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Stand Structure and Regeneration Pattern of *Kalopanax septemlobus* at the Natural Deciduous Broad-leaved Forest in Mt. Jeombong, Korea

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ABSTRACT: Since the demands not only for value-added timber but the environmental functions of forests had been increased, native tree species has been, and is rapidly being replaced by foreign tree species in many parts of the world. However, the studies on population structure and regeneration characteristics of native tree species were not conducted enough. Regeneration of *Kalopanax septemlobus* growing among other hardwoods in natural forests is very difficult because of its low seed viability and germination rate. The study examined the distribution of mature trees of *K. septemlobus* and their regeneration pattern at the 1.12 ha study plot in natural deciduous broad-leaved forest of Mt. Jeombong. The density and mean DBH of *K. septemlobus* was 97 trees per ha and 32 cm, respectively. The spatial distribution of *K. septemlobus* showed a random pattern (aggregation index is 0.935) in the 1.12 ha study plot. The age of 90 trees among 99 sample trees of *K. septemlobus* ranged from 90 to 110 years and represented a single cohort, thus suggesting that *K. septemlobus* in advance regeneration has regenerated as a result of disturbances such as canopy opening.

Key words: Age structure, *Kalopanax septemlobus*, Natural regeneration, Single cohort, Spatial distribution

INTRODUCTION

Since the demands not only for value-added timber but the environmental functions of forests (e.g. biodiversity conservation) had been increasing, native tree species have been, and is rapidly being replaced by exotic tree species in many parts of the world (Turnbull 1999, Zerbe 2003, Lee et al. 2004). However, there is little information on the population structure and regeneration characteristics of native tree species. Consequentially, it is difficult to develop conservation or restoration strategies of endangered or degraded population, and eco-friendly management of natural forest.

Castor Aralia, *Kalopanax septemlobus* (Thunb.) Koidz. is a deciduous tree species that can grow up to 30 m in height and 1.8 m in diameter at breast height (DBH). It is the only species in its genus of the *Araliaceae* family (Ohashi 1994). Its geographical distribution covers from 23° to 47° N and from 88° to 145° E in the Northeast Asia such as in the Korean peninsula, Japan, China and Russian Far East (Chang et al. 2003). The frequent appearance of *K. septemlobus* mixed with *Quercus*, *Acer*, *Betula* and *Carpinus* species was observed in the northern aspect and ridge slope where soil nutrient conditions were fertile in Gangwon Province, Korea (Lee and Kang 2002).

The importance of *K. septemlobus* in Korea has been recognized due to several reasons: good timber quality which makes this species valuable in the timber market; and saponin, one of the secondary metabolic products that could be used for several medicinal and edible purposes (Shin et al. 2005). The regeneration of *K. septemlobus* growing among other hardwood species in natural forest is very difficult because of its low seed viability and germination rate. Thus, the population density is usually low with only several adult individuals per ha and is considered as a “sparsely-distributed species” (Masaki et al. 1992, Fujimori 2002). Recently, due to the increasing market demand for non-timber forest products such as wild edible and/or medicinal herbs, illegal cuttings and overexploitation have resulted in the rapid depletion and destruction of the natural habitats of this species. However, there has been little research on its ecological characteristics, especially regeneration strategies.

The objectives of this study are to understand the stand structure and regeneration pattern of *K. septemlobus* in natural deciduous forest, Gangwon Province, Korea.

METHODS

Study Site

The study area was located at Natural Forest Reserve and designated as a UNESCO Biosphere Reserve in 1982. With strict protection from human activities, there were few disturbances in this area with natural growing broad-leaved forests in Korea. The study site (38°02’22” N, 128°26’17” E) was established in a rested fo-

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watershed of Mt. Jeombong, Gangwon Province.

The vegetation of the study site shows a temperate deciduous broad-leaved forest which is dominated by *Quercus mongolica* in the overstory and by *Acer pseudosieboldianum* in the sub-canopy layer, with other cool temperate species such as *Tilia amurensis* and *Abies holophylla*. The understory layer is very diverse with *Ainsliaea acerifolia* and *Sasa borealis* being the most abundant in the herb layer, while important edible herb species such as *Pimpinella brachycarpa*, *Erythronium japonicum* and *Ligularia fischeri* are abundantly found in the study site (Cho 1999).

Mean, minimum and maximum annual temperatures from June 2000 to May 2001 are 5.7, −1.6 and 12.1℃, respectively (HOBO pro RH/Temp data logger). The mean annual precipitation is 1,114 mm and more than 70 % of the rainfall occurred between June to September (Korea Meteorological Administration 2003).

