

[Research Paper]

The Spatial Distribution of *Quercus mongolica* and Its Association with Other Tree Species in Two *Quercus mongolica* Stands in Mt. Jiri, Korea

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ABSTRACT: Stand structure and spatial associations of the dominant tree species in *Quercus mongolica* stands were investigated to understand interspecific relationships and the persistent dominance of *Q. mongolica*. We examined the species composition, DBH (diameter at breast height) distribution, and spatial distribution of trees (≥ 2.5 cm DBH) in two permanent 100 m x 100 m plots in *Q. mongolica*-dominant stands on the western part of Mt. Jiri. Ripley's K-function was used to characterize the spatial patterns and associations of dominant tree species. *Q. mongolica* showed a continuous and reverse-J shaped DBH distribution with clumped spatial distribution in both study sites. *Q. mongolica* and *Abies koreana* exhibited a negative association implying potential interspecific competition. The positive spatial association between *Q. mongolica* and *Alnus hirsuta* var. *sibirica* and *Fraxinus sieboldiana* were affected by site characteristics: limited habitat conditions with a large proportion of rock surface. Our results suggest that interactions among species were complex and ranged from positive to negative. Differences in stand and site characteristics and regeneration mechanisms among the species play an important role in regulating their spatial distribution patterns, while competition between individuals also contributes to spatial patterning of these communities. The high density and the early developmental stage of spatial distribution and structural characteristics of *Q. mongolica* and the relatively low importance values of other species in the stands imply that *Q. mongolica* will remain dominant in the study sites in the near future.

Key words: clumped distribution, interspecific association, stand structure, sprouting

INTRODUCTION

Knowledge about the spatial relationships among species in a stand can help researchers to understand inter- and intraspecific relationships and to develop management plans that mimic natural processes (Salas et al. 2006). Accordingly, the spatial distribution patterns of species are a topic of interest among ecologists and forest managers (Anderson 1992, Yang and Kim 2002, Monzeglio and Stoll 2005). With the increasing use of statistics in biology, many methods for interpreting the spatial distributions of species have been introduced and developed, such as the Clark and Evans (1954) test, Pielou's (1960) index of non-randomness, the contiguous

quadrat technique (Greig-Smith 1983), and Morisita's (1962) index (Haase 1995).

Species in a stand compete with each other for resources such as light, soil moisture and nutrients. Species that require similar resources and similar environmental conditions have a tendency to be distributed in similar locations. However, the competitive exclusion principle (Hardin 1960) suggests that two species competing for the exactly same resources cannot coexist indefinitely, implying that species coexistence may indicate physical or temporal differentiation of the food resources used that reduces interspecific competition below the value of intraspecific competition, or that morphological differences among coexisting species enable the species to utilize different resources or slightly different types of

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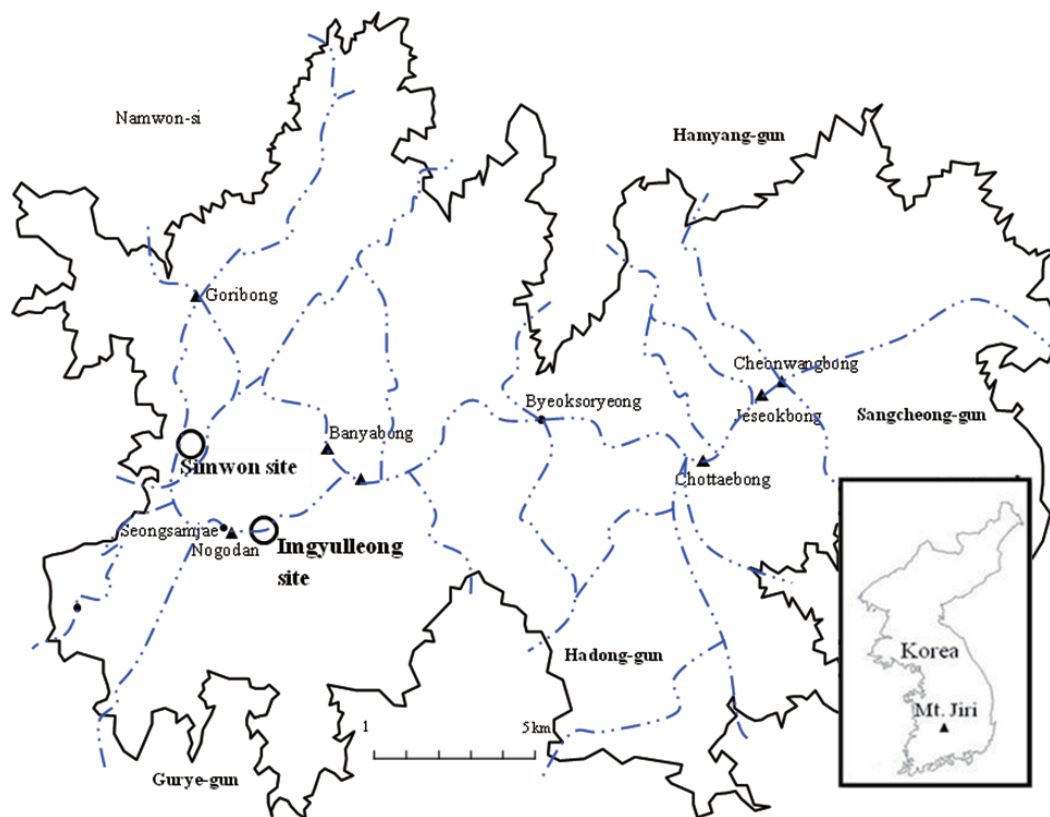


Fig. 1. Location of the study sites on Mt. Jiri, Korea. The Simwon site and the Imgyulleong site are located in the west part of Mt. Jiri.

environments.

