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RESEARCH PAPER

Ephemeropteran community structure and spatial stability of local populations of the major species group in the Keumho River

Sung Jin LEE[1], Jae Heung PARK[2] and Tae Ho RO[2]

1 Korean Entomological Institute, Korea University, Seoul, Korea
2 Korea Environment Institute, Seoul, Korea

Correspondence
Tae Ho Ro, Korea Environment Institute, Seoul 122-706, Korea.
Email: thro@kei.re.kr

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Abstract

This study was conducted to analyze the community structure of mayflies and stabilizing points for the local populations in relation to longitudinal changes in the Keumho River, Korea. A total of 22 ephemeropteran species occurred in the main riverine system during the sampling period of 3 years. The results indicated that *Baetis fuscatus* (mean density of 117.3 individuals/m^2), *Ecdyonurus levis* (54.1), *Uracanthella rufa* (51.3) and *Caenis* KUa (49.9) comprised the major species group of the ephemeropteran community. The results of statistical analyses showed that these four species were distinguished from the others in terms of their mean densities. Longitudinal patterns based on total species numbers and numbers of individuals were characterized into three phases. A new approach was applied to analyze stabilized points for local populations based on the River Continuum Concept and density-dependent mechanisms among local populations in a metapopulation. Stabilized local populations of *B. fuscatus* and *E. levis* occurred coincidentally at two points that were approximately 45 and 75 km away from the Youngchun Dam. *Caenis* KUa was locally stabilized at two points that were 40 and 60 km away from the dam. *Uracanthella rufa* showed only one stabilized local population at a point approximately 80 km away from the dam. The diversity index for the ephemeropteran community was compared with that calculated for the benthic macroinvertebrate community, and their similarity is discussed.

Key words: local population, mayfly, metapopulation, River Continuum Concept, stabilized local population.

Introduction

In the lotic community, aquatic insects may be the most important group; they comprise over 95% of total individuals or species of macroinvertebrates (Ward 1992). However, the functional importance of aquatic insect communities has been underestimated in many studies published in Korea, which in some cases could result in unjustified conclusions pertaining to the bio-indicators in a given area. Total input cost (time and energy) to obtain reliable results is higher in sampling and analyzing a whole benthic macroinvetebrate community than for an aquatic insect community only. Of the aquatic insects, mayflies are found in all types of freshwater system, with the exception of the high Arctic and Antarctic regions, and they show great diversity in lotic habitats in temperate regions (Williams & Feltmate 1992). Mayflies have been evaluated as one of the most important taxa in both functional and structural aspects in most studies on the benthic macroinvertebrate community because of their diversity and abundance (Yoon 1995; Aanes 1980). Therefore, results from a carefully designed structural analysis of a mayfly community could be representative for the whole macroinvertebrate community.

Arbitrary spatial limits are often set in studies on a population, because it is difficult or impossible to identify the real geographic boundaries of a population (Berryman 1981). The River Continuum Concept (RCC) (Vanote *et al*. 1980) provides an important conceptual framework for explaining the ecological phenomena in a riverine ecosystem. As a single synthetic framework, the RCC describes the function of lotic ecosystems from headwater to mouth, and explains the variation between sites (Allan 1995). Changes in species competition along a river's length establish longitudinal zonation resulting from the differences of local population composition. Therefore, we can apply the metapopulation concept to explain a specific population occurring in a single synthetic system by adopting the RCC. If net migration change is assumed as the response of population regulation, a diagram for the interaction between two local populations of the same species that occupy two spatially distinct environments can be drawn (Berryman 1981). Generally, the lotic system is a continuum of various environments along changes in longitude. The density of species, which is widely spread out within a particular lotic system, often fluctuates along longitudinal changes. With this point of view, an ecological argument may arise: Is it possible to identify one or more equilibrium areas where the density of a specific metapopulation is more stable than other points within a synthetic riverine ecosystem?

In the present study, we performed two major analyses that can possibly explain the ecological phenomena mentioned earlier. First, mayfly community structure was analyzed and compared with the results of a previous study (Won 1992) for the whole community in the river to elucidate whether the mayfly community is representative. Second, relatively more important mayflies (major species) were identified among mayfly populations, based on species composition and population density in the community. The local population densities of the major species group were analyzed to elucidate the stabilizing points of each metapopulation along longitudinal changes.

