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The Variation in the Species Composition of the Soil Seed Bank in the Natural Flood Plain Vegetation along the Urban Reach of Han River, South Korea

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We described the above-ground plant species composition and measured a range of soil physico-chemical properties and the composition and size of the soil seed bank in the remnant natural vegetations on the flood plains of the Han River within Seoul, South Korea. We used analysis of variance and multivariate analyses to analyse the data and Sørensen's similarity index to compare the composition of the vegetation and seed banks. The soils were circum-neutral and composed of mainly sand and silt fractions with a very limited clay component; a gradient based on sand/clay proportions was identified. The soil seed banks varied markedly between- and within-sites and had much greater species diversity than the above-ground vegetation. Two of the major dominants in the vegetation (*Miscanthus saccariflorus* and *Phragmites australis*) were found at very low densities in the seed bank. The site differences appeared to be correlated with the sand-clay gradient, suggesting that the soil properties differentially affected seed inputs into the soil, or that the processes than controlled sediment deposition during floods was also important in differentially affecting seed deposition. Lastly, there was relatively little similarity between the vegetation, dominated mainly by perennials, and the seed bank which contained a relatively large proportion of annuals and biennials. This result suggests that after disturbance caused by flooding there is the potential for many other species to colonize. This may impinge on the regeneration potential of the sites and cause concern for the future conservation of these important remnants of natural vegetation.

Key words : soil physico-chemical properties, regeneration, Sørensen's similarity index, life-history traits, conservation

INTRODUCTION

Riverine systems are important ecosystems from a conservation perspective and are under great threat from development especially in urban areas (Karr and Chu, 2000; Paul and Meyer, 2001; Gergel *et al.*, 2002), where damaging impacts range from complete removal, through various stages of re-alignment and embankment to direct and diffuse pollution from a variety of sources (Ward *et al.*, 2001). Where there is some natural vegetation present in refuges there is a need to gain a better understanding of the ecological processes that occur in these systems. At the very basic level there is a need to describe the vegetation that occurs in such sites and then to consider processes that will impact on their potential rege-

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neration such as the size and composition of the seed bank (Nilsson *et al.*, 1991; Hanlon *et al.*, 1998; Tabacchi *et al.*, 2005; Capon and Brock, 2006). The soil seed bank provides a stock of regeneration potential in many plant communities (Dessaint *et al.*, 1997; Richter and Stromberg, 2005) and is an important component of ecosystem resilience (Thompson, 2000).

The soil seed bank is especially important in flood plains because these ecosystems are affected on a regular basis by disturbance, through periodic flooding (Abernethy and Willby, 1999; Richardson *et al.*, 2007), summer drought (Liu *et al.*, 2006), fire and in some cases cultivation (Leck and Leck, 1998; Holmes, 2002). This disturbance creates bare ground for the colonization by new individuals or species derived either from the seed bank or dispersing via the water (Thompson and Grime, 1979; Richter and Stromberg, 2005; James *et al.*, 2007). Thus, a new succession is created. Flood plain vegetation is, therefore, constantly in transition and the soil seed bank is an important part of the ecosystem that will assist vegetation recovery (Ghorbani *et al.*, 2003; González-Alday *et al.*, 2009), and will be an important mechanism in regulating the biodiversity of flood plain ecosystems.

In South Korea there is a lack of information on the vegetation of flood plain systems and the regeneration potential available within the soil seed banks. The Han River is a major river, and the second longest river in South Korea. The river has been subject to substantial technological management for the control of floods during the heavy monsoonal rainfall period, and for securing irrigation water during drought periods (Woo, 2010). Within the city of Seoul the river has been channelized and embanked since the mid-1960s. Since the 1980's the narrow flood plain of the river has been developed as public and ecological parks, roads, and as car parks (Woo, 2010). As a result, the previous ecological functions derived from the natural riparian vegetation have been lost within the urban reach of the Han River. However, there are a few refuge areas within the confines of the city where natural vegetation remains or has regenerated after construction work. The remnant vegetation in the disturbed flood plains are very important with high ecological and environmental values from a conservation viewpoint due to their potential values of the specices source and the restoration prototype for the future river restoration (Kim and Ju, 2005; Jeon *et al.*, 2008).

The aims of this study were, therefore, to: (1) provide a description of the vegetation in the refuges within the Seoul stretch of the Han River, (2) assess the size and composition of the seed bank in each area, and this was determined by germinating the seedling in the soil (Dalling *et al.*, 1995; Hanlon *et al.*, 1998; Ter Heerdt *et al.*, 1999; Ghorbani *et al.*, 2003; Kim and Ju, 2005; Richter and Stromberg, 2005; González-Alday *et al.*, 2009), and (3) to test whether there was a correlation between the vegetation and soil seed bank. We hope that this preliminary assessment would provide information on the natural potential vegetation and soil seed bank in the urban food plains under severe disturbance to help inform their conservation planning.

METHODS

1. Study sites

This study was conducted on the flood plains of the Han River in Seoul, South Korea. The urban reach of the river in the Seoul metropolitan area has been subject to technological management such as channelization, embankment, damming and developing the leisure facility. There are many dams upstream from Seoul used for flood control, water supply and power generation (for example, the Soyang, Chungju and Paldang Dams), and at the seaward end there are two under-water barriers, the Shingok and Jamsil weirs, which regulate salt-water inflow and maintain water levels (Kim, 2008).

Four study sites, the only ones with semi-natural vegetation remaining, were selected along the flood plains of the Han River which goes through Seoul City (Fig. 1, Table 1). Janghang is located downstream of the Shingok weir and therefore has a tidal influence (Kim, 2008). This site has a flat, silty shore line and there is a succession of plant communities from the waterfront to the landward edge, dominated in order by *Phragmites australis*, *Salix* spp. and *Miscanthus saccariflorus*. The *Salix* community, comprised of *S. nipoponica* and *S. purpurea* var. *japonica*, has developed into the largest *Salix* forest along the Han River. The other three sites are above the Shingok weir and hence are unaffected by tidal inundation. The flood plain wetland in Kangseo was used for agri-

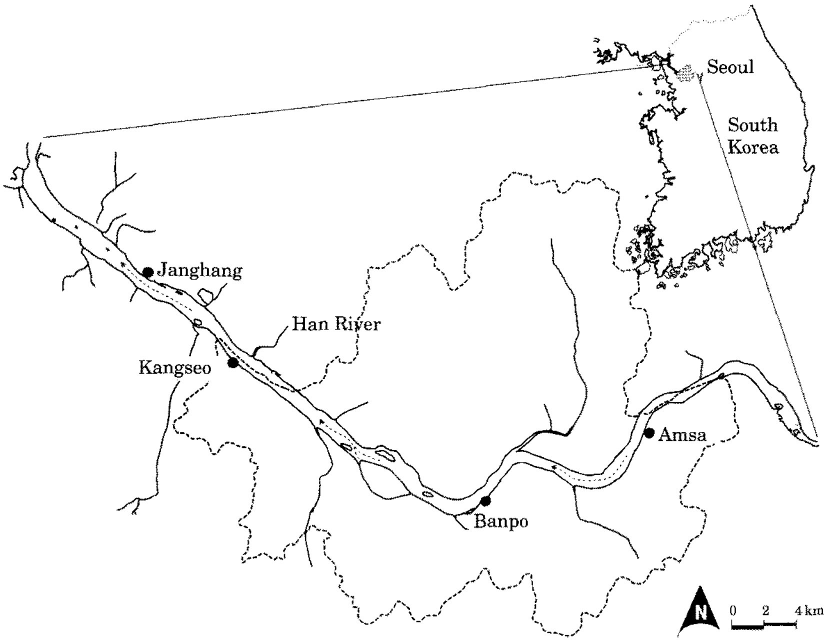

Fig. 1. Location of study sites along the Han River in Seoul, South Korea.

