METSÄNTUTKIMUSLAITOKSEN
JULKAISUJA

COMMUNICATIONES
INSTITUTI FORESTALIS FENNIAE

MEDDELANDEN FRÅN SKOGSFORSKNINGSINSTITUTET I FINLAND
MITTEILUNGEN DER FORSTLICHEN FORSCHUNGSANSTALT IN FINLAND
PUBLICATIONS OF THE FINNISH FOREST RESEARCH INSTITUTE
PUBLICATIONS DE L'INSTITUT DE RECHERCHES FORESTIÉRES DE LA FINLANDE

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73.1 Hakkila, Pentti & Panhelainen, Arja. 1970. On the wood properties of *Pinus contorta* in Finland. *Lyhennelmä:* Suomessa kasvatetun Pinus contortan puuaineen ominaisuuksista ..... 1— 43

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ON THE WOOD PROPERTIES OF PINUS CONTORTA IN FINLAND

PENTTI HAKKILA and ARJA PANHELAINEN

LYHENNELMÄ

SUOMESSA KASVATETUN PINUS CONTORTAN
PUUAINEEN OMINAISUUKSISTA

HELSINKI 1970

Helsinki 1971. Valtion painatuskeskus

Preface

The Department of Forest Technology, Finnish Forest Research Institute, began in autumn 1969 to study the wood properties of domestic tree species not hitherto investigated and of exotics that thrive in Finnish conditions. The study was conducted chiefly with reference to the needs of the pulp and paper industry. The first investigation of the project concerned *Alnus incana*. This part reports on *Pinus contorta*, and the next species to be studied will be some *Larix* species.

The present study was conducted by the Finnish Forest Research Institute. Close cooperation was maintained throughout the work with the Finnish Pulp and Paper Research Institute which, using the same sample trees, performed the pulping experiments of importance for the completeness of the project. The results recently appeared as a separate publication (S a l i n and P a l e n i u s 1970).

The material was collected in summer 1969 by Mr J o u n i Y l i n e n. Most of the laboratory and typing work was done by Miss A i r a P ä i v ö k e, Mrs A u n e R y t k ö n e n and Mrs I r m a S a a r i l a h t i. The manuscript was read by Professor, Dr. V e i j o H e i s k a n e n and Professor, Dr. V e i k k o K o s k i.

The manuscript was translated into English by Mr L. A. K e y w o r t h and Miss P ä i v i k k i O j a n s u u.

The authors wish to extend their best thanks to all those participating in the study. Their especial thanks go to Mr I l p o P a l e n i u s from the Finnish Pulp and Paper Research Institute and Mr R e i n o S a a r n i o from the Finnish Forest Research Institute for smooth cooperation.

Of the authors, Mrs Arja Panhelainen performed the statistical treatment and programming of the material. Dr Pentti Hakkila planned and directed the other parts of the research project and wrote the manuscript.

Helsinki, November 1970

Pentti Hakkila *Arja Panhelainen*

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1. INTRODUCTION

Growing an exotic species on a forestry scale presupposes that it offers a certain advantage over the domestic tree species. Cultivation may be argued on the grounds of, e.g., high yield, resistance to various diseases, thriving on barren sites and in severe climatic conditions, or the high quality and special characteristics of the timber.

One of the most promising exotics that thrive in Finland is lodgepole pine, *Pinus contorta*, the natural range of which covers a wide area of North America from Alaska to South California and, again, from the Pacific coast across the Rocky Mountains to the prairie regions (Fig. 1). In Alaska and British Columbia it grows from sea level to a height of 600 m, in California from sea level to 3 500 m and in the Rockies to 1 800—3 300 m (S a r v a s 1964).

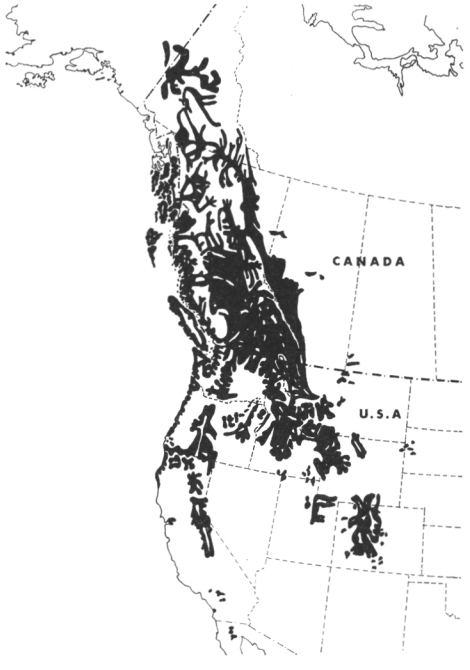


Figure 1. The natural range of lodgepole pine (S u d w o r t h 1917).

Kuva 1. Murrayn männyn luontainen levinneisyysalue (S u d w o r t h 1917).



Figure 2. A lodgepole pine plantation in Ruotsinkylä experimental forest of the Finnish Forest Research Institute.

Kuva 2. Murraymäntyviljelmä Metsäntutkimuslaitoksen Ruotsinkylän kokeilualueessa.

Lodgepole pine plantations have been established in various parts of Europe, especially in Germany, England, Denmark, Sweden, and Finland (Fig. 2). Some of the plantations have failed, but very encouraging results have also been achieved. The world-renowned plantations in Mustila, Elimäki, have shown that the seed source is a decisive factor and that the geographical race of British Columbia and Alberta (A. F. Tigerstedt 1922, C. G. Tigerstedt 1927), which is called *Pinus contorta var.latifolia* S. Wats., thrives in Finnish conditions. Norway, Sweden and Finland have again begun in recent times to pay great attention to discovering the most advantageous seed source (S. Hagner 1969, M. Hagner 1970, Dietrichson 1970, Metsänjalostussäätiö 1970).

Lodgepole pine when young is capable of faster growth than our domestic coniferous species in cultivations where the seed derives from climatic conditions similar to those in Finland (Metsänheimo 1926, C. G. Tigerstedt 1927, Lindfors 1937, Miettinen 1952, P. M. A. Tigerstedt 1970). The fast growth of lodgepole pine has been established also in Sweden (Lagerberg 1930, Johnsson 1957, Ingerstedt 1966, Nellbeck 1969, Remröd 1969). However, growth obviously culminates earlier than the increment of Scots pine (Ingerstedt 1966, Thomas 1966) and the economically best rotation age is hardly more than fifty years in South Finland (P. M. A. Tigerstedt 1970).

Some common fungous diseases infesting Scots pine have not damaged lodgepole pine seriously, but *Phacidium infestans* is one that has proved dangerous (C. G. Tigerstedt 1927, Schulenburg 1948 and 1949, Ingerstedt 1966). Other harmful fungi are *Sclerophoma* and *Crumenula*, and the *Hylobius abietis* weevil and *Diprion sertifer* sawfly also damage the species (Heikinheimo 1956, Sarvas 1964). Elks have also caused some damage. Lodgepole pine is generally regarded as quite a healthy tree species in the Nordic countries.

Because of its fast growth and soundness, cultivation of lodgepole pine has been begun recently in Norrland, Sweden (S. Hagner 1969, Nellbeck 1969). Finland has not yet started cultivation on a forestry scale despite the encouraging results in Mustila and the experiments of the Forest Research Institute. Interest is growing, however, and the National Board of Forestry has begun to establish experiments in Central and North Finland.

The worst obstacle to the generalisation of lodgepole pine is probably doubts about the technical quality of the timber. The dead branches are self-pruned very slowly (C. G. Tigerstedt 1927, Miettinen 1952, Sarvas 1964, Ericson 1969, P. M. A. Tigerstedt 1970) and lumber from lodgepole pine is therefore not equal to domestic timber. In Britain, however, where the area of lodgepole pine plantations was 53 000 hectares in 1966, this species is considered a satisfactory alternative to Scots pine for building uses such as roofing, flooring, interior framing, partitioning, cladding, etc. (Forest Products . . . 1968).

However, Finland is short first and foremost of pulpwood and what have traditionally been saw logs are now being used by the chemical and mechanical pulp industry. Growing a forest solely as pulp raw material may prove feasible in the future on certain conditions. Lodgepole pine makes very suitable raw material for sulphite and sulphate pulp (C. G. Tigerstedt 1927, Lindfors 1928, Metzger 1939, Ericson 1969, Eskilsson, Persson and Svensson 1969) and its cultivation has therefore often been recommended solely for the use of the pulp industry (Metsänheimo 1926, C. G. Tigerstedt 1927, Metzger 1928, v.d. Schulenburg 1948, Ericson 1969, Remröd 1969, Nellbeck 1969).

Despite successful plantations, the technical properties of lodgepole pine have not been studied so far in Finland. However, as often appears to be the case, exotic species when established and managed under plantation conditions on a comparatively short rotation produce fast-grown timber different in many respects from that of old growth from natural forests (cf. Brazier 1966). Before large-scale cultivation can be undertaken it is necessary to know the technical properties of also wood grown in our conditions. Attention should be paid specifically to the properties that are of great importance for the pulp industry.

The present study seeks to find an answer to the question of the serviceability of lodgepole pine grown in Finland as raw material for the pulp industry. It deals with the technical properties of wood, while the Finnish Pulp and Paper Research Institute, using the same basic material, performed the sulphate pulping experiments which gave been published as a separate paper (S a l i n and P a l e n i u s 1970).

The points selected for investigation were basic density, percentage of bark, knotwood and heartwood, and the quantity of acetone extractives. Clarification of the within-stem variation of the properties of the wood was regarded as important when defining the aims. In the variation between stems and stands attention was paid to the possible influence of the seed source in addition to other factors. Knowledge of the properties of lodgepole pine that grows in North Finland was regarded as important, for in addition to the interest in the southern part of the country, there is a special desire to cultivate this tree species in the north. However, as almost all of the older plantations are in South Finland it was possible to collect only a fraction of the material from northern conditions.

2. METHODS

The number of lodgepole pine plantations is rather limited in Finland. They are small in size and the majority contain permanent sample plots for silvicultural and yield studies. It was not possible for these reasons to make a fully random collection of sample trees as it was permissible to fell trees genereally only from a certain part of the stand, and then observing great caution. It was often the mantle of the sample plot, but actual peripheral trees were not accepted for the material.

From each sample tree, 5 cm thick discs were sawn from the butt cross-section at intervals of 1 m up to the crown. The discs were measured in the laboratory for total diameter, diameter of heartwood, area of knot-wood on both sides, green volume, dry weight of wood and dry weight of bark.

The laboratory work was performed using the customary methods, except that the disc volume was measured by a xylometer recently developed at the Finnish Forest Research Institute. This device gives the changes in the height of the water level to an accuracy of a hundredth of a millimetre. The reading device consists of platinum wire attached to micrometer and its contact with the water surface can be read from the ammeter scale (Fig. 3).



Figure 3. Electrically operated xylometer of the Finnish Forest Research Institute.

Kuva 3. Metsäntutkimuslaitoksen sähköisesti luettava ksylometri.

On the basis of laboratory measurements, the percentage of knotwood and heartwood by volume, basic density of wood and percentage of bark by weight were calculated for each disc. The stem means were calculated by weighting by the disc diameter.

From each sample tree was sawn also a 40 cm long bolt for sulphate pulping experiments by the Finnish Pulp and Paper Research Institute. The samples were taken from all the trees at the 25 per cent height. The Institute also determined the amount of acetone extractives in the material for the pulping experiments, treating the wood samples from each stand as a single entity.

The statistical treatment of the material was performed mainly on Datanet-30 and GE-235 computers of General Electric through the terminal station of the Finnish Forest Research Institute, using partly own and partly library programmes. The stepwise, selective analyses of regression were done on the Elliott-503 computer of the State Computer Centre.

The principal statistical method employed was regression analysis. It was applied to explain the within-stem variation of percentage of bark, percentage of heartwood and basic density. The longitudinal variation in the stem in the percentage of knotwood was described solely by means of averages calculated at different heights as the abnormal distribution of the observations made it impossible to use regression analysis.

To explain the between-stem variation stepwise, selective regression analysis was used. In this method the computer selects automatically the best independent variables for the model from among the given variables and their transformation. It uses the F-test as the criterion for selection. The smallest F-value for an accepted variable was 4.00. Analysis of variance was used for the separation of total variations into components arising from the within-stem variation and variation between stems and stands.

The significance levels used in the tests were 95, 99 and 99.9 per cent. The asterisk after the test quantity denotes that the result was significant with 5 per cent risk. Two and three asterisks signify correspondingly a 1 and 0.1 per cent risk.

The material of the study was not irreproachable in its statistical representativeness as the small size of the plantations and the experiments established in them prevented a perfectly random sampling procedure. However, the results probably give an adequate picture of the properties of the lodgepole pine cultivated in South Finland. Because of the paucity of material, the results for North Finland must be treated with considerably greater reserve.

3. MATERIAL

The main part of the material was collected in summer 1969 from the experimental forests of the Finnish Forest Research Institute in different parts of Finland (Fig. 4). Four experimental forests were located on land owned by the National Board of Forestry. Sample trees were obtained from 24 stands, only two of which in North Finland. With the exception of these two, all the existing plantations are in the south. The concentration on the southern part of the country is regrettable as the north has a special interest in lodgepole pine.

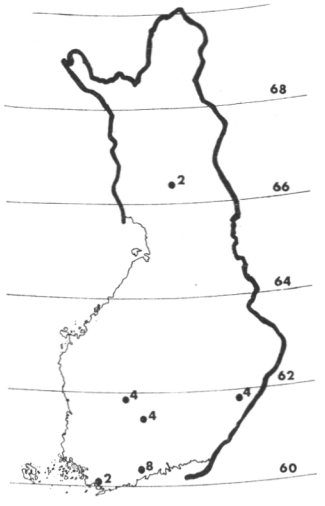


Figure 4. Location and number of the sample stands.
Kuva 4. Koemetsiköitten sijainti ja lukumäärä eri paikkakunnilla.

The material varied according to site, containing both dry and moist mineral soils and, in one case, a drained swamp. The stands in question were almost without exception pure, with a single tree species. The age of the growing stock was 29—43 years. The narrow age range was due to the fact that the lodgepole pine cultivations of the Finnish Forest Research Institute were established mainly at the end of the 1920s. The seed derived from Canada, from the states of Alberta and British Columbia, from between latitudes 50 and 51 deg. Thesource of the seed was unknown in four cases.

From each stand five sample trees were felled in the south and six in the north. The total material consisted of approx. 1 500 discs from a total of 122 trees. To clarify the variation between stems and stands a larger material would have been desirable, but the permanent sample plots on the plantations again constituted a limiting factor.

The mean age of the sample trees was 40 years, the mean diameter at breast height 12.8 cm, mean height 13.4 m and volume including bark 116 litres. The living crown accounted for an average of 52 per cent of the total height of the stem. The lowest branches were generally dead, but most had

not been self-pruned and the trees appeared to be rather branchy. On the other hand, the southern trees at any rate had a straight stem and narrow taper.

Table 1. Research material.
Taulukko 1. Tutkimusaineisto.

Stand *Metsikkö*	Seed source *Siemenen alkuperä*	Location *Sijainti*	Site *Metsätyyppi*	Age, years *Ikä, vuotta*	Dbh, cm $D_{1.3}$ *cm*	Height m *Pituus m*	Volume l *Tilav. l*	Crown porportion, % *Latvussuhde, %*
1	Alberta	Solböle	OMT	41	11.6	12.9	80.6	42
2	Alberta	Solböle	OMT	41	10.4	12.4	64.5	45
3	Alberta	Ruotsinkylä	VT-MT	41	13.4	12.6	98.0	67
4	Alberta	Ruotsinkylä	VT	41	13.6	13.4	102.7	65
5	Alberta	Ruotsinkylä	VT	41	13.4	14.2	116.1	53
6	Alberta	Ruotsinkylä	VT	40	12.0	12.6	76.1	55
7	Alberta	Ruotsinkylä	Swamp	40	13.0	16.6	132.6	41
8	Br. Columbia	Ruotsinkylä	VT	40	10.2	11.0	52.7	61
9	Br. Columbia	Ruotsinkylä	OMT	43	15.8	16.4	183.9	43
10	Br. Columbia	Ruotsinkylä	OMT	43	16.2	18.6	228.6	43
11	Br. Columbia	Vesijako	VT	40	15.8	16.7	198.6	53
12	Br. Columbia	Vesijako	MT	43	13.2	15.6	125.8	53
13	Br. Columbia	Vesijako	MT	43	18.4	17.8	261.6	54
14	Br. Columbia	Vesijako	MT	43	12.2	16.1	134.6	27
15	Unknown	Hyytiälä	CT	35	8.8	9.7	34.3	67
16	Unknown	Hyytiälä	VT	29	9.8	9.6	40.9	65
17	Unknown	Hyytiälä	VT	35	13.4	12.8	110.0	40
18	Unknown	Hyytiälä	VT	35	11.6	13.3	92.2	45
19	Alberta	Punkaharju	MT	41	14.4	15.9	157.5	46
20	Alberta	Punkaharju	MT	42	11.6	14.3	98.4	49
21	Alberta	Punkaharju	MT	42	11.8	13.3	88.3	43
22	Br. Columbia	Punkaharju	OT	43	15.0	16.5	160.0	38
23	Br. Columbia	Kivalo	HMT	43	13.5	9.8	80.0	..
24	Br. Columbia	Kivalo	HMT	39	12.5	10.0	71.9	..
Average Keskim.				40	12.8	13.4	116.2	52

4. RESULTS

41. Percentage of bark

The percentage of bark refers in general to the proportion of bark in the total volume of unbarked timber. However, the volume of bark changes with the moisture content of timber and depends also on the measuring method. Because of this, in the present study use was made of the bark percentage on a dry weight basis, which denotes the proportion of the dry weight of bark in the total dry weight of unbarked timber. It is independent of climatic conditions and changes only when the bark really is removed from the timber.

The variation in the percentage of bark was distributed into three principal components: within-stem, stem-to-stem and stand-to-stand. Regularity could be seen in within-stem variation only in the longitudinal direction of the stem. The table of variance for the disc material from South Finland shows the significance of the different sources of variation.

Source of variation *Vaihtelulähde*	SS *Neliö-summa*	d.f. *Vapaus-asteet*	MS *Keski-neliö*	EMS *Odotusarvo*	F
Between stands *Metsiköitten välinen*	3 286	21	156.5	$\sigma_0^2+10\sigma_1^2+50\sigma_2^2$	$F_{21,88} = 9.18^{***}$
Between stems within stand *Metsikön runkojen välinen*	2 161	88	24.6	$\sigma_0^2+10\sigma_1^2$	$F_{88,990} = 1.44^{**}$
Within stem + analytical error *Rungon sisäinen+koevirhe*	16 883	990	17.1	σ_0^2	
Total *Yhteensä*	22 330	1 099			

All the sources of variation tested are significant. Stem-to-stem variation within a stand is significant at the confidence level of 99 per cent and stand-to-stand variation at the confidence level of 99.9 per cent. The sampling methods made it impossible to differentiate between within-stem variation and the analytical error. However, variation in the percentage of bark in the longitudinal direction of the stem was so obvious that there was reason to examine each of the variation components individually.

411. Variation within the stem

Variation of the percentage of bark in the longitudinal direction of the stem is illustrated by a regression equation in which the independent variabel is the relative sampling height. The coefficient of determination is improved when the tree height is added to the equation.

	R^2	$S_{y.x}$
$Y = 10.4 - 0.198\ x_1 + 0.00325\ x_1^2$	0.549	3.4
$Y = 19.6 - 0.200\ x_1 + 0.00329\ x_1^2 - 0.62\ x_2$	0.622	2.9

Y = Bark percentage of a disc
x_1 = Relative height at the stem, per cent
x_2 = Stem height, m

In accordance with the pattern common to all tree species, the percentage of lodgepole pine bark decreases from the butt cross-section upwards to a certain height, then begins to rise again at an increasing rate. The bark percentage is highest and the longitudinal changes in the stem sharpest in small-sized trees (Fig. 5).

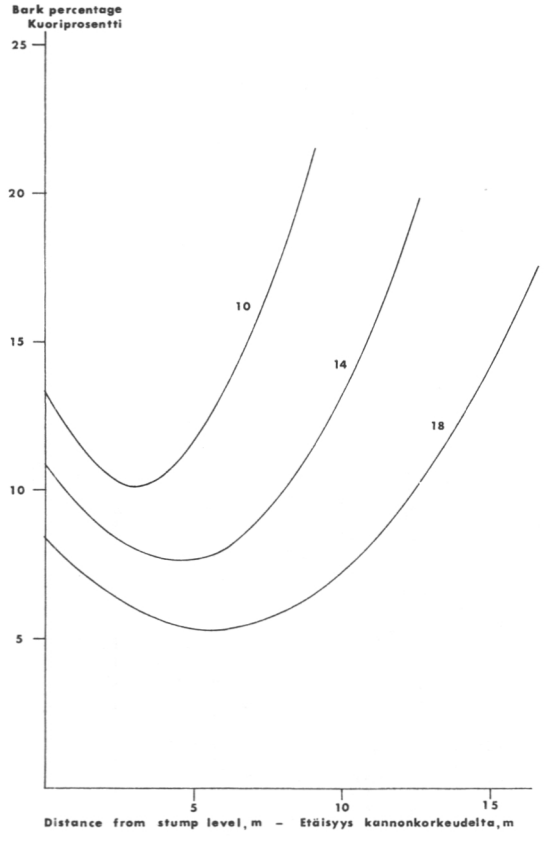


Figure 5. The longitudinal variation of bark percentage in 10, 14 and 18 meter lodgepole pine stems.
Kuva 5. Murrayn männyn kuoriprosentin vaihtelu rungon pituussuunnassa 10-, 14- ja 18-metrisessä rungossa.

Given the longitudinal variation, the average percentage of bark in the stem can be estimated from a single sample. The sample may be taken at, e.g., breast height or at 50 per cent height. The former gives a result that is an average of 1.2 per cent units too low and latter one that is 0.2 per cent units too high. The results can be corrected as follows by means of regression equations.

	R^2	$S_{y.x}$
$Y = 1.45 + 0.967\ x_1$	0.813	0.90
$Y = 1.82 + 0.787\ x_2$	0.876	0.74

Y = Average bark percentage of a stem
x_1 = Bark percentage at breast height
x_2 = Bark percentage at 50 per cent height

A disc sample taken from half way along the stem gives quite an accurate result. The equation gives the percentage of bark in an individual stem with 95 per cent reliability to an accuracy of 1.5 per cent units (cf. Fig. 6).

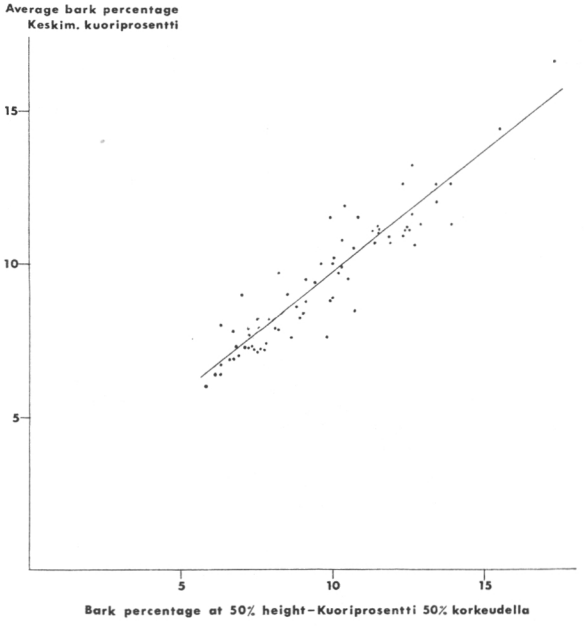


Figure 6. Correlation between the bark percentage at 50 per cent height and the average bark percentage of a lodgepole pine stem.

Kuva 6. Rungon 50 %:n korkeudelta mitatun ja rungon keskimääräisen kuoriprosentin välinen riippuvuus Murrayn männyssä.

The percentage of lodgepole pine bark is relatively low compared with the principal tree species in Finland. It seems to be lower in all parts of the stem than it is in birch and Norway spruce (Fig. 7).

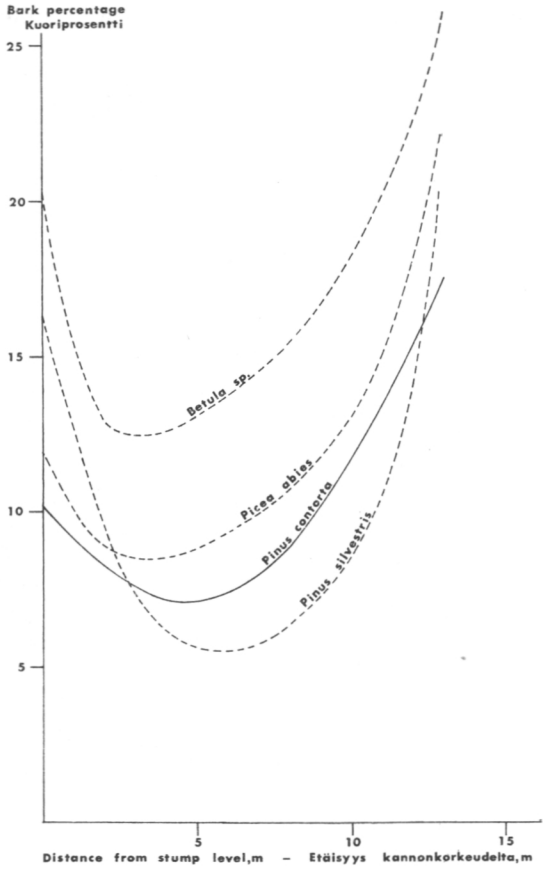


Figure 7. The longitudinal variation of bark percentage of a 15 meter lodgepole pine stem compared with spruce and birch.

Kuva 7. Murrayn männyn kuoriprosentin vaihtelu rungon pituussuunnassa mäntyyn, kuuseen ja koivuun verrattuna 15-metrisessä rungossa.

412. Variation between stems

Stem-to-stem variation of the percentage of bark can be studied either as an average for the total material or within the stand. As only five trees from each stand were available, analysis was performed for the total material.

The average bark percentage of all the stems in the material was 9.47. The standard deviation between stems was 1.91 per cent units, i.e. 20 per cent of the mean.

The external tree characteristics that best explain the variation of the bark percentage are the variables that represent the stem size, such as volume, height and diameter. If a single independent variable is sufficient, the following equation gives the best result.

	R^2	$S_{y.x}$
$Y = 24.0 - 4.89 \log x_1$	0.471	1.39

Y = Average bark percentage of a stem
x_1 = Stem volume in decilitres

Thus, the bark percentage decreases when the stem size increases. For instance, when bark accounts for 10.8 per cent of the dry weight of a 50-litre tree, the comparable figure for a 200-litre tree is no more than 7.9 per cent.

The percentage of bark is correlated also with stem form. The more slowly the tree tapers, the smaller is the bark percentage. When, in addition to volume, the height: diameter ratio is adopted as the second independent variable, 53 per cent of the between-stem variation is explained.

	R^2	$S_{y.x}$
$Y = 27.2 - 5.06 \log x_1 - 2.47 x_2$	0.525	1.32

Y = Average bark percentage of a stem
x_1 = Stem volume in decilitres
x_2 = Height/Dbh, m/cm

The coefficient of determination can be improved somewhat further by certain additional independent variables. For instance, a variable that separates the trees of South and North Finland raises the percentage of the explained variance to 59. The slight effect of age, on the other hand, was probably due here to the small age differences between the sample trees.

The percentage of bark of the sample trees was low for the small mean size of the stem. Comparison with domestic tree species is difficult because of the lack of information, but at least the following indicative results for the dry weight percentage of bark are available for conditions in South Finland (Hakkila 1967 a and 1970): Scots pine 8.0 (mean volume 166 litres), Norway spruce 10.0 per cent (138 litres), birch 14.8 per cent (148 litres), and grey alder 13.0 per cent (23 litres). The low bark percentage of the lodgepole pine has been reported by A. F. Tigerstedt (1922), Lindfors (1937), Miettinen (1952), and Sarvas (1964), although these authors were describing the bark percentage by volume.

413. Variation between stands

A part of the variation of bark percentage between stems can be separated into stand-to-stand variation. The latter is statistically significant.

Source of variation *Vaihtelulähde*	SS *Neliö-summa*	d.f. *Vapaus-asteet*	MS *Keski-neliö*	EMS Odotusarvo	F
Between south and north *Etelän ja pohjoisen välinen*	0.25	1	.25	$\sigma_0^2+5.9\sigma_1^2+21.6\sigma_2^2$	$F_{1,21} = 0.02$
Between stands *Metsiköitten välinen*	267.75	22	12.17	$\sigma_0^2+5.0\sigma_1^2$	$F_{22,98} = 6{,}51^{***}$
Within stand + analytical error *Metsikön sisäinen + koevirhe*	183.62	98	1.87	σ_0^2	
Total *Yhteensä*	451.62	121			

Although there were manifest differences between the stands, the means for South and North Finland did not differ significantly. The investigation material thus failed to reveal a geographical variation; the difference between the means for South and North was only 0.15 per cent units. However, as the stands of North Finland differ in many respects from the material for the South, only the latter are examined below.

The standard deviation of bark percentage between stands was 1.60 per cent units in South Finland, i.e., 17 per cent of the mean. It is explained by the same characteristics as stem-to-stem variation, in other words mainly by characteristics that illustrate primarily the average size of the trees. The mean height of the stem accounts for 74, mean volume for 60, mean diameter at breast height for 42, heartwood percentage for 39, age for 22 and knotwood percentage for 7 per cent of the variation. The following are the best equations.

	R^2	$S_{y.x}$
$Y = 17.20 - 0.560\ x_1$	0.736	0.82
$Y = 15.81 - 0.553\ x_1 + 1.279\ x_2$	0.828	0.66

Y = Average bark percentage of a stand
x_1 = Average stem height, m
x_2 = Average percentage of knotwood

A striking difference from the equations for stem-to-stem variation was the significance of the characteristic that describes the branchiness of the stand. It was probably solely because of the method of determining the

percentage of knotwood that it failed to explain the variation in the percentage of bark in an individual stem. On the other hand, the percentage of knotwood was essentially more accurate when determined as the mean of five stems. It then revealed a positive correlation with the bark percentage when the effect of stem size was taken into consideration.

The bark percentage averaged 8.0 in South Finnish stands in which the seed derived from British Columbia, whereas it was considerably higher, 9.8, for trees grown from seed from Alberta. The difference was probably due first and foremost to the size differences between the trees. The trees of British Columbian origin were distinctly taller (cf. Table 1) although both were almost coeval.

42. Percentage of heartwood

The heartwood percentage denotes the proportion of heartwood in the volume of the stem as a whole. The variation of heartwood percentage in the following analysis of variance based on material from South Finland was distributed between within-stem, stem-to-stem and stand-to-stand components.

Source of variation *Vaihtelulähde*	SS *Neliö-summa*	d.f. *Vapaus-asteet*	MS *Keski-neliö*	EMS *Odotusarvo*	F
Between stands *Metsiköitten välinen*	36 177	21	1 722.7	$\sigma_0^2+10\sigma_1^2+50\sigma_2^2$	$F_{21,88} = 6.08^{***}$
Between stems within stand *Metsikön runkojen välinen*	24 932	88	283.3	$\sigma_0^2+10\sigma_1^2$	$F_{88,990} = 2.26^{***}$
Within stem + analytical error *Rungon sisäinen + koevirhe*	124 148	990	125.4	σ_0^2	
Total *Yhteensä*	185 257	1 099			

The standard deviation of the disc material was 13.0 per cent. The share of both stand-to-stand and stem-to-stem variation was highly significant. It was impossible because of the sampling method used to distinguish between the variation within the stem and the variation caused by analytical error.

421. Variation within the stem

The variation of the heartwood percentage in the longitudinal direction of a defect-free stem in South Finland is depicted by a regression equation in

which the relative sampling height, the stem height and their transformations serve as independent variables. The equation explains 42 per cent of the variance.

$$Y = -13.77 + 0.8080\,x_1 - 0.018797\,x_1^2 + 0.00011958\,x_1^3 + 2.452\,x_2 - 0.02272\,x_1x_2$$

R^2 = 0.419; $S_{y.x}$ = 7.77

Y = Heartwood percentage of a disc
x_1 = Relative height at the stem, per cent
x_2 = Stem height, m

The heartwood percentage increases first upwards from the butt cross-section. It is at its maximum at the 10—20 per cent height and then declines towards the crown (Fig. 8). The corresponding height for Scots pine is 20—30 per cent (L a p p i - S e p p ä l ä 1952, H a k k i l a 1967 b).

Stem height affects the heartwood percentage materially. There is relatively more heartwood in a long than in a short stem. The difference is greatest in the butt and decreases towards the top.

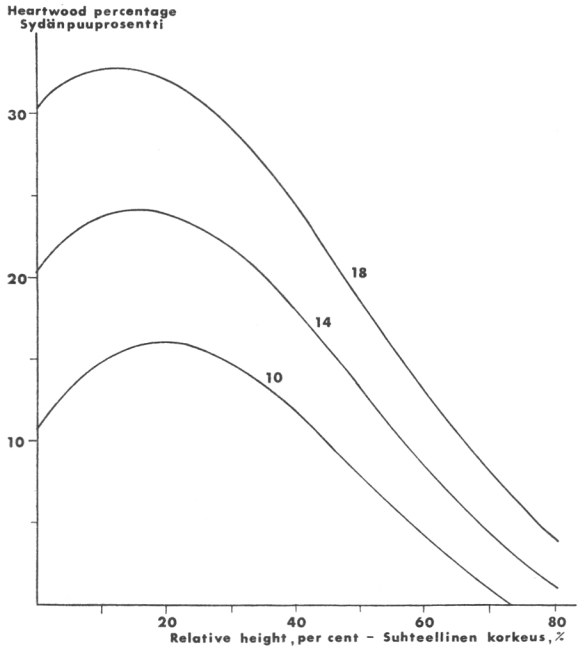


Figure 8. The longitudinal variation of heartwood percentage in 10, 14 and 18 meter lodgepole pine stems.

Kuva 8. Murrayn männyn sydänpuuprosentin vaihtelu rungon pituussuunnassa 10-, 14- ja 18-metrisessä rungossa.

The average heartwood percentage in a stem can be estimated from a sample taken at, say, breast height or at 40 per cent height. The former gives a result that is an average of 6.1 per cent units too high and the latter one that is 0.9 per cent units too low. The results can be corrected by using the following regression equations.

	R^2	$S_{y.x}$
$Y = -0.48 + 0.780\ x_1$	0.841	4.4
$Y = 3.03 + 0.874\ x_2$	0.875	3.4

Y = Average heartwood percentage of a stem
x_1 = Heartwood percentage at breast height
x_2 = Heartwood percentage at 40 per cent height

The equations give the average heartwood percentage of an individual stem with 95 per cent reliability to an accuracy of 8.6 per cent units for a sample taken at breast height and to an accuracy of 6.7 per cent units for a sample taken at 40 per cent height (Fig. 9).

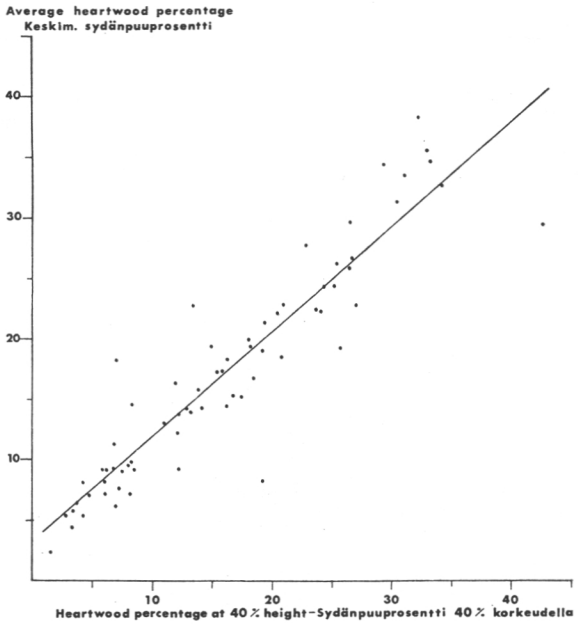


Figure 9. Correlation between the heartwood percentage at 40 per cent height and the average heartwood percentage of a lodgepole pine stem.

Kuva 9. Rungon 40 %:n korkeudelta mitatun ja rungon keskimääräisen sydänpuuprosentin välinen riippuvuus Murrayn männyssä.

422. Variation between stems

The average heartwood percentage of all stems in the material was 17.5 and standard deviation 9.1 per cent units, i.e. 52 per cent of the mean. Of the external tree characteristics, stem height is the one that explains best the variation in the percentage of heartwood. A regression equation in which the square of the height is the independent variable explains 35 per cent of the variance of heartwood percentage.

	R^2	$S_{y.x}$
$Y = 4.50 + 0.0653\,x$	0.353	7.31

Y = Average heartwood percentage of a stem
x = Stem height, m

423. Variation between stands

Stand-to-stand variation and the variation between South and North Finland can be separated from the stem-to-stem variation of heartwood percentage in the total material. The variation between stands is highly significant statistically.

Source of variation *Vaihtelulähde*	SS *Neliösumma*	d.f. *Vapausasteet*	MS *Keskineliö*	EMS *Odotusarvo*	F
Between south and north *Etelän ja pohjoisen välinen*	475.2	1	472.2	$\sigma_0^2+5.9\sigma_1^2+21.6\sigma_2^2$	$F_{1,21} = 1.67$
Between stands *Metsiköitten välinen*	5 443.2	22	247.4	$\sigma_0^2+5.0\sigma_1^2$	$F_{22,98} = 5.96^{***}$
Within stand + analytical error *Metsikön sisäinen + koevirhe*	4 067.0	98	41.5	σ_0^2	
Total *Yhteensä*	9 985.4	121			

The variation between South and North Finland is not significant according to the analysis, although the mean for North Finland is 6.6 per cent units lower. In the following, however, the analysis will be confined to the stands of South Finland as the North Finnish stands differ in many other respects from the southern material.

The standard deviation of heartwood percentage between stands is 7.2 per cent units in South Finland, i.e., 40 per cent of the mean. Of the individual characteristics, mean height explains 60 per cent of the variance of heartwood percentage. The average crown proportion like the mean volume ex-

plains 46, bark percentage 39, mean diameter at breast height 32, and age 30 per cent of the variance. The mean height, crown proportion and basic density of wood in the stand explain 75 per cent of the variance.

	R^2	$S_{y.x}$
$Y = -14.39 + 2.323\ x_1$	0.602	4.61
$Y = 7.19 + 1.712\ x_1 - 0.259\ x_2$	0.689	4.07
$Y = -48.03 + 1.336\ x_1 - 0.303\ x_2 + 0.145\ x_3$	0.749	3.66

Y = Average heartwood percentage of a stand
x_1 = Average height, m
x_2 = Average crown proportion, per cent
x_3 = Average basic density, kg/cu.m.

The average heartwood percentage in the South Finnish stands deriving from Alberta seed was 16.4. It was considerably higher, 24.4 ($t_{16} = 2.99^{**}$), in the stands grown from seed from British Columbia. The main reason was probably the size differences between the trees for those grown from British Columbian seed were distinctly taller.

43. Percentage of knotwood

The knotwood percentage indicates here the proportion of knotwood proper in the total volume of stem wood. It does not include the adjacent anatomically exceptional wood which cannot be clearly distinguished from defect-free wood. The percentage of knotwood by weight is greater than its volume percentage.

The sampling method provides no chances for statistical analysis of the variation of the knotwood percentage. However, figures indicative of the branchiness of lodgepole pine for pulping purposes can be presented from the means.

431. Variation within the stem

The number of branches in a whorl is nearly the same at different stem heights. As annual shoots are shortest at the butt of the stem, branches per longitudinal unit of the stem are likewise most numerous at the butt end. This is seen from the following figures for South Finland.

Relative stem height %	Percentage of knot-free discs
1	50
10—30	64
40—60	62
70—90	75

Branches at the butt end die young. They are self-pruned slowly (Fig. 10), but they remain thin. Higher up, branches survive longer and grow thicker, and the proportion of knotwood increases from the butt towards the top (Fig. 11).



Figure 10. Self-pruning of lodgepole pine is slow in Finnish conditions.

Kuva 10. Murrayn männyn kuolleet oksat karsiutuvat Suomen oloissa hitaasti.

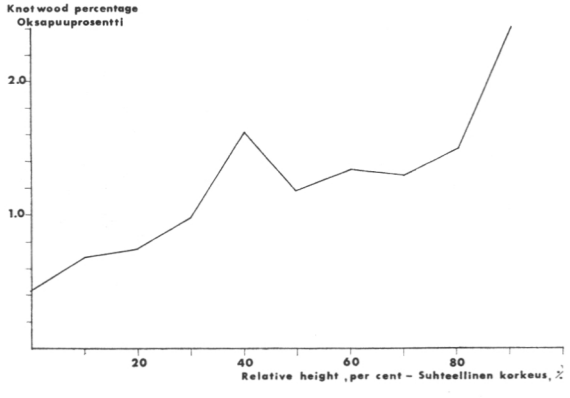


Figure 11. The longitudinal variation of knotwood percentage of lodgepole pine.

Kuva 11. Murrayn männyn oksapuuprosentin vaihtelu rungon pituussuunnassa.

Corresponding information is not available for Finnish tree species. However, the proportion of knotwood in 45—50-year-old plantations of Scots pine and Norway spruce at different stem heights has been measured in Sweden. The knotwood percentage of the total tree volume was 0.26 at the butt of the stem for Scots pine, 0.56 at 30 per cent height, 1.25 at 60 per cent height and 1.78 per cent at 90 per cent height. The corresponding figures for Norway spruce were 0.39, 0.64, 1.27 and 2.15 per cent (N y l i n d e r 1959).

432. Variation between stands

A disc sample taken at 1-metre intervals does not give a sufficiently reliable idea of the knotwood percentage of the stem. Therefore, because of the magnitude of the measuring error, there is no point in performing a per-stem analysis. Data per stand based on the averages for five stems provide a more reliable basis for statistical analysis.

The percentage of knotwood for South Finnish stands was significantly lower than for North Finnish stands ($t_{120} = 3.07^{**}$). This was true although the trees in South Finland had grown faster.

	Knotwood, per cent	
	$\bar{x}$	s
South-Finland — *Etelä-Suomi*	0.98	0.70
North-Finland — *Pohjois-Suomi*	1.67	1.09

The individual independent variable that explains best the knotwood percentage of a stand in South Finland is the bark percentage, but even then the variance explained only 7 per cent. If we add diameter at breast height as the second independent variable, the coefficient of determination increases considerably. If age and crown proportion are then added, 44 per cent of the variance can be explained.

	R^2	$S_{y.x}$
$Y = 0.25 + 0.082\ x_1$	0.071	0.375
$Y = -2.42 + 0.200\ x_1 + 0.121\ x_2$	0.344	0.315
$Y = -4.07 + 0.224\ x_1 + 0.097\ x_2 + 0.044\ x_3$	0.431	0.293
$Y = -3.82 + 0.257\ x_1 + 0.107\ x_2 + 0.037\ x_3 - 0.009\ x_4$	0.445	0.290

Y = Average percentage of knotwood in a stand
x_1 = Average bark percentage of a stand
x_2 = Average Dbh, cm
x_3 = Average age, years
x_4 = Average crown proportion, %

If the lodgepole pine is thick-barked for its age it also contains more than the average amount of knotwood. These two negative properties, branchiness and thick bark, are thus simultaneous and of strong influence.

The average knotwood percentage in a Scots pine plantation in Sweden, with 2-m spacing, at the age of 45—50 years was 0.69 and in a Norway spruce plantation correspondingly 0.72 (Nylinder 1959). A study in Central Finland found the knotwood percentage of spruce pulpwood to be 0.62 and of spruce saw logs 0.80 (Hakkila and Rikkonen 1970). The knotwood percentage of lodgepole pine seems thus to be higher than that of our domestic tree species. This is to be expected from the outward appearance of lodgepole pine alone (Fig. 10); its dead branches are self-pruned very slowly. Branchiness was established also in the pulping experiments of the Finnish Pulp and Paper Research Institute (Salin and Palenius 1970).

44. Basic density

The basic density of wood gives the dry matter content of a green volume unit in kilograms per solid cubic metre. In the present study, the stem means include the effect of knots and reaction wood. In contrast, analyses of the within-stem variation represent knot-free wood unless stated otherwise.

In the analysis of variance of South Finnish material the variation of basic density was distributed into within-stem, stem-to-stem and stand-to-stand components in the following way.

Source of variation *Vaihtelulähde*	SS *Neliösumma*	d.f. *Vapausasteet*	MS *Keskineliö*	EMS *Odotusarvo*	F
Between stands *Metsiköitten välinen*	163 605	21	7 791	$\sigma_0^2+10\sigma_1^2+50\sigma_2^2$	$F_{21,88} = 1.45$
Between stems within stand *Metsikön runkojen välinen*	471 725	88	5 361	$\sigma_0^2+10\sigma_1^2$	$F_{88,990} = 4.36^{***}$
Within stem + analytical error *Rungon sisäinen + koevirhe*	1 221 338	990	1 234	σ_0^2	
Total *Yhteensä*	1 856 668	1 099			

The standard deviation of the disc material was 41.1 kg/solid cu.m. The stem-to-stem variation is highly significant. The role of stand-to-stand variation, on the other hand, is not significant when tested in this way. Again, it was impossible to distinguish between within-stem variation and variation due to analytical error.

441. Variation within the stem

Within-stem variation of basic density depends primarily on the variation in the percentage of summerwood. The average basic density increases with the proportion of dense summerwood (cf. Figs. 12 and 13).

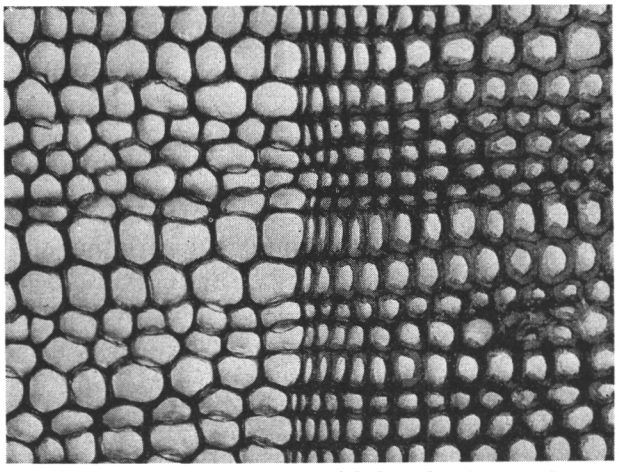


Figure 12. A cross-section of lodgepole pine wood.
Kuva 12. Poikkileikkaus Murrayn männyn puuaineesta.

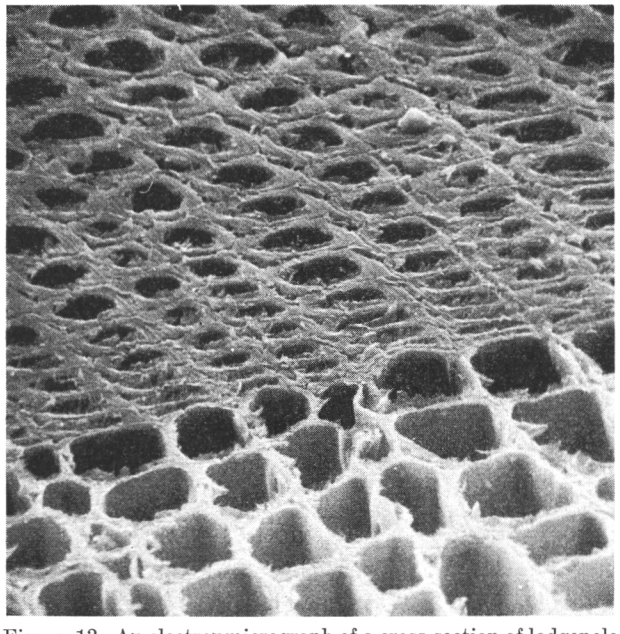


Figure 13. An electronmicrograph of a cross-section of lodgepole pine. 400 x. (Finnish Pulp and Paper Research Institute).
Kuva 13. Elektronimikroskooppikuva Murrayn männyn poikkileikkauksesta. Suurennus 400-kertainen. (Oy Keskuslaboratorio).

Within-stem variation is divided between two main components: radial variation and longitudinal variation. The latter, the more important for practical purposes and the sole object studied in this case, is partly the consequence of the former. There occurs, in addition, random variation in the tangential direction. The following regression equation describes the longitudinal variation of basic density in defect-free wood in South Finland.

	R^2	$S_{y.x}$
$Y = 467.0 - 2.000\,x + 0.01578\,x^2$	0.236	33.3

Y = Basic density of a defect-free disc, kg/cu.m
x = Relative sampling height, per cent

The equation explains only 24 per cent of the variation and is therefore of no value for predicting the basic density of an individual stem at a certain height. However, it gives an idea of the longitudinal variation pattern of the wood density in a stem for the lodgepole pine. The density decreases topwards from the butt to a height of approx. 60 per cent, after which it generally begins to rise again (Fig. 14). The increase in density in the topmost crown does not occur in all stems.

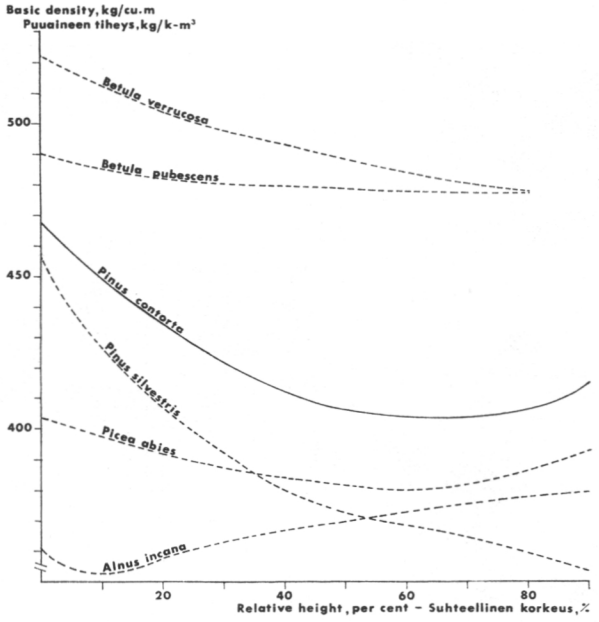


Figure 14. The longitudinal variation in basic density of lodgepole pine compared with some Finnish species.
Kuva 14. Murrayn männyn puuaineen tiheyden vaihtelu rungon pituussuunnassa rauduskoivuun, hieskoivuun, mäntyyn, kuuseen ja harmaaleppään verrattuna.

The defect-free wood of the lodgepole pine seems to be denser than that of Scots pine. The difference is fairly small in the butt, but the density of the lodgepole pine decreases more slowly towards the top. Compared with Norway spruce, the density of the lodgepole pine diminishes faster and over a longer distance towards the top. Both, however, increase in density at the top.