Materials and methods

Study area

The Keumho River is located in the Kyungbuk Province, south-eastern Korea (Fig. 1). It originates in the mountains and flows into the Nakdong River, one of the largest riverine systems in Korea. Its length is approximately 118.4 km and its area 2087 km^2. A multipurpose dam, approximately 18 km from the origin, is the conspicuous physical barrier that disturbs the natural riverine ecosystem of the river. Because impoundment and diversion of watercourses for electric power production and water supply can have profound effects on the mayfly fauna (Brittain & Saltveit 1989), we restricted the study area to between the mid and lower part of the river. The uppermost part of the study area was approximately 25 km downward from the dam. Therefore, the total length from this point to the lowermost part was approximately 75 km. An earlier study on the Savannan River (Hudson & Nichols 1986) reported that only three mayflies were recorded immediately below a hydropower station, while ten and twelve were recorded, respectively, at 4.5 and 12.5 km below it. Therefore, a distance of 25 km from the dam for the uppermost point of the study area seemed sufficient for mayflies to recolonize naturally. The river is 100–250 m wide, with 15–150 m of water width, and stream order ranged from 5 to 6 (map scale 1:50 000) according to Strahler's modified method (Ward 1992). The basin is composed of mainly cobble, but the river bottom varies from rock to sand (mainly gravel) along longitudinal changes. Although the river flows across two cities, one of which is a large city, most of its basin is not channelized or linearized. In summer before the rainy season, diatom and algae bloomed and covered most of the river bottom, except a limited area in the upper study area.

Sampling procedure

Samples were taken monthly from October 1990 to July 1993, except during the icy and the rainy seasons. A total of ten points were selected for the local samplings in the study area (Fig. 1). The mean distance between adjacent sampling points was approximately 8 km and the uppermost point was located approximately 25.1 km away from the Yongchun Dam.

Samples were taken twice at each point using Surber net (50×50 cm^2; mesh size 1 mm). To avoid bias in the community structure analysis, one sample was taken at the riffle area and another at the pool or run area at each point. Sampled specimens were contained in 500 mL plastic bottles with the substrate and fixed by 10% formalin in the field. All of the benthic macroinvertebrates were sorted out from the substrate in the laboratory. Ephemeropteran nymphs were identified under a dissecting microscope (7–40×) and identified specimens were preserved in the 80% ethyl alcohol.

Analysis

The mayfly community in the entire riverine system was analyzed by two approaches: qualitative (species composition) and quantitative (density of each species). The major species were distinguished from others based on three criteria: structural, distributional and seasonal characteristics. In other words, major species would be abundant and distributed widely in the riverine system as well as occurring more frequently during sampling periods. For the first criterion, ANOVA analysis (SAS Institute 1989) was applied to compare

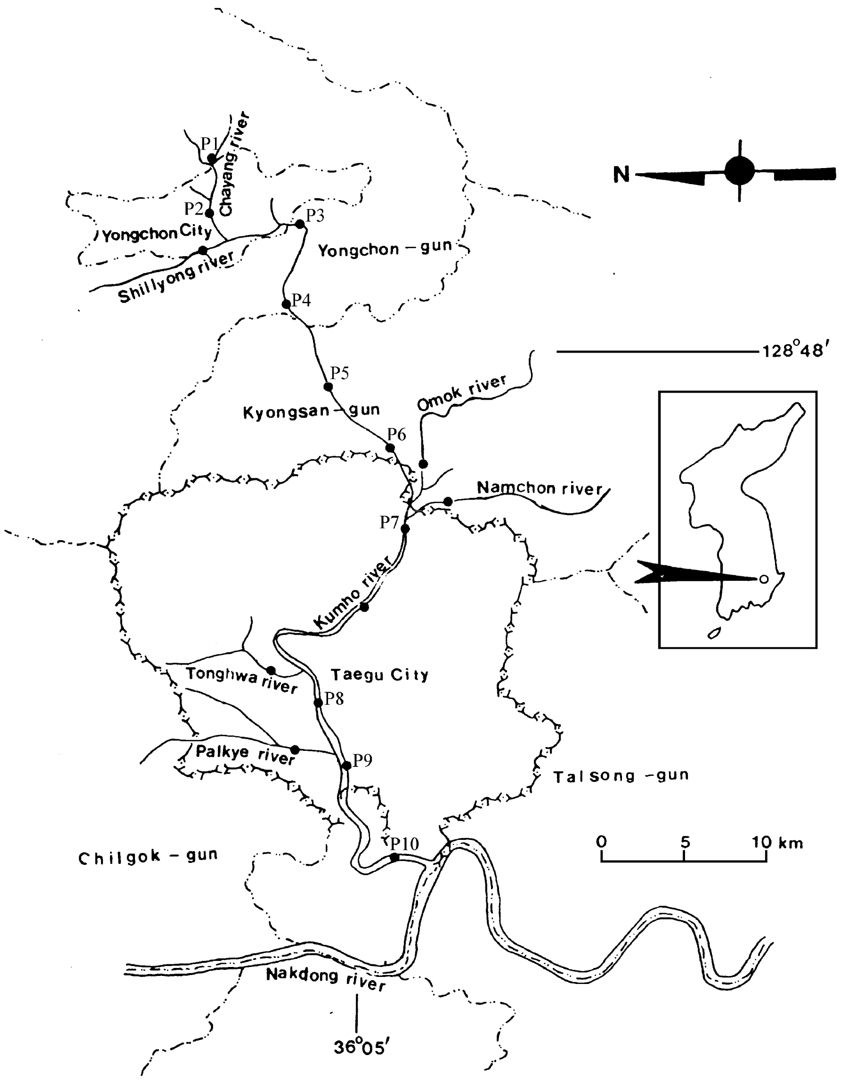

Figure 1 Sampling points in the Keumho River. ●, Sampling points for the previous study (Won 1992) and test annotations for the present study.

