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中国东北小兴安岭阔叶红松林更新及其恢复研究

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摘要：研究了中国东北小兴安岭地区阔叶红松林的更新和红松的生长及其影响因素。研究结果表明由于成树树冠的遮蔽作用所导致的光照减少是制约幼树生长和存活的关键因素。阔叶红松林是该区最典型和稳定的植被类型，但是在过去的 50a 中，由于皆伐和更新不良导致了它的分布面积和蓄积量的减少。阔叶红松林是地带性“顶极”植被，并通过具有连续性年龄结构的树种有规律的替代和演替过程中不同阔叶树种组成而处于优势地位。这种林型无疑应作为一种重要的基因库加以保护。次生阔叶林是在阔叶红松林受干扰后出现的，但它的种类组成简单，而且结构也很不稳定。因此，必须对现有的林分结构加以调整以利于林分的长期稳定和高产。同时，提出了红松阔叶林的恢复和重建的经营方式。

关键词：红松；光照强度；幼树；更新；恢复

Regeneration and restoration of broad-leaved Korean pine forests in Lesser Xing′an Mountains of Northeast China

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Abstract: This paper studied the regeneration and growth of Korean pine (*Pinus koraiensis*) and the influencing factors in broad-leaved Korean pine forests in Lesser Xing′an Mountains of Northeast China. Light solar radiation decrement within the forest stand overshadowed by the mature tree canopy was considered as the key factor that limited the seedling growth and survival. Broad-leaved Korean pine forest is the most typical and the most stable vegetation type in the region, but its area and stocking have been decreased in the last 50 years caused by the over-cutting and poor regeneration. Broad-leaved Korean pine forest is the zonal “climax” vegetation type and remains dominant through the regular replacement of succeeding age classes of tree species and the succession between different assemblages of species. This forest type should, undoubtedly, be conserved so as to preserve an important gene pool for future generations. The secondary deciduous forest occurring after disturbance of the broad-leaved Korean pine forest is much simpler in composition and highly unstable in structure. Forest structure must be adjusted so as to favor long-term stability and productivity. Suggestions for restoration and rehabilitation are made for future forest management schemes.

Key words: Korean pine; light intensity; seedling; regeneration; restoration

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1 Introduction

In the temperate climate region of Northeast China, broad-leaved Korean pine forest (BLKF) is the zonal climax vegetation type dominated by Korean pine (*Pinus koraiensis* Sieb. et Zucc.), an evergreen and long- lived species of great silvicultural and patrimonial value[1,2]. Although the forest is distributed also in Russia, Korea and Japan, northeast China is the center of its distribution[3,4]. BLKF shows a highly complicated structure and diversity and plays a very important role both in environmental protection and economical development in northern China. Unfortunately, this forest type had been heavily exploited since 1950s and therefore, its area and stocking volume decreased 56.0% and 70.4%, respectively from 1949 to 1986[3].

Of the various causes for the above situation on the BLKF, over-cutting is the most crucial. In order to prevent further damage to the forests, several nature reserves have been established since the 1960s in the Lesser Xing′an and Changbai Mountains where broad-leaved Korean pine forests dominated. Not only the forest cutting is completely limited but also human activities such as seed collecting, hunting, and fishing, were forbidden in the natural reserves. In addition, in 1998 the Chinese government launched a logging ban, in the form of the National Natural Forest Conservation Program (NFCP). Activities of this program cover all the Broad-leaved Korean pine forest regions of northeast China. Therefore, all the BLKF sectors outside the natural reserves will also be protected. Nevertheless, local people and foresters are worried about the future of the forest because of the natural decline of the dominant trees and slow recovery rate after disturbance.

Natural regeneration of Korean pine is very poor under the primary forest canopy. Two popular expressions of local people effectively describe the poor status of natural pine regeneration in the BLKF: "No Korean pines under their canopy" and "Seedlings but no saplings survive". For example, Korean pine, as with most other tree species, has a dual response to light conditions in the forest communities. It is both tolerant and intolerant, depending on habitat and age classes. Although the primary forests cover large areas of the northeast China forest lands and the Korean pine has been the dominant species in the region for thousands and millions of years, few of their saplings or young trees can be found in the forest[5]. Although forest regeneration and establishment depend on the rodents and birds to disperse and bury the heavy seeds for the natural regeneration, these animals also act as seed vectors consuming large amount of seeds[6~8]. Accordingly, regeneration and its limiting factors are the central issues of much forest dynamic research[9].

