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Changes in Benthic Macroinvertebrate Communities in Response to Natural Disturbances in a Stream

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ABSTRACT: Benthic macroinvertebrate communities were collected from six different sites in the Dobong Stream in Seoul, Korea to investigate spatial and temporal changes in benthic macroinvertebrate communities in response to natural disturbances such as floods and droughts. We collected samples monthly or semimonthly with a Surber net (30 cm × 30 cm), and measured environmental factors, including stream temperature, discharge, width, conductivity, dissolved oxygen and pH at each sampling site. Benthic macroinvertebrates were strongly affected by floods as well as droughts. In addition, benthic macroinvertebrate communities displayed different responses to the onset of the rainy season in summer 2006 and 2007, apparently due to differences in the intensity and amount of precipitation. Chironomids were particularly sensitive to heavy rain. Floods and droughts also affected the proportions of functional feeding groups during the survey period: the proportion of scrapers was high right after heavy rains, while the proportion of predators tended to increase in intermittent-type streams as the riffle zone decreased. Finally, although species richness and abundance were strongly influenced by heavy rain, they recovered to background levels for within one month, and varied consistently among stream types, indicating habitat stability.

Key words: Benthic macroinvertebrates, Community, Disturbance, Functional feeding groups, Heavy rain, Stream

INTRODUCTION

Environmental changes in stream ecosystems can cause changes in community composition, and benthic macroinvertebrates are good indicators for aquatic ecosystem assessment because their densities tend to respond to changes in water body conditions, such as floods, storms, droughts, anthropogenic disturbances, etc. (Power et al. 1988, Resh et al. 1988). Benthic macroinvertebrate community structure may largely depend on the amount, pattern and duration of precipitation. Floods, one of the major natural disturbances to streams and rivers, are usually pulse disturbances (Ward 1992, Lake 2000). They play an important role in controlling the distribution and richness of aquatic organisms within lotic ecosystems (Resh et al. 1988, Lake 2000) by altering the abiotic environment of the floodplain. In flooding streams, large volumes of rapidly moving water exert high shear forces that suspend sediments, move and redistribute bottom materials (from sand to boulders), scour and abrade the streambed, remove plants (from microscopic algae to macrophytes), move detritus, snags, debris dams, and the channel itself, leading to changes in the composition of the biota (Hart et al. 1996, Holomuzki and Biggs 1999, 2000). Generally, invertebrate communities respond to floods with reductions in density and taxonomic richness (Gjerlov et al. 2003).

Droughts occur due to a deficit in precipitation, leading to a loss in water volume that affects water quality, resource availability and the biota. Generally, droughts lead to reductions in benthic macroinvertebrate densities (Cowx et al. 1984).

Many studies on the effects of floods and droughts in benthic communities have been conducted in Europe and America, but few studies (e.g. Kwak et al. 2004, Lee 2008) have been conducted in Korean streams, which are affected by pronounced climatic variation due to Korea's monsoon climate. In Korea, > 70% of annual precipitation is concentrated in the rainy season (from June to September) while autumn and winter are usually dry. We aimed to characterize changes in benthic macroinvertebrate communities occurring in response to natural disturbances such as floods and droughts in stream ecosystems.

MATERIALS AND METHODS

Study Sites

We collected benthic macroinvertebrates at six different sampling sites in the Dobong Stream in Seoul, Korea (Fig. 1). The study sites were located in the Bukhansan National Park, so the study area was relatively clean and not heavily disturbed by chemical or domestic wastes. The main disturbance factors in this area are natural disturbances such as floods and droughts (Bae and Park 2008). The sam-

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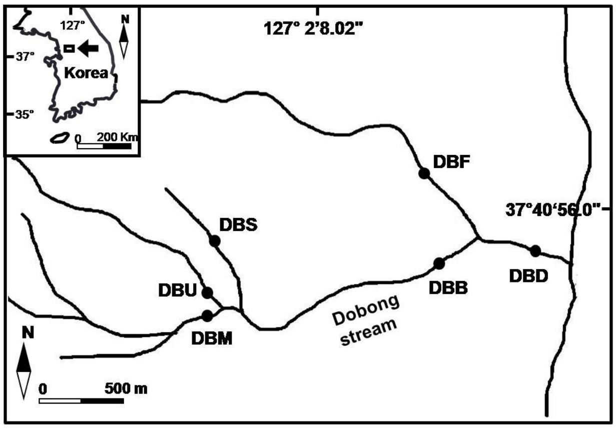


Fig. 1. Location of six sampling sites in the Dobong Stream in Seoul, Korea.

pling sites were classified into three types based on stream flow conditions: perennial streams (consistent water flow during the study period; DBM and DBF), intermittent streams (partial droughts with pools; DBS and DBU), and drought streams (complete droughts during the dry season. DBB and DBD).

