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The Preference on the Substrate Particle Size and Microdistribution of Two Potamanthid Mayflies, *Potamanthus yooni* and *Rhoenanthus coreanus* (Ephemeroptera: Potamanthidae)

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ABSTRACT : The preference on the substrate particle size in two Potamanthid mayflies (*Potamanthus yooni* and *Rhoenanthus coreanus*) was studied in the field and laboratory. In the field, the change pattern of density was different between two species, but the period of highest density was 23rd September in both species. Both species occurred most abundantly in small cobble (*P. yooni* : 163 individuals, *R. coreanus* : 93 individuals), and over 85% of total individuals of both species occurred in the substrate particles from large pebble to large cobble. The distribution pattern of each species was not changed significantly during the sampling period. The results from laboratory experiment were well consistent with those from field survey and certified the substrate particle size (SPS) preference of *P. yooni* and *R. coreanus*. The shape of the fundamental niche induced from the results of laboratory experiments was similar between two species, but the depth was deeper in *P. yooni* than in *R. coreanus*. The comparison of the realized and the fundamental niche of each species showed the relative importance of SPS as environmental factor. One of the potential factors that affected interspecific competition between two species would be the life cycle of each species.

Key words : substrate particle size, Potamanthidae, niche, preference, microdistribution

INTRODUCTION

The substratum is the stage upon which the drama of aquatic insect ecology is acted out (Minshall, 1984). Characters of the substrata composition are highly correlated with the water velocity, water temperature, chemical composition, and so on, thus substratum in the given area can represent the environmental conditions of microhabitat where aquatic insects inhabit. This means substratum is most important environment for aquatic insects. And many studies showed presence or absence of the particular species were correlated with the substrata composition (Cummins and Lauff, 1969; Lamberti and Resh, 1979; Wright and Mattice, 1981; Kim *et al.*, 1998). Because many substratum characteristics are directly related to the particle size (or diameter), particle size would be the basic but most important characteristics. Moreover, Bae and McCafferty (1994) showed substrate particle size alone could influence the distribution of *Anthopotamus verticis*.

Potamanthid mayflies have been known to inhabit within substrates, mainly granule or pebble, which is abundant in the metapotamon or epipotamon (McCafferty, 1981; Yoon, 1995; Merritt and Cummins, 1996; Kim *et al.*, 1998). They were considered as spawlers or clingers because of flatten body shape. Recently, however, their phylogenetic relationship was known to be closer to the burrowing mayfly (McCafferty

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1991; Bae and McCafferty 1994).

Two potamathid mayflies (*Potamathus yooni* and *Rhoenanthus coreanus*) were more abundant in Korea than others. The study on general habitat characteristics for these two species was already published (Kim *et al.*, 1998). In that paper, substrate particle size preference would be slightly different between two species. However, they couldn't show apparent evidence, because their study was originally designed for the description on the habitat of *P. yooni* and *R. coreanus*. Therefore, more concentrated studies on substrate preference of two species have been required for elucidating whether each species prefer particular substrate particle size or not and, if they show preference, preferred particle size is different between two species.

In this paper, preference on substrate particle size of *P. yooni* and *R. coreanus* would be analyzed and tested by field and laboratory experiments. In addition, the discussion on their niches on a single resource dimension would be proposed, as well.

MATERIAL AND METHODS

Four species in the Family Potamanthidae (*Potamanthus yooni*, *P. luteus oriens*, *P. formosus* and *Rhoenanthus coreanus*) were recorded in Korea (Bae and McCafferty 1991). Among four species, only *P. yooni* and *R. coreanus* were examined in this study, because distribution of the larvae of them was well-known and more abundant than *P. luteus* and *P. formosus* in Korea.

Field experiment

The study site was located in the Hwaak Creek (37° 53′ 59″ N, 127° 33′ 64″ E), a tributary of the Kapyong Stream (Fig. 1). The altitude of the study site was ca. 100 m and the stream order was 6. The water width on the study site was 10~20 m and the depth was 0.1~0.6 m. The water temperature ranged from 12°C to 26°C during the sampling periods. The study site divided into riffle and following pool. The water velocity was 0.21~0.79 ms^{-1} in riffle and near 0 ms^{-1} in pool.