The average wood density grows with the degree of knottiness. The basic density of knotwood is high and the adjacent wood is probably also denser than defect-free wood. In the following the first equation represents the variation of density in defect-free wood, the second is based on the total disc material and the last solely on discs which also contain a greater or smaller quantity of knotwood. The combined density-increasing influence of knots and adjacent wood is greatest slightly below the middle of the stem where the difference between the density of a knot-free disc and the average density is 2 per cent (Fig. 15).

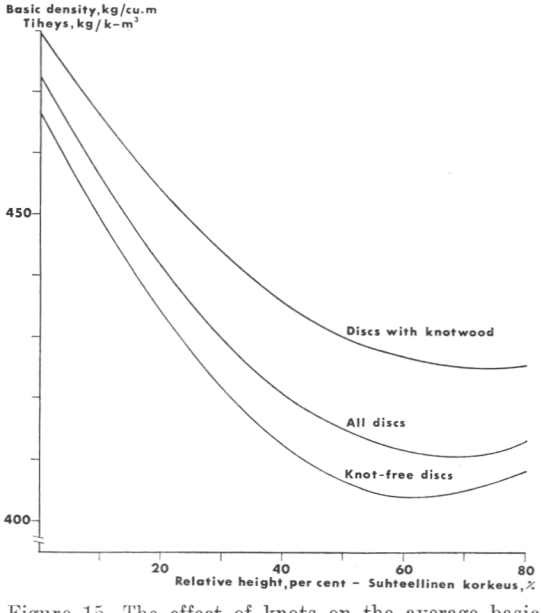


Figure 15. The effect of knots on the average basic density of lodgepole pine in different parts of the stem.
Kuva 15. Oksien vaikutus Murrayn männyn puuaineen keskimääräiseen tiheyteen rungon eri osissa.

	R^2	$S_{y.x}$
$Y_1 = 467.0 - 2.000\ x + 0.01578\ x^2$	0.236	33.3
$Y_2 = 479.8 - 1.526\ x + 0.01059\ x^2$	0.227	34.4
$Y_3 = 472.2 - 1.845\ x + 0.01379\ x^2$	0.235	35.0

Y_1 = Basic density of a knot-free disc
Y_2 = Basic density of a disc including knots
Y_3 = Average basic density of a disc
x = Relative sampling height, per cent

An unbiased estimate of the average stem density can be obtained from a knot-free sample taken from 20 per cent height (Fig. 16) — the difference of the means, 0.5 kg/solid cu.m., is not significant ($t_{156} = 0.13$). In pulping experiments on laboratory scale the wood sample representing the stem as a whole should be taken from this height for the significance of wood density is decisive for wood consumption and the quality of the end product. However, it must be remembered that the proportion of heartwood in the sample is then unusually great.

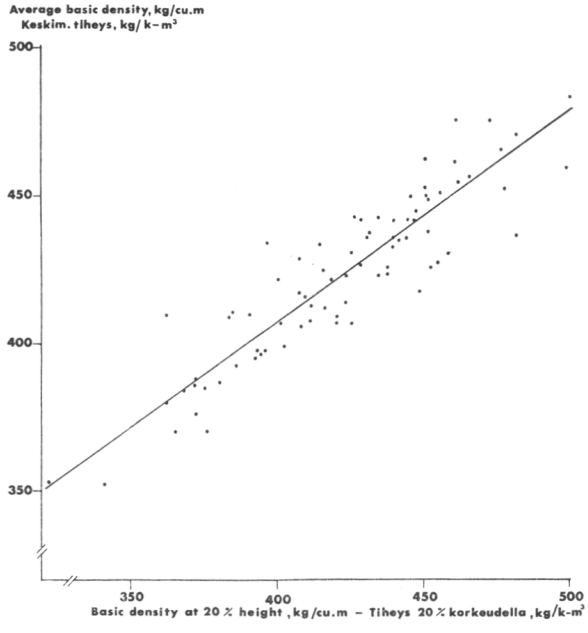


Figure 16. Correlation between the basic density at 20 per cent height and the average basic density of a lodgepole pine stem.

Kuva 16. Rungon 20 %:n korkeudelta mitatun ja rungon keskimääräisen puuaineen tiheyden välinen riippuvuus Murrayn männyssä.

	R^2	$S_{y.x}$
$Y = 117.6 + 0.723\,x$	0.828	11.9

Y = Average basic density of a stem, kg/cu.m
x = Basic density at 20 per cent height, kg/cu.m

If sample trees cannot be felled the wood sample can be taken from an increment core of a standing tree. For practical reasons this should be a sample bored at breast height. The average stem density is then obtained from the following formula.

	R^2	$S_{y.x}$
$Y = 96.6 + 0.740\ x$	0.832	12.30

Y = Average basic density of a stem, kg/cu.m
x = Basic density at breast height, kg/cu.m

The average stem density can thus be predicted from a sample taken at breast height. The standard deviation from the regression line is 12 kg/solid cu.m.

442. Variation between stems

External tree characteristics can explain little of the stem-to-stem standard deviation which, inclusive of North Finland, is 27.7 kg/solid cu.m. The best independent variable besides the variable which represents the variation between South and North Finland is the characteristic that describes the stem form, height divided by breast height diameter.

	R^2	$S_{y.x}$
$Y = 355.8 + 36.27\ x_1 + 3.691\ x_2$	0.310	23.0

Y = Average basic density of a stem, kg/cu.m
x_1 = 1 in South-Finland and 0 in North-Finland
x_2 = Height/Dbh, m/cm

The equation explains 31 per cent of the stem-to-stem variation. When bark percentage and another characteristic that describes form are added 35 per cent of the variation can be explained. Age which for Scots pine is the most effective independent variable of wood density, varied so little in the investigation material that it was of small effect. It was probably in part the even age of the sample trees that made the stem-to-stem variation and its coefficient of determination smaller for the lodgepole pine that for Scots pine.

The average density of the lodgepole pine is higher than that of defect-free wood of Scots pine ($t_{893} = 7.98$***), Norway spruce ($t_{859} = 15.28$***) and grey alder ($t_{588} = 30.63$***), but lower than that of common birch ($t_{357} = 19.20$***) and white birch ($t_{418} = 15.98$***). The point at issue in the following tabulation is stem-to-stem variation (H a k k i l a 1966 and 1970).

Basic density, kg/cu.m. — *Tiheys, kg/k-m³*

Species *Puulaji*	$\bar{x}$	s_x	Range *Vaihteluväli*	s %
Pinus silvestris	409	33	311—521	8.0
Picea abies	387	30	308—482	7.8
Betula verrucosa	497	31	407—571	6.3
Betula pubescens	482	29	397—561	6.1
Alnus incana	361	22	281—412	6.2
Pinus contorta	433	24	370—495	5.5

The data on domestic tree species represent naturally regenerated stands, whereas the lodgepole pine derives from plantations. Norway spruce on plantations at any rate yields wood that is 5 per cent lighter than in natural forests (H a k k i l a and U u s v a a r a 1968), but no information is available on other Finnish tree species on this point.

The literature contains hardly any earlier data on the basic density of lodgepole pine grown in the Nordic countries. However, J o h n s s o n (1957) measured the value 390 kg/solid cu.m. for a 17-year-old Swedish stand. The value 460 kg/solid cu.m. was reported by T h o m a s (1966) for lodgepole pine grown in the British Isles. His volume measurements were made at a moisture content of 12 per cent, however.

443. Variation between stands

The stand-to-stand density variation was not significant in the analysis of variance based on discs. When the analysis was based on stem values, this variation component too proved significant.

Source of variation *Vaihtelu*	SS *Neliö-summa*	d.f. *Vapaus-asteet*	MS *Keski-neliö*	EMS *Odotusarvo*	F
Between south and north *Etelän ja pohjoisen välinen*	25 836	1	25 836	$\sigma_0^2+5.9\sigma_1^2+21.6\sigma_2^2$	$F_{1,18} = 27.24^{***}$
Between stands *Metsiköitten välinen*	19 277	22	876.2	$\sigma_0^2+5.0\sigma_1^2$	$F_{22,98} = 1.84^{*}$
Between stems + analytical error *Runkojen välinen + koevirhe*	46 679	98	474.3	σ_0^2	
Total *Yhteensä*	91 592	121			

The standard deviation between stems was 27.7 kg/solid cu.m. The proportion of the variation between South and North Finland is highly significant. The mean for South Finland was 433, that for North Finland only 383 kg/solid cu.m., i.e. 11.6 per cent smaller. It is known, on the other hand, that the basic density of Scots pine also decreases towards the north (H a k k i l a 1968).

The standard deviation between stands was 13.3 kg/solid cu.m. in South Finland, i.e. 3.1 per cent of the mean. Of the external tree characteristics, the mean heartwood percentage of a stand explains 15, age 10 and height 7 per cent of the variance. The crown proportion and the knotwood percentage

which do not by themselves explain the variation of density, when they are written as independent variables into the equation significantly raise together with the heartwood percentage, the coefficient of determination.

	R^2	$S_{y.x}$
$Y = 416.3 + 0.844\ x_1$	0.153	12.9
$Y = 366.8 + 0.723\ x_1 + 1.572\ x_2$	0.278	11.9
$Y = 371.4 + 0.774\ x_1 + 1.667\ x_2 - 8.880\ x_3$	0.308	11.7

Y = Average basic density of a stand, kg/cu.m
x_1 = Average percentage of heartwood
x_2 = Average crown proportion, percent
x_3 = Average knotwood percentage

The averages for South Finnish localities or site types do not differ significantly from one another. Nor does there seem to be a significant difference between the seed from British Columbia and Alberta.

5. DISCUSSION

Lodgepole pine is one of the most promising exotics in Finland. It grows fast when young, in several cases even essentially faster than our domestic conifers, provided that the seed comes from a district with similar climatic conditions to those of Finland. Growth culminates in a relatively early phase, and the economic rotation age of a stand is hardly more than 50 years, but a short rotation period is in itself an advantage.

However, lodgepole pine has not been cultivated in Finland on a practical scale, partly because of doubts about its technical properties in particular. Its wood is considered to be knotty and it is therefore not equal to domestic pine and spruce as saw timber. On the other hand, because of the shortage of pulpwood in Finland, timber traditionally used as saw timber is already being utilised on a considerable scale for pulping, and the increase in wood consumption in the future is expected to occur just in pulpwood (cf. Ervasti, Heikinheimo, Kuusela and Mäkinen 1970).

When plantations are established in the future serious attention should be paid to the possibility of growing in some stands pulpwood only. The question of the technical properties of lodgepole pine will then be seen in a new light and information will be needed on its suitability as raw material for the pulp industry. The studies carried out by the Finnish Forest Research Institute and the Finnish Pulp and Paper Research Institute in 1969—1970 concentrated on this problem. A comparison was made primarily between lodgepole pine and domestic pine as raw material for the production of sulphate pulp.

It was established that lodgepole pine grown in Finland has a low bark percentage and high basic density compared with domestic softwoods, both properties of advantage from the pulping point of view. It is also known that lodgepole pine at an early age has a fairly long fibre which in Britain compares closely with Scots pine and may approach the average length of 3.1 mm recorded for mature lodgepole pine from America (Brazier 1966). The heartwood percentage remains relatively low if the rotation age is not higher than 50 years, and this too is a positive factor in the pulping process. In consequence to this, there are few extractives, which increases the pulp yield but decreases that of by-products. According to the analyses made by the Finnish Pulp and Paper Research Institute, the proportion of acetone ex-

tractives in a sample taken at 1/4 height of the stem was only 1.2 per cent in the total investigation material (Salin and Palenius 1970). In contrast, the percentage of knotwood, an average of 1.1 per cent in this study, is high and lowers the screened pulp yield.

It could be assumed on the basis of the wood properties that lodgepole pine gives in the sulphate pulping process a fully satisfactory yield and qualitatively good pulp compared with our domestic conifers. Pulping experiments confirmed this. The total sulphate pulp yield was 49.7 per cent and screened yield 45.7 per cent (Kappa SCAN 35). The total yield was one per cent unit higher than in the corresponding experiments with pine, but the proportion of screennig rejects was high partly because of the high percentage of knotwood (Salin and Palenius 1970).

Compared with Scots pine, sulphate pulp from lodgepole pine has a higher tensile and bursting strength and folding endurance, but a lower tearing strength. It could be assumed on the basis of the higher wood density of lodgepole pine that the differences would more likely be the contrary. However, what is probably decisive is that lodgepole pine obviously has fewer thick-walled summerwood fibres, although the differences in the cell wall thickness between spring- and summerwood are correspondingly smaller. The following example compares the properties of pulp made from lodgepole pine and Scots pine in the conditions of South Finland (Salin and Palenius 1970).

Property	Lodgepole pine	Scots pine
Breaking length, km ..	10.8	9.7
Burst, m^2	90.1	82.2
Tear, m^2	2.4	2.8
Specific gravity	0.74	0.70

The sulphate pulp from lodgepole pine resembles in its properties chiefly the corresponding Scots pine pulp of North Finland. It is fully acceptable in quality even as such. On the other hand, lodgepole pine cannot ever be cultivated on such a scale in Finland that its pulping separately from other tree species could be considered in practical conditions. Mixed pulping with Scots pine or Norway spruce is not expected to cause any problems (Eskilsson, Person and Svensson 1969).

As lodgepole pine is also wanted to help solve the regeneration problems in the North, it was sought in this study to pay attention to the differences between wood growing in North and South Finland. However, there were only two sufficiently old plantations in North Finland, and the figures in Table 2 must therefore be treated with great reserve as far as North Finland is concerned.

Table 2. Average properties of lodgepole pine in South and North Finland in the research material.

Taulukko 2. Murrayn männyn puuaineen keskimääräisiä ominaisuuksia tutkimusaineistossa Etelä- ja Pohjois-Suomessa.

Property *Ominaisuus*	South Finland *Etelä-Suomi*	North Finland *Pohjois-Suomi*	t-value of difference *Erotuksen t-arvo*
Bark, per cent *Kuoriprosentti*	9.5	9.6	$t_{120} = 0.26$
Heartwood, per cent *Sydänpuuprosentti*	18.1	11.5	$t_{120} = 2.45^{*}$
Knotwood, per cent *Oksapuuprosentti*	1.0	1.7	$t_{120} = 3.07^{**}$
Basic density, kg/cu.m. *Tiheys, kg/k-m³*	433	383	$t_{120} = 6.62^{***}$
Acetone extractives, per cent *Asetoniuutteita, %*	1.2	1.6	$t_{16} = 1.14$
Total pulp yield, per cent *Kokonaissellusaanto, %*	49.8	48.8	$t_{16} = 1.21$
Screened pulp yield, per cent *Lajiteltu sellusaanto, %*	46.1	42.9	$t_{16} = 4.16^{**}$

Most important from the practical point of view is the great difference in basic density which means in North Finland a correspondingly higher wood consumption in pulping. Yet it must be noted that the basic density of Scots pine, too, is lowest in North Finland (cf. Hakkila 1968). Wood consumption in the pulping process is as follows:

	Basic density kg/cu.m	Screened yield %	Wood consumption cu.m./ton of oven dry pulp
South Finland	433	46.1	5.0
North Finland	383	42.9	6.1

It can hardly be established on the basis of the lodgepole pine plantations in Finland which seed source gives the best wood properties. But it is clear that differences occur between provenances, not only in the growth rate but also in wood properties. The choice of provenance is likely to be governed by silvicultural considerations, but the character of the timber could influence it (Brazier 1966). Greater attention must consequently be paid in the future also to this point.

The study shows that the properties of the wood of lodgepole pine are equal to those of our domestic softwood species for the production of sulphate pulp. Hence, it does not offer any appreciable advantage in wood properties

over Scots pine and Norway spruce. On the other hand, nothing emerged from the studies conducted by the Finnish Forest Research Institute and the Finnish Pulp and Paper Research Institute to place in doubt its suitability as raw material for the pulp industry. As the growth of lodgepole pine is in certain conditions superior to that of our domestic tree species, the possibilities of growing it should be considered carefully. An interesting possibility is the afforestation of fields with clay sub-soil (cf. P. M. A. T i g e r s t e d t 1970).

6. SUMMARY

Pinus contorta var. latifolia S. Wats, the geographical race of the lodgepole pine that grows in British Columbia and Alberta, thrives well in Finland in certain conditions. An impediment to its cultivation is, however, the doubts expressed about its technical properties. A study was therefore conducted in 1969—1970 jointly by the Finnish Forest Research Institute and the Finnish Pulp and Paper Research Institute to establish the suitability for sulphate pulping of lodgepole pine cultivated in Finland. This article deals with the wood properties.

The investigation material was collected chiefly from the experimental forests of the Finnish Forest Research Institute in different parts of the country (Fig. 4). The small size and limited number of plantations made the selection of sample trees difficult. In addition to statistical standpoints, the requirements of the permanent sample plots located on the cultivations had to be taken into consideration. A total of 122 sample trees from 24 stands were felled. Twenty two of the stands were in South and only two in North Finland. The mean age of the trees was 40 years, breast height diameter 12.8 cm, height 13.4 m and volume 116 litres (Table 1).

The wood properties were determined from 5 cm thick discs which were sawn from the butt cross-section to the top at intervals of one metre. Bark percentage on the dry weight basis, heartwood percentage and knotwood percentage on the volume basis, and the basic density of the wood were studied. The most important results are summarised in the following.

In accordance with the pattern common to all tree species, the bark percentage of lodgepole pine decreases from the butt upwards to a certain height and then begins again to increase at an accelerating rate (Figs. 5 and 7). It is at its lowest at the 30 per cent height of the stem. The average bark percentage of the stem can be estimated with good accuracy from a sample taken at breast height or at the 50 per cent height (Fig. 6).

The average bark percentage of the sample trees was 9.5 which, taking the average size of the stem into consideration, is small compared with the domestic tree species. The standard deviation of the bark percentage between stems was 1.9 per cent units and it was explained best by stem size and form. Bark percentage decreases when size increases and tapering diminish-

es. There is a positive correlation between knotwood percentage and bark percentage. The external tree characteristics explain 53 per cent of the stem-to-stem variation and 83 per cent of the stand-to-stand variation.

The heartwood percentage was at its maximum at the 10—20 per cent height (Fig. 8). The average heartwood percentage of the whole stem was the same as the heartwood percentage at the 40 per cent height (Fig. 9).

The average heartwood percentage was a relatively low 17.5 and its standard deviation was 9.1 per cent units. The external stem characteristics explained 35 per cent of the stem-to-stem variation and 69 per cent of the stand-to-stand variation. The best individual variable was tree height which correlated positively with the heartwood percentage.

The knotwood percentage grows from the butt towards the top. It was 0.5 per cent at the butt end and 2 per cent at the top end (Fig. 11).

The average knotwood percentage was relatively high, 1.1. It was distinctly higher in the north than in the south (cf. Table 2). It was possible to explain 44 per cent of the stand-to-stand variation in the South Finnish material.

Basic density decreases from the butt to the 60 per cent height, then begins to increase again in most stems (Fig. 14). The average stem density can be estimated from a sample taken at breast height or at the 20 per cent height (Fig. 16).

The average wood density was higher than that of Scots pine and Norway spruce, being 433 kg/solid cu.m. in South and 383 kg/solid cu.m. in North Finland. These density values include the effect of the branches which causes an average increase of 1.5 per cent in the density of defect-free wood (Fig. 15). Only a small proportion of the standard deviation between stems could be explained with the help of external characteristics.

The total yield in the pulping experiments performed by the Finnish Pulp and Paper Research Institute was 49.7 per cent and the screened yield was 45.7 per cent (Kappa SCAN 35). The consumption of wood per oven dry ton of pulp, on the basis of wood density and screened yield, was 5.0 solid cu.m. for the South and 6.1 solid cu.m. for the North Finland material. The tensile and bursting strength and folding endurance of the pulp were better, but its tearing strength poorer than for Scots pine on the average. Pulp made of lodgepole pine resembles chiefly Scots pine pulp from the north.

The results warrant the conclusion that lodgepole pine makes very suitable raw material for the sulphate pulp industry in Finland. As the species is fast-growing its cultivation on a practical scale for the needs primarily of the pulp industry should be considered seriously.

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SUOMESSA KASVATETUN PINUS CONTORTAN PUUAINEEN OMINAISUUKSISTA

Lyhennelmä

Murrayn männyn Brittiläisen Kolumbian ja Albertan maantieteellinen rotu, *Pinus contorta var. latifolia* S. Wats, menestyy Suomessa tietyissä oloissa hyvin. Sen viljelyn esteenä ovat kuitenkin mm. puun teknisiin ominaisuuksiin kohdistuvat epäluulot. Tästä syystä tehtiin vuosina 1969—1970 Metsäntutkimuslaitoksen ja Keskuslaboratorion yhteistyönä tutkimus, jonka tavoitteena oli selvittää Suomessa kasvatetun Murrayn männyn soveltuvuus sulfaattisellun valmistukseen. Tässä artikkelissa keskitytään eräisiin puuaineen ominaisuuksiin, joitten tutkiminen on ollut Metsäntutkimuslaitoksen tehtävänä. Keskuslaboratorion keittokokeitten tuloksista on laadittu erillinen seloste (S a l i n ja P a l e n i u s 1970).

Tutkimusaineisto kerättiin pääasiassa Metsäntutkimuslaitoksen koeviljelmiltä maan eri puolilta (kuva 4). Koepuitten valintaa vaikeuttivat viljelmien pieni koko ja rajoitettu lukumäärä, niin että tilastollisten näkökohtien lisäksi oli otettava huomioon myös viljelmillä sijaitsevien pysyvien koealojen asettamat vaatimukset. Kaikkiaan kaadettiin 122 koepuuta yhteensä 24 metsiköstä, joista 22 sijaitsi Etelä-Suomessa ja vain 2 Pohjois-Suomessa. Puitten keski-ikä oli 40 vuotta, rinnankorkeusläpimitta 12.8 cm, pituus 13.4 m ja tilavuus 116 litraa (taulukko 1).

Puuaineen ominaisuudet määritettiin 5 cm:n paksuisista kiekoista, joita sahattiin tyvileikkauksesta lähtien metrin välein latvaan saakka. Tutkimuksen kohteena olivat kuoren kuivapainoprosentti, sydänpuun ja oksapuun tilavuusprosentti sekä puuaineen tiheys. Tärkeimmät tulokset olivat lyhyesti seuraavat.

Kaikille puulajeille yleisen mallin mukaisesti Murrayn männyn kuoriprosentti alenee tyvileikkauksesta ylöspäin tietylle korkeudelle saakka, minkä jälkeen kuoren osuus alkaa jälleen kiihtyvästi kasvaa (kuvat 5 ja 7). Alimmillaan se on rungon 30 %:n korkeudella. Rungon keskimääräinen kuoriprosentti voidaan huomattavalla tarkkuudella estimoida rinnankorkeudelta tai 50 %:n korkeudelta otetusta näytteestä (kuva 6).

Koko aineiston keskimääräinen kuoren painoprosentti oli 9.5, jota on rungon keskikoko huomioon ottaen pidettävä kotimaisiin puulajeihin verrattuna pienenä. Runkojen välinen kuoriprosentin hajonta oli 1.9 prosenttiyksikköä, ja sitä selittivät parhaiten rungon koko ja muoto. Koon kasvaessa, kapenemisen hidastuessa ja oksikkuuden vähentyessä kuoriprosentti pienenee. Rungon ulkoiset tunnukset selittävät runkojen välisestä vaihtelusta 53 % ja metsiköitten välisestä vaihtelusta 83 %.

Sydänpuuprosentti on suurimmillaan 10—20 %:n korkeudella (kuva 8). Koko rungon sydänpuuprosentti on keskimäärin sama kuin sydänpuuprosentti 40 %:n korkeudella (kuva 9).

Keskimääräinen sydänpuuprosentti oli verraten alhainen, 17.5, ja sen hajonta 9.1 prosenttiyksikköä. Ulkoiset tunnukset selittivät sydänpuuprosentin runkojen välisestä vaihtelusta 35 % ja metsiköitten välisestä vaihtelusta 69 %. Paras yksityinen selittäjä oli puun pituus, joka korreloi sydänpuuprosentin kanssa positiivisesti.

Oksapuuprosentti kasvaa tyvestä latvaa kohti. Tyvessä se oli 0.5 %, latvassa 2 % (kuva 11).

Keskimääräinen oksapuuprosentti oli verraten suuri, 1.1, pohjoisessa selvästi korkeampi kuin etelässä (vrt. taulukko 2). Metsiköitten välisestä vaihtelusta voitiin Etelä-Suomen aineistossa selittää 44 %.

Puuaineen tiheys laskee tyvestä 60 %:n korkeudelle, minkä jälkeen se useimmissa rungoissa alkaa uudelleen kohota (kuva 14). Rungon keskimääräinen tiheys voidaan estimoida rinnankorkeudelta ja 20 %:n korkeudelta otetusta näytteestä (kuva 16).

Keskimääräinen puuaineen tiheys oli korkeampi kuin männyn ja kuusen, Etelä-Suomessa 433 ja Pohjois-Suomessa 383 kg/k-m^3. Tällöin on tiheydessä mukana myös oksien vaikutus, joka aiheuttaa virheettömän puuaineen tiheyteen keskimäärin 1.5 %:n lisäyksen (kuva 15). Runkojen välisestä hajonnasta, 27.7 kg/k-m^3, voitiin ulkoisten tunnusten avulla selittää vain vähän.

Keskuslaboratorion keittokokeissa sulfaattimassan kokonaissaanto oli 49.7 % ja lajiteltu saanto 45.7 % (Kappa SCAN 35). Puun kulutus on puuaineen tiheyden ja lajitellun massan saantoprosentin perusteella Etelä-Suomessa 5.0 ja Pohjois-Suomessa 6.1 k-m^3 absoluuttisen kuivaa sellutonnia kohti. Massan veto- ja puhkaisulujuus sekä taittokestävyys ovat paremmat mutta repeämislujuus huonompi kuin männyllä keskimäärin. Murrayn männystä tehty massa muistuttaa lähinnä pohjoista mäntymassaa.

Tulosten perusteella voidaan päätellä, että Murrayn mänty soveltuu Suomen oloissa hyvin sulfaattiselluteollisuuden raaka-aineeksi. Ei myöskään näytä olevan esteitä Murrayn männyn ja kotimaisten havupuulajien sekakeitolle. Koska puulaji on nopeakasvuinen, on syytä vakavasti harkita sen viljelyä käytännön mittakaavassa lähinnä kuituteollisuuden tarpeita silmällä pitäen.

FACTORS INFLUENCING SILVICULTURAL ACTIVITY

A study of the influence of attitudes, individual farm backgrounds, and regional conditions on the silvicultural activity of forest owners in Karstula and Jämsä, Finland

VELI-PEKKA JÄRVELÄINEN

Tiivistelmä

METSÄNHOIDOLLISEEN TOIMINTAAN VAIKUTTAVAT TEKIJÄT

Tutkimus asenteiden, tilakohtaisten taustaedellytysten ja alueellisten edellytysten vaikutuksesta metsänomistajan metsänhoidolliseen toimintaan Karstulassa ja Jämsässä

HELSINKI 1971

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PREFACE

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Helsinki, January 1971

Veli-Pekka Järveläinen

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0. SUMMARY

The purpose of the present study was to analyze the forest owner's silvicultural activity, the work he undertakes which is directly or indirectly associated with tree growing. The effects of the forest owner's silvicultural attitudes, the individual farm backgrounds and the regional conditions were studied in an exploratory manner.

The material for the study was collected by personal interviews in the summer of 1966 in the communes of Karstula and Jämsä in Finland. A total of 289 forest owners, randomly selected, were interviewed.

The selection of the variables used in the analysis was carried out using mainly the theoretical basis of the characteristics of tree growing. The communes studied were selected on the basis of certain conceptual fundamentals suggestive of ideal types illustrating social change.

The empirical analysis focused on three tasks; condensing the information; review of relationships among variables; and comparison of the communes studied. The technique of factor analysis was used to condense the information of the numerous original variables and to construct composite variables. The review of relationships among the composite variables constructed was carried out by means of correlation analysis. The comparison of the communes studied was mainly restricted to an ocular comparison of correlation matrices describing relationships between composite variables, calculated separately for the communes.

Concerning the results of the study, it must be emphasized that no universally applicable regularities are arrived at. Rather, the results are presented as empirical generalizations which necessarily require further verification and specification.

It was observed that the forest owner's attitudes do not really affect his use of experts and the absolute extent of his silvicultural activity (total measures). These activities are determined in the first place by differences in individual farm backgrounds; good productive and economic resources at the forest owner's disposal increase his use of experts and the absolute extent of his activity,while the abandonment of farming is a reducing factor. On the other hand, the relative extent of silvicultural activity (measures/ha) and readiness to act (introduction of measures after taking over a farm)

depend almost equally on the forest owner's attitudes and individual farm backgrounds.

These findings reflect certain regularities at the individual level. Some generalizations concerning changes at the community level were also observed. The research suggested that while the rural environment proceeds towards industrialization and modernization, the forest owners' average silvicultural activity declines and their attitudes to silviculture, on the average, become less favourable than before. It also seems that functional, regional, and value differentiation may be expected in tree growing as the modernization of the rural environment advances.

1. INTRODUCTION

11. A study of the forest owner's behaviour; general basis

Lively discussions have been going on for some time in the sphere of the behavioural sciences concerning the basis of methodology. The nature of knowledge obtained by behavioural-science studies and the question of the role of values in these studies have been considered. According to some authors, separating values and moral judgements from behavioural-science studies is an illusory aim, arising from misconceptions concerning the ultimate nature of the information dealt with in these sciences (A h m a v a a r a 1969, pp. 19—73).

Values are believed to reveal themselves particularly in the problem to be studied (K a r l s s o n 1965, p. 3). The difficulty then is specification of questions, the study of which, for some reason, is considered interesting and important. This selection of interesting and important questions is very often a matter of value ordering and moral judgement. This is true particularly of applied behavioural-science research.

The role of value in applied research is something that cannot be overlooked if a study is to be critical. For this reason, studies should explicitly outline the general fundamentals on which the definition of the problem is ultimately based (M i l l s 1959, pp. 128—131; S e l l t i z et. al. 1965, p. 29). A study of the forest owner's behaviour is not exceptional on this point.

The general fundamentals of a study of the forest owner's behaviour are those typical of applied research. This type of study is usually prompted by public issues or practical difficulties, and its aims must ultimately be justified by referring to those issues or difficulties. Studying the forest owner's behaviour has proved important, for example, because

> »the various factors, motives and attitudes affecting the decisions made by the forest owner must be known before forest policy can be planned» (Suomen metsätieteellinen Seura 1967, p. 47).

The present study assumes the approache necessitated by this problem of forest-policy planning; in addition to the author's personal interest, the selection of the topic was governed by the following two interrelated views.

(1) How to carry out the requirements of forest policy and how this depends on the forest owner's behaviour.

The main goal of forest policy in Finland today is to secure sufficient timber production. Sufficient timber production means that an adequate and continuously increasing flow of raw materials for the forest industry, an important export industry in Finland, can be supplied by the country's forests. Since 65 per cent of the forests in Finland are privately owned (U u s v a a r a 1969, p. 21), and since the share of these forests in the timber production in the whole country is almost 80 per cent (H o l o p a i n e n 1967, p. 17), the problems of sufficiency and intensification of timber production are intimately connected with private forests. Attainment of forest-policy objectives is therefore essentially dependent on what happens in private forestry, i.e. on the behaviour of the individual forest owners, whose decisions vitally affect the production of timber.

It may be useful to point out, however, that the dependence of forest-policy plans on the forest owner's behaviour naturally is not limited to timber production alone. Whatever the goals of forest policy, it is hardly possible to reach a situation in which the realizations of the plans would be wholly independent of the forest owner's behaviour; the only case would be the complete absence of private ownership.

(2) Incomplete systematic knowledge of the forest owner's behaviour may lead to forest-policy decisions which are ineffective, creating more problems.

Planning presupposes systematic knowledge of the phenomena to be planned. Forest-policy planning presupposes knowledge of the phenomena to which forest policy applies, in order that estimating and forecasting the effects of forest-policy measures may be possible. This and only this creates a situation in which forest-policy actions may be expected to lead to the goals established (V e l i - P e k k a J ä r v e l ä i n e n 1969 a, p. 257). An important aspect in studying the effects of the means used by forest policy is inquiring into reasons for forest owner's behaviour. The importance of this research is enhanced by the large number of private forest owners in Finland; approximately 300 000 (Suomen Virallinen Tilasto, XVII A. 1969, pp. 41—42).

As recently as the early 1960 s, P ä i v i ö R i i h i n e n could conclude that

> »to date, the forest has been the almost exclusive subject of study in Finland, although a parallel study of the owner's motives, roles and behaviour might shed a more realistic light on the problems of farm forestry in particular» (P ä i v i ö R i i h i n e n 1963, p. 13).

This is why forest policy applying to the private forest owner, and its planning, often has had to replace systematic knowledge with frequently

unreliable assumptions and guesswork. In recent years, however, increasing attention has been devoted to the important position the forest owner holds in the problems of Finnish forestry and forest policy. The necessity of research into the forest owner's behaviour has been particularly stressed (Holopainen 1967, pp. 16—23; Keltikangas 1965; Päiviö Riihinen 1965).

12. The forest owner's roles; review of the essential concepts

Saari (1928, p. 5) defined forestry as a form of human activity which aimed at supplying commodities obtainable from the forest, either for direct consumption or for production other than forestry. According to this definition, many different activities can be included in forestry and forestry behaviour. This is also true of the forest owner's forestry behaviour. The forest owner grows, harvests and sells timber, but he also consumes timber in his own household, e.g. fuelwood and building material.

Such activities, however, need not always be considered as an entirety. In effect it is seldom possible to analyze all the different aspects of forestry behaviour in the same study; it is preferable to focus interest on some suitable grouped-component activities. In this grouping, the concept of role is helpful.

The social role refers to the sum of the expectations and norms to which the relevant person is subjected because he holds a given position in a group (Eskola 1964, pp. 562—564). The scientist's role, for example, is composed of the expectations made of man as scientists and research worker. Analogously, the forest owner's role may be said to consist of the expectations made of him just because he owns forest. These expectations, however, are not completely uniform. It seems, in fact, that a whole »role-set» (see Johnson 1966, pp. 34—39) is associated with the forest owner's position. The forest owner is judged as a tree grower by forestry experts employed by organizations for the promotion of forestry, as a timber harvester or seller by forest experts employed by the forest industry, as a timber consumer by scientists studying fuelwood consumption, and so on. It is therefore possible to designate several roles for the forest owner in forestry; the expectations and obligations these place on his behaviour are different. The forest owner's roles can be grouped in many different ways; the following is one alternative. There are

— the tree grower's role,
— the timber harvester's role,
— the timber seller's role, and
— the timber consumer's role.

The present study will focus, and also restrict, attention to the *forest owner as a tree grower*. The behaviour associated with the tree grower's role may be called *silvicultural behaviour*.

The concept of silvicultural behaviour, however, will be used in its comprehensive sense, as a wide concept including such more specific phenomena as silvicultural activity and silvicultural attitude. These latter concepts, essential to the present study, may be defined specifically in this way. *Silvicultural activity* refers to measures directly or indirectly associated with tree growing; *silvicultural attitude* meens attitude to various factors directly or indirectly associated with tree growing. The concept of attitude (see E s k o l a 1963, p. 62) is then limited to apply only to verbal attitudes, measured from the logic of verbal reactions alone.

13. The problem

It was said above that the forest owner's important position in the problems of Finnish forest policy has emerged increasingly in recent years. Interest in questions associated with the forest owner's hehaviour, however, is not of very recent origin. Apparently it has existed as long as forestry has been a means of livelihood. This is indicated, for example, by the private forestry topic the meeting of Finnish farmers in Turku in 1850 chose for discussion:

> »Is high cost or lack of skill responsible for poor forest management by the forest owners; or is there something else preventing clear-cutting, seeding and planting?» (T a u n o J ä r v e l ä i n e n 1940, p. 51).

The question of the factors affecting the forest owner's silvicultural behaviour has subsequently been discussed in many contexts in forestry. Many research workers and practical foresters have advanced their views and come to slightly differing conclusions. Some have stressed the importance of attitudes and found that the progress of private forestry is impeded by the forest owner's negative attitude to silviculture. It has been claimed that the forest owners in general are unwilling to take any silvicultural measures and therefore do not feel sufficiently responsible for the appropriate management and use of the forest they own. Others have placed more emphasis on material conditions. They have stressed that factors reducing silvicultural activity are not represented by the forest owner's attitudes as often as by the insufficient productive and economic means at their disposal. The forest owners are willing to practice silviculture but often lack the material requisites.

These discussions (cf. H o l o p a i n e n 1967, pp. 127—129) have contributed to providing the impulse for outlining the problem of the present

study. In fact, the study attempts preliminary elucidation of some of these questions. Generally speaking, the aim of the study is to develop a theoretical frame for studies concerning the forest owner's silvicultural behaviour and to explore, with aid of a relatively small body of empirical material, the relevance of this frame. The study will be restricted, however, to reviewing only problems of farm forestry. *Its purpose is to analyze factors affecting the forest owner's silvicultural activity.* The factors whose effects are to be analyzed can be divided into three main groups as follows (see Fig. 1):

(1) the forest owner's silvicultural attitudes;
(2) the individual farm backgrounds; and
(3) the regional conditions associated with changes in rural environment.

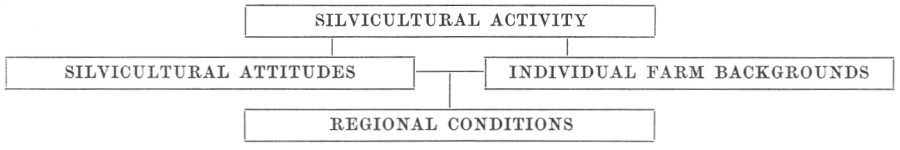


Fig. 1. Disposition of the present study.

However, it must be stressed here that the study is exploratory in character. Its purpose is more to construct than to test hypotheses. It may be interpreted as preliminary, designed to provide some results for use in the planning and implementation of more extensive and theoretically more advanced analyses.

2. FRAME OF REFERENCE

21. Precision of the theoretical basis

A theoretically justified basis is required for even an exploratory study in order to guide the selection of variables and to direct empirical surveys. A serviceable theoretical basis for this study of the factors affecting the forest owner's silvicultural activity in farm forestry might have been provided by an overall consideration of farm husbandry. The fact that forestry in farm husbandry is not a separate branch obeying its own rules, but is firmly intergrated in the overall management of the farm, seems to favour such a basis (D u e r r 1960, pp. 20, 54; H a h t o l a 1967a, pp. 7—8; S t r e y f f e r t 1956, pp. 20—22). In this case a major part of the study would have consisted of an analysis of the conditions of total farm management, their relationship to the forms of production (mainly agriculture and forestry), and their effect on tree growing and the forest owner's silvicultural activity.

Despite its theoretical interest, this basis of overall consideration was abandoned, since it was found to entail complicated issues and to lead to numerous special problems. Another basis, more limited theoretically and perhaps more easily controllable empirically, was sought to guide the selection of explanatory variables. *A theoretical basis resting on the special characteristics of tree growing* seemed suitable. The selection of explanatory variables in the present study is therefore based mainly on the views advanced in forestry literature concerning the most characteristic features of forest management and those inherent in tree growing (e.g. extensiveness of tree growing, the long-term economic nature, and the continuity of ownership). Guiding hints can be found also among empirical findings reported in studies concerning the adoption of agricultural innovations. Nevertheless, the selection of some variables must be based almost solely on intuition (e.g. propositions concerning silvicultural attitude).

An additional feature associated with the theoretical basis of this study can be seen in the conceptual apparatus which guided the selection of the communes to be studied. In defining the purpose of the study (p. 13), it was said that one of the aims is to analyze the possible effects of regional conditions associated with changes in the rural environment on the forest

owner's silvicultural avtivity. This means, above all, that the analysis of factors affecting silvicultural activity will be linked to the general processes of rural change. This may be called *the theoretical basis resting on change in the rural environment.*

22. Tree growing and the forest owner's attitudes

Originally, 30 propositions for reflecting the forest owner's silvicultural attitudes were worked out. They were selected mainly on the basis of intuitive consideration, even though the questionnaire in a study of the forest owner's economic and social behaviour by P ä i v i ö R i i h i n e n (1966) provided some hints. The propositions were selected to measure the forest owner's

— general interest in silviculture,
— attitude to the economic profitability of silviculture,
— attitude to legally imposed restrictions and obligations concerning silviculture,
— attitude to silvicultural methods, and
— attitude to forestry experts and forest management associations.

The discussions guiding the selection of propositions assumed that the owner's silvicultural attitude consists of several separate component attitudes which may be associated with his silvicultural activity in different ways. General interest in silviculture was assumed to be one component attitude. This assumption was based on views which indicate that a lack of general interest in silviculture among forest owners is one of the factors impeding silvicultural progress in private forestry (p. 12). It was further assumed that feelings about the economic profitability of silviculture might contribute to a specific attitude, bearing in mind the delayed returns from tree growing which compete with the other forms of farm production, primarily agriculture (H o l o p a i n e n 1957, pp. 216—217). Also, the fact that certain restrictions and obligations are legally imposed on the management and use of forests by private owners (e.g. The Law on Private Forests) is interesting in this connection. It could be assumed, considering the tendency towards a particularly independent life style often said to be a special characteristic of the Finnish farmer (H a h t o l a 1967 b, p. 20), that these restrictions on the forest owner's powers of decision and freedom of action might form one of the attitudes to be studied.

In addition, propositions reflecting two other component attitudes were finally included in the study. It seemed justifiable to assume that attitudes towards silvicultural methods, especially any new methods, might form one dimension, reflecting perhaps the forest owner's general attitude to inno-

vations. It also seemed correct to construct propositions by which the attitude to forestry experts and forest management associations could be measured. This latter stems from the lively and even sharp discussions of the work and usefulness of forest management association which have at times been conducted in public (see Metsänhoitoyhdistyslain tarkistamiskomitean mietintö 1959).

23. Tree growing and individual farm backgrounds

231. Structural conditions for farm production

When the theoretical basis of this study was defined it was indicated that the selection of variables to be used in analysis is best based on ideas concerning the specific characteristics of forest management and tree growing (p. 14). The primary reference guiding the selection of the explanatory variables was provided by the views S a a r i (1928) has advanced on the characteristics of the form of enterprise best suited for forestry. It may be assumed that factors considered indicative of the suitability of an enterprise form for forestry are also relevant when background factors affecting the forest owner's silvicultural activity are sought.

According to S a a r i (1928, p. 14), the form of enterprise best suited for forestry has attributes such as the following:

(1) far-reaching logic and sagacity;
(2) a continuity independent of the human life-span;
(3) the opportunity for undertaking large-scale production and making use of the advantages so offered;
(4) sources other than the forest for meeting short-term cash requirements;
(5) opportunities for investing funds in permanent forest improvements or in measures with long pay-back periods;
(6) the highest possible consideration for the public interest; and
(7) a willingness to operate as a business and the opportunity of doing so.

The third point is one of the most important items when considering the structural conditions relating to farm production. The general view in forestry literature is that large enterprises are better suited for forestry activities than small ones. H o l o p a i n e n (1957), defining the conditions under which the goals of forestry promotion (e.g. increasing timber production) can best be realized, emphasizes the importance of the size of the forest unit. According to him, *a sufficiently large forest unit* is able to meet six varying demands: (1) silviculture, (2) sustained-yield management, (3) marketing, (4) logging, (5) administration, and (the last three together)

(6) business economics (H o l o p a i n e n 1957, pp. 18—19). He points out, however, that a given forest-unit size need not meet all these requirements simultaneously. The requirement concerning silviculture is often met by even relative small forest units, whereas the administrative requirement presupposes extensive forest ownership. In any case, the size of the forest unit seems to be an important structural condition for farm production, and it may also integrally affect the silvicultural measures taken. Practically no empirical data concerning the effect of forest-unit size on the forest owner's silvicultural activity is available. But several investigations on the connections between forest-unit size and silvicultural state seem to agree that the silvicultural state often improves as the size of the forest unit increases (E r k k i l ä 1943, pp. 36—39; I l v e s s a l o & M ä k i n e n 1962, pp. 16—17; L i n n a m i e s 1943, pp. 41—44; M a n t e l 1956, p. 393; M c C l a y 1961, pp. 88—92; O s a r a 1935 a, pp. 165—170).

In addition to the absolute size of the forest unit, its *relative importance to the whole farm* may also constitute a factor deserving attention in this study. No empirical data is available concerning its effect on the forest owner's silvicultural activity, but connections between the relative amounts of arable and forest area on a farm and the silvicultural state of the forest unit have been analyzed in some studies. P ä i v i ö R i i h i n e n analyzed the regional variation (by forestry board districts) of farm forests, and E r k k i l ä discusses the silvicultural state of peasant-owned forests. On examining ecological relationships, R i i h i n e n came to the interesting conclusion that the distribution of landed property ultimately is a more important factor than its extent, from the point of view of good forest management (P ä i v i ö R i i h i n e n 1963, p. 33). E r k k i l ä concluded from his observations that when the relative amount of forest area increases the forest owner's concern for the silvicultural state of his forest at first increases, but as soon as the forest area greatly outweighs the arable area his interest declines (E r k k i l ä 1943, p. 45).

In the same study, the results E r k k i l ä reports on the effect of the extent of agriculture on the silvicultural state of the forest also are interesting. He came to the somewhat surprising conclusion that *the amount of arable land* has a more pronounced beneficial effect on the silvicultural state of the forest than the size of the forest unit (E r k k i l ä 1943, pp. 33—36). According to his interpretation, this effect is mainly the result of the availability of economic resources to the owner of a large agricultural unit. In this connection, it is perhaps also useful to quote P i h a's studies of the economic yield (business surplus) of Finnish farm-forests. He found that the best economic returns

> »apparently were obtained from rather small and medium-large forest units which were combined with a large agricultural unit» (P i h a 1941, p. 232).

The structural conditions of farm production which may influence the forest owner's silvicultural activity also include *fertility of the forest soil.* Soil fertility affects even the technical aspects of silvicultural measures (e.g. in forest regeneration), not to mention its crucial role in determining the quantitative yield of a particular site. Besides, one of the primary results noted in Riihinen's study was that a marked ecological correlation existed between silvicultural state and fertility of forest soil (Päivö Riihinen 1963, pp. 44—45). Osara (1935 a, pp. 170—171), on the other hand, failed to discover any correlation between the mean volume of the forest and the soil fertility in his analysis of individual farms and small forest units in Finland.[1])

The internal and external traffic facilities on a farm may also be taken as a background factor governing the forest owner's silvicultural activity. Internal traffic facilities refer to the location of different parts of the farm (i.e. land distribution conditions) while the external traffic facilities refer to the location of the farm vis-à-vis important marketing centers and roads (Hahtola 1967 a, p. 13). Special attention has been devoted to the silvicultural role of land-distribution conditions, especially by Alho (1966) and Hahtola (1967 a & b). According to Hahtola good forest-distribution conditions improve silviculture by increasing the importance of the forest to the farms as a whole which leads to increased owner-interest in forestry; if forests are located adjacent to a farm's management centre the forest unit is easier to inspect (Hahtola 1967 a, pp. 127—128). But if the whole farm lies far from centres of population, Hahtola (1967 a, pp. 137—138) finds that the forest treatment level is lowered. This finding agrees with observations made in certain studies of innovation-diffusion in agriculture. For example, the investigations by Tauriainen into the success of land-settlement farm holders seem to indicate that the spread of innovations and, generally, the adoption of rational farm-management principles is connected with the distance factor. Geographical isolation and the resulting decrease in social participation slow down the spread of innovations (Tauriainen 1966, pp. 79—80; see also Westermarck 1968, pp. 8—10).

232. The forest owner's economic position

According to Saari's list, other characteristics of the form of enterprise best suited for forestry were sources other than the forest for meeting short-term cash requirements, opportunities for investing funds in permanent forest improvements or in measures with long pay-back periods, and wil-

[1]) Osara has later commented on the lack of correlation. He points out that fertile forest lands on small farms were often used for grazing cattle and their growing stock was low as a result.

lingness to operate as a business (p. 16). Forestry is customarily termed »the rich man's trade», and many investigators have found it justifiable to emphasize the importance of *the forest owner's income level and wealth* as a background factor strongly affecting silvicultural activity. It is emphasized that silvicultural activity increases hand in hand with increase in the general living standard (cf. Cajander 1935, p. 30; Hermansen 1964, pp. 317—318; Piha 1941, p. 91; Zapf 1960, p. 56). Reference may also be made to a statement issued among the forest owners themselves:

> »Nothing else can be expected from the Finnish peasant class than that it coolly evaluates its means of living. For this reason, it has no interests in the management of the farm other than those yielding tangible profits. It cannot therefore sacrifice very much in its forests to show admiration of nature or worship of beauty. It considers the forest as another economic object which must yield an income . . . But even though the farmer may recognize the great value and importance of forest, there is always the risk that his economic position is weak and that he for this reason is compelled to take from his forest more than good silviculture or sustained-yield forest management permits. A private forest owner is therefore always somewhat incalculable, and if he is penniless he makes a poor forestry operator». (Extract from a speech made by Juho Koivisto, M. P., at the 75-year jubilee of the Finnish forest service. See, Metsänhoitolaitoksen 75-vuotisjuhla 19. IV. 1934.)

This opinion of the beneficial effect of solid economic standing on silvicultural activity is not shared by all investigators, however. Päiviö Riihinen, for example, believes that gradually increasing wealth probably does not increase the forest owner's initiative; in other words, the average proportion of his income the forest owner invests in forest improvement does not become larger with increasing wealth (Päiviö Riihinen 1968, p. 167).

Analyses of the possible effects of factors associated with the forest owner's economic standing should cover two other factors, viz. *supplementary income* from sources other than agriculture or forestry and *total debts*. The repercussions of these factors are very difficult to estimate in advance, but a few points may be worth making.

It may be assumed, firstly, that increased supplementary income indicates a development by which the forest owner liberates himself from farm husbandry and which increasingly directs his attention to other trades. If so, increased supplementary income might weaken silvicultural activity. This assumption seems to find support in certain result reported by Osara, according to which the mean cubic volume of the forests of small farmers with an outside source of income was distinctly smaller than of those belonging to farmers devoting themselves to small-farming alone (Osara 1935 a, pp. 168—169; see also Hahtola 1967 a, 13 and 19). On the other hand,

increased supplementary income may be assumed to be connected with a general increase in economic resources and, if so, it should have an improving effect on silvicultural activity (cf. P ä i v i ö R i i h i n e n 1963, p. 14).

Increased debts may also initially be interpreted in two different ways. On the one hand, an increase in loan capital may indicate a reduction of wealth which would then weaken the conditions for tree growing. According to P i h a

> »the economic pressure of debts and their interest, varyingly experienced by farms with forest units of different sizes, also affects the use and treatment of forests. Small forest units apparently are subjected to heavier cuttings than large units, even at the risk of reducing growing stock capital, because the debts of the farm must be managed» (P i h a 1941, p. 92; see also O s a r a 1935 a, pp. 188—189).

