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Population Dynamics of Predator (*Asplanchna* spp.) and its Impact on Herbivorous Rotifers Community in Three Tributaries of the Nakdong River (S. Korea)

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The herbivorous rotifers community (*Brachionus* spp.) and population dynamics of the predator rotifer (*Asplanchna* spp.) in three tributaries (Kumho R., Nam R., and Hwang R.) of the Nakdong River were evaluated on biweekly intervals from Jan. 2001 and Dec. 2002. High abundance of the herbivorous rotifers (peak density: - ca. >1000 Ind. L^{-1}) was observed from two tributaries (Kumho R. and Nam R.) during the spring and fall seasons, respectively. The high peaks of herbivorous rotifers were not evident in one tributary (Hwang R.). Among the herbivorous rotifers, brachionid rotifers (*Brachionus* spp. consisting of 7 species) were the characteristic rotifer community in this study. *Brachionus* spp. tended to occur together with the other perennial species, *Asplanchna*. *Asplanchna* was also present while two species of *B. angularis* and *B. calyciflorus* were highest in density. Subsequently, two populations (*B. angularis* and *B. calyciflorus*) rapidly declined, becoming rare after high peaks of *Asplanchna* occurred, except in one tributary (Hwang R.). We found community shifts in rotifer groups in mid-spring and mid-fall at the study site. The *Asplanchna* population could be appeared to play an important role in regulating the rotifer community and total plankton biomass in spring and fall at high trophic levels.

Key words : herbivorous rotifers, *Asplanchna*, *Brachionus*, Nakdong river

INTRODUCTION

Regulation of zooplankton density and diversity in freshwater bodies is the result of a number of factors. Among the abiotic factors, temperature of the lake (Hutchison, 1967) and hydrological parameters in the regulated river (Kim *et al*., 1999, 2000, 2001; Kim and Joo, 2000) while among the biotic interactions food availability and predation are the major forces influencing the abundance of zooplankton (Lampert and Sommer, 1997). Metazoan zooplankton in the river is mainly composed of rotifers and crustaceans. Most cladocerans, calanoid copepods, and planktonic rotifers are herbivorous (Kim, 1999; Dodson and Frey, 2001; Williamson and Reid, 2001). However, the family Asplanchnidae has members which are predominantly carnivorous, often engulfing other rotifers, ciliates and some crustaceans (Koste, 1978). A variety of invertebrates such as insects and the predatory genera of rotifers such as *Asplanchna*,

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Asplanchnopus, *Dicranophorus*, *Ploesoma*, and *Encentrum* also exert great pressure on the abundance of herbivorous zooplankton (Stemberger and Gilbert, 1987; Bevington *et al*., 1995).

According to *in situ* experiment research, *Asplanchna* is an important predator on smaller zooplankton, especially other rotifers, ciliates and, to some extent, cladocerans. Therefore *Asplanchna*−controlled changes in the abundance and diversity of herbivorous rotifers can be significant. Much literature is available on the food and feeding habits of *Asplanchna* in laboratory studies (Dumont, 1977; Pourriot, 1977; Williamson, 1983; Iyer, 1989; reviewed in Arndt, 1993). Since *Asplanchna* responds both functionally and numerically to increased prey densities, it could also play an important role in structuring zooplankton communities (Gaudy *et al*., 1995).

Therefore, in the present study, we compared the population dynamics of the herbivorous rotifers in the different water quality of the three tributaries. Especially, we also attempted to evaluate the population dynamics of the predator rotifers (*Asplanchna* spp.) fed brachionid rotifers raised on different categories of water sample in the three tributaries of the Nakdong River.

MATERIALS AND METHODS

General information of the Nakdong River and major tributaries

The river in the south−east of South Korea has been drastically modified during the last 3 decades (length: ca. 525 km, drainage area: ca. 23,817 km^2). The channel slope is very slight and the flow rate is slow, the retention time assumes similar aspects of the reservoir. The lower part of the river has become a "river−reservoir hybrid" due to these changes in hydrology (Kim *et al*., 1998, 2002). The mean annual rainfall was ca. 1,211 mm on the river basin. The rainfall during summer provides about 60% of total annual precipitation, while fall and winter are dry with little precipitation (Park, 1998). Because the river has relatively high nutrient concentrations, it experiences blooms of cyanobacteria that are indicative of cultural eutrophication (Ha *et al*., 1999).