Previous studies, on the population dynamics and life-history processes of Korean pine populations[10,11] have described some of the difficult circumstances of forest regeneration and development. This present paper, based on community structure and light condition analysis, studied the principal factors influencing pine regeneration and growth. Not only the BLKF but also the secondary deciduous forest has been studied so as to induce some general principles. The main hypothesis addressed here is that the over-accumulation of biomass has caused low light conditions under the forest canopy and therefore impacted seedling growth and development. Management aimed at progressive adjustment of the forest structure should therefore improve the growth and development of the BLKF.

2 Methods and materials

2.1 Study site

The study site is situated in the Liangshui Natural Reserve (128°53′E; 47°10′N), Yichun city of Heilongjiang Province, China. The reserve is exposed to the southern aspect of the Lesser Xing′an

Mountains and has a typical continental and monsoon climate. Annual average precipitation is 670～750 mm, with rainfall occurring mainly in the summer, from July to September. Annual average air temperature is about −0.3～−0.5℃, with a maximum of about 38℃ and a minimum of about −43～−44℃. The frost-free season ranges from 100～120 days. Major soil type under the Broad-leaved Korean pine forest is dark brown forest soil (Typ-Mol-Udic-Cambisols). The regional topography belongs to the low mountains with an elevation of about 300～800 m. The relative heights of the mountains are 100～200 m. According to the Ligneous Flora of Heilongjiang[4], these areas belong to the bio-geographical region of the Lesser Xing′an and Zhangguangci Mountains[1].

Primary broad-leaved Korean pine forests are mainly composed of four major forest types according to environmental conditions and co-dominate species in the stands at the Lesser Xing′an Mountain areas. (1) Oak (*Quercus mongolica* Fisch.) Korean pine forest (OKF); (2) linden (*Tilia amurensis* Rupr.) Korean pine forest (LKF), (3) Ribbed birch (*Betula costata* Trautv.) Korean pine forest (BKF) and (4) spruce-fir (*Picea koraiensis* Nakai and *Abies nephrolepis* Maxin.) Korean pine forest (SKF). However, the primary BLKF has been greatly decreased in recent years because of the over-cuttings and poor regeneration. The secondary vegetation types occurred on the remains of the original Korean pine forests were almost completely deciduous trees, with secondary birches being most prominent. These secondary forests regenerate and develop generally on the slash of LKF, BKF or SLF.

2.2 Forest survey and measurement

Permanent plots of 1000 m^2 were set up for long-term observation both in the linden Korean pine forest and in the secondary birch forest. Basic forest surveys have been conducted and some stand parameters and environmental factors such as stocking stock, density, growth, light intensity in the forest and water contents in the soils, etc. were collected. In addition to these plots we also used other methods, such as the stem ring accounting methods for the age determination, to obtain the necessary data so as to meet the needs of some special analysis.

For the regeneration inventory we measured in a watershed that was located by parallel lines across the watershed from north to south, the distance between the lines was 40 m. Plots were located at the point of every 50 m along the lines (except some places that trees were cut). All the plots were evenly dispersed over the entire area. The total area was 80 hm^2 in which 423 of 1 m×1 m and 423 of 4m×4 m plots were set up. The 1× 1 m^2 were used for the counting of seedlings (less than 1 meter in height) and saplings (more than 1 meter and less than 4 cm in diameter at breast height, *d b h*) and the plots of 4×4 m^2 were used for the counting of trees (>4cm in *d b h*). In order to describe the age structure of Korean pine populations two plots of 1.0 hm^2 in area were measured, in which 73 trees were randomly selected for stem analysis and statistical analysis. Tree age was determined by counting annual rings of all selected Korean pines in the clear-cut plots. In order to evaluate the light influence on the seedlings, two additional experiments were designed, as described below.

