An Examination of the Condition of Young Natural Asian White Birch Trees in Manhanshan National Forest Park (Inner Mongolia, China) and Its Early Thinning Technology

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Abstract

The goal of the study was to demonstrate forest thinning techniques that should be used beginning in 2011 for the ultimate purpose of timber production by analyzing the stand structure of unthinned natural Asian White Birch forests aged 10-25 years in Manhanshan National Forest Park. The results of the study led to the following three observations: (1) among dominant trees, those with relatively good characteristics should be selected as reserve trees. Any trees obstructing the growth of the reserve trees must be removed as thinned trees. In addition, dominated trees which do not have an impact on the growth of reserve trees are left unthinned to prevent the occurrence of epicormic shoots in reserve trees. (2) The forest at 8-15 year-old should preferably be thinned for the first time. (3) It is desirable to implement thinning frequently at low intensity.

Keywords: Asian White Birch, Manhanshan National Forest Park, Natural Forest Protection Policy, Natural thinning, Thinning technique, Reserve tree, Crown closure rate

1. Introduction

1.1 Background and objective of study

In the Asian White Birch (*Betula platyphylla* Suk.) forests in Manhanshan National Forest Park, where all the white birch forests have grown through natural regeneration, timber production was conducted before 1997, but a total ban on logging has been imposed by the Natural Forest Protection Policy (1998-2010). At present, trees aged 41 years or more, 30-40 years and 29 years or less account for less than 5%, approximately 20% and more than 75% of the forest area, respectively. Of these, almost all the trees aged 30 years or above have been thinned, whereas those aged 25 years or below, which comprise an overwhelming majority (i.e. more than 50%) of the entire area of the white birch forests, remained unthinned (MNFP, 2006). Because Manhanshan National Forest Park is situated in a semi-arid zone, the survival rate of newly planted trees is low, making seedling regeneration of white birches difficult. Therefore, sprout regeneration has been adopted as a forest regeneration method (IMFCC, 1989). White birch, a drought-enduring species, occupies the largest area in Manhanshan National Forest Park. Pure forests occupy more than 90% of the area of all white birch forests. The remaining is occupied by mixed forests comprising white birches and aspens (*Populus davidiana* Dode.), with the former accounting for at least 80% the total number trees.

Although natural thinning regulates forest density, it does not improve the quality of remaining trees because the process only weeds out slow-growing individual plants that are under selective pressure (Li, 1992). In China, forest thinning is conducted to create a favourable environment for remaining trees in order to promote their growth thickness and augment public function by reducing the density of forest areas with closed canopies. This practice is also aimed at enhancing healthiness of the forest and future use of its timber by improving the quality of remaining trees through logging of poor-quality trees (Li, 1992).

An interview survey was conducted in July 2008 with personnel of national forest parks, construction companies and furniture factories in the Manhanshan area. The results revealed that use of white birch timber produced in Manhanshan National Forest Park in 2011 or later, when the ban on logging is expected to be lifted, would be far greater in volume for pillars and beams than for rafters, with their prices (dollars/m^3) also be higher (IMARFANFPMB, 2008). Accordingly, it will be necessary to primarily consider the supply of pillar and beam materials while setting a production target of white birch timber.

State Forestry Administration of the People's Republic of China had decided that the white birch forests in Manhanshan National Forest Park would be designated as public utility forests after 2011 (MNFP, 2004). For this purpose, an important step will be to adopt an operational model that combined facets of both improved public function and timber production. However, such an operational model has not yet been proposed.

Against this background, the present study aimed to analyse and reveal the stand structure of unthinned white birch forests consisting of trees aged between 10 and 25 years in Manhanshan National Forest Park. Thereby, considering timber production, it proposed an effective forest thinning technique conducive to growth promotion and quality improvement of reserve trees that are yet to be logged for timber production.

1.2 Significance of study

In China, researchers have reported the significance of logging of 10- to 40-year-old white birches for successful sprout regeneration, because their stumps have relatively high sprout potential at this age (Feng, 1980). The researchers also reported that the logging interval for wood of sprouting deciduous broad-leaved trees should not exceed 40 years (Fujimori, 2003). Consequently, in the natural white birch forests in Manhanshan National Forest Park, the general practice has been to set an interval of maximum 40 years until the regeneration cutting (final cutting) age. Furthermore, if thinning is performed on the white birch forests comprising trees (aged 30 years or more) that have entered an age class period (Note 1) before the regeneration cutting age (40 years), reducing the time interval between thinning and the regeneration cutting age has a minimal growth-promoting effect on the diameters of the remaining trees. Therefore, it is suggested that forest thinning should be performed (aged less than 30 years) by an age class period before the regeneration cutting age (40 years), after crown closure (Li, 1992).

Previous research on the thinning technology for natural white birch forests in China focused on the evaluation of tree selection methods, with emphasis on tree height rather than tree characteristics (MFS, 1986), and the relationship between the forest thinning rate and growth ratio in case of the thinning-from-below method (Li, 1992). However, a study examining tree selection and thinning methods that emphasise on tree characteristics and diameter growth is not yet to be reported. In Japan and China, there has been hardly any research conducted on the forest thinning technology based on structural changes in the natural white birch forests with an increase in forest age. Against this backdrop, this article proposes a mode of forest thinning intended to enhance the quality and increase the diameter of reserve trees, on the basis of analysis and elucidation of the structure of 10- to 25-year-old white birch forests formed through sprout regeneration in Manhanshan National Forest Park. This study will provide the foundation for establishing a logical and sustainable operational system for the white birch forests in Manhanshan National Forest Park after the ban on logging is lifted.

2. Study Site and Research Method

2.1 Study Site

Manhanshan National Forest Park (Figure 1), a state-owned forest area located in the west of Inner Mongolia, has an area of 57,839 ha and an altitude of 1,300-2,300 m. It has mountainous terrain inclined at 14-25°, which accounts for more than 70% of the total area. The annual maximum and minimum temperatures are approximately 37°C and -35°C, respectively, with an average annual temperature of 5°C. Precipitation is concentrated between June and September, but the average annual rainfall is as low as approximately 400 mm (MNFP, 1991).

