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Macroinvertebrate Community Structure along Environmental Conditions in Ponds of Urban Parks, Korea

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Benthic macroinvertebrates were examined to elucidate community structures of a set of 9 shallow ponds from a total of 6 parks located in Seoul metropolitan area, Korea. The result showed that macroinvertebrates were diverse and abundant, and aquatic macrophyte provide habitat diversities in ponds. The differences among benthic macroinvertebrate community compositions seemed to be attributed to local biotic and abiotic interactions. We surveyed benthic macroinvertebrate, biotic (macrophyte), abiotic (turbidity, nutrient concentrations, conductivity, heavy metal concentration) and morphometric (area, depth) of the lentic systems. Generally, the benthic macroinvertebrates were dominated by *Cloeon dipterum* or *Coenagrion* sp.. Distribution of the aquatic macrophyte community was correlated with the species composition of macroinvertebrates. The result demonstrated a significant and positive relationship between habitat quality and macroinvertebrate composition.

Key words : benthic macroinvertebrate, aquatic macrophyte, heavy metals, urban park, pond, CCA

INTRODUCTION

Macroinvertebrates play an important role in the littoral zone of ponds as well as in running waters. They are often used to evaluate water quality and habitat quality. In recent years, there has been an increased interest in the development of methods for assessing water quality (Lenat, 1988; Barbour *et al.*, 1999; Southerland *et al.*, 2005). The abiotic variables such a habitat shape causes reductions in local species diversity. There have been many researches dealing with interactions between the environmental variables and macroinvertebrate community variables (Vannote *et al.*, 1980; Resh *et al.*, 1988; Cho *et al.*, 2003), and species composition of benthic communities has often been related to water quality (Battegazzore and Renoldi, 1995; Stuijfzand *et al.*, 1998). The occurrence of macrophytes is affected by abiotic conditions such as water quality and sediment properties (Gasith and Gafny, 1998). Biodiversity and functions of biological community are also applied to assess aquatic environment. For examples, functional feeding group measures have been used in biomonitoring approaches such as the "Benthic Index of Biotic Integrity" (Kerans and Karr, 1994).

Despite increasing knowledge of the interaction between physico-chemical variables and macroinvertebrate communities in littoral ponds, there have been few attempts to identify the importance of the degree of neighbor among lentic sites like ponds. Ponds are highly important aquatic environments in urbanized area. A large-scaled spatial approach will tend to reveal differences in ecological integrity among the ponds. A pond of urban region is often compared to an island. The understanding of large-scaled spatial interaction on the urban ponds is very important. The

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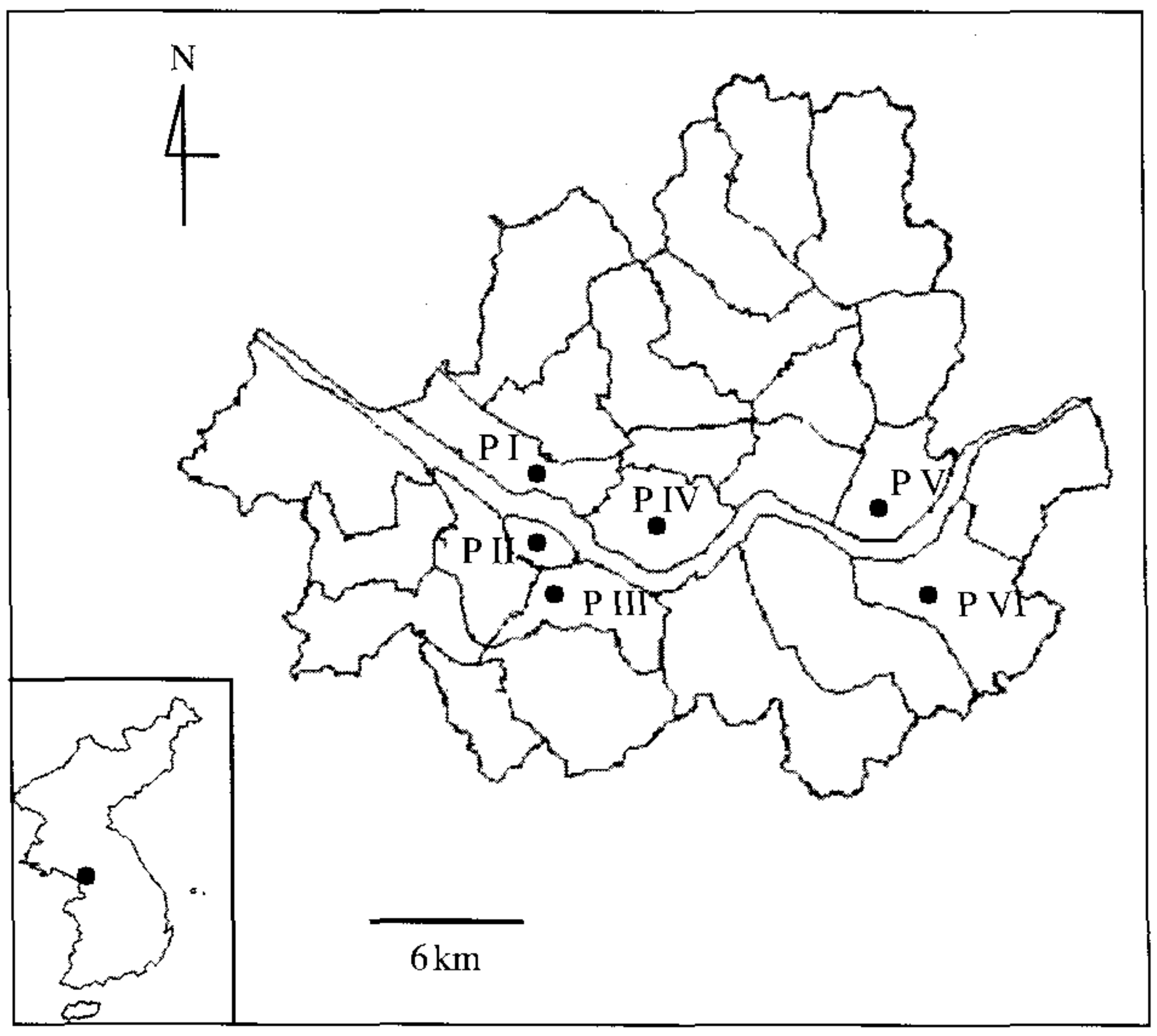

