Chapter 3

Establishment, Regeneration, and Succession of Korean Red Pine (*Pinus densiflora* S. et Z.) Forest in Korea

Chang Seok Lee, Young Mun Chun, Hansol Lee,
Jung Hoon Pi and Chi Hong Lim

Additional information is available at the end of the chapter

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Abstract

Seed production of Korean red pine (*Pinus densiflora* Siebold & Zucc.) was ranging from 25 to 27 seeds/m2 with a viability averaging between 42 and 44%. Seed dispersal reaches about 80 m. Germination rate of seed varied from 19 to 90%, and survival rate of seedling varied from 0 to 30% depending on moisture condition in field experiment. Survivorship curve of the pine population showed type III. Species composition of the pine forest was characterized by possessing plants with resistant capacity to water deficit such as *Rhododendron micranthum*, *Vaccinium hirtum* var. *koreanum*, *Spodiopogon sibiricus*, and *Lespedeza cyrtobotrya*. Ecological longevity of the pine was about 140 years based on mean age of gap makers. Natural maintenance of the pine forest depended on disturbance regime, which is dominated by endogenous factor. Natural regeneration of the pine forest is possible only in a very restricted site such as ridgetop with thin and infertile soil condition. Therefore, active and systematic management is required for artificial regeneration of the forest as is known in silivicultural method. Pine gall midge damage accelerated succession of the pine forest to the deciduous broadleaved forest dominated by oak except on the ridgetop where the forest can be maintained naturally.

Keywords: Korean red pine, life history, natural regeneration, pine gall midge damage, silviculture, succession

1. Introduction

Pinus densiflora S. et Z. (Korean red pine) has a home range that includes the Korean Peninsula, northeastern China, the extreme southeast of Russia, and the Japanese Archipelago [1]. Its latitudinal range on the Korean Peninsula is from Mt. Halla, on Jeju Island in South Korea (33° 20′ N), to Jeungsan, in North Korea (43° 20′ N) [2]. The height of this tree is 20–35 m. The pine prefers full sun on well-drained, slightly acidic soil. The needle leaves are 8–12 cm long, with two per fascicle. The cones are 4–7 cm long [3].

The most favorable soil type for this species is well-drained sand or gravel that is weathered from granite and eroded by storm waters during the monsoon months in summer [4]. With such a wide range of tolerance, Korean red pine normally occurs on the thin and infertile soils of rock outcroppings, weathered rocks, ridge tops, and the sandy or pebble shores of streams [5]. It also can grow well in disturbed soils along both mountain slopes and bases after forest thinning or brush removal near human settlements [6–9].

These Korean red pine forests are valued by Korean people for numerous amenities to basic life (e.g., material for buildings and ships, and oils such as terpenes), as well as for esthetics, recreation, and biological diversity [10–13]. Therefore, the expansion of these forests, through artificial plantings and maintenance, has been encouraged by Korean governments since early in the twentieth century [14]. However, natural stands of Korean red pine have declined to only about one-third of their extent currently for several reasons, including over-exploitation under Japanese occupation (1910–1945), the Korean War (1950–1953), pest defoliation, wildfire, and negligence [5]. Such losses are a concern among forest managers in Korea because of the reduction in forest products and biological diversity [15].

This pine produces pollen that is wind dispersed [16]. It takes 3 years to complete its reproduction cycle [17]: female bud formation is initiated in the summer, pollination occurs the following spring, and seeds maturate in the fall a year later. After 40–60 years, relative growth in diameter and height slows as a lognormal [18]. Cone production may begin at 7 years in isolated tree; it is delayed to 11—18 years when trees form stands [18]. On exposed rocky ridges, some trees survive to ages beyond 140 years [19].

According to pollen analysis, pine forests began to replace deciduous broad-leaved forests about 6500 years ago and it was accelerated 2300 years ago in the southwestern part, and 1400 years ago in the eastern part of the Korean Peninsula [20, 21]. This range expansion was in response to an increase in fire frequency associated with rising temperatures and agricultural activities [20, 21]. The persistence of these temperate pine forests in Korea has been speculated to be a result of the pine's adaptation to and dependence upon dry weather from fall through spring [20, 22, 23], the availability of large areas with coarse-textured soils [22, 23], and frequent disturbance by human activities [6, 20]. Disturbances were envisioned as creating gaps in the forest canopy and exposing bare soil that favored seed germination while coarse-textured soils would induce drought sufficient to limit competition from oak and other species [19, 22]. With a shift toward fossil fuels for heating homes, the kinds of disturbances that once perpetuated Korean red pine are now lacking [6, 24]. Clear felling or other alternatives serve the same role as fire [18].

It is useful to evaluate life history attributes of the species to clarify ecological characteristics of a species. The critical stages in a plant's life cycle are those having to do with reproduction, seed dispersal, germination, seedling establishment, and population dynamics including regeneration after disturbance [4, 19, 25–27]. If conditions for successful regeneration occur infrequently, then successful maintenance of a population is less assured because a favorable seed year must correspond with an appropriate disturbance. Knowledge of interannual variation in seed production and the distribution of age classes of trees can address the importance of synchronous events in perpetuating tree populations [28, 29]. Adequate dispersal is necessary to occupy new habitats and to expand a population [30–32]. Although seeds may germinate, seedling establishment may occur only under specific microclimatic and edaphic conditions that provide adequate moisture, light, and nutrients, without harmful pathogens and herbivores [29, 33].

Although most species in the genus *Pinus* grow well under high radiation [34, 35], the initial establishment stage is more sensitive to the availability of soil moisture than radiation [35, 36]. Because the Korean Peninsula customarily experiences a long dry season from fall to spring [37], it is worth to monitor of responses of plant on water stress at the time of germination and seedling establishment.

Korean red pine forest is the representative forest in Korea, which is not only familiar well with climate and soil but also economic value is very big in Korea. Therefore, a study on life history of the pine forest is required indispensably in order to clarify formation, maintenance mechanism, and transition process of forest, which occupies 2/3 of the whole national territory in Korea [4, 19].

Grime [38] divides life history into mature and regeneration phases in the life history strategy of plant and clarifies the duration and mechanism of each stage by dividing the latter stage into seed release, disposal, dormancy, and maturation of seedling. It is very difficult to clarify in detail each stage of the life history because perennial woody plant with long longevity has a very long life cycle. A serial regeneration process occurring after disturbance in the mature forest can provide critical information [39].

This chapter aims to clarify the whole life cycle from birth as a seed to regeneration and/or succession of Korean red pine forest as the representative forest community in Korea. To arrive at the goal, we analyzed the process by organizing this chapter as 10 sections including production and dispersal of seed, germination rate, survival rate of seedling, survivorship curve of Korean red pine population, species composition of Korean red pine community, disturbance regime in Korean red pine forest, regeneration of Korean red pine forest in natural condition, natural regeneration of Korean red pine forest disturbed by air pollution and by applying silvicultural method, and succession of Korean red pine forest damaged by pine gall midge.

This paper was prepared by reediting papers that prof. C.S. Lee and his colleagues had published to date.

2. Methods

2.1. Seed production

Seed production was tallied by counting the number of seeds fallen into twelve 1 m^2 seed traps made from nylon netting that were positioned 1 m above the soil surface. Seeds were collected over 3 years from 1 May 1985 to 30 April 1987.

2.2. Seed dispersal

Seed dispersal was measured using five seed traps per point, set at 0 (beneath the seed source), 5, 10, 20, 30 and 40 m distance from the exposed edge of the 70-year-old stand.

2.3. Emergence and survival of seedlings on forest floor

One hundred seeds were sown on the surface and at 1.0 cm depth at the 30–40-year-old stands at 3 cm × 3 cm spacing. All seedbeds were covered with a 0.5 cm thick layer of pine litter and had five replicates. Germination rate was obtained from percentage of the number of seedlings emerged to the number of sown seeds. The survival of seedlings was measured by tallying the number of live seedlings at 1-week intervals from the 5th week after sowing.

2.4. Survivorship curve

Survivorship curve of Korean red pine population was obtained by plotting density of Korean red pine investigated in stands with different ages including the number of germinable seed as a beginning cohort.

2.5. Species composition

The differences in species composition among Korean red pine forest and several oak forests, which form the late successional forest, were compared by applying NMDS ordination [40]. Vegetation survey was carried out by recording the cover class of the plant species appearing in the survey plot of 20 m × 20 m size [41]. Cover degree of each species was converted to the median value of percent cover range in each cover class. Relative coverage was determined by multiplying by 100 to the fraction of each species to the summed cover of all species in each plot [42]. The relative coverage of each species was then regarded as the importance value [43]. Finally, a matrix of importance values for all species in all plots was constructed and it was subjected to nonmetric multidimensional scaling (NMDS) for ordination [40] and detrended correspondence analysis (DCA) for ordination [44].

2.6. Disturbance regime

Disturbance regime is defined here the pattern of death of dominant individuals (canopy trees) in a community [45]. Disturbance regime was investigated based on death type of gap makers divided into three kinds of standing dead, uprooted, and stem broken.

Longevity of Korean red pine was determined from mean age of trees died naturally. Age was confirmed by counting annual rings on discs cut from dead tree.

Size of gap was obtained by applying equation of ellipse after measuring long (L) and short (S) radius of gap as the follows. Area = $\pi/4 \times L \times S$ [45].

2.7. Regeneration of Korean red pine forest

Natural regeneration of Korean red pine forest was confirmed by analyzing age class distribution of pine trees forming the forest. Age of sapling was determined by counting the number of nodes. Age of mature tree was obtained by counting the number of annual rings extracted at 30 cm above ground level by using increment borer. Age class distribution diagrams were depicted by the frequency distribution of each class divided at regular intervals. Growth of annual ring was measured with calipers under a dissecting microscope with a 0.05-mm precision.

Responses of plant on gap formation were analyzed by measuring height growth of saplings appeared within gap and branch growth of mature tree surrounding the gap. Height and branch growths were obtained by measuring node length of sapling and of branch cut from mature tree, respectively. Growth equations of height and branch were obtained from relationship between the accumulated years and growth values. The year of gap formation was determined from the year that height growth of saplings in gap and annual ring growth of trees surrounding the gap increased abruptly.