Of the total woodland covering (45%) of the forest park, 75% is occupied by shrubs, 23% by white birches and 2% by other species such as Chinese hard pines (*Pinus tabulaeformis* Carr.) and Japanese larches (*Larix principisrupprechtii* Mayr.). An overwhelming 89% of the total accumulation is located in the white birch forests, with the rest accumulated in the pine and larch plantations, established after 1958 (MNFP, 2006).

In this study, the unthinned white birch forests (aged 25 years or below) in the forest park were chosen as the investigation areas, every one of which was located on north-facing slope. Because the Manhanshan region is situated in a semi-arid zone, most of the white birch forests are distributed over northern slopes, where the humidity is relatively high and the trees are clustered together.

2.2 Research Method

In order to comprehend the present structures of the 10- to 25-year-old unthinned white birch forests, a sample plot (hereafter referred to as 'plot') was set in a spot that is deemed most representative of each of the forest stands (forest age: 10, 15, 20 and 25 years), the plot size of the forests aged 10, 15, 20, 25 year-old is 15m*15m, 20m*20m, 25m*25m and 25m*25m, respectively, every tree in the plots was investigated. The items of timber cruise were breast-height diameter (DBH; 1.3 m above the ground), tree height, crown height, crown diameter and standing location. Equalizing the conditions such as location and environment were focused on in selection of plots so that forest properties such as composition and characteristics at different ages could be compared accurately.

To evaluate the tree characteristics, the trees were classified according to Ohashi's tree form classification system (Ohashi, 1948). This method is characterized by use of four-figure numbers (crown story, crown form, trunk form and trunk defect) to classify trees in detail with respect to their growth and characteristics (Kanno, 1993). Distinction between dominant trees (upper-story trees) and dominated trees (lower-story trees) was made on the basis of the mean tree height in the plots; trees taller and shorter than the mean tree height were regarded as dominant trees and dominated trees, respectively.

Plots 1-4 constituted uniform, pure white birch forests were formed through sprout regeneration. The ages of white birches were determined by the number of annual rings of the standard tree selected in each plot. Circular discs were collected from the standard trees near the ground to observe the annual rings. The crown closure rate of each plot was calculated by dividing the crown projection area by the plot area. The crown projection area of each plot was measured using a digital planimeter. In addition, morishita's $I\delta$ index was used to represent the distribution of standing trees in each plot (Morisita, 1959).

None of plots 1-4 had any artificial disturbance or natural disaster (e.g. damage from snow, blight or insects) between the end of sprout regeneration and the time of the investigation (June-July, 2007). Since there was hardly any tree whose breast-height diameter measured less than 2 cm in the 10- and 15-year-old plots, those with breast-height diameters of at least 2 cm were investigated. Similarly, trees whose breast-height diameters were at least 3 cm in the 20- and 25-year-old plots were investigated.

3. Results and discussion

3.1 Conclusion of growth characteristics of young natural white birch forests

In Inner Mongolia, white birches are distributed in areas where precipitation is between 350 and 450 mm and relative humidity is between 65 and 70%. Excessive moisture hinders their growth, and their tolerance to shade is low (IMFCC, 1989).

Most stubs, made when 10- to 40-year-old white birch trees are logged, retain their sprout ability, with several dozens to 160 buds sprouting from each stub. Compared with these stubs, those made when 41- to 60- years-old white birch trees are logged have lower sprout ability, with fewer or no buds sprouting from each stub. Furthermore, sprout ability of stubs made when 60 years or older white birch trees are logged is almost absent (IMFCC, 1989). Therefore, for sprout regeneration, it is important that white birch trees should be logged before

40 years of age.

The sprout ability of stubs in white birch forests belonging to the same site class and age group differs depending on the difference in the regeneration cutting method. A previous research has reported that higher sprout ability was observed after clear-cutting of a small area (5 ha or less) than after strip-clear-cutting of a narrow area with a width of 5 m. Furthermore, strip-clear-cutting of an area with a width of at least 20 m resulted in higher sprout ability than intensive selection cutting (40% of all trees). This should be attributable to the fact that sprouting from stubs requires sufficient sunlight (IMFCC, 1989). Therefore, small area clear-cutting (5 ha or less) and wide area strip-clear-cutting (at least 20 m in width) techniques were adopted during regeneration cutting after sprout regeneration in Manhanshan National Forest Park, when the area of the clustered white birch forest was less than 10 ha and 10ha or more, respectively.

It has been reported that an outflow of water and soil does not occur after clear-cutting of an area of 5 ha or less inclined at 25° or less, or strip-clear-cutting of an area with a width of 20 m or more, thus making little impact on the growth of white birch saplings formed through sprout regeneration (Li, 1992). In addition, according to a report of an investigation conducted by Manhanshan National Forest Park, trees that grew from the same stub led to crown closure within approximately 7 years following their growth in the white birch forest formed through sprout regeneration (MNFP, 2000).

3.2 Condition of young natural white birch forests in Manhanshan National Forest Park

3.2.1 Changes of stand density, DBH and tree height

As shown in Table 1, in the plots 1-4, whose forest age ranges from 10 to 25 years, volume (m^3/ha) was greater but stand density (stems/ha) was lower in older forest stands. This tendency is believed to have resulted from natural thinning, because these forest stands were unthinned. Irrespective of the forest age, the coefficient of variation of the breast-height diameters and tree heights was maintained at 24-26% and 15-17%, respectively.

Figure 2 shows the number distribution by breast-height diameter (DBH) class (A) and that by tree height class (B) for each forest stand investigated. The figure shows an L-shaped distribution of breast-height diameters in the 10-year-old forest stand and an approximately normal distribution in any of the 15-, 20- and 25-year-old forest stands. Distribution of tree heights in any of the 10- to 25-year-old forest stands is close to normal. In all these forest stands, one peak appears in each of the number distribution by breast-height diameter class and tree height class, thus indicating uniform, pure forests.

