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Recolonization of benthic macroinvertebrates after anthropogenic disturbance in natural streams, South Korea[1a]

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ABSTRACT

Stream ecosystems are closely related to many human activities. Therefore, streams are affected by anthropogenic disturbances such as riverine development and gravel-mining as well as deterioration of water quality. The goal of this study was to elucidate the recolonization process of the macroinvertebrate community after a small-scale anthropogenic disturbance. Field studies were conducted at three sites in a natural stream. The number of recolonizing species tended to increase slightly over time, exceeding the total species number of the control. Ephemeroptera contributed the most to shaping the recolonizing pattern of the entire community. From the result of changes in dominant species, the early recolonizers of each site were the species that showed more frequent occurrence particulary at each sites. But the late recolonizers are Chironomidae at all the sites commonly. This result implies that the actual differences exist among the recolonizing trends of each benthic macroinvertebrate taxon. Collector-gatherers and scrapers comprised about 70% of the recolonizing species. These results indicate that the recolonizing process of an aquatic community after an artificial disturbance depends on the environmental conditions(particularly substratum composition or organic pollution) of the habitat.

KEY WORDS: COMMUNITY, ASSEMBLAGE, HABITAT, RESTORATION, FRESHWATER

INTRODUCTION

Stream dynamics are affected by a combination of abiotic and biotic variables. These lotic environments are the primary habitats for a variety of uniquely adapted plants, invertebrates, and vertebrates (Cairns 1988). Freshwater ecosystems are experiencing serious threats to both biodiversity and ecosystem stability (Suski & Cooke 2007). Ecosystem damage can also take on more subtle characteristics such as increased sediment loads, poor water quality from urban runoff, and unobserved declines in habitats (Newbold *et al*. 1980, Burgess & Bides 1980). Ecologically sustainable ecosystems are resilient or have the capacity to recover from natural disturbances (Webster *et al*. 1983), but careful planning and preliminary investigations are needed prior to conducting any restoration (Clarke *et al*. 2008). Biological monitoring appears to constitute

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the most appropriate means for detecting the effects of macroinvertebrates on the aquatic community.

Stream size and geomorphological characteristics may affect the duration and magnitude of a given disturbance (Wallace 1990). Many researchers have used replicate substratum treatments to examine the influence of a disturbance on macroinvertebrates. Several preceding reports suggest that the recovery of the macroinvertebrate community following disturbance is also related to the abundance of refugia, including organic debris, microhabitats. The contribution of recolonization process depends on the magnitude of the disturbance, the season in which this occurs. Many researchers generally focused on the recolonization after drought.

Macroinvertebrates play important roles in both structure and function in the aquatic community. Many factors affect the macroinvertebrate colonization process such as substrate characteristics, associated food sources, competition, and predation (Resetarits 2001). Recolonization depends mainly on individuals that arrive by drifting from communities in surrounding patches (Encalada & Peckarsky 2006, Blanca Rios-Touma *et al*. 2011). Korean streams are closely related to many human activities. Thus, many streams are affected by artificial disturbances such as riverine development and gravel-mining as well as physicochemical deterioration of water quality. And, macroinvertebrates are also affected by these anthropogenic disturbances, and their habitats are often physically damaged. Considering the important roles of macroinvertebrates to maintain stability of the stream ecosystem(Williams & Hynes 1974), it is essential to elucidate how disturbances affect them, and how they respond to these disturbances.

These objectives of this study are:

1. To elucidate the recolonization process of the macroinvertebrate community after a small-scale artificial disturbance(stream bed disturbance) to an aquatic habitat.
2. To elucidate if the recolonization process is affected by the environmental conditions of the ecosystem.
3. To provide fundamental data for ecological modeling of the macroinvertebrate recolonization process.

