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SPECIAL ISSUE ON LAKE POYANG

Drivers and Changes of the Poyang Lake Wetland Ecosystem

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Abstract

This paper serves as both a review of the latest science on the Poyang Lake wetland ecosystem and as an introduction to this Special Issue guest-edited by Jun Xu. Poyang Lake is the largest freshwater lake in China and one of the largest freshwater lake/wetland complexes in Asia. Poyang Lake's associated floodplain wetlands play a critical role for regional and global biodiversity conservation, particularly wintering migratory birds. Since the Three Gorges Dam became operative in 2003, the magnitude and frequency of extreme seasonal water-level fluctuations in Poyang Lake have increased significantly. We review the existing literature and contributions to this Special Issue on the Poyang Lake wetland ecosystem and their biota in relation to impacts from the Three Gorges Dam. Resulting impacts on, and adaptations of, Poyang Lake biota to the hydrological changes caused by operation of the dam are poorly understood. Adaptive management of this lake and its associated wetlands needs to be further assessed through comprehensive, long-term monitoring covering a wide range of parameters related to the system's hydrological characteristics, water quality, geomorphology, aquatic biota, wetland vegetation, and associated wetland fauna.

Keywords Three Gorges Dam · Hydrology · Migratory birds · Waterfowl · Wetland vegetation · Ecosystem services

Introduction

Poyang Lake is the largest freshwater lake in China and part one of the largest freshwater wetland complexes in Asia. It is in the mid reach of the Yangtze River about 500-km downstream of the Three Gorges Dam (TGD), the world's largest hydropower project (Fig. 1a). During the flood season lasting from April to August, water from the lake covers over 4000 km^2 (Shankman et al. 2006), but shrinks to less than 1000 km^2 during the dry season lasting from September to December (Wang et al. 2011; Fig. 1b, c). Poyang Lake's floodplain wetlands are characterized by complex topographical features that create 102 seasonal waterbodies of varying hydrological connectivity, with a total area of approximately 800 km^2 (Hu et al. 2015). These small, seasonal waterbodies are fully or partly connected to the main lake during flood seasons but become decoupled during dry seasons (Hu et al. 2015; Xia et al. 2016). Variations within floodplain topography act to retain water during periods of flood recession, and wetlands close to the main lake serve to extend the period of inundation, thereby acting as important habitats for wetland fauna. Due to their small water-surface area, and dynamic wetting and drying, these lake-adjacent wetlands are sensitive and respond rapidly to variations in the surrounding environment (Li et al. 2019). The extreme seasonal water-level regime of these wetlands is largely controlled by the hydrology of the Yangtze River and its five major tributaries (Gan River, Fu River, Xin River, Rao River, Xiu River) as influenced by the TGD, and by runoff from uplands

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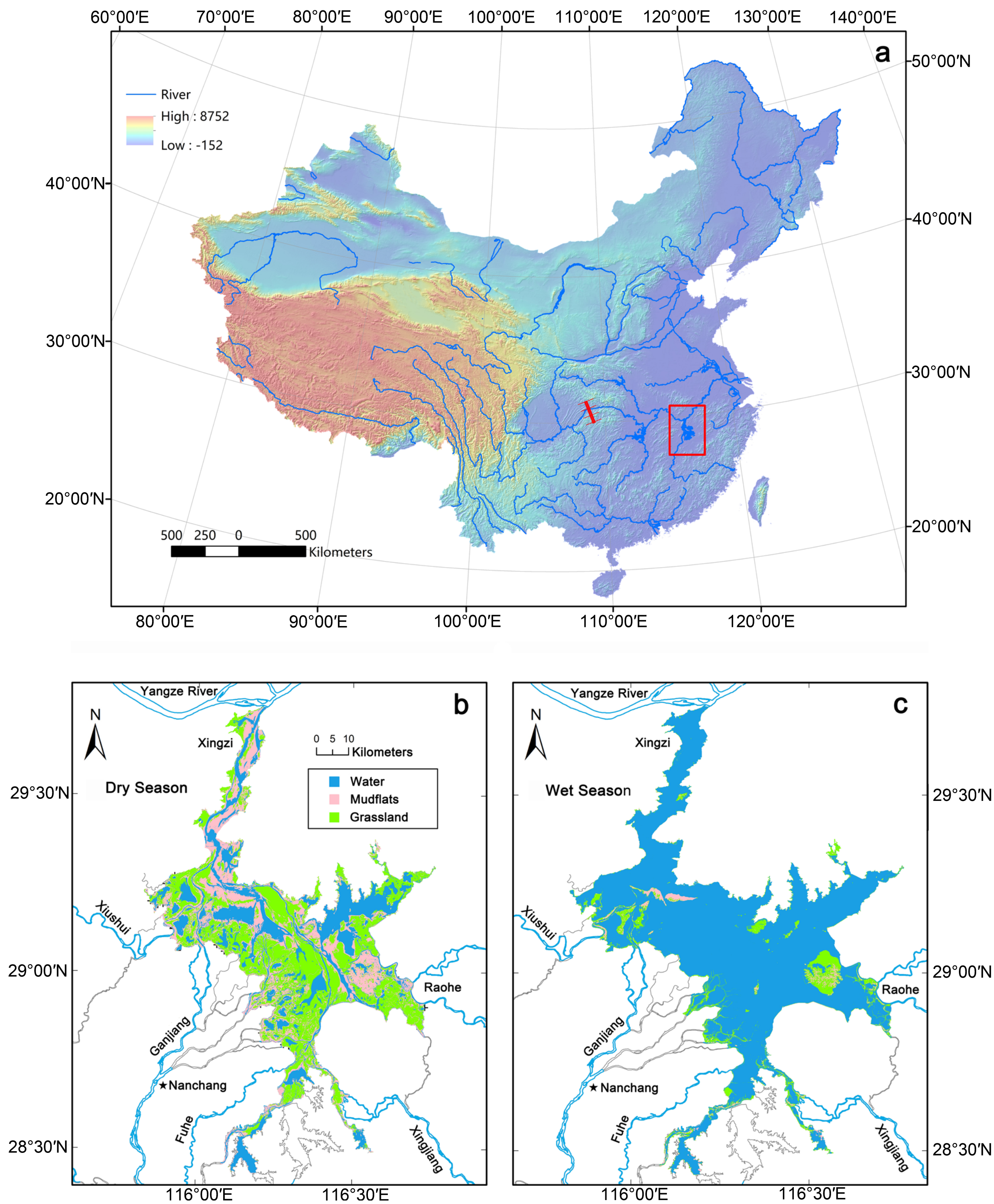

