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Ecological comparison of Mongolian oak (*Quercus mongolica* Fisch. ex Ledeb.) community between Mt. Nam and Mt. Jeombong as a Long Term Ecological Research (LTER) site

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Abstract

Species composition, frequency distribution of diameter classes, species diversity, and stem vitality of woody plants were analyzed in a Mongolian oak (*Quercus mongolica* Fisch. ex Ledeb.) forests in permanent quadrates of Mt. Nam and Mt. Jeombong, which were installed for Long Term Ecological Research (LTER). The principal objective of this study was to clarify the ecological characteristics of both sites by comparing the Mongolian oak communities established in Mt. Nam surrounded by urban area and in Mt. Jeombong as a natural area, to accumulate the basic data for long-term monitoring, and furthermore to predict possible changes in vegetation due to climate change. The species composition of the Mongolian oak community on Mt. Nam differed from that of Mt. Jeombong. Such differences were usually due to *Sorbus alnifolia, Styrax japonicus, Oplismenus undulatifolius, Ageratina altissima* and so on, which appeared in higher coverage in Mt. Nam. Species diversity of the Mongolian oak community in Mt. Nam was lower than that in Mt. Jeombong. This result was attributed to the fact that the Mongolian oak community in Mt. Nam is under continuous management and was dominated excessively by *S. alnifolia,* and *S. japonicus,* which were originated from artificial interference and chronic air pollution. As the results of analyses on the frequency distribution of diameter classes of major tree species and the transitional probability model based on Markov chain theory, the Mongolian oak community in Mt. Nam showed a possibility of being replaced by a *S. alnifolia.* Considering that this replacement species is not only a sub-tree but is also shade-intolerant, such a successional trend could be interpreted as a sort of retrogressive succession. The Mongolian oak community established in Mt. Jeombong differed from the community in Mt. Nam in terms of its probability of being continuously maintained.

Key words: diameter class distribution, Markov chain, Quercus mongolica, species composition, species diversity

INTRODUCTION

Earth's climate, biota, and ecosystems are changing constantly, and have been changing since life began billions of years ago. Only recently, though, have we begun to understand how these changes are regulated on

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a global scale. Some of the most exciting scientific discoveries of recent decades have shown us how physical, geological, chemical, biological, and human processes all interact with each other to control this never-ending process of global change.

Global Change Research is an attempt to increase our understanding of those processes and interactions that regulate the total Earth system, and of their cumulative effects on the future of our planet. The study of Global Change is particularly important, as it is now clear that human social and economic activities around the world are having an impact that can be measured at the level of the entire Earth and its atmosphere, oceans, and land surface. Human activities are probably the most rapidly changing component among the major regulators of the Earth system, and may, in the future, play a dominant role in the regulation of global climate, global biogeochemistry, and the diversity and stability of global ecosystems (http://www.lternet.edu/global_change) (Lee et al. 2006).

Our planet and global environment are witnessing the most profound changes in the brief history of the human species. Human activity is the major agent of those changes--depletion of stratospheric ozone, the threat of global warming, deforestation, acid precipitation, the extinction of species, and others that have not become apparent (Defries and Malone 1989).

Humans manage much of the Earth system, and their role in this regard is certain to increase in the future. However, this management of the whole Earth is not always acknowledged, much less clearly understood. It is incumbent on humans to understand how their actions have global effects, and to use that understanding to manage their impacts on the global as well as the local levels. For this reason, Global Change Research is a high national and international scientific priority (http://www.lternet.edu/global_change).

The term “Long Term Ecological Research (LTER)” was used for the first time as NSF of USA begins to supply research fund by the name. LTER is a method of ecological research which is progressed long time in a given ecosystem as a research system being required necessarily in the ecological study, in which spatial scale for research object is big and thereby long period is required for understanding the reality. This research system began long period to get agreement globally as the importance and research efficiency of LTER are embossed from 1990’s (Ministry of Environment of Korea 2004b) and similar research programs of various countries around the world were joined into ILTER in 1993 (Ministry of Environment of Korea 2004a).

LTER sites are windows to global change. As observatories, LTER sites serve to document long-term changes in plants, animals, microbes, and soils in relation to long-term climate and short-term weather changes. As locations for long-term experiments, LTER sites illuminate interactions among the physical, chemical, and biological components of ecosystems through controlled manipulations. As representatives of global biodiversity, LTER sites allow for comparisons of the relative sensitivity of populations, communities, and ecosystems to environmental changes. Finally, synthesis and modeling of results from LTER sites provides predictions of feedbacks, both positive and negative, on global change. Research at LTER sites spans a broad range from relatively less-managed landscapes such as arctic tundra, to intensively managed cities and farmlands.

The Korean National Long-Term Ecological Research (KNLTER) designated Mts. Jeombong, Worak, and Jiri as the representative research sites for the northern, central and southern areas of South Korea, respectively. In addition, Mt. Nam, the Yeocheon industrial complex, Wanju, Jeju Island, and Samcheok were designated as sites for researches on terrestrial ecosystem of urban, industrial, agricultural, island and burned areas, respectively. The Han River, Nakdong River, Upo swamp, Daecheong Dam, Saemangum tidal flat, Hampyung Bay, and Goraebul sand dunes were designated as research sites for the monitoring of the aquatic ecosystems.