Crown projection diagram was prepared by connecting margins of canopy measured from 8 directions for canopy tree appeared in quadrat installed in study site. Spatial distribution of major species was prepared by plotting X- and Y-coordinates of woody plants appeared in the quadrat. Stand profile was prepared by carefully depicting major plant species appearing in a belt transect installed in 5 m width.

2.8. Succession of Korean red pine forest

Succession of Korean red pine forest damaged by pine gall midge was investigated by analyzing coverage changes of major plant species appeared in Korean red pine stands with different damage stages and healthy pine stands and oak forests as reference stands. Coverage was surveyed by applying Domin-Krajina scale [46].

Vegetation change was analyzed by classifying vegetation layer. Analysis on successional change was reinforced by applying ordination method.

Duration of coning was investigated by counting the number of cones classified by node (year) of branch cut from pine trees in Korean red pine forests, which are in the first and the second stages of pine gall midge damage. Fifty individuals per site were selected as sample trees in four sites.

3. Seed production and dispersal

Annual seed production in the 70-year-old pine forest was consistent, ranging from 25 to 27 seeds/m^2 with a viability averaging between 42 and 44% (**Table 1**).

Period	Seeds collected from twelve 1 m^2 seed traps	Germinated seeds	Germination rate (%)
1985	301	127	42.2
1986	321	142	44.2
1987	296	126	42.6

Table 1. Interannual seed production recorded under a 70-year-old Korean red pine stand.

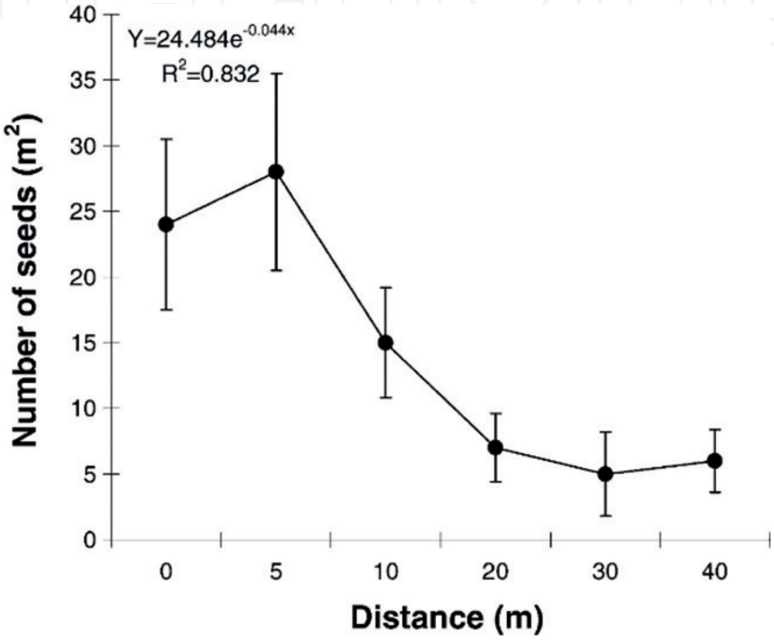

Figure 1. Changes of the number of seeds fallen in seed traps installed by distances from seed source stand. Equation on graph indicates relationship between distance and the number of seeds collected at each distance.

The number of seeds collected in traps set at varying distances from the seed source decreased exponentially out to 40 m (**Figure 1**). The exponential relationship developed between seed number and distance from the edge of the forest indicates by extrapolation that the maximum seed gravity dispersal would be about 80 m.

4. Germination

Germination of seeds sown on the soil surface varied from a high of 90% on the irrigated open (IO) treatment to a low of 19% on the open ground (OG) treatment. Germination rates on the canopy gap (CG) and closed canopy (CC) seedbeds were, respectively, 30 and 42% in 6 weeks after sowing (**Table 2**). Germination rates of seeds placed at 1 cm depth followed a similar response on the different seedbeds with only the OG and CG showing a significant difference from that measured on the soil surface (**Table 2**).

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Seedbeds	Germination rate (%)		P
	Soil surface	1 cm depth	
Irrigation, full exposure	89.8 ± 3.9	90.2 ± 4.4	0.88
Open ground	19.2 ± 4.1	29.6 ± 5.3	0.0001
Canopy gap	30.0 ± 4.0	40.0 ± 5.0	0.0005
Closed canopy	42.0 ± 3.4	42.4 ± 3.6	0.88

Table 2. Mean (%) and S.D. of seed germination from 100 per 9 cm^2 that were sown on the soil surface and at 1 cm depth across a range of selected seedbeds.

5. Seedling survival rate

Of those seeds that germinated, survival varied from 99% on IO treatment to 0% on open ground (OG) (**Figure 2**). The best survival without irrigation was observed under the closed canopy (about 30%), although growth of seedlings (not shown) was higher for those that survived in canopy gaps.

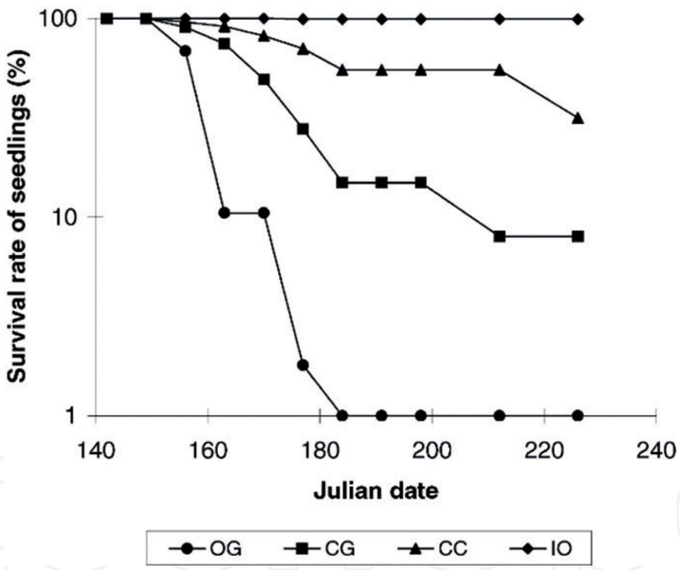

Figure 2. Survivorship curves of seedlings germinated on the different seedbeds on forest floor of the Korean red pine stand. Irrigated and exposed with soil supplement (IO), open ground (OG), canopy gap (CG), and closed canopy (CC).

6. Survivorship curve

Survivorship curve of Korean red pine population was shown in **Figure 3**. The number of germinable seeds was about 1,420,000 per ha and densities of 5, 28, 43, 80, and 130 years

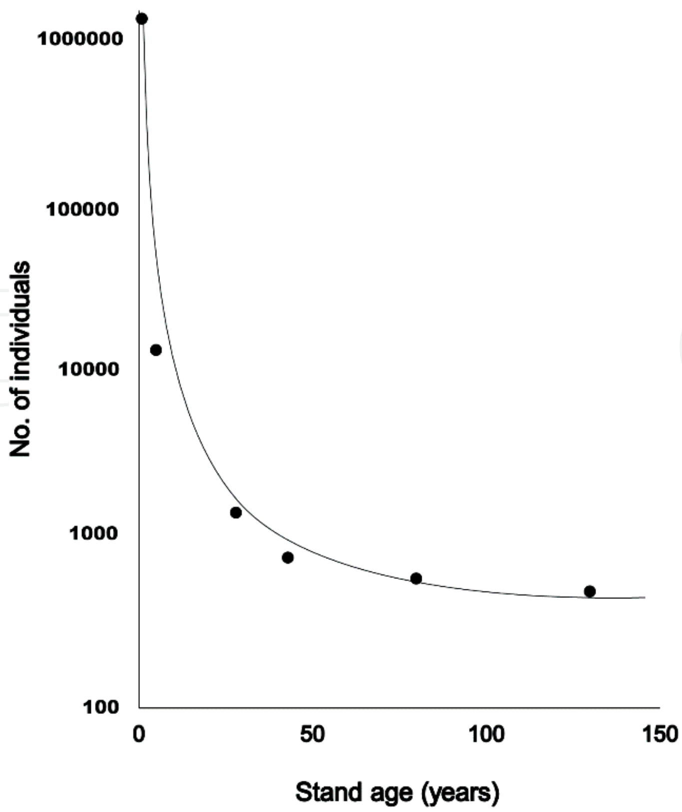

Figure 3. Survivorship curve of Korean red pine population.

old stands were shown as about 14,300, 1500, 800, 600, and 500 individuals/ha, respectively. Expressed the result as a semi-logarithmic graph, survivorship curve of Korean red pine population was shown in type III, which has the greatest mortality early in life, with relatively low mortality for those surviving this bottleneck [47].

7. Species composition of *P. densiflora* community

As the result of stand ordination based on vegetation data (**Figure 4**), stands of Korean red pine community were clearly divided from stands of oak communities and thus showed a difference in species composition. *Rhododendron micranthum* Turcz., *Vaccinium hirtum* var. *koreanum* (Nakai) Kitam., and *Lespedeza cyrtobotrya* Miq., which appear characteristically in the Korean red pine community but does not appear in the oak communities, dominate the difference.

Korean red pine community established on those sites usually forms pure stands. If any oak individuals are invaded to those sites, they usually showed severe desiccation damage on their leaves during spring dry season from May to June that experiences every year in Korea with Asian monsoon climate and consequently did not form erect stem as well as high stature of tree level (Lee, C.S. personal observation). *Rhododendron micranthum* Turcz., *R. mucronulatum* Turcz., *Fraxinus sieboldiana* Bl., and *Lespedeza cyrtobotrya* Miq. dominated shrub layer and *Carex humilis* var. *nana* (H. Lev. et Vaniot) Ohwi, *Spodiopogon sibiricus* Trin., *C. lanceolate* Boott, and *Arundinella hirta* Tanaka dominated herb layer of the Korean red pine community.