As described above, even with ageing, the coefficient of variation of breast-height diameters and tree heights was maintained at a nearly constant level in the 10- to 25-year-old forest stands, whose structure was similar to that of uniform forests. Therefore, the distributed structure of breast-height diameters and tree heights can be regarded as maintaining high uniformity, regardless of the forest age. This may have contributed to the absence of major changes in the growth environment (such as space for crown) for each standing tree in the 10- to 25-year-old unthinned natural white birch forests in the investigation area.

3.2.2 Distribution of crowns and positions of standing trees

Figure 3 shows the crown projections in the 10-, 15-, 20- and 25-year-old forest stands. The crown closure rate, mean number of trees that grew from one stub and mean planar crown diameter in the 10-, 15-, 20- and 25-year-old forest stands were 31%, 6, 1.1 m; 53%, 5, 1.4 m; 40%, 4, 1.5 m and 44%, 3, 1.7 m, respectively. This revealed that in the 10- to 25-year-old forest stands, natural thinning reduced the average number of trees that grew from one stub and increased the average planar crown diameter of the standing trees as the age of the forests increased. However, no changing trend was observed for the crown closure rate. In the white birch forests formed through sprout regeneration in Manhanshan National Forest Park located in a semi-arid zone, seedling regeneration is difficult. Therefore, white birches cannot grow in areas without stubs; their sprout regeneration occurs only in areas where stubs exist. Consequently, the positions of white birch stubs determine the positions of trees subject to sprout regeneration. In addition, all plots (1-4) had areas with no crown. On the other hand, in areas where crowns existed, most of the crowns of trees that grew from the same stubs as well as from the adjacent ones were seen overlapping with each other. Furthermore, the spaces between trees that grew from the same stub as well as from the adjoining ones, and the planar size of the crowns formed by those trees were not uniform. These results suggest the following facts: first, with small expansion space for their crowns, the dominated trees (lower-story trees) could grow only slowly in diameter without necessary sunlight. Second, the dominant tree (upper-story tree) that grew from a stub could not grow sufficiently in diameter if its crown densely overlapped with those from the same stub or adjacent ones, particularly those of other dominant trees, with the overlapped parts of the crown deprived of necessary growth space and sunlight. Third, none of the plots

1-4 showed that natural thinning alone led to optimum growth space for both dominant trees and dominated trees.

Figure 4 shows the relationship between the Iδ index and sub-plot (small plot) area of each forest stand investigated. The figure proves that the planar distribution of trees in plot 1 was an aggregated distribution because the Iδ index was more than 1.00 at 1.04, 1.12 and 1.09 when the sub-plot area was 25.0, 56.3 and 112.5m^2, respectively. Similarly, in plots 2, 3 and 4, the Iδ index approximated to 1.00 as the sub-plot area increased. This implies that the planar distribution of the trees was close to random distribution from aggregated distribution.

3.2.3 Characteristics of forest trees

Figure 5, 6 and 7 show the results of the classification of white birches in each plot in accordance with Ohashi's tree form classification system.

(1) Crown form

As shown in Figure 5, when the crown forms of all trees were compared between plots according to the forest age, the ratio (%) of well-grown crowns was lower while that of poorly grown crowns (overly-weak or lateralized ones) was higher in the older plots. The same trend was observed with the crown forms of the dominant trees (upper-story trees), with the ratio (%) of poorly grown crowns increased to 24%, 49%, 73% and 79% in the 10-, 15-, 20- and 25-year-old plots, respectively. Overly-weak or lateralized crowns were defined as poorly grown crowns because they were not expected to grow to a large extent in diameter (HFRI, 2000); considerable lateralization in crowns is known to induce trunk curvature (Kondo, 1951).

(2) Trunk form

Previous research has reported that in timber production, trunk curvature generates hard-to-process reaction wood, thereby decreasing the timber utilization ratio (Fujimori & Kawahara, 1994). Accordingly, it is desirable to increase the ratio of straight trunks in a forest stand intended for timber production. As shown in Figure 6, with regard to trunk characteristics, comparison of trunk form between plots by forest age revealed that the ratio (%) of straight trunks among all trees and upper-story trees slightly increased at the forest age of 10-15 years and 20-25 years, respectively and decreased at 15-20 years. Consequently, the ratio (%) of straight trunks among all trees was highest at the forest age of 15 years and lowest at 20 years. A similar trend was observed with the ratio (%) of straight trunks among the upper-story trees. These results suggest that the growth environment, such as overlapping of crowns, at the forest age of 15-20 years is unfavourable for improvement in the ratio (%) of straight trunks among all trees and upper-story trees in the unthinned white birch forests formed through sprout regeneration in the investigation area. It is difficult for a curved trunk to be recovered later. Therefore, for timber production, it is preferable that the first thinning is implemented before the ratio (%) of straight trunks starts declining (i.e. before the forest age of 15 years in this case).

(3) Trunk defect

Trunk defects signify the following three categories of shortcomings: 1) considerable adhesion of adventive buds and twigs (In this article, the former are defined as buds sprouting below the crown height of white birch trunks and the latter are produced from the former.); 2) conspicuous branch scars (traces left on trunk after branches fall) and 3) damage or infection. Trees that do not belong to the above categories are classified as faultless trees. As mentioned above, neither artificial disturbance nor natural disaster occurred between the end of sprout regeneration and the time of the investigation (June-July, 2007) in the white birch forest stands (aged 10-25 years) investigated. Consequently, the forests sustained no injury or damage from external pressure. In addition, as a tree grows, the adventive buds and twigs as well as the branch scars form either live knots or dead knots, which not only blemish the beauty of timber with scars but also lead to uneven strength of the processed wood. Therefore, live knots and dead knots can be major flaws in timber, thus decreasing its value. In particular, dead knots, which are often accompanied by decay and discoloration, can further lower the timber utilization rate (Takahara, 1961), thereby causing a serious loss in commercialization.