Forest environments are currently faced with severe environmental stress and disturbances. Excessive development of forests from population increases, climate change due to increases in warming gases, environmental pollution, and resultant severe changes are predicted. In order to cope with this real aspect and the changes that may occur in the future, the dynamics of forest communities need to be analyzed. The accumulation of basic data through the LTER could be helpful for understanding of the structure and function of the global ecosystem, and may also contribute profoundly maintenance and management of the ecosystem.

Mt. Nam is located in the center of Seoul, as a LTER site of urban area. The area, where Mt. Nam is located, has experienced very rapid changes in landscape structure due to urbanization and industrialization accelerated since the 1960s. Changes in the landscape structure of Seoul were attributable to increases of urbanized area. Forest and agricultural fields such as paddy and upper fields have decreased as the result of these changes. Excessive land use by humans has resulted not only in quantitative reductions but also qualitative degradation of greenery space, which absorbs and filters environmental stresses such as air pollution, acid rain, and the urban heat island effect. Causal factors of forest decline in Seoul are difficult to clarify through temporary and partial research as forest decline is result from the interaction of various factors. In this regard, Mt. Nam is a crucial site for long-term ecological research on the urban landscape (Cho et al. 2009a, 2009b).

Mt. Jeombong is located on Girin-myeon, Inje-gun, Gangwon-do, in central-eastern Korea, and is the representative forest area in Korea. Deciduous broad-leaved forest is well developed and diverse plant communities appear, and thus the area is of high academic value (Lee et al. 2000).

The objectives of this study are as follows: 1) to clarify the ecological characteristics of Mts. Nam and Jeombong by analyzing the structure and dynamics of the *Quercus mongolica* community, 2) to construct the basic data for monitoring of *Q. mongolica* communities on Mts. Nam and Jeombong, and 3) to predict changes in vegetation due to environmental changes, including climate change.

MATERIALS AND METHODS

Study areas

Mt. Nam

Mt. Nam is located in the central part of Seoul and ranged from 37°32' to 33' N in latitude and 126°58' to 127°00' E in longitude (Fig. 1).

Its northern and western slopes are steep with many outcrops, whereas its southern and eastern slopes are characterized by a gentle and simple topography (Seoul Metropolitan Government 2004).

