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The Grazing Rates and Community Dynamics of Zooplankton in the Continuous River Stretch Ecosystem Include with Brackish Zone

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The zooplankton community dynamics and grazing experiments was evaluated along a 40 km section of the lower Seomjin river system. Zooplankton was sampled twice a month from January 2005 to June 2006 at three sites (River mouth; RK0, Seomjin bridge; RK12 and Gurae bridge; RK36) in the main river channel. During the study period, the values of most limnological parameters in the three sites were fairly similar, except for conductivity. Annual variation of conductivity in River mouth and Seomjin bridge was more dramatic than which of the other site. There were statistically significant spatial and seasonal differences in zooplankton abundance (ANOVA, $P<0.01$). Total abundance of major zooplankton groups at both stations was much higher than in Gurae bridge. Among the macrozooplankton, cladocerans abundance was negligible in study sites during study periods. Community filtering rates (CFRs) for phytoplankton and bacteria varied from 0 to 50 mL L^{-1} D^{-1} and from 0 to 45 mL L^{-1} D^{-1}, respectively. The spatial variation of CFRs for phytoplankton was significant (ANOVA, $P<0.05$). The CFRs of copepods for phytoplankton and bacteria was much higher than that of cladocerans at study sites. Total zooplankton filtering rates on bacteria were slightly lower than filtering rates on phytoplankton. The CFRs of microzooplankton (MICZ) for bacteria were much higher than for macrozooplankton (MACZ) at all sites. Considering the total zooplankton community, MICZ generally were more important than MACZ as grazers of bacteria and phytoplankton in freshwater zone, while MACZ were more important than MICZ as grazers of phytoplankton in brackish zone.

Key words : rotifers, Seomjin River, community filtering rates, brackish, copepods

INTRODUCTION

Although zooplankton are generally considered to be an important component of the plankton food web in large rivers, studies of their function are relatively rare. In freshwater rivers, small-bodied zooplankton is often dominated throughout the year (Kim *et al*., 1999, 2000, 2002; Kim and Joo, 2000), with no marked development of large-bodied zooplankton populations (Kobayashi, 1997; Viroux, 1997). More recent research has considered other aspects of river zooplankton dynamics, including interactions between algae and zooplankton, and the factors regulating plankton biomass (Basu and Pick, 1997; Kim *et al*., 2003).

The rare studies that have devoted some effort to the analysis of the zooplankton distribution in the river mouth include brackish zone in S.

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Korea (Kim *et al*., 2000a, b). As large-bodied zooplankton are virtually absent from large rivers because of the short residence times (Pace *et al*., 1992; Marneffe *et al*., 1996), one would not expect a significant influence of grazing on algae structure and biomass. However, several authors (Jones *et al*., 1990; Simenstad *et al*., 1990) concluded that the roles of large-bodied zooplankton and major zooplankton groups can be changed by the principal physical and biological processes in river estuary zone (e.g., tidal flow, salinity patterns, etc). Furthermore, freshwater species are displaced by saline species at river mouth and estuarine areas (Egborge, 1987; Tafe, 1990; Conley and Turner, 1991).

The ecology of freshwater zooplankton in Korean rivers is still little investigated except for the Nakdong River (Kim *et al*., 1999). In the present study, the community structure and grazing rates of zooplankton was investigated at different sites in the Seomjin River, one of the coastal rivers is an example of the "regulated river" and it provides a good case study of the river without an estuarine dam in Korea. Especially, we compared microzooplankton (MICZ: mostly nauplii and rotifers) and macrozooplankton (MACZ: mostly copepods and cladocerans) grazing on bacteria and phytoplankton in a lowland river system.

MATERIALS AND METHODS

1. General information of the Seomjin River

The river shows typical characteristics of lowland Korean rivers, being hydrologically regulated by a series of multipurpose dams in the headwater tributary and upper part of the river (Fig. 1). The river flows in a southward direction of South Korea (34-35°N, 126-127°E). The length of the main river channel is approximately 212 km, with a total drainage area of 4,896 km^2. The mean annual rainfall was ca. 1,536 mm on the river basin (Fig. 2). The rainfall during summer provides about 60% of total annual precipitation, while fall and winter are dry with little precipitation.

