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Longitudinal variations of phytoplankton compositions in lake-to-river systems

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ABSTRACT

To test the hypothesis of longitudinal variations in phytoplankton compositions from a eutrophic lake to its river downstream and determine the length of the transition zone, we applied functional groups as well as taxonomical methods to this coupled aquatic system, which is composed of the Dianchi Lake upstream and the Tanglang River downstream, by sampling at 9 stations during *Microcystis* blooms in the Dianchi Lake in 2013. The longitudinal variations in phytoplankton compositions from lacustrine species to fluvial species were reflected by: (1) the shift from *Microcystis* to Chlorococcales green algae and centric diatoms; (2) the shift from the dominance of codon M to the coexistence of a variety of coda without one outstanding codon; and (3) except for codon M, the shift from lacustrine coda (H1, L_O, T) towards coda that are adapted to both lacustrine and fluvial circumstances (MP, X1, X2). The prominent difference of phytoplankton compositions between the Dianchi Lake and the lower reaches of the Tanglang River revealed that there was a transition zone in between. The upper and middle reaches of the Tanglang River with a length of approximately 26.4 km were considered the transition zone because: (1) the dominant lentic codon M in the Dianchi Lake disappeared at the lower reaches of the river; (2) the amount of codon P that is sensitive to stratification rose at the beginning of the river; and (3) the codon T, which is well adapted to the persistently mixed layer or epilimnia of lakes, lost a large number of biomass at the upper and middle reaches of the Tanglang River. In this study, we found that the eutrophic lake had a significant influence on the river downstream. In addition, we found that functional groups were sensitive to the changes of external aquatic conditions and helpful in determining the length of the transition zone.

1. Introduction

River eutrophication has attracted worldwide attention for decades. In the last thirty years, eutrophication has been a dominant pollution pressure on large rivers in Europe (Mischke et al., 2011). The Water Framework Directive (EC, 2000) of the European Parliament (WFD, 2000) recommends that researchers use phytoplankton data to assess river ecology. Generally, if the residence time is long enough, nutrient concentrations are high, water temperature and light intensity are satisfied, blooms may develop at the middle or lower reaches of large rivers rather than the upper reaches due to the small initial inocula at the sources of rivers (Hilton et al., 2006). The middle and lower reaches of rivers are usually dominated by centric diatoms, chlorococcalean colonial green algae (Bahnwart et al., 1998), Chrysophyta and occasionally Cyanobacteria when flow is slow (Jeppesen et al., 2005; Phillips et al., 2008). Researchers consider the accumulations of phytoplankton biomass along rivers to be a significant source of phytoplankton biomass for lakes (Mihaljević et al., 2010; Bridgeman et al., 2012; Soares et al., 2012; Kufel and Leśniczuk, 2014) or estuaries (Li et al., 2007). However, few researchers have studied the impact of a eutrophic lake on the river downstream, which is also an important and serious issue.

A large number of Cyanobacteria at the source of the river that is coming from a eutrophic lake upstream will stretch for a long distance in the river downstream (Chen et al., 2014). This eutrophic lake upstream and the outlet downstream comprise a coupled lake-to-river system. Today, Cyanobacterial blooms are a major problem in lakes (Paerl and Huisman, 2008; Bridgeman et al., 2012). During high bloom periods, the Cyanobacteria will be transferred by the flow to the river downstream, leading to visible blue-green assemblages at the beginning of the river (Chen et al., 2014), which is

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very different from other rivers without eutrophic lakes upstream as aforementioned. Because some Cyanobacteria can produce a toxin that is more harmful to aquatic organisms and humans than diatoms and other fluvial algae (Soares et al., 2012), polluted rivers would lead to a drinking water crisis for surrounding communities (Qin et al., 2010). However, draining water from eutrophic lakes to the rivers downstream is still a common method used in China to control lake eutrophication. Therefore, we should figure out the impacts of eutrophic lakes on the rivers downstream.

Traditional researches on eutrophication are based on Chlorophyll a (Chla) (Mischke et al., 2011), but Chla cannot reveal the spatial variations in phytoplankton compositions and the responses of individual species to changes in the external environment. Reynolds et al. (2002) first put forward functional groups. The original idea is to classify species into ecologically similar groups on the basis of phytoplankton's traits in lentic systems. The species belonging to the same subdivision share similar characteristics regarding the resources and energy, such as nutrients and light intensity (Reynolds et al., 2002). The functional groups have been successfully applied to many lakes and reservoirs (Becker et al., 2010; Xiao et al., 2011). Their application to lotic systems followed (Tavernini et al., 2011; Abonyi et al., 2012) after Devercelli (2006) had applied them to the Middle Paraná River and proved that they were also useful in rivers during extreme drought periods. On Reynolds' basis, Borics et al. (2007) proposed several new groups that can be applied to rivers. Additionally, Padisák et al. (2009) expanded the initial 31 groups to 40 groups by reviewing related published papers. Despite these successful cases and improved methods, they are rarely used in lake-to-river coupled systems or river-to-lake coupled systems. In view of their sensitive responses to changes of the external environment, the compositions of functional groups should show differences in lakes and rivers. In other words, we can detect the changes of external aquatic environment by examining the compositions of coda, which will be tested in this study.