On the other hand, one may assume that an increase in loan capital indicates intensified achievement motivation, a disposition towards investment and risk taking beyond that necessary for preserving the security of the status quo (E s k o l a 1965, pp. 172—173). An increase in loan capital would then indicate motivation to support active work and a readiness to invest. It may be pointed out that a positive correlation between agricultural innovativeness and the farmer's readiness to run a risk has been empirically demonstrated (W a l l s 1967, p. 140).

233. Farm ownership conditions

Another characteristic on S a a r i's list was a continuity independent of the human life-span (p. 16). This emphasizes the importance of ownership conditions as background factors governing forestry and the forest owner's silvicultural activity.

The importance of ownership conditions is particularly evident when one thinks how long it takes to grow a tree. It is fact that the revenue-yielding effects of silvicultural measures are often realized only after several decades. Therefore, it might be assumed that if *the continuity of ownership*, which here refers to the expectations for retention of the farm under the same owner or family, is threatened the forest owner's interest in silvicultural measures may be decisively weakened.

In addition to the continuity of ownership, *the duration of ownership*, i.e. the period of time during which the farm has been in the possession of the same owner or family, may be a background factor affecting the silvicultural activity of the forest owner. The effects of the duration of ownership attracted the attention of H o l o p a i n e n (1957, p. 217). According to him the neglecting of forest-improvement measures in farm forestry becomes more frequent when land changes hands often. His studies (in the forestry

board district of Keski-Suomi) revealed that an owner keeps possession of a farm for 34 years on the average. Furthermore, the duration of family ownership also may affect the implementation of silvicultural measures. One may assume that farms which have long been in a family's possession, thanks to their farm-husbandry traditions, are often managed with a view to long-term tree growing.

234. The forest owner's educational level and age

Among the conditions favourable to forestry promotion H o l o p a i n e n (1957, p. 19) suggests two requirements for the forest owner:

(1) He must have sufficient vocational skills for performing the tasks involved in forestry in the most appropriate way, i.e. using methods which are technically and economically optimum;
(2) He must have ambition and skill and the possibility of combining technical and economic knowledge with overall insight so that long-term investment in reforestation, drainage, machinery, etc. is most appropriate in view of the best development of forestry.

In their surveys of the background factors favouring tree growing, forestry researches have often emphasized the importance of the forest owner's educational level. S a a r i's list included the willingness to operate as a business (p. 16). This may be interpreted, at least partly, as requiring rational management principles and a certain educational level of forest owner. H a h t o l a describes the effects of the educational level when he says that

> »at present the forest owners are seldom able to estimate even approximately the economic profits obtainable from investment in intensified production or the time span within which returns may be expected. The result is that the funds available are invested elsewhere, and an economically highly justifiable investnent in forestry is foregone» (H a h t o l a 1964, p. 484; see also I l v e s s a l o 1948, p. 13; M i g n e r y 1956, pp. 102—105; O s a r a 1935 b, p. 18).

One indicator of the educational level, for the purposes of the present study, is *the forest owner's level of schooling*. The effect of schools has been analyzed, especially in studies of innovative behaviour in agriculture. A high level of schooling has been found to be associated with, for example, planning in farm management and rapid adoption of innovations (W a l l s 1967, p.24). On the other hand, studies placing less importance on the general level of schooling have also been published. According to the studies by T a u r i a i n e n concerning the success of land-settlement farm holders, school education is connected with a rapid adoption of innovations while its relationship with the work itself (farming) is less pronounced. T a u r i a i n e n places more

emphasis on use of sources of knowledge and membership in vocational organisations (T a u r i a i n e n 1966, pp. 87—88). Consequently, including variables measuring *the forest owner's use of sources of knowledge and organizational involvement* in the analysis of silvicultural activity seems justified.

Certain demographic background factors also merit discussion. The most important are perhaps *the forest owner's age and family structure*. The effects of age have been explored in the studies of innovativeness in agriculture. It was found that the farmer's aging correlated with a slower adoption of innovations, while his willingness to undertake long-term investment declined as well (W a l l s 1967, p. 139; see also H a h t o l a 1967 a, p. 20). It is possible that similar effects of aging on silvicultural activity can be traced. The assumption that family structure plays a part is based on the idea that the number of children and especially the presence or absence of a »prospective farm owner» may affect the forest owner's readiness to undertake silvicultural measures with returns expected only in the distant future (cf. H a h t o l a 1967 a, p. 19; T a u r i a i n e n 1966, p. 36).

235. The forest owner's attitudes towards occupation, economic security and enterprise

Some »emotional factors» have also been included here in the individual farm background of tree growing. The inclusion is based on the fact, repeatedly mentioned above, that tree growing is a particularly long-term activity, and may therefore require qualities promoting a kind of »emotional equilibrium» in its practiser. S a a r i may have had these qualities in mind when he said that the form of enterprise suited for forestry is characterized by far-reaching logic and sagacity (p. 16).

The emotional-background conditions are measured here by three indicators, viz. *satisfaction with occupation, feeling of economic security, and spirit of enterprise* (cf. U i t t o 1964, p. 196). Satisfaction with the occupation refers to the actual farming work. It is assumed that happiness with the farming occupation may stimulate the forest owner's silvicultural work. On the other hand, however, one may assume that forest owners who find their farming occupation particularly strenuous or otherwise contrary to their expectations, are neverthless more active than average in introducing improvements and adopting new ideas in their silvicultural activities. The feeling of economic security may be another emotional background factor governing silvicultural activity. It seems justifiable to believe that forest owners who feel particularly insecure economically, are not very interested in silvicultural measures requiring long-term economic planning. The factors measuring the forest owner's spirit of enterprise may also be expected to exert some influence.

24. Tree growing and regional conditions

241. Change in the rural environment; the general features of change

When defining the purpose of the study, it was suggested that the possible effects of change in the rural environment on the forest owner's silvicultural activity should also be explored. The task of this section is to outline the concepts and the theoretical framework suited to this analysis. To start with, it will be necessary to review certain essential changes in today's society and the associated background factors.

Today's society is often called a »changing society» with the processes of change being described by such concepts as »industrialization», »economic growth», »specialization», »modernization», »urbanization» and so on. These concepts naturally refer to the background factors which are seen as embodying the essence of the change processes.

When social change is described by urbanization the essential elements are population accumulation in towns and cities and a generally enhanced importance of urban culture. Such a description of change may, however, lead to mistaken conclusions if the urbanization is seen as a one-way process, a continuous sharpening of the contract between urban and rural areas (P i p p i n g 1963, p. 386). It is obvious that the rural districts also change, perhaps primarily through the spread of urban civilization and the urban »style of life» to the rural districts, which sometimes produces profound changes in human attitudes and activities. The fact is that considerable effort in the branch of sociology called rural sociology focuses on elucidating the diffusion of new cultural features, both immaterial and material, to the rural districts and the occurrences which precede, succeed, and accompany this diffusion (W a l l s 1967, pp. 17 and 21).

In describing and analyzing this change, certain conceptual starting points based on ideal types have proved serviceable.[1]) Several classifications into ideal types are presented in sociological literature. Here reference will be made to only two of them, viz. the pair of concepts presented by T ö n n i e s as early as 1887, »GEMEINSCHAFT—GESELLSCHAFT», and R o g e r s' (1968) dipartition into traditional and modern social systems.

According to T ö n n i e s all forms of social interaction can be classed as either the GEMEINSCHAFT or the GESELLSCHAFT type. The social system covered by GEMEINSCHAFT is aptly represented by the traditional rural environment characterized by:

[1]) Ideal types refer to concepts based on perceptions of reality and are intended to help in comparisons. They need not necessarily exist empirically, but it is essential that they be constructed by abstracting the characteristics of the behaviour under analysis to a logical extreme. Ideal types, therefore, primarily serve methodological ends. They are modes of analysis intended to facilitate the comparative study of empirical social systems (R o g e r s 1968, p. 60).

— a low level of division of labour, lack of occupational differentation, and a general wholism of activities;
— pronounced primary-group relationships (family) and the importance of personal interaction in general;
— a strong pressure towards conformity in social behaviour; and
— poorly developed communication media.

The social system described by GESELLSCHAFT is represented most clearly by an industrialized society. It is distinguished by:

— advanced division of labour, occupational differentiation, and a general splitting of wholistic systems into separate component systems;
— the importance of secondary-group relationships (formal organizations);
— reduced pressure towards conformity in social behaviour; and
— well developed communication media (modes other than personal interaction).

The community of the GEMEINSCHAFT type is therefore characterized most markedly by standards built on tradition and by the wholism of roles. Ultimately, it is a social system based on kinship and friendship. The GESELLSCHAFT type of society, in its turn, rests on shared interests and mutually recognized targets. Its standards are impersonal and rational and roles are differentiated. It is characterized by the major importance of economic institutions such as exchange, agreement and division of labour as forms of social interaction (see Olavi Riihinen 1965, pp. 51—60; Tauriainen 1966, pp. 16—19).

The recognition by Rogers of traditional and modern social systems is based on the differences in the adoption of innovations. The traditional and modern forms of society are understood as the two extremes of the continuum of innovativeness. The terms »traditional» and »modern» as used by Rogers refer to the social values governing the adoption of innovations in the society (Rogers 1968, pp. 59—62). A social system adhering to traditional standards is characterized by:

— undeveloped technology under conditions in which agriculture (including forestry) is distinctly the most important means of livelihood;
— a low educational level under conditions in which communication is based mainly on personal interaction;
— a low degree of interaction with those outside the social system;
— a lack of economic rationalization under conditions in which primary-group relations perceived as having values in themselves and not as a way of obtaining certain targets; and
— a lack of empathy (an inability of visualizing oneself in someone else's role especially those living outside the social system).

A social system observing modern standards is defined by:

— advanced technology and division of labour under conditions where the trading structure is many-sided;
— appreciation of science and education;
— active interaction with those outside the social system, facilitating the spread of new ideas;
— planning and economic rationalism which warrants the choice of the most efficient means for achieving targets; and
— empathy (an ability to visualize oneself in someone else's role).

The use of these ideal types, which resemble and complement each other, as a conceptual basis for an analysis comparing societies is not restricted to rural social systems alone. On the contrary, when the »best» empirical approximations of these ideal types are sought, the rural and the urban society are perhaps the two poles. But the ideal-type divisions nevertheless provide a useful conceptual apparatus for studies restricted to processes of change in the rural environment, especially under conditions where this change in the rural environment manifests itself in industrialization of rural districts and in the spread of urban cultural features to rural areas.

242. Change in the rural environment; effects pertaining to tree growing

The spread of urban cultural features probably most easily reaches the people who live in rural surroundings but work in industry or the service trades. But it does not leave unaffected the behaviour of people working in the traditional rural trades, agriculture and forestry (see V a l k o n e n 1965, p. 135), who are of primary interest in this study. It seems to be correct to assume that the forest owner's silvicultural activity may also change with changes in the rural environment.

A hypothetical examination of the effects of change in the rural environment should devote attention at least to the following three points:

— the average level of silvicultural activity;
— features suggesting specialization and general differentiation of activities, attitudes and values in tree growing; and
— the forms and methods of instruction for promoting forest management among forest owners.

An examination of the average level of the forest owner's silvicultural activity seems justified because, with industrialization and modernization of the rural environment, the relative importance of trades representing primary production is reduced. When the relative importance of forestry

in a given area diminishes, the results may be a reduced interest among forest owners in silviculture. This assumption seems to be supported by certain empirical findings of Hahtola. According to him the level of forest management tends to decline in inverse proportion to the rising trend of industrialization and regional differentiation, owing to increasingly difficult forest-distribution conditions, the reduced importance of forestry on farms, and the shifting of attention from farming to other trades (Hahtola 1967 b, pp. 52—53, 57—58). However, industrialization is usually also associated with occurrences such as a rise in economic standing and educational level which may be expected to stimulate silviculture. Further, according to Hahtola, the effects of the spread of cumulative industrialization had to improved forest management. This stems from the expanded economic opportunities these effects bring in their wake and from the decreased dependence on traditional methods of silviculture. On the other hand, Päiviö Riihinen came to the conclusion that the level of silviculture is practically independent of the main trend of industrialization being, rather, connected with the economic growth arising from the interaction of agriculture and forestry in farm husbandry (Päiviö Riihinen 1963, pp. 33 and 44 [1]).

An analysis of the effects of change in the rural environment should also consider the possible indications of specialization and general differentiation in tree growing. As has been stated in Section 241, differentiation in the economic and social structure is one of the most far-reaching aspects of modernization of the rural environment. Transition from a traditional to an industrialized and modern rural environment implies a transition from a wholistic system to a social system characterized by division of labour and differentiation of roles. From the point of view of tree growing, one may assume that differentiation results in development under which some forest owners specialize in tree growing while others devote their attention mainly to different and perhaps new forms of production in farm husbandry. An alternative to keep in mind is that some forest owners may almost entirely give up farm husbandry, with both agriculture and forestry remaining as subsidiary trades (see Walls 1968). Differentiation may also be assumed to take place at the goal-level in tree growing; on some farms the forest would serve mainly to promote economic security, while in other conditions profit making and liquidity would be the primary objectives (cf. Hahtola 1967 b, pp. 12—13; 1969, pp. 268—269).

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[1]) The studies by Päiviö Riihinen (1963) and Hahtola (1967 b) as far as their conceptual starting points are concerned, are based on Gunnar Myrdal's theory of cumulative process. It may be pointed out that the concept of »silvicultural level» as used by Riihinen coincides with that used in the national forest inventories in Finland and is different in content from the concepts of »level of forest management» or »standard of silviculture» used by Hahtola. The regional coverage and the timing of their studies are also different.

Change in the rural environment may also entail changes in the forms and methods through which promotion of and instruction in silviculture is practised among forest owners. As has been noted (p. 24), one feature associated with change in the rural environment is a weakening of personal interaction and primary-group relations with a parallel increase in the »impersonal and official» interaction centered or realization of a given target. It would seem natural, therefore, to assume a similar development in the promotion of silviculture (cf. H a h t o l a 1967 b, p. 21). The result would be silvicultural promotion in which there would be less and less personal and unofficial instruction and an increasingly important role for formal organizations. It seems that the overall efficiency and suitability of the organizations disseminating instruction would outweigh the personal qualities of the forestry agents engaged in the work.

3. MATERIAL

31. Selection of the communes studied

The communes of Karstula and Jämsä, located in the Keski-Suomi Forestry Board District, were selected for the study. The Keski-Suomi district was chosen because it seemed to contain both traditional rural communes of poor economic development and industrialized rural communes on their way towards modernization. It was also considered a suitable district because it is representative of the transition zone between industrially developed and rural Finland. The two communes were chosen from the same district in order to restrict the variables to the differences in economic and social structure between communes. Promotion of silviculture, for example, is supervised in both communes by one organization, the Keski-Suomi District Forestry Board.

Karstula was considered to represent a typically traditional rural environment. According to the 1960 census, 71 per cent of the population living in Karstula and engaged in an occupation was working in agriculture and forestry. Manufacturing and construction employed a total of »only» 10 per cent. The location of Karstula is more remote than that of Jämsä, and its traffic facilities are less developed (e.g. Karstula has no railway whereas Jämsä does).

Jämsä was considered to represent a well industrialized rural environment on its way towards modernization.[1]) The influence of two considerable woodworking plants, Kaipola (established 1952) and Jämsänkoski (established 1888), on the commune's economic and social life has been pronounced. The construction of a modern industrial plant is often the primary factor which activates economic and social development and rapidly produces regional differentiation (Olavi Riihinen 1965, p. 23). Good traffic connections and the short distance to Jyväskylä, the provincial centre, are characteristics of Jämsä. According to the 1960 census, 44 per cent of the population living in Jämsä and engaged in a occupation was employed in agriculture and forestry. Manufacturing and construction employed 34 per cent.

[1]) Jämsä became a market borough at the beginning of 1969.

A more detailed study is required to see how well these »empirical» rural communes approximate the ideal types outlined in Section 241; Karstula the traditional rural environment and Jämsä the industrialized and modern rural environment. Generalizations concerning the process of modernization can be used for this purpose. For example, according to Valkonen (1965, pp. 31—58), modernization of a traditional social system implies the following changes:

— the proportion of people employed in primary production is reduced;
— income level increases;
— school education increases;
— mass media develop and expand;
— geographical mobility increases; and
— birthrate falls.

As pointed above, the proportion of people employed in primary production as compared with the total population engaged in an occupation was distinctly smaller in Jämsä (44 per cent) than in Karstula (71 per cent). It was also pointed out that economic development in Jämsä was characterized by the presence of major industrial plants and in Karstula by the absence of such establishments. The results of the study's interview material will be utilized in the following review of a few other features connected with modernization. It should be borne in mind that the comparisons involve only the forest-owning populations of the communes.

The distributions of the forest owners interviewed, according to their income, educational levels and ownership of mass media, in the two communes were as follows:

Income, mk/year [1]	Karstula per cent of those	Jämsä interviewed
Less than 4 000	73	43
4 000—5 000	16	40
6 000 or more	11	17
	100	100
	(n = 139)	(n = 150)
	$X_2 = 37.4$	$p < 0.1$

Education	Karstula per cent of those	Jämsä interviewed
Not more than primary school	89	80
Primary school plus not more than two years of other schooling	9	13
Primary school plus more than two years of other schooling	2	7
	100	100
	(n = 139)	(n = 150)
	$X_2 = 5.8$	$p < 10$

[1] Taxable income in state taxation for 1964.

Ownership of mass media [1])	Karstula per cent of those	Jämsä interviewed
Owns one	38	15
Owns two	41	35
Owns three	21	50
	100	100
	(n = 139)	(n = 150)
	$X_2 = 54.8$	$p < 0.1$

The distributions showing geographical mobility and the number of children living at home (comparable to birthrate) were as follows:

Last visit to town	Karstula per cent of those	Jämsä interviewed
Less than 2 months ago	46	48
2—6 months ago	18	28
More than 6 months ago	36	24
	100	100
	(n = 139)	(n = 150)
	$X_2 = 9.4$	$p < 1$

Children living at home	Karstula per cent of those	Jämsä interviewed
One or none	35	46
Two	26	23
Three or more	39	31
	100	100
	(n = 139)	(n = 150)
	$X_2 = 5.1$	$p < 10$

The differences between Karstula and Jämsä seem to indicate that the selection of these communes satisfactorily fulfilled its purpose. The characteristics of the economic and social structure of Karstula and its forest-owning population are those of a traditional environment, whereas the conditions in Jämsä are closer to those customarily prevailing in an industrialized and modern environment.

32. Populations and samples

The first population consists of the males living in Karstula in 1966 who on their own or together with their wife owned not less than two hectares of arable land and ten hectares of forest. The second population was the comparable group of males living in Jämsä in the same year. They are called herein forest owners (being primarily farm-forest owners). The population lists were compiled from tax classification cards at the communal taxation offices and the samples were allotted from these lists. No precise basis for

[1]) Radio, television and telephone.

determining the size of the sample was available. However, two samples of about 150 persons each were assumed to be adequate for the planned statistical analyses. In fact, the primary purpose of the selection of the sample was not to obtain a sample as representative as possible of the population but, rather, to obtain empirical material on which a statistical analysis of the relationships among the variables of interest could be made (cf. R i l e y 1963, p. 283).

The size of the populations and the commune samples were as follows:

	Population	Sample
	Number of forest owners	
Karstula	604	154
Jämsä	662	166
	1 266	320

The sampling method used was unrestricted random sampling (M a t t i l a 1963, p. 9). This meant that every member of the population had an equal chance of being selected for the sample. An alternative would have been to use stratified random sampling arranging the sample into strata and using the aggregate forest area of the strata as a weigh (»proportional allocation», see M a t t i l a 1963, p. 10). Persons with large forest units would then have had a considerably greater probability of being included in the sample than those with small forest units. This was not considered useful for two reasons:

(1) The forest ownership situation in Finland is definitely characterized by a high proportion of small owners; it was felt that the sample should correspond to this situation.
(2) The problems associated with silviculture can be assumed to reveal their topical characteristics in the work of persons possessing small forest units, and the relationships of interest may manifest themselves particularly clearly.

The distribution of the forest owners included in the sample, according to the forest area owned, is presented in Table 1.

Table 1. Distribution of the forest-owner sample according to forest area owned.

Forest area, ha	Karstula (n = 154)	Jämsä (n = 166)
	Forest owners, per cent of sample	
10.0—19.9	34	24
20.0—29.9	18	23
30.0—49.9	27	30
50.0—99.9	13	15
100.0 or more	8	8
	100	**100**

33. Collection of the material

The material was collected mainly by personal interviews. Interviewing was considered appropriate because it combines certain favourable qualities of both inquiry and observation (Berner Öste 1965, pp. 123—165). The interview method, in general, can be applied to a sufficiently large sample which is seldom possible when using the observation method. Also the personal contact between the interviewer and the interviewed provides a good opportunity for checking the response situation, which is impossible if a postal inquiry is made. This latter point is particularly important when information on attitudes is collected (Riley 1963, p. 167).

A serviceable questionnaire, before it is compiled, presupposes a series of preliminary interviews. For this project, the preliminary interviews were carried out in the winter season of 1965/1966; both forest owners (a total of 26 inhabitants of the communes) and forestry experts working for private forestry organizations were interviewed.

The interviews proper were made in the summer of 1966, first in Jämsä and then in Karstula. A total of 289 acceptable interviews were obtained, 150 in Jämsä and 139 in Karstula. The main reasons why interviews (31 in all) were not obtained were the relevant person's death or severe illness, and changes in ownership conditions. The attitude to the interview was usually favourable, and many of those interviewed were even very interested in discussing problems of forest management. The favourable attitude is evidenced by the fact that only one forest owner refused the interview. In general, each interview took 1—2 hours.

In addition to interviews, the material was based on the tax classification cards and income tax returns in the communal taxation offices. When the sample was allotted, data concerning the area of the farm and its tax class was obtained from the tax classification cards and information concerning the economic standing of the person involved was taken from his income tax return for 1964.

Questions relating to the reliability and validity of the information obtained in the interviews are considered in Appendix 3.

4. SELECTION OF METHODS AND VARIABLES

41. The exploratory nature of the study and the main course of the empirical analysis

The whole process of the study can be divided into two phases, of which one can be termed empirical and the other interpretative. The empirical phase contains all measures and methods by which the research worker selects, collects, classifies and arranges the empirical observations used in the study. The empirical phase, therefore, is composed of the rules guiding the search for new research findings.

But a researcher is seldom happy if he presents the »raw» empirical facts as he found them; he usually also wants to interpret them. This interpretative phase of the study is composed of the measures and rules by which the researcher compares his empirical findings with the original theoretical starting points of the study and, in general, tries to link his findings with the theoretical basis. The interpretative phase, therefore builds a bridge between the theoretical and empirical material of the study (R i l e y 1963, pp. 4—7).

If the interpretative phase is specified in detail, it is found that the researcher may draw two-way conclusions (see M e r t o n 1967, pp. 139—171; Z e t t e r b e r g 1965, pp. 150—156). Firstly, he can reach his conclusions by beginning from theoretical starting points and moving towards the empirical findings. This is the case in studies testing hypotheses, in which the validity of hypotheses derived from a theory and given an exact form is tested with the aid of empirical material. Or, secondly, the researcher may adopt the opposite course in arriving at his conclusions, i.e. move from empirical findings to theory. This is the case in exploratory studies based on so few and such tenuous theoretical starting points that formulating specific study hypotheses is not rational or even possible. The purpose of exploratory studies, in fact, is primarily to formulate new hypotheses appropriate for future research. Under these conditions the conclusions must be drawn from empirical findings and aim at the construction or reconstruction of a theory.

Although the selection of variables here is based on some theoretical starting points, it seems to be correct to consider the study exploratory with

its purpose being to formulate hypotheses concerning the phenomenon studied rather than trying to test them. This is so because the primary purpose of the selection of variables has only been to indicate the factors or groups of factors that should be taken into account when the silvicultural activity of the forest owner is analyzed.

The hypotheses, however, cannot be formulated until the empirical findings of the study are presented. Therefore, it is first necessary to describe the course of the empirical phase of the study and the methods used.

Many decisions and measures affecting the type of empirical-research findings obtained have been made. Certain theoretical and conceptual starting points and the observation unit (the forest owner) have been selected. The method of taking the sample and of collecting the material have also been fixed. Subsequently, the empirical phase concentrates on the following three points:

— condensation of information;
— review of relationships among variables; and
— comparison of the communes studied.

42. Selection of methods

421. Condensing the information

Some authors have pointed out that the use of composite variables often may not be advisable. The construction of a composite variable involves a loss of information, for two or more numbers are combined to yield a single number; the composite variables cause so-called nuance effects to fade away. An analysis based on these variables will yield only a small number of empirical predictions relative to its complexity (cf. B l a l o c k 1964, p. 163). Furthermore, the validity of composite variables is not always easy to verify. As a result, an analysis based on composite variables alone may become misleading and less fruitfull (C o l e m a n 1964, pp. 83—84; R i l e y 1963, p. 366).

But sometimes there is another side to the problem. A dilemma may develop from the large number of variables used in the analysis; this is the predicament here. In a case of this type it may be necessary to group the original variables and to condense the information they contain into a few composite variables, which simplifies the next step of analysis very much.

A means of condensing the information of the original variables and of constructing composite variables is provided by the technique of factor analysis; this will be used here. The procedure is as follows. The information contained in silvicultural activity, silvicultural attitudes and individual farm backgrounds is condensed into factor dimensions describing activity, attitudes

and background separately. These factor solutions are computed from the combined material (Karstula+Jämsä) by the principal-factor method. »Inside» each factor solution, non- correlating factors are aimed at; for this reason the orthogonal varimax method is used in the rotation. The rotated factors are finally quantified into composite variables composed of normal scores (factor scores) using the estimation method developed by L e d e r m a n.

The theory of factor analysis will not be discussed here since it has been presented in many textbooks (C o o l e y & L o h n e s 1966, pp. 151—185; H a r m a n 1960; T h u r s t o n e 1953; Ü b e r l a 1968) and forestry publications (H a h t o l a 1967 a, pp. 34—39; M ä k e l ä 1968, pp. 39—43; P ä i v i ö R i i h i n e n 1963, pp. 27—30). But it may be useful to discuss the qualities of the method particularly as related to the forming composite variables. The discussion will include views published by H a h t o l a (1967 b, pp. 27—29), M a r k k a n e n (1964 a) and M ä k e l ä (1968, pp. 43—46).

This study's use of factor analysis for constructing composite variables is based on the following points which favour the use of such a method:

(1) The description of the information contained in the original variables is efficiently simplified by converting to factor scores, since the number of factors is usually considerably lower than the number of original variables. In this study, for example, the analysis can be made with 10 composite variables instead of the 47 original variables.

(2) Since calculation of the factor dimensions means combining several variables with mutual statistical dependence, it is possible that the use of factor scores tends to reduce the possibility of »overlapping» explanation. When separate items are used, they may be used misleadingly as different explanatory variables even though some of them may measure the same underlying phenomenon.

(3) Information in the form of factor scores may be considered more reliable than the information contained in the original variables, since the calculation of the factors is based only on the use of the common variance of the original variables (co-variance) and since the combination of several variables may be expected to reduce the random variation.

(4) When orthogonal rotation is used, composite variables with no mutual correlations are found. In analysis, the fact that the composite variables are orthogonal may be an important factor facilitating interpretation.

(5) Views have been advanced according to which the variables based only on measurement of their ordinal scale could also be used in factor analysis. These are represented here by the propositions measuring silvicultural attitudes.

The use of factor analysis and factor scores is, however, associated with certain remarkably adverse factors which are worth pointing out in this connection:

(1) When composite variables expressed in the form of factor scores are used, even essential information can be lost since the so-called unique factors (which contain the variance components corresponding to specific and error factors), and sometimes also a number of factors explaining common variance, are excluded. If so, a number of possibly important explanatory variables also remain outside the analysis based on factor scores.

(2) Coleman (1964, pp. 20—21) points out that the general approach of factor analysis is to locate statistically but not meaningfully independent factors. For this reason, two variables which are meaningfully quite independent but not at all statistically independent, cannot be separated by factor analysis. A question arises: what is the meaningful independence of isolated factors, or is there any such independence at all? This seems to be at the same time an interpretation problem in factor analysis and a validity problem of factors and factor scores (cf. Harman 1960, pp. 4—5, 97—98).

(3) Weaknesses are also inherent in the methods of estimating factor scores. The problem is whether the factor scores correspond to the interpreted factors in the way they have been designed to (Olavi Riihinen 1965, p. 234).

When the serviceability of the composite variables constructed for use here is evaluated below, the possible adverse effects of loss of information and weaknesses of the method of estimating the factor scores will also be discussed (see Section 54). However, a preliminary remark sheding light on the important validity problem will be made here.

In studies carried out with factor analysis, as in all other studies, the validity problem refers to the question of how well the theoretical concept is approximated by its measured, operational counterpart (»internal validity», see Zetterberg 1965, pp. 114—120). In connection with factor analysis, however, the problem is in a way the opposite of the usual problem. The normal situation is a study aimed at finding out how well a given operational counterpart corresponds to a given, pre-defined, theoretical concept. In the interpretation of factor dimensions, by contrast, theoretical concepts are »sought» which can be assumed to be best represented by »empirical» factors (factors are sometimes termed concealed variables, see Mustonen 1965, p. 3); hence the validity of composite variables expressed in the form of factor scores depends decisively on how succesful this interpretation is. This later conclusion is, however, based on the assumption that the estimation of factor scores involves no error.

422. Relationships among variables

In the preceding section, the method, factor analysis, was discussed. This will be used in preliminary arrangement of the study material, i.e. in condensing the information of the original, measured variables and constructing the new, composite variables. The next step of empirical analysis is the review of relationships among composite variables. This task, in turn, is intimately connected with the main purpose of the study and contains several difficult methodological problems.

The purpose of the study was defined as being to explore factors influencing silvicultural activity. For example, the effects of forest owner's attitudes and individual farm-background conditions should be analyzed. This means that some kind of causal relationships between variables included in the study are assumed and will be explored. But, is there any proper method for reviewing causal inferences at all and if so, how precise and perfect are the conclusions that could be made with the aid of such a method?

First, it must be emphasized that causal inferences based on correlation data from nonexperimental studies are necessarily made with considerable risk of error. The existence of a crude level of measurement and measurement error, effects of outside variables or confounding influences, intercorrelations among explanatory variables or multicollinearity, and the absence of over-time observations are examples of complicating issues in this connection. Therefore, it is quite obvious that much methodological work is required before the possibilities and restrictions of causal analysis in nonexperimental, behavioural-science studies are thoroughly identified. At the present time a high degree of precision cannot be expected, and the conclusions must be drawn with considerable caution.

In this study the author has adopted a procedure in which the causal analysis is carried out by means of correlations and partial correlations between factors of differing content level. In this case the analysis follows the ideas and rules presented by B l a l o c k (1964). The principal idea is that setting a particular partial correlation equal to zero gives the interpretation that there is no direct causal link between the two variables concerned, though there may be indirect linkages through other variables. In general, this partial will involve the relationship between two variables not connected directly by a causal arrow, with controls for variables that are either causally prior to or intervening between the two variables concerned (B l a l o c k 1964, pp. 64—69, 177—178). This is a procedure for eliminating a number of causal arrows and the conclusions are always relative to the particular variable system concerned.

In this study variables measuring individual farm-background conditions are assumed to be causally prior to both activity and attitude variables,

with variables measuring silvicultural attitudes intervening between background and activity variables.

Some special difficulties arise, however, due to the fact that the composite variables constructed with the aid of factor-analysis techniques are of primary concern in the present study. Consequently, one may point out that the rationale for factor analysis is consistent with special kinds of causal models and hence appropriate only in some special situations. Following B l a l o c k, it may be said that factor-analysis techniques and the interpretations given to the factors extracted ordinarily presuppose certain limited kinds of causal models; namely, those in which the measured, original variables (indicators) are caused only by the underlying variables (factors) with the intercorrelations among original variables assumed to be completely spurious (B l a l o c k 1964, p. 167). Furthermore, there is a case for pointing out that any given original variable may be an effect (or cause) of more than one underlying variable. If so, the predictions concerning underlying variables may be disturbed and confounded. (However, the rotation of factor axes in order to arrive at a simple structure may be viewed as an attempt to reduce just this complexity of original variables; see H a r m a n 1960, p. 113.) Also, the use of original variables that are related in complicated and unknown ways to a given underlying variable may lead to misinterpretations owing to the complexity of the causal situation (B l a l o c k 1964, pp. 162—166).

The above-mentioned difficulties associated with the use of factor-analysis techniques are at least partly eliminated here by computing factor solutions separately from activity, attitude and background variables. This procedure means at the same time that each factor solution contains only variables measuring the same given »field». It follows that the causal links between activity, attitude and background variables can be analyzed; the relationships between these variables need not be conceived as completely spurious. Also, the intricacy in the relationships between original and underlying variables (factors) can be expected to decrease, because the original variables included in each factor solution do not measure so many different things. (An exception is, however, the factor solution illustrating background dimensions; it contains variables measuring economic and social structure, activity, and personality.) All this means that interpretation of factor dimensions can be expected to be successful and hence the validity of the constructed composite variables may have a fair degree of precision. If so, the constructed composite variables can be considered valid variables, proper for use in further analysis.

423. Comparison of the communes studied

The analysis of the effects of a changing rural environment will be carried out by comparing the results obtained from a study of communes representing a traditional (Karstula) and a modern (Jämsä) rural environment. This comparison could be made by means of several different procedural solutions. Differences between the communes studied might be analyzed by testing the significance of the differences in mean values of each variable. Among the procedures of statistical multivariate analyses, the discriminant analysis would offer a means, based on the simultaneous consideration of several variables, of analyzing the differences in level between the communes (cf. Cooley & Lohnes 1966, pp. 116—133). Also, the transformation analysis used as a method of comparing factor results, such as the symmetrical transformation analysis developed by Mustonen, might be serviceable. In this case, the analysis of the structural differences between the communes studied would be based on examination of the abnormal transformation (Mustonen 1966, p. 5).

The present study, however, will be restricted to an ocular review of certain correlation matrices. The comparison of the communes takes place mainly by analyzing the relationships between the composite variables illustrating silvicultural activity, silvicultural attitudes and individual farm-background conditions per forest owner by means of correlation matrices computed from the separate material for Karstula and Jämsä. However, the factor solutions concerning basic dimensions are computed from a combination of the material (Karstula + Jämsä) in order to ensure comparability. This makes it possible to review the behaviour of the same basic dimensions in the two communes (»pooled factor analysis»; see Riley 1963, p. 467).[1]) The differences in the level of the communes will, in turn, be analyzed on the basis of the mean values of factor scores per commune.

The comparison of the two communes is associated with certain important methodological considerations which will be briefly discussed below.

Firstly, the effects of change in the rural environment can best be analyzed on the basis of longitudinal material, with observations at different points of time enabling a detailed analysis of the change and the affecting factors (Arosalo 1968, pp. 37—39; Valkonen 1965, p. 12). This study, however, is based on cross-sectional material. Therefore, the study of change rests on the assumption that the communes to be compared may be con-

[1]) Especially in the case of attitude dimensions the use of »separate factor analysis» to specify attitude dimensions separately in both communes might have been appropriate because the dependence of the attitudes on the social environment. However, the attitude dimensions calculated separately from the Karstula and Jämsä material and compared by means of transformation analysis proved to be quite similar (see Veli-Pekka Järveläinen 1968 b, pp. 54—56).

sidered to represent different stages in the development towards modernization, and the conclusions concerning possible effects on the forest owner's silvicultural activity are based on these »timing differences» in the development towards modernization. Secondly, the analysis of the relationships between change in the rural environment and forest owner's silvicultural activity is based only on a comparison between two communes. It is possible that the results obtained may be decisively affected by the specific characteristics of the communes studied. In any case, the results of the study can be considered only exploratory. Furthermore, the modes of the relationships discovered cannot be studied in detail in an analysis restricted to a comparison of two communes. Thirdly, in the analysis of the communes the analytical unit is no longer a forest owner but a given local community, in this case a rural community. This means that the phenomenon studied is no longer on the individual level but that regularities on the community level are analyzed. Therefore, it is important to bear in mind that correlations on the individual level cannot be transferred directly to correlations on the community level, or vice versa (V a l k o n e n 1966). If conclusions refer to community-level phenomena but analysis refers to correlations on the individual level, atomistic fallacy may easily follow. In the interpretation of the results, the power of explanation of the psychological processes is overestimated. But if the conclusions refer to the behaviour of individuals while the analysis is based on correlations at the community level, aggregative fallacy is possible. The power of explanation of the social structures and processes is then overestimated. Such a fallacy is possible, for example, in analysis based on ecological correlations and trying to draw conclusions concerning the behaviour of individuals (O l a v i R i i h i n e n 1965, pp. 88—91; R i l e y 1963, pp. 703—709).

The present data was collected mainly by interviewing individuals, i.e. forest owners. However, in addition to regularities on the individual level, conclusions can also be drawn concerning regularities at the community level. This is because there are two analytical units; the forest owner and the rural commune. Conclusions concerning any regional variation in the level of silvicultural activity are drawn on the basis of mean values per commune; those concerning specialization or differentiation in tree growing are based on examination of correlation matrices computed per commune. Once again, the conclusions concerning regularities on the community level in the present study, however, remain relatively uncertain because the comparison only involved two communes with observations at one point in time.

43. Selection of variables

431. Variables measuring silvicultural activity

In the Section 12 (defining the essential concepts) it was stated that silvicultural activity comprised all the measures directly or indirectly associated with tree growing. Silvicultural activity, for the purposes of the present paper, comprises silvicultural measures, use of expert assistance, and attendance at instructive meetings.

The various forms of silvicultural measures were grouped into four types:

(1) management of seedling stands;
(2) forest regeneration (comprising planting, seeding and site preparation, such as clearing, scarification and broadcast burning);
(3) forest drainage (new drainage and clearing of existing ditches); and
(4) forest fertilization.

The forest owner's answers to the question concerning the management of seedling stands were, however, so unreliable and uncertain that this measure is not included in the analysis as a separate variable. The last three groups and their total (for each farm studied) were illustrated by variables of three types constructed for the prupose. The variables measured

(a) the absolute extent of the measure in hectares;
(b) the relative extent of the measure per hectare of forest land; and
(c) the date when the measure was carried out for the first time.

A total of 12 measure-variables were constructed according to the above-mentioned principles. Only four were selected for use in this study. The variables measuring the date when the measure was carried out were excluded; they did not seem to supply any additional information compared with variables measuring the absolute extent of the measure (the intercorrelations were between .71 and .82). Furhermore, only the variables measuring forest regeneration were included as separate variables. This was because of the prime importance of forest regeneration in contemporary silviculture, and because of the proper distributions of these variables. The distributions of variables measuring forest fertilization were, for example, strongly skewed. Only 16 per cent of the forest owners interviewed had carried out this measure.

In addition to the above four variables, another four were selected measuring the number of measures taken, the delay before any measure was carried out for the first time, the use of expert assistance, and attendance at instructive meetings. The final number of original variables measuring silvicultural activity was thus eight:

(1) *Absolute extent of the measures taken.* The total area, in hectares, of forest regeneration, forest drainage and forest fertilization during the whole period the interviewed had been in possession of the farm. (Two hectares was taken to be the area over which a kilometre-long drainage ditch had an effect.)

(2) *Relative extent of the measures taken.* The total area, in hectares, of forest regeneration, forest drainage and forest fertilization during the period the interviewed had been in possession of the farm, divided by the forest area of the farm. (Two hectares was taken to be area over which a kilometre-long drainage ditch had an effect.)

(3) *Absolute extent of forest regeneration.* The total area, in hectares, of forest regeneration effected during the period of possession.

(4) *Relative extent of forest regeneration.* The total area, in hectares, of forest regeneration effected during the period of possession, divided by the forest area of the farm.

(5) *Number of different measures taken.* The number of different measures taken at least once during the period of possession. The measures taken into account were; (1) management of seedling stands, (2) forest regeneration, (3) forest drainage, and (4) forest fertilization.

(6) *Measure taken for the first time.* Length of time, in years, the interviewed waited to undertake a silvicultural measure after receiving posession of the farm. The measures taken into account were; (1) forest regeneration, (2) forest drainage, and (3) forest fertilization.

(7) *Last visit by forestry expert to farm.* The date of the forestry expert's last visit to the farm on forestry business.

(8) *Last attendance at instruction meeting.* The date of the forest owner's last attendance at a lecture on forestry, an excursion in the forest, a competition in forestry skills or in marking trees to be felled, or a meeting of a forest management association.

432. Variables measuring silvicultural attitudes

In Section 22 was listed the mainly intuitive, theoretical fundamentals on which the construction of the propositions measuring silvicultural attitudes was based. It was also mentioned that originally 30 propositions were prepared. All these propositions, however, are not included in the analysis. The composite variables reflecting silvicultural attitudes are constructed on the basis of the correlation matrices of only 19 propositions:

(9) »Forest owners are generally too little interested in forestry matters»
(10) »Forest management associations are not particularly worth supporting»
(11) »Forest owners today take sufficient care of the management of their forests»
(12) »Too small a share of the income from timber sales is used on silviculture»
(13) »If you think economically, it is not worthwhile spending money on silviculture»
(14) »It would not be right if forest owners were forced by law to recondition their forests»
(15) »One should have the right to cut more freely than today»
(16) »There is no point in prohibiting by law cuttings in a forest»
(17) »Silviculture needs more legislative supervision»
(18) »It is true that few owners practice sufficient silviculture unless obliged to by law»
(19) »An obligatory forest management fee is necessary»
(20) »Forest fertilization should be greatly increased»
(21) »The forest owner should personally mark the trees he intends to sell»
(22) »It is not necessary to plan silvicultural measures for future years»
(23) »Forest regeneration is too popular today»

(24) »New silvicultural methods are often very unpractical»
(25) »Forestry experts do not sufficiently understand the forest owners' needs»
(26) »The ability of managing forest used to be much better than today»
(27) »Forest regeneration must be considered economically unprofitable»

All the propositions were excluded when correlation with the other propositions, a sum scale of all propositions, and the activity variables proved to be »negligible» (cf. M a r k k a n e n 1964 b, p. 11). A point of interest is that the propositions measuring assistance by society, forest ownership of society, and necessity of joint timber sales among forest owners did not distinctly correlate with the other propositions concerning attitudes. This prompts the assumption that these opinions primarily reflect attitudes other than those related to silviculture. In addition, the elimination of two propositions was due to the fact that the analysis included two other propositions which measured almost exactly the same opinion. The final criterion for selection was in this case the mode of distribution. One proposition was eliminated since the interviewed were found the have misunderstood it.

433. Variables measuring individual farm backgrounds

Section 23 specified the theoretical starting-points on which the selection of the variables for measuring individual farm backgrounds of tree growing is based. A preliminary elimination of some of these variables was also required.

Firstly, the variables which failed to correlate with the variables measuring silvicultural activity were eliminated, e.g. the variables describing the family structure. Secondly, of alternative variables measuring the same background condition, only one was selected, viz. the one which was found to be of greater theoretical interest or which was best correlated with variables measuring silvicultural activity. For example, the relative importance of forest to the farms is measured by the ratio of income from forest land to income from the agricultural unit of the farm, and not by the ratio of forest area to arable area. Thirdly, it was not possible to construct valid variables for measuring all the background conditions discussed in connection with the frame of reference. For example, the variables intended to illustrate the traffic within the farm were excluded from the analysis. This was done because these variables seemed to measure the amount of forest property and »only» the land distribution conditions pertaining to forestry. Fourthly, the logarithmic transformation of certain background variables was also tested. Since, however, the correlations of the original background variables and of their logarithmic transformations with the variables measuring silvicultural activity differed but little, it was decided not to use the logarithmic transformations at all.

Following the preliminary elimination, the total number of remaining original variables for measuring the individual farm backgrounds was 20:

(28) *Forest area.* The forest area, in hectares, owned by the interviewed alone or together with his wife.

(29) *Fertility of forest soil.* The area of sites with soils better than the *Vaccinium* type as a percentage of the total forest area of the farm.

(30) *Relative yield.* The ratio of income from forest land to income from the agricultural part of the farm. Data collected from the 1964 tax returns.

(31) *Arable area.* The area of arable land, in hectares, owned by the interviewed alone or together with his wife.

(32) *Distance from main village.* The distance along a highway, in kilometres, between the farm and the main village of the commune.

(33) *Distance from bus route.* The distance, in hundreds of meters, between the farm and the nearest road with regular bus traffic.

(34) *Revenue.* The income, in marks, taxed in the state taxation of 1964.

(35) *Supplementary income.* The amount, in marks, of »other income» earned outside the agriculture and forestry work of the farm and taxed in state taxation. Data collected from the 1964 income tax returns.

(36) *Debts.* Total debts, in marks. Data collected from the 1964 income tax returns.

(37) *Level of fixtures I.* The farm has electricity, running water or WC.

(38) *Level of fixtures II.* The farm has a radio, television or telephone.

(39) *Continuity of ownership.* Refers to the question, »Do you think that your heirs will keep the farm?»

(40) *Duration of family possession.* The length of time, in years, during which the farm has been in the possession of the family of the interviewed or of his wife.

(41) *Age.* The age of the interviewed, in years.

(42) *Schooling.* The amount of formal education the interviewed has had. Each instructive period lasting longer than one month, either school or course, was included.

(43) *Activity in using sources of knowledge.* Measured by a sum scale composed of the following items: (1) number of forestry periodicals subscribed to, (2) number of other papers subscribed to, and (3) frequency with which the interviewed read articles on forestry subjects from papers other than forestry papers.

(44) *Activity in organizations.* Measured by a sum scale composed of the following items: (1) membership in co-operative societies, (2) membership in other organizations and societies, (3) frequency of attendance at organization meetings and society work, and (4) number of communal and other positions of responsibility held.

(45) *Satisfaction with occupation.* Refers to the question, »How satisfied are you with your occupation as a farmer?»

(46) *Security of subsistence.* Refers to the question, »How secure do you feel about your future subsistence?»

(47) *Spirit of enterprise.* Refers to the question, »Do you find it worthwhile straining yourself to achieve difficult objectives?»

5. GROUPING OF ORIGINAL VARIABLES

51. Activity dimensions

Factoring was based on the correlation matrix of eight original variables measuring silvicultural activity. The result of the principal-factor solution is shown in Appendix 8, and it is seen that the population of variables is very heavily cumulated. The first principal factor explained 44 per cent of the total variance (=8). This population of variables could well be considered an unidimensional group, measuring only the same basic dimension. Varimax rotation, however, was carried out separately with two and three factors (see Appendix 11) and a varimax solution of three factors computed from the combined material was selected for use (Table 2). The basis of the selection was that this solution proved to be useful for the research strategy. The comparison of the communes revealed differences interesting from the theoretical point of view when the three-factor solution was applied (cf. M a r k k a n e n 1964 a, p. 10). Also, the interpretability of this solution was fairly clear-cut, although the solution does not fulfill the criteria of a »simple structure» (see H a r m a n 1960, p. 113).

Table 2. Three-factor varimax solution. Activity vairables. Compined material (Karstula + Jämsä).

	I	II	III	h_3^2
(1) Absolute extent of measures taken	—.54	—.52	.01	.56
(2) Relative extent of measures taken	—.79	—.08	.26	.70
(3) Absolute extent of forest regeneration	—.65	—.51	.28	.76
(4) Relative extent of forest regeneration	—.80	—.14	.22	.71
(5) Number of different measures taken	—.47	—.33	.50	.58
(6) Measure taken for the first time	—.25	—.27	.65	.56
(7) Last visit by forestry expert to farm	—.18	—.53	.16	.34
(8) Last attendance at instructive meeting	—.02	—.44	.18	.23

The solution selected will be interpreted in the following. Here as well as later, only factor loadings exceeding .30 will be taken into account.

»*Relative extent of activity*» (T_1)
Relative extent of forest regeneration (4) ..... .80
Relative extent of measures taken (2) ..... .79

Absolute extent of forest regeneration (3) ..... .65
Absolute extent of measures taken (1) ..... .54
Number of different measures taken (5) ..... .47

The highest weight coefficients of this first factor definitely rest on the original variables measuring the relative extent of forest regeneration and of all measures (measures/ha). The factor, therefore, is interpreted to be a dimension illustrating the relative extent of silvicultural activity. This interpretation is supported by the fact that the variables measuring the relative extent of the measures do not, with other factors of the solution, acquire loadings that can be interpreted. The loadings to be interpreted, of the variables measuring the absolute extent of the measures of this factor, indicate the interconnection of the relative and absolute extent of the measures, and probably partly also a technical correlation between the variables. Variables 2 and 4, from the technical point of view, are formed in interdependence, and variables 1 and 3 contain some identical elements; see p. 42.

»*Use of expert*» (T_2)
Last visit by forestry expert to farm (7) ..... .53
Absolute extent of measures taken (1) ..... .52
Absolute extent of forest regeneration (3) ..... .51
Last attendance at instructive meeting (8) ..... .44
Number of different measures taken (5) ..... .33

This factor gives the highest loadings to the variable measuring the frequency of the utilization of expert assistance. The variables measuring the absolute extent of all measures and of forest regeneration also have nearly the same loadings. The factor, therefore, would seem to illustrate a close connection between the utilization of expert assistance among forest owners and the absolute extent of silvicultural measures taken. Also a higher-than-average frequency of attending forestry instructive meetings is associated with this dimension.

»*Readiness to act*» (T_3)
Measure taken for the first time (6) ..... .65
Number of different measures taken (5) ..... .50

The third factor is of a specific nature (see H a h t o l a 1967 a, p. 142, 144) and illustrates the interconnection between the wide range of silvicultural measures and the readiness to undertake these measures. The sooner after the beginning of possession a measure is taken, the wider the range of different measures that seems to develop. The factor is said to be the dimension describing readiness to act.

52. Attitude dimensions

The principal-factor matrix (Appendix 9) was computed on the basis of the correlation matrix of 19 propositions. Varimax rotation was carried out subsequently; separately with two, three and four factors (see Appendix 12). The four-factor varimax solution computed from the combined material was selected (Table 3). This selection was also based on strategical research grounds (cf. p. 45). In the four-factor solution the attitude to forestry experts and to forest management associations were differentiated into their own attitude dimensions, which revealed interesting differences between the communes compared.

Table 3. Four-factor varimax solution. Attitude variables. Combined material (Karstula + Jämsä).