There are more than ten tributaries in the Nakdong River. Among tributaries, Nam River and Kumho River have been provided more favorable conditions for plankton to develop, including low water velocity and high nutrients concentrations. Nam River is the longest tributary that totally reaches ca. 187 km long (river basin, ca. 3,493 km^2). The Kumho River was the primary pollutant sources in the middle and lower parts of the Nakdong River (Kim, 1996). Considering the present condition of the pollution, the pollution load in the Kumho River (length: ca. 118 km, drainage area: ca. 2,088 km^2) is 9.89 billion ton per day and is the principal offense of the pollution in the lower Nakdong River occupied by 39.2% of total pollution load in the Nakdong hydrosphere. In contrast, the Hwang River (length: ca. 111 km, drainage area: ca. 1,332 km^2) supported a smaller plankton community due to rapid flushing and low nutrient concentrations (Kim *et al*., 2001).

Sampling procedures

Sampling was carried out in the three tributaries of the Nakdong River on bi−weekly intervals from 2001 to 2002. Three tributaries are located from the estuary barrage of the river these sites are: 87.7 km (Nam River), 115 km (Hwang River), and 167 km (Kumho River) (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 8 h of after collection).

Basic limnology

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

Zooplankton sample collection and enumeration

For the determination of zooplankton density and biomass, 8 L samples of water were collected from 0.5 m depth. The collected water was filtered through a 35 μm mesh net, and preserved with 10% (final concentration) 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 (with the exception of juvenile copepods) according to Bayly (1992), Koste (1978), Koste and Shiel (1987), and Smirnov and Timms (1983).

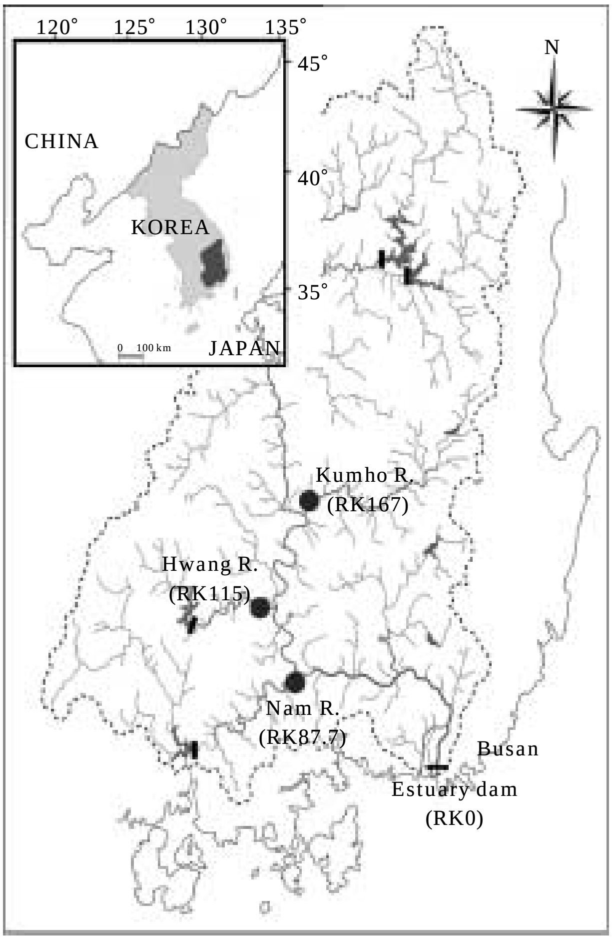

Fig. 1. Map showing the basin of the Nakdong River and study sites (●: Kumho R.; Hwang R.; Nam R.).

Statistical analysis

One-way analysis of variance (ANOVA) was used to compare environmental parameters among months of sampling. A Student's *t*-test was used to compare zooplankton biomass and abundance between years. Statistical analyses were performed using SAS Stat Version 6.12 (Statistical Analysis Systems Institute, 1996). Significant differences and correlations were identified as $P < 0.05$.