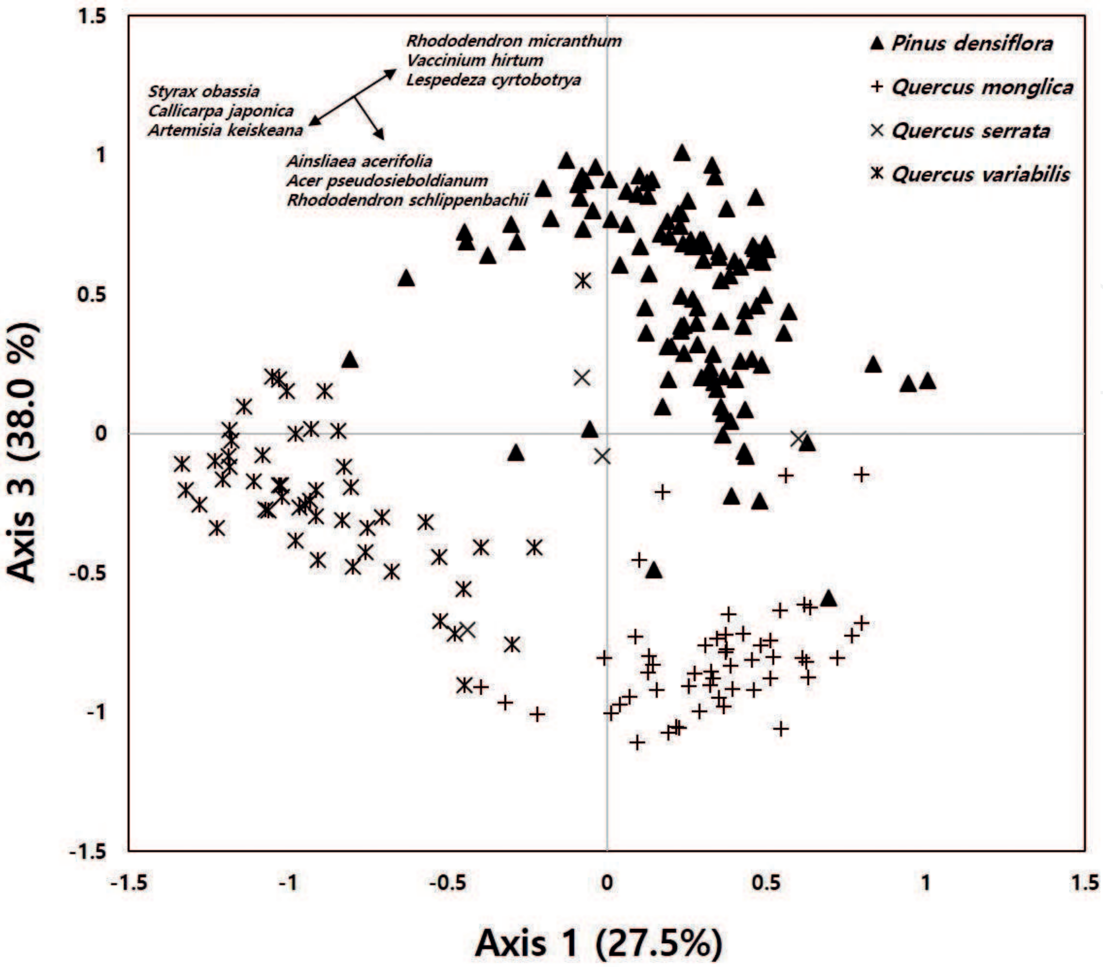

Figure 4. Stand ordination based on vegetation data collected from Korean red pine and oak forests.

Difference of species composition was also shown among oak communities. *Acer pseudosieboldianum* (Paxton) Kom., *Rhododendron schlippenbachii*, Max., and *Ainsliaea acerifolia* Sci.-Bip. of Mongolian oak (*Quercus mongolica* Fisch.) community and *Styrax obassia* S. et Z., *Callicarpa japonica* Thunb., and *Artemisia keiskiana* Miq. of Chinese cork oak (*Q. variabilis* Blume) community dominated the differences (**Figure 4**).

8. Disturbance regime

Disturbance regime was investigated in the sites such as ridgetop with dry and infertile soil where the Korean red pine forest is maintained as an edaphic climax (**Photo 1**). Standing dead type occupied the highest percentage and uprooted and stem broken types tended to be followed although a little difference exists depending on site (**Table 3**).

In general, both endogenous factors related to senescence of plant and exogenous factors such as typhoon, tornado, heavy snow, rainfall, and so on influence on death of gap makers. But if exogenous factors influence more strongly, frequency of uprooted or stem broken types increases in death type of gap maker [48]. In this respect, cause of disturbance in this Korean red pine forest would due to endogenous factors rather than exogenous ones.

Photo 1. Photos showing sites where Korean red pine forest is maintained naturally.

Sites	Death patterns of gap-makers		
	Standing dead	Uprooted	Stem broken
Youngwol	37 (53.6%)	19 (27.5%)	13 (18.8%)
Mt. Wolak	33 (63.5%)	10 (19.2%)	9 (17.3%)
Mt. Songni	5 (100.0%)	–	–
Uljin	3 (75.0%)	–	1 (25.0%)
Mt. Gaya	10 (71.4%)	3 (21.4%)	1 (7.2%)

Table 3. Death pattern of gap-makers in the Korean red pine forests.

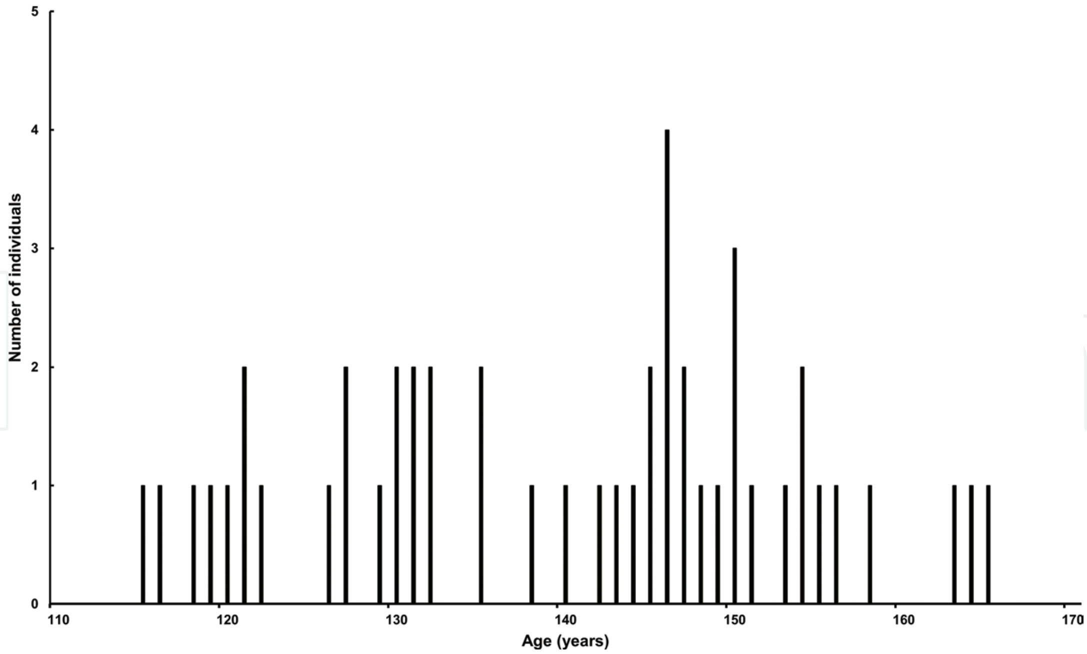

Figure 5. Age distribution of gap makers.

Gaps formed naturally in a forest is usually occurred by cooperative actions of both senescence of plant and exogenous factors [45, 48, 49]. Based on the fact, we can regard gap makers died by natural disturbance as trees that their longevity expired. Thus, we estimated ecological longevity

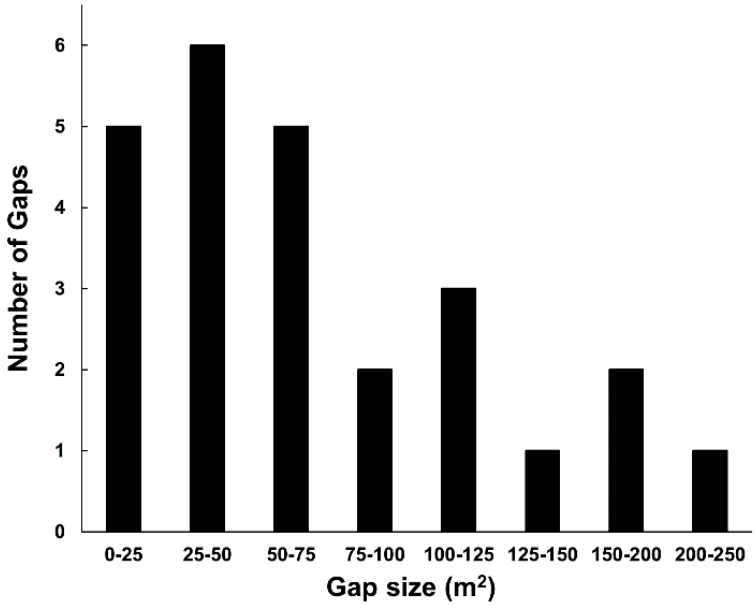

Figure 6. Frequency distribution of size class of gaps formed in *Pinus densiflora* forest.

of Korean red pine from age distribution of gap makers. Ages of gap makers ranged from 116 to 165 years and mean age was ca. 140 years (**Figure 5**). In most forest vegetation around the world, longevity of dominant species ranges from 100 to 1000 [50–53] and it is known that mean longevity of tree species forming temperate deciduous forest is about 300 years [54]. Compared with this information, longevity of Korean red pine was shorter, the reason would due to not only life history trait that the pine is early successional species [55, 56] but also poor environmental condition of site where the Korean red pine forest is maintained in an edaphic climax [19].

In a size class frequency distribution diagram of gaps occurred in the Korean red pine forest (**Figure 6**), gap size ranged from 20 to 235 m^2. Among them, 25.1–50.0 m^2 class occupied the highest frequency as 21.4% and below 25.0 m^2 and 50.1–75.0 m^2 classes (each 17.9%), 100.1–125.0 m^2 class (10.7%), 75.1–100.0 m^2, 150.1–175.0 m^2, and 175.1–200.0 m^2 classes (each 7.1%) and so on followed.

9. Natural regeneration of Korean red pine forest

Age distribution diagrams investigated in the Korean red pine stands of three sites where gap is formed due to disturbance and of one site without gap showed the reversed J-shaped pattern (**Figure 7**). This result implies that seedlings are recruited vigorously in these sites and the Korean red pine forest could be maintained continuously [57, 58]. Compared the periods that seedlings are recruited and gaps are formed, seedling began to be recruited in advance of gap formation. Seedlings appeared in Korean red pine forest where gap was not formed yet as well and thus support advance recruitment of pine seedlings.