MATERIALS AND METHODS

1. Study Site and Experimental Design

Macroinvertebrates were collected by field recolonization experiments including experimental and control sampling. Three recolonization experiments were conducted from 11 April to 2 November 2011; one from 11 April to 21 May 2011 at site G (Gapyoung stream, N37°57′49″, E127°27′03″), another from 21 April to 1 June 2011 at site M (Majang stream, N37°51′21″, E127°31′07″), and a third from 21 October to 2 November 2011 at site D (Daljeon stream, N37°48′54″, E127°31′05″) in South Korea. (Figure 1).

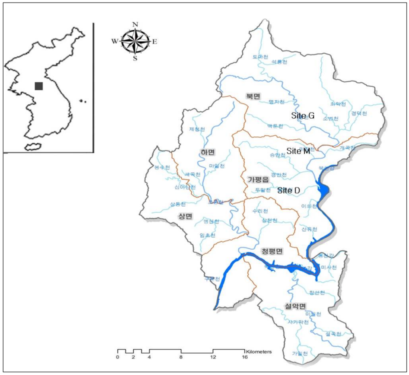

Figure 1. Study sites for recolonization experiment in three streams

Fifteen containers (44 cm × 32 ㎝ × 8 ㎝) were prepared for the field recolonization experiment at the three sites. The topside of the containers was open. The four sides and the bottom area of each box were latticed (lattice size = 1 ㎠) to allow macroinvertebrate movement. Each container was filled with the natural substrata of each site without organic matter. The size composition, density, shape, and color of the artificial substrata in each container were prepared to be similar to the natural substrata at each site. Each box was placed at the gently-flowing runs selected randomly in an upstream-downstream direction. The top of the box was flush with the stream bed surface. The mean upstream-downstream distance between the substratum containers was 5 m. The natural substrata at each location were completely substituted by one artificial substratum container, and the substratum within the 0.5 m range from each container was lightly disturbed with a small spade.

2. Macroinvertebrate Sampling

Three pairs of quantitative samples were collected with a Surber sampler (30 ㎝ × 30 ㎝, mesh size = 0.1 ㎟) to compare data from the experimental sampling with those for the control by simultaneously retrieving artificial substratum containers on days 1, 21, and 42, respectively. The recolonized organisms in the retrieved containers were washed from the substrata, and sieved(netmeshsize=0.1 ㎜). Then, the organisms were immediately fixed in Kahle's fluid and delivered to the laboratory.

3. Physical Characterization

Median diameter(M.D., Phi scale) and quartile deviation (Q.D.) were calculated from the weight ratios of the four substratum types composing each sample. The analysis was conducted by means of a standard sieve according to the Wentworth (1922) classification of substratum particle size (Minshall 1984).

4. Data Analysis

Data were expressed as the number of recolonizing species and individuals(/㎡) in the natural community. Simple regression analysis was applied to predict the changes in the number of recolonizing individuals during the recolonization period and to elucidate the functional relationships between the variables. A non-linear regression model(cubic polynomial) was applied for the experimental data, whereas linear regression was applied for the control data.

RESULTS AND DISCUSSION

1. Result

1) Physical Environment

Sites M and D were tributaries of Gapyoung stream. Mean water velocity, mean water depth, and substratum conditions are summarized in Table 1. The mean values of M.D. and Q.D. were not different between the experimental and control substrata, and the mean weight ratios of the four substratum types composing each sample also had no remarkable differences(Table 2). A paired *t*-test showed that artificial substratum structure was not significantly different from the natural condition at each site ($p>0.5$).