2.2.1 Light condition in the forest ground We measured the light conditions in the secondary white birch (*Betula platyphylla* Suk.) forest and in the primary Broad-leaved Korean pine forest. Light illumination was measured by an illuminometer (lx) and at the same time we also measured irradiance at 236 points of 10m×10 m systematically over the forest stand with the radiometer (kJ/(m^2 · min)), so that a regression equation was determined as follows:

$$y = 0.96 + 0.068x \ (n = 236, r = 0.95),$$

Where "y" is the radiation (kJ/(m^2 · min) and "x" is the illumination (lx).

This equation was used to transform illumination date into radiation data.

2.2.2 Shading experiment in nursery　According to the above measurement approximate 60% of the light was prevented from penetrate into the Korean pine forest ground from June to September. So a nursery experiment was designed to determine the impact of seasonal changes in light conditions on the growth of Korean pine seedlings. Four hundred of four-year old seedlings from Liangshui Natural Reserve were used for the experiment. Four shading treatments were carried out: (1) shading all-year round, (2) non-growing season shading (from October to May), (3) growing season shading (from June to September), and (4) control (no shading). The shading intensity used in this experiment was also proximate 60% of the light were prevented from penetrate into the overhead of the seedlings.

2.3 Biomass and solar radiation in the young growth

An additional plot was set up in order to study the growth and productivity of the Korean pine under the canopy of the broad-leaved trees. Young growth was formed by planting Korean pines in 1967 and was invaded, afterwards, mainly by the white birch afterwards. The broad-leaved trees grew more rapidly than the pine seedlings so that it is a two-layered coniferous and broad-leaved tree mixed forest. In order to release the conifers that have been seriously depressed by the overhead shading the young growth was treated by two different tending methods in 1975. (1) All the broad-leaved trees in the overhead canopy were removed, so as to produce a so-called "all-released stand" and (2) half of the broad-leaved trees in the canopy were removed, effectively producing a "half-released stand".

Leaf area index (*LAI*) and biomass were determined by the measurement of the mean trees that their d.b.h and their height are the mean d.b.h. and the mean height of the stands in 1988. Two mean trees of one Korean pine and one birch were selected and cut in each of the 2 stands every month from April to September in 1988. Fresh roots, stems, branches and leaves were weighed in the field and dry weight was calculated for oven-dried (105℃ and 8 h) samples in the laboratory.

A wooden observation tower of 8 m was used in each of the above 2 stands to measure the solar radiation in which global radiation, reflection and penetration were included. Solar radiation was measured daily every 2 hours from 6:00 to 18:00, for 6～7 typical days every month from April to September.

3 Results

According to the regeneration inventory in the 80hm^2 watershed of the broad-leaved Korean pine forest (constituted mainly by LKF and BKF) it was found that the total density of seedlings and saplings of Korean pines was 2 411/hm^2. In other words, pine regeneration was not very poor under natural conditions. However, tree density was only 170/hm^2. The survival rate was about 7% and most of the seedlings and saplings died before they grew up. This recalls the popular saying "No Korean pines under their canopy".

For a 1000 m^2 plot inventory it has been found that the density of Korean pine saplings in the typical White birch forest is about 540/hm^2 while in a typical primary Linden Korean forest the density is only 50/hm^2. We can describe seedlings by Figure 1 which indicated that the seedling numbers in the white birch forest decreased gradually from 30 cm to 100 cm in the 1000 m^2 plot while in the LKF most of the seedlings have a height of less than 30 cm. Again, recall the saying "Seedlings but no saplings survive" in the LKF.

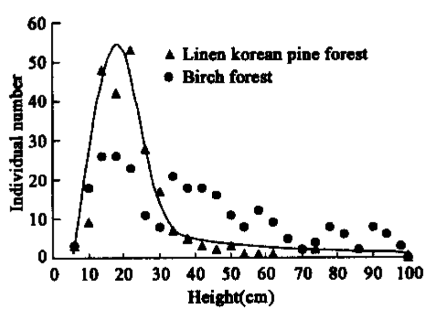
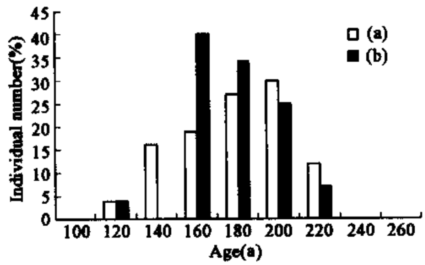


Fig. 1　Korean pines seedling allocations based on the height classes in the linden Korean pine forest

It can be seen from the two even-aged linden

Korean pine stands in the Figure 2 that the tree numbers in the old age classes have a tendency opposite to that in the young ones. The fewer the trees are in the old age class to the right, the more trees are present in the junior age class to the left (Fig. 2a); otherwise, very few or even no trees could be found in the junior age classes (Fig. 2b). Taking the peak age class as a dividing line, then the right side (older) trees limited the recruitment of the left side (younger) trees.

