (high water flow velocity, low water temperature in low water season and low water flow velocity, high water temperature in high water season). Diatoms dominated (40–87% of total) the community in periods of low water levels. In periods of high water levels, the community was dominated by cyanobacteria (45–93% of total). Various functional groups were also analyzed to assess the effects of hydrological conditions on phytoplankton community structure. The well-developed populations during the low water periods were representatives of functional groups P (*Aulacoseira granulata*, 28.7% of total) and Y (*Cryptomonas* spp., 12.4% of total). In the high water periods, *A. granulata* and *Microcystis* spp. (M and L_M) increased to 39.8% and 12.7% of the total phytoplankton biomass, respectively. We then used parabolic curves to identify the optimal lake water levels for each phytoplankton group. The total phytoplankton, diatom, cyanobacteria, and green algae responded positively to low water level and negatively to high water level. The water level of 14–15 m is crucial for phytoplankton biomass patterns and succession through the alternations of washing-out and dilution effects and biological competition. These results support the hypothesis that water level control projects (e.g., dams) may affect phytoplankton biomass and assemblage structure patterns in Poyang Lake by altering its seasonal hydrology.

Introduction

Floodplain lakes with a wide range of shapes are typical shallow and lentic water bodies in the subtropics and tropics, in contrast to temperate latitudes where lakes are predominately of glacial origin (Lewis, 2000). Another characteristic is their seasonal and generally predictable hydrological cycle with large water level fluctuations (WLFs) driven by annual flooding (Hamilton et al., 2002). The importance of WLFs in floodplain lakes is recognized as the primary factor that influences temporal limnological changes (Junk et al., 1989). Many recent studies have been undertaken to determine the responses of phytoplankton to water fluctuation in the floodplain lakes of the following tropical rivers: Amazon (Ibañez, 1997), Paraguay (De Oliveira and Calheiros, 2000), Araguaia (Nabout et al., 2006), Mary (Townsend, 2006), Murray (Butler et al., 2007), and Paraná (Izaguirre et al., 2001; Zalocar de Domitrovic, 2003). There is consensus that phytoplankton dynamics are mainly hydrologically driven, and phytoplankton species composition and abundance change in response to the duration and intensity of hydrological fluctuations in floodplain lakes (Engle and Melack, 1993; Garcia de Emiliani, 1997).

Water levels in floodplain lakes naturally fluctuate intra- and inter-annually depending largely on local meteorological and topographic characters and human activities (Blindow, 1992; Gafny and Gasith, 1999; Beklioglu et al., 2001). Certain human activities, such as regulation projects for the construction of dams and dykes and the over exploitation of water, can greatly change the hydrological conditions in floodplain lakes. Historically, all the lakes along the Changjiang River in China were connected with the mainstream of the river. Beginning in the 1950s, dams and thousands of kilometers of dykes were built for flood control, land reclamation, irrigation and the control of disease vectors, such as blood flukes. More than one hundred lakes were thus cut off and isolated from the Changjiang River channels (WWF UKCase Study, 2011). The isolated lakes have been separated by levees and have therefore become functionally extinct, because regular flooding and morphological dynamics are absent.

Poyang Lake is one of only three lakes that retain free connection with the Changjiang River. However, the anthropogenic regulation of Changjiang River, known as the Three-Georges Dam Project, intensifies the extremes of wet and dry conditions in the downstream area of Poyang Lake, and now, further reduces the water level over the dry

---

* Corresponding author.
E-mail address: ywchen@niglas.ac.cn (Y. Chen).

http://dx.doi.org/10.1016/j.jglr.2015.06.008
0380-1330/© 2015 Published by Elsevier B.V. on behalf of International Association for Great Lakes Research.

Please cite this article as: Liu, X., et al., Effects of water level fluctuations on phytoplankton in a Changjiang River floodplain lake (Poyang Lake): Implications for dam ope..., J. Great Lakes Res. (2015), http://dx.doi.org/10.1016/j.jglr.2015.06.008

period from late summer to autumn (Zhang et al., 2012). Indeed, the presence of dams in rivers induces numerous changes in the aquatic ecosystems both upstream and downstream from the dam (De Mèrona et al., 2001; Lorenzoni et al., 2005). There are growing concerns about the potential effects of river and lake regulation on the future environment in China. Controversy over the proposed large-scale water project, the Poyang Lake Dam which would alter the seasonality of outflow from the lake is continuing (Li, 2011; WWF China, 2014).

The Poyang Lake Dam has been designed as a 2.8 km wide dam with sluice gates across the narrowest part of the channel that links Poyang Lake and the Changjiang River. The sluice gates would allow provincial water authorities to adjust the amount of water discharged into the Changjiang River. Authorities of Jiangxi government would hold back water only in dry seasons and keep the level at a maximum depth of 12 m (Li, 2011). By changing the hydrological connectivity with the main river, dams interrupt the continuity of the lake water budget and impact most of its important ecological processes (Ligon et al., 1995). One potential point is that such variations in hydrological conditions can affect the biomass and structure of phytoplankton communities.

With the recognition of the importance of hydrological conditions, particularly WLFs in phytoplankton biomass and community dynamics, the main target of the present study was to determine whether and how changes in water level affect the phytoplankton biomass and community structure in Poyang Lake. For this reason, we carried out a comprehensive investigation on the phytoplankton biomass and community structure during different hydrological periods in Poyang Lake. A possible scenario that, quantifies the significance of water levels for phytoplankton biomass in this floodplain lake is then discussed.

