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STUDIES ON THE METHODS OF MANAGING NATURAL FORESTS IN HOKKAIDO

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Introduction

In Hokkaido, some efforts at managing natural forests were made mainly on Hokkaido prefectural forests and Imperial forests before the Pacific War. Although these attempts did not result in establishing any sort of system, due to shortage of various conditions, technical issues at the particular sites, based on an understanding of natural forests, timber cutting and regeneration are very useful in the present consideration of the management of natural forests.

After the Pacific War, as large-area, standardized, expansive afforestation was in progress, various problems arose regarding the loss of density control when improvement cutting and thinning were omitted, the practical use of woods after thinning, the quality of lumber, etc., in addition to meteorological damage (frost damage, cold-wind damage, etc.), pathologic damage (Shoot Blight, Scleroderris Canker, etc.), insect damage, and damage by wild mice and hares. Also, the deeper into the mountains the afforestation sites were, the worse conditions affecting management of them became. Reflecting upon the measures that caused the above problems, people have again begun to pay fresh attention to the management of natural forests.

The author has been working at the Teshio Experiment Forest of Hokkaido University (Fig. 1), located in the north of Hokkaido (Toikanbetsu, Horonobe Town) (hereafter called the "Teshio Experiment Forest"), for 25 years, since 1961. Based on his experience during the period, he has come to think that it is important to take the following views into consideration when it comes to systematizing management of natural forests.

The objective of natural-forest management is to create a woodland with diversity, by making good use of natural influences. Diversifying a forest is necessary. The more a forest has varieties of species, multiple stories, and different-aged trees, the better it is. Therefore, adequate means to manage a forest have to be dicided carefully after conducting thorough studies on the nature of all the tree species in the forest, the adaptability between the species, and specific local conditions. There is no standardized method for managing a

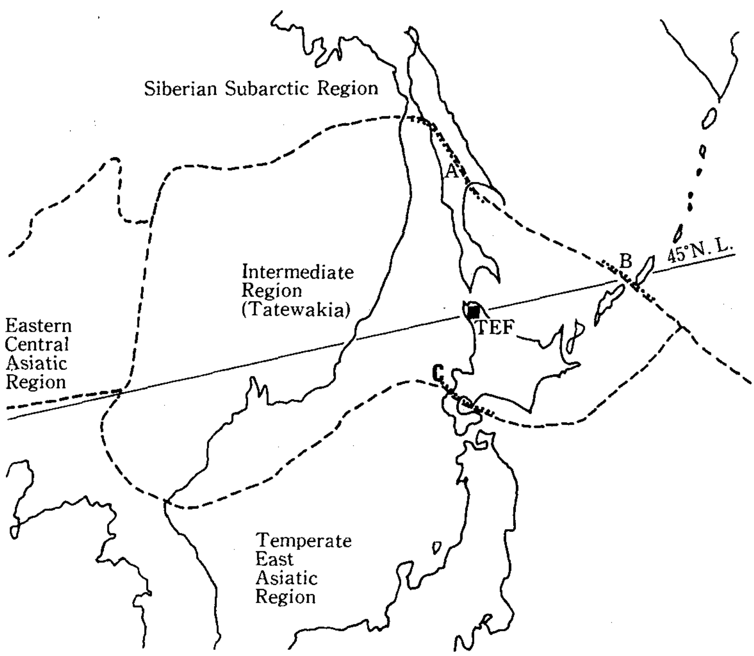


Fig. 1. Location of the Teshio Experiment Forest of Hokkaido Univ. and the essential lines of phytogeographical demarcation.
A…: SCHMIDT's Line, B…: MIYABE's Line, C…: Kuromatsunai Depression, TEF: the Teshio Experiment Forest of Hokkaido Univ.

natural forest that can be used everywhere. A high level of technique and long-term care are required to manage a natural forest.

The first thing to be done was to determine a regeneration technique. The following three techniques for regeneration were basically considered : (1) by natural seeding, (2) by sowing, and (3) by planting. A series of experiments using the three techniques were conducted at the Teshio Experiment Forest-a typical, mixed forest in Hokkaido. Part of the experimental results has already been published (by TAKIKAWA in 1975, MATSUDA and TAKIKAWA in 1985)[7][6].

Outline of Study Area

From the viewpoint of plant geography, the natural forests in Hokkaido, belong to the ecotone -- a transition zone from the northern part of the temperate zone to the sub-arctic zone, excluding a distributional zone of *Fagus crenata* in southern Hokkaido. To be more specific, the zone covers an area which is south of SCHMIDT's Line on Sakhalin, south-west of MIYABE's Line (the line of the strait between Etorofu Island and Uruppu Island) on the Kuriles, and north of the Kuromatsunai Depression, which is the Temperate East Asia Region. It is called

"Tatewakia," named after M. TATEWAKI[8] who defined it, but is commonly known as the pan-mixed forest zone, where broad- and needle-leaved trees, such as *Quercus mongolica* var. *grosseserrata*, a typical broad-leaved tree in the northern part of the temperate zone, and *Picea jezoensis* and *Abies sachalinensis*, both major needle-leaved trees in the sub-arctic zone, are mixed like a mosaic.

The major species of broad-leaved trees in these mixed forests are characteristically those which are valuable as big-diameter lumber, including *Quercus mongolica* var. *grosseserrata, Betula maximowicziana, Tilia japonica, Acer mono, Kalopanax pictus, Ulmus davidiana* var. *japonica, Fraxinus mandshurica* var. *japonica,* and *Cercidiphyllum japonicum.*

To describe the plant geography in Hokkaido from the vertical viewpoint, areas more than 700-800 meters above sea level in the central part of Hokkaido belong to the sub-arctic mountain zone, featuring northern needle-leaved trees, like *Abies sachalinensis, Picea jezoensis* and *Picea glehnii* ; those below, to the zone with sub-arctic mountain broad-leaved trees, including *Betula ermanii* and *Alnus maximowiczii.* The forest which is the subject of the experiments on management of natural forests can be said to be one of those pan-mixed forests which are the major part of the forests in Hokkaido. The size of each stand forming the mosaic seems to be around 30 to 40 meters.

The tree composition of the average natural forest (mixed forest) within the experimental area of the Teshio Experiment Forest, dealt with in this paper, is shown in Table 1. Big-diameter trees, such as *Picea jezoensis, Quercus mongolica* var. *grosseserrata, Ulmus davidiana* var. japonica, Betula ermanii, and *Betula maximowicziana,* form the forest, 559.2 cubic meters per hectare. Among them,

TABLE 1. Tree composition of the natural stand in the experimental area

Species	No. of trees(%)	Volume(m^3)/(%)
Abies sachalinensis	68 (51.1)	45.6 (32.6)
Picea jezoensis	43 (32.3)	82.6 (59.1)
Sorbus commixta	7 (5.3)	0.3 (0.2)
Kalopanax pictus	5 (3.8)	1.8 (1.3)
Betula ermanii	3 (2.3)	5.5 (3.9)
Acer mono	3 (2.3)	1.3 (0.9)
Acanthopanax sciadophylloides	3 (2.3)	1.6 (1.1)
Quercus mongolica var. *grosseserrata*	1 (0.8)	1.1 (0.8)
Total	133(100.2)	139.8 (99.9)

Note : 1. * over 6 cm in breast height diameter

2. Stand size is 50 m×50 m.

3. Data from OTA et al. 1973.

TABLE 2. Degree of cover of the plants on the unstocked land

Species Quadrat No.	1	2	3	4	5	6
Abies sachalinensis	+	•	•	•	•	•
Quercus mongolica var. *grosseserrata*	+	•	•	•	•	•
Kalopanax pictus	+	•	•	•	•	•
Acer mono var. *mayrii*	+	•	•	•	•	•
Sorbus commixta	+	•	•	•	•	•
Euonymus macropterus	•	•	•	•	•	+
Sambucus sieboldiana var. *miquelii*	•	•	•	•	•	+
Skimmia japonica forma *repens*	+	•	•	•	•	•
Vitis coignetiae	+	+	+	+	+	•
Hydrangea petiolaris	+	•	•	•	•	+
Rhus ambigua	•	+	•	•	•	+
Schizophragma hydrangeoides	+	•	•	•	•	•
Dryopteris austriaca	•	•	•	•	•	+
Sasa kurilensis	•	5	5	5	5	5

Note: 1. Coverage(+, 1, 2, 3, 4 and 5) after BRAUN-BLANQUET (1964)[1]
2. Each quadrat size is 2 m×5 m.

Picea jezoensis and *Abies sachalinensis* trees are distinguished both in number of trees and volume, which is 91.7 percent of the forest.

In the natural forest, there are blanks (forest gaps) in various sizes along streams, on ridges, and mountain sides. *Sasa* plants constitute most of the forest-floor vegetation, mainly consisting of *Sasa kurilensis* section (2-3 meters tall, growing in high-snowfall areas), and *Sasa senanensis* section (1-3 meters tall, growing in medium-snowfall areas), and *Sasa nipponica* section (0.5-1 meters tall, growing in low-snowfall areas), that is found only in the eastern part of Hokkaido. Those blank spots are very difficult areas for regeneration, and are commonly called "round bare areas." The species of plants found at those areas are shown in Table 2.

Geologically, the nature of the soil in these spots belongs to the fold zone of the neo-third period of the Cenozoic era, consisting mainly of clay rock and sandy clay rock with thin lime layers everywhere.

Shown in Table 3 are meteorological data in the Teshio Experiment Forest from 1976 to 1980[9]: annual average temperature, 5.7°C; the highest temperature, 35.1°C in August; the lowest, −35.9°C in February; strong west winds throughout the year; annual precipitation, approximately 980 millimeters; snowfall from November to April; Warmth index (W. I.), the average for the last ten years since 1970, 54° m. d.

