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COMPARISON OF ZOOPLANKTON COMMUNITY STRUCTURES IN THREE POLYCULTURE MODELS OF PONDS STOCKING *CTENOPHARYNGODON IDELLUS*

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ABSTRACT: *The Zooplanktons community structures in three polyculture models of pods, stocking mainly grass carp (Ctenopharyngodon idellus) were enumerated. We focused on the variability of a zooplankton community structure and compared its differences in the three polyculture models. Environmental factors and zooplankton abundance differed significantly among models. Nevertheless, model 2 had the minimum biomass of crustacean and zooplankton. Statistical analysis revealed that,* NO_2^-*-N, COD,* NO_3^-*-N, T, DO,* PO_4^{3-}*-P and pH are the most important environmental variables acting on the zooplankton assemblage. The differences in community structure of zooplankton and the growth rate of fish in the three Polyculture models showed that the model 2 was the most reasonable and efficient culture method, and Paddlefish (Polyodon spathula) can make more valuable contributions to market demand than bighead carp (Aristichthys nobilis).*

KEYWORDS: Zooplankton Community Structure, Pond Polyculture Model, Environmental Factors, Ctenopharyngodon Idellus

INTRODUCTION

Polyculture is one of the most important models of pond aquaculture system in China, in which, *Cyprinidae* fish is the main stocking species. Pond fish culture accounted for 70.6% of the freshwater aquaculture production in China (Fisheries statistic in China 2013). Though, China is the leading pond aquaculture production, but the problems of the unreasonable introduction of exotic species (Specify species, fish or other) and use of aquaculture drug become increasingly prominent during the culture period. These problems have restricted the further development of pond culture system. However, deformity of the ecological structure, blocking of material circulation and serious pollution of fresh water is the existing problems in aquaculture production system in China.

Zooplankton plays an important role in the water ecosystem structure and function. As a consumer of primary producers, it regulates the abundance of phytoplankton through predation, and as food of planktivorous fish. And its abundance directly impacts the resources of fish (Boudreau and Dickie 1992). Distribution of zooplankton is influenced by abiotic limitations. Some zooplankton species are limited by temperature, dissolved oxygen, salinity and other physicochemical factors; this may depends on the background of local environmental conditions. Compared with the large water area, such as reservoirs and lakes, the habitats of zooplankton communities in individual ponds may be different, due to the limited geographic range of certain species and chance events associated with colonization. Zooplankton community structure is influenced by many factors, such as predation, competition, but predation is the most important factor for variation of zooplankton assemblage. Some species have even been shown to have different environmental preferences in different regions (Patalas 1971).

Paddlefish (*Polydon spathula*)was introduced from the United States 20 years ago. Early investigations indicated that paddlefish is primarily planktivores and insectivores (Kofoid 1900; Eddy and Simmer 1929). Many studies had confirmed that paddlefish was an indiscriminate filter feeder on zooplankton, especially cladoceran (Rosen and Hales 1981; Michaletz et al. 1982). Paddlefish are suitable to be stocked in large areas of reservoirs and lakes. But in ponds, there are few reports about the model of using paddlefish as Polyculture fish in China. In Chen et al. (2011) replaced bighead carp (*Aristichthys nobilis*) with paddlefish in polyculture ponds to compare the variety of water quality factors (chlorophyll a, transparence, total ammonia nitrogen, total nitrogen, and total phosphorus). And also, replacing bighead carps with paddlefish in pounds of mainly stocking grass carp. This study was designed to explore the relationship between zooplankton community and environmental factors, and to compare models that is most suitable for Polyculture system.

MATERIAL AND METHODS

Study Area

The study was conducted from June to October in 2010 in nine ponds near the “Shaotanhe” reservoirs. They are located in Hubei Province, China (30°50′N, 114°58′E). The nine ponds have the same area (110 m^2) and similar depth (1.2 ± 0.2 m, mean ± SD). The water quality in “Shaotanhe” Reservoir is fresh and meets the water quality criteria in aquaculture.