2. Sampling procedures

Sampling was carried out in the three sites of the Seomjin River on twice monthly intervals

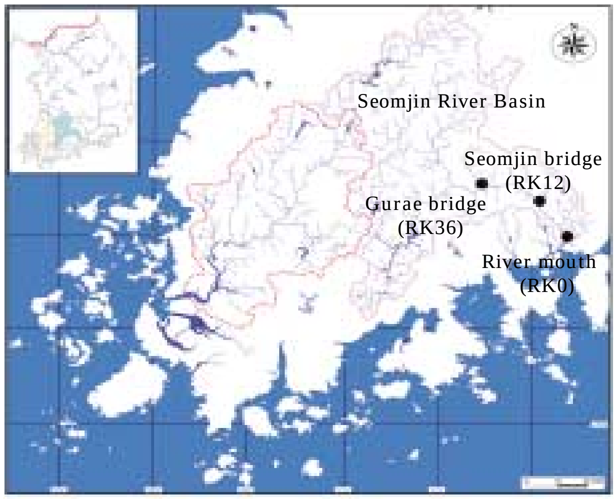

Fig. 1. Map showing the basin of the Seomjin River and study sites (●: River mouth; Seomjin bridge; Gurae bridge).

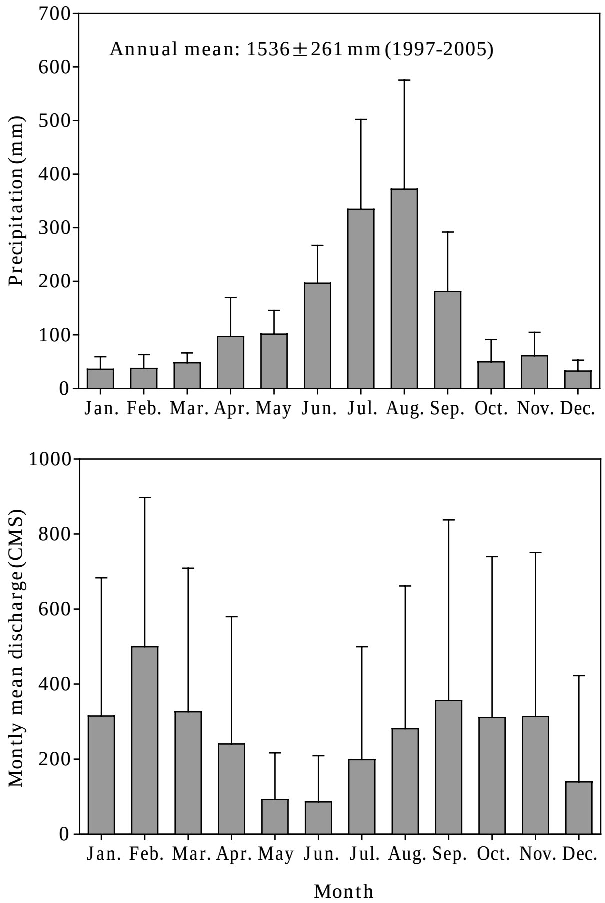

Fig. 2. Changes in monthly average precipitation (1997-2005) at central river basin and monthly average discharge (2005) at Hadong gauging station.

from Jan. 2005 to Jun. 2006. Three sites are located from the estuary of the river these sites are: 36 km (Gurae bridge), 12 km (Seomjin bridge), and 0 km (Seomjin river mouth) (Fig. 1). Water samples were obtained from 0.5 m depth with a Van Dorn sampler, placed into 20 L sterile polyethylene bottles, and kept in the shade at ambient temperatures until return to the laboratory (within 2 h of after collection).