Fig. 1. Map showing the sampling sites in Seoul, Korea.

biodiversity of a community is closely related to the number of potential niches (Heino, 2000). Dispersal mechanisms of invertebrates influence the relationships between species number, community composition and habitat size (Rundle *et al.*, 2002). Dispersal ability also influences their distribution and abundance (Guitierrez and Menendez, 1997).

The evaluation of habitat quality is receiving study in many countries. But, the lack of methods with acceptable levels of precision, accuracy, and compatibility accepted by a scientific community is an obstacle to measuring habitat quality (EPA, 1999). There is an observed pattern of habitat conditions that are necessary to support aquatic communities. Spatial variability can be addressed by grouping similar habitats at different scales.

The goal of this study was to investigate the relative importance of environmental variables and macroinvertebrate community structure in small ponds that are located in urban matrix.

MATERIALS AND METHODS

1. Study sites

The 9 ponds located in 6 urban parks in Seoul, South Korea (37°N, 127°E) were surveyed and sampled (Fig. 1). Seoul is a city of 10,280,000 people and an industrial capital. The region has a temperate climate with a mean annual rainfall of 1,350 mm and a mean annual air temperature of 12.2°C (Ministry of Environment, Korea).

First site (Park I, III, IV, V, and VI) are in a south-west or northern section of the city of Seoul. The second site (Park II) is located along the Han River. The substrate of sites is covered with poorly drained clay or sand soils. Generally, most of studied ponds were artificially excavated for developmental purposes. There are no major human influences in the study sites. The vegetation there is mainly hygrophytes dominating. There is also much areas of hydrophytes occur in the littoral areas. In general, the water of the ponds is slightly eutrophic status.

2. Sampling

From September and October 2005, aquatic macroinvertebrates and macrophytes from all sites were sampled for comparing species richness between the studied ponds. Macroinvertebrates samples were taken in the shallow biotopes near the pond bank. Macroinvertebrates were captured in a 900 μm mesh pond net using the standard 3-min kick sweep technique (ISO, 1985), which was repeated five times in shallow regions, and preserved with 5% formaldehyde and taken back to the laboratory for sorting and identification. Except diptera, most animals were determined at least to genus level.

Taxa were assigned to the 5 different categories of functional feeding groups (FFG): collector-gatherers, collector-filteres, predators, scrapers and shredders after Merritt and Cummins (1996) and Ro and Chun (2004). Vegetation cover was studied between May and October 2005. We classified data three groups of macrophytes: emergent vegetation, submerged macrophytes and species with floating leaves.

3. Physico-Chemical data

The physical and chemical variables (Table 1 and 2) were analysed seasonally during the period of study; pH and conductivity were determined with an YSI 650 MDS meter where the biological samples were being taken. The concentration values of the TSS were determined by the difference in weight of the filter before and after the filtration. Chlorophyll *a* concentrations were measured using the fluorometric method (APHA, 1998). Water samples were also taken and ana-

Table 1. Physical characters (habitats) in the ponds surveyed.

