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Population Dynamics of *Quercus mongolica* in Mt. Jumbong

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ABSTRACT: Distribution of size class, population regeneration and changes in the population structure of *Quercus mongolica* were studied from 1994 to 1999 in Mt. Jumbong (128°27′E, 38°04′N) of Mt. Sorak National Park and Biosphere Reserve in central Korea. Three 20m × 20m permanent quadrats were set up at the elevation of 900m. The vegetation of the study site was dominated by *Quercus mongolica* and *Acer pseudosieboldianum*, but little change was observed in the community structure from 1995 to 1999. Most mortality in the study site was observed in small trees of *A. pseudosieboldianum* and *Tilia amurensis*. Mean annual growth in dbh (diameter of breast height) of *Q. mongolica* for 4 years was only 0.09cm, and no ingrowth of saplings (dbh < 2.5cm) into tree class was observed during the study period. Among the 21 *Q. mongolica* trees studied in the permanent quadrats, all the smaller trees (dbh < 30cm) were established in 1920 ~ 1950, while many bigger trees (with 40cm < dbh < 80cm) were established in 1750 ~ 1800, indicating that its establishment was episodic. Distribution of dbh classes among *Q. mongolica* trees shows that smaller trees were poorly represented, and no saplings of *Q. mongolica* occurred in the permanent quadrats studied, indicating that currently *Q. mongolica* is not regenerating well in the study site. Total seed production of *Q. mongolica* in 1994 was estimated as 88 acorns per square meter in the study site. Rate of predation including caching of acorns was highest in 1994, then declined sharply thereafter. Most of the acorns which managed to survive in the first year were predated in the second year, and only 5% of the acorns produced in 1994 survived into the third year. No seeds produced in 1994 or seedlings germinated from them succeeded to survive to 5 years after seed production. However, seedling emergence rate and seedling survival were high in the early growing season in 1995. These results suggest that predation can be a significant factor in the regeneration of *Q. mongolica*, and that *Q. mongolica* is not regenerating well in Mt. Jumbong and needs large scale disturbances for its new recruitment.

Key Words: Diameter growth, Mt. Sorak, Population dynamics, *Quercus mongolica*, Seed predation, Seed production, Seedling survival.

INTRODUCTION

The temperate deciduous hardwood forests of central Korea are dominated by *Quercus mongolica* (Mongolian oak), *Quercus serrata*, and *Abies holophylla* (Yim 1977), and among them, *Q. mongolica* occupies the largest area and is dominant on drier sites. In Mt. Sorak National Park, most area is covered with *Q. mongolica* community, which is composed of *Q. mongolica* in the overstory and *Acer pseudosieboldianum* in the subcanopy layer (Yim and Baek 1985, Lee 1993). In Korea, *Q. mongolica* occurs with many different plant species according to the location and forms diverse subcommunities (Kim 1992).

The regeneration process of oak (*Quercus*) species have been studied extensively because of their timber value (Minckler 1957, Carvell and Tryon 1961, Weaver and Robertson 1981, Dawson *et al.* 1989), and especially much attention has been paid to the effect of natural and artificial disturbances on the regeneration (Bellefleur and LaRocque 1983, Lorimer 1984, Arriaga 1988, Abrams and Nowacki 1992, Cho 1992, Cho and Boerner 1991a, 1995). In many studies on the population dynamics of oaks, regeneration is considered to be closely associated with the size-frequency distribution: they are usually represented by small number of smaller individuals and by large number of larger individuals, and are thought to be shade-intolerant and usually regenerate poorly in many places (Hough and Forbes 1943, Whitney 1984, Boerner and Cho 1987, Seischab 1988, Cho and Boerner 1991b, Cho 1994).

Many studies have been carried out on the seed production and predation by predators during the regeneration process (Sork 1984). Many studies were also conducted on the characteristics of germination of different oak species (Marquis

1975, Harrison and Werner 1984). Regeneration is so important in the determination of community structure that the term "regeneration niche" is commonly used now (Grubb 1977). Regeneration is accomplished by sprouts, seed rain, buried seeds, seed bank and seedling bank, but is determined by the species and the environment (Koop 1987, Tiedemann *et al.* 1987, Crow 1988, Hughes and Fahey 1988, Houle 1991, White 1991).

Studies on *Q. mongolica* in Korea were carried out mostly in terms of community structure, nutrient cycle, productivity, and phytosociology (Mun *et al.* 1977, Kim *et al.* 1991, Kwak and Kim 1992, Song *et al.* 1998), but studies on the population dynamics and regeneration process of *Q. mongolica*, which are very important in understanding of the community structure of deciduous hardwood forests of Korea, are not many (Shin 1991, Cho 1992, Choi 1992). The purpose of this study is to investigate the distribution of size class and the regeneration of *Q. mongolica* and to predict the change of population structure of *Q. mongolica*.

