Scots Pine Breeding (Pinus sylvestris L.) at Waldsieversdorf and its Impact on Pine Management in the Northeastern German Lowland

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Summary

Against the background of the increasing importance of ecological silviculture in the industrial countries of Central Europe the long-term tree improvement program by (A) selection and (B) breeding is discussed retrospectively and future oriented using *Pinus sylvestris*.

Considering selection breeding, provenance research, crossbreeding as well as progeny testing, the questions of stability, vitality, quantity and quality, practical application of the results in forest management, and gene preservation are focussed on in this report.

Key words: Scots pine research program, provenance, selection and crossing, progeny test, stability, form types.

Introduction and Objectives

Forest history shows us that Scots pine became the "breadfruit tree" of the eastern part of Germany during the big afforestation wave of the past century. The consequent high demand and intensive trade with seed and the large natural range of pine, reaching from the European to the Asiatic continent, contributed to the development of the scientific disciplines of seed management, provenance research and, last but not least, forest tree breeding. Scots pine covers 81.6% of the land area of Brandenburg, 53% of Mecklenburg-West Pomerania, and 52.1% of Saxony-Anhalt. In spite of new afforestations of former farmland the proportion of Scots pine will rather decline because of ecological considerations.

IUFRO's 100th anniversary gives us the occasion to recall Schwappach (1914) and his booklet on "Die Bedeutung und Sicherung der Herkunft des Kiefernsamens" (Importance and protection of pine seed provenance). The birthplace of our present breeding centre can be attributed to those developments.

The Director of the Kaiser-Wilhelm Institute, Erwin Baur, perceived these facts and wanted to take remedial measures by the creation of a breeding centre. The same endeavours for forest plant breeding motivated the Eberswalde Professor of Silviculture Alfred Dengler (1929).

In view of the significance of pine for northeastern German silviculture, the Department of Forest Tree Breeding at Waldsieversdorf set up the following goals within the framework of a breeding program, for the improvement and rationalization of pine management:
- preservation of genetic variability,
- preservation and improvement of adaptability to site conditions und climate changes,
- improvement of resistance to biotic and abiotic hazards,
- increase of yield and quality,
- improved transfer of valuable genetic material into practice.

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The following breeding measures can be considered as possible methods:
- selective breeding,
- provenance research and progeny tests,
- seed orchards,
- crossings,
- preservation of gene resources.

A. Tree improvement by selection

Individual selection

A method often used in breeding practice is selection of plus trees which are characterized by higher vitality, volume yield and quality when compared with their phenotype. By 1968, 1098 pines had been selected and recorded in northeastern Germany. Scions were collected from 729 of these trees and planted in 3 clonal archives. The greater part of the clonal archives was the basis for the future establishment of seed orchards in forest enterprises. The initial supply of nursery stock was adequate to meet the requirements, which is an essential condition for breeding in order to combine desired characters in the respective progeny.

Plus-tree plantations cover 94.1 ha and include grafts of 798 clones. An average of 15% of the total seed supply in the northeastern German lowland was produced from seed orchards in the past 20 years. In general, this meant that 8 kg of seed of a high genetic value could be produced per hectare of seed orchard and that genetic improvement could begin in pine management. Comparative studies between young stands derived from seed orchard seed and those from commercial seed were made in a dissertation, not yet finished, that shows the qualitative and quantitative superiority of seed from seed orchards.

Positive mass selection

Provenance trials

The sytematic selection and testing of pine provenances started at the beginning of the 20th century in almost all countries situated within the natural range of pine. This provenance research made it possible to detect the now well-known large differences in quantity, quality and stability (resistance to biotic and abiotic damaging agents and mortality rate) among the provenances from this very wide natural range.

The provenance trials observed during several decades in the northeastern German lowland showed that significant differences exist among progenies from different provenances on fertile, medium and poor sites, as shown by phenotypic behavior, volume, quality and survival capacity.

In summary, it can be said that native, Polish and northeastern European (Baltic) provenances have been shown to be particularly useful for planting in northeastern Germany (Dittmar, 1977). Given this information, breeders directed their attention to the provenance trials that contained pine provenances from eastern Europe, including the test replicated in the forest districts of Eiserbude and Schwärze-West, managed by the Eberswalde Forest Office.