RESULTS

Basic limnology

During the study period, the values of most limnological parameters in the three tributaries were fairly similar, except for conductivity and turbidity (Table 1). The range of water temperature was 1.8°C through 30.8°C in the three tributaries during the period January 2001 through December 2002. Average water temperatures were not highly variable in the three tributaries. Ranges of average pH and dissolved oxygen (DO) concentration were 7.2–7.6 and 10.2–10.3 mg L^{-1} in the three tributaries during the study period. The average dissolved oxygen was saturated (>100%) in the three tributaries. Conductivity and alkalinity in the Kumho R. generally were high. Annual variation of conductivity (341–1,376 μS cm^{-1}) and alkalinity (40–134 mg L^{-1}) in the Kumho R. was more dramatic than which of the other sites (Table 1). Conductivity at Hwang River was consistently lowest.

Table 1. Means, standard errors, and ranges of limnological parameters in major three tributaries of the Nakdong River during 2001–2002 (n = 50).

	Unit	Kumho R. (RK167)	Hwang R. (RK115)	Nam R. (RK87.7)
Water temperature	°C	17.3±1.1 (4.7–30.8)	15.3±1.0 (2.4–26.7)	15.5±1.2 (1.8–28.4)
pH		7.6±0.1 (5.2–10.0)	7.2±0.0 (5.5–8.1)	7.4±0.1 (5.2–8.6)
Conductivity	μS cm^{-1}	952±38 (341–1376)	97±2 (39–136)	229±12 (84–399)
Alkalinity	mg L^{-1}	89±3 (40–134)	24±1 (4–48)	39±1 (20–65)
Dissolved Oxygen	mg L^{-1}	10.3±0.3 (6.0–16.1)	10.2±0.2 (7.1–15.1)	10.2±0.3 (6.1–15.2)
Dissolved Oxygen	%	103±3.8 (71–186)	100±1.6 (69–122)	100±2.0 (64–126)
Turbidity	NTU	6.8±0.5 (2–27)	13.1±1.9 (1.3–88)	12.5±2.1 (0.6–2)

* RK: river kilometer from Nakdong estuary barrage.

High turbidity was observed at both stations (Nam R. and Hwang R.), while the low turbidity was observed in the Kumho R. during the study period (Table 1).

Zooplankton community dynamics

There were statistically significant spatial and seasonal differences in zooplankton abundance (ANOVA, $P < 0.05$). Total abundance of major zooplankton groups at both stations (Kumho R. and Nam R.) was much higher than in the Hwang R. ($P < 0.01$, t-test, $n = 50$) (Fig. 2). In general, in the three tributaries, the zooplankton community was strongly dominated by planktonic rotifers.