3. Environmental variables

Water temperature and dissolved oxygen were measured with a YSI Model 58 meter. Chemical features (conductivity, oxygen and pH) were determined from water samples. Conductivity was measured using a Fisher conductivity meter (Model 152). Dissolved oxygen (mg L^{-1}) was measured using a DO meter (YSI Model 58). pH was measured using an Orion Model 407A pH meter.

4. Zooplankton sample collection and enumeration

For the determination of zooplankton density and biomass, 20 L samples of water were collected from 0.5-1 m depth. The collected water was filtered through a 35 μm mesh net, and preserved with 10% (final conc.) formalin. Macrozooplankton (cladocerans and copepods) were counted at 50× magnification, and microzooplankton (nauplii and rotifers) were counted at 100× magnification using an inverted microscope. Zooplankton were identified to genus or species level according to Bayly (1992), Koste (1978), Koste and Shiel (1987), and Smirnov and Timms (1983).

5. Laboratory grazing experiments

Grazing experiments were conducted on 10 occasions from Jan. 2005 to Jun. 2006. Species-specific filtering rates (SFR: mL $ind.^{-1}$ h^{-1}) were directly measured based on time course measurements (0, 1, 2, 5, 10 and 30 min, n=3) with both size of fluorescent microspheres (FM: 0.75 and 10 μm diameters) were made (Kim *et al.*, 2000). Community filtering rates (mL L^{-1} D^{-1}) was determined as the sum of SFRs from all taxa observed.

6. Statistical analysis

A two-way nonparametric ANOVA was used to test for significant effects of location and season on the abundance of total zooplankton, rotifers, cladocerans, copepods and nauplii. Statistical analyses were performed using SAS Stat Version 6.12 (Statistical Analysis Systems Institute, 1996). Significant differences were identified at 95% level.

RESULTS

1. Environmental variables

During the study period, the values of most limnological parameters in the three sites were fairly similar, except for conductivity (Table 1). The range of water temperature was 0.4°C through 31.9°C in the three sites during the period January 2005 through June 2006. Average water temperatures were not highly variable in the three sites. Ranges of average pH and dissolved oxygen (DO) concentration were 8.0-8.3 and 9.7-10.5 mg L^{-1} in the three sites during the study period. Conductivity in the river mouth generally was higher than that of other sites. Annual variation of conductivity in the river mouth and Seomjin bridge was more dramatic than which of the other site (Table 1). High variation of turbidity was observed at both stations (Gurae bridge and River mouth), while the low variation of turbidity was observed in the Seomjin bridge during the study period (Table 1).

Table 1. Means, standard deviations, and ranges of limnological parameters in study sites of the Seomjin River during 2005-2006 (n=28).

	Unit	Gurae bridge (RK36)	Seomjin bridge (RK12)	River mouth (RK0)
Temperature	°C	14.5±9.0 (0.4-31.9)	13.9±8.4 (2.4-31.2)	14.4±7.8 (3.8-30.2)
pH		8.3±0.6 (7.0-9.7)	8.3±0.3 (7.7-8.9)	8.0±0.3 (7.0-8.5)
Conductivity	μS cm^{-1}	129±22 (86-164)	7,251±13,339 (90-51,000)	20,505±8,104 (7,530-47000)
Dissolved oxygen	mg L^{-1}	10.5±3.0 (6.6-16.9)	10.0±2.5 (7.3-15.4)	9.7±2.1 (6.4-13.6)
Turbidity	NTU	7.9±11.4 (2.2-58.3)	5.5±4.3 (2.2-21.2)	7.0±6.7 (1.8-31.8)