Until they are 30 years of age, white birches have a thin bark, and hence, they are susceptible to sunburn because of prolonged exposure of their trunks to direct and strong rays of the sun. The affected parts generate adventive buds and twigs (Sakaguti, 1964). As mentioned above, the mean number of trees that grew from one stub was 6 and 5, and the mean crown height (mean crown height ratio) was 1.4 m (38%) and 2.4 m (44%) in the 10- and 15-year-old forest stands, respectively. Because of the formation of forest crowns that blocked direct sunrays against self and the adjacent trees, most trees may have received a relatively small amount of sunlight directed towards their trunks. This probably prevented growth of a considerable number of adventive buds and minimized the number of trees with defects, i.e. considerable adhesion of adventive buds and twigs. The growth of tree branches is hindered unless their leaves receive a certain amount (above the light compensation point) of sunlight, including direct and diffused reflection light, leading to gradual withering of their branches and formation of branch scars (BFU, 1981). In the 10- and 15-year-old forest stands, trees that grew from the same stubs experienced only a relatively short period of growth under crown closure that had started at 7 years of forest age. This suggests that a certain amount of sunlight may have entered into their crowns and there were no conspicuous branch scars.

Figure 7 shows defects in the trunks of all trees and upper-story trees in the 20- and 25-year-old forests stands. The following two categories of defects were observed: 1) considerable adhesion of adventive buds and twigs and 2) conspicuous branch scars. The former defect tended to occur more frequently in dominant trees (upper-story trees) with progression of forest age, while the latter defect had a tendency to increase among all trees and upper-story trees with progression of forest age. In the white birch forest stands that have grown as a result of repeated natural thinning over a long time, some of the forest trees, especially lower-story trees, suppressing the emergence of adventive buds and twigs are weeded out. Crown height increased with increase in tree height, thereby creating a condition in which the trunks of some upper-story trees were exposed to strong and direct rays of the sun. This has contributed to considerable adhesion of adventive buds and twigs (MNFP, 2000). Furthermore, the possible factors behind the conspicuous branch scars observed over all trees are as follows: the mean tree height and mean crown length of the 20- and 25-year-old forest stands was higher and longer than that of the 10- and 15-year-old forest stands, respectively. Because the forest trees that grew from the same stubs experienced a long period of growth under crown closure conditions, the light intensity below the crowns in the dense forests decreased below a certain level. This probably contributed to formation of the conspicuous branch scars. Similarly, comparison between the 20- and 25-year-old forest stands revealed that the percentage of trunk defects tended to be higher in the latter forest stand.

3.3 Thinning technology for natural white birch forests in Manhanshan National Forest Park

Regulations regarding the thinning of natural white birch forests in China stipulated that the crown closure rate should be up to 70% when performing thinning in a forest for the purpose of promoting tree growth and it should be up to 50% after thinning (SFAPRC, 1978). According to these criteria, none of plots 1, 2, 3 and 4 required thinning as their crown closure rates were 31%, 53%, 40% and 44%, respectively. However, as mentioned above, most of the crowns of trees that grew from the same stubs overlapped with each other in all these four plots. Therefore, if an increase in diameter growth and improvement in characteristics in the reserve trees (i.e. dominant and relatively good characteristic trees that are yet to be harvested) were expected, it will be desirable to implement forest thinning. In thinning of broad-leaved forests, if the rate of thinning is determined solely on the basis of the difference in the crown closure rate before and after the thinning, some of the reserve trees may not be able to sometimes grow sufficiently in growth thickness or epicormic shoots may grow in their trunks below crown height. For example, if the tree thinning rate based solely on the difference in the crown closure rate before and after thinning is lower than that necessary for promoting the growth thickness of the reserve trees and for preventing the growth of epicormic shoots in their trunks below crown height, the growth thickness of some of the reserve trees will be inhibited by some of the adjoining trees. Conversely, if the former rate is greater than the latter, some of the auxiliary trees (dominated trees) suppressing the growth of epicormic shoots should be logged after the thinning to allow growth of epicormic shoots in the trunks (below crown height) of some reserve trees. Therefore, it would be inappropriate to determine the time and rate of thinning for a white birch forest formed through sprout regeneration solely on the basis of the crown closure rate. In this regard, considering timber production, some approaches were contemplated towards thinning of the sprouting white birch forests in Manhanshan National Forest Park on the basis of the actual circumstances of the abovementioned 10- to 25-year-old forest stands. The results were as follows.

3.3.1 Methods for tree selection and thinning

All trees in a simultaneously formed broad-leaved secondary forest are virtually of the same age, albeit with a certain range in diameter class. Since tending the middle- and lower-story trees is not expected to bring about a substantial growth thickness effect in such a forest stand, it is advisable to spare only the straight dominant trees as reserve trees and log other trees, including both dominant and dominated trees, which are obstructing the growth of the reserve trees (HFRI, 2000). According to the results of investigations related to thinning of broad-leaved forests for timber production in Japan after 1975, there have been two instances: 1) thinning was not effective for promoting the growth of reserve trees because middle- and lower-story trees were primarily thinned; 2) epicormic shoots grew in trunks (below crown height) of some reserve trees because auxiliary trees (training trees), which suppress the growth of epicormic shoots, were thinned with the removal of poor-quality dominant trees (Fujimori & Kawahara, 1994). In addition, the lower-story thinning method (Note 2) in accordance with the Chinese five-level tree classification method (Table 2) that emphasizes on tree height growth rather than tree characteristics has been reported to be disadvantageous to diameter enlargement and quality improvement of remaining trees in sprouting white birch forests (MNFP, 2000). If a sprouting white birch forest is to be thinned according to this method, the dominant trees (upper-story trees) should be tended later. In the first thinning, good-quality trees (reserve trees) that will be harvested are selected from among the dominant trees in a way that they will be positioned properly, while trees that are deemed to be detrimental to the growth of the reserve trees are thinned. To prevent the growth of epicormic shoots in the trunks (below crown height) of the reserve trees, dominated trees that are not likely to adversely affect the growth of the reserve trees are left unthinned. Tree selection and thinning methods in the later practices of thinning are almost similar to those in the first thinning, with new reserve trees selected from among the existing ones.

