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Journal of Freshwater Ecology

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/tjfe20>

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Published online: 06 Jan 2011.

To cite this article: Shuchan Zhou , Xiangfei Huang & Qinghua Cai (2007) Vertical Distribution and Migration of Planktonic Rotifers in Xiangxi Bay of the Three Gorges Reservoir, China, *Journal of Freshwater Ecology*, 22:3, 441-449, DOI: [10.1080/02705060.2007.9664174](https://doi.org/10.1080/02705060.2007.9664174)

To link to this article: <http://dx.doi.org/10.1080/02705060.2007.9664174>

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Vertical Distribution and Migration of Planktonic Rotifers in Xiangxi Bay of the Three Gorges Reservoir, China

Shuchan Zhou^{a,b}, Xiangfei Huang^a, and Qinghua Cai^{a,c}

ABSTRACT

We investigated diel vertical migrations (DVM) and distributions of rotifers in summer, 2004 and spring, 2005, in Xiangxi Bay of the Three Gorges Reservoir, China. Water temperature, pH, conductivity, and phytoplankton were closely related to rotifer vertical distribution, while dissolved oxygen had no relationship with the vertical distribution of rotifers. The species composition and population density of rotifers changed significantly between seasons. However, rotifer vertical distributions in both seasons were similar. They aggregated at specific depths in the water column. All the rotifer species inhabited the surface layers (0.5-5 m). Generally, the rotifers did not display DVM except for *Polyarthra vulgaris* (in summer), which performed reverse migration. The reason that rotifers did not perform DVM may be explained by the low abundance of competitors and predators and the high density of food resources at the surface strata.

INTRODUCTION

Although zooplankters are sometimes described as “floating” in the water column, their populations show distinct horizontal and vertical distribution patterns; the vertical distribution is the result of active habitat choice (Lampert 2005). The daily change in vertical abundance of zooplankton, termed diel vertical migration (DVM), is a widespread phenomenon in marine and freshwater ecosystems (Hays 2003, Sims et al. 2005). DVM of zooplankton is usually considered a response to environment change (Kuczyńska-Kippen 2001), and many factors can influence it. The relative change in light intensity is usually considered the proximate cause, and predator avoidance is usually considered the ultimate cause of this behavior (Reichwaldt et al. 2004). The strongest DVM can be found in the presence of chemical trigger substances of fish (kairomones) (Dodson 1988, Loose and Dawidowicz 1994, Winder et al. 2003). However, DVM is a complex behavioral trait and cannot be explained by any single factor (Lass et al. 2000). Water temperature, food resource, oxygen content, UV radiation, and macrophytes can affect the distribution and migratory behavior of zooplankton (Mikschi 1989, Kuczyńska-Kippen 2001, Leech et al. 2005).

Vertical distribution and diel migration are two of the most interesting aspects of zooplankton ecology. The largest number of freshwater DVM studies has been on crustaceans; only a few were on rotifers (George and Fernando 1970, Stewart and George 1987) because crustaceans are bigger and better swimmers than rotifers, and their manipulation and observation are easier than for rotifers (Armengol and Miracle 2000). Among the studies about rotifer DVM (Miracle and Vicente 1983, Miracle and Alfonso 1993, Armengol et al. 1998), most were conducted in stratified lakes, while those on reservoirs are scanty (Bernot et al. 2004). This is likely because stratified lakes have some unique advantages. Thermal stratification of the water column creates conditions for structural heterogeneity (Galkovskaya and Mityanina 2005), and the stratification

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process is important in controlling rotifer vertical distribution (Baião and Boavida 2000).

With impoundment of the Three Gorges Reservoir, water depth in the outlet of Xiangxi River has increased from about 20 to 70 m; water current velocity has decreased from 0.43-0.92 m.s⁻¹ to 0.0020-0.0041 m.s⁻¹ (Zeng et al. 2006). The downstream segment (about 25 km) of the river is now called Xiangxi Bay (Zhou et al. 2006). We were interested in how zooplankton distributes vertically in a large water body, such as Xiangxi Bay. Because rotifers are the most diversified and abundant zooplankton group in this reservoir, we elected to conduct DVM research of the rotifers here. We specifically posed the following questions. How do rotifers distribute in the water column? Do the rotifers move in a diel cycle? Does the DVM change in different seasons? And, which factors are most important in inducing rotifer migration?