Ecological Data

We collected three replicate samples of benthic macroinvertebrates using a Surber sampler (30 cm × 30 cm, 300 μm mesh; APHA et al. 1985) at approximately 10-cm depth at each sampling time. Sampling was conducted biweekly right after heavy rain from July to August 2006, and monthly in the remainder of the survey period (from September, 2006 to January 2008). The macroinvertebrates collected were preserved in 70% alcohol solution and transported to the laboratory. In the laboratory, invertebrate specimens were sorted and identified mostly to the species level and counted under microscopes (Nikon SMZ800). Specimens of chironomids were prepared on microscope slides for identification. The microscope slide preparation involved a sequential procedure of cleaning with a 10% KOH solution for 15~25 minutes (depending on individual size) at 85℃, followed by neutralization at room temperature, initiation of dehydration with 70% ethanol, and then mounting with CMC-10 mounting media. Identification of macroinvertebrates was based on Yoon (1988), Brigham et al. (1982), Merritt and Cummins (2006), Pennak (1978), and Quigley (1977). Chironomidae was identified according to Wiederholm (1983), while the identification of Oligochaeta was conducted following Brinkhurst and Jamieson (1971) and Brinkhurst (1986).

Benthic macroinvertebrates were categorized into five functional feeding groups (FFGs) −collector-gatherers, collector-filterers, predators, scrapers, and shredders− according to their feeding types based on Merritt and Cummins (2006). Changes in the relative proportions in FFGs were examined for correlation with the natural disturbances such as floods.

Environmental variables were also measured at each sampling time. Water temperature (℃), dissolved oxygen (DO, mg/L), conductivity (μS/cm) and pH were measured *in situ* with a multifunction meter (CX401®, Elemetron). Discharge was calculated by integrating medium depth (m), width (m) and current velocity (m/s). Precipitation data during the study period were obtained from the record for Seoul from the Korea Meteorological Administration (http://www.kma.go.kr).

Community Analyses

In order to compare community variables such as species richness, abundance, Shannon diversity index and evenness across different sampling sites, we used the Kruskall-Wallis (K-W) test. We also used the Dunn's nonparametric multiple comparison test (Zar 1999) to further examine variation in community indices among sampling sites. Statistical tests were carried out using the statistical software STATISTICA (StatSoft 2004).

We used Nonmetric Multidimensional Scaling (NMS) to characterize spatial and temporal changes in benthic macroinvertebrate communities in response to natural disturbances such as floods and droughts. NMS is a data reduction ordination method that maintains the rank ordering of distances in a low-dimensional space, expressed as a monotonic function (Shepard 1962, Kruskal 1964, Borg and Groenen 1997, Cox and Cox 2001, Mahecha et al. 2007). NMS calculates the best position of the data in reduced dimensions through an iterative search that minimizes the stress of the reduced dimensions. “Stress” is a measure of departure from monotonicity in the relationship between the dissimilarity distance in the original dimensional space and distance in the reduced dimensional ordination space. The value of stress, based on Kruskal’s rules of thumb, is between 0 and 100 (Daniel and Scott 2007). If the value is close to zero, we can conclude that it is appropriate to use the NMS result. In this study, we used a Monte Carlo test with 999 randomizations to determine whether the observed stress value of the final solution is significantly different in randomized data (Bae and Park 2008).

RESULTS

Characteristics of Environmental Factors

Monthly rainfall in the study area was highly variable, and higher annual precipitation observed in 2006 (1,681.9 mm) than in 2007 (1,212.3 mm). Physical environmental factors such as water depth, width, and discharge were also highly variable at all study sites during the survey period (Fig. 2). Depth, width, and discharge

