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Grazing Rates of Rotifers and Their Contribution to Community Grazing in the Nakdong River

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ABSTRACT: Rotifer grazing rates in both species and community levels on bacteria and phytoplankton were determined by using representative models (fluorescent beads: 0.75 μm for bacteria and 10 μm for phytoplankton) at biweekly intervals. One-year study at the lower part of the Nakdong River (Mulgum) indicated that the seasonal pattern of rotifer biomass was similar to that of total zooplankton biomass. Total mean biomass of rotifers was significantly higher than that of other groups (rotifers, 148±327 μgC/l; cladoceran, 25±69 μgC/l; copepodids, 58±159 μgC/l). For laboratory grazing experiments, mean specific filtering rate (SFR: ml · l^{-1} · day^{-1}) for rotifers varied from 0.001 to 0.726, and > 90% individuals of rotifer species took up fluorescent microspheres. The high SFRs were achieved by ***Brachionus angularis, B. calyciflorus,*** and ***Filinia longiseta.*** Community filtering rates (CFRs, ml · l^{-1} · day^{-1}) varied in the range from 2 ~ 1,670. Rotifer filtering rates on phytoplankton were much higher than bacterial filtering rates, especially in the late growing season (May, June, and November). Rotifers appear to be important in transferring both bacterial and phytoplankton carbon to higher trophic levels at the lower Nakdong River.

Key Words: Community filtering rates, Nakdong River, Rotifer grazing rates, Specific filtering rate.

INTRODUCTION

Although zooplankton herbivory (Thompson *et al.* 1982, Gosselain *et al.* 1996) and bacterivory (Urabe and Watanabe 1991, Hart and Jarvis 1993, Hwang and Heath 1999) have received increasing attention in freshwater ecosystems, the studies have mainly focused on the dynamics of certain limited taxa of organisms. Moreover, the relative importance of bacterivory and herbivory by various zooplankton taxa have been rarely assessed in river ecosystems (Kim 1999).

Rotifers are considered to be opportunistic r-strategists with a great reproductive potential (Allan 1976), capable of rapidly restoring populations following storm events. The natural systems, such as river with high flushing rates favor the growth of small zooplankton (Sprules and Jin 1990). Rotifers are capable of feeding on suspended solids and benthic detritus, bacteria, small phytoplankton, and protozoans (Bogdan *et al.* 1980, Bogdan and Gilbert 1982). Although rotifers affect phytoplankton assemblages in freshwater ecosystems, they are also important bacterial grazers in certain environments (Hwang and Heath 1999). Species that survive in hypertrophic systems consist mainly of efficient bacterivores and can alter relative proportions of bacteria and phytoplankton in their diet (Pejler 1983).

Due to a limited number of grazing studies in the river ecosystems (Sellner *et al.* 1993, Gosselain *et al.* 1996, Kobayashi *et al.* 1996), the question remains whether bacterial and phytoplankton biomass ultimately serves as a link or sink for higher trophic level, that is whether a significant proportion of bacterial and phytoplankton biomass is utilized or not in the microbial food web. In order to address this question, we compared rotiferan grazing on bacteria and phytoplankton in a hypertrophic river system. The contribution of rotifers to community grazing also was evaluated.

MATERIAL AND METHODS

Study site

The study site (25°44′N and 128°59′E) is located at Mulgum, about 26.5km upstream of the mouth of the Nakdong River (length of main channel, 528 km; catchment area, 23,817 km^2) (Fig. 1). The mid to lower stretch of the Nakdong River is almost devoid of side-habitats (over 90% composed of sand substrata) and its course is homogenous. The discharge at the lower part of the river is regulated by four major dams at tributaries and main channel of the river. In particular, the residence time of the lower Nakdong River has been strongly controlled by the estuarine dam built in 1987.