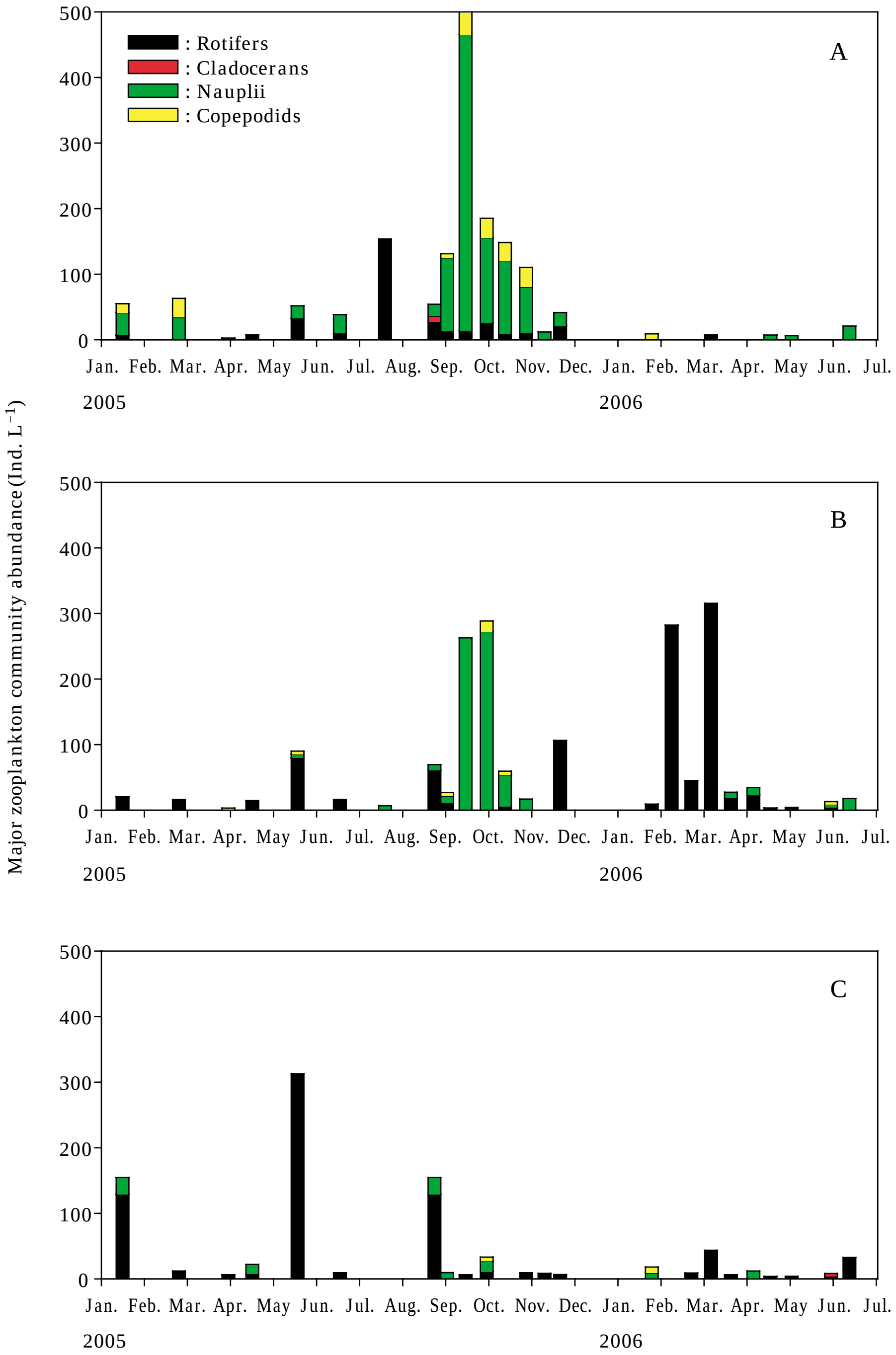

Fig. 3. Seasonal changes of major zooplankton community abundance (Ind. L^{-1}) at three sampling sites (A: River mouth, B: Seomjin bridge, C: Gurae bridge).

