Ecological Engineering 99 (2017) 238–245

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Effects of filter-feeding planktivorous fish and cyanobacteria on structuring the zooplankton community in the eastern plain lakes of China

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ARTICLE INFO

Article history:
Received 17 June 2016
Received in revised form 25 October 2016
Accepted 13 November 2016
Available online 19 November 2016

Keywords:
Eutrophication
Aquaculture
Planktivorous fish
Filter-feeding
Cyanobacteria
Zooplankton

ABSTRACT

To explore the changes of the zooplankton community in response to excessive interferences of anthropogenic eutrophication and aquaculture on aquatic ecosystem, we performed a survey to determine the variations in these communities in 100 eastern plain lakes of China in summer. Our results showed that when filter-feeding planktivorous fishes were in high yield, Rotifera and medium cladocera accounted for a large proportion of the community; when they were in low yield, small cladocera increased with the increased nutrient level. The detrended correspondence analysis demonstrated that planktivorous fish and cyanobacteria were important factors influencing the zooplankton community. The linear regression analysis showed that the fraction of Rotifera increased and Calanoida decreased with the increasing fish yield; the fraction of small cladocera increased with the increasing cyanobacteria. The results implied that zooplankton community succession was strengthened by the combined effects of planktivorous fish and cyanobacteria. The effects of filter-feeding planktivorous fish on zooplankton depend on the survival ability of different zooplankton species as well as the size. With the combined effects of planktivorous fish culture and eutrophication, the zooplankton community tend to be dominated by r-strategy species and good escape ability species.

1. Introduction

Zooplankton are studied widely as indicator of ecological change due to their sensitive response to environmental variation (Hessen et al., 1995; Jeppesen et al., 2011) and their specific biological properties, such as, geographically widespread, having short reproduction cycles, and occupying a central position in aquatic food webs (Lampert, 2006). A large body of studies have documented that excessive interferences of anthropogenic eutrophication and aquaculture seriously influence aquatic ecosystem all over the world (Smith et al., 1999; Naylor et al., 2000; Jackson et al., 2001; Smith, 2003; Smith and Schindler, 2009), leading to collapse of vascular plant communities, increased proportion of inedible phytoplankton, increased fish production with alteration of fish community (Smith et al., 1999; Smith, 2003). These effects strongly influenced the zooplankton community by eutrophication of cyanobacterial blooms (Sun et al., 2012) and strong fish predation (Zhang et al., 2013).

Eutrophication is a global problem among oceans, rivers, and lakes (Smith, 2003; Smith and Schindler, 2009; Azevedo et al., 2015; Snickars et al., 2015). Cyanobacterial blooms is the key symptom of eutrophication, which is mainly caused by the increase of total nitrogen (TN) and total phosphrous (TP) nutrients (Elser et al., 2007; Conley et al., 2009; Paerl et al., 2011). Basically the cycles of the key nutrient elements of nitrogen and phosphorus have been massively altered by anthropogenic activities (Smith et al., 1999; Smith, 2003), followed by water environmental degradation with low dissolved oxygen, unpleasant smell, and algal toxins et al. (Smith et al., 1999; Codd et al., 2005), and these may negatively affect trophic structure through food web (de Figueiredo et al., 2004; Malbrouck and Kestemont, 2006). Eutrophication of cyanobacteria blooms leads to the succession of the zooplankton community to more tolerant species (Ghadouani et al., 2003; Sun et al., 2012). What is more, in many freshwater ecosystems, the

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http://dx.doi.org/10.1016/j.ecoleng.2016.11.040
0925-8574/

decrease of piscivorous fishes and the increase of planktivorous fishes reduced the strength of top-down effects on phytoplankton as the loss of effective predator of zooplankton (Andersson et al., 1978; Christoffersen et al., 1993; Vanni and Layne, 1997; Osterblom et al., 2007). Previous study experimentally showed that the zooplankton community changed much with the increasing filter-feeding planktivorous fishes. On the one hand, the gizzard shad (filter feeder) directly reduced zooplankton via predation; on the other hand, they indirectly affected zooplankton by reducing edible phytoplankton abundance to zooplankton (DeVries and Stein, 1992). However, the large scale study of the combined effects of eutrophication and filter-feeding planktivorous fish culture on the zooplankton community is few.

In this study, 100 eastern plain lakes were surveyed to explore the effects of filter-feeding planktivorous fish and cyanobacteria on the zooplankton community, covering about 16900 km^2 and accounting for nearly 20% of the total lake area in China. We investigated the zooplankton community composition of these lakes and then analyzed the changes in the structure of these communities in response to the combined effects of planktivorous fish and cyanobacteria.

2. Sampling and analyses

2.1. Study area

100 subtropical and shallow lakes (mean depth, <3 m) along the eastern plain areas of China were studied from 2008 to 2009 (Fig. 1). The longitudes and the latitudes of studied lakes range from 111.7° E to 121.7° E and 28.5° N to 38.9° N respectively. Most lakes have been interfered by human activities, like aquaculture and eutrophication. Due to the regional difference of aquaculture, these lakes can be divided into two types according to the result of K-Means Cluster with planktivorous fish yield as the parameter for clustering (type 1: low fish yield, type 2: high fish yield). The aquacultural planktivorous fishes were *Hypophthalmichthys molitrix* and *Aristichthys nobilis* in these lakes, which are filter-feeding feeders.

