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RESEARCH ARTICLE

Seasonal variation and longitudinal distribution of copepods in the main river area of the Three Gorges Reservoir

Jianliang YAO[1,3], Junzeng XUE (✉)[2,3], Dengyuan WANG[1], Qinghua CAI[3], Xiangfei HUANG[3], Jiankang LIU[3]

1 Agronomy College, Xinjiang Agriculture University, Urumqi 830052, China
2 College of Aquatic-life Sciences and Technology, Shanghai Fisheries University, Shanghai 200090, China
3 State Key Laboratory of Freshwater Ecology and Biotechnology, Wuhan 430072, China

Abstract The ecosystem of the Three Gorges in the Yangtze River was changed into an artificial lake (reservoir) ecosystem after impoundment in June 2003. We surveyed the seasonal variation and spatial distribution of copepods from April 2004 to January 2005 in order to provide data for clarifying the successional pattern of the ecosystem. From Jiangjin to Maoping, eight copepod species were collected and classified into Calanoida (2), Harpacticoida (1), and Cyclopoida (5). Among them, *Mesocyclops pehpeiensis*, *M. leuckarti* and *Sinocalanus dorrii* had a relatively wide distribution. No distinct difference in species number was found among the sampling sites, but the species composition was different. Species composition, distribution and density of copepods showed significant seasonal variations. In addition, copepod density showed an obvious gradient with the distance from the reservoir dam: the nearer to the dam, the denser the copepods.

Keywords copepod, zooplankton, community ecology, Three Gorges Reservoir, Yangtze River

1 Introduction

The Three Gorges Reservoir lies in the upper reaches of the Yangtze River, ranging from east longitude 106°–110°50′ to north latitude 29°16′–31°25′. The dam is located at Sandouping. The main river from the source of the Yangtze River to the Three Gorges Dam is about 4486 kilometers long. The water system of the reservoir is quite developed such that the total water resource reaches 462.442 billion cubic meters. The Three Gorges Reservoir began impoundment on June 1, 2003. The water level reached the anticipated height on June 10 and it formed a river gorges reservoir. The reservoir's water level in the first phase impoundment varied between 135 and 139 meters according to changes from rainy season to dry season. The marginal backwater of the reservoir head is located between Fuling and Fengdu, at a distance of about 450 kilometers from the dam. When the water level reached 139 meters, the marginal backwater appeared in Lidu in Fuling. The copepod is a significant part of the autopotamic zooplankton and of river ecology (Kim and Joo, 2000; Velho et al., 2001; Burger et al., 2002; Matsumura-Tundisi and Tundisi, 2003). There are a variety of distributaries, lakes and reservoirs along the 4000 kilometer long main river of the Three Gorges Reservoir. The composition of the copepods will influence the composition of the copepod species in the Three Gorges Reservoir. Investigations on copepods in small water bodies in the submerged area of the Three Gorges Reservoir in the 1950s predicted the composition of the copepod species after the reservoir would be built. However, no copepod was collected in the main river area of the future reservoir at that time (Borutsky et al., 1959). After the first phase impoundment in the Three Gorges Reservoir, changes in copepod species in the dam forepart (from Maoping to Guizhou), before and after the first phase impoundment, were reported (Xue et al., 2006). We conducted an investigation into annual seasonal changes in copepod species above the whole reservoir, including the area of the first phase impoundment reservoir and some regions that will eventually be reservoirs after the second and third phase impoundment. We studied ecology-related factors to provide a theoretical basis for the succession of the copepod species, water environment management, research-based knowledge of the copepods after the second and third phase impoundment, and the use of fisheries resources for the water ecosystem in the Three Gorges Reservoir.

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E-mail: jzxue@shfu.edu.cn

2 Materials and methods

We set up 11 sampling points along the main river of the Three Gorges Reservoir (from Jiangjin to Maoping, about 600 kilometers long) from April 2004 to January 2005, and collected specimens of copepods at different seasons, using plankton nets with 64 μm mesh size and 5 L water samplers to complete the qualitative and quantitative acquisition. We quantitatively collected 50 L water samples in rivers and quantitatively collected 20 L water samples in the reservoir. We identified the species and analyzed the data after the copepod samples were filtered and fixed.

3 Results

3.1 Temporal and spatial distribution of the species

3.1.1 Species composition

Eight species of copepods were collected in ten sections from Jiangjin to Maoping in the Three Gorges Reservoir throughout the four seasons (Table 1), including two species of Calanoida, one species of Harpacticoida and five species of Cyclopoida, in which *Mesocyclops pehpeiensis*, *M. leuckarti* and *Sinocalanus dorrii* were widely distributed. The number of the Cyclopoida species composition was higher than that of the other two both in the river area and the lake area of the reservoir.

