

Characterization of Benthic Macro-Invertebrate Communities and Hydraulic Factors in Small-Scale Habitats in a Polluted Stream

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Benthic macro-invertebrates were collected in a 200 m reach located in the 3rd order Yangjae Stream, a tributary of the Han River, Seoul, from April 1996 to March 1998. Although species richness was relatively low due to organic pollution, community abundance patterns appeared to be different depending upon location of the sampling sites. At the sample sites in the straight zone with high water velocity and large substrates, species richness was high and species relatively less-tolerant to organic pollution was additionally present. At the sample sites in the pool zone with lower velocity and high sedimentation, species richness was low and a few tolerant species to organic pollution were abundantly collected. The principle component analysis indicated that some sample sites in the straight zone appeared to be related to water velocity and shear velocity, and associated with diverse taxa less tolerant to organic pollution. Additionally the sample site transplanted with large substrates was associated with hydraulic characters such as substrate diversity and roughness, and was related to species indicating partial recovery of water. The sample sites located at the pool zone tended to be associated with organic matter that had sedimented on to the substrates and the taxa tolerant to organic pollution, including *Oligochaeta* and *Chironomus*.

Key words : Community structure, benthic macro-invertebrates, stream, habitats, multivariate analysis

INTRODUCTION

Spatial heterogeneity plays a governing role in determining biological communities and subsequently causes complex environment-community relationships (Turner and Gardner, 1991; Levin, 1992; Tilman, 1994). The environment factors produce spatial heterogeneity in different scales in rivers and streams (Hynes, 1970; Minshall *et al.*, 1983; Minshall, 1984; Giller *et al.*,

1994). Specifically for mobile macro-invertebrates, substratum patches and habitat types could form units in 1-10 m scale respectively in temperate region (Hubbell and Foster, 1986).

The previous studies on the habitat-community relationship, however, were mainly conducted in large scales (Frissell *et al.*, 1986; Coddington, 1988; Resh *et al.*, 1988; Fisher, 1990). Benthic macro-invertebrates were generally surveyed in the range of 1-10 km. Geomorphology and watershed environments are highly different in this

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case and community composition is correspondingly diverse in the large scale of space. Consequently, species traits in different survey area have been useful for community characterization (e.g., Resh *et al.*, 1994).

In small scale in space, however, environment and community would not be distinctively different among sample sites, and species traits could not characterize community efficiently. There have been various accounts of studying benthic macro-invertebrate communities in a relatively small scale in hundred-meter distance (e.g., Cummins and Lauff, 1969; Hildrew *et al.*, 1980). In this case, however, the total sampling periods have usually been short while sampling frequencies were relatively sparse with seasonal or yearly collections. Community variations have been rarely covered in 10 m distance scale with monthly collections. In this study, we intended to characterize communities and their relationships to hydraulic variables in a small-scale of 10 m, especially when the streams were polluted in an urban area.

MATERIALS AND METHODS

Study area and sample sites

The survey was carried out in a 200 m reach (Hakyeoul) located in the 3rd order downstream of the Yangjae Stream, a tributary of the Han River in south of Seoul, Korea (37° 24'–37° 29'N, 126° 57'–127° 04'E) (Fig. 1). It flows through the metropolitan and agricultural area in the city, and has been mainly polluted with organic matter (KICT, 1997). The stream has a year-round flow in 20–30 m width and 10–60 cm in depth. Water discharges are rapidly increased in the period of summer flooding, while decreased in dry winter season.

Based on topography of the surveyed area, four sub-areas were conventionally categorized, generally covering 30–50 m in longitude and 5–10 m in transverse (Fig. 1): 1) the upstream Area I, 2) the downstream Area II, 3) the outer concave bank Area III and 4) the pool Area IV (Table 1). Some parts of the edge area in the surveyed reach were reconstructed for the purpose of restoration of the stream.

Usually water velocities and depths were relatively high in the straight upstream Area I, while the reverse situation occurred in the pool

Area IV. The other environmental factor such as substrate composition was correspondingly contrasted between these areas: substrates were larger and diverse in Area I while smaller and less diverse in Area IV (Fig. 2). In Area III located at the outer concave bank (Fig. 1), velocity was in intermediate range (20–30 cm/s) and substrates mainly consisting of middle-sized pebbles occurred abundantly (Table 1). Area II was wide, and velocity was in intermediate range while relatively small-sized gravels were mainly present.