	I	II	III	IV	h_4^2
(9) Forest owners are generally too little interested in forestry matters	—.09	—.62	—.01	—.02	.39
(10) Forest management associations are not particularly worth supporting	—.29	—.05	—.51	.18	.38
(11) Forest owners today take sufficient care of the management of their forests	—.25	—.57	—.04	.08	.39
(12) To small a share of the income from timber sales is used on silviculture	—.10	—.50	—.09	.21	.31
(13) If you think economically, it is not worthwhile spending money on silviculture	—.13	—.09	.00	.38	.17
(14) It would not be right if forest owners were forced by law to recondition their forests	—.27	—.26	—.04	.30	.23
(15) One should have the right to cut more freely than today	—.56	—.17	—.19	.12	.39
(16) There is no point in prohibiting by law cuttings in a forest	—.31	—.21	—.10	.04	.15
(17) Silviculture needs more legislative supervision	.03	—.34	—.24	.32	.28
(18) It is true that few owners practice sufficient silviculture unless obliged to by law	.01	—.53	—.10	.17	.32
(19) An obligatory forest management fee is necessary	—.06	—.15	—.64	.04	.42
(20) Forest fertilization should be greatly increased	.03	—.06	—.26	.41	.24
(21) The forest owner should personally mark the trees he intends to sell	—.63	—.03	—.02	.12	.41
(22) It is not necessary to plan silvicultural measures for future years	—.44	—.04	.09	.38	.35
(23) Forest regeneration is too popular today	—.37	—.14	—.16	.56	.50
(24) New silvicultural methods are often very unpractical	—.50	—.03	—.30	.27	.41
(25) Forestry experts do not sufficiently understand the forest owners' needs	—.62	—.04	—.14	.05	.40
(26) The ability of managing forest used to be much better than today	—.41	—.13	.12	.23	.25
(27) Forest regeneration must be considered economically unprofitable	—.32	—.21	—.09	.60	.51

The interpretation of the solution describing attitude dimensions was as follows. To facilitate the presentation, all attitude propositions are rendered in a form indicating a positive attitude to silviculture and are abbreviated.

»Attitude to forestry experts» (A_1)

An expert should mark trees for felling (21)	.63
Experts understand (25)	.62
Freedom to cut is sufficient (15)	.56
New methods are suitable (24)	.50
Planning is necessary (22)	.44
Skills are better today (26)	.41
Forest regeneration is not favoured too much (23)	.37
Forest regeneration is an economic proposition (27)	.32
Restrictions on cutting are necessary (16)	.31

The highest loadings on this factor were acquired by propositions measurig the opinions towards forestry experts (should mark the trees to be sold; understand sufficiently the forest owners' needs). This agrees with the view that restrictions imposed on the use of forest, with forestry experts supervising their observation, are not considered unduly heavy (freedom to cut is sufficient). The factor illustrates the attitude to forestry experts, and a review of its loadings shows that the positive reaction to forestry experts is associated with a positive attitude to current silviculture in general, to new silvicultural methods, and to the planning of silvicultural measures.

»Forest owner's self-appraisal» (A_2)

Forest owners show too little interest (9)	.62
Forest owners do not care enough (11)	.57
Forest owners do not tend forests without a law (18)	.53
Sales income is insufficient for silviculture (12)	.50
Silviculture should be supervised more (17)	.34

The highest loadings in this factor are consistently associated with the propositions measuring the opinions of the interviewed towards forest owners today and their »willingness» to practice silviculture. The view that forest owners are too little interested in forestry matters is connected with the view that forest owners take insufficient care of the management of their forests and do not tend them unless compelled to by law. There seems to be an attitude dimension, associated with self-appraisal, in which the extremes of critical and approving attitudes towards the forest owners' silvicultural activity today are seen. The forest owner's self-appraisal is probably a suitable name for this factor.

»Attitude to forest management associations» (A_3)

A forest management fee is necessary (19)	.64
Forest management assosiations deserve support (10)	.51

In this factor the two propositions with loadings that need interpretation measure opinions towards the work of forest management associations. The factor is specifically an attitude dimension describing the attitude to forest management associations.

»*Attitude to methods*» (A_4)

Forest regeneration is an economic proposition (27)	.60
Forest regeneration is not favoured too much (23)	.56
Fertilization should be greatly increased (20)	.41
Planning is necessary (22)	.38
Silviculture is worth financial investment (13)	.38
Silviculture should be supervised more (17)	.32

This factor would seem to reflect the attitudes towards silvicultural methods. A positive attitude to forest regeneration means that the need of forest fertilization is also emphasized and planning in forest management is acceptable. Furthermore, the proposition measuring the economic profitability of silviculture (silviculture is worth financial investment) acquires with this dimension a low loading which nevertheless can be interpreted. This agrees well with the fact that the factor illustrates especially the attitudes to such silvicultural methods (forest regeneration and forest fertilization), the adoption of which requires economic sacrifice, sometimes considerable, by the forest owner.

53. Background dimensions

The principal-factor matrix (Appendix 10) was computed on the basis of the correlation matrix of 20 original variables. Rotation was again carried out by the varimax method.

Table 4. Three-factor varimax solution. Background variables. Combined material (Karstula + Jämsä).

	I	II	III	h_3^2
(28) Forest area	—.75	—.19	—.21	.64
(29) Fertility of forest soil	—.16	.06	.01	.03
(30) Relative yield	—.44	—.42	.04	.37
(31) Arable area	—.60	.22	—.35	.49
(32) Distance from main village	.06	—.63	.07	.41
(33) Distance from bus route	.09	—.58	—.01	.34
(34) Revenue	—.74	.08	.13	.57
(35) Supplementary income	—.17	.04	.51	.29
(36) Debts	—.16	.39	.08	.17
(37) Level of fixtures I	—.53	.38	.03	.43
(38) Level of fixtures II	—.65	.20	.08	.47
(39) Continuity of ownership	—.15	—.04	—.41	.19
(40) Duration of family possession	—.39	—.19	—.09	.20
(41) Age	.23	—.03	—.35	.18
(42) Schooling	—.51	.16	.03	.29
(43) Activity in using sources of knowledge	—.53	.17	—.20	.35
(44) Activity in organizations	—.56	.22	—.09	.38
(45) Satisfaction with occupation	—.05	.13	—.43	.20
(46) Security of subsistence	—.15	.00	—.38	.17
(47) Spirit of enterprise	—.09	.19	—.13	.06

Even here it might have been fruitful to vary the number of factors in the rotation and to study how interesting the different solutions were from the standpoint of further analysis, as was done above when the activity and attitude dimensions were determined. This procedure, however, was not applied here because the three-factor varimax solution (Table 4), computed from the combined material and selected for use was found to be sufficiently clear in interpretation and interresting theoretically.

The selected three-factor varimax solution is interpreted below.

»*Resources*» (E_1)

Forest area (28)	.75
Revenue (34)	.74
Level of fixtures II (38)	.65
Arable area (31)	.60
Activity in organizations (44)	.56
Level of fixtures I (37)	.53
Activity in using sources of knowledge (43)	.53
Schooling (42)	.51
Relative yield (30)	.44
Duration of family possession (40)	.39

The highest loadings on this factor are held by the variables measuring the primary productive and economic prerequisites (forest area, arable area and revenue). The factor, therefore, is termed the dimension illustrating the forest owner's productive and economic resources. It is also interesting to note that the original variables measuring the forest owner's educational level (activity in organizations, activity in using sources of knowledge, and schooling) acquired loadings qualifying for interpretation. This is an indication of the interconnection of economic resources and educational level among the forest owners studied. It seems also that productive and economic resources are above average on farms where the relative importance of the forest is great and which have long been in the possession of the same family.

»*Location*» (E_2)

Distance from main village (32)	.63
Distance from bus route (33)	.58
Relative yield (30)	.42
Debts (36)	—.39
Level of fixtures I (37)	—.38

This factor illustrates specifically the location of the farm. The original variables measuring the distance to a centre of population and to a bus route have the highest loadings. It can also be concluded from factor loadings

that the relative importance of the forest, on average, is greater on farms with a distant location whereas the level of fixtures in the dwelling unit is higher and the total of debts greater on farms located closer to centres of population and transport routes.

»*Abandonment of farm husbandry*» (E_3)

Supplementary income (35)	.51
Satisfaction with the occupation (45)	—.43
Continuity of ownership (39)	—.41
Security of subsistence (46)	—.38
Arable area (31)	—.35
Age (41)	—.35

This factor is perhaps best interpreted as a background dimension illustrating abandonment of farm husbandry. The highest loading on this factor lies in the original variable measuring the amount of supplementary income obtained from sources other than agriculture and forestry connected with the farm. This increase in supplementary income is, according to this factor interpretation, associated with dissatisfaction with the farmer's profession, uncertainty of continuity in the farm's ownership, and insecurity about future subsistence. The interpretable loading of the variables measuring area of arable land and farmer's age can be taken to indicate that abandonment of farm husbandry is characteristic of rather young forest owners holding small areas of arable land.

54. Serviceability of composite variables

The conclusions will be drawn on the basis of the mutual correlations of the composite variables describing activity, attitude and background dimensions which were interpreted above. It is therefore important to review the serviceability of these variables in some detail.

In Section 421 the general features of composite variables formed using the technique of factor analysis were discussed. Certain adverse factors were also pointed out. It was stressed, that even essential information can be lost when composite variables expressed in terms of factor scores are used, since the so-called unique factors (and sometimes also a part of the common variance) are excluded from the analysis. For this study, the explanation percentages of the various solutions in the total variance of the original variables was:

	Activity dimensions (T)	Attitude dimensions (A)	Background dimensions (E)
Number of dimensions 3	59 %		31 %
» » » 4		34 %	

As can be seen, the percentages are relatively low, even though they approximately correspond to the level generally found in Finnish sociological studies (M a r k k a n e n 1964 b, pp. 6—7). The low explanation percentages of the present study are probably mainly due to the low reliability of the interview measurement itself (see Appendix 3). Since the error variance thus becomes considerable, the result is a corresponding reduction in the explanation percentage. An advantage of the composite variables constructed with the aid of factor analysis techniques is, on the other hand, that they utilize only the most reliable part of the variance of the original variables.

But it is apparent that the composite variables do not even contain all the reliable information of the original variables. Factor analysis is a method oriented towards co-variance, leaving the specific variance of each separate, original variable outside the analysis. It seems that for an original variable which can be reliably measured, such as fertility of forest soil (29), the problem is that the specific variance of the variable excluded from analysis becomes considerable. In fact, the fertility of forest soil correlates poorly with other background variables; see Appendix 5—7. Furthermore, a number of factors explaining common variance, especially in the solutions describing attitudes and background conditions, may have remained outside the analysis. Rotation in these solutions was carried out with numbers of factors corresponding to computed communality sums lower than the starting communality sums (cf. H a r m a n 1960, pp. 208—210; see Appendices 9 and 10). Therefore, although the *composite variables employed can definitely be considered more reliable than the original variables*, it must be made clear that *these variables do not contain all reliable information contained in the original variables.*

A typical validity problem in the use of composite variables is the question of joint coverage of the theoretical concept and the corresponding operational counterpart. As stated above (p. 36), in studies based on factor analysis this problem is one of factor interpretation. The question arises, are the statistically determined factors once extracted available for meaningful interpretation? If so, the composite variables constructed with the aid of factor-analysis techniques can be considered valid variables appropriate for use in further analysis. If not, the composite variables expressed in terms of factor scores are only vaguely defined variables and sometimes quite trivial.

It may be said that the activity, attitude and background dimensions of the present study could be given a meaningful interpretation relatively easily. *This meaningful interpretation is considered as sufficient justification of the validity of the composite variables constructed.* However, some weaknesses are present. For example, in the factor solution describing activity dimensions the complexity of some original variables (e.g. variables measuring the num-

ber and absolute extent of measures taken), is obvious; they are indicators for more than one underlying dimension. This means that the predictions concerning activity dimensions may to some extent be confounded.

The weaknesses associated with the methods of estimating factor scores are also an adverse aspect of using composite variables constructed by the technique of factor analysis. A validity problem may develop; do factor scores correspond to the interpreted factor in the way they are meant to? A similarity in structure between the original-factor matrix and the coefficients of regression on the standardized variables of the factors estimated by L e d e r m a n's method is involved here. L e d e r m a n's coefficients of regression were not, however, available for use here. For this reason the study of the structural similarity between these coefficients and the factor matrices must be omitted. But a review of the factor loadings and the mutual correlations between original variables and factor scores reveals that the factor loadings and the corresponding correlations show parallel variations and are practically equal (Appendix 13). Since both factor loadings and correlations with factor scores can be considered weights of the original variable, the former in the factor dimension and the later in the composite variable, and since these weights are nearly equal, it may be said that *the factor scores in the present study seem to correspond to the interpreted factors just as intended.*

The conclusion that can be drawn from this is that weaknesses are inherent in the constructed composite variables for two main reasons. First, some information contained in the original variables has been lost in grouping them. Second, no definite conclusions can be drawn concerning the validity of composite variables. Despite these weaknesses, the serviceability of composite variables is evaluated as fairly satisfactory. They apparently do contain most of the reliable information contained in the original variables. In addition, the fairly meaningful interpretation suggests satisfactory validity.

6. RESULTS

61. Attitudes and background conditions correlated to silvicultural activity

611. Attitudes and background conditions correlated to the use of expert

Information contained in the original variables measuring silvicultural activity was condensed above into the basic dimensions describing the relative extent of activity (T_1), the use of expert (T_2), and readiness to act (T_3). This section focuses on the second activity dimension which illustrates a close connection between the utilization of expert assistance among forest owners and the absolute extent of silvicultural measures taken (p. 46). The relationships between the use of expert and the forest owner's attitudes and individual farm-background conditions will be discussed. The original and partial correlation coefficients of factor scores, reflecting these relationships, are given in Table 5.

First, however, will be presented the squares of the multiple correlation coefficients which serve to illustrate the contribution of both attitude and background dimensions in explaining the use of expert. This is done because there is disagreement concerning the importance of attitude and background factors in explaining forest owner's silvicultural activity. Some people have stressed the importance of attitude factors and others, in turn, the effects of background conditions (p. 12). The explanation shares are as follows:

Independent variables	Per cent of variance in use of expert (T_2) explained	
	Karstula	Jämsä
Attitude dimensions (background dimensions controlled)	4	3
Background dimensions (attitude dimensions controlled)	49	32
Background and attitude dimensions together	53	36

As can be seen, the research findings indicate that among the forest owners studied *the individual farm-background conditions largely determine the use of expert assistance and the accompanying absolute extent of silvicultural measures taken.*

The explanation share of attitude dimensions is very low. A closer review of the connections between attitude dimensions and the use of expert di-

Table 5. Attitudes and background conditions correlated with the use of expert. The original and partial correlation coefficients of the factor scores. Karstula and Jämsä.

Karstula $r_{.05}$ = .17	Criterion: T_2 = the use of expert									
(A_1) Attitude to forestry experts	**.19**	*	**.19**	**.20**	**.21**	*	—.05	**.22**	**.20**	—.04
(A_2) Forest owner's self-appraisal	—.10	—.09	*	—.11	—.10	*	—.08	—.10	—.10	—.08
(A_3) Attitude to forest management associations	.05	.07	.07	*	.05	*	.10	.05	.04	.09
(A_4) Attitude to methods	—.08	—.11	—.08	—.08	*	*	—.12	—.07	—.10	—.14
(E_1) Resources	**.69**	**.67**	**.68**	**.69**	**.69**	**.67**	*	**.68**	**.69**	*
(E_2) Location	.09	.13	.09	.09	.08	.13	.01	*	.09	*
(E_3) Abandonment of farm husbandry	—.25	—.25	—.25	—.24	—.25	—.26	—.27	—.25	*	*
Jämsä $r_{.05}$ = .16										
(A_1) Attitude to forestry experts	.08	*	.08	.04	.07	*	.04	.08	.08	.05
(A_2) Forest owner's self-appraisal	—.12	—.12	*	—.10	—.12	*	—.11	—.12	—.11	—.10
(A_3) Attitude to forest management associations	**.23**	**.22**	**.22**	*	**.22**	*	.14	**.23**	**.22**	.14
(A_4) Attitude to methods	.02	—.00	.03	.01	*	*	.05	.02	.02	.05
(E_1) Resources	**.58**	**.58**	**.58**	**.57**	**.59**	**.57**	*	**.59**	**.58**	*
(E_2) Location	—.02	—.02	—.04	—.02	—.02	—.04	.05	*	—.02	*
(E_3) Abandonment of farm husbandry	—.07	—.08	—.05	—.04	—.07	—.04	—.05	—.07	*	*

Note: The asterisk indicates that the composite variable in question has been controlled.

mension, however, provides an opportunity for drawing tentative conclusions about the importance of forest owner's attitudes in this connection.

It is seen, for example, that the only attitude dimensions with statistically significant correlation to the use of expert are, in Karstula, the attitude to forestry experts (A_1) and, in Jämsä, the attitude to forest management associations (A_3) (see Table 5). This finding would seem to justify the assumption that a favourable attitude to forestry experts in Karstula and a similar attitude to forest management associations in Jämsä tend to increase the use of expert and the absolute extent of silvicultural measures. However, this is not so according to the present study. A review of the partial correlation coefficients in Table 5 reveals that the correlation of attitudes to forestry experts, and partly also to forest management associations, with the use of expert disappears when the productive and economic resources (E_1) of the farm are controlled. Correlations between attitudes and activity here prove to be spurious and misleading. Specifically, the attitudes to forestry experts have not effect of their own and the variations

in the use of expert and the absolute extent of silvicultural measures are ultimately explained by differences in productive and economic resources. The positive attitude to forestry experts in Karstula and to some extent also the positive attitude to forest management associations in Jämsä are, rather, to be interpreted as indicators of »mutual solidarity» between local forestry experts and wealthy forest owners (cf. Rogers 1968, p. 257; Vainio-Mattila 1969, pp. 61—68).

It is also worth pointing out that the attitude dimension expressing the forest owner's self-appraisal (A_2) correlates weakly but consistently in the negative with the use of expert dimension. This means that forest owners who consider the present silvicultural activity among forest owners to be inadequate and think that forest owners generally show too little interest in forestry matters do not themselves seem to be particularly active in silviculture. Their critical attitude towards the present silvicultural activity of all forest owners is rather symbolic since it does not result in actions complying with the attitude.

In a review of the connections between attitudes and the use of expert it can further be seen that the attitude to methods (A_4) in Karstula is correlated more negatively than positively to the use of expert dimension. If correlations between the original variables are studied, a negative correlation is found to »arise» so that forest owners who frequently seek the help of forestry experts, do not find it necessary to increase forest fertilization, thereby taking a negative attitude to forest regeneration and to the economic profitability of silviculture in general (see Appendix 5). The finding is unexpected and it cannot be properly interpreted here. Whether it is a »protest» against the views forestry experts are likely to hold concerning the economic profitability of silvicultural measures is impossible to estimate with the information available here.

In the study of connections between the individual farm-background conditions and the use of expert dimension, conclusions can be drawn on the basis of relatively high statistical correlations.

As stated before, the individual farm-background conditions largely determine the use of expert assistance and the accompanying absolute extent of silvicultural measures taken. The importance of each of the various background conditions, however, is different on this point. Particularly firm is the connection between the use of expert dimension and the background dimension illustrating the productive and economic resources of the farm (E_1) (see Table 5). This means that *with increasing productive and economic resources, the use of expert assistance and the absolute extent of silvicultural measures increase*. This finding seems to agree with some observations made in studies of innovation diffusion in agriculture. As Rogers (1968, pp. 64—65) points out, the modern innovative farmer usually has the fol-

lowing characteristics, among others; he lives on a larger- than-average farm, is wealthy and educated, and is active in farmer organizations. These characteristics seem to be peculiar also to the forest owner who has carried out silvicultural measures more than average, and who frequently seeks the help of a forestry expert in his silviculture.

It is justifiable, however, to ask whether such a research finding supports the view that sufficient productive and economic prerequisities create the primary conditions for active silviculture and, on the whole, for fruitful forestry. The frame of reference of the present study considered these views (see Sections 231 and 232). The answer to the question tends toward the negative. The correlation between the use of expert dimension and the resource dimension indicates only that the use of expert asistance and the range of silvicultural measures for wealthy forest owners with large forest units were above average. This finding, in a way, is self-evident and trivial. It is natural to expect that, with increasing forest-unit size, the range of silvicultural measures increases and the visits by a forestry expert to the farm become numerous.

More interesting is, on the contrary, the connection between the use of expert dimension and the background dimension describing the forest owner's abandonment of farm husbandry (E_3). Research findings indicate that *abandonment of farm husbandry is connected with the reduced use of expert assistance* (see Table 5). Although this correlation was clearly discernible only among the Karstula forest owners, the result may be considered as supporting the view that factors indicating abandonment of farm husbandry, such as growth of supplementary income, uncertainty of the continuity of ownership, and dissatisfaction with the occupation as a farmer, are connected with a weakening in the forest owner's silvicultural activity (see Sections 233 and 235). It is also worth pointing out that some research findings presented by R o g e r s indicate a similar development among the farmers of Ohio in the United States. R o g e r s found that the farmers leaving farming were much more likely to be laggards than innovators. His conclusion is that »laggards are most likely to drop out of the social system» (R o g e r s 1968, p. 191). In addition, R o g e r s found that those leaving farming were older, less educated, and had smaller farms than the farmers staying in the social system. The present study, however, seems to give a slightly different picture of the forest owners leaving the farm husbandry; they are rather young forest owners holding small areas of arable land who are dissatisfied with their occupation as a farmer and uncertain of the continuity of ownership (p. 51). It must be kept in mind that these conclusions only apply to farm-forest owners. No conclusions can be drawn, on the basis of the present study, concerning the silvicultural activity of forest owners not at all engaged in farm husbandry.

The background dimension describing the location of the farm (E_2) does not correlate significantly with the use of expert dimension (see Table 5). It is true, however, that the correlation coefficients in Karstula are consistently positive. Accordingly, the use of expert assistance and the absolute extent of silvicultural measures taken are above the average level on farms with a distant location in Karstula. A study of the partial correlation coefficients reveals, however, that this does not result from the location, since the connection between location and the use of expert dimension disappears if the productive and economic resources are standardized.

612. Attitudes and background conditions correlated to the relative extent of activity and readiness to act

This section deals simultaneously with factors affecting the relative extent of activity (T_1) and the readiness to act (T_3). This procedure is considered justified since the correlations of these two activity dimensions with the forest owner's attitudes and individual farm backgrounds proved to be largely similar. The original and partial correlation coefficients of the factor scores describing these correlations are given in Tables 6 and 7. First, however, the contribution of both attitude and background dimensions to explaining the relative extent of activity and readiness to act, will be presented. These explanation shares are as follows:

Independent variables	Per cent of variance explained in relative extent of activity (T_1)		in readiness to act (T_3)	
	Karstula	Jämsä	Karstula	Jämsä
Attitude dimensions (background dimensions controlled)	3	7	3	10
Background dimensions (attitude dimensions controlled)	2	11	2	7
Background and attitude dimensions together	5	19	4	17

A review of the above explanation shares reveals that the attitude and background dimensions can explain a very small portion of the variation in the composite variables describing the relative extent of silvicultural activity and readiness to act. In effect, the present study can explain practically none of the differences among the forest owners of Karstula.

Although the explanation shares are low, they do, however, suggest a regularity concerning the factors defining the relative extent of activity and readiness to act. The research findings seem to support the assumption that the *relative extent of silvicultural activity and readiness to act depend almost equally on the forest owner's attitudes and the individual farm backgrounds.* While the variation in the use of expert dimension was explained almost

exclusively by the differences in individual farm background conditions, especially the productive and economic rescources, the relative importance of attitude factors is distinctly increased in explaining the relative extent of activity and readiness to act.

The research findings show, further, that *attitudes to silvicultural methods* (A_4) *have a fairly high correlation with the relative extent of activity and readiness to act* (see Tables 6 and 7). These correlations, however, are clear-cut only among the forest owners of Jämsä. The extent of silvicultural measures taken per hectare of forest exceeds the average, with the first measure being taken sooner than average after the beginning of ownership for those forest owners of Jämsä whose attitudes to forest regeneration, forest fertilization and the economic profitability of silviculture were favourable. In addition to the attitudes to methods, the attitudes to forest management associations (A_3) are of importance in this connection. The correlations of these latter attitudes with the relative extent of activity and readiness to act dimensions decrease slightly when the effects of resources are controlled

Table 6. Attitudes and background conditions correlated to the relative extent of activity. The original and partial correlation coefficients of the factor scores. Karstula and Jämsä.

Karstula $r_{.05} = .17$	Criterion: T_1 = the relative extent of activity									
(A_1) Attitude to forestry experts	.09	*	.09	.11	.09	*	.06	.08	.09	.05
(A_2) Forest owner's self-appraisal	—.03	—.03	*	—.06	—.03	*	—.03	—.03	—.03	—.03
(A_3) Attitude to forest management associations	.14	.15	.15	*	.14	*	.14	.14	.14	.14
(A_4) Attitude to methods	.02	.01	.02	.02	*	*	.02	.02	.01	.01
(E_1) Resources	.08	.06	.08	.09	.08	.06	*	.09	.08	*
(E_2) Location	—.07	—.05	—.07	—.07	—.07	—.05	—.08	*	—.07	*
(E_3) Abandonment of farm husbandry	—.12	—.12	—.12	—.11	—.12	—.11	—.11	—.12	*	*
Jämsä $r_{.05} = .16$										
(A_1) Attitude to forestry experts	—.01	*	—.00	—.04	—.06	*	—.03	—.00	.01	—.01
(A_2) Forest owner's self-appraisal	—.04	—.04	*	—.03	—.05	*	—.03	—.07	—.02	—.04
(A_3) Attitude to forest management associations	**.20**	**.21**	**.20**	*	**.20**	*	**.16**	**.21**	**.19**	.15
(A_4) Attitude to methods	**.19**	**.20**	**.19**	**.19**	*	*	**.21**	**.18**	**.20**	**.20**
(E_1) Resources	**.30**	**.30**	**.30**	**.27**	**.31**	**.29**	*	**.29**	**.30**	*
(E_2) Location	—**.18**	—**.18**	—**.19**	—**.19**	—**.16**	—**.17**	—**.16**	*	—**.18**	*
(E_3) Abandonment of farm husbandry	—.13	—.13	—.13	—.11	—.15	—.11	—.12	—.13	*	*

Note: The asterisk indicates that the composite variable in question has been controlled.

Table 7. Attitudes and background conditions correlated to readiness to act. The original and partial correlation coefficients of the factor scores. Karstula and Jämsä.

Karstula $r_{.05} = .17$	Criterion: T_3 = readiness to act									
(A_1) Attitude to forestry experts	—.03	*	—.03	—.02	—.04	*	—.07	—.03	—.03	—.06
(A_2) Forest owner's self-appraisal	.06	.05	*	.03	.05	*	.06	.06	.06	.06
(A_3) Attitude to forest management associations	.14	.14	.14	*	.14	*	.15	.14	.15	.15
(A_4) Attitude to methods	.04	.04	.04	.03	*	*	.04	.04	.04	.04
(E_1) Resources	.09	.10	.09	.09	.09	.11	*	.08	.09	*
(E_2) Location	.04	.04	.05	.05	.05	.05	.04	*	.05	*
(E_3) Abandonment of farm husbandry	.04	.04	.04	.05	.04	.05	.05	.04	*	*
Jämsä $r_{.05} = .16$										
(A_1) Attitude to forestry experts	**.19**	*	**.19**	.15	.14	*	**.17**	**.19**	**.19**	**.17**
(A_2) Forest owner's self-appraisal	.00	—.01	*	.03	—.01	*	.02	.00	.00	.02
(A_3) Attitude to forest management associations	**.25**	**.22**	**.25**	*	**.25**	*	**.21**	**.25**	**.25**	**.21**
(A_4) Attitude to methods	**.21**	**.17**	**.21**	**.20**	*	*	**.22**	**.21**	**.21**	**.23**
(E_1) Resources	**.28**	**.28**	**.29**	**.25**	**.30**	**.26**	*	**.29**	**.29**	*
(E_2) Location	—.02	—.02	—.02	—.02	.09	.00	.01	*	—.02	*
(E_3) Abandonment of farm husbandry	—.00	—.02	—.00	.03	—.01	.00	.02	—.00	*	*

Note: The asterisk indicates that the composite variable in question has been controlled.

(see Tables 6 and 7). Hence, the correlations are partly spurious (cf. p. 55). It is justifiable to say, however, that a *positive attitude to forest management associations is connected with an above average relative extent of activity and readiness to act.*

In fact, the attitudes to forest management associations arouse some interest. It was seen from the interview that only 41 per cent of the Jämsä forest owners found forest management associations worth supporting and a still lower percentage, 23 per cent, found that a compulsory forest-management fee is necessary (Veli-Pekka Järveläinen 1969 b, pp. 165—166; cf. Matilainen 1963, p. 149). Hence, there is considerable opposition to the work of forest management associations among the Jämsä forest owners. On the other hand, the relatively small group of forest owners with favourable attitudes to forest management associations, proved to be more active than others in their silviculture. The situation in Karstula is similar though not so clear-cut as in Jämsä.

The correlation coefficients reveal, furthermore, that a favourable attitude to forestry experts (A_1) was associated in Jämsä with an above-average

readiness to act (see Table 7). The interconnection of attitudes to forestry experts and readiness to act can, however, be partly explained by attitudes to methods or attitudes to forest management associations. The correlations between attitudes to forestry experts and readiness to act decrease after these other attitude dimensions are standardized.

As indicated above, the ability of individual farm-background conditions to explain differences in the relative extent of silvicultural activity and readiness to act is very low, much lower than the ability of these conditions to explain the variation in the use of expert dimension. Nevertheless, certain conclusions concerning the effect of background conditions can be made from the correlation coefficients. The research findings reveal, among other things, that the *relative extent of silvicultural activity and readiness to act, especially in Jämsä, depends on the farm's productive and economic resources* (E_1) (see Tables 6 and 7). When the size of the forest unit grows and the forest owner's economic position improves, the extent of silvicultural measures per hectare of forest seems to increase and the measures seem to be taken sooner after the farm is acquired. This finding can be said to support the view that sufficient productive and economic resources are the primary prerequisities for active silviculture (see Sections 231 and 232; cf. p. 57). However, an alternative interpretation can also be given. — This was clear-cut only for Jämsä. It is possible that in Jämsä the forest owners with good resources carried out a large number of silvicultural measures per hectare of forest and started their measures soon after having taken possession of the farm *following particularly intense fellings* on these farms. The fellings may have been necessary to finance investment in agriculture or to secure a rising standard of living (cf. P i h a 1957, pp. 53—54). If so, the large relative extent of activity and readiness to act would not reflect exclusively a tendency towards intense tree growing, but some would follow from the legally imposed silvicultural obligations associated with timber fellings. It was noted that the forest owner's agricultural innovativeness was associated in Jämsä with the relative extent of silvicultural activity and readiness to act, that correlation coefficients were .18 and .22, and that forest owners introducing innovations in agriculture sold timber more often and in larger quantities than was the average; correlation coefficients were .15 and .20 in Jämsä.[1])

The findings also revealed that the background dimensions describing the location of the farm (E_2) and forest owner's abandonment of farm husbandry (E_3) had a consistently negative correlation to the relative extent of silvicultural activity in both communes studied (see Table 6). Also, the correlation on this point was higher in Jämsä than Karstula. In any case,

[1]) Agricultural innovativeness was measured by a sum scale of the following items: (1) fertility analysis, (2) chemical weed control, and (3) ownership of a milking machine (cf. P u r o h i t 1963, pp. 70—76).

the findings suggest that not only the lack of productive and economic resources, but also *distant location of the farm and the forest owner's abandonment of farm husbandry were connected with the sub-average relative extent of silvicultural activity.* The information collected, however, showed that these background conditions had no clear-cut connection with the readiness to act dimension.

An additional comment is required concerning the factors affecting the forest owner's readiness to act. A rewiev of the original variables shows that the introduction of silvicultural measures soon after taking over the farm was characteristic of young forest owners in both communes studied (see Appendices 5 and 6). This indicates that a factor affecting the readiness to act is the forest owner's age. However, the increased intensity of forestry-promotion work of late may ultimately explain the observed correlation between readiness to act and the forest owner's age.

62. The changing rural environment and silvicultural activity

621. Average level of activity

In the section dealing with the frame of reference of the study, the question of how the forest owner's silvicultural activity will change in the course of industrialization and modernization of the rural environment was discussed. It was assumed that silvicultural activity may be weakened as the relative importance of trades representing primary production diminished and, consequently, interest was shifted to the developing »urban» means of livelihood (industry and service trades). But it was also pointed out that change in the rural environment involves factors, such as a rise in economic standing and educational level, which may be expected to increase silvicultural activity (see Section 242).

The results of this study support the former view. Firstly, *the average level of the silvicultural activity of forest owners in Karstula, representing the traditional rural environment, proved to be distinctly higher than in Jämsä, the industrialized rural environment on its way to modernization.* Specifically, the relative extent of activity (T_1) and readiness to act (T_3), taken on the average, were greater in Karstula (see Table 8). The low level of silvicultural activity in Jämsä need not, however, follow exclusively from the industrialization and modernization of the commune. Factors other than those connected with the development towards modernization may contribute to this result. For example, the high fertility of forest soil characteristic of Jämsä makes silvicultural measures difficult and reduces their »need».[1])

[1]) However, in Jämsä the fertility of forest soil did not correlate with the forest owner's silvicultural activity. In Karstula, on the other hand, a statistically significant negative correlation could be found (see Appendices 5 and 6).

Table 8. Silvicultural activity, silvicultural attitudes and individual farm-background conditions in Karstula and Jämsä.

	Per cent of the interviewed	
	Karstula (n = 139)	Jämsä (n = 150)
Silvicultural activity [1])		
(T_1) Great relative extent of activity	48	27
(T_2) Repeated use of expert	48	45
(T_3) Great readiness to act	58	41
Silvicultural attitudes [1])		
(A_1) Favourable attitude to forestry experts	60	49
(A_2) Critical self-appraisal of forest owner	68	46
(A_3) Favourable attitude to forest management associations	53	33
(A_4) Favourable attitude to methods	67	47
Individual farm backgrounds [1])		
(E_1) Plentiful resources	37	49
(E_2) Location close to population centre and transport route	42	64
(E_3) Little abandonment of farm husbandry	55	53

[1]) The composite variables describing activity, attitude and background dimensions have been divided into two classes on the basis of the mean value of factor scores. The percentages in the table indicate the proportions exceeding this mean of all those interviewed. It should be emphasized that the percentages are intended to indicate only the relative differences between the communes studied.

Secondly, it was found that *attitudes to silviculture in Karstula, on the average, were more favourable than in Jämsä.* The percentages in Table 8 reveal that the Karstula forest owners considered the current silvicultural activity (A_2) among forest owners inadequate more frequently, on the average, than did their counterparts in Jämsä.[1]) Also, the attitudes to forest management associations (A_3), to silvicultural methods (A_4), and to forestry experts (A_1) were more favourable in Karstula than in Jämsä. This result, however, needs a comment concerning its interpretation.

The study recorded as silviculturally favourable the forest owner's attitudes which foresters employed by Central Forestry Board Tapio (a central organization for the promotion of private forestry) found favourable (see Appendix 2). For this reason, the favourable attitude of forest owners

[1]) It was also found that the forest owners in Karstula rated the silvicultural level of their forests lower (more closely corresponding to the estimation of forestry experts) than was the case in Jämsä:

Silvicultural level of forest	Per cent of replies			
	Forest owners		Forestry experts	
	Karstula	Jämsä	Karstula	Jämsä
Good	39	53	37	21
Average	53	43	56	53
Bad	8	4	8	26
	100	100	100	100

may partly indicate that these forest owners more readily accepted standards and objectives in silviculture imposed on them »from above» than did the forest owners with a negative attitude who appreciated the individual's right to choose and set targets. *This conformity in silvicultural attitudes was characteristic especially of Karstula, i.e. forest owners living in a traditional rural environment.* For example, the Karstula forest owners definitely more often than the Jämsä forest owners were of the opinion that the supervision of forest management should be increased and that a legally imposed forest-management fee was necessary (Veli-Pekka Järveläinen 1969 b, p. 176).

Thirdly, reference can be made to findings, based on the same interview material and published earlier, concerning the level of forestry knowledge among forest owners in Karstula and Jämsä (Järveläinen & Vadén 1968, pp. 215—217). This report revealed that the *knowledge about certain forestry questions was, on the average, greater in Karstula than in Jämsä*, even though the differences between the communes was not very clear-cut on this point. The findings concerning the level of forestry knowledge, however, need detailed discussion since they provide a good illustration of viewpoints which must be taken into account in a comparison of the two communes.

The earlier report came to the conclusion that a high level of forestry knowledge was characteristic of those interviewed whose income was above average (ibid. p. 217). This raises the question of whether the findings might not be contradictory; it was claimed, on the one hand, that a high level of forestry knowledge is characteristic of wealthy forest owners and, on the other hand, that the level of forestry knowledge is relatively low in a commune in which the average forest owner's income level is high. This apparent contradiction, however, seems to be artificial. It indicates merely the fact that the *forest owner's silvicultural behaviour is regionally determined.* For this reason, in an analysis of the forest owner's behaviour, variables which in fact measure the same thing, e.g. income level, may behave differently in analysis at the individual level then they do at the community level (cf. p. 40). Here, for example, the review of individual forest owners shows that the level of forestry knowledge and silvicultural activity, and to some extent also the silvicultural attitudes (see Appendices 14 and 15), correlate positively with the forest owner's income level and other productive and economic resources. But the comparison between communes shows a corresponding negative correlations; in a modern rural environment with a high average level of income and other resources (Jämsä) the forest owner's forestry knowledge and silvicultural activity, on the average, are lower, and attitudes to silviculture less favourable, than among forest owners in a traditional rural environment with a low average level of income and other resources (Karstula).

The conclusion that can be drawn from this is that the rise in the level of productive and economic resources and also in the level of general knowledge which accompanies modernization in the rural environment do not seem to reinforce and increase the forest owner's silvicultural activity, silvicultural attitudes, or even the level of forestry knowledge. *The average silvicultural activity is higher in a traditional environment, where forests and forestry are still important and are an essential means of subsistence.* This finding does not necessarily contradict the general rule of innovatiness, according to which innovativeness of individuals is related to a modern rather than a traditional orientation (R o g e r s 1968, p. 67). In effect, this finding may primarily illustrate the fact that as a rural environment modernizes, fewer forest owners will realize their innovativeness in silviculture and forestry.

622. Features reflecting differentiation in tree growing

When the theoretical basis of this study was described, it was pointed out that as the rural environment was industrialized and modernized, tree growing may be accompanied by increased specialization and, generally, features reflecting a differentiation of activities. The differentiation of economic and social structure into separate component systems from wholistic systems is a series of events fundamentally associated with the processes of social change (see Section 242).

Some possible phenomena indicating differentiation in tree growing can be explored by studying the relationships between the composite variables reflecting silvicultural activity and those describing silvicultural attitudes and individual farm backgrounds in the two communes. These relationships are already presented in Tables 5, 6 and 7 in the form of the original and partial correlation coefficients of factor scores.

The correlation coefficients of Table 5 (p. 55) showed that the use of expert and the absolute extent of silvicultural measures taken (T_2) increase in the two communes as the productive and economic resources (E_1) at the forest owner's disposal increased. But the relative extent of activity (T_1) and the readiness to act (T_3) increased as the resources increased only in Jämsä (see Tables 6 and 7, pp. 59 and 60).[1]) These research findings seem to suggest that during the transition to conditions representing a modern rural environment *functional differentiation* in tree growing may be expected in the form of *forest owners with good productive and economic resources under-*

[1]) As stated before (p. 38), the predictions concerning activity dimensions may be confounded owing to the complexity of some original variables measuring silvicultural activity in factor solution. This conclusion, however, seems to be correct because the correlation coefficients between factor dimensions and between corresponding original variables are similar. See Appendices 5 and 6.

taking active silviculture. However, another interpretation is also possible. As stated before (p. 61) extensive silvicultural measures per hectare of forest and introduction of these measures soon after the farm was acquired are not exclusively the result of increased effort towards intense tree growing. They may follow from legally imposed silvicultural obligations associated with timber fellings.

Functional changes associated with tree growing might assume another form. The correlation coefficients of Table 5 (p. 55) also revealed that in the traditional rural environment the use of expert dimension (T_2) is connected not only with resources, but also with the abandonment of farm husbandry dimension (E_3), i.e. the strength of the forest owner's »ties» to farming. In the modern rural environment this correlation was not so clear-cut. These findings suggest that *as a rural environment advances toward modernizations silvicultural activity no longer depends on the type of farm*, whether the farm is of the traditional type exclusively bound to the traditional forms of farm-husbandry production (agriculture and forestry) or is a farm unit of heterogenous activity including supplementary earnings.

Certain research findings of this study would also seem to support the opinion that under conditions representing a modern rural environment tree growing may be expected to show some kind of *regional differentiation*. It was shown earlier that the location of the farm (E_2) in the traditional rural environment did not appreciably affect the forest owner's silvicultural activity, although distances in this environment often are considerable. But in the modern rural environment the relative extent of activity (T_1) was below average on farms with a distant location, i.e. far from population centres and transport routes (see Table 6, p. 59). The statistical correlations underlying this conclusion, however, are noticeably weak.

Social changes modify human attitudes and values as well. Therefore, it may be assumed that the forest owner's attitudes and values change as the rural environment is industrialized and modernized. But this does not only mean that some traditional attitudes and values are replaced by new ones; differentiation also takes place in this field.

Conclusions concerning some kind of differentiation in the field of silvicultural attitudes can be drawn from the differences noted in the silvicultural behaviour of Karstula and Jämsä forest owners. The correlation coefficients in Tables 5, 6 and 7 (pp. 55, 59 and 60) reveal that in Karstula the forest owner's attitudes had little connection with his silvicultural activity. In conditions representing a traditional rural environment, silvicultural activity may be said to depend almost exclusively on the individual farm-background conditions, especially on the productive and economic resources (E_1) at the forest owner's disposal. In other words, silvicultural activity is »in keeping with resources». But in Jämsä, which represented a modern rural environ-

ment, the forest owner's attitudes could explain some of the differences in the relative extent of activity (T_1) and readiness to act (T_3). This discrepancy between the communes will be interpreted by referring to the concept of »pressure to conform» (see Olavi Riihinen 1965, pp. 60—68).

Although the Karstula forest owners had silvicultural opinions which sometimes differed considerably (Veli-Pekka Järveläinen 1969 b, pp. 160—167), it seems that their opinions and attitudes were emotional outbursts rather than expressions leading to action (cf. Allardt — Littunen 1961, pp. 196—198). It is possible that the pressure to conform, characteristic of a traditional rural environment, does not »permit» such differences in attitudes to lead to action differing from the norm, in this case silvicultural activity »not in keeping with the resources»; differences in attitudes remain at the level of emotional outbursts. In a traditional social system, therefore, this kind of particularly active as well as particularly passive forest owners are types of deviants (cf. Rogers 1968, pp. 196—198). But *in conditions representing a modern rural environment, there are differences in silvicultural activity which can be referred back to differences in attitudes*, e.g. attitudes to silvicultural methods (A_4) and to forest management associations (A_3).

Hypothetical examination of the effects of change in the rural environment on tree growing led to the assumption that differentiation may also be expected at the goal level (see Section 242). Findings of this kind have already been published on the basis of the same interview material (Veli-Pekka Järveläinen 1968 a, pp. 88—89).

The question measuring the goals had the following wording in the questionnaire: »What is the order of importance of the following goals in the management and use of the forests of your farm?». The alternatives given were:

— saving the forest;
— reconditioning the forest;
— obtaining income from timber sales; and
— obtaining income from work in my own forest.

Analysis of the replies showed that obtaining income from timber sales was relatively more important in Jämsä than in Karstula. The forest owners of Karstula emphasized the importance of saving the forest, a goal guiding the management and use of forest. It was also noted (from a study of the intercorrelations of the estimated goals), that in Karstula the alternatives were not differentiated and all four goals seemed to incorporate the same ultimate aim for the forest owner. *But in Jämsä saving the forest and obtaining income from timber sales were differentiated as two opposite and alternative goals of forestry.*

623. Forms of instruction given to the forest owner

As the community changes, the forms of social interaction tend to develop towards reduced importance of personal interaction and unofficial primary-group relations and increased importance of formal group relations. It was assumed in the frame of reference that development in accordance with this general regularity could be expected in the promotion of silviculture during the transition from traditional conditions to conditions representing a modern rural environment (see Section 242). This assumption is supported by some of the research findings.

It may be pointed out, firstly, that opinions concerning the work of forest management associations were differentiated into a separate attitude demension only in factor solutions computed from the combined material and the Jämsä material. In the solution calculated from the Karstula material, opinions on the work of forest management associations did not form a separate attitude dimension, obtaining instead loadings capable of interpretation primarily on the dimension describing the attitude to forestry experts (Veli-Pekka Järveläinen 1968 b, p. 56). This may be considered to indicate the »predominant position» of the opinions about forestry experts among the Karstula forest owners.

Secondly, the correlation coefficients of Tables 5, 6 and 7 (pp. 55, 59 and 60) reveal that the attitudes to forestry experts among forest owners are significant in Karstula, while the attitudes to forest management associations are important in Jämsä. In Karstula the attitude to forestry experts (A_1) is the only attitude dimension with a statistically significant connection to the forest owner's silvicultural activity.[1]) But in Jämsä the favourable attitudes to forest management associations (A_3) stimulated silviculture. These findings seem to indicate that *in conditions representing a modern rural environment the importance of formal, professional organizations in the promotion of silviculture increases compared to unofficial, personal instruction.*

Reduced importance of unofficial, personal instruction in forest management is also suggested by certain findings on the diffusion of vocational knowledge in farm forestry, obtained from the same interview material. The forest owners were asked which sources they considered most important for obtaining vocational knowledge of forestry. Thirty-six per cent of the forest owners of Karstula replied that forestry experts were their most important source of knowledge, against 20 per cent in Jämsä. The forest owners of Jämsä also emphasized the importance of forestry lectures and courses (Järveläinen — Vadén 1968, pp. 213—215). It seems, therefore, that the diffusion of vocational knowledge in conditions representing

[1]) The favourable attitude to forestry experts in Karstula is, however, primarily an indication of the »mutual solidarity» between forestry experts and wealthy forest owners, see p. 56.

a modern rural environment increasingly takes place by means other than unofficial, personal instruction.

63. Factors affecting silvicultural activity; the main findings of the study

When considering the main research findings it should be borne in mind that no universally applicable regularities, sufficiently tested empirically, are presented. What is presented are *empirical generalizations in the form of hypotheses* concerning the forest owner's silvicultural activity in farm forestry, verification and specification of which must necessary be left to future studies with more extensive coverage. The factors most emphatically restricting the applicability of the results will be repeated:

(1) The study is based on a small body of interview material (n = 289). Strictly speaking, the results represent only the conditions prevailing in the communes studied (Karstula and Jämsä) in the summer of 1966.
(2) The effects of change in the rural environment were reviewed by comparing only two communes with observations at one point in time. It follows that, among other things, the specific characteristics of these communes may have decisively affected the results of the study.
(3) Certain correlations observed in the study could be given several interpretations, each of which could be justified. In addition, certain conclusions are based on weak statistical correlations.

The generalizations based on empirical reseach findings and illustrating regularities on the individual level will be listed first. These generalizations are concerned with the effects of silvicultural attitudes and individual farm-background conditions on the forest owner's silvicultural activity.

I. A forest owner's attitudes to silviculture do not appreciably affect the use of experts and the absolute extent of silvicultural measures which are governed primarily by the individual farm-background conditions.
   a. A favourable attitude to forestry experts indicates primarily the »mutual solidarity» between local forestry esperts and wealthy forest owners.
   b. Good productive and economic resources increase the use of expert assistance and the absolute extent of silvicultural measures.
   c. Forest owner's abandonment of farm husbandry reduces the use of expert assistance and the absolute extent of silvicultural measures.

II. The relative extent of silvicultural activity and the readiness to act depend almost equally on the forest owner's silvicultural attitudes and individual farm-background conditions.

a. A favourable attitude to silvicultural methods increases the relative extent of activity and readiness to act.
b. A favourable attitude to forest management associations increases the relative extent of activity and readiness to act.
c. Good productive and economic resources increase the relative extent of activity and readiness to act.
d. A distant location of the farm reduces the relative extent of activity.
e. A forest owner's abandonment of farm husbandry reduces the relative extent of activity.

The generalizations concerning changes on the community level will be presented next. According to the study, in the course of modernization in a rural environment, the following changes may be expected.

III. The forest owner's silvicultural activity, on the average, is reduced.

IV. The forest owner's attitudes to silviculture, on the average, are less favourable than before.

V. Functional differentiation takes place in tree growing; the forest owners holding good productive and economic resources »specialize» on active silviculture.

VI. Regional differentiation takes place in tree growing; the relative extent of silvicultural activity declines on farms with a remote location.

VII. Value differentiation takes place in tree growing.
a. The differences in the attitudes to silvicultural methods and forest management associations no longer remain at the emotional level but produce differences in the forest owner's activity.
b. The forestry goals of forest owners will differentiate; saving the forest and obtaining income from timber sales become opposite and alternative forestry goals.

In addition, as modernization of a rural environment advances, promotion of silviculture among forest owners may be expected to change as well.

VIII. The importance of formal vocational organizations in the promotion of silviculture increases compared with unofficial, personal instruction.

7. DISCUSSION

In conclusion, the utilization of the results of this study will be briefly discussed. Two different questions are considered: (1) How can the present results assist in forest-policy planning and forestry-promotion work? and (2) What are the most important recommendations concerning expanded studies? Once again, it will be stressed that the results of this study and the conclusions based on these results are only preliminary.

Projecting from the results of this study it seems justifiable to conclude that forest policy aiming at increased wood production in farm forestry might be expected to be successful if it focuses on the structural rationalization of farm-forest units. This follows because a forest owner with good productive and economic resources at his disposal seems to increase extent of his silvicultural activity (both absolutely and relatively) and at the same time make use of expert assistance. In addition, the structural conditions determining his satisfaction with his occupation as a farmer and the continuity of farm ownership may be stressed on this connection. However, the owner's attitudes to silviculture are also important. In forestry-promotion work it might be reasonable to pay attention especially to his attitudes towards silvicultural methods and forest management associations.

As a further consideration it seems correct to point out that the industrialization and modernization of the rural environment will create a number of new problems for forest policy and forestry-promotion work concerning farm forestry.

In general, it seems likely that the goal of forest policy (greater wood production) will become increasingly difficult to achieve due to the modernizing in the rural environment. This is so because the forest owners' average silvicultural activity will decline, and their attitudes to silviculture, on the average, will become less favourable as the modernization advances. Furthermore, modernization leads to differentiation of activities, attitudes and goals in tree growing. Forest policy and forestry-promotion work should also take into account this undeniable course of events which includes, among other things, the following tendencies:

(1) The tendency for forest owners with little productive and economic resources to lag in silviculture.

(2) The tendency for forest owners on farms remotely located with respect to population centres and transport routes to lag in silviculture.
(3) The tendency of forest owners to reject more readily than before the standards and objectives of silviculture imposed »from above», and the parallel tendency towards negative silvicultural attitudes.
(4) The tendency towards differentiation of forestry goals in farm forestry. This means that the same standards of silviculture are no longer useful for all forest owners, that the special conditions of each case will play a more important role than before.