Pond	Area (m^2)	Depth (m)	Bank structure	Bed sediment
Park I	24,500	1	concrete (A)+(N)	pebble+sand
Park II-1	3,532	1	stone (A)	sheet+silt
Park II-2	476	1	stone (A+(N)	sheet+silt
Park II-3	629	1	(N)	sheet+silt
Park III	9,070	1.7	stone (A)	soil
Park IV	6,708	1.2	stone (A)+(N)	soil
Park V-1	4,665	1.5	stone (A)	silt
Park V-2	5,100	0.7	stone (A)+(N)	silt
Park VI	674	0.6	stone (A)+(N)	sheet+pebble

(A): Artificial structure, (N): Natural structure

Table 2. Water quality analysis in the ponds surveyed. The following abbreviations were used: TSS=total suspended solids, TP=total phosphorus concentration, TN=total nitrogen concentration, Chl-*a*=chlorophyll-*a* concentration, DO=dissolved oxygen, Cond=conductivity.

Pond	Turbidity (NTU)	TSS ($mg\ L^{-1}$)	TP ($mg\ L^{-1}$)	TN ($mg\ L^{-1}$)	Chl-*a* ($mg\ m^{-3}$)	pH	DO ($mg\ L^{-1}$)	Cond ($\mu s\ cm^{-1}$)
Park I	10.8	3.6	0.040	1.93	6.1	8.0	10.2	
Park II-1	11.1	10.0	0.053	0.93	9.3	7.9	12.8	348
Park II-2	12.8	20.1	0.251	1.72	11.3	7.9	11.0	411
Park II-3	3.3	4.4	0.279	3.47	14.4	7.9	11.8	462
Park III	13.3	14.1	0.222	0.55	15.2	7.17	10.7	370
Park IV	5.4	4.5	0.039	0.34	7.4	8.0	12.4	253
Park V-1	15.9	24.0	0.060	3.97	14.5	7.5	12.7	392
Park V-2	33.1	19.6	0.164	2.24	59.8	7.7	13.2	350
Park VI	4.1	4.3	0.092	3.29	6.2	8.2	14.6	320

lysed for total phosphates, total nitrates and metals (copper, calcium, magnesium, lead, and iron) using atomic flame spectrophotometry. Pond area calculated from the maximum circumference was used as a measure of size of each pond.

4. Statistical analyses

In order to analyse the relationships between community composition of macroinvertebrates and selected environmental variables, a Canonical Correspondence Analysis (CCA) was investigated by using CANOCO (Ter Braak and Šmilauer, 1998). Canonical correspondense analysis is a direct gradient analysis technique, which assumes an underlying response of the taxa along the environmental variables (Ter Braak and Prentice, 1988).

RESULTS AND DISCUSSION

1. Physico-Chemical characteristics

Most ponds were shallow (mean depth of 1.05 m) and had the clear-water equilibrium state. However, ponds V-1 and V-2 showed more or less eutrophic state. Environmental variables included in the analysis: water body area, depth, water temperature, turbidity, total suspended solid, conductivity, total nitrogen and total phosphorus. Within the certain range in habitat sizes of ponds, there was no significant relationship between the pond area and the number of species ($P = 0.074$). Changes in benthic macroinvertebrates assemblage were related to factors indicating variation in physical habitat, particularly bed sediment (Roy *et al.*, 2003). In the park I, IV, and VI-2, the composition of bed sediment was composed of more diverse and large particles than others. Many macroinvertebrates need large particles and the associated interstitial space for protection from predators, substrate for periphyton food sources, attachment sites for filter feeding and increased oxygen exchange (Wood and Armitage, 1997).

Table 1 shows that the subsurface water temperature varied from 13.2 to 17.8°C. Turbidity was relatively high in parks I, II, III and V compared with the others, and its value tends to be proportional to TSS values. The values of total phosphate and total nitrogen were the highest in park II. Dissolved oxygen concentration varied from 10.2 to 14.6 mg · L^{-1}. Chlorophyll *a* was detected from water column in every pond with the range 4.1 mg · m^{-3} to 59.8 mg · m^{-3}. The average values of pH varied from 7.17 to 8.5. There was no major difference in water pH among each station. DO was not significantly correlated with TSS or nutrients. The large-size ponds were deep, in general, also pond depth was correlated with temperature.

Our study examined the effects of environmental variables on aquatic macroinvertebrates. Physico-chemical factors (Table 1 and 2) were likely to influence aquatic organisms in the studied 9 ponds. Park III showed the lowest species number in aquatic macrophytes. On the other hand, park I and V-2 was indicated high values. This result is due to a pond area or bank structure. The lack of submerged hydrophytes is mainly responsible for the types of bed sediment (Table 4). Artificial sheet is composed of shallow soil layer. In general, main difference among the ponds was seen in area, turbidity, TSS, TP, TN, Chl-*a* and conductivity. Water chemistry and habitat characteristics of a pond can influence the distribution of macroinvertebrates (Smith *et al.*, 2003). Ponds of park II, park III and park V were eutrophic, while the other six ponds were mesotrophic. It was related to the amounts of TP, TN and Chl-*a* in water column. The mean concentrations (mg · L^{-1}) of metals are given in Table 3. The total metal concentrations of Fe, Cu and Mg are in the range of 0.02～2.34, 0.00～0.67, and 0.6～33.8 mg · L^{-1} respectively. The results show that concentrations of heavy metals in ponds of park II were higher than the others (Table 3). High concentrations of Fe and Mg were extracted in ponds of park V.

