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Distribution of Zooplankton Population in Different Culture Ponds from South China

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ABSTRACT

To understand the population distribution characteristics of zooplankton in typical densely populated freshwater fish ponds, we intensively studied the species composition, abundance, and biodiversity of zooplankton in the *Oxyeleotris marmoratus*, *Ctenopharyngodon idellus*, *Micropterus salmoides*, and *Channa argus* culture ponds in the Pearl River Delta region in China during May to December in 2012. The number of zooplankton species in the four ponds were 66, 54, 55, and 68, respectively. The average abundance was 16466.78 ind./L, 8408.17 ind./L, 7397.77 ind./L, and 33632.53 ind./L, respectively. The average biodiversity index and species evenness were 1.360 and 0.628 in the *Oxyeleotris marmoratus* culture pond, 1.150 and 0.587 in the *Ctenopharyngodon idellus* culture pond, 1.438 and 0.755 in the *Micropterus salmoides* culture pond, and 1.234 and 0.580 in the *Channa argus* culture pond. The canonical correspondence analysis (CCA) results indicated that the most significant environmental factors that significantly affected the distribution of zooplankton species were: dissolved oxygen was for *Oxyeleotris marmoratus* culture pond, total phosphorus content for *Ctenopharyngodon idellus* culture pond, chlorophyll *a* for *Micropterus salmoides* culture pond and pH value for *Channa argus* culture pond. These study results demonstrated that different culture fish species might change the contents of environmental factors in the pond, and significant environmental factors would further impact the species composition, abundance, and biodiversity of zooplankton. The research results could provide a scientific basis for the management of pond water quality.

INTRODUCTION

Zooplankton are important biological components of aquatic ecosystems. They play important roles in the fisheries production as the bait for commercial fishes, and regulate the genesis and development of phytoplankton and microorganisms in water (Sun 2001). In addition, zooplankton are important components of the matter cycle and energy flow in the aquatic ecosystems. The composition and biodiversity of zooplankton species directly reflect the structure and function of an aquatic ecosystem (Luo 2004, Pinel-Alloul et al. 1991, Wei et al. 2013).

The biodiversity and community structure of zooplankton varied in different culture ponds due to different cultivation modes (Zhang et al. 2015). Several indicators, including species composition, abundance, and biomass of zooplankton can be used to show the productivity of the culture ponds (Gozdziejewska & Tucholski 2011). Zhang et al. (2014) studied the characters of the zooplankton community structure in *Ctenopharyngodon idellus* culture ponds, and found that the dominant species of zooplankton were *Coleps irtus*, *Askenasia faurei*, *Askenasia volvox*, *Tetrahymena pyriformis* and *Halteria grandinella*. Zhao et al. (2014) investigated the effects of *Channa argus* culturing on the community structure of zooplankton and found the dominant species *Daphnia magna* and *Brachionus calyciflorus*. So far, few studies have focused on the impact of aquaculture species on zooplankton species, and this study will explore the relationships between aquaculture species and zooplankton species.

Oxyeleotris marmoratus, *Micropterus salmoides*, *Ctenopharyngodon idellus*, and *Channa argus* are important commercial freshwater products in Pearl River Delta region of south China. In the present study, the zooplankton species composition, abundance, and biodiversity in these aquaculture ponds were analysed, so as to demonstrate the ecological and environmental conditions of the aquaculture ponds, and to provide a scientific basis for the maintenance of the quality of aquaculture pond water and the improvement of aquatic breeding.

MATERIALS AND METHODS

Sampling timing and location: The investigation was carried out by continuous sampling for 13 times from May to December in 2012. In May, June, July, September, and October, the samples were collected semi-monthly. In August, November, and December, the samples were collected monthly.

Table 1: The locations of the four aquaculture ponds.