In fact, the two linden Korean pine stands in Figure 2 are highly similar in most stand parameters, such as mean height, tree species composition, site class, and mean age (Table 1). The only differences between them were stocking volumes in the stands: (a) is higher than (b) in stand volume, but the density and volume in Korean pine trees of the latter (b) is still higher than in the former (a). Clearly, the Korean pine tree's volume (or biomass) has some negative effects on the species' seedling survival, and, therefore brought about the different age structure. When volume accumulation of the old trees approaches some threshold, self-regulating effects will prevent younger trees from further development. The threshold is represented by the over-accumulated biomass that, in turn, changes the environmental conditions within the forest stands, for example, light illumination decrease, soil (water) nutrient depletion or microorganism inactivation, etc.



(a): General age structure linden Korean pine stands, (b):Old age structure linden Korean pine stands

Fig. 2 The age structure of Korean pine (*Pinus Koraiensis*) populations in the Broad-leaved korean pine forest.

Table 1 Structure description of two different linden Korean pine stands

Stand	Stand height (m)	Stand volume (m^3/hm^2)	Stand composition	Site class	*PK* Individual/hm^2	*PK* Volume (m^3/hm^2)	Mean age of *PK*	Calculated *PK* individuals
(a)	28.5	411	9*PK*1*PS*	Ⅱ	168	371	188.1	35
(b)	28.2	552	9*PK*1*PS*	Ⅱ	378	509	188.6	38

PK: *Pinus koraiensis*, *PS*: *Picea koraiensis*.

The similar results as above showed between the trees at different aged classes can be further proved by the following three forests in the studied region (Table 2). Seedling height growth under the dense canopy of linden (*Tilia amurensis* Rupr.) Korean pine forest and spruce-fir Korean pine forest was 1.333 ±0.325 and 1.205±0.119 cm/a., respectively. They were significantly lower ($P<5\%$) than that under the dense birch forest canopy 1.882±0.332 cm/a. Some stand characteristics of the three forest types in Table 2 showed that the site conditions, such as position of slope, aspect and soil type in the spruce-fir Korean pine forest is as poor as that in the birch forest for the seedling growth. Korean pine seedlings are particularly intolerable to and grow badly in "ground-water dark brown forest soil". But the seedling height growth of the former is significantly lower than that of the latter ($P<5\%$). On the contrary, the primary linden Korean pine forest was situated at the most suitable site conditions for the seedling growth, e.g., upper-middle mountain position, south aspect and typical dark-brown forest soil. Nevertheless, the seedling growth in LKF has no significant difference with the SKF ($P<5\%$). It must be noted that the greatest difference is also the volume, the higher the stand volume the lower is the height growth of the Korean pine seedlings among the three forest types. In many cases Korean pine trees should grow well on the sites with steep slope (16～25°), south aspect and upper mountain position without considering the stand volume. But Table 2 showed the most important limiting factor for seedling growth is the stand structure itself.

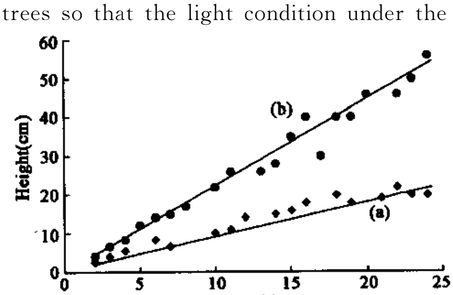
Table 2　Some characters of community structure and Korean pine seedling growth in the primary linden Korean pine forest (*LKF*), spruce-fir Korean pine forest (*SKF*) and birch forest

