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Effect of Juvenile Fish Predation on the Zooplankton Community in the Large Regulated Nakdong River, South Korea

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In the large regulated Nakdong River, the predation effect of juvenile fish on the zooplankton community was evaluated by gut and stomach analyses of fish in 1999. Juvenile fish of five species showed high density from May to early June when river discharge was low and water body became stagnant. During this period, large rotifers, *Asplanchna* spp. and *Brachionus* spp. declined and the decrease of cladoceran (*Moina micrura* and *Bosminopsis deitersi*) density was also obeserved. At this time, small rotifers including *Polyarthra* spp. reached maximum density. Gut analysis of fish demonstrated that small-sized juvenile fish (<15 mm in total length) preferred large rotifers as well as cladocerans, while large sized fish (>15 mm) selected only cladocerans. On the other hand, juvenile *Micropterus salmoides* of which size was larger than other juvenile fish consumed not only zooplankton but also other small juvenile fish. Based on these results, the decline of large rotifers and cladocerans during early summer in the river seems to be result of predation by juvenile fish. However, the period when juvenile fish maintained their high density was as short as one month and the decreased density of cladocera rapidly recovered as soon as juvenile fish became scarce. Such a short period of juvenile fish development in the river can be attributed to the consumption of juvenile fish by the young-of-the-year cohorts as well as adults of *M. salmoides*. The high trophic state of the river might permit the rapid recovery of the cladoceran community. The predation impact of juvenile fish in the Nakdong River seems to be affected by the existence of piscivore as well as high trophic status.

Key words : Predation, Juvenile fish, Cladocera, Zooplankton, Nakdong River

INTRODUCTION

The predation by zooplanktivore has been recognized as a major factor determining zooplankton community structure in lakes. Fish predation results in a decrease in the mean body size of zooplankton and induces a replacement of larger prey species by smaller ones (Lynch, 1979; Vanni, 1986; Luecke *et al.*, 1990; Lazzaro *et al.*, 1992; Rudstam *et al.*, 1993). Recently, the effect of age-0 juvenile fish predation on zooplankton has been also studied frequently (DeVries and Stein, 1992; Qin and Culver, 1995; Boersma *et al.*,

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1996; Mehner *et al*., 1998a, b). Especially mid-summer declines of large cladocerans and consequent change in the cladoceran community have been attributed to the predation by newly hatched fish in June and July (Cryer *et al*., 1986; Whiteside, 1988; Romare and Bergman, 1999).

The predation impact of juvenile fish has been considered to be very important in regulating the zooplankton community since they are planktivorous regardless of species and may remain abundant and increase the biomass until piscivores cause their decline (Gliwicz and Pijanowska, 1989). The impact of juvenile fish is different from that of adult zooplanktivore. Unlike adult zooplanktivore, larval planktivores change their main prey items from small plankters to larger prey as they grow because they are gape−limited predators (Mehner *et al*., 1998a). In addition, ontogenetic shifts in the foraging behavior of planktivorous fish and strong relationships with piscivores may result in a high temporal variability in the predation impact on the zooplankton community (DeVries and Stein, 1992; Post *et al*., 1997).

The Nakdong River is a large regulated river in Korea and is a river−reservoir hybrid type of which flow regime is controlled by an estuary dam and multi−purpose dams (Ha *et al*., 1998; Kim *et al*., 1998). The hybrid characteristic of this river induces a lake−like pattern in the succession of zooplankton from winter to early spring when the water body becomes stagnant and river−like succession during summer and fall when high discharge is maintained (Lim *et al*., 1997; Kim *et al*., 2000).

To evaluate the predation impact of age−0 fish on the zooplankton community in the Nakdong River, prey selectivity and predation effects of age−0 fish were estimated by gut and stomach analyses with the seasonal changes of zooplankton and juvenile fish development.

MATERIALS AND METHODS

Zooplankton and juvenile fish were sampled in the lower part of the Nakdong River (35° 44′N and 128° 59′E), Mulgum (27 km upstream of the mouth of river) from March to September 1999. The river is the second largest in Korea (length, 528 km and catchment area, 23,817 km^2) and highly eutrophic (Ha *et al*., 1999).