But the non-gap site showed a difference from gap sites. Age of saplings was restricted below 10 years and dead individuals also appeared in non-gap site. This results suggest a necessity

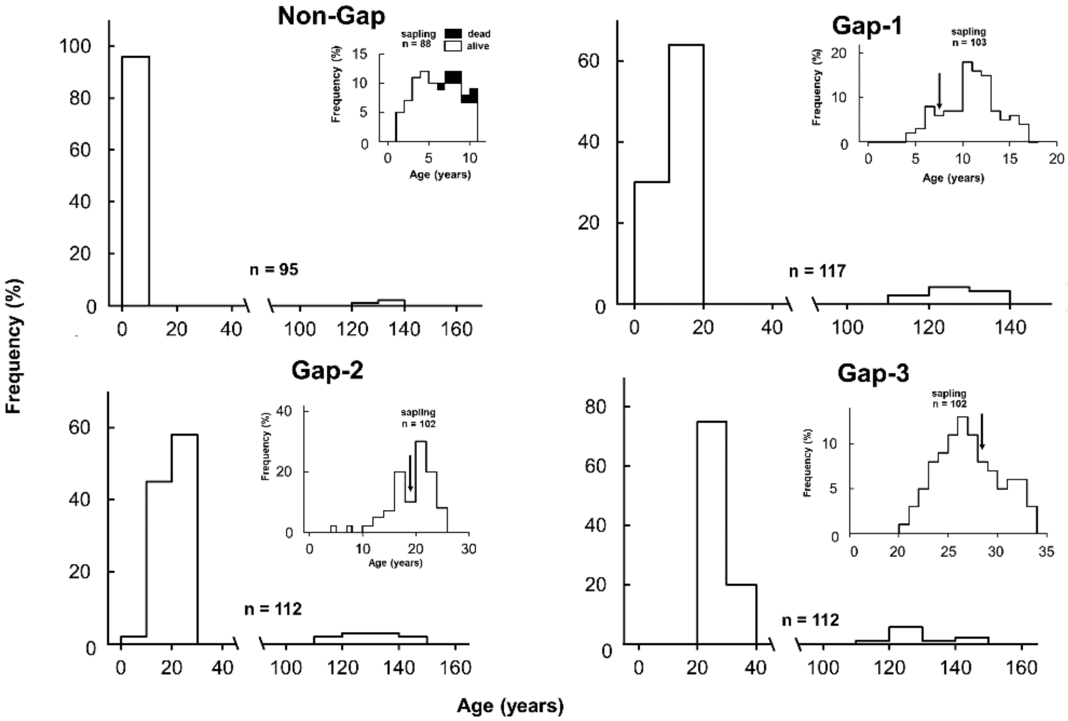

Figure 7. Age distribution diagrams of *Pinus densiflora* population in Korean red pine stand with gap and without gap (non-gap). In each diagram, lower diagram indicates age distribution of all the individuals including mature trees and regenerating young trees and saplings and upper diagram indicates that of the only regenerating individuals. Vertical arrows indicate the estimated year of gap formation. This result shows that many regenerating individuals were recruited in advance of gap formation. Sapling group established in a Korean red pine stand without gap reinforces the result. N numbers indicate the number of trees surveyed. Vertical arrows indicate the estimated year of gap formation.

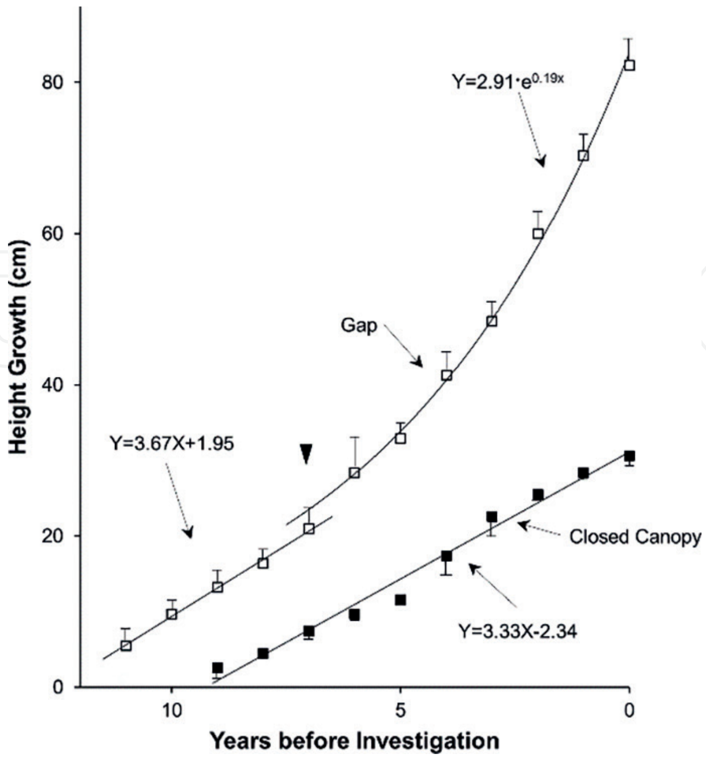

Figure 8. Height growth of saplings of *Pinus densiflora* within gap and under the closed canopy. Vertical arrows indicate the estimated year of gap formation.

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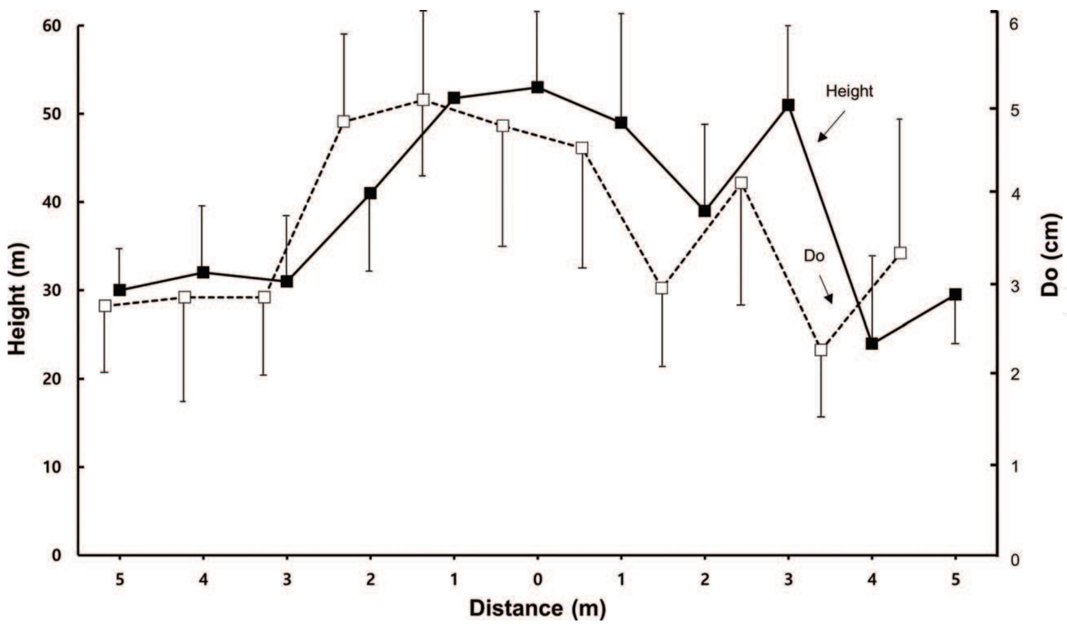

Figure 9. Changes of height, diameter (D_o) and density of saplings of *Pinus densiflora* according to the distances from the center of gap. 0 m indicates the center of gap.

of gap formation for natural regeneration of the Korean red pine forest. In fact, not only shade intolerant species dominated forest but also shade tolerant species dominated forest necessitate gap formation for natural regeneration [59].

Growth of saplings established in advance gap formation showed a linear growth before gap formation but the growth was accelerated exponentially since gap formation (**Figure 8**). This result implies that gap formation promotes the growth of saplings established in gap and consequently contribute to natural regeneration of the Korean red pine forest.

Both height and diameter of saplings were larger at the center of gap and tended to be smaller as move toward the margin of gap (**Figure 9**). It was interpreted that the differences in height and diameter of saplings appeared along the distances from the center of gap would be a response on the spatial differences of light intensity [19].

10. Regeneration process of Korean red pine forest

The regeneration process that gap occurred from a disturbance is closed, is different depending on the disturbance regime such as scale or intensity. If the disturbance scale is small and the intensity is not severe, the gap is closed by branch growth of mature trees surrounding the gaps. But if the disturbance scale is large and the intensity is severe, regeneration is progressed by height growth of saplings established within the gap or replaced by different kinds of forests [45].

Growth of saplings growing within gap showed a big difference from that of saplings under closed canopy without gap (**Figure 8**). The growth was similar to each other before gap formation, but the difference between both got larger after gap formation. Growth of the former showed a linear growth before gap formation but the growth was accelerated as exponential one since gap formation (**Figure 8**). Meanwhile, growth of the latter maintained a linear growth without any difference before and after gap formation (**Figure 10**).

Compared branch growth of mature pines surrounding the gap with that of mature pines, which form a closed canopy without gap, growth of the former showed an increasing trend although the difference was a little, whereas that of the latter was vice versa (**Figure 10**). But a difference between both was not so big.

Mean size of gaps occurred from death of one individual was 28.3 m^2 and the radius of gap of this size was about 3 m [19]. As annual mean branch growth of mature trees surrounding the gap was 6.5 cm per year, 46 years were required to close the gap by branch growth of this level (**Figure 11**) [19].