The timing and magnitude of major community

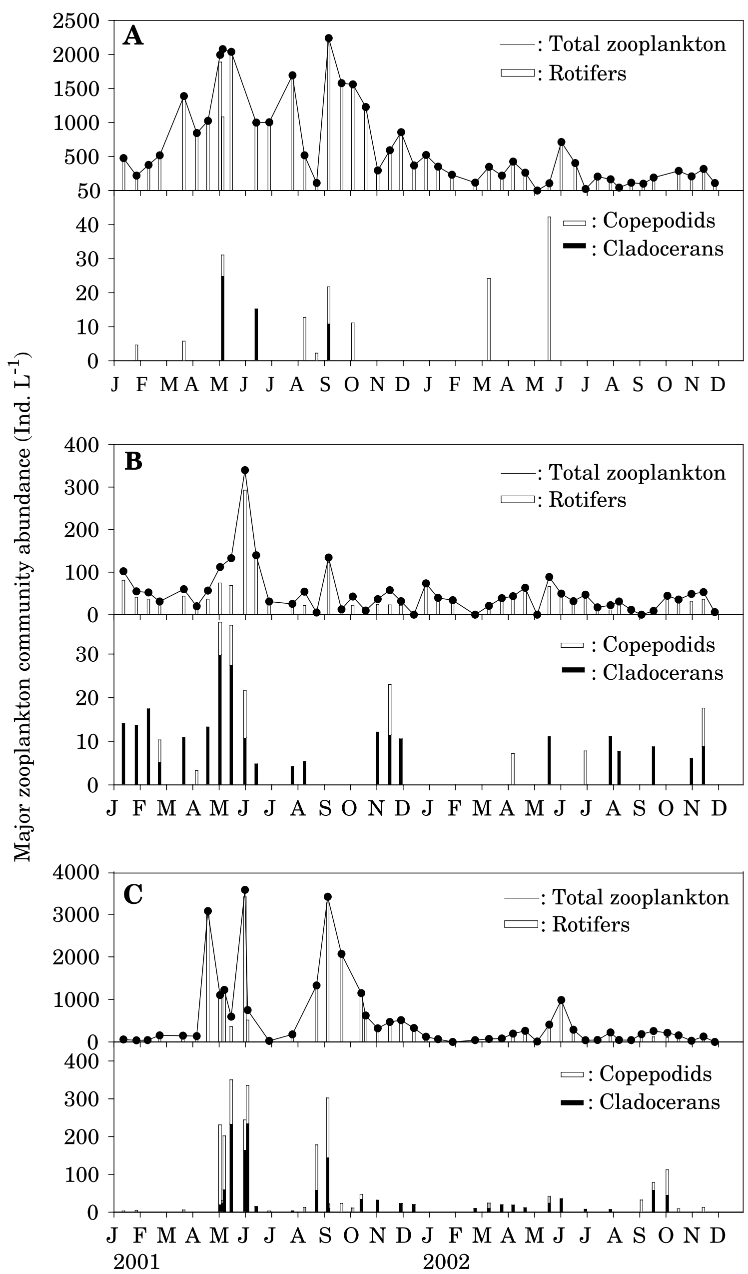

Fig. 2. Seasonal changes of total zooplankton, rotifers, cladocerans, and copepodids abundance during study periods (2001-2002) (A: Kumho R, B: Hwang R., C: Nam R.).

occurrences appeared to be consistent across seasonal cycles of zooplankton in the three tributaries (Fig. 2). The inter-annual variation of total zooplankton abundance in the three tributaries was significant between 2001 and 2002 (ANOVA, $P < 0.01$), while that of macrozooplankton (copepodids and cladocerans) was not significant except in the Hwang R. In 2001, zooplankton abundance rapidly increased during spring and fall by more than 2000 ind. L^{-1} at both stations (Fig. 2A, B) and more than 100 ind. L^{-1} in the Hwang R. (Fig. 2C). However, sharply increasing peaks in total zooplankton abundance in 2002 were not observed during spring and fall (Fig. 2). At those times, the dominant zooplankton was rotifers.

Population dynamics of the predator rotifers (*Asplanchna* spp.)

Overall, both stations (Kumho R. and Nam R.) contained higher *Asplanchna* spp. densities than the Hwang R. during the study period (Fig. 3). The two tributaries (Kumho R. and Nam R.) provided more favorable conditions for *Asplanchna* to develop, including low water velocity and high *Brachionus* spp. abundance, while the Hwang R. supported a smaller zooplankton community and