Fig. 1 Location of Poyang Lake, China (**a**), and the Poyang Lake wetland landscape during dry (**b**) and wet (**c**) seasons

within the Poyang Lake basin as influenced by the subtropical monsoonal climate. Hydrology influences habitat quality and heterogeneity, the quantity and distribution of sediment and nutrient flows, as well as the timing and growth of flora and faunal in Poyang Lake adjacent wetlands that are critical for regional and global biodiversity conservation, especially for migratory birds of the East-Asian, Australasian Flyway.

The TGD has substantially altered the downstream flow regime of the Yangtze River as a result of an increase in the drawdown period from March to April and a decrease in the impoundment period from mid-September to November (Guo et al. 2012; Lai et al. 2014a). The altered flow regime has contributed to an earlier onset and extension of the dry season in Poyang Lake. In addition, the frequency and magnitude of drought has also increased since the TGD became operational

(Lu et al. 2018). These hydrological changes have prompted proposals for construction of flow-regulation structures in the Poyang Lake, which may further fragment the floodplain-wetland ecosystems if developed.

Due to these rapid and drastic changes in Poyang Lake's hydrology, and the high population density and human activities associated with the lake, several issues have been identified as potential threats to its ecological integrity, including hydrological modification and climatic extremes, increased pollution and nutrient loading, and altered inundation and sediment regimes (Fig. 2). We review each in the following sections.

In this special issue, research topics such as the response of wetland vegetation communities to hydrological changes, long-term and short-term response of waterbirds to wintering habitat changes, effects of anthropogenic disturbances on soil microbial community, food-web changes of fish community, and environmental assessment of heavy metals and toxic organic pollutants are addressed. Based on comprehensive studies of the changes to the Poyang Lake wetland ecosystem, we also provided suggestions on effective restoration and management.

Why is the Wetland Ecosystem of Poyang Lake Changing?

Hydrologic Change

Changes in the Yangtze River discharge caused by the TGD have altered the relationship between the river and Poyang Lake, disturbing hydrological processes throughout the lake basin. A major consequence of changing river discharge has been a weakening in the Yangtze River forcing on the lake, allowing increased lake outflow into Yangtze River from July to March. Three Gorges Dam operation has reduced the dry season of the Yangtze River flow with a subsequent decrease of the Poyang Lake water level from late summer to autumn (Zhang et al. 2012c). This effect of the TGD fulfills the TGD's mission to mitigate flood risks in the lake basin, especially during the peak wet season of the Yangtze River basin from July to September. In the six years following the initial operation of the TGD, the annual average number of severe outflow events from Poyang Lake between July and September increased by 74% (Guo et al. 2012). As a result, the magnitude of seasonal water-level fluctuation has changed considerably since 2003. Water levels now both rise and retreat earlier in the season, with an overall effect of lowered water levels (Dai et al. 2015) (Fig. 3).