the differences in mean densities of all species from each sampling ($\alpha = 0.05$). The mean number of occurring point frequency (OPF), which indicates the number of points where each species occurred, was also analyzed and compared using ANOVA for the second criterion. The third criterion was examined by linear regression analysis between total and average individual numbers of each species.

The degrees of dominance and diversity were estimated for characterizing each community at each point. The most and second-most dominant species were determined from the individual number per unit area (1 m^2) of each species, and the diversity index was calculated using Shannon's function (H′) (Pielou 1966) as follows:

$$H' = -\sum \frac{n_i}{N} \log_2 \frac{n_i}{N} \quad (1)$$

where n_i = individual number of i species and N = total individual number.

The dominance index (DI) was calculated by McNaughton's method (McNaughton 1967):

$$DI = \frac{n_1 + n_2}{N} \quad (2)$$

where n_1 = individual number of the most dominant species; n_2 = individual number of the second-most dominant species; and N = total individual number.

The mean density of each major species was estimated at each sampling point, to show the changing pattern of density with increasing distance. The changing rates of mean density (CR) in between successive sampling points for major species were calculated as follows:

$$CR = \frac{D_{j+1} + D_j}{D_j} \quad (3)$$

where D_j = mean density of jth point and D_{j+1} = mean density of $j+1$th point.

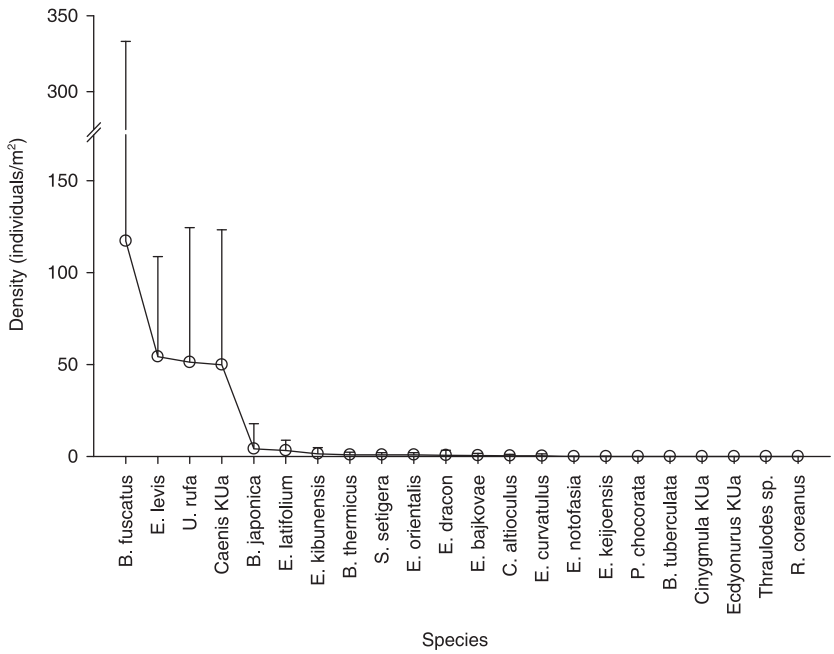

Figure 2 Density of each mayfly species in the Keumho River during the sampling period. ○, Mean with standard deviation (bars).

Results

Community structure and major species

A total of 22 mayfly species occurred in the Keumho River during the study period (Fig. 2). The ephemeropteran community consisted of 14 genera in seven families. The species belonging to the Heptageniidae showed the most diverse species composition (eight species), followed by Baetidae and Ephemerellidae (four species), and Leptophlebiidae (three species). The mean densities of *Baetis fuscatus*, *Ecdyonurus levis*, *Uracanthella rufa* and *Caenis* KUa were relatively high (≥ 50 individuals/m^2), while those of other species were low (< 5) (Fig. 2). A baetid species, *B. fuscatus*, was the most abundant species of the mayfly species in the whole riverine system, with a mean density of 117.3 individuals/m^2 (range: 0 to 1073.2). The mean density of *E. levis* was 54.3 followed by *U. rufa* (51.3) and *Caenis* KUa (49.9). The results of ANOVA showed that mean densities of mayfly species were significantly different and grouped into three categories ($F = 7.84$, $P < 0.001$, d.f. = 21, 258), which were not significantly different. The mean density of *B. fuscatus* was significantly different from those of *E. levis*, *U. rufa* and *Caenis* KUa. Other species occurred at very low densities (< 4.2 individuals/m^2).

