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Spatial and temporal variations reveal the response of zooplankton to cyanobacteria

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ABSTRACT

The effects of cyanobacteria on zooplankton abundance, structure and diversity were investigated, based on a systematic study on spatial and temporal variations of cyanobacteria and zooplankton in Lake Taihu from 1998 to 2007. It was found that similar increasing trends of cyanobacteria/phytoplankton ratios were accompanied by different trends in biomass, composition and biodiversity of zooplankton in different regions of the lake; the cladocerans benefitted from the increase in cyanobacteria; however, rotifers and protozoans were negatively affected by cyanobacteria. The biomass-based biodiversity of phytoplankton and zooplankton was negatively affected by cyanobacteria as well, and the adverse effects were in proportion to the cyanobacteria/phytoplankton ratio. These results indicated interestingly that higher amounts of cyanobacteria do not necessarily reduce zooplankton biomass, as the biomass of larger zooplankton such as cladocerans was positively related to cyanobacteria. The findings are essential to understand the complex ecological effects of cyanobacteria blooms in lakes.

1. Introduction

Cyanobacterial blooms are globally widespread and constitute a threat to the ecological health of many eutrophic systems (Bullerjahn et al., 2016; Carmichael and Boyer, 2016; Chorus and Bartram, 1999; Davis and Gobler, 2016; Paerl and Huisman, 2009). Blooming cyanobacteria such as *Microcystis*, *Anabaena*, *Cylindrospermopsis*, *Planktothrix*, *Aphanizomenon* and *Nodularia* dominate the phytoplankton community and disturb food web processes due to their high abundance, high toxicity and poor food quality for grazers (Ger et al., 2014; Paerl and Paul, 2012). Zooplankton consume phytoplankton and play important roles in transferring carbon and energy to upper trophic levels in the food web (Dahms et al., 2012). Therefore, the interaction between phytoplankton and zooplankton, especially the relationship between cyanobacteria and zooplankton, has gathered increasing attention (Ger et al., 2014; Sun et al., 2012).

Cyanobacteria are among the most important primary producers in lake ecosystems. However, they alter the food web through their interactions with zooplankton and can have multiple adverse effects on them (Harke et al., 2016). In high abundance, they physically disturb the filtering apparatus of zooplankton (DeMott et al., 2001), they are of poor food quality for the zooplankton because they lack sterols and polyunsaturated fatty acids (Brett and Muller-Navarra, 1997; von Elert et al., 2003), and they are toxic since they produce neurotoxins or hepatotoxins (Hansson et al., 2007), with microcystins (MCs) being one of the most common cyanobacterial toxins that negatively affect the fitness of zooplankton. Detrimental effects of cyanobacteria on zooplankton have been widely reported (Bednarska et al., 2014; Burian et al., 2014; Dembowska et al., 2015; Ferrao et al., 2000; Ger and Panosso, 2014; Jiang et al., 2013; Rollwagen-Bollens et al., 2013; Urrutia-Cordero et al., 2013) with adverse effects on cladocerans, including reduced population growth, decreased reproductive output, paralysis and death; the negative effects are generally proportional to cyanobacterial abundance or the number of toxic cells in the diet, i.e. the higher the abundance/number of cells, the more adverse are the effects (da Ferrao-Filho et al., 2009; Ferrao et al., 2000). For instance, at high abundance, *Microcystis* may cause significant mortality of copepods (Ger and

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Panosso, 2014; Ger et al., 2010b) and suppress survival and reproduction of rotifers (Geng and Xie, 2008; Silva Soares et al., 2010). Besides, toxic cyanobacterial strains may result in high mortality rates for protozoans (Urrutia-Cordero et al., 2013). Some of the adverse effects of cyanobacteria have been attributed to the presence of MCs, among which are lower copepod survival (Reinikainen et al., 2002), inhibition of respiration and population growth, and thus high mortality rates of protozoans (Urrutia-Cordero et al., 2013) and a general negative effect on zooplankton biomass (Hansson et al., 2007).

Most of the current studies about cyanobacterial effects on zooplankton have been conducted in the laboratory and rarely been carried out under more complex and natural conditions, such as in long-term cyanobacteria-dominated lakes where some zooplankton, such as cladocerans and copepods, have been reported to develop tolerance against toxic cyanobacteria (Druga et al., 2016; Ger et al., 2011). Lake Taihu, located in the Yangtze River Delta of China, plays an important role in fisheries, drinking water supply, recreation and flood control (Sun et al., 2012). The lake has, however, suffered from cyanobacterial blooms for several decades (Qin et al., 2007), which seriously threaten fisheries and drinking water safety (Wilhelm et al., 2011). Lake Taihu has been well studied for its cyanobacterial blooms and cyanotoxins (Chen et al., 2003; Liu et al., 2011; Otten et al., 2012; Xu et al., 2016), but less is known about the potential effects of a high abundance of cyanobacteria on the food web, especially on the zooplankton community. Only a few studies indicated that *Microcystis* blooms could shape the bacterioplankton community (Niu et al., 2011) and crustacean zooplankton community (Sun et al., 2012) in Lake Taihu. Some long-term investigations (Chen et al., 2003; Xu et al., 2016) revealed that cyanobacterial blooms have extended from the Wuli Bay to the main region of Lake Taihu during the period 1970–2007, and there were significant spatial differences in intensity and frequency of cyanobacterial blooms in Lake Taihu (Duan et al., 2009; Xu et al., 2010; Sun et al., 2012), which offer an ideal case for evaluating the effects of cyanobacteria on zooplankton communities in natural systems.