Height of the tallest tree measured in the sites where Korean red pine forest can be maintained naturally, was about 20 m and annual maximum height growth of the tree was about 60 cm. Meanwhile, height growth of saplings within the gap showed an exponential growth ($Y = 2.92\ e^{019x}$) as was mentioned above. Based on the results, Lee [4] hypothesized that exponential growth of saplings is progressed until the annual growth is arrived at 60 cm, annual maximum growth and since then, maintains the growth rate continuously. To arrive at 60 cm/year,

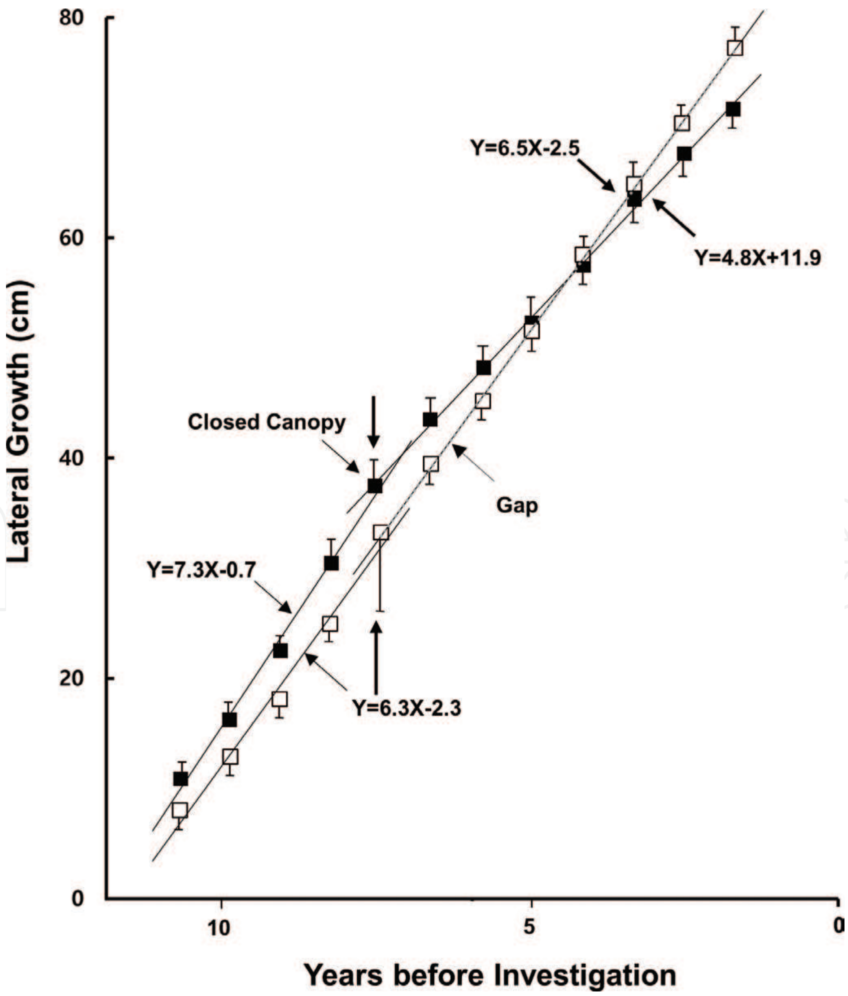

Figure 10. Branch growth of mature trees of *Pinus densiflora* bordering on gap and those on *Pinus densiflora* forest of the closed canopy. Vertical arrows indicate the estimated year of gap formation.

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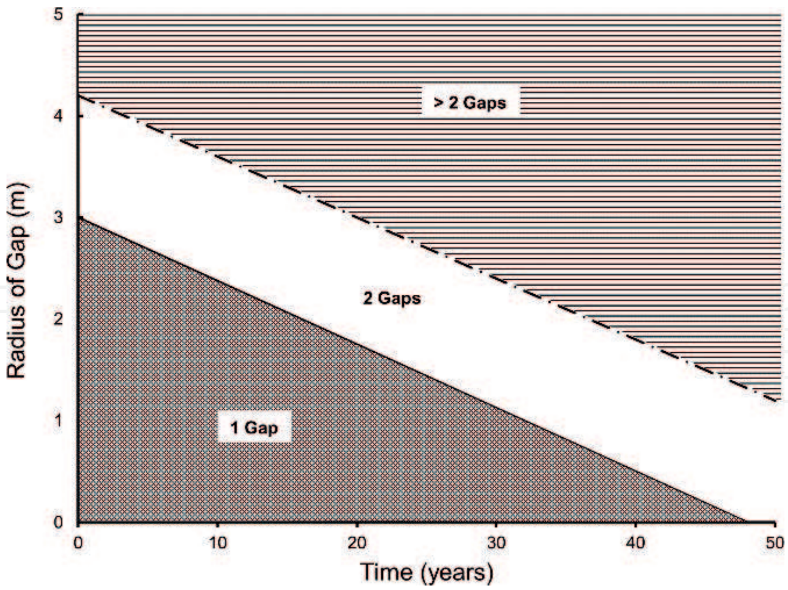

Figure 11. Decreasing curves of gap area. 50 years on X-axis indicate the year required for the saplings to enter the forest canopy. Straight lines inclined to the right indicate the case in which gap area is decreased by the branch growth. When these lines meet X-axis, it means that gap is closed and X-value at the moment indicates the year required for the gap to be closed. 1 gap, 2 gaps and >2 gaps indicate gaps formed by the death of 1, 2, and more than 2 trees.

the annual maximum height growth rate by the exponential growth of the level, 22 years are required and height of saplings at that time reaches about 2 m. Since then, if the saplings reach the canopy level, 20 m, by annual maximum growth rate, 60 cm, 30 years are required more [4]. Synthesized those results, it is calculated that 52 years are required until saplings grow to mature trees, which form overstory canopy by height growth (**Figure 11**) [4]. Compared years required for gap filling by height growth of sapling and branch growth of mature tree, the gap formed by death of one individual would be closed before the saplings within gap arrive at the canopy by height growth if multiple gap events are not occurred there (**Figure 11**).

This result was similar to that of Lee and Kim [18], which was carried out in the Korean red pine forests with different stand ages. But the growth rate, in particular, in early stage was very slow compared with the result of Lee and Kim [18]. This slow growth would due to that they were in the shading state under the closed canopy as individuals established in advance of gap formation. In fact, it is known that growth of individuals established through advance regeneration is very slow in most trees including shade tolerant trees [26].

On the other hand, size of gap formed by death of two individuals becomes 56.6 m^2 and the radius is 4.2 m, calculated the size by hypothesizing as twice of gap size occurred from death of one individual. About 65 years are required to close the gap of this scale by branch growth of trees surrounding the gap (**Figure 11**). Consequently, the gaps formed by death of more than two individuals would be regenerated by height growth of saplings established within gap before the gap is filled by branch growth of surrounding trees [4].

Based on the size class frequency distribution of gaps (**Figure 6**), large gaps occupied about 80% of total gaps. From this result, it was estimated that regeneration of the pine forest is usually achieved by growth of seedling established within the gap in these sites where pine forest can be maintaining continuously.

But as was mentioned above, gentle and endogenous factors dominate the disturbance regime in this region. Therefore, we have to find a background that large gaps are formed. It is known that most large gaps are originated from multiple gaps due to overlapped disturbance events [34, 45]. In general, gaps formed naturally are small ones, which are occurred from death or uprooting of one individual at first. Canopies of trees composing a forest are connected with each other before gap formation and thereby inflow of wind into forest interior is blocked effectively. But if the canopy is opened due to a disturbance, the effect of wind is flowed into the forest interior easily and thus the effects of following disturbance become stronger. Consequently, trees around the gap become more susceptible to disturbance [45]. Moreover, if a tree grows and becomes a mature tree, growth stage of the other trees surrounding the tree are also in similar stage because age range of trees composing the pine forest is narrow and thus close an even-aged stand. This result could be a causal factor that multiple gap is occurred [60].

11. Regeneration of pine forest treated artificially

In managing pine forests for timber, silvicultural methods are applied. The methods are classified three types depending on harvesting method, which is the method of removing products from a forest to make room for a new generation of trees. Clearcutting method is removing the mature stand completely and is usually applied in the upper slope in Korea. Seed trees is usually remained on the ridge above upper 80% in the slope length (**Figure 12**, **Photo 2**).

The seed tree method is removing most of the mature overstory and leaving a portion standing. Mature trees left in low density function as a seed source only. The residuals from this cut are too few and scattered to provide shelter (**Figure 12**, **Photo 2**).

The shelterwood method involves the removal of most of the mature stand at the end of the rotation, but a portion of the mature stand is left standing. The shelterwood method serves three basic purposes: firstly, to prepare the stand for production of abundant seed, secondly, to modify the environment in a way that promotes germination and survival of the selected species, and finally, to build up the amount and size of advance regeneration to ensure the prompt restocking of the new stand following overstory removal. The shelterwood method involves a sequence of three cuttings: firstly, preparatory cuttings make the seed trees more vigorous and set the stage for regeneration. Secondly, establishment/seed cuttings open up enough vacant growing space to allow establishment of the new regeneration. Finally, removal cuttings are uncover the new crop to allow it to fill the growing space [61].

These silvicultural methods are usually applied in the sites beyond the range that natural regeneration of the Korean red pine forest is possible to ensure higher productivity. But the sites are covered with trees including oak competitively superior to Korean red pine. Therefore, in order to achieve successful regeneration of Korean red pine forest as a shade intolerant, management of undergrowth including oak sprouts is required in the level that can expose mineral soil beyond creating gap in the overstory in Korea [18].

