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Urban Thermo-profiles and Community Structure of *Quercus mongolica* Forests along an Urban-rural Land Use Gradient: Implications for Management and Restoration of Urban Ecosystems

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ABSTRACT: Land cover changes associated with urbanization have driven climate change and pollution, which alter properties of ecosystems at local, regional, and continental scales. Thus, the relationships among urban ecological variables such as community composition, structure, health, soil and functioning need to be better understood to restore and improve urban ecosystems. In this study, we discuss urban ecosystem management and research from a futuristic perspective based on analyses of vegetation structure, composition, and successional trends, as well as the chemical properties of soils and the distribution of heat along an urban-rural gradient. Urban thermo-profile analysis using satellite images showed an obvious mitigating effect of vegetation on the Seoul heat island. Community attributes of *Quercus mongolica* stands reflected the effects of urbanization, such as pronounced increases in disturbance-related and pollution-tolerant species, such as *Styrax japonica* and *Sorbus alnifolia*. Retrogressive successional trends were detected in urban sites relative to those in rural sites. Changes in the urban climate and biotic environment have the potential to significantly influence the practice and outcomes of ecological management, restoration and forecasting because of the associated changes in future bio-physical settings. Thus, for management (i.e., creation and restoration) of urban green spaces, forward-thinking perspectives supported by historical information are necessary.

Key words: Futuristic restoration, Heat island, *Quercus mongolica*, Seoul, Urban climate, Urbanization

INTRODUCTION

Urban forests are not important only habitats including diverse species (Spellerberg et al. 1991, Hudson 1991, Saunders and Hobbs 1991), but also serve important roles in environmental protection by buffering against environmental stresses in urbanized area (Bradly 1995). Studies on urban ecology have clarified the relationships between urban forest structures and specific functions such as visual quality (Schroeder 1986), energy savings (McPherson 1993), removal of atmospheric carbon dioxide (Rowntree and Nowak 1991), urban heat island mitigation (Huang et al. 1987, Oke 1989, McPherson 1994), sound reduction (Cook and Van Haverbeke 1977), and service as wildlife habitats (DeGraaf and Wentworth 1986). Urban ecosystems display clear and significant differences in soils, plant and animal species composition, atmospheric deposition, nutrient cycling, and community dynamics from rural or natural ecosystems (McDonnell and Pickett 1990, Pouyat and McDonell 1991, Goldman et al. 1995).

Korea has pursued rapid urbanization and industrialization since the 1960's. Seoul, which covers 605 km^2 and is home to more than 25% of the Korean population, has been a metropolitan area since the 1970's and is well known among the representative metropolitan areas in Asia (Yokohari et al. 2000). Land-use in the Seoul metropolitan area has changed from primarily agricultural and forested land to areas of human habitation and industry as the population has increased and industrialization (Lee et al. 2000, Lee et al. 2001, Kim et al. 2003). In Korea, the vegetation in urban ecosystems has begun to show symptoms of decline in the vicinity of industrial complexes and big cities (NIER 1981, Lee et al. 2008). Loss of basic cations, such as Ca^{2+} and Mg^{2+}, coupled with increases in toxic Al^{3+} in the soil due to acidification have caused further ecosystems degradation (Rhyu and Kim 1994).

Urbanization is occurring worldwide on a massive scale (Alig and Healy 1987, Meyer and Turner 1992), and has induced various types of alterations to our abiotic and biotic surroundings (Grimm et al. 2008a, Grimm et al. 2008b, Pavao-Zuckerman and Byrne 2009). In particular, land cover changes associated with urbaniza-

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tion have driven climate change and pollution, which alter properties of ecosystems at local, regional, and continental scales (Bonan 2000, Lee et al. 2007, Lee et al. 2008). Thus, the relationships among urban ecological variables (composition, structure, health, soil and functioning) need to be better understood because appropriate urban landscape and vegetation policy and management decisions will maximize the ecological benefits for residents and future generations.

This study aims to diagnose the actual state of vegetation in urban forests based on their species composition, chemical properties of the soil, and urban heat effects. In addition, we will discuss sustainable management plans from a forward-thinking perspective based on landscape and restoration ecological principles.