Sampling pond	Longitude	Latitude
OM	113°05’46.6"	22°48’26.5"
CI	113°11’54.6"	22°50’20.7"
MS	113°09’32.0"	22°49’33.0"
CA	113°07’43.0"	22°52’12.1"

OM, *Oxyeleotris marmoratus*; CI, *Ctenopharyngodon idellus*; MS, *Micropterus salmoides*; CA, *Channa argus*

The samples were collected from four aquaculture ponds that were culturing *Oxyeleotris marmoratus*, *Ctenopharyngodon idellus*, *Micropterus salmoides*, and *Channa argus* in Shunde District, Foshan, Guangdong Province, PR China. The location of the four aquaculture ponds is given in Table 1.

Methods: The methods for the collection, identification, and quantification of zooplankton were carried out according to the Research Methods of Freshwater Plankton (Zhang & Huang 1995).

***Protozoans and rotifers*:** The samples for the species identification were collected by No. 25 plankton net (mesh size of 64 µm, produced by the Institute of Hydrobiology, Chinese Academy of Sciences in Wuhan, PR China) in a "∞" shape movement across the water for 3 to 5 minutes. The collected samples were then taken to the lab for species identification. The samples for quantification were collected by taking 1 L of surface water using a water sampler, and immediately fixed with formalin solution (formalin was added to a final concentration of 4%). The samples were taken to the lab and concentrated into 10-20 mL. For protozoan counting, 0.1 mL of well mixed concentrated water sample was taken and examined under microscope at 10×20 fold magnification. For rotifer counting, 0.1 mL of well mixed concentrated water sample was taken and examined under microscope at 10×10 fold magnification. Two slides were counted for each sample.

***Cladocerans and copepods*:** The samples for species identification were collected by No. 13 plankton net (mesh size of 113 µm, produced by the Institute of Hydrobiology, Chinese Academy of Sciences in Wuhan, PR China) in a "∞" shape movement across the water for 3 to 5 minutes. The samples for quantification were collected by taking 30 L of surface water using a 5 L water sampler, then filtered with No. 25 plankton net, and immediately fixed with formalin solution (formalin was added to a final concentration of 4%). The samples were then taken to the lab and concentrated into 20 mL. The numbers of cladocerans and copepods were counted under microscope at 10×10 fold magnification using 1 mL plankton counting chamber.

The water temperature, pH value, dissolved oxygen, and transparency were detected during the sampling. Additional water samples were collected to determine chlorophyll *a* content and nutrients in the lab.

Data processing: Dominance index (Y) = $f_i \bullet n_i / N$. In the formula, f_i indicates the frequency of the species *i* in each sampling site, n_i indicates the abundance of species *i*, N indicates the total abundance (Xu et al. 1995).

Shannon-Wiener diversity index (*H*) =

$$-\sum_{i=1}^{S}(n_i / N)\log_2(n_i / N)$$

In the formula, *S* indicates the number of species, n_i indicates the number of species *i*, *N* indicates the total number (Shannon & Weaver 1963).

Evenness index (*J*) = $H / \log_2 S$. In the formula, *H* indicates Shannon-Wiener diversity index, *S* indicates the number of species (Pielou 1966).

SPSS 18.0 software was used for data analysis, Origin 8.6 software was used for chart plotting, and Canoco 4.5 software was used to analyse the correlation between zooplankton community and environmental factors. $P<0.05$ was considered statistically significant.

RESULTS

Environmental factors: The mean values of the main environmental factors in the four culture ponds are shown in Table 2. In all of the four ponds, the total nitrogen, total phosphorus, ammonia nitrogen, and chlorophyll *a* were at high levels (Table 2).

Table 2: Levels of main environmental factors in the four ponds.

Sampling ponds	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Ammonia nitrogen (mg/L)	Chlorophyll *a* (µg/L)
OM	5.39±3.31	0.36±0.12	1.56±1.01	45.18±22.27
CI	5.09±1.91	0.42±0.11	1.47±0.73	271.45±69.57
MS	9.06±5.33	0.47±0.26	1.17±1.14	92.64±36.41
CA	16.34±7.62	1.57±1.42	3.39±3.58	154.77±63.46

OM, *Oxyeleotris marmoratus*; CI, *Ctenopharyngodon idellus*; MS, *Micropterus salmoides*; CA, *Channa argus*

Table 3: Richness of zooplankton species in the four ponds.