For sampling of benthic macro-invertebrates, each area was further divided into two to three sample sites in 5–10 m distance based on location, geomorphic characters and sampling direction. Except the sites of JHU and JHJ, which were the beginning and end points of the survey-

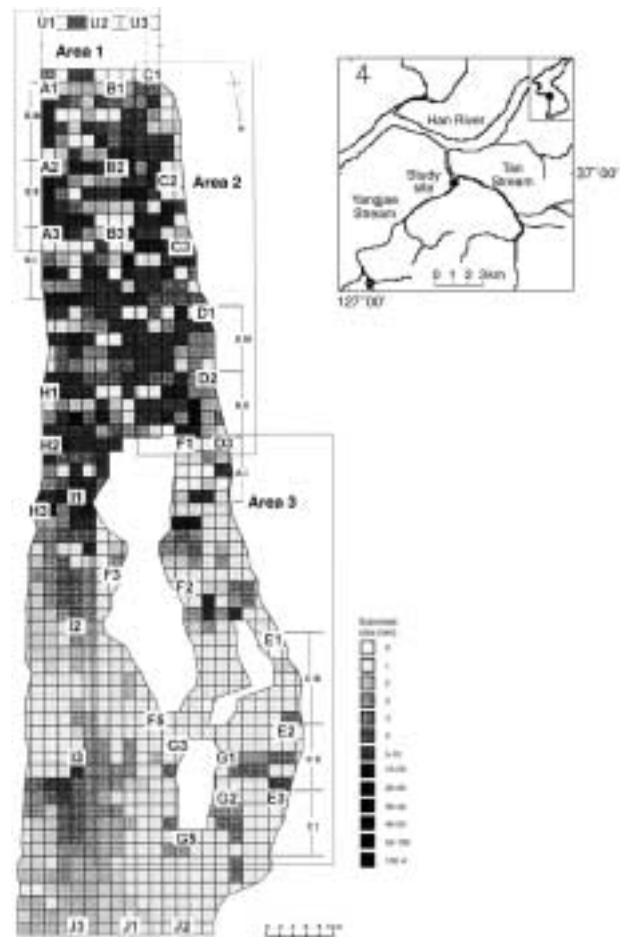


Fig. 1. Map of the sampling sites at the Hakyeoul reach in the Yangjae stream, Han River (Surveyed in March, 1996).

Table 1. Description of the sample sites located at the Hakyoul reach in the Yangjae Stream, Han River.

Area	Sites	Location	Shape	"Sampling direction" ¹⁾	Velocity ²⁾	Depth ³⁾	Substrates ⁴⁾	R ⁵⁾
Area I	JHU	Middle	Straight	T	Fast	Medium	Cobble	No
	JHA	Edge	Straight	L	Medium	Medium	Cobble	Yes
	JHB	Middle	Straight	L	Fast	Medium	Pebble	No
Area II	JHH	Edge	Straight	L	Medium	Deep	Gravel	No
	JHI	Middle	Straight	L	Fast	Medium	Gravel	No
	JHJ	Middle	Straight	T	Medium	Deep	Gravel	No
Area III	JHC	Edge	Oblique	L	Medium	Medium	Pebble	No
	JHD	Edge	Oblique	L	Medium	Medium	Pebble	Yes
Area IV	JHE	Edge	Curved	L	Slow	Shallow	Sand	Yes
	JHF	Edge(Islet)	Curved	C	Slow	Shallow	Sand	Yes
	JHG	Edge(Islet)	Curved	C	Slow	Shallow	Sand	No

¹⁾ T; Transverse, L; Longitudinal, C; Curvilinear

²⁾ Slow; less than 20 cm/s, Medium; equal to or greater than 20 cm/s and less than 30 cm/s, Fast; greater than 30 cm/s

³⁾ Shallow; less than 10 cm, Medium; equal to or greater than 10 cm and less than 15 cm, Deep; greater than 15 cm

⁴⁾ Substrate size category by Minshall (1984)

⁵⁾ R; The project of reconstruction conducted

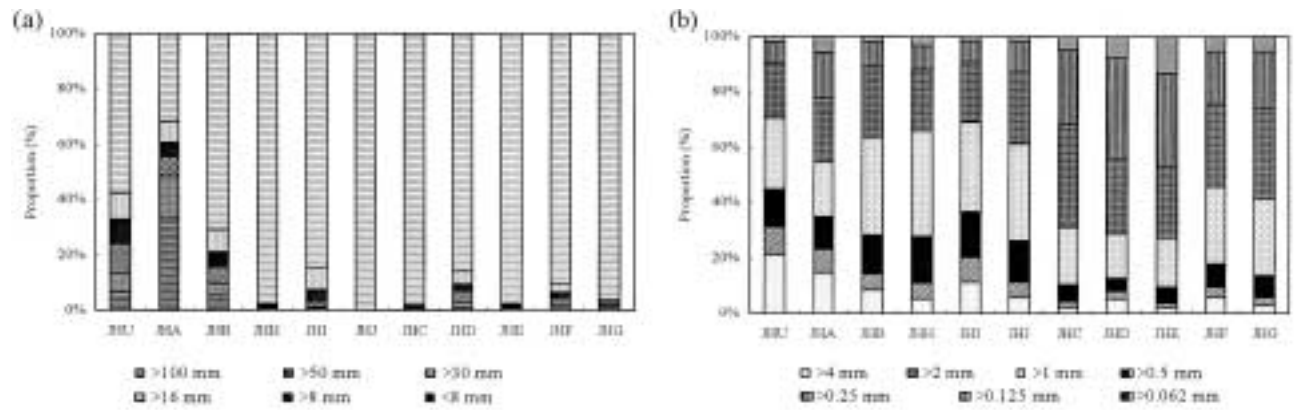


Fig. 2. Substrate composition (%) in different sizes (diameter; mm) collected at the sample sites of the Hakyoul Reach in the Yangjae stream, Han River, at monthly intervals from April 1996 to March 1998. a) Overall size, b) Small size (< 8 mm).

ed reach respectively, longitudinal or curvilinear sampling was conducted (Table 1).