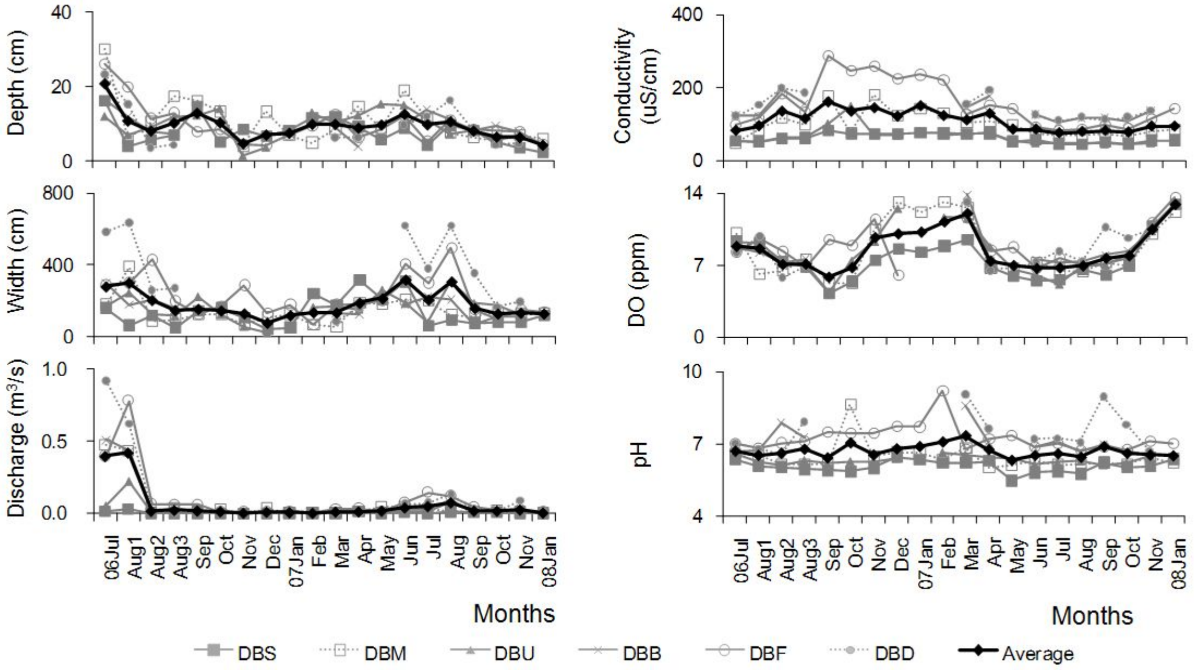


Fig. 2. Changes in environmental factors at the six sampling sites from July 2006 to January 2008.

tended to be dramatically higher in periods of heavy rain in summer, while values for these variables were lower during other periods when the amount of precipitation was relatively low. Water depth and discharge also varied between the two years. Water depth and discharge were higher after a heavy rain in July and August 2006 than in the same months in 2007. Conductivity was higher in autumn and winter of 2006, especially at site DBF, due to autumn fallen leaves. DO was higher in winter.

Substrate composition also reflected the effects of heavy rain (Fig. 3). For the six different study sites, more than 50% of substrate on average was composed of cobble (64～256 mm) in July 2006, right after a heavy rain, whereas the substrate composition was more variable after early August 2006. During the drought season in autumn and winter, the substrate composition for the study sites mainly consisted of small particles. In occasion July and August of 2007, the ratio of small to large particles in the substrate was also relatively high compared with that in July and August 2006.

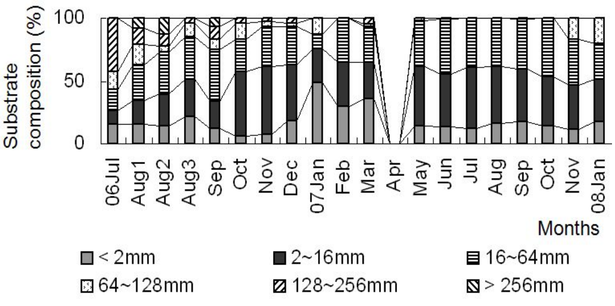


Fig. 3. Changes in mean substrate composition (%) at the six study sites during the survey period. Data were not available from April 2008. Aug1: the beginning of August, Aug2: the middle of August, and Aug3: the end of August.

Changes of Benthic Macroinvertebrate Communities

A total of 168 species (3 classes, 10 orders, 44 families) were identified in 102 samples collected at the six different study sites in the Dobong Stream during the survey period. Insects comprised more than 95% of total abundance and around 95% of total species richness. Among insect orders, Diptera had the highest species richness (87 species) caused mainly by high richness of Chironomidae (75 species), followed by Ephemeroptera (28 species) and Trichoptera (20 species). Community indices were different at the different sample sites. Species richness was significantly higher at site DBF (a perennial stream) than at the other sites (Dunn’s multiple comparison test, $p < 0.05$) (Fig. 4), and the Shannon diversity index and evenness were significantly lower at sites DBB and DBD (drought streams) (Dunn’s multiple comparison test, $p < 0.05$). Overall abundance, however, was variable and did not significantly different among the sites.

The effects of heavy rain were reflected in changes in species richness and abundance of benthic macroinvertebrates at each sampling site. Fig. 5 shows changes in species richness as the number of arriving and departing species between two sequential sampling times. The upper bar represents the number of arriving species (i.e., those not collected in the previous sample) in each sample, and the lower bar indicates the number of species not found in the present sample but collected in the previous sample. Right after a heavy rain in the summer of 2006, species richness and abundance were low at every study site (Figs. 5, 6). As the number of newly arrived species gradually increased while few species departed, spe-