Quercus mongolica Fisch. ex Ledeb. is a representative deciduous species in temperate forests in Northeast Asia. *Q. mongolica* is widely distributed across Korea and dominates Korean deciduous forests, especially on ridges and upper slopes. The topographical distribution of *Q. mongolica* on upper slopes and ridge areas may indicate that this species is adapted to dry soils and cold weather conditions. *Q. mongolica* individuals live for 100-300 years, and dominate the upper canopy layer (Abrams et al. 1999). They regenerate both by seeds and sprouts. In South Korea, more than 70% of *Q. mongolica* seedlings in natural forests were found to have originated from sprouts (Suh and Lee 1998). Their ability to sprout enables them to quickly reoccupy areas after catastrophic disturbances, especially fires, while their acorns are favored animal foods and make a relatively low contribution to *Q. mongolica* emergence. Although sprouting allows the species to reoccupy an area faster than other species due to its rapid early growth after a disturbance, it limits the spatial dispersion of the species to within the boundaries of the root distribution and competition with neighboring species has a substantial influence on *Q. mongolica* survival. Therefore the spatial

relationships between *Q. mongolica* and neighboring species are important factors in *Q. mongolica* stands, especially stands with trees from sprout origin. However, little information is available about the spatial relationships of *Q. mongolica* with neighbor species despite the fact that *Q. mongolica* in Korean forests has been a major research subject. Our study aims to examine stand structural characteristics and the spatial relationship of *Q. mongolica* with neighboring woody species and to estimate the probability of persistence of this species in the study areas.

MATERIALS AND METHODS

Study sites

This study was conducted in two *Q. mongolica* stands on the western part of Mt. Jiri, which is located in the southern part of Korea. Mt. Jiri is the second highest mountain in South Korea with most ridges and peaks reaching altitudes over 1000 m asl. *Q. mongolica* is found at altitudes above 850 m asl on Mt. Jiri (Yim and Kim 1992, Korea National Park Service 2008). One study site (the Simwon study site) was located at the lower altitudinal limit of the *Q. mongolica*-dominant area and

Table 1. Site description in the Imgyulyeong and Simwon study sites in Mt. Jiri, Korea

	Imgyulyeong	Simwon
GPS (plot center)	N 35°17'50.0", E 127°33'18.6"	N 35°19'7.9", E 127°31'31.1"
Mean altitude (m)	1357.4	968.0
Aspect	N	N, NE, E
Topography	Ridge, upper slope	Ridge, upper slope, lower slope
Slope (%)	29.8 (0-63)	67.5 (1-110)
Rock exposure (%)	12.7 (0-80)	35.8 (0-90)
Soil depth (cm)	26.6 (10-50 <)	24.9 (10-60)
Depth of A Layer (cm)	10.0 (2-30)	7.7 (3-18 <)

Numbers in the parenthesis indicate the range of the values.

the other site (Imgyulleong study site) was located within the altitudinal range of *Q. mongolica*-dominant areas on Mt. Jiri (Fig. 1). The Simwon site was located from ridgetops to lower slopes near a valley on a steep slope (Table 1). The Imgyulleong site was about 0.7 km west of Imgyulleong at 1357.4 m asl. The Imgyulleong plot was located on an upper slope and included a small peak on a gentle slope. While the Simwon plot was in a quite rocky area because it was near a valley, rock exposure in Imgyulleong plot was less than 20%. Both stands had trees with fire scars, indicating that they had experienced forest fire in the past.

Climate data from the Seongsamjae weather station, which was located between two study sites at 1100 m asl, for 3 years from April 2002 to April 2005 showed an annual mean air temperature in the study area of 7.8°C and annual mean precipitation of 2083.5 mm (Korea Meteorological Administration, 2008). Based on meteorological data from Hobo weather stations (HOBO H08-032-08, Onset Computer Corporation, USA) placed in both study sites, the difference in annual mean temperature between the two plots was 2.1°C.

Data collection

Data were collected in a 1-ha plot (100 m x 100 m) in each study site. The study plots were divided into twenty-five 20 m x 20 m subplots. All trees with ≥ 2.5 cm diameter at breast height (DBH) were measured, and the species name, DBH, and height of individual trees were recorded. All standing trees ≥ 2.5 cm in DBH were mapped and their geographic coordinates were recorded. Height was measured using a hypsometer (Vertex laser, Haglöf, Sweden), and DBH was measured at a height of 1.3 m above the ground. We determined whether the stems had originated from seeds or sprouts by examining the stem numbers of a tree. Single-stemmed trees were recorded as being of seed origin and multi-stemmed trees were considered to be of sprout origin (Dolezal et al.

2009).

Data analysis

Species composition was investigated using importance values (IV) for each species, which were calculated by summing relative density, relative coverage and relative frequency (Curtis and McIntosh 1951). Coverage was calculated based on stem basal area at breast height (1.3 m). We considered the 4-5 species with the greatest importance values in each plot to be major species. The relative density and relative basal area for major species in each plot were calculated and averaged for covariation analysis. Covariations of major species was investigated using Pearson's correlation (Ludwig and Reynolds, 1988). The correlation coefficients represented the relative strength of covariation for each pair of species. A positive covariation between the two species indicates that the abundance of the two species tended to increase or decrease together, whereas a negative covariation between the two species indicates that the abundance of one species increases with decreasing abundance of the other species. We used SPSS 12.0K for the analyses.