The soil of Mt. Nam is composed of sandy loam, clay

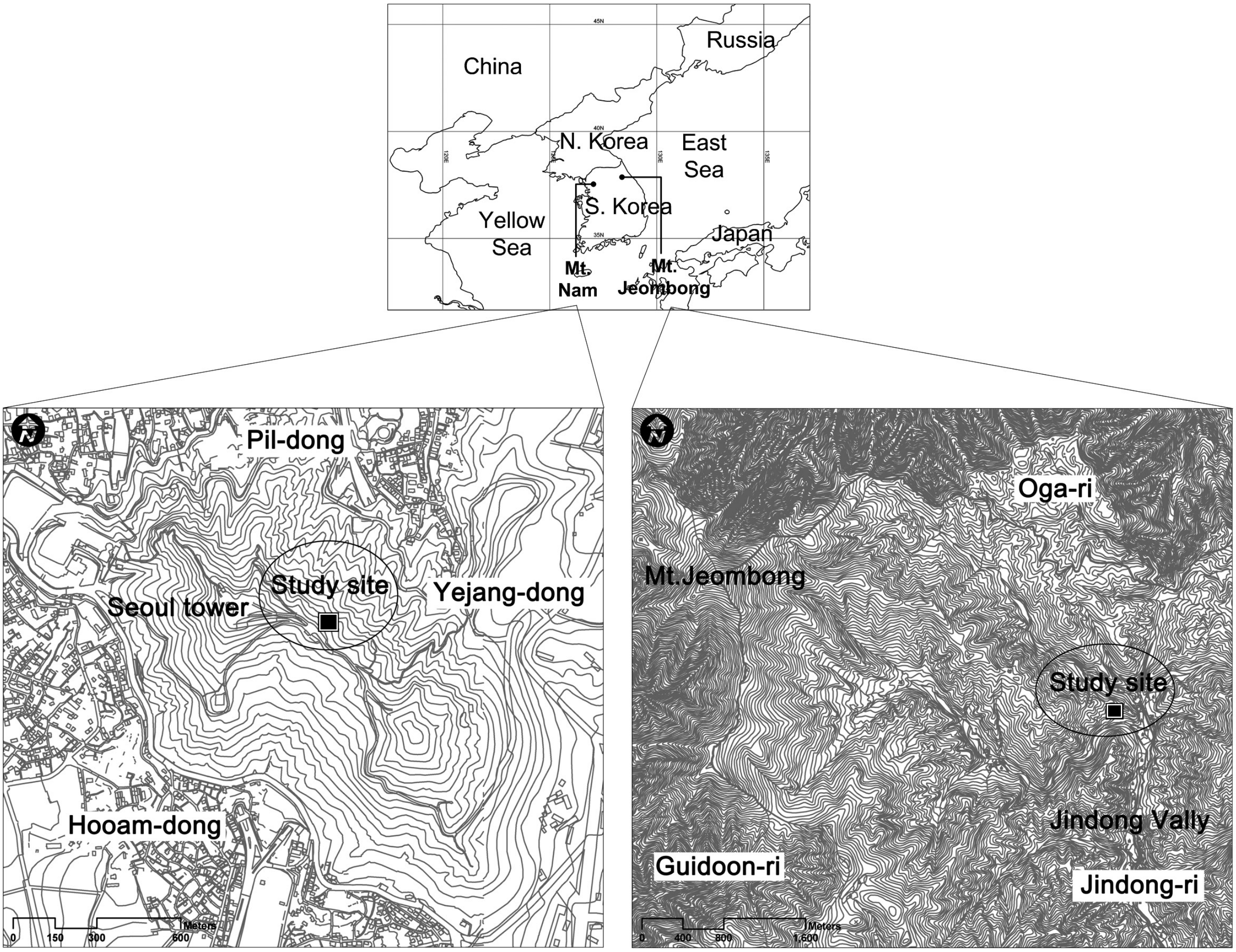

Fig. 1. Physiognomic vegetation maps of Mts. Nam and Jeombong showing the location of study sites.

loam and sand, the northern slope in usually covered with clay loam, and the southern slope with sandy loam. Soil depth is usually deep, and the soil moisture condition is medium to moist (Seoul Metropolitan Government 2004).

The landscape of Mt. Nam is composed of secondary forest, plantation, plantation for landscape architecture, and urbanized areas. The secondary forest is usually consisted of *Q. mongolica* and *Pinus densiflora* communities. The plantation area is composed of *Robinia pseudoacacia* community, *P. densiflora* community, *Populus tomentiglandulosa* community and *Pinus rigida* community, and so on (Lee et al. 1998). The urbanized area is dominated by various public facilities and roads. Annual mean temperature and precipitation are 13.3°C and 1,212.3 mm, respectively and the mean temperature of January--the coldest month--and August--the warmest month--are 0.4°C and 26.5°C, respectively (http://www.kma.go.kr).

Mt. Jeombong

Mt. Jeombong stretches out Inje-gun and Yangyang-gun, Gangwon-do, from 128°25' to 30' E in longitude and from 38°0' to 5' N in latitude, and is located on the southern tip of Mt. Seorak National park. This mountain was designated as a Biosphere Reserve by United Nations Educational, Scientific and Cultural Organization (UNESCO)'s Man and Biosphere Project (Fig. 1) (Lee and Cho 2000).

The annual mean temperature and precipitation of Inje-gun, where Mt. Jeombong is located, are 10.2°C and 1,135.7 mm, respectively. The mean temperature in January--the coldest month--and August--the warmest month--are -4.8°C, and 16.6°C, respectively (http://www.kma.go.kr).

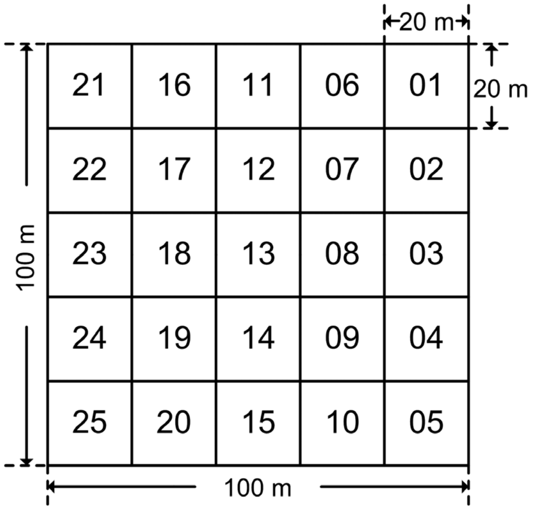

Fig. 2. A configuration of a permanent quadrate. Numbers in subquadrates indicate the quadrate numbers installed in the study sites.

In Mt. Jeombong, artificial disturbances are relatively rare and thus the forest condition is close in natural forest. The dominant tree species are *Q. mongolica, Carpinus cordata, Tilia amurensis,* and *Fraxinus rhynchophylla. Abies holophylla, Taxus cuspidata, Abies nephrolepis* etc. appear sporadically (Jin et al. 2002).

Methods

Installation of permanent plots

Permanent study plots of 1 ha (100 m × 100 m) per site were installed in the *Q. mongolica* stands of Mts. Nam and Jeombong, which maintains homogeneous stands, and artificial disturbances are relatively rare.

In order to carry out survey and management efficiently, the 1 ha plots were divided into 25 subplots of 20 m × 20 m each (Fig. 2).

Measurement of topographic factors

Altitude above sea level (m), longitude, and latitude were measured by GPSMAP 60CSx (Garmin Inc., Olathe, KS, USA) and the slope and aspect of each subplot were measured with a clinometers (SUNNTO) and compass (SUNNTO), respectively.

Collection and analysis of vegetation data

The vegetation survey was conducted from April to October, 2005 at the Mt. Nam site and in May, 2009 at Mt. Jeombong. The dominance of each species in each site was evaluated on the Braun-Blanquet (1964) scale, and each ordinal scale was converted to the median value of the percent cover range in each cover class. Differences in species composition among study sites were analyzed via detrended correspondence analysis (DCA) (Hill and Gauch 1980) using PC-ORD 4 (McCune and Mefford 1999).

Vegetation stratification was analyzed by constructing stand profile diagrams by height range and mean coverage of each vegetation layer collected in 25 subplots of each site. Species diversity was compared via Shannon-Wiener index and species rank-dominance curve (Shannon 1948, Magurran 2003).