Samplings were taken bimonthly using the Surber net (frame size : 50 × 50 cm, mesh size : 0.02 cm), but monthly in the rainy season (July and August), from April to October 1997. In every sampling period, area of 1 m^2 (4 times by Surber net) was surveyed both in the riffle and the pool, and sampling points were selected at random. In order to measure the substrate particle size (SPS) and individual number of each species attached on the particle, every substrate particle within the surber net was picked up carefully one by one until all particles larger than granule were removed. To catch the individuals within the smaller particles, substrates were suspended. Because water velocities were extremely low in the pool area, individuals were collected by hand net (frame diameter : 15 cm, mesh size : 0.05 cm) after suspending. Each particle size and individual number of each species on the particle was recorded. Field data on the particle size were sorted according to the Wentworth classification system (Wentworth, 1922). *P. yooni* and *R. coreanus* occurred rarely in the riffle area (unpublished data). Thus, only the data from the pool area were used in the analysis. In the field situation, other factors influencing the distribution of two species except particle size couldn't be removed perfectly. Therefore laboratory experiment was needed to confirm the results from field survey and to compare the SPS preference between two species.

Laboratory experiment

The laboratory experiment was carried out from April to May 1998. The substrate particles were sampled at the field study site. To remove the organic matter, substrate particles were washed carefully and sorted to size by sieves (Bae and McCafferty, 1994). For this experiment, transparent glass aquarium (110 × 45 × 45 cm) was filled with the dechlorized tap water, and two boxes (45 × 30 × 10 cm) containing the substrate were settled in the aquarium.

The movement of the individuals between two boxes was inhibited by plastic plate. Each box contained 4 homogeneous substrate types [small pebble (phi = −4, 16-32 mm), large pebble (phi = −5, 32-64 mm), small cobble (phi = −6, 64-128 mm), large cobble (phi = −7, 128-256 mm)] which arrange sequentially (Fig. 2). When the substrates were arranged in the box, thin stainless plates were used for preventing the substrate mixing. For the free movement of test indivi-

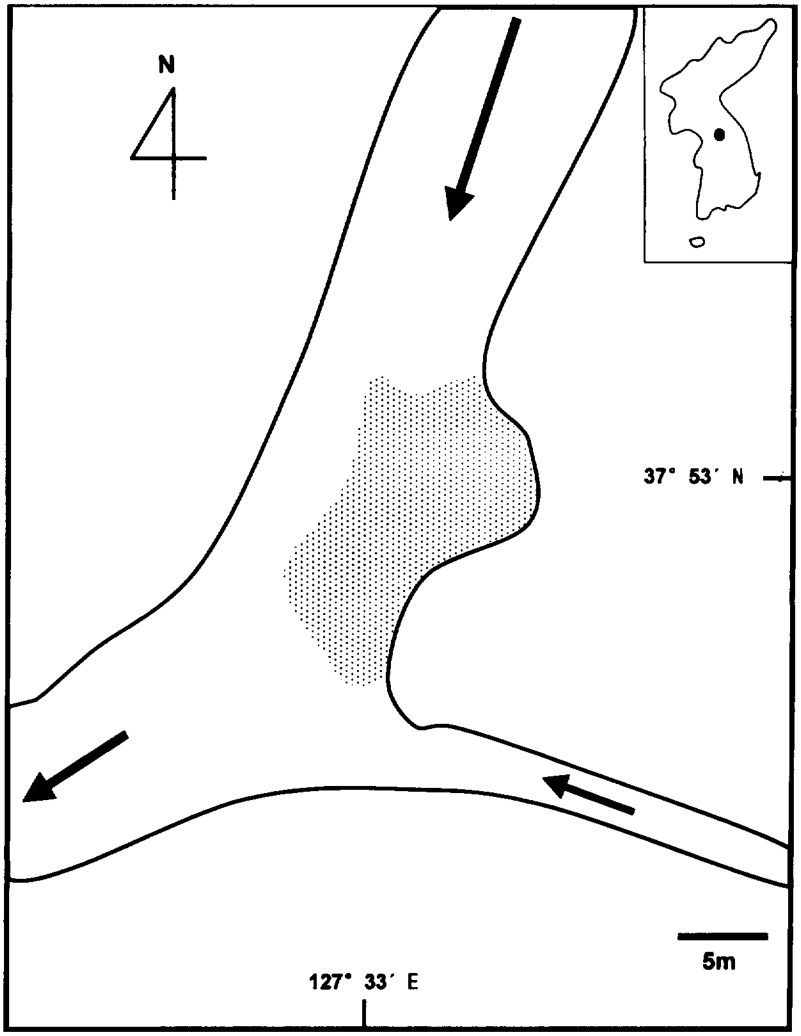


Fig. 1. Survey site for this study located in Kapyong-gun, Kyonggi-do, Korea. Dot area indicates the main pool in the survey site.

duals, these plates were removed after the arrangement of substrates was completed. The water temperature was maintained at 18~20°C. In order to protect test individuals from death caused by reduced DO level, airstones were placed at each side of the boxes. Photoperiod was not controlled, because experimental periods were relatively short and natural photoperiod was not changed seriously during the experiment periods.