This experiment, which included pine stands from provenances situated south of Riga, in Poland, Brandenburg and the Main plain was established in 1944 by Prof. SCHMIDT with a spacing of 1 m × 1 m.

Evaluation of this experiment indicated that 7 stand progenies were particularly appropriate for cultivation. They are characterized by:

— good form with wide spacing,
— good growth and quality,
— good stability and high adaptability.

In 1975 to 1976 a seed crop stand was especially established for 3 selected provenances, which had to be checked because the trees were from seed from a F_2-generation plantation.

The favourable results to date led breeders to start a second series of provenance trials based on their own collections. The objective was to ensure the reproducibility of provenance performance by the harvest of grafts for seed orchards. In cooperation with numerous forest enterprises in the countries mentioned, the following stands were selected:

25 provenance stands from the northeastern German lowland
10 provenance stands from the highland and hilly country
9 provenance stands from Russia
1 provenance stand from Ukraine
6 provenance stands from Latvia
2 provenance stands from Lithuania
11 provenance stands from Poland
6 provenance stands from Bulgaria
6 seed orchards from Germany.

Twenty-five trees of superior phenotype and good fruiting ability were chosen from each selected stand. Cones and scions were collected and the most significant characteristics were recorded. Grafts were made from the scions and placed in clonal archives in order to preserve the original genotypes. This provided for the establishment of a seed orchard with the same material in case the original stand should be removed. It also made possible a fast transfer of the material into general use.

With these objectives in mind, a trial series with three and four replicates was established on 34.2 ha in 6 forest enterprises (*Table 1*).

The objective of the trial series was to answer the following questions:

1. Which provenances are most appropriate for the future plantation sites and can be proposed as sources of "tested reproductive material"?[3])
2. Which consequences are resulting for silviculture?

Method

Field surveys

At age 5, all experimental plots were checked. Mortality was scored, total height was measured, and biotic damage was recorded. Lammas shoot production was scored for two of the experimental plots.

Measurements for the determination of provenances to be included in the category "tested reproductive material" were taken at age 10 at the same time as the inventory of quantitative and qualitative characteristics, including height, diameter, branch thickness and classification of

[3]) The initial material is checked through comparative tests of its progenies to determine its hereditary, improved value for planting (German law on forest reproductive material moving in trade, 1979).

Table 1. — Provenance-trial series, 3 and 4 replicates on 34.2 ha in 6 forest enterprises.

Growth area and forest enterprise	Site class	Area in ha	Spacing
1. Western Mecklenburg Perleberg	Z2	3.12	2.0 x 0.5 m
2. Northern Brandenburg Neustrelitz	M2	2.90	2.0 x 0.5 m
Northern Brandenburg Neustrelitz	M2	2.87	2.0 x 1.0 m
3. Central Brandenburg Strausberg	M2	2.99	2.0 x 0.5 m
Central Brandenburg Strausberg	M2	5.70	2.0 x 1.0 m
4. Western Brandenburg Zerbst	M2 m	3.40	2.0 x 0.5 m
5. Lower Lausetia Weißwasser	A2	3.15	2.0 x 0.5 m
Lower Lausetia	Z2	5.84	2.0 x 1.0 m
6. Central and Eastern Thuringian variegated sandstone Jena	M2 w	4.20 ---- 34.17	2.0 x 0.5 m

M2 = moderately eutrophic, averagely fresh sites
Z2 = rather oligotropic averagely fresh sites
A2 = oligotrophic, averagely fresh sites
M2 w = moderately eutrophic, averagely fresh site with alternating moist subsoil
M2 m = averagely eutrophic, averagely fresh sites with moderately dry climate

stem form and growth type (1a or 1b). The methodology was that of Kräuter (1965).

Assessment

The data analysis considered each characteristic by variance analysis for incomplete blocks, and by one- and two-way analysis of variance (Model I). Site interaction was checked by two-way analysis (Model I), using the same class frequency and interaction. The "maximum-modulus" test was used for comparison of the provenance means with the test mean (Enderlein, 1971). The effect of spacing on height, branch thickness and diameter was determined by a least significant difference method (Rasch et al., 1973). Relationships between characteristics were determined by regression and correlation analysis. Plot means were used in all statistical calculations.