Age distribution diagram in the Korean red pine stands treated by applying silvicultural methods for timber production showed a reverse J-shaped pattern that young trees were

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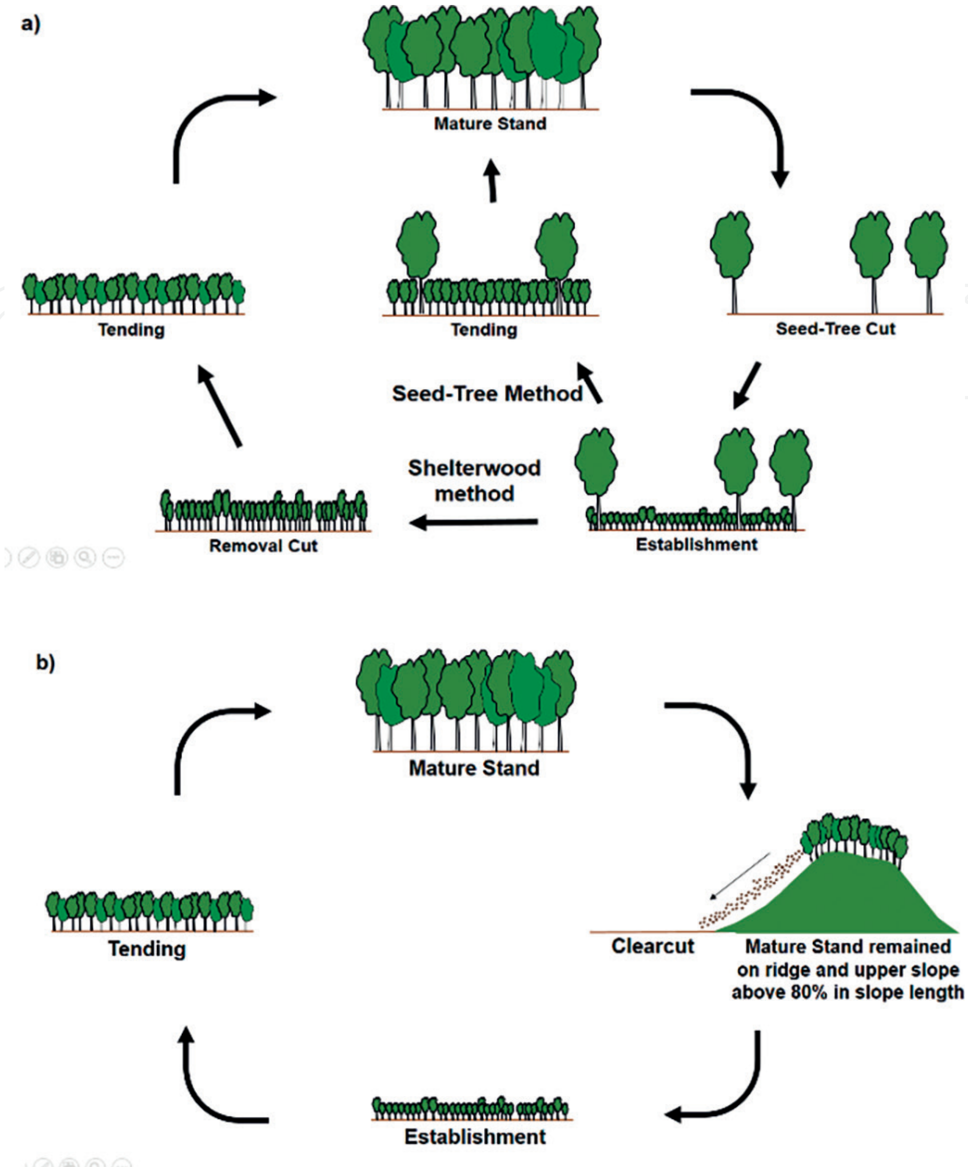

Figure 12. A diagram showing examples of the seed tree and shelterwood (a), and clearcut (b) regeneration methods.

Photo 2. Photos showing cases that the seed tree and shelterwood (a), and clearcut (b) regeneration methods are applied.

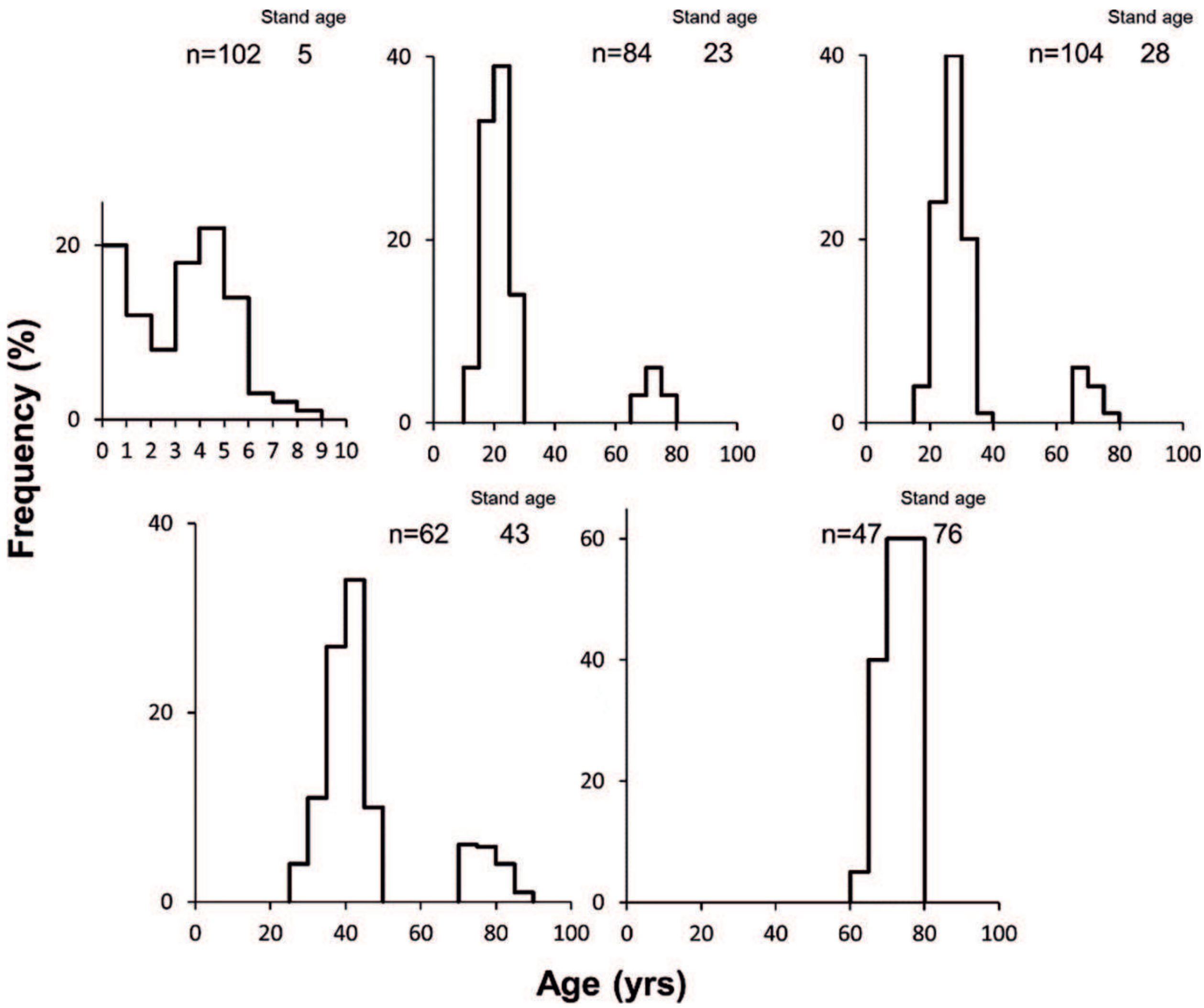

Figure 13. Age distribution diagrams of *Pinus densiflora* population in Korean red pine stands treated by silvicultural method. N numbers indicate the number of trees surveyed. Stand ages were estimated from the median value of peaked age class of regenerating successor tree population.

recruited vigorously except 76 year-old mature stand. Age distribution diagram is composed of two peaks of seed tree group and successor tree group recruited after treatment except 76 year-old stand and each cohort tends to a normal distribution (**Figure 13**). Based on age distribution range of successor group of the diagrams, period that recruitment is continued, was about 20 years.

12. Regeneration of Korean red pine forest damaged by air pollution

Dynamics of the Koran red pine forest damaged by air pollution were investigated around the Yeocheon industrial complex, a representative industrial complex in Korea [62]. Annual ring growth of pine trees, which survived from air pollution damage, was suppressed for about 10 years since 1974 when industrial facilities began to be operated in this area but since then such suppressed growth tended to be recovered (**Figure 14**). It was supposed that the suppressed growth was originated from air pollution and that improvement of growth

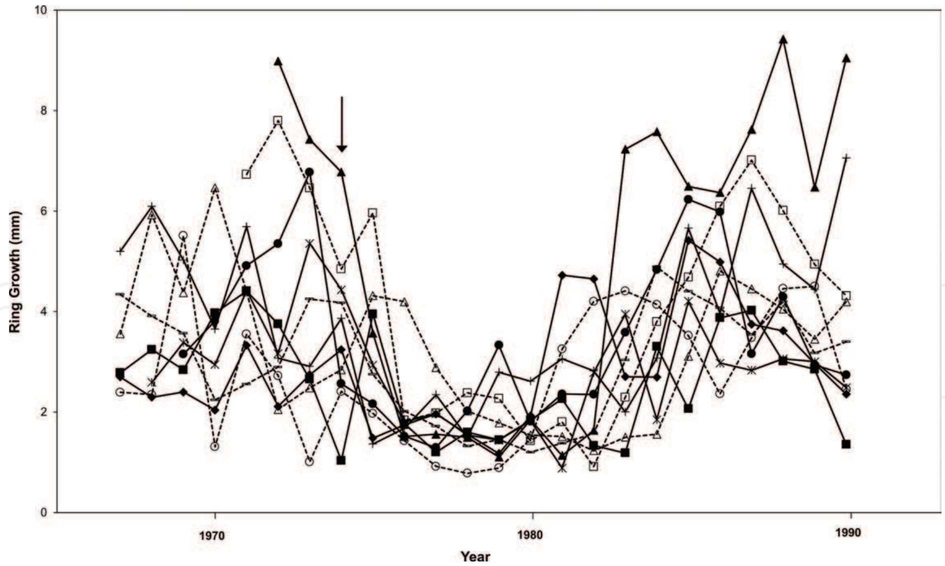

Figure 14. Yearly changes of annual ring growth in the mature Korean red pine. Vertical arrow indicates the year when the Yeocheon industrial complex began to be operated. Symbols indicate different individuals.