In order to predict the likelihood of continuous maintenance and successional trends of actual vegetation, frequency distribution diagrams by diameter class of major species were prepared (Daubenmire 1968, Oh and

Choi 1993, Lee et al. 1998) and a transitional probability model based on Markov chain was applied (Jin and Kim 2005). Diameters were measured with measuring tape at a height of 1.3 m from ground level for woody plants more than 2.5 cm in diameter at breast height. Height was measured with an ultrasonic distance meter (Haglöf Vertex Laser VL400; Haglöf Company Group, Langsele, Sweden). Basal area and density were obtained based on the collected data, and the importance value of each species was obtained by dividing the sum of the relative values of two indices by two.

Plant growth was measured by analyzing annual ring growth. Core samples of annual rings were collected at a height of 30 cm from the ground surface of *Q. mongolica* selected randomly in the permanent plots using an increment borer (Haglöf Increment Borer; Haglöf Company Group). Ten annual ring samples of *Q. mongolica* were collected at both Mts. Nam and Jeombong, whereas those of *S. alnifolia* were collected only at the Mt. Nam site. The number and breadth of annual rings were measured using a core measuring instrument (CORIM Maxi; Taejonsurvey, Daejeon, Korea).

The age of *S. alnifolia* was calculated based on the regression equation of the accumulative growth curve, which was prepared by adding the mean growth value of each age with the increase in age.

Analysis on air pollution

Air pollution was analyzed based on SO_2, NO_2, and O_3 concentrations. Recent states of air pollution from 2006 to 2009 were measured with a passive sampler installed in the *Q. mongolica* forests of Mts. Nam and Jeombong.

Long-term changes in air pollution from 1979 to 2006 were compared based on data from the weather stations of Seoul and Goseong (http://www.airkorea.or.kr) (Ministry of Environment of Korea 1992).

Statistical analysis

All descriptive statistics were analyzed using Excel 2007 and SigmaPlot 2001 ver. 7.0 (SPSS Inc., Chicago, IL, USA) and were conducted using SPSS ver. 10 (SPSS Inc., Chicago, IL, USA) for correlation analysis. DCA ordination was conducted using PC-ORD ver. 4.20 (McCune and Mefford 1999).

RESULTS

Vegetation stratification

The vegetation stratification of Mt. Nam is composed of four layers of tree (18-21 m), subtree (6-12 m), shrub (1-2.5 m) and herb strata (below 0.5 m) and the coverage of each stratum was shown in 82.8%, 57.3%, 30.9% and 33.3%, respectively (Fig. 3).

The vegetation stratification of Mt. Jeombong is composed of four layers of tree (19-23 m), subtree (7-12 m), shrub (1-4 m) and herb strata (below 0.6 m) and the coverage of each stratum was shown in 78.2%, 36.2%, 66.6% and 59.8%, respectively (Fig. 3).

Species composition

As the results of the DCA ordination based on the vegetation data of Mts. Nam and Jeombong, the total vari-

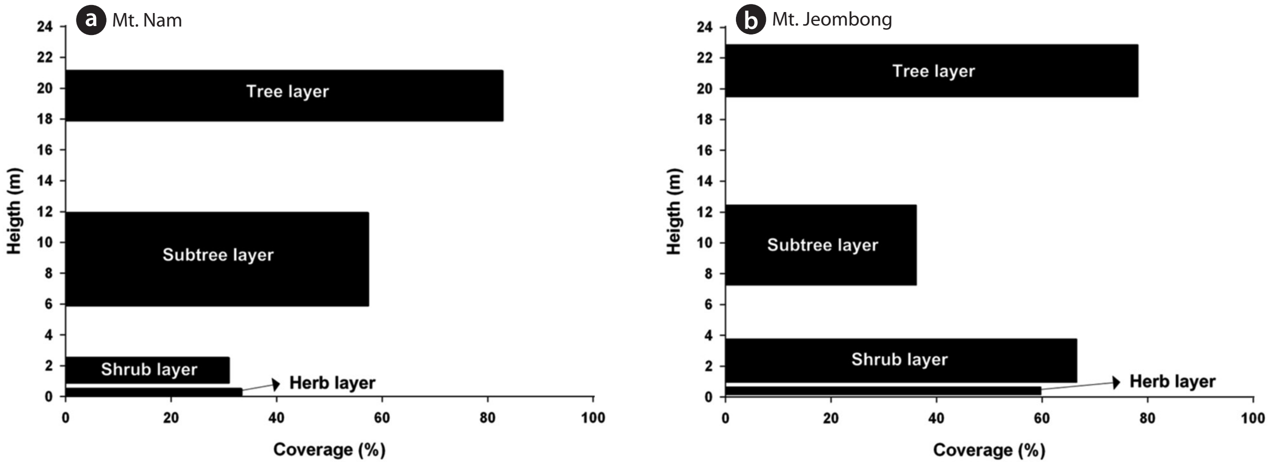

Fig. 3. Canopy profiles of *Quercus mongolica* community established in Mts. Nam and Jeombong. The height of the horizontal bars represents the average span of canopy height and the length of each bar represents total coverage of all species in the height ranges.

ance was 4.2188, and the eigenvalue of axes 1 and 2 were shown in 0.933 and 0.349, respectively. Species composition tended to show local characteristics, as subplots of Mts. Nam and Jeombong were distributed on the left and right tips. In the subplots of Mt. Nam, which is restricted in the left side on axis 1, *Robinia pseudoacacia, S. japonica, Oplismenus undulatifolius* and *Ageratina altissima* showed higher frequency, whereas *Populus davidiana, Rhododendron schlippenbachii, Sasa borealis, Abies holophylla, Viburnum dilatatum,* and *Lysimachia clethroides* showed higher frequency at the Mt. Jeombong site, concentrated on the right side (Fig. 4).