culture until 2006 and since then has been developed into a wetland ecological park. There was a small amount of extant natural vegetation (*Phragmites australis*, *Miscanthus saccariflorus* and *Salix* spp.) but at the time of sampling time had communities dominated by invasive alien plant species such as *Ambrosia trifida*. The dominant communities at Kangseo were *Ambrosia trifida*, *Miscanthus saccariflorus*, *Phragmites australis*, *Phalaris arundinacea* and *Salix* woodland (*S. koreensis*, *S. nipoponica* and *S. pseudo-lasiogyne*). The Banpo wetland is within a public park that is mainly used for leisure activity and car parking, but there is a small area with natural flood plain vegetation. Here the plant communities were dominated by *Bidens frondosa*, *Humulus japonica*, *Miscanthus saccariflorus* and *Phragmites australis*. Finally, the Amsa wetland ($0.1\ \mathrm{km}^2$) was designated as a conservation area in 2002, and has been fenced to prevent human access. Amsa is close to natural riverine wetland upstream of the Shingok weir, and the communities were dominated by *Chenopodium album* var. *centrorubrum*, *Chenopodium ficifolium*, *Humulus japonica*, *Miscanthus saccariflorus*, *Persicaria perfoliata*, *Phragmites australis* and *Salix* woodland (*S. koreensis*, *S. nipoponica* and *S. pseudo-lasiogyne*).

In each of the study sites there were communities dominated by either *Phragmites australis* or *Miscanthus sacchariflorus*. At each site between 2～5 different plant community types were identified and a total of 15 plant communities were sampled (Table 1). The presence of all higher plant species was recorded in five $0.25\ \mathrm{m}^2$ quadrats positioned randomly in each of the 15 plant communties.

Table 1. The four river flood plain study sites along the Han River, Seoul, South Korea, along with the dominant vegetation types sampled; sites are in seaward to landward order (Fig. 1).

Flood plain site	Dominant plant community sampled	Code
Janghang	Waterfront	WF
	Phragmites australis	Pa
	Salix spp.	Ss
	Miscanthus sacchariflorus	Ms
Kangseo	*Phragmites australis*	Pa
	Salix spp.	Ss
	Miscanthus sacchariflorus	Ms
	Ambrosia trifida	At
Banpo	*Phragmites australis*	Pa
	Miscanthus sacchariflorus	Ms
Amsa	Waterfront	WF
	Low Channel Bank	Bn
	Salix spp.	Ss
	Phragmites australis	Pa
	Miscanthus sacchariflorus	Ms

2. Assessment of soil physico-chemical properties

Soils were sampled in March 2005 for soil chemical analysis. Within each of the 15 plant communities (Table 1) seven positions were located randomly and soil samples collected for analysis. Soil pH and electrical conductivity were measured in a 1 : 2 mixture of fresh soil in distilled water. Soil moisture content was then measured by weighing before and after drying a sub-sample at 105°C for 48 hours. The soil organic matter content was estimated by loss-on-ignition (Heiri *et al.*, 2001). Soil texture analysis was carried out by shaking 40 g in 300 mL of 5% sodium hexametaphosphate solution overnight. Following dilution to 1,000 mL with the distilled water and shaking for 1 minute at 60 rpm density measurements were made using a Bouyoucos hydrometer (USA/ASTM 151H) after 40 seconds and 7 hours. Isoamyl alcohol was fallen in drops for removing bubbles if necessary (Sheldrick and Wang, 1993). Total soil nitrogen was analysed using a protein/nitride auto analyzer (Kjeldahl Protein/Nitrogen Analyzer (Automatic); Kjeltec Auto 1035/1038 System). Extractable soil phosphorus (EP) and exchangeable cations (Na, Mg, K, Ca) were extracted using Mehlich III solution (Sims *et al.*, 2002); EP was analyzed using the ascorbic acid method (APHA, 1992) and exchangeable cations using an induced coupled plasma (ICP) Emission Spectrometer (Shimadzu/ICPS-7510).

3. Assessment of species in the seed bank

The main purpose of this study was to determine the size and composition of the germinable seed bank, and therefore the soils were sampled in March 2006 at the beginning of Spring when all seed available for germination during the sampling year should be available. Within each of the 15 plant communities (Table 1) five replicate 1 m^2 quadrats were located randomly. At each of these quadrats five soil cores were taken using a soil crer (Eijkelkamp BV, Netherlands; corer dimensions=5 cm diameter, 5 cm deep). As the seed density is usually greatest in the uppermost soil layer (Roberts, 1981; Galatowitsch and Valk, 1996) we sampled the surface layer of soil with 5 cm deep core. The layers were pooled by quadrat to produce a surface and sub-surface sample for each quadrat. There were in total 75 soil samples for seed bank analysis (15 communities × 5 replicate quadrats). All samples were stored in at 4°C until the seedling emergence experiment started (Looney and Gibson, 1995).

Initially, each soil was prepared by hand-removal of roots and plant stems from the sample.

Thereafter the soils were placed in individual seed trays (44 cm × 30 cm × 7 cm) and transferred to the glasshouse. The soils were watered daily. The minimum and maximum temperatures recorded in the glasshouse were 10.4°C and 35.8°C respectively. Seedling emergence was observed for 16 weeks. Emergent seedlings were identified using (Asano, 2005) and counted every two weeks; where identification was not possible the seedling was transferred to a separate pot and grown on until identification was possible. The seed numbers emerging were converted to seed densities on an area basis (m^{-2}).

4. Statistical analysis

The species detected in each of the 15 communities are presented in full in Appendix I. Summary data on number of species (total and sub-divided into annuals, biennials and perennials) were analysed using analysis of variance (ANOVA; SAS Institute, 2009). The inter-relationships of the soil environmental physico-chemical factors were investigated using the principle component analysis (PCA; SAS Institute, 2009). Multivariate analysis of the soil seed bank species composition was also carried out unconstrained analysis. Decorana (DCA, Hill and Gauch, 1980) was used to analyse the species composition using the Vegan package (function 'decorana', Oksanen, 2005) within the R statistical environment (Team, 2008). Species present in less than five quadrats were excluded and the downweighting option was used. The environmental factors were then correlated with the DCA ordination using the 'envfit' function within Vegan (Oksanen, 2005); here significance was assessed using a permutation test ($n=1{,}000$) and only variables significant ($P<0.05$) are discussed. The species composition of the vegetation and seed bank were compared using Sørensen's similarity index (Hopfensperger, 2007; Boudell and Stromberg, 2008).