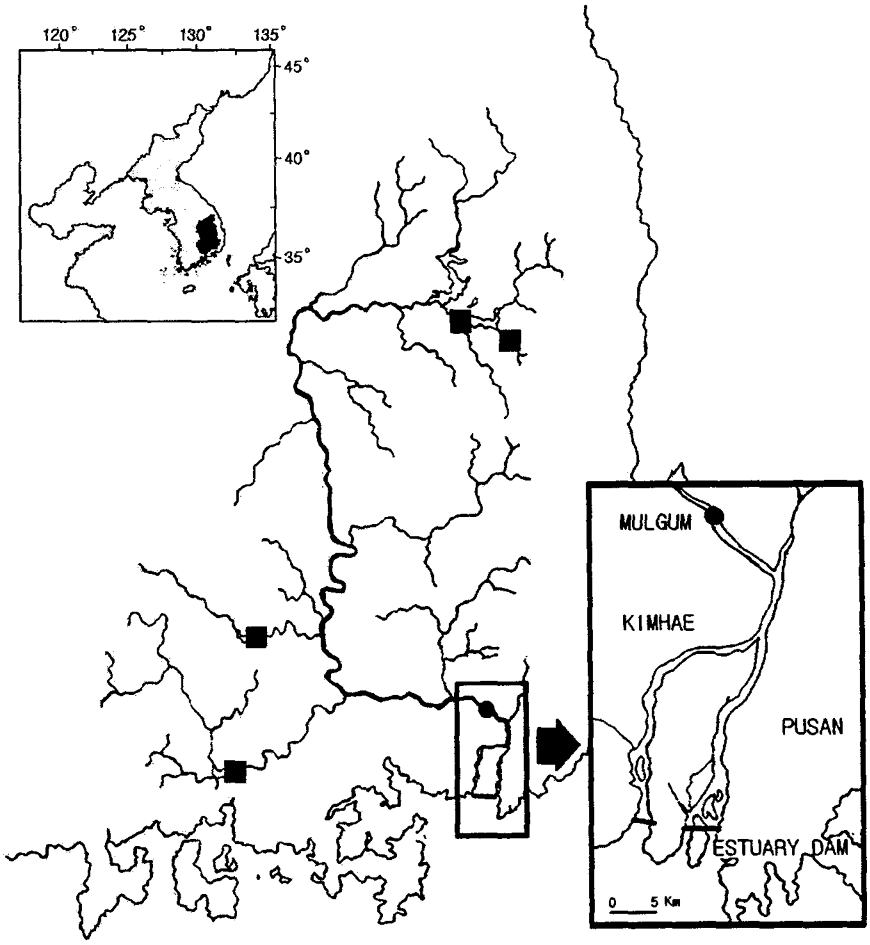

Fig. 1. Map showing the basin of the Nakdong River, major tributaries, and the study site. l: Mulgum, n: Multipurpose dams.

The lower part of the river became a "river-reservoir hybrid type" due to these changes in hydrology and eutrophication (Joo *et al.* 1997, Kim *et al.* 1998).

Measurement of basic limnological variables

Samplings were conducted from March 1998 to March 1999 at Mulgum at biweekly intervals. Water samples were collected at 0.5m depth with a 3.2 L Van Dorn water sampler, placed in 20L sterile polyethylene bottles, and kept in the shade at ambient temperatures until returned to the laboratory, within 1h of collection. Water temperature was measured using a YSI thermistor (Model 58). pH was measured using an Orion Model 407A pH meter. Dissolved oxygen was measured using DO meter (YSI 58), and the values were corrected by the Winkler titration method (APHA 1995).

Zooplankton collection and enumeration

Water samples for zooplankton was collected at 0.5m depth with a Van Dorn water sampler. Eight liters of river water was filtered through a 35μm mesh net, and collected zooplankton were preserved with a 10% formaldehyde solution in a plastic bottle. Rotifers were counted with an inverted microscope (Carl Zeiss Telaval 31) at 100 - 400 × magnification, and identified in genus or species levels with reference to Koste (1978), and Koste and Shiel (1987). Zooplankton biomass was estimated from length-dry weight relationships previously determined (Bottrell *et al.* 1976, Bird and Prairie 1985, Culver *et al.* 1985). The dry weights of rotifer taxa except bdelloids were taken from those available in the literature (Dumont *et al.* 1975, Bottrell *et al.* 1976, Makarewicz and Likens 1979). The dry weight of bdelloids was estimated from their volume measurements. Carbon content (μgC) was converted from the dry weight by the factor of 0.48 (Anderson and Hessen 1991).

