Korean J. Ecol. 28(6): 365~373, 2005

The Relationship of Vegetation and Environmental Factors in Wangsuk Stream and Gwarim Reservoir: I. Water Environments

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ABSTRACT: Understanding the relation of water environmental factors and vegetation is critical to restoration and management of wetlands. To reveal relationships between representative plant groups and water environments, we measured cover and abundance of plant species, water depth, temperature, pH, conductivity, dissolved oxygen, NH_4-N, NO_3-N, and PO_4-P concentration in water in Wangsuk stream (WS) and Gwarim reservoir (GR). This study was conducted monthly from May to October, 2004. Six vegetation groups (W1~W6) in WS and five vegetation groups (G1~G5) in GR were identified using TWINSPAN. WS was characterized by *Phragmites japonica*, *Digitaria sanguinalis*, *Phalaris arundinacea*, *Beckmannia syzigachne* and *Persicaria hydropiper*, *Persicaria thunbergii*, *Typha angustifolia*. GR was characterized by *T. angustifolia*, *Scirpus tabernaemontani*, *P. thunbergii*, *Humulus japonicus* and *Scirpus fluviatilis*, *Typha orientalis*, *Zizania latifolia*. The vegetation in WS experienced greater seasonal changes than in GR. A correspondence analysis suggests that water depth was the major environmental factor influencing the distribution of most plants communities in both wetlands.

Key words: CCA analysis, Reservoir, Stream, TWINSPAN, Water environment, Wetland plants

INTRODUCTION

The wetland, which supports many plant species, is an ecotone between aquatic and terrestrial ecosystems. Wetlands have high species diversity and productivity, control flood, reduce erosion and shoreline damage, purify water, and supply ground water (Mitsch and Gosselink 2000). However, most wetlands in the world including Korea would have been destroyed to utilize as agricultural, urban, and industrial lands. Recently, the importance of wetlands has been recognized as a functional unit. Therefore, significant efforts are now being focused on the conservation, restoration, and creation of wetlands (Mitsch and Gosselink 2000, Kim 2003). There are few reports indicating the success of wetland restoration and creation (Mitsch and Gosselink 2000). Most failures came from the lack of knowledge about specific environmental factors required by specific wetland organisms.

The plant communities in wetlands have multiple roles in the functioning of wetlands; they improve water quality, fix the solar energy through photosynthesis, influence the hydrology, and supply oxygen to other biota (Cronk and Fennessy 2001) and the successful establishment of plant community is necessary to restoration and creation of wetlands. Therefore we need to know the detailed knowledge of environmental requirements for plant species and the critical season when environments affect on the distribution of vegetation because vegetation and environment show seasonal changes (Ostendorp 1991, Rea and Ganf 1994).

Although there are many research on the relationship between vegetation and environmental factors in other countries (Spence 1982, Toivonen and Huttunen 1995, Sabbatini *et al* 1998), there have been few studies of the relationship between the distribution of native wetland plants and their environment in Korea (Ri *et al* 1985, Baek *et al* 1997, Cho *et al* 2001).

Our goal is to find the major factor affecting the distribution of vegetation in wetlands in each season. In particular, we focus only on the water environment in this paper (the effect of the soil environment on the distribution of species will be described soon in another paper). Vegetation and environmental factors in the lotic water (Wangsuk stream) might be different from the lentic water (Gwarim reservoir).

The specific objectives of this study are (1) to know representative plant groups and their water environmental characteristics, and (2) to identify the major water environmental factor which determines the distribution of individual plant groups in the reservoir and the stream in each season. This investigation will provide the basic information for conservation, ecological restoration, and creation of wetlands.

METHODS

Study Areas

Two wetlands, Wangsuk stream (WS) and Gwarim reservoir (GR), were selected for this study as a lentic and lotic ecosystem, respectively (Fig. 1). WS (37°37′N, 127°12′E) flows from