Experimental Design

The experiment was designed into three polyculture models, stocking mainly, grass carp with few silver carp (*Hypophthalmichthys molitrix*), bighead carp, crucian carp (*Carassius auratus*) and paddlefish. The nine reconstructed ponds were divided into three groups, with triplicates in each group. Group one (model 1) including 250 Grass Carp, 35 Silver Carp, 40 Big head Fish, and 15 Goldfish, group two (model 2) 250 Grass Carp, 35 Silver Carp, 20 Big head Fish, 20 Paddlefish, and 15 Goldfish, and group three (model 3) 250 Grass Carp, 35 Silver Carp, and 15 Goldfish respectively. The individual weight of Grass Carp, Silver Carp, Big head Fish, Goldfish and Paddlefish was 87.31±9.19 g, 63.66±7.30 g, 55.01±3.89 g, 63.66±7.30 g and 150.15±11.9 g, respectively. The environmental factors of the three models were measured throughout the experimental period (Table 5). The experiment was conducted during the aquaculture production period in central China.

Pond Preparation and Fish Stocking

Prior to the trial, ponds were renovated with the same silt substrate. Aquatic vegetation, fish and other larger aquatic organisms were eradicated. Ponds were subsequently treated with lime (CaO, 250 kg ha^{-1}) and filled with water from “Shaotanhe” Reservoir. During the cultural period (June-October), 1/3 of the pond water was changed weekly. Ponds were unfertilized no longer during the entire experimental period.

On day 12, fingerlings collected from “Shaotanhe” Reservoir aquaculture farm; were released into the ponds. The fish were fed at a daily commercial floating juveniles grass carp feed to satiation during the culture period. All of the fish were harvested by fishing net in December. The daily weight and net weight of paddlefish and bighead carp were calculated from the correlation formula (Chen et al. 2012).

Sampling of Zooplankton

Zooplankton samples were collected monthly (Jun 22, July 24, Aug 23 and Sep 23) at 08:30-10:30 in the morning. Horizontal hauls sampling (for qualitative samples), were taken, using a 64-µm mesh zooplankton net on the surface of water.

Laboratory Analysis

The collected samples were preserved in 5% buffered formaldehyde solution. Observation and identification of zooplankton to species level were done with the aid of an Olympus model microscope (magnification×400) model 230485 (Olympus America Inc., Center Valley, PA, USA) in the zooplankton laboratory. All cladoceran, Copepoda, rotifersand protozoan were identified to species using keys of Chiang and Du (1979), Sheng (1979), Shen (1990) and Wang (1965).

Rotifers and protozoan quantitative samples were obtained by filtering 1L water through a plankton net (mesh size 64 µm) and preserved in 5% buffered formaldehyde solution. The samples subsided for 48hrs in glass columns; then the supernatant was removed carefully and concentrated to 30 ml. Rotifer and protozoan samples were counted using 1 ml and 0.1 ml Sedgwick-R after counting chamber, respectively.

Crustacean and zooplankton samples were taken monthly. At each point, 10L mixed water, collected at two depths (0.5 m below the surface and 0.5 m away from the bottom), was filtered by a plankton net (mesh size 64 µm) and preserved with 5% formalin. Crustacean and zooplankton samples were all counted siding a 1Ml. Sedgwick-R after counting chamber. Biomass of crustaceans were calculated from regression equations (Huang et al. 1984) of wet body weight and body length. Length measurements of cladoceran were made from the top of the head (helmet of *Daphnia* excluded) to the base of the shell spine; in Copepoda (copepodite and adult), from the top of the head to the end of the caudal Remus (Yang et al. 1999). Average body length of crustacean was calculated from 20 animals. Weight of maple was estimated to be 0.003 mg. Samples were collected from mid-layers of the ponds so as to determine physical-chemical parameter using a 2.5 L organic glass hydrosphere, and preserved with chloroform.

Dissolved oxygen (DO), water temperature (T) and pH were measured in HQd Meters and IntelliCALTM Probes (Hach Co., Loveland, CO, USA). Transparency (SD) was measured with a Secchi disc. All the water quality parameters, including total phosphorus (TP), phosphate (PO_4^{3-}-P), Ammoniacal nitrogen (NH_3-N), nitrite nitrogen (NO_2^--N), nitrate nitrogen (NO_3^--N), total nitrogen (TN), chemical oxygen demand (COD) and chlorophyll a (Chl-a) were measured within 24hrs in the hydration laboratory according to following standard methods (Greenberg et al. 1992; National Environmental Protection Bureau 2002).

Statistical Analysis

The software packages IBM SPSS Statistics 19 and CANOCO version 4.5 (Braak and Smilauer 2002) were used for statistical analyses. Redundancy analysis (RDA) was widely used to explain the relationship between the zooplankton communities and environmental factors (Marta 2012).