The aims of the present research were to (1) identify the spatial and temporal variations in abundance, biomass, composition and biodiversity of phytoplankton and zooplankton in Lake Taihu, which is typically dominated by cyanobacteria; (2) explore whether the zooplankton respond to the clear spatial variation of cyanobacteria, and (3) test if a long-term relationship exists between cyanobacteria and zooplankton.

2. Materials and methods

2.1. Study area

Lake Taihu, located at the centre of the Yangtze River Delta in East China (30°56′–31°33′N, 119°55′–120°54E), is the second largest freshwater lake in China (Zhang et al., 2013). It has a total surface area of 2338 km^2, with a mean depth of 1.9 m and a maximum depth of 2.6 m. The northern half of the lake, consisting mainly of Meiliang Bay (MLB), Gonghu Bay (GHB) and West Coast (WC), has suffered from *Microcystis* blooms; while East Taihu (ETH) rarely experiences cyanobacterial blooms (Otten et al., 2012).

2.2. Sampling of phytoplankton and zooplankton

Phytoplankton and zooplankton were monitored monthly at 16 sites located in MLB (site 1–7), ETH (site 11–13) and areas near GHB (site 8–10) and WC (site 14–16) of Lake Taihu from January 1998 to November 2007 (Fig. 1), with a total of 1411 records. At each site, samples of both phytoplankton and zooplankton were collected. Water at 0.5 m depth was taken for phytoplankton and zooplankton identification, since the average water depth of Lake Taihu is less than 2 m and the water is well mixed in the vertical direction.

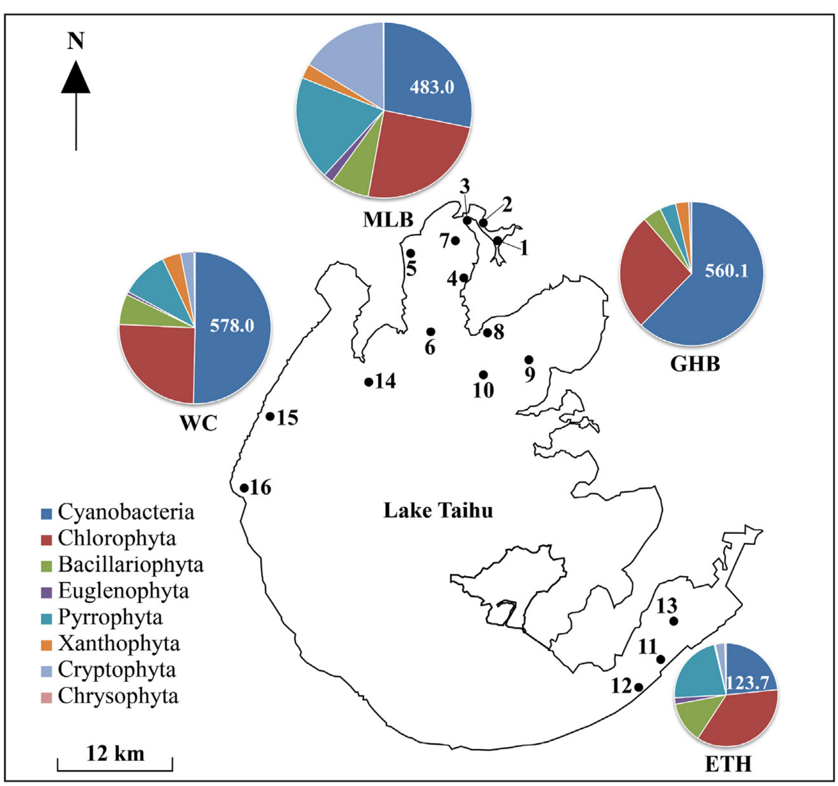

Fig. 1. Lake Taihu sampling sites of phytoplankton and zooplankton in West Coast (WC), Meiliang Bay (MLB), Gonghu Bay (GHB) and East Taihu (ETH) during 1998–2007. Each pie graph shows average phytoplankton abundance (10^4cell/L) and composition in each area during 1998–2007.