Item	Birch forest	LKF	SKF
Slope(°)	6	18	6～18
Aspect	West	South	West
Position of slope	Lower part	Up-middle part	Lower part
Altitude(m)	356	421	354
Soil moisture(%)	47.5	49.0	49.5
Soil type of the different stands	Ground-water dark brown forest soil	Typical dark brown forest soil	Ground-water dark brown forest soil
Woody species composition	10*BC*+*PD*-*PJ*	8*PK*1*TA*1*PD*+*BC*+*QM*	8*PK*1*AN*1*PJ*+*AM*-*FM*
Stand volume(m^3/hm^2)	161.58	593.30	605.20
Mean age of seedlings(a)	9.33	9.75	9.40
Age range of seedlings(a)	5～14	2～16	2～18
Height growth (cm/a)	1.882±0.332	1.333±0.325*	1.205±0.199*

TA, *Tilia amuresis*; *BC*, *Betula costata*; *PK Pinus koraiensis*; *PJ*, *Picea jezoensis*; *PD*, *Poplus davidiana*; *QM*, *Quercus mongolica*; *AH*, *Abies hephrolepis*; *AM*, *Acer mono*; *FM*, *Fraxinus mandshurica*; * Represents significance difference between the two Broad-leaved Korean pine stands and the birch forest ($P<5\%$)

Another interesting aspect of the Korean pine seedlings is that they can maintain a low growth rate for a longtime under the canopy of the over stocked BLKF forest. Some times this growth rate is even less than 1 cm/a (Fig. 3). The high tolerance ensures that seedlings survive under the shading of pine canopy for many years. Once the trees in the over story age and fall down the seedlings or saplings have a good opportunity to increase their growth rate rapidly. Certainly the high tolerance can provide necessary individual numbers to occupy the gap created by old tree fall, then to grow up, and finally to enter into the upper story canopy. This may be one kind of regeneration strategies for the K-strategy species.

However, stand volume or biomass accumulation must not be a direct factor limiting the seedling growth. It may play the impacting role indirectly through influencing some key environmental factors among which light is considered to be the most likely. An obvious fact was that the primary broad-leaved Korean pine forest was composed of many evergreen trees so that the light condition under the canopy would be relatively lower than that under deciduous trees. Particularly this decrement was both in growing season (from May to October) and in non-growing season (from October to May next year). The light intensity under the BLKF canopy was no more than 1/3 of the secondary birch forest (Fig. 4). So the low light condition under the BLKF canopy was considered an important limiting factor for the seedling growth.



◆Under the canopy of Korean pine forest(cm)

●Under the canopy of birch forest (cm)

Fig. 3　The height growth process of the seedlings and saplings in Korean pine (*Pinus koraiensis*) in the natural forest conditions

A shade experiment for testing the light effects to the seedling growth was done in the nursery (Table 3). It showed that both above ground (stem) and under ground (root) growth of the seedlings was significantly inhibited under shading ($P<5\%$). Shading has decreased the seedling growth and development not only during the growing season (when the broad-leaved trees have their foliage) but also during the non-growing season (leaves of the broad-leaved trees had fallen) shading has decreased the seedling growth and development. In particular the non-growing season shading decrease the seedling growth more significantly than that the growing season shading did. The reason for this result may be that the pine seedlings may continue to absorb energy or assimilate organic compounds in their bodies during the non-growing season[12]. These energy and compound will be use in the height during the June to September period. In fact during the growing seasons broad-leaved trees in the canopy can also form a shading condition for the seedlings. It has been recognized that the evergreen pines bear their needles both in growing and non-growing season so that they may make the low light condition under the forest canopy all year round, including the non-growing season (October to May).

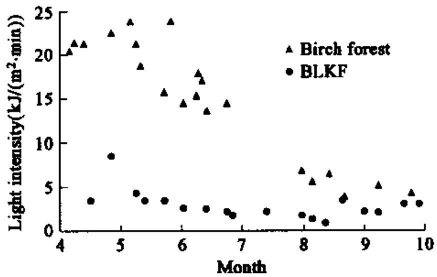


Fig. 4 Seasonal changes of light intensity in the Broad-leaved Korean pine forest (BLKF) and the secondary birch forest

Table 3 Seedling stem and root growth under different shading conditions, the growth amount was measured at the end of the October after twelve month experiment