RESULTS

1. Above-ground vegetation

The total number of species in each community

Table 2. Number of plant species found in the above-ground vegetation at the 15 communities along the Han River, Seoul, South Korea. Total numbers are presented along with numbers and % of the species in each life-history category (annual, biennial and perennial plants). Community codes are given in Table 1.

Life history		Janghang				Kangseo				Banpo		Amsa				
		WF	Pa	Ss	Ms	Pa	Ss	Ms	At	Pa	Ms	WF	Bn	Ss	Pa	Ms
Annuals	Species no	1	4	3	4	10	14	11	8	11	9	15	20	27	13	4
	%	25	36	30	19	33	47	41	38	50	47	44	53	48	48	33
Biennials	Species no	1	2	4	10	10	7	9	6	6	7	9	10	12	7	5
	%	25	18	40	48	33	23	33	29	27	37	26	26	21	26	42
Perennials	Species no	2	5	3	7	10	9	7	7	5	3	10	8	17	7	3
	%	50	45	30	33	33	30	26	33	23	16	29	21	30	26	25
Total		4	11	10	21	30	30	27	21	22	19	34	38	56	27	12

varied between 4~56 with a mean of 24 in five 0.25 m^2 quadrats (Table 2 and Appendix 1). The site nearest the sea (Janghang) had the lowest species number (4~21) and the greatest species numbers were found in Kangseo and Amsa which had the greatest protection. Banpo was intermediate and this is a small site with considerable human disturbance. The distribution of life-forms types varied also between the different communities. The disturbed Banpo and Amsa sites had a relatively high proportion of annuals (33~53%), otherwise there was no real consistent pattern in the distribution of life-form types (Table 2).

2. Soil sampling and analysisi of physico-chemical properties

The soils were circum-neutral with a pH between 6.4 and 7.4 and this was reflected in relatively high concentrations of exchangeable cations in particular Ca and Mg. Exchangeable Na was only elevated at the waterfront community at Janghang, the site nearest the sea (Table 3). The soils were predominantly composed of sand and silt with a maximum of 9% clay content. The organic matter content and total nitrogen content was also relatively low peaking at 9% and 2% respectively.

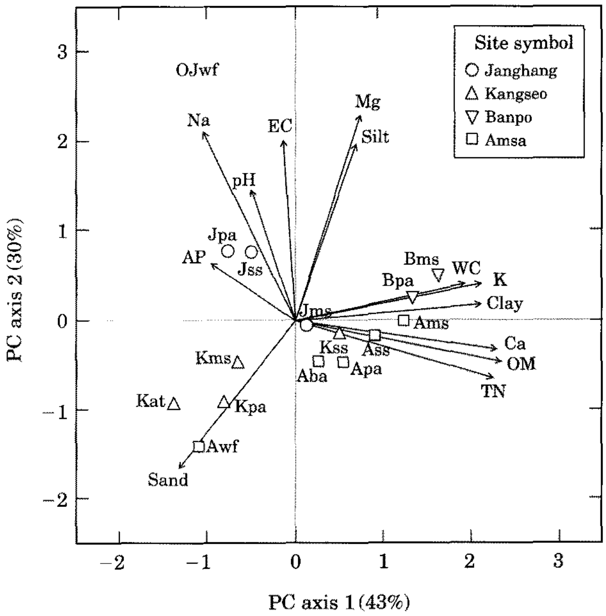

Fig. 2. Ordination biplot derived from the first two axes of principal components analysis (PCA) of the soil data from 15 plant communities along the Han River, Seoul, South Korea. Site codes: A=Amsa; B=Banpo; J=Janghang; K=Kangseo. Community codes: at=*Ambrosia trifida*; WF=waterfront; bn=Bank; pa=*Phragmites australis*; ms=*Miscanthus saccariflorus*; ss=*Salix* spp. Soil chemical property codes: EP=extractable phosphorus; EC=electrical conductivity; OM=organic matter; TN=total nitrogen; WC=water content; Na=exchangeable Na; Mg=exchangeable Mg; K=exchangeable K; Ca=exchangeable Ca.

The first two axes of the PCA of the soil data produced eigenvectors of 5.439 and 3.909 which explained 43% and 30% of the variance; two obvious gradients were detected on these axes (Fig. 2). The first axis represented a gradient from sandy conditions at the negative end through to soils with a greater content of clay, organic matter, total nitrogen and exchangeable K and Ca at the positive end. Also correlated with the positive end was an increased water content. Axis 2 showed a gradient of increasing soil pH, electrical conductivity silt content and high exchangeable Mg and exchangeable P (EP) concentrations. The most maritime sites were correlated with high electrical conductivity, pH and Na, Banpo the most dis-

Table 3. Physico-chemical properties of the soils at 15 plant communities along the Han River, Seoul, South Korea. The soil properties are coded: WC=Water content; OM=Organic matter content; EC=Electric conductivity; TN=Total Ni-trogen; EP=Extractable Phosphorous. Community codes (Com) are given in Table 1. Mean values (mean±SE; n=7).

Site	Com	pH	WC	OM	Sand	Silt	Clay	TN	EC	EP	K	Na	Ca	Mg
					(%)			(mg g^{-1})	(mS m^{-1})			(μg g^{-1})		
Janghang	WF	7.4±0.04	24.7±0.5	1.2±0.1	31±4	64±3	6±0	0.2±0.02	61.4±3.5	27.8±0.5	190±5	823±24	532±23	439±4
	Pa	7.2±0.06	26.9±0.5	2.3±0.1	30±1	65±1	4±0	0.3±0.05	11.4±0.6	20.5±1.1	164±9	479±10	710±7	295±8
	Sa	6.5±0.07	27.0±0.3	2.1±0.1	20±1	72±1	8±0	0.4±0.04	25.0±1.7	22.9±0.8	148±4	473±12	881±73	298±24
	Ms	6.4±0.10	27.4±0.5	4.7±0.4	28±4	56±3	17±1	1.0±0.07	11.7±1.6	24.9±1.8	210±23	426±5	1076±99	241±25
Kangseo	Pa	6.7±0.08	21.1±2.1	2.6±0.5	53±5	38±4	9±1	0.8±0.09	8.2±0.5	20.9±2.9	99±12	366±8	1048±59	95±6
	Ss	6.7±0.03	26.5±1.5	6.0±0.5	36±3	49±3	16±1	1.3±0.14	19.7±0.8	25.8±1.1	258±4	393±4	2085±129	184±7
	Ms	6.6±0.08	23.7±0.5	4.1±0.2	51±3	41±4	7±1	0.9±0.07	17.4±1.8	31.6±2.5	197±14	355±7	907±46	129±19
	At	6.8±0.06	12.3±0.4	2.6±0.1	68±3	24±2	9±1	0.4±0.02	12.1±1.1	28.2±2.3	168±8	399±4	881±44	80±6
Banpo	Pa	6.6±0.07	33.3±0.2	6.8±0.1	14±1	59±1	27±0	1.4±0.04	22.7±1.3	20.3±1.0	281±17	349±2	1993±32	285±10
	Ms	6.9±0.05	35.6±0.3	8.7±0.1	15±2	59±2	26±1	1.4±0.05	25.9±9.0	21.5±0.8	370±41	357±4	1988±29	296±6
Amsa	WF	6.7±0.05	29.5±1.3	3.0±0.4	85±2	12±1	3±1	0.6±0.05	13.6±1.6	16.8±1.4	62±6	368±3	662±83	100±11
	Bn	6.7±0.03	31.7±0.6	5.9±0.3	57±5	34±4	9±1	13.0±0.14	25.6±1.3	18.6±0.6	233±14	363±1	1476±59	228±12
	Ss	6.8±0.03	29.9±0.4	6.0±0.2	47±3	42±2	11±1	1.9±0.09	23.3±1.7	16.9±1.0	389±33	386±11	1888±68	252±18
	Pa	6.9±0.02	30.1±1.7	6.0±0.5	50±7	39±5	11±2	1.5±0.20	16.9±2.3	18.9±1.4	335±42	370±4	1533±171	186±25
	Ms	6.7±0.05	34.0±0.4	8.2±0.3	33±3	50±3	17±1	1.8±0.11	14.3±0.6	21.3±1.5	307±24	412±12	1925±89	289±23