Vegetation Analysis

To understand the characteristics of a *K. septemlobus* stand, a 1.12 ha (80 m×140 m) study plot which showed high dominancy of *K. septemlobus* was established and divided into 28 subplots of 0.04 ha (20 m×20 m).

All individual trees with DBH greater than 2 cm were recorded and the importance value (IV) was calculated from relative species density (RD) and relative coverage (RC) (Curtis and McIntosh 1951). The methods for calculation are as follows:

RD (%) = (Number of species of individuals / total number of individuals) × 100

RC (%) = (Basal area at breast height for a species / total basal area at breast height for all species) × 100

IV (%) = (RD + RC) / 2

Shannon species diversity index (*H'*) and evenness (*E*) were calculated with PC-ORD ver. 4.0 (McCune and Mefford 1999).

$$H' = -\sum_{i}^{s} Pi \log Pi \qquad E = \frac{H'}{\ln(s)} \quad \cdots\cdots (1)$$

Where *Pi* is the portion of the total sample occupied by species *i* and *s* is the number of species.

Spatial Distribution of *K. septemlobus*

To examine the spatial distribution of *K. septemlobus*, Cartesian coordinates (x, y) of all *K. septemlobus* trees were mapped and analyzed by aggregation index (Clark and Evans 1954). It is defined as:

$$R = \frac{\bar{r}_{oberved}}{E(r)} \quad where\ E(r) = \frac{1}{2\sqrt{\lambda}} \quad \cdots\cdots (2)$$

While $\bar{r}_{observed}$ denotes the mean of the distances from the trees to their nearest neighbours in a given forest stand, *E* (*r*) is the mean nearest neighbour distance in a stand with completely random tree locations of intensity $\lambda = N/A$ with *A* = area of the forest stand and *N* = number of trees. If the spatial pattern of *K. septemlobus* is random, *R* = 1. When clumping occurs, *R* approaches zero; in a regular pattern, *R* approaches an upper limit around 2.15 (Krebs 1999, Pommerening 2002).

Age Distribution of *K. septemlobus*

To measure the age of *K. septemlobus*, increment core samples of all the *K. septemlobus* in the study plot were collected. The cores (one or two cores per tree) were extracted at approximately 50 cm height on opposite sides of the boles with an increment borer and tree rings were counted using microscope (Olympus sz60, ×10). Where the pith was not present, the additional number of rings to the pith was inferred from the disk samples of *K. septemlobus*.

RESULTS

Stand Characteristics

The mean altitude and slope of this study site were 1,050 m above sea level and 22.5°, respectively. The topography of the middle part of the study plot is a ridge with valley areas on both sides (Fig. 1).

Twenty-six tree species were observed in the 1.12 ha study site: one conifer (*Abies holophylla*) and 25 deciduous broad-leaved species. Total number of *K. septemlobus* was 105 and the density was 94 trees per ha.

The highest IV was 16.3 for *Quercus mongolica* and other dominant species were *Acer pseudosieboldianum* with IV of 14.8, *Carpinus cordata* with 14.3, *K. septemlobus* with 11.9, and *Acer pictum* subsp. *mono* with 9.3 (Table 1).

The Shannon species diversity and evenness were 2.049 and 0.836, respectively. In particular, the maximum DBH of *Acer pseudosieboldianum* which is known as a sub-canopy species was 34 cm. While the average DBH of *K. septemlobus* was 32 cm, there were none with less than 10 cm. The stand was considered as an older stand compared to other natural deciduous forests in Korea (Fig. 2).

Spatial Distribution of *K. septemlobus*

The results of the study on spatial distribution of 105 *K. septemlobus* trees that were growing in the study plot showed that this species was mainly distributed in ridge areas (Fig. 3). The naturally regenerated *K. septemlobus* seedlings in natural forest were known to be distributed in aggregation pattern. However, the aggregation index of *K. septemlobus* in this study site was 0.935 that indicates a randomly distributed pattern (Yang and Kim 2002).

Relationship between Age and DBH of *K. septemlobus*

Among 105 *K. septemlobus* trees in the study plot, the age data of 99 trees were collected with the exception of decayed ones. The distribution of age was from 66 to 114 years (mean age was 100.5 years) and 91 % of them belonged to ages between 91 and 110 years (Fig. 4).

