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Effects of low-head dam removal on benthic macroinvertebrate communities in a Korean stream

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This study was conducted to examine how a low-head dam removal (partial removal) could affect benthic macroinvertebrate communities in a stream. Benthic macroinvertebrates and substrates were seasonally sampled before and after dam removal (March 2006–April 2007). Benthic macroinvertebrates and substrates were quantitatively sampled from immediately upstream (upper: pool) and downstream (lower: riffle) sites, the location of the dam itself (middle), and immediately above the impoundment (control: riffle). After the removal, species richness and density of benthic macroinvertebrates as well as the EPT group (Ephemeroptera, Plecoptera and Trichoptera) increased to higher levels than those before the removal, while functional feeding groups and habitat orientation groups changed more heterogeneously at the upper site. At the lower site, species richness and density decreased somewhat immediately after dam removal, which was associated with an increase of silt and sand, but recovered after monsoon floods which helped to enhance substrate diversity at the upper site. Decreased dominance index and increased diversity index in both the upper and lower sites are evidence of positive effects from the dam removal. In conclusion, we suggest that even a partial removal of a dam, resulting in increased substrate diversity in the upper site, could sufficiently help rehabilitate lost ecological integrity of streams without major habitat changes.

Keywords: benthic macroinvetebrates; community composition; functional groups; dam removal; flood; stream restoration

Introduction

Dams are constructed in streams and rivers for a variety of reasons, including water-level maintenance, agricultural water supply, flood control, energy generation, and recreation. As concerns about the ecological impacts of small dams on stream ecosystems have increased in recent years (Doeg and Koehn 1994; Poff and Hart 2002; Tiemann et al. 2004), their removal is increasingly being considered as an effective way to carryout ecological restoration (Born et al. 1998; Bednarek 2001; Heinz Center 2002; Stanley and Doyle 2003; Thomson et al. 2005).

Dam removals not only reduce sedimentation of upstream reaches by altering flow velocity, but also increase species diversity of benthic macroinvertebrates by transforming the impoundment zone from lentic to lotic environments (Benarek 2001; Hart et al. 2002; Stanley et al. 2002; Doyle et al. 2005). Dam removals may also affect downstream macroinvertebrate communities through transporting sediments previously stored in upstream impoundments (Doeg and Koehn 1994; Benarek 2001; Poff and Hart 2002). However, benthic macroinvertebrate communities can be differently influenced by dam removals, not only according to attributes of stream ecosystems such as channel form, substrate type, flow and thermal regimes, and water quality, but also according to dam characteristics and ways of removal (Graf 1999; Benarek 2001; Hart et al. 2002). Removals of small dams, which have short retention time and limited reservoir capacity, induce minimal impacts on stream ecosystems and may temporarily reduce benthic macroinvertebrate density and diversity (Doyle et al. 2005; Thomson et al. 2005). Changes of macroinvertebrate communities after dam removals are known to be rapid in upstream reaches, but are limited in reaches immediately below the dams (Hart et al. 2002; Doyle et al. 2005).

Benthic macroinvertebrates have received particular attention by stream ecologists because of their trophic status and consequent roles in local food web systems. They are the most abundant and diverse group of biota in streams and have been used as indicators of stream water quality and environment changes (Rosenberg and Resh 1993; Resh et al. 1996).

In northeast Asia, a region subjected to the monsoon climate and heavy summer floods, streams and rivers are heavily dammed to control floods, to conserve water all year around for agricultural and industrial supplies, and to generate electricity. Across Korea, approximately 18,000 small dams have been installed in streams to maintain stream water levels for

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mainly agricultural water supply. Although more and more dams are being abandoned due to land-use changes in this region, the removal of abandoned or defective small dams is a controversial issue. The fact remains that few studies have looked at the effects of dam removal on benthic macroinvertebrate communities; hence the existing lack of information with which sound decisions need to be made.

The aim of this study was to investigate the effect of dam removal on benthic macroinvertebrate communities in a stream in central Korea. We specifically documented the chronological changes of substrates and macroinvertebrate community before and after dam removal.