TABLE 3. Climatological data in the Teshio Experiment Forest

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Temperature (°C)													
Mean Max.	−4.5	−3.4	1.7	7.7	16.3	20.7	24.6	24.8	21.3	14.8	6.4	0.6	10.9
Mean Min.	−15.6	−17.2	−11.5	−1.3	4.4	9.7	15.3	14.5	9.3	2.8	−2.0	−8.5	0.0
Mean	−9.2	−9.6	−3.9	3.0	9.7	15.3	19.9	19.5	15.5	9.1	2.5	−3.3	5.7
Humidity (%)	88.9	85.2	84.3	82.2	77.9	84.3	84.8	84.8	83.9	82.0	85.4	89.5	84.4
Precipitation(mm)	60.5	39.9	42.0	56.4	58.0	74.8	92.5	103.0	111.4	120.4	134.4	86.7	980.4
Mean velocity of wind (m/sec.)	3.2	3.6	3.7	3.9	4.4	3.5	2.9	2.7	2.7	3.4	3.6	3.4	3.4
Max. snow depth (cm)	119	126	128	104	3	0	0	0	0	6	30	74	128

* Data observed by the Teshio Experiment Forest of Hokkaido Univ. from 1976 to 1980.

Planning and Implementation of Experiments

A. Surface Raking

Surface raking is an important process for regeneration by both natural seeding and sowing, in order to help tree seeds stabilize on the soil, and to prepare the soil for planting nursery stocks. As mentioned in the previous sections, the *Sasa senanensis* and *Sasa kurilensis* sections on the forest floor prevent the trees from regenerating. A lot of tree seeds drop, but most of them are caught on the litter of *Sasa* leaves, to be eaten by animals and insects, or get rotten. Even if they are fortunate enough to survive and germinate, they die eventually due to lack of luminous intensity. Thus, it is necessary to rake the surface of the forest floor by such means as removing *Sasa* plants, and to disturb the A_0 layer.

It is said that raking was manually done by hoes and the like at the Imperial forests before the Pacific War to promote regeneration by natural seeding. But manual raking was not employed officially as a means of forest management due to area restrictions, etc. After the Pacific War, though, experiments on surface raking were started in many places, assuming that surface raking was effective in promoting regeneration by natural seeding, based on the following examples:

(a) Regeneration of broad-leaved trees by sprouting and natural seeding were often seen where the soil was prepared by burning for the purpose of afforestation of larch trees.

(b) Regeneration of broad-leaved trees by natural seeding was often seen where the land was prepared regularly by scythes or brush cutters, and brush cutting was done repeatedly.

(c) Natural-seeding regeneration occurred better where the surface of the soil was disturbed by bulldozers that were used, specifically, to clear trees damaged by the wind during a big typhoon in 1954, and, generally to transport wood as part of the mechanization of logging.

(d) Broad-leaved trees regenerated better after bulldozers started being used to prepare the soil.

In the Teshio Experiment Forest, experiments to reforest *Betula ermanii* started in 1962 at a wind-beaten blank spot, which experienced a forest fire several years before, and had become thickly grown with *Sasa kurilensis*. Seeds of *Betula ermanii* were sowed at several plots which were prepared in different ways: raked by a bulldozer, brush-cut by a brush cutter, had the A_0 layer removed, and cultivated by a hoe. It was proved that surface raking by a bulldozer was most effective from a forest management point of view[2].

Since then, surface raking by bulldozers has been used at many places in Hokkaido, and it has become clear that the method is most effective from both technical and efficiency viewpoints.

The method was used in the Hokkaido prefectural forests from late 1965 till recently. The total area prepared by this method reached approximately 8,600 hectares, 75 percent of which got good regeneration by natural seeding -- altogether 90 percent of the area had regeneration, and only 5 percent had nothing at all. After around 1973, bulldozers were gradually replaced by rake-dozers[3].

At the Teshio Experiment Forest, rake-dozers started working in the fall of 1972, and a 170-hectare area had been raked by them by 1983. The regeneration results here were almost the same as those obtained in the Hokkaido prefectural forests.

A bulldozer removes the surface soil so completely that cultivation of the sub -surface is impossible, because of unadjustable raking power. On the other hand, it is possible to adjust power and cultivate the subsurface if the soil is raked by a rake-dozer. The size of the claw of the rake-dozer used at the Teshio Experiment Forest was 40 centimeters. As the shapes of the blanks grown with *Sasa* plants in the Teshio Experiment Forest were different, (general) overall weeding was available, except for large areas. The surface soil is raked along a contour line; if it should be done towards a slope-side direction because of topographical reasons, raking of the sub-surface soil along the contour line at the end is recommended, which is helpful to avoid creation of water ways, and to improve regeneration as well.

Erosion is hardly a problem in the Hokkaido *Sasa* sections. Annual average rainfall at the Teshio Experiment Forest (at 43°N. L.) is c. 600 millimeters, and the maximum rainfall in one day is 83 millimeters. The snow period in the forest is from November to April; everything is under snow during this time. For the rest of the year, it doesn't rain so much. The monthly average rainfall from May to July is around 75 millimeters; 110 millimeters from August to October. Accordingly, there is no need to worry about erosion. On the other hand, some consideration should be given to maintaine the places where water accumulates and stays. Also, while it is raining, or immediately after a rain, raking should be avoided because there is a risk that the soil will become muddy.

1. Large-sized Machines

As large-sized machines for surface raking, tractors (mainly crawler tractors) are used with the following attachments: dozers, rakes, back hoes, hammer-knives, rotary cutters, shredders, etc. Dozers for engineering works were used at the beginning to cut *Sasa* plants, twiner plants, other shrubs, and to remove branches, fallen trees and stumps, but they were gradually replaced by rakes. As already mentioned, there are several merits in using rakes. They create conditions suitable for cultivation of sub-surface soil, which results in good regeneration performance, and also good ground, which is easy for planting and leads to a high survival rate. As the recovery of *Sasa* plants is very slow, weeding can be omitted for a few years. The biggest advantage of all, however, is that use of a rake-dozer is very economical -- it is not a special machine, but can be used for many purposes, just by changing the dozer of an engineering bulldozer to a rake.

Raking performance of rake-dozers is shown in Table 4. In 1973 and 1974, an 11-ton rake-dozer was used. The 11-ton one did much better than a 9-ton rake-dozer, especially on flat areas along streams. The volume of work differed largely depending on, not only the driver's experience and skill, but also weather and locational conditions, including conditions of *Sasa* plants, number of stumps and fallen trees, and degree of slope.

Hammer-knives and rotary cutters have advantages, too, but they are not versatile enough to be used anywhere -- are usable only in limited places under limited conditions.

2. Brush Cutter

Brush cutters or regular long-handle scythes for cutting *Sasa* are used instead of rake-dozers to cut *Sasa* plants growing on areas with more than 15 degrees slope, on round-shaped spots, and in areas mixed with young trees -- to cut at their roots by doing strip weeding or overall weeding, just like preparing the soil. The time for *Sasa* to recover completely depends on the kind of *Sasa*: It takes

TABLE 4. Amount of raking work by rake-dozer

Rake-dozer type	Working period	Working hours	Working areas(ha)	Working ratio (hours/ha)	Land features
9-ton crawler type for marsh	Aug. 30-Sept. 23, 1972	193.0	15.0	12.9	sloping on ridges
11-ton crawler type for marsh	Oct. 9-19, 1973	36.5	5.9	6.2	sloping on ridges and mountain sides
11-ton crawler type for marsh	June 12-14, 1974	23.5	7.8	3.0	flat along streams

Sasa nipponica 2 to 4 years; *Sasa senanensis*, 6 to 8 years; and *Sasa kurilensis*, 10 to 15 years. Overall weeding, especially when done in July and August, is most effective in delaying their recovery.

In order to promote good regeneration by seeding, it is necessary not only to cut *Sasa* plants, but also to push the cut trunks and leaves down the slopes and rake litter away. Thus, when cutting *Sasa* is planned, where and how to push and rake the litter should also be considered.

The following species are suitable for planting according to general reforestation arrangements after the soil is prepared by brush cutters: *Abies sachalinensis, Picea jezoensis*, and *Picea glehnii*. Planting of broad-leaved trees is not recommended except in some special cases, because there is a risk of cutting nursery stocks by mistake during weeding, etc.

3. Burning and Others

Prescribed burning is another of the soil-preparation methods. Special preparation before burning is required, as the result of the burning depends on how the *Sasa* plants were cut in advance. Some good effects of the burning can be seen in the forests that fully regenerated at old forest-fire sites. However, the implementation of this method is restricted by topographical features and seasonal factors, and requires a lot of manpower. It is, therefore, necessary to investigate its supplemental use at forest gaps in natural forests in the future. In the Hakodate Regional Forest Branch Office, they have successfully used the burning method since the latter 1950's to facilitate regeneration of the *Betula* species by natural seeding[4]. There is another way to remove *Sasa* plants, by weedicides, but overall introduction of this will have a great effect on the ecosystem, and only its supplemental use should be considered.

Grazing cattle worked successfully on an experimental basis, but this seems to be unsuitable in a big natural forest deep in the mountains.

B. Work on Regeneration by Natural Seeding

The lay-out of mother trees near seeding areas is most important, but to determine a method of regeneration, the following points for each species should be taken into consideration: seeding /fruiting condition, time of falling seeds and how they drop, growing process after germination, etc. Seeding conditions of major trees are as follows:

Rich seeding every year	-*Juglans ailanthifolia*
Rich seeding every other year	- *Betula* species; *Ulmus laciniata*; *Phellodendron amurense* var. *sachalinense*; *Cornus controversa*
Seeding every two years	- *Abies sachalinensis*; *Quercus mongolica* var. *grosseserrata*; *Fraxinus mandshurica* var. *japonica*; *Alnus hirsuta*

Seeding every three years - *Picea jezoensis* ; *Picea glehnii* ; *Ulmus davidiana* var. *japonica* ; *Cercidiphyllum japonicum* ; *Acer mono* ; *Kalopanax pictus.*

Betula species trees show the best results of regeneration at the following areas : *Betula ermanii* near the ridges, *Betula maximowicziana* and *Betula ermanii* around sides of the mountain, and *Betula platyphylla* var. *japonica* at the foot of the mountain. Wherever mother trees of the *Betula* species are found, when surface raking is done, they germinate all at once.