Juvenile fish were sampled from May to June 1999 with a towing net (mesh size 100 μm, net diameter 60 cm, and net length 1.5 m, 4 m of towing distance, 5∼6 seconds per each towing, 15 times of towing a sampling) in the surface water. Body lengths of collected juvenile fish were measured. Among the collected fish, 50∼100 individuals were used for gut and stomach analyses. Zooplankton in the gut and stomach was identified at the species level.

Food preferences of juvenile fish were established 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). Chesson's α uses i as the prey class considered and j for all other classes. The proportion of the prey item in the gut is r_i or r_j and the proportion in the environment is p_i or p_j. α ranges from 0 (negative selection) to 1 (positive selection) and non−selectivity is 0.5.

$$\alpha = (r_i/p_i)/(r_i/p_i + r_j/p_j)$$

Zooplankton was sampled using a vertical net towing with a 32 μm mesh net (diameter 60 cm) and the body length and the number of eggs of collected cladoceran species were measured. An egg−ratio analysis (Paloheimo, 1974) was completed for *Moina micrura* and *Bosminopsis deitersi*. The egg−ratio analysis allows calculation of instantaneous birth rate (b), given the information on the number of eggs in the population (E) and the duration of the egg stage (D):

$$b = \ln[(E+1)/D]$$

D is calculated from the empirical equations fit to egg development rates (Hanazato and Yasuno, 1985):

$$\ln D = 4.522 + [-0.399(\ln T)^2] \text{ for } M.\ micrura$$
$$\ln D = 3.102 + [-0.261(\ln T)^2] \text{ for } B.\ deitersi$$

where T is water temperature. In the case of *B. deitersi*, coefficients of *Bosmina longirostris* whose size is similar was used in the calculation of the duration of the egg stage.

Phytoplankton biomass (Chlorophyll *a*) was determined spectrophotometrically using a monochromatic method (Wetzel and Likens, 1991). Daily precipitation data (Miryang) and monthly discharge data (Samryangjin) were obtained from the Korea Meteorological Administration and Flood Control Center in Pusan, respectively.

RESULTS

Juvenile fish composition and size distribution

A total of five juvenile fish species *Hemiramphus sajori* (half beak), *Rhinogobius brunneus* (common freshwater goby), *Acanthorodeus macropterus* (deep body bitterling), *Opsariichtys bidens* (Korean piscivorous chub), and *Micropterus salmoides* (largemouth bass) were collected by the net from May to June. *H. sajori* comprised most of the juvenile fish community in the early period of fish development and dominated until June 1 except the period of May 29. *R. brunneus*, *A. macropterus*, and *O. bidens* were collected in June. *M. salmoides* were collected only in the late period of the juvenile fish flourishing season (June 10) and their size exceeded 3 cm when they were caught first in the net. After June 10, the abundance of juvenile fish became scarce and were not collected in the net. The density of collected juvenile fish peaked at May 17 and fluctuated greatly thereafter (Fig. 1a). The average size of juvenile fish was 7.4 mm in May and 18.2 mm in June (Fig. 1b). Juvenile fish less than 10 mm accounted for 92% of the total juvenile fish in the early period of their development, and were gradually replaced by larger sizes of fish ranging from 15 ~ 20 mm (Fig. 1c). Among the juvenile fish species, *H. sajori* was smallest with average size of 9.1 mm, whereas the average size of *M. salmoides* exceeded 30 mm and was largest.

Zooplankton composition and abundance

In the Nakdong River, rotifers dominated the zooplankton communities during the study period and comprised 91% of the total zooplankton density (Fig. 2). The average density of rotifer was 30,600 (41,600 (n = 52) ind./m^3. The rotifer density increased from March and reached its first peak (141,000 ind./m^3) with abundant densities of larger species, *Asplanchna* spp. and *Brachionus* spp. in late April. The high density of rotifers then rapidly decreased in early May, when juvenile fish began to increase. The second peak of rotifer density, mainly consisted of small *Polyarthra* spp., was observed in early June and