To be precise, the abovementioned tree selection and thinning methods in the first thinning of a sprouting white birch forest are as follows: with trees taller than the mean tree height in the forest stand defined as dominant trees and those shorter as dominated trees, reserve trees are selected among dominant trees that grew from each stub. First, a reserve tree should preferably have a highly straight trunk. According to Ohashi's tree form classification system, the order of priority in selecting reserve trees is straight trees, slightly-bent trees, greatly-bent trees and bifurcated trees. Second, it should have a high crown height and large breast-height diameter. Any negative influence that it may have on the growth of the adjacent reserve trees should be eliminated, and any trees obstructing the growth of the reserve tree must be removed as thinned trees. To prevent the growth of epicormic shoots in the trunks (below crown height) of reserve tree, some dominated trees should be left unthinned.

3.3.2 Time of thinning

among all trees and upper-story trees, the crown form deteriorated as the forest age progressed, and the ratio (%) of straight trunks slightly increased at the forest ages of 10-15 years and 20-25 years, respectively and decreased at 15-20 years. The ratio (%) of forest trees with trunk defects (considerable adhesion of adventive buds and twigs, conspicuous branch scars) tended to increase after 20 years. These results indicate that as the forest age progresses, natural thinning alone is insufficient to enhance the characteristics of the remaining trees and to promote their growth thickness adequately. Therefore, it can be safely assumed that relying solely on the natural thinning process will be insufficient to substantially improve timber usage in future in terms of its characteristics and utilization rate. Thus, if pillars and beams are to be manufactured, an early selection of reserve trees and a thinning process that promotes diameter growth in a sprouting white birch forest would be necessary. To achieve this, it is desirable to plan the first thinning to coincide with the timing of crown closure in trees that grew from the same stubs (e.g. at 7-8 years or maximum 15 years of forest age). In determining the time of subsequent sessions of thinning, the conditions of the forest, such as overlapping of the crowns of the existing reserve trees with those of the adjoining trees, should be considered.

3.3.3 Rate of thinning

In the management of broad-leaved forests, it is important to grow straight trees with high crown height through density control and adopt a management way that would not allow growth of epicormic shoots in trunks (below crown height) of reserve trees. For this, it is necessary to focus on auxiliary trees and regard reserve trees and training trees (remaining auxiliary trees) as belonging to a single group. A forest stand that has lost its auxiliary trees because most of the dominated trees are under selective pressure is an overdue forest stand, a forest stand that has missed an opportunity for thinning. Therefore, it is imperative to perform thinning as frequently as possible before the forest loses its auxiliary trees (Fujimori & Kawahara, 1994). In a broad-leaved forest consisting of trees of the same species and age, the ratio (%) of straight trunks and the mean crown height rate are higher in high-density forest stands than in low-density forest stands (MFS, 1986). To improve the characteristics of reserve trees (presence of knots, straightness and crown height) in a sprouting white birch forest, it is desirable to implement thinning frequently at low intensity after crown closure is achieved by trees that grew from the same stubs. To determine the thinning rate, methods to secure the necessary growth space for the reserve trees as well as to improve their characteristics should be considered.

4. Conclusion

This article has analysed the present forest stand structure of 10- to 25-year-old unthinned white birch forests in Manhanshan National Forest Park, thereby examining a prospective mode of thinning for these forests after the ban on logging is lifted in 2011. The arguments made in the article can be summarized as follows:

1) Instead of adopting the lower-story thinning method in accordance with the conventional five-level tree

classification method that emphasises on tree height growth, it is preferable to employ a tree-form classification method considering both growth and characteristics of trees as well as a thinning method that eliminates trees negatively affecting the growth of reserve trees throughout all storeys. In the first thinning, among the dominant trees, those with relatively good characteristics should be selected as reserve trees, with some dominated trees left around them to prevent growth of epicormic shoots in their trunks. In the subsequent sessions of thinning, the tree selection method should be almost similar to that in the first thinning, and new reserve trees should be selected from among the existing ones.

2) It is desirable to implement the first thinning at the forest age of around 8 years or maximum by 15 years. In determining the time of the subsequent sessions of thinning, factors such as the overlapping of the crowns of the existing reserve trees with those of the adjacent trees should be considered.

3) It is desirable to implement thinning frequently at low intensity. In determining the thinning rate, methods to secure the necessary growth space for the reserve trees as well as to improve their characteristics should also be considered.

4) In future thinning sessions, for determining the time and rate of thinning instead of relying solely on the crown closure rate, it will be necessary to improve the thinning method considering other qualitative elements, including the overlapping of crowns of the reserve trees with those of others including upper-story trees and lower-story trees.

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Notes

Note 1. In China, tree species are divided into fast-growing species, medium-growing species and slow-growing species depending on the age of maturation. Every age class period of the fast-growing, medium-growing and slow-growing species is set at 5, 10 and 20 years, respectively. The Asian white birch belonged to the medium-growing species, with one age class period lasting for 10 years.

Note 2. The lower-story thinning method according to the five-level tree classification method is a technique that emphasises on the height growth of trees rather than their characteristics in determining trees requiring thinning. With the height of trees as a criterion, Class 5 and Class 4 trees are logged first. Depending on the situation, other unintended trees, Class 3 trees and some Class 2 trees are also logged considering the crown closure rate.

Table 1. General condition of investigated forest stands, from 2007 investigation

Forest stand	Plot 1	Plot 2	Plot 3	Plot 4
Forest age (years)	10	15	20	25
Slope direction	N	N	N	N
Altitude (m)	1,690	1,729	1,705	1,784
Slope angle	23°	21°	24°	22°
Area (ha)	0.0225	0.0400	0.0625	0.0625
Density (Stems/ha)	7,200	5,725	4,384	3,152
Volume (m^3/ha)	15.8	24.6	40.7	63.1
Management history	without	without	without	without
Mean DBH (cm)	3.1	4.2	5.7	7.5
Min-Max	2.0-6.0	2.0-7.7	3.1-10.1	3.5-13.1
Coefficient of variation (%)	24	25	25	26
Mean tree height (m)	3.7	5.1	6.2	7.1
Min-Max	2.0-5.3	2.6-6.8	4.2-9.6	4.3-10.9
Coefficient of variation (%)	16	17	15	17
Mean crown height (m)	1.4	2.4	3.2	3.9
Mean crown height ratio (%)	38	44	52	56
Mean crown length* (m)	2.3	2.7	3.0	3.2

*: The crown length is the difference between the tree height and crown height.