Materials and methods

Study area

The Gokneung stream is located approximately 30 km north of Seoul, on the other side of the Bukhansan (Mt.) National Park from Seoul. The stream is 45.7 km long, flows through agricultural rural areas and empties downstream into the Han River. Mean annual precipitation (1971–2000) within the basin area is 1344 mm, with 50.3% precipitation falling in the monsoon season (July and August). In the study year (2006), annual precipitation was 1682 mm and 60.3% (1014 mm) of the precipitation fell in the monsoon season (July only). The sampling was conducted around a low-head dam, called Gokneung (37°40′N, 126°54′E), located approximately 12 km downstream from the head water. A low-head dam is defined as a constructed barrier in a river with a hydraulic height, ranging from head water to tail water, not exceeding 25 feet (ICF Consulting 2005). This low-head dam is about 76 m long with a height of 1.5 m. The dam was built in the 1970s to supply agricultural water to rice fields. Because of changing land-use and decreases in the number of rice fields, agriculture water supply was no longer needed. As a result, the dam was removed in April 2006 to restore ecological functions and form an eco-corridor. Only the head-part of the dam (the structure above the stream bed) was removed, but the foundation was left intact.

Field sampling

Benthic macroinvertebrates were seasonally sampled in March (before dam removal), June (soon after dam removal), August (after monsoon flood), September, and December of 2006 and April of 2007 (1 year after dam removal). Before dam removal, sampling was conducted at three sites: control, upper, and lower sites. The control site was located roughly 400 m upstream from the dam. The upper site was within the impoundment where a pool was formed, and the lower site was immediately downstream from the dam where the riffle was formed. After dam removal, sampling was conducted at another site where the dam was previously located (Figure 1).

Benthic macroinvertebrates were quantitatively sampled using a Surber sampler (30×30 cm, mesh size 0.2 mm) with three random replications at each sampling site. The collected samples were preserved with Kahle's solution and transported to the laboratory. Benthic macroinvertebrates were sorted and identified to the species level (Wiederholm 1983; Yoon 1995; Kawai and Tanida 2005; Merritt and Cummins 2008).

In addition to macroinvertebrate sampling, substrates inside the Surber sampler quadrat (up to 15 cm depth) were also analyzed. Sampled substrates were sieved and categorized into five size classes, boulder (>128 mm), cobble (64–128 mm), pebble (16–64 mm), gravel (2–16 mm), and silt and sand (<2 mm). Other general habitat parameters including current velocity, air and water temperatures, pH, dissolved oxygen, and conductivity were measured using a portable analyzer (YSI-650MDS, USA) during sampling according to standard methods (Clesceri et al. 1998).

Data analysis

Taxon richness and composition, EPT group (Ephemeroptera, Plecoptera, and Trichoptera) richness and density, McNaughton's species dominance index, and Shannon species diversity index were calculated based on quantitative sampling data (Smith and Smith 2001). In order to investigate the degree of habitat change, habitat orientation groups (HOGs) and functional feeding groups (FFGs) were analyzed according to Merritt and Cummins (2008). The Kruskal-Wallis test and Wilcoxon two-sample test (Proc NPSRIWAY; SAS institute 1996) were employed to test the effects of dam removal on species richness and the EPT group richness. We tested the Bray-Curtis similarity measure (Bray and Curtis 1957) with species and the number of individuals for each species to compare the changes of the benthic macroinvertebrate community before and after dam removal for collection date and site (PC-ORD; McCune and Mefford 1999, version 4.2).