Ripley's $K(t)$ function was used for univariate spatial point pattern analysis (Ripley 1977). The formula for Ripley's $K(t)$ function that we used was:

$$\hat{K}(t) = n^2 |A| \sum_{i \neq j} \sum w_{ij}^{-1} I_t(u_{ij}) \quad (1)$$

Where n is the number of trees, A is the plot size (m^2), and u_{ij} is the distance between trees i and j . The weight function, w_{ij} provides the edge correction. $I_t(u)$ is the counter, which has a value of 1 if $u \leq t$ (the tree is within the circular plot of radius t) or 0 otherwise (Haase 1995, Salas et al. 2006). If a tree is distributed at random, the the expected value of $K(t)$ is equal to πt^2 . We used the $L(t)$ function, modified from $K(t)$ as follows, to check the difference between the observed value and the expected value (zero) under a random distribution (Besag 1977,

Salas et al. 2006).

$$\hat{L}(t) = \left[\frac{\hat{K}(t)}{\pi} \right]^{\frac{1}{2}} - t \quad (2)$$

We used Monte Carlo simulations to test the hypothesis of random distribution of trees. We conducted each simulation 99 times to determine 95% confidence envelopes (Haase 1995). If $L(t)$ was greater than, equal to or less than the confidence envelopes, then we described the spatial pattern of trees as clumped, random or regular at any distance, respectively (Ripley 1977, Leemans 1991, Fajardo and Alaback 2005, Salas et al. 2006). The value of t ranges from 0 to 50 m with 1-m intervals.

We conducted bivariate spatial pattern analysis to detect the degree of repulsion, attraction or indifference between two species (Anderson 1992, Haase 2001, Salas et al. 2006, Song 2007). The bivariate estimator, $\hat{K}_{12}(t)$ is calculated from $\hat{K}_{12}^*(t)$ and $\hat{K}_{21}^*(t)$, which represents the interaction between species 1 and 2, and species 2 and 1, respectively. The formulas for $\hat{K}_{12}^*(t)$, $\hat{K}_{21}^*(t)$ and $\hat{K}_{12}(t)$ were as follows:

$$\hat{K}_{12}^*(t) = \frac{A}{n_1 n_2} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} \frac{1}{w_{ij}} I(u_{ij}) \quad (3)$$

$$\hat{K}_{21}^*(t) = \frac{A}{n_1 n_2} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} \frac{1}{w_{ji}} I(u_{ij}) \quad (4)$$

$$\hat{K}_{12}(t) = \frac{n_2 \cdot \hat{K}_{12}^*(t) + n_1 \cdot \hat{K}_{21}^*(t)}{n_1 + n_2} \quad (5)$$

where, n_1 and n_2 are the numbers of trees in species 1 and 2, respectively. $\hat{K}_{12}(t)$ can be modified in the manner of the univariate analysis, as follows:

$$\hat{L}_{12}(t) = \sqrt{\frac{\hat{K}_{12}(t)}{\pi}} - t, \quad (6)$$

We conducted each simulation 99 times to determine 95 % confidence envelopes. If $\hat{L}_{12}(t)$ was inside of the confidence envelope, we considered the association between two species to be independent, whereas if $\hat{L}_{12}(t)$ was greater than the upper limit of the confidence envelope we concluded that there was attraction between the two species at distance t , and if $\hat{L}_{12}(t)$ was below the lower limit of the confidence envelope, we concluded

that the two species displayed repulsion. The value of t was allowed to range from 0 to 10 m at 1-m intervals. We used the spatial statistics program SPPA 2.0.3 (Haase 2004) for the spatial point pattern analysis.

RESULTS

Forest composition and inter-species association

The species composition of the Imgyulleong and Simwon study sites differed (Table 2). At the Imgyulleong site, *Rhododendron schlippenbachii* Maxim., *Tilia amurensis* Rupr., and *Abies koreana* Wilson were the species with the greatest importance values, whereas in the Simwon site, the species with the greatest importance values (in order of decreasing importance) were *Q. mongolica*, *Fraxinus sieboldiana* Blume, *Alnus hirsuta* var. *sibirica* C. K. Shneide, *Acer pseudosieboldianum* (Pax) Kom., and *Magnolia sieboldii* K. Koch.

The overall density of trees at the Imgyulleong site was 1807 individuals/ha which was slightly higher than the density of 1575 individuals/ha at the Simwon site. The Imgyulleong site had a *Q. mongolica* density of 884 individuals/ha, which is double the *Q. mongolica* density at Simwon of 430 individuals/ha. The overall basal area of trees at the Imgyulleong site was 17.4 m²/ha, which was also greater than the basal area of 11.2 m²/ha at the Simwon site. The proportion of *Q. mongolica* trees of sprout origin was estimated as 44% at Imgyulleong and 24.2% at Simwon. *A. pseudosieboldianum*, *Q. mongolica* and *S. pseudocamellia* had a high proportion of individuals of sprout origin. Most shrub species in both study sites seemed to originate from sprouts.

Q. mongolica showed a reverse-J shaped DBH distribution at both study sites (Fig. 2). In Imgyulleong site, *A. koreana* was evenly distributed in most DBH classes, and *T. amurensis* and *Salix caprea* L. were evenly distributed in lower DBH classes. At Simwon, *A. hirsute* var. *sibirica* was evenly distributed in most DBH classes, and *F. sieboldiana* was evenly distributed in DBH classes < 15 cm DBH. The largest tree DBH was 39.9 cm (*A. koreana*) and the largest *Q. mongolica* DBH was 36.9 cm at Imgyulleong, indicating that few trees > 40 cm DBH existed at the Imgyulleong study site. The Simwon site had more large trees than Imgyulleong. At Simwon, the largest tree DBH was 58.0 cm (*Q. mongolica*), and several trees had DBH > 40.0 cm, including an individual *Fraxinus chiisanensis* Nakai with 45.0 cm DBH.