Table 2. Five-level tree classification method

Class 1 trees: relatively high trees in a forest stand
Class 2 trees: trees a slightly shorter than the Class 1 trees
Class 3 trees: medium trees
Class 4 trees: suppressed trees
Class 5 trees: dying trees, trees damaged by blight and insects and fallen trees

Source: excerpted from Li, G. Y. (1992). *Northern Secondary Forest Management*. (1st ed.). Beijing: China Forestry Publishing Company, (Chapter 4).

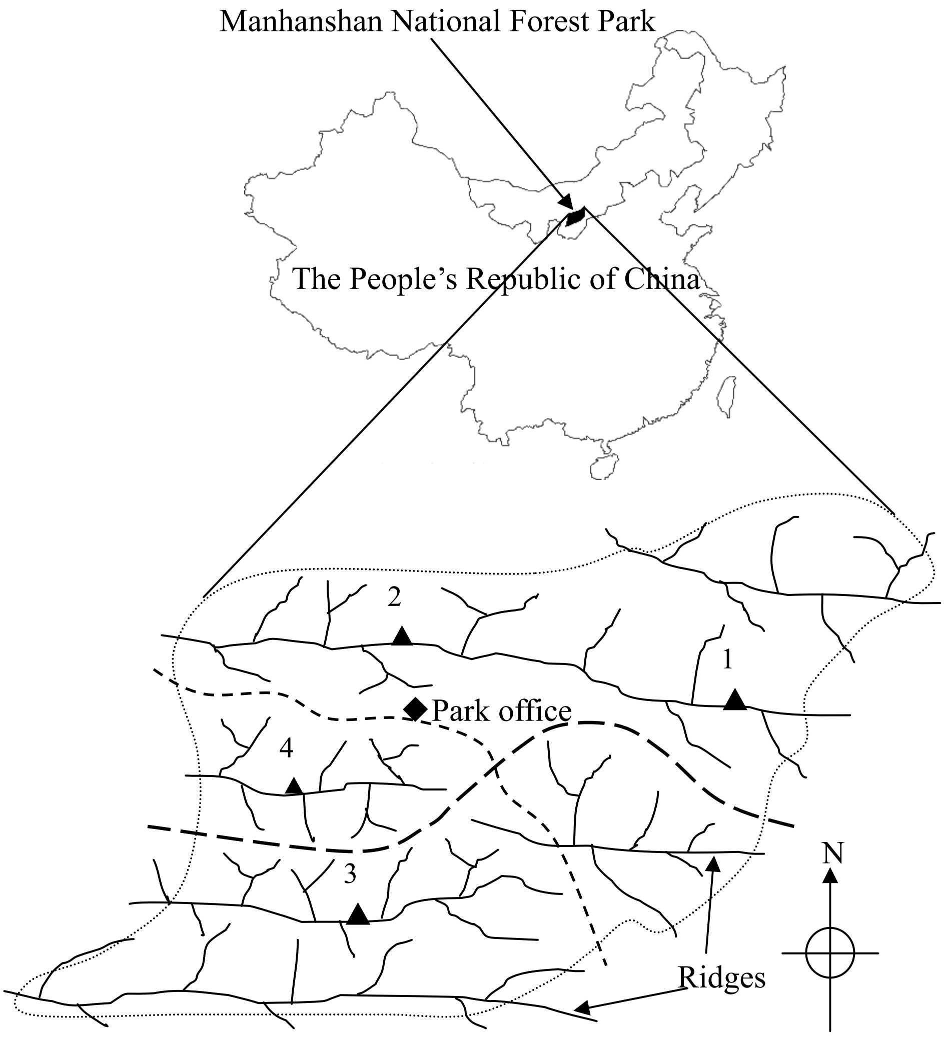


Figure 1. Location of study site

Note: Borders of Manhanshan National Forest Park

Prefectural roads Dahei River Plot location ▲

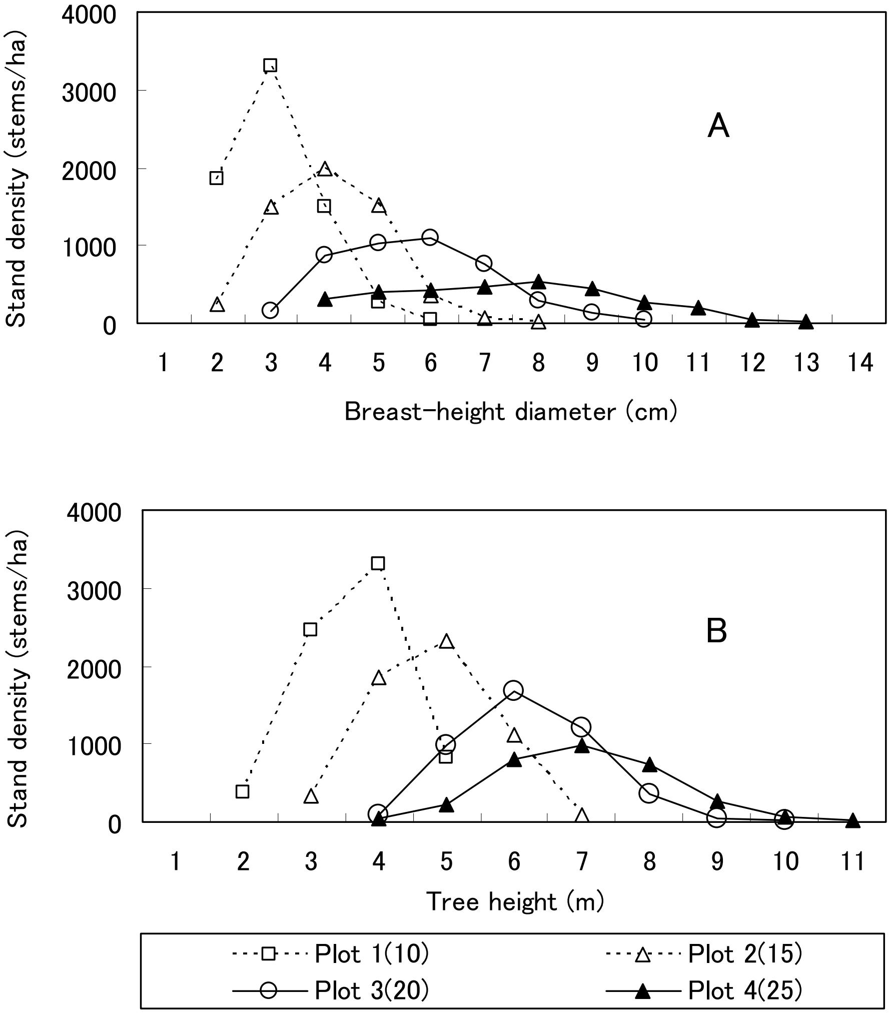
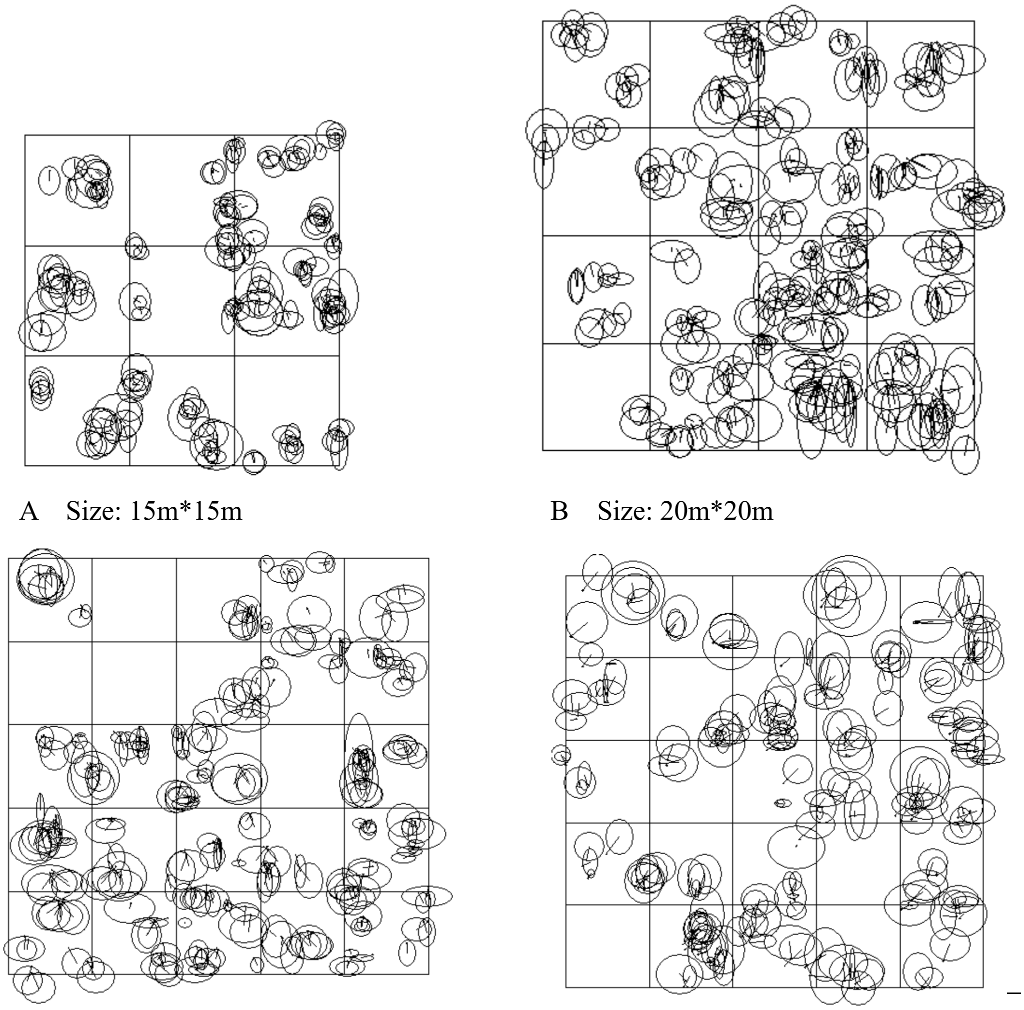