Results

Habitat characteristics and substrate composition

Boulders started to appear soon after the dam removal at the upper site. After the monsoon flood in August 2006, the substrates became similar in composition within all study sites (Figure 2). The proportion of silt and sand decreased from 41.2% to 9% soon after dam

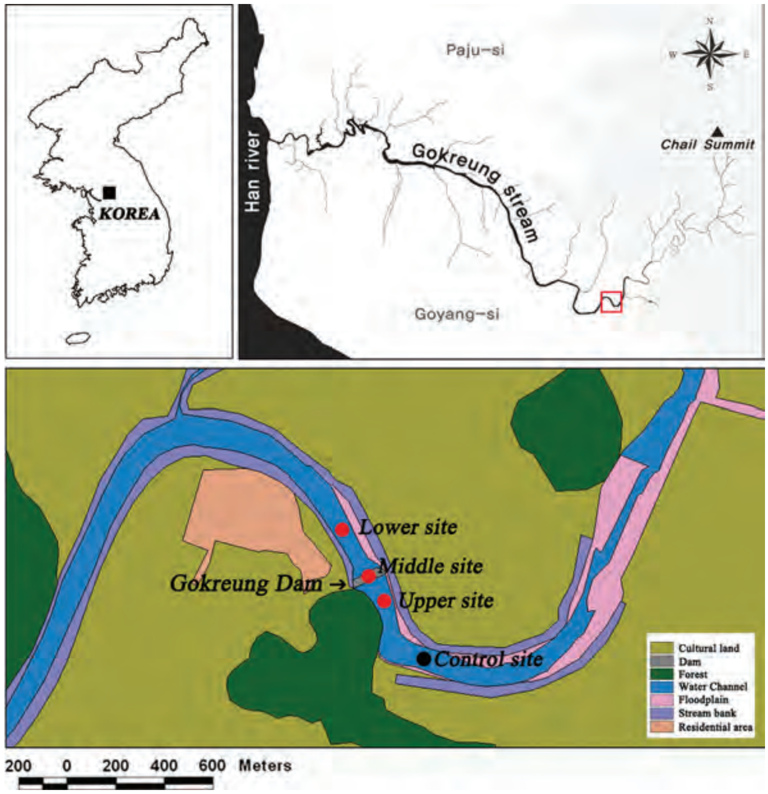

Figure 1. Sampling site locations in the Gokneung stream, Gyeonggi-do, Korea.

removal in August 2006, but increased again to 27.2% 12 months later. At the lower site, the proportion of boulders decreased while that of silt and sand increased to 7.6% soon after dam removal, but decreased again to 2.1% after monsoon floods. At the middle site, where the dam was located, the substrate composition was similar to that of the lower site.

The current velocity, which is closely related to the substrate, was different between the upper and other sites, and this flow regime has not changed substantially since the partial dam removal (Table 1). Other general environmental factors such as air and water temperatures, pH, dissolved oxygen, and conductivity were not substantially different between the study sites.

Macroinvertebrate community

The species richness of benthic macroinvertebrates at the study sites differed with sampling events (Figure 3A). The Kruskal-Wallis test indicated that, at the control site, species richness ($P = 0.047$) and EPT group richness ($P = 0.020$) differed significantly with sampling events. At the upper site, however, only the EPT group richness was significantly ($P = 0.031$) different between sampling events, while at the lower site species richness and EPT-group richness were not significantly different ($P > 0.05$).

In most sampling events, the species richness of benthic macroinvertebrates was lowest at the upper site, but the average number of species increased slightly after dam removal (Figure 3A). At the upper site, benthic macroinvertebrates inhabiting a lentic habitat with silt and sand, such as chironomid midges (Chironomidae), dragonflies (Odonata), and tubificid worms (Tubificidae), were dominant before the removal, but lotic taxa such as mayflies (Ephemeroptera) and caddisflies (Trichoptera) were also found after dam removal. At the lower site, species richness decreased soon after dam removal as rhyachophilid and psycomyiid caddisflies (Rhyacophilidae and Psychomyiidae) disappeared, while arhynchobdellid leeches (Arhynchobdellidae) appeared anew. After the monsoon flood, however, these species re-appeared, with increased densities of water beetles (Coleoptera) and chironomid midges. Species richness was significantly different ($P = 0.044$) between the sites before the removal, and not significantly different soon after the removal ($P > 0.05$), while it became significantly different again 1 year after the removal ($P = 0.048$).