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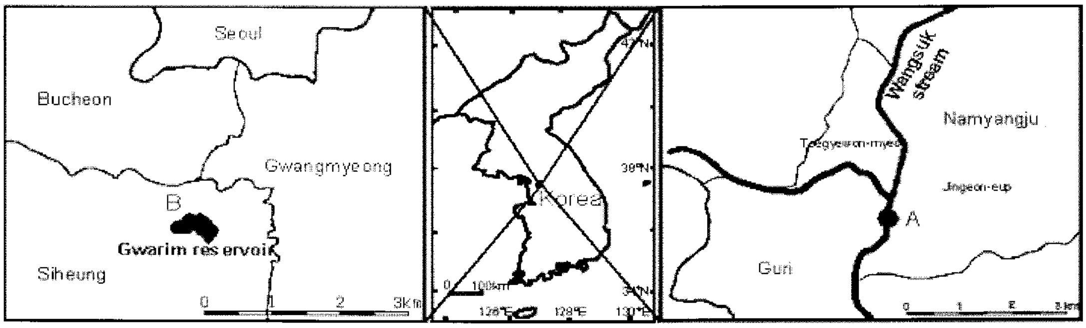

Fig. 1. Study areas. A: Wangsuk stream, B: Gwarim reservoir.

Pocheon-Gun, Gyeonggi Province to Han river via Guri City and Namyangju City. The drainage area of WS is 276.6km^2 and the length of river channel is 37km. The average width of this drainage basin is 7.47km. The study sites were located between the midstream and the downstream that come in contact with Namyangju City. GR (39°19′ N, 126°44′ E) is located in Siheung City. The drainage area of GR is 0.1km^2. There were 8 puddles in the western side of GR, and our study was conducted at these puddles. WS and GR were adjacent to the agricultural field, and used for a fishing. Therefore they were influenced by agricultural chemicals, wastewater, and other wastes.

The annual mean temperature in Gyeonggi Province is 12.9℃. The monthly mean temperature in the wetland is 19.7℃ in spring (May~June), 25℃ in summer (July~August), and 18℃ in autumn (September~October). The annual precipitation ranged from 1,300 mm to 1,500mm (Fig. 2). Forty percent of the annual precipitation falls between July and August (K.M.A 2004). Distances from weather station to the study sites of WS and GR are 47.69km and 14.85 km, respectively.

Vegetation Survey

Vegetation is investigated once a month from 7 May to 31 October 2004 in WS and GR. Permanent line-transects were established at the sites where the representative vegetation grows in a riparian zone of WS and lake shoreline of GR; they were established to the direction perpendicular to the shoreline. We decided the starting point of a transect where submerged plants exist and the ending point where wetland herbaceous plants begin to disappear, i.e., bank. There were two 40m and three 15m line- transects in WS, and two 10m and four 25m line transects in GR. Eighteen permanent 1m×1m quadrats were set up in representative vegetation along line-transects of each wetland. Percentage cover and abundance of plant species were measured in the quadrat (the abundance of plant species means the number of individual plant belonging to the species in each quadrat). A shoot number in the quadrat was regarded as the abundance in the case of grasses, sedges etc. Taxonomic nomenclature followed Lee (2003). Each vegetation data were grouped into May-June (spring), July-August (summer), September-October (autumn).

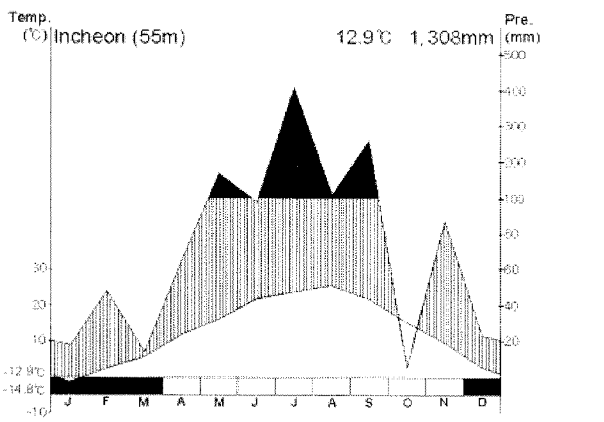

Fig. 2. Climate diagram of Incheon in Korea near the study area.

Water Characteristics

The measurements of water environment variables were conducted in every quadrat where vegetation was investigated. We measured twice a month the water depth (WD) between water surface and soil surface, and monthly water temperature (WTem; Testo 110), pH (Fisher AP 63), dissolved oxygen concentration (DO; Corning checkmate Ⅱ), and conductivity (Con; Corning checkmate Ⅱ) near the water surface (nominal depth=20cm) of water in the middle of the quadrat. Water depth below soil surface was measured after digging a hole and allowed water to be refilled there; when the depth is too deep to measure, we estimated it using the elevation, the slope at the quadrat, and distance from the starting point of the transect. Negative value of the water depth means the depth of standing water below the ground surface. We collected the undistributed water samples near the water surface for analysis of nutrients (NH_4-N, NO_3-N, and PO_4-P). However, we used the refilled water after digging a hole, when the water depth was negative. After water samples were carried immediately to the laboratory, the samples were filtered through a membrane filter (pore size 0.45 μm). Thereafter, NH_4-N was analyzed with Indophenol method (Solorzano 1969, Liddicoat *et al.* 1975), NO_3-N with Hydrazine Method (Kamphake *et al.* 1967), and PO_4-P with Ascorbic Acid Reduction Method (Murphy and Riley 1962).