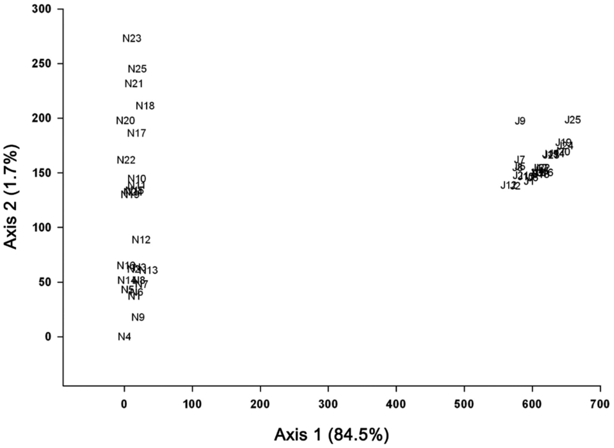

Fig. 4. Ordination of the Mongolian oak stands based on vegetation data collected in 50 plots of permanent quadrates installed in Mt. Nam and Mt. Jeombong. N numbers indicate plot numbers in the Mt. Nam and J numbers indicate plot numbers at the Mt. Jeombong site.

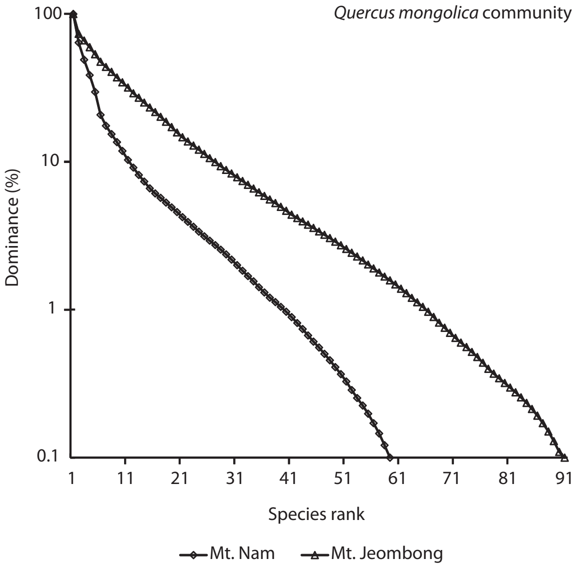

Fig. 5. Species rank-abundance curves of *Q. mongolica* community in Mts. Nam and Jeombong. H': Shannon-Wiener index, (a) Mt. Nam, (b) Mt. Jeombong.

The species composition of subplots of Mt. Jeombong showed a homogeneous pattern, as the subplots were concentrated in a small area. Meanwhile, species composition in Mt. Nam differed widely among subplots, as they were scattered broadly along axis 2. Their distribution was divided depending on aspects, as subplots on the western (N10-11, N14-15, N17-25) and eastern (N1-9, N12-13, N16) slopes were distributed to the upper and the lower parts, respectively (Fig. 4). *Dryopteris chinensis, Forsythia koreana,* and *Polygonatum odoratum* appeared in high frequency in the former subplots and *Liriope spicata, D. chinensis*, and *Viburnum erosum* showed high frequency in the latter subplots.

Species diversity

The Shannon-Wiener diversity index (H') of the *Q. mongolica* community established in Mt. Jeombong was higher than that in Mt. Nam, as the indices of Mts. Nam and Jeombong were shown in 1.799 and 2.427, respectively.

Species rank-dominance curves of both sites reflected such a trend as Mt. Jeombong showed higher richness; the curve was more gentle at the Mt. Jeombong site than at the Mt. Nam site (Fig. 5).

Frequency distribution of diameter classes

In a frequency distribution diagram of major tree species in Mt. Nam, *Q. mongolica, Q. serrata* and *Prunus leveilleana,* and *S. alnifolia, S. japonica, Acer pseudosieboldianum* and *Euonymus oxyphyllus* were found at higher frequency in mature tree classes of more than 10 cm and in young tree classes of smaller than 10 cm, respectively, at the Mt. Nam site (Fig. 6).

In the frequency distribution diagram of major tree species in Mt. Jeombong, *Q. mongolica, Tilia amurensis, Carpinus laxiflora,* and *Acer mono,* and *Q. mongolica, Acer pseudosieboldianum, Carpinus laxiflora,* and *S. obassia* showed higher frequency in mature tree classes greater than 10 cm and in young tree classes smaller than 10 cm, respectively, at the Mt. Jeombong site (Fig. 6).