Treatment	Stem (cm)	Root system (cm)
All-year shading	13.55±2.66 (a), (b)	13.27±1.56 (a), (b)
Non-growing season shading (from October to May)	14.18±1.47 (a), (b)	13.77±1.27 (a), (b)
Growing season shading(from June to September)	16.00±1.90 (a)	14.55±2.94 (a)
Control	19.73±1.90	16.83±1.33

Four shading treatments: (1) shading all-year round, (2) non-growing season shading (from October to May), (3) growing season shading (from June to September), and (4) control (no shading at all). The shading intensity was approximate 60%. (a), (b) represent significant difference ($p<5\%$) in comparison with the control (a) and growing season shading (b) seedlings, respectively

The shading experiment in the nursery showed that the most favorable light condition for the Korean pines is the control, an open space overhead on the seedlings. But this is not always true from the viewpoint of the natural stand. It can be seen form Table 4 that all the forest growth parameters such as *d b h*, height and stand volumes in the half-released stand was markedly higher than that in the all-released stand. The leaf area index (*LAI*) and productivity of the latter were 28% and 31% lower than that of the former. This marked difference may be caused by the different stand structures. Because after cutting the mean height of the survived birch was about 12～18 m and Korean pine trees are 6.3～7.0 m in the half-released stand, clearly two separate layers have been formed in the forest canopy. While in the all-released stand the mean height of both birch and Korean pine was within 5.5～7.0 m, an obvious mono-layered story in the forest canopy. Clearly, the two layered forest stands enlarged the living space and increased the whole stand biomass. In addition, the canopy story birches did not limit the growth of Korean pines, and therefore it showed a relatively higher *LAI* and productivity in comparison with the pine under the mono-layered canopy.

Some obvious advantages in the half-released stand can be seen from the seasonally solar radiation (Table 5). Although the two stands received the same amount of solar radiation, the half-released stand absorbed 100.3% more solar radiation than the all-released stand during the total growing season (from April to September). This is caused by the lower reflection in the half-released stand. Reflection is considered to be the most important part of the global radiation lost in the sky. The more the radiation is captured by the plants the higher is the productivity of the stand. The multi-stories structure ensured the young growth to capture more solar radiation for the productivity.

Table 4 Structure, biomass and productivity of 2 young growth of Korean pine and Broad-leaved tree

Stand type	All-released stand		Half-released stand	
	KP	BLT	KP	BLT
Density (individual/hm^2)	3851	3201	2906	2621
Mean *d b h* (cm)	6.9	5.0	7.3	9.3
Mean height (m)	5.9	5.5～7.0	6.3	7.0～18.0
Stand volume (m^3/hm^2)	52.3	22.8	45.0	84.2
Leaf area index (LAI)	2.0322	2.0853	1.5932	3.9253
LAI of KP + BLT		4.1175		5.5185
Biomass (kg/hm^2)	36777.1	18279.3	28757.2	67369.7
Biomass of KP+BLT (kg/hm^2)		55056.4		96126.9
Productivity (kg/(hm^2 · a))	1889	1828	1438	3318
Productivity of KP+BLT (kg/(hm^2 · a))		3717		4756
Plot area (m^2)		415.5		419.8

The young growth, measured in 1988, was tended by two different methods in 1975: (1) All the Broad-leaved trees in the overhead canopy were removed, so called all-released stand; and (2) half of the Broad-leaved trees in the canopy were removed, so called half-released stand; KP: Korean pine; BLT: Broad-leaved tree

Table 5 Seasonal budget of solar radiation in the half- and all-released stands

Solar radiation (MJ/(m^2. month))	April	May	June	July	August	September	Total season (MJ/m^2)
Global radiation	384.2	684.1	699.9	503.7	438.8	251.6	2962.3
Reflection							
All-released stand	63.8	113.6	116.2	83.6	72.8	41.8	491.8
Half-released stand	49.2	87.6	89.6	64.5	56.2	32.2	379.3
Penetration							
All-released stand	76.6	144.5	98.2	34.7	35.5	14.5	404.0
Half-released stand	88.9	141.4	94.0	40.6	34.6	16.7	416.2
Absorption							
All-released stand	243.8	426.0	485.5	385.4	330.5	195.3	2066.5
Half-released stand	246.1	455.1	516.3	398.6	348.0	202.7	2166.8