Data Analyses

Importance values (I.V.) of plants were calculated based on the relative cover and the relative density. Two-way indicator species analysis (TWINSPAN) was used to classify vegetation, based on species importance values (Hill 1979). Each environmental factor was averaged in each clustering group, and the result was compared between groups using *post hoc* Tukey's HSD tests where the significant difference between groups was determined by ANOVA (SPSS 12.0). To investigate the relationship between vegetation and water environmental factors, we performed a canonical correspondence analysis (CCA) using CANOCO version 4.5 (microcomputer power). CCA is the method to arrange species along environmental variables (Ter Braak and Smilauer 2002). The data of all variables used in the analysis were used without any transformation. This ordination technique was used to detect the relationship between environmental variables and the distribution of plant species. An unrestricted Monte Carlo permutation test was used to evaluate the statistical validity of resulting environmental axes. CCA produces an ordination diagram on which points represent species, and vectors represent environmental variables. Vectors with lengths proportional to their importance and directions show their correlations with each axis. Input data matrix of the vegetation consisted of importance values of each species, and environmental data matrix consisted of water depth, pH, dissolved oxygen, water temperature, conductivity, NH_4-N, NO_3-N, and PO_4-P. The *t*-values of each environmental variable are compared with Student t-distribution to infer the significance of environmental factors (Jongman *et al.* 1987).

RESULTS AND DISCUSSION

Vegetation Classification

Seventy seven species from 25 families and 61 genera were found in WS and thirty seven species from 21 families and 31 genera were recorded in GR (Table 1). There were 24 emergent plants in WS and 14 emergent plants in GR. One submerged and one floating species were found only in GR.

Based on the cluster analysis, six vegetation groups (W1~W6) in WS and five vegetation groups (G1~G5) in GR were recognized (Fig. 3). In particular the groups G1, W5 and W6 were composed of only one species of helophyte.

Group W1 was dominated by *Artemisia princeps* var. *orientalis*, *Trifolium repens*, *Phragmites japonica*, and *Setaria viridis*. Group W2 was represented by the dominance of *Digitaria sanguinalis*, and *Equisetum arvense*, *Alopecurus aequalis* var. *amurensis*, *Potentilla paradoxa* and *Phragmites communis* were also common. In group W3, *Phalaris arundinacea*, and *Panicum bisulcatum* were common. Group W4 was dominated by *Beckmannia syzigachne*, *Scirpus tabernaemontani*, *Echinochloa crus-galli* var. *oryzicola*, and *Persicaria hydropiper*. Group W5 was represented by the predominance of *Persicaria thunbergii*. Finally, group W6 was composed of *Typha angustifolia* only. The composition of the dominant species had greatly changed seasonally in WS. *Artemisia princeps* var. *orientalis*, *P. thunbergii* and *T. angustifolia* were constantly dominated in WS. On the other hand, *A. tsukushiense* var. *transiens*, *B. japonicus*, and *B. syzigachne* were dominated only in spring. *Digitaria sanguinalis* and *P. bisulcatum* were dominated only in autumn. *Phalaris arundinacea* and *P. japonica* were dominated from spring to summer. *Echinochloa crus-galli* var. *oryzicola*, *P. hydropiper*, and *S. tabernaemontani* were dominated from summer to autumn. The vegetation in WS was experienced greater seasonal changes than in GR.