2. Zooplankton community dynamics

There were statistically significant spatial and seasonal differences in zooplankton abundance (ANOVA, $P<0.01$). Total abundance of major zooplankton groups at both stations (RK0 and RK12) was much higher than in Gurae bridge (RK36) (Fig. 3). The timing and magnitude of major community occurrences appeared to be consistent across seasonal cycles of zooplankton in the three sites. Total mean abundance of rotifer was much higher than observed for other zoo-

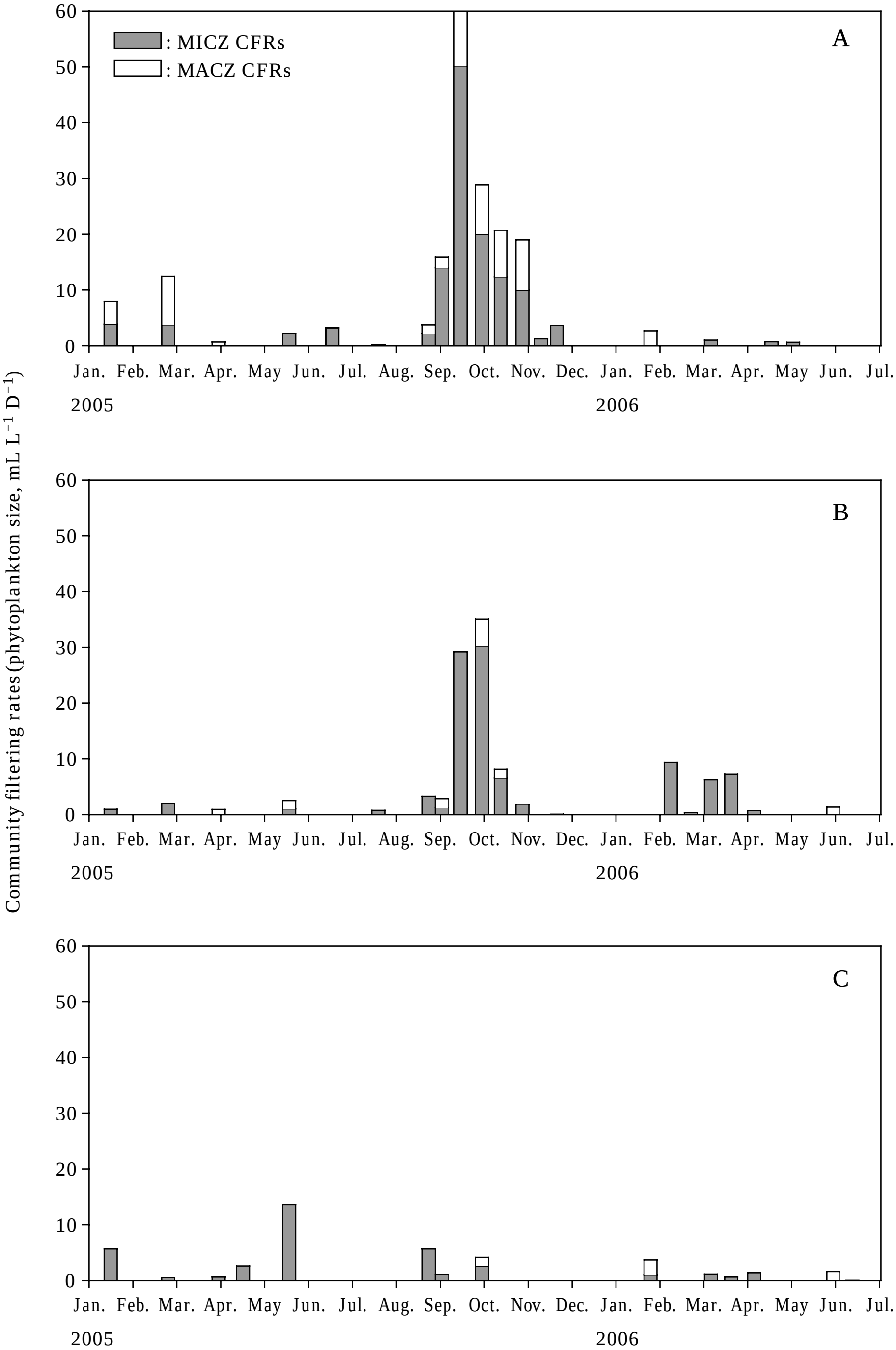

Fig. 4. Seasonal changes of micro-macrozooplankton community filtering rates (CFRs; mL L^{-1} D^{-1}) on phytoplankton (MICZ: microzooplankton=nauplii+rotifers, MACZ: macrozooplankton=cladocerans+copepods) (A: River mouth, B: Seomjin bridge, C: Gurae bridge).