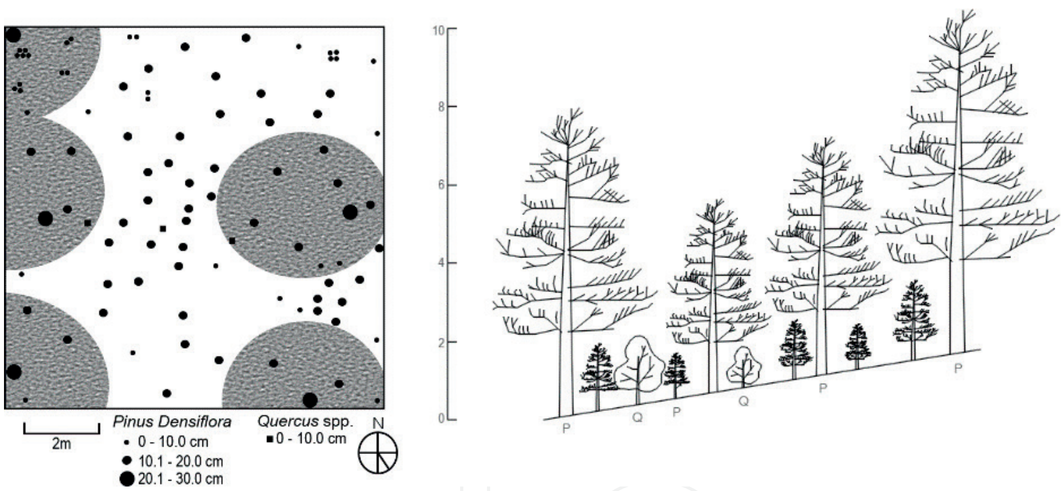

Figure 15. Crown projection and spatial distribution (left) and stand profile (right) of major species in a *Pinus densiflora* stand regenerated after air pollution damage. Shaded parts indicate canopy area of the seed trees survived from pollution damage. Circular and rectangular dots indicate pine and oak saplings, respectively. P: *Pinus densiflora*, Q: *Quercus* spp.

since then was due to release from competition by selective death of neighboring trees as well as mitigation of air pollution [62]. Therefore, physiognomy of the pine stands showed a mosaic pattern composed of different patches like stands regenerated by applying silvicultural method (refer to **Photo 2**). Spatial distribution pattern of individuals and stand profiles prepared there were similar to those of pine stands regenerated after natural and artificial disturbances (**Figure 15**). In an age class distribution diagram (**Figure 16**), ages of the pine trees ranged from 1 to 33 years. Among those individuals, those from 10 to 15 years old occupied more than 40% and the period when those individuals were recruited corresponded to the period when annual ring growth of the pine trees survived from air pollution was suppressed (**Figures 14** and **16**). This result suggests that this pine stand of mosaic pattern is the product of air pollution damage and natural regeneration of the damaged pine forest.

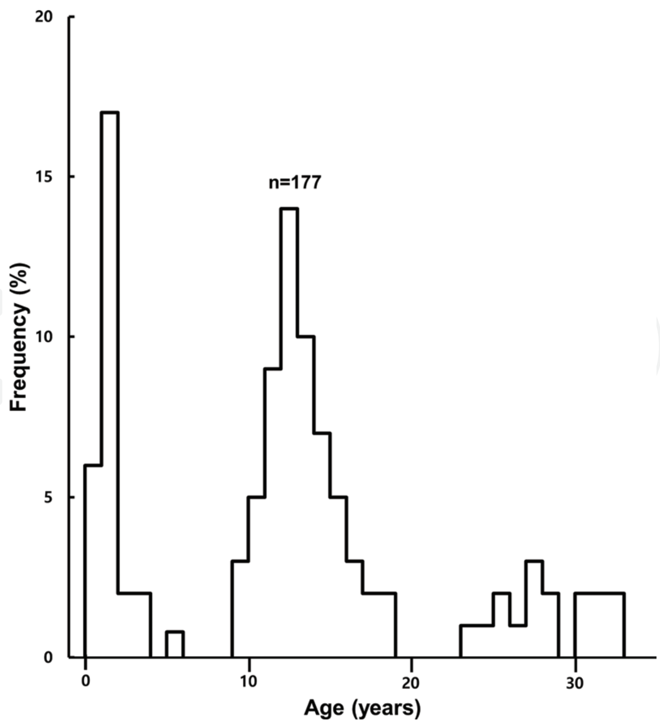

Figure 16. Age distribution diagram of *Pinus densiflora* population in a Korean red pine stand regenerated after air pollution damage. N numbers indicate the number of individuals surveyed.

13. Succession of pine forest damaged by pine gall midge

Changes of the Korean red pine forest damaged by pine gall midge (*Thecodiplosis japonensis* Uchida & Inouye) were investigated by classifying into four damage stages of the first (infested 3 years ago), the second (infested 8 years ago), the third (infested 13 years ago) and the fourth (infested 18 years ago). Damage stage were determined by the damage class and the years lapsed after outbreak.

Annual ring growth began to decrease from the first stage and decreased greatly in the second stage after infestation by pine gall midge (**Figure 17**). Reproduction based on coning was usually for 3 or 4 years and until 7 years after infestation (**Figure 18**). Many damaged pines died and their coning was interrupted in the second stage.

Coverage of pine in the Korean red pine forest damaged by pine gall midge decreased to 10% in the third stage and disappeared in the fourth stage. The pine forest was replaced by oak forest (**Figure 19**). Replacement of damaged pine forest was made by rapid growth of oaks released from suppression of overstory pine due to pine gall midge infestation.

As the result of ordination (DCA) based on vegetation data, stands tended to be arranged depending on the damage stage and thus reflected above mentioned change (**Figure 20**). Damaged pine forests of the third and the fourth stages were arranged near the oak forests and were located far from the healthy and the damaged pine forests of the first and the second stages. But the results in the shrub and herb layers were not so differently from that in the tree layer. That is, floristic composition of tree layer in the third and the fourth stages was changed but that of undergrowth was not.

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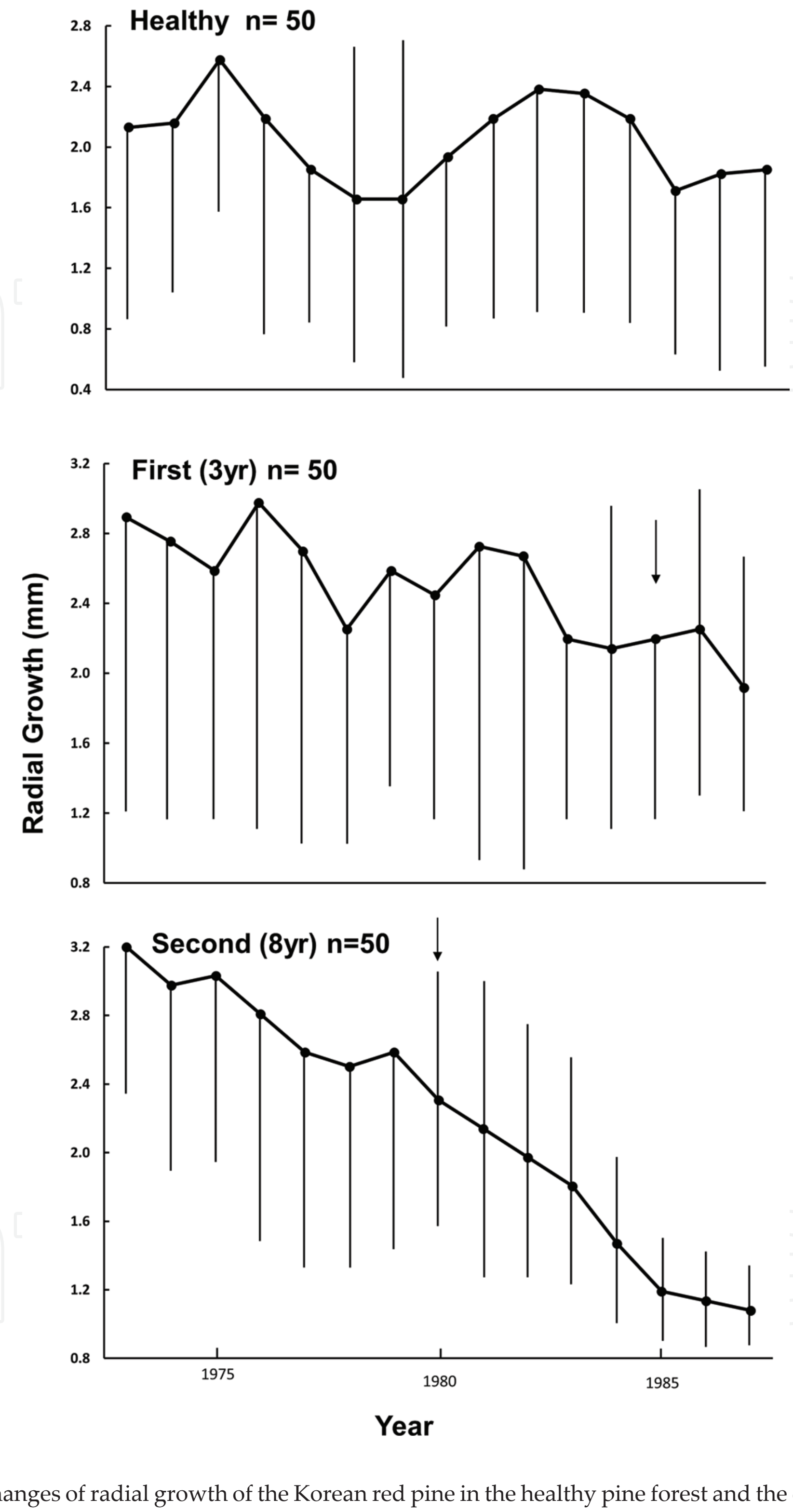

Figure 17. Yearly changes of radial growth of the Korean red pine in the healthy pine forest and the damaged pine forests of the first and second stages. Vertical arrows indicate the year that damage was begun. N numbers are the number of trees surveyed. Healthy, first, and second indicate Korean red pine stands non-infected and infected of the first and second stages, respectively. Vertical lines indicate standard deviation.

As was shown in above mentioned results, pine gall midge damage led to succession of the Korean red pine forest to oak forest during short period within 20 years. That is, pine gall midge damage accelerated succession as in the case of chestnut blight [63].

