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Contrasting patterns of macroinvertebrates inshore vs. offshore in a plateau eutrophic lake: Implications for lake management

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ABSTRACT

Worldwide there has been deterioration of lakeshore habitat and increasing eutrophication. These stresses have impacted littoral macroinvertebrate communities. However, bioassessment and rehabilitation have been largely carried out offshore, and the inshore macroinvertebrates have received less attention especially in shallow plateau lakes. In this study, we compared inshore and offshore macroinvertebrate communities in a shallow plateau lake, Lake Dianchi, China. The environmental parameters determining the distribution of macroinvertebrates were analyzed with partial redundancy analysis. Our results showed that macroinvertebrate communities differed significantly between inshore and offshore. Taxonomic richness was much higher inshore than offshore, due to higher habitat heterogeneity. By contrast, both density and biomass inshore were significantly lower than those of offshore. Generally, vegetation and substrate type were the key environmental parameters shaping macroinvertebrate communities. Eutrophication exerted great effect on offshore communities, while its impacts on inshore communities varied spatially. Shoreline degradation and seasonal eutrophication effects resulted in the limited density and biomass of inshore communities. Our results emphasized the significance of inshore habitats for macroinvertebrates in Lake Dianchi, and provided important implications for bioassessment and ecological rehabilitation in shallow lakes.

1. Introduction

The Lakeshore is the transitional zone between a lake and its surrounding land (Ostendorp et al., 2004; Schmieder, 2004; Wetzel, 2001). It includes both the riparian zone where reciprocal influences between land and water occur and the littoral zone where macrophytes cease (Ostendorp et al., 2004). In shallow lakes, the lakeshore can extend to where a shelf break occurs in the lake profile (Wang, 2012). This zone is an important ecotone where substantial exchanges of organisms, matters, and energy occur. Compared to offshore zones, the lakeshore can support a much higher level of biodiversity and many key ecological processes and ecosystem functions such as production provision, pollutant retention and soil stabilization (Benson and Magnuson, 1992; Wetzel, 2001). Therefore, conservation and rehabilitation of lakeshores are of great importance in maintaining the ecosystem health of lakes.

The lakeshore is particularly vulnerable to natural disturbances and anthropogenic activities. The degradation of lakeshores has been well documented (Elias and Meyer, 2003; Ostendorp et al., 1995). Several major threats have been identified including bank erosion, geomorphological modification, hydrological alteration, eutrophication and organic pollution (Bachelet, 2000; Wang, 2012). In most cases, these threats occur either simultaneously or successively, exerting strong detrimental effects on local biodiversity and ecosystem health (Brauns et al., 2007b). Therefore, conservation and rehabilitation of lakeshores has become an urgent issue in whole-lake system rehabilitation worldwide. However, while many previous studies have been carried out in offshore zones, inshore areas have been largely neglected. In 2002, the lakeshore was first considered as an essential part of the whole lake ecosystem assessment in the European Water Framework Directive (WFD) (Ostendorp, 2004). In most developing countries, assessments of lakeshore zones have not received much attention. For example, nearly all monitoring and assessment sites in Chinese lakes are set offshore in deeper waters (Li et al., 2011; Wang et al., 2003; Xing et al., 2005; Zhang et al., 2012). Moreover, existing rehabilitation measures are mainly developed for the purposes of shoreline stabilization and pollutant retention, and are much less concerned about rehabilitation of biodiversity and other key ecological processes (Wang, 2012).

Macroinvertebrates are good ecological indicators and commonly included in bioassessments of lakes and rivers (Rafia and Ashok, 2014;

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Wetzel, 2001). Macroinvertebrates are taxonomically diverse and include numerous functional groups (e.g. functional feeding group); furthermore, they respond differently to environmental changes, which makes them useful as indicators of sensitivity to disturbances and pollution (Brauns et al., 2007a; Brauns et al., 2007b; Rafia and Ashok, 2014). Inshore habitats have been shown to have particularly high diversity. Studies by Scheuerell and Schindler (2004) and Vadeboncoeur et al. (2011) have suggested that over 60% of lake macroinvertebrate species are supported by or even restricted to inshore habitats. Moreover, degraded water quality (such as eutrophication) has shaped many lake macroinvertebrate communities (Heip, 1995; Langdon et al., 2006). Whereas shoreline modification has led to the declining of inshore diversity and abundance (Jennings et al., 2003; McGoff et al., 2013; Pätzig et al., 2012). Surprisingly, the responses of macroinvertebrates to these disturbances have not yet been well studied in lakeshore areas (Brauns et al., 2007a). These stressors often occur simultaneously, and different macroinvertebrates groups can respond differently, making understanding the relative importance of different stressors had to tease apart. Therefore, it is important to investigate how different macroinvertebrates respond to these factors and which factor is more important, considering conservation and rehabilitation of lakeshore habitats.

In the present study, we compared the distribution for macroinvertebrates between inshore and offshore in a plateau hypereutrophic lake. There were two specific purposes. First, we aimed to determine if there were differences between inshore and offshore communities. Due to the higher heterogeneity of inshore habitat, we assumed that taxonomic richness, density and biomass of macroinvertebrates would be higher inshore than offshore. Second, we aimed to test the importance of major environmental parameters in shaping macroinvertebrate community in a hypereutrophic lake. We assumed that substrate rather than water quality would be more important in structuring the benthic community.

