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Prey Preference of Juvenile Fish Based on the Laboratory Experiments and its Impact on Zooplankton Community of the Nakdong River

Chang, Kwang-Hyeon, Hyun-Woo Kim[1], Geung-Hwan La[2], Kwang-Seuk Jeong[2] and Gea-Jae Joo[2]*

Research and Education Center for Inlandwater Environment, Shinshu University 5-2-4 Kogandori, Suwa 392-0027, Japan
[1]Department of Environmental Education, Sunchon National University, Suncheon, Jeonnam 540-742, S. Korea
[2]Department of Biology, Pusan National University, Pusan 609-735, S. Korea

치어의 먹이선호도 및 포식이 낙동강 동물플랑크톤군집에 미치는 영향. 장광현 · 김현우[1] · 라긍환[2] · 정광석[2] · 주기재[2]* (일본 슈대학교 내륙환경연구 및 교육센터, [1]순천대학교 환경교육학과, [2]부산대학교 생물학과)

저수지화성향을 띤 낙동강은 수체가 정체되는 시기에 높은 동물플랑크톤 밀도를 보인다. 이 시기의 높은 치어개체군 밀도는 지각류 개체군 밀도의 감소와 윤충류 개체군 밀도의 증가를 유도하는 주요요인으로 제시되었다. 본 연구에서는 실험실실험을 통해 치어의 먹이선호도와 포식이 낙동강 동물플랑크톤 군집에 미치는 영향을 평가하였다. 여러 종류의 치어의 먹이선호도 및 크기가 다른 치어의 먹이선호도를 실험실 수조내에서 평가하는 한편, 대형 수조에서 이들 치어의 포식이 동물플랑크톤군집에 미치는 영향을 모니터링하였다. 실험에 사용된 세종류의 치어 (*Hyporhamphus sajori*, *Rhinogobius brunneus*, *Opsariichtys uncirostris*) 및 크기가 다른 치어 (*O. uncirostris*) 모두 지각류 *Moina micrura*에 가장 높은 먹이선호도를 나타냈다. 야외수조에서 실시된 실험에서 치어의 포식은 지각류 *M. micrura*를 억제하는 한편 윤충류인 *Polyarthra* spp.의 우점을 유도하였다. 본 실험결과, 치어의 섭식은 낙동강에서 동물플랑크톤 군집구조를 결정하는 중요한 요인으로 사료된다.

Key words : fish predation, prey selectivity, zooplankton, Nakdong River, *Moina micrura*, rotifer

INTRODUCTION

Predation is an important environmental factor that affects the community structure of freshwater zooplankton (Kerfoot and Sih, 1987). Zooplankton communities are influenced by the predation of various invertebrate and vertebrate predators having different foraging behaviors. The presence of predators can alter the species composition or size structure of zooplankton communities (Lynch, 1979; Gliwicz *et al*., 2000; Rettig, 2003). Zooplanktivorous fishes in lakes are known to have strong prey selectivity and tend to consume large zooplankton. They often have a great impact on the composition of zooplankton species by reducing the number of dominant large-bodied zooplankton as compared to the corresponding

* Corresponding Author: Tel: +82-51-510-2258, Fax: +82-51-583-0172, E-mail: gjjoo@hyowon.pusan.ac.kr

number of small individuals or species (Brooks and Dodson, 1965). Such predator interaction may also be an important factor for zooplankton community in rivers (Bøhn and Amundsen, 1998). However, the zooplankton community of rivers and their response to fish predation remains still fragmentary (Jack and Thorp, 2002).

The Nakdong River in Korea is a large regulated river controlled by multi−purpose dams and an estuary barrage (Ha *et al.*, 1998; Kim *et al.*, 1998). The succession of zooplankton in the river shows a reservoir−like pattern from winter to early summer, owing to the stagnant characteristics of the water body (Lim *et al.*, 1997; Kim *et al.*, 2000). In particular, zooplankton including cladocerans and rotifers is abundant during the spring and summer, and demonstrates a succession pattern of cladoceran dominance followed by rotifer dominance. Chang *et al.* (2001) suggested that the abundance of juvenile fish from late spring to early summer is an important factor regulating the zooplankton community of the river, based on an analysis of the stomach contents of fish in the river. However, there is little information on the impact of juvenile fish predation on zooplankton community of the river, based on experimental approaches.