The mean OPF of each species is shown in Figure 3. Results indicated that four species occurring with high mean density also showed a relatively higher value of OPF, significantly different from other species ($F = 40.99$, d.f. = 21, 528, $P < 0.01$). *B. fuscatus* showed the highest mean value among the four species. *Ecdyonurus levis*, which was the second-most abundant species, occurred at fewer points than the other three species. *Caenis* KUa, the least abundant of the four species, occurred at more points than *E. levis* and *U. rufa*. This showed that the distribution of *E. levis* was relatively restricted in a limited range whereas *B. fuscatus* was distributed in a broad range in the Keumho River. Other species occurred at highly limited points, and their OPF ranged from 0.4 to 1.2. This group consisted of several subgroups that were not significantly different. In addition, the result of the regression analysis between total and mean individual number discriminated the four species (*B. fuscatus*, *E. levis*, *U. rufa* and *Caenis* KUa) from the others. The slope of this group was 20.3 ($r^2 = 0.999$, $P < 0.01$), while the slope of the minor species group was 10.4 ($r^2 = 0.951$, $P < 0.01$) (Fig. 4).

The common feature of the results from the above three analyses was that *B. fuscatus*, *E. levis*, *U. rufa* and *Caenis* KUa were the representative mayfly species (i.e. major species) in the Keumho River. Therefore, the mayfly community in the Keumho River could be divided into two groups: a major species group that was highly abundant in individual numbers with high occurrence frequencies both in time and space; and a minor species group that occurred in low numbers of individuals with lower frequencies.

Longitudinal changes in community structure, H′ and DI

Longitudinal changes in both species numbers and individual numbers in this riverine system had a similar pattern (Fig. 5). The changing pattern could be divided into three phases. Phase I occurred in the upper part of the riverine system

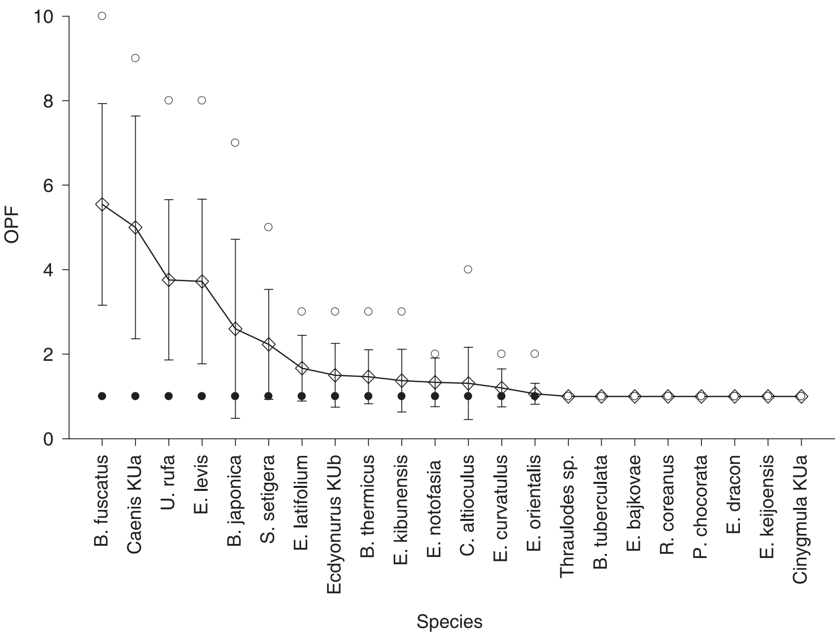

Figure 3 Occurring point frequency (OPF) of each mayfly species in the Keumho River during the sampling period. ◇, mean with standard deviation (bars); ○, maximum OPF; and ●, minimum OPF.