For the purpose of learning in advance how many seeds will fall, and differences according to species, seed-traps were placed at places where surface raking had just been done. The results are shown in Table 5.

The investigation plots were small forest gaps of less than 0.3 hectare grown with *Sasa* plants, and surrounded by mixed forests, including *Abies sachalinensis* and *Picea jezoensis*. In the center of each plot, a square seed trap, 50 centimeters on each side, was set. Within several weeks, a large amount of seeds dropped in the traps. The total amount of the seeds collected both inside and outside of the traps was enormous. An interesting point about the result was that a lot of seeds of *Betula maximowicziana* were found, although its mother trees were not seen near the traps. This must be partly because seeds of *Betula maximowicziana* can fly longer in the wind, having bigger wings than those of the other *Betula* species. Species reproduced at raked areas and the number of individuals are described in Table 6.

The reliable distance that seeds can fly is considered to be approximately 100 meters, but *Betula maximowicziana* seeds, which have the biggest wings, are said to fly as far as several times that distance, depending on wind conditions. Among *Betula* species trees in the Teshio Experiment Forest, the regeneration rate of *Betula maximowicziana* is the highest. In a year of rich seeding of the *Betula* trees, tens of millions of seeds drop per hectare. They germinate in the following spring from May to July, and a million seedlings per hectare are produced. As to vertical growth rates, *Betula platyphylla* var. *japonica* always stands at the top, followed by *Betula maximowicziana* and *Betula ermanii*. *Betula maximowicziana*

TABLE 5. Seed dispersal rate of tree species on the land raked

Items \ Species	*Betula ermanii*	*B. maximowicziana*	*B. platyphylla* var. *japonica*	*Picea jezoensis*	*Abies sachalinensis*	*Acer mono*	Total
Mean numbers of seed dispersed	509(90.2%)	11(1.9%)	7(1.2%)	31(5.5%)	6(1.1%)	0.2(0.0)	564.2(99.9%)
Numbers/ha	20,377,143	448,571	282,857	1,220,000	251,429	5,571	22,585,571

Note : 1. Dispersed seeds were investigated near Akagawa forest road from early September to mid-November in 1972.

2. Fourteen seed collecting boxes (50 cm × 50 cm) were used here.

TABLE 6. Species reproduced at raked areas and the number of individuals

Species	No. of trees(%)	No./ha
Tree		
Picea jezoensis	39 (9.2)	97,500
Abies sachalinensis	2 (0.5)	5,000
Betula ermanii	353 (83.5)	882,500
Betula maximowicziana	4 (0.9)	10,000
Phellodendron amurense var. *sachalinense*	19 (4.5)	47,500
Acer mono	2 (0.5)	5,000
Salix hultenii var. *angustifolia*	2 (0.5)	5,000
Magnolia obovata	1 (0.2)	2,500
Aralia elata	1 (0.2)	2,500
Subtotal	423(100.0)	1,057,500
Liana, shrub and herb		
Sambucus sieboldiana var. *miquelii*	16	40,000
Vitis coignetiae	12	30,000
Other liana and shrubs	6	15,000
Herbs	32	70,000

Note: 1. Surface raking was made in 1972.
2. 4 small quadrats (1 m×1 m) were investigated in 1973.

grew as much as several meters tall in ten years, and several tens of thousands of trees per hectare survived. Several years after that, they had become about ten meters tall, and approximately ten thousand trees remained. At this stage, it is appropriate to start cutting bad trees for improvement -- those bad trees which were eaten by hares, damaged by snow, etc. Improvement cutting and thinning are recommended especially for *Betula maximowicziana* to produce large-diameter trees as early as possible. The target periods for building the following stands of trees with 40-centimeter breast-high diameter are as follows: 50 years for a stand of *Betula platyphylla* var. *japonica*; 100 years for *Betula maximowicziana*; and 120 years for *Betula ermanii.*

At present, the accumulation status of broad-leaved trees in Hokkaido is that *Betula* species and *Quercus mongolica* var. *grosseserrata* are plentiful. The number of stands of *Betula* trees, which can regenerate well by natural seeding, will continue to increase significantly, because the area to be raked as a result of active implementation of natural-forest management will increase, and the surface of the soil will be disturbed more and more by bulldozers engaged in logging. On the other hand, valuable broad-leaved trees, such as *Kalopanax pictus, Fraxinus mandshurica* var. *japonica, Ulmus davidiana* var. *japonica, Quercus mongolica* var. *grosseserrata,* etc., will be decreasing.

Reproduction of these broad-leaved trees, as well as *Abies sachalinensis* and *Picea jezoensis*, will be seen partially on a single-tree basis, but the young trees will not survive, being overcome by *Betula* trees where there are many *Betula* trees. Yet, regeneration by natural seeding of these difficult species will be quite possible by giving special care, including weeding, improvement cutting, and the like. As for *Picea jezoensis* and *Abies sachalinensis*, it will be helpful to trim broad-leaved trees forming an upper story, to let in more sunlight, and to help the growth of sprouts at the tops of the trees.

C. **Regeneration by Sowing**

Sowing and planting are used when regeneration by natural seedings is not suitable even if surface raking is done, or when stand cultivation of various species should be secured. Sowing is possible for any species of both needle- and broad-leaved trees, but weeding and other aftercare are required, except for the Betula species. *Kalopanax pictus, Tilia japonica, Picea jezoensis* and *Abies sachalinensis,* whose nursery stocks grow very slowly, are not good for sowing, as they are easily overwhelmed by *Sasa* and other weeds. The seeds of *Kalopanax pictus, Tilia japonica* and *Fraxinus mandshurica* var. *japonica* often germinate after two or three winters. As the *Betula* species needs no weeding care later, it is sufficient just to scatter the seeds over the raked soil surface, at the following respective areas : Seeds of *Betula maximowicziana* are sowed at places with good soil and weather conditions ; *Betula ermanii,* at wind-beaten spots and along the ridges ; and *Betula platyphylla* var. *japonica,* along streams and flat areas at the foot of mountains.

The best time to sow the seeds of the *Betula* species is after gathering the seeds in the fall and before the snowfall. If sowing is planned the following spring, the seeds have to be stored at low temperature. *Quercus mongolica* var. *grosseserrata* and *Juglans ailanthifolia* can also be used for regeneration by sowing with necessary care.

The seeds of *Quercus mongolica* var. *grosseserrata* -- selecting only those seeded from relatively-good-character mother trees -- are collected at areas where soil surfaces were raked in the same year, or areas along forest roads, where seed collection is easy. The seeds found at frosty places have low germination rates ; seeds damaged by frost can be easily distinguished because of their damaged, soft coats. It is ideal to sow the seeds at the same time as they are gathered. If they are stored for a short period, there should be special care to stop them from germinating and the like.

Shown in Table 7, a few seeds are sowed at one spot and covered with soil of one- to two-centimeters in depth, with two to three meters between the tree lines and one to three meters between the spots. Only weeding is required once in a while as *Sasa* plants regrow and other tall vegetations intrude into the area,

TABLE 7. Number of seeds of *Quercus mongolica* var. *grosseserrata* sowed at one spot and the number germinated

No. of seeds germinated at one spot	0	1	2	3	Total
No. of spots	4(8.0%)	8(16.0%)	21(42.0%)	17(34.0%)	50(100.0%)

Note: 1. Seeds were sowed at the same time as they were gathered in Oct. 1973.
2. Investigation of experiments was conducted in Oct. 1974.

but it is quite alright to leave the trees to grow freely with the *Betula* species trees which regenerate in the area, instead of taking 100-percent care of them, so that they will grow straight. According to the results of experiments conducted in IMADA (1974), one of the experimental forests in Hokkaido managed by Kyushu University, the character of trees can be improved by truncation[5]. But, in the Teshio Experiment Forest, located in an area of heavy snowfall, it is more important and advantageous to let trees grow tall as quickly as possible without truncation. To produce trees with 40-centimeter breast-high diameter in approximately 130 years is ideal. It will be worthwhile to attempt to produce shiitake mushroom by crude woods of more than 10-centimeter diameter in 20 years, and to attempt regeneration by sprouting afterwards, too.

When the seeds of *Juglans ailanthifolia* are sowed over the rich soil, they grow quickly. It is enough to sow one piece of seed with sarcocarp at each spot. The sowing arrangements and aftercare are exactly the same as those for *Quercus mongolica* var. *grosseserrata*. It is better to rake the soil surface rather mildly to leave humus.

The above three trees (*Betula* species, *Quercus mongolica* var. *grosseserrata*, and *Juglans ailanthifolia*) are easily regenerated by sowing. Other broad-leaved trees, such as *Fraxinus mandshurica* var. *japonica*, *Acer mono*, *Phellodendron amurense* var. *sachalinense*, *Magnolia obovata*, etc., are also possible. As weeding and other care are required later, it is necessary to sow the seeds either in rows, in belts, or in spots, but to avoid random sowing. Disposal of cut weeds should be taken into consideration.

Trees such as *Kalopanax pictus*, *Tilia japonica*, and *Ulmus davidiana* var. *japonica* are not suitable for regeneration by sowing, and have to depend on the planting of natural seedlings, for they grow so slowly for the first several years that they are easily overwhelmed by other vegetation. The sowing arrangements conducted in the Teshio Experiment Forest are as follows:

a. *Betula ermanii*

Sowing in rows — 1 meter wide, 1 gram per square meter (1 gram = approximately 1,200 seeds)

Sowing in hole — 1 meter between lines and holes, 10,000 holes per hectare,

1 hole(20 centimeters in diameter) 0.5 grams
At some places, base manure of 80 grams per hole is given.