In the present study, we examined prey selectivity of juvenile fishes and their impacts on the zooplankton community in the laboratory to show how predation by the juvenile fish can affect the species composition of zooplankton at the community level in the Nakdong River.

MATERIALS AND METHODS

1. Experiments in individual level

We observed the prey selectivity of three juvenile fishes (*Hyporhamphus sajori*, *Rhinogobius brunneus* and Opsariichtys uncirostris) in the experimental aquarium. We also compared their prey selectivity according to the body size of the juveniles of *O. uncirostris*; i.e. between the juveniles (average body size, 1.5 cm) and young fishes (average body size, 2.3 cm).

For the experiments, juvenile fish and zooplankton were collected at the Nakdong River (Mulgum) during May and June 1999. Juvenile fish were collected by shoreline seining in shallow areas of the river. They were held in the experimental aquarium (semi−transparent plastic container, 30 × 20 × 18 cm) in the laboratory for 3 days of acclimation before the experiments. Fish were starved for at least 24 h in order to ensure gut clearance before the experiments. At the beginning of the experiment, eight liters of river water, which included zooplankton, was introduced into the experimental aquarium, and two individuals of juvenile fish were added to the aquarium. The river water used in the experiment was sampled from two−meter−depth of the water column using a Van−Dorn sampler at Mulgum of the Nakdong River. To investigate prey availability, two aliquots of river water (8 L) were filtered through a 40 μm−mesh−net and preserved with 10% formalin before the experiments. Zooplankton abundance and species composition were analyzed using the preserved samples. Juvenile fishes were fed for 3 h in the aquarium, and then the stomach contents were analyzed. Prey selectivity of juvenile fish was determined by the selectivity index (α) of Chesson (Chesson, 1978) which is widely used to estimate the selective feeding of fish (Parrish and Margraf, 1991; Boersma *et al.*, 1996, Equation 1).

$$\alpha = \frac{\dfrac{r_i}{p_i}}{\dfrac{r_i}{p_i} + \dfrac{r_j}{p_j}} \qquad \text{Equation 1.}$$

Here, r is the proportion of the prey item in the investigated gut, and p is the proportion in the environment. For each proportion parameter, both i (the prey class) and j (all other classes) were considered. α ranges from 0 (negative selection) to 1 (positive selection), while 0.5 indicates nonselectivity.

For each experiment, four individual juvenile fish was examined as replicates. The difference of prey selectivity was analyzed by two−way ANOVA (α = 0.05). In the statistical analysis, both species prey items and fish species were considered.

2. Experiments at the community level

To estimate the effect of juvenile fish predation on the zooplankton community, six plastic experimental tanks (150 × 80 × 60 cm) were used. Those tanks were divided into three groups (control, low fish density, and high fish density tanks) with two replicates. River sediment including the resting eggs of zooplankton was collected at the shore line from the Nakdong River (1 m depth) and spread over the bottom of each tank (1 cm thickness). River water containing plankton was collected from a depth of 1 m and the tanks were filled with 100 L of river water. All tanks were located outdoor and covered with net (1 mm-mesh) to prevent insects spawning. Juvenile fishes (body size 1~1.5 cm) were introduced 24 h after the impoundment of river water. Two species of juvenile fish (*R. brunneus* and *O. uncirostris*) were added to the tanks. Six juvenile fishes (three individuals of *R. brunneus* and three individuals of *O. uncirostris*) were added to the low fish density tanks and 24 individuals (12 individuals of *R. brunneus* and 12 individuals of *O. uncirostris*) into the high fish density tanks as well. No fish were added into the control tanks.