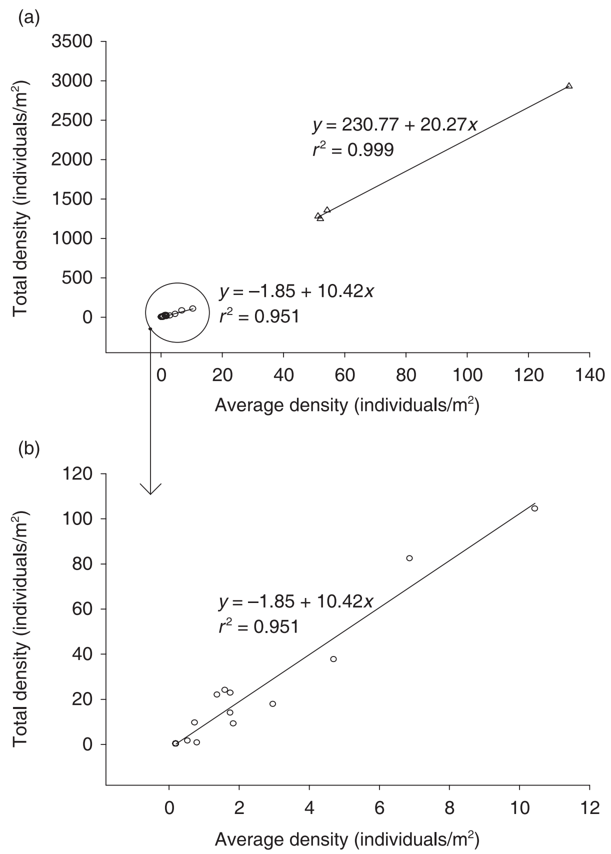

Figure 4 Regression analysis showing two different groups in frequency during the sampling period. The slope of each line indicates the mean frequency of each group. (a) Both major and minor species groups; (b) minor species group.

(< 43 km away from the dam). In this phase, both species numbers and individual numbers in the ephemeropteran community decreased rapidly along with longitudinal changes downstream. Phase II was characterized by stabilized patterns in both species numbers and individual numbers. These patterns were observed from the fifth (approximately 50 km away from the dam) to the eighth sampling point (approximately 82 km away from the dam). In this phase, species numbers and individual numbers fluctuated slightly during the study period of 3 years. From the eighth to the last sampling point (> 82 km), Phase III, both species numbers and individual numbers declined, and their values reached almost zero at the end point.

The species diversity indices (H′) declined along with the longitude (Fig. 6a). The values of H′ in this riverine system were generally very low, ranging from 0 to 2.17, and the individual numbers of the major species group at each point mainly affected the change of diversity indices along the increment of distance. This was also supported by the analysis of DI, which showed an exactly reversed pattern to the changing pattern of H′. At most points, the most and second-most dominant species were the species that belonged to the major species group, and DI values were very high, ranging from 0.84 to 1.00 (Fig. 6b).

Changing density of the major species group along the increment of distance, and spatial stability of the metapopulation

The density of each major species changed along with the longitudinal assembly of the local population (Fig. 7). ANOVA

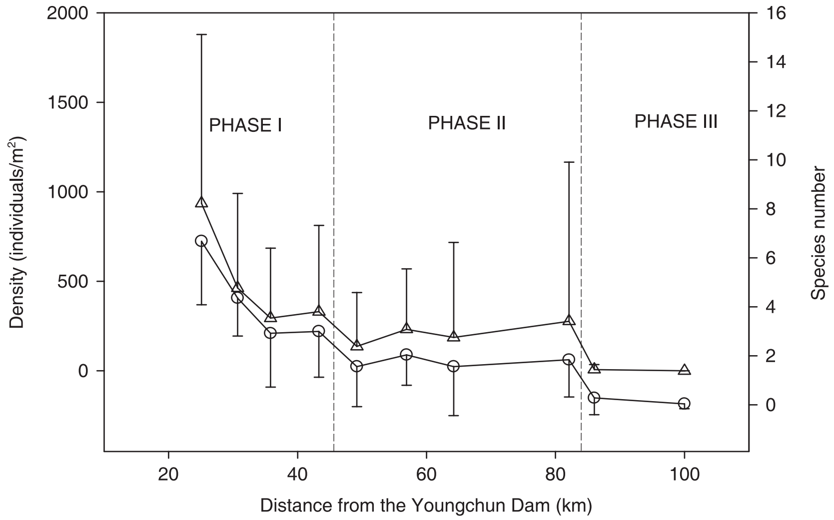

Figure 5 Changing pattern in mean individual number (△) and mean species number (○) along with the distance from the origin. Bars indicate standard deviation.

Table 1 Results of ANOVA with post hoc comparison by Least Squares Difference (LSD) method for the density among major group species

	Species				Statistics		
	BFU	ELE	URU	CAK	*P* > F	d.f.	LSD
Density	58.62[a]	27.15[b]	25.64[b]	24.96[b]	0.0001	12, 987	22.23

[a,b]Groups of different arithmetic means; there are no significant differences in mean between species with the same letter.
BFU, *Baetis fuscatus*; ELE, *Ecdyonurus levis*; URU, *Uracanthella rufa*; CAK, *Caenis* KUa.

showed the pattern of change, and its pattern of change is significantly different from each other. A statistical method (Least Squares Difference; LSD) indicated that the pattern in *B. fuscatus* was distinct from those in the other major species (Table 1). *B. fuscatus* showed two peak densities at the second sampling point (30.7 km downstream from the dam) and eighth point (82.1 km), with a maximum value (239.8 individuals/m^2) at the eighth point (Fig. 7a). The standard deviation at the eighth point was greater than at the other points. This means that the density of this species at this point fluctuated greatly from year to year; the maximum value was attributed to the density (4282 individuals/m^2) sampled in October 1991. Distribution of *E. levis* was restricted to the first sampling point (25.1 km from the dam), and its density decreased drastically with minor fluctuation in longitudinal changes in the riverine system (Fig. 7b). The density at the first point was significantly different from the density at other points. This indicated that the local population of *E. levis* was more or less limited in longitudinal distribution. The density of the *U. rufa* local population gradually reduced (Fig. 7c), and more individuals occurred in the upper area than in the lower area. The density of *Caenis* KUa fluctuated along with longitude (Fig. 7d). The changing pattern in the upper area was similar to that of *U. rufa*. Peak densities were observed in both the upper (25.1 km) and mid parts (56.9 km) of the riverine system.