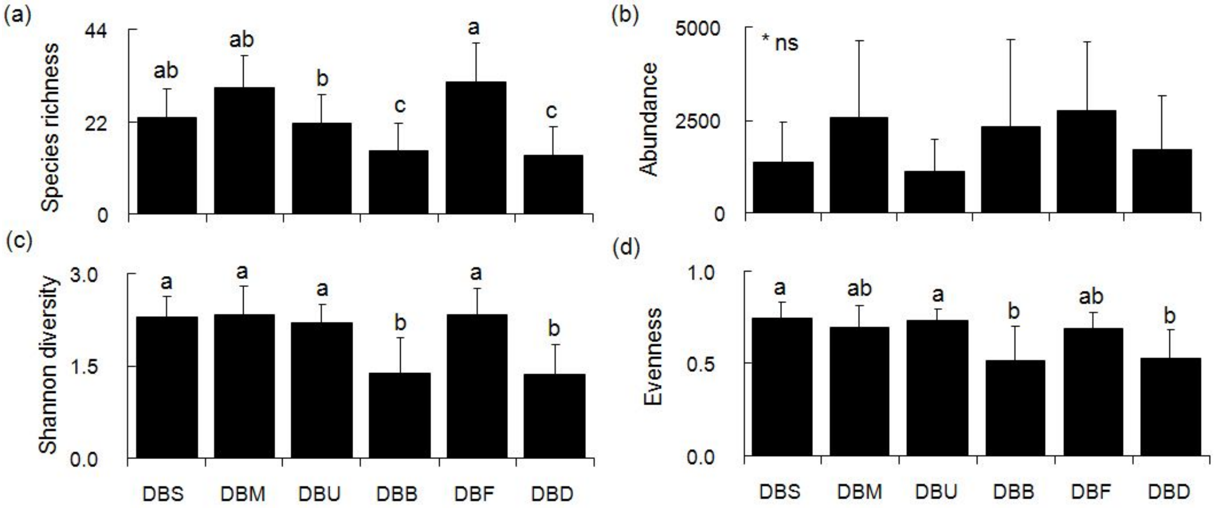


Fig. 4. Differences in species richness (a), abundance (b), Shannon diversity index (c) and evenness (mean ± SD) (d). Different letters indicate significant differences between clusters based on the Dunn's multiple comparison test ($p < 0.05$). *ns: not significantly different.

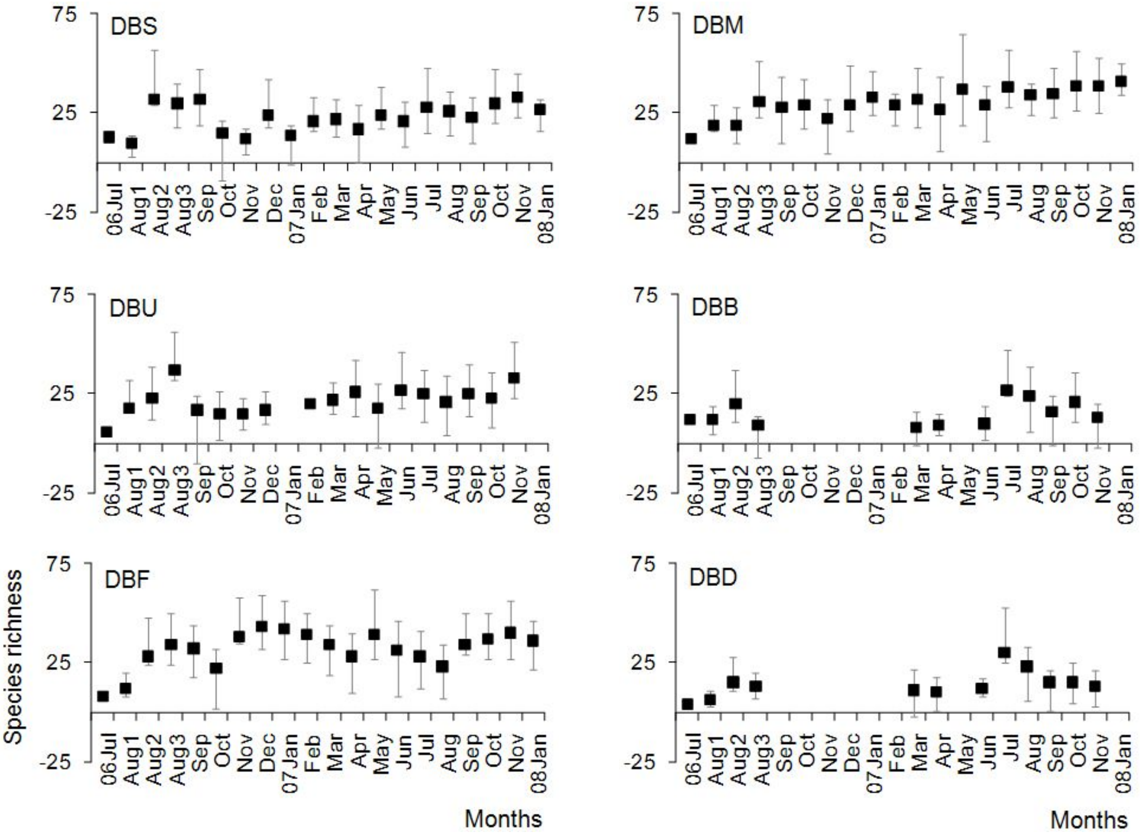
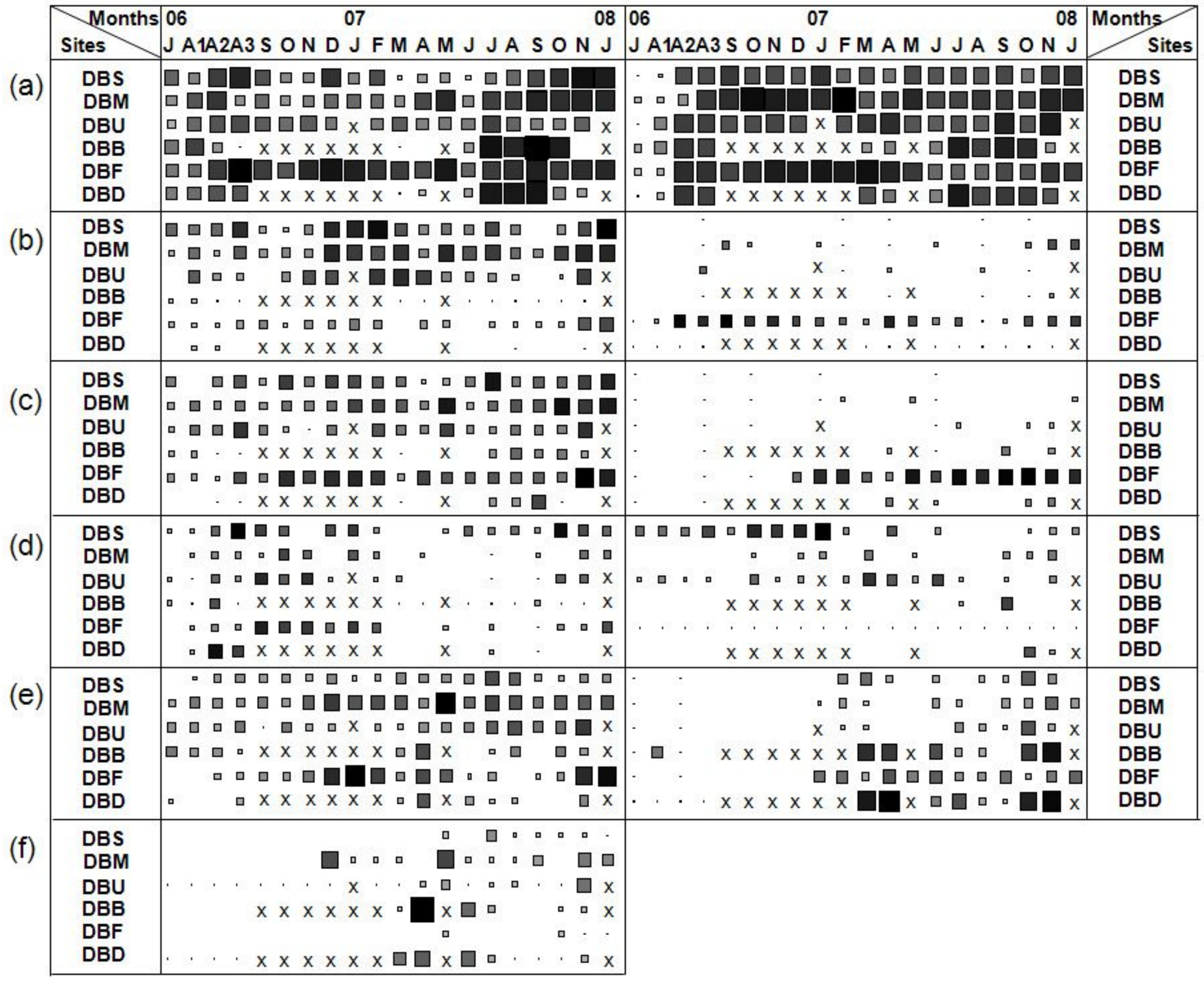