Figure 2. Number distribution by breast-height diameter class in 10- to 25-year-old unthinned forest stands (A) and number distribution by tree height class (B)

Note: The number in the parenthesis is the age of white birch forest of the investigation plot. For example, Plot 1(10) signifies the plot 1 of the 10-year-old forest stand.



A Size: 15m*15m

B Size: 20m*20m

C Size: 25m*25m

D Size: 25m*25m

Figure 3. Crown projection in 10- to 25-year-old unthinned forest stands. (A) Plot 1(10); (B) Plot 2(15); (C) Plot 3(20); (D) Plot 4(25)

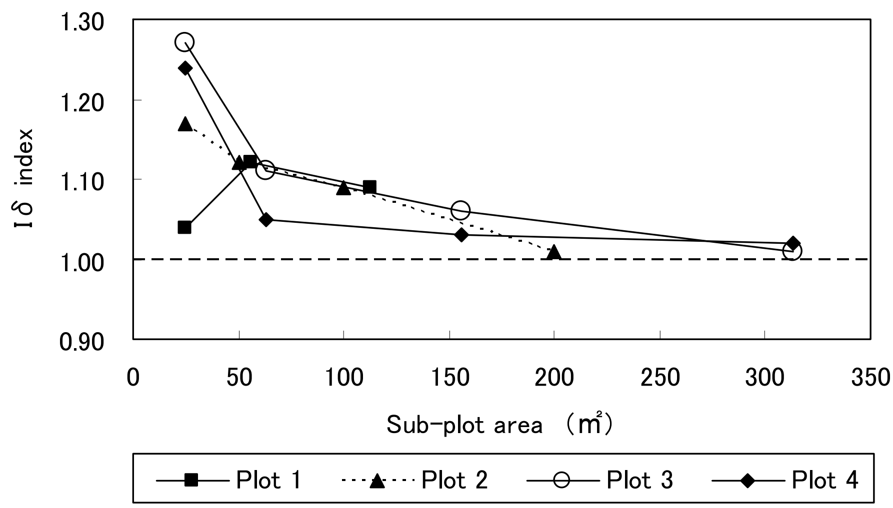


Figure 4. Relationship between Iδ index and sub-plot area in 10- to 25-year-old unthinned forest stands