#1(slope) 1) 1 2) 10 3) 7 4) 2.377	#2(ridge) 1) 0 2) 5 3) 5 4) 2.395	#3(ridge) 1) 3 2) 30 3) 8 4) 2.136	#4(ridge-slope) 1) 0 2) 17 3) 4 4) 2.267
#5(slope) 1) 0 2) 14 3) 6 4) 2.168	#6(ridge) 1) 4 2) 16 3) 9 4) 2.237	#7(ridge) 1) 5 2) 31 3) 11 4) 2.187	#8(ridge-slope) 1) 0 2) 22 3) 7 4) 2.198
#9(ridge-slope) 1) 1 2) 22 3) 9 4) 2.019	#10(ridge) 1) 10 2) 9 3) 13 4) 2.148	#11(ridge) 1) 12 2) 31 3) 9 4) 1.775	#12(ridge-slope) 1) 0 2) 26 3) 7 4) 1.939
#13(ridge-slope) 1) 3 2) 19 3) 8 4) 1.980	#14(ridge) 1) 11 2) 17 3) 6 4) 1.772	#15(ridge) 1) 6 2) 27 3) 11 4) 2.167	#16(ridge-slope) 1) 0 2) 25 3) 5 4) 1.999
#17(ridge-slope) 1) 1 2) 28 3) 5 4) 1.889	#18(ridge) 1) 7 2) 17 3) 3 4) 1.797	#19(ridge) 1) 10 2) 28 3) 7 4) 1.956	#20(ridge-slope) 1) 0 2) 29 3) 8 4) 2.011
#21(ridge) 1) 7 2) 26 3) 9 4) 1.648	#22(ridge) 1) 4 2) 20 3) 3 4) 1.663	#23(ridge) 1) 8 2) 31 3) 7 4) 2.066	#24(valley-slope) 1) 0 2) 25 3) 7 4) 2.215
#25(ridge-slope) 1) 0 2) 37 3) 3 4) 2.270	#26(ridge) 1) 4 2) 34 3) 5 4) 1.847	#27(ridge) 1) 7 2) 28 3) 9 4) 2.013	#28(valley-slope) 1) 1 2) 5 3) 6 4) 2.233

20m

Fig. 1. Site characteristics of 28 subplots.
Dotted line indicates ridge position, #1: subplot number, 1) number of *K. septemlobus*, 2) slope(°), 3) depth of litter layer (cm), 4) Shannon diversity index.

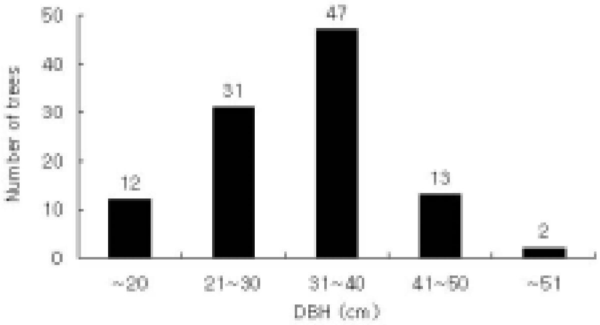

Fig. 2. Number of *K. septemlobus* trees from DBH classes.

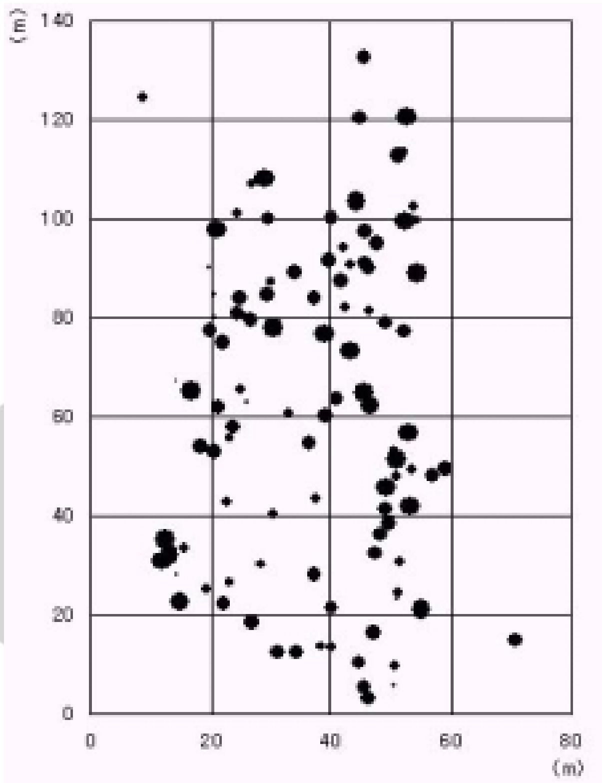

Fig. 3. Spatial distribution of *K. septemlobus* from DBH classes. (• : DBH<20, ● : 20≤DBH<30, ● : 30≤DBH<40, ● : 40 ≤DBH)

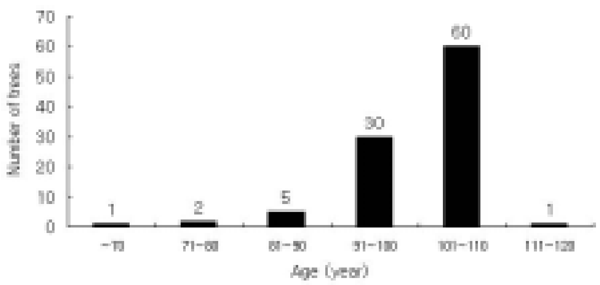

Fig. 4. Age distribution of mature trees of *K. septemlobus*.