As for as the recommendations for further studies are concerned it may be noted firstly that the coverage of the present study was very small. Therefore, studies based on more representative samples are needed. Secondly, it seems justifiable to conclude that, if one wishes to explain and »understand» as far as possible the forest owner's behaviour as a tree grower, it is not reasonable to restrict the analysis to silvicultural activity alone, but to include also timber-sale decisions and the underlying motivation. It may be pointed out that a positive correlation between silvicultural activity and the forest owner's willingness to sell has been demonstrated empirically (V i r t a 1970). Thirdly, the effects of a changing rural environment on the forest owner's silvicultural activity should be analyzed in detail in future studies. For example, the relationship between the forest owner's silvicultural activity and modernization in a rural environment need not be linear at all. In fact, some empirical evidence has been provided which supports the conclusion that such a relationship tends to be curvilinear (P ä i v i ö R i i h i n e n 1970).

ABBREVIATIONS

AFF = Acta Forestalia Fennica
ATT = Alkoholipoliittisen Tutkimuslaitoksen Tutkimusseloste
FF = Folia Forestalia
MA = Metsätaloudellinen Aikakauslehti
MTJ = Metsäntutkimuslaitoksen Julkaisuja
PS = Pellervo-Seuran Markkinatutkimuslaitoksen Julkaisuja
SF = Silva Fennica
SJ = Helsingin Yliopiston Sosiologian Laitoksen Julkaisuja
ST = Helsingin Yliopiston Sosiologian Laitoksen Tutkimuksia
SVT = Suomen Virallinen Tilasto
SY = Sosiaalipoliittisen Yhdistyksen Tutkimuksia
TT = Tampereen Yliopiston Tutkimuslaitoksen Monistesarja
YK = Yhteiskuntatieteiden käsikirja

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METSÄNHOIDOLLISEEN TOIMINTAAN VAIKUTTAVAT TEKIJÄT

Tutkimus asenteiden, tilakohtaisten taustaedellytysten ja alueellisten edellytysten vaikutuksesta metsänomistajan metsänhoidolliseen toimintaan Karstulassa ja Jämsässä

TIIVISTELMÄ:

Tehtävä, lähtökohdat ja aineisto

Tämän tutkimuksen tehtävänä on analysoida metsänomistajan metsänhoidolliseen toimintaan vaikuttavia tekijöitä maatilametsätaloudessa. Metsänhoidollisella toiminnalla tarkoitetaan tällöin sellaisten toimenpiteiden suorittamista, jotka välittömästi tai välillisesti liittyvät puun kasvatukseen. Tarkastelu kohdistuu metsänomistajan metsänhoidollisten asenteiden, tilakohtaisten taustaedellytysten ja yhteiskunnan muutosilmiöihin liittyvien alueellisten edellytysten vaikutuksiin. Tutkimus on luonteeltaan eksploratiivinen.

Tutkimuksen aineisto kerättiin henkilökohtaisen haastattelun avulla kesällä 1966 Karstulan ja Jämsän kuntien alueella. Karstulassa haastateltiin 139 ja Jämsässä 150, yhteensä siis 289 metsänomistajaa. Haastateltavat valittiin satunnaisesti kaikista mainittujen kuntien alueella asuvista miespuolisista henkilöistä, jotka itse tai puolisonsa kanssa yhteisesti omistivat vähintään kaksi hehtaaria peltoa ja kymmenen hehtaaria metsää.

Analyysissä käytettävien muuttujien valinta nojautuu pääasiassa puun kasvatuksen ominaispiirteisiin perustuvaan teoreettiseen lähtökohtaan. Muuttujien valinta suoritettiin tällöin ottamalla huomioon mm. puun kasvatuksen laajaperäisyyttä, taloudellista pitkäjänteisyyttä ja omistuksen jatkuvuutta korostavat piirteet. Tutkimuskunnat valittiin puolestaan eräisiin yhteiskunnan muutosilmiöitä kuvaaviin ideaalityyppeihin viittaavien käsitteellisten lähtökohtien perusteella. Pyrittiin siihen, että toinen tutkimuskunta (Karstula) edustaisi tyypillistä perinnäistä maaseutuympäristöä, ja toinen tutkimuskunta (Jämsä) taloudellisesti voimakkaasti kehittynyttä, uudenaikaista maaseutuympäristöä.

Menetelmät

Tutkimuksen empiirinen analyysi keskittyy kolmeen tehtävään, jotka ovat informaation tiivistäminen, riippuvuussuhteiden tarkastelu ja tutkimuskuntien välinen vertailu.

Lukuisten lähtökohtamuuttujien sisältämän informaation tiivistämisessä ja yhdistettyjen muuttujien konstruoimisessa käytettiin hyväksi faktorianalyysin tekniikkaa. Menetelmä mahdollistaa informaation tehokkaan tiivistämisen ja sen avulla on mahdollista päästä yhdistettyihin muuttujiin, joiden reliabiliteetti on lähtökohtamuuttujien reliabiliteettia selvästi korkeampi.

Kun metsänhoidollista toimintaa, metsänhoidollisia asenteita ja tilakohtaisia taustaedellytyksiä kuvaavat yhdistetyt muuttujat oli konstruoitu, suoritettiin näiden muuttujien välisiä kausaalisia yhteyksiä kuvaava tarkastelu. Tutkimuksessa päädyttiin menettelyyn, jossa yhdistettyjen muuttujien välisten yhteyksien erittely suoritettiin käyttämällä hyväksi sisällöllisesti eri tasoisten faktoreiden välisiä korrelaatioita ja osittaiskorrelaatioita. Metsänhoidollisten asenteiden ja tilakohtaisten taustaedellytysten vaikutusta metsänomistajan metsänhoidolliseen toimintaan analysoitiin vakioimalla vuoron perään sekä asenteita että taustaedellytyksiä mittaavat yhdistetyt muuttujat.

Tutkimuskuntien välinen vertailu olisi ollut mahdollista suorittaa useitakin eriluonteisia menetelmäratkaisuja soveltaen. Tässä tutkimuksessa tyydyttiin kuitenkin ainoastaan eräiden molemmista tutkimuskunnista erikseen laskettujen, faktoreiden välisiä yhteyksiä kuvaavien korrelaatiomatriisien silmämääräiseen vertailuun. Lisäksi käytettiin hyväksi kuntakohtaisia faktoripistemäärien keskiarvoja tutkimuskuntien välisten tasoerojen analysoimiseksi.

Tulokset

Siirryttäessä tutkimuksen tulosten tarkasteluun on erityisesti korostettava, että kysymys ei ole joidenkin empiirisesti riittävästi testattujen ja yleistysvoimaisten säännönmukaisuuksien esittämisestä, vaan pikemminkin sellaisista metsänomistajan metsänhoidollista toimintaa koskevista, hypoteesien luonteisista empiirisistä yleistyksistä, joiden verifioiminen ja täsmentäminen jää pakostakin uusien ja toivottavasti laaja-alaisempien tutkimusten tehtäväksi. Voimakkaimmin tämän tutkimuksen tulosten yleistävyyttä rajoittaa kolme seuraavaa seikkaa:

(1) Tutkimuksen aineisto on pieni (n = 289). Ankarasti ottaen tutkimustulokset edustavat ainoastaan tutkimuskunnissa (Karstula ja Jämsä) kesällä 1966 vallinneita olosuhteita.
(2) Maaseutuympäristön muutosilmiöiden vaikutusten tarkastelu perustuu ainoastaan kahden tyyppipaikkakunnan välillä suoritettuihin vertailuihin ja ainoastaan yhtä ajankohtaa koskeviin havaintoihin. Tällöin on mm. mahdollista, että vain ao. tutkimuskunnille spesifisesti ominaiset piirteet ovat vaikuttaneet ratkaisevastikin saatuihin tuloksiin.
(3) Eräille tutkimuksessa havaituille riippuvuussuhteille voitiin antaa useampia toisistaan poikkeavia ja kuitenkin samalla perusteltavissa olevia tulkintoja. Sitäpaitsi eräät tutkimuksessa tehdyt johtopäätökset perustuvat varsin heikkoihin tilastollisiin riippuvuussuhteisiin.

Aluksi esitetään ne empiirisiin tutkimushavaintoihin perustuvat yleistykset, jotka koskevat yksilötasolla ilmeneviä säännönmukaisuuksia. Nämä yleistykset kuvaavat metsänhoidollisten asenteiden ja tilakohtaisten taustaedellytysten vaikutusta metsänomistajan metsänhoidolliseen toimintaan:

I Ammattiavun käyttö ja metsänhoidollisen toiminnan absoluuttinen laajuus määräytyvät ensisijaisesti tilakohtaisten taustaedellytysten perusteella. Metsänomistajan asenteet eivät juuri niihin vaikuta.
   a) Myönteinen asenne metsäammattimiehiin ilmentää ensi kädessä metsäammattimiesten ja varakkaiden metsänomistajien »sosiaalista yhteenkuuluvuutta».
   b) Runsaat tuotannolliset ja taloudelliset resurssit lisäävät ammattiavun käyttöä ja toiminnan absoluuttista laajuutta.

c) Irtautuminen maatilataloudesta vähentää ammattiavun käyttöä ja toiminnan absoluuttista laajuutta.

II Metsänhoidollisen toiminnan suhteellinen laajuus ja toimintavireys ovat riippuvaisia jokseenkin samassa määrin metsänomistajan asenteista ja tilakohtaisista taustaedellytyksistä.

a) Myönteinen asenne metsänhoidollisiin menetelmiin lisää toiminnan suhteellista laajuutta ja toimintavireyttä.

b) Myönteinen asenne metsänhoitoyhdistystoimintaan lisää toiminnan suhteellista laajuutta ja toimintavireyttä.

c) Runsaat tuotannolliset ja taloudelliset resurssit lisäävät toiminnan suhteellista laajuutta ja toimintavireyttä.

d) Tilan syrjäinen sijainti vähentää toiminnan suhteellista laajuutta.

e) Irtautuminen maatilataloudesta vähentää toiminnan suhteellista laajuutta.

Seuraavaksi esitetään yhteisötasolla ilmeneviä säännönmukaisuuksia koskevat yleistykset. Tutkimuksen mukaan voidaan maaseutuympäristön uudenaikaistuessa odottaa puun kasvatuksen piirissä seuraavia muutoksia:

III Metsänomistajien metsänhoidollinen toiminta on keskimäärin vähäisempää kuin aikaisemmin.

IV Asenteet metsänhoitoa kohtaan muodostuvat keskimäärin aikaisempaa kielteisemmiksi.

V Puun kasvatuksen piirissä tapahtuu toiminnallista eriytymistä siten, että runsaita tuotannollisia ja taloudellisia resursseja omistavat metsänomistajat »erikoistuvat» aktiiviseen metsänhoitoon.

VI Puun kasvatuksen piirissä tapahtuu alueellista eriytymistä siten, että metsänhoidollisen toiminnan suhteellinen laajuus pienenee syrjäisen sijainnin omaavilla tiloilla.

VII Puun kasvatukseen liittyvien asenteiden ja arvojen alueella tapahtuu eriytymistä;

a) metsänhoidollisiin menetelmiin ja metsänhoitoyhdistystoimintaan kohdistuvissa asenteissa ilmenevät eroavuudet eivät enää jää tunnepurkausten tasolle, vaan aiheuttavat eroja metsänomistajien metsänhoidollisessa toiminnassa;

b) metsän säästäminen ja toisaalta myyntitulojen saaminen metsästä muodostuvat toisilleen vastakkaisiksi metsätaloudellisiksi tavoitevaihtoehdoiksi.

Lisäksi maaseutuympäristön uudenaikaistuessa voidaan metsänomistajien keskuudessa suoritettavan metsänhoidon edistämistyön odottaa muuttuvan siten, että

VIII ammatillisten organisaatioiden (metsänhoitoyhdistys) merkitys metsänhoidon edistämistyössä lisääntyy »epävirallisen» henkilökohtaiseen neuvontaan verrattuna.

Metsäpolitiikkaan ja jatkotutkimuksiin liittyvät näkökohdat

Tutkimuksessa käsitellään lopuksi sen tulosten hyväksikäyttöä metsäpolitiikan ja jatkotutkimusten kannalta.

Tutkimuksessa tehtyjen alustavien havaintojen perusteella päädytään käsitykseen, että lisääntyvään puun tuotantoon tähtäävän metsäpolitiikan olisi tarkoituksenmukaista kiinnittää erityistä huomiota maatilametsätalouden rakennerationalisointiin liittyviin tehtäviin. Tämä siitä syystä, että metsänomistajan käytettävissä olevat tuotannolliset ja taloudelliset resurssit määrittelevät huomattavalta osalta hänen metsänhoidollisen

toimintansa absoluuttisen sekä osittain myös suhteellisen laajuuden. Sitäpaitsi runsaita tuotannollisia ja taloudellisia resursseja omistavat metsänomistajat käyttävät hyväkseen keskimääräistä enemmän metsätaloudellisen neuvonnan suomia mahdollisuuksia ja heidän metsätiedon tasonsa on tavanomaista korkeampi. Myös ne rakenteelliset olosuhteet, joista riippuu metsänomistuksen jatkuvuus sekä metsänomistajan tyytyväisyys yleensä maanviljelijän ammattia kohtaan, ovat tässä yhteydessä huomioon otettavia tekijöitä.

Lisäksi metsänomistajan asenteilla on oma merkityksensä. Tutkimuksen perusteella näyttää siltä, että metsätalouden edistämistoiminnassa olisi tarkoituksenmukaista kiinnittää erityistä huomiota metsänomistajan metsänhoidollisiin menetelmiin ja metsänhoitoyhdistystoimintaan kohdistuviin asenteisiin.

Edelleen maaseutuympäristön teollistuminen ja uudenaikaistuminen näyttävät asettavan metsäpolitiikan ja metsätalouden edistämistoiminnan monien uusien ja ehkä vaikeastikin ratkaistavien kysymysten eteen. Yleisesti voidaan sanoa, että metsäpolitiikan keskeisen tavoitteen (lisääntyvän puun tuotannon) toteutuminen muodostuu yhä vaikeammin saavutettavaksi päämääräksi uudenaikaistuvaa maaseutuympäristöä edustavissa olosuhteissa. Tämä johtuu siitä, että maaseutuympäristön teollistuessa ja uudenaikaistuessa metsänomistajien metsänhoidollinen toiminta pyrkii keskimäärin vähenemään ja metsänomistajien asenteet metsänhoitoa kohtaan muodostuvat keskimäärin aikaisempaa kielteisemmiksi. Lisäksi puun kasvatuksen piirissä tapahtuu toiminnallista, alueellista sekä asenteiden ja arvojen alueella havaittavaa eriytymistä. Metsäpolitiikassa ja metsätalouden edistämistoiminnassa olisikin tarkoituksenmukaista kiinnittää huomiota mm. seuraaviin maaseutuympäristön uudenaikaistumiseen liittyviin kehitysilmiöihin:

(1) Erityisesti vähäisiä tuotannollisia ja taloudellisia resursseja omistavien metsänomistajien metsänhoidollinen aktiviteetti pyrkii heikkenemään.
(2) Metsänhoidollinen aktiviteetti pyrkii heikkenemään myös syrjäisen sijainnin omaavilla tiloilla.
(3) Metsänomistajien asenteet metsänhoitoa kohtaan muodostuvat aikaisempaa kielteisemmiksi ja samalla metsänomistajat eivät enää helposti hyväksy »ylhäältä käsin» asetettuja metsänhoitoa koskevia tavoitteita ja toimintamalleja.
(4) Maatilametsätaloudessa tapahtuu tavoitteiden eriytymistä. Tämä merkitsee sitä, että yhtenäisiä tavoitteita on entistä vaikeampi soveltaa kaikkia maatilametsälöitä koskevina.

Jatkotutkimusten kannalta voidaan esittää seuraavat näkökohdat ja suositukset:

(1) Jatkotutkimuksissa tulisi pyrkiä metsänomistajakuntaa kokonaisuudessaan hyvin edustaviin näytteisiin.
(2) Pyrittäessä selittämään ja »ymmärtämään» metsänomistajan puun kasvattajan rooliin liittyvää käyttäytymistä, analyysiä ei ole tarkoituksenmukaista rajoittaa koskemaan ainoastaan metsänhoidollista toimintaa, vaan lisäksi puun myyntejä koskevan päätöksenteon ja siihen liittyvien motiivien samanaikaista tutkimista on pidettävä tarpeellisena.
(3) Maaseutuympäristön teollistumisen ja uudenaikaistumisen vaikutukset metsänomistajien metsänhoidolliseen toimintaan ja metsänhoidollisiin asenteisiin tulisi jatkotutkimuksissa analysoida yksityiskohtaisesti.

APPENDICES

Appendix 1. Mean values and standard deviations of the original variables used in the analysis.

Variable [1]	Karstula		Jämsä		Combined material	
	Mean value	Standard deviation	Mean value	Standard deviation	Mean value	Standard deviation
1.	8.26	12.35	4.96	10.42	6.55	11.49
2.	16.76	16.66	8.58	12.73	12.52	15.28
3.	3.36	1.83	2.61	1.79	2.97	1.85
4.	8.08	8.84	5.17	8.21	6.57	8.63
5.	2.40	0.91	2.03	0.98	2.21	0.96
6.	3.97	2.16	3.16	2.10	3.55	2.16
7.	6.05	1.99	5.88	2.12	5.96	2.06
8.	3.29	2.67	4.35	2.71	3.84	2.74
9.	3.94	1.24	3.52	1.19	3.72	1.23
10.	3.14	1.55	2.77	1.62	2.95	1.60
11.	3.71	1.36	3.32	1.35	3.51	1.37
12.	3.97	1.30	3.73	1.19	3.85	1.25
13.	4.42	1.08	4.39	0.91	4.41	0.99
14.	3.98	1.28	3.55	1.46	3.76	1.39
15.	4.10	1.30	3.83	1.43	3.96	1.37
16.	4.14	1.22	4.11	1.22	4.12	1.22
17.	3.52	1.45	2.77	1.35	3.13	1.44
18.	4.45	0.99	4.03	1.25	4.24	1.15
19.	2.65	1.69	2.06	1.41	2.34	1.58
20.	3.70	1.10	3.48	1.22	3.59	1.16
21.	3.98	1.25	3.68	1.45	3.82	1.36
22.	4.19	1.27	4.04	1.30	4.11	1.29
23.	4.22	1.19	3.27	1.52	3.73	1.45
24.	3.18	1.30	2.77	1.22	2.97	1.28
25.	3.16	1.51	3.03	1.49	3.10	1.50
26.	4.53	1.02	4.55	0.95	4.54	0.98
27.	4.49	0.85	3.97	1.18	4.22	1.06
28.	3.20	2.13	3.14	2.02	3.17	2.07
29.	1.90	1.56	4.13	1.83	3.06	2.04
30.	3.38	1.50	3.56	1.27	3.47	1.38
31.	2.09	0.97	2.32	1.08	2.21	1.04
32.	3.55	1.42	2.76	1.11	3.14	1.32
33.	2.89	1.95	2.15	1.36	2.51	1.71
34.	2.86	1.73	3.82	2.01	3.36	1.94
35.	2.54	1.99	2.31	1.96	2.42	1.97
36.	2.60	1.55	2.95	1.78	2.78	1.68
37.	1.24	0.91	1.83	0.92	1.54	0.96
38.	1.12	1.05	1.70	1.03	1.42	1.08
39.	2.15	1.13	1.99	1.13	2.07	1.13
40.	4.47	1.84	4.92	1.84	4.70	1.85
41.	4.50	1.07	4.75	1.00	4.63	1.04
42.	2.01	0.83	2.33	1.17	2.18	1.03
43.	3.14	1.06	3.28	1.33	3.21	1.21
44.	3.33	1.62	3.58	1.72	3.46	1.67
45.	1.86	0.75	1.72	0.75	1.79	0.75
46.	2.12	0.73	2.00	0.74	2.06	0.74
47.	2.04	1.00	1.94	0.98	1.99	0.99

[1]) The original variables are classified as follows:

Unclassified	Nos. 1—4	Six-class	Nos. 5, 36, 41, 42 and 43
Three-class	Nos. 39 and 47	Seven-class	Nos. 6, 29, 32, 33 and 40
Four-class	Nos. 37 and 38	Eight-class	Nos. 7, 8, 35 and 44
Five-class	Nos. 9—27, 31, 45 and 46	Nine-class	Nos. 28, 30 and 34

Appendix 2. Determining silviculturally favourable attitudes

When attitudes are studied, the aim may be to establish only those aspects to which the subjects have a positive or negative attitude. It is then not necessary to know which attitudes, from some general point of view, are positive or negative. This study, however, deals with such a general and basically subjective topic, »silviculturally favourable attitude», that the problem is to define the attitudes that can be considered generally favourable to silviculture. No objective criterion by which to settle the issue is available.

In order not to leave the choise between favourable and negative silvicultural opinions to the author's discretion, an inquiry was made concerning the propositions used in the study. Foresters employed by the Central Forestry Board Tapio in Helsinki were asked to point out the propositions the forest owner should accept in order to disclose his favourable or negative silvicultural attitude. This is an application of the so-called judge method (Allardt — Littunen 1961, pp. 139—144).[1]) Replies were received from 25 foresters, and the distribution of the replies was the following:

	Accepting the proposition indicates		
	silvi-culturally favourable attitude	cannot say	silvi-culturally negative attitude
	Number of replies		
(9) Forest owners are generally too little interested in forestry matters	19	0	6
(10) Forest management associations are not particularly worth supporting	2	0	23
(11) Forest owners today take sufficient care of the management of their forests	3	2	20
(12) Too small a share of the income from timber sales is used on silviculture	23	0	2
(13) If you think economically, it is not worthwhile spending money on silviculture	2	2	21
(14) It would not be right of forest owners were forced by law to recondition their forests	2	0	23
(15) One should have the right to cut more freely than today	0	4	21
(16) There is no point in prohibiting by law cuttings in a forest	0	2	23
(17) Silviculture needs more legislative supervision	20	2	3
(18) It is true that few owners practice sufficient silviculture unless obliged to by law	20	3	2
(19) An obligatory forest management fee is necessary	21	3	1
(20) Forest fertilization should be greatly increased	25	0	0
(21) The forest owner should personally mark the trees he intends to sell	4	4	17
(22) It is not necessary to plan silvicultural measures for future years	2	0	23
(23) Forest regeneration is too popular today	0	2	23
(24) New silvicultural methods are often very unpractical	1	5	19
(25) Forestry experts do not sufficiently understand the forest owners' needs	5	3	17
(26) The ability to managing forest used to be much better than today	0	1	24
(27) Forest regeneration must be considered economically unprofitable	0	2	23

[1]) The questionnaires used the wording »attitude favourable to forestry». Since the propositions to be judged contained mostly questions associated with tree growing, no serious error will arise although a more precise wording, »silviculturally favourable attitude», is used here.

Symptomatic disagreement is noted only for propositions 9, 21 and 25. Otherwise the respondents were unanimous concerning the nature of the propositions. In the present study, those forest owner's opinions have been classified as silviculturally favourable which the *foresters (or a majority of them) found to be so.*

Appendix 3. Serviceability of the interview data

The material was collected mainly by interview measurement of information remembered by the interviewed. Investigating the reliability of measuring this information is, therefore, an important component of the study. The strength of the information depends in its reliability.

Erroneous variation can occur in the measurement for many reasons. For example, factors producing fallacy may be connected with the measuring instrument (the questionnaire) or with the measurement situation (the interview situation) (see S e l l t i z et.al. 1965, pp. 150—154). Therefore, in reliability investigations it is usually not adequate to ask simply whether or not the information is reliable; generally it is necessary to determine how reliable it is (K u u s i 1959, p. 111). The analysis should then point out the questions and propositions in which the information is so obviously unreliable that this should be taken into account when conclusions are drawn (K a l i m o 1962).

In the behavioural sciences, different types of errors are usually combined under the concepts of reliability and validity. The validity of a measurement determines that it measures just what it was meant to measure. The reliability of measurement, on the other hand, means that measurement is able to provide non-random information.

Reliability analysis varies in importance depending on the variables involved. It may be safely assumed that, for example, the age, number of children, and school education of a man can be ascertained more reliably than his intelligence level or his silvicultural attitudes. The reliability problem is of particular importance in the measurement of behavioural frequencies. In the present study, the variables are classified for reliability analysis as follows: (1) »facts», (2) attitude variables, and (3) activity variables (cf. Seppänen 1964, p. 1028).

(1) The facts refer to variables such as the type mentioned (age, number of children, school education) which usually can be measured reliably »straight away». The only variable in this group for which the reliability of measurement was quantitatively verified, was the forest area of the farm (No. 28). It was measured by asking the interviewed himself, and by taking data from the taxation classifications. The correlation between these two measurements, producing a numerical value that can be considered the reliability coefficient, was high; for both the combined material and the component materials, Karstula and Jämsä, it was .98.

(2) The reliability coefficients concerning the individual attitude propositions did not prove to be very high. Parallel measurement was used by computing the correlation between two propositions measuring nearly identical opinion (»One should have the right to cut more freely than today» and »Cutting is free enough today»). The correlation obtained for the combined material was .56, for the Karstula material .47 and for the Jämsä material .61. An extensive use of parallel measurement was restricted by the fact that it would have been difficult to compile several pairs of propositions measuring the same opinion without their interfering with the interview itself.

But examining the reliability of the attitude measures based on a sum scale comprising 17 propositions gave a satisfactory result. The reliability coefficient was calculated by the split-half method (see V a h e r v u o 1962, p. 175); the value obtained

for the combined material was .84 and for the Karstula and Jämsä material .83. These values agree with the average level obtained (Eskola 1962, p. 64).

(3) Variables describing behavioural frequencies were relatively numerous. Particular interest was devoted, in compliance with the subject of the study ,to variables measuring silvicultural activity. A study of their reliability would have been important. However, the chances of analysing them in connection with the present study were slender. Only for two variables measuring silvicultural activity could the reliability be quantitatively determined. The forestry expert's last visit to the farm (No. 7) and the membership of the interviewed in a forest management association were questions posed to the interviewed themselves. But information was also obtained from the local forestry experts concerning a subsample (n = 92) alloted specifically for reliability calculations. The value of the reliability coefficients calculated from the subsample were .43 and .49 for the variable measuring the frequency of forestry expert's visits and for that measuring membership in forest management association, respectively. The coefficient values are extremely low even though they may give a slightly too negative view of the reliability of the measurement.[1])

In the absence of precise reliability calculations, extracts of reports by the interviewers concerning the reliability of the interviews will be quoted:

> After even the sceptics had been convinced that the study was in no way connected with taxation or the like, the interview situation could be considered relatively or even highly reliable. The interviewed frequently showed quite unnecessary openness. From the point of view of the interview, it was perhaps useful that the interviewer came from a different locality, since it was easier to be frank with him . . . . The areas and dates of the measures, based on memory alone, may be slightly erroneous. The error tends to expand the areas on which silvicultural measures were reported. But, admittedly, it is difficult to estimate the areas involved. The silviculturally treated areas have had indefinite boundaries, they may have been numerous, and their total coverage was difficult to estimate. (Jorma Hytti)
>
> Most farmers took the interview seriously and seemed to spare no pains in trying to answer the most awkward questions. No one tried to joke or take the interview lightly. The reliability of the data is perhaps most affected by bad memory. The majority complained of their bad memory at least in the »information quiz» (the questions measuring the level of forestry knowledge), and recalling various figures often took very long. There were, however, a few farmers who looked things up in their notes wherever possible. Lack of time hardly caused much bias, since the farmers laid down their work for the duration of the interview, devoting themselves to the interview without any rush and very seriously. There was hardly any intentional distortion of facts; some may have tended to distort the picture in a favourable direction. The second greatest factor causing bias was perharps the family members', primarily the wife's, presence during the interview. (Totte Vadén)

As was pointed out, the purpose of reliability analysis is to indicate the questions and propositions for which the reliability of the measurement is particularly low. The study on this point was, however, so incomplete that only a few hints concerning the reliability of the data can be put foreword. An overall conclusion is perhaps that the reliability of the information dealt with is not very high on all points. *In the measurement of attitudes and behavioural frequencies the reliability apparently has remained relatively low.*

The serviceability of the information, however, does not depend on its reliability alone; an analysis of the validity of the measurement is also important. The gist of

[1]) When local forestry experts were asked about their last visit to the farms studied, one of them did not check the replies he gave against the documents available, but entered »no visit» in all uncertain cases. On the other hand, forestry experts may have recorded visits to the farms following the interview, which naturally did not appear in the responses in the interview.

the problem of validity can be given the following formulation: Is the measurement of silvicultural attitudes and silvicultural activity, as carried out in the study, valid? In other words, did the measurement really involve silvicultural attitudes and silvicultural activity and not some other factors?

The analysis of the reliability of the measurement led to the result that, when attitudes and behavioural frequencies were measured, reliability apparently was relatively low. It follows that the validity of the measurement cannot possibly be particularly high, since low reliability always means a low validity (Eskola 1962, p. 56). It is, useful, however, to examine in detail whether the present study could measure at all the factors it set out to measure.

According to some opinions the validity of a measurement in a given case might be proved by means of logical inferences alone (»internal validity», see Zetterberg 1965, pp. 114—120). For example, when the propositions refer to an attitude with a distinctly measurable content, the measurement can be considered valid by definition alone. In the present study, silvicultural attitudes referred to attitudes to various aspects directly or indirectly connected with tree growing; silvicultural activity referred to taking the steps directly or indirectly connected with tree growing. On this basis it is justified to say that the attitude propositions used, and the activity variables selected, are derived in content from the definition of these phenomena, adopted for the study. Consequently, the measurement is valid.

Any deliberation based on logical inferences alone may, however, be considered uncertain. For example, when logical inferences are used without examining whether intentional distortion by the interviewed has reduced the validity, conclusions drawn concerning the validity of the measurement will be erroneous. An empirical check is therefore required to support logical inferences (»external validity», see Zetterberg 1965, pp. 120—123). The usual procedure is to verify the validity of the measurement with the aid of criteria from outside the measurement. This produces certain problems which are difficult to solve. In principle, it is easy to calculate the validity for it is only necessary to compare the result of measurement with true information on the phenomenon measured. In practice, however, it is difficult to find »true information», i.e. a good criterion variable. If such a variable were easy to find no measurement would be necessary.

In the present study, result obtained by attitude measurement are compared with three different criterion variables: (1) the interviewer's estimate of the silvicultural attitudes of the interviewed; (2) the forestry expert's estimate of the silvicultural attitudes of the interviewed; and (3) the silvicultural activity of the interviewed. Correlations between attitudes and activity were already discussed in Sections 611 and 612 when reporting the results of this study. These correlations will not be discussed here. In the following, however, correlation coefficients illustrating the connections between attitude measurement and the estimates by interviewers and local forestry experts will be presented. They can be considered the validity coefficients of attitude measurement in the present study:

	Validity criterion			
	Interviewer's estimate		Forestry expert's estimate	
	Karstula	Jämsä	Karstula	Jämsä
(A_1) Attitude to forestry experts ..	.44	.53	.03	.19
(A_2) Forest owner's self-appraisal .	.36	.13	.19	.04
(A_3) Attitude to forest management associations	.15	.16	.15	.18
(A_4) Attitude to methods	.40	.41	.13	.09

Karstula: $r_{.05} = .17$
Jämsä: $r_{.05} = .16$

As can be seen, the coefficients presented are not particularly high. The validity of attitude measurement, therefore, seems to have been relatively low, as could be expected from the analysis of the reliability of the measurement. However, *attitudes to forestry experts (A_1), forest management associations (A_3) and silvicultural methods (A_4) are attitude dimensions whose correlations with criterion variables are consistently positive*, and in most cases also statistically significant. At least these attitude variables can be considered to measure silvicultural attitudes. But the weight of the attitude dimension describing the forest owner's self-appraisal (A_2) seems to vary depending on the commune studied. The extent to which this attitude dimension measures attitudes to silviculture remains unclear in the present analysis.

It can be seen that estimates by the interviewers are the validity criteria best correlated with the result of attitude measurement. This is probably due to the fact that the replies by the interviewed at the interview itself affected these estimates; in other words, the interviewers' estimates and the results of attitude measurement are not logically independent of each other. On the other hand, the correlation between forestry experts' estimates and attitude measurement proved to be low. This finding leads to two possible interpretations; either the attitude measurement was very unsuccessful, or the forestry experts' estimates of the silvicultural attitudes of the interviewed cannot be considered valid. Certain critical observations can be made concerning the validity of the forestry experts' estimates.

The local forestry experts were asked for estimates of the silvicultural attitudes of the interviewed, and of the silvicultural state of the forest unit the interviewed owned. These estimates were found to show a high intercorrelation (in the Karstula material, $r = .74$, Jämsä material $r = .46$, and in the re-inquiry concerning the subsample allotted only for reliability calculations, $r = .82$), but a very weak correlation with practically all the other variables used in the study.[1]) It is probable, however, that the silvicultural state was affected by many different factors, some independent of the forest owner. In light of this, the estimates of attitudes given by forestry experts on the basis of the silvucultural state seem somewhat erroneous. Evidently the silvicultural state of the forest unit and the forest owner's attitudes to silviculture have been too closely linked.

The question of the validity of the measurement of silvicultural activity is particularly difficult to solve. Even theoretically it is difficult to infer what validity criteria can be rationally compared with the measurement results. Should the criterion selected be the mean growing-stock volume, the business surplus from forestry, or perhaps a subjectively determinable »silvicultural state»?

As mentioned above, the local forestry experts were asked to estimate the silvicultural state of the forest units owned by the interviewed. The correlation coefficients describing the connections between these estimates and the composite variables measuring silvicultural activity are presented belowe. These correlation coefficients can be considered validity coefficients of the measurement of silvicultural activity:

	Validity criterion: Forestry expert's estimate of silvicultural state	
	Karstula	Jämsä
(T_1) Relative extent of activity ..	.07	.12
(T_2) Use of expert	.29	.12
(T_3) Readiness to act	.11	.07

Karstula: $r_{.05} = .17$
Jämsä: $r_{.05} = .16$

[1]) The re-inquiry was carried out about three months after the interview.

It can be seen that only *the use of expert dimension (T_2) in Karstula showed statistically significant correlation with the forestry experts' estimates of the silvicultural state.* The other correlation coefficients were consistently positive, but at the same time low. This need not, however, indicate a low validity of measurement. It indicates, rather, that the silvicultural state was affected perhaps more decisively by factors other than the forest owner's silvicultural activity.

Appendix 4. Questionnaire

MMAT-66

Date / 1966

Name of the forest owner _____

Name and address of the farm _____

Instruction: I am Mr. _____ from the Finnish Forest Research Institute and am collecting information for a study concerning forest owners. The aim of the study is to review what the forest owners themselves think about silviculture and forestry matters in general, and how they practice in their silviculture. You have been selected randomly for the interview. The interview data will be used in the Research Institute only for statistical purposes. I hope that you will take a trustful stand towards my questions.

1—5 (Reservation)

I should like to ask first:

6. How old are you?
   1. Less than 20 years old
   2. 20—29
   3. 30—39
   4. 40—49
   5. 50—60
   6. More than 60 years old

7. Your marital status?
   1. Married
   2. Unmarried (move over the quest. 10).
   3. Divorced or widow

8. How many children (at home) have you?
   0. None (go to question 10)
   1. One
   2. Two
   3. Three
   4. Four
   5. Five
   6. Six
   7. More than six

9. How many of them (children) are over 15 years old?
   0. None
   1. One
   2. Two
   3. Three
   4. Four
   5. More than four

10. Your schooling?
1. Less than public school
2. Public school
3. Part of intermediate school
4. Intermediate school
5. People's institute
Other schools and courses _____

Questions 11 and 12 will be asked only of married persons:

11. Your wife's schooling?
1. Less than public school
2. Public school
3. Part of intermediate school
4. Intermediate school
5. People's institute
Other schools and courses _____

12. Your childrens' schooling?
First child. _____ Second _____
Third _____ Fourth _____

13. What is in your house? The number of heated rooms including kitchen _____
and
the number of people living in the house _____

14. Which of the following fixtures are in your house?
1. Electricity
2. Running water
3. Drainpipe
4. WC
5. Washing machine
6. None

15. Do you have a
1. Radio
2. Telephone
3. Television
4. Car
5. None

In the following I will ask some facts about your farm:

16—26. What is: the whole area of your farm _____ ha
the arable area _____ ha
the forest area _____ ha

27. What is the shortest distance from the forest to the farm management centre (if the forest has been divided into several parts, specify size)?
_____ ha _____ km, _____ ha _____ km, _____ ha _____ km.

28. How many years has the farm been in your posession?
_____ years

29. How many years has the farm been in the posession of your family or your wife's family? _____ years

30. How was the farm acquired?
1. Inherited from parents or other relatives
2. Bought from parents or other relatives
3. Bought on free market
4. Free purchase according to the settlement law
Other _____

	Yes	Undecided	No
31. a) Do you expect the farm to remain in the family during your lifetime?	3	2	1
b) Do you plan to will the farm to a member of your family (if yes to a)?	6	5	4
c) Do you believe that your heirs will retain ownership of the farm (if yes to b)?	9	8	7

In the following I will read some propositions concerning forestry matters. I ask you to give your opinion about them only *according to your own conviction*. Use one of the five alternative answers on the attached card A.

	I agree fully	I agree in part	Cannot say	I disagree in part	I disagree completely
32. There is to much discussion about silviculture at present	1	2	3	4	5
33. Forest owners are generally too little interested in forestry matters	5	4	3	2	1
34. Forest management associations are not particularly worth supporting	1	2	3	4	5
35. Forest owners today take sufficient care of the management of their forests	1	2	3	4	5
36. A forestry club should be founded in every village	5	4	3	2	1
37. Organized instruction is sufficient	1	2	3	4	5
38. Silviculture pays better than agriculture	5	4	3	2	1
39. Forest regeneration is economically very profitable in the long-run	5	4	3	2	1
40. Too small a share of the income from timber sales is used on silviculture	5	4	3	2	1
41. Society should pay a larger share of the cost of silviculture	1	2	3	4	5
42. Investing money in silviculture is not often worthwhile to the owner	1	2	3	4	5
43. If you think economically, it is not worthwhile spending money on silviculture	1	2	3	4	5

	I agree fully	I agree in part	Cannot say	I disagree in part	I disagree completely
44. It would not be right if forest owners were forced by law to recondition their forests	1	2	3	4	5
45. One should have the right to cut more freely than today	1	2	3	4	5
46. There is no point in prohibiting by law cuttings in a forest....	1	2	3	4	5
47. Silviculture needs more legislative supervision	5	4	3	2	1
48. It is true that few owners practice sufficient silviculture unless obliged to by law	5	4	3	2	1
49. An obligatory forest management fee is necessary	5	4	3	2	1
50. Forest fertilization should be greatly increased	5	4	3	2	1
51. The forest owner should personally mark the trees he intends to sell	1	2	3	4	5
52. Forest owners should try to organize joint sales	5	4	3	2	1
53. It is not necessary to plan silvicultural measures for future years	1	2	3	4	5
54. Forest regeneration is too popular today	1	2	3	4	5
55. New silvicultural methods are often very unpractical	1	2	3	4	5
56. Forestry experts do not sufficiently understand the forest owners' needs	1	2	3	4	5
57. Forests would be better managed if they were state-owned	5	4	3	2	1
58. The ability of managing forest used to be much better than today	1	2	3	4	5
59. The current cutting rights are adequate	5	4	3	2	1
60. Forest regeneration must be considered economically unprofitable	1	2	3	4	5
61. Taxation based on income from timber sales could be more appropriate than the present-day taxation system	5	4	3	2	1

62—66. (Reservation)

67. Have you been sometimes to a forestry instruction meeting?
1. Yes
2. No (go to question 70)

68. Do you remember when the last time (year)?
in _____

69. Do you remember what kind of meeting it was?
_____

70. Has the forestry expert sometimes visited your farm on forestry matters?
1. Yes
2. No (go to question 73)

71. When was the last time (year)?
in _____

72. Do you remember what kind of business was in question?
_____

73. How often have you made timber sales?
1. Every year
2. Every second year
3. Every third year
4. More rarely than every third year

74. Would you declare approximately the income from your last timber sale?
0. No sale (go to question 77)
1. Less than 500 mk
2. 500—900 mk
3. 1 000—1 900 mk
4. 2 000—2 900 mk
5. 3 000—4 900 mk
6. 5 000—6 900 mk
7. 7 000— 9 900 mk
8. 10 000—20 000 mk
9. More than 20 000 mk

75. Was it:
1. Business by delivery contracts
2. Sale of standing trees

76. Do you more frequently do business by delivery contracts or sale of standing trees?
1. Business by delivery contracts
2. Sale of standing trees

77. What is your opinion; is the demand for wood (in your region):
1. Very strong
2. Quite strong
3. Average
4. Quite weak
5. Very weak

78—85. (Reservation)

86. Do you have forest management plan for your forest?
1. Yes (go to question 89)
2. No

87. Do you have any intention of making such a plan *in the very near future?*
1. Yes (go to question 89)
2. No

88. Do you intend to make such a plan *sometime in the future?*
1. Yes
2. No

89—90. Have you carried out any of the following silvicultural measures:
0. None (go to question 101)
1. Forest drainage
2. Management of seedling stands
3. Forest regeneration
4. Forest fertilization
Others _____

91—95. In what year did you do for the first time?
1. Forest drainage, in _____
2. Management of seedling stands, in _____
3. Forest regeneration, in _____
4. Forest fertilization, in _____
Others _____, in _____

95—100. How much have you carried out in total?
1. Forest drainage, _____ km
2. Management of seedling stands, _____ ha
3. Forest regeneration, _____ ha
4. Forest fertilization, _____ ha

101. Have you carried out any silvicultural measures on your own initiative?
1. Yes
2. No (go to question 104)

102. What kind of measures? _____

103. How often have you carried out these measures on own initiative?

_____

104. What, in your opinion, is the state of silvicultural prerequisites on your farm?
1. Very good
2. Quite good
3. Average
4. Quite bad
5. Very bad

105. What is the silvicultural state of your forests, in your opinion; is the silvicultural state:
1. Very good
2. Quite good
3. Average
4. Quite bad
5. Very bad

106. What is your opinion about the so-called forest union in which 5—10 forest owners combine their forests, and manage these forests and sell the timber from these forests jointly? _____

In the following I will give you a short information guiz:

	Right	Wrong
107. a) Do you know who is the director of the State Board of Forestry?	1	0
b) Which of the forest sites, Vaccinium site or Myrtillus site, is superior in fertility?	1	0
c) What kind of organization is the Central Forestry Board Tapio?	1	0
d) What is meant by scarification?	1	0
e) Is spruce used for the production of sulphate or sulphite cellulose?	1	0
f) How many spruce seedlings are used per hectare in planting?	1	0
g) Which is the tree species best suited for growing on a Vaccinium site?	1	0
h) Who is the chief forester of the Keski-Suomi Forestry Board District?	1	0
i) Which gives a pile of greater density, 1 or 2-metre pulpwood?	1	0
j) The seed-tree method is most frequently used for the the regeneration of which tree species, pine or spruce?	1	0

Total _____ points

Now will I ask some facts about your agriculture:

108. How many milk cows do you have?

0. None at all
1. 1—2
2. 3—5
3. 6—9
4. 10—14
5. 15—20
6. More than 20

109. How much of your arable land is drained?

1. All
2. Nearly all
3. More than half
4. Around half
5. Less than half
6. A little
7. None at all

110. Has a fertility investigation been made concerning your arable land?

1. No
2. Yes, in _____

111. Have you controlled weeds chemically on your farm?

1. No
2. Yes, since _____

112. Do you have a milking machine?

1. No
2. Yes, since _____

113. If you think of the last two years, how many weeks or months yearly you have been working for supplementary wages (outside the farm)?

0. 0—2 weeks
1. 3—4 weeks
2. 1—2 months
3. 3—4 months
4. 5—6 months
5. More than 6 months

114. To which professional magazines do you personally subscribe?

_____

115. To which other magazines and newspapers you personally subscribe?

_____

116. How often do you read professional articles from other than professional magazines?

1. Every day
2. A few times in a week
3. A few times in a month
4. A few times in a year
5. Never

Questions 117—129 were used to gather information for a study about the diffusion of professional insight in farm forestry and have therefore been omitted here.

130—133. What is the order of importance of the following goals in the management and use of the forests of your farm (Card B)?

	Most important	Second in importance	Third in importance	Least important
Saving the forest	1	2	3	4
Reconditioning the forest	1	2	3	4
Obtaining income from timber sales	1	2	3	4
Obtaining income from work in my own forest	1	2	3	4

134. Are you member of any of the following cooperative associations?

1. Cooperative creamery
2. Cooperative credit society
3. Cooperative shop
4. Cooperative slaughter house

Other _____

135. Are you member of any of the following organizations?

1. Association for artificial breeding
2. Forest management association
3. Association for cattle control
4. Sport association
5. Farmers' club
6. Small-farm owners' association
7. Workers' association

Other _____

136. How often do you participate in organization activities?
1. At least once in a week
2. About once in a month
3. Some times in a year
4. Less than once in a year
5. Never

137. Have you ever visited an agricultural exhibition?
0. Never
Yes; when was the last time?

_____

138. Do you have any communal or other positions of responsibility?
0. Not any
Yes, what?

_____

139. When was your last visit to town?

_____

140—142. What is the distance from your farm to:
the nearest town _____ km
the nearest main village _____ km
the bus route _____ km

Finally, I will ask to you some questions »about life»:

143. What is your opinion: is it worthwhile worrying about goals which are difficult to reach?
1. Yes
2. Cannot say
3. No

144. Are you willing to wait for things that you really want?
1. Yes
2. Cannot say
3. No

145. Do you lose interest in your plans if you must wait a long time for their realization?
1. Yes
2. Cannot say
3. No

146. Is the livelihood given by your farm at this very moment, according your opinion,
1. Much better than the average in this commune
2. Better than the average in this commune
3. As good as the average in this commune
4. Worse than the average in this commune
5. Much worse than the average in this commune
___ Cannot say

147. How secure is your future livelihood?
1. Very secure
2. Quite secure
3. Quite uncertain
4. Very uncertain
___ Cannot say

148. How satisfied are you with your occupation as a farmer?

1. Very satisfied
2. Quite satisfied
3. Quite dissatisfied
4. Very dissatisfied

___ Cannot say

CHECK THAT YOU HAVE GONE THROUGH ALL THE QUESTIONS!