Results

Combined assessment using a selection index showed that the fastest-growing progenies of indigenous provenances came from the northern German lowland and Poland. They were characterized by excellent height growth on all plantation sites and a nonsignificant genotype x environment interaction.

Growth rate

Mean progeny height was selected as the criterion for vigor. The volume of 48 different stand progenies was determined in collaboration with the Yield Department of the Eberswalde Forestry Research Institute and related to the corresponding height. The coefficient of correlation (r) between height and volume was 0.94. Similar results were obtained from 28 different stand progenies in an 28-yr-old trial, where the correlation coefficient was 0.91.

Surveys of lammas shoots (prolepsis) from 72 and 62 stand progenies on two experimental plots revealed significant differences among provenances. A significant relationship between tree height and proportion of lammas shoots could also be demonstrated; a higher frequency of prolepsis resulted in a larger height value.

Uniformity of tree height

Homogeneity of tree height was determined from the coefficient of variation for this trait. On all trial series the mean coefficients of variation of provenances proposed for the category "tested reproductive material" were below the average value of the remaining provenances.

Stem form

No significant differences were found in stem form. The explanation appears to be (1) that the individual trees from different provenances were selected for straightness of the bole, and (2) that trees from indigenous stands were of genotypes similar in this trait.

Branch diameter

Since branch thickness is influenced by spacing, there are limited possibilities of selection for slender branches in widely-spaced plantations. Therefore branch diameter was related to spacing, using the ratio of branch thickness to diameter. The fastest-growing progenies, however, did not have thicker branches under wide spacing (2.0 m × 1.0 m) compared with closer spacing (2.0 m × 0.5 m). In spite of a larger growing space, their mean ratio of branch thickness to diameter was significantly lower than it was with closer spacing. As expected, comparisons of actual branch diameters gave opposite results. Evidently the progenies examined and planted in wide spacing reacted more through diameter growth than through branch diameter growth.

Resistance to SO_2 injury, mortality rate

In addition to general assessment of mortality, tolerance to emissions and particularly to sulfur dioxide was estimated from reference plots established in the vicinity of a lignite power station. The damage criterion was needle injury, scored on a scale of 1 to 5. Mortality was also measured. The faster growing families had a consistently lower mortality rate compared with the mean for all families. This was also the case for the trial affected by sulfur dioxide.

Resistance to needle cast

In order to estimate resistance to Lophodermium seditiosum, a special trial was established in cold frames with the same provenances and artificially infected over a 2-year period. After artificial infection with Lophodermium, families of provenances tentatively categorized as "tested reproductive material" had an obviously lower susceptibility to needle cast than the mean of all provenances.

Progenies from Russia, including the Baltic region, had a significantly higher infection from needle cast, and a decrease of needle cast in an east-west direction could be demonstrated.

Figure 1. — Branch thickness.
Left hand: a-type; right hand: b-type.

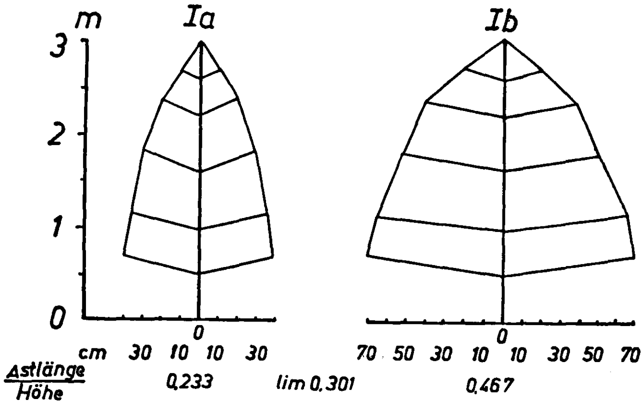

Figure 2. — Left hand: a-type; right hand: b-type.

Specific gravity

Breeding for higher specific gravity requires an early assessment of this trait and its relation to juvenile wood and mature wood. The large variation of this characteristic within a stem, between single trees, on different growing spaces, and on different sites necessitates a large number of studies. This has, so far, not been possible.

Growth forms

A type of "eugenic" improvement of pine through silviculture practice is selective thinning, which consists in recognizing the undesirable b-types (wolf trees) in each progeny, removing them and thus favouring the a-types (*Figures 1* and *2*).