Broadcast sowing 1 gram per square meter

b. *Betula maximowicziana*

Broadcast sowing 1 gram per square meter

c. *Quercus mongolica* var. *grosseserrata*

Sowing in hole 1 to 2 meters between lines and holes, 5,000-10,000 holes per hectare, 2-3 seeds per hole.
Manure was partially given.

d. *Juglans ailanthifolia*

Sowing in hole 1-2 seeds per hole. Others are same as *Quercus mongolica* var. *grosseserrata.*

e. *Tilia japonica* and *Kalopanax pictus*

Broadcast sowing 200 seeds per square meter

f. *Magnolia obovata, Acer mono, Fraxinus mandshurica* var. *japonica*

Broadcast sowing 100 seeds per square meter

D. **Planting**

Planting nursery stocks in a raked area is the most reliable means of cultivating a stand of a target species successfully. The method can be said to be a small-area (less than one hectare here), group afforestation, and is available for any species. But the primary purpose of planting is to cultivate stands of valuable trees, which requires skill to produce nursery stocks of various species at seedbeds. But seedlings of all species are naturally regenerated at the areas where the soil surfaces are continuously raked for the purpose of either sowing or planting. By giving additional care to those seedlings, a certain amount of natural seedlings can be produced every year.

A large amount of seedlings of the *Betula* species can be obtained without any care. Seedlings of other needle-leaved trees, such as *Picea jezoensis* and *Abies sachalinensis,* are also obtainable by conducting weeding and trimming to stimulate growth of trees of the target species.

If seedlings are planted densely, their tree tops will become crowded sooner and shut out the sunlight, which will help to shorten the period requiring weeding. However, it is recommended that less seedlings are planted, and that their growth is stimulated through competition with trees of other species regenerated by natural seedings. It seems enough to plant 1,100 seedlings, leaving a three-meter space around each one, per one hectare, or 600 seedlings, with four-meter space per one hectare. These arrangements are eventually more efficient, considering necessary labor and the trouble of improvement cutting when they are planted densely. It is also acceptable to let the seedlings grow partially mixed with single trees which are regenerated by natural seeding, instead of replanting additional seedlings of the same species originally planted.

According to the author's experience, natural seedlings which were used for planting and survived well are *Picea jezoensis, Kalopanax pictus, Quercus mongolica* var. *grosseserrata,* and *Phellodendron amurense* var. *sachalinense.* If places to collect natural seedlings are selected beforehand, a female worker can gather approximately 200 seedlings per day using an end-pointed shovel. The seedlings thus collected are transplanted by vinyl or jiffy pots. The seedlings thus collected are transplanted by vinyl or jiffy pots. The good time for transplantation is either spring or autumn, but autumn is more recommendable as it is easier to distinguish broad-leaved trees by their leaves.

Nest planting, in contrast to single-tree planting discussed above, is used for group reforestation -- to ease interference from competitive plants outside the nest by using the mutual supporting power of the seedlings within the nest group. In addition, it aims at saving labor in preparing the soil and other care. The arrangements for nest planting vary from planting five to two seedlings per nest, as shown in Fig. 2.

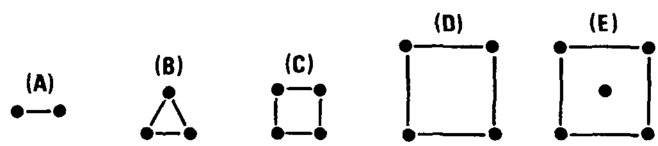


Fig. 2. Arrangements for nest planting.
(A) : planting two seedlings per nest, with 50 cm space, (B) : planting three seedlings per nest, 50 cm on each side, (C) : planting four seedlings per nest, 50 cm on each side, (D) : planting four seedlings per nest, 1 m on each side, (E) : planting five seedlings per nest, 1 m on each side.

Results

A. Plots Regenerated by Natural Seeding

Shown in Table 8 and 9 are regeneration results of trees of the tall-tree species at small, hole-shaped areas--120 to 130 meters above sea level with enough sunlight -- after they were raked in 1972. Table 8 describes the results at the places where *Betula ermanii* trees are dominant, and Table 9 at the locations where *Betula maximowicziana* trees are superior. In Table 8, *Betula ermanii* trees which are 3 to 5 meters tall (approximately 16 to 17 percent) form the upper stories, and among *Betula maximowicziana* trees, only individual trees of the top story, which are comparable to the upper-storied *Betula ermanii* trees, are

TABLE 8. Growing conditions of trees (mainly composed of *Betula ermanii*) regenerated by natural seeding in the place raked

Species	Height class(m) Year	-0.5	0.5-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	Total (/ha)
Betula ermanii	1978	130,370	70,000	67,037	3,704	0	0	271,111
	1981	9,990	8,325	24,420	8,325	6,660	3,330	61,050
B. maximowicziana	1978	5,556	0	370	741	0	0	6,667
	1981	0	0	0	0	0	0	1,110
Abies sachalinensis	1978	16,667	0	0	0	0	0	16,667
	1981	28,332	0	0	0	0	0	28,332
Picea jezoensis	1978	3,333	0	0	0	0	0	3,333
	1981	24,444	0	0	0	0	0	24,444
Other broadleaved trees*	1978	18,334	22,592	12,592	7,778	0	0	61,296
	1981	27,777	23,889	13,890	2,220	0	555	68,331
Total (/ha)	1978	174,260	92,592	79,993	12,223	0	0	359,074
	1981	90,543	32,214	38,310	10,545	6,660	4,995	183,267

Note: 1. Three quadrats (3 m × 3 m) were investigated here.
2. * Other broadleaved trees are *Betula platyphylla* var. *japonica, Phellodendron amurense* var. *sachalinense, Acer mono, Kalopanax pictus, Quercus mongolica* var. *grosseserrata, Aralia elata* and *Sambucus sieboldiana* var. *miquelii*.
4. This table was based on the research data in the field exercises for students of Dept. of Forestry, Fac. of Agr., Hokkaido Univ.

surviving. The number of trees of the other species combined is equivalent to the whole of the *Butula* trees, but they are being overwhelmed by the *Betula* trees. Although production of needle-leaved trees has been continuing due to good conditions for germination, their growing conditions are extremely bad, as they are under strong pressure from the broad-leaved trees.

According to Table 9, the *Betula maximowicziana* trees have been growing excellently, becoming 6 to 7 meters tall approximately 10 years after the germination. On the other hand, other broad-leaved trees, including *Betula ermanii* trees, are overwhelmed by these trees (approximately 5 percent) forming the upper story. Also, some needleleaved trees, like *Phellodendron amurense* var. *sachalinense*, are almost totally overwhelmed because of big tree crowns of *Betula maximowicziana* trees. Also Table 10 describes the results investigated in 1984 and 1989 at the places where *Betula maximowicziana* are superior, followed by *Betula ermanii* trees 12 and 17 years after raking. The number of trees of *Betula ermanii* is equivalent to the number of *Betula maximowicziana* trees. But, *Betula maximowicziana* trees which are 8-12 meters tall form the upper stories.

As to the conditions for growing tall, *Betula platyphylla* var. *japonica* was superior at the beginning, followed by *Betula maximowicziana* and *Betula ermanii*.

TABLE 9. Growing conditions of trees (mainly composed of *Betula maximowicziana*) regenerated by natural seeding in the place raked

Species	Height class(m) Year	-0.5	0.5-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5.0-6.0	6.0-7.0	Total (/ha)
Betula maximowicziana	1978	2,917	3,333	20,000	15,000	14,167	2,083	0	0	57,500
	1981	0	0	1,248	6,249	10,626	4,374	8,751	624	31,872
B. ermanii	1978	1,250	3,750	10,000	2,917	0	0	0	0	17,917
	1981	5,625	0	9,375	3,126	0	0	0	0	18,126
Picea jezoensis	1978	55,625	0	0	0	0	0	0	0	55,625
	1981	5,001	0	0	0	0	0	0	0	5,001
Abies sachalinensis	1978	12,500	0	0	0	0	0	0	0	12,500
	1981	5,001	0	0	0	0	0	0	0	5,001
Other broadleaved	1978	20,000	2,500	1,250	0	0	0	0	0	23,750
trees*	1981	11,250	3,126	3,123	0	0	0	0	0	17,499
Total	1978	92,292	9,583	31,250	17,917	14,167	2,083	0	0	167,292
(/ha)	1981	26,877	3,126	13,746	9,375	10,626	4,374	8,751	624	77,499

Note: 1. Three quadrats (2 m × 2 m) were investigated here.
2. Surface raking was conducted in 1972.
3. * Other broadleaved trees are *Betula platyphylla* var. *japonica, Phellodendron amurense* var. *sachalinense, Acer mono, Kalopanax pictus, Quercus mongolica* var. *grosseserrata, Aralia elata* and *Sambucus sieboldiana* var. *miquelii*.
4. This table was based on the research data in the field exercises for students of Dept. of Forestry, Fac. of Agr., Hokkaido Univ.

But, after ten years, *Betula maximowicziana* surpassed the other two in its growing pace. Because of its broad tree crown, the tree density is low and diameter class is big. During the periods when tree tops are above the snow, they are selectively eaten by hares, but recover from the damage quickly.

A million young *Betula* trees were reproduced in the following year after the seeds dropped. *Betula maximowicziana* trees reached several meters high after about 10 years, and enough numbers of individual trees -- that is to say, tens of thousands of grown-up trees per hectare -- were produced. Although *Sasa* plants are recovering, the litter is still thin, and young trees are still coming in. However, it seems that they die soon because of suppression by the upper-story trees -- there is no hope for them to grow more in the future.