The interspecific spatial association for the five major species at Imgyulleong showed that *Q. mongolica* had a negative relationship with *A. koreana* and *Pinus densiflora*

Table 2. Importance value (IV; %), stem density (DBH ≥ 2.5 cm) ha⁻¹, mean height of stems (DBH ≥ 5 cm) and the percentage of multi-stemmed individuals (R; %) of 10 dominant species in each study site. Importance values were calculated as (Relative density + Relative coverage using basal area + Relative frequency)/3.

	Imgyulleong				Simwon			
	IV (%)	Numbers ha ⁻¹	Mean height (m)	R (%)	IV (%)	Numbers ha ⁻¹	Mean height (m)	R (%)
<i>Quercus mongolica</i>	44.6	884	6.6	44	28.6	430	9.2	24.2
<i>Rhododendron schlippenbachii</i>	12.6	394	3.3	60.4	5.6	148	4.2	31.8
<i>Tilia amurensis</i>	8.2	154	6.1	38.3	-			
<i>Abies koreana</i>	6.3	63	7.8	7.9	-			
<i>Salix caprea</i>	4.9	99	4.3	28.3	-			
<i>Betula costata</i>	4.1	56	6.2	28.6	-			
<i>Pinus densiflora</i>	3.9	22	7.9	31.8	-			
<i>Acer pseudosieboldianum</i>	3.3	28	5.6	67.9	7	110	7.3	72.7
<i>Pinus koraiensis</i>	3	40	5.7	7.5	-			
<i>Carpinus cordata</i>	2.1	16	4.8	31.3				
<i>Fraxinus sieboldiana</i>	-				10.2	278	6.4	50
<i>Alnus hirsuta var. sibirica</i>	-				8.1	69	9.9	31.9
<i>Magnolia sieboldii</i>	-				5.9	125	5.3	68.8
<i>Lindera obtusiloba var. obtusiloba</i>	-				3.7	66	5.1	37.9
<i>Stewartia pseudocamellia</i>	-				3.6	43	7.6	60.5
<i>Sorbus alnifolia</i>	-				3.5	72	7.2	25
<i>Fraxinus chiisanensis</i>	-				3.4	31	13.8	29

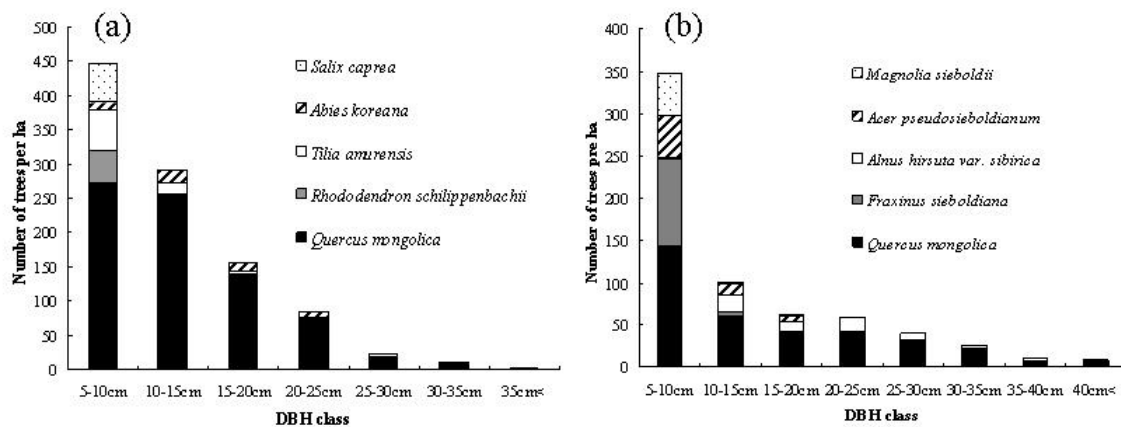


Fig. 2. DBH distribution of dominant tree species at (a) the Imgyulyeong site and (b) the Simwon site.

Table 3. Interspecific spatial associations based on the bivariate $L_{1,2}$ -function among dominant species at the Imgyulyeong study site, Mt. Jiri, Korea.

	<i>Quercus mongolica</i>	<i>Rhododendron schlippenbachii</i>	<i>Tilia amurensis</i>	<i>Abies koreana</i>	<i>Pinus densiflora</i>
<i>Quercus mongolica</i>	1.000				
<i>Rhododendron schlippenbachii</i>	0.006	1.000			
<i>Tilia amurensis</i>	- 0.043	0.593**	1.000		
<i>Abies koreana</i>	- 0.596**	- 0.287	0.024	1.000	
<i>Pinus densiflora</i>	- 0.628**	- 0.384	- 0.412	0.292	1.000

* $P < 0.05$; ** $P < 0.01$, $n = 25$.

Siebold & Zucc. ($P < 0.01$), while *R. schlippenbachii* had a positive relationship with *T. amurensis* ($P < 0.01$, Table 3). At Simwon, the spatial associations were not significant

for most species except for the negative relationship between *Q. mongolica* and *A. pseudosieboldianum* ($P < 0.01$) and the positive relationship between *F. sieboldiana*

Table 4. Interspecific spatial associations based on the bivariate $L_{1,2}$ -function among dominant species at the Simwon study site, Mt. Jiri, Korea.

