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Benthic macroinvertebrate community structure in Lake Taihu, China: Effects of trophic status, wind-induced disturbance and habitat complexity

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ABSTRACT

Lake Taihu, the third largest lake in China, is subjected to severe eutrophication and cyanobacterial blooms as a result of development and urbanization. However, little is known about the macroinvertebrate assemblages and their relationship with eutrophication and other environmental factors in this lake. To characterize the community structure of macroinvertebrates and to examine the benthos-environmental relationships in Lake Taihu, a quarterly investigation was conducted from February 2007 to November 2008. A total of 42 taxa was recorded; *Limnodrilus hoffmeisteri*, *Rhyacodrilus sinicus*, *Corbicula fluminea*, *Bellamya aeruginosa*, *Tanypus chinensis* and *Gammarus* sp. dominated the community in abundance and biomass. Cluster analysis and one-way analysis of similarity (ANOSIM) identified three groups of stations that had significantly different macroinvertebrate communities. Stations in the north bays and three river mouths had the lowest diversity and were dominated by pollution-tolerant species such as *L. hoffmeisteri* and *R. sinicus* while Gonghu Bay, the Central Region and the Western Region contained intermediately diverse communities mainly dominated by *C. fluminea*. Diversity and evenness were highest in the East Bays where aquatic macrophytes were abundant; the zoobenthos were characterized by gastropods. One-way ANOVAs revealed that environmental characteristics differed significantly among the three groups of stations. Canonical correspondence analyses showed that community structure and spatial patterns of macroinvertebrates in Lake Taihu were strongly correlated to three ecological factors—trophic status, wind-induced disturbance and habitat complexity. Our results could provide valuable information that could be used by managers and policy makers to evaluate and modify restoration practices.

Introduction

Zoobenthos play important roles in shallow lakes, altering the geochemical condition of sediments (Vaughn and Hakenkamp, 2001), promoting nutrient cycling and facilitating the transfer of energy among food webs (Covich et al., 1999). Zoobenthos are also commonly used as indicators of aquatic ecosystem health because of their wide range of sensitivity to pollution and relative longevity (Beck and Hatch, 2009; Donohue et al., 2009; Richman and Somers, 2010). Although benthic macroinvertebrate communities in small shallow lakes have been well characterized, little is known about benthic assemblages and the environmental factors regulating their dynamics in large shallow lakes (Lozano et al., 2001; Nalepa et al., 1998, 2003; Scheifhacken et al., 2007; Tolonen et al., 2001).

Large shallow lakes differ from small lakes in many ways. One of the most important features of large shallow lakes is intensive wind-induced disturbance resulting in high concentrations of suspended solids (Scheffer, 1998). Numerous studies have demonstrated that high concentrations of suspended solids significantly affect community structure and diversity of freshwater biota (see review of Bilotta and Brazier, 2008 and references therein). Many of these studies, however, focused on phytoplankton, periphyton, macrophytes and fish, with relatively few studies examining the effects on benthic invertebrates in shallow lakes. Large shallow lakes often show great heterogeneity in water quality (e.g., trophic status, pollution) and habitat (e.g., macrophyte- and phytoplankton-dominated lake habitats, different substrate types) (Noges et al., 2008; Scheffer, 1998); such heterogeneity provides opportunities for investigating how these factors influence the composition of benthic communities in such lakes. Furthermore, large shallow lakes tend to be located in lowlands where the catchment has been extensively modified by humans for agricultural, industrial and residential uses, and nutrient inputs usually are very high (Bachmann et al., 2000). Many large lakes are socio-economically important with multiple uses (e.g., drinking water supply, flood attenuation, shipping, aquaculture and recreation) and, as a consequence, experience

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concomitant environmental degradation (Jin, 2003; Smith et al., 2006). Therefore, understanding how biological communities are influenced by environmental variables is important to restore and maintain key ecological services.

In the present study, we investigated the benthic macroinvertebrate communities in a large shallow eutrophic lake. Lake Taihu, the third largest freshwater lake in China, is located in the southern Changjiang (Yangtze) River Delta, one of the most densely-populated regions in China. The lake is important for aquaculture, tourism and recreation, transportation, and is also a drinking water source for several cities including Shanghai, Suzhou, Wuxi and Huzhou. In recent decades, the lake has undergone serious water quality deterioration with increasing development and urbanization (Qin et al., 2007). In the past two decades, cyanobacterial blooms (*Microcystis* spp.) have extended their coverage and duration (Duan et al., 2009; Ma et al., 2011), leading to a water supply crisis in summer 2007 (Qin et al., 2010). Aquatic biota in Lake Taihu have been well documented with spatial heterogeneity in aquatic communities related to trophic status, wind-induced disturbance and habitat features (Chen et al., 2003, 2008; Jiang et al., 2010; Liu et al., 2011; Qin, 2008; Tang et al., 2009; Wu et al., 2007). However, detailed information about macroinvertebrate assemblages was not available due to incomplete investigation and lower taxonomic resolution. Although Cai et al. (2011) surveyed the macroinvertebrate community structure at 18 stations belonging to three different habitats, the spatial patterns of macroinvertebrate assemblages and possible regulating factors have not been thoroughly evaluated due to their limited macroinvertebrate data and environmental data. Here, we investigated the spatial heterogeneity of macroinvertebrate assemblages in Lake Taihu building on Cai et al. (2011). The objectives of this study were to characterize the community structure and spatial patterns of benthic macroinvertebrates in Lake Taihu and to identify environmental factors (both anthropogenic and natural) that could cause significant differences in the composition and distribution of macroinvertebrates.