Zooplankton was sampled every 2~3 days from each tank. Two liters of tank water were collected and filtered through a 32 (m-mesh-net and preserved with 10% formalin (final concentration, 4%). Water temperature and dissolved oxygen (DO) concentration in the tanks was measured using YSI model 58 (YSI Inc., Ohio, USA). pH was measured using Orion model 250A (Thermo Electron Co., MA, USA). Phytoplankton biomass (Chl. *a*) was analyzed at 4~5 day intervals using a monochromatic method (Wetzel and Likens, 1991). The experiment was set up on June 1 and ended on June 28, 1999.

RESULTS

1. Experiments at the individual level

All three juvenile fishes (*Hyporhamphus sajori*, *Rhinogobius brunneus* and *Opsariichtys uncirostris*) prefered *Moina micrura*, which showed the highest individual preference values (Table 1). The degree of preference on the *M. micrura* was similar among the fish species (two-way ANOVA, $0.25 > p > 0.10$). On the other hand, they showed different prey selection on other prey species. *Rhinogobius brunneus* selected copepods as well as *M. micrura*, while *O. uncirostris* selected *Bosmina longirostris*. All three juvenile fishes showed negative selection on *Diaphanosoma brachyurum* or did not consume this prey during the experiment. *Rhinogobius brunneus* and *O. uncirostris* did not consume small rotifer species

Table 1. Means of individual preference value (Manly/Chesson index), based on the selectivity experiments in the laboratory for three juvenile fish species. BC, *Brachionus calyciflorus*; KC, *Keratella cochlearis*; MM, *Moina micrura*; BL, *Bosmina longirostris*; DB, *Diaphanosoma brachyurum*; CO, copepodid; N, the number of fish.

Juvenile fish species	N	Mean preference value					
		BC	KC	MM	BL	DB	CO
H. sajori	4	0.60	0.08	0.89	0.27	0.29	0.41
R. brunneus	4	0.59	–	0.88	0.35	–	0.80
O. uncirostris	4	0.55	–	0.89	0.68	–	–

Table 2. Means of individual preference values (Manly/Chesson index) for different size class of *O. uncirostris* from the selectivity experiments (KC, *Keratella cochlearis*; BC, *Brachionus calyciflorus*; MM, *Moina micrura*; BD, *Bosminopsis deitersi*; BL, *Bosmina longirostris*; N, number of fish; NP, does not exist in the plankton prey community in the aquarium).

Size class	Mean size	N	Mean preference value				
			KC	BC	MM	BD	BL
Small	1.6	2	0.06	0.23	0.98	0.44	0.90
	1.8	2	0.04	–	0.92	0.04	NP
Large	2.6	2	–	0.21	0.98	0.95	–
	2.2	1	–	0.68	0.98	0.88	NP

except *Brachionus calyciflorus*, the largest rotifer species in the aquarium. However, *H. sajori* consumed small rotifer species such as *Keratella cochlearis*, but preference values showed negative selection.

Both small and large juvenile *O. uncirostris* selected *M. micrura* at the highest individual preference values. However, they showed different prey selection patterns on other cladocerans. Though small sized fish fed on small rotifers, the preference values were very low (Table 2). The small-bodied juvenile fish selected a wide range of prey, from small rotifer, *K. cochlearis* to large *M. micrura* (Fig. 1).On the other hand, larger fish consumed only cladocerans and large rotifer, *B. calyciflorus*. The amount of consumption of cladoceran prey increased in tandem with an increase in body size. The large fish in particular consumed more of *M. micrura*, *B. longirostris* and *Bosminopsis deitersi* than the small fish.