Table 1. Mean values of the physical factors at the three Gapyoung experimental sites

Site	Water Depth (㎝)	Water Velocity (㎝/sec)	Substrata			
			Median diameter (M.D.)		Quartile deviation (Q.D.)	
			AS	CON	AS	CON
Site-G	18.0±1.31	43.5±0.85	-5	-4	1.0	1.0
Site-M	15.3±0.56	48.4±0.67	-4	-4	0.5	0.5
Site-D	14.7±0.42	40.8±0.57	-3	-3	0.5	0.5

AS, artificial substrata; CON, control

Table 2. Composition percentage of four substratum types at each sampling site

Site	Substratum Type							
	Cobbles		Pebbles		Gravels		Sands	
	AS	CON	AS	CON	AS	CON	AS	CON
Site-G	30	30	45	50	20	15	5	5
Site-M	25	20	50	50	20	25	5	5
Site-D	10	15	60	55	15	20	15	10

unit = %; AS, artificial substrata; CON, control

Table 3. The list of dominant benthic macroinvertebrates at the three sites during each experiment period

Site	Times	1st Dominant Species	2nd Dominant species
site G(AS)	1st	*Glossosoma* KUa (22.05 %)	*Epeorus pellucidus* (13.23 %)
	2nd	*Glossosoma* KUa (33.18 %)	*Uracanthela rufa* (11.65 %)
	3rd	*Glossosoma* KUa (20.49 %)	*Uracanthela rufa* (12.73 %)
	4th	Chironominae sp.1 (38.82 %)	Chironomidae sp.4 (15.52 %)
sites M(AS)	1st	*Baetis ursinus* (51.50 %)	Chironomidae sp.1 (21.07 %)
	2nd	*Baetis ursinus* (59.05 %)	Chironomidae sp.1 (15.28 %)
	3rd	*Baetis ursinus* (37.32 %)	Chironomidae sp.1 (13.50 %)
	4th	Chironomidae sp.1 (54.35 %)	*Hydrosyche kozhantschikovi* (9.40 %)
sites D(AS)	1st	*Erpobdella lineata* (29.72 %)	Chironomidae sp.1 (29.62 %)
	2nd	Chironomidae sp.1 (73.50 %)	Chironomidae sp. (pupa) (8.20 %)
	3rd	Chironomidae sp.1 (73.19 %)	Chironomidae sp. (pupa) (11.38 %)
	4th	Chironomidaee sp.1 (85.79 %)	Chironomidae sp. (pupa) (6.58 %)

unit = %; AS, artificial substrata

2) Macroinvertebrate Assemblages

The total number of benthic macroinvertebrate species was greatest at site G and the least at site D. At site G, 10 orders 28 families, and 67 species were documented during the recolonization experiment. 11 orders, 21 families, and 38 species occurred at sites M and D.

The result of the control sampling demonstrated that Ephemeroptera and Trichoptera were generally abundant during the entire experimental period at site G. Ephemeroptera and Trichoptera such as *Glossosoma* sp. and *Uracanthella rufa* were dominant until the fourth sampling of the recolonization experiment, and then Chironomidae sp. was predominant. The results of control sampling at site M showed that Chironomidae sp. was mainly dominant. Baetis ursinus (Ephemeroptera) was most dominant until the third sampling of the recolonization experiment. However, Chironomidae sp. was mainly dominant and *Hydropsyche kozhantschikovi* was the second most dominant species for the subsequent samplings. Chironomidae sp. were also mostly dominant during control sampling at sites D and M. Chironomidae sp. was dominant over the entire sampling period during the recolonization experiment(Table 3).

3) Macroinvertebrate Recolonizing Patterns

The recolonizing patterns of the macroinvertebrates are shown in Tables 4 and 5. Each site showed a constant increase in species or individual numbers over the entire experimental period. The recolonizing patterns in terms of total species numbers were very similar between sites G and M. But, the pattern at site D showed a gradual increase in taxa until the middle period of sampling. However, the recolonizing patterns in terms of total number of individuals showed an increasing trend at all sites. These trends were abrupt at sites M and D but gradual at site G. Ephemeropteran seemed to be the most dominant early recolonizers at site G. In contrast, Chironomidae sp. were the predominant late recolonizers. The recolonizing rate for species was higher than that for individuals. Ephemeroptera spp. appeared to be early recolonizers at site M. In contrast, Chironomidae sp. were the late recolonizers. These results were similar at site G. Other invertebrates (mostly annelids) appeared to be early recolonizers at site D. In contrast, Chironomidae sp. were the late recolonizers (Tables 5).