Examined individuals of each species were captured 2~4 days before each experiment. In experiments, individuals of *P. yooni* were released at one of the box and those of *R. coreanus* at another box in the aquarium. Therefore, there were no significant differences in the experiment condition between two species. The individuals were released evenly at each substrate and recaptured 2 days after. Over 30 individuals in each species were examined in each experiment, but 16 and 25 individuals in the 1st and 2nd experiment for *R. coreanus*.

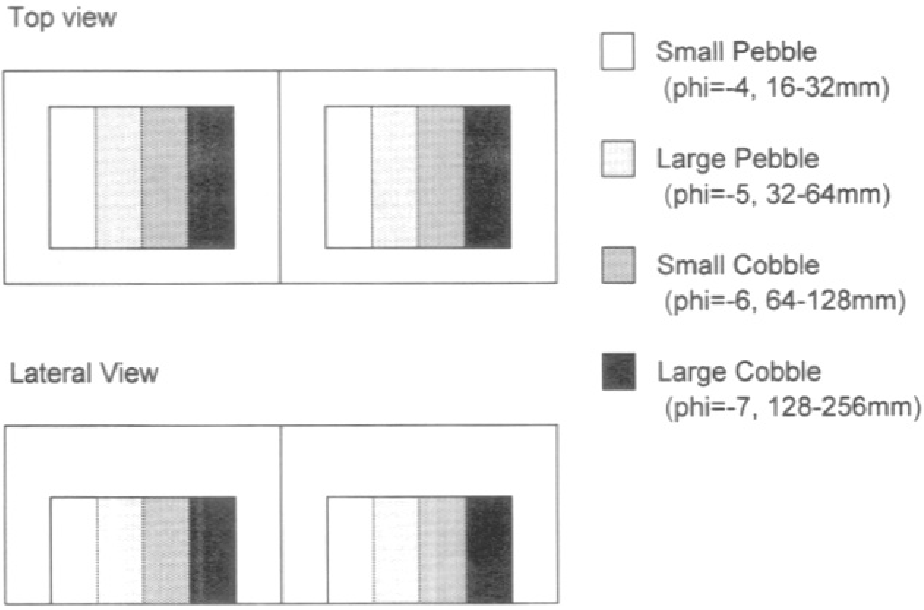


Fig. 2. Laboratory experimental scheme; arrange of the various substrate.

RESULTS

1. Field survey

Total individual number collected during the study period was 363 individuals for *P. yooni* (mean density : 36.3 m^{-2}) and 205 individuals for *R. coreanus* (mean density : 20.5 m^{-2}), respectively (Table 1). On the basis of total individual number in each substrate, overall distribution pattern on the substrate particle seemed to be very similar in two species and showed both species were most abundant in the small cobble (*P. yooni* 163 individuals, *R. coreanus* 93 individuals). Large cobble was the next substrate particle where each species was abundant (*P. yooni* 89 individuals, *R. coreanus* 46 individuals), and Large pebble was the third individual rich substrate in both species (*P. yooni* 59 individuals, *R. coreanus* 40 individuals).

The forth and fifth substrate were boulder and small pebble in *P. yooni*, but small pebble and boulder in *R. coreanus*. Most individuals of two species were collected on the substrate particles ranged from large pebble to large cobble (*P. yooni* : ca. 85.7% and *R. coreanus* : ca. 87.3%).

The density of both species was changed during the sampling period (Fig. 3). *P. yooni* showed the highest density at 23rd September (115 m^{-2}) and extremely low density from 14th July to 5th August (6 and 5 m^{-2}). The density of *P. yooni* was decreased abruptly at 14th July and increased again at 5th September (Fig. 3). *R. coreanus*, also, showed the highest density at 23rd September (43 m^{-2}). However, the changing pattern of the density during sampling period was different from that of *P. yooni*. The density of *R. coreanus* was gradually increased and reached to maximum density at 23rd September and reduced at the last survey (Fig 3). In the early of field survey, *P. yooni* was more abundant than *R. coreanus* but difference in the density was reduced as the emergence period of *P. yooni* was coming (Fig. 3). From 23rd June to 4th September, *R. coreanus* was more abundant than *P. yooni*. After 4th September, densities of both species were reduced at 26th October in comparison to those at 4th September, but still higher than those at other survey periods (Fig. 3).