METHODS

Study Area and Vegetation Sampling

The study area is the city of Seoul, the capital of South Korea, and the surrounding areas in central Korea. The study area is classified as a cool temperate forest zone. The mean (30-year) annual precipitation and temperature in Seoul are 136.9 cm and 12.2℃, respectively. Seoul's mean temperature is about 0.7℃ higher than those of the adjacent big cities Incheon, Suwon, and Chuncheon (Korea National Statistical Office 2002). A vegetation survey was carried out from July to October, 2005 in 34 plots distributed across five sites of different distances from the urban center of Seoul (Fig. 1). The five sampling sites are Mt. Nam (N37° 33' 6", E126° 59' 15"), Mt. Gwanak (N37° 26' 44", E126° 57' 49"), Mt. Surak (N37° 41' 56", E127° 4' 53"), Mt. Jookyup (N37° 47' 28", E127° 11' 8") and Mt. Wunak (N37° 52' 36", E127° 19' 30"). Mt. Nam, Mt. Gwanak and Mt. Surak are located within the Seoul metropolitan area and the others are in rural areas in Gyeonggi-do.

Field sampling followed the quadrat method (Barbour et al. 1999). As oak stands represent late successional forest and are distributed widely in Korea (Kim and Kil 2000), we collected vegetation data in *Quercus mongolica* stands in upper slopes of the sampling sites. Six 20 × 20 m plots were placed in each study area except for Mt. Nam, in which 10 plots were placed. We identified all woody species appearing in each plot and determined their basal area (at 1.3 m height) and density of each woody species. We followed the species nomenclature of Lee (1985), Park (1995), and the Korea Forest Service (2003).

Soil and Satellite Image Analyses

We collected five soil samples from each sample plot within the top 10 cm of and pooled them. Each soil sample was dried for 10 days in shaded conditions in the laboratory and sieved through a 2 mm-mesh frame. Soil pH was measured with a bench-top probe after mixing soil with distilled water (1:5 ratio, w/v) and filtering the extract (Whatman No. 44 paper).

Exchangeable K^+, was measured using a flame photometer (Jenway PFP 7), exchangeable Ca^{2+} and Mg^{2+} were measured using the EDTA (ethylene-diamine tetraacetic acid) titration method, and soluble Al^{3+} was measured using the XRF (X-ray fluorescence analyzer, Spectrace Quan XⅡ) method (National Institute of Agricultural Science and Technology 2000).

We extracted surface temperatures and Normalized Difference Vegetation Indices (NDVI) from Landsat TM (3 June 2002 and 12 September 2006) images and the ERDAS IMAGINE 8.6 modeler. Temperatures were extracted from the thermal band of the Landsat

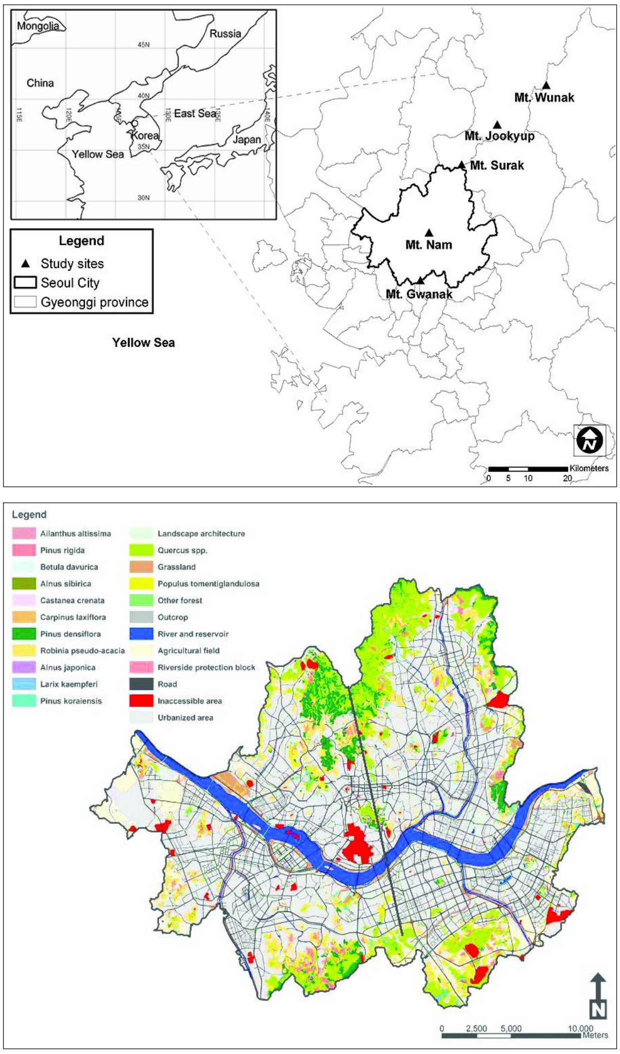

Fig. 1. Maps showing the location of the five standard study sites (upper), and the landscape of Seoul city (lower, Seoul city 2000). In the lower map, the bold line indicates the track for the thermo-profile extraction.