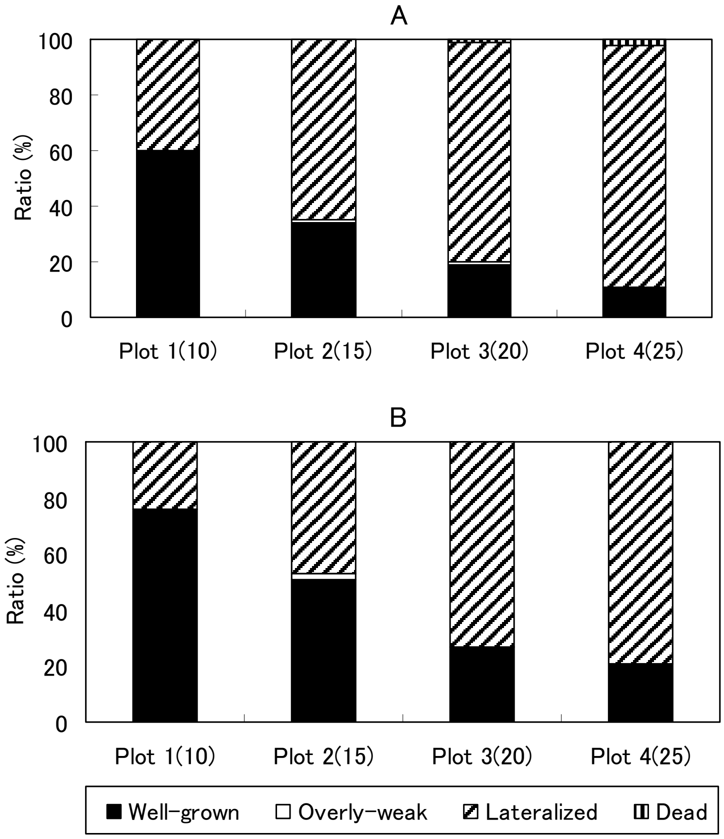


Figure 5. Ratio of crown form (%). (A) All trees; (B) Upper-story trees

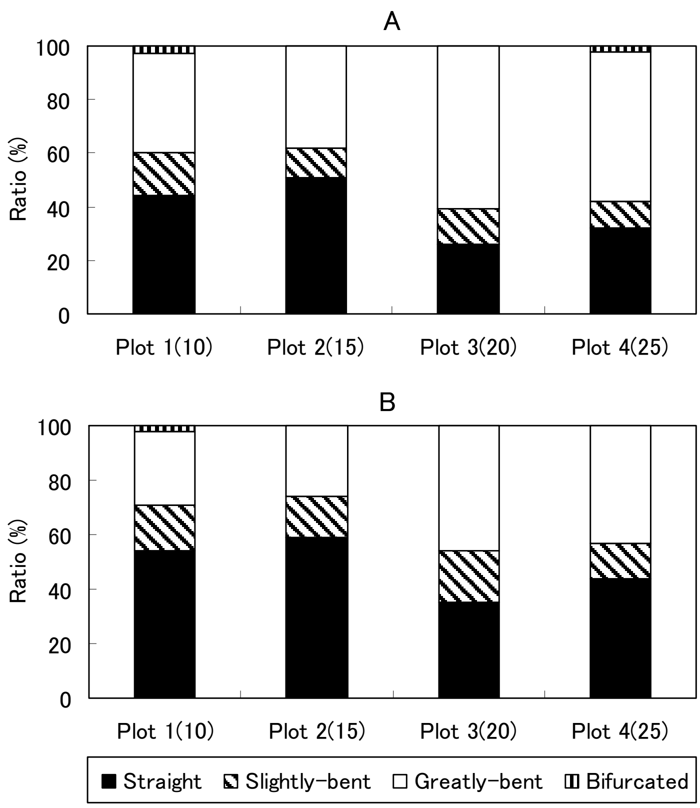


Figure 6. Ratio of trunk form (%). (A) All trees; (B) Upper-story trees

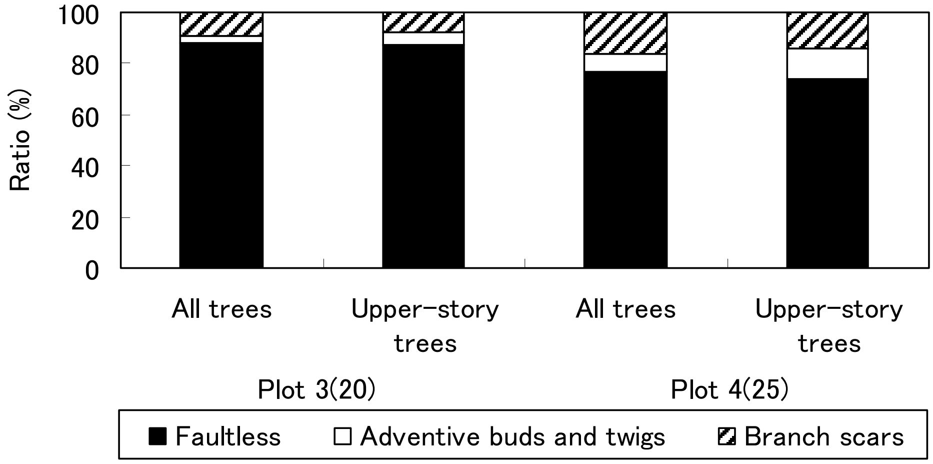


Figure 7. Ratio of trunk defect (%)