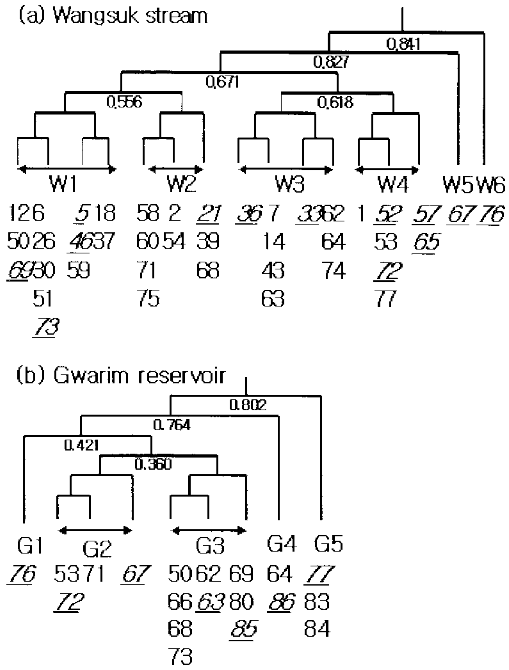

Fig. 3. Dendrograms indicating vegetation groups determined by TWINSPAN. Eigen values and species for each group are shown. For species number, see Table 1. (a) W1~W6, (b) G1~G5 are the vegetation groups. The numbers below vegetation group names represent co-occurred species. The dominant species in each vegetation group are designated with underline.

Group G1 was characterized by monotypic stand of *T. angustifolia* like group W6. Group G2 was dominated by *S. tabernae-*

Table 1. A list of species occurred in the study sites (a) Wangsuk stream, (b) Gwarim reservoir

No.	Scientific name	I. V. (%)		No.	Scientific name	I. V. (%)	
		(a)	(b)			(a)	(b)
1	*Aeschynomene indica*	4.9		44	*Stellaria media*	2.6	
2	*Alopecurus aequalis* var. *amurensis*	7.3		45	*Taraxacum officinale*	2.0	
3	*Aneilema keisak*	45.2		46	*Trifolium repens*	30.9	
4	*Artemisia capillaris*	1.4		47	*Veronica persica*	19.8	
5	*Artemisia princeps* var. *orientalis*	25.4		48	*Veronica undulata*	6.0	
6	*Artemisia selengensis*	20.9		49	*Xanthium strumarium*	3.1	
7	*Arenaria serpyllifolia*	9.2		50	*Agropyron tsukushiense* var. *transiens*	21.3	27.9
8	*Aster pilosus*	6.5		51	*Ambrosia artemisiifolia* var. *elatior*	4.1	1.8
9	*aster sululatus*	4.6		52	*Beckmannia syzigachne*	26.6	8.5
10	*Bidens tripartita*	5.3		53	*Bidens frondosa*	12.2	10.1
11	*Boehmeria nivea*	1.4		54	*Cardamine flexuosa*	3.2	0.7
12	*Bromus japonicus*	14.8		55	*Chelidonium majus* var. *asiaticum*	3.8	46.8
13	*Capsella bursa-pastoris*	2.7		56	*Commelina communis*	20.7	0.5
14	*Carex neurocarpa*	5.3		57	*Echinochloa crus-galli* var. *oryzicola*	35.8	3.4
15	*Cerastium holosteoides* var. *hallaisanense*	1.8		58	*Equisetum arvense*	17.4	4.5
16	*Centipeda minima*	3.5		59	*Erigeron annuus*	3.0	2.3
17	*Chenopodium album* var. *centrorubrum*	1.0		60	*Erigeron canadensis*	5.6	1.5
18	*Cyperus amuricus*	17.6		61	*Galium spurium*	1.6	17.3
19	*Cyperus pacificus*	4.6		62	*Glycine soja*	8.9	9.7
20	*Cyperus sanguinolentus*	13.3		63	*Humulus japonicus*	5.8	11.4
21	*Digitaria sanguinalis*	39.3		64	*Oenanthe javanica*	30.2	9.3
22	*Echinochloa crus-galli*	3.3		65	*Persicaria hydropiper*	20.0	1.1
23	*Eleusine indica*	21.7		66	*Persicaria perfoliata*	1.3	33.4
24	*Galinsoga ciliata*	1.4		67	*Persicaria thunbergii*	33.8	35.9
25	*Hemistepta lyrata*	5.9		68	*Phragmites communis*	21.8	29.7
26	*Lepidium apetalum*	5.5		69	*Phragmites japonica*	32.3	19.7
27	*Leonurus sibiricus*	4.5		70	*Ranunculus sceleratus*	5.0	5.5
28	*Mazus japonicus*	1.9		71	*Rumex crispus*	2.8	7.0
29	*Mentha arvensis* var. *piperascens*	13.1		72	*Scirpus tabernaemontani*	43.5	70.2
30	*Miscanthus sacchariflorus*	35.1		73	*Setaria viridis*	34.3	45.4
31	*Mosla punctulata*	8.4		74	*Stellaria aquatica*	8.3	7.0
32	*Oenothera odorata*	6.0		75	*Trigonotis peduncularis*	3.3	1.1
33	*Panicum bisulcatum*	21.9		76	*Typha angustifolia*	14.2	14.6
34	*Panicum dichotomiflorum*	53.6		77	*Zizania latifolia*	30.3	23.1
35	*Paspalum thunbergii*	57.6		78	*Cuscuta australis*		4.7
36	*Phalaris arundinacea*	20.9		79	*Duchesnea chrysantha*		3.5
37	*Plantago asiatica*	2.7		80	*Iris pseudoacorus*		17.1
38	*Portulaca oleracea*	3.8		81	*Ixeris dentata*		2.0
39	*Potentilla paradoxa*	8.9		82	*Lactuca indica* var. *laciniata*		2.4
40	*Poa sphondylodes*	3.5		83	*Lemna paucicostata*		24.8
41	*Rorippa islantica*	1.3		84	*Potamogeton crispus*		52.2
42	*Rumex acetosa*	7.6		85	*Scirpus fluviatilis*		22.3
43	*Salix koreensis*	2.2		86	*Typha orientalis*		34.9