METHODS AND MATERIALS

The investigation was carried out at a point of maximal depth (30 m) in Xiangxi Bay (31.004°N, 110.763°E) over two 24-h periods -- July 2004 and April 2005. Each time, samples were collected every four hours from 0200 to 2200 h. The depths of sampling were 0.5 m, 2 m, 5 m, and then at every 5 m interval down to the bottom. Samples were collected with a 5-L modified Schindler-trap, fixed with Lugol's iodine, and concentrated by sedimentation. At each biological sampling, the following physicochemical parameters in the vertical profile were measured *in situ* (Horiba multimeter W-23XD): water temperature, pH, conductivity, and dissolved oxygen (DO). DO was only measured in April. Water transparency was measured in the daytime (1000, 1400, and 1800 h).

Rotifers were counted in two Sedgewick-Rafter subsamples. Densities of rotifers were determined for discrete species, and identification of rotifer species was according to Wang (1961), Koste (1978), Zhang and Huang (1991), and Zhuge (1997). Phytoplankton was quantified by 0.1 mL counting chamber. Phytoplankton density was expressed in terms of total cells of all species collectively.

A modified Kolmogorov-Smirnov test as used by Solow et al. (2000) was used to test the difference of the vertical distribution patterns of rotifers at different sampling times during the 24-h period. Simth et al. (1998) considered the two-sample Kolmogorov-Smirnov statistic was very suitable to test for equality of two population abundance profiles along a gradient, and the statistic was insensitive to large departures from the simple random sampling assumption. The significance level (P value) of the modified Kolmogorov-Smirnov test was assessed by running 1,000 randomizations and estimating the proportion of simulated values that exceeded the observed values. The criterion of significant level was 0.05. DVM was detected by comparing the daytime vertical profile and the night vertical profile.

RESULTS

During the 24-h sampling periods, Secchi transparency remained approximately constant, and there was no significant difference ($P>0.05$) between July (110 ± 12 cm) and April (133 ± 15 cm). Water temperature ranged from 23.9 to 30.2 °C in July, and from 13.9 to 17.5 °C in April. The vertical profiles were not significantly different between July and April, and there was no thermocline (Fig. 1). In July pH ranged from 7.9 to 9.8; in April it ranged from 7.9 to 8.8. The vertical profile of pH between the two seasons was significantly different ($P=0.03$). In July conductivity ranged from 129 to 182 $\mu\text{s} / \text{cm}$; in April it ranged from 464 to 495 $\mu\text{s} / \text{cm}$. The vertical profile in July was significantly different from that in April ($P=0.002$). The vertical profiles of all the environmental factors changed significantly during the 24-h periods. Water temperature and pH were significantly higher in daytime than that at night; conductivity was the reverse.

In both seasons, phytoplankton obtained higher density in the surface layers. In the upper layer (0.5-10 m), it was more abundant during daylight than that at night; in the deeper layers (>10 m) there was less change during the 24-h period (Fig. 2). In July the vertical profiles of phytoplankton at 0200, 0600, and 1000 h were significantly different ($P=0.019$) from those at 1400, 1800, and 2200 h. However, in April no significant differences in vertical profiles were detected among the sampling times. Although densities in July were higher than in April, overall the vertical distribution pattern of phytoplankton in July was similar to that in April ($P=0.126$).

Altogether 44 rotifer species were observed, but here we have elected to focus on