For the purpose of restoration, vegetation channel revetment technique was conducted in the riparian zone close to JHA (Fig. 1; KICT, 1997). The stream bed was artificially planted with large-sized cobbles approximately 5 cm in diameter (Fig. 2). The upstream islet, where JHF was located nearby, was artificially constructed for management of siltation as well as for providing habitats for birds and other animals, while the downstream islet, around which JHG was sampled, was naturally formed. Restoration was also conducted on the riparian zone close to

JHD, but stream bed was not affected by the restoration project in this case. JHE was located close to the edge area at the pool zone, and silts were highly accumulated.

Sample collection and environmental measurement

At each sample site three to four benthic samples were collected with the Surber sampler (30 cm × 30 cm, 500 μm mesh; Surber, 1937; APHA *et al.*, 1985) in about 10 cm depth at monthly intervals for two years from April 1996. The collected macro-invertebrates were preserved in

7% Formalin solution. In the laboratory the invertebrate specimens were sorted, identified and counted under microscopes. Identification was based on Yun (1988), Brighnam *et al.* (1982), Merritt and Cummins (1984), Pennak (1978) and Quigley (1977). Chironomidae was separately identified based on Wiederholm (1983), while Oligochaeta was checked with Brinkhurst *et al.* (1971) and Brinkhurst (1986).

At each site of collection, volume of substrate was measured in different diameters (D): coarse cobbles (mean D sizes ≥ 100 mm), fine cobbles ($100 \text{ mm} > D \geq 50$ mm), pebbles ($50 \text{ mm} > D \geq 30$ mm), fine pebbles ($30 \text{ mm} > D \geq 16$ mm), coarse gravel ($16 \text{ mm} > D \geq 8$ mm), and the smaller substrates ($8 \text{ mm} > D \geq 4$ mm, $4 \text{ mm} > D \geq 2$ mm, $2 \text{ mm} > D \geq 1$ mm, $1 \text{ mm} > D \geq 0.5$ mm, $0.5 \text{ mm} > D \geq 0.25$ mm, $0.25 \text{ mm} > D \geq 0.1$ mm and $0.1 \text{ mm} > D \geq 0.062$ mm) (Cummins and Lauff 1969). The volumes of larger substrates (≥ 8 mm) were determined by the volumetric bucket in the field, while substrates smaller than 8 mm in diameter were separately sampled into plastic containers (50 ml) in triplications. Subsequently dry weights were estimated in the laboratory and volumes were calculated in different mesh sizes. Substrate heterogeneity was expressed by diversity using Simpson's index (Simpson, 1949; Minshall, 1984). The total sediment organic matter at the sampled sites was additionally determined by the ashing method, after being dried at 550°C for 4 h (Wrona *et al.*, 1986).

The hydraulic variables were estimated for each sample site according to Statzner *et al.* (1988). Roughness was expressed as $K = (5C_1 + 3C_2 + C_3)/9$ where the subscripts 1, 2 and 3 represent the 1st, 2nd and 3rd most dominant substratum type, respectively. Coarseness value C was correspondingly assigned to the size of dominant substrates; 1, 2, 3 and 4 if the size, k, is in the range of $k < 0.125$ mm, $0.5 \text{ mm} \leq k < 4$ mm, $8 \text{ mm} \leq k < 30$ mm, $k \geq 30$ mm respectively. The coarse classes have been slightly modified from those given by Statzner *et al.* (1988) to the size used in this study. The other hydraulic parameters were obtained as follows:

$$\text{Froude number } (Fr) = U/\sqrt{(gD)} \dots\dots\dots (1)$$

$$\text{Reynold number } (Re) = UD/\nu \dots\dots\dots (2)$$

$$\text{Shear velocity } (U^*) = U/5.57\log_{10}(12D/K) \dots\dots (3)$$

$$\text{Viscous sublayer thickness } (VST) = 11.5\nu/U^* \dots (4)$$

where U is mean water velocity (cm/s), D is depth (cm), g is acceleration due to gravity (981 cm/s^2), and ν is kinematic viscosity ($0.011 \text{ cm}^2/\text{s}$ at 15°C).

Data analysis

The Principal Component Analysis (PCA) was conducted to examine associations among variables and sample sites. The abundance of the selected taxa in community and the values of environmental factors were separately provided as input to PCA. Taxa collected with extremely low densities were not used for input and abundant 6 taxa were provided as input: Oligochaeta, *Chironomus*, *Orthocladius*, *Cricotopus*, Hirudinae and Gastropoda. Densities in benthos were log-transformed as $\ln(x+1)$ where x is density of the selected taxa. Log transformed densities and hydraulic data were normalized between 0.0–1.0. All analyses were carried out by using the MVSP (Multi Variate Statistical Package) software, which was available on the internet at “<http://www.kovcomp.com/mvsp/index.html>”.