	<i>Quercus mongolica</i>	<i>Alnus hirsuta</i> var. <i>sibirica</i>	<i>Fraxinus sieboldiana</i>	<i>Acer pseudosieboldianum</i>	<i>Rhododendron schlippenbachii</i>
<i>Quercus mongolica</i>	1.000				
<i>Alnus hirsuta</i> var. <i>sibirica</i>	- 0.369	1.000			
<i>Fraxinus sieboldiana</i>	- 0.058	0.539*	1.000		
<i>Acer pseudosieboldianum</i>	- 0.741**	0.270	- 0.047	1.000	
<i>Rhododendron schlippenbachii</i>	0.317	- 0.160	- 0.077	- 0.391	1.000

* $P < 0.05$; ** $P < 0.01$, $n = 25$.

and *A. hirsuta* var. *sibirica* ($P < 0.05$, Table 4).

Spatial distribution

Q. mongolica is distributed throughout the plot at the Imgyulleong site (Fig. 3a), while *Q. mongolica* is concentrated in the southeast part of the plot in the Simwon site (Fig. 3b). *Q. mongolica* individuals > 30 cm DBH were found near the north end of the plot whereas *Q. mongolica* individuals < 10 cm DBH were more frequent in the south part of the plot in Imgyulleong site. The density of *Q. mongolica* < 10 cm DBH had a distinctive division in a diagonal direction (SW-NE), which coincided with the ridge direction in the Simwon site. The northwest part of the plot in Simwon was rocky in the area leading down into the valley. *Q. mongolica* < 10 cm DBH were mostly distributed in the southeast part of the plot, which consisted of the ridge and the upper slope.

In the Imgyulleong site, all trees showed a clumped distribution for distances > 3 m. For distances < 3 m, most trees showed a random distribution (Fig. 4a). All trees showed a clumped distribution for all distances at the Simwon site (Fig. 4c). *Q. mongolica* showed a clumped distribution for all distances at both sites (Fig. 4b, d).

At Imgyulleong and Simwon, the bivariate spatial patterns differed between *Q. mongolica* and other major species (Fig. 5). *Q. mongolica* at Imgyulleong had a distribution that was independent of *T. amurensis* and negatively related with that of *A. koreana* (Fig. 5a, b), while *Q. mongolica* at Simwon was positively related with *A. hirsuta* var. *sibirica* and *F. sieboldiana* (Fig. 5d, e). The spatial relationship between *Q. mongolica* and snag was random at Imgyulleong and positive at Simwon (Fig. 5c, f).

DISCUSSION

Species composition and stand structure

The Imgyulleong site could be characterized as a *Quercus mongolica*-*Tilia amurensis* community and

the Simwon site was occupied by a *Quercus mongolica*-*Fraxinus sieboldiana* community following the categories established by Song et al. (2003). Previous studies of the environmental characteristics of *Q. mongolica* communities have shown that *Quercus mongolica*-*Tilia amurensis* communities have rich soil nutrients, low available soil P, and gentle slopes and that *Quercus mongolica*-*Fraxinus sieboldiana* communities have high available soil P, low soil nutrients and steep slopes (Song et al. 2003). The Imgyulleong site had a gentler slope and a deeper soil A layer than the Simwon site, corresponding to the typical characteristics of *Quercus mongolica*-*Tilia amurensis* communities, and the Simwon site had characteristics similar to typical *Quercus mongolica*-*Fraxinus sieboldiana* communities.

Both study sites had higher stem density, lower basal area and evidence of past fires, indicating that they have become established after recent fire disturbance relatively recently compared with other stands in Mt. Jiri (Park et al. 2006). The Imgyulleong site had a higher stem density and more *Q. mongolica* individuals than the Simwon site, while the Simwon site had more large trees. The Imgyulleong site seemed to have been disturbed more recently than the Simwon site. Although *Q. mongolica* showed a reverse-J shaped DBH distribution and the DBH distribution was continuous in both sites, this does not mean that *Q. mongolica* has been continuously regenerating. Rather, the majority of *Q. mongolica* individuals may belong to a single cohort. Large numbers of *Q. mongolica* in the lower DBH classes might be suppressed trees, and small number of trees > 30 cm DBH might be the fastest-growing trees or remnant trees that survived past disturbances.

Although *Q. mongolica* is known to have a relatively loose crown structure, providing better light conditions for shade-tolerant late successional species to become established and survive in the understory (Jang and Im 1985), the high densities of *Q. mongolica* and relatively low importance values of other species in both study