TM satellite images. To exhibit the spatial distribution of surface temperatures, we developed a thermo-profile of Seoul city by interpreting satellite images from 12 September 2006. The NDVI is based on the ratio of the maximum absorption of radiation in the red spectral band to the maximum reflection of radiation in the near infrared spectral band. NDVI values range between −1.0 and +1.0 (Jensen 1996), with those approaching +1.0 indicating the presence of dense vegetation cover (closed canopy forest). These values were derived using ArcView GIS software (ESRI 2005).

Statistical Analyses

We measured the basal area and density of all woody species in plot. Importance values were calculated for all woody species for each sampling plot as the sum of relative density and relative basal area (Curtis and McIntosh 1951). A matrix of importance values for all species in all plots was established and subjected to Detrended Correspondence Analysis (DCA, Hill 1979) and Canonical Correspondence Analysis (CCA, ter Braak 1986) for ordination with MVSP 3.1 (Kovach 2004). We also conducted CCA ordination on the soil parameters pH, K^+, Ca^{2+}, Mg^{2+}, and Al^{3+}. Stand dynamics were analyzed using a diameter class distribution diagram.

We then used the Kruskal - Wallis test (a non-parametric ANOVA) in SPSS ver. 12.0 (SPSS Inc. 2003) to compare the differences in means of soil properties among study sites. Indicator species for each sampling site were identified with ISPAN (indicator species analysis; Dufrêne and Legendre 1997; McCune and Mefford 1999) using PC-ORD ver. 4.0 (McCune and Mefford 1999).

RESULTS

Heat Distribution in Seoul City

Severe imbalances in the heat distribution were detected in Seoul City (Fig. 2). Major green spaces (especially forest vegetation, such as Mt. Bukhan, Mt. Nam and Biwon) and water bodies (Han River) were associated with lower temperatures, whereas the developed areas displayed much higher temperatures (see lower part of Fig. 1).

Stand Structure and Species Composition

Mt. Nam and Mt. Gwanak, which were close to the urban center, showed higher densities and basal areas of *Sorbus alnifolia* and *Styrax japonicas* than the other study areas, whereas other dominant species including *Q. mongolica*, showed the reverse trend (Table 1).

DCA ordination of *Q. mongolica* stands was carried out in order to compare species compositions among study areas that were different distances from the urban center (Fig. 3). The eigenvalues of Axis Ⅰ and Axis Ⅱ were 0.65 and 0.25, respectively. Stands were generally arranged in the order of distance from the urban center in

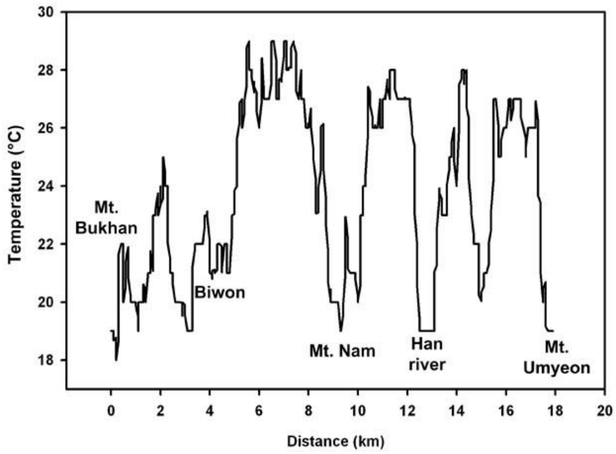

Fig. 2. Thermo-profile diagram of Seoul city extracted using Landsat TM satellite imagery (12 September 2006).

the diagonal direction between Axes Ⅰ and Ⅱ except for the stands on Mt. Jookyup. The results of the CCA ordination are shown in Fig. 4. The eigenvalues of Axis Ⅰ and Axis Ⅱ were 0.337 and 0.139, respectively. The dominant environmental variable correlated with Axis Ⅰ was K^+ (intraset correlation is 0.716), whereas Al^{3+} and pH showed higher correlations with Axis Ⅱ (intraset correlations were −0.703 and 0.477, respectively). On Axis I, the stands on Mt. Jookyup were spread across the right side, whereas the other stands were located close to each other on the left. On Axis Ⅱ, stands tended to be distributed in the order of distance from the urban center; that is, in the order of Mt. Nam, Mt. Gwanak, Mt. Surak, Mt. Jookyup, and Mt. Wunak from the bottom to the top.

Our ISPAN listed a total of 23 species as indicator for the five study sites (Table 2). In study sites located in Seoul, disturbance-related and pollution-tolerant species such as *S. japonicus*, *Kalopanax septemlobus* and *S. alnifolia* were listed as indicator species. The importance values of *S. alnifolia* and *S. japonicus* were highest on Mt. Nam and decreased with distance from the urban center while those of the dominant species, *Q. mongolica*, and the other species tended to increased with distance from the center (Fig. 5).