Species numbers	Sampling ponds			
	OM	CI	MS	CA
Protozoa	18	15	12	20
Rotatoria	22	29	21	29
Cladocera	14	6	11	10
Copepoda	12	4	11	9
Zooplankton	66	54	55	68

OM, *Oxyeleotris marmoratus*; CI, *Ctenopharyngodon idellus*; MS, *Micropterus salmoides*; CA, *Channa argus*

Species composition: We identified 66 and 68 zooplankton species in the *Oxyeleotris marmoratus* and *Channa argus* culture ponds. In comparison, we found fewer zooplankton species in *Ctenopharyngodon idellus* and *Micropterus salmoides* culture ponds (54 and 55 species, respectively). Microzooplankton were dominant in all the four ponds, and the number of rotifer species was the highest, followed by protozoans, cladocerans and copepods (Table 3).

Dominant species and dominance index: The dominant zooplankton species varied in different types of culture ponds ($Y > 0.02$) (Table 4). The numbers of dominant species in *Oxyeleotris marmoratus*, *Ctenopharyngodon idellus*, *Micropterus salmoides* and *Channa argus* ponds were 8, 5, 5 and 5, respectively, and all the dominant species belonged to microzooplankton including protozoans and rotifers. *Paramecium caudatum* was the most dominant species in *Oxyeleotris marmoratus* and *Channa argus* ponds.

Species abundance and distribution: The distribution of zooplankton in the four types of ponds is shown in Fig. 1. At all the sampling times, abundances of zooplankton in *Oxyeleotris marmoratus* pond ranged from 570.00 ind./L to 59339.00 ind./L, with an average value of 16466.78 ind./L. The lowest value appeared on September 11 and the highest value on May 10. The *Ctenopharyngodon idellus* pond had the lowest zooplankton abundance on September 11 (3352.33 ind./L) and the highest abundance on August 20 (22600.00 ind./L), with an average abundance of 8408.17 ind./L. The abundances of zooplankton in *Micropterus salmoides* culture pond ranged from 3209.00 ind./L to 14124.44 ind./L, with an average value of 7397.77 ind./L. The lowest value existed on September 26 and the highest value on October 10. The abundances of zooplankton in *Channa argus* culture pond ranged from 3984.00 ind./L to 59415.00 ind./L, with an average value of 33632.53 ind./L. The lowest value appeared on August 20 and the highest value on November 22.

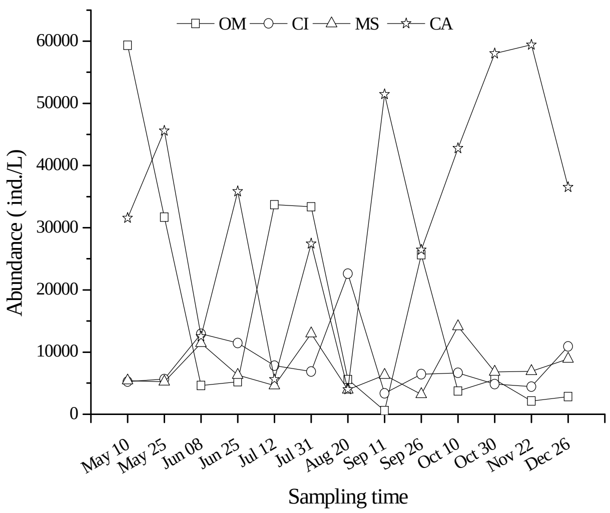

Fig.1: The distribution of zooplankton in four types of ponds.