The runoff within the basin and Yangtze River discharges are both significant contributors to the flood dynamics of Poyang Lake and its associated wetlands. Rainfall-generated runoff played a primary role in influencing the water level of Poyang Lake and the development of severe floods, enhanced by the blockage effect exerted by the Yangtze River at the lake outlet. The relative contribution of these two effects is nonetheless unevenly distributed in time and space as was shown by simulation results from a hydrodynamic model (Li et al. 2016a, b, c, d). Local-catchment runoff had greater influence from April to May in the middle parts of the lake, and its influence decreased toward the northern and southern ends. However, from July to August, the most extreme lake-level changes were observed at the northern part of the lake basin and decreased towards the south (Li et al. 2016d). The Yangtze River's blocking effect also diminishes when the Poyang Lake water level is high from receiving large amounts of within-basin runoff (Hu et al. 2007).

Climate Change

Over the past 50 years, the climate of the Poyang Lake basin has been subject to a significant warming trend and higher variability of precipitation as reflected by increasing precipitation extremes (Zhang et al. 2016a). The Poyang Lake basin suffers from severe periodical floods because of irregular precipitation, with the El Niño-Southern Oscillation (ENSO) being a major determinant of precipitation patterns in the region (Shankman et al. 2006; Shao et al. 2016). The connection between ENSO and precipitation extremes in the Poyang Lake basin is evident with a lag of more than three months (Zhang et al. 2016a). The basin effect became stronger from 1960 to 2003, in agreement with the increase in the warm season rainfall across the Poyang Lake basin.

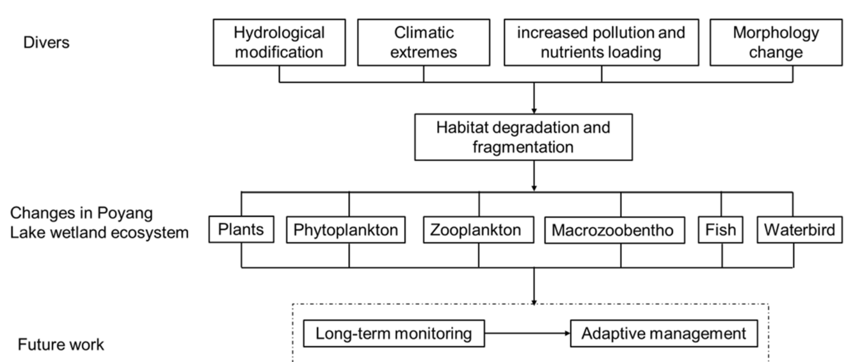

Fig. 2 Concept flowchart for adaptive manage Poyang Lake wetland ecosystem

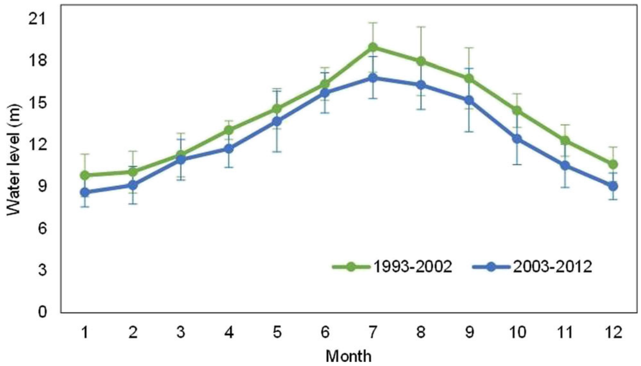

Fig. 3 Monthly mean water-level fluctuations in Poyang Lake before (green line) and after (blue line) operation of the Three Gorges Dam

In the past decade, the lake droughts have worsened in terms of duration, frequency, intensity and severity, especially in 2006 and 2011 (Gao et al. 2014). Drought exacerbation in Lake Poyang has resulted from a combination of decreased inflow to the lake, mainly from reduced catchment precipitation and increased evapotranspiration, and increased outflow from the lake (Liu and Wu 2016). Although the TGD impoundment has intensified the droughts and changed the frequency of classified droughts in Poyang Lake (Gao et al. 2014), its relative contribution is still lower than that from hydroclimatic factors (Liu and Wu 2016). For example, a 12-year multisource satellite study found that a severe drought affecting the lake in 2011 was primarily caused by significantly low precipitation across the catchment rather than the direct effect of the TGD (Feng et al. 2012).

Geomorphological Change

The construction of the TGD has changed the sediment budget of Poyang Lake by trapping a considerable amount of sediment in the reservoir formed behind the dam. This change in sediment loads below the dam is causing significant geomorphology changes, including extensive bank erosion and channel-bed degradation (Li et al. 2016c); Poyang Lake has changed from a depositional system to an erosional system by construction of the TGD. Gross sediment loss of 120.19 Mt. $yr.^{-1}$ occurred in Poyang Lake from 2001 to 2010 (Gao et al. 2014). In addition, sediment losses were exacerbated by sand mining that resulted in a wider and deeper outflow channel for Poyang Lake. The conveyance capacity of Poyang Lake into the Yangtze River at low water levels has increased by 1.5 to 2 times the values before the initiation of the sand-mining activities (Lai et al. 2014b).