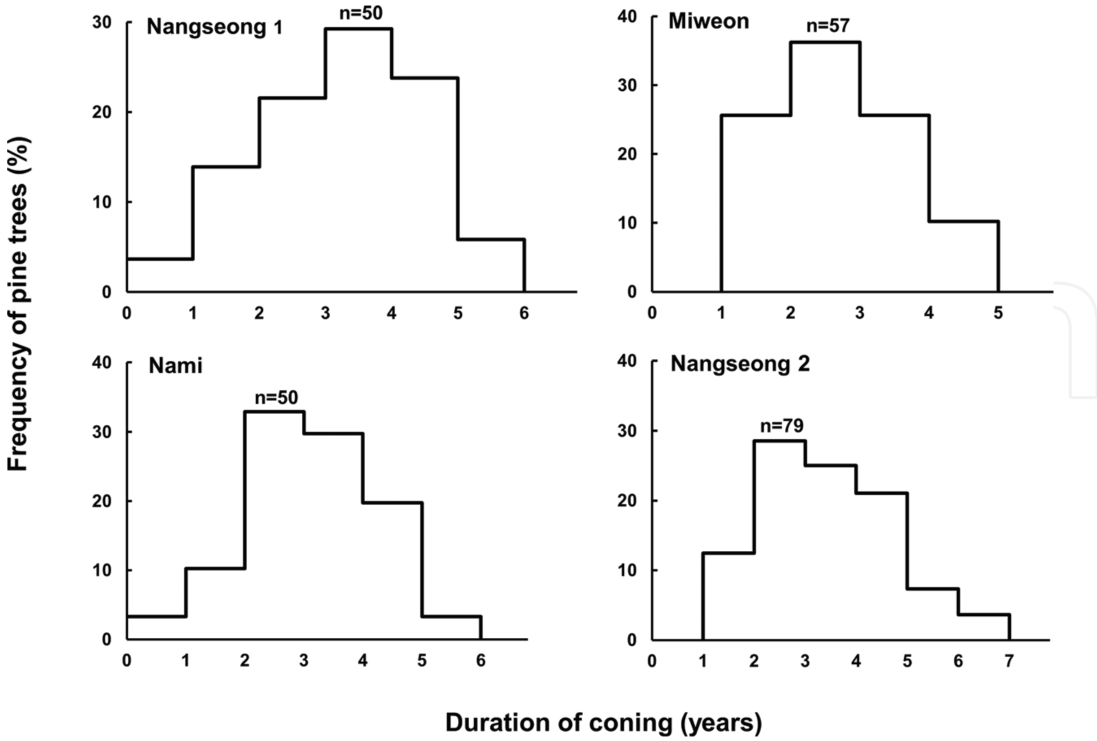

Figure 18. Frequency distribution of trees with different duration of coning in the Korean red pine stands of the first and the second damage stages. N numbers are the number of trees surveyed. Nangseong 1 and 2, Miwon indicate names of sites surveyed.

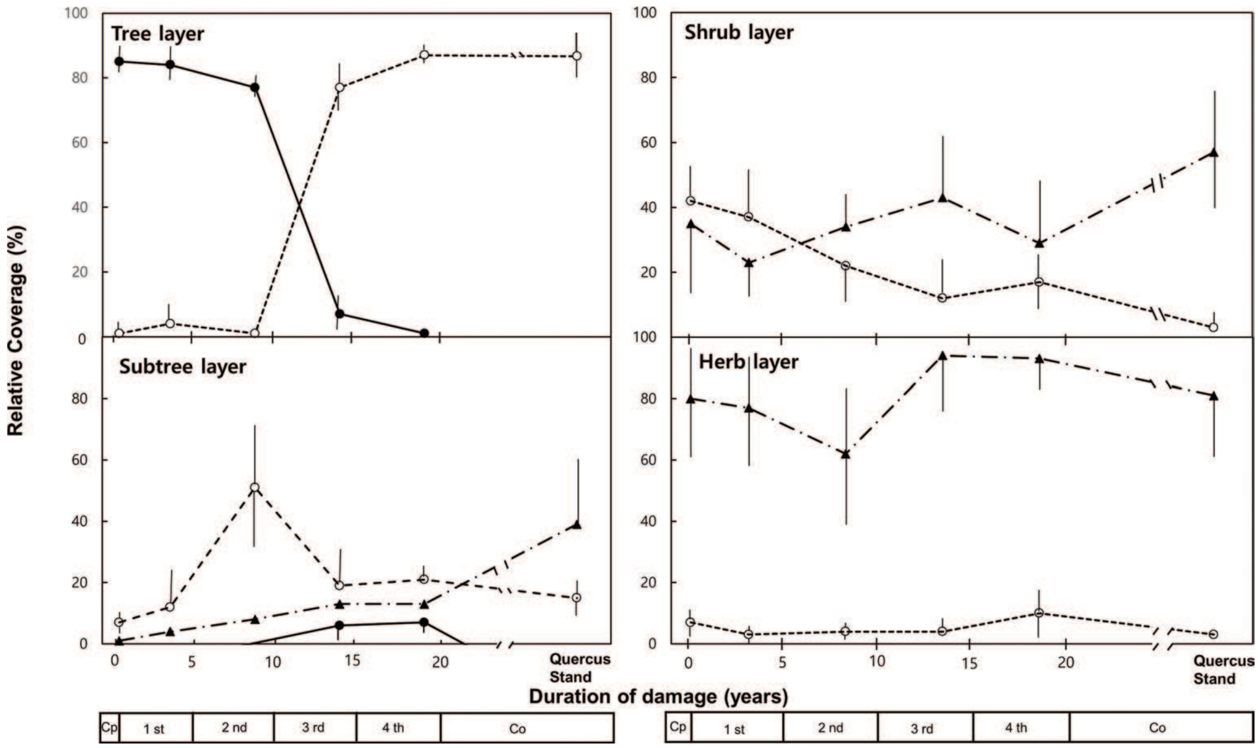

Figure 19. Changes of coverage along the period that pine gall midge damage continued. Cp: Control plot of pine, 1st, 2nd, 3rd, and 4th: Infected pine stands of the first, second, third, and forth damage stages, co: Control plot of oak. N numbers indicate the number of individuals surveyed.

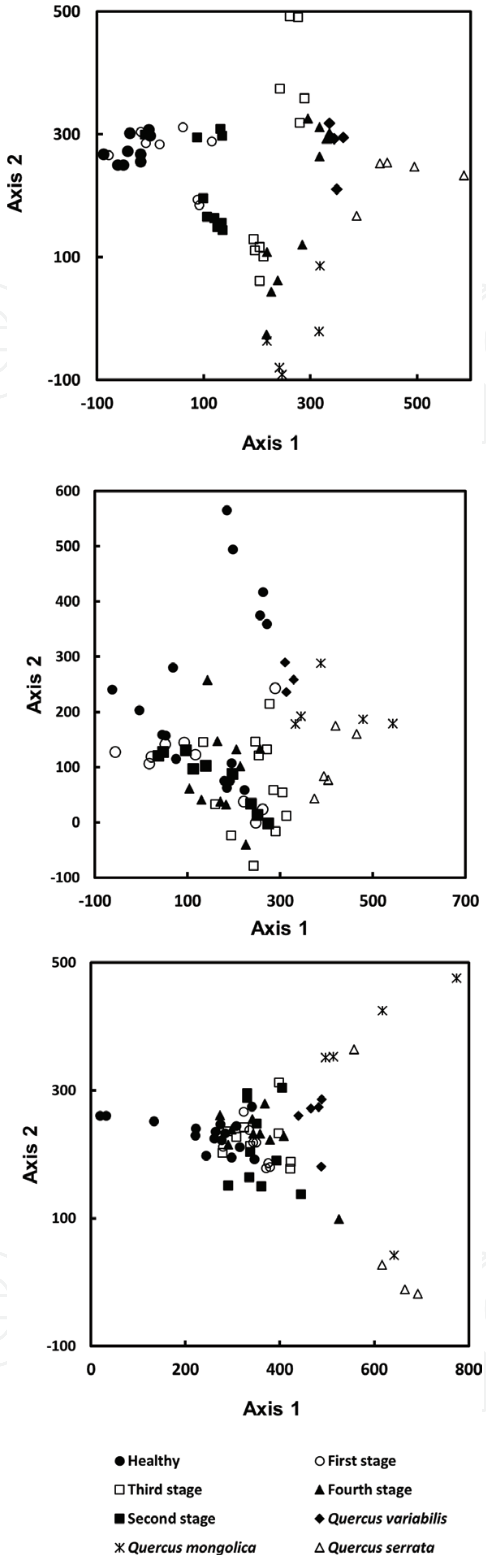

Figure 20. DCA ordination of stands based on vegetation data obtained from Korean red pine stands with different pine gall midge damage stage.

But vegetation change occurred in the Korean red pine forest as a response on pine gall midge infection was different depending on topographic condition [64]. The result is due to that dry and infertile condition of the ridgetop site are not suitable for inhabitation of pine gall midge [65]. Vegetation change was occurred in most areas except ridgetop and replacer trees were different depending on slope aspect and elevation. Mongolian oak and Chinese cork oak dominated vegetation change on Northern and Eastern and Southern and western slopes, respectively. On the other hand, Konara oak dominated vegetation in lowland [64].

14. Conclusions

Pinus densiflora grows throughout the whole national territory of the Korean Peninsula and the community is the representative forest community as it is one of the forest communities occupying the most extensive area. Korean red pine forest showed the life history traits typical of the forest, which is in the early successional stage. Seed production was consistent without a mast year and survivorship was shown as type III. Natural maintenance of the forest was possible only in the restricted sites such as rock outcroppings, weathered rocks, ridgetops, and the sandy or pebble shores of streams where can escape competition with oak forests composing the late successional stage in the region. Natural regeneration of the Korean red pine forest in those sites depended on disturbance regime, which is dominated by endogenous factors. The forest had dominated forest ecosystem in Korea in the past that artificial disturbance for the forest ecosystem was severer than the present days. But the area that Korean red pine forest occupies declined greatly due to socio-economic change in these days in Korea. In particular, reduction of human interference for forest and infection of alien pest occurred in a continued series in the order of pine caterpillar (*Thaumetopoea pityocampa* (THAUPI)), pine gall midge, and pine wilt disease (*Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle) dominated such changes. The former induced succession of the Korean red pine forest to the deciduous (cool temperate zone in northern and central parts of the Korean Peninsula) and/or evergreen (warm temperate zone in southern part of the Korean Peninsula) broadleaved forests dominated by oaks and the latter accelerated the process [6, 24]. However, other trends are also detected in these days. Climate change expands not only the distributional range of the Korean red pine forest to higher elevation [66] but also growing season beyond the normal growing season from April to early July [67].

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Conflict of interest

This paper was prepared by reediting papers that prof. C.S. Lee had published [4, 5, 18, 19, 62, 64, 68].

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Author details

Chang Seok Lee[1]*, Young Mun Chun[2], Hansol Lee[3], Jung Hoon Pi[4] and Chi Hong Lim[5]

*Address all correspondence to: leecs@swu.ac.kr

1 Seoul Women's University, South Korea

2 Suncheon National University, South Korea

3 Fordham University, New York, USA

4 Baekdudaegan National Aboretum, South Korea

5 National Institute of Ecology, South Korea

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