RESULTS AND DISCUSSION

Characterization of sampling sites

Values of BOD (Biochemical Oxygen Demand) measured during the survey period were in the range of 2.7–9.3 mg/L (Table 2). These values were generally matched to α -meso saprobity (Sládeček, 1979). Biological indicators were also correspondingly low. The index of BMWP (Biological Monitoring Working Party; Hellawell, 1986) was in the lower range of 3–43 (Kwak, 2001). Nitrate and COD levels in the water were relatively high, probably originated from the agricultural runoff and the urban sewage produced in the watershed area. However, the stream was fairly well oxygenated throughout the year with dissolved oxygen mostly exceeding 8 mg/L.

Although general environmental condition was similar in the survey area (Table 2), hydraulic parameters at each sample site appeared to be diverse according to location (Table 3). Water was deeper in Area II (13.35–17.90 cm) and Area I (11.99–14.15 cm) in the straight zone, while shallow at the pool Area IV (6.40–8.53 cm). Velocity was correspondingly higher at the straight zone in Area I (22.59–31.77 cm/s) and Area II

Table 2. Physico-chemical measurements at the Hakyoul reach in the Yangjae stream, Han River, from March 1996 to October 1997¹⁾.

	Mean	SD ²⁾	n ³⁾	Range
Water temperature (°C)	15.8	10.0	34	0.7–33.7
pH	7.5	0.5	34	6.1–8.6
Conductivity (mm/cm)	410.0	74.0	34	260.0–540.0
Alkalinity (mg/L)	88.0	29.0	32	26.0–142.0
Dissolved oxygen (mg/L)	10.0	2.8	34	5.7–14.2
BOD (mg/L)	5.2	1.8	34	2.7–9.3
COD (mg/L)	9.4	2.4	34	3.6–12.7
NO ₃ -Nitrogen (mg/L)	2.9	0.9	32	1.3–4.9
NH ₄ -Nitrogen (mg/L)	4.1	1.6	31	0.2–6.2

¹⁾ The data are obtained from the second report (KICT, 1997).

²⁾ SD; standard deviation

³⁾ n; number of samples

(21.59–30.65 cm/s), while slow in Area IV (13.14–18.02 cm/s). In Area III at the outer concave bank (Fig. 1) water was relatively shallower than Area I and Area II, while deeper than Area IV. Water velocity in Area III was similar to Area IV, while slower than in the straight zone.

Roughness (K) was highest in Area I (2.44–3.10), while mostly low at the other sites in the range of 1.48–2.12 (Table 3). Especially at JHA in Area I, where substrates in larger size were artificially planted through the restoration project as mentioned before, roughness was highest with $K = 3.10$. Although located in the straight zone, the sites of JHH and JHJ in down-stream showed relatively lower roughness (1.50). The

sample sites in Area III and Area IV also showed lower values of roughness (1.48–1.77).

Froude numbers (Fr) (Equation 1) showed a narrow range of 0.16–0.28. The values were relatively higher in Area I while JHH showed the lowest value with 0.16. In contrast, Reynold numbers (Re), which were represented by multiplication of water velocity and depth (Equation 2), varied widely depending upon location of the sample sites. At the straight Area I and Area II, Reynold numbers were high (31043–48882), while the values were lowest at the curved Area IV (9600–17924) followed by Area III (29308–33736). The shear velocities (U^*) (Equation 3) showed the similar trend with the Reynold numbers, but with less variation: high at the straight Area I (2.47–3.22 cm/s) and Area II (1.79–2.95 cm/s) while low in Area III (1.98–2.16 cm/s) and Area IV (1.45–1.93 cm/s). Viscous sublayer thickness (VST) appeared in the reverse manner: high in Area IV (0.08–0.10 cm) and Area III (0.07–0.08 cm) while low in Area I (0.04–0.06 cm) (equation 4). Substrates diversities (H) were relatively invariable, slightly higher in Area I (0.81–0.87) than in the other areas (0.71–0.82). Values in substrate diversity were also consistent with values of Roughness (K).

Sediment organic matter (SOM) was accumulated highly in Area III and Area IV (3.66–5.82 mg/100 mL), especially high at JHE (5.82 mg/100 mL). In Area I, sediment organic matter was relatively low with 2.46–3.83 mg/100 mL. At JHA

Table 3. Averages in hydraulic measurements at different sample sites at the Hakyoul reach in Yangjae stream, Han River, from April 1996 to March 1998 (Methods of measurements are listed in the text.).