Time distribution of zooplankton diversity: In *Oxyeleotris marmoratus* pond, the zooplankton diversity index ranged from 0.530-2.002, with an average value of 1.360; and the evenness index ranged from 0.228-0.881, with an average value of 0.628 (Fig. 2). In *Ctenopharyngodon idellus* pond, the lowest zooplankton diversity index and evenness index values were 0.727 and 0.293, respectively, both appearing on August 20, while the highest values were 1.742 and 0.905, respectively, both appearing on June 8 (Fig. 2). In *Micropterus salmoides* pond, the average zooplankton diversity index value was 1.438, with the lowest value (1.020) appearing on October 30 and the highest value (1.759) appearing on October 10 (Fig. 2). The average zooplankton evenness index for the *Micropterus salmoides* pond was 0.755, with the lowest value (0.440) appearing on October 30 and the highest value (0.925) on June 8 (Fig. 2). In the *Channa argus* pond, the lowest zooplankton diversity value was 0.813, appearing on June 8, and the highest value was 1.932, appearing on July 31 (Fig. 2). The zooplankton evenness indexes of the *Channa argus* pond ranged from 0.369-0.891, with an average value of 0.580 (Fig. 2).

Relationship between zooplankton community and environmental factors: The dominant zooplankton species in the four aquaculture ponds were listed in Table 4 based on their frequencies. The canonical correspondence analysis (CCA) was carried out using Canoco software to investigate the correlation between the abundance of dominant zooplankton and the environmental factors such as water temperature, pH value, dissolved oxygen, total nitrogen, total phosphorus, and chlorophyll *a* content (Fig. 3).

CCA analysis results showed that the first two ordination axes accounted for 78.6%, 80.3%, 65.7%, and 62.4% of the species variables in ponds culturing *Oxyeleotris marmoratus*, *Ctenopharyngodon idellus*, *Micropterus*

Table 4: Dominance of dominant zooplankton species in the four ponds.

Sampling pond	Dominant species	Dominance
OM	*Paramecium caudatum*	0.631
	Polyarthra trigla	0.089
	Brachionus angularis	0.046
	Trichocerca gracilis	0.043
	Tintinnopsis wangi	0.039
	Askenasia volvox	0.026
	Pompholyx complanata	0.021
CI	*Trichcoerca cylindrica*	0.085
	Brachionus angularis	0.030
	Polyarthra trigla	0.028
	Acanthocystis chaetophora	0.026
	Dileptus binucleatatus	0.025
MS	*Askenasia volvox*	0.060
	Polyarthra trigla	0.050
	Tintinopsis conus	0.050
	Tintinnidium fluviatile	0.041
	Paramecium caudatum	0.038
CA	*Paramecium caudatum*	0.426
	Filinia maior	0.103
	Polyarthra trigla	0.047
	Brachionus calyciflorus	0.034
	Brachionus forficula	0.025

OM, *Oxyeleotris marmoratus*; CI, *Ctenopharyngodon idellus*; MS, *Micropterus salmoides*; CA, *Channa argus*

salmoides and *Channa argus*, respectively. Thus, the first two ordination axes can be considered as the significant canonical axes. The coefficients of the correlation between environmental variables and species variables and the two significant canonical axes were shown in Table 5.

In the *Ctenopharyngodon idellus* pond, the abundance of dominant zooplankton species including *Tintinnopsis wangi*, *Askenasia volvox*, *Trichocerca gracilis*, *Pompholyx complanata* and *Polyarthra trigla* was significantly negatively correlated with the dissolved oxygen content; the abundance of dominant zooplankton species including *Tintinnopsis wangi*, *Askenasia volvox*, *Trichocerca gracilis* and *Brachionus angularis* was significantly negatively correlated with the total dissolved solid content and significantly positively correlated with the total nitrogen content; and the abundance of *Pompholyx complanata*, *Paramecium caudatum* and *Polyarthra trigla* showed significant positive correlation with the nitrite content (Table 5, Fig. 3a).

In the *Ctenopharyngodon idellus* pond, the abundance of dominant zooplankton species *Acanthocystis chaetophora* and *Trichcoerca cylindrical* showed a significant positive correlation with the total dissolved solids content, and significant negative correlation with water temperature and the nitrite nitrogen content; and the abundance of *Brachionus angularis* and *Polyarthra trigla* showed a significant positive correlation with total phosphorus content (Table 5, Fig. 3b).