The variation of zooplankton density and biomass in different model ponds were analysed by SPSS 19.0. Diversity of zooplankton community was assessed using Simpson diversity index (Simpson 1949), Shannon-Wiener diversity index (Shannon et al. 1949) and Pielou index (Pielou 1975).

The dominant species of zooplankton were calculated according to Xu (1989), the computational formula is, where, N_i means the abundance of the species I, Imeans the occurrence frequency of this species, and N indicates the total abundance of zooplankton. A species are confirmed as the dominant species when the value of $Y \geq 0.02$.

The relationship between zooplankton and environmental factors and sampling Units

Redundancy analysis (RDA) was used to describe the relationships between the zooplankton abundance and the environmental variables (CANOCO program; Ter Braak and Smilauer 2002). RDA was chosen because the length of the gradient of the first DCA (Detrended Correspondence Analysis) axis running on zooplankton density data was 0.163; therefore, we used linear ordination techniques (Ter Braak and Prentice 1988). All zooplankton density data were log (x+1) transformed. Environmental factors (TP, PO_4^{3-}-P, NH^{4+}-N, NO_2^--N, NO_3^--N, TN, COD, DO, pH, T and Chl-a) were selected by the automatic forward selection with 499 unrestricted Monte Carlo permutations. Bi-plot of relationship between environmental factors and zooplankton abundance (Fig. 3) And relationship between sampling units and zooplankton abundance (Fig. 4) Were presented using Cano Draw of CANOCO 4.5 (ter Braak and Smilauer 2002).

RESULTS

Zooplankton Community Composition

The dominant species of zooplankton in the three models were almost similar, which were absolutely dominated by protozoa and rotifer. *Urotricha factual* and *Lagynophrya conifers* were the dominant species of protozoan, ratifiers were dominated by *Trichocerca possible*, Cladocera were dominated by *Moina micrura* and Copepoda dominated by *Thermocyclops holiness*. The zooplankton assemblage consisted of 133 genera (233 species), among which protozoan represented the highest number of species (154), approximately 66.5% of the total species of zooplankton, rotifers (60), which accounted for 25.4%. Cladocera (15) and Copepoda (4) accounted for 6.4% and 1.7%, respectively.

Density and biomass

Protozoa dominated the zooplankton assemblage in the three different models, with the highest density and biomass, followed rotifer the second dominant taxa, Cladocera and Copepoda accounted for only a small proportion (Table 1 and Table 2). The highest biomass of the total zooplankton occurred in model 1 (39.19 mg·L^{-1}), while model 2 and model 3 were very similar, their biomass were 24.70 mg·L^{-1} and 23.32 mg·L^{-1}, respectively (Table1). The highest density and biomass of microzooplankton (Protozoa and Rotifer) was model 1 (5.78×10^5 Ind·L^{-1}, 37.84 mg·L^{-1}), while model 2 (4.09×10^5 Ind·L^{-1}, 22.85 mg·L^{-1}) and model 3 (4.02×10^5 Ind·L^{-1}, 22.12 mg·L^{-1}) had similar value.

Model 3 had the highest biomass (2.57 $mg \cdot L^{-1}$) of macrozooplankton (Cladocera and Copepoda), while model 2 showed the least value (0.54 $mg \cdot L^{-1}$). There was significant difference of macrozooplankton biomass between model 3 and model 2 ($P<0.05$), also between model 3 and model 1 ($P<0.05$).

Biodiversity Variation of Zooplankton

The results of the three diversity indices indicated that the biodiversity of zooplankton gradually reduced in the sequence of model 1, model 2 and model 3. The diversity indices of the three models showed a similar trend (Table 3).

Growth Parameters of Bighead Carp and Paddlefish

The parameters showed that the daily weight and net weight of bighead carp in model 2 significantly higher than model1 ($P<0.05$); in model 2, the daily weight and net weight of paddlefish significantly higher than bighead carp (Table 4).

Water Quality Parameters

Water temperature and pH showed a similar temporal trend in the three model ponds. The level of DO was low during the whole experiment. The concentrations of TP, PO_4^{3-}-P and TN were low in model 2, and there was a significant difference between model 1 and model 2 ($P<0.05$), model 3 and model 2 ($P<0.05$), there was no significant difference between model 1 and model 3. NH_4^+-N, NO_3^--N and COD decreased in order of sequence; model 1, 2 and 3. NO_2^--N was significantly high in June, and its concentration of model 1 and model 3 was lower than model 2.