Area	Sites	D	U	K	Fr	Re	U*	VST	H	SOM
Area I	JHU	13.83	31.77	2.75	0.28	47799	3.22	0.04	0.87	2.60
	JHA	11.99	22.59	3.10	0.21	31043	2.47	0.06	0.87	3.83
	JHB	14.15	30.87	2.44	0.26	48882	3.02	0.05	0.81	2.46
Area II	JHH	17.90	21.59	1.50	0.16	46683	1.79	0.09	0.73	2.94
	JHI	13.35	30.65	2.12	0.27	45160	2.95	0.05	0.82	2.68
	JHJ	17.67	24.29	1.50	0.19	46677	2.04	0.07	0.73	2.68
Area III	JHC	10.97	21.08	1.52	0.21	29308	1.98	0.08	0.71	3.83
	JHD	11.68	22.55	1.77	0.22	33736	2.16	0.07	0.76	4.42
Area IV	JHE	8.53	18.02	1.48	0.20	17924	1.76	0.08	0.75	5.82
	JHF	7.55	18.01	1.76	0.22	15824	1.93	0.08	0.79	4.23
	JHG	6.40	13.14	1.58	0.18	9600	1.45	0.10	0.73	3.66
	Sum	134.06	254.27	21.70	2.39	372638	24.75	0.76	8.57	39.15
	Mean	12.19	23.14	1.97	0.22	33876	2.25	0.07	0.78	3.56
	SD	3.76	5.93	0.56	0.04	14397	0.58	0.02	0.06	1.03
	CV	0.31	0.26	0.28	0.18	0.42	0.26	0.25	0.07	0.29

D; Depth (cm), U; Velocity (cm/s), K; Roughness, Fr; Froude number, Re; Reynold number, U*; Shear velocity (cm/s), VST; Viscous sublayer thickness (cm), H; Substrate diversity, SOM; Sediment Organic Matter (mg/100 mL)

where large substrates were artificially planted, however, sediment organic matter was higher with 3.83 mg/100 mL compared with the nearby site JHH with 2.94 mg/100 mL.

Large substrates occurred abundantly at the straight Area I in upstream (Fig. 2(a)), most highly collected at JHA followed by JHU and JHB, while small substrates were abundantly present at the other sample areas. Considering substrates smaller than 8 mm (Fig. 2(b)), substrates ranging 0.062–0.5 mm were present abundantly at all sites and appeared to be in different patterns according to location (Fig. 2(a)). Substrates in 0.062–0.5 mm were most highly accumulated in Area III at the outer concave bank followed by Area IV at the pool zone: distinctively high at 'JHC, JHD and JHE' followed by 'JHF and JHG'. While substrate larger than 8 mm were relatively more present in JHD compared with JHC, substrates in 0.062–0.5 mm were equally present between JHC and JHD. At JHI, in contrast, substrates in these sizes less occurred (Fig. 2(b)), although substrates less than 8 mm were dominantly collected (Fig. 2(a)). The reason why distribution pattern is different in smaller sizes is unknown for the present time. However, the location of the sample sites and water velocity appeared to play an important role in determining sedimentation of smaller substrates. JHE in Area IV and additionally JHC and JHD at Area III are located at the pool zone and at the outer concave bank respectively, and are consequently good positions to receive water current (Fig. 1). Water velocity was also

lower (Table 3), and sedimentation would occur with a higher chance at these sample sites.

Invertebrate community structure

Due to organic pollution, species richness appeared to be low, and 10–20 species were collected during the survey period (Table 4). Oligochaeta, mainly consisting of *Limnodrilus* and *Tubifex*, was distinctively dominant, making up 70–91% of relative abundance in total (Fig. 3). The second dominant taxon was genus *Chironomus*, occupying 8–17% of the total abundance.

Although species richness was generally low, densities in the collected taxa were characteristically different at different sample sites (Table 4). Specimens were most abundantly collected in Area IV at the pool zone with low species richness. In contrast, total densities were low at JHB, JHI and JHJ in the straight areas. In Area III at the outer concave bank benthic macro-invertebrates were also more abundantly collected, compared with those in the sample sites in the straight area. As previously mentioned this may be due to the fact that the outer concave bank was located in the position of receiving water flow, and consequently benthic macro-invertebrates may be more frequently drifted to this area. But this needs further confirmation.

Densities at the sample sites of JHH were also higher compared with the other sample sites located in the straight area (Table 4). This may be due to hydraulic characters of JHH. JHH was located at the edge area and showed lower water

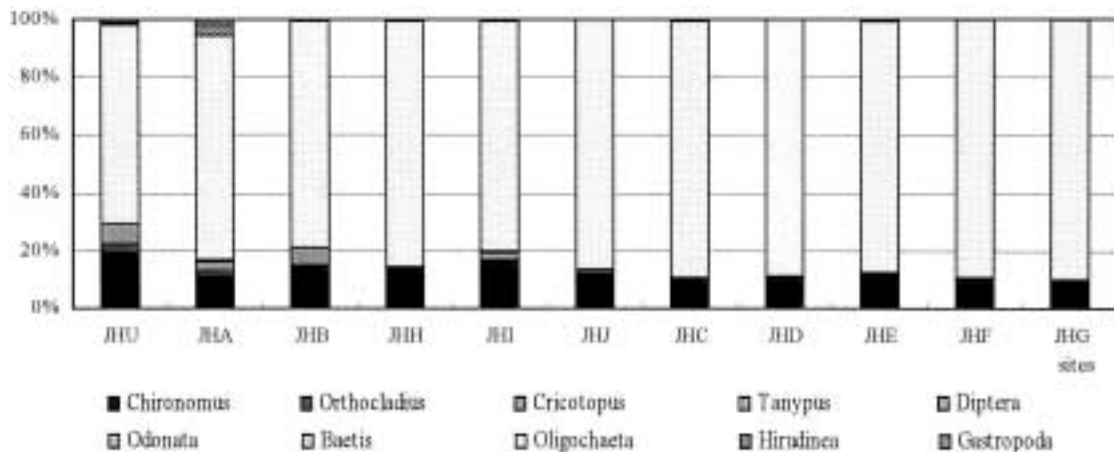


Fig. 3. Mean relative abundance (%) of the selected taxa of benthic macro-invertebrates collected at the sample sites of the Hakyaeoul Reach in the Yangjae stream, Han River, collected monthly from April 1996 to March 1998.