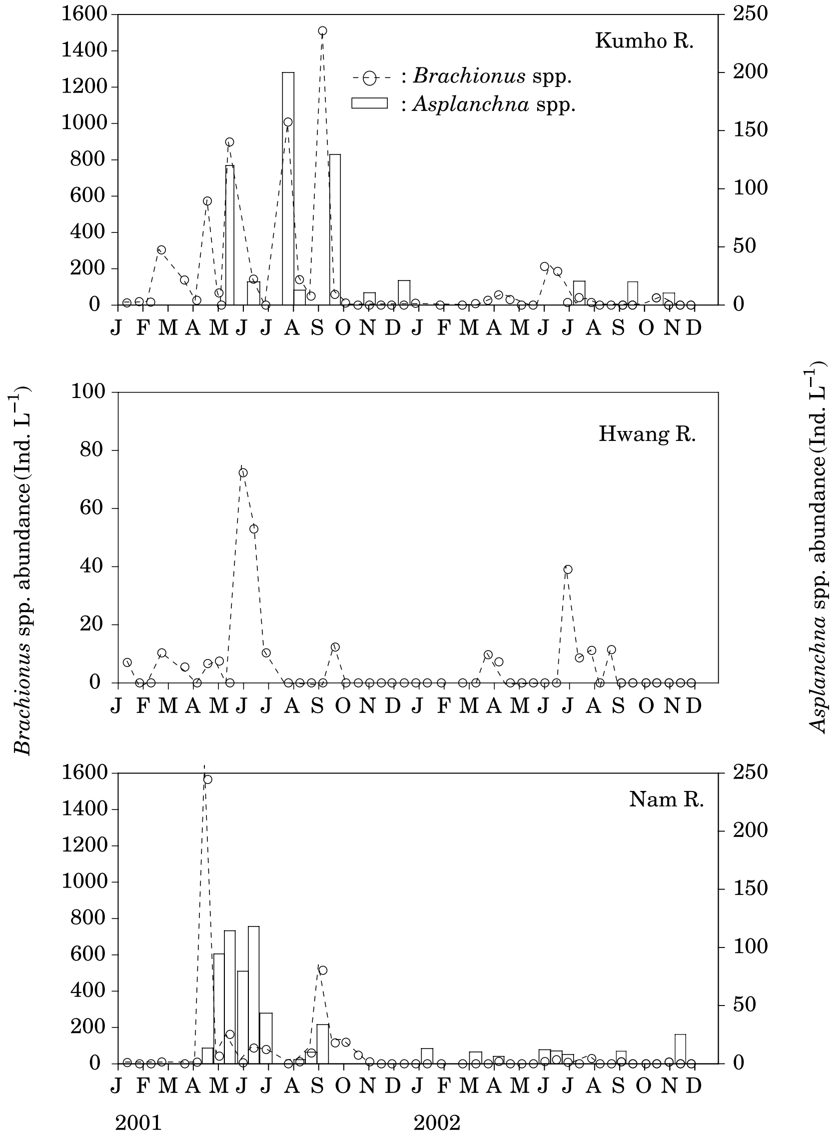

Fig. 3. Seasonal changes of herbivorous rotifers community (*Brachionus* spp.) and predator abundances (*Asplanchna* spp.) during study periods (2001–2002).

lower total densities (Fig. 2C) due to rapid flushing.

The genus *Brachionus* spp. was represented by 7 species and was the most common rotifer in the three tributaries. Three species of *Brachionus* (*B. angularis*, *B. calyciflorus*, and *B. rubens*) dominated the rotifer community at various times in the three tributaries (Fig. 3). From spring and fall in 2001, *Brachionus* frequently displayed abundance peaks but sharply decreased after peaks of *Asplanchna* spp. abundance. During the spring season of 2001 in both stations (Kumho R. and Nam R.) but not in the Hwang R., there was an inverse relationship between *Brachionus* spp. and *Asplanchna* spp. abundance. In particular, the *B. angularis* and *B. calyciflorus* biomasses sharply declined during the peaks of *Asplanchna* spp. in the two tributaries (Kumho R. and Nam R.).

Peaks of population growth of *Brachionus* spp. were observed in June and July 2001 and 2002 in the Hwang R (Fig. 3), although there was inter-annual variation in its density peak timing. It accounted for most of the steep rise in total rotifers abundance. However, there were not distinct patterns of herbivorous rotifers in the Hwang R. compared with the dynamics of herbivorous rotifers in the other tributaries (Fig. 3).

DISCUSSION

We found that there were notable differences in rotifer community structure and abundance among the three tributaries of the Nakdong River, reflecting the heterogeneous nature of this large river ecosystem. Previous studies on zooplankton dynamics in the Nakdong River (Kim *et al*., 2002) reported that short retention times (Kim *et al*., 2000) could have favored the development of microzooplankton including rotifers.

As is true of most large rivers, the major tributaries of the Nakdong River have experienced both cultural eutrophication and alterations to their natural hydrology. The high organic source and food quantity (e.g., high phytoplankton biomass and bacteria density) (Ju, 1999; Kim *et al*., 2002) can facilitate the proliferation of microzooplankton rather than macrozooplankton in both stations (Kumho R. and Nam R.), while in the Hwang River, where there was good water quality (Kim, 1996, 1999), the total zooplankton and rotifer abundance was low (less than 500 ind. L^{-1}) in the present study.