Methods

Study area

Lake Taihu (30° 55′ 40″–31° 32′ 58″ N and 119° 52′ 32″–120° 36′ 10″ E) is in a subtropical region strongly influenced by monsoons, with an average annual precipitation of 1182 mm (733–1644 mm) and an average annual air temperature of 16.0 °C(15.1–17.5 °C) from 1954 to 2006 (Huang and Xu, 2009). The monsoon climate is characterized by prevailing southeasterly winds in summer and northwesterly winds in winter (Qin, 2008). Lake Taihu has an area of 2338 km^2 with a catchment area of about 36500 km^2. Its maximum length is 68.5 km and the maximum width is 56 km (Fig. 1). The mean depth is about 1.9 m and the mean residence time is about 309 days (Qin, 2008). There are strong environmental gradients and habitat patterns in Lake Taihu. For example, nutrient and chlorophyll *a* levels increase across the lake from the southeast to northwest where some of the major polluted tributaries enter the lake (Qin, 2008). The north bays (Meiliang Bay and Zhushan Bay) are subject to severe seasonal algal blooms and total phosphorus concentrations in the water column are also elevated in this region (Liu et al., 2011). Sediments also show high spatial heterogeneity. The north bays are covered with soft organic sediment approximately 20 cm deep. Much of the open area (Central region and Western region) and Gonghu Bay is underlain by a thin layer of more inorganic mud–sand sediment (James et al., 2009). Wind-induced disturbance of sediment is very intensive in the open area due to its long wind fetch and high dynamic ratio [sqrt(surface area)/mean depth = 25, ratios above 0.8 indicate high susceptibility] (Håkanson, 1982). Aquatic macrophytes (mainly *Potamogeton* spp., *Vallisneria natanus*, *Nymphoides peltatum*, *Hydrilla verticillata*, and *Trapa incise*) are found mainly in the protected waters of the East Bays (Qin, 2008).

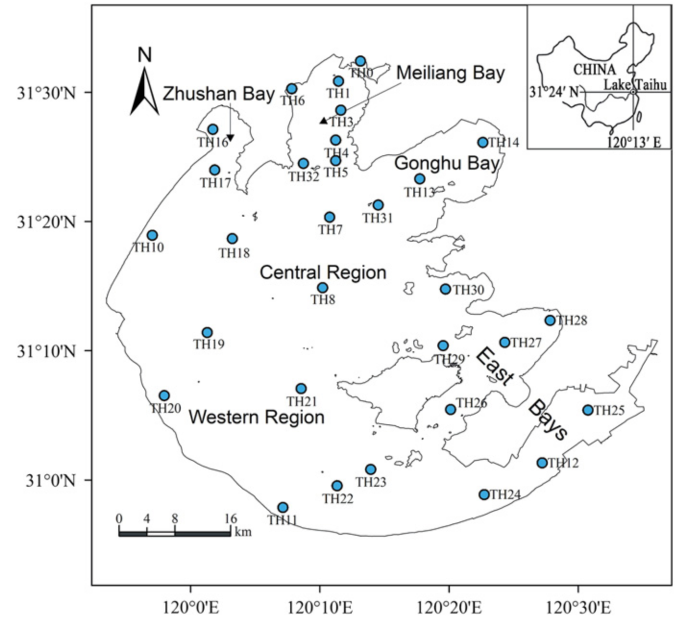

Fig. 1. Locations of the benthic macroinvertebrate sampling sites in Lake Taihu.

Macroinvertebrate sampling

Benthic samples were collected quarterly at 30 stations (Fig. 1) from February 2007 to November 2008. These stations are regular monitoring stations of the Taihu Laboratory for Lake Ecosystem Research (TLLER) within the Chinese Ecosystem Research Network (CERN). Stations TH0, TH6 and TH10 were located near three main inflowing rivers in order to assess the influence of nutrient inputs from catchments. Samples were collected with a 0.025 m^2 modified Peterson grab; two grabs comprised a sample and were sieved in situ through 250 μm aperture mesh size sieve. The materials retained on 250 μm sieve were maintained in a low temperature incubator and transported to laboratory the same day. In the laboratory, the samples were then sorted in a white tray and the specimens preserved in 7% buffered formalin solution. Specimens were identified to the lowest level possible, blotted dry and weighed with an electronic balance (Sartorius BS-124, precision: 0.1 mg). Mollusca were weighed with their shells. The identification and classification of macroinvertebrates were based on Liu et al. (1979), Morse et al. (1994) and Wang (2002). Species were divided into five functional feeding groups (gatherers, filterers, scrapers, shredders, and predators) according to food source and feeding mechanism (Liu et al., 1979; Morse et al., 1994; Liu, 2006).

Measured environmental parameters

Water depth, pH and Secchi depth were measured in the field. At each site, a depth-integrated water sample was taken using a 2 m long and 10 cm diameter plastic tube. Physicochemical variables such as electrical conductivity (EC), dissolved oxygen (DO), total nitrogen (TN), total dissolved nitrogen (TDN), ammonium (NH_4-N), nitrite (NO_2-N), nitrate (NO_3-N), total phosphorus (TP), total dissolved phosphorus (TDP), orthophosphate (PO_4-P), total suspended solids (TSS), chemical oxygen demand (COD_{Mn}), biochemical oxygen demand (BOD_5) and chlorophyll *a* (Chl *a*) were measured in the laboratory based on standard methods (Jin and Tu, 1990). All of these quarterly data were available for the calendar years 2007 and 2008 from TLLER.

In May 2007 and May 2008, an additional Peterson grab sediment sample was collected at each station to determine total nitrogen (TNs) and total phosphorus (TPs) in surficial sediments (ca. the upper 5 cm). Sediments were dried and then ground with a mortar and pestle.