4) Recolonizing Patterns of the Functional Feeding Groups

We detected a greater diversity of collector-gatherers and scrapers (Figure 2). As recolonizing commenced, the composition of collector-gatherers increased. Thus, collector-gatherers and scrapers appeared to be the most diverse early recolonizers. However, only collector-gatherers were late recolonizers at high diversities. The recolonizing rate for species was higher than that for individuals. In summary, collector-gatherers shaped the recolonizing pattern for the entire community.

5) Regression for the Secondary Communities

The regressions of the recolonization patterns for all secondary communities at the three Gapyoung sites during

Table 4. Mean number of species and macroinvertebrate individuals at the study sites during each experiment period

(a) Site-G

Duration (Day)	Species Number		Individual Number(/㎡)	
	AS	CON	AS	CON
1	16	28	88	3610
3	21		241	
7	31		793	
15	33		1144	
20	30	29	1509	4278
27	39		1774	
34	36		1533	
41	37	30	2669	3356

(b) Site-M

Duration (Day)	Species Number		Individual Number(/㎡)	
	AS	CON	AS	CON
1	11	19	1060	7073
4	22		2392	
7	20		2545	
15	24		3577	
22	22	16	6192	4534
29	26		10613	
36	24		13094	
42	24	18	15805	16420

(c) Site-D

Duration (Day)	Species Number		Individual Number(/㎡)	
	AS	CON	AS	CON
1	8	8	595	1306
4	9		1769	
8	12		2062	
16	16		2200	
22	15	13	3287	2645
30	17		8386	
37	12		7485	
43	10	11	12295	10605

AS, artificial substrata; CON, control

each experimental period are shown in Fig. 3. In terms of species number, the two regression lines for recolonization and the control intersected first at almost the same points at all sites.

The recolonization line for sites G and M was constantly above the control line from the day of the first intersecting point. In contrast, the recolonization line for site D intersected again on the downward side of the control line on about day 40. The first intersection occurred on days 5-7 from the beginning for all sites. The recolonization lines showed a steeper gradient during the early period and then stable progression to the end of the experimental periods for all sites. The two lines indicating the number of individuals intersected at different points at the sites. The intersecting day for site G was not in range for the entire period, but the recolonizing line became closer to the control line. However, the recolonization line intersected immediately again down from the control line and the second upward intersection was on about day 33. But, the two regression lines for site D almost overlapped during the entire experimental period. The control lines had little slope at all sites, except the lines for individual numbers at sites M and D. which had steep slopes for individual number(Figure 3).

Table 5. Species compositions of the macroinvertebrate taxa at the study sites during each experiment period

(a) Site-G ([%])

Dur-ation (Day)	Ephemeroptera		Trichoptera		Diptera (Chironomidae)		Other Insects		Other Invertebrates	
	AS	CON	AS	CON	AS	CON	AS	CON	AS	CON
1	8[50.0]	10[35.6]	4[25.0]	8[28.6]	2[12.5]	4[14.3]	2[12.5]	5[17.9]	0[0]	1[3.6]
3	10[47.6]		4[19.0]		3[14.3]		2[9.5]		2[9.5]	
7	12[38.7]		7[22.6]		4[12.9]		4[12.9]		4[12.9]	
15	14[42.4]		7[21.2]		4[12.1]		6[18.2]		2[6.1]	
20	11[36.6]	12[41.5]	9[30.0]	7[24.1]	5[16.7]	5[17.2]	3[10.0]	3[10.3]	2[6.7]	2[6.9]
27	13[33.4]		10[25.6]		6[15.4]		7[17.9]		3[7.7]	
34	14[39.0]		7[19.4]		5[13.9]		7[19.4]		3[8.3]	
41	15[40.6]	13[43.4]	6[16.2]	7[23.3]	6[16.2]	5[16.7]	7[18.9]	4[13.3]	3[8.1]	1[3.3]