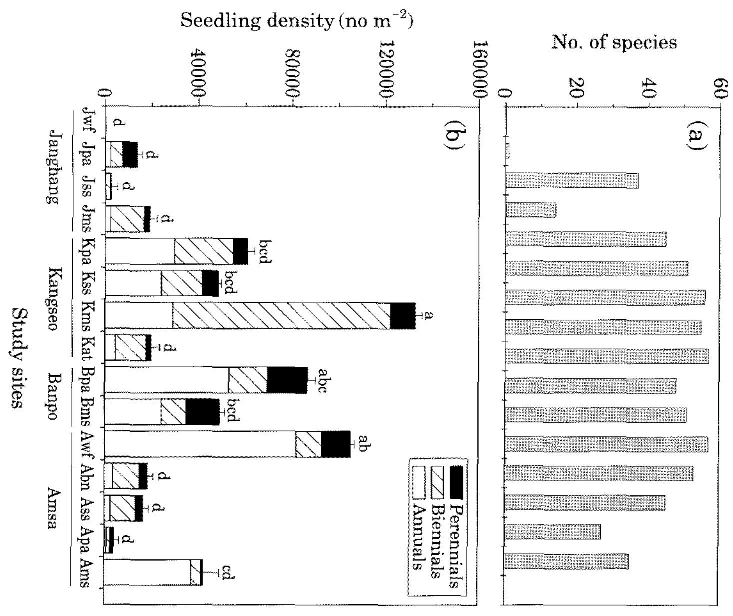

Fig. 3. Summary on seed bank composition from 15 plant communities along the Han River, Seoul, South Korea. (a) species number, and (b) total seed density (number of seedlings m^{-2}), separated into different life-history strategies. Communities are coded (at: *Ambrosia trifida*; ba: Bank; pa: *Phragmites australis*; ms: *Miscanthus saccariflorus*; ss: *Salix* spp.; wf: waterfront). Values are mean density±standard error (n=5). The same latter are not significantly different by Tukey's test (α=0.05).

turbed site had was correlated with both a high clay content and water holding capacity, Kangseo was correlated with high sand content and Amsa showed a gradient across the communities from sandy soils through to soils with a relatively greater clay and silt content.

3. Seed banks

The diversity of the seed banks in terms of species number varied markedly both between and within sites (Fig. 3). Kangseo and Banpo were the most diverse having between 42～57 species in all communities, Amsa was intermediate; there three communities (water front, river bank, *Salix* spp.) had more than 40 species but the *Phragmites australis* and *Miscanthus saccariflorus* communities had 35 and 30 species respectively. The

Table 4. Similarity between the species detected in the seed bank with and field vegetation in 15 plant communities along the Han River, Seoul, South Korea. The number of species in each, the number of common species and Sørensen's similarity index are presented. Community codes are given in Table 1.

Contents		Site																	
		Janghang					Kangseo					Banpo			Amsa				
		WF	Pa	Ss	Ms	Total	Pa	Ss	Ms	At	Total	Pa	Ms	Total	WF	BN	Ss	Pa	Ms	Total
Species no																				
in	Seed bank	1	36	13	45	61	51	56	54	55	82	48	49	61	57	52	44	27	34	83
	Vegetation	4	11	10	21	39	30	30	27	21	55	22	19	24	34	38	56	27	12	75
	Common	0	4	2	9	18	17	15	20	16	42	13	11	15	19	24	26	11	8	50
Sørensens's similarity index (%)		0	17	17	27	36	42	35	49	42	61	37	32	35	42	53	52	41	35	63

Janghang site had the lowest species number: two communities had fewer than five species (Water front and *Phragmites australis*), the *Miscanthus saccariflorus* one had 12 and only the *Salix* dominated community had a modest species count (35 species).

The results for the total number of seedlings to some extent reflected these sites and community differences (Fig. 3). Overall Kangseo and Banpo had greater than 40,000 seeds m^{-2} in all but one community (*Ambrosia trifida* at Kangseo). Amsa had more than 40,000 seeds m^{-2} in two communities, the waterfront and the *Miscanthus saccariflorus* communities and much less than 20,000 seeds m^{-2} in the other three communities. Janghang had less than 20,000 m^{-2} seeds in all communities, and seedling densities were especially low at the water front. The distribution of life forms also differed between sites. At Kangseo and Banpo there was a mixture of annuals, biennials and perennials (mainly biennials), whereas at Janghang and Amsa most communities were composed of mainly mainly biennials and perennials. There were few annuals at Janghang. However, the *Miscanthus saccariflorus* community at Amsa had a substantive annual component, but whilst the seed density of annuals in this community was high it was mainly of a single species (*Chenopodium ficifolium*).

The seed bank showed a relatively poor similarity with the vegetation data (Table 4). At the site level Janghang and Banpo had the lowest similarity coefficients (35∼36%) whereas Janghang and Amsa had greater values (61∼63%). However, at the individual community level the similarity coefficients were much small ranging from 0∼27% at Janghang to a maximum of 53% on the bank at Amsa.

Table 5. Correlation between the soil physico-chemical properties and the first two axes of the Decorana analysis of the soil seed bank composition in 15 plant communities along the Han River, Seoul, South Korea. The correlation coefficients were derived from a permutation test (n=1,000). The site centroids were also significantly correlated with the species composition (r^2=0.6589; P=0.021). Significance level: ***$P<0.001$, **$P<0.01$, *$P<0.05$.