Water Quality Change

The combined effect of large water-level fluctuations and point source pollution from sewage effluents are principal drivers for physicochemical variables in the wetland ecosystems of Poyang Lake. (Liu et al. 2016b). A recent study showed that periods of high water are mainly characterized by enhanced chlorophyll-*a* concentrations, while periods of low water coincide with the non-growing season and are associated with peak concentrations of nitrogen, highest turbidity, and lowest water temperatures (Li et al. 2016a). All pollutant parameters were significantly higher in the river-dominated phase (water level < 14 m) than in the lake-dominated phase (water level > 14 m) (Li et al. 2016a). Water levels correlated positively with concentrations of NO_3-N and PO_4-P but negatively with turbidity, total nitrogen, total phosphorus, NO_2-N, and NH_4-N concentrations (Liu et al. 2016b). The water quality of sites in the northern Poyang Lake-Yangtze River waterway was influenced by different environmental parameters compared to sites in the central lake, especially for Chl-*a* concentrations. The status of the lake water near the inflow rivers was better than that of the central lake (Zhang et al. 2016b). Dilution was the controlling factor driving the seasonal variability in the water quality of the lake (Li et al. 2016a).

Total phosphorus concentrations largely increased with hydraulic residence time, especially during extreme drought years, with a generally rising trend in trophic status (Wu et al. 2016). The lower water levels caused by the changes in hydrological conditions was one of the major factors affecting bioavailable organic phosphorus dynamics. Long exposure of sediments resulted in high organic phosphorus content and increased availability. Sediment exposure time and area have considerably expanded since 2003. As a result, the amounts of organic phosphorus and orthophosphate in the sediments have increased by up to 120 tons in the lake every year. Although the increase in orthophosphate only accounted for 6% of the total phosphorus entering into the system, the region may exhibit a higher risk for organic phosphorus release from the sediments. Therefore, maintaining reasonable hydrological conditions is important to protect Poyang Lake water quality (Ni et al. 2015). As the lake water level falls, the ammonia nitrogen output from the lake to the Yangtze River increases and the total ammonia nitrogen amount within the lake region decreases. The average ammonia nitrogen concentration within the lake region tends to increase slightly and the TGD impounding influence magnitude on the concentration is reduced from north to south (Li et al. 2016a).

Mineral mining activities in the Poyang Lake basin have produced large amounts of heavy-metal containing wastewater and residues that discharge into Poyang Lake (Shao et al. 2019, this issue). Metal levels in the sediments from Poyang Lake averaged 30-mg Cu kg^{-1}, 68-mg Pb kg^{-1}, and 76-mg Zn kg^{-1}. These values are significantly higher than the background concentrations of 4.75-mg Cu kg^{-1}, 17.6-mg Pb kg^{-1}, and 45.8-mg Zn kg^{-1} (Zhang et al. 2012a). Metal concentrations in the wetland soils ranged between 6.83-mg to 342.54-mg Cu kg^{-1} and 34.39-mg to 195.36-mg Zn kg^{-1} (Wang et al. 2019a, b, c, this issue). The eastern areas of

Poyang Lake influenced by inflow from the Raohe, Xinjiang, and Fuhe rivers, had higher concentrations of metals. These three rivers are sources of substantial industrial wastewater inputs to the lake. In addition, higher toxicity was found in sediments at the eastern area of the lake; relative abundances of Pb and Cr were higher than other metals (Niu et al. 2019, this issue) and persistent organic pollutants were detected accumulated in the eggshells and feathers of Little Egret (*Egretta garzetta*) (Zhao et al. 2019, this issue).

Habitat Degradation and Fragmentation

Globally, habitat degradation and fragmentation have been the leading cause of biodiversity changes in many freshwater ecosystems. Good habitat conditions with high habitat availability and heterogeneity support higher biodiversity (Guan et al. 2016; Xia et al. 2017b). In Poyang Lake, the reduction of Yangtze River flow resulting from the operation of the TGD has caused a marked loss of the lakes ability to function as wildlife habitat for biota such as fish (Wang et al. 2011) and migratory birds (Wang et al. 2013; Jia et al. 2016). Combined with the effects of overfishing, fish communities in the lake have become simplified and dominated by small-sized and young fish (Wang et al. 2014). However, as water levels continue to recede, Poyang Lake is being divided into numerous sub-lakes that still offer key habitat as bird foraging grounds in winter, which is crucial for maintaining species richness and population size (Xia et al. 2016).