3.1.2 Spatial distribution

In the nearly one year collection, the four sampling points from Jiangjin to Changshou were in the status of 'river', while the sampling points from Wanzhou to Maoping were in a status of 'reservoir'; Fuling was in a status of 'reservoir in dry season' (From November to May of the following year) just as the water level reached 139 meters, and in a status of 'river' in the rainy season (From June to October) when the water level reached 135 meters. The absolute value of the discrepancy of species from the sampling points was quite slight since the total species from

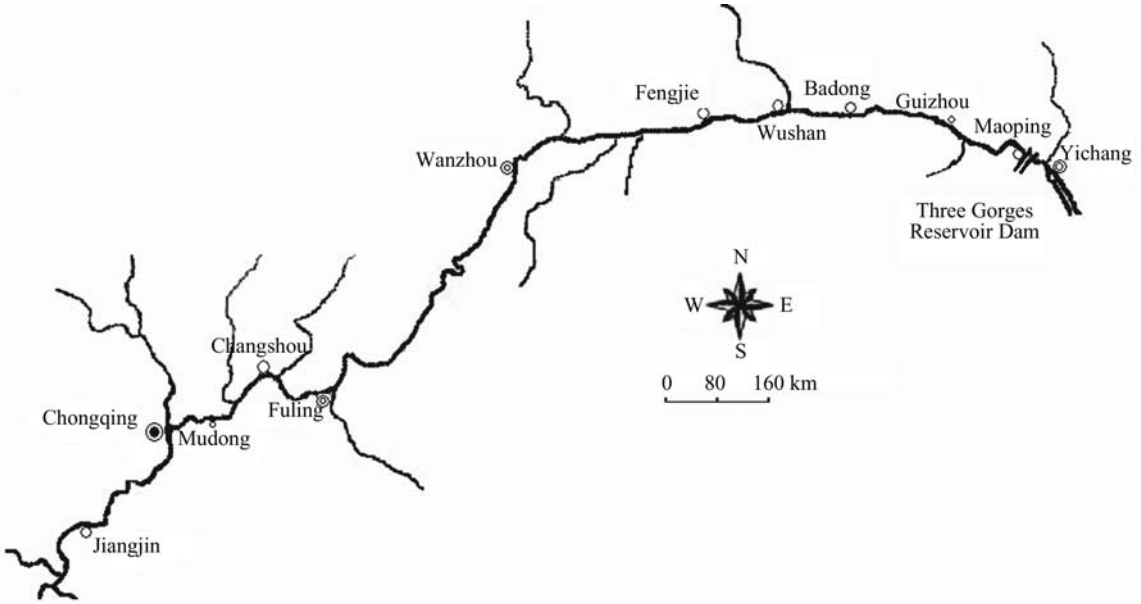

Fig. 1 Location of sampling sites in the Three Gorges Reservoir, China

Table 1 Species composition and spatial distribution of copepod zooplankton in the Three Gorges Reservoir

species	Jiangjin	Chongqing	Mudong	Changshou	Fuling	Wanzhou	Wushan	Badong	Guizhou	Maoping
Calanoida										
Sinocalanus dorrii	+	+	+	+		+	+	+	+	+
Schmackeria forbesi			+						+	+
Harpacticoida										
Onychocamptus mohammed		+					+			
Cyclopoida										
Eucyclops serrulatus serrulatus										+
Mesocyclops pehpeiensis	+	+	+	+	+				+	+
M. leuckarti	+	+	+		+		+	+	+	+
Thermocyclops taihokuensis	+		+			+	+	+		
Psammophilocyclops sp.				+	+					
total	4	4	5	3	3	2	4	3	4	5

every sampling point was relatively low; however, they had significant differences in species composition. *Sinocalanus dorrii* was collected in almost all of the sampling points except in Fuling, while *Eucyclops serrulatus serrulatus* was not collected in almost all of the sampling points except in the Maoping section in front of the dam. One species of *Psammophilocyclops* sp. was not collected either from the sampling points with reservoir status or the sampling points from the upper reaches of the river-status rivers from Jiangjin to Mudong; however, it was seen in two sampling points in Changshou and Fuling. The other species were only distributed in some sampling points with river or reservoir status.

3.1.3 Seasonal variation

The species composition and spatial distribution of copepods in the Three Gorges Reservoir were characterized by an obvious seasonal variation (Tables 1 and 2). There were two species in winter, and six species each in spring, summer and autumn, respectively. However, their species compositions were different. *M. leuckarti* and *Sinocalanus dorrii* were collected the whole year round; *Mesocyclops pehpeiensis* and *Thermocyclops taihokuensis* were collected in spring, summer and autumn; *Onychocamptus mohammed* and *Schmackeria forbesi* were collected in spring and summer, and in summer and autumn, respectively, while *Eucyclops serrulatusserrulatus* and *Psammophilocyclops* sp. were only collected in autumn and summer, respectively.