In the *Micropterus salmoides* pond, the abundance of *Tintinopsis conus* was significantly positively correlated with the total dissolved solids content and chlorophyll *a*; and the abundance of *Polyarthra trigla* and *Paramecium caudatum* showed significant negative correlations with the total phosphorus content and water temperature (Table 5, Fig. 3c).

In the *Channa argus* pond, the abundance of *Polyarthra trigla* and *Filinia maior* was significantly negatively correlated with water temperature, but significantly positively correlated with pH value (Table 5, Fig. 3d).

DISCUSSION

Many studies have shown that fish predation strongly in-

Table 5: The coefficients of the correlation between environment variables, species variables, and the two significant canonical axes.

Environmental factors	OM SPAX1	OM SPAX2	CI SPAX1	CI SPAX2	MS SPAX1	MS SPAX2	CA SPAX1	CA SPAX2
Water temperature	0.233	0.339	-0.494*	0.194	-0.420*	-0.194	0.324	-0.549*
Transparency	-0.323	-0.344	0.386	-0.013	-0.007	0.267	-0.317	-0.135
pH value	-0.105	-0.015	-0.112	0.257	-0.165	-0.070	0.053	0.460*
Dissolved oxygen	-0.700*	-0.103	-0.318	0.076	0.310	-0.299	-0.032	-0.370
Total dissolved solids	0.009	-0.530*	0.543*	-0.219	0.422*	0.238	-0.253	-0.367
Total phosphorus	-0.003	-0.125	-0.080	0.566*	-0.444*	-0.070	0.326	0.362
Total nitrogen	0.481*	0.007	0.187	0.484*	0.246	0.268	-0.248	0.049
Nitrite	0.554*	-0.076	-0.453*	0.123	0.291	-0.059	-0.080	0.100
Ammonia nitrogen	0.301	0.083	-0.186	-0.228	-0.217	-0.222	-0.338	-0.221
Chlorophyll *a*	-0.178	-0.339	0.013	0.072	0.450*	0.254	0.073	-0.060

*$P \leq 0.05$

SPAX1 indicates the first ordination axis and SPAX2 represents the second ordination axis.

OM, *Oxyeleotris marmoratus*; CI, *Ctenopharyngodon idellus*; MS, *Micropterus salmoides*; CA, *Channa argus*