Laboratory grazing experiments and statistical analysis

Grazing measurements were conducted on 25 occasions from March 1998 to March 1999. Samples in 2 and 4 L sterile polyethylene carboys were added with 0.75μm or 10μm fluorescent microspheres, representing 7~10% of natural bacterial and phytoplankton density. Incubations lasted for 10 to 30 min, and samples were filtered with a 35μm-mesh plankton net. Number of beads in zooplankton gut were counted and averaged from at least 5~20 individuals of each taxon. The following equation was used to calculate the specific filtering rate (SFR, ml · ind^{-1} · day^{-1}), with the assumption that fluorescent beads were non-selectively ingested with natural plankton communities:

$$\text{SFR} = (\text{B}_\text{A} \times 1440\ \text{min/day}) \ / \ (\text{B}_\text{M} \times \text{feeding time (min)})$$

where, SFR = specific filtering rate, B_A = mean number of beads in the species (beads/ind.), B_M = mean number of beads in the carboys (beads/ml), t = grazing time in minutes.

Rotifer community filtering rate (CFR; ml · l^{-1} · day^{-1}) was determined as the sum of SFRs from all taxa observed. Clearance rates (%/day) were expressed as the percentage of water volume cleared per day. Student's t - test was used to compare zooplankton biomass and abundance among different communities.

RESULTS

Basic limnology

During the experimental periods, water temperature of the river varied in the range of 2.5~27.7℃. In spring and winter, water temperaturs was dramatically changed. In summer, due to the frequent precipitation, water temperature much lower than the previous summers (~25 ℃) and low secchi transparency (mean ± s.d, 67 ± 33cm; n = 25) was observed. Annual mean pH and DO concentration were 8.0±0.9 and 10.9 ±3.6mg/l (n = 25), respectively. Both low pH (< 7) and DO concentration (< 7mg/l) were maintained during the summer (July and August).

Total zooplankton and rotifer biomass

Seasonal variation of total zooplankton biomass was significant. Total mean biomass of rotifers was significantly higher than other groups (rotifers, 120±144; cladocerans, 20±66; copepods, 40±130μgC/l) (t-test, $P<0.001$). Seasonal pattern of rotifer biomass variation was similar to that of total zooplankton biomass (Fig. 2).

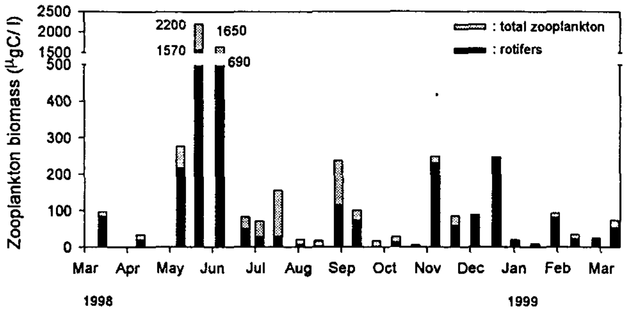

Fig. 2. Seasonal variation of total zooplankton and rotifer biomass.

The maximum zooplankton biomass was observed in late May. During rainfall events in August, zooplankton biomass sharply decreased. After flooding events, rotifer biomass rapidly increased and recovered to the pre-rain level within one month.

Specific filtration rate (SFR) and community filtering rate (CFR)

The results of laboratory grazing experiments are summarized in Table 1. Most of the zooplankton observed during the study period consistently took up microspheres of both bacterial and phytoplankton sizes, whereas some taxa never showed microspheres in their guts. Mean SFR (ml · ind^{-1} · day^{-1}) for rotifers varied from 0.002 to 0.726, and over 90% the individuals of rotifer species took up both sizes of fluorescent microspheres (Table 1). The high SFRs were achieved by *Brachionus angularis*, *B. calyciflorus*, and *Filinia longiseta*. Rotifer filtering rates on phytoplankton were much higher than those of bacteria, especially late in the growing season (May, June, and November) (Fig. 2). Based on the results of grazing experiments, *Brachionus angularis*, *B. rubens*, *Conocilus unicornis*, and *Filinia longiseta* were the most important bacterivorous zooplankton (Fig. 3). In contrast, *B. calyciflorus*, and *Notholca labis* showed high filtering on phytoplankton.