Table 3. Heavy metals in the ponds surveyed (mg L^{-1}).

Pond	Fe	Cu	Mg
Park I	·	·	·
Park II-1	0.12	0.51	18.0
Park II-2	0.18	0.67	16.7
Park II-3	0.03	0.01	33.8
Park III	1.33	0.00	22.0
Park IV	0.06	0.00	12.2
Park V-1	0.05	0.15	17.8
Park V-2	2.34	0.00	6.5
Park VI	0.07	0.01	7.5

2. Aquatic macrophytes

A total of 80 aquatic macrophytes were found in the investigated ponds (Table 4). Emergent macrophytes showed the highest diversity (17 species) among the hydrophytes, but hygrophytes (56 species) were found in more than 67% of the investigated flora. Aquatic macrophyte communities were primarily located in shallow water region where the depth was less than 1 m depth. The most common species were the emergents *Typha angustifolia*, subemergeds *Hydrilla verticillata* and rooted plants with floating leaves *Nymphoides etragona* var. *angusta* (Table 4).

As expected, the species numbers of macoinvertebrates were positively correlated with the species number of aquatic macrophytes (Fig. 2). There was a positive relationship between the

Table 4. The number of species of aquatic macrophytes investigated at 9 ponds.

Pond	Hydrophyte			Hygrophyte	Total
	Floating hydr'ophyte	Emergent hydrophyte	Submerged hydrophyte		
Park I	2	9		27	38
Park II-1	1	3		16	20
Park II-2	2	6		9	17
Park II-3	6	1		21	28
Park III		1	4	9	14
Park IV	4		1	19	24
Park V-1		3		19	22
Park V-2	4	9		22	35
Park VI	1	6		18	25
Total	5	17	2	56	80

number of macrophyte flora and macroinvertebrates. The distribution of emergent and floating species was correlated with water conductivity and total phosphorus (Khedr and EL-Demerdash, 1997). The ponds of park II and park V showed more diverse macrophyte taxa than the others, possibly affected by high value of the water conductivity and total phosphorus. Macrophytes enhance food availability to macroinvertebrates by retaining organic material, and they also provide refuge from predators (Diehl and Kornijow, 1998). Macroinvertebrates are important as detritus decomposers (McQueen *et al.*, 1986) and occur in the sediment and the water column as well as among submerged plants (Berg *et al.*, 1997).

The metal concentrations of Fe, Cu and Mg were not related to the distribution of macroinvertebrates. Benthic organisms may be directly or indirectly were impacted by metals in water (Kiffney and Clements, 1996). There is no evidence to show that concentrations of Fe, Cu and Mg decrease the quality of water. There is a negative relationship between the studied metal concentrations and the species number of aquatic macrophytes: the plants may remove heavy metals by surface adsorption or absorption plus incorporation into their own system, or store it in a bound form (Tam and Wong, 1997). On the other hand, the species diversity did not showed positive correlation with the concentration of heavy metals and the chemical variables. These aquatic macrophytes did not seem to be particularly sensitive to the measured water quality variables.