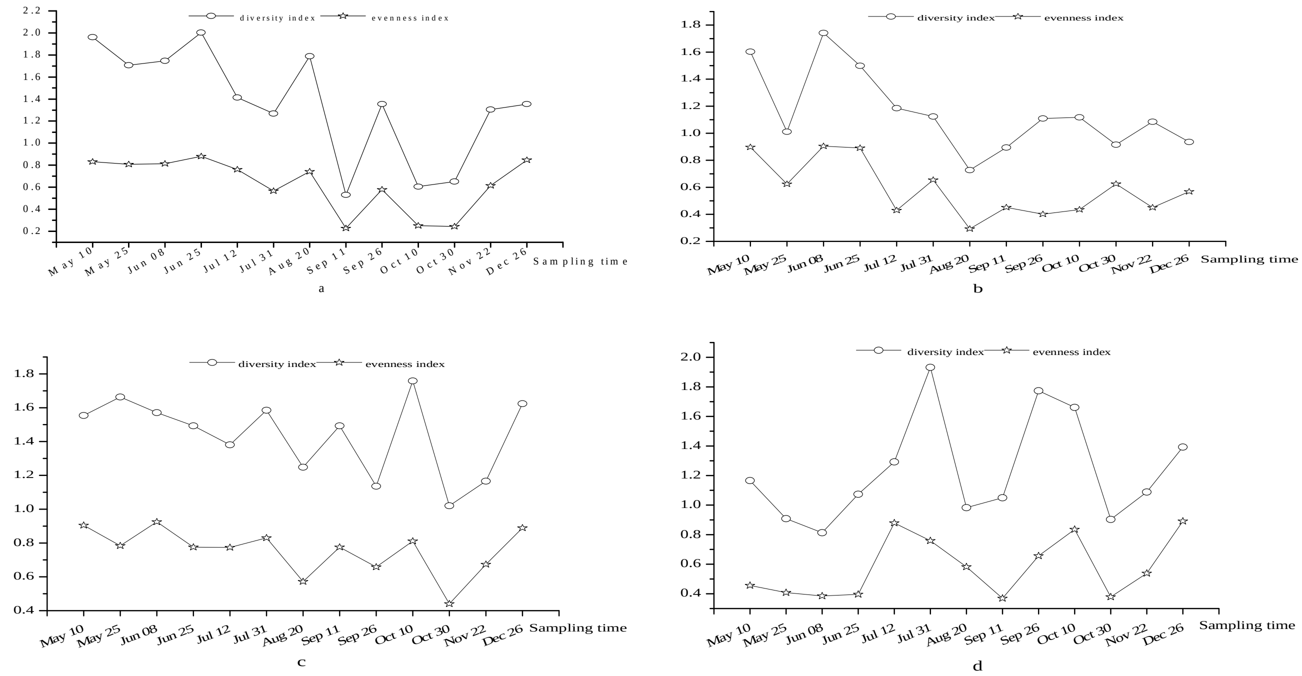

Fig.2: Time distribution of zooplankton diversity index and evenness index.

fluenced the community structure of zooplankton (Anton-Pardo & Adámek 2015). According to the studies of Zheng et al. (2009) and Wu et al. (2011), in the culture ponds of filter-feeding fishes *Aristichthys nobilis* and *Hypophthalmichthys molitrix*, macrozooplankton such as copepods were favoured by these two types of fishes, which helped the growth of protozoans and rotifers, and thus they became the major zooplankton components in these ponds. Macrozooplankton larvae were the main food for the cultured juvenile fish. When no macrozooplankton larvae was put into the ponds as supplement, and the adult fish continued to feed on macrozooplankton, the proportion of macrozooplankton in aquaculture ponds would become low.

Zhang (2014) found that the dominant species of zooplankton in the *Ctenopharyngodon idellus* ponds in May to October 2012 were protozoa and rotifer, and the number of protozoa and rotifer accounted for 92.5% of the total number of species of zooplankton. Li (2012) found that protozoans and rotifers were the major zooplankton species in partitioned pond culturing ground fish, followed by cladocera, and copepod was the least. Chen et al. (2012) reported that the mini type protozoa increased and remained superiority from April to December in 2009 in the ponds with paddlefish as the assistant cultured species. Consistent with the above findings, in the ponds we studied, as far as the number of species and abundance were concerned, the proportion of microzooplankton (protozoans and rotifers) was highest among all zooplankton species, while the proportion of cladocerans and copepods was much less.

In aquaculture ponds, artificial influences are significant. For example, sludge clearing and disinfection in the ponds before adding the fries and regular disinfection with quicklime or copper sulphate greatly affected the growth of zooplankton (Hu et al. 2007). In these processes, since the protozoans and rotifers were of small size, and fast growing with short life cycle, they would quickly become dominant zooplankton groups in the aquaculture ponds. Eutrophication will lead to the decrease of the number of intolerant species and the increase of tolerant species (Dumont 1983, Dussart et al. 1984). Our results showed that the four ponds were in a eutrophic state. In all the four ponds, tolerant species, such as *Paramecium caudatum*, *Polyarthra trigla*, *Brachionus angularis* and *Brachionus calyciflorus*, became dominant species in these ponds, which were of certain indication function for the eutrophic state of the ponds (Shen et al. 1990, Wang et al. 2006). Our results can be confirmed by the comprehensive evaluation based on Shannon-Wiener diversity index and Pielou evenness index of zooplankton. The high eutrophic state might be due to the high content of nitrogen and phosphorus from bait residues and fish faeces in the ponds.