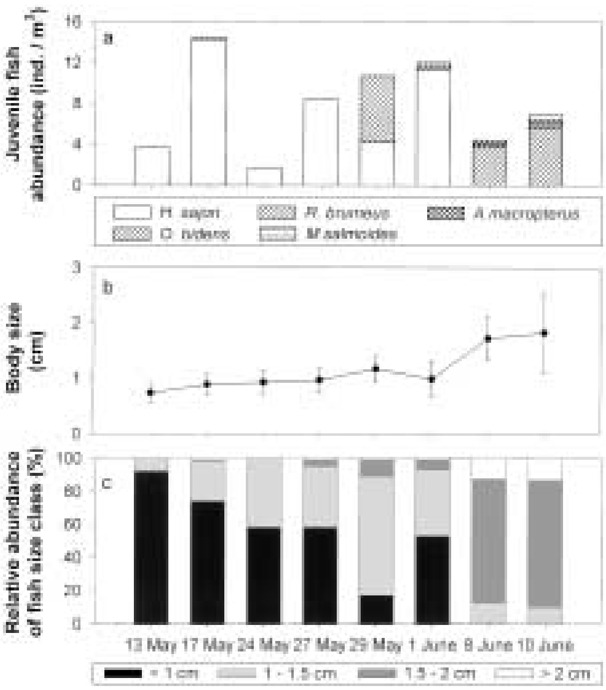

Fig. 1. Changes of juvenile fish (a) abundance and species composition, (b) mean body size, and (c) proportion of size class in the lower Nakdong River.

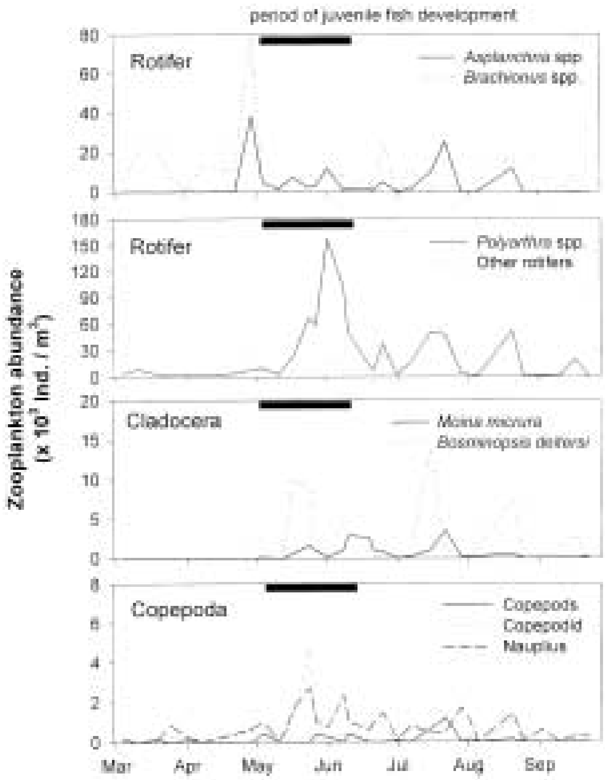

Fig. 2. Seasonal changes of rotifer, cladoceran, and copepods densities in the lower Nakdong River. Thick bars indicate the period of juvenile fish development.

reached its maximum density of 188,000 ind./m^3. Cladoceran species built up their density from May. From late May to early June, cladoceran density decreased from 10,000 ind./m^3 to 1,000 ind./m^3 and then recovered thereafter. Dominant species were *Bosminopsis deitersi* and *Moina micrura* which occupied about 80% of total cladocera. The density of copepoda and nauplius was low (average density copepoda, 400 ± 700 ind./m^3; nauplius, 600 ± 900 ind./m^3) and consisted of only 1% and 2% of the total zooplankton density, respectively. The adult cyclopoid copepoda was rare throughout the study period except for mid July.

During the rainy season from July to early September, the density of total zooplankton was strongly affected by high discharge mainly caused by high precipitation. Sixty percents of the total precipitation was concentrated during this season and monthly discharges during this time were about two to five times higher than those in spring. Flooding events often occurred and rise and fall of zooplankton density was repeated (Fig. 3).