These two extreme growth types (a and b) are clearly recognizable, but nothing is known about their genotypes. Studies based on isoenzyme and DNA markers may eventually contribute to knowledge of the genetic base of phenotypic expression.

Stands yielding "tested reproductive material"

The application of multiple-trait selection indices (*Table 2*) that considered different quantitative and qualitative characteristics associated with resistance led to the stand progenies Niesky, Löbau, Nedlitz, seed orchard in Roßlau, Colbitz, Oranienburg, Güstrow, Rostock (Germany), Rychtal, Pokoj, Suprasl, Rytel, and Taborz (Poland) being characterized as follows:

— significantly higher growth performance and high site tolerance,
— branches finer than average, straight bole, homogeneous growth,
— high adaptability to different environmental conditions,
— survival rate higher than average
— higher resistance to needle cast and higher tolerance to sulfur dioxide.

Since each stand was represented in the clone bank by the trees selected for the progeny tests, seed orchards were established on 98.4 ha with families of the best provenances. The first ones are already bearing cones. Until all seed orchards supply a sufficient amount of seed, the initial stands are harvested.

Effects of genetic selection on silvicultural practice

Through indivicual selection, mass selection and progeny testing, the genetic value of seed can be significantly increased and tree form can be improved. An initial spacing of 10,000 seedlings per hectare of tested material is considered optimum for the best tree form, crown

Table 2. — Provenance-trial series, combined evaluation
a) evaluation factor (al) for different variants of silvicultural regimes
b) selection index for the 15 best provenances.

a

Selection index	Height	Diameter	Stem form	Branch thickness : Stem diameter
Normal variant	4	2	1	4
Quantity variant	6	3	1	2
Quality variant	3	2	2	5

b

Provenance no./name	Index normal var.	Provenance no./name	Index quantity var.	Provenance no./name	Index quality var.
17 Colbitz	11,2	17 Colbitz	16,21	17 Colbitz	10,24
21 Niesky	9,85	21 Niesky	13,59	21 Niesky	9,94
58 Rytel	8,22	25 Löbau	11,58	25 Löbau	9,65
9 Oranienburg	8,08	9 Oranienburg	11,55	58 Rytel	7,60
18 Rostock	8,03	18 Rostock	11,19	18 Rostock	7,36
25 Löbau	7,32	58 Rytel	10,88	9 Oranienburg	6,92
57 Suprasl	7,25	59 Pokoj	10,10	57 Suprasl	6,80
59 Pokoj	7,06	33 Roßlau Sa.	9,34	50 Gorodok	6,27
63 Taborz	6,39	56 Rychtal	9,30	59 Pokoj	6,01
56 Rychtal	5,94	63 Taborz	9,22	63 Taborz	5,68
26 Nedlitz	5,76	57 Suprasl	9,10	26 Nedlitz	4,54
33 Roßlau	5,64	26 Nedlitz	8,64	33 Roßlau	4,29
50 Gorodok	5,49	22 Güstrow	7,90	56 Rychtal	4,03
22 Güstrow	5,28	20 Tharandt	7,84	55 Plaska	3,53
34 Rostock AK	4,34	28 Jena	7,56	22 Güstrow	3,43

$$X)\ I_w = \sum_{i=1}^{k} a_i \frac{V_i - \bar{V}_i}{Sv_i}$$

a_i = evaluation factor
v_i = characteristics according selection aim
V_i = trial mean
Sv_i = standard diviation i^{th} variable

Table 3. — Proportions of tree form types 1a and 1b (*figures 1* and *2*) in tested and untested Scots pine progenies.
1a — is a narrow-crowned tree;
1b — is a wide-crowned tree.

Tested pine progenies	60 : 40 %
Untested pine progenies	45 : 55 %

shape, root development, vigor, and capacity to resist insects, diseases as well as abiotic hazards. Silvicultural practices influencing tree form are designed to contribute to production targets, namely volume and quality, while sustaining the health of the trees (*Table 3*).

The synthesis of these results provides a basis for the evaluation of genetic resources in the form of stands with the label "selected" or "tested reproductive material", and plantations designated as material for gene preservation.

B. Tree improvement by breeding

Objectives

Intraspecific crossing should increase the genetic potential of Scots pine. It can be particularly useful for farmland afforestation using pine as nurse crop for deciduous trees and a short rotation for pine.