Benthic macroinvertebrate density was lowest during the study period at the upper site, where average density increased from 37 inds 900 cm^{-2} before dam removal to 158 inds 900 cm^{-2} 12 months later (Figure 3B). It was highest at the lower site, where the

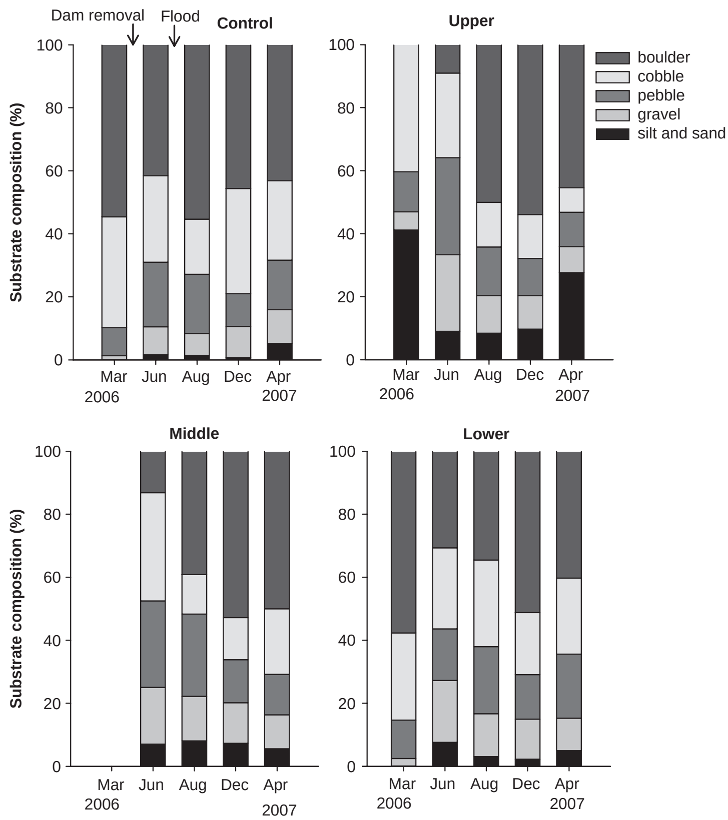

Figure 2. Average composition (%) of substrates at sampling sites before and after dam removal.

number increased from 819 inds 900 cm^{-2} before dam removal to 1634 inds 900 cm^{-2} 12 months later. At the middle site, benthic macroinvertebrates were introduced rapidly soon after dam removal (Figure 3A, B). Species richness and density decreased immediately after the monsoon flood, but gradually increased after dam removal at the middle site.

The dominance indices at the upper site were much higher than those of the other sites, and showed a general tendency to decrease up to 1 year after dam removal, particularly at the upper and lower sites (Figure 4A). The diversity indices showed a counter trend to the dominance indices (Figure 4B). The monsoon flood negatively affected the changes of dominance and diversity indices particularly at the upper site.

Before dam removal, only two EPT group species (*Ephemera orientalis* and *Mystacides* sp.), which favored slow flow and fine sediments, were found at the upper site of the stream. After dam removal, EPT group richness greatly increased at the upper site, due to the appearance of mayflies (Baetidae, Heptageniidae, and Caenidae) and caddisflies (Hydropsychidae). The ratio of EPT group to total species richness reached 51.2%, although that of other sites did not change greatly (Figure 5A). Comparison of EPT group species

Table 1. Habitat environment at the study sites of the Gokneung stream measured during the sampling period (mean ± SD).

	Site			
Variable	Control	Upper	Middle	Lower
Microhabitat type	Riffle	Pool	Riffle	Riffle
Current velocity (m s^{-1})	0.85 ± 0.32	0.14 ± 0.04	0.41 ± 0.22	0.81 ± 0.22
Air temperature (°C)	19.6 ± 12.5	20.4 ± 11.3	20.5 ± 13.0	20.7 ± 12.7
Water temperature (°C)	19.0 ± 12.5	17.9 ± 11.3	18.5 ± 10.0	17.8 ± 11.1
pH	8.0 ± 0.9	7.7 ± 0.9	6.8 ± 3.0	7.9 ± 0.7
DO (mg L^{-1})	11.5 ± 2.9	12.4 ± 1.7	11.1 ± 4.7	12.5 ± 1.7
Conductivity (μS cm^{-1})	252 ± 38	256 ± 31	226 ± 96	271 ± 16