Quite a large number of young trees of the needle-leaved species were reproduced in the areas immediately after raking was done, but they grew very slowly, after the *Betula* trees grew enough to form the upper stories, which suppressed them completely. There is still a possibility of their recovery some time later, when numbers of grown trees will be thin out. But it is difficult to

TABLE 10. Growing conditions of trees (mainly composed of *Betula maximowicziana* and *B. ermanii*) 12 and 17 years after raking

Species	Height class(m) Year	-0.5	0.5-1.0	1.0-2.0	2.0-4.0	4.0-6.0	6.0-8.0	8.0-10.0	10.0-12.0	Total (/ha)
Picea jezoensis	1984	3,000	0	0	0	0	0	0	0	3,000
	1989	1,133	0	0	0	0	0	0	0	1,133
Abies sachalinensis	1984	2,133	67	0	0	0	0	0	0	2,200
	1989	3,200	67	0	0	0	0	0	0	3,267
Betula maximowicziana	1984	67	133	533	3,467	2,467	2,333	0	0	9,000
	1989	0	0	133	600	1,000	733	1,467	733	4,666
B. ermanii	1984	200	667	2,200	3,867	2,200	200	0	0	9,334
	1989	0	0	333	2,067	1,267	933	333	67	5,000
Magnolia obovata	1984	267	67	267	0	0	0	0	0	601
	1989	133	67	133	200	133	0	0	0	666
Quercus mongolica	1984	533	133	200	200	0	0	0	0	1,066
var. *grosseserrata*	1989	0	133	133	200	0	0	0	0	466
Phellodendron amurense	1984	1,533	667	333	1,133	0	0	0	0	3,666
var. *sachalinense*	1989	133	0	267	533	133	0	0	0	1,066
Acer mono	1984	3,733	800	200	133	0	0	0	0	4,866
	1989	933	267	200	133	0	0	0	0	1,533
Other broadleaved	1984	2,200	333	200	200	467	67	0	0	3,467
*trees**	1989	200	200	0	133	267	133	0	0	933
Total	1984	13,666	2,867	3,933	9,000	5,134	2,600	0	0	37,200
(/ha)	1989	5,732	734	1,199	3,866	2,800	1,799	1,800	800	18,730

Note: 1. Surface raking was conducted in this area of Block No. 27 of Kasai in 1972. Plot size is (5 m × 30 m).
2. * Other broadleaved trees are *Betula platyphylla* var. *japonica*, *Kalopanax pictus*, *Aralia elata*, *Sorbus commixta* and *Cornus controversa*.
3. This table was based on the research data in the field exercises for students of Dept. of Forestry, Fac. of Agr., Hokkaido Univ.

expect many of the trees to keep growing, as various conditions, including gradual recovery of *Sasa* plants, will become worse.

There are some places where many needle-leaved trees, especially *Picea jezoensis*, regenerated according to whether the soils were raked heavily or lightly, and the lay-out of the mother trees, as shown in Table 11. In the places that were raked heavily, with the roots of the *Sasa* plants and humus soil completely removed, to the extent that the sub-surface soil appeared, recovery of *Sasa* plants was slow, regeneration of *Betula* trees and other plants was difficult, and germs of the Snow Blight and others were less -- those factors were advantageous to regeneration of *Picea jezoensis* trees. Yet the growth rate of the *Picea jezoensis* trees, occupying 31-70 percent of the total trees of all species there, is much less than that of all *Betula* trees. Although *Picea jezoensis* is said to be

TABLE 11. Growing conditions of *Picea jezoensis* regenerated by natural seeding in the place raked

Quadrat No.(/ha)	Size(m^2)		Year 1977	1978	1979
1	(1 × 1)	No.(/ha)	69(690,000)	37(370,000)	23(230,000)
		H. max.(cm)	13.1	14.0	17.0
2	(1 × 1)	No.(/ha)	49(490,000)	39(390,000)	31(310,000)
		H. max.(cm)	29.0	41.5	44.3
3	(2 × 2)	No.(/ha)	42(105,000)	46(115,000)	48(120,000)
		H. max.(cm)	20.7	31.5	31.7
4	(5 × 5)	No.(/ha)	127(50,800)	125(50,000)	124(49,600)
		H. max.(cm)	46.0	52.0	64.3
5	(2 × 2)	No.(/ha)	107(267,500)	108(270,000)	101(252,500)
		H. max.(cm)	10.3	23.0	26.0
6	(2 × 2)	No.(/ha)	191(477,500)	181(452,500)	147(367,500)
		H. max.(cm)	17.7	24.2	25.2)

Note: 1. Surface raking was conducted in the quadrat Nos. 1-4 in 1972, and in the Nos. 5-6 in 1973.
2. H: Tree height

relatively strong against shady circumstances, the number of trees that died by suppression increased, if they were uncared for, when, as the soil conditions became stable, *Betula* species and other vegetation were reproduced increasingly in the areas.

B. Areas Regenerated by Sowing

According to the sowing arrangements explained in a previous section, seeds of *Quercus mongolica* var. *grosseserrata, Magnolia obovata, Tilia japonica, Fraxinus mandshurica* var. *japonica,* and *Juglans ailanthifolia* were sowed in the fall, 1973, and an investigation on the above was conducted in the fall, 1982, as well as on the effects of applying manure. Table 12 is the results for *Quercus mongolica* var. *grosseserrata.* The three seeds that were sowed in each spot mostly germinated and grew together. There were some trees which were broken by snow, but they recovered by sprouting, and the like. The breast-high diameter was 3 centimeters at the time of the investigation, and damage by snow had been decreasing.

As shown in the chart, some effects of base manure were found -- especially, the relatively quick growth of *Quercus mongolica* var. *grosseserrata* trees was characteristic. But the number of trees used for the investigation was not enough to confirm the effects.

The results of trees other than *Quercus mongolica* var. *grosseserrata* are described in Table 13. Such trees as *Kalopanax pictus* didn't germinate at all, even

TABLE 12. Growing conditions of *Quercus mongolica* var. *grosseserrata* regenerated by sowing

Treatment	Height (cm) max.	min.	mean	Coefficient of variation (%)	No. of samples
Manuring & cared	393	110	245	26.0	17
Manuring & uncared	279	61	157	34.0	30
Non-manured & cared	302	45	183	37.0	42
Non-manured & uncared	248	46	131	42.0	26

Note: 1. Surface raking and sowing were conducted in Oct. 1973, and the investigation of experiments were conducted in Nov. 1982.
2. "Cared" means weeding and liberation cutting exclusive of *Quercus mongolica* var. *grosseserrata.*
3. Uncared stands are oppressed by *Betula maximowicziana.*

if seeded. Among the four kinds -- *Magnolia obovata, Tilia japonica, Fraxinus mandshurica* var. *japonica,* and *Juglans ailanthifolia* -- the growth rate in height of *Juglans ailanthifolia* was the best ; *Magnolia obovata* and *Fraxinus mandshurica* var. *japonica* was the best; *Magnolia obovata* and *Fraxinus mandshurica* var. *japonica* were similar both in respect of average height and maximum height; and *Tilia japonica* was the least.

TABLE 13. Growing conditions of *Magnolia obovata, Tilia japonica, Fraxinus mandshurica* var. *japonica* and *Juglans ailanthifolia* regenerated by sowing

Species	Height (cm) max.	min.	mean	Coefficient of variation (%)	No. of samples	Remarks
Magnolia obovata	25	8	17	25.0	37	Broadcast sowing: 100 seeds/m^2
Tilia japonica	23	5	11	38.0	26	Broadcast sowing: 100 seeds/m^2
Fraxinus mandshurica var. *japonica*	23	8	16	27.0	21	Broadcast sowing: 100 seeds/m^2
Juglans ailanthifolia	215	14	78	72.0	30	Sowing in hole: 2 seeds/hole, 10,000 holes/ha

Note: 1. Surface raking and sowing in the trees such as *M. obovata, T. japonica* and *F. mandshurica* var. *japonica* were conducted in Sept. 1977.
2. Surface raking and the sowing of *J. ailanthifolia* was conducted in Sept. 1976.
3. Weeding and liberation cutting are conducted.
4. Investigation of experiments were made in Nov. 1982.

C. **Planting**

1. Planting in Hole

The results of planting according to different sizes of hole and the number of trees per hole, part of the experiments in raked areas, are shown in Table 14. After the plantings, all the trees were left uncared for, and were growing, mixed with *Betula ermanni* trees naturally produced there. *Sasa* plants completely recovered on the forest floor. As the Table shows, a group of trees planted four per square meter showed good growth. So far as the numerical results are concerned, this method is almost equivalent to the one in which groups of trees were planted in rows and cared for afterwards. Growing conditions of trees in a nest, one or two trees in the same nest -- up to four-tree plantings per hole -- showed distinguished growth. Differences in growth appeared within the same hole, not among different nests. In the nests where five trees were planted, the middle one often faded; and there was a tendency that the trees didn't grow well if the size of the nest was small. Anyway, trees have been growing mixed with *Betula ermanii* trees, and the ones as tall as the *Betula ermanii* trees are growing equally, without suppression by the *Betula* trees.

TABLE 14. Growing conditions of *Abies sachalinensis* conducted planting in hole and in row

Planting arrangement	Height (cm) max.	min.	mean	Coefficient of variation (%)	No. of samples
Nest planting*					
5 per nest ($1\ m^2$)	450	120	265	32.0	45 (10 nests)
4 per nest ($1\ m^2$)	453	150	300	27.0	40 (10 nests)
4 per nest ($0.25\ m^2$)	375	87	252	29.0	40 (10 nests)
3 per nest ($0.125\ m^2$)	341	91	208	34.0	30 (10 nests)
2 per nest	369	90	241	32.0	20 (10 nests)
Planting in rows**					
2,500 per ha.	418	204	304	21.0	20

Note: 1. Surface raking and planting were conducted in Sept. 1972, and the investigation of experiments were conducted in Nov. 1982.

2. *: 2 m between holes and holes in the nest planting, uncared after planting. *Betula* and other trees regenerated as shown in Table 8.

**: 2 m between lines and seedlings in the planting in rows, with weeding and liberation cutting after planting.

2. Planting in Rows

Experiments ranging from the common practice of planting 2,000-3,000 trees per hectare, to densely planting 10,000 trees per hectare, were conducted. The

TABLE 15. Growing conditions of *Abies sachalinensis* trees densely planted

Treatment	Height(cm) max.	min.	mean	Coefficient of variation(%)	No. of samples
Manuring*,**	481	164	291	26.0	50
Non-manured*	384	69	251	27.0	51

Note : 1. Surface raking and planting were conducted in Oct. 1973, and the investigation of experiments were conducted in Nov. 1982.
2. * : 1 m between lines and seedlings, 10,000 seedlings of 7 years of age were planted. With weeding and liberation cutting after planting.
3. ** : Base manure of 80 grams per seedling.