Methods

Between 1970 and 1976, a comprehensive intraspecific crossing program was carried out in seed orchards and clonal archives at Waldsieversdorf. Of 182 cross combinations, 117 were successful enough to be included in a performance test. Only 3 out of 22 self pollinations yielded enough viable seed to be included in the test.

Mortality was assessed when the plants were 7 years old. All other characteristics were assessed at age 10.

Results

The mean yield of seedlings from all controlled crosses was 39.8%. This gave an 11.3% higher yield than that obtained from open-pollinated clones, indicating that the successful crosses had good combining ability with respect to survival rate, which together with a high self-incompatibility offers the necessary conditions for the establishment of biclonal plantations. With respect to growth rate, mean heights of cross progenies exceeded that of reference families by 1.29 m (3.42 — 7.91), i. e. the most vigorous crosses exceeded the least vigorous ones by 38%, with a superiority of 16% over the test mean and of 15% compared with reference families.

In comparison with the Scots pine yield table of Lembcke, Knapp and Dittmar (1975), all significantly superior progenies are up to 50% over class I. The average height of crosses higher than standard value or test mean equals

Table 4. — Performance test of crossing progenies.
Characteristics of cross combinations yielding progenies significantly exceeding the mean (for height).

No. combination	Height (m)	Diameter (cm)	Stem form[1]	Branch thickness : diameter	Branch length : height	Damage by air pollution[2]	Mortality rate %
13 Rostock x Oelsnitz	4,51	5,2	1,40	0,292	0,235	6,83	27,3
17 Rostock x Klingenthal	4,71	5,0	1,47	0,267	0,250	4,05	18,5
80 Nedlitz x Oelsnitz	4,63	5,2	1,36	0,282	0,280	6,70	25,6
84 Nedlitz x Rostock	4,54	5,4	1,51	0,255	0,242	4,30	12,6
85 Nedlitz x Schleiz	4,56	5,3	1,38	0,268	0,254	6,58	14,4
86 Nedlitz x Klingenthal	4,48	5,2	1,46	0,255	0,254	6,23	19,6
118 Klingenthal x Oelsnitz	4,67	4,9	1,27	0,256	0,233	6,20	11,4
$\bar{x}$	4,59	5,2	1,41	0,268	0,250	5,84	18,5
Reference family	4,06	4,9	1,52	0,274	0,279	5,30	20,3

1) score 1 — straight stemmed, score 5 — crooked stemmed
2) score 1 — strongly damaged, score 9 — not damaged

Table 5. — Performance test of crossing progenies.
Combined evaluation without stability (resistance to biotic and abiotic damaging agents and mortality rate), selection-index according *table 2*.

Selection-index	Height	Diameter	Stem form	Branch thickness	Crown form
Normal variant	4	2	1	4	1
Quantity variant	6	3	1	2	1
Quality variant	3	2	2	5	2

Cross combination	Index			Rank	Mean
	Normal variant	Quantity variant	Quality variant		
No. 84 SA 512 M 116 Nedlitz x Rostock	12,66	13,93	13,89	1	13,49
No. 118 V 534 V 606 Klingenthal x Oelsnitz	11,93	12,42	14,07	2	12,81
No. 86 SA 512 V 521 Nedlitz x Klingenthal	10,90	11,37	12,09	3	11,45
No. 85 SA 512 V 22 Nedlitz x Schleiz	9,13	11,60	9,69	4	10,14
No. 17 M 116 V 521 Rostock x Klingenthal	8,83	11,02	8,88	5	9,58
No. 80 SA 511 V 606 Nedlitz x Oelsnitz	5,23	9,41	4,09	6	6,24
No. 13 M 114 V 606 Rostock x Oelsnitz	2,62	7,52	1,86	7	4,00

4.6 m, whereas the class I mean equals 3.9 m. All open-pollinated progenies were close to standard values.

Progenies with a significantly better height growth had a mean diameter growth 6% higher than standard values. *Table 4* shows the characteristics of crosses with a significantly superior height growth.

The crosses 84, 118, 86 and 85 were top-ranking and crosses 17, 80 and 13 ranked lowest when index selection was applied to determine the most significant performance parameters by the use of a normal, a quantity and a quality class (*Table 5*).