MATERIALS AND METHODS

Study site

This study was conducted in Mt. Jumbong (128° 27′E, 38°04′N) in Yangyang-gun, Kangwon-do Province. The study site is located about 2.5km south of Osaek Hot Spring Resort, and at the elevation of 900m. The slope is gentle (about 10°) and facing north. The study site is included within the nature conservation zone of Mr. Sorak National Park and within the core area of the Mt. Sorak Biosphere Reserve. The vegetation of the study site is dominated by *Quercus mongolica* in the overstory and by *Acer pseudosieboldianum* in the subcanopy layer, and has cool temperate species such as *Tilia amurensis* and *Abies holophylla* (Table 1). Understory layer of the study site was very diverse: *Ainsliaea acerifolia* and *Sasa borealis* were the most abundant in the herb layer, and important edible herb species such as *Pimpinella brachycarpa*, *Erythronium japonicum*, and *Ligularia fischeri* were abundantly found in the study site (Baek 1996).

Population structure of *Quercus mongolica*

Three 20m × 20m permanent quadrats were established in 1995, and dbh (diameter of breast height) and species were recorded for all woody plants with dbh ≥ 2.5cm. Four 5m × 5m quadrats and nine 1m × 1m quadrats were also set up in each permanent quadrat to count the saplings and seedlings, respectively, of *Q. mongolica*. Size-frequency distribution of *Q. mongolica* was drawn from the tree data. Dbh of all trees was measured again in 1997 and 1999.

Seed production and seed predation of *Q. mongolica*

Seed production in 1994 was measured from the seed rain and seed bank. On September 15, 1994, ten 1m × 1m quadrats were set up and the number of newly produced cups and nuts of oak acorns were counted from the quadrats. The difference between the number of new cups and that of new nuts was considered as the amount predated by animals such as mammals and birds. Eleven seed traps (diameter: 50cm) made of nets were established at the height of 50cm from the ground on Sep. 15, 1994, and the number of acorns collected was counted on Nov. 9, 1994. The sum of acorns in the seed bank on the ground before Sep. 15, 1994 and those in the seed rain counted from the seed trap between Sep. 15 and Nov. 9, 1994 was considered as the total seed production in 1994. To measure the seed predation rate, ten newly produced nuts were numbered with permanent marker and placed under the leaf-litter in each 1m × 1 m quadrat. Total of 100 nuts from ten quadrats were monitored for predation, germination, and survival for five years.

Seedling emergence, seedling survival, and radial increment of *Q. mongolica*

Annual growth of dbh is usually very small and sometimes measurement error can be bigger than the growth itself. To supplement the data, 1 ~ 3 increment cores were taken from each *Q. mongolica* tree and the mean annual radial growth was measured for the recent 5 years from 1990 to 1994, and the year of establishment was also determined from the increment cores. Seedling emergence was measured and its survival was calculated from four 4m × 4m quadrats from March 1995 to July 1995.

RESULTS

Vegetational change of the study site

The vegetation of the study site was dominated by *Quercus mongolica* and *Acer pseudosieboldianum*, with the former represented about 3/4 of the total basal area and the latter represented 1/3 of the total density of the study site (Table 1). Other important species were *Tilia amurensis*, which is a cool temperate species, and *Carpinus cordata*, which is a subcanopy shade-tolerant species. Little change was observed either in relative density or relative basal area for the 4 years of study. Most mortality was observed in

Table 1. Changes of density and importance values (%) of trees in permanent quadrats in Mt. Jumbong. Importance values (IV) are mean of relative density (RD) and relative basal area (RBA)

Species	1995				1999			
	Number /0.12ha	RD(%)	RBA(%)	IV(%)	Number /0.12ha	RD(%)	RBA(%)	IV(%)
Quercus mongolica	21	11.86	75.37	43.62	20	12.12	75.17	43.65
Acer pseudosieboldianum	62	35.03	6.43	20.73	57	34.55	5.85	20.20
Tilia amurensis	42	23.73	2.42	13.07	38	23.03	2.56	12.80
Carpinus cordata	24	13.56	3.92	8.74	23	13.94	3.97	8.95
Acer mono	12	6.78	3.11	4.95	12	7.27	3.26	5.26
Kalopanax pictus	2	1.13	2.59	1.86	2	1.21	3.37	2.29
Sorbus alnifolia	3	1.69	1.82	1.76	3	1.82	1.92	1.87
Abies holophylla	1	0.57	2.52	1.54	1	0.61	2.65	1.63
Prunus sargentii	2	1.13	0.80	0.96	2	1.21	0.84	1.03
Symplocos sinensis	3	1.69	0.09	0.89	3	1.82	0.09	0.96
Maackia amurensis	2	1.13	0.15	0.64	2	1.21	0.18	0.70
Fraxinus rhynchophylla	2	1.13	0.12	0.63	2	1.21	0.13	0.67
Styrax obassia	1	0.57	0.67	0.62	0	0.00	0.00	0.00