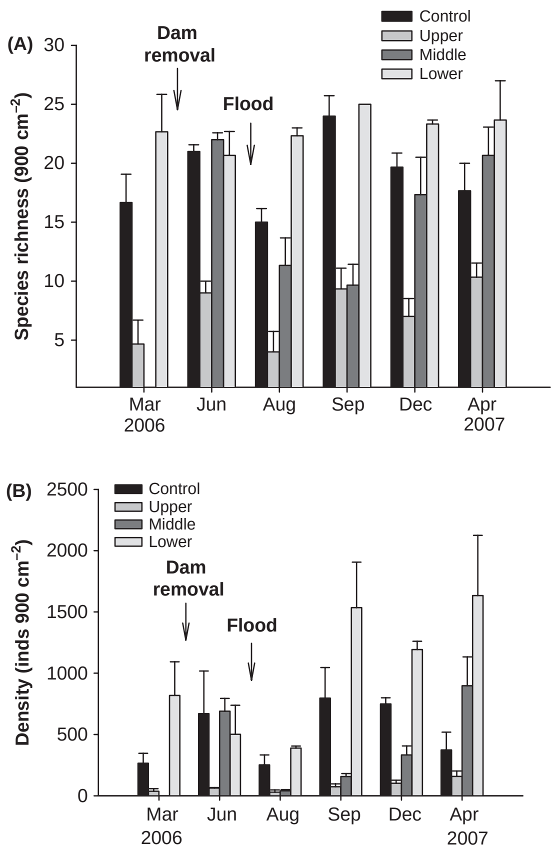

Figure 3. Comparison of benthic macroinvertebrate species richness (A) and density (inds 900 cm^{-2}) (B) at each site before and after dam removal. Species richness (900 cm^{-2}) was the average number of species for each site. All values are shown as mean ± SE.

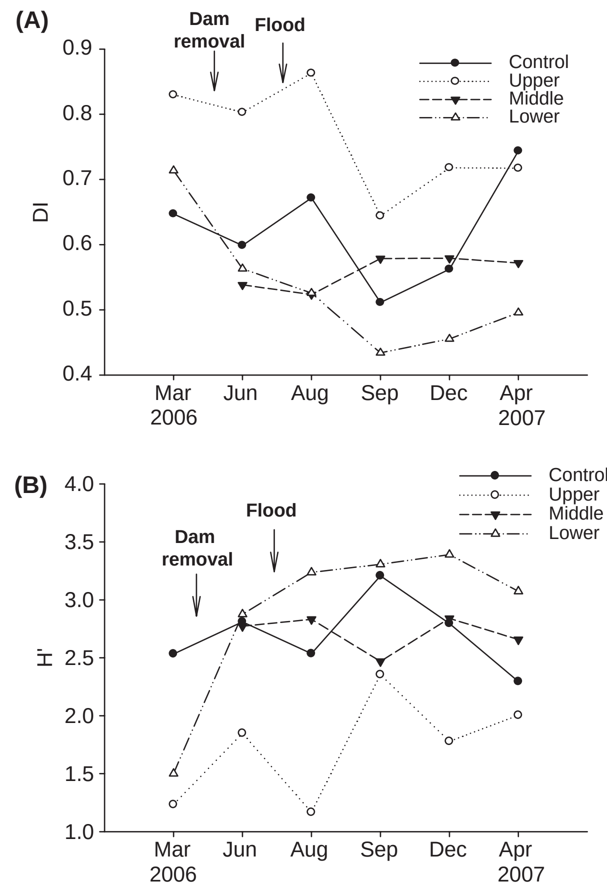

Figure 4. McNaughton's dominance indices (DI) (A) and Shannon species diversity indices (H′) (B) of benthic macroinvertebrates at sampling sites before and after dam removal.

richness before and 1 year after dam removal using the Wilcoxon two-sample test indicated significant difference ($P < 0.05$) at the upper site, while no significant difference ($P > 0.05$) was established at the control and lower sites. The ratio of EPT group to total species density increased significantly (approximately four times larger 1 year after dam removal) at the upper site, although the variations were generally large in sampling at all sites (Figure 5B).