The high rotifer densities may indicate a high rate of energy transfer between the producers and herbivores in the regulated river ecosystems (Kim *et al*., 2000, 2002, 2003). In addition, among the rotifer community, brachionid rotifers are generally the most common prey of *Asplanchna* species (Gilbert, 1999), therefore changes in the densities of *Brachionus* species could cause oscillations in the abundance of their predator. At present, the community shifts of *Brachionus* spp. groups were observed in late spring and fall in the Kumho R. and the Nam R. when the *Asplanchna* spp. densities sharply increased during the study period. The *Asplanchna* has a grasping mastax and is predatory upon other rotifers. Its diet also includes large algae, which are ingested whole in latespring and fall. There were distinct patterns between *Asplanchna* spp. CFR (community filtration rate) and rotifers density (Kim, 1996). Furthermore, the prolonged presence of *Asplanchna* greatly influenced the structure of the rotifer taxocoenosis. Co-existence of *Asplanchna* in nature with its prey is usually attributed to defence mechanisms developed by prey in the presence of a predator (Conde-Porcuna and Sarma, 1995). We also observed that loricate brachionids may develop spines to deter predation from *Asplanchna*.

Rotifers in general are opportunistic and have high population growth rates (r) (Allan, 1976). The r values of certain *Brachionus* species such as *B. calyciflorus* can be higher than 1 day^{-1}, while most other herbivorous rotifer species usually have r values around 0.5 day^{-1} (Sarma *et al*., 2001). On the other hand, carnivorous genera of rotifers may have r values higher than 0.5 up to 1.5 day^{-1} (Sarma *et al*., 1998). Dumont and Sarma (1995) have shown that predatory rotifers of the genus *Asplanchna* in general had r values higher than 1 day^{-1}. It was shown that the density-dependent effects are visible in population growth studies resulting in r values. In comparison with many herbivorous rotifers, the population growth of *Asplanchna* generally lacks an initial lag phase due to its short pre-reproductive period. In the present study too, *Asplanchna* spp. began to grow immediately after peaks of *Brachionus* spp. abundance.

Considering these results on rotifers community dynamics in the river system, the *Asplanchna* population could be appeared to play an important role in regulating rotifer community and total plankton biomass at high trophic levels. Further studies on the ability of rotifers to reduce levels of pathogenic bacteria and improve water quality need to be conducted. Furthermore, regulation of plankton abundance by hydrologic regimes of tributaries need to be studied. The problems of bioaccumulation of toxic substances in zooplankton cultured on urban wastewaters also need to be addressed in future studies.

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<국문적요>

낙동강(한국)의 세 지류에서 포식 윤충류 개체군 동태 및 초식 윤충류 군집에 미치는 영향

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낙동강의 세 지류에서(금호강, 남강, 황강) 지난 2001년 1월부터 2002년 12월까지 격주 간격으로 초식 윤충류 군집(*Brachionus* spp.)과 포식 윤충류(*Asplanchna* spp.) 간의 개체군 동태에 대해서 평가 하였다. 초식 윤충류들의 높은 군집 밀도(최고 밀도: 약 >1000개체/리터)는 두 지류에서(금호강과 남강) 봄과 가을 시기에 반복적으로 나타났으나 다른 하나의 지류(황강)에서는 관찰되지 않았다. 초식 윤충류 중, *Brachionus* spp. (7종으로 구성) 군집들이 본 조사지점에서 대표적인 종으로 파악되었다. *Brachionus* spp.와 연중 비슷한 시기에 출현하는 종은 *Asplanchna*였다. *Asplanchna*는 *B. angularis*와 *B. calyciflorus* 종들의 높은 개체군 밀도 시기와 유사하게 개체수가 증가하였다. 그 결과로, 두 개체군들의(*B. angularis*와 *B. calyciflorus*) 밀도는 *Asplanchna* 출현 이후 급속히 감소하였다(금호강과 남강). 그러나 다른 한 지류인 황강에서는 뚜렷한 포식 및 초식 윤충류 간의 상호관계는 파악되지 않았다. 본 조사 결과로 봄 및 가을 중순 기간의 조사지점에서는 윤충류 군집 간의 뚜렷한 변화 양상이 파악되었다. 특히, *Asplanchna* 개체군은 높은 영양 단계 지류 시스템 내에서 봄과 가을의 총 플랑크톤 생물량과 윤충류 군집의 주요한 조절자로써의 역할을 할 것으로 파악된다.