(b) Site-M ([%])

Dur-ation (Day)	Ephemeroptera		Trichoptera		Diptera (Chironomidae)		Other Insects		Other Invertebrates	
	AS	CON	AS	CON	AS	CON	AS	CON	AS	CON
1	4[36.4]	6[31.6]	0[0]	3[15.8]	3[27.3]	3[15.8]	1[9.0]	2[10.5]	3[27.3]	5[26.3]
4	6[27.3]		3[13.6]		4[18.2]		3[13.6]		6[27.3]	
7	5[25.0]		3[15.0]		3[15.0]		2[10.0]		7[35.0]	
15	5[20.8]		5[20.8]		4[16.7]		2[8.3]		8[33.4]	
22	4[18.2]	3[18.8]	4[18.2]	3[18.8]	3[13.6]	3[18.8]	2[9.0]	2[12.5]	9[41.0]	5[31.1]
29	5[19.2]		5[19.2]		4[15.4]		2[7.7]		10[38.5]	
36	5[20.8]		4[16.7]		3[12.5]		3[12.5]		9[37.5]	
42	3[12.5]	3[16.7]	5[20.8]	5[27.7]	3[12.5]	3[16.7]	3[12.5]	3[16.7]	10[41.7]	4[22.2]

(c) Site-D ([%])

Dur-ation (Day)	Ephemeroptera		Trichoptera		Diptera (Chironomidae)		Other Insects		Other Invertebrates	
	AS	CON	AS	CON	AS	CON	AS	CON	AS	CON
1	1[12.5]	0[0]	0[0]	0[0]	3[37.5]	3[37.5]	0[0]	1[12.5]	4[50.0]	4[50.0]
4	1[11.1]		0[0]		3[33.3]		0[0]		5[55.6]	
8	2[16.7]		0[0]		4[33.3]		0[0]		6[50.0]	
16	4[25.0]		1[6.3]		4[25.0]		2[12.5]		5[31.2]	
22	3[20.0]	4[30.7]	2[13.3]	2[15.4]	3[20.0]	3[23.1]	1[6.7]	1[7.7]	6[40.0]	3[23.1]
29	3[17.6]		2[11.8]		4[23.5]		2[11.8]		6[35.3]	
36	2[16.7]		2[16.7]		3[25.0]		1[8.3]		4[33.3]	
42	0[0]	1[9.1]	0[0]	1[9.1]	4[40.0]	3[27.3]	1[10.0]	1[9.1]	5[50.0]	5[45.4]

AS, artificial substrata, CON, control

2. Discussion

Many studies have demonstrated that water depth and water velocity are very important factors for distributing benthic macroinvertebrates, and that most benthic macroinvertebrates adapt to variations in these factors (Williams & Hynes 1974; Ward 1992). Only slight differences in mean measured water depth and velocity were observed among the three sites, indicating that the sites generally had common physical conditions for macroinvertebrates. Substrata characteristics are also one of the most important physical factors of habitats for benthos. Substratum conditions generally determine the suitable habitats for macroinvertebrate, regardless of water quality.

No differences were observed in the substrata characteristics for the recolonization experiment or the control, indicating that the artificial and natural substrata worked similarly as aquatic habitats for macroinvertebrates. Because the artificial substratum containers for the

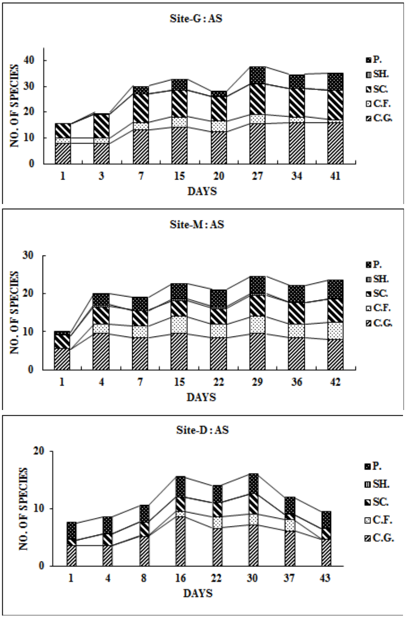

Figure 2. Species compositions of the macroinvertebrate functional feeding groups at the study sites during each experiment period (AS, artificial substrata; P, predator, SH, shredder, SC, scraper, C.F., collector-filterer, C.G., collector-gatherer)