How is the Poyang Lake Wetland Ecosystem Changing?

Plants

The distribution of plants in the Poyang Lake wetlands shows a well-documented pattern of zones, caused by the hydrological gradients from periodic water-level fluctuations. Three distinct zones, i.e., bulrush zone, sedge zone, sparse emergent-vegetation zone, occur along a moisture gradient from the highland to the lake shoreline. The bulrush zone is composed of tall semi-aquatic emergent vegetation (e.g. *Phragmites australis* and *Triarrhena lutarioriparia*) and occupies the relatively high elevation areas in the lake basin. The sedge zone is composed of emergent aquatic vegetation (e.g. *Carex* spp.) and occupies the relatively intermediate-elevation areas. The sparse emergent-vegetation zone, composed mostly of *Phalaris arundinacea* or *Potamogeton malaianus* is found at the lower elevations of the basin (Dai et al. 2016).

The plant species in the sedge zone were found to favor longer inundation duration and deeper inundation depth compared to species occurring in the bulrush zone. In addition, sedge-zone species could survive in a wider range of hydrological conditions than species of the bulrush zone (Zhang et al. 2012b; Tan and Jiang 2016). *Carex* spp. have evolved to respond to water-level fluctuation quickly and efficiently. From April to May, *Carex* actively grows until inundation depths become great in June or July. The plants then go dormant until September. *Carex* spp. start growing again when lake water-level retreat in October and temperatures fall with the approach of winter. The overlap between this second period of plant growth and the arrival of wintering birds makes *Carex* spp. an important food source for many herbivorous wintering bird species, especially geese (Xia et al. 2017a).

Cynodon dactylon and *Artemisia selengensis* are mainly distributed in the upland parts of the lake basin, with lower nutrient concentration and moisture content, whereas *Cardamine lyrate*, *Triarrhena lutarioriparia* and *Carex cinerascens* are mainly found near the lake shore where the moisture and nutrients accumulate, demonstrating a legible zonal distribution along the edaphic gradient (Fan et al. 2019, this issue). Anthropogenic disturbances such as burning and reclamation not only affect the vegetation distribution and composition but also affect the soil microorganism community, subsequently influencing plant growth (Jin et al. 2019, this issue; Huang et al. 2019, this issue; Zhang et al. 2019, this issue).

After the TGD was established, the wetland-plant zones in the lake basin fluctuated dynamically with the decline of water levels, with vegetation patterns experiencing a substantial shift in recent years (Li et al. 2016b; Jiang et al. 2019, this issue). Most significantly, the bulrush zone dominating the highest basin elevations expanded into lower regions of the basin that previously were too wet for their regeneration. In contrast, sedges cannot tolerate dry conditions and thus areas of sedge zone declined in the higher parts of the lake basin (Wan et al. 2019, this issue). For example, as a result of the advance in the dry season causing the bottomlands in the lake region to be exposed earlier, over 34% of wetlands at lower elevations in the Poyang Lake basin had experienced an increasing trend in the enhanced vegetation index (EVI), indicate increasing in vegetation ground cover and biomass (Tan and Jiang 2016), including the expansion of *Phalaris* to the mudflat zone (Wu et al. 2017). Whereas, the EVI in about 11% of the wetlands at higher elevations has decreased significantly (Tan and Jiang 2016). Meanwhile the number of submerged days for the bottomland and wetland have decreased, further accelerating the degradation succession of wetland vegetation (Li et al. 2016b). These changes will undoubtedly influence the migrating birds of East Asian and migratory fishes of Yangtze River.

Phytoplankton

The phytoplankton community of Poyang Lake consists of seven main groups. Chlorophyta were the most abundant group, representing 48.1% of the total number of genera, followed by Bacillariophyta, Cyanobacteria, Euglenophyta, Cryptophyta, Dinophyta, and Chrysophyta (Wu et al. 2013). Field survey and moderate-resolution imaging spectroradiometer (MODIS) data all revealed that the chlorophyll-a concentration in Poyang Lake has significant seasonality characteristics that present low values in the winter and spring, and present relatively high values in the summer and autumn (Wang et al. 2015; Cao et al. 2016). 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) (Cao et al. 2016).