Of HOGs, only burrowers (91.7%) and sprawlers appeared at the upper site before dam removal. However, after the removal, mayflies (Baetidae, Heptageniidae and Potamanthidae) and water beetles (Dytiscidae) appeared at the upper site, within which they enhanced the diversity of HOGs. At the lower site, the more dominant clingers decreased, whereas swimmers increased after dam removal (Figure 6A). At the upper site, the composition of FFGs was only gatherer-collectors (72.2%) and predators before dam removal, but after dam removal filterer-collectors and scrapers increased, while predators decreased (Figure 6B).

The Bray-Curtis similarity classification indicated that before dam removal the composition of macroinvertebrates was relatively similar between control and lower sites, but relatively dissimilar from the upper site (Figure 7). After dam removal, similarity at the upper site was also different from the control and lower sites, but that between control and lower sites was not greatly different. The composition of macroinvertebrates within the upper site remained relatively similar despite the different seasonal sampling.

Discussion

Habitat characteristics, including temperature, flow velocity, and substrate composition, regulate the occurrence and distribution of organisms in streams (Hynes 1970). Dams disconnect stream channels, reduce connectivity from upstream and downstream habitat, and result in negative effects on the dynamics and composition of stream biota (Junk et al. 1989; Doeg and Koehn 1994; Hart et al. 2002, Tiemann et al. 2004). Fine substrate material is an important factor affecting

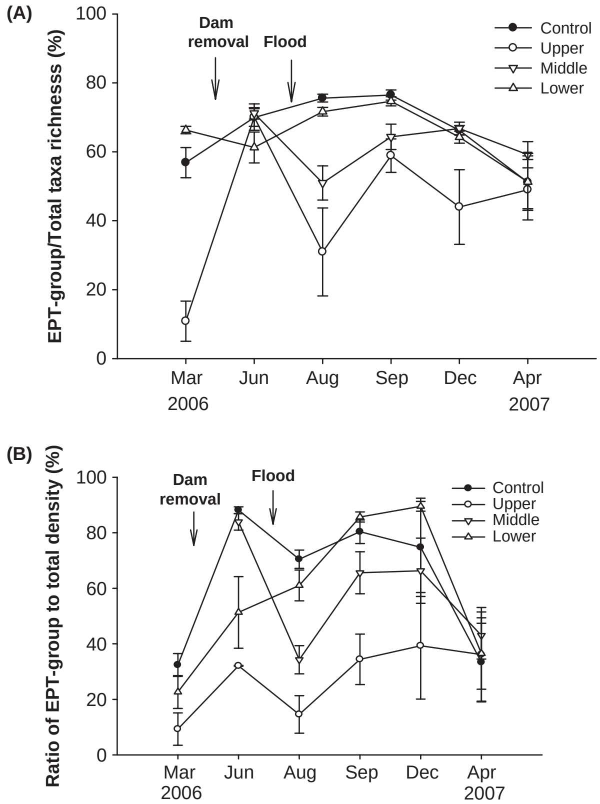

Figure 5. Species richness of EPT group (A) and ratio of EPT group density (inds 900 cm^{-2}) to total density of benthic macroinvertebrates (B) at sampling sites before and after dam removal. All values are shown as mean ± SE.