Vegetation dynamics based on transitional probability model

As the result of prediction on successional trends via application of the transitional probability model based on Markov chain theory (Horn 1971, Kim 1993, Ze and

Kim 2005), *Q. mongolica* showed high occupancy of 57.3%; however, it was predicted that the percentage decreased over generations; it was predicted that the percentage would decline to 44% in the fifth generation in the tree layer of the Mt. Nam site. *S. alnifolia* showed occupancy of 18.4% at present, but it was expected that its percentage would increase over generations and thus would become codominant with *Q. mongolica* since the third generation (Table 1). This change was also expected in the subtree layer, and thus it was predicted that the oc-

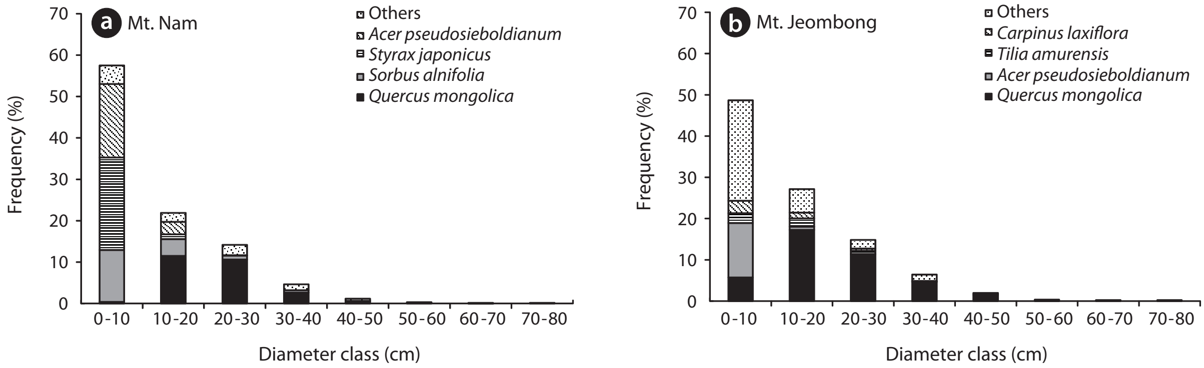

Fig. 6. Frequency distribution diagrams by diameter classes of major tree species established in *Q. mongolica* community permanent quadrate of Mts. Nam and Jeombong.

Table 1. Predicted proportion (%) of species composition during successional generation simulated from mid-story to overstory and understory to mid-story on *Quercus mongolica* community in Mt. Nam

Species	Midstory to overstory						Understory to midstory					
	0	1	2	3	4	5	0	1	2	3	4	5
Q. mongolica	57.3	51.2	45.3	44.2	44.1	44.0	14.7	1.6	1.6	1.6	1.6	1.6
Sorbus alnifolia	18.4	40.7	44.9	45.6	45.7	45.7	17.9	2.3	2.3	2.3	2.3	2.3
Robinia pseudoacacia	4.4	0.7	0.7	0.7	0.7	0.7	2.0	-	-	-	-	-
Quercus serrata	6.2	0.4	0.4	0.5	0.5	0.5	2.5	-	-	-	-	-
Prunus spp.	6.5	4.9	5.0	5.0	5.0	5.0	4.3	-	-	-	-	-
Styrax japonicus	-	-	-	-	-	-	29.4	46.4	46.4	46.4	46.4	46.4
Acer pseudosieboldianum	-	-	-	-	-	-	26.3	40.0	40.0	40.0	40.0	40.0
Others	7.2	2.2	3.8	4.1	4.1	4.1	2.9	9.8	9.8	9.8	9.8	9.8

Table 2. Predicted proportion (%) of species composition during successional generation simulated from mid-story to overstory and understory to mid-story on *Quercus mongolica* community in Mt. Jeombong

Species	Midstory to overstory						Understory to midstory					
	0	1	2	3	4	5	0	1	2	3	4	5
Q. mongolica	55.9	64.5	64.6	64.6	64.6	64.6	51.5	8.2	8.2	8.2	8.2	8.2
Acer pseudosieboldianum	-	-	-	-	-	-	18.6	15.4	15.4	15.4	15.4	15.4
Tilia amurensis	7.6	7.1	7.0	7.0	7.0	7.0	3.6	2.0	2.0	2.0	2.0	2.0
Styrax obassia	-	-	-	-	-	-	7.2	12.2	12.2	12.2	12.2	12.2
Carpinus laxiflora	5.1	12.0	12.0	12.0	12.0	12.0	6.4	1.2	1.2	1.2	1.2	1.2
Fraxinus rhynchophylla	8.5	5.1	5.1	5.1	5.1	5.1	5.9	1.6	1.6	1.6	1.6	1.6
Acer pictum	4.2	4.9	4.9	4.9	4.9	4.9	3.7	0.9	0.9	0.9	0.9	0.9
Others	18.6	6.4	6.4	6.4	6.4	6.4	3.1	58.5	58.5	58.5	58.5	58.5

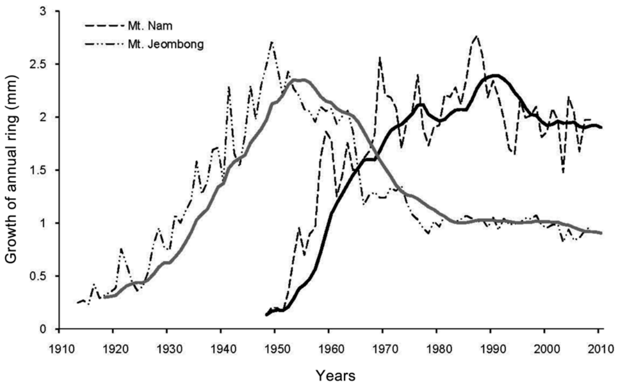

Fig. 7. Changes of annual ring growth of *Quercus mongolica* growing in Mt. Nam and Mt. Jeombong. Annual data are represented by dotted lines; trends based on 9-year running average are highlighted.