Notably, bloom-forming cyanobacteria have been observed with increasing frequency in Poyang Lake since 2000. The cyanobacteria biomass in the Eastern Bay (lentic region) was significantly greater than that in Northern Poyang Lake (lotic region), and negative correlations were observed between cyanobacteria biomass and nutrient concentrations in the Eastern Bay (Liu et al. 2016a). However, no significant correlations were found between cyanobacteria biomass and nutrient concentrations in Northern Poyang Lake. The cyanobacteria biomass is high in the south and low in the north; a possible result of the greater underwater light availability and high nutrient concentrations in the southern area (Wu et al. 2013) (Fig. 4). The peak in abundance of cyanobacteria at the Northern Poyang Lake lagged behind abundance in the Eastern Bay peak by approximately one month. This suggests colonies of cyanobacteria are first generated in the Eastern Bay lentic region and then flushed offshore by large-scale horizontal transport processes, with the colonies subsequently found in Northern Poyang Lake lotic region. A high rate of water flow with short retention times was the key factor preventing the accumulation of cyanobacteria in these eutrophic lakes. Therefore, the mean cyanobacteria biomass was significantly lower in the Yangtze-connected lakes (Poyang Lake, 1.01 mg L^{-1}; Dongting Lake, 1.71 mg L^{-1}) than in Taihu Lake at Meiliang Bay (13.54 mg L^{-1}) or the mouth (3.45 mg L^{-1}). Hydrological parameters are known to dominate the accumulation of cyanobacterial blooms in the Yangtze-connected eutrophic lakes in eastern China (Liu et al. 2016a).

The total phytoplankton, diatom, cyanobacteria, and green algae responded positively to low water level and negatively to high water level. A water level of 14 to 15 m is crucial for phytoplankton biomass patterns and succession through the alternations of washing-out and dilution effects and biological competition. Thus water level control projects (e.g., dams) may affect phytoplankton biomass and assemblage structure patterns in Poyang Lake by altering its seasonal hydrology (Liu et al. 2015).

Zooplankton

A total of 150 species of zooplankton were described from Poyang Lake during field surveys conducted in 1999. The most abundant taxonomic groups were rotifers,

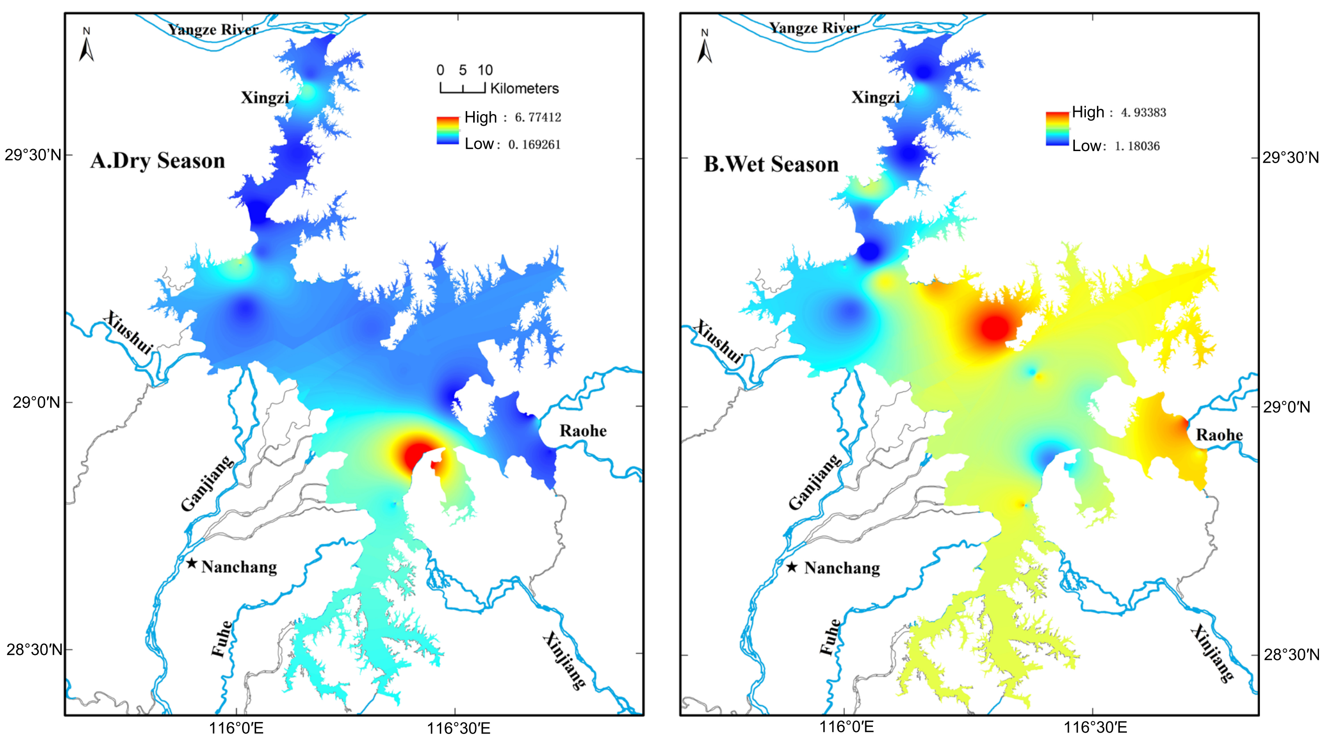

Fig. 4 Spatial distribution of chlorophyll a in the Poyang Lake basin during dry (**a**) and wet (**b**) seasons