This table shows the identification numbers and their abbreviation codes used in the figures. The mean importance value is abbreviated with I.V. (%).

montani, and *P. thunbergii*. Group G3 was dominated by *Humulus japonicus* and *Scirpus fluviatilis*. Group G4 was composed of *Typha orientalis* as dominant species. *Zizania latifolia* was dominant, and *Lemna paucicostata* and *Potamogeton crispus* were co-occurred in group G5. GR had few seasonal changes. Compared with WS, the plants in GR grew better in foliar width and the height until autumn. *Typha angustifolia*, *P. thunbergii*, *S. tabernaemontani*, and *Z. latifolia* were dominant through all seasons. But *A. tsukushiense* var. *transiens* dominated only in spring, and *H. japonicus* dominated only in autumn; it began to grow late. *Typha orientalis* was dominated from spring to early autumn. In common, the emergent species were prominent all through the growing season.

Vegetation in riparian zone of both the stream and the reservoir showed seasonal changes because of variation in the water level associated with seasonal rainfall (Kadlec 1962, Millar 1973, Ostendorp 1991, Rea and Ganf 1994, Cirujano *et al.* 1996). However the groups W6, G1, and G5 composed of perennial helophytes, which preferred the habitat in deep water, showed unchanged composition of species as season passed by.

Water Environmental Characteristics

The water depth of surveyed wetlands ranged more widely from −4.85m to 0.83m in the lotic water (WS) than from −1.80m to 0.77m in the lentic water (GR). The mean water depth, however, was usually higher in the lentic water than in the lotic water (Table 2). These results were caused by the difference between flowing and static water; there was no drainage in reservoir. Considering the seasonal changes in water depth, its mean value was not significantly different with seasons in WS, but it increased from spring to autumn in GR (Table 2).

The water in two wetlands was neutral or slightly alkaline with pH 6.5~9.3 and the mean pH was not significantly different among groups. In particular, the mean pH was lowest in summer among seasons in WS. The dissolved oxygen concentration in water did not depend on study-sites and seasons; the value ranged from 0.9 to 13.9mg/L in two wetlands. The conductivity of water was always lower in WS (192~516 μS/cm) than in GR (283~762 μS/cm) where organic matters were accumulated in the static reservoir. The mean conductivity was highest in spring and lowest in summer in both wetlands (Table 2); this might be related to the fact that a heavy rainfall could dilute the concentration of the dissolved matters in summer. Water temperature ranged from 10 to 30℃ in two wetlands. It showed the typical result of the higher value in hot summer (Table 2).