TABLE 16. Growing conditions of *Picea glehnii* trees densely planted

Treatment	Height(cm) max.	min.	mean	Coefficient of variation(%)	No. of samples
Nanuring & cared*,**	388	88	269	29.0	29
Manuring & uncared*,**	304	45	176	37.0	31
Non-manured & cared*	370	150	267	23.0	30
Non-manured & uncared*	322	72	176	34.0	30

Note : 1. Surface raking and planting were conducted in Oct. 1973, and the investigation of experiments were conducted in Nov. 1982.
2. * : 1 m between lines and seedlings, 10,000 seedlings of 7 years of age were planted. "Cared" means weeding and liberation cutting after planting.
3. ** : Base manure of 80 grams per seedling.
4. Uncared stands are oppressed by *Betula maximowicziana* regenerated.

TABLE 17. Growing conditions of *Fraxinus mandshurica* var. *japonica* trees densely planted

Treatment	Height(cm) max.	min.	mean	Coefficient of variation(%)	No. of samples
Manuring & cared*,**	485	189	343	21.0	30
Manuring & uncared*,**	480	140	293	26.0	30
Non-manured & cared*	448	87	317	22.0	30
Non-manured & uncared*	486	90	283	36.0	30

Note : 1. Surface raking and planting were conducted in Oct. 1973, and the investigation of experiments were conducted in Nov. 1982.
2. * : 1 m between lines and seedlings, 10,000 seedlings of 9 years of age were planted. "Cared" means weeding and liberation cutting after planting.
3. ** : Base manure of 80 grams per seedling.
4. Uncared stands are oppressed by *Betula maximowicziana* regenerated.

growing conditions of *Abies sachalinensis, Picea glehnii,* and *Fraxinus mandshurica* var. *japonica,* when they were densely planted, are shown in Table 15, 16, and 17 respectively. *Fraxinus mandshurica* var. *japonica* trees, which are usually planted in low, damp ground along streams, have been growing well in this high afforestation area on the ridges, and haven't had frost damage at all.

Discussion

A. Regeneration by Natural Seeding and Sowing

Judging from the fact that *Betula* and other various species produced and survived well on raked ground, it can be considered possible to cultivate them into stands in the future. On the other hand, there are many problems to be solved regarding needle-leaved trees that produce in raked grounds : elucidation of their production ; improvement cutting and thinning of upper-story trees ; use of young trees produced in great quantities as natural seedlings, etc.

Regeneration of *Fraxinus mandshurica* var. *japonica, Ulmus davidiana* var. *japonica, Alnus maximowiczii,* and *Salicaceae* was carried out in raked areas along streams, where seedlings of other various species were produced. There are big problems to be solved in dealing with this kind of natural-seeding regeneration : Species to be regenerated will be controlled according to seeding conditions (rich or poor), timing of seed fall, lay-out of mother trees, raking conditions (heavily or lightly), etc. ; and control of density and survival species, depending on means of aftercare. Forest gaps have been used as sites of regenerations, but anywhere in the forest should be considered as the sites from now on, for which many problems will have to be solved, including development of machines.

Quercus mongolica var. *grosseserrata* trees grow rather quickly, and there is not much need to weed recovering *Sasa* plants and other vegetation, but they are apt to be overcome by *Betula* trees which regenerate by natural seeding. So, improvement cutting and other care against trees of different species which invade into the area will be needed, at least a few times after sowing. Still, there may be no need to take care of them so nervously, when thinking of the possible reforestation of mixed-forests.

As for the other broad-leaved trees listed in Table 12, *Juglans ailanthifolia* can be treated the same as *Quercus mongolica* var. *grosseserrata,* but the trees of *Magnolia obovata, Tilia japonica* and *Fraxinus mandshurica* var. *japonica* grow so slowly that they are easily overcome by *Sasa* plants and other vegetation and trees, and weeding is necessary, and much extra labor will be required when they are broadcast-sowed. Thus, from the forest management viewpoint, regeneration of the above three species seems to be a problem.

Based on the above results, the following problems can be pointed out :

(1) Seeds of the *Betula* species can regenerate almost anywhere, well mixed

with the others that fall naturally, and weeding and other care are required. Accordingly, there seems to be no reason to do regeneration by sowing, except where there are particular unfavorable circumstances, such as poor natural seeding, no existing mother trees nearby, and the like.

(2) *Quercus mongolica* var. *grosseserrata* and *Juglans ailanthifolia* grow well, reliably, if their seeds are sowed immediately after they are gathered. But there remains the problem of aftercare, as they are apt to be overwhelmed by large-scale vegetation, recovering *Sasa* plants, and *Betula* trees produced by natural seeding. Also, there is a risk of broken damage by snow in high snowfall regions.

(3) There are some species -- such as *Kalopanax pictus, Tilia japonica*, etc. -- which have very bad rates of germination even if their seeds are sowed. At the same time, at some places, they regenerate well by natural seeding. It is, therefore, necessary to think of means for trees of these species to be planted and grown in nurseries, or to use young trees produced by natural seeding as natural seedlings.

(4) The purpose of using manure is to save the labor of weeding and other care, by promoting early-stage growth. Although some good effects were found in this investigation, there are problems which remain to be solved, including the economic aspects.

(5) It is necessary to consider more positively the introduction of machines and chemicals in the areas of weeding and improvement cutting, rather than depending on manpower.

(6) When dealing with trees which grow slowly at the beginning, including needle-leaved trees, is planned, long-term and complex care will be required. So, comprehensive study of methods of raking and sowing, as well as aftercare, will have to be done. However, there will be a great possibility of afforesting a serpentine area by seeding *Picea glehnii* -- an area where other plants are difficult to produce.

(7) At present, seeds are gathered only at places and from trees easy for collection, but, from a development point of view, it is necessary to select character and other factors of trees from which seeds are to be taken.

(8) Afforestation by seeding has been practiced since long ago, but new potential exists in the practice of afforestation by seeding in areas which are raked in Hokkaido. Regeneration of wider varieties of species will be expected, combining natural seeding and planting.

B. **Planting**

Most trees of different species which were planted have been growing reasonably well, but competition with broad-leaved trees, such as the *Betula* species, which have become settled around the trees, is a problem. Certain methods of care will have to be decided upon, based on growing or diminishing conditions of the invading trees, especially of the *Betula* species, in the future.

The following are problems at present:

(1) Species from which it is difficult to build a forest by natural seeding should basically be determined to be subjects for planting. Accordingly, at present, major object species for afforestation by planting are needle-leaved trees, but it is quite possible that they will grow mixed with other broad-leaved trees produced by natural seeding, resulting in mixed forests. Thus, the primary purpose of the planting methods -- planting in holes and in bundles -- is to save the labor of aftercare. Competition with other intruding trees in the raked areas is more of a problem than recovering *Sasa* plants, and there are still many problems awaiting solution, even if the planted trees are left uncared for, allowing mixed forests.

(2) The main issue in using manure is the extent to which it is possible to promote the early-stage growth of trees, relating to (1) above; but it should also be considered in respect of costs and the trouble required. However, a remarkable effect seems to occur when manure is used with soil which has physio-chemically deteriorate, for example, a place in a forest used for piling up logs temporarily before they are moved out.

(3) It is necessary to think of the introduction of machines and chemicals for weeding and improvement cutting, the same as in afforestation sites by seeding. For example, even caterpillar-tread tractors can be used easily, just by readjusting planting spacing. Anyway, overall introduction of machines into the forest management -- rippers to be used when planting, and mechanization of the whole planting processes -- should be considered.

(4) Natural seedlings were used mainly to build needle-leaved forests before the Pacific War, which worked successfully in many cases. At that time, it seems this practice was attempted because of problems associated with growing nursery stocks, etc. But, still, there must have been a lot of difficulties in collecting the seedlings themselves. Now, the work of collecting seedlings in raked areas is much easier by comparison. Use of seedlings of both broad-and needle-leaved trees, which are produced in quantities, will have to be considered from new points of view, including the rearing of new species.

C. Regeneration Techniques and Systematic Management of Forest

In this presentation, felling methods and forest types haven't been mentioned; it won't be too late to consider them after the advantages of better regeneration

TABLE 18. Results of regeneration experiments at the Teshio Experiment Forest

Species	Regeneration by (A) natural seeding	(B) sowing	(C) planting of natural seedling	(D) planting of man-made seedling
Abies sachalinensis	+	+	+	++
Picea jezoensis	+	+	++	++
P. glehnii	+	+		++
Betula maximowicziana	++	++	−	−
B. ermanii	++	++	++	+
B. platyphylla var. *japonica*	++	++	++	
Quercus mongolica var. *grosseserrata*	+	++	++	+
Fraxinus mandshurica var. *japonica*	+	+		++
Kalopanax pictus	+	−	++	
Ulmus davidiana var. *japonica*	−	−		++
Juglans ailanthifolia		++		+
Phellodendron amurense var. *sachalinense*	+	+	+	−
Magnolia obovata	+	+	+	
Acer mono	+	+		
Tilia japonica	−	−		

Note: 1. ++ : fine performance, + : ordinary performance, − : poor performance.
2. Raking heavily is effective for needle-leaved trees in (A) natural seedling.
3. Raking lightly is effective for the planting of (C) natural and (D) man-made seedlings.

methods are established.

At present, it seems that surface preparation by rake-dozers is the key process for making regeneration by various methods work most effectively, as mentioned in previous sections. The results of regeneration experiments, conducted on areas raked by rake-dozers for the past several tens of years at the Teshio Experiment Forest, are shown in Table 18. Natural seedlings, which were collected from the areas where the surface soils were raked, are described as "C" ; "D" stands for the seedlings grown at nurseries.

Regarding more systematic management of forests, a few examples and thoughts, based on the experiments conducted at the Teshio Experiment Forest, are mentioned as follows :

First of all, the network of forest roads will have to be improved. If there is no time to wait for that, the systematization of forest management will be pursued in parallel with construction of the road network.

When both cutting and regeneration are planned, the felling of obstacle trees to forest-road construction, and the cutting for income, will be carried out simultaneously ; and raking will be done following them.

Selective cutting (single tree or groups of trees), small-area clear cutting (less than one hectare), and preregeneration system (cutting gradually), according to the forest type, will be also included, taking space arrangements into account. Depending on forest types, there are various possibilities, but it should be kept in mind, first, to promote regeneration at forest gaps grown with *Sasa* plants in natural forests, and also to conduct selective cuttings, in order to improve forest types in the future.