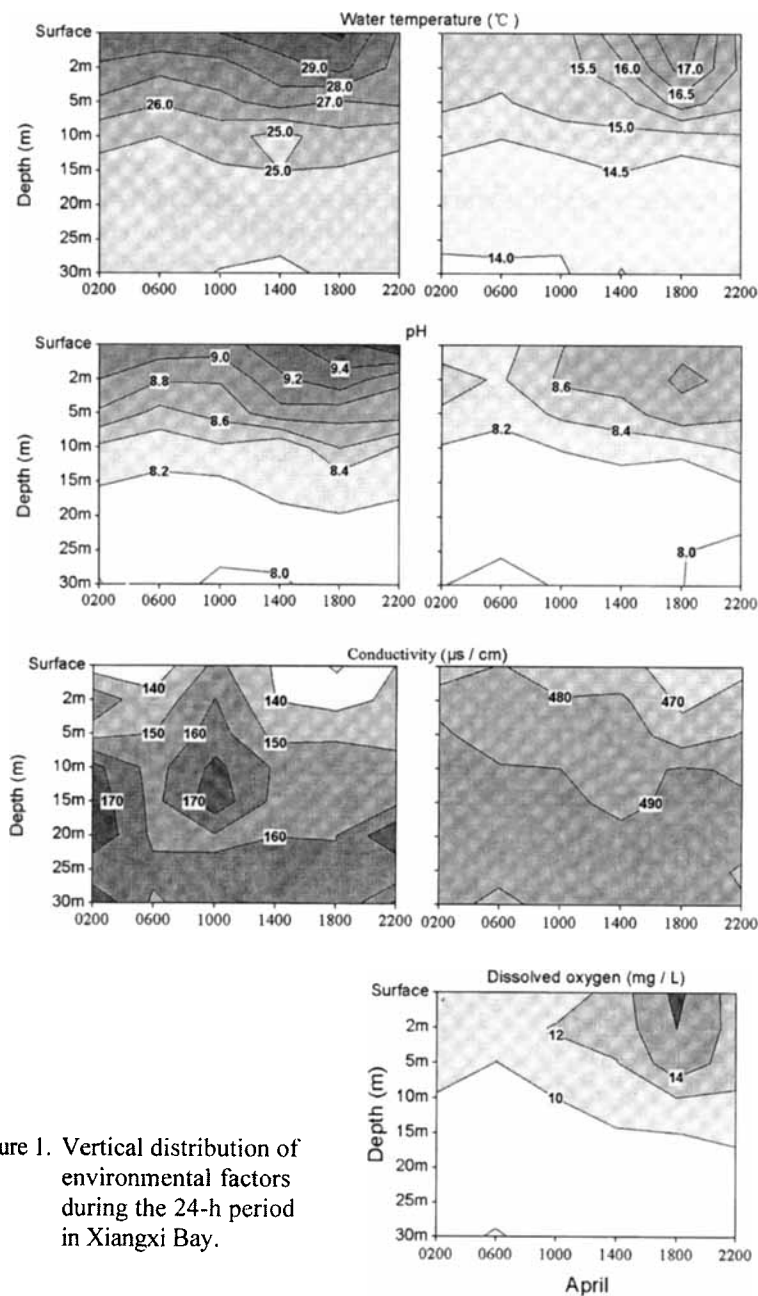


Figure 1. Vertical distribution of environmental factors during the 24-h period in Xiangxi Bay.

species whose mean densities were greater than 100 ind. /L. During the two sampling periods, the consistently dominant species were only three -- *Polyarthra vulgaris*, *Brachionus angularis*, and *Synchaeta tremula*. *B. angularis* was dominant in July; *S. tremula* was dominant in April. *P. vulgaris* was a co-dominant species. *Keratella valga* and *Keratella cochlearis* were the only other species whose mean densities were greater than 100 ind. /L.

P. vulgaris was a co-dominant species in both seasons. Its mean density was 646 ind. /L in July and 312 ind. /L in April. In July the highest density occurred at 1800 h at the depth of 2 m. In April the highest density occurred at 1000 h at the depth of 2 m (Fig.3). In July, there were more rotifers in surface layers at daytime than at night. The vertical profile of daytime was significantly different from that at night ($P=0.008$), which implied significantly migration had occurred during this period. *P. vulgaris* performed a reverse migratory pattern, staying in the upper layers at daytime and moving deeper at night. In April the vertical profiles were similar among the sampling times and no DVM was detected.

In July *B. angularis* was highly abundant in the bay. Its mean density was 707 ind. /L, with the highest of 2, 800 ind. /L at the depth of 2 m at 1800 h (Fig. 3). Most of them inhabited the surface layers. Although there were two peaks at the depth of 2 m, there was not any significantly difference of the vertical distributions in a diel cycle. Therefore, it did not perform any DVM.

S. tremula was one of dominant species in April. Its mean density was 358 ind. /L, with the highest of 1, 210 ind. /L at the depth of 0.5 m at 2200 h (Fig. 3). The vertical profile was similar during the diel cycle ($P>0.05$). No significant DVM was found.