Table 2. Growth in dbh (cm) of *Quercus mongolica* for 4 years from 1995 to 1999 in three 20m × 20m permanent quadrats in Mt. Jumbong

Tag number	Dbh* in 1995 (cm)	Dbh* in 1999 (cm)	Change in dbh	Change in dbh class**	Radial growth (mm/year)***
003	3.0	Dead	-3.0	-	-
123	15.7	16.9	1.2		1.61
137	22.8	25.2	2.4	+	2.00
162	25.3	26.1	0.8		0.92
974	25.8	26.8	1.0		0.99
109	40.6	41.4	0.8		0.91
979	40.8	42.2	1.4		0.96
158	46.4	46.6	0.2		1.12
147	46.6	46.2	-0.4		0.35
174	48.3	48.4	0.1		0.24
112	50.2	50.2	0.0		0.72
140	50.3	51.4	1.1		1.04
108	51.7	51.7	0.0		0.47
160	52.0	47.4	-4.6	-	0.46
115	53.1	54.4	1.3		-
953	78.2	78.5	0.3		0.54
986	60.9	61.7	0.8		0.87
106	63.7	64.6	0.9		0.66
105	69.4	70.2	0.8	+	0.56
143	76.2	76.2	0.0		-
961	105.2	106.7	1.5		1.42
Mean****±SD	51.15±21.17	51.64±21.07	0.48±1.36		0.88±0.45

* For dbh of trees with multiple stems, geometric mean was used.
** Dbh class was separated by 5 cm interval.
*** Annual radial growth was calculated as the mean of the growth of 5 years (1990-1994) from 1-3 increment cores from each tree.
**** Tree number 003 was not used for the calculation of mean and standard deviation.

small trees of *A. pseudosieboldianum* and *T. amurensis*.

Growth of *Q. mongolica*

Table 2 shows changes in the dbh of *Q. mongolica* for 4 years. Dbh change was very small: mean dbh change was + 0.37cm (i.e. mean annual dbh growth was 0.09cm). Mean annual diameter growth calculated from the tree cores was 0.18cm per year (Table 2). The difference between directly measured dbh growth and diameter growth calculated from increment cores might be due

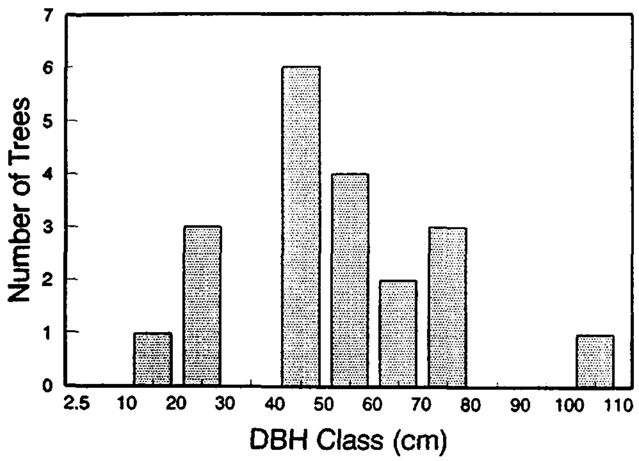

Fig. 1. Size frequency distribution of *Quercus mongolica* in 1999 in Mt. Jumbong. Data are from three 20m × 20m permanent quadrats.

to ignoring of the dead branches in calculation of the latter. Dbh was measured in 1995, 1997, and 1999, and because the growth rate was very small, data of 1997 were used to correct the measurement error. Among the 21 *Q. mongolica* trees studied in the permanent quadrats, only one tree (tag number 003, dbh 3.0cm) died during the study period. Some trees showed negative growth in dbh, due to the death of small multiple stems. Among the 21 trees, two trees succeeded in growth into next dbh class, but in two trees, dbh class was changed into the next lower class. No ingrowth of saplings (dbh < 2.5cm) into tree class was observed during the study period.

Age of the oak trees was estimated from the tree cores except for big trees with rotten trunks. All the four trees with dbh < 30cm (Table 1) were established in 1920 ~ 1950, while all the four bigger trees (with 40cm < dbh < 80cm) which could be dated were established in 1750 ~ 1800 (data not shown).