In *P. yooni*, overall distribution pattern on the SPS was alternated during sampling period (Fig. 4a), and difference in distribution pattern was significant among sampling periods ($F_{9, 50, 0.05} = 2.53$, $p < 0.05$). However, LSD (11.09) indicated

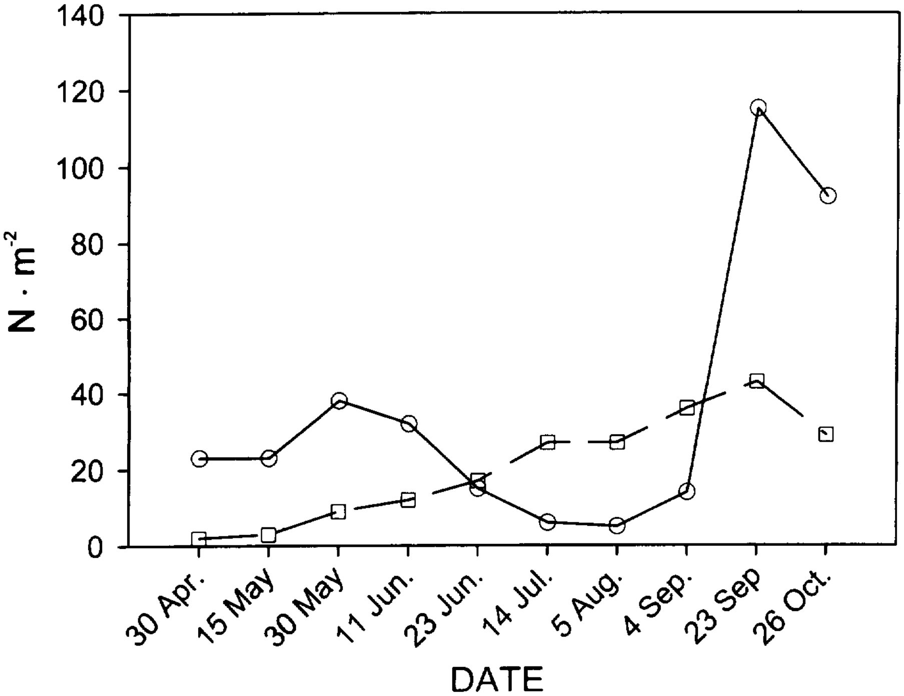


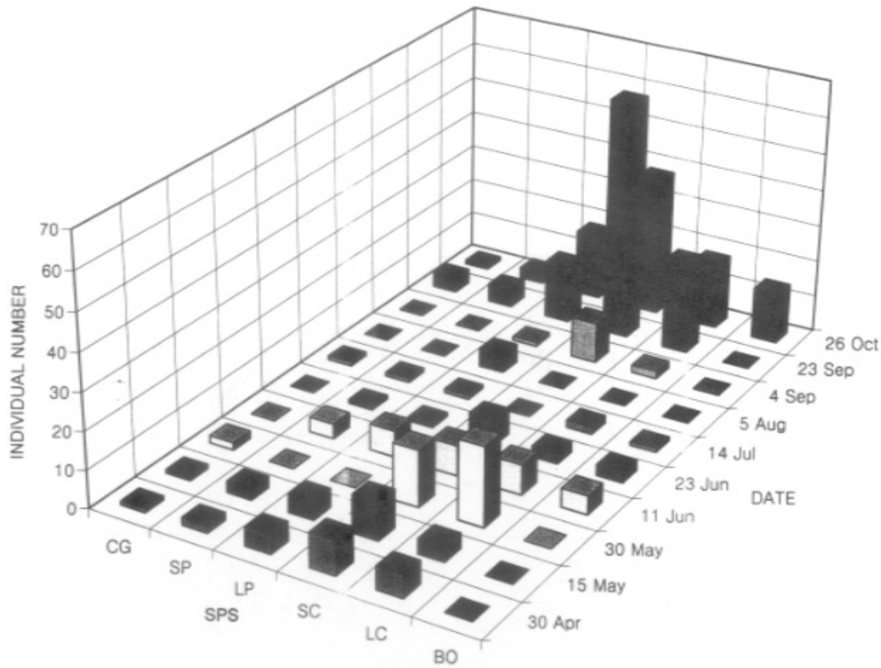
Fig. 3. Change of density of each species during the survey periods. Circle with solid line is for *P. yooni* and square with dashed line for *R. coreanus*.

Table 1. Total, mean and SD of individual number collected from various size of substrate from coarse gravel to boulder during the sampling period.