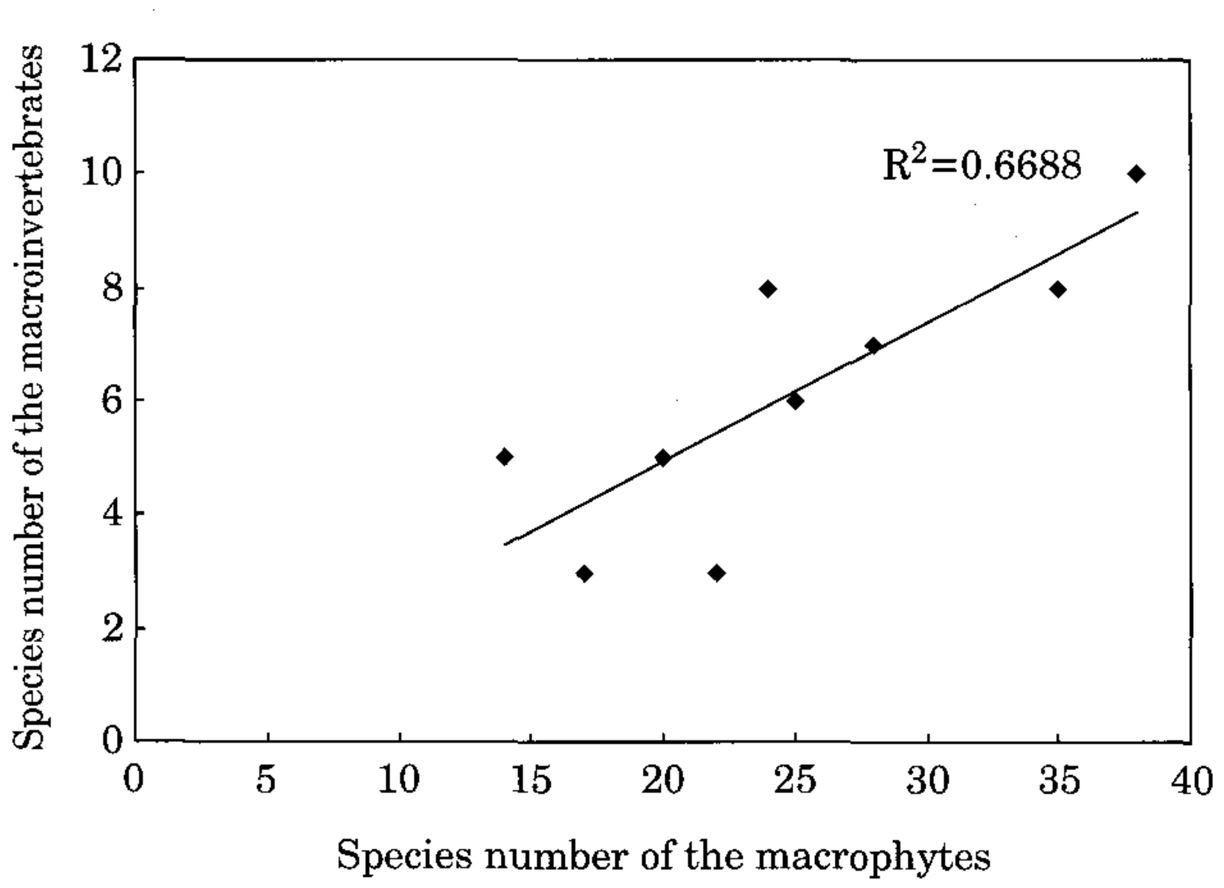

Fig. 2. Regression analysis for the relationship between the species number of macroinvertebrates and the species number of macrophytes.

3. Macroinvertebrates composition

Macroinvertebrate fauna in the studied ponds comprised 4 phyla and 23 species: Ephemeroptera (1 species), Odonata (3 species), Coleoptera (5 species), Hemiptera (3 species) and Diptera (5 species) (Table 5). Of the 23 taxonomic groups identified, aquatic insects represented 73.9% (17 species) of the total number of species collected. The assemblages from the 9 ponds were predominated by *Cloeon dipterum* and *Coenagrion* sp., which were mainly collected in the shallow regions. The *Cloeon dipterum* and *Coenagrion* sp. are characteristic of standing and slow flowing sites and also associated with macrophytes (Nieisen *et al.*, 1999).

Macroinvertebrate were grouped according to their feeding activity. Figure 3 shows the pattern of FFG cumulative composition at each park. Their distribution patterns and FFG composition were not considerable variability at each park. Predators were the most abundant functional feeding group, whereas scrapers were the least commons. Collector-gatherers occupied the second largest portion in benthic groups, comprising 19.5% of the total fauna. Collector-gatherers and predators were found at all sites (Fig. 3). It seems

Table 5. List of benthic macroinvertebrates collected from sampling of the 9 ponds.

Insecta		Gastropoda	Turbellaria	Oligochaeta
Cloeon dipterum	*Noterus japonicus*	*Physa acuta*	*Phagocata kawakatsui*	*Limnodrilus gotoi*
Coenagrion sp.	*Micronecta sedule*	*Gyraulus convexiusculus*		
Cercion calamorum	*Hesperocorixa kolthoffi*	*Radix auricularia coreana*		
Cercion hieroglyphicum	*Sigara substriata*	*Semisulcospira forticosta*		
Orthetrum lineostigma	*Tipula* sp.			
Potamonectes hostilis	Orthocladiinae sp. 1			
Potamonectes sp.	Orthocladiinae sp. 2			
Rhanyus pulverosus	*Chironomus* sp.			
Hyphydrus japonicus				