Relationship between Zooplankton and Environmental Factors

In the current study Eigenvalues of the first and second axis were 0.794 and 0.156, respectively, and the two axes accounted for 92.1% of the variance in the zooplankton-environmental relationship (Table 6). Automatic forward selection indicated that the most significant variable of the 11 environmental variables were NO_2^--N, which explained 36% of the total variance, followed by COD (28%), NO_3^--N (10%), T (8%), DO (7%), PO_4^{3-}-P (5%), pH (4%). Axis 1 was positively related to TN (the correlation coefficient was 0.6097) and negatively related to NO_2^--N (-0.6409). Axis 2 was positively related to TP (0.6961) and NH_4^+-N (0.6217), it was negatively related to DO (-0.8576) (Table 7).

As it is indicated on Fig.3, the protozoa and rotifer showed a positive relationship to COD, NH_4^+-N and TP but were negatively related to DO and T. Cladocera was positively related to PO_4^{3-}-P, TN and TP but negatively related to NO_2^--N and DO, while Copepoda showed a positive relationship with T, TN and PO_4^{3-}-P but was negatively related to NO_2^--N and COD. (Fig. 4) Showed the relationship between the four taxa of zooplankton and sampling units.

This bi-plot showed that the nine culture ponds were divided into three groups, the first group, including ponds 1, 2 and 3, which belongs to model 1 in this study. The second group, including pond 4, 5, 6 and 7 belongs to model 2 (except pond 7), Ponds 8 and 9 were the third group belonging to model 3. The largest abundance of protozoa and rotifer was the first group, followed by the second and third group; the second group had the least abundance of Cladocera, while the third group had the largest abundance of Cladocera and Copepoda.

DISCUSSION

Variation of zooplankton community structure and composition in three model culture ponds

The result of GU (1994), GU and Liu (1996) indicated that the average biomass of zooplankton in pounds of high production is about 10-20 mg/L in China, and microzooplankton (protozoa and rotifer) always dominated in these ponds, while macrozooplankton (Cladocera and Copepoda) is relatively low. It has been demonstrated that zooplanktivorous fish selectively prey on larger and more conspicuous zooplankton, mainly the large cladoceran (Elhigzi et al. 1995). Yang et al. (2011) also reported, zooplanktons were dominated by protozoa and rotifer in polyculture pond of grass carp, silver carp and common carp (*Cyprinus Carpio*). All these results of the various studies were similar to this research. Both silver carp and bighead carp can pray zooplankton (Cremer and Smitherman 1980), but the feeding capacity of bighead carp for zooplankton was greater than silver carp (Dong and Li 1995). Bighead carp has great water absorbing capacity and it can prey on Cladocera and Copepoda efficiently.

Yang and Huang (1992) studied the influence of silver carp and bighead carp on zooplankton community structure using the enclosure method, they found that in the enclosures where silver carp and bighead carp were stocked, the protozoa and some small-sized ratifiers were dominated, while crustacean and large-sized ratifiers were less. Similarly, Arcifa et al. (1986) have the same conclusion in their enclosure experiment.

In the present study, small-sized rectifiers, such as *Trichocerca possible* and *Trichocerca gracilis* and protozoa were the dominant species in all the ponds. The activities of fish also influence the zooplankton community composition. The activity of crucian carp can make the resting eggs of rotifer hatched, increases the biomass of rotifer (Liu 1992). Macrozooplankton consume a broader size spectrum of particles and have a lower threshold food density below which they cannot maintain metabolic demand (Burns 1968). Some cyclopoids are omnivorous and prey on protozoans and rotifers. So the fish culture ponds, the number of small species was much greater than zooplankton.

Comparing with the average biomass of macrozooplankton (Cladocera and Copepoda) in the three model culture ponds, we found that model 3 had the largest value (10.40%), because there were no bighead carp and paddlefish in model 3. The biomass of Cladocera in model 2 was significantly lower than in model 1 and 3; due to a replacement of 6% bighead carp from model 1 to model 2. Paddlefish fed on zooplankton, especially Cladocera, it also preyed on Chironomidae larvae, juvenile fish and prawn, and its feeding habit, living habits and living space were similar with bighead carp (John and David 1986). Zhu et al. (2009) studied the food selection of paddlefish and pointed out that larval and juvenile paddlefish had the obvious food selection; they almost prey on cladoceran only, less copepods and aquatic insects, and barely prey on rotifers and phytoplankton. This shows paddlefish has great predation pressure on large zooplankton (Cladocera and Copepoda).