followed by protozoans. The amount and composition of zooplankton changed seasonally. In spring the average abundance of protozoan, rotifer, cladocera and copepoda was 99.71 individuals L^{-1}, while in autumn it decreased to 47.27 individuals L^{-1} (Wang et al. 2003). In regions with high nutrient concentration and abundance of phytoplankton, zooplankton numbers tend to be also large (Wang et al. 2003). Surveys in sub-lakes at the delta of the Gan River and Xiu River in August during 2011 found a standing crop of zooplankton (expressed as abundance) over 3000 ind L^{-1}, representing over a four-fold increase than previously recorded in 1997. The number of small rotifers and protozoa increased significantly, and the community composition tended to be dominated by small species (Zhang et al. 2014). The dominant species included *Difflugia lobostoma*, which favors oligotrophic environments, and *Stentor amethystinus*, *Brachionus diversicornis*, *Brachionus caudatus*, *Trichocerca rousseleti*, *Trichocerca longiseta*, with affinity for eutrophic environments.

Macrozoobentho

A total of 42 macrozoobenthic taxa were recorded during surveys in 2012. *Corbicula fluminea*, *Limnoperna fortunei*, *Gammaridae* sp., *Nephtys polybranchia*, *Polypedilum scalaenum* and *Branchiura sowerbyi* dominated the community in terms of abundance. The bivalves *Corbicula fluminea*, *Lamprotula rochechouarti*, *Arconaia lanceolata* and *Lamprotula caveata* dominated the community in biomass due to their large body size. The mean abundance of the total macrozoobenthos varied from 48 to 920 individuals m^{-2}, and the mean biomass ranged from 28 to 428 g m^{-2} (Cai et al. 2014). The substrate type strongly affected the abundance, biomass, and diversity of the macrozoobenthos, with muddy-sand substrates showing the highest values (Cai et al. 2014). Compared with historical data, remarkable changes were observed in the abundance of macrozoobenthos and the identity of the dominant species. The mean total abundance decreased from 724 individuals m^{-2} in 1992 to 228 m^{-2} in 2012. Surveys conducted from 1997 to 1999 found 58 benthic taxa, including, 22 annelids, 8 mollusks, 26 arthropods, and 2 miscellaneous invertebrates (Wang et al. 2007). The dominant species shifted greatly between these studies. Large unionids were dominant before 1998, whereas pollution-tolerant species (e.g., *Branchiura sowerbyi*) increased in dominance after 2008 (Cai et al. 2014). Substrate stability of the bottom sediment at Poyang Lake, important for mussel habitats, has been compromised by intensive sand extraction (de Leeuw et al. 2010; Lai et al. 2014b). Similarly, decreasing water levels and amplified fluctuations can have a deleterious effect on macroinvertebrate fauna. A 1998–2002 study on the relationship between water level and *Oncomelania hupensis hupensis* densities, the snail host for *Schistosoma japonicum*, found that decreased water levels occurring between two and three months prior to fall were correlated with decreases in mean and variance of fall snail densities (Seto et al. 2008). Nevertheless, the ecological impacts of these changes remain speculative, and additional research is needed to clarify the factors regulating the macrozoobenthic community of the Lake Poyang.

Fish

A total of 130 species belonging to 25 families and 78 genera has been recorded in Poyang Lake. The most abundant were fishes of the Cyprinidae and Bagridae families, which made up 52.2% and 8.8% of the total fish community, respectively (Zhang and Li 2007). Anthropogenic influences including habitat alteration, overfishing, pollution and soil erosion have severely reduced the fish biodiversity in Poyang Lake Basin. River modifications (i.e. dam construction and sand excavation) and heavy-metal pollution are the most significant threats to fish diversity and ecosystem functioning in the majority of the rivers flowing into Poyang Lake (Huang et al. 2013). Alterations on the Yangtze River flow dynamics have not only resulted in a reduction of floodplain fish habitats but also diminished ecosystem productivity and recruitment of migratory fishes in the Poyang Lake ecosystem. The proportion of migratory fish is gradually declining and resident fish are becoming the dominant species (Wang et al. 2014). For example, the four major Chinese carps, silver carp (*Hypophthalmichthys molitrix*), bighead carp (*H. nobilis*), grass carp (*Ctenopharyngodon idella*), and black carp (*Mylopharyngodon piceus*), are among the fishes in Poyang Lake being most negatively affected by the operation of TGD. There was a sharp decrease of total catch of the four major Chinese carps in Poyang Lake right after the operation of TGD in 2003, from an average of 3297 tons per year from 2000 to 2002 to an average of 1205 tons per year from 2004 to 2006 (Huang and Gong 2007).

