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Impacts of flood-driven water level fluctuations on macroinvertebrate assemblages in different zones of a long and narrow subtropical reservoir-bay

Min Zhang [a, b, c], Qinghua Cai [c, *], Xiaodong Qu [a, b]

[a] State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China
[b] Department of Water Environment, China Institute of Water Resources and Hydropower Research, Beijing 100038, China
[c] State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Science, Wuhan 430072, China

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ABSTRACT

Macroinvertebrate communities of reservoirs are known to be affected by water level fluctuations (WLF), however, studies on the effects of WLF within the profundal zones of reservoirs are rarely reported. We examined the impacts of WLF caused by floods in the Three Gorges Reservoir (TGR) on the macroinvertebrate assemblages within different regions along the longitudinal axis of the Xiangxi Bay – a tributary of the TGR. Before the floods, macroinvertebrate density, biomass and diversity all displayed a spatial pattern of increase from the edges to center of the bay, similar to that of sediment organic matter (OM). After the floods and associated WLF, macroinvertebrate density declined substantially. In the downstream region, the flood-driven WLF did not cause obvious changes to the macroinvertebrate community. In the middle region, Chironomidae abundance increased with WLF, but total macroinvertebrate density declined due to a decline in the abundance of Tubificidae. In the upstream region, taxonomic richness increased after the floods, which may have been due to flood-driven inputs of macroinvertebrates arriving from further upstream. Pearson correlation analysis indicated that OM was positively associated with macroinvertebrate density. However, OM content in the middle and the upstream regions increased after the floods while macroinvertebrate density declined. This suggested the effect of the sedimentation and water disturbance exceeded that of OM. Although average Shannon-Wiener diversity of the Xiangxi Bay increased after the floods, beta diversity declined, implying that the dramatic flood-driven WLF caused negative effects on the stability of the Xiangxi Bay ecosystem.

1. Introduction

In lakes and reservoirs, environmental changes caused by water level fluctuations (WLF) affect ecological processes and patterns in several ways, for example leading to loss of aquatic habitat and food web collapse (Wantzen et al., 2008; Obolewski et al., 2016). However, natural WLF are necessary for the survival of many species and the maintenance of biodiversity (Wantzen et al., 2002; Churchwell et al., 2016). As such, it is the dramatic WLF caused by extreme floods or droughts that are likely to be deleterious ecologically (Sparks et al., 1998; Bond et al., 2008).

WLF are very important for structuring aquatic macroinvertebrate communities. The responses of macroinvertebrates to WLF depend on a series of interrelated variables including the extent, duration and frequency of the WLFs (Valdovinos et al., 2007). Extreme WLF may influence macroinvertebrate composition (Brauns et al., 2008; Szczerkowska-Majchrzak et al., 2014), and decrease macroinvertebrate diversity (Aroviita and Hämäläinen, 2008). However, most studies have focused on lake ecosystems. Reservoirs, especially long and narrow reservoirs (e.g., Three Gorges Reservoir, China), usually differentiate from natural lakes in morphological features (Straskraba and Tundisi, 1999). Zonations that exist along the longitudinal gradient of reservoirs are likely associated with different responses of the biota to WLF.

WLF within reservoirs depend on reservoir operation, which is directly related to the quantity of inflow discharge and downstream

* Corresponding author.
E-mail address: qhcai@ihb.ac.cn (Q. Cai).

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water demand. Floods, for example cause sudden, dramatic changes in reservoirs, most obviously in water inflow, but also nutrients and sediment input (Godlewska et al., 2003; Bei et al., 2011). High inflow discharge from upstream also causes dramatic WLF in reservoirs, leading to sediment re-suspension (Dusini et al., 2009). All of these factors directly affect the habitat of macroinvertebrates, and thus macroinvertebrate community structure. Moreover, the high intensity of the flood-driven disturbance may decrease reservoir biodiversity (Limberger and Wickham, 2011). Biodiversity is considered to be an important factor in maintaining ecosystem functioning (Fischer et al., 2006; Evans, 2016), and plays important roles in the resilience of ecosystems to disturbance (Folke et al., 2004; Oliver et al., 2015). Usually, ecosystems with higher diversity have greater ecosystem stability in the face of disturbance (Interlandi and Kilham, 2001; Cardinale et al., 2002).

Most recent studies investigating the effects of WLF on macroinvertebrates were performed in the shallow regions or the littoral zones of reservoirs (McEwen and Butler, 2010; White et al., 2011), possibly because the macroinvertebrates in the shallow regions may be more readily affected by WLF. For example, by comparing 20 natural lakes and 28 regulated reservoirs, White et al. (2011) indicated that only in regions with annual WLF more than 2 m were macroinvertebrates inhabiting littoral zones affected significantly. In the profundal zones, however, little was known about the response of the macroinvertebrates. In some large reservoirs, the inter-annual WLF can be up to more than 10 m or even several tens of meters, e.g., Danjiangkou Reservoir and Three Gorges Reservoir of China. Whether such dramatic WLF causes significant effects on the profundal macroinvertebrates is unknown.