Studies have shown that the species composition and abundance of zooplankton are closely correlated with the nutritional state of water (Chen et al. 2008, Dumont 1983). The nitrogen and phosphorus contents are important fac-

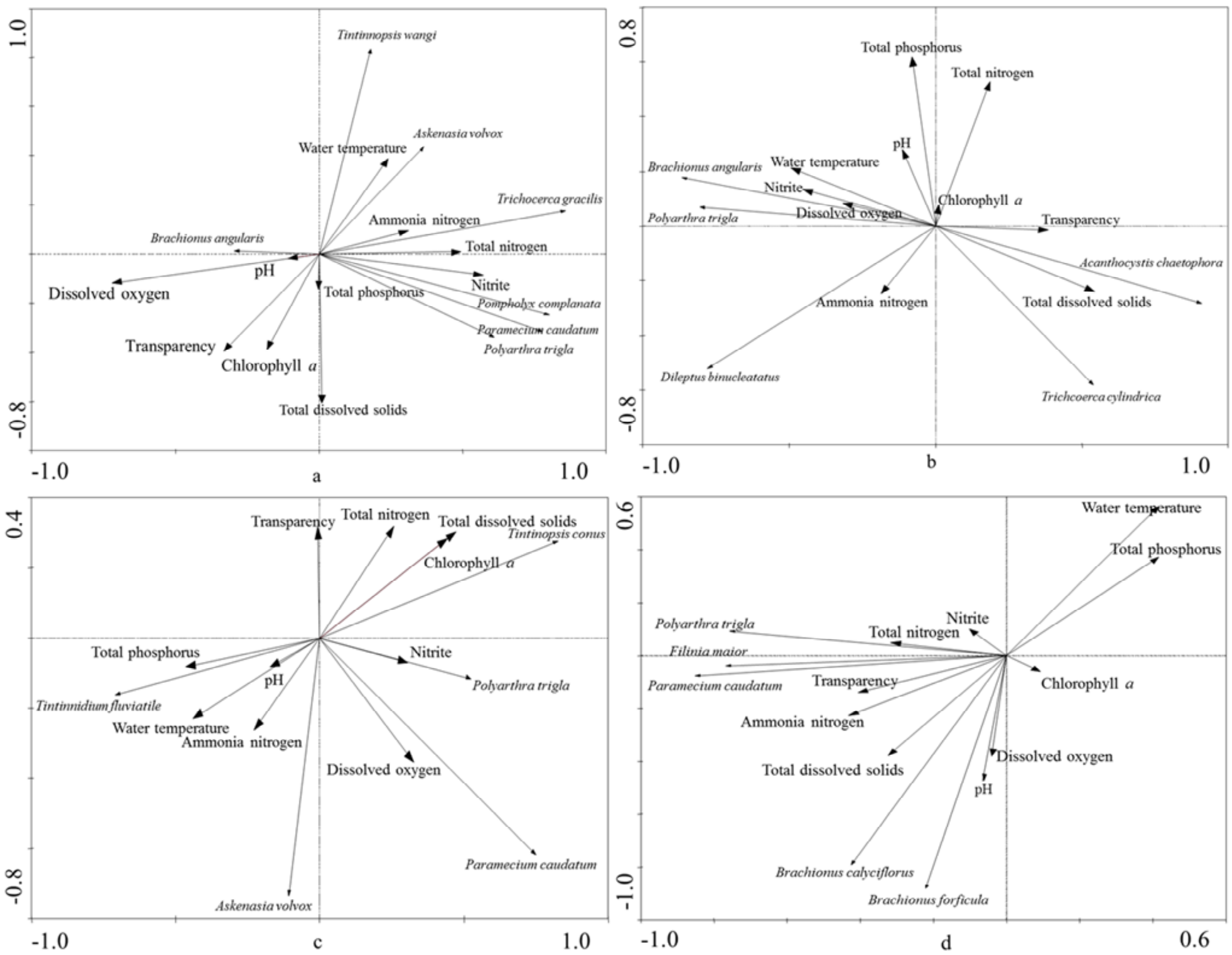

Fig. 3: Ordination diagram of the first two axes of canonical correspondence analysis of zooplankton community index and environmental factors. a, *Oxyeleotris marmoratus*; b, *Ctenopharyngodon idellus*; c, *Micropterus salmoides*; d, *Channa argus*