Soil variable	Axis 1	Axis 2	r^2	P
Clay content	0.794	0.608	0.759	0.004**
Exchangeable Mg	1.000	−0.013	0.735	0.007**
Water content	0.799	−0.602	0.737	0.006**
Exchangeable Ca	0.797	0.604	0.738	0.014*
Exchangeable K	0.816	0.578	0.579	0.046*
Organic matter content (LOI)	0.916	0.400	0.728	0.011*
Sand content	−0.715	−0.699	0.593	0.044*
Total N	0.902	0.432	0.591	0.040*
Extractable P	−0.459	0.889	0.512	0.102
Electrical conductivity	0.984	0.177	0.255	0.345
Exchangeable Na	0.444	−0.896	0.024	0.903
pH	0.509	−0.861	0.099	0.735
Silt content	0.655	0.756	0.425	0.162

4. Relationship between the seed bank composition and soil characteristics

The DCA analysis produced eigenvalues of 0.567, 0.394, 0.292 and 0.073 and gradient lengths of 3.04, 2.71, 2.33 and 2.68 for the first four axes respectively. The distribution of species in the seed bank was not easily explained in terms of thee major species composition or the three life-forms tested (Fig. 4a). Apart from two outlier species, the annual species *Digitaria violascens* and the biennial species *Oenothera odorata*, there was

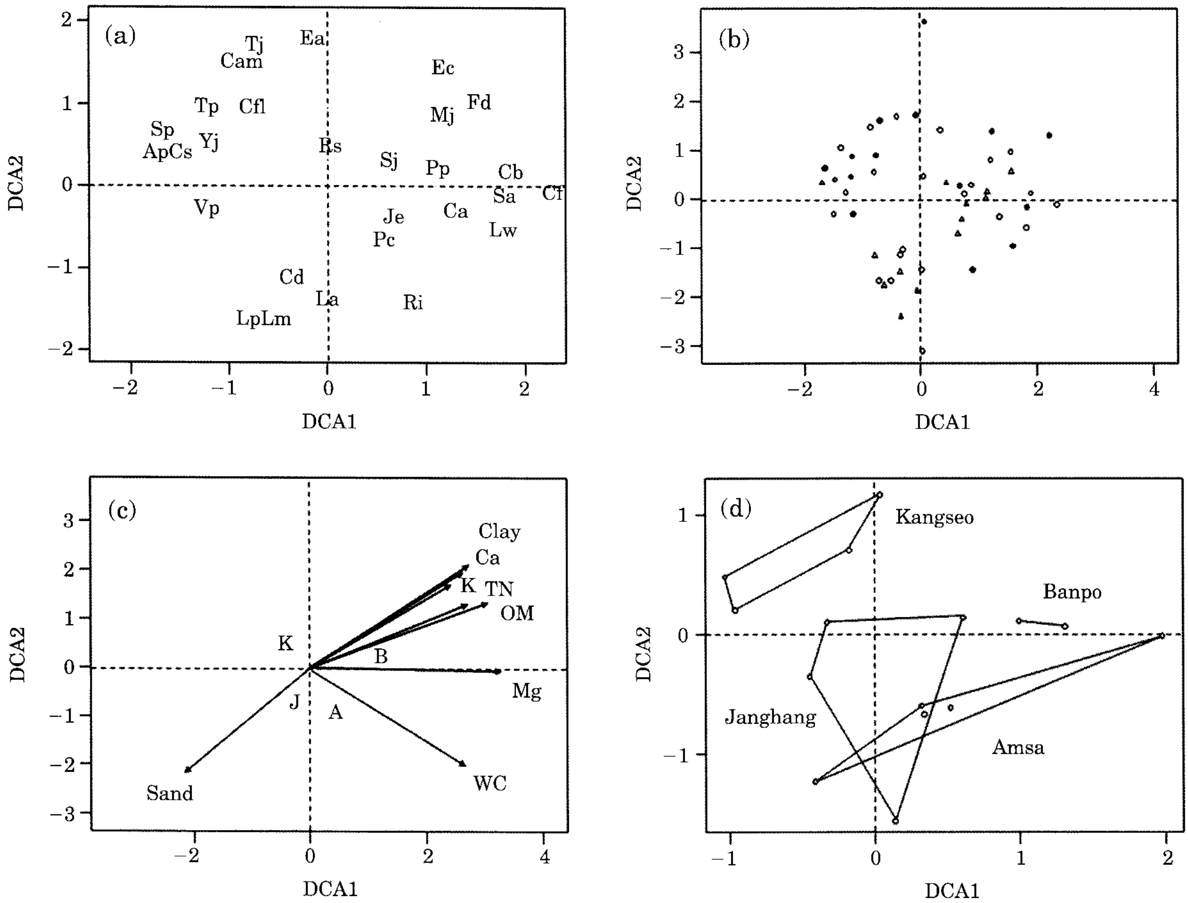

Fig. 4. Detrended correspondence analysis (DCA) ordination of the seed bank species in the 15 plant communities along the Han River, Seoul, South Korea. (a) the most abundant species; (b) all species with more than 5 occurrences displayed by life-form (○ =annuals, ● =biennials, △=perennials); (c) significant ($P<0.05$) environmental variables, these are coded: OM=organic matter, TN=total nitrogen, WC=water content, Mg=exchangeable Mg, K=exchangeable K, Ca=exchangeable Ca, sites coded: A=Amsa, B=Banpo, J=Janghang, K=Kangseo; (d) community centroids linked in site clusters. Species are shown: Ap=*Artemisia princeps* var. *orientalis*; Cam=*Cyperus amuricus*; Cb=*Capsella bursa-pastoris*; Cd=*Cyperus difformis*; Cf=*Chenopodium ficifolium*; Cfl=*Cardamine flexuosa*; Cs=*Cyperus sanguinolentus*; Ea=*Erigeron annuus*; Ec=*Erigeron canadensis*; Fd=*Fimbristylis dichotoma*; Je=*Juncus effusus* var. *decipiens*; La=*Lindernia attenuata*; Lm=*Lindernia micrantha*; Lp=*Lindernia procumbens*; Lw=*Ludwigia prostrata*; Mj=*Mazus japonicus*; Pc=*Potentilla paradoxa*; Pp=*Poa sphondylodes*; Ri=*Rorippa islandica*; Rs=*Ranunculus sceleratus*; Sa=*Stellaria aquatica*; Sj=*Sagina japonica*; Sp=*Salvia plebeia*; Tj=*Torilis japonica*; Tp=*Trigonotis peduncularis*; Vp=*Veronica peregrina*; Yj=*Youngia japonica*.

considerable overlap between the three groups (Fig. 4b). However, there were significant differences between the four sites tested and some of the soil physico-chemical properties (Table 5); there was a major gradient across the sites based on substrate physical composition across the ordination space (Fig. 4c) from a more sandy soil (lower left quadrant) to a more clay soil (upper right quadrant). The high clay content is also correlated with high concentrations of exchangeable Ca and Mg and organic matter and nitrogen content. The water holding capacity of the soils measured at the time of sampling was orthogonal to this main gradient. The four sites and their constituent communities occupied different parts of the ordination space showing a gradation from Janghang and Banpo at the sandy end of the spectrum through to Kangseo and Amsa with a greater clay content (Fig. 4d). Amsa, however, showed the largest variation along this sand-clay gradient.