Therefore, we conducted surveys of macroinvertebrates in the Xiangxi Bay, a tributary of Three Gorges Reservoir, China, before and after floods (in 2010), aiming to illuminate: (1) whether the dramatic WLF caused by the floods had significant effects on the macroinvertebrate assemblages within the bay, (2) the different responses of the macroinvertebrates to flood-driven WLF in different regions along the longitudinal axis of the bay, and (3) what kind of impact might be caused by WLF on the macroinvertebrate diversity and ecosystem stability of the Xiangxi Bay.

2. Materials and methods

2.1. Study area

Three Gorges Reservoir (TGR), the largest man-made reservoir in China, is located in the subtropical monsoon climate region (Fig. 1). Precipitation is very high in summer, causing frequent floods. The main purpose of the TGR is flood-control. Therefore, before each flood season begins, the reservoir's water volume must be reduced to prevent flooding. The flood-control water level of the TGR is 145 m, and the normal water level is 175 m. Water level increases during the flood season due to increased inflow volumes. However, the flood-control water level must be maintained in this period, which leads to dramatic WLF.

Xiangxi River, located 38 km upstream of the Three Gorges Dam and is the largest tributary of TGR in Hubei Province, with a watershed area of 3099 km^2. After the impoundment of the TGR, the lower reach of the river evolved as Xiangxi Bay (Fig. 1). Xiangxi Bay is a long and narrow valley bay with steep banks, about 30 km long during the low water level period.

2.2. Field sampling and data analysis

Nine sites were established in the bay (Fig. 1): XX00, XX01, XX02, XX03, X005, X007, XX08, XX09 and XX10. The deepest region (XX00) of the bay is located at the confluence of the Xiangxi Bay and the mainstream of the TGR, with a depth of 70 m during the low water level period. The water depth gradually decreases from the mouth to the end of the bay. At the most upstream site (XX10), the depth is about 5 m in the low water level period.

The first survey was carried out before the increase of the water level in 17 July 2010 as the reference sample. Then the water level increased dramatically due to the high inflow discharge (Fig. 2). Based on the fluctuations of the water level of the TGR, subsequent surveys were carried out on 13 August, 27 August and 19 September 2010.

Sediment and macroinvertebrates were sampled with a modified Petersen grab (size = 1/16 m^2) (Shao et al., 2010; Zhang et al., 2010). To collect the macroinvertebrates, sediment samples were passed through a 500 μm mesh sieve; materials retained by the sieve were collected. Macroinvertebrates were preserved in 10% formaldehyde. Most taxa were identified to species level. Density and biomass (in wet weight) were expressed as individuals/m^2 (ind/m^2) and g/m^2 respectively. All the sampling methods used in this study are based on protocols for standard observation and measurement of the Chinese Ecosystem Research Network (CERN) (Cai, 2007).

Sediment for chemical analysis was stored at 4 °C before measurement. Organic matter (OM) was extracted using potassium dichromate ($K_2Cr_2O_2$) and concentrated H_2SO_4, and then quantified using the manual titrations method ($FeSO_4$). Total nitrogen (TN) and total phosphorus (TP) concentrations within sediment were quantified by first extracting the nutrients with concentrated H_2SO_4, and then measuring concentrations with a segmented flow analyzer (FIAstar-5000).

The water level data of the TGR was provided by China Three Gorges Project Company.

Diversity of the macroinvertebrate community was measured with the Shannon-Wiener diversity index and species richness. The beta diversity of the Xiangxi Bay macroinvertebrate community was measured by the Bray-Crutis distance (PC-ORD software) between the nine sites of the bay.

Pearson correlation analysis was performed to analyze the relationships between sediment OM, TN, TP and the biotic parameters (macroinvertebrate density, biomass, Shannon-Wiener diversity, taxonomic richness) (software SPSS 16.0).

3. Results

3.1. Water level fluctuations

The flood in July 2010 was the most serious to occur in the TGR after the construction of the Three Gorges Dam. From 19 July, the average daily inflow discharge exceeded 60 000 m^3/s and reached a peak on 20 July of up to 67 200 m^3/s (Fig. 2). Due to the dramatic increase in inflow discharge, the water level of the TGR likewise increased dramatically. The amplitude was up to 12 m within 5 days. From 22 August, the water level again increased, with the amplitude up to 12 m in 6 days. In the later stage of the study period, the water level increased again due to high inflow discharge. In September, the impoundment operation of the reservoir was started, and the water level of the TGR remained very high.

3.2. Sediment chemistry

Sediment OM, TN and TP concentrations all displayed a pattern of “high in the middle and low in the two ends” before the floods (Fig. 3). After the floods, the OM content in the middle and upstream region increased substantially and TN concentration of the whole bay displayed an increasing trend. However, TP showed

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