(1) Regeneration by natural seeding will be stimulated by surface raking, and even overmature forests should be cut after they are utilized as mother trees. If cutting trees and their transportation are done when snow covers the ground, the seedlings are not damaged much.

(2) Surface raking will be done after felling of overmature trees, expecting seedlings to be produced from middle-aged mother trees in the forest. Regeneration from the seeds which dropped one or two years previously can be expected, too. It is also possible to rake areas that are inconvenient to be raked topographically, taking advantage of new passages used for wood transport.

(3) Raking for the purpose of regeneration will be conducted in blank spaces grown with Sasa plants, which are not included in cutting plans. In this case, the areas should be selected mainly along the existing forest roads, or newly-built ones.

Shown in Fig. 3 is one example from the Teshio Experiment Forest. Sowing and planting methods that require a lot of care are employed in the areas near the forest roads. Areas away from the roads, or at isolated spots, mainly depend on

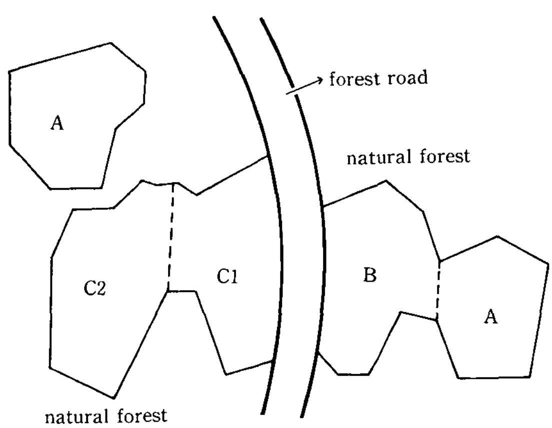


Fig. 3. An example of regeneration work conducted after surface raking in the Teshio Experiment Forest of Hokkaido Univ. A : by natural seeding, B : by planting trees such as *Picea jezoensis, Abies sachalinensis* and the other broad-leaved tree species, C1 : by sowing of *Quercus mongolica* var. *grosseserrata* and *Juglans ailanthifolia*, C2 : by sowing *Betula maximowicziana*.

regeneration of *Betula* trees by sowing or natural seeding, which require no extra effort. It is easy to take care of areas near the forest roads manually, and natural seedlings can be produced at these places.

Natural forests in Hokkaido are composed of a compound mixture of broad- and needle-leaved trees, and regeneration and growth mechanisms are yet to be clarified. Technology to control them has not been established so far. Yet, based on the current, incomplete knowledge, forestry business is actually carried out. It is not going too far to say that maintenance of natural forests with regenerative power is becoming difficult. In these circumstances, it is very significant that machine power has been employed in management of natural forests -- not only for cutting, but also afforestation. In particular, raking areas grown with *Sasa* plants by machines holds good potential, thinking of efficiency, as well as versatility. Diversification of species to be regenerated, and utilization of overall forest space, even under tree crowns, will have to be considered, for which, however, there are many problems to be solved, relating to topographical features, development of machines, care of the trees, etc.

In short, it will be important to build forests comprising various species and forest types, by selecting appropriate locations, methods and techniques. These forests will eventually be strong against natural damage, and can be managed economically.

Summary

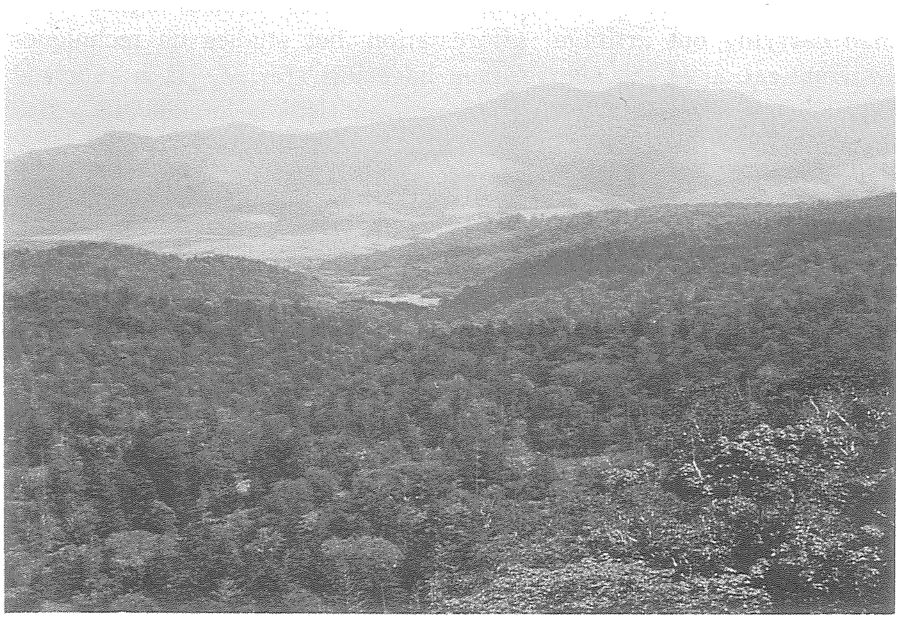
The results of experiments regarding management of natural forests within pan-mixed forests, conducted in the Teshio Experiment Forest of Hokkaido University since 1961, have been discussed in this paper.

1. In order to establish regeneration methods, which is the basic requirement to systematize natural-forest management in the forest areas mainly grown with tall *Sasa* plants, such as *Sasa kurilensis* and *Sasa senanensis*, various experiments on regeneration were conducted: (1) by natural seeding, (2) by sowing, and (3) by planting.
2. At the present stage, as a regeneration method, the method of surface raking by large-scale machines, especially rake-dozers, can be said to be most efficient.
3. The three methods -- natural seeding, sowing, and planting -- were tested on areas where surface soils were raked. As a result, it is judged that stand cultivation is secured and easy, so far as various conditions at respective sites are met.
4. *In natural-forest management, as explained in this paper, there seem to be many points which can be applied to the natural-forest management of Fagus crenata* trees in the south of Hokkaido, broad-leaved forest management, multi-story forest management, management of forests regenerated by

sprouting, and others. Managing natural forests requires higher techniques than carrying out artificial afforestation, but studies on techniques and systematization of the management have just started. It is expected that experiments on natural-forest management will be conducted actively in many places in Japan.

Literature Cited

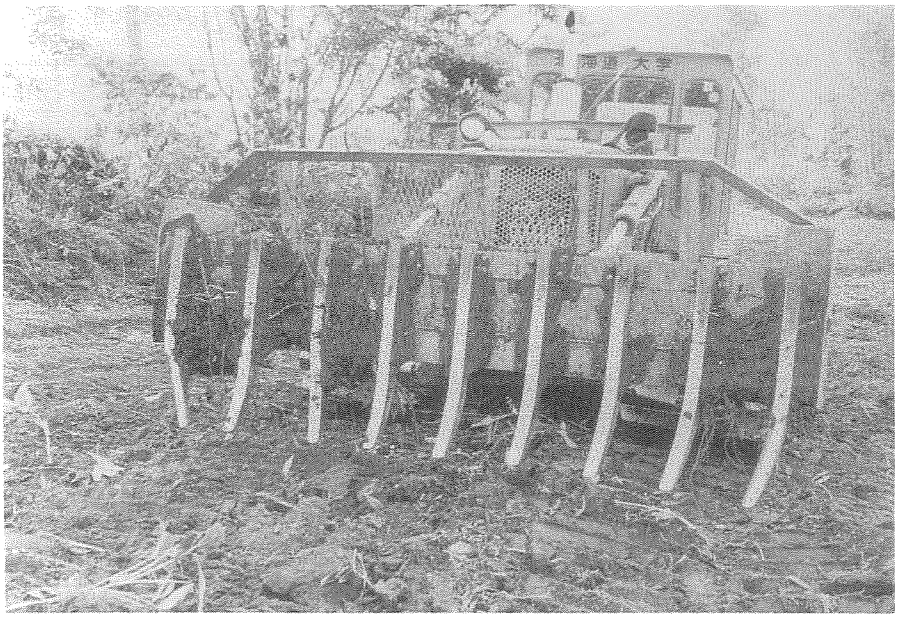
1. BRAUN-BLANQUET J. (1964, translated by SUZUKI T.): Pflanzensoziologie. 29-34, Kokon-Shoin, Tokyo, 1971
2. College Experiment Forests, Hokkaido University: Outlines of College Experiment Forests, Hokkaido University, 1988. 10-13, Sapporo, 1988
3. Department of Forestry, Hokkaido Prefecture: Forestry improvement and technical development in Hokkaido Prefectural Forest. 271-280, 329-335, 1987 (in Japanese)
4. Hakodate Regional Forest Office: Regeneration of *Betula* by natural seeding. 53-65, Hakodate, 1968 (in Japanese)
5. IMADA M.: Study on the high forest system of Mizunara(*Quercus crispula* Blume). Bull. Kyushu Univ. For., **45**: 81-225. 1972 (in Japanese with English summary)
6. MATSUDA K. and TAKIKAWA S.: Practical study on promotional treatment of natural regeneration. Res. Bull. Exp. For. Hokkaido Univ., **42**, 4: 909-940. 1985 (in Japanese with English summary)
7. TAKIKAWA S.: Regeneration of broad-leaved tree species by natural seeding made by using rake-dozer. Hoppo Ringyo, **27**, 1: 22-24, 1975 (in Japanese)
8. TATEWAKI M.: Forest ecology of the islands of the north Pacific Ocean. J. Agr. Hokkaido Univ., **50**, 4: 371-380, 451-464. 1958
9. Teshio Experiment Forest, College Experiment Forests, Hokkaido University: Outlines of Teshio Experiment Forest, College Experiment Forests, Hokkaido University. pp. 6. 1983 (in Japanese)