149. Interviewer's estimate of the silvivultural attitudes of the interviewed:

1. Very favourable
2. Favourable
3. Cannot say
4. Negative
5. Very negative

To be asked of the local forestry experts:

150. What is the silvicultural state of the forest of the interviewed?

1. Very good
2. Quite good
3. Average
4. Quite bad
5. Very bad

___ Cannot say

151. How interrested is the interviewed in silviculture?

1. Very interested
2. Quite interested
3. Quite uninterested
4. Very uninterested

___ Cannot say

Interviewer: _____ _____

Appendix 5. Correlation matrix of original variables. Karstula.
n = 139, $r_{.05}$ = .17

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.	41.	42.	43.	44.	45.	46.	47.
1.																																																
2.	.45																																														
3.	.65	.47																																													
4.	.38	.68	.73																																												
5.	.49	.57	.53	.34																																										
6.	.26	.32	.53	.38	.46																																									
7.	.30	.24	.48	.30	.32	.31																																								
8.	.31	.08	.21	.09	.19	.17	.23																																							
9.	−.01	.12	−.08	−.04	.11	−.03	.01	.07																																						
10.	.18	.02	.14	.03	.14	.02	.12	.25	.11																																					
11.	.00	.09	−.05	−.04	.04	.01	.01	.13	.46	.18																																				
12.	−.00	.10	−.10	−.02	.07	−.04	.02	.13	.34	.24	.40																																			
13.	.05	.03	−.06	−.10	.05	−.05	−.09	.06	.00	.21	.14	.20																																		
14.	.00	.07	−.05	−.05	.05	−.01	.03	.03	.10	.20	.07	.18	.19																																	
15.	.06	.03	−.01	−.03	−.00	−.08	−.08	.13	.23	.13	.19	.15	.13	.10																																	
16.	−.02	−.07	−.05	−.06	−.02	−.03	.09	−.06	.14	.12	.10	.11	.21	.10	.26																																
17.	−.06	.11	−.05	.02	.12	.03	−.11	.09	.22	.22	.13	.36	.22	.10	.07	.08																															
18.	−.08	−.08	−.04	−.06	.04	−.07	−.04	−.04	.29	.05	.29	.27	.06	.02	.01	.14	.33																														
19.	.03	.11	.03	.10	.13	.06	.06	.07	.11	.34	.06	.23	−.00	−.06	.02	.04	.18	.25																													
20.	.09	.14	.03	.05	.08	−.04	−.20	.03	.10	.18	.13	.26	.30	.16	.06	.09	.45	.23	.09																												
21.	.17	.16	.09	.07	.13	.09	.19	.23	.13	.29	.26	.16	.14	.24	.36	.22	.01	−.06	−.10	.01																											
22.	.13	.10	.06	.01	.12	−.00	−.00	.28	.01	.20	.08	.08	.25	.15	.28	.13	.18	.00	−.11	.16	.39																										
23.	.16	.16	.08	.09	.14	.05	.06	.07	.14	.18	.15	.20	.25	.31	.30	.19	.22	.06	.16	.29	.33	.31																								
24.	.20	.13	.25	.20	.13	.11	.14	.08	.18	.23	.11	.15	.12	.08	.32	.24	.15	.15	.12	.24	.30	.15	.42																							
25.	.24	.19	.19	.08	.21	.16	.27	.21	.09	.28	.24	.16	.15	.22	.37	.20	.03	.04	−.05	.07	.53	.22	.28	.40																						
26.	.11	.10	.02	−.02	.04	−.03	−.01	.13	.07	.17	.13	.14	.07	.24	.25	.01	.08	.04	−.02	.11	.47	.33	.36	.20	.24																					
27.	.06	.12	−.02	−.01	.11	.01	−.10	.08	.18	.26	.33	.29	.32	.37	.21	.12	.32	.22	−.01	.42	.33	.33	.44	.24	.30	.44																				
28.	.65	.00	.56	.05	.31	.31	.36	.29	−.04	.13	−.07	−.06	.01	.02	.02	.05	−.15	−.05	−.08	.01	.11	.12	.03	.13	.19	.00	−.10																			
29.	−.17	−.19	−.27	−.26	−.04	.05	−.08	.20	.07	.08	.06	.11	.07	−.13	.11	.05	.06	−.10	−.02	.04	−.02	.05	.03	−.03	−.01	.03	−.01	−.03																	
30.	.35	−.00	.35	.08	.19	.14	.22	.06	.01	.08	.02	−.11	.05	−.03	−.12	.06	−.19	.02	−.11	−.01	−.01	.00	−.14	.10	.06	−.16	−.11	.49	.04																
31.	.47	.13	.41	.14	.30	.23	.27	.35	.05	.11	.05	.08	.02	−.01	.14	−.06	−.03	−.00	.01	−.15	.14	.15	.12	.10	.22	.14	.00	.56	−.03	−.03															
32.	−.01	−.04	−.06	−.05	−.03	.00	−.05	−.08	−.03	.05	.07	.19	−.03	.04	−.10	−.15	−.09	−.04	.03	.20	−.08	−.07	−.01	−.10	−.03	−.03	−.01	−.01	.25	.23	−.16														
33.	−.15	−.16	−.09	−.14	−.02	−.00	−.10	−.12	.02	−.06	.01	.05	.06	.03	−.00	−.01	−.08	.03	−.10	−.00	−.17	−.13	−.03	−.03	−.12	−.10	−.03	.06	.17	.07	.02	.55													
34.	.38	.03	.26	−.03	.08	.23	.21	.20	.09	.08	.12	.02	.04	.08	.10	−.04	.03	.12	−.13	.02	.16	.11	−.01	.12	.19	−.05	−.05	.52	−.07	.25	.44	−.00	.01												
35.	−.03	.03	−.09	−.07	−.18	.02	−.01	−.06	.12	−.07	.23	.00	.00	−.00	.06	.13	.01	.11	−.10	.05	.12	−.02	−.06	.03	.07	−.16	.04	−.15	−.11	.15	−.20	.07	−.04	.51											
36.	.02	.12	.11	.18	−.01	.21	.15	.15	−.10	.07	.06	.05	.17	−.03	−.07	−.02	−.03	−.15	−.02	−.07	.04	.11	.08	.12	.04	.02	.00	−.11	−.02	−.09	.10	−.16	−.13	−.02	.14										
37.	.28	.13	.26	.08	.18	.21	.35	.33	.05	.13	.07	−.01	.01	−.06	.07	.09	−.05	−.04	.03	−.14	.27	.18	.09	.08	.31	.12	.04	.34	−.03	.18	.34	−.24	−.19	.26	.05	.16									
38.	.33	.10	.24	−.02	.17	.11	.22	.23	.01	.11	.06	−.09	−.01	.05	.17	.02	.00	−.08	−.05	.03	.24	.12	.09	.22	.28	.08	.02	.41	−.05	.21	.41	−.02	.01	.52	.20	−.01	.46								
39.	.19	.10	.14	.06	.21	.00	.07	.07	.00	.05	−.12	−.05	−.02	−.02	−.02	.01	.07	−.02	−.02	−.08	.01	.04	.01	.00	.13	−.08	.04	.16	.03	.17	.21	.01	.06	.08	−.10	−.14	.07	.13							
40.	.25	.05	.09	−.07	.20	−.06	.01	.09	−.09	.03	−.18	.01	−.02	.19	.10	−.01	−.06	−.02	−.09	.04	.07	−.01	−.02	.00	.20	.15	.09	.27	−.00	.23	.15	.17	.13	.07	−.16	−.33	.03	.33	.07						
41.	.14	.14	.12	.17	.03	−.37	−.02	−.14	−.10	−.03	−.09	−.12	−.07	−.06	−.13	−.07	−.06	.06	.03	−.00	−.16	−.15	−.12	−.13	−.17	−.07	−.14	−.07	−.18	.07	−.13	−.02	−.09	−.23	−.15	−.28	−.20	−.21	.14	−.02					
42.	.04	−.06	.02	−.03	−.14	.11	.05	.21	−.07	.07	−.03	.02	.12	.12	.23	.19	.11	−.11	−.06	.17	.27	.26	.25	.22	.31	.22	.20	.04	.11	−.12	.04	−.00	−.10	.21	.12	.12	.30	.23	−.10	−.02	−.27				
43.	.27	.04	.13	−.01	.12	.08	.10	.28	−.04	.12	−.07	.03	.04	−.02	.07	.07	−.09	−.10	.02	−.09	.19	.11	.07	−.03	.10	.15	.01	.35	.11	.10	.38	−.03	.05	.29	−.03	.01	.33	.23	.03	.15	−.07	.19			
44.	.24	.08	.14	−.02	.23	.08	.24	.47	.05	.18	.09	.09	.05	.18	.22	.03	.03	−.02	−.07	.03	.33	.34	.23	.15	.32	.28	.25	.25	.15	.09	.36	.00	−.05	.28	.05	.05	.45	.42	.08	.31	−.14	.26	.35		
45.	−.03	−.11	−.02	−.10	−.04	−.13	.07	.08	.14	−.04	−.04	.15	.06	−.06	.14	.10	.06	.11	.06	.06	−.02	−.01	−.05	.04	−.08	−.05	−.01	.08	−.08	−.06	.14	−.13	.01	.10	−.01	.01	.08	.09	.15	−.11	.04	−.07	.18	.04	
46.	.03	−.03	−.05	−.12	.12	−.02	.12	.13	.12	−.01	.17	.18	.03	.13	.16	.09	.18	.03	−.06	.07	.05	.13	.09	.00	.18	−.04	.07	.10	.08	.07	.09	.01	−.07	.14	.03	−.11	.19	.10	.16	−.01	.01	.04	.13	.23	.30	
47.	.20	.20	.17	.21	.14	.13	.21	.27	.04	.11	.12	.19	.18	.12	.08	.03	.10	−.06	.13	.02	.25	.16	.31	.13	.21	.15	.19	.04	.02	−.05	.26	−.11	−.20	.11	.04	.21	.16	.15	.13	.01	−.11	.13	.07	.12	.14	.04	

Appendix 6. Correlation matrix of original variables. Jämsä.
n = 150, $r_{.05}$ = .16

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.	41.	42.	43.	44.	45.	46.	47.
1.																																																
2.	.54																																														
3.	.59	.55																																													
4.	.40	.72	.74																																												
5.	.52	.61	.64	.43																																										
6.	.23	.35	.44	.38	.59																																									
7.	.27	.25	.41	.27	.24	.25																																								
8.	.23	.25	.42	.27	.35	.40	.32																																							
9.	−.18	−.15	−.04	−.03	−.14	−.07	−.08	−.08																																						
10.	.04	.16	.22	.19	.29	.23	.19	.20	−.09																																					
11.	−.15	−.05	−.03	.01	−.07	.02	.05	.09	.31	.19																																				
12.	.01	.11	.12	.13	.11	.21	.07	.17	.30	.04	.33																																			
13.	.03	.15	.02	.15	−.01	.19	−.01	.17	−.02	.12	.17	.13																																		
14.	−.05	.12	.05	.04	.10	.18	.05	.08	.22	.17	.24	.17	.16																																	
15.	−.06	.09	−.02	.11	.05	.12	−.01	.12	.07	.31	**.25**	.18	.12	.33																																
16.	−.11	−.12	.01	.05	−.06	.15	−.11	.09	.15	.10	.28	.11	.15	.20	.32																															
17.	−.02	−.03	−.04	−.05	−.13	.01	−.03	−.14	.11	.02	.15	−.02	.01	.24	.20	.12																														
18.	−.18	−.05	−.05	.11	−.19	−.02	−.09	−.11	.25	.08	.27	.21	.17	.32	.16	.13	.30																													
19.	.13	.16	.25	.21	.27	.25	.19	.23	−.01	.51	.11	.06	.03	.15	.29	.21	.10	.08																												
20.	.23	.29	.24	.19	.35	.33	.08	.12	−.01	.14	−.00	.07	.04	.08	.19	.06	.11	−.15	.18																											
21.	−.03	.08	.09	.05	.15	.26	.36	.13	−.02	.21	.11	.01	.14	.15	.32	.13	.16	.06	.17	−.05																									
22.	−.13	.07	−.03	.04	.00	.14	.18	.32	.05	.15	.25	.17	.23	.28	.29	.21	.03	.07	.10	.09	.31																							
23.	−.00	.22	.15	.27	.06	.18	.21	.15	.02	.24	.18	.19	.22	.25	.31	.16	.17	.21	.17	.11	.27	.42																						
24.	.00	.14	.18	.18	.22	.20	.22	.13	.03	.33	.15	.15	.10	.21	.42	.18	.05	−.07	.22	.23	.39	.33	.49																					
25.	−.04	.03	−.05	−.05	.04	.11	.10	.12	−.01	.19	.15	.02	.08	.29	.47	.19	.09	.03	.30	.04	.33	.27	.20	.36																			
26.	−.14	.02	.04	.10	.02	.17	−.04	.02	.16	.14	.23	.26	.12	.17	.21	.22	−.03	.18	.05	−.01	.22	.27	.29	.24	.18																		
27.	−.13	.20	.06	.23	.06	.21	.16	.10	.08	.30	.21	.27	.27	.27	.31	.12	.03	.18	.15	.17	.17	.35	.53	.38	.28	.26																	
28.	.53	.23	.51	.29	.40	.30	.40	.39	−.14	.07	−.06	.06	−.10	−.15	.00	.01	−.14	−.21	.19	.13	.15	−.04	.03	.08	.03	−.13	−.07																	
29.	.01	−.08	.00	−.06	.05	.01	−.01	.01	.03	.03	.05	−.13	−.09	.01	−.03	.10	−.03	−.10	.01	−.02	−.02	.12	.05	.17	−.01	−.03	−.02	−.13																
30.	.27	.10	.28	.13	.34	.23	.21	.14	−.14	−.03	−.05	−.02	−.15	−.13	−.04	.02	−.12	−.20	.03	.04	−.03	−.06	−.04	.07	−.10	−.02	−.22	.58	.17															
31.	.41	.22	.40	.25	.21	.16	.30	.29	.03	.07	−.02	.02	.00	−.16	−.04	−.01	−.03	−.15	.18	.09	.18	−.05	.01	−.00	−.06	−.17	−.01	.65	.02	−.02													
32.	−.01	−.07	−.12	−.12	−.00	.07	.02	−.11	−.04	−.06	−.14	−.19	−.00	−.01	−.11	−.10	.03	−.06	−.02	−.13	.15	.04	.01	.01	.09	.02	−.07	.02	−.05	.18	−.17												
33.	−.16	−.26	−.22	−.29	−.16	−.23	−.15	−.23	−.07	.03	−.06	−.09	−.17	−.05	.09	−.07	.01	.08	−.05	−.22	−.03	−.12	−.08	−.10	−.01	−.07	−.06	−.07	−.01	.04	−.16	.26											
34.	.41	.16	.38	.21	.28	.17	.30	.41	−.01	.08	.01	.15	.03	−.19	.08	.04	−.08	−.21	.24	.18	.09	−.02	.01	.09	.08	−.11	.03	.67	.02	.26	.58	−.11	−.18										
35.	.05	.01	.04	.10	.04	−.00	−.06	.02	.09	−.04	.08	.16	.15	−.02	.06	−.01	−.02	−.05	.04	.01	−.12	−.02	−.08	.15	.09	.12	.07	−.02	−.04	.09	−.13	−.02	−.08	.38									
36.	.28	.25	.21	.24	.06	.23	.20	.14	−.03	−.05	.02	.03	.17	.07	−.14	−.15	−.02	.04	.01	.09	.10	.02	.09	−.16	−.15	.04	.05	.18	−.04	−.13	.37	−.11	−.32	.14	.00								
37.	.27	.22	.39	.22	.28	.11	.10	.31	.08	−.09	.06	.05	.08	−.02	.04	.02	−.02	.02	.10	.08	.06	−.03	−.11	−.02	.01	−.14	−.06	.33	−.04	.08	.34	−.27	−.31	.40	.13	.20							
38.	.28	.22	.36	.23	.30	.25	.29	.37	−.02	.07	.12	.18	.11	.09	.11	.16	−.08	−.02	.15	.19	.09	.03	−.00	.02	.08	−.04	−.03	.41	.06	.12	.38	−.20	−.17	.42	.20	.28	.47						
39.	.17	.11	.25	.15	.17	.08	.08	.15	−.03	.04	−.00	−.00	−.07	−.15	−.08	−.08	.10	.04	.02	−.04	.23	−.06	−.06	.02	.02	−.00	−.11	.19	−.04	.01	.30	−.01	−.09	.10	−.08	.12	.05	.04					
40.	.14	.08	.21	.13	.24	.22	−.02	.32	.00	.12	−.04	.04	.12	−.12	.04	.07	−.08	−.04	.11	−.02	.03	.13	.04	.01	−.00	.03	−.06	.34	.07	.23	.23	.06	−.06	.29	−.09	−.01	.25	.20	.04				
41.	−.09	−.07	−.06	−.06	−.08	−.39	−.07	−.14	−.16	−.05	−.09	−.11	−.19	−.20	−.17	−.10	.01	−.07	−.05	−.26	−.13	−.17	−.16	−.11	−.20	−.21	−.19	−.18	.11	−.07	−.06	−.11	.02	−.21	−.22	−.27	−.13	−.20	.21	−.15				
42.	.33	.16	.37	.23	.30	.28	.28	.37	−.02	.20	.07	.15	−.01	−.04	.13	.11	−.24	−.23	.13	.01	.15	.15	.16	.19	.15	−.02	.04	.55	.17	.32	.38	−.08	−.14	.42	.08	.16	.20	.26	.19	−.12				
43.	.23	.18	.31	.16	.33	.33	.21	.48	−.03	.07	.02	.19	−.02	.01	.02	.11	−.09	−.20	.06	.21	.06	.09	.08	.06	.07	−.10	.01	.45	−.00	.16	.41	−.31	−.26	.37	−.02	.19	.22	.37	.15	.20	−.13	.51		
44.	.24	.19	.31	.25	.26	.27	.26	.55	−.04	.15	.08	.08	.20	.01	.07	.16	−.14	−.11	.23	.15	.15	.22	.09	.10	.13	.08	.06	.37	−.04	.05	.36	−.11	−.29	.35	.13	.23	.29	.47	.21	.20	−.13	.45	.49	
45.	.18	.11	.12	.14	.01	−.03	−.04	−.01	−.08	−.02	−.14	−.09	−.07	−.02	−.16	−.10	.06	−.02	.04	.01	−.12	−.21	−.01	−.20	−.21	−.20	−.10	.08	−.16	−.04	.18	.06	−.03	−.04	−.13	.17	−.02	−.08	.26	−.05	.16	−.02	.14	.11		
46.	.20	.11	.11	.07	.06	−.04	−.04	−.03	.02	.03	−.03	.08	.11	.08	.04	.01	.01	−.01	.05	−.01	.01	.01	.09	.06	.06	−.08	−.00	.16	−.02	.06	.13	.05	.01	.07	−.12	−.02	−.07	.00	.23	.13	.18	.12	.12	.07	.31		
47.	.08	.04	.14	.06	.15	.08	.05	.28	−.10	.15	.01	−.01	.09	−.01	.06	.07	−.12	−.00	.09	−.05	−.01	.19	−.00	.05	.10	−.09	.05	−.02	−.22	−.04	−.01	.01	−.01	−.00	.02	−.07	.05	−.02	.12	−.01	.10	.12	.12	.21	.14	.05	

Appendix 7. Correlation matrix of original variables. Combined material (Karstula + Jämsä).
n = 289, $r_{.05}$ = .14

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.	41.	42.	43.	44.	45.	46.	47.
1.																																																
2.	.50																																														
3.	.63	.53																																													
4.	.40	.71	.74																																												
5.	.51	.60	.60	.41																																										
6.	.27	.36	.51	.40	.54																																									
7.	.29	.25	.44	.29	.28	.29																																								
8.	.24	.10	.27	.14	.23	.24	.27																																							
9.	−.06	.05	−.02	−.00	.01	−.02	−.03	−.04																																						
10.	.12	.11	.20	.13	.24	.15	.16	.19	.03																																					
11.	−.05	.06	−.01	.01	.01	.04	.03	.08	.40	.20																																				
12.	.02	.13	.03	.07	.10	.10	.05	.13	.33	.15	.37																																			
13.	.04	.08	−.02	.02	.02	.06	−.05	.11	−.00	.17	.16	.17																																		
14.	−.00	.13	.04	.02	.10	.12	.05	.03	.19	.20	.18	.18	.18																																	
15.	.02	.08	.01	.06	.05	.05	−.04	.11	.16	.24	.23	.18	.12	.25																																
16.	−.06	−.08	−.01	−.01	−.04	.06	−.02	.02	.14	.11	.19	.12	.18	.16	.29																																
17.	−.00	.12	.01	.03	.04	.07	−.05	−.08	.20	.14	.17	.20	.12	.21	.16	.10																																
18.	−.10	−.01	−.01	.06	−.06	−.00	−.06	−.12	.29	.09	.30	.25	.12	.22	.11	.14	.34																															
19.	.10	.17	.17	.18	.23	.18	.13	.10	.08	.43	.11	.17	.02	.07	.17	.12	.18	.19																														
20.	.17	.23	.16	.14	.25	.17	−.03	.06	.06	.17	.07	.16	.17	.12	.14	.07	.28	.02	.15																													
21.	.09	.14	.11	.08	.16	.20	.29	.15	.06	.25	.19	.09	.14	.20	.35	.17	.12	.03	.06	−.02																												
22.	.01	.10	.03	.04	.07	.08	.10	.28	.04	.18	.17	.13	.24	.23	.29	.18	.11	.05	−.00	.13	.35																											
23.	.11	.25	.18	.24	.15	.18	.16	.04	.12	.24	.21	.21	.22	.31	.32	.17	.26	.21	.21	.20	.31	.37																									
24.	.13	.17	.24	.21	.20	.18	.19	.07	.13	.30	.15	.17	.11	.17	.38	.21	.14	.06	.19	.24	.36	.25	.48																								
25.	.11	.12	.08	.02	.12	.14	.18	.15	.05	.24	.19	.10	.12	.26	.43	.20	.07	.04	.12	.05	.42	.25	.23	.39																						
26.	−.00	.06	.03	.03	.03	.06	−.02	.08	.11	.15	.18	.20	.09	.19	.23	.12	.02	.11	.01	.05	.33	.30	.29	.21	.21																					
27.	−.01	.21	.08	.17	.12	.17	.07	.04	.15	.30	.28	.29	.28	.33	.29	.12	.21	.23	.12	.28	.25	.34	.54	.34	.28	.31																				
28.	.59	.10	.53	.17	.35	.30	.38	.33	−.09	.10	−.06	−.00	−.04	−.07	.01	.03	−.13	−.14	.05	.08	.13	.04	.04	.11	.11	−.06	−.07																				
29.	−.14	−.25	−.21	−.22	−.10	−.08	−.06	.18	−.05	−.02	−.03	−.07	−.02	−.13	−.03	.06	−.14	−.18	−.11	−.05	−.08	.05	−.15	−.02	−.03	.01	−.15	.00																		
30.	.30	.02	.29	.09	.25	.17	.21	.11	−.07	.02	−.02	−.07	−.04	−.09	−.08	.04	−.17	−.11	−.06	.01	−.03	−.03	−.10	.07	−.02	−.09	−.17	.53	.12																		
31.	.41	.14	.37	.17	.22	.17	.28	.33	.02	.07	−.00	.04	.01	−.11	.02	−.03	−.06	−.11	.07	−.03	.15	.04	.01	.03	.07	−.02	−.03	.60	.06	−.02																
32.	.03	.03	−.02	−.03	.04	.08	.00	−.14	.02	.04	.02	.05	−.01	.06	−.07	−.12	.04	.01	.07	.07	.07	−.00	.10	−.00	.04	−.01	.04	.01	−.09	.18	−.19															
33.	−.12	−.13	−.09	−.15	−.03	−.05	−.10	−.20	.02	.01	.01	.02	−.03	.03	.06	−.03	.02	.09	−.03	−.08	−.08	−.11	.02	−.02	−.06	−.09	.01	.01	−.05	.04	−.08	.47														
34.	.33	.02	.26	.05	.14	.14	.24	.35	−.00	.05	.02	.06	.03	−.11	.06	.00	−.09	−.12	.01	.09	.09	.02	−.08	.06	.11	−.08	−.06	.57	.12	.26	.53	−.12	−.12													
35.	.01	.04	−.01	.02	−.05	.02	−.04	−.03	.11	−.05	.16	.09	.07	−.00	.06	.06	.01	.03	−.02	.04	−.01	−.02	−.05	.10	.08	−.02	.07	−.09	−.09	.12	−.17	.05	−.04	.41												
36.	.13	.14	.14	.19	.01	.19	.17	.16	−.08	−.01	.03	.03	.16	.01	−.12	−.09	−.05	−.05	−.02	.01	.07	.05	.05	−.05	−.07	.03	.01	.05	.03	−.10	.27	−.15	−.23	.10	.06										
37.	.21	.07	.24	.09	.16	.09	.19	.36	.01	−.03	.01	−.01	.04	−.09	.02	.05	−.11	−.06	.00	−.05	.11	.05	−.13	−.02	.14	−.00	−.09	.32	.14	.14	.35	−.32	−.29	.39	.07	.20								
38.	.25	.07	.23	.06	.18	.12	.24	.34	−.05	.06	.05	.02	.04	.02	.11	.08	−.11	−.10	−.01	.09	.12	.05	−.06	.07	.16	.02	−.07	.39	.15	.18	.41	−.18	−.12	.50	.17	.17	.51							
39.	.19	.12	.21	.12	.20	.06	.08	.09	−.00	.05	−.05	−.02	−.04	−.08	−.04	−.04	.10	.03	.01	−.05	.14	−.01	−.00	.02	.08	−.04	−.03	.18	−.04	.09	.25	.02	.01	.07	−.09	−.00	.04	.06						
40.	.18	.03	.12	.01	.19	.06	−.02	−.23	−.06	.06	−.12	.01	.04	.06	.05	.03	−.10	−.06	−.02	−.01	.04	.06	−.03	−.01	.09	.09	−.03	.30	.10	.23	.20	.08	.02	.21	−.13	−.13	.18	.29	.04					
41.	.02	.01	.00	.04	−.05	−.39	−.05	−.11	−.15	−.05	−.11	−.12	−.13	−.15	−.16	−.09	−.06	−.04	−.03	−.15	−.16	−.16	−.17	−.13	−.19	−.13	−.19	−.12	.04	.01	−.08	−.09	−.07	−.18	−.19	−.26	−.12	−.17	.16	−.07					
42.	.17	.01	.19	.09	.10	.18	.18	.33	−.07	.13	.01	.08	.04	−.00	.15	.14	−.14	−.21	.02	.06	.17	.18	.13	.17	.20	.08	.05	.33	.21	.13	.26	−.09	−.14	.36	.09	.16	.27	.28	.06	.12	−.16				
43.	.23	.09	.21	.07	.23	.21	.16	.40	−.04	.08	−.03	.11	.00	−.01	.04	.09	−.10	−.17	.03	.08	.10	.09	.06	.01	.08	.02	−.01	.40	.07	.13	.40	−.18	−.11	.34	−.03	.12	.27	.31	.09	.19	−.10	.41			
44.	.22	.11	.21	.10	.23	.16	.25	.52	−.01	.15	.07	.08	.12	.07	.13	.10	−.07	−.08	.06	.09	.22	.27	.11	.11	.21	.18	.11	.31	.08	.07	.36	−.07	−.17	.33	.09	.16	.37	.45	.14	.25	−.13	.38	.44		
45.	.05	−.03	.03	.01	−.03	−.10	.01	.05	.01	−.04	−.10	.02	.06	−.05	−.03	−.00	.04	.01	.03	.02	−.09	−.12	−.05	−.09	−.15	−.12	−.09	.07	−.06	−.04	.17	−.07	−.03	.04	−.08	.11	.05	.03	.20	−.07	.11	−.02	.16	.08		
46.	.10	.01	.01	−.04	.07	−.05	.07	.06	.05	.00	.05	.12	.07	.09	.09	.04	.07	−.01	−.02	.02	.02	.06	.06	.02	.12	−.06	.01	.13	.06	.07	.12	.00	−.05	.12	−.15	−.05	.08	.07	.19	.07	.11	.10	.13	.15	.31	
47.	.14	.11	.14	.13	.14	.09	.12	.28	−.04	.12	.06	.09	.14	.04	.07	.05	−.02	−.04	.10	−.02	.10	.17	.10	.08	.15	.04	.09	.01	−.07	−.04	.12	−.07	−.12	.06	.03	.06	.11	.07	.12	.00	.00	.13	.10	.17	.14	.05	

Appendix 8. Principal factor matrix, factors I—VI. Activity variables. Combined material (Karstula+Jämsä).

	I	II	III	IV	V	VI	h^2_3	h^2
1.	—.68	—.05	—.33	—.29	.07	—.00	.57	.63
2.	—.75	.36	.05	—.10	—.20	.04	.70	.71
3.	—.86	—.05	—.11	.12	.18	—.05	.76	.74
4.	—.77	.34	—.01	.30	.05	.05	.70	.74
5.	—.73	—.09	.19	—.27	—.04	—.03	.58	.60
6.	—.60	—.22	.39	.03	.07	—.01	.56	.54
7.	—.46	—.32	—.14	.23	—.21	—.10	.33	.44
8.	—.31	—.36	—.06	.04	—.03	.19	.23	.27
Eigen value	3.55	.54	.34	.33	.13	.05	4.43	4.67
Eigen value %	44.32	6.77	4.19	4.07	1.62	0.67		
Cumulative eigen value %	44.32	51.09	55.28	59.35	60.97	61.64		

Appendix 9. Principal factor matrix, factors I—VI. Attitude variables. Combined material (Karstula+Jämsä).

	I	II	III	IV	V	VI	h^2_4	h^2
9.	—.32	.45	.24	—.18	—.04	—.16	.39	.40
10.	—.46	.06	—.38	—.15	.25	.14	.38	.43
11.	—.47	—.31	.23	—.16	.11	.06	.39	.40
12.	—.42	—.36	.09	—.01	.13	—.02	.31	.37
13.	—.33	—.00	.01	.25	—.02	.34	.17	.28
14.	—.46	—.06	.09	.08	—.04	.09	.23	.33
15.	—.57	.17	.04	—.21	—.19	.00	.39	.43
16.	—.35	.00	.08	—.16	—.23	.21	.15	.29
17.	—.37	—.32	—.15	.11	—.23	—.01	.27	.34
18.	—.34	—.44	.06	—.01	—.01	.04	.32	.34
19.	—.31	—.16	—.50	—.26	.13	.02	.44	.43
20.	—.30	—.10	—.28	.25	—.18	—.03	.24	.28
21.	—.50	.34	.16	—.14	.05	.00	.42	.42
22.	—.48	.24	.15	.18	.03	.11	.35	.37
23.	—.65	.08	—.08	.24	.01	—.19	.50	.53
24.	—.58	.23	—.15	—.07	—.13	—.25	.41	.48
25.	—.50	.32	.06	—.24	—.08	.03	.41	.43
26.	—.42	.15	.23	.05	.22	—.08	.25	.33
27.	—.65	—.00	—.01	.31	.14	—.06	.52	.53
Eigen value	4.02	1.15	0.76	0.64	0.37	0.34	6.54	7.41
Eigen value %	21.08	6.05	4.01	3.34	1.95	1.77		
Cumulative eigen value %	21.08	27.13	31.14	34.48	36.43	38.20		

Appendix 10. Principal factor matrix, factors I—VI. Background variables. Combined material (Karstula+Jämsä).

	I	II	III	IV	V	VI	h^2_3	h^2
28.	—.69	—.38	—.13	.04	—.08	—.24	.64	.60
29.	—.17	.01	.04	.28	—.06	.17	.03	.21
30.	—.30	—.52	.08	.30	.23	—.07	.37	.53
31.	—.68	.05	—.27	—.18	—.25	—.24	.54	.60
32.	.24	—.59	.03	—.26	—.01	.16	.41	.48
33.	.24	—.54	—.05	—.27	—.16	.04	.35	.48
34.	—.71	—.12	.22	—.08	.17	—.19	.57	.52
35.	—.11	—.02	.53	—.20	.41	—.03	.29	.41
36.	—.24	.33	.12	—.23	—.12	—.07	.14	.27
37.	—.61	.22	.11	.17	.01	—.03	.43	.51
38.	—.67	.01	.17	.04	—.02	.02	.48	.51
39.	—.18	—.07	—.39	—.10	.15	—.03	.20	.25
40.	—.33	—.28	—.05	.20	—.16	.15	.19	.30
41.	.19	.04	—.37	.28	.19	—.04	.17	.26
42.	—.52	.02	.10	—.02	—.02	.28	.28	.41
43.	—.58	.02	—.12	—.06	—.06	.18	.35	.44
44.	—.60	.06	—.01	—.10	—.01	.31	.38	.45
45.	—.14	.12	—.42	—.22	.24	—.02	.21	.31
46.	—.20	.03	—.36	—.03	.30	.14	.17	.31
47.	—.15	.16	—.11	—.14	.12	.11	.06	.17
Eigen value	3.79	1.37	1.11	0.69	0.62	0.48	6.26	8.01
Eigen value %	18.97	6.84	5.56	3.46	3.11	2.41		
Cumulative eigen value %	18.97	25.81	31.37	34.83	37.94	40.35		

Appendix 11. Activity variables; two-factor varimax solution. Combined material (Karstula + Jämsä).

Variable	I	II
1.	—.53	—.43
2.	—.82	—.14
3.	—.67	—.54
4.	—.82	—.17
5.	—.55	—.49
6.	—.36	—.53
7.	—.19	—.53
8.	—.04	—.47

Appendix 12. Attitude variables; two and three-factor varimax solutions. Combined material (Karstula + Jämsä).

Variable	I	II	I	II	III
9.	—.01	—.55	—.06	—.60	—.01
10.	—.42	—.21	—.29	—.03	—.53
11.	—.21	—.52	—.25	—.55	—.04
12.	—.15	—.53	—.15	—.52	—.15
13.	—.28	—.19	—.26	—.16	—.14
14.	—.35	—.31	—.35	—.29	—.13
15.	—.56	—.18	—.54	—.14	—.18
16.	—.29	—.20	—.29	—.19	—.08
17.	—.12	—.47	—.06	—.38	—.34
18.	—.03	—.56	—.03	—.54	—.15
19.	—.17	—.31	—.01	—.10	—.60
20.	—.20	—.25	—.10	—.12	—.39
21.	—.61	.00	—.63	—.01	—.03
22.	—.53	—.08	—.55	—.09	—.04
23.	—.58	—.30	—.53	—.21	—.34
24.	—.61	—.14	—.54	—.03	—.35
25.	—.59	—.02	—.58	.00	—.11
26.	—.43	—.12	—.47	—.16	.05
27.	—.54	—.37	—.50	—.30	—.29

Appendix 13. Factor loadings of original variables, and their correlations with factor scores.

		Factor loadings in varimax solutions calculated from combined material	Correlations with factor scores	
			Karstula	Jämsä
T_1	(4) Relative extent of forest regeneration	.80	.90	.91
	(2) Relative extent of measures taken	.79	.88	.88
	(3) Absolute extent of forest regeneration	.64	.70	.73
	(1) Absolute extent of measures taken	.54	.56	.60
	(5) Number of different measures taken	.47	.49	.51
T_2	(7) Last visit by forestry expert to farm	.53	.57	.64
	(1) Absolute extent of measures taken	.52	.66	.55
	(3) Absolute extent of forest regeneration	.51	.63	.68
	(8) Last attentance at instructive meeting	.44	.52	.56
	(5) Number of different measures taken	.33	.34	.48
T_3	(6) Measure taken for the first time	.65	.81	.89
	(5) Number of different measures taken	.50	.58	.68
A_1	(21) An expert should mark trees for felling	.63	.79	.67
	(25) Experts understand	.62	.71	.67
	(15) Cutting is free enough	.56	.60	.66
	(24) New methods are suitable	.50	.46	.61
	(22) Planning is necessary	.44	.46	.52
	(26) Skills are better today	.41	.46	.45
	(23) Forest regeneration is not favoured too much	.37	.43	.45
	(27) Forest regeneration is an economic proposition	.32	.34	.38
	(16) Restrictions on cutting are necessary	.31	.32	.38

		Factor loadings in varimax solutions calculated from combined material	Correlations with factor scores	
			Karstula	Jämsä
A_2	(9) Forest owners show too little interest	.62	.72	.67
	(11) Forest owners do not care enough	.57	.69	.64
	(18) Forest owners do not tend forests without a law	.53	.58	.61
	(12) Sales income is insufficient for silviculture	.50	.66	.52
	(17) Silviculture should be supervised more	.34	.38	.32
A_3	(19) A forest management fee is necessary	.64	.82	.76
	(10) Forest management associations deserve support	.51	.55	.73
A_4	(27) Forest regeneration is an economic proposition	.60	.71	.73
	(23) Forest regeneration is not favoured too much	.56	.60	.73
	(20) Fertilization should be greatly increased	.41	.62	.36
	(22) Planning is necessary	.38	.42	.48
	(13) Silviculture is worth financial investment	.38	.51	.39
	(17) Silviculture should be supervised more	.32	.43	.20
	(14) Regulatory laws for silviculture are acceptable	.30	.39	.31
E_1	(28) Forest area	.75	.80	.88
	(34) Revenue	.74	.76	.82
	(38) Level of fixtures II	.65	.72	.64
	(31) Arable area	.60	.63	.69
	(44) Activity in organizations	.56	.55	.58
	(37) Level of fixtures I	.53	.57	.52
	(43) Activity in using sources of knowledge	.53	.50	.60
	(42) Schooling	.51	.28	.65
	(30) Relative yield	.44	.47	.45
	(40) Duration of family possession	.39	.35	.42
	(29) Fertility of forest soil	.16	.04	.08
E_2	(32) Distance from main village	.63	.76	.67
	(33) Distance from bus route	.58	.68	.60
	(30) Relative yield	.42	.53	.55
	(36) Debts	—.39	—.41	—.48
	(37) Level of fixtures I	—.38	—.36	—.44
E_3	(35) Supplementary income	.51	.69	.65
	(45) Satisfaction with occupation	—.43	—.44	—.58
	(39) Continuity of ownership	—.41	—.47	—.55
	(46) Security of subsistence	—.38	—.35	—.50
	(31) Arable area	—.35	—.48	—.45
	(41) Age	—.35	—.38	—.45
	(47) Spirit of enterprise	—.13	—.14	—.16

Appendix 14. Correlation matrix of factor scores. Karstula.
n = 139, $r_{.05} = .17$

	T_1	T_2	T_3	A_1	A_2	A_3	A_4	E_1	E_2	E_3
T_1										
T_2	.12									
T_3	.21	.10								
A_1	.09	.19	—.03							
A_2	—.03	—.10	.06	—.04						
A_3	.14	.05	.14	—.12	.19					
A_4	.02	—.08	.04	.15	.04	.05				
E_1	.08	.69	.09	.33	—.06	—.04	.01			
E_2	—.07	.09	.04	—.18	—.01	—.00	—.08	.12		
E_3	—.12	—.25	.04	.01	.01	—.03	—.08	—.07	—.02	

Appendix 15. Correlation matrix of factor scores. Jämsä.
n = 150, $r_{.05} = .16$

	T_1	T_2	T_3	A_1	A_2	A_3	A_4	E_1	E_2	E_3
T_1										
T_2	.22									
T_3	.17	.30								
A_1	—.01	.08	.19							
A_2	—.04	—.12	.00	.06						
A_3	.20	.23	.25	.18	—.08					
A_4	.19	.02	.21	.26	.05	.05				
E_1	.30	.58	.28	.07	—.05	.19	—.03			
E_2	—.18	—.02	—.02	.02	—.16	—.00	—.12	—.10		
E_3	—.13	—.07	—.00	.11	.13	—.11	.05	—.05	.03	

Appendix 16. Correlation matrix of factor scores. Combined material (Karstula + Jämsä).
n = 289, $r_{.05} = .14$

	T_1	T_2	T_3	A_1	A_2	A_3	A_4	E_1	E_2	E_3
T_1										
T_2	.16									
T_3	.23	.20								
A_1	.06	.13	.09							
A_2	.01	—.11	.06	.03						
A_3	.21	.13	.23	.04	.09					
A_4	.17	—.03	.17	.22	.09	.10				
E_1	.14	.62	.16	.17	—.08	.05	—.06			
E_2	—.03	.04	.07	—.06	—.02	.05	—.01	—.05		
E_3	—.12	—.15	.02	.06	.07	—.08	—.01	—.06	.00	

ON THE BIOLOGY OF *NALEPELLA HAARLOVI* BOCZEK VAR. *PICEAE-ABIETIS* LÖYTTYNIEMI *(ACARINA, ERIOPHYIDAE)*

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Helsinki 1971. Valtion painatuskeskus

INTRODUCTION

In the 1960's a previously unknown type of injury to spruce needles began to occur in the nurseries in eastern Finland. The damage was caused by the mite *Nalepella haarlovi* Boczek var. *piceae-abietis* Löyttyniemi, an Eriophyid species living as a vagrant on the needles of spruce (see Boczek 1962, Löyttyniemi 1969 a). Investigations on the distribution and harmfulness of the species revealed that under certain conditions it is a pest of great economic importance, and that control measures are necessary (see Löyttyniemi 1969 c, 1970 a). Because the life history of this *Nalepella* species was completely unknown, and the biology of the Eriophyidae in general, and especially in the northern climatic zones, has been quite inadequately studied, the habits of the species were also investigated. The results and other observations concerning the biology of the species are presented in this paper. Because, since Nalepa's (1911) treatise, no general account of the biology and ecology of Eriophyid species has been presented, the literature dealing with these subjects has also been reviewed here to a considerable extent.

Investigations were carried out from 1965 to 1970. The methods and much of the spruce material were those used in a simultaneous study of the spruce spider mite (Löyttyniemi 1969 b, 1970 b). Laboratory studies were carried out in the entomological laboratory of the Finnish Forest Research Institute, and field investigations mainly in the nurseries at Tuusula and Punkaharju, from which the material used in the laboratory experiments originated.

ERIOPHYID SPECIES OF CONIFEROUS TREES

Altogether approximately 40 species of Eriophyidae living on conifers are known, and most conifer genera have been mentioned as hosts (e.g. Keifer 1938, 1939 a, 1939 b, 1944, 1946, 1951, 1953, 1954, 1961, 1962, 1969 a, 1969 b, Postner 1968, Löyttyniemi 1969 a). Most of the known species cause galls or bud and shoot deformations; only a few are vagrants, feeding on the needles. However, the difference between vagrant

and gall-forming species is not always completely clear (see Ševtšenko 1961, Kruel 1963). The following Eriophyid species are known to live on the genus *Picea: Phytoptus piceae* (= *Trisetacus* sp.?), which causes swelling of the buds in *Picea abies* (Roivainen 1951, Buhr 1964), *Trisetacus grosmanni*, which has the same effect on *Picea sitchensis* (Keifer 1959); *Epitrimerus pungiscus*, which is free-living on *Picea pungens* (Keifer 1962) and *Nalepella haarlovi* on *Picea sitchensis* (Boczek 1962); and the object of this study, *Nalepella haarlovi* var. *piceae-abietis*, which lives as a vagrant on the needles of *Picea abies* (Löyttyniemi 1969 a). All known species of the genus *Nalepella* are free-living and feed on the needles of conifers; in addition to *Picea*, they have been observed on the genera *Abies*, *Larix*, *Pinus* and *Tsuga* (Keifer 1944, 1969 a, Roivainen 1953, Postner 1968).

In this study the principal host of *Nalepella haarlovi* var. *piceae-abietis* was observed to be the Norway spruce, *Picea abies* (L.) Karst. The mite occured throughout the range of the Norway spruce in Finland and was common everywhere. Mass outbreaks were observed only on some exceptionally sturdy seedlings in the nurseries in eastern Finland. In addition to *Picea abies*, a species native to Finland, *Nalepella* occurred on at least the following exotic species: *P. asperata* Mast., *P. engelmanni* (Parry) Engelm., *P. glauca* (Moench) Voss., *P. mariana* (Mill.) B.S.P., *P. pungens* Engelm., *P. rubens* Sarg. and *P. sitchensis* (Bong.) Carr.

In addition to *Nalepella*, another vagrant Eriophyid species was found on *Picea abies*. Vagrant Eriophyid species were also found on the genera *Abies* and *Pseudotsuga*. The observations concerning these are not included here and will be presented in another paper.

BIOLOGY OF *NALEPELLA HAARLOVI* VAR. *PICEAE-ABIETIS*

Overwintering

Eriophyid species have been observed to hibernate in the buds or in small cracks in the bark. Nothing is known about the hibernation sites of many species. Overwintering takes place at the stage of development reached in the fall and the adult female can also undergo diapause (e.g. Nalepa 1911, Jordan 1918, Hassan 1928, Van de Vrie 1967, Rota & Ciampolini 1968). In studies on hibernation carried out in Poland, no differences were found between gall-forming and free-living species (Boczek 1961). According to Börner's (1907) observations in Germany, at least one Eriophyid species living as a vagrant on *Abies* apparently overwinters in the egg stage (see also Landois 1864, Nalepa 1925). The eggs of some

species have been observed to be very resistant to cold (Slykhuis 1955, Domes 1957, Taksdal 1967).

In this study *Nalepella* was observed to overwinter as the egg exclusively. All other developmental stages disappeared in southern Finland before the end of November. In laboratory experiments adult mites survived storage for several days at a temperature of about —18°C. Thus the disappearance of the species in late fall is not due solely to the low temperatures of the season.

In early winter the eggs were in diapause. The eggs that were observed to go into diapause were laid by the last two generations towards the end of August and in September. Most of the eggs of the former generation continued their development without any arrest, whereas most of the eggs of the latter generation went into diapause. The break-off of diapause was studied by taking winter eggs into the laboratory for hatching early in the winter of 1968 at Tuusula (see Löytyniemi 1970 b, Fig. 9). The eggs taken in on 7 December and earlier did not yet begin to develop, but about half of those taken in on 26 December hatched, and of those collected on 8 January 1969 and later all the viable eggs apparently hatched normally (see also Fig. 1). It was found that the majority of winter eggs survive until the spring, even when situated above the level of the snow cover and even in northern Finland (cf. Löytyniemi 1970 b).

It is worth mentioning here that the other Eriophyid species found on conifer needles in connection with this study were also observed to overwinter as diapausing eggs.

Rate of development

Data on the rate of development of some Eriophyid species in natural and laboratory conditions, and the effect of temperature upon this rate have been presented by several workers, including Börner (1907), Nalepa (1911), Jordan (1918), Massee (1927), Yothers & Mason (1930) and Domes (1957). The generation time in Germany, for example, is about 3—4 weeks and vagrant species develop faster than gall-forming ones. Boczek (1961), in Poland, has studied the rate of development of several Eriophyid species. He has found that the gall-forming species are bivoltine, while the free-living ones have 3—5 generations a year. *Cecidophyopsis ribis* has been stated to have two or five generations a year (Savsdarg 1957, Collingwood & Brock 1959). *Eriophyes cracilis* has its developmental zero level at about +11°C according to laboratory experiments, but in some species, apparently, development has taken place at even lower temperatures (Taksdal 1967, Postner 1968).

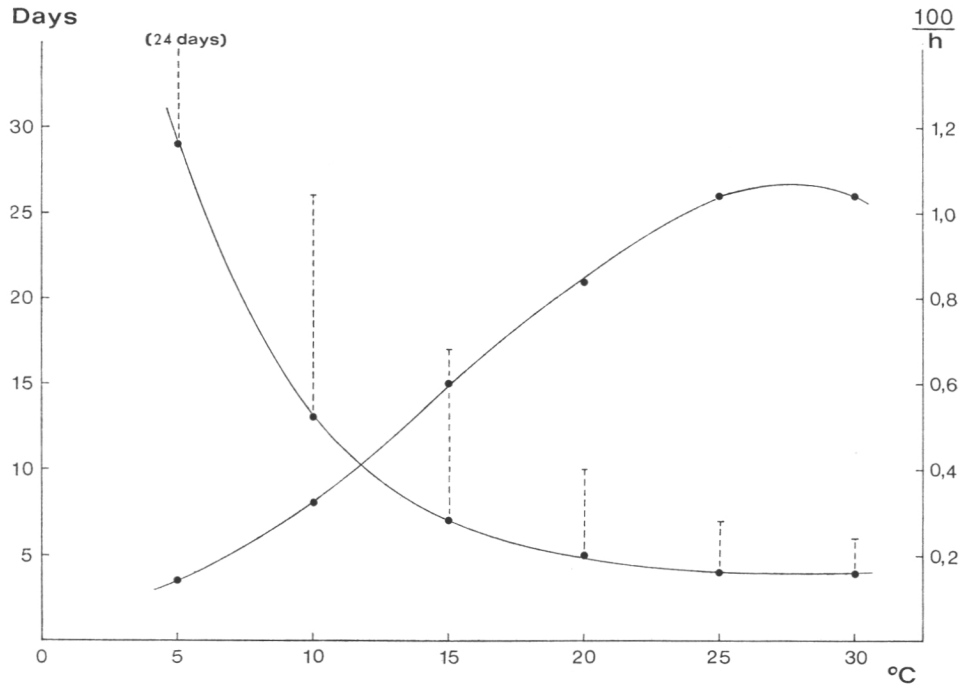


Fig. 1. The minimum time of development and the length of the hatching period of winter eggs of *Nalepella haarlovi* var. *piceae-abietis* in laboratory experiments at constant temperatures and in 75 % R.H.

The effect of temperature upon the rate of development of *Nalepella* was studied in natural and laboratory conditions. To detect the length of the generation time, the mites were allowed to lay eggs on shoots of Norway spruce during a 24-hour period, after which the adults were removed. The ambient temperature in the laboratory was about +23°C and the relative humidity 40 %. The experiment consisted of 30 shoots and altogether about 800 eggs. With the method used, only the minimum periods of development could be observed. Endeavours were made to study the development of individual mites, but these failed because the mites disappeared from the shoots. The minimum time of development of *Nalepella* was found to be 11 days, of which the egg stage took 5 days, the pre-imaginal period 5 days and the pre-oviposition period 1—2 days. Evidently the average generation time was at least 2—3 days longer than the observed minimum.

The rate of development of winter eggs was studied in detail, for, because of the diapause, only the winter eggs yielded enough material of acceptable homogeneity in respect of stage of development. The development of the eggs was studied in incubators at seven constant temperatures between +5° and +35°C, with two levels of relative humidity, 75 % and 100 %, at each. The

material for the experiments at 100 % R. H. was collected at Punkaharju on 10 January 1967 and for those in which 75 % R. H. was used on 24 February 1968. The number of eggs in individual experiments varied from 230 to 1236.

The results of the experiments in 75 % R. H. are presented in Fig. 1. In 100 % R. H. hatching began after 17 days at 10°C, after 10 days at 15°C and seven days after the beginning of the experiment at 20°, 25° and 30°C. Development at 100 % R. H. was thus clearly slower than at 75 % R. H. (cf. B e c k e r 1952). It should be kept in mind that in the eggs collected in the beginning of January diapause was possibly not yet completely broken, so the experiments are not fully comparable as far the rate of developments is concerned. The percentages of hatched eggs are presented in the following table.

R.H.	5°	10°	15°	20°	25°	30°	35°C
75 %	96.3	93.5	98.5	ca. 95	ca. 90	5.3	0.0
100 %	—	88.8	69.1	54.1	15.3	1.7	0.0

Even if allowance is made for the differences in the material, it is evident that an increase in relative humidity, especially when accompanied with a rise in temperature, led to an increase in egg mortality. At 35°C some of the eggs showed quite advanced development, although no larvae hatched. Because it was impossible to distinguish diapause eggs from summer eggs on the basis of external features, it is possible that the eggs which did not hatch at lower temperatures were not in diapause and were therefore destroyed.

In nature, development was investigated in nurseries, where the species lived on the shoots of four-year-old transplants of Norway spruce. Shoot samples were taken at intervals of 1—7 days, and the stage of development of the mites was examined. In the nursery at Tuusula some additional rearing experiments were carried out in isolated parts of the transplants. These experiments took place in summer 1970. Observations were also made in the forest, but owing to the low population density the results could not be considered reliable. As in the laboratory experiments, investigations in nature only yielded information about the minimum time of development. The observations on the voltinism of *Nalepella* in the nursery at Tuusula in summer 1970 is presented in Fig. 2. In this experimental area, seven complete generations developed during the summer, and the eighth generation apparently reached the adult stage in September—October but was not observed to lay eggs. However, the majority of the mite population produced 1—2 generations fewer. The laying of winter eggs began on about 25 August. At the same time in the forest at Tuusula development was clearly slower than in the nursery. In summer 1968, at least 5—6 generations were produced at Punkaharju, Iisalmi, Vaasa and Juupajoki, and apparently four generations

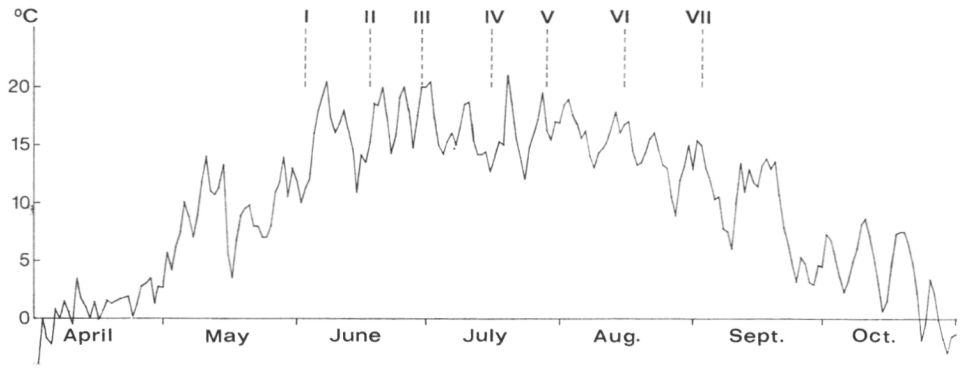


Fig. 2. The first dates of appearance of the generations of *Nalepella haarlovi* var. *piceae-abietis* in the nursery and daily mean temperatures (2 m above the ground). Tuusula summer 1970).

at Rovaniemi in northern Finland. In summer 1970 six generations occurred at Punkaharju.

In the nurseries in southern Finland larvae began to hatch from winter eggs in the end of April or beginning of May. In some cases the lower parts of transplants were still under snow when hatching began. It should be mentioned that in southern Finland buds of Norway spruce usually open in late May or early June. The dates of the beginning of hatching in some of the nurseries included in this study and corresponding temperature sums as degree-days (d.d.) are presented in the following table.

Locality and year		Beginning of hatching		
		Date	d.d. ±0°C	d.d. +5°C
Helsinki	1967	25 April	79	3
Espoo	1970	5 May	93	12
Tuusula	1968	29 April	108	20
Tuusula	1970	5 May	75	30
Heinola	1969	5 May	118	75
Punkaharju	1970	7 May	90	40

As compared with the values recorded in the laboratory, the temperature sums obtained in nature are slightly smaller on an average (cf. also Löyttyniemi 1970 b).