The changing rates of the major species' density along the distance from the dam are shown in Figure 8. The changing rate of the local population density in *B. fuscatus* was 0 at approximately 40, 45, 55 and 75 km away from the dam (Fig. 8a). Stabilization occurred when the density of the local population reached potential carrying capacity at each point. Thus, of the places where the changing rate was 0, the *B. fuscatus* population stabilized at the points approximately 45 and 75 km away from the dam. Stabilized local populations of *E. levis* were observed 45 and 75 km away from the dam (Fig. 8b), with a mean density of 15.2 individuals/m^2. There were two places where the changing rate was 0 in *U. rufa* (Fig. 8c). Among these places (approximately 55 and 80 km away from the dam), the population was stabilized at the latter places. In *Caenis* KUa, the changing rate was 0, approximately, at 35, 40, 45 and 60 km away from the dam, and stability reached a maximum at places of approximately 40 and 60 km away (Fig. 8d). The distance between the stabilizing points was the shortest in *Caenis* KUa (approximately 20 km) among the major species (Fig. 8). *B. fuscatus*

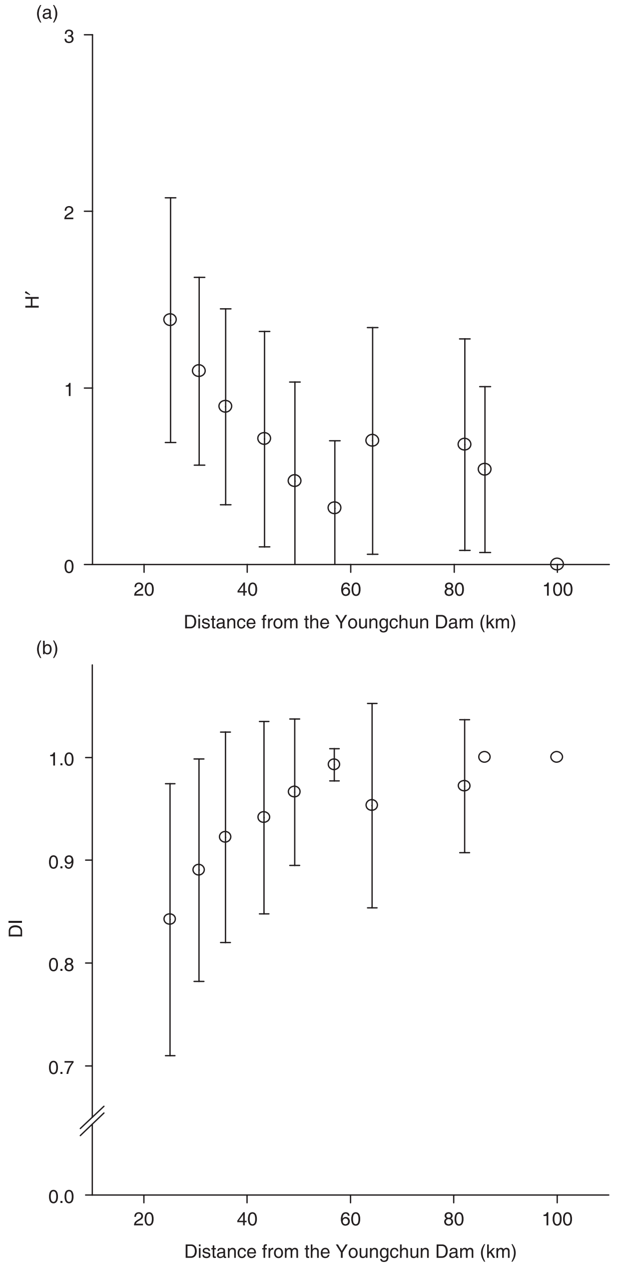

Figure 6 Changing pattern in community indices (mean with standard deviation): (a) diversity index (H′) and (b) dominant index (DI).