Finally, for nutrients, the concentration of PO_4-P and NH_4-N ranged from 0.02 to 1.02ppm, and from 0.02 to 14.02ppm in GR, respectively, and from 0.01 to 0.24ppm, and from 0.07 to 5.62ppm in WS, respectively. Particularly in WS, the mean concentration of

Table 2. Mean values of each water environmental factor in each season

Season \ Study site	WS			GR		
	Spring	Summer	Autumn	Spring	Summer	Autumn
Water depth (m)	−2.64	−1.63	−1.94	−0.27	−0.08	0.05
	a	a	a	a	ab	b
pH	8.3	7.0	7.7	7.6	7.8	7.5
	c	a	b	a	a	a
Dissolved oxygen (mg/L)	8.6	8.1	6.4	5.9	8.2	5.5
	a	a	a	a	a	a
Conductivity (μS/cm)	393	262	317	478	352	389
	b	a	ab	b	a	ab
Water temperature (℃)	21.8	24.7	19.7	23.2	27.4	17.7
	a	b	a	b	b	a
PO_4-P (ppm)	0.18	0.11	0.14	0.23	0.10	0.11
	b	a	ab	a	a	a
NH_4-N (ppm)	1.82	0.38	0.20	4.09	0.62	0.55
	b	a	a	b	a	a
NO_3-N (ppm)	2.99	3.41	3.27	1.01	1.89	1.18
	a	a	a	a	a	a

The different letters below the mean values indicate significantly different at $P<0.05$ (Tukey's test).

PO_4-P and NH_4-N was higher in spring than the one in summer. In GR, the mean concentration of NH_4-N in spring was highest among seasons (Table 2). The mean concentration of NO_3-N in two wetlands had no significant difference with study-sites and seasons; it ranged from less than 0.01 to 7.92ppm.

However actually there was correlation between environmental factors; specially as nutrients, NH_4-N and PO_4-P showed the highest correlation among environmental factors (both concentrations of NH_4-N and PO_4-P had higher values in spring simultaneously); NH_4-N was also related to conductivity; in case of NO_3-N, it was correlated with water depth and water temperature (Table 3).

The Relationship of Vegetation and Water Environment

The 19 species (I.V. > 5%) among total 37 species in GR and the 40 species (I.V. > 5%) among total 77 species in WS were used for CCA in Fig. 4.

For the data of WS, the first two axes sufficiently explained the relation between species and environment; 59.8, 61.5, and 77.6% of the relation in spring, summer, and autumn, respectively. The first

Table 3. Correlation matrix among water environmental variables surveyed

	Water depth	pH	Dissolved oxygen	Conductivity	Water temperature	PO_4-P	NH_4-N	NO_3-N
Water depth								
pH	+0.064							
Dissolved oxygen	+0.318*	+0.752**						
Conductivity	+0.017	−0.187	−0.175					
Water temperature	+0.017	+0.342**	+0.417**	−0.157				
PO_4-P	+0.139	−0.067	−0.156	+0.181	+0.059			
NH_4-N	+0.051	−0.092	−0.172	+0.409**	+0.033	+0.789**		
NO_3-N	+0.429**	−0.109	+0.065	−0.046	+0.351**	+0.251*	+0.174	

*: Significant at P<0.05, **: Significant at P<0.01.