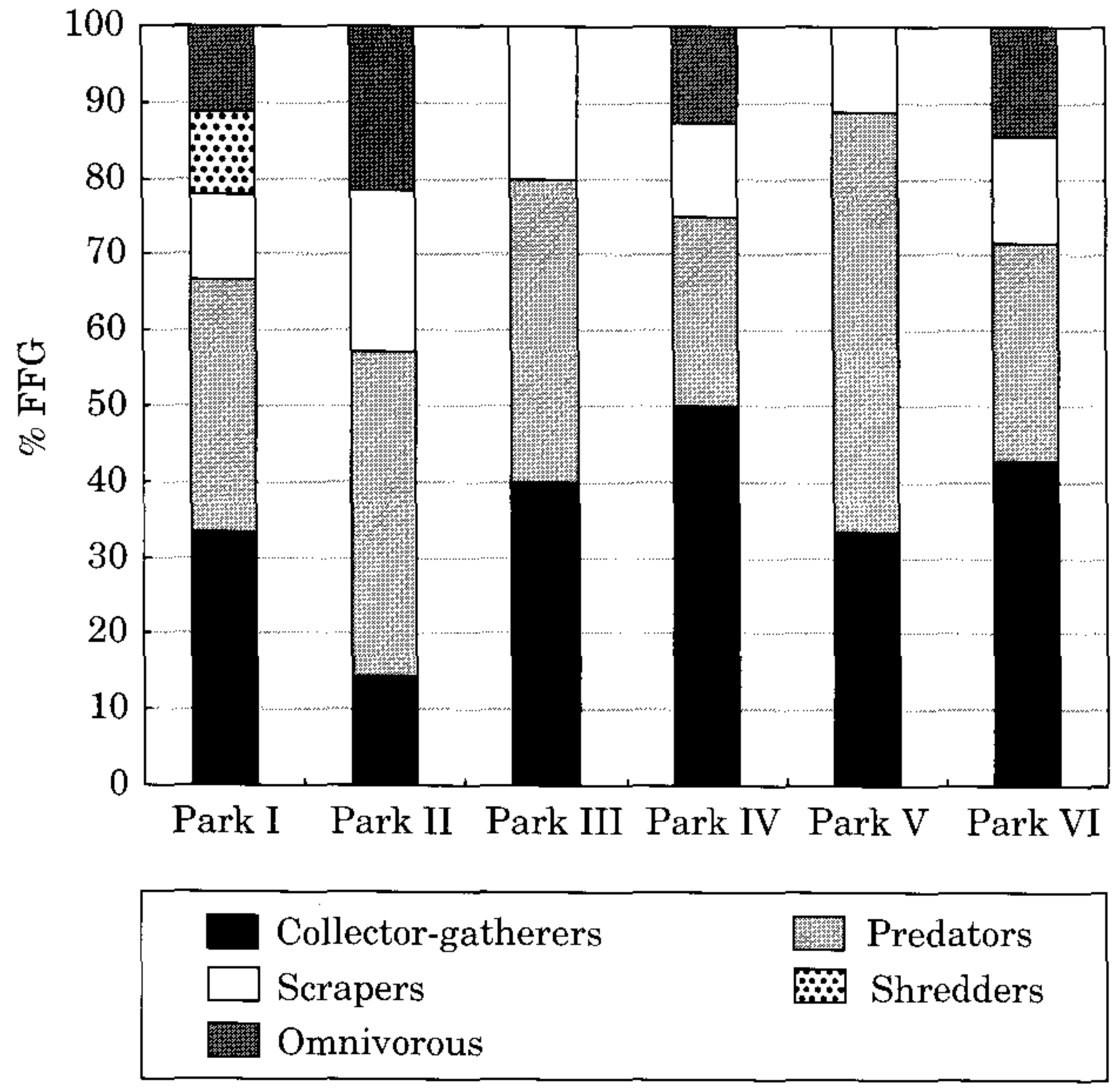

Fig. 3. Distribution of the functional feeding group (FFG) of the macroinvertebrates at 9 ponds on the 6 parks.