In the experiments, juvenile fish selected large cladoceran, *M. micrura*, which accounted for less

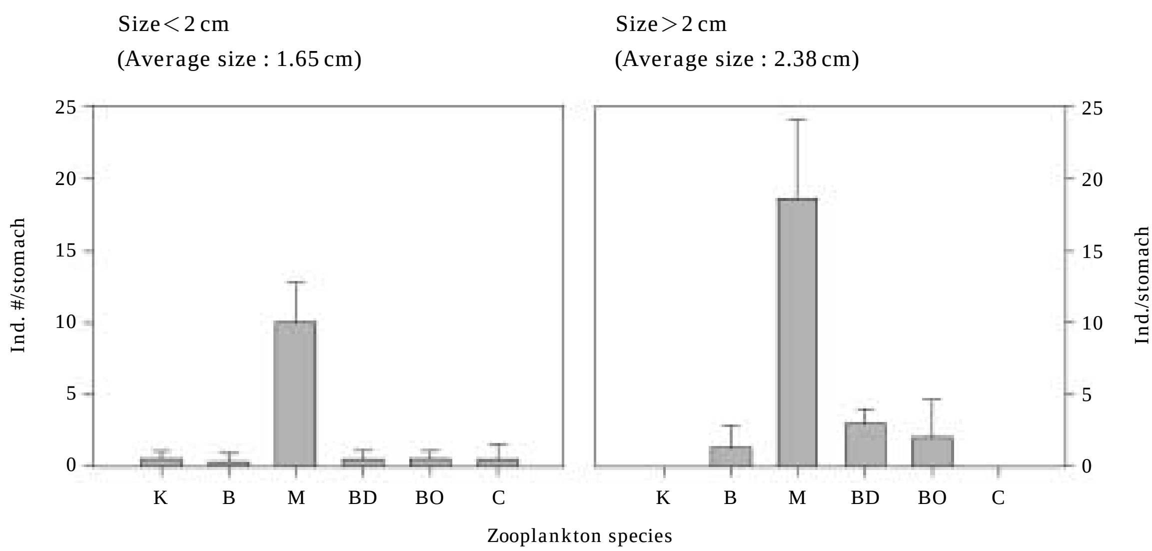

Fig. 1. Comparison of the stomach contents of *O. uncirostris* with different body size (K, *K. cochlearis*; B, *Brachionus* spp.; M, *M. micrura*; BD, *B. deitersi*; BO, *Bosmina* spp.; C, *Chydorus* sp.)

than 1% of the total prey abundance in the experimental aquarium. In contrast, the fish selected only *B. calyciflorus* and did not select small rotifer species, such as *Polyarthra* spp. and *K. cochlearis*, though these prey were abundant, i.e. more than 100 ind. L^{-1} in the experimental aquarium.

2. Experiment at the community level

The basic limnological parameters of the experiment are summarized in Table 3. Values in the parameters were similar in all tanks except for Chlorophyll *a* values which was higher at the "Low fish density−2" and "High fish density−2" tanks than the control tanks. However, the chl. *a* became similar among treatments after about 17 days (Table 3). The changes in the zooplankton community were different among treatments. In the control tanks, *M. micrura* was dominant throughout the experimental period and the density increased after 10 days and reached more than 50 ind. L^{-1} around day 20. On the other hand, few *M. micrura* were observed both in the low fish density and the high fish density tanks. They were not found in the samples after day 15 (Fig. 2). Dominant rotifer species in the tanks, *Polyarthra* spp. also showed different succession patterns among tanks. Their density was very low in the control tanks, but much higher in the low and high fish density tanks. Their density