		<Large gravel	Small pebble	Large pebble	Small cobble	Large cobble	Boulder	Tot. Ind.
P. yooni	Total	10	19	59	163	89	23	363
	Mean	1.00	1.90	5.90	16.30	8.90	2.30	
	SD	1.25	1.79	6.31	20.14	9.01	4.45	
R. coreanus	Total	4	12	40	93	46	10	205
	Mean	0.40	1.20	4.00	9.30	4.60	1.00	
	SD	0.52	1.40	4.22	8.93	3.44	1.89	

the possibility of type-I error, and T-grouping did not showed discrete boundary between the groups. Thus the difference could be resulted from extremely low density from 14th July to 5th August. The result of ANOVA on the data excluding the low density period, showed that distribution pattern in each sampling periods was not significantly different from each other ($F_{7,40,0.05} = 2.12$, $p > 0.05$). In case of *R. coreanus*, also, there were some differences in distribution pattern during the sampling periods (Fig. 4b), but this difference was not statistically significant ($F_{9,50,0.05} = 1.26$, $p > 0.05$).

Individual number in each size of particle was significantly different from others in both *P. yooni* ($F_{5,42,0.05} = 4.40$, $p < 0.05$) and *R. coreanus* ($F_{5,54,0.05} = 5.86$, $p < 0.05$) during the sampling periods. The distribution of both species was concentrated to the small cobble in almost every sampling period. The distribution pattern on the various size of substrate particle, thus, was somewhat coincident to the overall distribution



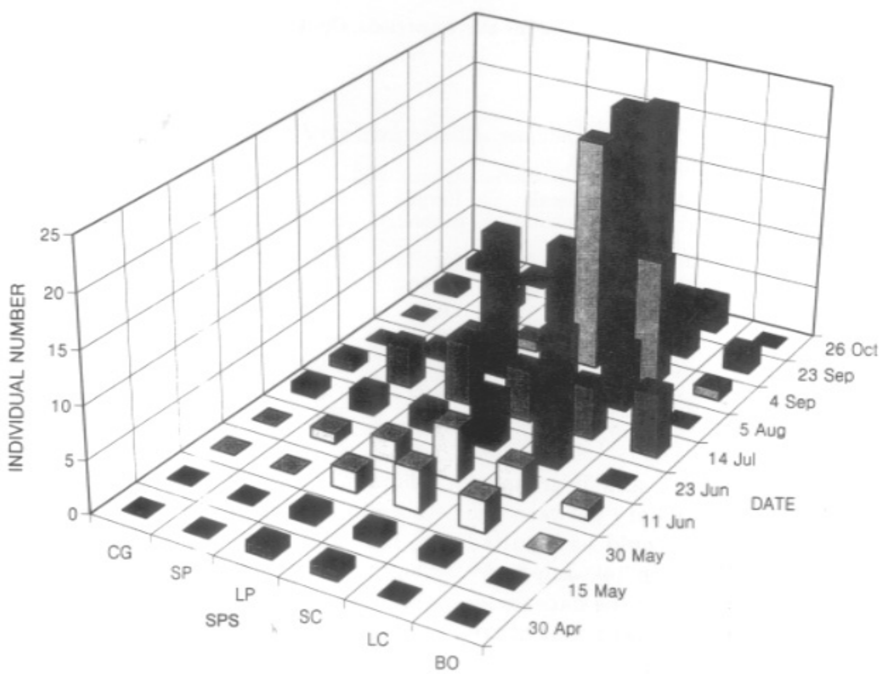


Fig. 4. Distribution of each species along with the SPS during the survey periods; a) *P. yooni* and b) *R. coreanus*. (CG : coarse gravel, SP : small pebble, LP : large pebble, SC : small cobble, LC : large cobble, and BO : boulder).

Table 2. Total, mean and SD of individual number of each species recaptured from 4 experimental substrate type (5 replications). D indicated the dead individual during the experiments.

		Small pebble	Large pebble	Small cobble	Large cobble	D	Tot. Ind
P. yooni	Total	18	44	67	23	40	192
	Mean	3.60	8.80	13.40	4.60	8.00	
	SD	1.82	1.30	2.88	2.30	2.35	
R. coreanus	Total	17	38	54	22	17	148
	Mean	3.40	7.60	10.80	4.40	3.40	
	SD	2.07	1.82	3.27	1.67	2.79	