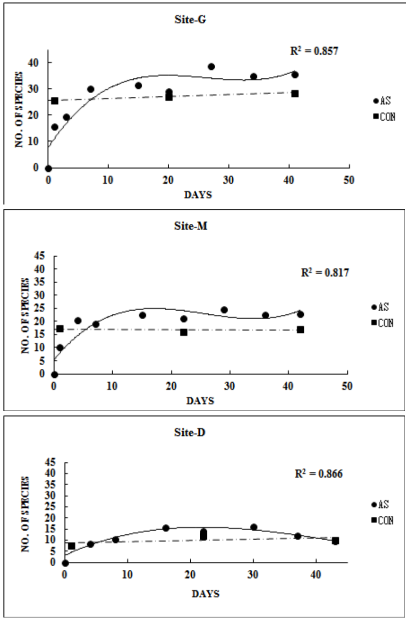

Figure 3. The regressions of the recolonization patterns (AS) of all secondary communities at the study sites during each experiment period (AS, artificial substrata; CON, control)

recolonization experiment were similarly placed at each site, the differences among the recolonization patterns at each site were not due to errors in experimental design, but due to distribution and abundance of existing taxa.

In general, the more favorable environmental conditions are in a certain region, the more species will occur. The result of species occurrence indicated that the presence of species was somewhat affected by the environmental factors at each site such as physical habitat conditions and water quality. In terms of functional feeding groups, shredders and predators are relatively abundant in regions with upstream region, whereas collectors and scrapers occur in regions with gentle current flow (Merritt & Cummins 1996). In this study, collector-gatherers, and scrapers occurred most frequently at all sites. This agreed with the explanation provided above, and indicates that the experiments were conducted properly.

Townsend and Hildrew (1976) found that 82 % of macroinvertebrate movement was a result of drift within the stream water column. Movement within substrata is considered the main source for small-scale colonization. Therefore, the source for recolonization in this study was drift or within-substrata movement. Generally, species colonization patterns can be explained by mobility, feeding habits, or competition between taxa. In general, the characteristics of recolonizing patterns of each functional feeding group could be accounted for by their foraging habits.

In this study, as the recolonizing taxa were generally similar among all sites (just differed in density), the differences in recolonizing patterns among the study sites were due to the different functions of recolonizing sources induced by different environmental conditions (particularly substratum composition or organic pollution) at each site. The results of this study agree with the observation that the number of recolonizing organisms is expected to increase and then stabilize or decline over time. However, the detailed trends at each site showed somewhat different patterns. Experimental studies showed macroinvertebrates dynamics, but interpretation of their results is difficult because conclusions from manipulations conducted at small scales and replicates.

This result was thought to be caused by differences in the environmental maturity at each site. Here, maturity means potential complexity or diversity that stabilizes the ecosystem and makes it resistant to external disturbances (Clarke *et al*., 2008).. Environmental maturity represents the complexity or diversity in habitats. Thus, habitat maturity is the result of biological maturity or complexity and diversity of communities. The physical and chemical features of a site such as habitat conditions and water quality are commonly favorable for macroinvertebrate communities. The change in benthic macroinvertebrate community structure (species, dominance, abundance) is caused by positive or negative actions within a particular habitat. It has been recognized that physical disturbances modify the abitic and biotic conditions.

These approaches to the study of disturbance in natural stream will present significant interpretation of particular events and restoration. Also, the results will provide fundamental data for ecological modeling of the macroinvertebrate recolonization process.

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