2. Materials and methods

2.1. The study lake

The study was conducted in Lake Dianchi (24°40′ ~ 25°02′N, 102°36′ ~ 102°47′E), a hypereutrophic plateau lake on Yunnan-Guizhou Plateau in the southwest of China. It is the sixth largest freshwater lake in the country, with a total basin area of 2920 km^2, a surface area of 300 km^2 and a shoreline length of 163 km (Liu et al., 2004). The average depth is 4.4 m and the maximum depth is 10.0 m. The lake is currently a hypereutrophic lake (Hou et al., 2004). Its water quality has deteriorated since the 1980s, and its trophic state shifted to eutrophic rapidly in the succeeding decades (Li et al., 2014). Heavy cyanobacteria bloom occurs during April–October every year ever since. In the 2010s, macrophyte coverage declined to 1%, which was once around 90% in the 1960s (Yu et al., 2000; Zhao et al., 1999). Embankment and reclamation have resulted in deterioration of natural shoreline habitats. About 72% shoreline has been modified, and near 10% of the surface area has been transformed into farmland (Li et al., 2014).

2.2. Environmental parameters

Field investigations of inshore and offshore sites were carried out in March, August and November 2015 and March 2016. A total of 18 sampling sites were visited each time, including 10 from inshore and 8 from offshore (Fig. 1). The inshore sites were all set between water edge and the shelf break of the lake basin. At each site, data were collected on vegetation and substrate types, substrate characteristics and water chemistry.

Vegetation type was classified according to the dominant group of macrophytes, including “bare” (no macrophytes), “emergent” (emergent macrophytes), “floating” (floating-leaved and free-floating macrophytes), “submerged” (submerged macrophytes) and “filamentous” (attached filamentous algae). Substrate was classified into four groups, i.e. “silt”, “sand”, “boulder” and “leaf litter”. The “leaf litter” included substrate covered with large woody debris. Water chemistry parameters measured included pH, temperature (Temp), oxidation-reduction potential (ORP), dissolved oxygen (DO), salinity (Sal) of bottom water (0.5 m above substrate). These were measured *in situ* with a portable water quality sensor (Aquaread AP-2000). Bottom water was sampled with a 5L water sampler, stored in polyethylene bottles within a 4 °C ice-chilled box and sent directly back to the laboratory for analyses of total nitrogen (TN), total phosphorus (TP) and total organic carbon (TOC). A subsample was filtered through Whatman GF/C filter (1.2 μm) for analyses of NH_4-N, NO_3-N, PO_4-P and dissolved organic carbon (DOC).

Substrate samples at offshore sites were collected using a $1/16\ m^2$ Peterson grab. At each inshore site, three random samples of the top 5 cm sediment were collected with a shovel. Substrate temperature and pH were measured in the field with a pH meter (Spectrum IQ150). Samples were stored in polyethylene bottles, kept in a 4 °C ice-chilled box and brought back to the laboratory to analyze total nitrogen (TN), NH_4-N, NO_3-N, total phosphorus (TP), total organic carbon (TOC) and dissolved organic carbon (DOC). All chemical analyses were conducted according to national standards in “Monitoring and analysis methods for water and wastewater (Fourth Edition)” (Wei, 2002).

2.3. Macroinvertebrate sampling

Macroinvertebrates were sampled quantitatively from the inshore and offshore area. In inshore area, samples were taken with a D-shaped kick-net (diameter 30 cm, mash size 0.5 mm) considering the habitat heterogeneity, i.e. various types of substrate and vegetation defined above. At each inshore site, we sampled a 10 m distance along the shoreline. This attempted to cover all major habitats if possible. The sampling area of each inshore site was calculated by multiplying sampling distance with the kick-net diameter. In offshore area, a modified Peterson grab ($1/16\ m^2$) was used. A single sample was taken from each site on each occasion. Samples were sieved through a 0.42 mm sieve, and animals were picked out and preserved in 10% formalin. Specimens were identified to genus level if possible following the identification guides of Epler (2001), Liu et al. (1993) and Morse et al. (1984). The dry mass of each specimen was converted from wet mass using the dry-wet ratios from previous studies (Liang and Yan, 1999; Yan, 1998; Zhao, 2010). For molluscs, the shell-free dry mass was used. All taxa were classified into major taxonomic groups as oligochaetes, leeches, gammarids, molluscs and insects. Chironomids dominated the insects and were treated as a separate group in environmental analyses.

2.4. Statistical analysis

Wilcoxon rank-sum tests were performed on the coefficients of variation of environmental parameters to detect the differences between inshore and offshore. Spatial and temporal variations in macroinvertebrates were detected by two-way ANOVA. The significance threshold was set at 0.05. Normality of variables was examined by Shapiro-Wilk test, and homogeneity of variances by Bartlett’s Test. To improve normality and homogeneity of variances, environmental parameters were log or square-root transformed before analyses. As some taxa density (ind./m^2) and biomass (mg/m^2) were zeros, all density and biomass data were transformed to $\log_{10}(1 + x)$.

Partial redundancy analysis was performed to determine the key environmental parameters influencing macroinvertebrate distribution and community composition. Since macroinvertebrate communities showed obvious seasonal variations in this region (Wang, 2011), we treated season as a covariate. Data were analyzed both at taxa and group levels, and three types of models were constructed, i.e.