2.2. Sampling and analyses

For 100 lakes of the eastern plain of China, sampling sites were evenly distributed for each lake, of which the numbers set for each lake changed with the surface area from 1 to 30. All sites were sampled once during June to August of 2008–2009. In this study, to understand the relationships among the trophic status, cyanobacteria, zooplankton, and fish, all parameters of the eastern plain lakes of China were represented by the mean values of the summer. The eight lakes with incomplete data were excluded from the study, and a total of 92 lakes with summer samples were used.

Water temperature (T), pH value, dissolved oxygen (DO), conductivity (COND) were measured in 0.5 m below the water surface in situ by multi-parameter water quality meter YSI ProPlus (YellowSprings, OH, USA). Secchi depth (SD) was surveyed by a black and white Secchi disk (20 cm) to determine water transparency. Water samples from each site were collected at the upper (i.e., 0.5 m below the water surface), middle (midway between the surface and the bottom), and lower (i.e., 0.5 m above the sediment surface) parts of the water column using a 5-L Schindler sampler respectively and then mixed together for subsequent analyses. Hydrochemical parameters and biotic samples were disposed and measured for each sample in the laboratory according to the methods described in detail by Yang et al. (2005).

Total nitrogen (TN) and total phosphorus (TP) were measured for each sample in the laboratory according to the methods described in detail by Huang et al. (1999). 1L water sample was preserved in acetic Lugol's solution and concentrated to 50 mL after sedimentation for 48 h for analysis of phytoplankton and rotifers (Huang et al., 1999). Phytoplankton were counted and measured under 400× magnification using an Olympus BX41 microscope (Olympus, Tokyo, Japan). For *Microcystis* colonies, an ultrasonic crusher (JY88-II, Scientiz, Ningbo, Zhejiang, China) was used to separate and count the single cells. Taxonomic identification of phytoplankton was performed according to Hu (2006). Rotifers were counted and measured under 200× magnification using an Olympus CX 21 microscope (Olympus, Tokyo, Japan) and identified according to Voigt and Koste (1978). For crustacean zooplankton, 10 L water samples were sieved through 64 μm plankton nets and preserved with 5% formalin for further analysis (Huang et al., 1999). In the crustacean zooplankton samples, all individuals were counted and, if possible, the body of at least 30 individuals of each species were measured under 40× magnification by using an Olympus CX 21 microscope (Olympus, Tokyo, Japan). Crustacean zooplankton were identified according to Shen et al. (1979) and Chiang and Du (1979). The biomass of each plankton species was calculated using methods described by Huang et al. (1999). Fish yield data were obtained from the fishery management committee of each lake. To isolate the effects of planktivorous fishes on the zooplankton community, we used fish yield of planktivorous fishes for analysis.

2.3. Statistical analyses

First, K-Means Cluster was conducted to separate the different trophic status in two types of lake respectively with TN, TP and SD as the trophic status parameters for clustering. Each type can be divided into high nutrient level and low nutrient level. Thus there are four gradients of the eastern plain lakes of China as follows: low fish yield with low nutrient (1L, the number of lakes (n) = 36), low fish yield with high nutrient (1H, n = 31), high fish yield with low nutrient (2L, n = 7), and high fish yield with high nutrient (2H, n = 18). Second, differences in the nutrient level and biotic parameters among gradients of the eastern plain lakes of China were tested with one-way analysis of variance (ANOVA). Least significance difference test (LSD) was used for variables with constant variances and Games-Howell (A) was used for variables with unequal variances. The analysis was carried out with IBM SPSS Statistics v. 19 for Windows software (SPSS, Inc., Chicago, IL, USA). Third, a detrended correspondence analysis (DCA) was performed using CANOCO 5.0 (Braak and Šmilauer, 2002) to assess the effects of the environmental variables on the zooplankton community (biomass) with a short gradient length. The assessed environmental variables were lake area, longitude, latitude, T, TN, TP, TN: TP ratio, DO, SD, pH, COND, total phytoplankton biomass, *Microcystis* biomass, and fish yield. The dependent variables were the biomass of Rotifera, small cladocera, medium cladocera, large cladocera, Calanoida, and Cyclopoida. After forward selection, only the significant independent variables ($p < 0.05$) were included in the final DCA ordination. Last, a linear regression analysis was employed to gain a greater understanding of the linkage between the zooplankton community composition and the most important influencing variables. The independent variables were fish yield and cyanobacteria; the dependent variables were the relative biomass of Rotifera to crustacean zooplankton (Rotifera/crustacean zp), the relative biomass of Cyclopoida to Calanoida (Cyclopoida/Calanoida) and the relative biomass of small cladocera (Ceriodaphnia, Bosminidae, Chydoridae and Macrothricidae) to others cladocera (medium cladocera, Diaphanosoma, Moina and Sida; large cladocera, Daphnia, Simocephalus and Leptodora) (small cladocera/others cladocera) respectively. The linear regression was implemented in R using the car package; a leverage plot was produced (Sall, 1990).