4 Discussion

Broad-leaved Korean pine forest is the zonal vegetation type in the temperate region of Northeast China. Its stability and development was realized and maintained through population fluctuation and species succession processes[5]. Korean pine, a long living and dominant species of the BLKF, suffered from a high mortality during the seedling stage and low growth rate during the sapling stage and young growth stage. These were caused by the over accumulation of the biomass and mono-storied structure in the forest. The direct influencing factors are the low light intensity and high solar reflection. However we believe that other elements might have some roles in addition to the solar radiation for the various growth status in the different structured stands.

During the long-term development processes Korean pine population changed its age structure with the different stand status. The young successive trees decreased their numbers suddenly when the stand volume was over accumulated. Most seedlings and saplings can not survive longer in the stand whose volume is over accumulated. A dominant species that can adjust the amount of the young individuals showed a negative interaction between the stand volume and the young pine trees (including seedling and saplings, too) and feedback[13～15]. It may be considered a necessary mechanism for the stability and adaptation of the long life-span species.

It is recognized that light condition in the BLKF has an impact on the seedling and sapling development under the forest canopy. The above age structure changes are an adaptation to the over shaded light condition. So that the decrease of the numbers in seedlings and saplings in the over mature primary forest is a normal fluctuation process[5]. Certainly light is not the only condition affecting the forest fluctuation. It is pointed out that all factors such as stand structure and solar radiation absorbed by trees, seedling growth and sapling tolerance, and young growth leaf area index and biomass are accompany the dynamic process. Accordingly four different regeneration stages could be distinguished from the above results and discussion (Fig. 5).

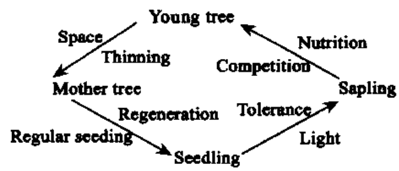


Fig. 5 There exist four stages in the Korean pine regeneration processes

The first is that the seedlings that tolerate the low light condition under canopy survive and grow into saplings this process is controlled by the light (environmental) factors. The second is that the saplings develop to the young trees with competition for nutrients. The third is that the young trees become mother trees through self thinning and this process is limited by the living space. The fourth stage is that the mother trees produce seeds which, in turn, transform to seedlings through the regeneration process, but this process is controlled by the regular seeding of the mother trees and the over volume accumulation in the stand

The first is the seedling stage. Seedling emergence in the forest is the results of the germination of seeds that have avoided predation and happened to be transported to the suitable site for the germination[16~18]. However, during the first several days of emergence, rodents and birds could also damage the new recruited seedlings[5]. Seedlings generally have a long period of time to tolerate the under canopy condition. The second is the sapling stage. Saplings must compete with the other plants for the nutrients or take the advantage of gaps in the forest. The third stage is the young tree stage. Young trees will continue to exploit their living space through self-thinning process. The fourth is the mother tree stage. The mother trees ensured the new seedlings through a regeneration process. This process is controlled by the regular seeding of the mother trees and the over volume accumulation and other physiological mechanism in the stand. In natural conditions, Korean pine reproductively matures at about 120 years, and good harvest occurs at about 140 years. The mature trees produce seed till 260 years old[7].

In general, trees may have different niche characteristics or requirements in different stages of their lives. Competition may be intensive in some phases of the life cycle resulting in regulation of the population to a steady state in the other phases. The Korean pine could dominate in its colonized region because it has experienced long life span and strong adaptability in the fluctuating environments. Although the seedlings didn't grow well under the closed canopy of virgin broad-leaved Korean pine forest, they could tolerate unfavorable conditions for many years under the canopies and wait for gaps for their release to develop into the canopy layer. Populations of the Korean pine fluctuated with the dynamic patterns of forest cycles. The pollination and fertilization of Korean pine were influenced by both the genetic and ecological factors, but the ripen cones could produce hundreds and thousands of seeds to add into the seed banks and seedling banks to replace the old ones. Even though many young seedlings died soon after emergence, sufficient numbers still survived, so the seedling bank is enough to keep the population viable. That was the result of long term development adaptation in the natural forest.

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