Relationship of environmental factors and zooplankton composition

The composition of zooplankton was influenced by physical, chemical, biological and geographic factors (MacArthur 1967). Olive and Pastuchova (2012) suggested that nutrients and dissolved oxygen were the most important physical-chemical factors for plankton diversity when they investigated the zooplankton communities with different traffic conditions in two catchments. Karl et al. (2001) pointed out ponds with clear-water state was characterized by large cladoceran species and low chlorophyll-a concentration, unlike in the turbid-water ponds, high abundances of rotifers and inverse environmental conditions appeared.

In this present study, RDA indicated that most environmental factors were positively related to protozoa and rotifer, such as COD, NH_4^+-N, chlorophyll-a, NO_3^--N and TP, and these variables were all had the highest concentrations in model 1. As the flood of zooplankton, phytoplankton biomass is closely related to zooplankton biomass, and the concentration of chlorophyll-a can reflect the phytoplankton biomass. The bi-plot of the RDA indicated that ammonium showed the closest relationship with chlorophyll-a. Due to the favourable energy requirement, ammonium utilization is preferred by algae (Ward and Wetzel 1980), therefore, a slight increasing tendency of phytoplankton biomass can be expected even in the eutrophic-hypertrophic range. So ammonium influenced zooplankton indirectly. Guevara et al. (2009) also suggested that the enhancement of eutrophication could possibly increase rotifer abundance since they are able to thrive in the traffic environment.

In the current study, model 1 has the highest concentration of nutrients and highest abundance of protozoa and rotifer. This was consistent with the conclusion that with the increasing of nutrient concentration and eutrophication, small-sized species dominated in the zooplankton community (Chen et al. 2012), while Copepoda was highly negatively related to nutrient concentrations (Tadesse 2011). The bi-plot of Redundancy Analysis for zooplankton and environmental variables (Fig. 3) also showed similar results.

Feasibility analysis of polyculture of grass carp, silver carp, bighead carp, crucian carp and paddlefish

Grass carp, silver carp, bighead carp, crucian carp and paddlefish move at different water layers and feed on different preys in polyculture ponds; they enable a more efficient utilization of pond resources. Shi (2013) studied that during the period of juvenile, the feed coefficient of bighead carp is significantly higher than paddlefish, this indicates that paddlefish has higher utilization rate and conversion efficiency on zooplankton than bighead carp. GU et al. (2012) compared the benthic macroinvertebrates in three culture model stocking grass carp ponds, and deduced that the paddlefish can make valuable contributions to the biodiversity and ecosystem stability of fish ponds. Paddlefish has high value of ornament, nutrition and medicine (Chen 2011), and Chen (2011) discussed the value of replacing bighead carp with paddlefish, he concluded that paddlefish has higher economic value and social value than bighead carp. In this study, model 2 has lower biomass of zooplankton, especially macrozooplankton than model 1, which indicated that paddlefish can make higher utilization of zooplankton than bighead carp. In addition, the daily weight and net weight of paddlefish were significantly higher than bighead carp in model 2, and the market value of paddlefish is much higher than bighead carp in the Chinese market today, therefore, paddlefish more accords with the demand of people in China, and replacing bighead carp with paddlefish in polyculture pond is feasible.

CONCLUSIONS

The microzooplankton (protozoa and rotifer) dominated in the polyculture ponds, and associated with most of nutrients in the water, while macrozooplankton (Cladocera and Copepoda) were less in the three culture models, among which model 2 has the least biomass of Cladocera and Copepoda. In addition, model 2 is the best aquaculture model of the three models. From this, we concluded that the first and second group (model 1 and model 2) was dominated by microzooplankton (protozoa and rotifer), while the third group had the largest abundance of macrozooplankton (Cladocera and Copepoda) compared to the former two groups. To confirm suitable combinations of fish species stocked in polyculture ponds, the factors of the utilization of fish for space resource, water, environment, the stability of ponds and market requirements should be taken into consideration.