Table 2 Seasonal variations in density of copepod zooplankton in the Three Gorges Reservoir (ind./L)

species	spring	summer	autumn	winter
Calanoida				
Sinocalanus dorrii	0.856	0.082	0.060	0.004
Schmackeria forbesi	–	0.172	0.020	–
Harpacticoida				
Onychocamptus mohammed	0.002	0.002	–	–
Cyclopoida				
Eucyclops serrulatus serrulatus	–	–	0.004	–
Mesocyclops pehpeiensis	0.022	0.034	0.006	–
M. leuckarti	0.046	0.372	0.062	0.006
Thermocyclops taihokuensis	0.016	0.012	0.026	–
Psammophilocyclops sp.	0.004	–	–	–
copepodids + nauplius	1.730	0.872	0.392	0.014

3.2 Temporal and spatial distribution of the copepod density

The copepod density in the Three Gorges Reservoir showed obvious temporal and spatial distributions. The highest copepod density was seen in spring. With the changing seasons the density gradually decreased, and the lowest copepod density was seen in winter (Fig. 2). Moreover, the copepods had the most plentiful species and the greatest number in spring. They were distributed in every sampling point, and the highest density of copepods was found in Maoping, at 14.66 ind./L. The second highest density was in Guizhou at 9.63 ind./L. The lowest density of copepods was seen in winter, when copepods were collected only from three sampling points located in Fuling, Guizhou and Maoping.

In terms of spatial distribution, the densities in the river-status rivers and upper reaches of the reservoir were generally lower in all of the four seasons. However, the density in the lower reaches of the reservoir, especially near the dam, was relatively higher, and the density exhibited an obvious distribution gradient along the longitudinal axis of the reservoir (Fig. 2). In addition, the lowest density of copepods was in Wanzhou, where a small quantity of copepods only appeared in spring. Maoping was the region which hosted the highest density of copepods, where copepods were collected all year round and the density was higher in spring and summer.

4 Discussion

The fresh water copepod is widely distributed in some relatively stable bodies of water such as reservoirs and lakes (Yang et al., 1994; Davidson et al., 1998; Li and Yu, 2002; Matsumura-Tundisi and Tundisi, 2003). Although planktonic copepods are not absolutely dominant in number in large rivers, they are a significant part of zooplankton (Thorp et al., 1994; Kim and Joo, 2000; Burger et al., 2002), and are even distributed in riptides with benthonics as the primary species (Lewis, 1986; Gaviria, 1998; Rundle et al., 2000). Previous studies suggest that water velocity will influence the existence and distribution of zooplankton in rivers; a faster flow velocity environment is not suitable for crustacean plankton to live in. A majority of crustacean plankton in rivers is heterologous and possibly come from non-torrent environments such as the slack water bodies of bilateral river sides and the retarded flow of rivers or gulfs (Chen, 1990). Copepods are distributed in large rivers throughout China (Xu, 1990; Du and Lan, 1997; Tang and Liang, 1999; Sun et al., 2000; Hong and Chen, 2002; Xiang et al., 2004; Jiang et al., 2006). They are also distributed in different parts of the main rivers and large-scale tributaries along the Yangtze River (Chen, 1985; Wu et al., 2004; Xiang et al., 2004). The annual seasonal collection in multiple sections in the Three Gorges Reservoir shows that the ecological characteristics of copepods are inseparably related to the status of the sampling points and that the copepods are also distributed in many sections of the main river-status river water bodies in the Yangtze River.

The current study shows that some copepods species have adapted to the running water of large-scale rivers. The copepods were once collected in the river-status rivers