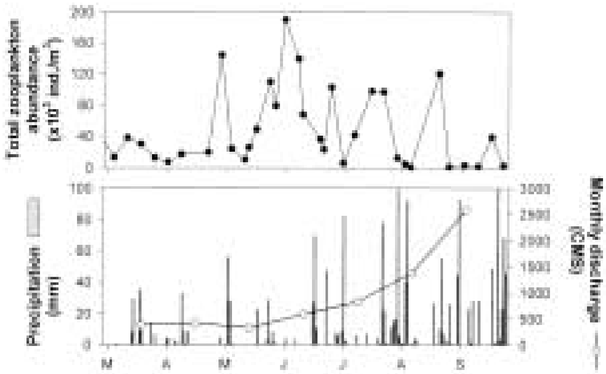

Fig. 3. Seasonal changes of total zooplankton, precipitation, and monthly discharge in the lower Nakdong River (1999).

Effects of juvenile fish predation

The data of gut and stomach analysis indicated that juvenile fish species mainly consumed large rotifers including *Asplanchna* spp. and *Brachionus* spp. during the early period of their development, and cladocera (*M. micrura*) during the later period (Table 1). They rarely consumed small rotifers and nauplius (less than 2% of total prey consumed). The species composition of zooplankton in the gut and stomach contents was similar for same size of *H. sajori*, *R. brunneus*, and *O. bidens*. During the beginning of the developmental period when the juvenile fish size is smaller than 10 mm, fish selected large rotifers and copepodid as their prey. As their size increased, their prey item changed to cladoceran species and *M. micrura* occupied 85% of total contents of gut and stomach of fish near the end period of juvenile fish development. Individual preference values (Chesson's α index) also indicated a similar pattern (Table 2). However, preference values suggested that large rotifers were still positively selected by juvenile fish even in the later period. Different from other species, *A. macrop-*

Table 1. Relative abundance (%) of zooplankton species in the gut and stomach of juvenile fish in the lower Nakdong River, Mulgum.

	Relative abundance (%)							Total %
	13 May	17 May	24 May	27 May	1 Jun.	8 Jun.	10 Jun.	
Rotifer								
Asplanchna spp.			13.3	5.8	11.0			3.0
B. calyciflorus	22.7	12.1	26.7	29.2	3.7	9.9		9.8
Brachionus spp.	45.5	45.5		8.8	5.5			8
K. cochlearis					3.7			1
Polyarthra spp.					4.1		3.5	2
Cladocera								
M. micrura	5.5	40.0	38.6	33.0	62.5	85.3	52	
B. longirostris	12.1	13.3	5.8	14.7	9.9	2.3	8	
B. deitersi	18.2			22.0	14.9			10
Daphina sp.					2.7	1.5	3.5	2
Copepoda								
Cyclops spp.	18.2		8.0	11.4		1.2	5.6	4
Nauplius	15.2	6.1						1

Table 2. Means of individual prey selectivity (Chesson's α index) of five juvenile fish in the lower Nakdong River, Mulgum.

	13 May	17 May	24 May	27 May	1 Jun	8 Jun	10 Jun
H. sajori	(7.4)	(7)	(9.3)	(9.7)	(11.6)		
Asplanchna spp.			0.85	0.57	0.54		
B. calyciflorus	0.61	0.77	0.80	0.76	0.88		
Brachionus spp.	0.96	0.90		0.81	0.79		
M. micrura		0.97	0.99	0.99	0.99		
B. longirostris		0.95	0.92	0.81	0.88		
B. deitersi		0.40			0.88		
Nauplius	0.95	0.85					
R. brunneus					(11.7)	(15.9)	(15.8)
Asplanchna spp.					0.97		
B. calyciflorus						0.61	
M. micrura					0.99	0.98	0.99
B. longirostris					0.97	0.86	0.84
B. deitersi					0.94		
Daphnia sp.					0.86		
Copepoda					0.86		
O. bidens		(12)		(11.7)	(15.5)	(26)	
Asplanchna spp.				0.66	0.96		
B. calyciflorus		0.74		0.99		0.70	
Brachionus spp.		0.98		0.95			
M. micrua					0.96	0.98	
B. longirostirs		0.94			0.99	0.91	
B. deitersi		0.56		0.86		0.92	
Daphnia sp.					0.96		
A. macropterus						(21)	(27)
M. micrura						1.00	1.00
M. salmoides							(35)
M. micrura							0.99
Daphnia sp.							0.84
Copepoda							0.91
Juvenile fish							0.3*

( ): average body size (mm) of juvenile fish
*: average individual numbers of juvenile fish in the stomach of juvenile largemouth bass