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ABSTRACT

Table 1.The change of different months of density (ind.·L^{-1}) and biomasses (mg·L^{-1}) of zooplankton in different culture models

Species	Month	Model Ⅰ		Model Ⅱ		Model Ⅲ	
		Density	Biomass	Density	Biomass	Density	Biomass
Protozoa	6	0.80×10^5	2.93	2.37×10^5	7.66	2.83×10^5	8.86
	7	6.49×10^5	31.39	4.25×10^5	15.41	3.52×10^5	14.04
	8	8.70×10^5	39.28	4.12×10^5	18.25	3.58×10^5	11.76
	9	6.64×10^5	36.38	5.16×10^5	18.73	5.76×10^5	17.60
	Avg.	5.66×10^5	27.50	3.98×10^5	15.01	3.92×10^5	13.07
Rotifer	6	1.19×10^4	16.02	0.89×10^4	10.10	0.27×10^4	1.87
	7	1.20×10^4	8.21	0.93×10^4	4.27	1.44×10^4	22.24
	8	1.40×10^4	9.75	1.61×10^4	11.04	0.69×10^4	9.36
	9	0.99×10^4	7.41	1.02×10^4	5.92	1.44×10^4	2.76
	Avg.	1.20×10^4	10.35	1.12×10^4	7.83	0.96×10^4	9.06
Cladocera and Copepoda	6	212.03	3.79	78.75	0.77	174.10	2.66
	7	34.57	0.33	29.10	0.34	50.70	0.43
	8	33.57	0.37	25.45	0.36	342.40	3.99
	9	81.53	0.89	56.70	0.67	305.00	3.21
	Avg.	90.43	1.35	47.50	0.54	218.05	2.57
Total zooplankton	6	0.92×10^5	22.74	2.46×10^5	18.53	2.86×10^5	13.39
	7	6.61×10^5	39.93	4.34×10^5	20.02	3.66×10^5	36.71
	8	8.84×10^5	49.40	4.28×10^5	29.65	3.65×10^5	25.11
	9	6.74×10^5	44.68	5.26×10^5	25.32	5.91×10^5	23.57
	Avg.	5.78×10^5	39.19	4.09×10^5	23.38	4.02×10^5	24.70

Table 2.The percentage of mean density and biomass of protozoa, rotifer, Cladocera and Copepoda among the total zooplankton

Models	Percentage of mean density from the total (%)					Percentage of mean biomass from the total (%)				
	Total ($\times10^5\cdot L^{-1}$)	Protozoa (%)	Rotifer(%)	Cladocera (%)	Copepoda (%)	Total ($mg\cdot L^{-1}$)	Protozoa (%)	Rotifer (%)	Cladocera (%)	Copepoda (%)
Model Ⅰ	5.78	97.924	2.060	0.007	0.009	39.19	70.162	26.406	2.314	1.118
Model Ⅱ	4.09	97.250	2.738	0.003	0.009	23.38	64.210	33.500	0.922	1.368
Model Ⅲ	4.02	97.565	2.381	0.015	0.039	24.70	52.911	36.683	4.029	6.377

Table 3. Average diversity indices of zooplankton in each month in different culture models

Diversity Index	Models	Jun	Jul	Aug	Sep	Average
Simpson index	Model Ⅰ	9.4395	10.0782	13.7885	16.6463	12.4881
	Model Ⅱ	4.7070	11.5470	14.6039	15.3586	11.5541
	Model Ⅲ	4.0273	10.2802	14.0140	17.1775	11.3748
Shannon-Wiener index	Model Ⅰ	2.8864	2.9359	3.0898	3.2558	3.0420
	Model Ⅱ	2.3052	2.8817	3.1759	3.1271	2.8725
	Model Ⅲ	2.1425	2.8713	3.0389	3.1541	2.8017
Pielou index	Model Ⅰ	0.4656	0.4613	0.5004	0.5238	0.4878
	Model Ⅱ	0.3710	0.4703	0.5164	0.5102	0.4670
	Model Ⅲ	0.3409	0.4582	0.4958	0.5112	0.4515

Table 4. Growth parameters of bighead carp and paddlefish in the three polyculture models

Growth parameters	Bighead carp		paddlefish
	Model 1	Model 2	Model 2
Initial weight (g)	55.01±3.89	55.01±3.89	150.09±6.88
Harvest weight (g)	140.33±8.95^{a}	176.83±13.72^{b}	323.56±11.10^{c}
Daily weight (g▪d^{-1})	0.71±0.05^{a}	1.02±0.09^{b}	1.45±0.05^{c}
Net weight (g)	85.32±5.87^{a}	121.82±10.71^{b}	173.47±6.36^{c}

Note: Values with different letters in the same row indicated significant differences (P<0.05).