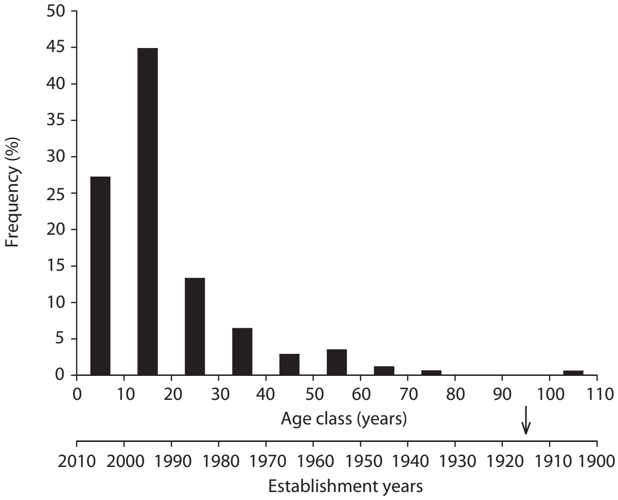

Fig. 8. Frequency distribution diagrams of age classes of *Sorbus alnifolia* established in *Quercus mongolica* community of Mt. Nam.

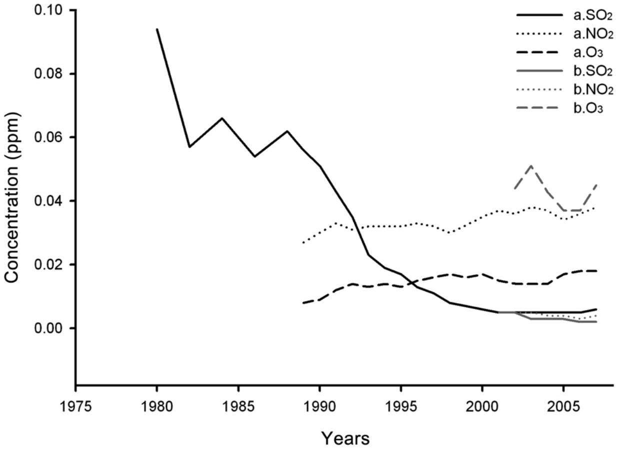

Fig. 9. Concentration of air pollutants from 1980 to 2007 at study sites (a, Mt. Nam; b, Mt. Jeombong). Source: Environmental Management Corporation of Korea.

cupancy of *S. japonica* would increase greatly, and would become codominant with *Acer pseudosieboldianum*.

As the results of prediction of successional trends in Mt. Jeombong via the same procedures, it was predicted that the *Q. mongolica* community in Mt. Jeombong would experience little change (Table 2 and Fig. 6).

Annual ring growth of *Quercus mongolica*

The results of analyses on the annual rings of *Q. mongolica* are shown in Fig. 7. In the case of Mt. Nam, the growth increased from the 1950s to 1990s with the exception of the period from the late 1970s to the early 1980s, and tended to decline since then. In the case of Mt. Jeombong, growth increased continuously from early 1910 to early 1950 and decreased since that time, but showed little change since the early 1980s. Annual ring growths of both sites were very similar, not only in breadth but also in yearly growth patterns, but growth of the period when growth acceleration trend was blunted, since in the early 1980s and late 1990s, was higher at the Mt. Nam site than at the Mt. Jeombong site.

Age distribution of *Sorbus alnifolia*

In order to clarify the period of appearance of *S. alnifolia* established in the *Q. mongolica* community in Mt. Nam, a frequency distribution diagram of age classes was prepared (Fig. 8). The diagram showed a reversed J shape, which means that new individuals are recruited continuously, those born since the mid 1970s occupied a big proportion as approximately 90%. This period when individuals of *S. alnifolia* began to increase sharply usually accords with the period that the trend of growth acceleration of *Q. mongolica* was halted temporarily, from the late 1970s to mid 1980s (Fig. 7).

Air pollution

Yearly changes in SO_2, NO_2, and O_3 concentrations measured at Mt. Nam and in the vicinity of Mt. Jeombong from 1980 to 2007 are shown in Fig. 9 (http://www.airkorea.or.kr). In the case of Mt. Nam, SO_2 concentrations declined sharply, from 0.094 ppm in 1980 to 0.006 ppm in 2007. Even at the Mt. Jeombong site, the concentration was continuously reduced from 0.005 ppm in 2001 to 0.002 ppm in 2007. In the case of NO_2, the concentration increased from 0.027 ppm in 1989 to 0.038 ppm in 2007 on Mt. Nam, whereas it barely changed at the Mt. Jeombong site. O_3 concentrations at the Mt. Nam site increased continuously from 0.008 ppm in 1989 to 0.018 ppm in 2007. O_3 concentrations at Mt. Jeombong showed periodic fluctuations rather than change. As is shown in the results referenced above, SO_2 and NO_2 concentrations were higher at the Mt. Nam site than the Mt. Jeombong site, but O_3 concentrations showed reversed results.