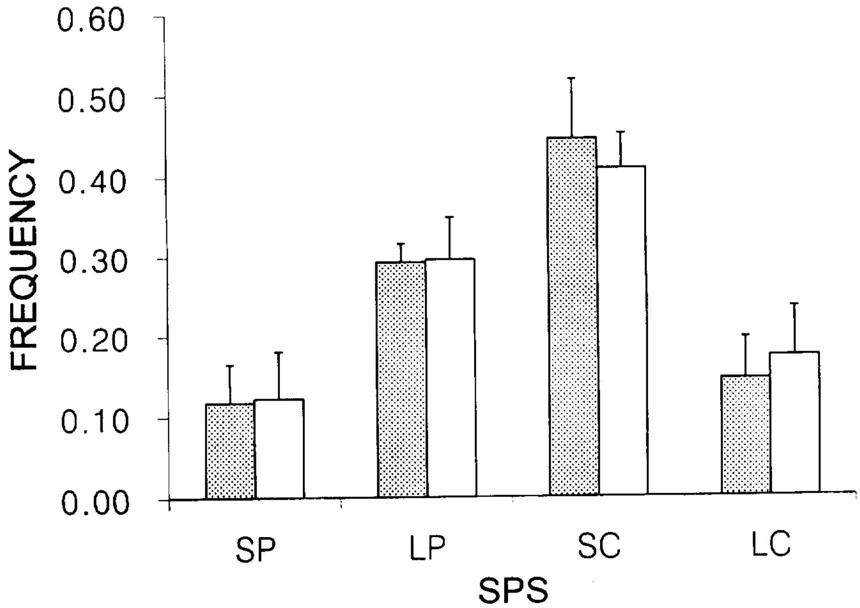


Fig. 5. Occurrence frequency of each species in the various size of particle. Dotted bar indicate the frequency *P. yooni* and the Hollow bar that of *R. coreanus*. Vertical error bar means SD. (SP: small pebble, LP : large pebble, SC: small cobble, and LC: large cobble).

pattern in the both species (Table 1, Fig. 4). Putting the results from the field sampling together, it was highly possible that both species should have preference on the particular SPS.

2. Laboratory experiment

Total 192 individuals of *P. yooni* and 148 individuals of *R. coreanus* were examined in laboratory experiments (Table 2). Among examined individuals of each species, 152 individuals of *P. yooni* and 131 individuals of *R. coreanus* were recaptured alive during the experimental periods. The survivor rate of each species in this experiment, thus, was 78.86±6.48% for *P. yooni* and 89.78±6.57% for *R. coreanus*, respectively. The descriptive statistics on the recaptured individuals showed that occurrence of both species concentrated to the large pebble and small cobble (Table 2). ANOVA showed different occurrence in the various size of substrate particle was significant in both *P. yooni* ($F_{3, 16, 0.05} = 21.53$, $p < 0.05$) and *R. coreanus* ($F_{3, 16, 0.05} = 10.65$, $p < 0.05$). And the comparison of distribution pattern among replications by ANOVA showed the distribution pattern was not significantly different among replications but rather consistent in both *P. yooni* ($F_{4,15,0.05} = 0.40$, $p > 0.05$) and *R. coreanus* ($F_{4,15,0.05} = 0.79$, $p > 0.05$). When the individual number in each substrate particle converted to the occurrence frequency, the distribution pattern was quite similar to each other in *P. yooni* and *R. coreanus* (Fig. 5). ANOVA also showed difference in the distribution pattern between two species was not significant ($F_{1,38,0.05} = 0.67$, $p > 0.05$). All the results from laboratory experiment indicated the apparent SPS preference in the *P. yooni* and *R. coreanus* and their preferred SPS was small cobble.

DISCUSSION

Which features of the substratum are important to an aquatic insect are not apparent, but they certainly include some aspect of size, stability and heterogeneity (Minshall, 1984).

These three features are strongly implicated as important ecological factors from the works in freshwater environments (Hart, 1978; Shelly, 1979; Reice, 1980). Among three features, the results from our study indicated the possibility that *P. yooni* and *R. coreanus* had strong preference on the particular SPS. Because the particle size may be the most important substratum characteristics in the burrowing form (Eriksen, 1968), their particle size preference seem to be highly possible.

The preference for the substrate particle size has been known in various aquatic insects (Cummins and Lauff, 1969; Brusven and Prather, 1974; Mackay, 1977; Bae and McCafferty, 1994). Although Minshall (1984) agreed that some of the strongest evidence of preference came from the laboratory experiments of Cummins and Lauff (1969), he argued that the results were not totally satisfying because (1) species were examined only at certain points in their life cycles; (2) current velocity were low; (3) there was not always agreement between results obtained in the laboratory and those found in nature. However, the problem of correct velocity in the laboratory experiment did not matter in our study because two species occurred mainly in the pool where the current velocity was near 0 m sec^{-1}. Addition to this, field survey showed preference pattern was consistent statistically during the study period and the results from the laboratory experiments were coincident with those from the field survey. Thus our results seemed to be a good evidence for the SPS preference of two species.