tors that affect the abundance of zooplankton. Zooplankton species vary in different water systems depending on their demands of nutrients. In the freshwater ecosystems, nitrate, nitrite and ammonia nitrogen at certain concentration showed suppressing effects on the growth of zooplankton. Chen et al. (2008) found that, in the West Lake of Huizhou, the nitrogen and phosphorus contents affected the abundance and biomass of zooplankton to a certain degree, and the phosphate content was positively correlated with zooplankton biomass. The study of Qiu & Zhao (2012) in Sand Lake found that the total phosphorus content was negatively correlated with zooplankton abundance.

In the present study, the zooplankton community structures in all the four ponds were highly correlated with total nitrogen, total phosphorus and nitrite contents. These results were consistent with published studies (Li 2013, Zhang 2014, Zhou et al. 2010). Excessively high levels of total dissolved solids in water will deteriorate the conditions of macrozooplankton (cladocerans and copepods), especially cladocerans as they will die due to the clogging of the filter. In this study, the total dissolved solids were negatively correlated with zooplankton abundance, and the increase in suspended solids will cause rapid growth of algae, and microzooplankton (protozoans and rotifers) with short life cycle will also multiply. Water temperature is a distinctively important environmental factor that affects the growth, development, community composition, quantity and distribution of zooplankton (Dussart et al. 1984). Jin et al. (1991) found that the abundance of zooplankton increased with the temperature when it is between 20°C and 30°C. However, the abundance of zooplankton decreased in July and

August, when the temperature was highest. This might be due to the diapause of zooplankton under excessively high temperature (Marcus 1982). Our study also demonstrated that the dominant zooplankton abundance was negatively correlated with the water temperature in July and August. The dissolved oxygen level in water, which varies in different culture ponds and shows remarkable seasonal variation, directly determines the living condition of most aquatic organisms. As the biological metabolism level and oxygen utilization rate of organisms increase with water temperature, the dissolved oxygen level in water directly determines the biological abundance under high temperature (Wang 2007). In spring and winter, the level of dissolved oxygen is high, the activity and standing stock of the zooplankton are low, hence the dissolved oxygen level is not the limiting factor for zooplankton abundance. However, in summer and autumn, when the dissolved oxygen level decreases, while zooplankton activity become frequent and the standing stock of zooplankton is high, their oxygen demand increases, and thus the dissolved oxygen will be a factor affecting the living of zooplankton. The acidity or alkalinity of water is indicated by the pH value, which is closely related to the number of rotifer species in freshwater. Rotifers, according to their pH value preference, can be divided into alkaliphile species, acidophile species, and facultative species. The abundance of rotifers is high in water with high pH value, and low in water with low pH value (Zhou 2007). In the present study, the abundance of dominant rotifers in *Channa argus* ponds, such as *Polyarthra trigla* and *Filinia maior*, showed a significant positive correlation with pH value of the water.

In addition to the direct effects, environmental factors may also indirectly influence the standing stock of zooplankton through affecting the growth of phytoplankton (Lu & Zhu 2008), which sometimes even counteracts the direct effects. In the present study, the zooplankton community structure showed a remarkable positive correlation with the chlorophyll *a* content in the *Micropterus salmoides* pond, which is an indicator for phytoplankton abundance, and is also an indirect indicator for the regulation effects of phytoplankton on zooplankton populations.

CONCLUSIONS

The species composition, abundance and biodiversity of zooplankton varied in different types of culture ponds. Changes of the structure and dynamics of zooplankton in the investigated ponds were determined mostly by trophic relationships and interspecies interactions, while fish predation pressure supported greater species diversity and its reinstatement.

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