plankton groups (rotifers=35.7±77.4 Ind. L^{-1}; cladocerans=0.1±0.1 Ind. L^{-1}, copepods=1.3±3.3 Ind. L^{-1}, nauplii=23.2±68.4 Ind. L^{-1}) in Gurae bridge. Among the macrozooplankton, cladocerans abundance was negligible in study sites during study periods.

In early fall, high peaks of nauplii abundance were observed at both stations (River mouth and

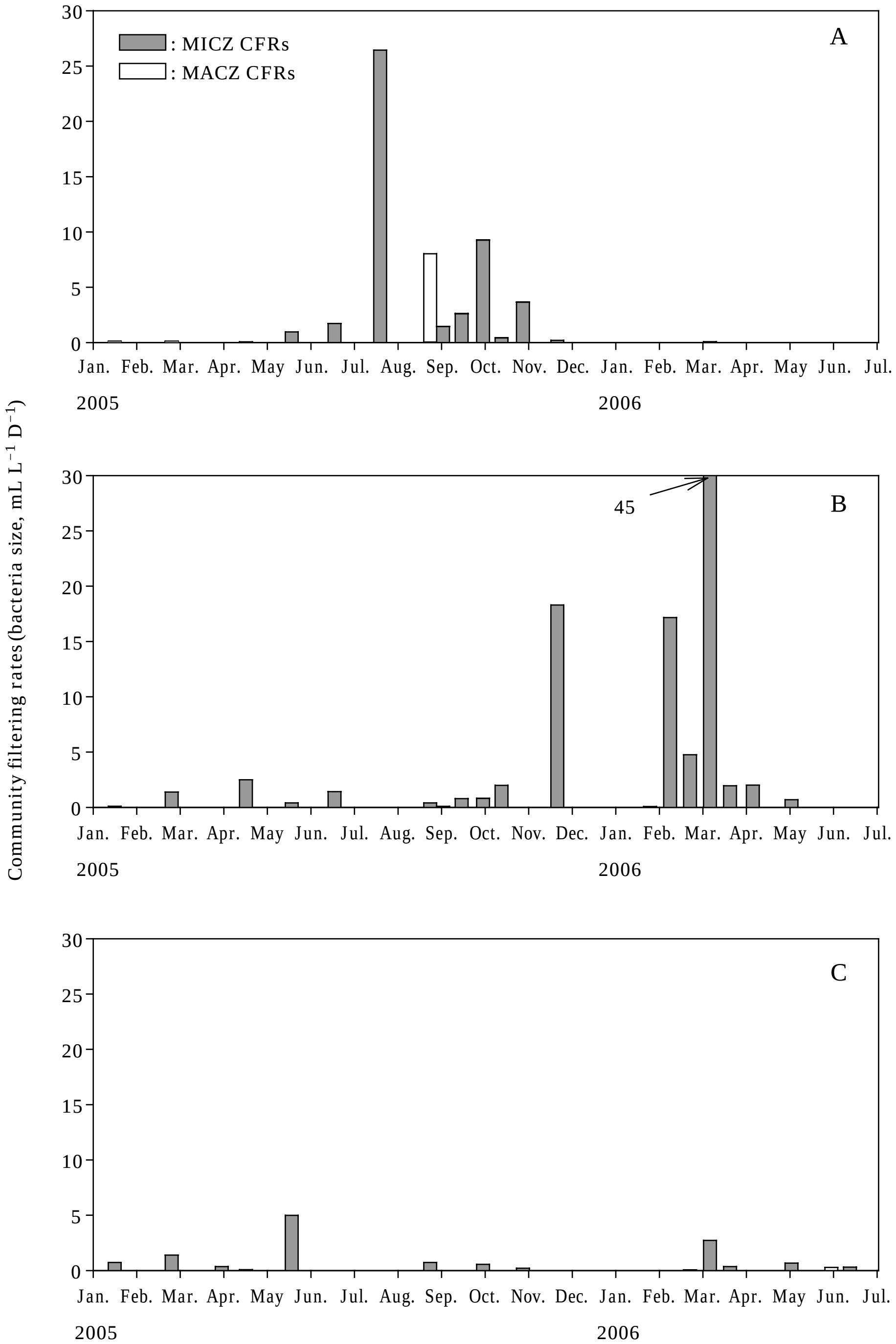

Fig. 5. Seasonal changes of micro-macrozooplankton community filtering rates (CFRs; mL L^{-1} D^{-1}) on bacteria (MICZ: microzooplankton=nauplii+rotifers, MACZ: macrozooplankton=cladocerans+copepods) (A: River mouth, B: Seomjin bridge, C: Gurae bridge).

Seomjin bridge), while high abundance of nauplii were not observed in Gurae bridge. In river mouth, copepods abundance was much higher than that of other sites (Fig. 3). In the early spring of 2006, high peaks of rotifers density at Seomjin bridge were observed due to the both species (*Colurella* and *Synchaeta*).

3. Community filtering rates (CFRs) based on microsphere uptake

Community filtering rates for phytoplankton and bacteria varied from 0 to 50 mL L^{-1} D^{-1} and from 0 to 45 mL L^{-1} D^{-1}, respectively. The spatial variation of CFRs for phytoplankton was significant (ANOVA, $P < 0.05$). The CFRs of microzooplankton (MICZ: rotifers and nauplii) for phytoplankton were much higher than for macrozooplankton (MACZ: cladocerans and copepods) at both sites (Seomjin and Gurae bridge), while the CFRs of MICZ for phytoplankton were slightly higher than for MACZ at river mouth (Fig. 4). Among CFRs of MICZ, the average CFRs of nauplii (4.03 ± 9.76 mL L^{-1} D^{-1}) for phytoplankton was nearly tenfold higher than the average CFRs of rotifers (0.43 ± 1.13 mL L^{-1} D^{-1}) at river mouth. The CFRs of copepods for phytoplankton and bacteria was much higher than that of cladocerans at study sites. The CFRs of copepods for phytoplankton at river mouth was much higher than that of other sites (Fig. 4).