Fig. 5. Changes in species richness with number of arriving (upper bar) and departing (lower bar) species between sampling times.

cies richness increased until winter. However, different sites showed different patterns of changes in species richness and abundance during the survey periods. Species richness and abundance were higher at sites DBM and DBF. At these sites, we observed seasonal changes with high values for species richness and abundance in winter and low values in summer. Species richness and abundance were generally low at sites DBS, DBU, DBB, and DBD.

Chironomidae and Ephemeroptera consistently comprised a large proportion of the total number of taxa (Fig. 6). In July 2006, the proportion of Ephemerptera was particularly high because of the high density of *Baetis fuscatus* and *Ecdyonurus dragon*. However, Chrionomidae comprised a relatively low density in July 2006 right after a heavy rain, which suggests that they are sensitive to the amount of precipitation. Collembola were observed after periods of drying at sites DBB and DBD, Odonata were continuously observed at site DBS, and Coleoptera were collected at sites DBS and DBU (intermittent streams), while Gastropoda, including *Semisulcospira libertina* and *Semisulcospira gottaschei,* were observed at site DBF after autumn of 2006.

Community dynamics appeared to be different in different years, reflecting differences in rainfall. In 2007, when summer precipitation was much lower than in 2006, Epheremeroptera such as *Ecdyonurus levis, Epeorus pellucidus, Baetiella tuberculata,* and *B. fuscatus,* and Tricoptera such as *Cheumatopsyche* Kua and *Hydropsyche kozhantschikovi* were observed at sites DBB and DBD, although some of these species were present at very low abundance. It is not able that these species were not observed at sites DBB and DBD in previous survey periods (except *B. fuscatus*). Subsequently, some



* X represent frozen (DBU) and dry periods (DBB and DBD)

Fig. 6. Changes in taxon richness recorded at six different sites in different months. The sizes of the rectangles indicate proportions of taxon abundance (log x-transformed) for a) Ephemeroptera, b) Plecopetra, c) Tricoptera, d) Odonata, e) Diptera excluding Chironomidae, f) Collembola, g) Chirnomidae, h) Megaloptera, i) Gastropoda, j) Coleoptera and k) Oligocheata.

of these species, such as *E. pellucidus* and *B. tuberculata*, continued to be collected until the end of the survey period.

