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Spatial variations of macrozoobenthos and sediment nutrients in Lake Yangcheng: Emphasis on effect of pen culture of Chinese mitten crab

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ABSTRACT

We determined the effect of Chinese mitten crab (CMC) pen culture on the quantified spatial distribution of the macrozoobenthic community and sediment nutrients in Lake Yangcheng. Redundancy analysis indicated that water temperature, macrophyte occurrence, sediment type, and crab culture were the main environmental factors that influence the spatiotemporal macrozoobenthic distribution. Macrozoobenthic assemblages in the lake were characterized by eutrophic indicator species. In the most polluted estuaries, the abundance and diversity indices of the whole community and abundance of chironomids and oligochaetes were significantly depressed, and sediment carbon (C) and phosphorus (P) were significantly enhanced compared with those in the western, middle (MB), and eastern basin (EB). Crab culture in this lake had significant effects on the species composition of the macrozoobenthic community in one of three CMC culture pens (CP), and generally depressed the abundance of most chironomid and oligochaete species. Significantly increased diversity, evenness, sediment carbon and nitrogen content, and sediment C:P ratio in the CP were found compared with those in the three basins. However, no conspicuous difference in sediment P content between the CP and the two basins of MB and EB was detected. Our results showed that the enhanced diversity and evenness of macrozoobenthos might be associated with the joint effect of macrophyte planting and crab predation, and macrophyte planting may modify the effects of CMC culture by leading to disproportional accumulation of C and N in the sediment relative to P in the CP of the lake.

Introduction

Given its strong influence in the lake trophic status and biodiversity, bottom sediment plays a significant role in the overall nutrient dynamics of shallow lakes as both a nutrient sink and a nutrient source (Søndergaard et al., 2003; Zhang et al., 2013). Knowledge of the nutrient abundance of sediments in lake bottoms is a critically significant indicator for dissolved nutrient availability in the water column and in understanding the equilibrium of an ecosystem with its external nutrient load (Trolle et al., 2009). The horizontal distribution of sediment carbon (C), nitrogen (N), and phosphorus (P) in lakes reflects long-term spatial differences in organic production in the water column, and sediment focusing and deposition of the influent-borne load (Viner, 1989). Furthermore, it is associated with the distance of sampling stations to estuaries, pollution sources, and macrophyte distribution (Rooney et al., 2003; Squires and Lesack, 2003; Xu et al., 2003a; Ławniczak, 2011).

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Benthic macroinvertebrates that inhabit the sediment are important components of lake benthic systems, and their composition and dynamics play an important role in the biodiversity, energy flow, and material cycling of the lake ecosystems. They exhibit heterogeneous spatial patterns that coincide with the heterogeneity of both biotic and abiotic factors. The spatial distribution of zoobenthos and the relationship between them and environmental variables have been extensively investigated. The structure and spatial patterns of communities are affected by many environmental factors, such as habitat characteristics, nutrient concentration, sediment quality, and biological factors (*e.g.*, aquatic plants) (Lods-Crozet et al., 2001; Żbikowski and Kobak, 2007; Wu and Legg, 2011).

Aquaculture is an important anthropic activity with potential detrimental environmental effects. Numerous reports have been published in the last decades on the effects of aquaculture practices on the water column (Sarà, 2007), sediments (Yucel-Gier et al., 2007; Jelbart et al., 2011) and the biota, including zoobenthos (Guo and Li, 2003; Pavlova, 2008; Wang et al., 2009; Primavera et al., 2010; Jelbart et al., 2011). Most of the reports relative to zoobenthos and bottom sediments dealt with the effects of fish, bivalves, and shrimp culture. By contrast, few studies have investigated the effects of crab culture (*e.g.*, Xu et al., 2003b; Primavera et al., 2010; Cai et al., 2012; Zeng et al., 2013). Moreover, researchers have focused more on the effects of aquaculture on sediment C and/or N concentration and less on the sediment P content. Although aquaculture practices generally enhance sediment C, N, and/or P content (Karakassis et al., 2000; Nickell et al., 2003; Das et al., 2004; Huang et al., 2008) and depress the abundance and diversity of zoobenthic communities (Brown et al., 1987; Xu et al., 2003b; Yu and Jiang, 2005; Klaoudatos et al., 2006; Pavlova, 2008), the effects of aquatic cultures on the structure of zoobenthic communities are contingent on the stocked species and culturing model *etc.* (Karakassis et al., 2000).