Total zooplankton filtering rates on bacteria were slightly lower than filtering rates on phytoplankton (Figs. 4, 5). CFRs on bacteria differed significantly by season and location (ANOVA, $P < 0.01$). The CFRs of MICZ for bacteria were much higher than for MACZ at all sites (Fig. 5). The CFRs of rotifer for bacteria were much higher than for other zooplankton groups.

DISCUSSION

There were notable differences in zooplankton community structure and abundance along the main channel of the Seomjin River, reflecting the heterogeneous nature of this continuous river stretch ecosystem include with brackish zone. The biomass of zooplankton in Seomjin River was substantially higher in the tidal freshwater portion than that in the non-tidal portion (Fig. 3). Kim and Joo (2000) reported that all major zooplankton taxonomic groups significantly increased in their abundance toward the mouth of the river. This is consistent with the pattern described by De Ruyter Van Steveninck *et al.*, (1992). According to this study, zooplankton cannot maintain significant densities in the middle reaches of a river, because reproductive rates cannot keep up with losses due to high flushing rates.

River zooplankton are often characteristically dominated by small forms such as rotifers and juvenile copepods (Kim *et al.*, 2003). The high rotifer densities may indicate a high rate of energy transfer between the producers and herbivores in the regulated river ecosystems (Pace *et al.*, 1992; Kim *et al.*, 2003). At present, owing to the predominance of small-bodied zooplankton (mostly nauplii) and large-bodied zooplankton (mostly copepods) in the river mouth, the impact of zooplankton community grazing appears likely to be linked to a small-size fraction of the algae community during growing seasons. Functionally, such grazing rates are influenced primarily by body size and biomass of grazers. Community grazing rates increase with increasing community biomass (Cyr and Pace, 1992). Considering these results on zooplankton community dynamics and grazing effects in the river system, the small-bodied population (mostly nauplii) and copepods could be appeared to play an important role in regulating total microbial food web.