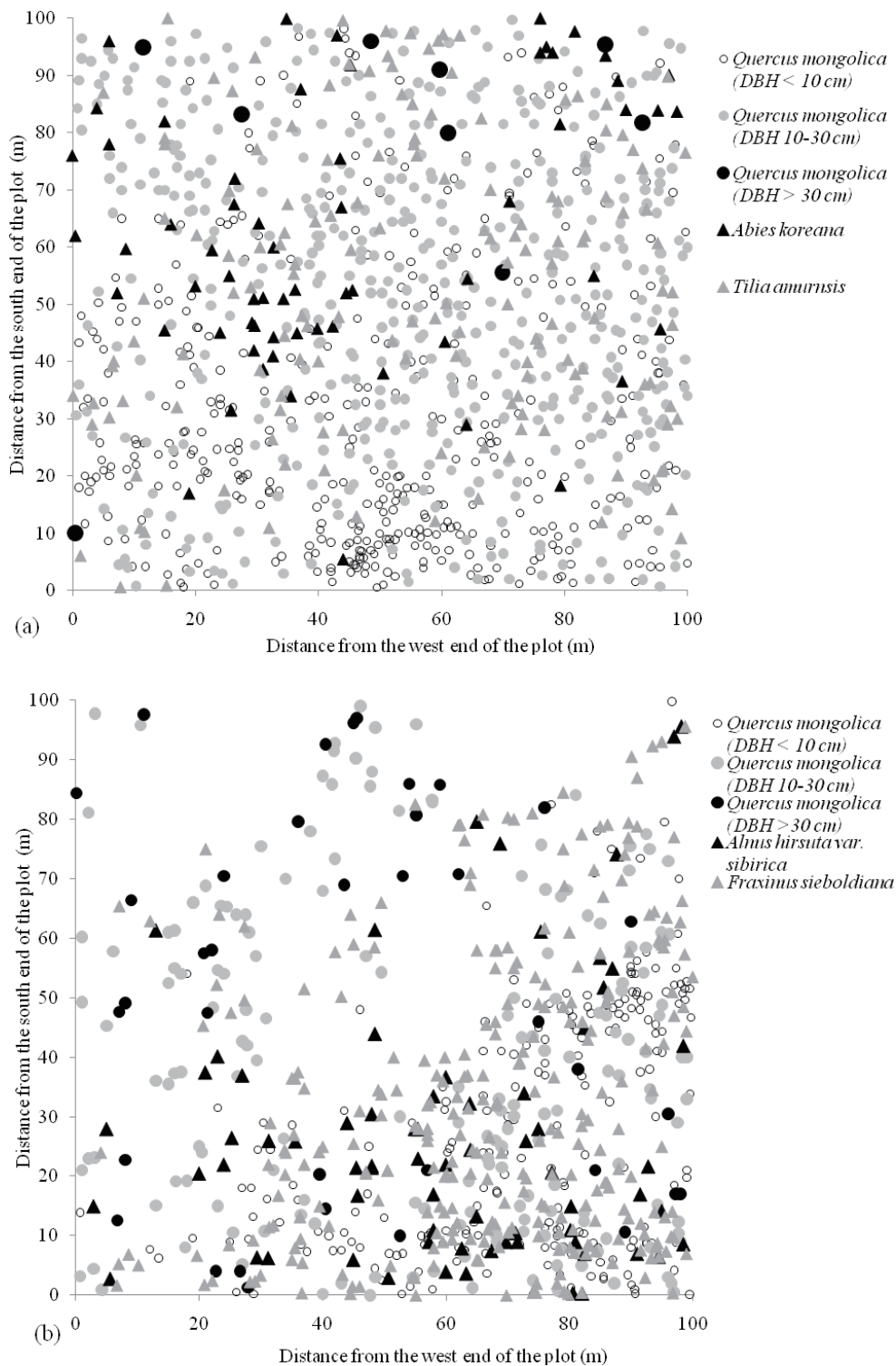


Fig. 3. Mapped locations of major tree species in the 1-ha plot in *Quercus mongolica* stands in Mt. Jiri, Korea. (a) Imgyulleong site and (b) Simwon site.

sites suggest that the dominance of *Q. mongolica* in both study sites is likely to continue for a while. However, the continuous DBH distributions of *A. koreana* in most DBH classes in the Imgyulleong site, the relatively low

shade tolerance of *Q. mongolica* (Lee and Lee 2001), and the results of previous studies of succession from *Q. mongolica* to *A. koreana* (Park and Chung 1990) all suggest that *A. koreana* has the potential to increase in