Table 1. Importance value of tree species in the 1.12 ha study plot at Mt. Jeombong

Plot	QUMO*	ACPS	CACO	KASE	ACPI	FRRH	TIAM	FRMA	SOAL	BECO	ULLA	ACMA	ABHO	COCO	EUSA	PRSA
1	–	6.6	4.5	3.5	20.4	6.6		–	6.8	–	4.4	22.3	2.3	1.6	7.4	–
2	25.3	11.6	3.9	–	7.0	1.8	9.9	–	2.3	–	2.5	5.1	13.3	6.1	5.2	1.0
3	1.9	9.9	9.7	19.9	16.5	–	2.2	–	5.4	22.3	5.2	2.4	–	3.5	1.1	–
4	9.3	–	3.6	–	12.8	22.9	2.5	–	2.8	20.5	5.7	1.8	1.8	2.0	7.3	–
5	16.7	18.7	16.4	–	17.7	–	1.1	–	–	–	7.2	5.8	2.2	–	2.4	–
6	23.0	11.9	10.9	8.8	7.9	–	3.8	–	4.1	–	–	–	16.8	0.7	3.4	2.8
7	11.4	15.5	17.0	20.5	7.0	–	3.8	–	3.7	13.8	1.1	0.9	0.9	–	1.8	1.7
8	25.9	11.8	3.2	–	17.7	–		7.2	–	5.5	11.3	2.6	1.4	3.8	6.6	–
9	24.5	22.9	17.9	2.2	10.6	2.0	6.6	–	2.2	–	–	–	4.1	–	2.9	4.2
10	17.3	14.0	9.9	23.4	4.6	1.4	12.9	–	4.7	–	–	–	3.5	–	0.7	5.5
11	6.4	19.4	4.6	44.9	11.1	1.2	2.2	–	–	2.6	1.1	1.0	1.0	3.4	1.0	–
12	12.1	24.0	10.3	–	20.5	–	3.1	19.6	–	–	2.2	1.0	–	5.8	–	–
13	28.3	17.0	20.7	13.9	–	–	4.3	2.3	1.4	–	–	–	–	3.3	1.1	2.7
14	23.9	21.0	11.0	27.0	5.3	–	7.5	–	3.3	–	–	–	–	–	–	–
15	3.6	10.3	15.1	25.0	15.7	–	3.4	11.0	3.7	5.8	–	2.0	–	1.5	3.0	–
16	15.4	29.0	9.7	–	12.5	–	5.1	17.1	4.2	3.2	–	2.0	1.0	–	1.0	–
17	19.7	16.3	30.0	–	2.4	1.3	5.8	–		–	–	11.4	7.8	–	–	–
18	32.2	18.4	20.1	15.1	–	–	3.4	–	4.1	–	–	–	0.9	–	2.0	3.3
19	13.4	8.3	17.8	34.3	3.5	–	3.3	–	4.9	–	–	2.1	–	2.0	1.0	9.4
20	10.8	18.9	13.7	–	10.9	27.2	3.0	1.2	0.6	3.1	0.9	–	0.6	9.1	–	–
21	1.1	10.1	38.8	27.0	8.1	–	9.4	–	1.8	–	–	–	–	–	–	1.9
22	43.0	18.1	15.7	8.9	1.7	–	1.8	–	6.4	–	–	–	–	–	–	3.1
23	13.0	9.0	24.9	21.4	7.0	7.5	0.9	–	7.0	–	0.9	–	–	2.3	–	6.0
24	3.6	15.0	15.0	–	12.8	20.7	1.5	9.9	0.9	3.1	10.6	1.7	–	3.3	–	–
25	23.7	12.6	17.3	–	8.9	2.8	1.4	8.9	2.9	–	4.9	5.0	–	2.6	4.6	–
26	30.2	16.5	14.7	13.8	0.8	10.2	4.6	–	9.2	–	–	–	–	–	–	–
27	21.8	15.5	20.2	17.8	7.5	7.3	3.1	–	2.4	–	1.5	–	–	2.2	0.6	–
28	–	10.9	4.2	4.7	9.6	20.2	–	21.6	1.0	–	14.3	2.9	–	4.4	1.9	1.5
Avg.	16.3	14.8	14.3	11.9	9.3	4.8	3.8	3.5	3.1	2.9	2.6	2.5	2.1	2.1	2.0	1.5