Fig. 1 shows the distribution of dbh classes among the *Q. mongolica* trees. The graph looks more or less normal, indicating that smaller trees are poorly represented. Higher frequency was found in the dbh classes of 40 ~ 80cm. There were no saplings (dbh < 2.5cm, height > 50cm) of *Q. mongolica* in the permanent quadrats studied.

Production and predation of seeds of *Q. mongolica*

Seed production of *Q. mongolica* was measured for 1994 (Table 3). Most acorns fell to the ground in or before September in the study site which is located about 900 m in elevation. Total seed production of *Q. mongolica* in 1994 was estimated as 88 acorns per square meter in the study site.

The seeds produced in 1994 were monitored for their predation and survival (Table 4). Rate of predation (including removal and caching by mammals or birds for later predation) was highest in the fall of the same year in which acorns were heavily produced, then declined sharply from the winter of the same season. Most of the acorns which survived in the fall or early winter of 1994 were predated in the second year, and only 5% of the acorns produced in 1994 survived into the third year. No seeds produced in 1994 or seedlings germinated from them succeeded to survive to 5 years after seed production (Table 4).

Seedling emergence and survival of *Q. mongolica*

Seedlings originated from seeds produced in

Table 3. Seed production of *Quercus mongolica* in Mt. Jumbong

Period	Number of acorns produced per m^2	Calculation
Jul. 15, 1994 ~ Sep. 15, 1994	73.3 ± 42.3	Mean of 73.3 new cups on the ground per m^2
Sep. 15, 1994 ~ Nov. 9, 1994	14.4 ± 12.8	Mean of 2.82 acorns collected per seed trap (D=0.5m)
Total seed production in 1994	87.7 ± 55.1	Sum of acorn production from Jul. 15 to Nov. 9, 1994

Table 4. Ratio and rate of seed predation and survival of *Quercus mongolica* in Mt. Jumbong

Period	Number of nuts eaten* /available	Predation ratio (%) for the period	Survival ratio (%) for the period	Predation rate per month (%)
Jul. 15, 1994 ~ Sep. 15, 1994	21.6 /73.3	29.5	70.5	15.0
Sep. 15, 1994 ~ Nov. 9, 1994	19.8 /66.1	30.0**	69.0**	16.7
Nov. 9, 1994 ~ May. 19, 1995	6.0 /46.3	13.0**	85.0**	2.1
May. 19, 1995 ~ Jul. 12, 1996	36.3 /40.3	90.0**	4.0**	6.5
Jul. 12, 1996 ~ May. 28, 1999	36.3***/36.3	100.0***	0.0	-

* includes the nuts cached by squirrels or birds for later predation
** When the sum of predation and survival does not equal to 100%, the difference means the ratio of seeds rotten by fungus
*** includes number of rotten seeds

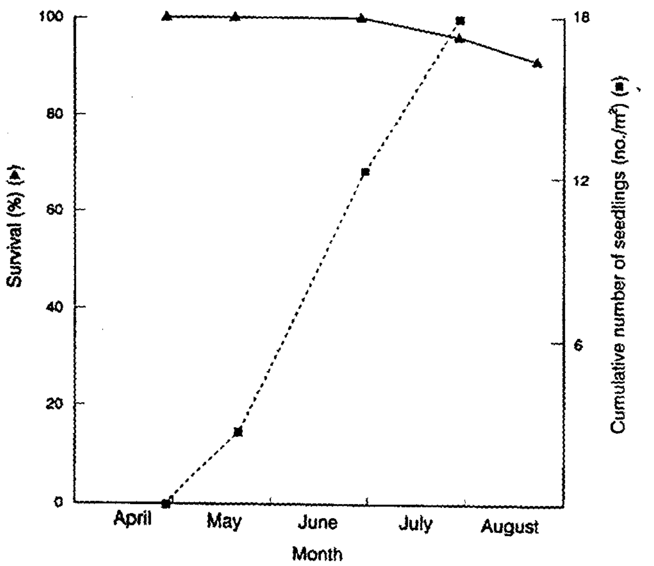

Fig. 2. Rates of seedling emergence and seedling survival of *Quercus mongolica* in Mt. Jumbong.

1994 did not emerge until May 1995 because of snow cover in the study site, and in late July 1995, the number of emerged seedlings reached to 18 per square meter (Fig. 2). Monthly survival rate of emerged seedlings were very high: more than 90% survival rate was observed for the first three months of emergence (Fig. 2).