Seasonal variation of filtering rates on bacteria and phytoplankton were observed. Among the species filtering on bacteria, *B. angularis* (May-June and August), *B. rubens* (May), *C. unicornis* (May-June and August), *F. longiseta* (May-June and November), *B. calyciflorus* (May-June and November-December), and *N. labis* (November through March in 1999) were important grazers of phytoplankton (Fig. 3).

Rotifer CFRs were much higher than the macrozooplankton CFRs. CFRs (ml · l^{-1} · day^{-1}) and clearance rates (%/day) at Mulgum varied in the range of 2-1,670 ml · l^{-1} · day^{-1} and 0.1-167

Table 1. Specific filtering rate (SFR; ml · ind^{-1} · day^{-1}) by zooplankton species in the lower Nakdong River during March, 1998 - March, 1999 on the fluorescent microspheres (N = 6 ~14). Data are mean ± s.d.

Species	Bacteria Size(0.75 μm)	Phytoplankton Size(10 μm)
ROTIFERA		
Anuraeopsis fissa	0.036±0.027	*
Aspalnchna spp.	0.110±0.238	0.195±0.203
Brachionus angularis	0.726±0.285	0.043±0.040
B. calyciflorus	0.039±0.046	0.684±1.012
B. forticula	*	0.037±0.027
B. rubens	0.172±0.186	0.030±0.019
B. ureolaris	0.144±0.138	0.116±0.180
B. quadridentatus	0.017±0.016	0.081±0.064
Conochilus unicornis	0.172±0.074	*
Filinia longiseta	0.653±0.486	0.040±0.042
Hexarthra mira	0.342±0.318	0.215±0.243
Keratella cochlearis	0.009±0.008	0.002±0.002
K. valga	0.012±0.017	0.002±0.001
Lecane spp.	0.007±0.006	0.001±0.001
Lepadella oblongata	0.022±0.030	0.002±0.001
Monostyla spp.	0.007±0.010	*
Notholca labis	0.011±0.016	0.145±0.149
Philodium spp.	0.085±0.029	0.123±0.090
Polyarthra spp.	0.004±0.004	0.127±0.112
Synchaeta spp.	0.003±0.003	0.031±0.019
Trichocerca spp.	0.002±0.001	0.009±0.009

*; not found,

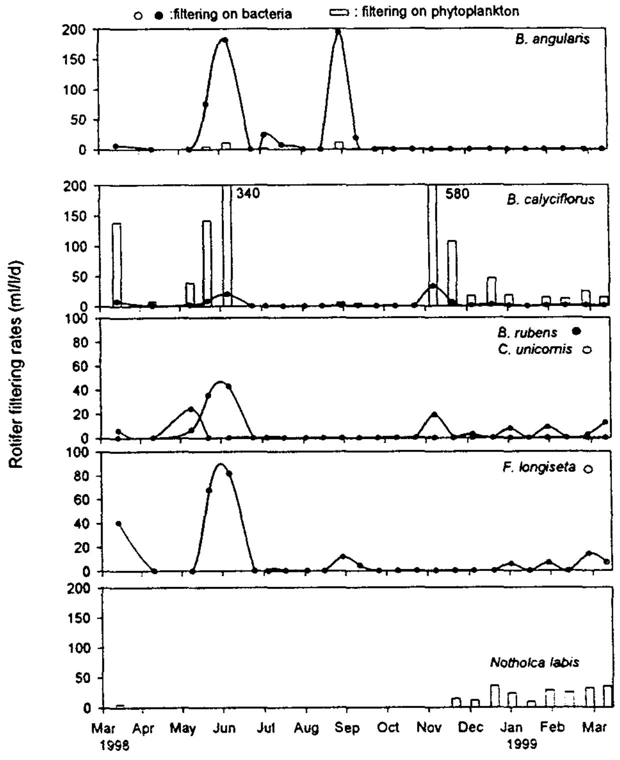

Fig. 3. Filtering rates (ml · l^{-1} · day^{-1}) of rotifer species on bacteria- and phytoplankton-sized microspheres.