*: Species list of which average importance value is greater than 1.0.
(QUMO: *Quercus mongolica*, ACPS: *Acer pseudosieboldianum*, CACO: *Carpinus cordata*, KASE: *Kalopanax septemlobus*, ACPI: *Acer pictum* subsp. *mono*, FRRH: *Fraxinus rhynchophylla*, TIAM: *Tilia amurensis*, FRMA: *Fraxinus mandshurica*, SOAL: *Sorbus alnifolia*, BECO: *Betula costata*, ULLA: *Ulmus laciniata*, ACMA: *Acer mandshuricum*, ABHO: *Abies holophylla*, COCO: *Cornus controversa*, EUSA: *Euonymus sachalinensis*, PRSA: *Prunus sargentii*).

DISCUSSION

The prevalence of a particular regenerative strategy in a forest community may depend on the disturbance regime of the forest (Akahi 1996, Asselin et al. 2001). Successive changes in species dominance after a major disturbance have long been recognized by many researchers (Drovyshev 2001). Stands developing after major disturbances have been described as “even-aged” stands, since all component trees have been assumed to regenerate shortly after the disturbance. In particular, stands developing after a minor disturbance were referred as single-cohort stands (Oliver and Larson 1996).

Natural disturbance regimes specific to topography also affect the structure and dynamics of stand development; the disturbance temporarily modifies both the physical environment and the biota of the forest in a topographic unit, resulting in a mosaic of patches at different developmental stages (Perry 1994).

In general, it is very difficult to identify the real age of hardwood trees in natural deciduous forests. Moreover, if intermediate and late-successional species are shade tolerant or regenerate by sprouting, older trees with comparatively smaller DBH can be found among bigger trees (Crawley 1997).

In the study plot, although the DBH values ranged from 13 to 54 cm, they were represented by a “single cohort” (Fig. 5).

This suggests that *K. septemlobus* regenerated after a major disturbance such as canopy layer opening (Oliver and Larson 1996). As *K. septemlobus* has good shade tolerance and photosynthetic efficiency under low to moderate light intensities at the early stage, we suppose that many advance regenerations of *K. septemlobus* were distributed under the canopy before the disturbance (Abe et al. 1995).

Even though we found a naturally regenerated *K. septemlobus* by root-sucker, the sprouting of *K. septemlobus* after gap formation was not often in this site (Fig. 6).

However, it needs further study to identify the genetic relationship among the mature *K. septemlobus*.

We could not find any naturally regenerated seedlings or saplings in this 1.12 ha study site and in circumference. Iida and Nakashizuka (1998) examined the role of bird dispersal in seed and seedling dynamics of *K. septemlobus* in natural broad-leaved fore

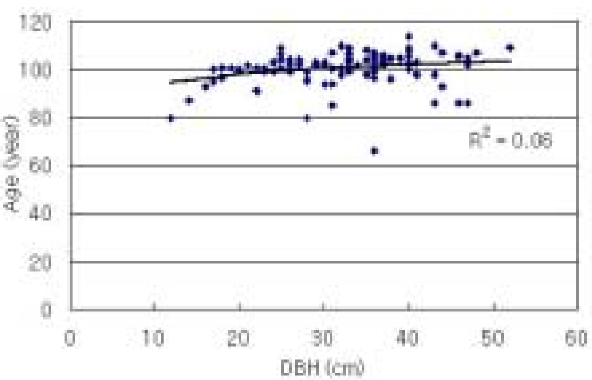

Fig. 5. The relationship between DBH and age of *K. septemlobus*.

Fig. 6. Naturally regenerated *K. septemlobus* tree by root-sucker.

stand indicated the seeds scattered by birds appear to increase the possibility of reaching the present safe sites in distant areas with quick germination.

Janzen (1970) and Connell (1971) suggested that seeds and seedlings beneath the parent trees would suffer disproportionately high mortality from specialist predators or pathogens and this maintains high species diversity in tropical forests. High mortality of seedlings near conspecific trees seems to be also observed in temperate forests (Maeto and Fukuyama 1997).

To understand the natural regeneration of *K. septemlobus*, additional studies should be conducted not only on genetic diversity and spatial distribution, but also on the monitoring of seed production and seedling survival.

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