If SO_2 tolerance and mortality rates are considered, combinations 118, 86, 85 and 84 ranked higher (*Table 6*). Excluding stability, progeny 84 ranked first except for the quality variant. Even considering its low stability, it still ranked fourth in the combined analysis.

Further breeding activities

From 1978 to 1982, 160 cross combinations were carried out with clones from the northeastern German lowland, Poland, Sweden and Russia. Interspecific crossings were also made with 3 combinations of *Pinus contorta* × *Pinus silvestris* and their reciprocals. One performance test included 126 crossing combinations, 28 open-pollinated clones and 8 stand progenies. The performance tests were established in 1985 on two experimental plots and in 1990 height and mortality rates were assessed at age 6. The data are not yet available.

In the spring of 1990, experimental plots for performance tests were established with 81 control-pollinated progenies, 6 open-pollinated progenies and one stand (standard) progeny. The parents are in outstanding stands in Poland and in the northeastern German lowland. The objective is to identify further cross combinations with good performance, quality and high stability that may meet requirements for the category "tested reproductive material" in the year 2000.

In the period 1988 to 1991, further intraspecific hybridizations were carried out in the Waldsieversdorf gene plantation among grafts from the significantly-superior provenances of the best of the pine natural range. Seventy cross combinations with 46 backcrosses were used, and 30 self-pollinations were made to determine self-sterility. The experimental plots will be established in 1994 with the objective of proposing further cross combinations in 2005 for the category "tested reproductive material".

For a transfer, it is planned to establish a biclonal plantation for each confirmed cross combination of a test series. The seed will be harvested, stored for several years, and mixed before sowing. In this way, an increase in genetic variability can be attained without limiting the value for use. It should be noted that substantial yield improvement is obtained by planting progenies from controlled crosses of selected trees, which would be appropriate particularly for the afforestation of former farmland.

These results clearly demonstrate the value of crossing selected trees. Wide crossing of provenances would increase genetic variation and could utilize standard topcross and polycross procedures. A pollen mixture of tested provenances could be prepared, crossed with the corresponding mother trees of tested provenances and the progeny could be checked in a performance test.

Seed crop stands

At present, priority in our pine breeding program is given to the selection and testing of pine stand gene

Table 6. — Performance test of crossing progenies.
Combined evaluation with stability, selection-index according *table 2.*

Selection-index	Height	Diameter	Stem form	Branch thickness	Crown form	Stability
Normal variant	4	2	1	4	1	6
Quantity variant	6	3	1	2	1	6
Quality variant	3	2	2	5	2	6
Stability variant	3	1	1	3	1	8

Cross combination	Index				Mean
	Normal variant	Quantity variant	Quality variant	Stability variant	
No. 118 V 534 V 606 Klingenthal x Oelsnitz	18,00	18,49	20,14	19,53	19,04
No. 86 SA 512 V 22 Nedlitz x Schleiz	15,63	18,10	16,11	15,41	16,31
No. 85 SA 512 V 521 Nedlitz x Klingenthal	14,71	15,18	15,90	13,11	14,72
No. 84 SA 512 M 116 Nedlitz x Rostock	11,91	13,18	13,14	9,12	11,84
No. 80 SA 511 V 606 Nedlitz x Oelsnitz	8,90	13,08	7,26	9,97	9,80
No. 13 M 114 V 606 Rostock x Oelsnitz	6,26	11,16	5,50	4,07	6,75
No. 17 m 116 V 521 Rostock x Klingenthal	5,44	7,63	5,49	2,41	5,24

pools in order to produce genetically valuable seeds. To date, 30 to 40 trees have been selected from each of 23 stands in phenotypically-superior 50- to 70-year-old pine stands of the northeastern German lowland, and seed has been harvested from most of them. Further tests are planned of other potentially-valuable stands. In the most important growth and plantation areas of Scots pine, stand progeny tests are established in close cooperation with forest managers. If evaluations after 5 to 10 years are positive, it can be expected that they will be admitted as "tested propagation material". Utilization areas for seed and planting stock will be established after progeny testing. Silvicultural practices in the stands classified as „tested reproductive material" focus on the maintenance and increase of seed yield by

- heavy thinning and maintaining crowns of the best trees (cone crop trees) and nitrogen fertilization when necessary to improve fruiting,
- providing all necessary forest protection measures,
- repeated harvesting of the standing trees.

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