K. valga was a third abundant species, with a mean density of 134 ind. /L, and highest density of 770 ind. /L at the depth of 2 m at 1800 h (Fig. 3). The vertical patterns were similar except for a little rise at the surface from 1800 to 2200 h. Still, there was no significant difference of vertical distribution between day and night ($P=0.758$). This indicated that no significant DVM of this species occurred.

K. cochlearis frequently occurred in the samples although its density was not high. Its mean density was 130 ind. /L; the highest density was 690 ind. /L at the depth of 2 m at 1800 h. The vertical patterns were similar except for a little rise at the surface at 1800 h (Fig. 3). There was no significant difference of vertical distribution between day and night ($P=0.337$). It did not perform any DVM.

Stepwise multiple regression indicated that rotifer vertical distribution had a strong relationship with water temperature, pH, conductivity, and phytoplankton density.

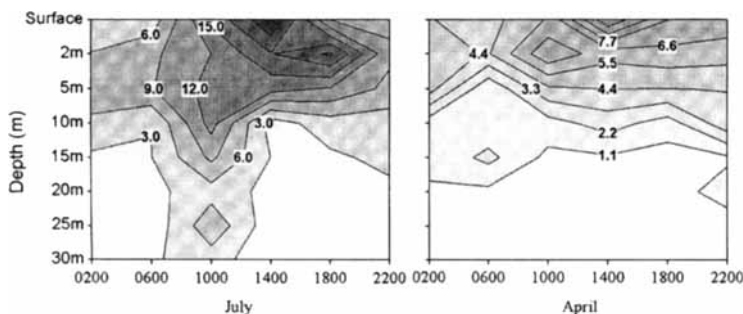


Figure 2. Diel vertical distribution of phytoplankton in Xiangxi Bay. Densities are given in cell $\times 10^6$ / L.

DISCUSSION

Although DO is often reported as one of key factors in restricting rotifer occurrence, distribution, and vertical migration (Hofmann 1977, Mikschi 1989, Baião and Boavida 2000, Arora and Mehra 2003), it had no relationship with the vertical distribution of rotifers in Xiangxi Bay. This is likely because DO was consistently high.

The vertical distribution of phytoplankton in Xiangxi Bay was dissimilar to that of those lakes which have a deep water algal maximum (highest algal densities are not found in the epilimnion but in the upper hypolimnion, below the thermocline) (Winder et al. 2003, Reichwaldt and Stibor 2005). In this bay, phytoplankton reached its highest numbers in the epilimnion. In a field study, phytoplankton was observed to perform a reverse migration which was an upward movement towards the surface during daylight and a downward movement in late afternoon or early evening (Jones 1993). Our result in July agrees with that pattern. Phytoplankton in July displayed an upward movement towards the surface strata from sunrise (0600 h) until to sunset (1800 h) and then descended to deeper layers at night. However, the vertical distribution in April was similar between day and night. This may be due to the weather conditions, since there was a cloudy sky on the sampling date in April.