Stand Dynamics

Diameter class distribution diagrams of major woody species investigated on Mt. Nam usually showed a reverse J-shape (Fig. 6). *Q. mongolica* dominated the larger diameter classes and showed a high frequency even in the smallest classes (<5 cm), but *S. alnifolia* and *S. japonica* dominated the smaller diameter classes. The diagram for Mt. Gwanak showed a similar pattern to that for Mt. Nam except for the low occupancy of *Q. mongolica* in smaller diameter classes (<5 cm). On Mt. Surak and Mt. Wunak, *Q. mongolica* dominated all diameter classes. Mt. Jookyup was clearly different

Table 1. Summary of basal area (BA; m^2) and stem density (stems / ha) in the five study areas

Species	Mt. Nam		Mt. Gwanak		Mt. Surak		Mt. Jukyup		Mt. Wunak		Freq.
Tree species	BA	Density	BA	Density	BA	Density	BA	Density	BA	Density	
Quercus mongolica	29.2	1,460	30.9	917	29.1	1,500	43.9	833	24.0	4,133	100.0
Sorbus alnifolia	4.4	1,400	2.4	1,533	0.6	417	1.3	67	< 0.1	17	70.6
Fraxinus	1.3	130	0.4	217	< 0.1	150	6.5	750	0.1	1,333	67.6
Acer	0.7	1,380	0.1	317	< 0.1	117	1.2	717	< 0.1	17	64.7
Fraxinus rhynchophylla	–	–	< 0.1	67	< 0.1	33	1.7	733	< 0.1	33	35.3
Acer pseudosieboldianum	3.2	990	0.2	167	–	–	–	–	–	–	32.4
Acer pictum	–	–	< 0.1	17	–	–	1.6	717	< 0.1	133	26.5
Q. serrata	< 0.1	90	–	–	–	–	< 0.1	50	–	–	23.5
Prunus serrulata var. *pubescens*	1.2	40	0.1	133	< 0.1	200	< 0.1	17	–	–	17.6
Castanea crenata	–	–	–	–	< 0.1	200	< 0.1	33	–	–	14.7
Cornus controversa	< 0.1	10	–	–	1.0	317	6.7	717	–	–	14.7
Cornus kousa	–	–	–	–	–	–	1.4	183	–	–	11.8
Carpinus laxiflora	–	–	–	–	–	–	3.5	233	–	–	11.8
Robinia pseudoacacia	< 0.1	30	-	-	< 0.1	50	–	-	–	–	11.8
subtotal	2.8	395	2.4	241	2.2	213	4.8	361	1.7	405	
Shrub species											
Rhododendron mucronulatum	0.1	180	0.3	1,021	2.1	2,033	0.2	383	0.2	733	73.5
Symplocos chinensis	< 0.1	50	0.1	217	0.3	767	< 0.1	200	0.1	700	67.6
Lindera obtusiloba	< 0.1	10	< 0.1	427	0.1	1,483	0.1	967	1.5	6,700	67.6
Stephanandra incisa	< 0.1	880	< 0.1	517	< 0.1	883	< 0.1	17	–	–	55.9
Rhus tricocarpa	< 0.1	250	0.2	200	0.3	200	< 0.1	200	0.1	100	52.9
Euonymus oxyphyllus	< 0.1	150	< 0.1	400	–	–	1.3	3,550	< 0.1	50	50.0
Callicarpa japonica	< 0.1	200	< 0.1	100	< 0.1	83	< 0.1	17	< 0.1	100	38.2
Viburnum erosum	0.1	1,570	–	–	–	–	< 0.1	83	–	–	35.3
Lonicera praeflorens	–	–	< 0.1	50	–	–	< 0.1	217	< 0.1	50	32.4
Rhododendron schlippenbachii	–	–	1.3	1,317	< 0.1	217	–	–	–	–	29.4
Weigela subsessilis	< 0.1	10	< 0.1	83	–	–	–	–	< 0.1	50	26.5
Zanthoxylum schinifolium	–	–	< 0.1	17	< 0.1	167	–	–	< 0.1	67	23.5
Euonymus alatus	< 0.1	10	< 0.1	33	< 0.1	33	< 0.1	583	–	–	23.5
Lespedeza maximowiczii	< 0.1	120	< 0.1	83	< 0.1	17	< 0.1	50	< 0.1	67	20.6
subtotal	0.1	312	0.5	343	0.7	588	0.2	448	0.5	862	
Others	< 0.1	3	< 0.1	11	< 0.1	15	0.1	84	< 0.1	12	

from the other areas. Other species, such as *Carpinus laxiflora*, *Acer picum, Fraxinus rhynchophylla,* dominated all diameter classes except for classes > 30 cm, which were dominated by *Q. mongolica*.