Functional Feeding Groups (FFGs)

Collector-gatherers comprised the largest proportion of benthic macroinvertebrate species in the Dobong Stream, representing 52.7% of total species richness, followed by predators (23.0%), shredders (10.7%), scrapers (7.4%) and collector-filterers (6.2%). Collector-gatherers were also the most abundant taxa, comprising 49.1% of the individuals collected. The abundance of shredders was higher at sites DBS and DBU than other sites, and the abundance of collector-gatherers and collector-filterers was highest at sites DBB and DBD (Fig. 7). Predators showed high abundance at all study sites. FFGs were also affected by precipitation. In July 2006, when the intensity and amount of precipitation was extremely high, the proportion of scrapers was high at sites DBS, DBM and DBU. However, in July 2007, the relative ratio of FFGs did not change much relative to the previous periods.

Patterning the Benthic Macroinvertebrate Communities

The 102 samples were analyzed with NMS ordination based on benthic macroinvertebrate community data (Fig. 8). The NMS ordination showed 29.2 stress values for axes 1 and 2 (Monte Carlo test, $p < 0.01$). Samples collected in July 2006 (i.e., 106JU, 206JU, 306JU, 406JU, 506JU, 606JU, etc) were generally located in the lower right part of the ordination map. The results reflected the effects of heavy rain in summer, showing positive correlations with factors related to flooding such as discharge, width, depth, and velocity. The sampling sites DBB and DBD were also generally in the lower part of the ordination map. On the other hands, samples collected in winter periods (from December 2006 to February 2007) were mainly located in the upper left part, while the samples collected in the summer of 2007 (i.e., 107JU, 207JU, 307JU, 407JU, 507JU, 607JU, etc.) were located near the center of the NMS ordination map.

DISCUSSION AND CONCLUSION

We characterized changes in benthic macroinvertebrate communities in response to natural disturbances such as floods and droughts in the Dobong Stream. In Korea, precipitation is usually concentrated in the summer (Bae and Park 2008). In stream ecosystems,

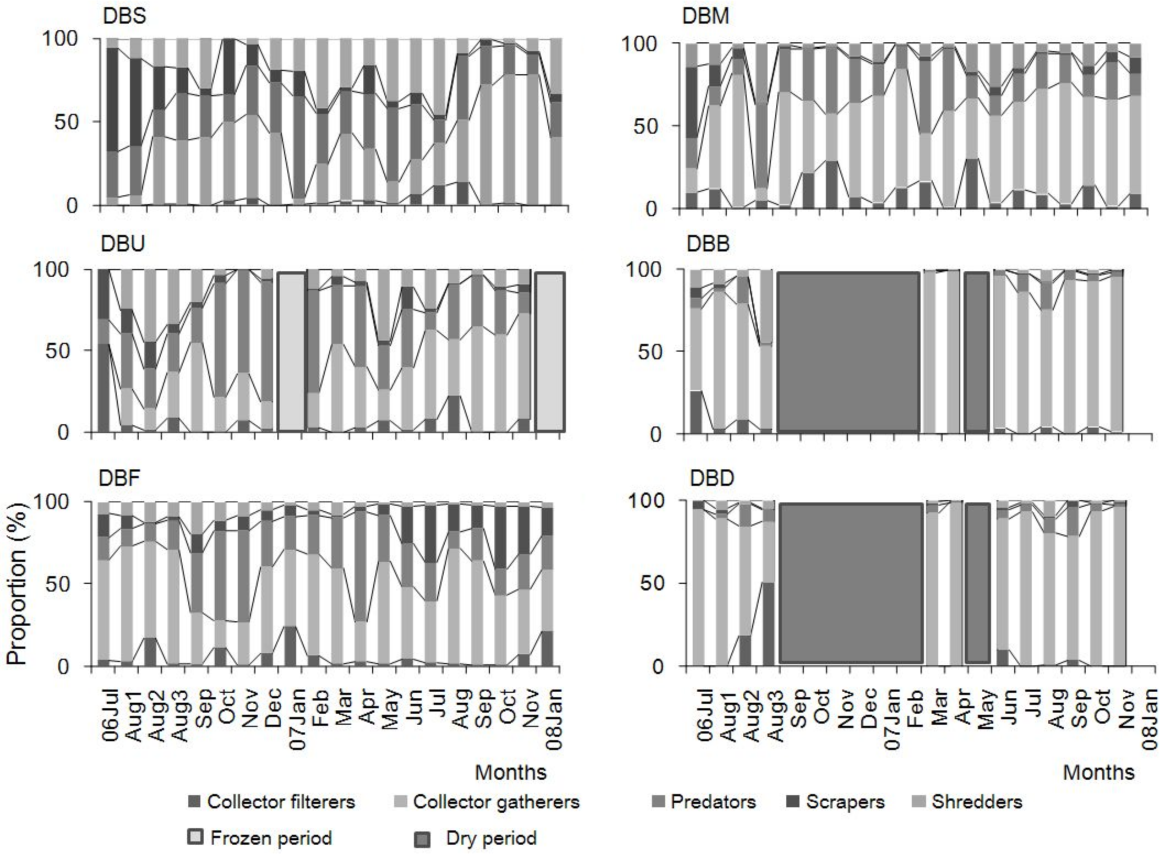


Fig. 7. Changes in functional feeding groups (FFGs) of benthic macroinvertebrates in the Dobong Stream during the survey period.