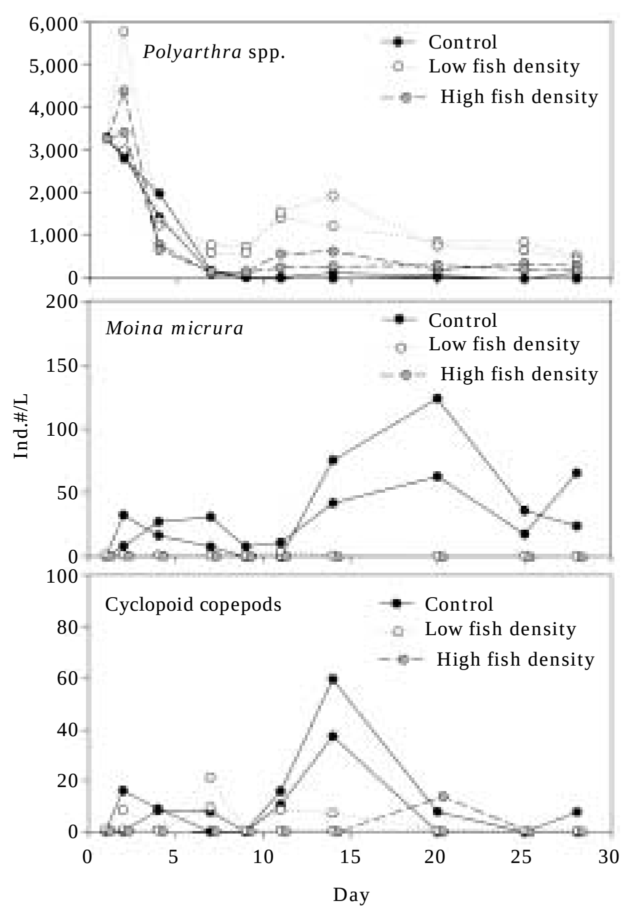

Fig. 2. Changes of zooplankton in the experimental tanks during the experiment.

Table 3. Mean (±SD) values of basic limnological parameters during the experiments in outdoor tanks.

Tanks	Water temperature (°C) (n = 10)	DO (mg L^{-1}) (n = 10)	pH (n = 10)	Turbidity (NTU) (n = 10)	Chl. *a* (μg L^{-1}) (n = 6)
Control - 1	27.1±3.4	11.5±0.9	8.6±0.3	3.3±2.8	5.4±3.9
Control - 2	27.3±3.5	11.1±0.9	8.6±0.2	2.9±2.8	5.3±4.8
Low fish density - 1	27.1±3.5	11.3±1.4	8.7±0.3	3.0±3.0	5.4±3.9
Low fish density - 2	27.0±3.5	11.5±1.4	8.7±0.2	3.0±2.9	6.2±3.6
High fish density - 1	26.9±3.5	11.7±1.4	8.7±0.2	2.8±3.0	5.1±3.4
High fish density - 2	26.7±3.3	11.5±1.2	8.7±0.2	3.0±2.9	6.7±2.5

was highest in the low fish density tanks and often reached more than 1,000 ind. L^{-1}. Cyclopoid copepods showed higher densities in the control tanks than the low and high fish density tanks.

DISCUSSION

The large cladoceran *M. micrura* was the preferred prey by three fish species and did not show body size preference among the fishes in the laboratory experiments. The presence of juvenile fish completely consumed *M. micrura* in the experimental tanks. Previous studies (Chang *et al*., 2001) found that in the Nakdong River, a decrease in the density of *M. micrura* coincided with the high abundance of juvenile fish, and the stomach contents of fish also showed that *M. micrura* is the preferred prey item for fish. The present results support the suggestion that predation by juvenile fish is a major factor in the rapid decrease in cladoceran density in the river. Our results also showed that the presence of the juvenile fish greatly impacts cladoceran populations and possibly suppresses their development in the field. However, contrary to our experimental results, the population of *M. micrura* was not consumed and recovered soon after the short-term decline of their density in the Nakdong River (Chang *et al*., 2001). It seems that the environment of the river, i.e. the changes in juvenile fish density related to the occurrence of piscivore fish and the high trophic state of the river, provided more favorable conditions for cladocerans to recover their populations as suggested by Chang *et al*. (2001).