Table 4. Mean density (indi/m²) of selected taxa, and species richness, and diversity indices of benthic macro-invertebrates sampled monthly at the sample sites at the Hakyoul reach in Yangjae stream, Han River, from April 1996 to March 1998.

Area Sites	Area I			Area II			Area III		Area IV		
	JHU	JHA	JHB	JHH	JHI	JHJ	JHC	JHD	JHE	JHF	JHG
<i>Chironomus</i>	671	429	272	571	294	240	507	612	835	536	601
<i>Orthocladius</i>	73	19	2	8	1	13	13	1	17	4	
<i>Cricotopus</i>	246	115	110	33	57	18	21	41	10	17	2
<i>Tanytus</i>	4	5	1	2	0	0	2	0	0	1	0
Diptera	0	2	0	0	0	0	2	0	0	1	1
<i>Odonata</i>	0	3	0	1	0	0	1	1	1	1	0
Baetis	2	3	1	0	0	0	1	5	0	0	0
Oligochaeta	2433	2949	1508	3705	1469	1643	4463	5207	6058	4976	5354
Hirudinea	19	142	7	17	4	4	23	5	16	3	2
Gastropoda	40	74	2	5	4	1	9	10	20	7	2
Richness	15	20	11	16	12	11	15	15	15	15	10
Diversity (H')	0.97	1.03	0.64	0.52	0.58	0.45	0.55	0.53	0.48	0.43	0.41
Total density (indi/m ²)	3525	3795	1920	4335	1837	1907	5042	5895	6942	5560	5966

velocity compared with JHB and JHI. In contrast, JHB and JHI were low in densities (Table 4). These sample sites were not in the place of receiving water current and their water velocity was relatively high. JHI was also distributed frequently due to the restoration project conducted at the area near JHF. The low density in *Chironomus* in JHJ located at the end point of the survey area in downstream (Fig. 1) may be partly due to its location; drifting invertebrates may be landed in Area IV at the pool zone before they reach JHJ.

Species richness was higher (11–20) in Area I at the straight zone than in the other areas (10–16) (Table 4). Especially species richness was distinctly high at JHA where large substrates were abundantly present. At JHA roughness and viscous sublayer thickness were correspondingly high. Additionally sediment organic matter was highly accumulated at JHA. This revealed the effects of transplanting large substrates in the restoration project as mentioned previously. Diverse Chironomids including *Orthocladius*, *Cricotopus* and *Tanytus* were additionally collected in Area I, especially at JHA and JHU. Genus, such as *Baetis*, *Orthocladius* and *Cricotopus* are indicators for partial recovery of water quality (Ferringto and Crisp, 1989). *Chironomus flaviplumus* and other taxa including Hirudinea and Gastropoda were more abundantly collected at JHA. This was clearly contrasted with low

diversity observed at the nearby site JHH (Table 4, Fig. 3), where the restoration project was not conducted. This indicated that the artificial planting of stones could provide refugia for benthos and consequently could be utilized for monitoring.

Relative abundance patterns of the selected taxa were also different at different sample sites (Fig. 3). Dominant taxa, Oligochaeta were especially abundant in Area IV (86.62–90.71%) followed by Area III (83.84–87.63%), while less abundantly collected in Area I (69.55–81.42%). At JHJ relative abundance of Oligochaetes were exceptionally high with 87.67% among the sample sites in the straight area. The fact that lowest number of Oligochaeta was collected in Area I may be related to environmental conditions. Environmental factors such as high water velocity and large substrates composition are in general not favourable to Oligochaeta (Brinkharst, 1971).

Chironomids, the second dominant group, tended to be more abundant in Area I (11.00–16.57%) than in Area III (9.31–13.52%) in contrast with the case of Oligochaeta. Chironomids further showed different abundance patterns among different sample sites in Area I and II at the straight zone (Fig. 4). *Orthocladius* was collected in higher densities at JHU and JHA in Area I, however, it was not much present at JHB. *Cricotopus* occurred more abundantly collected at JHU, JHA and JHB in the straight area, where

substrate diversity appeared to be high (Table 4).