Chemical Properties of Soil

The mean concentrations of K^+, Ca^{2+} and Al^{3+} exhibited significant differences among sites (Table 3). Soil pH was highest on Mt.

Wunak (4.92), followed by Mt. Nam (4.71), Mt. Jookyup (4.70), Mt. Gwanak (4.51) and Mt. Surak (4.51). The Al^{3+} contents of most sites were similar, except for Mt. Wunak, which had a much lower level. Ca^{2+} and Mg^{2+} tended to increase with distance from the ur-

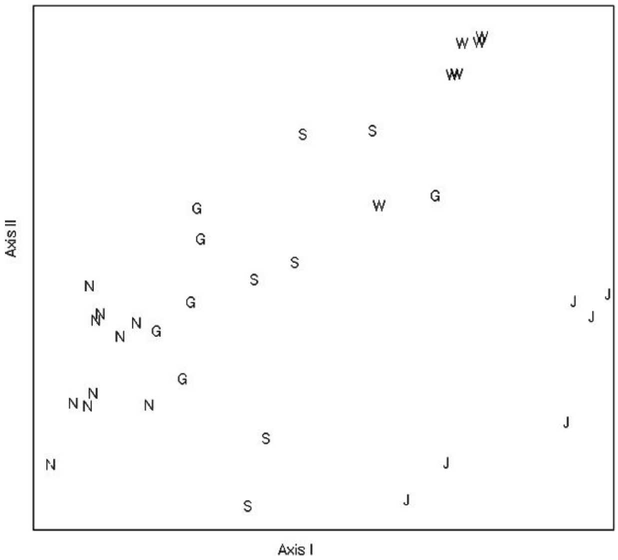

Fig. 3. Results from DCA ordination based on vegetation data collected in oak (*Q. mongolica*) forests at five study sites representing different distances from the center of Seoul. The five study sites: Mt. Nam (0 km; N), Mt. Gwanak (11 km; G), Mt. Surak (17 km; S), Mt. Jookyup (33 km; J), and Mt. Wunak (47 km; W).

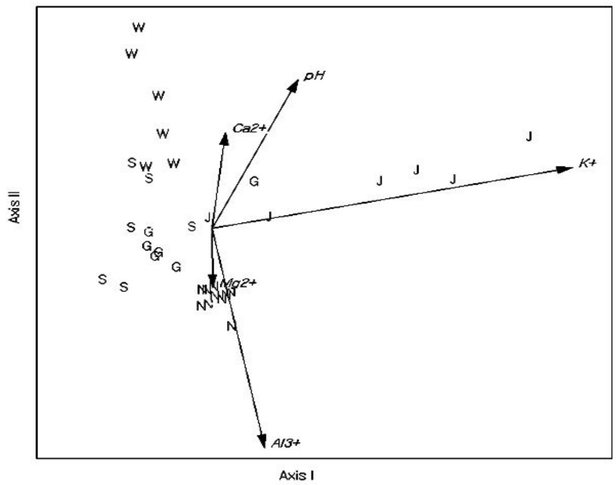

Fig. 4. Results from CCA ordination based on soil and vegetation data collected in oak (*Q. mongolica*) forests at five study sites representing different distances from the center of Seoul. The biplot overlay shows vectors strongly related to the three environments, K^{+}, Al^{3+}, pH. The five study sites are indicated as in Fig. 3.

Table 2. Tree species showed significant associations ($p < 0.05$) with the sampling sites, based on indicator species analysis (ISPAN). "Max group" is the site in which a species exhibited its maximum observed indicator value, IV_{max}

Species	Max group	IV_{max}	*p*
Acer pseudosieboldianum	Mt. Nam	90.9	0.001
Styrax japonicus	Mt. Nam	59.0	0.001
Kalopanax septemlobus	Mt. Nam	42.1	0.045
Quercus serrata	Mt. Nam	30.0	0.03
Sorbus alnifolia	Mt. Gwanak	45.6	0.008
Castanea crenata	Mt. Surak	59.6	0.005
Juniperus rigida	Mt. Surak	50.0	0.015
S. obassia	Mt. Jookyup	87.2	0.001
Cornus controversa	Mt. Jookyup	66.7	0.002
Cornus kousa	Mt. Jookyup	66.7	0.003
Carpinus laxiflora	Mt. Jookyup	65.4	0.002
A. pictum	Mt. Jookyup	58.0	0.007
Pinus koraiensis	Mt. Jookyup	50.0	0.01
Carpinus cordata	Mt. Jookyup	50.0	0.016
Celtis jessoensis	Mt. Jookyup	50.0	0.016
Q. mongolica	Mt. Wunak	25.0	0.013