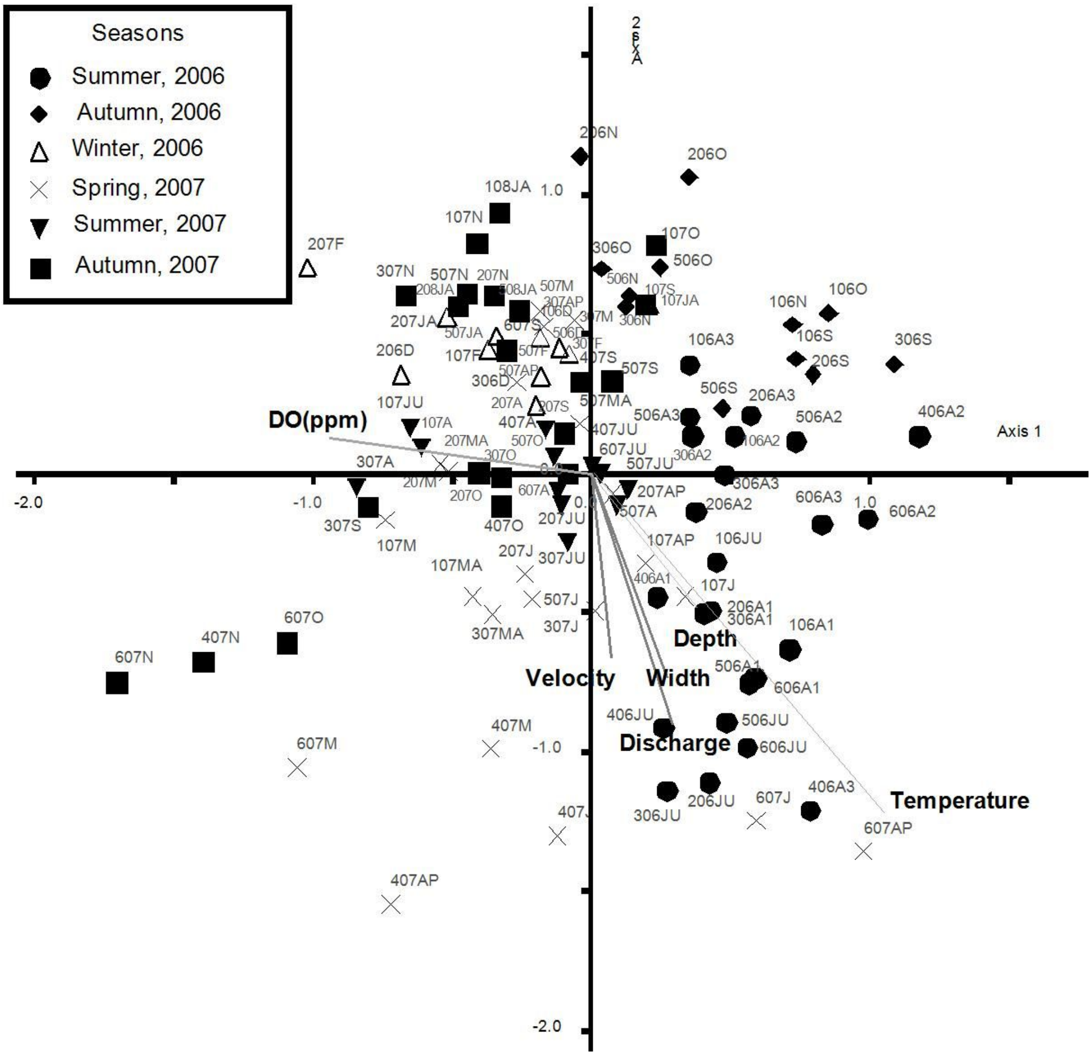


Fig. 8. Nonmetric multidimensional scaling (NMS) ordination of 102 samples based on benthic macroinvertebrate communities with 29.2 stress value for axes 1 and 2 (Monte Carlo test, $p < 0.01$). Acronyms in the ordination stand for the samples. The first number presents the sampling sites (1: DBS, 2: DBM, 3: DBU, 4: DBB, 5: DBF and 6: DBD), 06 and 07 are years for 2006 and 2007, and the last one or two letter(s) indicate the sampling month.

floods amplify hydrological connectivity and increase discharge, making benthic macroinvertebrates drift downstream (Lake 2003). Conversely, low precipitation causes sequential declines in soil moisture, ground water levels, stream flow, stream depth and wetted width (Changnon 1987, Grigg 1996, Dahm et al. 2003), which in turn decreases the availability, diversity, and suitability of habitats (Cowx et al. 1984, Stanley et al. 1997, Cazaubon and Giudicelli 1999, Brasher 2003).