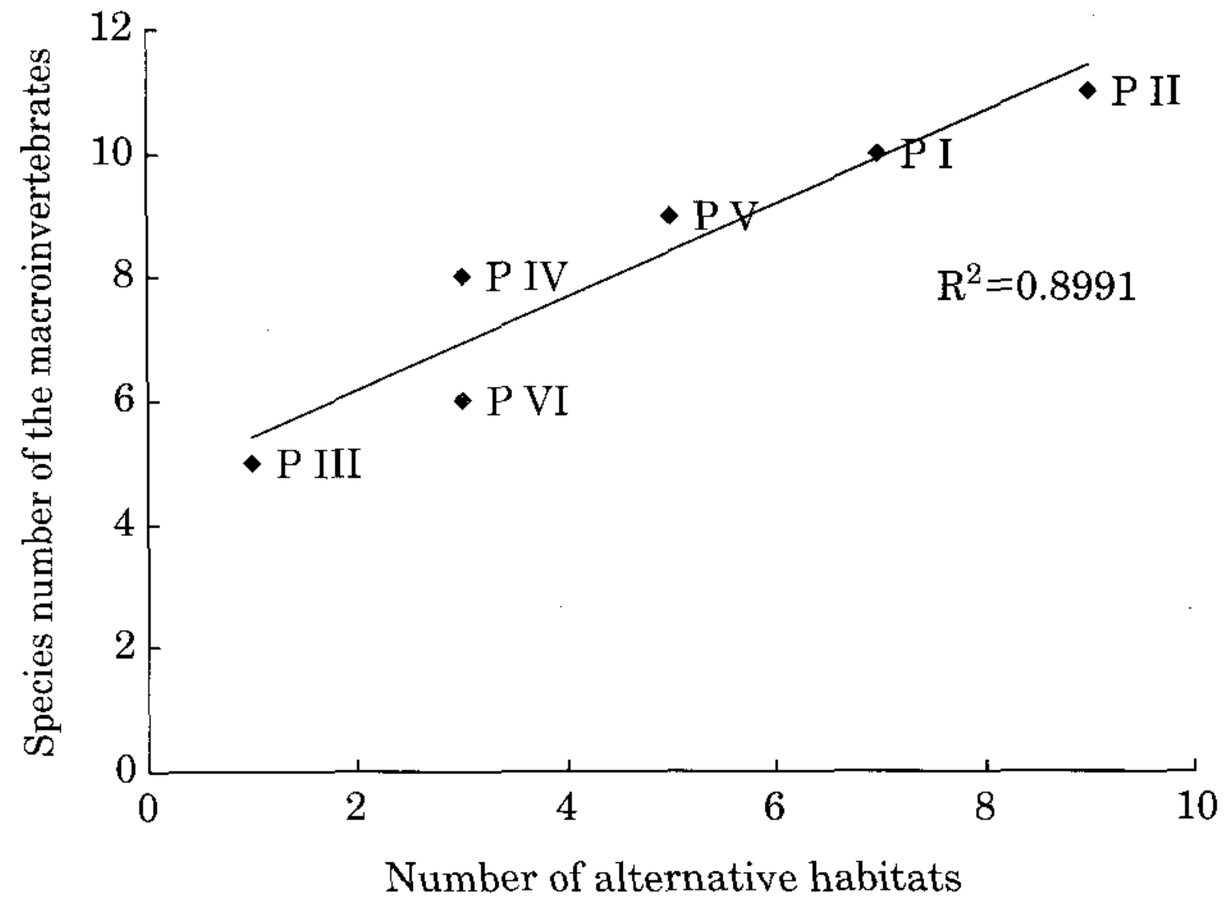

Fig. 4. Relationship between the species number of macroinvertebrates and the number of alternative habitats.

to be associated with abundant detritus and more diverse coleoptera species. The functional feeding group based on a hypothetical particle size range ingested or mode of feeding (Cummins and Klug, 1979). A specific functional feeding group of macroinvertebrates termed 'shredders', primarily larvae of stoneflies and caddisflies, process whole tree leaves to small organic particles through their feeding activities (Cummins and Merritt, 1996). Generally, shredder distribution suggests that it could be related to an environmental filter (Poff, 1997; Heino *et al.*, 2004), although we found a shredder only in the pond within park I. The pond was connected with a small-scale stream, which seems to influence the distribution of FFGs. Ponds or streams with relatively low taxonomic richness of shredders seems to be associated with its urbanization. In fact, our result showed that the ponds were not extremely heterogeneous environments.

4. Proximity

We examined other groups of ponds (area: > 300 m^2) and streams (stream width: >10 m) as alternative habitats within a 2 km radius of the studied ponds. We were not conducted a sampling in the alternative habitats. But, we regarded alternative habitat as a potential dispersal source. The correlation between number of alternative habitats and macroinvertebrate number was significant (r^2=0.8991) (Fig. 4). The examined streams were mainly shallow and stagnant, and that dominant species was investigated as *Cloeon dipterum*.

The process of dispersal is of fundamental ecological importance, influencing community succession (Clobert *et al.*, 2001). Dispersal mechanism is related to the colonization ability and distribution of species (Rundle *et al.*, 2002). Patchily distributed habitats must offer valuable opportunities to species distributions. Most ponds contain active and passive dispersers. For examples, water beetles are considered particularly active dispersers of newly available sites (Fernando, 1958; Fairchild *et al.*, 2000; Rundle *et al.*, 2002). In our study, coleopteran taxa were found at many ponds. Adults of coleoptera are generally mobile and can fly to the adjacent habitats.

As a whole, morphological characterisitics are more reliable predictors for both species diversity and community structure than chemical ones (Mäkelä *et al.*, 2004).