Materials and methods

Site description

Poyang Lake (28°22′–29°45′N, 115°47′–116°45′E), which is located in the Jiangxi Province, is the largest freshwater lake in China, with a watershed area of 1.62×10^5 km^2. At its northern end, Poyang Lake drains into the Changjiang River, the longest river in China, through a narrow channel. The five major rivers in Jiangxi basin (Xuishui River, Ganjiang River, Fuhe River, Xinjiang River, and Raohe River) that flow into Poyang Lake have headwaters in the surrounding mountains (Zhu and Zhang, 1997). As a connected lake located at the junction of the middle and lower reaches of the Changjiang River, Poyang Lake exhibits large annual water fluctuations (Zhu and Zhang, 1997). The lake's highest water levels generally range from approximately 18 to 21 m above mean sea level during the summer rainy season in southern China but may be higher or lower during unusually wet or dry years (Zou et al., 2011). Consistent with WLFs, the lake area changes seasonally and reaches its peak in the summer. The annual discharge and storage capacity of the lake are approximately 1.46×10^{11} and 2.95×10^{10} m^3, respectively (Zhu and Zhang, 1997).

The analyses included in this paper focused on six primary sampling sites (S1–S6), which are located near the city of Xingzi (Fig. 1). We selected these sites because the region is between the north and middle part of Poyang Lake, and its water level is strongly affected by the Changjiang River stage and the amount of precipitation in the catchment area.

Sampling protocol and physicochemical analyses

To investigate the roles of water level in phytoplankton dynamics, different sampling frequencies and sites were adopted. A weekly sampling program over 14 months was conducted at S1, S2 and S6 from May 2012 to November 2013. Two additional surveys were added from May 2012 to December 2012 and May 2013 to November 2013, with two (S3 and S5) and one (S4) additional sites, respectively. To extend our data on phytoplankton abundance and composition, we have also included data from September to November 2011.

Measurements of water temperature (WT), specific conductance (Cond) and turbidity (Turb) were collected at multiple depths at the study sites using a Hydrolab Datasonda 5 sensor. The Secchi depth (SD) was also determined at the same time. The vertically integrated water samples were collected with an acid-cleaned 2 m long and 10 cm diameter plastic tube and kept cool and shaded before transport to the laboratory. Suspended solids (SS) and nutrient concentrations, namely, total nitrogen (TN), total phosphorus (TP), ammonium N (NH_4-N), nitrite N (NO_2-N), nitrate N (NO_3-N), and orthophosphate (PO_4-P), were analyzed following APHA (American Public Health Association) (1998). Chlorophyll a (chl a) was collected by filtration through GF/F filters (47 mm, Whatman) and measured according to Lorenzen (1967) with spectrophotometric measurements after extraction in hot 90% ethanol.

Phytoplankton composition and biomass

Phytoplankton samples were fixed with Lugol's iodine solution (1% v/v) and allowed to settle for 48 h prior to counting by light microscopy (Chen et al., 2003); the taxonomic identification was performed according to Hu and Wei (2006). Mean cell volume was calculated using the appropriate geometric configurations and volume formulae (Hillebrand et al., 1999). Volume values were converted to biomass assuming that 1 mm^3 of volume was equivalent to 1 mg of fresh-weight biomass (Chen et al., 2003).

Hydrological data

Water level data for the period January 2012 to December 2013 were available on the hydrology of the Jiangxi Province websites (http://www.jxsw.cn/Category275/Index.aspx and http://www.jxsw.cn/Category55/Index.aspx). Low and high water level periods were defined by days when the water levels were below and above 14 m, respectively. Thus, the high water level periods refer to April 28 to October 5 of 2012 and May 14 to August 18 of 2013.

The velocity data were obtained from the 2D hydrodynamic model MIKE 21 of Poyang Lake (Li et al., 2014). The model was calibrated and validated for 2000–2005 and 2006–2008, respectively. Details of the model performance can be found in Li et al. (2014). Hence, the observed catchment inflows of the five rivers, the Hukou water levels and the precipitation and evaporation were used as model input in 2010. The velocity time-series data can be obtained from the predicted model results.

Data analysis

All statistical analyses were performed with the Statistical Program for Social Sciences (SPSS-IBM, New York, NY) 13.0 software, SigmaPlot 10.0 (Systat Software, Chicago, Ill) and PAST (Paleontological Statistics v2.15). Significant differences in phytoplankton biomass and environmental parameters, during the different water level periods were tested using a Kruskal–Wallis test. Different regression equations were derived to predict the values of the dependent variables (phytoplankton biomass) by the independent variable (water level). The best regression equations were defined as those having the highest r^2 and those that were significant ($p < 0.05$) for all parameters as well as for the total modal. When necessary, data were $\log(x + 1)$ transformed and standardized to improve normality and homoscedasticity.

Phytoplankton community structure, on both temporal (different water level periods) and spatial (different sampling sites) levels, was compared using analysis of non-metric multidimensional scaling (NMDS) on a Bray–Curtis similarity matrix obtained from $\log(x + 1)$ transformed and standardized biomass data.

Please cite this article as: Liu, X., et al., Effects of water level fluctuations on phytoplankton in a Changjiang River floodplain lake (Poyang Lake): Implications for dam ope..., J. Great Lakes Res. (2015), http://dx.doi.org/10.1016/j.jglr.2015.06.008