DISCUSSION

The flood plain ecosystems along the urban stretch of the Han River within Seoul has been considerably altered by river engineering (Kim, 2008). There are few remnants of flood plain vegetation remaining and these represent small foci of natural habitats within this managed system which provide some conservation interest (Kim and Ju, 2005). Here, fifteen different community types were identified across four of these remnant sites and there were considerable difference in plant species number in these areas. The soils in the communities were sampled and their physico-chemical properties analysed. The soils were composed mainly of sand and silt with a maximum of 9% clay content. The organic matter content was relatively low and they were circum-neutral. Multivariate analysis identified sand-clay and sand-silt gradients across these communities, and there was an increase in most physico-chemical properties associated with the soils with the greatest silt and clay contents (Cho, 1995).

The soil seed banks varied markedly between- and within-sites and this will almost certainly impinge on regeneration after disturbance, a common feature in flood plain situations (Dessaint *et al.*, 1997; Richter and Stromberg, 2005). In most communities studied here, the seed bank composition had a greater species richness than the above-ground vegetation; this is in contrast to some other studies where more species were detected in the above-ground vegetation (Valk and Davis, 1978; Thompson and Grime, 1979; Bakker and Berendse, 1999). At the site level there was a gradation in terms of species number and seed density in the seed bank form the site with the most saline influence having the lowest at Kanseo and Banpo having the greatest. The seed banks were dominated by a few species and the species were mainly annual and biennial ones; this appears typical; of flood plain soils (Van Der Valk and Davis, 1979; McDonald *et al.*, 1996; Abernethy and Willby, 1999; Richter and Stromberg, 2005; Boudell and Stromberg, 2008). For example, the seed bank in the perennial *Miscanthus saccariflorus* community at the Amsa was dominated by the annual *Chenopodium ficifolium* (84% of the total seed density). Even where *Miscanthus saccariflorus* and *Phragmites australis* were the dominant species in the vegetation, these species had a very low seedling density in the seed bank (Van Der Valk and Davis, 1979; Baldwin *et al.*, 2010). It is possible that some of the species found in the above-ground vegetation did not emerge as seedlings either because they have short-lived seed longevity (*Salix* spp., Niiyama, 1990; Karrenberg *et al.*, 2002) or the experimental conditions were not suitable for their germination, i.e. the aquatic species, *Spirodela polyrhiza*. However, the tests used here provide a reasonable approximation of the geminable seed in the soil bank that will be available for regeneration after disturbance.

One of the main results to emerge from this study was that the seed bank showed a very poor similarity with the overlying vegetation with a maximum of 53% on the bank at Amsa. This implies that there is only limited potential for direct regeneration of the current vegetation from the seed bank. In all communities, there was a mixture of annuals, biennials and perennials with some site and community differences. One reason for this low similarity is that the riverine vegetation was dominated by perennial species (e.g. *Miscanthus saccariflorus*, *Phragmites australis* and *Salix* spp.), whereas the seed banks contain a relatively high number of annual and biennial species.

The site differences in seed bank composition were highlighted in the unconstrained multivariate analysis where the sites were clearly separated in seed bank species space. Moreover, the distribution was correlated with a sand-clay gradient which also reflected a fertility gradient for most soil variables measured. This is an intriguing result because the soil seed bank in these riverine systems must have two major inputs, from aquatic sources and from the overlying vegetation. Given the relatively weak similarly between seed bank and vegetation this result suggests that deposition processes results in differential seed addition to the seed bank. Clearly aquatic-borne inputs will depend on (a) upstream distance from natural habitat sources (and downstream distance in the case of the tidal Janghang), (b) current flows, and (c) the vegetation structure of the ecosystem which will regulate sediment (and seed) capture. The results here suggest the process that control sediment deposition also affects the deposition of seed of different species differentially. Irrespective, there are clear differences in regeneration potential in the different sites and communities and this will inevitably impinge on the resilience of these flood plain ecosystems to disturbance.

From a management perspective it is very difficult to be able to predict the way communities will recover after major disturbance. The perennial species will be able to regenerate from stem bases (Uchida *et al.*, 2003; Cho and Cho, 2005) but the potential for colonization by species that are currently not present in the above-ground vegetation is considerable and at the moment unpredictable. Further experimental studies are, therefore, needed to assess the effects of such disturbance on both the vegetation and the role of the seed bank in its regeneration.

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Appendix 1. Number of seedlings (m^{-2}) emerged from the top soil (0~5 cm depth) of 15 plant communities along the Han River, Seoul, South Korea (n=5). Community codes are given in Table 1.

Scientific name	Janghang								Kangseo								Banpo				Amsa									
	WF		Pa		Ss		Ms		Pa		Ss		Ms		At		Pa		Ms		WF		Bn		Ss		Pa		Ms	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Annuals																														
Acalypha australis							20	20	120	58	20	20	1000	613																
Aeschynomene indica			20	20					100	55	600	456			20	20	20	20												
Amaranthus mangostanus							20	20																						
Ambrosia artemisiifolia var. *elatior*													40	40	20	20														
Ambrosia trifida															340	178														
Androsace filiformis																									40	24				
Artemisia annua									220	73	40	24	2040	545	20	20			20	20			40	40	160	60			20	20
Arthraxon hispidus					20	20					900	781																		
Bidens bipinnata											100	63																		
Bidens frondosa																	300	207	300	184	40	24	20	20			20	20		
Bromus japonicus									40	40			60	40			20	20												
Callitriche verna																					20	20								
Capsella bursa-pastoris			20	20			240	150	1480	322	1340	326	820	275	360	150	22980	8439	4980	409	20	20	340	121	120	58			680	322
Centipeda minima			60	40							340	316									760	229	180	58	160	40	20	20	20	20
Chenopodium album var. *centrorubrum*									40	40	40	24			40	40	380	273	140	140	60	40	1420	473	620	107	20	20	240	240
Chenopodium bryoniaefolium									20	20											20	20								
Chenopodium ficifolium			140	51			200	130	340	140	600	243	80	58	340	268	8720	5252	5420	3094	360	81	80	20	380	284	20	20	35660	6024
Commelina communis															20	20			20	20										
Cyperus amuricus			440	271			280	80	2300	1155	1500	647	540	169	1200	648	120	73	20	20										
Cyperus difformis			140	117			40	24	640	298	1960	1485	160	93			160	98	2180	1368	9100	3308	40	24	120	58	20	20	20	20
Cyperus flaccidus									20	20											200	155								
Cyperus glomeratus							60	40			40	40			40	40					60	24	20	20					20	20
Cyperus orthostachyus							20	20													740	398	80	20	100	55			60	40
Cyperus sanguinolentus			20	20			100	77	20100	10549	8220	4030	20220	7888					760	375	4000	2647	120	58	120	97	20	20	20	20
Digitaria violascens			640	371			20	20	20	20					160	81	20	20			60	40			40	40				
Echinochloa crus-galli			60	40					120	37	120	80	260	93	120	73	280	166	100	100	100	32							100	45
Eclipta prostrata			40	24															100	63			20	20						
Eleocharis acicularis for. *longiseta*											980	510	300	300							1120	500					20	20		
Eragrostis multicaulis							60	40													20	20	20	20						
Fimbristylis dichotoma											4300	2427			40	24	6660	6262	5100	3448	60	60	80	20						
Humulus japonicus									60	24			40	24	20	20							60	40	140	75	20	20	40	24
Hypericum japonicum																					20	20								
Lindernia attenuata					20	20	40	40					20	20			20	20	920	271	2380	1122	20	20			40	24	20	20
Lindernia micrantha			100	77			60	40					20	20			540	154	2320	287	22580	11828	120	49	40	24	40	24	40	24
Lindernia procumbens			140	93			140	68	600	259	40	24	100	55	200	84	420	156	640	199	35000	15943	380	150	140	75	500	114	120	58
Ludwigia prostrata			20	20							20	20	20	20			4100	4100			820	365	20	20	40	24				
Mazus japonicus					40	40	600	179	420	97	1820	1037	1920	978	660	316	7340	4456	700	152	480	156	400	63	120	20	100		240	150
Panicum dichotomiflorum			20	20					280	58	120	58	100	45	20	20	20	20	60	24	40	24			40	24				
Persicaria hydropiper			100	63	40	24															20	20								