5. Community analyses

Ordination of macroinvertebrate showed a relationship with physico-chemical variables (Fig. 5). A positive correlation was found between nutrients (TP, TN), Chl-*a*, conductivity and DO, whereas pond depth, area and temperature were negatively correlated with DO. The left portion of the diagram shows the warm, deep, oligotrophic

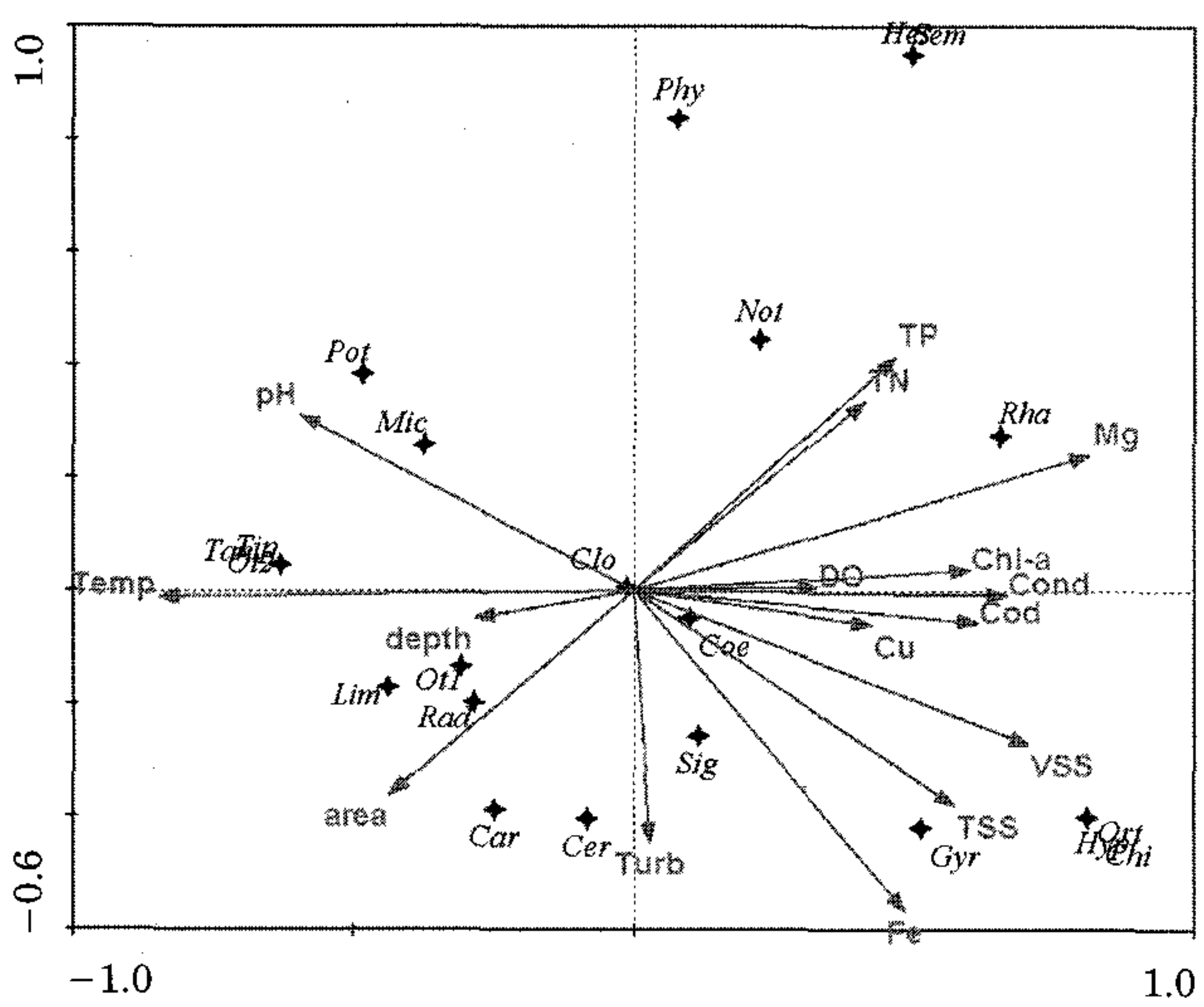

Fig. 5. Ordination diagram based on canonical correspondence analysis (CCA) of macroinvertebrates with respect to environmental variables from 9 ponds. For taxon names see Table 5.

and large ponds characterized by taxa such as *Tipula* sp., Tanypodinae sp., and *Orthocladius* sp. To the right in the diagram taxa such as *Rhantus pulverosus, Hyphydrus japonicus* and *Orthetrum lineostigma* are characteristic of cold, shallow and nutrient rich ponds.

The distinct reduction of macroinvertebrate species number examined in park II-2 and park V-1 probably reflected the fact that the two ponds were disturbed by channelization or cement barriers. The deleterious effects of channelization on the distribution of macroinvertebrates are well known (Pehofer and Sossau, 1995; Jansen *et al.*, 2000). Also, urbanisation reduces infiltration of water through the loss of natural macrophytes cover. However, relatively few studies document the effects of inpond barriers on macroinvertebrates.

Overall, our study has demonstrated that macroinvertebrate community variation in ponds of urban parks was more related to habitat quality than chemical variables. This also demonstrated the important need for conservation of habitat structure and maintaining heterogeneity on macroinvertebrate distribution.

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