DISCUSSION

Quercus mongolica is one of the dominant tree species in the deciduous hardwood forests of Korea (Yim 1977, Yim and Baek 1985, Lee 1993), and its population dynamics are important in understanding and the management of oak forests in Korea. In this study, size-frequency distribution, changes in the population structure, seed production, seed predation, seedling emergence, and seedling survival were examined in Mt. Jumbong in central Korea.

The vegetation of the study site was dominated by *Quercus mongolica* and *Acer pseudosieboldianum*, but there was very little change in the community structure for the 4 years of study, and it indicates that four years might be too short to see the change in the forest structure or there were no large scale natural or artificial disturbances for the same period. Most mortality was observed in small trees of *A. pseudosieboldianum* and *T. amurensis*. The former has a lot of advanced regeneration in the understory and the latter can reproduce itself by sprouting, and thus they may not be affected by decrease in density. Therefore, little change could be predicted in the structure of the forest community over the next decades if large scale disturbances do not happen.

During the study period, changes in the dbh of *Q. mongolica* was very small, and some trees grew into next dbh class, but some trees fell into the next lower size class due to negative growth by the death of one of the multiple stems. No ingrowth of seedlings into sapling class or of saplings into tree class was observed during the study period. These results indicates that drastic change in the population structure of *Q. mongolica* may not occur in the proximate future if the current disturbance regime remains the same (Cho and Boerner 1991a, 1995).

Age distribution of the *Q. mongolica* shows that, although not all the trees could be dated due to rotten trunks, two groups of trees appeared: younger trees with dbh < 30cm established in 1920 ~ 1950, and older trees with dbh > 40cm established before 1800. It means that establishment of *Q. mongolica* in the study site was not continuous, but sporadic. This episodic establishment of *Q. mongolica* is easily found in other Mt. Sorak Biosphere Reserve area, where even-aged oak forests frequently appear after fire (personal observation).

The distribution of dbh classes among the *Q. mongolica* trees showed that smaller trees were less frequent than medium or larger ones. In addition, there were no saplings of *Q. mongolica* in the permanent quadrats studied. It means that currently *Q. mongolica* is not regenerating well in the study site.

Seed production of *Q. mongolica* was measured for 1994, which is believed to be a mast year for the species (personal observation). Masting behavior is common in many other species (Rim *et al.* 1991, Rim and Hong 1998). The rate of predation (including removal and caching by predators) of 1994 seed rain was highest in the fall of 1994, and then declined sharply thereafter. Higher predation rate in the fall of 1994 in this study might be due to the high rate of caching rather than direct predation by the predators because the predators might have been satiated in the fall of the mast year. Survival rate of 1994 seed rain to May 1995 was 46.0%, but that to July 1996 was 4.6% (calculated from Table 4). Most of the acorns which managed to survive in the first year were predated in the second year in which acorn production was poor. Sork (1984) found that more than 99% of the acorns of *Quercus rubra* were eaten by vertebrate predators, and that even in masting years seed predation can be quite intense. Similar intense predation effect was observed in Mt. Jumbong. Thus predation seems to play an important role in the regeneration of *Q. mongolica*.

Seeds of *Q. mongolica* are large, and mean weight of its nut is 3.2g, which is about three times heavier than that of *Quercus serrata* (Baek 1996). Because of the large size and rich nutrients, *Q. mongolica* seeds which were managed to escape from predation could survive well during the first of year of their germination (Fig. 2). However, survival rate of seedlings in the next years were very low, and no seedlings survived after 5 years. It might be possible that seedling mortality can be caused by low light intensity (Baek and Cho 1996) under the intact canopy or cotyledon predation by mammals. These results indicate that high seed production, large seed size or masting behavior do not guarantee the successful regeneration of *Q. mongolica*.

The above results suggests that failure of regeneration might be partly due to seed predation by predators, but failure of ingrowth from seedlings to saplings and from saplings to trees might be due to lack of large scale disturbances such as drought (Clinton *et al.* 1993), wind storm (Matlack *et al.* 1993), and fire (Reich et al. 1990) which are needed to open the canopy for the growth of shade-intolerant *Q. mongolica* species.

Population dynamics can be studied easily with Leslie matrix model (Leslie 1945) to predict the distribution of size class of trees and for management of forests (Usher 1969, Roberts and Hruska 1986, Brisbin and Dale 1987). However, to use the matrix model, transition matrix should be constructed based on the change of size class or stages over time. In this study, it is proved that five years is not long enough to construct a robust transition matrix for trees because of very slow growth rate and low mortality rate of trees. When the same study site is monitored for longer periods (McCune and Cottam 1985), accurate prediction of population and community structure by the matrix model would be possible.

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