Appendix 1. Continued.

Scientific name	Janghang								Kangseo								Banpo				Amsa									
	WF		Pa		Ss		Ms		Pa		Ss		Ms		At		Pa		Ms		WF		Bn		Ss		Pa		Ms	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Persicaria nodosa			60	40	40	24	20	20	360	246	80	49			20	20					20	20								
Persicaria perfoliata			60	40					120	58	20	20			40	24											20	20		
Persicaria thunbergii																					20	20								
Phyllanthus ussuriensis											460	246																		
Pilea peploides							140	98													80	80								
Portulaca oleracea							120	58	40	40	20	20	20	20	80	58							80	58	20	20				
Ranunculus sceleratus			240	68			40	40	1240	709	240	129	420	196	460	460	840	244	460	169	180	92	220	107	80	37				
Rotala indica																					3520	2345								
S.e.taria viridis									1000	336	160	136	980	263	200	114			120	58					60	24				
Solanum nigrum									20	20					40	40														
Biennials																														
Alopecurus aequalis var. *amurensis*									100	55	100	55	80	37	160	87	40	40	20	20							20	20	600	207
Arenaria serpyllifolia																					20	20	40	24	40	40				
Barbarea orthoceras			20	20					20	20	20	20	200	114	40	40														
Beckmannia syzigachne			140	51							20	20	40	24							20	20	180	86						
Cardamine flexuosa							2380	586	20	20	20	20	2000	2000	20	20	40	40	80	80	80	20	400	105	360	81	80	37	40	24
Cerastium holosteoides var. *hallaisanense*							260	147																						
Chelidonium majus var. *asiaticum*													20	20	1600	1526														
Cyperus exaltatus var. *iwasakii*																					40	24								
Draba nemorosa var. *hebecarpa*							20	20			80	58	440	254									40	24	20	20				
Erigeron annuus			60	24			2040	1157	2620	1484	9760	3844	7420	882	7120	1965	1120	404	3200	792	380	213	740	144	580	171	80	49	1060	539
Erigeron canadensis							500	105	320	132	380	58	580	153	380	188	20	20	360	163	20	20			120	49			580	458
Galinsoga ciliata																	20	20					40	24						
Galium spurium													160	160			20	20	140	117									420	26
Gnaphalium affine																					20	20								
Hemistepta lyrata									20	20					80	37	40	40	100	32										
Lactuca indica var. *laciniata*							40	40	20	20					60	60	120	49	1280	421										
Lepidium apetalum							20	20					20	20									40	24						
Oenothera odorata											40	40	20	20	1620	1222	20	20	20	20			20	20						
Rorippa islandica			4400	1574	220	102	1460	183	440	160	340	103	340	129	100	55	6420	1779	3060	903	2360	756	3700	581	5980	3467	1240	211	280	183
Sagina japonica																					60	60	40	40			20	20		
Salvia plebeia			40	24			20	20	14200	8047	3040	2245	10380	6387	120	37	40	40	20	20	160	136	60	40	20	20			20	20
Stellaria alsine var. *undulata*							20	20					40	24					20	20	560	154	740	368	40	40			360	186
Stellaria aquatica			20	20			20	20	40	40			120	80	100	32	5100	1907	1480	899	40	24	1300	327	140	51				
Torilis japonica									660	144	840	492	1320	569	800	472	220	92	140	75			40	24	80	37				
Trigonotis peduncularis			20	20			260	147	640	591	380	107	3500	785	460	244			180	92			160	87	80	37			60	24
Veronica arvensis															60	40			20	20										

Appendix 1. Continued.

Scientific name	Janghang								Kangseo								Banpo				Amsa									
	WF		Pa		Ss		Ms		Pa		Ss		Ms		At		Pa		Ms		WF		Bn		Ss		Pa		Ms	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Veronica peregrina			440	163	1740	1740	7460	3776	5600	3308	2020	1372	63800	20383	240	87	3020	2038	520	58	7000	3716	3700	1736	3440	2062	180	49	920	577
Veronica persica															60	24	20	20												
Veronica undulata			20	20									40	40			100	55			280	146	80	37						
Youngia japonica							80	58	220	174	360	336	2660	1466	160	68	140	68	120	58	20	20	20	20	20	20			20	20
Perennials																														
Achyranthes japonica							20	20																						
Artemisia princeps var. *orientalis*									1840	396	80	37	3060	665	220	80			20	20	60	40			40	40				
Aster koraiensis									60	24	60	40			20	20	340	218	120	58	20	20								
Aster pilosus							40	40			280	196	60	60			80	80												
Calamagrostis epigeios									1060	987					20	20														
Calystegia japonica																			20	20										
Cirsium japonicum var. *ussurien SE*									20	20	40	24	20	20																
Equisetum arvense					20	20									80	20														
Erechtites hieracifolia									100	55	540	227	20	20	40	40													280	97
Isachne globosa											1780	1681					300	276	260	160										
Ixeris chinensis var. *strigosa*			20	20	20	20	40	24			80	37	60	40					60	60			60	24	20	20			20	20
Juncus alatus																					60	40	40	24			20	20		
Juncus effusus var. *decipiens*			220	58			60	40	20	20	860	835	160	93	180	156	1180	784	1020	442	1300	509	240	129	40	40	80	37	20	20
Juncus papillosus																					40	40	20	20			20	20		
Juncus tenuis									60	60	20	20					20	20			20	20			20	20				
Lemna paucicostata															20	20											20	20		
Mentha arvensis var. *piperascens*											540	447							140	93										
Miscanthus sacchariflorus							180	49					80	58			80	80											180	80
Oxalis corniculata																									80	20				
Penthorum chinense			20	20			20	20	40	40	420	191	200	114	40	40	1560	988			1440	856	20	20						
Phragmites australis					80	20			60	40					20	20	200	84	40	24							1300	454		
Plantago asiatica							20	20																						
Poa pratensis																							60	40						
Poa sphondylodes	20	20	4720	233	40	40	640	266	140	75	140	140	440	304	300	300	40	24	100	45	6880	2602	1480	440	700	288			80	80
Potentilla paradoxa			200				860	330	2560	641	1600	635	5460	733	1020	372	13040	4223	11980	3424	740	175	340	157	1660	1017			80	80
Ranunculus japonicus																			20	20										
Rorippa globosa			160	160			20	20	140	68	20	20	540	275	40	24	60	24	20	20			100	45	60	60	20	20		
Rumex crispus			300	158					20	20	100	45	400	164	40	40					360	181	220	49	20	20	40	24		
Scirpus radicans															40	40	120	37	80	20			400	152	120	49			20	20
Triadenum japonicum																					180	180	20	20						
Trifolium repens					20	20	20	20																	20	20			20	20
Typha angustifolia			560	194	100	32	420	159			180	97	20	20	20	20	120	97					20	20						
Veronica americana			20	20															20	20	1120	397	260	40	360	103	40	24		