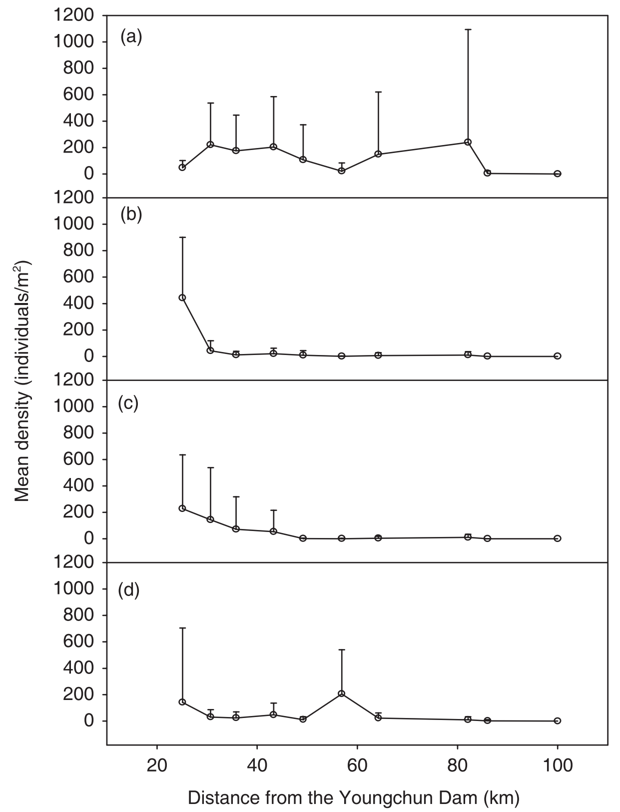

Figure 7 Changes in the density (mean with standard deviation) of each major species along with distance from the dam: (a) *Baetis fuscatus*, (b) *Ecdyonurus levis*, (c) *Uracanthella rufa* and (d) *Caenis* KUa.

and *E. levis* showed a similar distance, approximately 30 km. In *U. rufa*, there was only one stabilizing point.

Discussion

The total species number (22 species) of the mayfly community was not much less than those in other relatively well preserved riverine systems in Korea (Yoon *et al*. 1990), although the study period was longer in the present study. In some water bodies (Park & Chon 1995), however, a greater number of species (39 species) have been found than in the present study. The number of species that occurred at a point during the sampling period did not exceed half of the total number of species. Because most aquatic insects, including the mayfly, have a seasonal pattern in their life history (Williams & Feltmate 1992), it is possible that most mayfly species occur seasonally with a different density in the Keumho River.

The H′ and DI of the mayfly community at each sampling point were different from a previous study using the whole macroinvertebrate community (Won 1992); the results of that study were a higher H′ value (mean 1.72) but a lower DI value (mean 0.76). However, a *t*-test showed that the difference in H′ value was not significant (d.f. = 18, $P > 0.05$). This similarity supports the assumption that the mayfly community is able to represent the whole macroinvertebrate community and, furthermore, indicates the possibility that a major species could be representative of the whole macroinvertebrate community of the Keumho River. Unlike H′, DI was significantly different between the two studies by *t*-test (d.f. = 18, $P < 0.05$). In addition, the relationship between biological oxygen demand

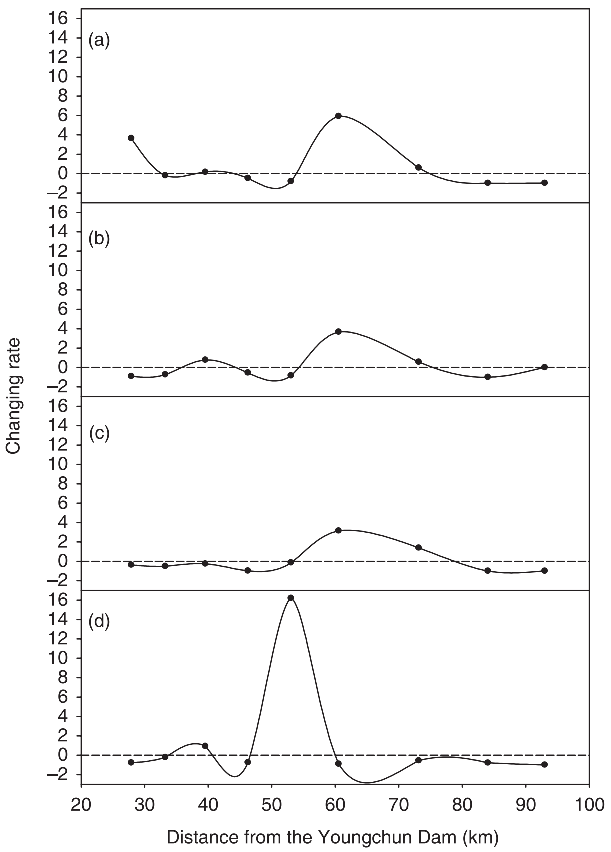

Figure 8 Fluctuation of changing rate along with distance in the major species: (a) *Baetis fuscatus*, (b) *Ecdyonurus levis*, (c) *Uracanthella rufa* and (d) *Caenis* KUa.