Quoted from Chen et al. (2012)

Table 5.The results of physico-chemical parameters of water in three model ponds

Models	Time	TP, mg.L^{-1}	PO_4^{3-}-P, mg.L^{-1}	NH_4^+-N, mg.L^{-1}	NO_2^--N, mg.L^{-1}	NO_3^--N, mg.L^{-1}	TN, mg.L^{-1}	COD, mg.L^{-1}	DO, mg.L^{-1}	pH	T, ℃	Chlorophyll a, mg.L^{-1}
Model I	Jun.	0.125	0.066	0.504	0.011	0.131	0.888	6.952	2.307	7.977	28.967	0.041
	Jul.	0.119	0.072	0.554	0.000	0.030	0.916	6.344	4.277	8.137	30.200	0.094
	Aug.	0.123	0.010	0.212	0.000	0.000	1.650	6.344	2.187	7.497	30.267	0.229
	Sep	0.095	0.022	0.346	0.002	0.000	1.254	6.890	1.813	7.200	24.933	0.179
	Oct.	0.109	0.024	0.310	0.002	0.086	1.548	6.833	2.937	7.227	20.800	0.356
	Mean	0.114	0.039	0.385	0.003	0.049	1.251	6.672	2.704	7.607	27.033	0.180
Model Ⅱ	Jun.	0.048	0.013	0.484	0.027	0.178	0.756	6.578	4.263	8.083	28.533	0.058
	Jul.	0.055	0.023	0.557	0.000	0.039	1.029	6.410	5.010	8.050	30.333	0.087
	Aug.	0.092	0.010	0.216	0.000	0.000	0.947	6.410	3.173	7.580	30.500	0.155
	Sep.	0.073	0.032	0.405	0.002	0.000	0.961	5.980	2.327	7.133	25.100	0.152
	Oct.	0.085	0.037	0.075	0.003	0.008	1.311	6.593	4.497	7.283	20.833	0.275
	Mean	0.071	0.023	0.347	0.007	0.045	1.001	6.394	3.854	7.626	27.060	0.145
Model Ⅲ	Jun.	0.070	0.023	0.399	0.006	0.101	0.863	7.473	2.933	7.820	29.233	0.053
	Jul.	0.109	0.032	0.520	0.000	0.018	1.214	5.929	3.853	7.850	30.600	0.094
	Aug.	0.092	0.014	0.149	0.000	0.000	1.212	5.929	3.467	7.613	30.900	0.173
	Sep.	0.095	0.049	0.303	0.002	0.000	1.379	5.048	2.223	7.277	25.167	0.141
	Oct.	0.090	0.053	0.088	0.005	0.000	1.470	5.563	5.230	7.667	21.267	0.261
	Mean	0.091	0.034	0.292	0.003	0.024	1.228	5.989	3.541	7.645	27.433	0.144

Table 6.Summary statistics of RDA

Axes	1	2	3	4
Eigenvalues	0.794	0.156	0.041	0.009
Species-environmental correlations	1.000	1.000	1.000	1.000
Cumulative percentage variance of species data	79.4	95.0	99.1	100
Sum of all eigenvalues	1.000			
Sum of all canonical eigenvalues	1.000			

Table 7.Redundancy analysis Inter-set correlations of environmental variables with axes

Environment variable	Axis 1	Axis 2	Axis 3	Axis 4
TP, $mg.L^{-1}$	0.3518	0.6961	-0.3731	0.3684
PO_4^{3-}-P, $mg.L^{-1}$	0.5402	0.4662	-0.2380	0.1882
NH_4^+-N, $mg.L^{-1}$	0.0254	0.6217	0.0627	0.5939
NO_2^--N, $mg.L^{-1}$	-0.6409	-0.3914	0.5469	-0.2402
NO_3^--N, $mg.L^{-1}$	-0.2508	0.4296	0.7235	-0.0149
TN, $mg.L^{-1}$	0.6097	0.4333	-0.5291	0.1825
COD, $mg.L^{-1}$	-0.2338	0.6179	-0.5728	-0.0566
DO, $mg.L^{-1}$	-0.2703	-0.8576	0.2117	-0.2859
pH	0.0459	-0.3534	0.1139	-0.3320
T, ℃	0.5052	-0.5516	-0.2860	0.3104
Chl-a, $mg.L^{-1}$	0.0901	0.5767	-0.5265	0.2637