In this research, we set nine sampling stations in the Dianchi Lake-to-Tanglang River system to study spatial variations in phytoplankton compositions. The objectives of this research were: (1) to judge if the phytoplankton assemblages (surface blooms) at the source of the Tanglang River came from the Dianchi Lake upstream and if the initial phytoplankton compositions would change along the Tanglang River; (2) to evaluate the influence of the eutrophic lake on the river downstream by evaluating the length of transition zone; and (3) to test the usefulness of functional groups in the eutrophic lake-to-river system. To achieve these goals, Reynolds' functional groups as well as traditional taxonomical methods, were applied to the Dianchi Lake-to-Tanglang River system.

2. Materials and methods

2.1. Study area

The study area, including the mouth of the Dianchi Lake and the entire Tanglang River (Fig. 1), lies in Yunnan Province, Southwest China (N24°45′–N25°22′ and E102°30′–E102°37′). The Tanglang River is a part of the Pudu River, and it flows 120 km north, covering approximately 3187 km^2. The surrounding communities of the river are seriously affected by industry and agriculture (Yu et al., 2013). The Dianchi Lake is one of the most polluted lakes in China. Toxic *Microcystis* blooms frequently occur in this lake. During bloom periods, the blue-green surface scum may produce abundant microcystin toxin. Additionally, the local warm and humid subtropical highland variety of the oceanic climate may lengthen the bloom period, leading to more lasting harms.

According to previous studies and field experiments during 2010–2011 (Yu et al., 2013), the Tanglang River is the most seriously polluted section of the Pudu River. One of the reasons is that the Tanglang River flows through densely populated farmlands while the downstream of the Pudu River flows through sparsely populated mountainous areas. Another more important reason is that the Tanglang River accepts water directly from the Dianchi Lake upstream. As the single greatest outflow river from the Dianchi Lake, it receives most of outflows with large amounts of *Microcystis* biomass. Despite the many studies on eutrophication in the Dianchi Lake, phytoplankton identification at the Tanglang River was performed only once, by Qian et al. (1985), in 1982, and even that was qualitative rather than quantitative.

2.2. Sampling and analysis

Sampling was done in the daytime of June 19, 2013 at nine monitoring stations during *Microcystis* blooms in the Dianchi Lake (Fig. 1). There was no rain during the samplings. The nine stations included two stations at the mouth of the Dianchi Lake, at −2.04 km (D1) and 0 km (D2, reference station), and seven others along the Tanglang River: 1.47 km (T1), 4.83 km (T2), 5.46 km (T3), 6.46 km (T4), 11.38 km (T5), 27.84 km (T6) and 114.60 km (T7). Among them, T6 was located at the converging point of a small tributary and the main stream. In addition, there was a large number of emergent plants between stations T3 and T4. The samples of surface water (0.5 m) were taken from the shore of the lake and the middle of the river. They were immediately preserved in situ with Lugol's iodine solution. The one-litre samples of each station were brought back to the laboratory in darkened bottles. After 24 h of standing in the laboratory, the supernate was siphoned and the remaining 30-mL residue was prepared for further phytoplankton identifications. All phytoplankton samples were identified and counted by using a Nikon E100 biological microscope (10×40) at species level according to Hu and Wei (2006). Water temperature was measured in situ at all stations using a YSI6600 multiparameter water quality sonde (Yellow Spring Instruments, USA). Flow velocity was detected in situ using an LS300 portable flow meter (Nanjing, China).

Phytoplankton species were classified into corresponding functional groups according to Reynolds et al. (2002) and Padisák et al. (2009). The method is to put species that share similar features together. Reynolds et al. (2002) named the subdivisions in capital letters. Padisák et al. (2009) has summarized phytoplankton species that have corresponding coda. To avoid mistakes, we classified only those species summarized by Padisák et al. (2009) into the corresponding coda. Because of the difficulty in the identification of some phytoplankton at species level, such as centric diatoms and Oscillatoriales, we classified them into corresponding coda based on their morphologies.

3. Results

3.1. Environmental variables

Flow velocities at three stations (T4, T5 and T7) were detected. The flow velocities at T4 and T5 were 0.19 m/s and 0.17 m/s, respectively. The flow velocity reached its highest value at T7 (1.90 m/s). The velocities at T1–T3 were not detected because the flow velocities were below the lower limit of the LS300 (0.10 m/s). The flow velocity at T6 was not detected in situ because the velocity was significantly disturbed by the tributary. The surface water temperature ranged between 25.5 °C and 28.0 °C at the nine stations in June 2013. The highest water temperature was at T1, while the lowest water temperature was at T5.