In many North American and European rivers (Cohen *et al.*, 1984; Welker and Walz, 1998), benthic bivalves also appear to be important to the carbon and nutrients dynamics. Hwang *et al.* (2004) noted that strong filtering by *Corbicula leana* caused dramatic changes in phytoplankton composition and density in Korean lakes. Based on the C-flux to biomass ratio, *Corbicula leana* consumed 170-754% (avg. 412%) of phytoplankton standing stock in Lake Soyang per day (Hwang *et al.*, 2004). Although the role of these animals has not been quantified in the Seomjin River, I believe that their impacts (on the algae and bacteria) may be large relative zooplankton because their densities are high. In recent collections in study site (Seomjin bridge), I found that bivalves (*Corbicula* sp.) occurred at densities $> 1{,}000$ Ind. m^{-2}. This is quite high in comparison with other rivers where theses populations exert grazing impacts.

In conclusion, these results suggest that microzooplankton (especially nauplii) and copepods is a significant channel through which bacterial and algal carbon flows to higher trophic levels in the lower Seomjin River food web.

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<국문적요>

기수 지역을 포함한 연속적인 강 구획 생태계 내에서의 동물플랑크톤의 군집 동태와 섭식율

김 현 우

(순천대학교 환경교육과)

섬진강 하류 약 40 km 구간에서 동물플랑크톤 군집 동태 파악과 동물플랑크톤 섭식율 실험을 수행하였다. 강 본류 구간 내 3지점(강 하구: RK0, 섬진교: RK12, 구례교: RK36)에서 2005년 1월 부터 2006년 6월까지 2주 간격으로 동물플랑크톤 시료를 채집하였다. 조사기간 동안 3지점간 대부분의 육수학적 항목의 변화는 유사하였으나, 전기전도도는 조사 지점간 변이가 높았다. 강 하구와 섬진교 지점의 전기전도도 연간 변이는 구례교 지점의 전기전도도 변이보다 매우 역동적인 변화를 나타내었다. 동물플랑크톤 밀도의 지점별, 계절별 차이는 통계적으로 유의하였다 (ANOVA, $P<0.01$). 강 하구와 섬진교 지점의 주요 동물플랑크톤 군집 총 개체수는 구례교 지점보다 높았다. 대형동물플랑크톤 군집 중, 지각류 밀도는 조사기간 동안 매우 낮았다. 식물플랑크톤 및 박테리아에 대한 동물플랑크톤의 군집 섭식율 변이는 각각 0에서 50 mL L^{-1} D^{-1} 그리고 0에서 45 mL L^{-1} D^{-1} 였다. 식물플랑크톤에 대한 CFR의 지점별 변이는 통계적으로 유의하였다(ANOVA, $P<0.05$). 전 조사지점 내에서 식물플랑크톤과 박테리아에 대한 요각류의 CFR은 지각류에 비해 현저히 높았다. 박테리아에 대한 총 동물플랑크톤 섭식율은 식물플랑크톤의 섭식율에 비해 다소 낮았다. 박테리아에 대한 소형 동물플랑크톤의 CFR은 대형 동물플랑크톤에 비해 매우 높았다. 총 동물플랑크톤 군집 조성을 고려 해볼 때, 담수지역에서는 박테리아와 식물플랑크톤에 대한 섭식율이 대형동물플랑크톤 보다는 소형 동물플랑크톤의 역할이 상대적으로 중요하며, 반면에 기수역 지역에서는 담수지역에 비해 상대적으로 식물플랑크톤에 대한 소형 동물플랑크톤의 섭식율 보다는 오히려 대형 동물플랑크톤의 섭식 기여도가 높은 것으로 파악되었다.