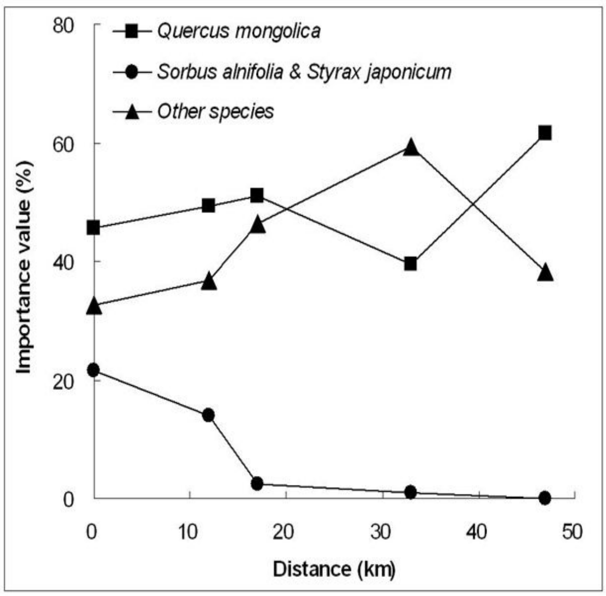

Fig. 5. Changes in the importance value of *Q. mongolica*, *S. alnifolia*, and *S. japonica*, and other species with distance from the urban center of Seoul.