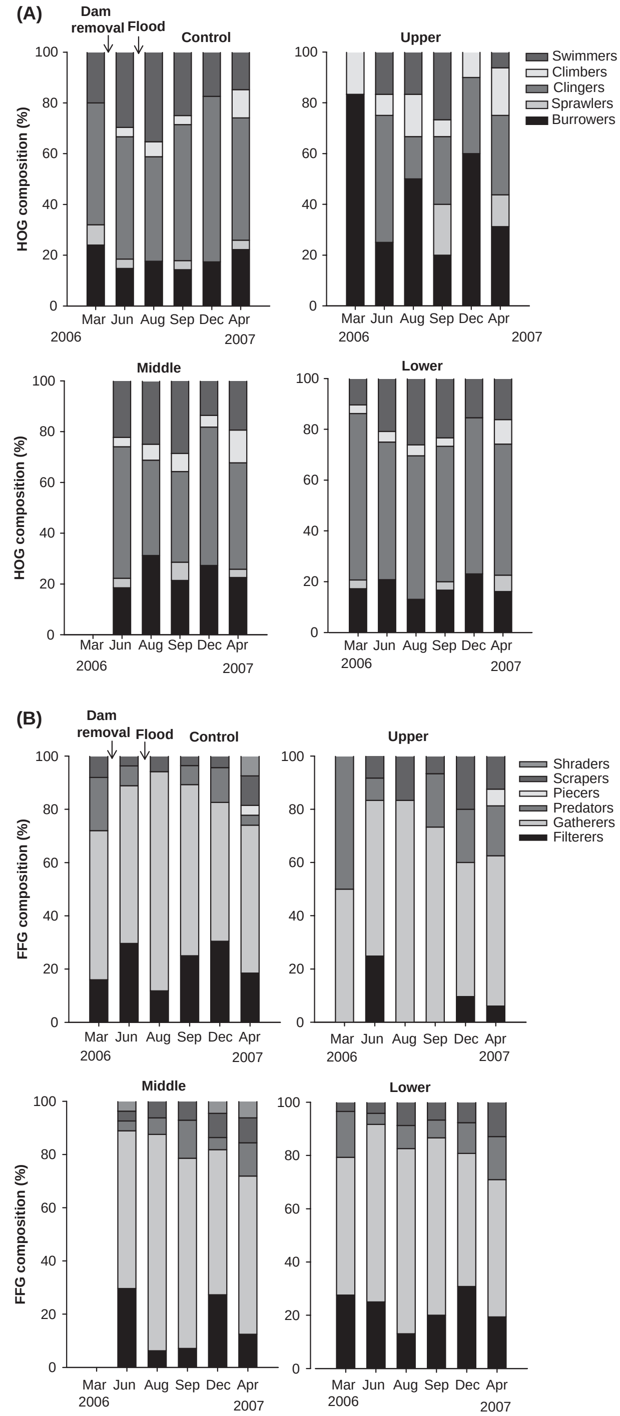

Figure 6. Composition (%) of habitat orientation groups (HOGs) (A) and functional feeding groups (FFGs) (B) of benthic macroinvertebrates at sampling sites before and after dam removal.

invertebrate distribution while having some negative effects on benthic assemblages (Statzner and Hibler 1986; Brown and Brussock 1991; Wohl et al. 1995; Wood and Armitage 1997). Our study showed how benthic macroinvertebrate communities changed after removal of the head part of a small dam. This lentic habitat negatively affected benthic macroinvertebrate communities in terms of species richness and density as in other studies cited above. The impoundment habitat formed in the upper site, in particular, negatively influenced the EPT group, which generally favors riffle habitats and coarse substrates. The functional groups such as HOGs and FFGs were also different between the upper and lower sites, as were the substrate and species compositions.

Our study showed how benthic macroinvertebrate communities change after removal of the head part of a small dam. In the upper site, fine particles decreased and coarse particles, including cobble and boulder, increased rapidly as the silt and fine sand, which covered the surface of stream bottom, were washed away. This increased substrate heterogeneity in the upper site resulted in the increase of benthic macroinvertebrate species richness, especially the EPT group. As a result, species richness and diversity indices increased while dominance indices decreased. Although the stream flow in the upper region remained very slow after dam removal, most lentic macroinvertebrates inhabiting fine sediments of the surface of the stream