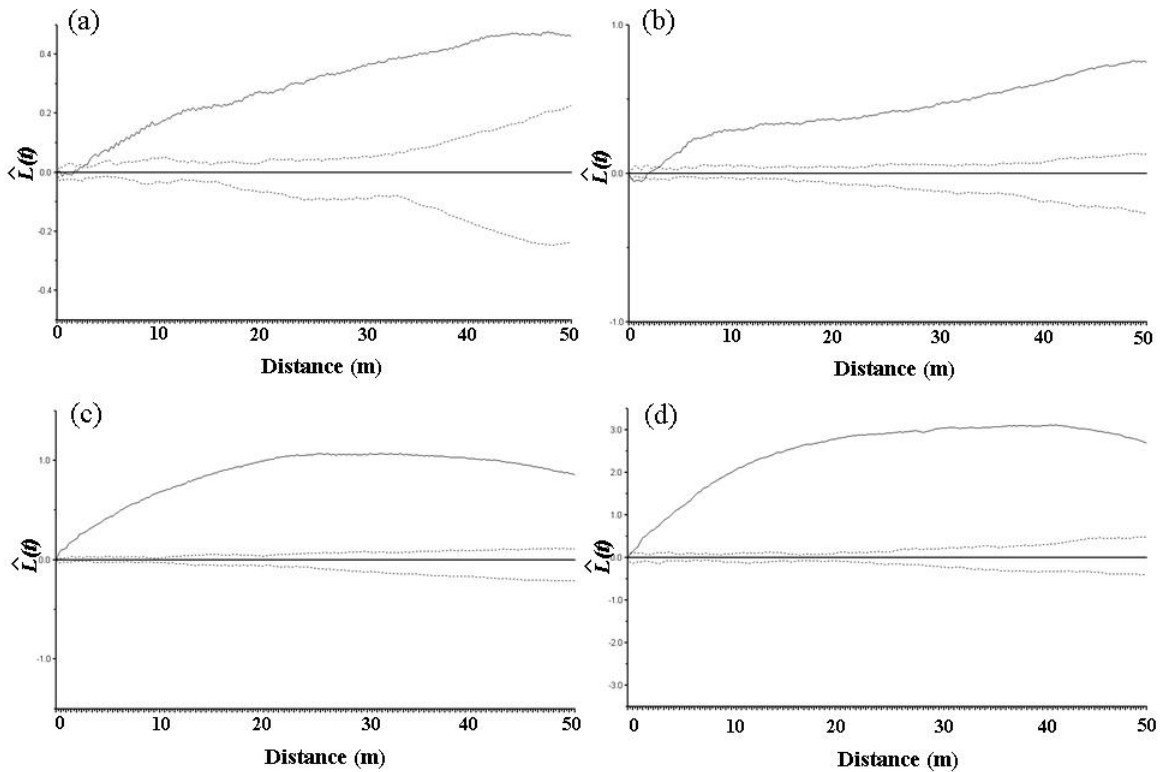


Fig. 4. Univariate spatial point pattern analyses for each study site; (a) all trees in the Imgyulleong site, (b) *Quercus mongolica* in the Imgyulleong site, (c) all trees in the Simwon site, and (d) *Q. mongolica* in the Simwon site. The black line indicates observed statistics $K(t)$. The dotted lines represent the 95% confidence envelope.

dominance in this area. In the same way, the importance values of *F. siboldiana*, *F. chiisanensis* and *Stewartia pseudocamellia* Maxim. may increase resulting in increased codominance of those species at the Simwon site under *Q. mongolica* dominance (Park et al. 2006).

Spatial distribution patterns and interspecific associations of *Q. mongolica*

The univariate spatial point pattern analysis showed that trees in both study sites had clumped distributions (Fig. 4). The clumped distribution of trees can be partly explained by stand developmental stages in the study sites. As a stand develops after a disturbance, the spatial distribution of trees changes from being clumped to being random or regular distribution. The stand structure and evidence of fire in both sites indicate that these stands have not yet reached the old growth stage (Kim and Kuen 1991).

The large size of *Q. mongolica* acorns may contribute to relatively the small dispersion range of this species, which also results in clumped distributions (Venable and Brown 1988). Wildlife such as rodents, which are major acorn-dispersing agents, have limited ranges of movement (Miyaki and Kikuzawa 1988), contributing to

the small dispersion ranges of *Q. mongolica* and resulting in a clumped distribution pattern. Another explanation for the clumped distribution of *Q. mongolica* could be the irregular distribution of proper habitats for *Q. mongolica*, especially in the Simwon site. A large part of the Simwon site was steep and rocky, and *Sasa borealis* (Hack.) Makino covered quite a large portion of the area, limiting the opportunities for establishment of *Q. mongolica* from seeds (Chung and Chung 2004).

A high proportion of *Q. mongolica* seemed to originate from sprouts in the study sites. Sprouting often produces short, crooked, and multi-stemmed tree forms, which may be favored over tall, straight, single-stemmed trees in ridges or mountain tops where wind damage is prevalent, such as the study sites. The deep root systems of *Q. mongolica* that allow them to exploit soil water more effectively also enable them to become distributed in upper slopes or ridges where soil water is often deficient. Sprouting and the deep root systems of *Q. mongolica* gives this species the ability to dominate communities in ridges and mountaintops. However, sprouting also limits the spatial dispersion of this species, resulting in clumped distributions (Peterson and Squiers 1995). Where dispersion is more limited, interspecific associations with