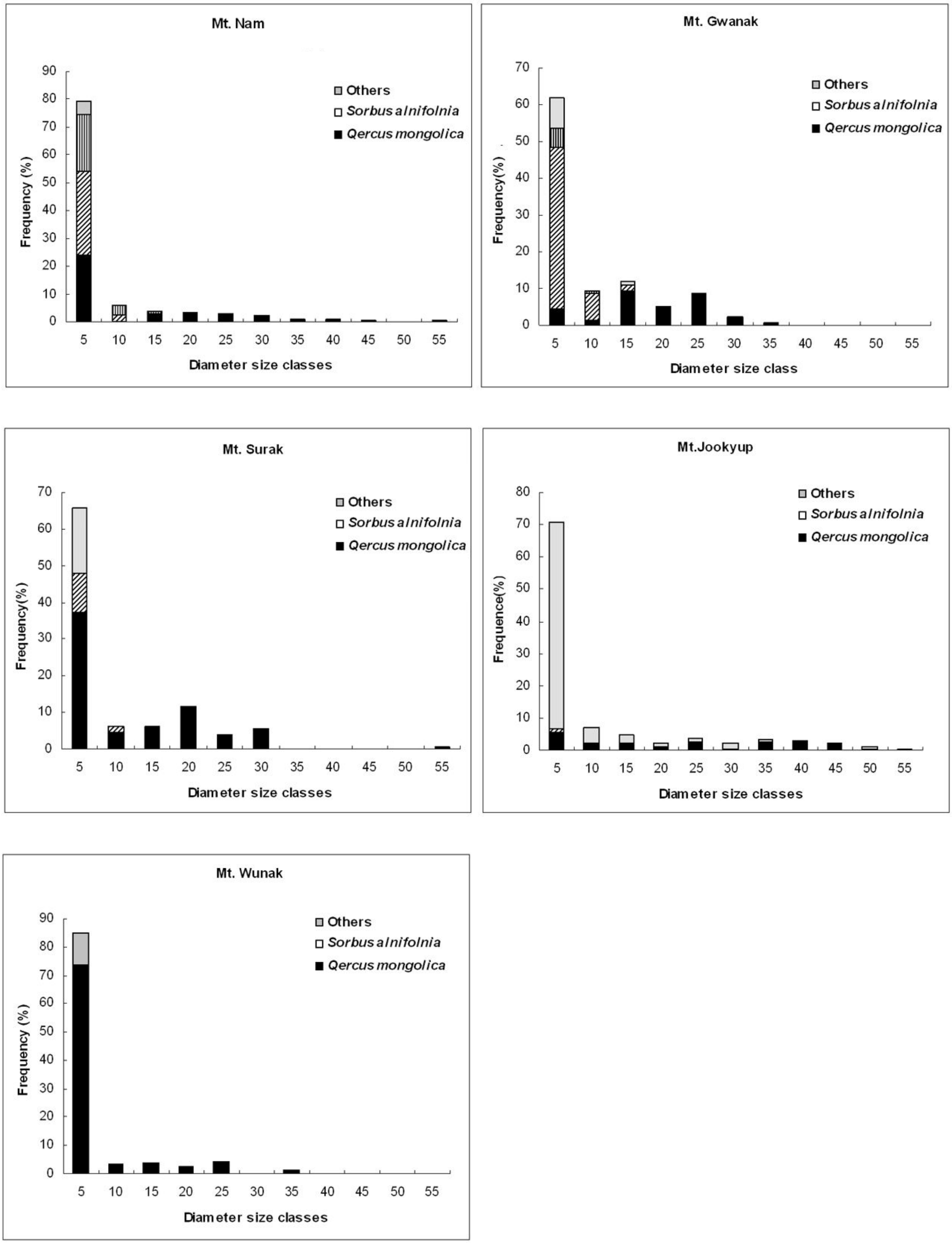

Fig. 6. Frequency distribution of diameter classes of major tree species in each study site.

Table 3. Comparisons of soil environmental factors (mean ± standard deviation) among study areas

Sites	pH	K^+ ($cmol^+/kg$)	Ca^{2+} ($cmol^+/kg$)	Mg^{2+} ($cmol^+/kg$)	Al^{3+} ($cmol^+/kg$)
Mt. Nam	4.71 ± 0.37	0.65 ± 0.08	3.18 ± 2.42	1.15 ± 0.68	10.36 ± 0.50
Mt. Gwanak	4.51 ± 0.22	0.51 ± 0.13	1.16 ± 0.93	0.59 ± 0.44	9.81 ± 1.75
Mt. Surak	4.51 ± 0.19	0.38 ± 0.08	0.54 ± 0.27	0.43 ± 0.13	10.97 ± 1.37
Mt. Jookyup	4.70 ± 0.29	0.72 ± 0.10	1.54 ± 0.77	0.58 ± 0.32	10.49 ± 0.52
Mt. Wunak	4.92 ± 0.29	0.58 ± 0.13	3.51 ± 3.88	0.77 ± 0.44	8.37 ± 0.77
KW* tests	H = 7.45 p = 0.11	H = 18.99 p = 0.001	H = 16.2 p = 0.003	H = 8.48 p = 0.076	H = 13.96 p = 0.007

* KW means Kruskal-Wallis test.

ban center except on Mt. Nam, perhaps because most of the forested land on Mt. Nam had been limed to improve soil acidification.

DISCUSSION

Urbanization and Response of Vegetation

Low soil pH in the Seoul metropolitan area is explained usually by acid deposition, which originates from air pollution resulting from urbanization and industrialization (Kim et al. 1999). The effects of heavy particles originating from concrete buildings may also contribute to the increase of soil pH (Miller 1997, Lee et al. 2008). The relatively high soil pH in Mt. Nam, however, is undoubtedly due to liming used to ameliorate acid soil. The high Ca^{2+} and Mg^{2+} contents there are also consistent with this explanation.

The relationship between community structure (and species composition) and soil pH results partly from other soil chemical processes related to soil pH, as the direct effects of soil pH on plants are very limited (Barbour et al. 1999). For example, certain toxic metals, such as aluminum and manganese, are more soluble at lower pH. Indeed, forest decline is usually recognized as being caused by soil acidification and the resulting Al^{3+} toxicity (Ulich 1980). Forest decline, which was found in European countries and United States decades ago, has not been reported in Korea until now, but unusual species compositions and retrogressive succession originating from chronic air pollution and acid rain have been observed in many Korean urban and industrial areas since the 1980s (Kim et al. 1985, Kim 1994, Rhyu and Kim 1994, Ryu and Lee 1992, Seoul City 1997, Lee et al. 1998a, Lee et al. 1998b, Seoul City 2000, Lee et al. 2001, Lee et al. 2008).

Deterioration or changes in forest vitality in urban areas caused by environmental stressors such as air pollution, soil acidification (mainly in the 1970's and 1980's), and heat have been detected in NDVI analyses, as well as severe imbalances in pollution sources and sinks (vegetation) (Cho 2006). Changes in urban environments have modified vegetation structure (Lee et al. 2008) resulting in changes in light condition for undergrowth layers in *Q. mongolica* stands (Seol 2008). These changes in turn led to an increase in disturbance- and stress-tolerant species, such as *S. alnifolia* and *S. japonicus* in the shrub and subtree layers of urban forests. *S. japonicus* was selected as an air-pollution-tolerant species for a management plan to restore degraded forests in industrial areas (Lee et al. 2001, 2004). Accordingly, the high density and basal area of *S. japonicus* in the urban center may be explained as a result of air pollution. *S. alnifolia* generally performs best under full sunlight and is not only cold-resistant but also tolerant of heat, drought, and insect stress (Gilman and Watson 1994). *S. alnifolia* communities usually emerge in urban areas and appear as a result of retrogressive succession after the degradation of plant communities including *Q. mongolica* stands (Cho and Choi 2003).