Egg-laying

The eggs of the *Nalepella* species were round, transparent and yellowish, and about 0.06 mm in diameter. After the eggs were laid and development had already begun, they turned opaque and became slightly elongated. The

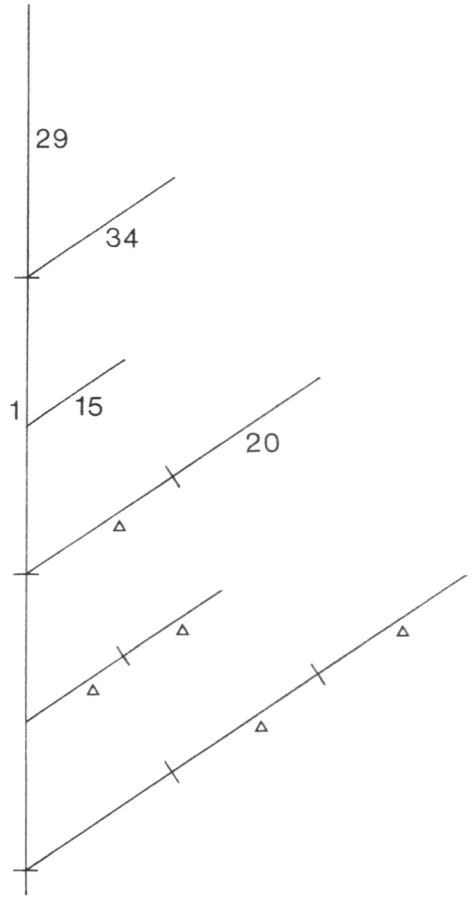


Fig. 3. The distribution of winter eggs of *Nalepella haarlovi* var. *piceae-abietis* in four-year-old transplants of Norway spruce. The figures give the percentages of eggs in various parts of the transplants (sample 300 transplants). Varkaus spring 1965.

diapause eggs were in general a little darker in color, but there was no feature by which they could be distinguished from the summer eggs. According to the literature, the eggs of Eriophyid species are about 0.03—0.06 mm in size and may be beanlike in form (Landois 1864, Hassan 1928, Baker 1939, Domes 1957, Boczek 1961).

The eggs of *Nalepella* were found exclusively on the needles. It was only in mass outbreaks that some individual eggs could exceptionally be found on the bark of the youngest shoots. In the nurseries the eggs and, in fact, the whole mite population were located in the tops of spruce transplants, and only in mass occurrences, when the needles in the tops began to wither, were the mites also abundant in the lower parts of the plants. The distribution of eggs in four-year-old transplants of Norway spruce, according to a sample studied, is presented in Fig. 3. The largest number of eggs observed on a single needle was 70.

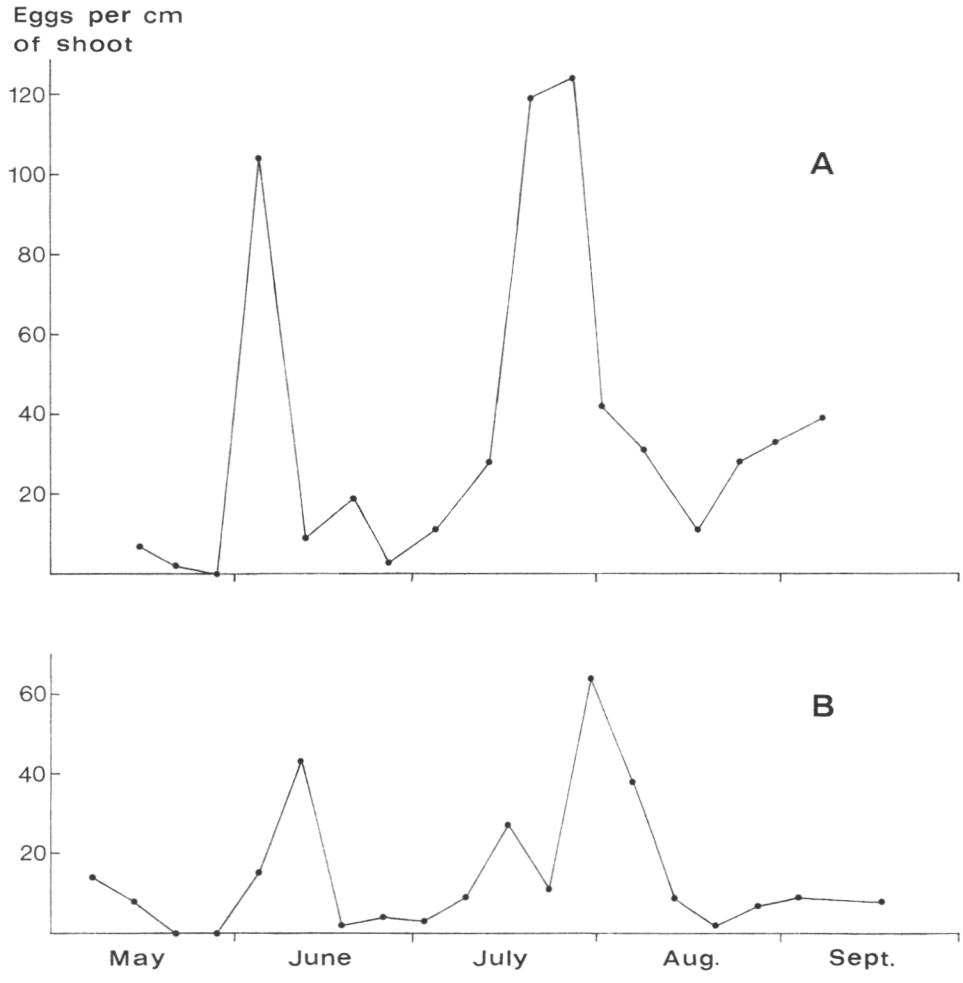


Fig. 4. The variation in the abundance of the eggs of *Nalepella haarlovi* var. *piceae-abietis* in the nurseries; (A) three-year-old transplants of Norway spruce, Punkaharju summer 1968; (B) four-year-old transplants of Norway spruce, Iisalmi summer 1968. Each sample consisted of 20 to 50 shoots.

The number of eggs laid by a female of *Nalepella* was studied in the laboratory. Altogether, 78 female mites which had hatched from winter eggs but had not yet begun to oviposit were allowed to lay eggs on the shoots of Norway spruce. A total of 2822 eggs were laid by these mites, an average of 36 eggs per female. The amount may actually have been greater, but some of the mites disappeared from the shoots too soon. In another experiment an individual mite laid altogether 52 eggs, and another 6 during a 24-hour period. More extensive experiments to detect the numbers of eggs of individual mites failed. According to previous reports, *Cecidophyopsis ribis* has produced more

than 100 eggs per female (Massee 1927), and some other species have been observed to average about 20 eggs per female. No differences have been observed in the numbers of eggs laid by vagrant and gall-forming species (Yothers & Mason 1930, Boczek 1961).

In nursery conditions two obvious peaks in the population density of *Nalepella* were regularly observed during the summer. The first occurred when the females that had hatched from winter eggs began to oviposit and the second about July—August. Two series of observations illustrating these trends are presented in Fig. 4. Corresponding peaks have also been observed in *Cecidophyopsis ribis* (Collingwood & Brock 1959, Smith 1960, Van de Vrie 1967). The reason for this, whether depending on differences in reproductive capacity between generations or on the effect of some external factors, has not apparently been solved. The current observations also show that at least for the *Nalepella* species in question it is not possible to determine the number of generations per year simply by observing the variations in abundance (cf. e.g. Collingwood & Brock 1959).

In the laboratory *Nalepella* was observed to lay eggs even when the ambient temperature was as low as 5°C (cf. Taksdal 1967).

Dispersal

The long-distance dispersal of Eriophyid species is apparently mainly anemochorous. The mites have also been observed to be carried attached on insects and in plants or parts of plants transferred by man. Gall-forming mites can disperse actively within an individual plant and also migrate to other plants if their branches are in contact. These gall-forming species move actively during a migration period (e.g. Nalepa 1911, 1926, Wolf 1921, Massee 1927, Yothers & Mason 1930, Slykhuis 1955, Domes 1957, Taksdal 1967, Van de Vrie 1967, Nault & Styer 1969).

As reported previously (Löyttyniemi 1969 c), *Nalepella* was observed to be carried into the nurseries by wind, and this transport was evidently very effective. The same phenomenon was observed in the experiments on the methods of dispersion of the spruce spider mite (see Löyttyniemi 1970 b). *Nalepella* mites were found on all the solitary Norway spruces inspected, and glue-plate traps yielded *Nalepella* and specimens of many other Eriophyid species, which were not identified. In the experiments the species did not migrate from a withering host plant to a fresh one across 10 cm of bare soil. On the other hand, they migrated in abundance from one spruce transplant to another through points of contact and especially when the host began to wither. This was observed both in the laboratory and in the

nurseries. Because mites of this *Nalepella* species are present in practically all nursery stocks of Norway spruce in Finland (see Löyttyniemi 1969 c), they are also carried to new localities when seedlings are transplanted by man.

Natural enemies

The following enemies of Eriophyid species are mentioned: *Thysanoptera*, *Diptera* and *Coccinellidae* (*Col.*) species, *Tetrastichus eriophyes* Taylor (*Hym.*) living in mite galls and numerous predatory mites. Of these, the most important are the predatory mites. During their migration period, gall-mites run a great risk of attack by their enemies (Nalepa 1911, Wissmann 1926, Massee 1927, Yothers & Mason 1930, Baker 1939, Domes 1957, Smith 1960, Boczek 1961).

In this study, various developmental stages of *Nalepella* were observed to be devoured in nursery conditions by the following predators: *Thysanoptera* and *Cecidomyidae* (*Dipt.*) larvae, *Phytoseiidae* mites and a lady bird, *Coccinella septempunctata* L. These predators seemed only occasionally to eat *Nalepella*, and mostly attacked spruce spider mites and *Cinara* aphids living on the same seedlings. During mass occurrences of *Nalepella* its enemies were not observed to be more numerous than usual, except in one case at Varkaus in summer 1965, when there was about one *Coccinella septempunctata* larva per seedling in the stand of four-year-old transplants of Norway spruce. The predators of the spruce spider mite were not observed to increase considerably until the second year of the mass occurrence (see Löyttyniemi 1970 b). Because the mass occurrence of *Nalepella* in the areas studied only lasted one summer, and the population crash took place in the fall, when the needles turned yellow, it was not possible to ascertain whether there was a corresponding increase in the enemies of *Nalepella*. No information was obtained about the enemies of the species in the forest.

No *Nalepella* mites killed by fungus diseases were observed. However, this does not necessarily prove that such diseases did not occur, for dead and dying mites apparently drop from the needles, and do not remain attached like spider mites. Fungus diseases have been observed to destroy gall-forming species (e.g. Nalepa 1911, Massee 1927, Yothers & Mason 1930).

DISCUSSION

In Finland, according to the results of this study, a relatively rich fauna of vagrant Eriophyid species lives on the needles of conifers. They have attracted little attention, apparently because in natural conditions they have

not caused clearly observable damage. These species, however, merit more detailed investigation.

Especially the wintering of *Nalepella haarlovi* var. *piceae-abietis* described in this study contributes new information to the life history of the Eriophyidae. In Finland some other Eriophyid species were also observed to produce hibernating diapause eggs, and this mode of overwintering may be more common than has been supposed. It is possible that such a diapause is limited to the cold temperature zones and the evergreen conifers (see also Börner 1907). The mechanism of hibernation is fully analogous to that of the Tetranychidae of the northern regions (see Löyttyniemi 1970 b).

These observations on the rate of development of *Nalepella* show that its morphogenesis is clearly more rapid than that of the other Eriophyid species studied previously. Development was also observed to take place at exceptionally low temperatures. In this respect, the rate of development of *Phyllocoptes oleivorus*, which lives on *Citrus*, has been observed to be in the same order as that of *Nalepella* (Yothers & Mason 1930). It is possible that the vagrant mite species living on *Abies* in Germany also have quite a rapid morphogenesis (Börner 1907). According to the observations on the development and occurrence of *Nalepella* species, it seems that the rate of development depends on the temperature, and, in addition, to a considerable extent on the quality of the nutrition provided by the host. When compared with the Tetranychid species the development of *Nalepella* is clearly faster. The heat resistance of the eggs of *Nalepella* was approximately the same as that of the ecologically close spruce spider mite (cf. Löyttyniemi 1970 b).

The *Nalepella* mite was observed to lay slightly larger numbers of eggs than some other Eriophyid species studied previously (see also Massee 1927), and in this respect to be comparable with the Tetranychid species (see e.g. Löyttyniemi 1970 b). It is possible, however, that in favorable conditions the reproductive capacity of *Nalepella* might be even greater than in these laboratory experiments. Of factors directly limiting the population density of *Nalepella* only natural enemies were considered in the observations. It seems evident that in the case of this species its enemies are not of such great importance as in the control of the Tetranychid species (see Löyttyniemi 1970 b).

Mass outbreaks of *Nalepella* have occurred only in exceptionally thriving stands of Norway spruce seedlings in nurseries in eastern Finland (see Löyttyniemi 1969 c). In the light of the information obtained in this study about the occurrence and biology of the species, the most probable cause of these mass outbreks is the condition of the hosts. The availability of food has been exceptionally good, clearly better than usual in natural conditions, and this has been reflected in increased reproduction (cf. Löyttyniemi

niemi 1970 b). The wind, being an important means of dispersal of the mite, and the short developmental period contribute to mass outbreaks, which may occur quite soon after favorable conditions are reached.

In the light of the results obtained, it is not possible to explain why these mass outbreaks were especially liable to occur in eastern Finland. Apparently, climatic factors, at least, do not play a decisive role in this (see Kolkki 1966, Helimäki 1967). Probably this regional occurrence of damage is due to the differences in the techniques and facilities used (plastic greenhouses, water sprinklers, etc.), as well as to the quality of the nurseries (cf. Löyttyniemi 1969 b, 1969 c).

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FERTILIZER TREATMENT AND SEED CROP OF PICEA ABIES

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HELSINKI 1971

Helsinki 1971. Valtion painatuskeskus

PREFACE

This study was carried out at the Department of Soil Science of the Forest Research Institute, where I am stationed as a research assistant of the National Research Counsil for Agriculture and Forestry.

Professor P. J. Viro, Head of the Department of Soil Science, drew my attention in 1967 to the possibilities, which various fertilizer experiments give for investigating the seed crop of trees. From the very start of the study project, I received valuable advice from Professor Risto Sarvas, Head of the Department of Silviculture. Professors Viro, Sarvas, and Veikko Koski, Head of the Department of Forest Genetics, perused the manuscript and gave helpful advice. Professor Hannu Väliaho, Head of the Department of Mathematics, checked the statistical part of the study. The translation from Finnish into English was done with the help of Mr. John Derome, B.Sc. (Birmingham.)

The realization of the study was largely carried out with the aid of grants from the National Research Counsil for Agriculture and Forestry.

Many other people, too, have helped me in this study. I extend my sincere thanks to them all and to the institutes mentioned above.

Helsinki, April 1971.

Eino Mälkönen

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1. INTRODUCTION

The flowering and seed production of forest trees have attracted increasing attention year by year, because both natural and artificial reforestation are primarily dependent upon viable seed. It is especially typical for spruce that in good seed years, its flowering and production of seed are very abundant, but in the intermediate years they are very poor or hardly anything.

Truly good seed years have occurred for example in Southern Finland during this century at intervals of 10—13 years: 1905, 1917, 1929, 1942, 1955 and 1965 (S a r v a s 1957, p. 538 and 1968, p. 64). Between these peak years the seed crop is relatively small and it is of poor quality. An increase in the seed crop, above all in »off» years, would be extremely important for seed production.

The factors which cause one bud to become a flower bud and another a vegetative bud are not yet fully understood. However, it is known that the abundance of flowers is affected partly by the different inherent factors of trees and partly by external factors. The principal external factors affecting the flowering appear to be temperature, light, water supply and nutrition. Thinning, pruning, strangulation, irrigation and fertilizer treatment have been used to change these external factors.

The aim of this study is to see if fertilizer treatment has any beneficial effect on the flowering and seed crop of spruce, within the limits of one experimental stand. In this case for instance, temperature, which is one of the most important external factors affecting flowering, has an influence on the results only in the case of trees which have crowns at different levels in the canopy layer. It is known that the principal factors, affecting the flowering capability, are the genetic quality of the trees, but it is impossible to consider it in this investigation.

It has been shown in many cases that fertilizer treatment has increased the flowering and seed crop of trees (M a t t h e w s 1963, B a r n e s & B e n g t s o n 1968, S m i t h et al. 1968). Due to the contradiction of previous results it has been impossible to make reliable recommendations about fertilizer application.

2. MATERIAL AND METHOD

21. Collection of material

The material was collected from an experimental plot of the Department of Soil Science of the Forest Research Institute at Kuorevesi during the years 1967—69. The fertilizer experiment was established in June 1964 in a 90-year old spruce stand (*Myrtillys* type), which had been naturally regenerated. The trees of the 4th height class were removed from the stand before the establishment of the experiment. The most important inital data from the stand were:

number of stems	586	st./ha
dominant height	24.8	m
dominant diameter	32.6	cm
basal area	25.2	m^2/ha and
volume	260	m^3/ha

The experiment was established by the single tree method (V i r o 1967, p. 597). In the factorial experiment, both phosphorus and potassium were applied at 3 levels and nitrogen at 4 levels. The nutrient amounts of the different levels were:

	Doses of nutrients kg/ha		
Levels	N	P_2O_5	K_2O
0	0	0	0
1	81	69	100
2	162	139	200
3	243	—	—

The experiment was established with two replications, in which the trees were stratified into 3 strata according to diameter. The treatments were randomized for each stratum. The experiment consisted of 216 experimental units altogether. Nitrogen was given as urea, phosphorus as Kotka phosphate (a mixture of finely ground rock phosphate and superphosphate) and potassium as potassium chloride over a 6 m radius (113 m^2) around the sample tree. Between each sample plot an untreated mantle was left, the breadth of which was at least 2 m. The plots, which initially received an N_1 dose, received the same dose of nitrogen in the years 1966 and 1968. The plots, which initially received an N_2 dose, received an N_1 dose in 1968. So, all plots fertilized with nitrogen received the same amount of nitrogen after 4 years from the establishment of the experiment.

It was thought that the single tree method would give a possibility to study the influence of fertilizer treatment on the number of female flowers, the number of cones, the size of cones, the weight of the viable seeds and the number of seeds per cone.

A telescope is generally used in counting the female flowers and cones. However, the counting of female flowers encounters difficulties, especially when the trees are high and the flowers exist abundantly. The counting of female flowers was carried out with a telescope from the southern side of tree during 1—2 weeks after flowering, at which time the strobili are usually easier to discover than later, due to their red color. Naturally the method did not give exact values, but it gave a class of magnitude. According to Vilikainen (1962, p. 25), one third of the female flowers can remain unnoticed when counting is carried out this way.

The cones were collected from the sample trees at the beginning of October in the years 1967 and 1969. In the year 1968, the cone yield was so poor, that it was useless to collect it, because the sample trees had only 30 cones altogether. The old cones were separated during cone collection. According to the observations made, the cone damages were quite low and it did not seem to be reasonable to study more closely the causes of injuries. From the cones, which were collected in the year 1967, a random sample was taken to determine the quantity and quality of seed. The random cone sample had no visible fungi or insect injuries. The seeds were extracted in the laboratory of the Forest Research Institute. The entire cone yield of 1969 was subjected to extraction at the Forest Government Research Station at Patama.

Separation of viable seeds was done by X-raying, whenever possible, a sample portion of 500 seeds. Using X-ray photographs, the viable seeds were separated as the ones which contained fully developed embryos (Müller-Olsen et al. 1956). Weighing was done after drying the viable seeds at a temperature of 105°C for 24 hours.

In connection with cone collection in the year 1967, needle samples were also taken. Whenever possible, the samples were taken from the third branch whorl from the top of the tree. The needle samples were analyzed in the Department of Soil Science of the Forest Research Institute.

22. Statistical procedures

Multiple regression analysis was used to determine the factors affecting flowering and seed crop. The addition or exclusion of an independent variable was based on the F-test. In this case, F was given the critical value 4.00. The significance of the regression coefficient was tested with the t-test.

In the preliminary examination, the logarithmic transformation of the number of female flowers and cones proved to be useful. Because nought values occurred in the observation material, $\log(x+1)$ was used instead of log x. Different fertilizer treatments were taken into consideration as dummy variables. The importance of different fertilizer treatments can thus be seen directly as the significance of the regression coefficient.

Dependent variables represented alternately the number of female flowers or cones, the mean length of cones, the weight of 1 000 viable seeds and the number of seeds per cone. The independent variables were correspondingly:

x_6 = diameter at breast height, cm
x_7 = height of tree, m
x_8 = growth area of tree, sq m
x_9 = competition index
x_{10} = basal area increment in a year, sq dm
x_{11-13} = potassium fertilizer treatment:
if the dose is K_1, $x_{11} = 1$, otherwise $x_{11} = 0$
if the dose is K_2, $x_{12} = 1$, otherwise $x_{12} = 0$
if the dose is K_3, $x_{13} = 1$, otherwise $x_{13} = 0$
x_{14-16} = phosphorus fertilizer treatment:
if the dose is P_1, $x_{14} = 1$, otherwise $x_{14} = 0$
if the dose is P_2, $x_{15} = 1$, otherwise $x_{15} = 0$
if the dose is P_3, $x_{16} = 1$, otherwise $x_{16} = 0$
x_{17-20} = nitrogen fertilizer treatment:
if the dose is N_1, $x_{17} = 1$, otherwise $x_{17} = 0$
if the dose is N_2, $x_{18} = 1$, otherwise $x_{18} = 0$
if the dose is N_3, $x_{19} = 1$, otherwise $x_{19} = 0$
if the dose is N_4, $x_{20} = 1$, otherwise $x_{20} = 0$
x_{21} = nitrogen content of needles, per cent dry matter
x_{22} = phosphorus content of needles (P_2O_5), per cent dry matter
x_{23} = lime content of needles (CaO), per cent dry matter
x_{24} = potassium content of needles (K_2O), per cent dry matter
x_{25} = ash content of needles, per cent dry matter.

The independent variables, x_8 = the growth area of the tree and x_9 = competition index, were computed in the Department of Soil Science according to J a c k's (1967 pp. 379—403) method. The variable x_8 indicates the area surrounding the sample tree, which is limited by neighbouring trees. When the mean height of the neighbouring trees, which is weighted by the area of the influence wedge of the same trees, is divided by the height of the sample tree, it gives a characteristic value, which is termed the competition index.

The residuals were examined from the final equations according to Draper and Smith (1968 pp. 86—95) in order to establish the qualifications of the test.

3. RESULTS

31. Number of female flowers

While investigating the possibilities of affecting the development of the flower buds, the first essential is to determine when the flower buds are initiated. It is known that in many tree species, flower primordia are formed early in the growing season preceding the spring in which the flowers appear, so that the formation of new buds would be already completed by the middle of the growing season (Sarvas 1966, p. 253, Brøndbo 1970, p. 10). The most effective time to apply fertilizers for purposes of stimulating flower bud formation is generally in early spring before the new flower buds are differentiated (Matthews 1963, p. iv.). Since the seeds of spruce mature during one season, the fertilizer treatment, which is made early in spring, should affect flowering the next spring, and the seed crop the following autumn. The established fertilizer treatment of this experiment was not done until the beginning of June in the year 1964, which obviously means that the initiation of flower primordia was not affected earlier than 1965 and flowering not earlier than 1966. The nitrogen fertilizer treatment was partly repeated on the 17th of May 1966 and 1968. It was possible to verify, on the basis of the growth measurement, that the diameter growth did not begin until one week later, so it is possible that the repetition of fertilizer treatment could affect the differentiation of the buds in the years in question.

The following equations were obtained as the result of stepwise regression analysis in order to express the number of female flowers for the year 1967. R represents the multiple correlation coefficient and S_e the residual standard deviation.

		R	S_e
(1)	$Y_1 = -0.936 + 0.095\ X_6$	0.61	0.73
(2)	$= -2.010 + 0.098\ X_6 + 1.148\ X_{24}$	0.65	0.70
(3)	$= -2.463 + 0.092\ X_6 + 1.040\ X_{24} + 0.478\ X_{21}$	0.66	0.70

It appears from the equations that the diameter of a tree is the best variable. Despite the fertilizer treatments, which did not enter into the regression model, the result shows that the nutrient status of trees, as far as the potassium and nitrogen content of needles is concerned, had a favourable effect upon the flowering. The determination coefficient of the regression model was however quite low. The multiple correlation coefficient was 0.66, which means that only about 44 per cent of the variance in flowering was explained.

However, it does not necessarily mean that the low determination coefficient signifies erroneous coefficients.

The correlation coefficients between the female flowers and some independent variables are presented in appendix 1. Because the unequal variation and the mutual correlation of the independent variables makes it more difficult to interpret the correlation coefficients, the standard partial regression coefficients (beta coefficients) were calculated. These coefficients explain the relative importance of every variable. They have been calculated by multiplying the regression coefficient by the ratio between the standard errors of the independent and dependent variable (Ezekiel & Fox 1959, p. 196).

	Beta coefficient
x_6 = diameter at breast height	0.59
x_{24} = potassium content of needles	0.21
x_{21} = nitrogen content of needles	0.19

In this case the standard partial regression coefficients, however, did not change the impression which was obtained from the first regression coefficients. It can be seen that in the regression model obtained, the relative importance of the variables is the same as the order of the entrance of the variables into the regression equation.

The following equations were obtained in order to express the number of female flowers for the year 1969:

		R	S_e
(4)	$Y_1 = -0.617 + 0.052\ X_6$	0.43	0.66
(5)	$= 0.699 + 0.037\ X_6 - 0.984\ X_9$	0.47	0.64
(6)	$= 0.681 + 0.026\ X_6 - 0.896\ X_9 + 2.336\ X_{10}$	0.49	0.64

In this case the diameter of the tree comes into the model as the first variable. In addition to the other variables, the competition index and the basal area increment, are closely correlated with the diameter (appendix 2). Needle analyses were not done for the year 1969, so it was not possible to use the nutrient content of needles as an independent variable. On the other hand none of the fertilizer treatments increased the determination coefficient of the regression model. The determination coefficient was still lower than for the year 1967, but it is useful to present it for comparison.

The importance of individual variables in equation 6 may be examined on the basis of the following beta coefficients:

x_6 = diameter at breast height	0.22
x_9 = competition index	0.22
x_{10} = basal area increment in 1969	0.16

As stated previously, the independent variables of equation 6 are closely correlated with each other (appendix 2). For this reason their relative importance digresses considerably from that which would be expected on the basis of the separate correlation coefficients.

The number of female flowers can fluctuate very much in successive years as is apparent in the following examples.

Number of sample tree	Diameter cm	Fertilizer treatment	Number of female flowers 1967	1968	1969
40	25	$K_2P_2N_1$	0	2	116
128	30	$K_2P_2N_3$	801	0	4
160	33	$K_1P_1N_1$	727	0	34
172	27	P_2N_2	71	48	170
194	49	P_2N_1	695	0	13

In connection with flowering abundancy T i r é n (1935, p. 422) has observed the formation of vegetative buds, from which female flowers can develop. The number of the terminal and lateral buds may be to such a degree reduced after the years of abundant flowering, that during the following 2—3 years the new flower buds are reduced in number, until the new shoots have had time to develop. The number of the female flowers of the preceding years should be taken into consideration when adjusting the factors affecting the flowering abundance (B r ø n d b o 1970, p. 11). On the basis of this material it was possible to examine the dependence of the number of female flowers in the years 1967—68 upon the number of female flowers in 1969. Because most of the flowers were found on the larger trees, only the number of female flowers on the dominant trees was examined; there appeared no correlation between them. It is evident that the number of female flowers was, however, during the examination period so small that it did not prevent the formation of the new flower buds.

32. Cone yield

Not all female flowers develop cones, because the development may be interrupted by frost and insect injuries, and according to some opinions, also by nutrition definiency. The greatest number of cones found on one tree was 1 123 in 1967, only 8 in 1968, and 328 cones in 1969.

The following equations were obtained in order to show the number of cones on the sample trees for the year 1969:

		R	S_e
(7)	$Y_2 = -1.105 + 0.103\ X_6$	0.57	0.87
(8)	$= -2.364 + 0.106\ X_6 + 1.346\ X_{24}$	0.62	0.83
(9)	$= -3.020 + 0.097\ X_6 + 1.190\ X_{24} + 0.692\ X_{21}$	0.63	0.82

Exactly the same independent variables as for the examination of female flowers, were selected for the regression model which shows the number of cones. In both cases the determination coefficient is about the same.

The mutual correlations of the variables in equation 9 can be seen in appendix 1. The beta coefficients, which are calculated from the same equation, are as follows:

x_6 = diameter	0.36
x_{24} = potassium content of needles	0.20
x_{21} = nitrogen content of needles	0.16

Comparison between the beta coefficients from equations 3 and 9 which show the number of female flowers and cones, indicates that the relative importance of diameter is greater in the explanation of the number of female flowers than in the explanation of cone yield. On the other hand the relative importance of the nitrogen content of needles is greater in the explanation of cone yield than in the explanation of the number of female flowers.

On the basis of the 1969 cone yield, the following equations were obtained:

		R	s_e
(10)	$Y_2 = -0.687 + 0.057\ X_6$	0.51	0.58
(11)	$= 0.686 + 0.042\ X_6 - 1.026\ X_9$	0.56	0.56
(12)	$= 0.666 + 0.030\ X_6 - 0.932\ X_9 + 2.514\ X_{10}$	0.57	0.55

In this case, the cone yield is best explained by the same independent variables as the flowering abundancy. The determination coefficient is, however, with respect to the cone yield, a little higher. The beta coefficients of the variables were obtained correspondingly:

x_6 = diameter	0.27
x_9 = competition index	0.24
x_{10} = basal area increment in 1969	0.19

Thus there was no essential difference between the relative importance of the variables, which show the number of female flowers and the cone yield for 1969.

The application of fertilizers did not have a significant effect upon the size of cones and the number of seeds per cone. The quality of seed was clarified by means of the dry weight of the seeds. The application of fertilizers did not have a significant effect upon the weight of the viable seeds.

Table 1. The influence of different fertilizer doses on the dry weight of 1 000 viable seeds in 1967

	N_0	N_1	N_2	N_3	
K_0	5.19±0.23	5.21±0.21	5.91±0.24	5.14±0.21	5.34±0.12
K_1	5.66±0.26	5.37±0.24	5.94±0.31	5.27±0.36	5.58±0.14
K_2	5.43±0.34	5.30±0.19	5.72±0.29	5.33±0.33	5.45±0.15
P_0	5.20±0.36	5.29±0.20	5.81±0.27	5.32±0.18	5.38±0.13
P_1	5.39±0.19	5.50±0.20	6.13±0.26	5.09±0.33	5.54±0.12
P_2	5.74±0.24	5.04±0.26	5.64±0.31	5.28±0.44	5.44±0.16
	5.41±0.16	5.29±0.13	5.87±0.16	5.24±0.16	

	P_0	P_1	P_2	
K_0	5.55±0.22	5.24±0.16	5.24±0.24	5.34±0.12
K_1	5.38±0.23	5.82±0.24	5.50±0.30	5.58±0.14
K_2	5.19±0.25	5.56±0.23	5.66±0.28	5.45±0.15
	5.38±0.13	5.54±0.12	5.44±0.16	

Table 2. The influence of different fertilizer doses on the dry weight of 1 000 viable seeds in 1969

	N_0	N_1	N_2	N_3	
K_0	4.32±0.19	4.80±0.21	4.85±0.16	4.73±0.15	4.67±0.09
K_1	4.82±0.26	4.58±0.23	4.87±0.24	5.10±0.54	4.82±0.16
K_2	4.84±0.29	4.80±0.14	4.94±0.21	4.88±0.21	4.85±0.10
P_0	4.33±0.29	4.78±0.22	5.00±0.21	4.90±0.18	4.74±0.12
P_1	4.78±0.22	4.86±0.20	5.07±0.20	4.74±0.21	4.82±0.10
P_2	4.91±0.25	4.51±0.13	4.68±0.18	5.11±0.58	4.76±0.14
	4.63±0.14	4.73±0.11	4.88±0.12	4.89±0.18	

	P_0	P_1	P_2	
K_0	4.75±0.21	4.79±0.14	4.45±0.12	4.67±0.09
K_1	4.63±0.29	4.80±0.20	5.00±0.33	4.82±0.16
K_2	4.82±0.16	4.92±0.22	4.84±0.19	4.85±0.10
	4.74±0.12	4.82±0.10	4.76±0.14	

4. DISCUSSION

The fertilizer experiment, from which the material of this investigation was collected, was established primarily for the development of research technique. V i r o (1967, p. 606) has verified, on the basis of the increment results, that the single tree method used, is suitable at least for short-term

fertilizer experiments. Up to now the neighbouring differently treated experimental units have not affected each other.

Since the trees use large amounts of nutrients for flowering and seed production, it seems possible that the application of fertilizers could increase the seed crop. In many foreign investigations, it has been concluded that the nutrient amounts used by trees for flowering and production of seeds, represent 15—20 per cent of that used for production of wood. On the other hand it would be expected that trees producing more stem wood than average, would react more to the application of fertilizers than trees, which are flowering and producing above average seed crops (S a r v a s 1967, p. 289). Due to the genetic factors of trees, which produce above average seed crops, the summer wood percentage is smaller than in trees producing stem wood abundantly. An attempt was made to obtain information about the genetic flowering capability of trees on the basis of this dependence. However, in the explanation, it was found that the correlation coefficient between the summer wood percentage and the number of female flowers of the trees was only —0.10, so it did not give any information about the genetic variation of flowering and seed crop.

It has been found that the annual development period of forest trees, including among other things the formation of buds, flowering and maturing of seeds, are very strongly governed by temperature. In addition to this, the different genotypes react with varying sensivity to temperature due to genetic differences. Obviously temperature in the annual development of forest trees has a threshold, which when surpassed, for example in fertilizer treatment, can have a more effective influence. This is also indicated by the results of F a u l k n e r (1965, p. 218), according to which the fertilizer application did not increase the flowering and seed crop in »off» years.

In this investigation tree diameter was found to be the best independent variable in the account of the number of female flowers and cones. It is found that the cone yield is concentrated on the largest tree of the stand (H a g n e r 1958, p. 9). According to M a t t h e w s (1963, p. viii) the better cone yield of large trees is caused obviously by their well developed crown which gives greater possibilities for the utilization of nutrients than smaller trees. In addition to the diameter, the potassium and nitrogen contents of the needles entered as significant variables into the regression equations explaining the abundant flowering and cone yield in the year 1967. In this case, the nutrient content of the needles was found to be a better variable than the single levels of fertilizer treatment. The regression equation accounted, however, for only about 44 per cent of the number of female flowers in 1967 and correspondingly about 40 per cent of the cone yield.

The cone yield in 1969 was only 16 per cent of the cone yield of 1967, so it was relatively poor. The determination coefficients of the equations,

explaining the number of female flowers and cone yield 1969, were very low. Only 24 per cent of the number of female flowers and 32 per cent of the cone yield were accounted for.

This investigation suggests that in good seed years a suitable fertilizer treatment can to some extent increase the seed crop of spruce. In »off» years, however, it is perhaps too much to hope that fertilizer treatment could improve the seed crop.

SUMMARY

The factors affecting the flowering and seed crop of Norway spruce were examined during three years on a single tree fertilizer experiment. In the factorial experiment, both phosphorus and potassium were applied at 3 levels and nitrogen at 4 levels. The experiment consisted of 216 experimental units altogether.

The dimensions and position of the tree, fertilizer treatments and nutrient content of the needles were used as the independent variables in a multiple regression analysis to try to explain the flowering abundance and seed crop. In a good seed year the diameter at breast height, and the potassium and nitrogen content of the needles accounted for about 44 per cent of the number of female flowers and correspondingly about 40 per cent of the cone yield. Only 24 per cent of the number of female flowers and 32 per cent of the cone yield were accounted for in an »off» year. In this case the best independent variables were the diameter at breast height, the competition index and the basal area increment. The application of fertilizers did not have a significant effect upon the size of cones, the number of seeds per cone or the weight of the viable seeds.

Appendix 1. Correlations between variables in 1967

	X_6	X_{21}	X_{24}
X_6 = diameter	1.00		
X_{21} = nitrogen content of needles	0.30	1.00	
X_{24} = potassium content of needles	—0.07	0.16	1.00
Y_1 = number of female flowers	0.61	0.33	0.19
Y_2 = number of cones	0.57	0.35	0.20

Appendix 2. Correlations between variables in 1969

	X_6	X_9	X_{10}
X_6 = diameter	1.00		
X_9 = competition index	—0.52	1.00	
X_{10} = basal area increment	0.62	—0.42	1.00
Y_1 = number of female flowers	0.43	—0.40	0.39
Y_2 = number of cones	0.51	—0.46	0.46

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ROUGH-LIMBING AND OCULAR MARKING FOR CROSSCUTTING IN THE PREPARATION OF SAWLOGS OF PINE

MATTI AHONEN

TYNKÄKARSINNAN JA SILMÄVARAISEN APTEERAUKSEN VAIKUTUKSESTA MÄNTYSAHAPUIDEN TEKOON

TIIVISTELMÄ

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FOREWORD

Studies on the logging of sawtimber were commenced at the Forest Research Institute, Department of Forest Technology in 1967. The present investigation report deals with the first part of this research series in which different pine sawlog logging methods and their effect on sawlog measurements and prices were studied.

The chief forest supervisor of Kemi Oy, Mr Uolevi Sarapää, and Mr Klaus Rantapuu, B. Forestry, from Enso-Gutzeit Osakeyhtiö, contributed to the organization of the field work involved. I express my best thanks to them. To Professor Veijo Heiskanen, chief of the Department of Forestry Technology, Forest Research Institute, I am thankful for many pieces of advice concerning the composition and subject matter of the study.

Forest technicians Teuvo Koljonen and Toimi Pietarinen from Enso-Gutzeit Osakeyhtiö, undergraduate Markku Mäkelä and field assistant Paavo Kähkönen, from the Forest Research Institute, participated in the collection and handling of the material. Among the persons who participated in the treatment of the material I wish to mention Mr Pertti Harstela, B. Forestry, who wrote his proof-of-learning thesis on the part dealing with the limbing of pine sawlogs. The typing was done by Mrs Aune Rytkönen. The report was translated into English by Miss Päivikki Ojansuu, Mag. Phil., and checked by Mr L. A. Keyworth, M. A. (Cantab.). I thank all of them.

The undersigned directed the collection and treatment of the investigation material and wrote the report.

Helsinki, March 4, 1971

Matti Ahonen

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Abbreviations used in the study:

$d_{1 \cdot 3}$ = DBH outside the bark, cm
$d_{6 \cdot 0}$ = tree diameter outside the bark at a height of 6 m from the theoretical felling point, cm
d_k = stem diameter outside the bark, cm
$d_{1/2}$ = diameter outside the bark in the middle of the bolt, cm
d_t = log top diameter inside the bark, in.
v_k = unbarked volume of the usable portion of the stem, solid cu.m.
v_{tt} = technical volume of the sawlog portion, cu.ft.
v_t = barked volume of the sawlog portion, solid cu.m.
h_k = length of the usable portion of the stem, m
h_t = length of the sawlog portion, m
l = lower limit of the living crown from main cut of the stump, m
h_k-l = length of the living crown on the usable portion, m
h_t-l = length of the living crown on the sawlog portion, m
s_k = relative length of the living crown on the usable portion, %
s_t = relative length of the living crown on the sawlog portion, %
$d_{1 \cdot 3}/h_k$ = slenderness of the stem (ratio of the breast height diameter to the length of the usable portion), cm/m
f = tapering ($d_{1 \cdot 3}$—$d_{6 \cdot 0}$), cm
n_k = number of sawlogs and pulpwood bolts made from the tree, units
n_t = number of sawlogs made from the tree, units

1. INTRODUCTION

11. Sawlog conversion methods

The quantity of sawlogs cut in the cutting season 1966···67 in Finland was 275.4 million technical cu.ft., the largest part of it pine sawlogs. The shortwood system has been and continues to be the commonest sawlog conversion method in our country. According to Savolainen (1967), it accounted for 90 per cent of the total quantity cut in the cutting season 1966···67. The full-tree methods have not been used in Finland. It is very probable that the tree-length method is employed chiefly for the logging of sawtimber trees as it is most suitable for large-sized timber. As the proportion of pulpwood in the total cut was 58 per cent, the ratio between the shortwood system and the tree-length system for sawtimber trees in 1966···67 was roughly 3: 1. The development of the ratio between the methods is greatly dependent on what transport equipment will be acquired in the next few years. If more forwarders are procured the shortwood systems will maintain their dominant position also in sawtimber logging for many years. A possible future method of logging sawtimber trees is the procedure in which the part of the stem meeting sawlog requirements is brought uncut to the mill. However, conditions for the introduction of this method are an increase in the maximum lenth of trucks and the siting of separate crosscutting plants at sawmills.

Conversion of sawlogs into timber assortments comprises several elements which are as follows in the traditional shortwood system:

— Movements
— Felling
— Limbing
— Dividing the stem into logs, i.e., marking for crosscutting
— Crosscutting the part of the stem that meets sawlog requirements into logs
— Crosscutting the pulpwood portion into bolts or poles
— Dragging pulpwood bolts or poles to the cutter's strip or to a storage alongside the strip road as agreed.

In addition, the work consists of various auxiliary elements, lost time and interruptions. Sawlog conversion proper is considered to comprise the limbing of the sawlog portion, the dividing of the sawlog portion into logs, i.e., marking for crosscutting, the crosscutting of the sawlog portion into logs, and auxiliary elements.

12. Possibilities of reducing the time expended on limbing

It seems probable with the cost level as it is in Finland that mechanisation of limbing will not be possible during the first half of the 1970s on a large scale relative to the whole wood-harvesting procedure of the country. When seeking to rationalise limbing in the short-term view, instead of the mechanisation alternative the possibilities offered by the production unit comprising the cutter and the power saw should be considered. A starting point to note is that the power saw speeds up the limbing of large-sized timber relatively more than of small-sized pulpwood. It is possible by reducing the expenditure of time on limbing to achieve easily a relatively great saving in the time expended on conversion per tree as limbing is the most time-consuming element, 40···60 per cent of the effective conversion time (Andersson 1967, Kahala 1969).

The following elements are regarded as belonging to limbing in the shortwood systems (Levanto 1965):

1. Limbing-sawing proper and the moving of the saw in this connection, moving about and clearing of branches that interfere with the work.
2. Cutting of the top that is left in the forest.
3. Turning of the stem or the crosscut bolts for the limbing of the under side.
4. Jobs common to the group of elements that are associated with limbing.
5. Moving from the site of performance of the previous job to the site where limbing begins or moving from stem to stem for continuous limbing.

A point to be considered in the rationalisation of limbing is the share of each component phase mentioned above in the total time expended on the element in question. Levanto (1965) reported it to be as follows in the conversion of pine sawlogs:

Table 1. Distribution of limbing into different work phases

Moving (component phases 5 and 4)	8 %
Limbing proper and crosscutting the top (component phases 2 and 4)	83 %
Turning (component phases 3 and 4)	9 %

It appears from this that limbing-sawing proper predominates over the other phases of the element.

Actual limbing may be divided between the limbing of the dry and the living part of the crown, depending on the composition of the crown to be limbed. Expenditure of time is then influenced essentially by the relative proportion of the dry part in the length of the crown to be limbed. The limbing time of a dry crown per linear metre is 35···40 per cent of the limbing time for a living crown (A g e r 1964). Depending on the method employed, different work phases can be distinguished in limbing, e.g. limbing the length of the upper side of the stem, limbing the length of the under side, limbing the under side as bolts and limbing in connection with crosscutting (L e v a n t o 1965). For stem limbing of pine sawlogs the method generally used is first to limb the upper side of the stem for the length of the butt log and then to mark the butt for crosscutting and separate it from the butt. The next phase is to turn the butt log and limb the under side of the log. It is customary after this to limb at least the upper side of the remaining sawlog-part of the stem and, when trees with more branches are cut, also the upper side of the pulpwood-part of the stem so that the remaining sawlog-part can be divided. When the middle log and the top log have been marked for crosscutting, their under sides are limbed after crosscutting and turning. The procedure is the same for bolts from the pulpwood part in the top.

The following limbing methods are available in power-saw limbing:

1. Only a part of the crown on the usable portion of the stem is limbed, for which the following alternatives are available:

a.



The upper side and sides of the usable portion are limbed. The stem or bolts are not turned for the limbing of the under side (half-limbing). The quality of limbing on the limbed portion can be reduced by permitting e.g. branch stubs of under 5 cm in length.

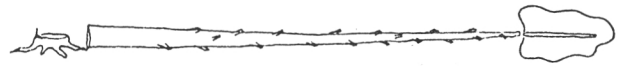
b.



The upper side and sides of only the living crown on the usable portion are limbed. The dry crown is not limbed at all (half-limbing). The stem or bolts are not turned.

2. At least living crown part on the usable portion of the stem is limbed, but the quality of limbing is reduced by permitting branch stubs shorter than 5 cm especially on the under side of the stem (rough-limbing). The following alternative methods are available:

a.



The dry and living crown portions are limbed as described above. The stem and bolts must be turned for limbing the under sides.

b.



The living crown portion is limbed as described above. The dry crown portion is not limbed at all (rough-limbing).

c.



Only the living crown on the sawlog-portion of the stem is close-limbed on all sides. The quality requirements for limbing are the same as in item b for the other portions of the stem.

When choosing from these limbing methods the changes or inconveniences caused by changing from close-limbing to the sawn goods production process must be borne in mind. If the quality of limbing is reduced, the saving in harvesting costs should be greater than the possible additional costs in the production process. Otherwise the change is not rational. The alternatives presented will therefore be discussed in the following also from the raw material technical standpoint.

In the half-limbing methods 1 a and 1 b entire branches are left on the logs and must be removed before sawing. The alternatives are close-limbing at the terminal landing or limbing by power saw or limbing machine at the log storage of the sawmill. This applies above all to the limbing of the living portion of the crown as dry branches are expected to break off and be self-pruned during transport. However, because of the necessity of close-limbing these limbing methods give no essential advantage over the traditional methods.

Doubts are being raised in the sawmill industry also about rough-limbing. Above all, there is fear of the problem of barking and sawing, and the increased proportion of bark in chips. But these problems have not been studied. Some of the doubts are probably motivated if present methods are used in the production process. The barking phase in particular would seem to be most troublesome as sawmills nowadays use ring barkers for which fairly large obstacles on the surface of the bolt, e.g. long branch stubs, may disturb smooth operation. If the sawmill industry changes on a larger scale to chipper canters it will not be necessary, at least not in sawing, to take into consideration the difficulties caused by branch stubs. Method 2 b would thus seem to be the most advantageous rough-limbing method. A cross section of a tree limbed in this way is illustrated in Fig. 1.

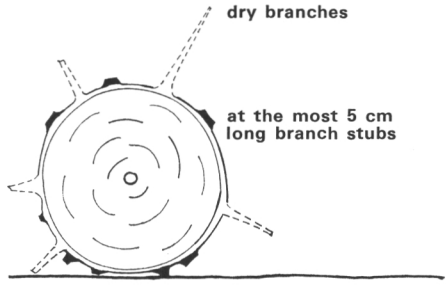


Fig. 1. Cross section of a rough-limbed tree

13. Possibilities of reducing the expenditure of time on marking for crosscutting and on crosscutting

The share of the time expended on the marking of logs for crosscutting and on crosscutting is 22···24 per cent, according to K a h a l a (1969). Included in the time spent on marking for crosscutting are the measuring of the log length by measuring stick or tape measure, possibly measuring of the top diameter by diameter gauge, examination of the quality of the stem for selection of the correct crosscutting point, moving along the stem during the measuring process and marking the log measurements. Marking for crosscutting is usually done by the cutter. It may be done at the cutting strip, at the terminal landing or at the sawmill. With the shortwood system marking for crosscutting is always done at the cutting strip. With the tree-length systems the stems are marked for crosscutting at the terminal landing after skidding. There then is usually a separate scaler and the measuring performed by him is accepted as the delivery measurement. To the costs of the cutting phase must thus be added the expenditure incurred through the use of the cross-cutter. With a harvesting method in which the part of the stem meeting sawlog requirements is brought uncut to the mill the actual marking for crosscutting must be done at the sawmill. This method is not used in Finland as the sawmills have no suitable equipment for the job. Moreover, the maximum legal truck length is too small for major use of this harvesting method.

An essential feature of marking for crosscutting compared with other elements of the cutting phase is that it requires human decision and is consequently extremely difficult and expensive to mechanise. If measuring the length of the logs must be included in the marking for cross-cutting the chances of rationalisation are slender. However, it will probably be possible to abandon the current methods of marking for crosscutting as measuring on the stump and measuring by truck load progress. It will

then be possible to change over to so-called ocular marking for cross-cutting. In this method the log length is not measured and the main consideration in selecting the crosscutting points is the quality of the sawlogs. This in selection the crosscutting points is the quality of the sawlogs. This reduces the time spent on marking for crosscutting to the time required for selecting the correct crosscutting point.

In ocular marking for crosscutting, deciding the size and quality of sawlogs is still up to the cutter who is often not sufficiently familiar with the quality requirements for sawlogs. Great attention should therefore be paid to the training of cutters. Indeed, in ocular marking for crosscutting the effect of the stem quality on the selection of the crosscutting points emerges very distinctly. The tariff should also be such that it does not lead to maximation of the technical volume of the sawlog portion. The aim is expressly maximation of the returns of the sawmills industry which is influenced very strongly by the quality of the available raw material. A feature of ocular marking for crosscutting is that the traditional trimming allowance concept must be abandoned.

14. Review of studies concerning the conversion of sawlogs

Conversion of sawlogs was one of the first objects of forest work in Finland. Several reports have been published also in Sweden and Germany. Of the work done in Finland, mention is made of the studies by Vuoristo and Makkonen on which working method tariffs still in general use are based in the main.

The effect of rough-limbing and ocular marking for crosscutting on the conversion of stems of sawlog size when the tree-length system is used was studied by Kahala and Rantapuu (1968). Studies on the effect of rough-limbing and ocular crosscutting on the pulpwood conversion time were published by Kahala (1965, 1966 a, 1966 b, 1967) and Silander (1967 and 1968). Johansson (1968 and 1969) and Duus-Otterström and Pettersson (1969) in Sweden carried out corresponding investigations. Comparative values for the results of the present study are available from Ager's (1967) »Time formulae for felling operations». For power-saw limbing, reference is made to Levanto's (1965) investigations.

In addition to time study results, men working on the harvesting and utilization of saw timber are probably interested in information on the effect of rough-limbing and ocular marking for crosscutting on the measurements and quality of sawlogs. The present author has published some preliminary data on the investigation results now reported (Ahonen 1968). Kahala and Rantapuu (1968) published results of the effect of

ocular marking for crosscutting on the mean length of sawlogs, allowance for trimming and the amount of under- and over-sized logs. The studies conducted by Asikainen (1968) provide information on the effect of ocular marking for crosscutting on the sawlog trimming allowance and the sawing utilisation ratio.

The effect of the length of timber and the quality of limbing on harvesting costs was analysed by Väisänen (1968).

Investigation methods differing from the conventional methods used in logging studies were employed by Tidenberg (1966) and Harstela (1968). The former studied the use of the power saw in limbing and the effect of different branchiness properties on limbing time. Harstela examined the influence of various wood properties on the limbing time of pine sawlogs. This study, for which a part of the material of the present work was used as primary material, gave a preliminary report on the serviceability of regression analysis for illustrating the expenditure of time on work elements. Regression analysis was used also in the basic study carried out in Norway (Samset, Strömnes, Vik 1969).