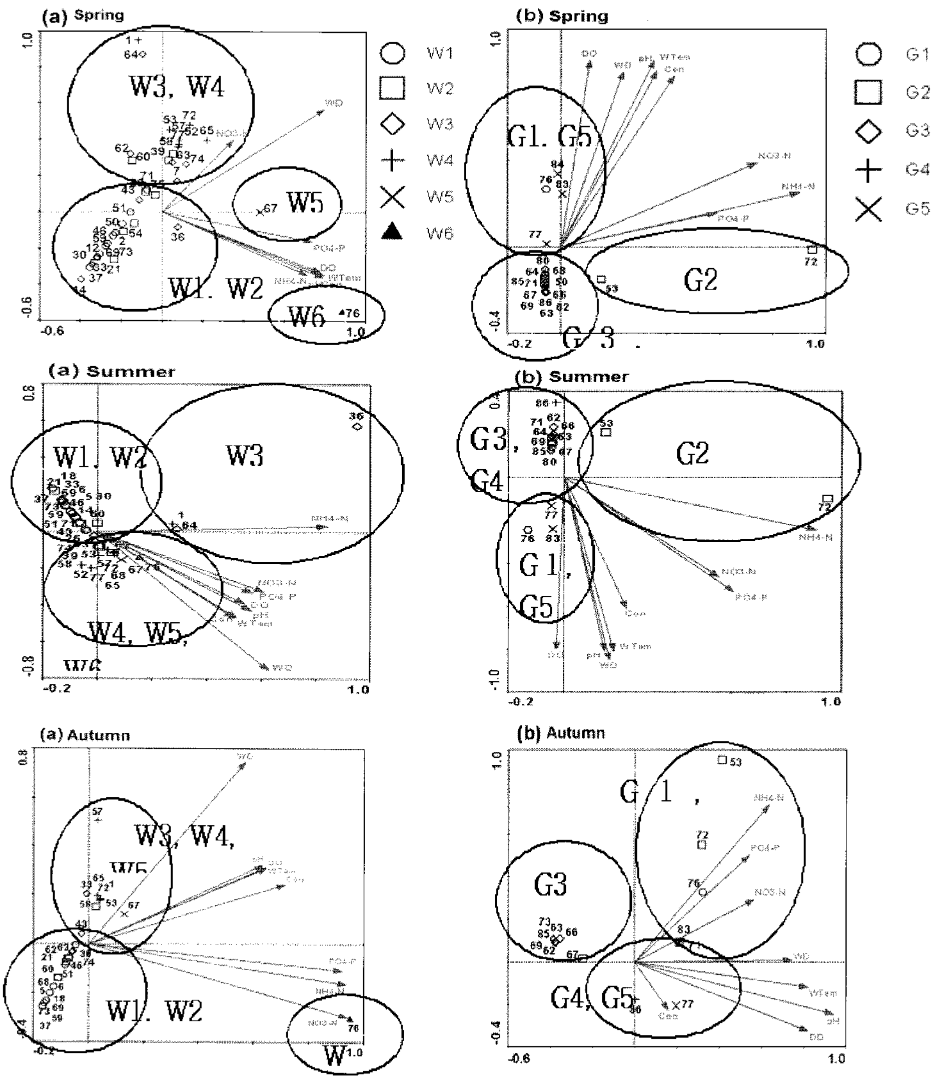

Fig. 4. Canonical correspondence analysis diagrams of each season (Spring, Summer, and Autumn) (a) in Wangsuk stream and (b) in Gwarim reservoir. For species codes, see Table 1. Numbers designate species, and vectors represent water environmental variables. Each group divided by TWINSPAN has the same symbols. Environmental factors: Water depth (WD), Water pH (pH), Dissolved oxygen (DO), Conductivity (Con), Water temperature (WTem), Soluble reactive phosphorus (PO_4-P), Ammonia (NH_4-N), and Nitrate (NO_3-N).

axis with a correlation of 0.923, 0.932, and 0.966 between species and environmental factors explained 33.1, 32.0, and 43.3% of the relation, and 7.6, 7.0, and 9.2% of species variation in the three respective seasons. The second axis with a correlation of 0.864, 0.904, and 0.893 between species and environmental factors explained 26.7, 29.5, and 34.3% of the relation, and 6.1, 6.4, and 7.3% of species variation in spring, summer, and autumn, respectively.

For the data of GR, the first two axes sufficiently explained the relation between species and environment; 57.2, 60.6, and 73.3% of the relation in spring, summer, and autumn, respectively. The first axis with a correlation of 0.991, 0.963, and 0.928 between species and environmental factors explained 33.8, 34.0, and 43.4% of the relation, and 13.4, 15.5, and 15.1% of species variation in the three respective seasons. The second axis with a correlation of 0.838, 0.882, and 0.763 between species and environmental factors explained 23.4, 26.6, and 29.9% of the relation, and 9.4, 12.1, and 10.4% of species variation in spring, summer, and autumn, respectively. The ordination results of two wetlands were significant at $P < 0.05$ by an unconstrained Monte Carlo permutation test.

In WS, water depth primarily affected the distribution of vegetation in the three seasons (t-value=0.334~0.458), and NH_4-N also affected the distribution (t-value=0.327~0.608) in spring and summer, considering the relation with the axis I in CCA (Fig. 4). On axis I, the contribution of other variables was negligible (t-values <0.1). Most groups were strongly correlated with water depth; group W6 was established in the deepest water, while groups W3, W4, and W5 were established in shallow water, and groups W1 and W2 were established in the sites where the water level was below the soil surface in every seasons (Fig. 4 and Table 4). For NH_4-N, *P. arundinacea* in group W3 in summer and *T. angustifolia* in group W6 in spring and autumn were established in the water with high concentration of NH_4-N. On the other hand, the axis II in CCA was related to NO_3-N (t-value = 0.348) only in spring (Fig. 4); two groups W1 and W2 were related negatively, oppositely two groups W3 and W4 were related positively.