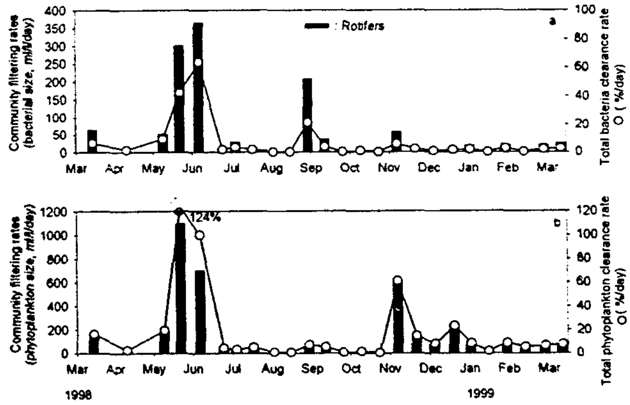

Fig. 4. Community filtering rates (ml · l^{-1} · day^{-1}) and rotifer clearance rates (%/day) on bacteria- and phytoplankton-sized microspheres.

%/day, respectively (Fig. 4). Average rotifer CFR on bacteria and phytoplankton was 50±95 and 151±262 ml · l^{-1} · day^{-1}, respectively. Average macrozooplankton (cladocerans and copepods) CFR on bacteria and phytoplankton was 20±58 and 22±65 ml · l^{-1} · day^{-1}, respectively.

DISCUSSION

In the lower Nakdong River, rotifers played an important role in grazing of bacteria- and phytoplankton-sized suspensions. Similar results were found at the coastal and offshore site of Lake Erie, where microzooplankton (mostly rotifers) were usually more important than macrozooplankton (primarily cladocerans) as bacterivores (Hwang and Heath 1999).

Zooplankton grazing rates in this river were within the range found in the literatures for zooplankton grazing in lakes. Rothhaupt (1990b) reported that SFR of *Brachionus calyciflorus* was about 0.72 ml · l^{-1} · day^{-1}. He noticed that SFRs increased with particle size and were highest for particles of about 10 μm ESD (equivalent spherical diameter) (Rothhaupt 1990a). Bogdan and Gilbert (1982) reported values between 0.024 and 1.272 ml · l^{-1} · day^{-1} for *Keratella* spp.. For other species, it was 0.001~0.336 ml · l^{-1} · day^{-1} for *Synchaeta* (Bogdan *et al.* 1980, Gilbert and Bodgan 1984), 0.008~0.05 ml · l^{-1} · day^{-1} for *Polyarthra* spp. (Bogdan *et al.* 1980), 0.042~0.096 ml · l^{-1} · day^{-1} for *B. angularis* (Walz 1983, Rothhaupt 1990a), and 0.072~0.264 ml · l^{-1} · day^{-1} for *B. rubens* (Rothhaupt 1990a).

Rotifer filtering rate on phytoplankton was slightly higher than that on bacteria. Christoffersen *et al.* (1990) reported that total zooplankton had high ingestion rates on phytoplankton, but low ingestion rates on bacteria in *in situ* grazing experiments. The efficiency on the small-sized fraction (bacteria) was 2 to 4 times lower than that on larger particles (phytoplankton). The results were similar to those of our study. From these results, we suspect that relatively more important food source for rotifer community would be phytoplankton rather than bacteria in this study. Nakdong River system generally contains an abundance of cyanobacteria in summer (Ha *et al.* 1998, 1999). Because colonial cyanobacteria are considered to be an inadequate food source of zooplankton (Lampert 1985), the role of bacterivorous zooplankton in summer may be potentially important in this river.

The large variability of filtering rates observed in this study, even within the same species, may depend on the ecological condition (temperature, grazable materials, competition with other zooplankton, etc.). Even though grazing activity of zooplankton (SFR) and grazing rates (%/day) of food source differed, rotifers appeared to be the important bacterial and phytoplankton grazers in this study. Overall, our results suggest that rotifers are a significant channel through which bacterial and phytoplankton C flows to higher trophic levels in this river food web.

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