Anthopotamus verticis had been known as preferring the particular size from coarse gravel to small pebble (Bae and McCafferty 1994). This wide preference was caused by preference alternation between smaller and larger larvae. In our study, more larvae of *P. yooni* collected from large cobble than small cobble in 30th May when mature larvae were abundant (identified by wing pad color), After this period, much of young larvae were collected, but most of them on the small cobble. In the field at 30th May, the last instar and exuviae were often found on the upper side of the substrate particle, which extruded out the water. Thus this change of the SPS preference may not be related to the change in the body size but emerging behavior of *P. yooni*. In case of *R. coreanus*, the particle size of maximum density was changed between large pebble and large cobble in the short period (from 23rd June to 5th August) only. Because there were no distinct variation in the larval body size of *R. coreanus* during sampling period, the relationship between the body size and change in the SPS preference seemed not to be clear.

All results in this study evidently showed that SPS acted as the limiting factor that restricted the distribution of two species. To the burrowers, pore space, which closely related to the SPS, would be the actual stage of their life. Certain SPS collected detritus more efficiently than others, presumably due to the attainment of optimal spacing of the substrates (Rabeni and Minshall, 1977; Williams and Mundie, 1978). Although the food habit of *P. yooni* and *R. coreanus* did not studied in this study, they were considered as the detritivore possibly, because Potamanthid mayflies were widely known as the collectors-filterers (Merrit and Cummins, 1996). Therefore adequate substrate size can give these burrowers the potential food more. In this sense, the pore space could be regarded as the translating factor that could make the environmental factor (SPS) act as the limiting factor.

Because the SPS is not the discrete variable (Minshall, 1984), arrange of various SPS could be regarded as the resource continuum. Thus,