Although all juvenile fishes positively selected *M. micrura*, their prey preference values on other prey items were different among species. It is known that fish usually select the largest prey (Brooks and Dodson, 1965; Werner and Hall, 1974). On the other hand, the swimming behavior of zooplankton is also known as an important factor affecting the foraging behavior of fish. Zooplankton species have different evasion efficiencies against fish foraging attempts (i.e. suction attack). Copepods and *Diaphanosoma* have better evasion capacity than other crustacean zooplankton species (Drenner and McComas, 1980). The negligible selection of *Diaphanosoma* by fish in the present experiment also shows that this species is less vulnerable to juvenile fish predation. By contrast, *Diaphanosoma* is very vulnerable to predation by cyclopoid copepods (Chang and Hanazato, 2003). Thus, it seems that *Diaphanosoma* in the Nakdong River are mainly affected by invertebrate predation rather than by fish predation. Different selection behaviors by the juvenile fish on copepods and *B. longirostris* suggest that their foraging abilities and prey preferences may differ among species (e.g. *R. brunneus* as bottom dweller and predating small invertebrates).

In the outdoor experiment, juvenile fish consumed large cladocerans, and the numbers of rotifer *Polyarthra* increased in the low and high fish density tanks. Similar zooplankton succession patterns induced by fish predation and consequent changes in the competitive relationships between cladocerans and rotifers have been well reported (Dodson, 1974; Qin and Culver, 1995; Attayde and Hansson, 2001). However, our result clearly shows the different densities of rotifer between the low and high fish density tanks with higher densities in the low fish density tanks. It is known that the presence of fish induces a high density of rotifers due to the exclusion of cladocerans, a rotifer competitor and enhancing the availability of food with increased nutrient excretion by fish (Qin and Culver, 1995; Vanni *et al*., 1997; Attayde and Hansson, 2001). The exclusion of invertebrate predators by fish predation also results in an abundance of rotifers in the presence of fish (Hanazato *et al*., 1990; Zagarese, 1990). However, the difference in rotifer density in our experiment suggests that high predation pressure by fish reduces the rotifer density when there is a high fish density. Although prey preference values and consumption amounts were low, juvenile *O. uncirostris* consumed small rotifers in the individual level experiments. Thus, a high density of fish may suppress the rotifer population as well as cladocerans and copepods.

The 'top−down' effects of fish on zooplankton in rivers have been considered less significant than in lakes since the zooplankton communities of many rivers are dominated by rotifers and small −bodied crustacean zooplankton, and their densities are often very low (Jack and Thorp, 2002). However, in regulated rivers such as the Nakdong River, large−bodied cladoceran and rotifer populations are often large due to the stagnancy of the water body and phytoplankton development. Our experiments do not replicate realistic field conditions of the river. However, our results have shown that the presence of fish is a significant factor in controlling the zooplankton community. This suggests that a 'top−down' effect, such as interactions between fish and zooplankton, is one of the important factors affecting the succession of zooplankton in the river. Especially, S. Korean region has lower rainfall during spring when zooplankton and juvenile fishes may abundant. The increased stagnancy in this period can increase the fish predation effects on the zooplankton communities.

ABSTRACT

In the present study, prey preference of juvenile fishes was examined using an experimental approach. Zooplankton composition, as a prey of the fish, was evaluated by taking into account the species as well as body size of juveniles in the aquarium. The predation of juvenile fishes is known to be an important factor in changes of zooplankton communities. In some previous studies at the regulated Nakdong River, the collapse of large cladcoerans and an increase in the rotifer population by selective predation during spring and summer were observed. This study focused on the predation of juvenile fishes such as *Hyporhamphus sajori*, *Rhinogobius brunneus*, and *Opsariichtys uncirostris amurensis* on zooplankton community structure in mesocosm scale experiments. These fishes selected the cladoceran *Moina micrura* with highest individual preference value (Manly/Chesson index) among zooplankton prey in the experimental aquarium. When the size−selective prey preferences of the juvenile fish were compared, both small (body size <2 cm) and large (body size >2 cm) juveniles of *O. uncirostris* positively selected *M. micrura*. In the outdoor experimental tanks, juvenile fishes consumed the cladoceran *M. micrura*, resulting in an high abundance of the rotifer, *Polyarthra* spp. The results suggest that juvenile fish predation may play an important role in regulating the zooplankton community structure by reducing the cladoceran density and increase of rotifers in the Nakdong River during spring and summer.

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