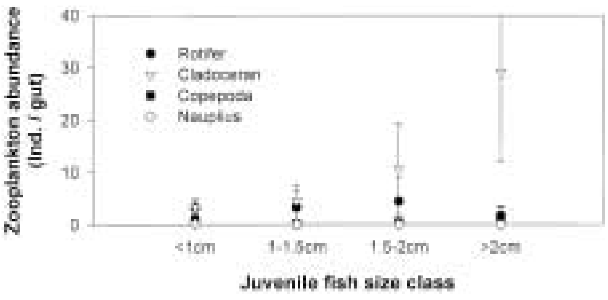

Fig. 4. Gut and stomach contents of each size class of juvenile fish (individual numbers of zooplankton/single fish gut and stomach, mean ± SD) collected from the lower Nakdong River (1999).

terus and *M. salmoides* of which sizes were larger than other juvenile fish, selected only large cladocerans. In particular, 30% of collected *M. salmoides* contained other juvenile fish in their gut and stomach. Not only food preference but also the consumption amount of fish changed according to their body size. The consumption amount of juvenile fish increased according to body size (Fig. 4).

DISCUSSION

The dynamics of river zooplankton have been often considered to be controlled by transport of populations and hydrology of rivers (Hynes, 1970; Pace *et al*., 1992; Thorp *et al*., 1994). However, in the Nakdong River, control of the water flow by four dams on tributaries and an estuary dam led to the river having river-reservoir hybrid hydrology (Kim *et al*., 1998; Kim *et al*., 2000). Thus the reservoir-like environment of the river during spring and early summer induced a high abundance of cladoceran species as well as juvenile fish. Thus, the possibility of juvenile fish to control zooplankton in this circumstance is opened.

Our results of the gut analysis indicate that the main prey items of juvenile fish in the Nakdong River are large rotifers and cladocerans. The food selection by juvenile fish seems to be determined by body size of fish since the gape size of fish larvae restricts their feeding range (Hartmann, 1983; Mehner *et al*., 1998a). In the Nakdong River, regardless of species, food items of the juvenile fish shifted from large rotifer to cladocera with the increase of body size of the fish. High density of smaller size of juvenile fish and their high selectivity on large rotifer may explain the decrease of *Brachionus* and *Asplanchna* during the same period. In early June, as juvenile fish grew, selective feeding on cladoceran species may induce the decrease of *M. micrura* and *B. deitersi*. High phytoplankton biomass (average chl. *a* : 26.7 μg/l, mainly consisting of Chlorophyta and Crysophyta from May to June) and decrease of maturity size (Fig. 5) of these species support that juvenile fish predation would be a main reason for the decrease of their densities rather than food limitation, which often induces a mid−summer decline of cladoceran species combined with size−selective predation by age−0 juvenile fish (Lin and Culver, 1991; Hülsmann and Mehner, 1997). On the contrary, the decline of birth rate seems to be the result of intense juvenile fish predation on the large individuals bearing more eggs than smaller individuals (Gliwicz and Pijanowska, 1989; Gliwicz *et al*., 2000).

Changes in the juvenile fish community seems to be one of the factors which contributed to minimizing the predation impact in the Nakdong River. On June 10, juvenile largemouth bass, *M. salmoides*, were collected in the net and all individuals exceeded 3 cm in body size. Different from other juvenile fish, the gut and stomach contents of bass contained other juvenile fish as well as zooplankton. Olson (1996) reported that the prey item of the largemouth bass changed from crustaceans to fish in the size c.a. 2 cm and a distinct diet shift from crustaceans to fish occurred when their size reached near 4 cm of length. The juvenile largemouth bass feeds first on zooplankton, and then its foraging behavior shifts to piscivorous. As it becomes progressively