The sites, JHC and JHD in Area III at the outer concaved bank and additionally JHE in Area III at the pool zone were favourable to sedimentation processing and consequently showed high amount of small substrate with low substrate diversity (Table 3 and Fig. 2). Thus this condition was preferred by burrowing types such as *Oligochaeta* (Fig. 3). Although located closely, community composition was also contrasted between JHC and JHD. While Hirudinea were more abundantly present at JHC, *Cricotopus* and *Baetis* were collected in higher densities at JHD (Table 4 and Fig. 3). The differences in Hirudinea, Gastropoda and species richness were observed between JHU and JHB. This may be due to the sampling method. While macro-invertebrates were collected longitudinally at JHB, the samples were collected transversely for the case of JHU (Fig. 1).

Principle component analysis (PCA)

As PCA was conducted on environmental factors (Eigenvalues: Axis I; 6.070 (67.45%), Axis II; 1.965 (21.83%)) (Fig. 4), SOM and *VST* were located against the other groups of hydraulic variables along the Axis I (Fig. 4(a)). On the positive side of the Axis I, *U* and U^* were highly associated. Also *H*, *K* and *Fr* were grouped and were located in opposite to the group of *Re* and *D*. On the positive side of the Axis II, SOM was

located in opposite to *VST* on the negative side. As compared with sample sites (Fig. 4(b)), JHB, JHI and JHU tended to be associated with U^* and *U*. JHA was located relatively apart from the other sites of Area I on the positive side (Fig. 4(b)), and tended to be associated with *H*, *K* and *Fr* (Fig. 4(a)). Although the degree was not strong, JHF was located in the similar area in the PCA where SOM was placed, while JHC was located in the position related to *VST*.

When the data of taxa were analyzed with the PCA, the group of *Orthocladius*, *Cricotopus*, Hirudinea and Gastropoda were located closely on the positive side of the Axis I (Eigenvalues: Axis I; 2.818 (46.97%), Axis II; 2.294 (38.23%)) (Fig. 5(a)). Chironomids in this group were indicators of partial water recovery (Ferringto and Crisp 1989). On the negative side of the Axis II, *Oligochaeta* and *Chironomus* were located closely (Fig. 5(b)). The sample site of JHE tended to be associated with *Oligochaeta* and *Chironomus*. In contrast JHU and JHA were more closely related to the group of species indicating water recovery (Figs. 4(a) and 4(b)).

Considering Figs. 4(a) and 4(b) together the sample sites located in the straight area (Area I and Area II) appeared more strongly related to water velocity and shear velocity. Similarly JHA and JHU in the straight area strongly associated the group of diverse taxa including species indicating water recovery such as *Orthocladius* and *Cricotopus* (Figs 5(a) and 5(b)). Especially, it is

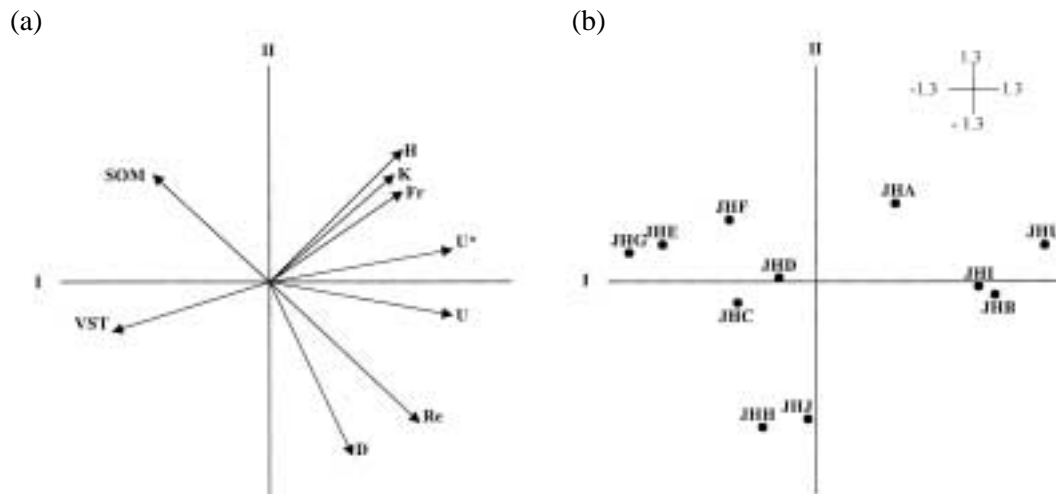


Fig. 4. Principle component analysis on average values of hydraulic measurement at eleven sample sites at the Hakyеoul reach in Yangjae stream, Han River, from April 1996 to March 1998. a) Hydraulic measurements and b) Sample sites. (Eigenvalues: Axis I; 6.070 (67.45%), Axis II; 1.965 (21.83%))