Community indices such as species richness, abundance, Shannon diversity index and evenness were influenced by floods and droughts, showing different patterns under different stream conditions in this study. Species richness and abundance of benthic macroinvertebrates were higher at sites DBM and DBF, the perennial streams, and lower at sites DBB and DBD, the drought streams (Fig. 4). At sites DBS and DBU, intermittent streams, species richness and abundance were lower than those at perennial stream sites DBM and DBF. These differences might be due to different degrees of stability in different stream types. For instance, sites DBS and DBU, the intermittent streams, are influenced by the frequent absence of flow and low water levels when it flows (Kinzie et al. 2006). This instability resulted in decreased wetted width and reduction in available habitat (Cowx et al. 1984, Stanley et al. 1997, Brasher 2003), reduction of habitat diversity (Cazaubon and Giudicelli 1999), and alteration of habitat suitability (Cowx et al. 1984). Species richness and abundance were the lowest in the drought streams at sites DBB and DBD because these sites had unstable habitat condition. In other words, the existence of these streams depended on precipitation and melting upstream water in the winters. Consequently, the introduction and settlement of benthic macroinvertebrates was difficult.

In addition, species richness and abundance showed seasonal variation at the study sites, reflecting the effects of changes in environmental conditions (Figs. 5, 6). Species richness and abundance of benthic macroinvertebrate communities in the Dobong stream were strongly influenced by precipitation. During the survey periods, floods (or heavy rain) reduced species richness and abundance at all study sites (Suren and Jowett 2006).

The amount and intensity of annual precipitation in summer 2007 were lower than those in 2006, leading to a different response in benthic macroinvertebrates. In July 2006, when the monthly precipitation was 1014.0 mm, species richness and abundance was extremely low at all study sites, and then around one month later, species richness and abundance started to gradually increase. In July 2007, on the other hand, abundance decreased, but species richness did not show a clear difference before and after the period of heavy rain. This difference may be associated with the response of the stream substrates to heavy rain. In July 2006, more than 50% of the stream substrate was composed of large cobbles (128～256 mm), while smaller substrates (< 2 mm), gravel (2～16 mm) and pebbles (16～64 mm) were mainly observed in other survey periods, including July 2007 (Fig. 3). The response of the substrate to the amount, intensity and duration of precipitation may be an important factor affecting the benthic macroinvertebrate community composition (Imbert et al. 2005).

Community composition also reflected differences of the amount, intensity, and duration of precipitation in 2006 and 2007 (Figs. 6, 8). Among the taxa sampled, chironomids showed the most sensitive response to heavy rain. The abundance of chironomids was very low at all sampling sites in the early part of the sampling period, right after the heavy rains in 2006, but rapidly recovered within one month. At sites DBB and DBD, which have unstable environmental conditions, some species in Ephemeroptera and Trichoptera such as *Ecdyonurus levis, Epeorus pellucidus, Cheumatopsyche* Kua, and *Hydropsyche kozhantschikovi* that had not been observed in the previous surveys were collected in July 2007. This may be closely related changes in the stream discharge due to changes in the intensity and amount of precipitation. In July 2006, discharge was extremely high because of high precipitation (relative to July 2007). So the habitat was disrupted due to drifting of a large amount of substrates, including relatively large substrates such as pebbles and cobbles. So in most of the study sites in 2006, the substrate was composed >50% of large cobbles. Thus, even though some species drifted downstream, they could become established in their new habitats because of extreme habitat disruption and high rates of discharge. However, in 2007, although the discharge increased relative to previous months, it was not high enough to affect the substrate composition. So some species drifting in from upstream became established in their new habitats.

Flooding and drought also affected the relative abundance of FFGs during the survey period (Fig. 7). In July 2006, the relative abundance of scrapers was relatively higher than in other survey periods. After July, however, as the stream habitat stabilized, the relative abundance of other FFGs increased. This was caused by the high abundance of *Ecdyonurus dragon*, which usually lives under stones or rocks in streams with high velocity. However, at sites DBS and DBU, as the streams dried out in the autumn and winter, the relative abundance of predators tended to be higher. The proportion of predators was also higher in pools than in flowing water in a large subtropical river (Nhiwatiwa 2009). This pattern may be observed for two reasons. First, as the stream gradually dried out, the habitat size was reduced and the individuals remaining were concentrated in a smaller area (Gore 1977, Wright and Berrie 1987). Second, in streams with incessant water flow (e.g., sites DBM and DBF in this study), predators may prefer alternative habitats. Most predator taxa do not complete their life cycles in intermittent pools, so in the adult stage, they should migrate to find suitable sites for oviposition (Batzer et al. 2004). The dominance of predator taxa in pools suggests that these dry-season pools may be important for reproducing adults (Nhiwatiwa 2009).

In conclusion, benthic macroinvertebrates were strongly affected by both floods and droughts, which suggests that precipitation patterns are a dominant factor affecting benthic macroinvertebrate community composition and structure. In addition, benthic macroinvertebrate communities displayed different responses according to the intensity and amount of precipitation in the summers of 2006 and 2007. Chironomids showed a more sensitive response to heavy rain than other taxa. Floods and droughts also affected the relative abundance of each FFG during the survey period, with a high relative abundance of scrapers right after heavy rains, and an increased proportion of predators in intermittent streams as the riffle zone decreased. Finally, although species richness and abundance were strongly influenced by heavy rain, they started to recover within one month, and varied consistently among stream types, indicating substantial habitat stability.

ACKNOWLEDGMENTS

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