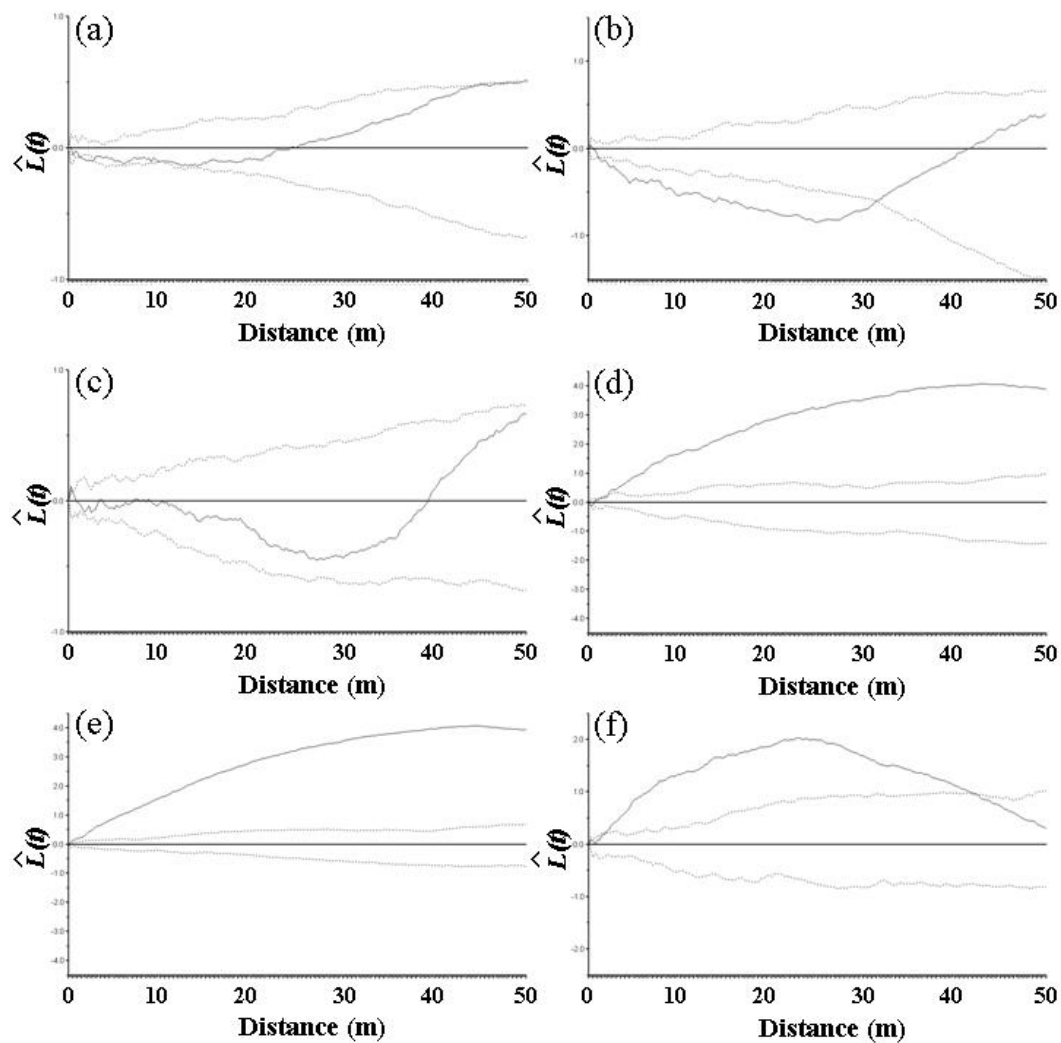


Fig. 5. Bivariate spatial point pattern analyses for each study site; (a) *Quercus mongolica* – *Tilia amurensis* in the Imgyulleong site, (b) *Q. mongolica* – *Abies koreana* in the Imgyulleong site, (c) *Q. mongolica* – snags in the Imgyulleong site, (d) *Q. mongolica* – *Alnus hirsuta* var. *sibirica* in the Simwon site, (e) *Q. mongolica* – *Fraxinus sieboldiana* in the Simwon site, and (f) *Q. mongolica* – snags in the Simwon site. The black line indicates observed statistics $K(t)$. The dotted lines represent the 95% confidence envelope.

other species may become more important as the species compete for light and soil moisture and nutrients within their limited distribution ranges.

The bivariate spatial pattern analysis for the Imgyulleong site showed that *Q. mongolica* and *T. amurensis* are distributed independently while *Q. mongolica* and *A. koreana* were negatively correlated, which may indicate repulsion. Although covariation analysis showed slightly negative associations between *Q. mongolica* and *T. amurensis*, the correlation was not significant, because most *T. amurensis* were in the lower DBH classes, so *T. amurensis* was not an important competitor for *Q. mongolica* in the upper canopy layer, whereas *A. koreana* was as competitor with *Q. mongolica*, as indicated by a

significantly negative correlation for their interspecific spatial association ($r: -0.596, P < 0.01$). The random spatial association between snags and *Q. mongolica* indicated that trees died out from competition on an individual basis, not as a result of interspecific competition with *Q. mongolica*.

The bivariate spatial pattern analysis for *Q. mongolica* and *A. hirsuta* var. *sibirica* and *F. sieboldiana* in Simwon showed evidence of attraction, suggesting that those species share similar environmental preferences with *Q. mongolica*. The results of attraction between *Q. mongolica* and *F. sieboldiana* in the Simwon site were different from the previous study reporting that *Q. mongolica* and *F. sieboldiana* had different habitat preferences (Song et al.

2003). The attraction among species at Simwon might be due to the irregular site conditions at Simwon, as available tree establishment sites were limited by exposed rock area or dwarf bamboo, and trees were concentrated only in available locations. The interspecific spatial associations between *Q. mongolica* and *A. hirsuta* var. *sibirica* and *F. sieboldiana* in Simwon site were slightly negative (Table 4), but the associations were not significant. We could not exclude the possibility of competition between *Q. mongolica* and *A. hirsuta* var. *sibirica* as they exhibited negative relationships in other study sites (Ahn and Lee 1998). Unlike the Imgyulleong site, the positive spatial association of snags and *Q. mongolica* at Simwon indicated that the mortality of trees might be due to suppression of *Q. mongolica* in the upper canopy.

An interaction between the developmental stages of the stands, *Q. mongolica* acorns and ecological characteristics, and the environmental characteristics of the study sites might result in the current clumped distribution of *Q. mongolica* in the study sites. Considering that the spatial distribution of *Q. mongolica* in temperate old growth forests is random (Hao et al. 2007), the spatial distribution of *Q. mongolica* in the study sites may shift to a random distribution if conditions change with stand development. However, the enhanced competitiveness of trees resulting from sprouting and neighboring species interacting with *Q. mongolica* in the study sites may result in ongoing *Q. mongolica* dominance and a clumped distribution of species in the study sites for years into the future.

CONCLUSION

Q. mongolica stands in the western part of Mt. Jiri showed different species compositions and spatial association depending on site and stand characteristics. On the upper slope of Mt. Jiri near ridge areas, *A. koreana* and *T. amurensis* were associated with *Q. mongolica*, and *A. koreana* had the potential to compete against *Q. mongolica*. In the lower elevational limit of *Q. mongolica*-dominant stands, *A. hirsuta* var. *sibirica* and *F. sieboldiana* were codominant species. Trees in the study sites showed a clumped distribution, indicating either that the stands have not reached a mature developmental stage yet or that a clumped distribution was favored by the environmental characteristics in the stands. The continuous reverse J-shaped DBH distribution of *Q. mongolica* demonstrates that the dominance of *Q. mongolica* in this area is likely to continue for a while.

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