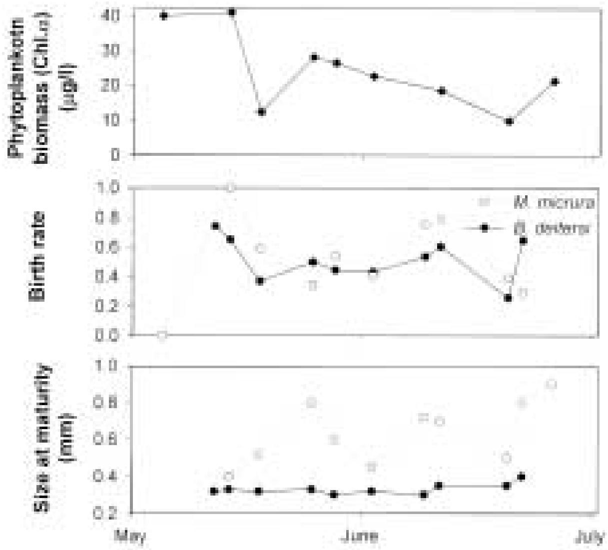

Fig. 5. Changes of phytoplankton biomass (chl. *a*), instantaneous birth rates, and maturity sizes (smallest size of individual containing eggs in the brood chamber) of two major cladoceran species (*Moina micrura* and *Bosminopsis deitersi*) in the Nakdong River (1999).

more piscivorous, its impact on food web structure reverses and induces the dominance of larger bodied zooplankton such as cladocera since it removes other planktivorous juvenile fish (Post *et al*., 1997). In the lower part of Nakdong River, adult largemouth bass occupied 12% of total fish abundance (The Ministry of Environment, 2000). Predation by adult largemouth bass may control the food web structure through intense predation on other fishes as well as juveniles (Carpenter and Kitchell, 1993; Mittelbach *et al*., 1996). Thus, the presence of the piscivorous largemouth bass might induce the decline of other juvenile fish in the Nakdong River.

In the Nakdong River, the decrease of cladoceran density rapidly recovered after their density declined. The high trophic status of the river may be one of the reasons for the rapid recovery of cladoceran density. Vijverberg *et al*. (1990) and Mehner *et al*. (1998b) also reported a rapid recovery of cladoceran species during the development of juvenile fish in shallow eutrophic lakes. Their results suggest that the high trophic state of the environment makes food limitation less obvious, and that the predation impact of age−0 planktivores is more important and consequently had a low influence of age−0 fish predation on decline of large cladoceran.

In conclusion, the low discharge and water body stagnancy in the regulated river induced a lake–like succession of zooplankton community during a dry season. In this circumstance, juvenile fish predation seems to be one of the important factors controlling the zooplankton community, by suppressing large rotifers and cladocerans. However, the impact of juvenile fish predation seems to be modified by the high trophic state of the river and/or changes in the predator community such as predation of piscivorous bass on other juvenile fish by leading to the recovery of the cladoceran species.

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<국문적요>

저수지화 성향을 띤 낙동강에서 치어 섭식이 동물플랑크톤 군집에 미치는 영향

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낙동강에서 치어섭식이 동물플랑크톤에 미치는 영향을 채집된 치어의 소화관조사를 통해 고찰하였다. 조사지역인 낙동강 하류 물금에서는 유량이 감소하고 수체가 정체되는 5월에서 6월사이 5종류의 치어가 높은 밀도를 나타내었다. 같은 시기, 동물플랑크톤 군집내에서는 대형윤충류인 *Asplanchna* spp.와 *Brachionus* spp., 지각류인 *Moina micrura* 및 *Bosminopsis deitersi*의 밀도가 큰 폭으로 감소하였다. 반면, *Polyarthra*속의 소형윤충류는 최대 밀도를 나타내었다. 채집된 치어의 소화관 조사 결과, 15 mm 이하의 치어는 대형윤충류 및 지각류를, 15mm 이상의 치어인 경우 지각류를 선택적으로 섭식하는 것으로 나타났다. 큰입배스의 치어의 경우, 같은 시기 채집된 치어에 비해 대형이었으며 동물플랑크톤 뿐 아니라 다른 치어를 포식하는 것으로 조사되었다. 조사 결과, 이 시기의 낙동강 동물플랑크톤 군집내의 대형 윤충류와 지각류의 급격한 밀도 감소는 치어의 섭식으로 인한 것으로 사료된다. 반면, 이러한 밀도감소는 치어의 수가 감소함에 따라 회복되는 경향을 보였다. 부영양화된 낙동강의 경우 배스치어의 섭식으로 인한 치어밀도의 급속한 감소, 풍부한 먹이농도 등이 감소한 지각류의 밀도회복을 유도하는 것으로 사료된다.