Appendix 2. Plant species found in the above-ground vegetation at the 15 communities along the Han River, Seoul, South Korea. Community codes are given in Table 1.

Life history	Species	Janghang				Kangseo				Banpo		Amsa				
		WF	Pa	Ss	Ms	Pa	Ss	Ms	At	Pa	Ms	WF	Bn	Ss	Pa	Ms
Annuals	*Acalypha australis*						○									
	Aeschynomene indica						○					○				
	Ambrosia artemisiifolia var. *elatior*					○	○	○								
	Ambrosia trifida							○	○							
	Androsace filiformis											○			○	
	Artemisia annua					○		○						○	○	
	Arthraxon hispidus						○									
	Bidens frondosa		○			○	○		○	○	○	○	○	○		
	Bromus japonicus					○		○		○	○		○	○		
	Chenopodium album var. *centrorubrum*				○							○	○		○	○
	Chenopodium bryoniaefolium													○		
	Chenopodium ficifolium					○		○		○	○					
	Cnidium monnieri						○	○		○	○	○	○	○	○	
	Commelina communis						○		○		○					
	Cyperus amuricus									○	○					
	Cyperus difformis												○	○		
	Cyperus glomeratus												○	○		
	Cyperus orthostachyus							○				○	○	○	○	
	Cyperus sanguinolentus												○	○		
	Digitaria sanguinalis	○								○			○	○		
	Echinochloa crus-galli			○				○				○		○		
	Eclipta prostrata					○									○	
	Eleusin indica												○	○		
	Eragrostis multicaulis												○			
	Euphorbia supina													○		
	Fimbristylis dichotoma											○		○		
	Glycine soja					○	○	○	○	○	○					
	Humulus japonicus				○	○		○	○	○	○	○	○	○	○	○
	Kummerowia striata				○							○				
	Lindernia attenuata												○	○	○	
	Lindernia micrantha											○	○	○	○	
	Lindernia procumbens											○	○	○	○	
	Ludwigia prostrata											○	○	○		
	Mazus japonicus											○	○	○	○	○
	Panicum bisulcatum						○									
	Panicum dichotomiflorum						○		○	○	○		○	○		
	Persicaria nodosa		○	○			○						○	○		
	Persicaria perfoliata		○		○	○	○	○	○	○			○	○	○	○
	Persicaria thunbergii											○				
	Phyllanthus ussuriensis						○									
	Portulaca oleracea													○		
	Ranunculus sceleratus			○											○	
	Rotala indica													○		
	Setaria viridis					○										
	Sicyos angulatus		○				○		○					○		
	Solanum nigrum													○		
	Stachys riederi var. *japonica*									○						
Biennials	*Agropyron ciliare*				○					○	○					
	Alopecurus aequalis var. *amurensis*			○												
	Arenaria serpyllifolia				○											
	Barbarea orthoceras					○		○								
	Beckmannia syzigachne		○	○								○				
	Cardamine flexuosa				○	○						○	○	○		
	Chelidonium majus var. *asiaticum*					○	○							○	○	○

Appendix 2. Continued.

Life history	Species	Janghang				Kangseo				Banpo		Amsa				
		WF	Pa	Ss	Ms	Pa	Ss	Ms	At	Pa	Ms	WF	Bn	Ss	Pa	Ms
	Erigeron annuus				○	○	○	○	○	○	○	○	○	○	○	○
	Erigeron canadensis				○		○	○	○	○	○		○	○	○	○
	Galinsoga ciliata				○		○		○			○	○			
	Galium spurium		○			○		○								
	Hemistepta lyrata													○		
	Lactuca indica var. *laciniata*							○								
	Leonurus sibiricus									○	○		○			
	Oenothera odorata						○	○	○	○	○	○	○	○	○	○
	Ranunculus chinensis			○												
	Rorippa islandica	○		○	○	○	○		○		○		○	○	○	
	Rorippa islandica									○	○	○	○	○		
	Stellaria alsine var. *undulata*				○	○		○				○		○		
	Stellaria aquatica					○			○			○	○	○	○	
	Trigonotis peduncularis				○	○	○	○						○	○	
	Veronica peregrina				○	○		○				○				○
	Youngia japonica												○	○		
Perennials	*Achyranthes japonica*						○			○			○			
	Artemisia princeps var. *orientalis*				○				○					○		
	Artemisia selengensis											○	○	○	○	
	Aster pilosus					○		○								
	Boehmeria nivea														○	
	Calamagrostis epigeios					○	○	○	○							
	Calystegia sepium var. *americana*									○	○					
	Chrysanthemum boreale													○		
	Cirsium japonicum var. *ussuriense*					○		○								
	Equisetum arvense				○	○	○		○							
	Geranium koraiense													○		
	Gnaphalium japonicum													○		
	Isachne globosa					○	○									
	Ixeris chinensis var. *strigosa*							○								○
	Ixeris dentata				○									○		
	Lycopus ramosissimus var. *japonicus*			○												
	Mentha arvensis var. *piperascens*		○		○							○	○	○		
	Metaplexis japonica					○			○							
	Miscanthus sacchariflorus		○		○	○		○		○	○		○		○	○
	Phalaris arundinacea					○	○					○	○	○	○	
	Phragmites australis		○			○			○	○		○	○		○	○
	Plantago asiatica													○		
	Poa pratensis				○											
	Poa sphondylodes							○	○	○	○					
	Potentilla paradoxa					○		○				○	○	○	○	
	Robinia pseudo-acacia		○													
	Rorippa globosa											○	○	○		
	Rumex crispus						○		○			○		○	○	
	Salix gracilistyla											○		○		
	Salix koreensis						○							○		
	Salix nipponica			○			○							○		
	Salix pseudo-lasiogyne						○							○		
	Scirpus radicans											○				
	Sium suave			○												
	Spirodela polyrhiza	○														
	Trifolium repens				○											
	Typha angustifolia		○													
	Veronica americana													○		
	Zizania latifolia	○										○				