In GR, NH_4-N primarily affected the distribution of vegetation in all seasons (t-value=0.278~0.636) considering the relation with the axis I in CCA (Fig. 4). On axis I, the contribution of other variables was negligible (t-values<0.1). On the other hand, the axis II in CCA

Table 4. Mean values of each water environmental factor in each group

Group \ Study sites	WS						GR					
	W1	W2	W3	W4	W5	W6	G1	G2	G3	G4	G5	Total mean
Water depth (m)	−3.90	−2.67	−1.54	0.01	0.05	0.27	0.36	−0.28	−0.43	−0.99	0.17	−1.19
	a	ab	bc	d	d	d	d	cd	cd	cd	d	
pH		7.7	7.6	7.3	7.7	7.5	7.8	7.3		7.3	7.6	7.5
		a	a	a	a	a	a	a		a	a	
Dissolved oxygen (mg/L)		6.8	7.9	7.5	7.4	7.9	8.4	3.6		3.5	6.3	6.8
		abc	c	c	bc	c	c	ab		a	abc	
Conductivity (μS/cm)		315	308	274	298	343	441	429		480	347	346
		ab	ab	a	ab	abc	bc	bc		c	abc	
Water temperature (℃)		19.6	23.0	23.4	22.4	21.4	23.6	20.7		15.4	21.6	21.9
		ab	ab	b	ab	ab	b	ab		a	ab	
PO_4-P (ppm)		0.11	0.15	0.11	0.14	0.18	0.13	0.24		0.05	0.12	0.13
		a	a	a	a	a	a	a		a	a	
NH_4-N (ppm)		1.27	1.14	0.43	0.55	1.15	1.32	3.01		0.31	1.00	1.04
		a	a	a	a	a	a	a		a	a	
NO_3-N (ppm)		3.43	3.27	3.43	3.56	3.27	1.98	2.22		0.32	0.83	2.42
		c	bc	c	c	bc	abc	abc		a	ab	

The different letters below the mean values indicate significantly different at $P<0.05$ (Tukey's test). Water environmental factors except water depth of W1 and G3 were not significant because of small sample numbers.

was related to water depth (absolute *t*-value=0.327~0.331) in spring and summer; there were significant differences of water depth between groups G1~G5 in spring and summer, indicating the additional importance of the role of water depth to the distribution of vegetation (Fig. 4 and Table 4). Firstly, group G2, where *S. tabernaemontani* is dominant, was separated from the other groups along axis I related to NH_4-N in all seasons. *Scirpus tabernaemontani* in group G2 showed maximum growth at 45ppm NH_4-N, and could tolerate in maximally 350 ppm NH_4-N because it had high capability to absorb nitrate, ammonia, and soluble reactive phosphorus (Finlayson and Chick 1983, Gray 1989). For group G1, where *T. angustifolia* was dominant, their vegetation was established in the water with high NH_4-N concentration only in autumn like the group W6 in which *T. angustifolia* was also dominant. Secondly, groups G1 and G5 were separated from the other groups G3 and G4 along axis II related to water depth; Groups G1 and G5 were established in the deepest water, but groups G3 and G4 were established in shallow water in spring and summer.

Summarizing above results, water depth was the major factor affecting the distribution of the wetland plants in both wetlands, which was consistent with the previous studies (Kadlec 1962, Mitsch and Gosselink 2000, Coops *et al.* 2004). In addition, nutrients such as NH_4-N and NO_3-N were also important factors to the distribution of several groups at the specific seasons.

Water depth affects directly or indirectly the growth of wetland plants. Light limitation, composition and chemicals of sediments which are dependent on water depth affects photosynthesis, the growth and the distribution of plants (Grace and Wetzel 1982, Spence 1982, Keddy 1983). In addition, the capability increasing the length of shoots when water depth increase, may change the distribution of wetland plants (Blanch *et al.* 1999, Vretare *et al.* 2001). Not only surface water level but also water level below soil surface affects the distribution of plants (Patten 1968, Lee *et al.* 1977). Water depth, therefore, should be considered to establish vegetation appropriately for the conservation, restoration, and creation of wetlands.

ACKNOWLEDGEMENT

This work was supported by the Korean Research Foundation Grant funded by the Korean Government (grant No. R08- 2004-000-10225-0).

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(*Received November 19, 2005; Accepted December 23, 2005*)