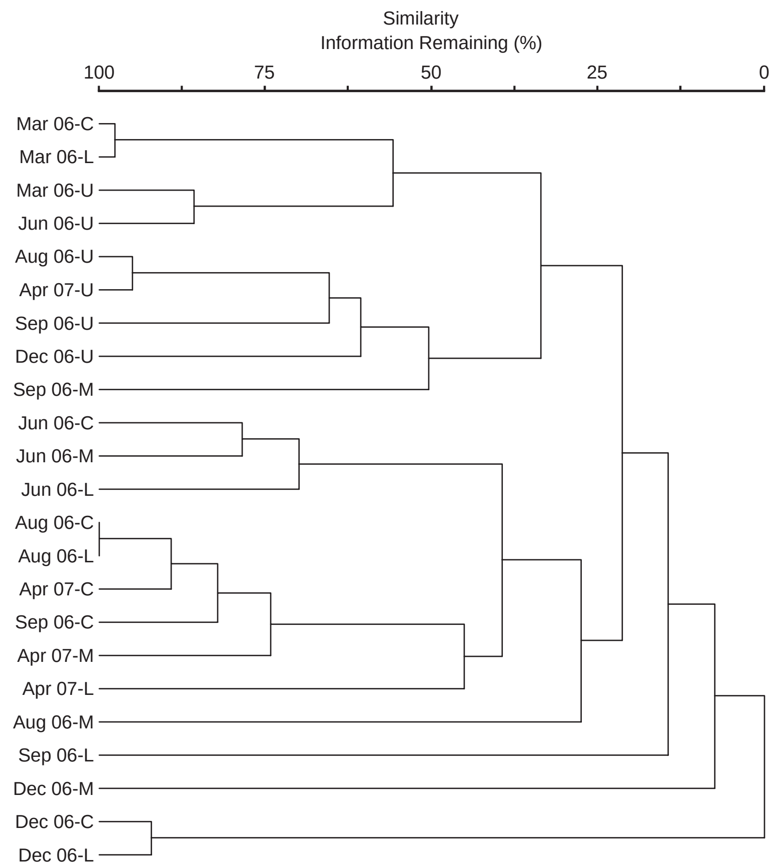

Figure 7. Bray-Curtis similarity of benthic macroinvertebrates between sampling events before and after dam removal. C, control site; U, upper site; M, middle site; L, lower site.

bottom disappeared. It is probable that they rapidly drifted away during floods to the lower stream reaches along with the fine substrates of the upper site. The decreasing number of species and individuals immediately after the dam removal in the lower site was probably affected by the transport of fine sediments from the upper stream (Stanley et al. 2002).

It has been reported that floods could have an important role in stream habitat recovery (Ortiz and Puig 2007). In this study, it is probable that the flood of July 2006 contributed to the recovery of species richness and density observed after the dam removal. The benthic macroinvertebrate community in the middle site (dam site) changed similarly to that of the lower site. This is also an expected occurrence as a riffle habitat was formed at the dam site. Kil et al. (2007) also showed similar changes of benthic macroinvertebrate communities in the middle site of a Korean stream.

Stanley et al. (2002) and Chaplin et al. (2005) stated that, after dam removal, the reservoir in the upper stream shifted to a lotic habitat within 1 year to exhibit similarities with the community assemblage of a free-flowing reach. Kil et al. (2007) also demonstrated that the lentic fauna and communities of benthic macroinvertebrates in the upper reservoir site changed fundamentally to lotic ones in the lower site 1 year after the complete removal (including foundation) of a small dam in a Korean stream. However, in this study, even after dam removal, species richness, density, and diversity of macroinvertebrates in the upper site were still different from those of the lower site, although the degree of the difference became smaller. This may be a reflection of the effect of microhabitat structure (e.g. low velocity and pool habitat) in the upper site, where a pool habitat still remained as a result of the partial dam removal. As the foundation of the dam remained, no fundamental changes in benthic macroinvertebrate composition accompanied the remaining pool-riffle sequence in the stream area.

In conclusion, we suggest that even a partial removal of a dam, resulting in increased flow, substrate heterogeneity, and benthic diversity, could sufficiently help recover the ecological integrity of streams without major habitat changes. Therefore, partial dam removals may provide an alternative strategy in stream restoration projects.

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