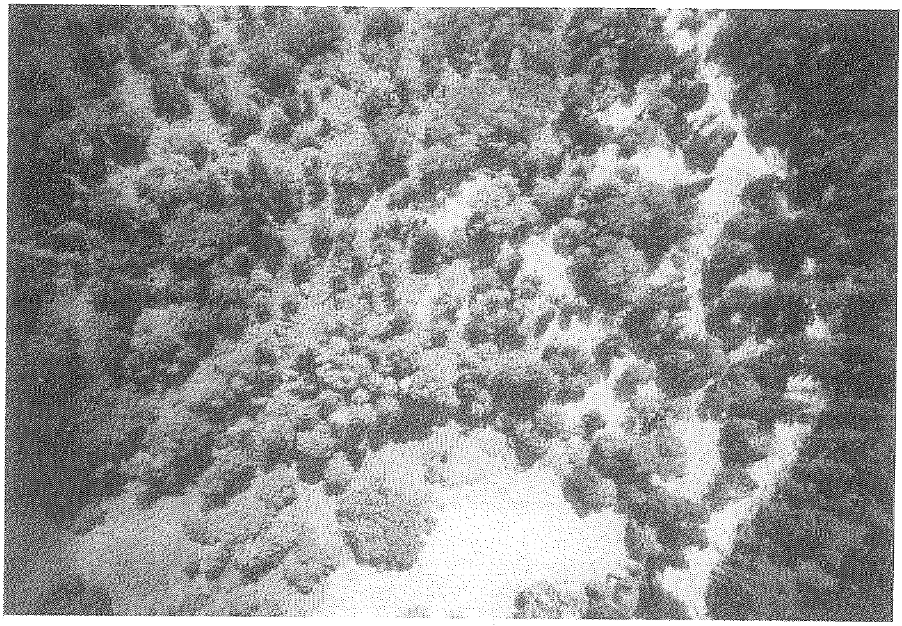
a. A view of natural forest in the Teshio Experiment Forest of Hokkaido University (photographed eastwards from Block No. 4 of Okuchi in 1986)

b. A forest gap covered densely by tall *Sasa kurilensis* in the natural forest. Raking for the purpose of regeneration will be conducted here. (photographed in the Block No. 2 of Okuchi in 1986)

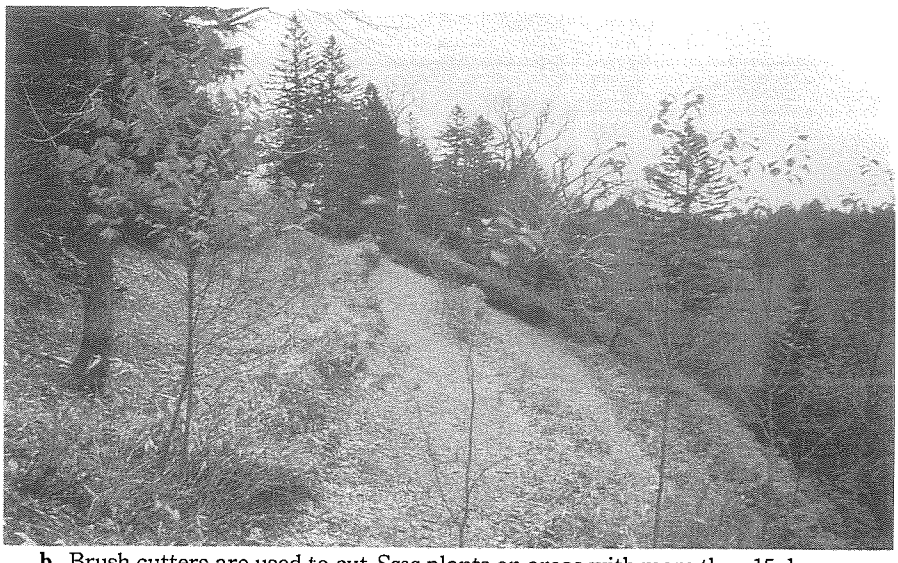
a. Raking work by rake-dozer in a forest gap covered densely by tall *Sasa kurilensis* in the natural forest. (photographed in the Block No. 27 of Kasai in 1981)



b. A rake-dozer used for raking at the Teshio Experiment Forest. The size of claw of the rake-dozer is 40 cm. (photographed in the Block No. 27 of Kasai in 1981)



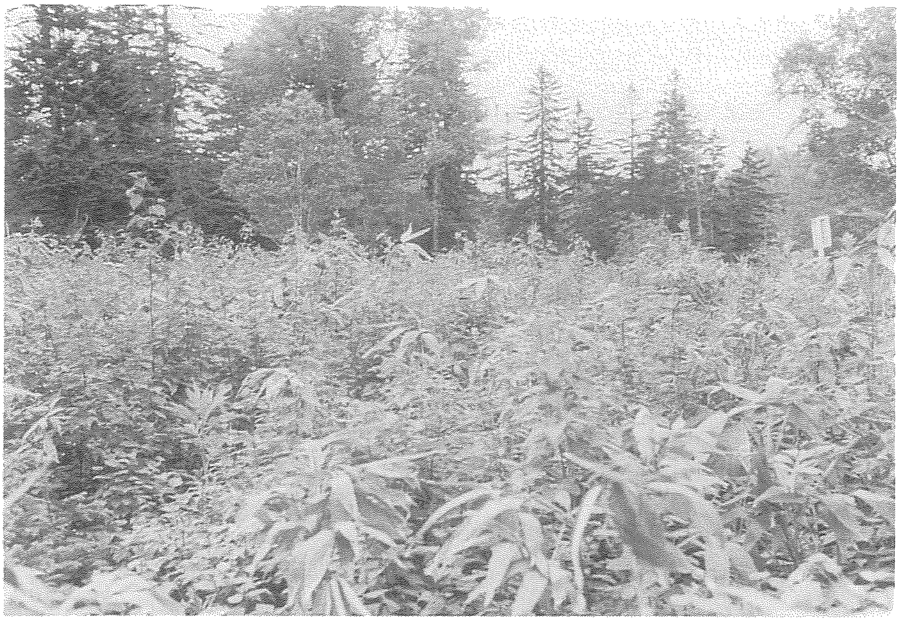
a. An aerophotograph directly after raking work by rake-dozer in forest gaps near forest road (right side) in the natural forest. (photographed in the Block No. 2 of Okuchi in 1980)



b. Brush cutters are used to cut *Sasa* plants on areas with more than 15 degrees slope. In order to promote good regeneration by seeding, it is necessary not only to cut at *Sasa's* roots by doing strip weeding or overall weeding, but also to push the cut trunks and leaves down the slopes and rake litter away. (photographed in the Block No. 30 of Kasai in 1980)

a. Seeding regeneration of trees 3 years after the raking. Good regeneration was enjoyed in the places (the upper part) that were raked lightly, as compared with the lower part (in the places raked heavily). (photographed in the Block No. 2 of Okuchi in 1983)

b. Seeding regeneration of trees 4 years after the raking. It was mainly composed of *Betula ermanii* here. (photographed in the Block No. 4 of Okuchi in 1984)



a. Seeding regeneration and growing conditions of *Betula* trees 7 years after the raking. (photographed in the Block No. 27 of Kasai in 1979)

b. Growing conditions of *Betula* trees 10 years after the raking. It was mainly composed of *Betula maximowicziana* here. (photographed in the Block No. 29 of Kasai in 1981)

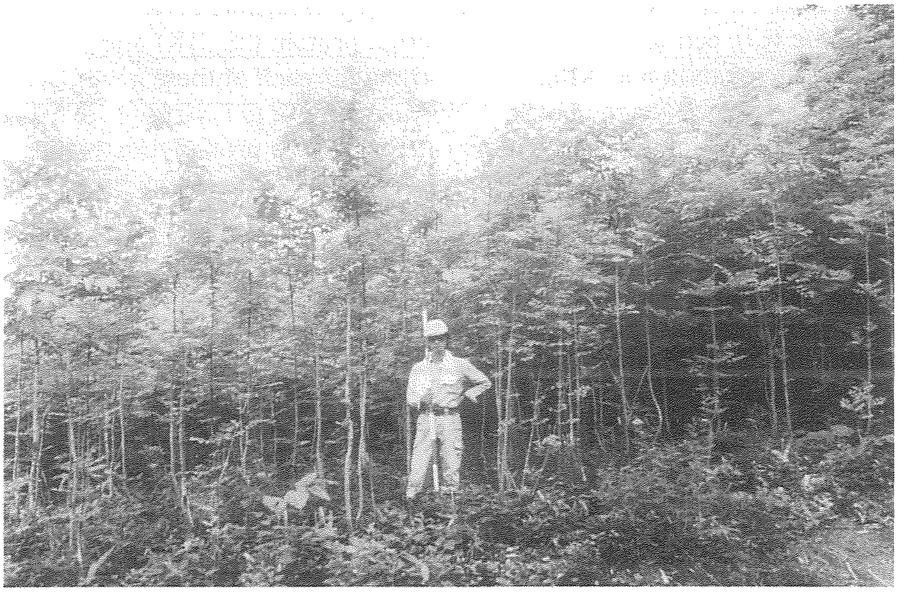
a. Growing conditions of *Betula maximowicziana* trees 10 years after the raking. Several individuals taped were damaged by hares. (photographed in the Block No. 35 of kasai in 1983)

b. Seeding regeneration and growing conditions of *Picea jezoensis* and other trees 10 years after the raking. (photographed in the Block No. 30 of Kasai in 1981)

a. Growing conditions of *Juglans ailanthifolia* trees 8 years after sowing at the area which soil surface was raked. (photographed in the Block No. 51 of Kato in 1982)

b. Growing conditions of *Quercus mongolica* var. *grosseserrata* trees 9 years after sowing at the area which soil surface was raked. (photographed in the Block No. 35 of Kasai in 1982)

a. Planting of *Abies sachalinensis* trees (nursery stocks) in a raked area. Growing conditions of individuals were investigated here. (photographed in the Block No. 35 of Kasai in 1976)



b. Growing conditions of *Fraxinus mandshurica* var. *japonica* trees 9 years after planting at the area which soil surface was raked. (photographed in the Block No. 35 of Kasai in 1982)