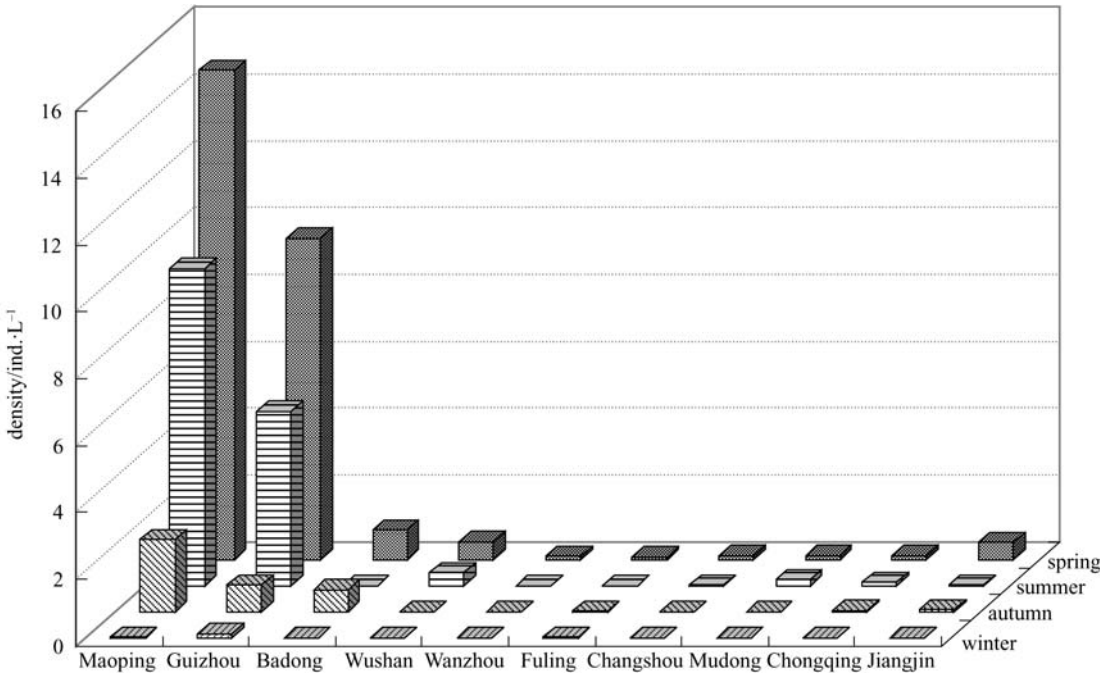

Fig. 2 Spatial and temporal distribution of copepod density in the Three Gorges Reservoir

and swift-flowing Xilinxia ravine before the Three Gorges Reservoir impoundment. The number of the copepod species in the reservoir lake county after the impoundment obviously increased, but the composition of the species has been quite different from that before the impoundment, as most species disappeared after the impoundment (Xue et al., 2006). Previous research also indicates that some copepods are not exogenous species and have already adapted to life in the fluvial environment. Most sections in river status had copepods, but the density was quite low. This suggests that even though some copepods have adapted to life in the lotic environment, it is difficult for them to achieve mass propagation.

The reservoir district from the down-drift river (the end of the backwater zone) to the area submerged by the water in the dam is commonly separated into three parts: the riverine zone, the transition zone, and the lacustrine zone. The significant differences in the physical and chemical factors of the water and its hydrologic characteristics are the main causes of the differences in the species and quantity of the zooplankton (Marzikf, 1990; Lin and Han, 2001). The spatial distribution of the zooplankton is a significant part of reservoir ecologic research (Betsil and Van Den Avely, 1994; Bini et al., 1997; Bernot et al., 2004). There are three types of distribution for zooplankton abundance: the nonlinear increase, the exponential growth and the anisomerous frequency distribution expression from the river to the dam (Marzikf, 1990).

The copepod density in the established part of the Three Gorges Reservoir was relatively low, caused by the seasonal change to winter. Apart from this, the density was quite high in the river status sections during the other three seasons. The copepod density distribution on the ordinate axis showed a nonlinear increase from the river to the dam. Similar findings have also been reported in other researches on the abundance ratio distribution in ravine-style reservoirs that the closer to the dam, the higher the copepod density is. This growth pattern is in connection with the difference in the stream between the rivers in the reservoir basin and the lacustrine regions. The environment in the front part of the dam along the downstream reservoir is habitable for copepods, thus the abundance ratio of the copepods in the slack water region (lacustrine regions) is relatively higher (Velho et al., 2001).

The species composition of copepods shows their otherness on the horizontal distribution of different sections along the reservoir ordinate axis. On the one hand, this otherness is due to the biologic and ecologic characteristics of the copepods during their long-term evolution. Some species have adapted to life in the lotic environments with river status and some have adapted to life in the relatively still river state environment, which results in composition differences between the regions with river status and reservoir status. On the other hand, since the Three Gorges Reservoir is a ravine-shaped reservoir with long and narrow river channels, long spacing from the upper reaches to the lower reaches, mass compositions of anabranches, and the afflux of these anabranches cause differences in the physical and chemical characteristics and the biological environment of water bodies in the different sections. The unique characteristics of the three zones result in the physical and chemical features and the hydrological regime of the water body being much more complex than any other ecumenic reservoir in the world,

and this composite factor is the direct cause of the expressional otherness of the copepods in different parts of the reservoir.

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