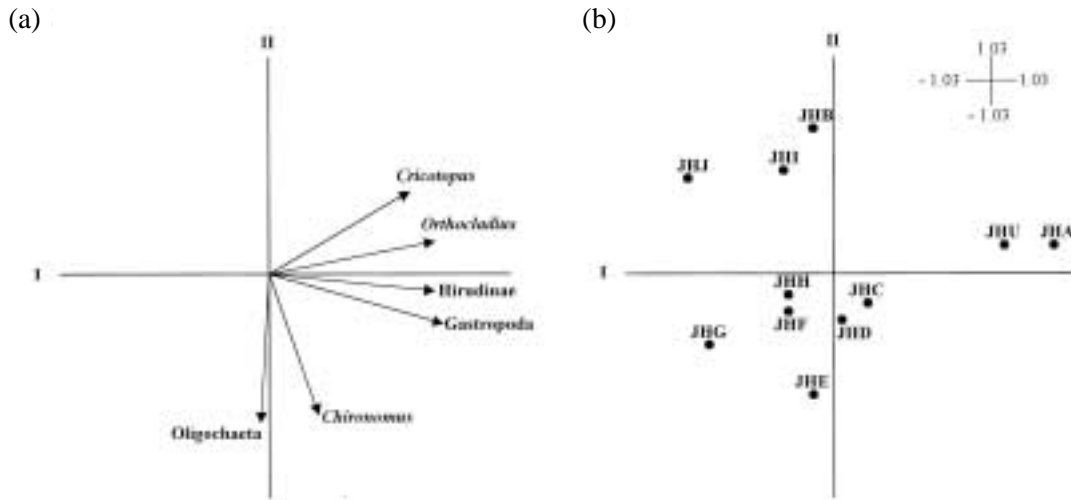


Fig. 5. Principle component analysis on densities (individuals per square meter plus 1) benthic macro-invertebrate communities collected at the Hakyoul reach in Yangjae stream, Han River, from April 1996 to March 1998. a) Selected taxa and b) sample sites. (Eigenvalues: Axis I; 2.818 (46.97%), Axis II; 2.294 (38.23%))

notable that JHA, where large substrates were artificially transplanted for the project of restoration, was associated with species indicating water recovery. Additionally, the sample site located in Area IV tended to be associated with SOM (Fig. 4), and JHE was located correspondingly to the group of Oligochaeta and *Chironomus* (Fig. 5). However, the degree of association appeared to be not as strong as shown in the case of the sample sites, JHA and JHU associated with U and U^* (Fig. 4) and the taxa such as *Orthocladus*, *Cricotopus*, Hirudinae and Gastropoda (Fig. 5). This indicated that the habitats with large substrates and high velocity in the straight area have higher association with the corresponding taxa mentioned above. In this case, however, we only used average data with 11 sample sites (cases) for the PCA. Thus the number of sample sites exceeds the number of hydraulic characters (9) and the number of taxa (6) used for the analyses. This may not provide efficient grouping on the sample sites (Q-mode). Additionally non-linearity may be resided in the data. Further study is required to verify these associations by increasing the number of sample units as well as by development of analytical tools applicable to non-linear data. Also the detailed description among the sample collected in curvilinear shape in the islets at the pool zone needs to be further investigated, and this will be discussed elsewhere.

CONCLUSION

In small-scale survey in 10 m in distance in a polluted stream, hydraulic parameters and community abundance patterns of benthic macro-invertebrates were differently characterized according to location of sample sites. At the sample sites in the straight zone with high water velocity and large substrates, species richness was relatively higher and species less-tolerant to organic pollution was additionally present. At the sample sites in the pool zone with lower velocity and high sedimentation, species richness was lower and a few tolerant species to organic pollution were abundantly collected. The principle component analysis indicated that the sample sites in the straight zone appeared to be related to water velocity and shear velocity, and correspondingly to diverse taxa less tolerant to organic pollution. Especially the sample site transplanted with large substrates was associated with hydraulic characters such as substrate diversity and roughness, and further related to indicator species for partial recovery of water. Additionally the sample sites located at the pool zone were associated in some degree with sediment organic matter and taxa tolerant to organic pollution such as Oligochaeta and *Chironomus*.

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< 국문적요 >

오염하천 소규모 서식처에서의 저서성 대형 무척추 동물군집과 수리학적 인자의 특성화

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1996년 4월부터 1998년 3월까지 서울의 한강지류 3차 하천인 양재천 200m 구간에서 저서성 대형 무척추동물을 채집하였다. 유기물 오염으로 인해 종풍부도가 상대적으로 낮았지만 군집 풍부도 양상은 조사지점에 따라 다르게 나타났다. 유속이 높고 큰 하상구성물이 많은 직류부 조사지점에서는 종풍부도가 높았고, 유기물오염에 상대적으로 내성이 낮은 종들이 추가적으로 출현하였다. 반대로 유속이 느리고 퇴적이 많이 이루어진 소(pool)에 위치한 조사지점에서는, 종풍부도는 낮았고, 유기오염물에 내성이 강한 수 종이 많이 채집되었다. 중요요인분석에서 직류부의 조사지점은 유속, 마찰유속(shear velocity)과 관련성이 있었고, 유기물오염에 내성이 비교적 낮은 다양한 종들과 연관성을 나타냈다. 특히 큰 하상구성물을 심은 지점은 하상구성물의 다양도나 조도(roughness)와 같은 수리학적(hydraulics) 특징과 관련되었고, 하천의 부분적 회복을 나타내는 종들과 관계가 있었다. 소에 위치하는 조사지점은 하상구성물에 퇴적한 유기물과 유기물오염에 내성이 강한 빈모류나 깔따구류와 연관을 나타내었다.

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