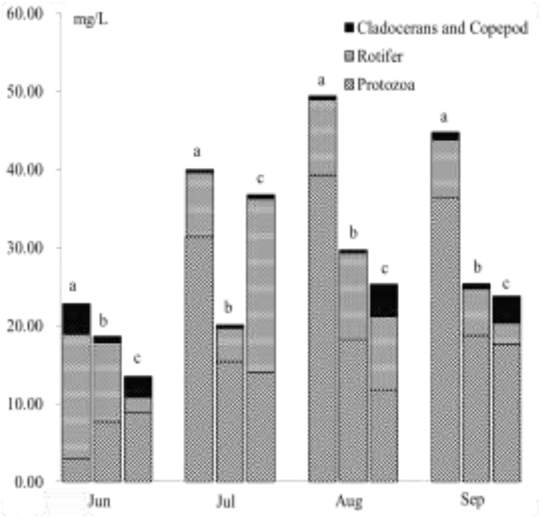

Fig 1.The biomass of zooplankton in each month in different stocking models (a, b, c represent model Ⅰ, Ⅱ, Ⅲ, respectively)

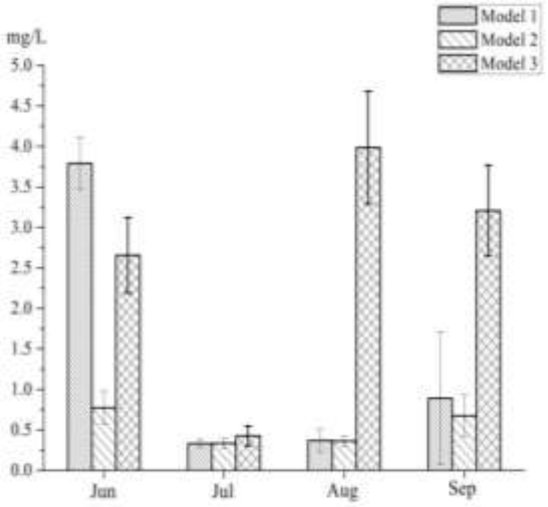

Fig 2.The biomass of crustacean in each month in different stocking models

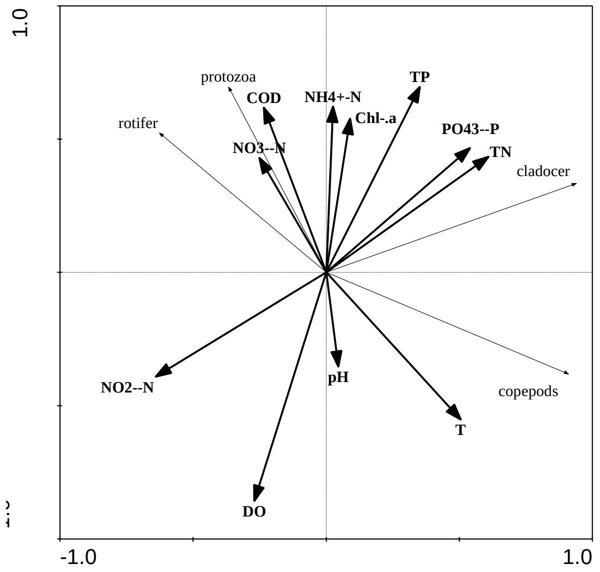

Fig 3. Bi-plot of the Redundancy Analysis for zooplankton abundance and environmental variables. Broken arrows represent taxa of zooplankton whereas bold arrows are environmental variables (rotifer-rotifer; protozoa-protozoa; cladocera-cladocera; copepods- copepods)

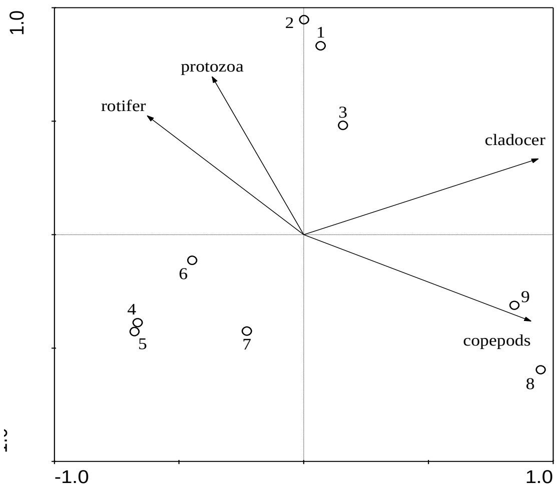

Fig 4. Bi-plot of the Redundancy Analysis for zooplankton abundance and sampling units (1, 2 and 3 were three ponds of model Ⅰ, 4, 5 and 6 were three ponds of model Ⅱ, 7, 8 and 9 were three ponds of model Ⅲ)