Stable isotope carbon and nitrogen analyses revealed that trophic links within the aquatic communities of Poyang Lake are modified by water-level fluctuations (Wang et al. 2011, 2012; Zhang et al. 2013). The most important food sources for common lake fauna were seston in the dry season and aquatic macrophytes and terrestrial plants in the wet season. The fish community was more omnivorous in the wet season than in the dry season. Aquatic food-web dynamics of Poyang Lake are strongly influenced by changes in the abundance and accessibility of different basal food sources that occur because of seasonal flood pulses. Fish collected at northern and southern part of Poyang Lake also showed different trophic niche width and niche overlap due to spatial variation in food resource abundance (Wang et al. 2019a, b, c, this issue).

Birds

Poyang Lake provides important habitat for an internationally significant assemblage of birds in winter. Wintering birds mainly arrive at Poyang in October and depart for their breeding sites in March. A total of 159 waterbird species have been recorded at Poyang Lake: half of which are wintering migrants. For example, Siberian Crane (*Leucogeranus leucogeranus*), Hooded Crane (*Grus monacha*), White-naped Crane (*G. vipio*), and Common Crane (*G. grus*) are found wintering at the lake annually. Sandhill Crane (*G. canadensis*) and Demoiselle Crane (*Anthropoides virgo*) occur occasionally as vagrant birds (Jia et al. 2019, this issue).

The abundance of these migratory populations is substantial, with over 400,000 migratory birds using the Poyang wetlands as their wintering ground annually. This includes more than 95% of the global population of Siberian Crane, 20% of the global population of White napped Crane, 3% of the global population of Hooded Crane, 2% of the global population of Common Crane, and almost 60% of the global population of Oriental Storks (*Ciconia boyciana*). In addition to the cranes and storks, seventeen other threatened species use the Poyang wetlands (Wang et al. 2013). Recent survey data from 1997 to 2013 also revealed an increase in the population size (Wang et al. 2017, 2019a, b, c, this issue).

Waterbird species richness in Poyang Lake is closely related to habitat quality and quantity (Guan et al. 2016; Xia et al. 2017a). The hydrological droughts arguably caused by the TGD greatly impacted the distribution and development of wet meadows and shallow-water areas. A study on the Siberian crane in the lake showed that this bird could shift diet when facing deterioration of habitat quality, but spent significantly less time foraging and more time alerting in meadows than in shallow waters (Jia et al. 2013). More studies are needed to assess the consequences of such diet and habitat shifts on bird survival resulting from habitat degradation.

Conclusions

Large water-level fluctuations are the principal drivers of physicochemical variables in this floodplain lake ecosystem. The effect of hydrologic-cycle change (caused by human activity and global climate change) on ecosystems are attracting increasing attention around the world. Frequent and intensive human activities have caused enormous ecological and environmental pressures on Poyang Lake and its associated wetland ecosystems.

After the TGD impoundment altered inundation and sediment regimes, wetland vegetation distribution and development patterns in the Poyang Lake basin experienced a substantial shift, i.e. reed communities began to expand into shallow regions of the lake basin, whereas sedges, which cannot tolerate dry conditions, subsequently declined. The mismatch between the sedges and the arrival of birds affected wintering quality for migrating birds. Cyanobacteria blooms have been observed with increasing frequency in Poyang Lake since 2000 especially at its lentic basin. A high rate of water flow with short retention time was the key factor preventing the accumulation of cyanobacteria in Poyang Lake. The proportion of migratory fish has gradually declining in the fishery catch after TGD operation. Although the total number of wintering waterbirds increased in Poyang Lake wetlands in the past 15 years, duck abundance has declined because of the disappearance of aquatic plants.

The Poyang Lake wetland ecosystem is characterized by hydrological complexity and human-induced modifications and the local government has proposed several restoration projects, including fishing restrictions and a sluice to manage water level at the outlet of Poyang Lake. However, each component in this dynamic wetland system has its own unique ecological requirement. For example, maintaining natural hydrological regimes during September to November is needed to conserve quality and quantity of food resources for wintering waterbirds. For fishes, winter water level is important to provide enough size and quality of habitat, and for submerged aquatic plants, both water level and light intensity are the key factors determine their growth and development. Management must therefore simultaneously meet multiple resource management objectives. However, the data needed to make informed decisions is largely absent. Therefore, management of this complex ecosystem needs to be complimented with long-term monitoring of the lake ecosystem, monitoring that covers a wide range of parameters related to hydrology, water quality, geomorphology, aquatic biota, wetland vegetation and other characteristics of the lake and its associated wetland ecosystems.

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