Lake Yangcheng is a medium-sized shallow lake and an important drinking water source for Suzhou District, Jiangsu Province, China. The lake is famous for producing high-quality cultured Chinese mitten crab (*Eriocheir sinensis*, CMC), a well-known food in China. However, as an invasive species, it is considered a perpetual nuisance in Europe, North America, and Western Asia. CMC is cultured in pens in Lake Yangcheng. In 2008, the lake produced approximately 1500 tons of CMC, with an economic output exceeding 100 million Yuan. Crabs cultured in lakes and kept in tanks depress the abundance, biomass and diversity, and change the species composition of zoobenthos (Xu et al., 2003b; Yu and Jiang, 2005; Czerniejewski et al., 2010), similar to other aquatic commercial animals worldwide (Brown et al., 1987; Živić et al., 2009). However, the effects of CMC pen culture on water quality, zoobenthos, and sediment nutrients might differ from those of other aquatic commercial animals because of differences in the culture model. For example, CMC pond farming caused minor negative impact on the trophic status of Lake Taihu compared with fish and shrimp pond farming (Cai et al., 2012). The highlighted difference depends on the presence of submerged macrophytes, which are often planted in culturing pens to increase CMC production and maximize farming profit. In natural bodies of water, macrophyte abundance disproportionally changes the concentration of sediment C, N, and P (Schulz and Gücker, 2005; Marinho et al., 2010). It also influences the abundance and diversity of zoobenthos by promoting habitat complexity and through other mechanisms (Gong et al., 2000; Taniguchi et al., 2003). The effects of CMC culture on the zoobenthos in lakes without macrophyte planting, and on the water quality, sediment nutrients and aquatic community in farming ponds with planting activity, have been documented (Xu et al., 2003b; Cai et al., 2012; Zeng et al., 2013). However, the effects of CMC pen culture on zoobenthos and sediment nutrients in lakes with macrophyte planting are less known. This study aims (i) to determine the spatial distributions of macrozoobenthos and sediment C, N, and P and quantify the relationship between zoobenthos and environmental factors and (ii) to determine the effects of CMC culture practices with macrophyte planting on zoobenthos and sediment nutrients.

1. Study area and methods

1.1. Study area

Lake Yangcheng is located northeast of the Taihu Lake Basin and Suzhou City, Jiangsu Province, China (31°21′–31°30′ N, 120°39′–120°50′ E). It is one of the most important freshwater lakes in the province. The lake has a total surface area of approximately 120 km^2 and an average depth of 2.1 m, stretching for about 17 km from north to south and 8 km from east to west. Two nearly parallel narrow strips of land divide the lake into three basins with limited interconnection channels, among which the eastern basin is the largest (Fig. 1). The lake catchment has a humid subtropical monsoonal climate, with an annual mean air temperature of about 15.7 °C and rainfall of 92.6 mm.

1.2. Pen culturing of Chinese mitten crab

The CMC is catadromous; pelagic larvae are released into coastal waters and metamorphose into benthic juvenile crabs that migrate into brackish and freshwaters. Its natural stocks from China have decreased dramatically since the 1960s because of intensified exploitation and habitat destruction, and capture of wild CMC from lakes has not been reported. After a breakthrough in larviculture techniques, CMC aquaculture based on reproduction in captivity has developed extensively since the early 1990s (Cheng et al., 2008). The pen culture of CMC in Yangcheng Lake was started in 1992 and reached its peak in 2001, accounting for 79.8% of the lake water area. Subsequently, the pen area began to shrink year by year for the purpose of protecting the drinking water source, and it was reduced to 30.7 km^2, accounting for 25.6% of the lake area, and confined to the middle and east basins in 2008. Each pen, made of 2–3 cm stretched mesh polythene netting tied to a bamboo framework, covers an area of about 1.3 ha with a length of 130 m and a width of 100 m. The bamboo poles (8–10 cm in diameter and 4–5 m in length) of the framework were vertically inserted 60–100 cm into the bottom of the lake at intervals of 1.5–2.0 m. Cylindrical net-wrapped stone-gabions with a diameter of approximately 15 cm tied to the net bottom margins were buried 20 cm into the mud, while the inner side of the upper net margin was lined with 40-cm-wide polythene net to prevent crab stock