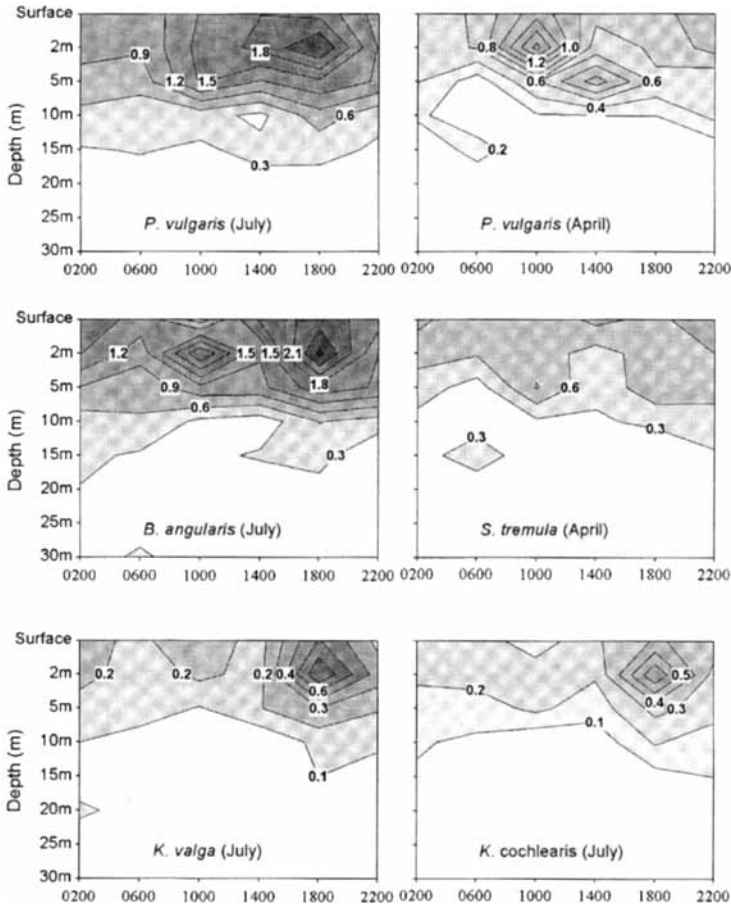


Figure 3. Diel vertical distributions of the dominant rotifer species in Xiangxi Bay in July and April. Densities are given in $\text{ind.} \times 10^3 / \text{L}$.

In stratified lakes, planktonic rotifers show a distinct vertical structure, and the structure was very much related to the depth of the thermocline and the depth of anoxic water (Burns and Mitchell 1980, Armengol-Díaz et al. 1993). The thermocline can serve as a refuge for some species to avoid visual predators. And the vertical distributions of rotifers in this water body were flexible. Sometimes they gathered just at the top of thermocline or oxycline; sometimes they assembled at the epilimnion stratum. However, they did not exhibit random distributions in the vertical profiles. That rotifers inhabited special layers in stratified water has been shown to be inherent in many rotifer species (Galkovskaya and Mityanina 2005). Planktonic rotifers in our study also inhabited in specific layers. It may also be inherent that rotifers inhabit specific layers whether or not the water body is stratified.

In many lakes planktonic rotifers did perform DVM (Stewart and George 1987, Jose de Paggi 1995, Armengol and Miracle 2000). However, in Xiangxi Bay planktonic rotifers (except for *P. vulgaris* in July) did not perform any DVM, although the vertical distribution of environmental and biotic factors were spatially heterogenous. Most of them developed large populations near the surface. Greater food availability in the surface layers may be the reason. There are many evidences that phytoplankton is the primary food resource for rotifers (Kirk 2002, Yoshida et al. 2003), and the dominant species of rotifers in Xiangxi Bay are herbivorous grazers (Kirk 2002). For instance, *P. vulgaris* was recognized as a rapid swimmer and a macrofilter-feeder, which feeds on small and large algae (Grzegorz et al. 2006). Therefore, it is not surprising that this rotifer followed the distribution of phytoplankton. It has been reported that phytoplankton concentration can modify zooplankton vertical distribution (Haney 1993).

On the other hand, DVM has been interpreted as a behavioral response to escape visual predators (Yamaguchi et al. 2004). The strength and pattern of DVM are related to predator abundance (Forward and Rittschof 1999). When predators are absent, it is not necessary to perform DVM. Hence, the fact that rotifers in Xiangxi Bay did not perform any DVM may be due to the lack of predators. There is evidence that crustaceans can effectively influence rotifer populations via predation and competition (Fussmann 1996). In this bay, the dominant crustacean was *Bosmina coregoni*, and its density was no more than 45 ind. / L (Xue et al. 2006). Although rotifers were described as the food resource for many species such as cladocerans, cyclopoid and calanoid copepods, predatory rotifers (*Asplanchna* sp.), and *Chaoborus* sp. (Conde-Porcuna and Declerck 1998, Bettez et al. 2002, Diéguez and Gilbert 2002), these kinds of predators were ephemeral species in Xiangxi Bay. At the same time, rotifers have evolved many defense mechanisms against invertebrate predators (Zurek 2006). In Xiangxi Bay all the dominant rotifers had the ability to escape predation due to having hard lorica, spines, or escape responses. Hence, it was not necessary for them to perform DVM and leave the higher food resource strata.

ACKNOWLEDGMENTS

We thank Daofeng Li, Ruiqiu Liu, Junzeng Xue, Lin Ye, and Fengqing Li for assistance with sample collection. We are grateful to Naicheng Wu for providing the phytoplankton data. This study was supported financially by the Key Project of Knowledge Innovation Program of CAS (No. KSCX2-SW-111), the Key Project of National Natural Science Foundation of China (No. 30330140), and the National Basic Research Priorities Programme (973 Programme) (No. 2002CB412300).

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