(BOD) and DI was higher when the DI was calculated from the whole benthic macroinvertebrate community ($r = 0.89$). However, the regression analysis showed a significant relationship between BOD and DI from ephemeropteran community ($F_{0.05,1,8} = 23.75$, $P < 0.01$ and $r = 0.86$), as well as the whole community ($F_{0.05,1,8} = 31.58$ and $P < 0.01$). The DI from the ehpemeropteran community alone, therefore, seemed to be a reliable value.

The ephemeropteran community showed a distinct dominant species after the seventh point, where BOD increased abruptly. In the ephemeropteran community, the dominant species was *B. fuscatus* consistently after the seventh point, while various dominant species resulted from the local invertebrate community. Consistency of the dominant species is a good criterion in biological water quality assessment. Therefore, community analysis using the Ephemeroptera alone would be sound both statistically and biologically, and with some advantages in application to water quality assessment, such as clear criteria, low cost and easy access.

The major species comprised approximately 95% of the total number of individuals that occurred in the study area, and showed high seasonal frequency. Fourteen species in the minor group occurred less than three times of the total 25 sampling times, and six species occurred only once. The extremely low frequency means that most species of the minor group might be visitors or weak competitors in feeding and/or reproduction. In relation to OPF, the major species group was distributed more widely than the minor species group. The representative species for a certain ecosystem might be observed more abundantly and consistently in local patches at anytime in the given ecosystem. In this sense, the major group in our study would be a good representation of the ephemeropteran community of the Keumho River.

The populations of each major species at each sampling point were not independent from other populations at other points. Each population was formed along with the resource, which was distributed in the form of a patch. Populations at the different points could be mixed, however, by drift, upstream movement, adult emergence and oviposition. These dispersal mechanisms are a common feature in aquatic insects (Allan 1995). The population of the major species, therefore, should be considered as a metapopulation (*sensu* Hanski & Simberloff 1997) and each population at a point as its local population.

In the present study, the distance between adjacent points (mean approximately 8 km) seemed to be somewhat large for mayflies to migrate to adjacent points. However, most of the studied area is known as a mayfly–chironomid-rich region (Won 1992; Yoon *et al*. 1992), and so it was apparent that a similar composition of functional feeding group (FFG) occurred continuously almost in all studied area. According to the RCC, FFG composition tends to be decided by the longitudinal resource gradient and the physico-geomorphic characteristics of a given area (Vanote *et al*. 1980). In other words, environmental conditions in a given area can be induced from the changing FFG composition. At this point of RCC, our entire study area seemed to have a rather homogeneous environment and not to be harsh for the mayfly to live in. Therefore, mayflies could occur in almost every habitat in our study area, and the distance between sampling points should not be a serious barrier that prevents mayfly nymphs or adults from migrating.

Generally, stability of a given local population is related to the changing rate of mean density and the number of individuals during the time interval (Berryman 1981: Putman & Wratten 1984). However, if net migration change is assumed as the response of local population regulation, a diagram for the interaction between two populations of the same species that occupy two spatially distinct environments can be drawn (Berryman 1981). Thus, if the environmental factors were different and the distances between adjacent points were short enough for migration to take place, each major species population would show density-dependant regulation along longitude.

Three major species had two stabilizing points in this study; *U. rufa* had only one point. *B. fuscatus*, *E. levis* and *Caenis* KUa had a similar fluctuation in the changing rate, and in the case of *B. fuscatus* and *E. levis*, stabilizing points were almost the same. It is difficult to say which point was more stable of the two stabilizing points of these three species.

In the case of *Caenis* KUa, both stable points were established before the seventh sampling point. Of the two points, the second point seemed to be more stable; higher density would give stronger resilience and resistance to the local population. Many researchers in Korea assumed that *U. rufa* would be more tolerant to water pollution than other mayflies (Won 1992; Yoon 1995). In this study, *U. rufa* also seemed to have stronger tolerance to deterioration of water quality, because its stable point was subjected to a higher BOD regime. The continuous decrease in density of *U. rufa* before point seven showed that this species would not be a good competitor in the well preserved water system, and its stabilization would result from both reduced density of other competitors and lower carrying capacity caused by pollution. This could mean that its own potential for density-dependent regulation was less influential to its stabilization mechanism in the Keumho River than environmental conditions. Ultimately, all of the major species seemed to be disappear from the Keumho River after point eight, and this disappearance was caused by deterioration of environmental conditions, particularly the chemical environment.

In conclusion, community analysis using the ephemeroptera could produce similar results to analysis using the whole macroinvertebrate community in the Keumho River. The ephemeropteran community was represented by the major group, which was outstanding in density, occurrence frequency and distribution range in the riverine system. The major group was considered to be a metapopulation, which had several stabilizing points in density fluctuation among local populations.

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