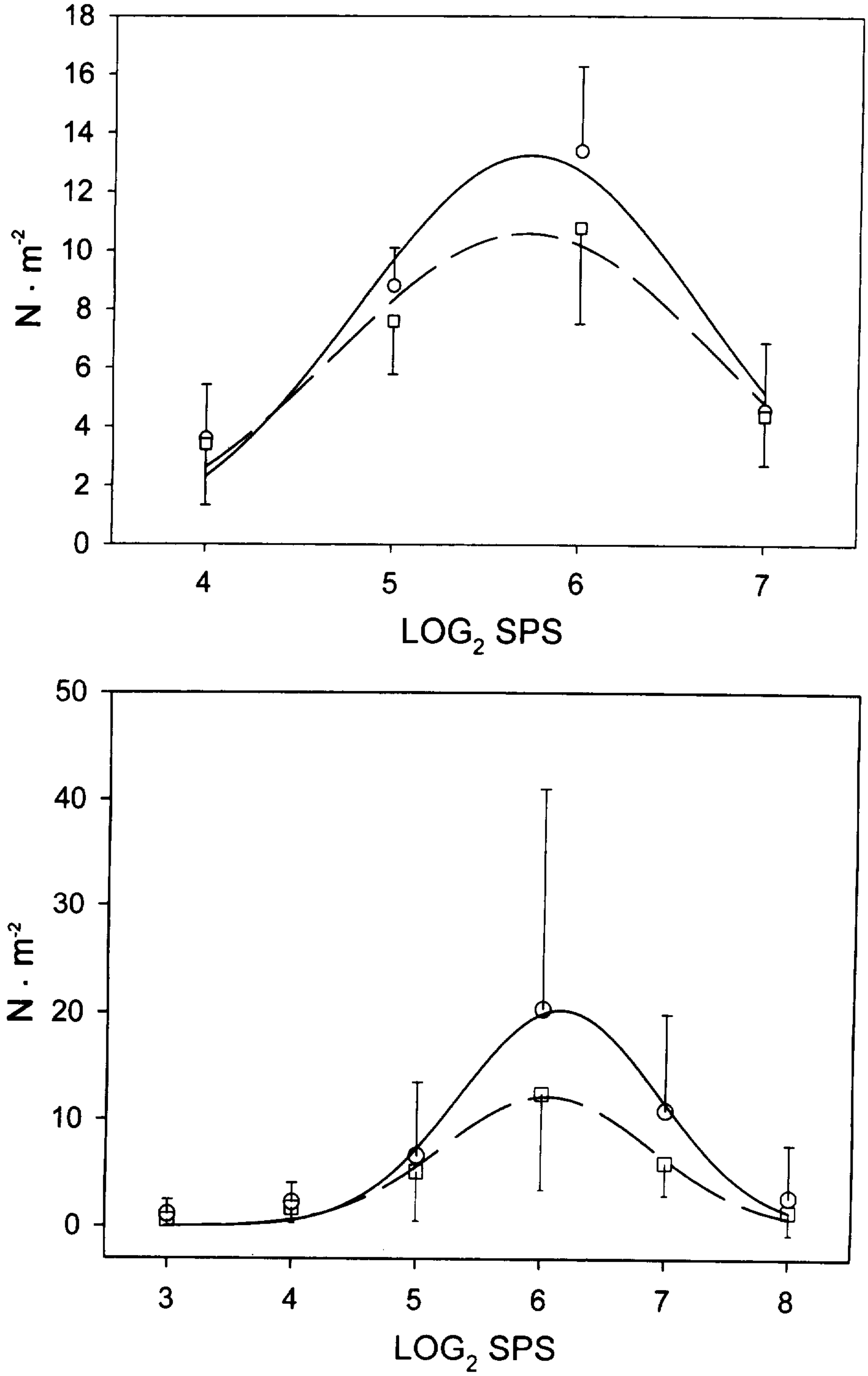


Fig. 6. Fundamental niche and realized niche of each species; a) show the fundamental niche and b) the realized niche. Circle with solid line is for *P. yooni* and square with dashed line for *R. coreanus*.

the fundamental niches on a single resource (SPS) dimension and the realized niches of two species could be induced from our results (Fig. 6). The shape of the fundamental niche was very similar between two species, but the niche depth was different (Fig. 6a). Similarity of the niche shape indicated the potential competition for the limited resource between two species. The realized niches (Fig. 6b) of two species showed coincidence to the fundamental niches. This similarity between the fundamental and realized niches indicated favorable SPS was most important factor among various environmental factors, because niche shape and depth of realized niche would be different from those of fundamental niche, if only one of the other factors was more influence to the distribution of two species.

Similarity in the shape of niche between two species could facilitate the interspecific competition for the favorable SPS. In the field survey, the negative effect in densities of both species occurred at 26^{th} October, but the densities were still higher than those at other survey periods (Fig. 3). This negative effect would be caused by interspecific competition between the larvae of *R. coreanus*, which occupied empty microhabitat after emergence of *P. yooni* and newly recruited larvae of *P. yooni*. Although *R. coreanus* acted like the specialist during the emergence period of *P. yooni*, they would become generalist on the continuum of the resource (SPS) after *P. yooni* was recolonizing (Fig. 4). Although more data would be needed to reveal the interspecific competition between two species, the difference in life cycle between *P. yooni* and *R. coreanus* seemed to be the one of the environmental factors which affected their competition for the favorable SPS.

Conclusively, this study showed preference of *P. yooni* and *R. coreanus* on the Small cobble (64-128 mm). Although high similarity in the SPS preference of both species indicated the possibility of competition on the favorable SPS between two species, there was no severe competition observed except later period of survey. The different life cycle would be one of the possible factors that affected competition for the favorable SPS between two species.

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국문적요 : 한국산 강하루살이류, 2종 (Ephemeroptera: Potamanthidae)의 저질크기 선호성과 미소분포에 대하여. 이성진, 배연재[1], 윤일병 (고려대학교 생물학과, [1]서울여자대학교 생물학과). 금빛하루살이와 장수하루살이의 저질입자크기 선호성과 미소서식처에서의 분포를 밝히기 위하여 야외조사와 실험실내 실험을 수행하였다. 야외조사에서 조사기간 중 각 종의 밀도는 서로 다른 양상을 띠며 변화하였으나 가장 밀도가 높은 시기는 동일하였다 (9월 3일). 두 종은 모두 입자크기 64~128 mm 사이의 저질입자에서 가장 풍부하게 출현하였으며 (*P. yooni* : 163 개체, *R. coreanus* : 93 개체), 총 출현개체수의 85% 이상이 입자크기 32~256 mm 사이의 저질입자에서 출현하였다. 저질입자크기에 따른 각 종의 분포는 조사시기에 따라 큰 차이를 나타내지 않았다. 이러한 결과는 각 종의 저질입자크기 선호성을 잘 보여주는 것으로 사료된다. 실험실내 실험은 야외조사의 결과를 충분히 뒷받침해 주었다. 본 실험의 결과를 토대로 각종의 생태적 지위를 분석해 본 결과, 두 종은 매우 유사한 형태의 생태적 지위를 갖는 것으로 나타났다. 이러한 생태적 지위의 유사성으로 인해, 두 종이 동일 지역에서 공존할 경우, 자원에 대한 심각한 종간경쟁이 예상되었다. 그러나 야외조사에서 이러한 경쟁의 징후는 비교적 짧은 시기에서만 관찰되었다. 두 종에서 종간경쟁의 발생여부는 생활사에 영향을 받는 것으로 사료된다.

검색어 : 저질입자크기, 강하루살이, 생태적지위, 선호성, 미소분포