Structural changes in vegetation due to the sudden emergence of disturbance- or stress-tolerant species could also affect the herbaceous cover, and as a consequence, lead to decreased plant abundance (cover and diversity) and changes in the species composition (Vacek et al. 1999). Loss of diversity in the groundcover due to dominance of one or several species such as *Disporum smilacinum* and *Oplismenus undulatifolius* is likely explained by urbanization disturbance (Lee et al. 1998c).

Implications for Urban Ecosystem Research and Management

Restoration of degraded urban vegetation offers an opportunity to get the public involved in healing, managing, and understanding local ecosystems (Miller and Hobbs 2002, Jordan 2003, Light 2003, Vidra and Shear 2008). Environmental stresses on urban forests and the plant and animal species in them are continuously increasing because of sustained human population growth, pollution, climate change, and other threatening factors. Urban ecosystems have already been changed substantially by human activities. As a response to the changed urban environment, plant communities display abnormal structure and retrogressive succession even large distances from the origin of the disturbance (Cho 2006). Environmental degradation also affects the forest functions that benefit humans, such as air filtration, water retention, and so on. Unbalance between the sources of air pollutant and the ability of forests to filter this pollution or serve as a sink is severe in the Seoul metropolitan area (Cho 2006). Increases in pollution sources and decreases in the capacity of urban forests to buffer pollution cause various problems such as heat island effects, forest decline, global warming and human disease. In addition, these imbalances could lead to unexpected effects in other ecosystem components in urban areas and their environs. Unfortunately, plans for improvement and sustainable management of urban ecosystems are still far away, and partial restoration or rehabilitation is unlikely to be insufficient to solve the problem.

Ecological diagnosis and management planning for urban ecosystems that are severely affected by urbanization require balanced perspectives and approaches. Recently, several researchers have suggested that ecological approaches related to environmental change require an active and forward-thinking perspective (Choi 2004, Harris et al. 2006, Choi et al. 2008). Future changes in urban climates and biotic environments have the potential to significantly influence the practice and outcomes of ecological restoration and forecasting because of the changed bio-physical settings that will occur in the future. Current changes in environmental conditions seem to be outside of the historical ranges of variation (Jentsch et al. 2007). Urban vegetation can not only mitigate urban climates, but also lead to imbalances in thermo-distribution, which could result in micro-weather events such as heavy rainfall in the city. Thus, landscape- and regional-level management planning and policy for urban ecosystems is required, and balanced improvements in urban green spaces are recommended. The effects of urban heat islands on plant communities are not yet clear because the effects of high temperatures on stand structure are complex. However, it is clear that the effects of urbanization on ecosystems will be ongoing. Thus, for management (creation and restoration) of urban systems, forward-thinking perspectives are necessary.

We have suggested a solution for the problems associated with urbanization by creating green spaces in the urban center through a green network linking core vegetation elements in the urban ecosystem (Lee et al. 2008). Currently, the distances between the existing green spaces are too large. Alternatively, green spaces can be linked by improving the ecological quality of linear elements in cities, such as rivers, streams and extra spaces along sidewalks (Lee et al. 2008).

Urban forests and environments in Seoul have been degraded as a result of urbanization, and creative approaches will be required to solve this problem and to enhance environmental quality. Moravčik (1994) found that spontaneous regeneration of *Sorbus aucuparia* in declining spruce forests contributed to the development of new forest ecosystems in heavily polluted regions. Such adapted system may be an alternative for rehabilitation of urban ecosystems because it is questionable whether the use of reference systems and historical data for urban ecosystem management is appropriate in changed environments.

As vegetation responds to urban environments affected by heat islands, drying, other weather events and pollution, growing differences between urban and rural vegetation may reflect a process of ecosystem adaptation. Thus, urban ecosystem research is very important for forecasting changes of systems in response to global warming originating from urbanization and industrialization. Generally, it is assumed that movement of vegetation zones following climate change is a slow and gradual process. However, in light of the urbanization that has occurred over the last 30～40 years in Korea, responses of plants and communities to environmental change appears to be occurring faster than expected (e.g. Lee et al. 2007), and historical vegetation trajectories may not be good predictors of future changes. For instance, in urbanized areas such as roadsides and urban forests (e.g., Mt. Nam and Mt. Gwanak), a portion of the leaves of *Q. mongolica* individuals remain on the tree over the winter and fall in spring of the next year (Seol 2008), it is a phenomenon that must be interpreted in terms of the warming and drying effects of urbanization. Therefore, current and future adaptations of plant communities to environmental change in urban areas should be considered in the forecasting and modeling of vegetation zone movement.

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LITERATURE CITED

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