DISCUSSION

Structural differences in vegetation

The *Q. mongolica* community in Mt. Nam and Mt. Jeombong, which maintain representative natural vegetation of Korea (Kim and Kil 2000), showed large differences in the stratification and species composition of vegetation. Compared with vegetation stratification, the coverage of the other strata (except for the subtree stratum) were higher at the Mt. Jeombong site than at Mt. Nam. This result is attributable to the fact that the coverage and frequency of *S. alnifolia* and *S. japonica* are extremely high in the subtree layer of Mt. Nam. Lee et al. (1998) interpreted this change of *Q. mongolica* community in Mt. Nam was originated from effects of environmental pollutants occurred from surrounding areas and of direct interference by humans. In fact, the concentration of air pollutants such as SO_2 and NO_2 was higher at the Mt. Nam site than at the Mt. Jeombong site, although there were some exceptional case like O_3 (Fig. 9).

Differences in the species composition of the *Q. mongolica* community in Mt. Nam relative to that observed in Mt. Jeombong were generally due to *S. alnifolia* and *S. japonica* in the subtree layer and the appearance of *Oplismenus undulatifolius* and *A. altissima* in the herb layer. Among those plants, *S. alnifolia* and *S. japonica* flourish in severely polluted areas such as industrial complexes (Lee et al. 2002, 2004), and *O. undulatifolius* and *A. altissima* thrive in disturbed areas (Lee et al. 2004, Lee and Lee 2006).

As was shown in the results referenced above, the plant species that dominate specific species composition of *Q. mongolica* community of Mt. Nam prefer to disturbed sites. This result reflects that Mt. Nam is exposed to human interference, including severe environmental pollution (Lee et al. 2002, 2004, Lee and Lee 2006).

The species diversity of *Q. mongolica* at the Mt. Nam site was substantially lower than at the Mt. Jeombong site (Fig. 5). This low species diversity is attributable to the fact that undergrowth disappeared due to deep shading by the excessive proliferation of *S. alnifolia* and *S. japonica* due to severe air pollution and human disturbance.

Mts. Nam and Jeombong also exhibited differing successional trends (Fig. 6). In particular, the high frequency of shade-intolerant trees such as *S. alnifolia* shown in young tree classes below 20 cm in diameter at the Mt. Nam is very different results from those observed at the Mt. Jeombong site. Considered that *S. alnifolia* and *S. japonica* were early successional species as shade-intolerant species, this result could be interpreted that *Q. mongolica* community, the representative late successional vegetation experiences a retrogressive successional process (Lee et al. 2008). Moreover, this result was particularly noticeable, as *S. japonica* forms communities in sites in which pollution is very severe and human disturbances are frequent (Lee et al. 2004).

The age distribution of *S. alnifolia,* which dominates the retrogressive succession of *Q. mongolica* in Mt. Nam, shows that individuals born since the mid-1970s have increased substantially. During this period, Seoul experienced rapid urbanization and SO_2 concentrations six to ten times compared with the current values (Fig. 9). Therefore, factors caused flourishing of *S. alnifolia* can be found in vitality reduction of *Q. mongolica* due to severe air pollution during this period. In fact, the slowdown of annual ring growth that *Q. mongolica* showed could be considered as an evidence of this interpretation.

This retrogressive successional trend exemplified by the case of the *Q. mongolica* community of Mt. Nam can be regarded as representative evidence of forest decline in urban areas. Therefore, intensive studies to clarify the background of the causes of this result, the dynamics of corresponding vegetation, and the competitive relationship between current and futuristic dominants and so on should be conducted in the future (Lee et al. 2008).

Plant growth

Among SO_2, NO_2, and O_3, SO_2 has been measured for the longest time, and also evidences the most obvious changes. The concentration of SO_2 at the Mt. Nam site has been greatly reduced since the 1980s, after then it fluctuated and finally settled at approximately 0.002 ppm, which is a very low level. The stable state of SO_2 concentration at the Mt. Nam site differs only slightly from the measured levels at the Mt. Jeombong site. According to Roberts (1984) and Fowler (1992), who outlined the criteria for SO_2 damage, the previous concentrations probably contributed to a reduction in the growth of the Mongolian oak, which is relatively sensitive (Lee and Bae 1991).

The NO_2 concentration at the Mt. Nam site was not high enough to disrupt plant growth; rather, it is likely to have increased growth (Luttermann and Freedman 2000).

Conversely, the SO_2 concentrations prior to 1990, which exceeded the environmental standard value of 0.05 ppm, was quite high and almost certainly affected the growth of plants in the area, including *Q. mongolica*.

Although the O_3 concentrations at the Mt. Nam site were lower than the environment standard values, the concentrations at Mt. Jeombong were more than double the Mt. Nam values. This raises some concerns regarding vegetation damage due to O_3 in the future.

Precursors of O_3 occurrence, such as NO_x (NO + NO2), hydrocarbons, CO, etc. which originate from automobiles, can be eliminated by combination with the precursor, NO. The lower O_3 concentration measured at the Mt. Nam site compared with the Mt. Jeombong site may be attributable to this mechanism (Kim and Kwon 2004).

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