2. PURPOSE OF THE INVESTIGATION

The purpose of the present work was to establish:

1. The effect of rough-limbing on the limbing time of pine sawlogs and the wood characteristics that explain the limbing time best.
2. The effect of ocular marking for crosscutting on the time expended on marking for crosscutting and crosscutting of pine sawlogs and the wood characteristics that explain best the expenditure of time on marking with a measuring stick for crosscutting.
3. The wood characteristics that explain best the time expended on the conversion of timber (limbing + marking for crosscutting + crosscutting).
4. The combined effect of rough-limbing and crosscutting by eye on the working-site time in the conversion of pine sawlogs.
5. The effect of the conversion methods under examination on the measurements and quality of the timber converted.

As the study was primarily methodologic, the conversion methods given in Table 2 were selected as the objects of study.

Table 2. The conversion methods studied

Work site	Worker	Conversion method	Felling		Limbing		Marking for crosscutting and crosscutting of the sawlog portion		Crosscutting of the pulpwood		Dragging of the pulpwood portion	
			random	directional	rough	close	by measuring stick	ocular	into 2- or 3-m bolts	into poles	into piles alongside the strip road for grapple loading	into piles scattered on the cutting strip for grapple loading
A	I	1	—	×	—	×	×	—	—	×	×	—
A	I	2	—	×	—	×	—	×	—	×	×	—
A	I	3	—	×	—	×	×	—	×	—	×	—
A	I	4	—	×	×	—	—	×	—	×	×	—
A	II	3	—	×	—	×	×	—	×	—	×	—
A	II	4	—	×	×	—	—	×	—	×	×	—
B	III	2	×	—	—	×	—	×	—	×	—	×
B	III	3	×	—	—	×	×	—	×	—	—	×
B	III	4	×	—	×	—	—	×	—	×	—	×

As can be seen from the table, three methods of limbing and two of marking for crosscutting are compared in the study. The limbing methods are:

Limbing method 1

The usable portion of the stem is close-limbed to a minimum top diameter of 6 cm and the top pulpwood is left as a pole.

Limbing method 2

The usable portion of the stem is close-limbed and the top pulpwood is crosscut into 2- or 3-m bolts.

Limbing method 3

The dry crown on the usable portion of the stem is not limbed and the living crown is limbed to the minimum top diameter satisfying the quality requirements of rough-limbing, i.e. branch stubs of a maximum length of 5 cm may be left on the bolts.

The methods of marking for crosscutting studied were:

1. Marking for crosscutting by the cutter with a measuring stick, including measurement of the log length, fetching the measuring stick, moving along the stem to do the work, choosing the correct crosscutting point and making of the marks in the log. Controlling the top diameter of the sawlog portion was sometimes included in the time expended on marking for crosscutting.
2. Ocular marking for crosscutting in which the marking time is restricted to the time expended on selecting the correct crosscutting point.

The first part of the study thus aimed at finding out the relative expenditure of time of the limbing, marking for crosscutting and conversion methods described above and the factors influencing the time. The basic methods with which the other methods are compared are limbing method 2, marking for crosscutting method 1 and conversion method 3. In this part of the study use was made mostly of conventional investigation methods as the funds available for the project did not permit collection of the material required for the compilation of mathematical models.

The second object was to establish on the basis of the available material the wood properties that best explain the limbing, marking for crosscutting and conversion time of pine sawlogs and, thus, how to develop investigation methods of better practical application and to establish the reliability of the results. The argument behind this part of the investigation was that the treatment of the material by a method of statistical analysis, in this case regression analysis, gives the researcher a better chance of elucidating also factors that affect the results of the methodological study. It is then possible also to test the reliability of the material and results to some extent.

Finally, on the basis of the results, the economically and technically best methods of converting pine sawlogs for the next few years are suggested. This is confined to manual logging without taking a fundamental stand to the possibilities of mechanisation of the conversion phase.

3. INVESTIGATION METHOD

31. Collection of material

The plan for the collection of the material was made in August 1967. The field work commenced on September 18 in the same year at the work site of Kemi Oy (work site B) in the rural commune of Rovaniemi, and ended on January 17, 1968, at the work site of Enso-Gutzeit Osakeyhtiö (work site A) in Ilomantsi. Material was collected from three work sites in all, but the results for only two of them are presented here as the weather conditions were very exceptional at the third.

The strip maps for the work sites are known in Appendix 1 (p. 77). At work site A two workers were studied, at B only one worker. The material was collected by a measuring team consisting of the time-study man and one or two measuring assistants.

The general breakdown of the work site times used in the study is presented in Fig. 2.

The measuring assistant performed the following measurements and classifications for stems, logs and bolts of the pulpwood portion in the top or poles.

Stems:

— species of wood
— stump diameter, inches (descending ½ in. classification)
— d 1.3, cm (levelling 1 cm classification)
— d 6.0, cm (levelling 1 cm classification)
— length of the branchless portion, m
— length of the part of the stem that meets sawlog requirements, m

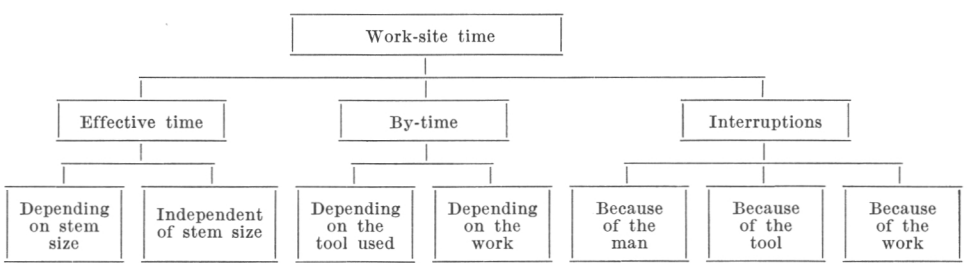


Fig. 2. General breakdown of the work-site time.

Sawlogs:
— diameter in the middle of the log over bark, cm (levelling 1 cm classication)
— top diameter inside the bark, in. (descending ½ in. classification)
— length, ft. and in.
— log quality class according to branchiness
— log quality class taking all defects into consideration
Portion of pulpwood in the top:
— diameter in the middle of the bolt over bark, cm
— length, dm

The length of the crown left in the forest was estimated. Remarks concerning abnormal points, e.g. branchiness, stem form and errors in marking for crosscutting, were also entered on the measuring form. The area of the cutting strips was calculated from the work-site maps. The terrain difficulty classification was performed by cutter's strips.

A diary was kept during the collection of the material of weather conditions (temperature, wind, rain, depth of snow) and special remarks relating to the work. Personal data on each worker were entered in it, the tools he used, the methods of work, attitude to new forms of work. In addition, his occupational skill was assessed according to the classification given on p. 22. Before the collection of the material began, the workers under observation practised the new conversion method for a few days.

32. Treatment of the material

The majority of the time study results were treated by computer. In the analyses of the limbing, marking for crosscutting and conversion times use was made of stepwise regression analysis prepared by Suomen Kaapelitehdas Osakeyhtiö and available as a library programme. It involves automatically controlled stepwise regression analysis in which the F-test is employed as the criterion in the selection of the independent variable to be added or deleted. The course of the F-test will not be described in detail here. The test variable F is obtained from the formula

$$F = \frac{s_{p-1} - s_p}{s_{p/m-p-1}} \text{ in which}$$

s_{p-1} = sum of squares of the standard errors of the regression estimate before adding the pth variable
s_p = sum of squares of the standard errors of the regression estimate after adding the pth variable
m = the number of observations

A further feature of the analysis is that the F-value used as the basis of selection and both the independent variables to be deleted and those to be added may be changed. The F-value used most in the analyses is 4.0.

The hypothetical theoretical property of the model is the independence between the independent variables. They must be given values independently of one another. This is in fact one of the weaknesses of an automatically functioning regression analysis of this type. Variables with a strong mutual correlation may supplant one another or join the model at the same time. The analysis is most effective when variables that are not correlated with one another are selected as independent variables. Factorial or correlation analysis, for example, could be used in their selection. The latter method was employed to some extent in the present work. Free models were used to explain the superiority of the various independent variables. The F-value of the independent variables to be removed or added was mostly 4.0.

Regression analysis was used also in the methodological analysis proper. The straight lines or curves depicting the expenditure of time in the different phases of work were plotted in this way. Departing from this practice, completely or partly tied models in which the volume (v_k) of the usable portion of the stem was the obligatory variable were applied in the calculation. For curves illustrating the expenditure of time drawn up in this way 95 per cent confidence limits (confidence range) were calculated. The appendices which give the regression equations show the multiple correlation coefficients (R) and the standard errors of regression estimates (s_e). The significance of the regression coefficients was tested by the t-test.

The work-site times of the conversion methods were compiled from the sum of the different phases of work. Multiple variable equations were not used for this as the material was considered to be too concise in e.g. its length and diameter distributions. The growing stock of the cutter's strips was very homogeneous. In order to improve the predictive model of the results, the material was limited to trees of limbing class 1 in work-site A and class 2 in work-site B. In the former work site all trees included in the analysis belonged to the 3rd and in the latter to the 1st length class. All the trees studied were included in the regression analysis.

In the calculation of the work-site times the same delay percentage of 21.9 of the effective working time on the conversion of timber was applied to all the men. The share of interruptions in the work-site time was 18 per cent. The power saw by-times were calculated in accordance with the ratio between the effective working time of the conversion and of the power saw. The other by-times, which represented a very small proportion of the effective working time, were calculated for stems of varying size on the basis of the usable portion of the stem.

4. INVESTIGATION MATERIAL

41. Size of the material

The material consisted of a time study material for the logging of 1 289 pine sawtimber stems and the results of stem, sawlog and top-pulpwood measurements. The material was divided as follows between the conversion methods studied:

Table 3. Size of the investigation material

Work site	Worker	Conversion method	Stems, units
A	I	1	117
A	I	2	129
A	I	3	144
A	I	4	162
A	II	3	107
A	II	4	120
B	III	2	186
B	III	3	153
B	III	4	171
			1 289

Sawlogs were made at all work sites in accordance with at least method 3, the so-called basic method. This made it possible to link up the results of sawlog logging studies made earlier and currently in progress in other institutions and to compare the achievements of different workers. Conversion methods 2 and 4 were also studied at all the work sites.

42. Quality of the material and factors affecting it

The factors that influence the technical performance of logging and through it the quality of the investigation material may be divided between permanent factors linked to the stand marked for cutting and the variable factors per stand. The latter include the time of the investigation which may sometimes have a pronounced effect on the quality of the results.

Important factors related to the stand are the terrain and the climate. The most important variable factor which the investigator cannot influence is the weather. The effect of climate is manifested in two ways. Stand A was much further than stand B and this appeared in the size, branchiness and stem form of the trees.

The investigation was carried out partly in the autumn, partly in early winter, which may have affected the results to some extent. Weather is the most important of the changing factors which the investigator cannot influence. The variation in weather conditions is presented in Appendix Tables 1 and 2 (p. 82) which show the mean temperature, precipitation and wind force.

Terrain characteristics that affect logging are the gradient, stoniness, stumpiness and hummockiness of the ground and the undergrowth. Both the marked stands were on mineral soil. There was no notable gradient in stand A. Stand B was located on the gently rising slope of a wooded hill where the angle of declivity was about 10°. Both stands were poor in stones and neither of them had stumps or hummocks that interfered with work. The accumulation of logging residues per unit of area was greater in stand A where the quantity of growing stock per hectare was greatest. The stands belonged to terrain class I according to the classification given in the wage tables for tractor transport.

Table 4 shows the mean volumes of the part of the stem meeting sawlog requirements, the portion of pulpwood in the top and the usable portion of the stem as well as the mean limbing class of the sawlog-portion in the stands.

Table 4. Some characteristics illustrating the growing stock of the work sites

Stand	Mean size of the sawlog portion		Mean size of the top-pulpwood solid cu.m.	Mean size of the usable portion of the stem solid cu.m.	Mean limbing class of the sawlog portion
	solid cu m.	cu.ft.			
A	0.67	16.4	0.06	0.73	1.3
B	0.45	11.0	0.06	0.51	2.3

The mean volume per hectare was 141.5 solid cu.m. at site A and 17.9 solid cu.m. at site B. The former was 5.0 and the latter 28.5 hectares in size. The distribution of the quantity of the growing stock into diameter classes is given in Appendix 2. The differences between the cutter's strips are shown in Appendices 3, 4, 5, 6, 7 and 8 (p. 78···81).

The accompanying maps show the shape of the marked stands and the cutting strips and the location and size of the strips.

The maximum length of the logs at work site A was 20 and at work site B 22 ft. and the fixed length of top-pulpwood bolts 3 m for A and 2 m for B. The mean length of the logs was not fixed at site A, it was 16 ft. at site B.

43. The workers studied and the tools used in the work

Of the three men under investigation, I and III were forest workers by trade, while II was a farmer who did forest work in the winter. In occupational skill all three were either middling or better. Table 5 gives a rough general assessment of their occupational skill in the different phases of work. It is based on occular assessment of cutting, limbing and bunching in which the working rate and the use of a working technique reducing the strain of the work were taken into consideration. In the evaluation of ocular marking for crosscutting the number of marking errors observed was noted.

Table 5. Occupational skill of the workers

Worker	Element				
	Cutting	Limbing		Marking for crosscutting	Dragging technique
		close-limbing	rough-limbing		
I	1	2	2	1	1
II	3	2	3	2	2
III	3	2	3	3	2

Scale: 1 = very good
2 = good
3 = satisfactory
4 = poor

Workers I and II were 35—40, whereas worker III was much younger, 26. Workers II and III were in good health. Number I suffered from a back injury which hampered his work to some extent, especially the exacting lifting and carrying jobs. All the workers had used a power saw for several years, but limbing with a power saw was fairly new to workers I and II. However, all three had been limbing with a power saw for at least one year. Rough-limbing was a relatively novel method of work for all of them. However, I and II had previously participated in a time study in which rough-limbing had been one of the limbing methods employed.

The tools used by the workers are listed in Table 6.

Table 6. Tools used by the workers

Worker	Tool		
	Power saw	Other tools	Measuring device
I	Raket 60	Measuring stick, 10′	Felling wedge Cant hook
II	Raket 60	Measuring stick, 10′	Felling wedge Cant hook
III	Homelite	Measuring stick, 7′ and scaling rule	Cant hook

5. RESULTS

51. Time study results

5101. Felling

Felling time in this study is expressed as man-time regardless of the method or order of performance of the other job elements. It comprised deciding the direction of felling, clearing the butt, making the notch, the felling cut proper, pushing the tree over and removing the crest between the undercut and felling cut and the flares of the butt. Felling time is influenced greatly by various random factors, such as the direction and force of the wind. To eliminate these factors use is made in all the conversion methods compared of the same felling time for trees of the same size felled by the same worker.

The volume of the usable portion of the stem was selected as the variable explaining felling time. Regression analysis performed by computer revealed a linear correlation between the felling time and the volume of the usable portion of the stem. The equations obtained are given in Appendix Table 3.

The felling times calculated from the equations used to calculate the work site times are given in Table 7.

5102. Limbing the usable portion

51021. Wood characteristics that describe the time

The limbing methods applied are presented on p. 15. The mutual significance of the wood properties for limbing time was established by stepwise

Table 7. Effective time expended on felling

Worker	Volume of the usable portion of the stem, solid cu.m.							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
	cmin./stem							
I	62	68	75	82	89	95	101	108
II	62	73	83	93	104	114	124	135
III	45	54	63	72	81	90	99	108

regression analysis. A free model was calculated for the different limbing methods. The following variables were used in explaining the expenditure of time on limbing:

— breast height diameter
— tapering
— unbarked volume of the usable portion of the stem
— crown height (= lower limit of living crown)
— length of living crown on the usable portion of stem
— length of the sawlog portion of stem
— length of the usable portion of stem
— relative length of living crown on the usable portion
— slenderness of the tree (= ratio between breast height diameter and length of the usable portion of the stem)
— number of logs

New variables transformed from the variables given above were also included in the analyses. Examples are $d_{1\cdot3} \cdot (h_k - 1)$ and $d_{1\cdot3} \cdot h_k$. The coefficients of correlation between these variables and the limbing time and the intercorrelations of the variables are given in Appendix Tables 4 and 5.

The variables included in the analyses can be divided into the following groups:

1. Characteristics illustrating wood volume
   — $d_{1\cdot3}$
   — v_k
2. Characteristics illustrating tree length
   — h_k
   — h_t
   — n_t
3. Characteristics illustrating stem form
   — f
   — $d_{1\cdot3}/h$
4. Characteristics illustrating limbing class
   — $h_k - 1$
   — s_k
   — l
5. Combined characteristics
   — $d_{1\cdot3} \cdot (h_k - l)$
   — $d_{1\cdot3} \cdot h_k$

The course of the regression analysis step by step is shown in Appendix Tables 6 and 7. They also show the t-values obtained for the regression coefficients of the final equation. The significance of the t-values is denoted by asterisks. The following conclusions were drawn from the regression analysis:

1. $D_{1\cdot3}$ by itself was a better independent variable than the other variables used except for limbing method 3 for worker I. In this case, the best variable was the product of the breast height diameter and the length of the living crown, $d_{1\cdot3} \cdot (h_k—l)$. The reason for this was that limbing method 3 does not include the turning of heavy butt logs.
2. To explain the limbing time with a single characteristic illustrating wood volume there is a choice between two alternatives ($d_{1\cdot3}$ or v_k). According to the analysis, breast height diameter gave an explanation that was better than the explanation given by the volume of the usable portion of the stem by 5···8 per cent units for limbing method 1, 1···3 per cent units for method 2 and 3···8 per cent units for method 3. Tidenberg (1966) and Harstela (1968) came to the same conclusion.
3. As regards close-limbing (limbing methods 1 and 2) a characteristic entered the model after breast height diameter that illustrates the branchiness of the tree, crown height (s_k or l), whereas a form characterictic, tapering (f) or slenderness ($d_{1\cdot3}/h_k$) was included instead in rough-limbing.
4. After characteristics describing branchiness, characteristics illustrating tapering of wood or length were included in the models in the equations explaining close-limbing. The length of the sawlog portion (h_t) was in most cases the variable that explained the length of the usable portion of the stem better.

It can be concluded from the analyses that the combination of variables usually applied, v_k and limbing class, of which the former is cumbersome to determine at least by cubing bolt and latter contains many subjective factors, could be replaced at any rate in the illustration of limbing time by combinations of variables based solely on wood scaling. The model describing limbing time should include in addition to $d_{1\cdot3}$ also the absolute ($h_k—l$) or relative length (s_k) of the living crown. If we wish to include in the model still a third independent variable, it should be a characteristic that describes the stem form or length of the tree. The characteristic describing the stem form may be either tapering (f) or slenderness ($d_{1\cdot3}/hk$). For wage tables, however, wood characteristics should be used that can be measured as easily as possible, and thus tapering should be avoided. This suggests the use of the combination $d_{1\cdot3}$, h_k, l, their transformation yield both the length of the crown to be limbed and the slenderness of the tree. The combination would be simpler and easier to treat as tariff bases, too, than the present method of fixing the tariff by the volume of the usable portion of the stem and length and limbing class.

For a comparison of these results with other studies the most important sources are from Sweden and Norway. Ager (1967) recommended for

standard time value equations for limbing the use of $d_{1\cdot3}$, h_k—l and of the length and form class (L & F) or, alternatively, limbing class in the standard time value equations that he presented for limbing. Andersson (1967) used standard time equations in which either solely measured or measured and estimated variables could be used alternatively as independent variables. In equations illustrating limbing time the measured variables are the average breast height diameter and mean height of the growing stock in the strip. Norwegian investigators (Samset, Strömnes, Vik 1969) decided on the use of $d_{1\cdot3}$ and the relative length of the tree and the top to be limbed. The equations also include the depth of the snow. The relative length of the tree, the ration between the true length and the mean length of the diameter class are closely correlated with form characteristics such as slenderness or tapering. The coefficient of multiple correlation in the above-mentioned equation was 0.84.

No attempt was made in the present work to write standard time value equations. The study was confined to establishing the methodological conditions for the calculation of these equations. The primary materials of almost all recent logging studies would be required to work out universally applicable equations, and it was impossible to obtain them. For this reason, it must be emphasised that the results reported are valid only for the primary material of this study.

51022. The effect of the limbing methods on the expenditure of time

To establish the expenditure of time with the various methods of limbing, the independent variables used were the volume of the usable portion of the stem and the limbing class of the part of the stem meeting sawlog requirements because this combination has been used in all recent logging studies and wage tables published in Finland. While their use involves a potential error, this can be reduced by introducing results relating only to the parts of the material for which the number of observations is greatest.

The regression equations for the volume of the usable portion of the stem and the limbing time were calculated for all the limbing methods studied from both the total material and the dominant limbing class with the exception of worker II whose material was inadequate for such treatment.

The equations for limbing times, their coefficients of multiple correlation and the deviations of the standard errors of the regression estimate are shown in Appendix Table 9 (p. 86).

The correlation between the limbing time and the volume of the usable portion of the stem is given in graphical form in Figs. 3, 4, 5, 6 and 7. They also show the 95 per cent confidence limits for the stem size classes 0.5, 0.8 and 1.0 solid cu.m.

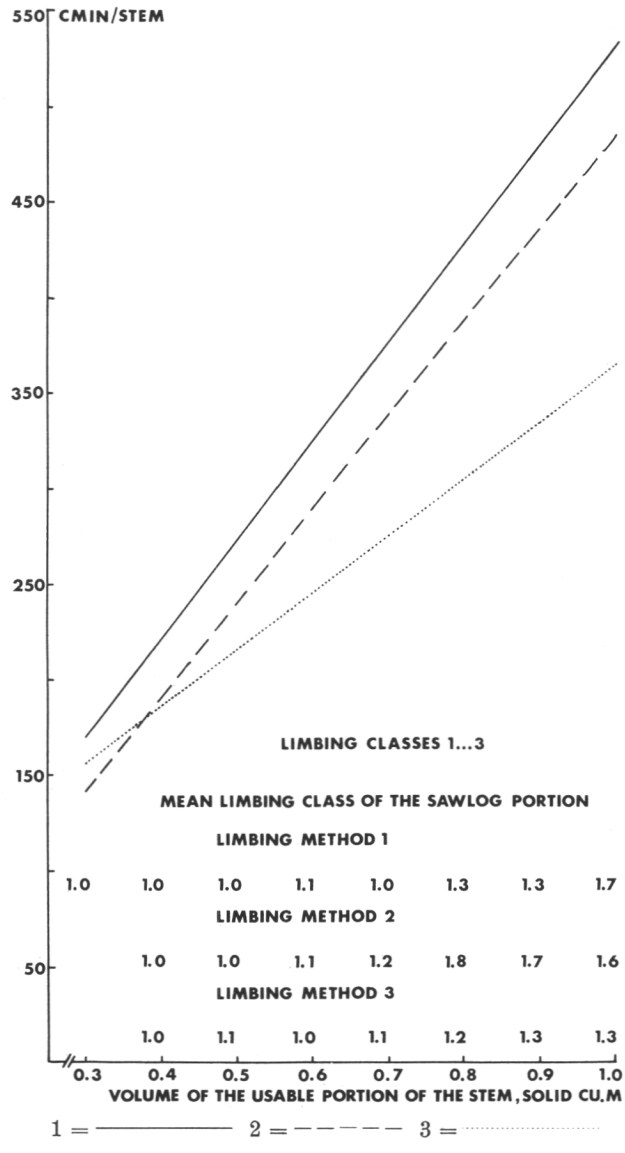


Fig. 3. Correlation between the effective limbing time and the volume of the usable portion of the stem for worker I.

The difference between the various limbing methods were highly significant, with the exception of the difference between limbing methods 2 and 3 for worker III. The reason for this exception was that the share of the

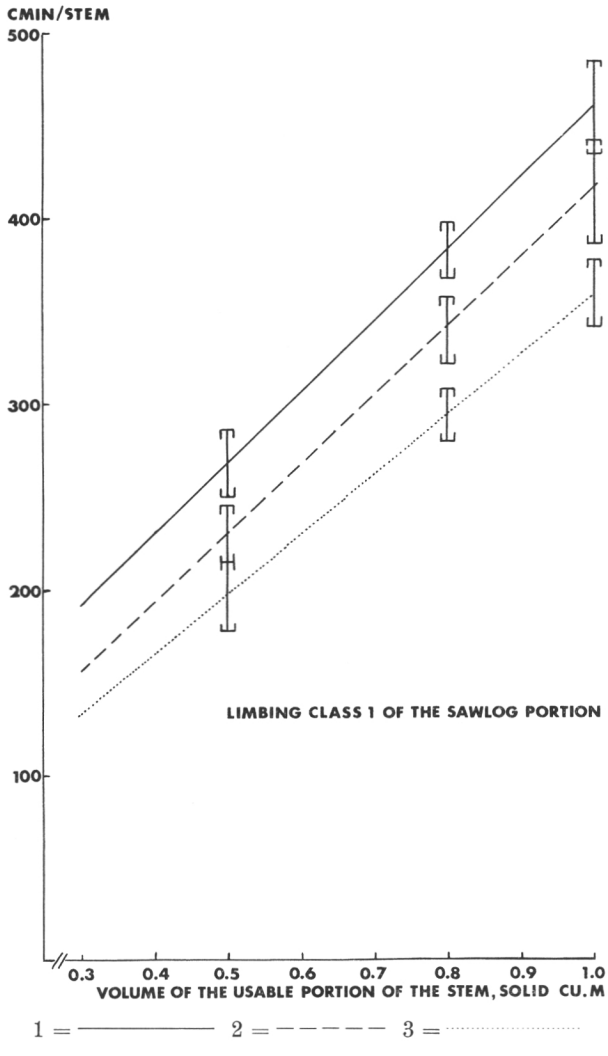


Fig. 4. Correlation between the effective limbing time and the volume of the usable portion of the stem for worker I.

dry crown in the total stem length at work site B was small and the branches considerably thicker than at site A. The consequence was that the saving in time achieved by rough-limbing remained small. The application of the test was limited to the differences in the limbing of logs of 0.5 solid cu.m. The T-values for the different methods of limbing are given in Table 8.

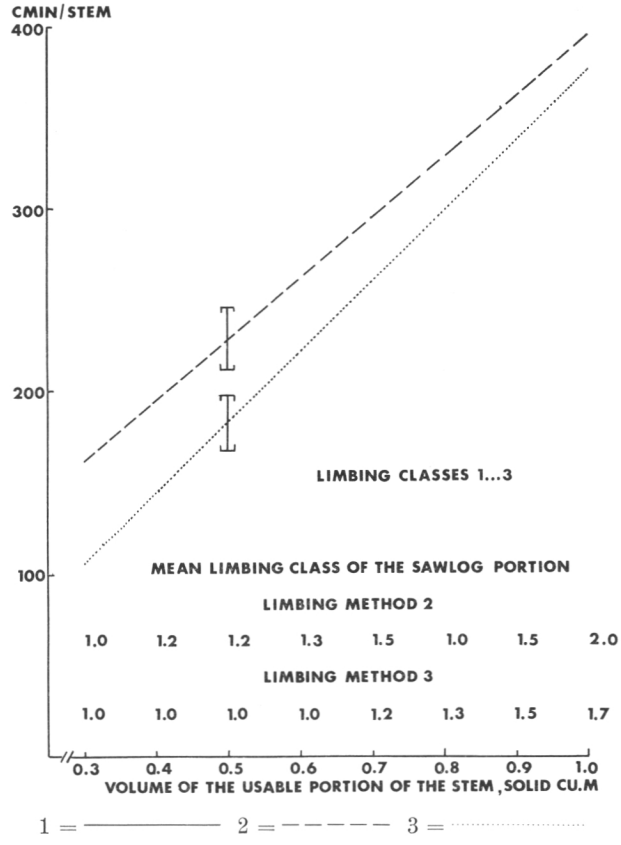


Fig. 5. Correlation between the effective limbing time and the volume of the usable portion of the stem for worker II.

Table 8. T-values for the different limbing methods for expenditure of time on the limbing of logs of 0.5 solid cu.m.

Worker	Limbing class	Limbing methods compared	T-value
I	1	$^1/_2$	4.2***
I	1	$^1/_3$	8.2***
I	1	$^2/_3$	3.7***
II	1···2	$^2/_3$	4.7***
II	2	$^1/_2$	4.1***
III	2	$^1/_3$	7.4***
III	2	$^2/_3$	2.4*

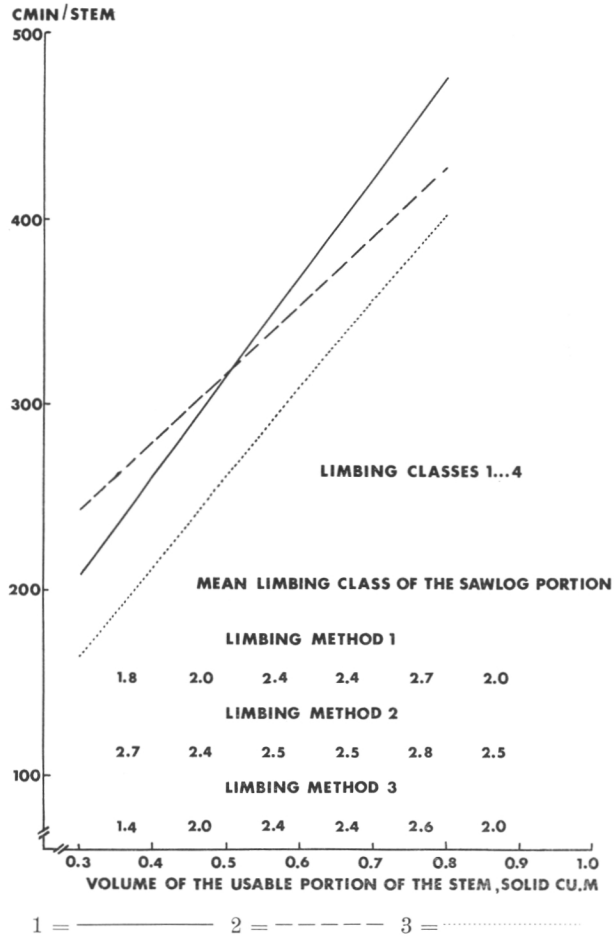


Fig. 6. Correlation between the effective limbing time and the volume of the usable portion of the stem for worker III.

Table 9. Relative expenditure of time on the limbing methods studied

Worker	Method of limbing	Volume of the usable portion of the stem, solid cu.m.					
		0.4	0.5	0.6	0.7	0.8	0.9
		%					
I	2	100	100	100	100	100	100
I	1	—	116	115	113	112	111
I	3	—	86	86	86	86	86
II	2	—	100	100	100	100	—
II	3	—	80	84	88	91	—
III	2	100	100	100	100	—	—
III	1	123	122	121	121	—	—
III	3	87	88	89	88	—	—

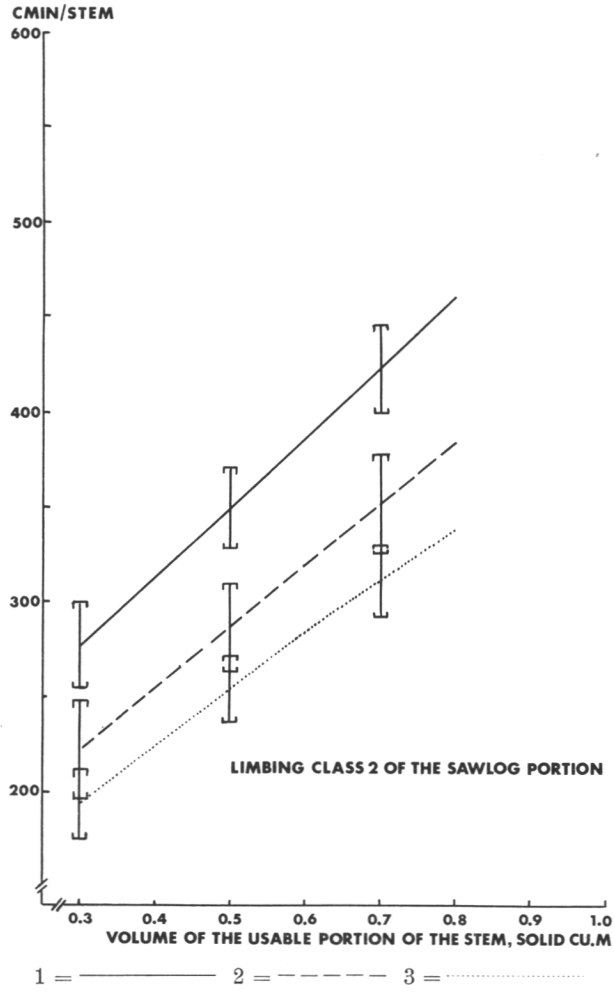


Fig. 7. Correlation between the effective limbing time and the volume of the usable portion of the stem for worker III.

It may be concluded from the confidence limits that the time-expenditure values given by the lines of regression are most reliable for workers I and II for logs of 0.5···0.9 solid cu.m. and for worker III for logs of 0.4···0.7 solid cu.m. However, the difference between limbing methods 2 and 3 in the latter case is so small that it is only just significant statistically and thus the ratios reported for these methods must be viewed conservatively.

Table 9 shows the relative expenditure of time on the limbing methods studied. Methods 1 and 3 were compared here with method 2 (= 100).

The table reveals that the decrease in the expenditure of time when changing from limbing method 2 to 3 was independent of the volume of the usable portion of the stem with workers I and III, but did affect the relative expenditure of time by worker II. This was because his results were calculated from the total investigation material whatever the limbing class of the stems. The results for worker I relate only to trees of limbing class I and for worker II to limbing class II, regardless of stem size. In contrast, the stem volume appears to have affected somewhat the relative expenditure of time on limbing method 1. The difference in the expenditure of time are accounted for by the following factors:

1. When limbing down to the minimum diameter, the length of the part to be limbed increases compared with a conversion method in which pulpwood is crosscut into bolts of fixed length.
2. Turning a top pole to permit limbing of the under side is more cumbersome than turning 2- or 3-m bolts because of the length of the piece to be handled. This was especially evident at work site B where the pulpwood portion was thick-branched and slightly larger than at site A.

The true difference in the expenditure of time between close- and rough-limbing is found by comparing limbing methods 1 and 3. Comparison of limbing methods 2 and 3, which is admittedly more rational from the practical point of view, means in fact comparing two different work assignments. The following table sets out the expenditure of time on rough-limbing compared with limbing method 1.

This way of calculation gives ratios of roughly the same magnitude as K a h a l a's (1966 a and b, 1967). On the other hand, the ratios in Swedish studies are 7···10 per cent lower than the Finnish.

Where the saving in time really takes place in the crown portion is partly undisclosed. The greatest saving is probably achieved by leaving the dry crown entirely unlimbed. This is suggested by the proportion of dry crown in total crown, which was 36···48 per cent according to some random sample measurements. If it is not limbed it is generally not necessary to turn the butt log to limb the under side, which of course reduces the expenditure

Table 10. The relative expenditure of time on limbing methods 3 and 1

Worker	Method of limbing	Volume of the usable portion of the stem, solid cu.m.					
		0.4	0.5	0.6	0.7	0.8	0.9
		Relative expenditure of time, %					
I	1	100	100	100	100	100	100
I	3	72	73	75	76	77	78
III	1	100	100	100	100	—	—
III	3	72	73	73	73	—	—

of time. For comparison, a Swedish study (A g e r 1964) established that the time expenditure per unit of length on limbing dry branches of pine stems of 20···30 cm in diameter by power saw was only 35···45 per cent of the time spent on limbing a green crown.

5103. Limbing of the part of the stem that meets sawlog requirements

51031. Wood characteristics that describe the time

Close-limbing and rough-limbing were selected as the limbing methods to be compared. The code 1 + 2 will be used for the former and 3 for the latter. The limbing time of the sawlog portion was studied by regression analysis. Appendix Tables 10 and 11 give the correlation coefficients between the limbing time for the sawlog portion and the wood characteristics and the intercorrelations of the wood characteristics. The process of the analysis will be seen from Appendix Tables 12. As no distinction was made between the limbing time for the sawlog portion and the portion of pulpwood in the top as regards worker 3, and the material of worker 2 lacks some wood characteristics because of the prevailing conditions, the equations apply only to worker 1. The independent variables for the limbing time for the sawlog n_t, the technical volume (v_{tt}) of the sawlog portion, the absolute and relative height (h_t—l and s_t) of the living crown on the sawlog portion and the slenderness ($d_{1{\cdot}3}/h_t$) of the sawlog portion.

As regards the characteristics describing the limbing time for the sawlog portion, the following observations emerge from the correlation and regression analyses:

1. In close-limbing (limbing method 1 + 2) $d_{1{\cdot}3}$ entered the model first, as in the limbing of the usable portion of the stem, and it kept a better statistical significance than the other variables also in the final model. The volume (v_k) of the usable portion of the stem by itself would have given a 54.1 per cent degree of determination, the height (h_t—l) of the living crown 40.8 per cent and the technical volume of the sawlog portion (v_{tt}) 56.7 per cent. The other variables entering the model increased the degree of determination by only about 10 per cent units in all.
2. The best independent variable in rough-limbing is the height of the living crown (h_t—l) on the sawlog portion; it gave by itself a better degree of determination (50.4 per cent) than v_k (23.9 per cent), $d_{1{\cdot}3}$ (34.5 per cent) or v_{tt} (16.7 per cent). In addition to h_t—l, the other

variable which increased the degree of determination most significantly is $d_{1\cdot3}/h_t$, i.e. the slenderness of the sawlog portion. The increase was 6.3 per cent units.

3. Four independent variables gave a roughly equal degree of determination (62···66 per cent) in both cases. The variables h_t—l, f and $d_{1\cdot3}/h_t$ entered all the models.
4. It is worthy of note that the volume of the usable portion of the stem proved to be a weak variable in rough-limbing. The same phenomenon was observed also in analyses of the limbing time for the usable portion.

The final regression equations are given in Appendix Table 13.

To describe the limbing time for the sawlog portion by means of variables other than the volume of the usable part of the stem, the following combinations appear to be the best: $d_{1\cdot3}$, f and h_{t-1}, $d_{1\cdot3}$, h_t and l or $d_{1\cdot3}$ and n_t. The last-mentioned of these would be the best from the practical standpoint, but it determines limbing time less well than the other combinations.

Comparison of the analyses of the limbing time for the sawlog portion with those for the usable part of the stem shows that multiple correlation is slightly smaller when the same combinations of variables are used. The main reason for this phenomenon is the difficulty of separating the limbing times for the sawlog portion and the portion of pulpwood in the top in the performance of time study.

51032. The effect of the limbing methods on the expenditure of time

For the examination of the relative expenditure of time on the different limbing methods, the per-stem limbing time as a function of the volume of the usable portion of the stem and of the limbing class was adopted as the point of departure.

The regression equations that describe the limbing time for the sawlog portion are given in Appendix Table 14 and the expenditure of time is presented graphically in Fig 8 which also shows the confidence limits. When the significance of the times expended on the limbing of logs of 0.5 solid cu.m. was tested the t-values 5.78*** and 7.50*** were obtained for closs-limbing and rough-limbing for worker I. The former was calculated from the total material and the latter from material representing limbing class I. For worker II the t-value calculated from the total material was 5.73***. The figures show that there is a highly significant difference between the different limbing methods. It is also noteworthy that the smallest sawtimber trees (< 0.3 solid cu.m.) in sparsely branched marked sawtimber stands have no crown to be limbed on the sawlog portion, and the straight line denoting time expenditure therefore intersects the x axis already at trees of 0.3···0.4 solid cu.m.

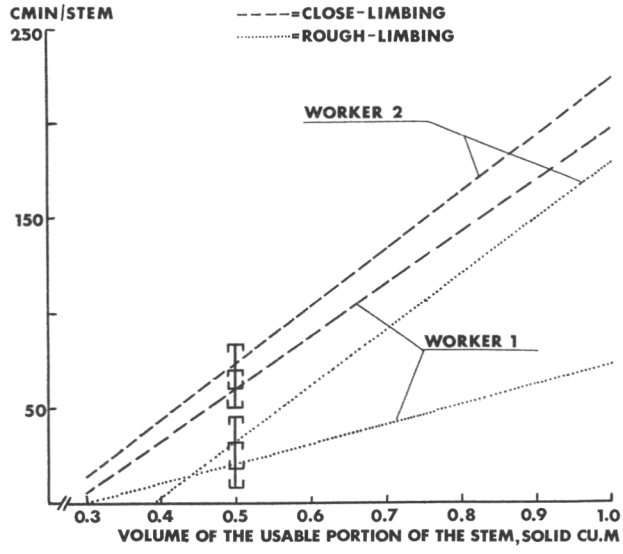


Fig. 8. Correlation between the effective time in the limbing of the sawlog portion and the volume of the usable portion of the stem.

Table 11. Relative expenditure of time on the limbing of the sawlog portion

Worker	Limbing method	Limbing class	Volume of the usable portion of the stem, solid cu.m.				
			0.5	0.6	0.7	0.8	0.9
			Relative expenditure of time, %				
I	1+2	1···3	100	100	100	100	100
I	3	1···3	42	40	39	39	39
I	1+2	1	100	100	100	100	100
I	3	1	34	35	36	37	37
II	1	1···3	100	100	100	100	100
II	3	1···3	42	57	65	70	73

Table 11 gives the relative time expenditure for the different limbing methods calculated from regression equations.

The saving in time for worker I on changing from close- to rough-limbing was the same on the whole for all trees of limbing class I regardless of the volume of the usable portion of the stem. It is to be noted, however, that the saving in the expenditure of time on limbing class I was 3···5 per cent units greater. The explanation is the smaller proportion of living crown on the sawlog portion in trees of limbing class I than in trees of the other limbing classes. This is also indicated by the result for worker II in which the saving in time decreases as the volume of the usable part of the stem and at the same time the limbing class grow. The saving in time expenditure

Table 12. The effect of rough-limbing on the limbing time for the different parts of the stem

Limbing phase	Limbing method					
	1		2		3	
	cmin.	%	cmin.	%	cmin.	%
Limbing of the sawlog portion	60	26	60	26	21	9
Limbing of the portion of pulpwood in the top	208	90	170	74	177	77
Limbing of the usable portion of the stem	268	116	230	100	198	86

Worker I
Limbing class I
Volume of the usable portion of the stem 0.5 solid cu.m.

achieved by rough-limbing was greater (about 50 per cent units) in limbing the sawlog portion than the usable portion. The primary reason is that the dry branches which are not limbed in rough-limbing are on the sawlog portion of the stem. The difference diminishes, however, with the increase in branchiness.

Table 12 gives the percentage for the part of the crown on which the true saving in limbing time was achieved.

Limbing of the pulpwood portion was hardly speeded up at all by rough-limbing. The actual saving in time was achieved on the sawlog portion; it was 15 per cent for 0.5 solid cu.m. pine sawlogs in limbing class I. If the basis of comparison is limbing method 1, the total saving achieved by rough-limbing is 26 per cent, of which 14 per cent is on the sawlog portion and 12 per cent on the portion of pulpwood in the top.

5104. Marking for crosscutting

15041. Wood characteristics that describe the time expended on marking for crosscutting

The marking-for-crosscutting time refers in this study to the time expended by the worker on dividing the stem into logs. Marking with a measuring device comprised fetching the measuring instrument, measuring the log length, moving alongside the stem in connection with the work, choosing the crosscutting point and marking the length on the log. In some cases the top diameter of the sawlog portion was also checked. Because of the inadequate measuring technique, it is difficult in ocular marking for crosscutting to establish accurately the time spent on selecting the crosscutting point as this is usually decided in connection with the performance of the other phases of work. Comparison of the marking times alone is

therefore not rational. On the other hand, combining of the marking time and the crosscutting time gives the comparison a considerably more reliable basis. This is suggested also by the crosscutting times for stems marked by the eye which were 20···30 cmin. greater per stem than the corresponding times for stems marked by measuring. The crosscutting time obviously included »deliberation phases» of a couple of cmin. before the actual crosscutting sawing is done, as is shown in the chapter of crosscutting. A part of the marking work is performed when the worker moves from the stump to the first branch to be limbed. This part was separated in the study into an element of its own and was included in the comparison of the marking times.

The marking methods selected for study were marking by the worker with a measuring device and ocular marking by the worker. The former did not include measuring the top diameter of the log. It was essential for ocular marking in this study to consider the quality more than the dimensions of the logs. The need for distinguishing the u/s quality class from the fifths was emphasised to the workers.

The wood characteristics that describe the marking time best were established first. The analysis was confined to marking with a measuring instrument. Regression analysis was used. The independent variable was marking time per stem. The variable wood characteristics selected were:

— volume of the usable portion of the stem, solid cu.m. (v_k)
— breast heigh diameter, cm ($d_{1\cdot3}$)
— tapering, cm (f)
— length of the sawlog portion, ft. (h_t)
— number of sawlogs (n_t)

Appendix Table 15 shows the correlation coefficients between the marking time and these characteristics for the different workers.

As it was to be expected from earlier studies (M a k k o n e n 1950) that the correlation between the marking time and the wood volume forms a non-linear curve, resembling chiefly a logarithmic curve, the logarithmic transformations of v_k and $d_{1\cdot3}$ were included in the analysis. Appendix Table 16 (p. 89) shows the intercorrelations of the independent variables. The process of the analysis can be seen in Appendix Table 17 (p. 90), from which the following conclusions may be drawn:

1. The best variable for the marking-for-crosscutting time is the number of logs (n_t) obtained from a stem. The variables entering the model in addition to it, that is the length (h_t) of the sawlog portion or $d_{1\cdot3}$ were of considerably smaller significance.
2. The number of logs (n_t or n_t^2) alone determined 56 per cent of the marking-for-crosscutting time for worker 1, 51 per cent for worker II and 37 per cent for worker III. When the volume of the usable portion

of the stem (log v_k) was employed as a variable — it proved to be superior to $d_{1.3}$ — degrees of determination amounting to 34, 39 and 31 per cent, respectively, were obtained.

3. However, n_t and h_t are variables with a relatively strong mutual correlation and their mutual superiority may change in some cases.
4. The correlation coefficients between the marking-for-crosscutting time and these variables also suggest the conclusions made above.

If it is desired to obtain standard values for the marking-for-crosscutting time they should be presented as time consumed per log. In addition, auxiliary variables that might be used are e.g. the mean length of the logs obtained from the stem or the breast height diameter. The final regression equations are given in Appendix Table 18.

51042. The effect of the marking methods on the expenditure of time

As the other calculations of work-site time are presented as a function of the volume of the usable portion of the stem, the marking-for-crosscutting times were calculated in the same way. The average marking-for-crosscutting time when measuring with a stick was 1.60 min./stem for worker I, 1.66 min./stem for worker II and 0.96 min./stem for worker III.

Fig. 9 shows the correlation between marking-for-crosscutting time and the volume of the usable portion of the stem. The equations used to calculate the variables are given in Appendix Table 19 (p. 90).

As appears from Fig. 9 there was a non-linear correlation between marking for crosscutting with a measuring device and the volume of the usable part of the stem at work site A, whereas the correlation was linear at work site B. The difference is explained by the smaller number of stems in the series at site B; it consisted chiefly of trees yielding one or two logs. However, it is clear that if the distribution of the number of stems had comprised a greater number of 30—40 cm trees, the correlation for worker III would also have been non-linear. The time values are reliable for trees of 0.4···0.8 solid cu.m.

Table 13 gives the relative expenditure of time on ocular marking for crosscutting and crosscutting compared with marking for crosscutting with a measuring device for different stem size classes.

The share of the time spent on ocular marking for crosscutting and on crosscutting in the expenditure of time on marking with a marking device and on crosscutting varies from 39 to 59 per cent in the conversion of e.g. trees of 0.5 solid cu.m. The results (53···54 per cent) obtained by Kahala (1968), Duus-Otterström and Pettersson are in the same range. The ratio calculated by Ager (1967) using standard time values was 61 per cent. The greatest saving in time was achieved by worker III,

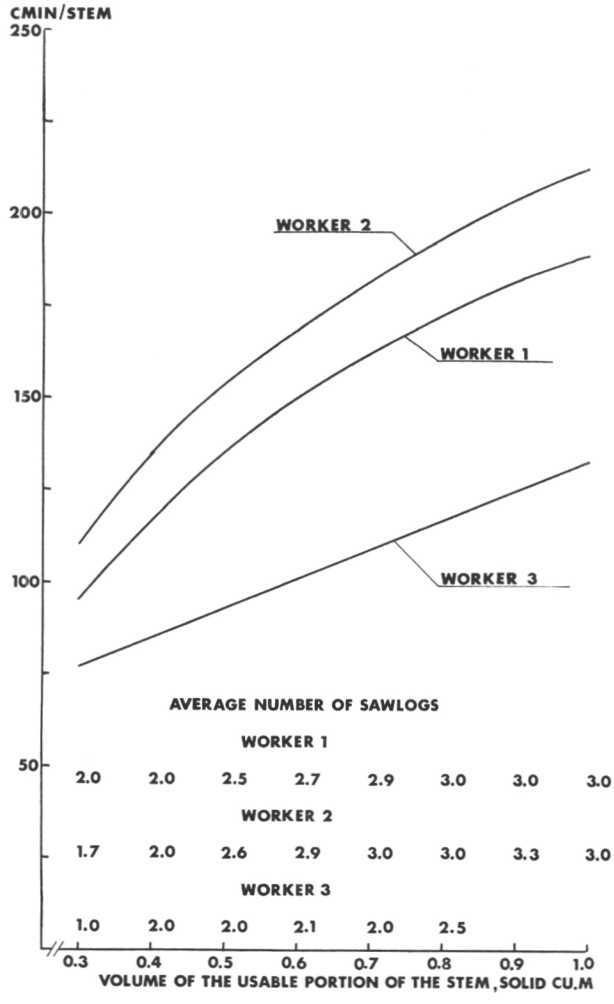


Fig. 9. Correlation between the effective time spent on marking-for-crosscutting with a measuring device and the volume of the usable portion of the stem

Table 13. Relative expenditure of time on ocular marking for crosscutting and crosscutting (marking with a measuring device = 100)

Worker	Volume of the usable portion of the stem, solid cu.m.					
	0.4	0.5	0.6	0.7	0.8	0.9
	Relative expenditure of time, %					
I	—	59	56	54	53	52
II	—	48	46	44	43	43
III	39	39	38	38	38	—

61···62 per cent. Closest to the 49 per cent mean value of the present study are the results reported by Kahala and Duus-Otterström—Pettersson. On the other hand, Ager's figures are based chiefly on standard values for the conversion of pulpwood.

The statistical significance of the difference in the times spent on the two methods of marking for crosscutting was not tested because of the mode of calculation employed.

5105. Crosscutting

Crosscutting of the sawlog portion and the pulpwood portion in the top were distinguished between. There was no crosscutting of the pulpwood portion in the top in conversion methods 1, 2 and 4 in which the top was left as a pole. The time expended on the crosscutting of the crown left in the forest was only 3···5 cmin. and it was therefore impossible to separate from the limbing time. This element was in fact combined with limbing. In conversion method 3 pulpwood was crosscut at site B into 2-m and at site A into 3-m bolts. The equations used in the calculation of the crosscutting times are shown in Appendix Tables 20 and 21, and the absolute cutting times are given in Figs. 10 and 11.

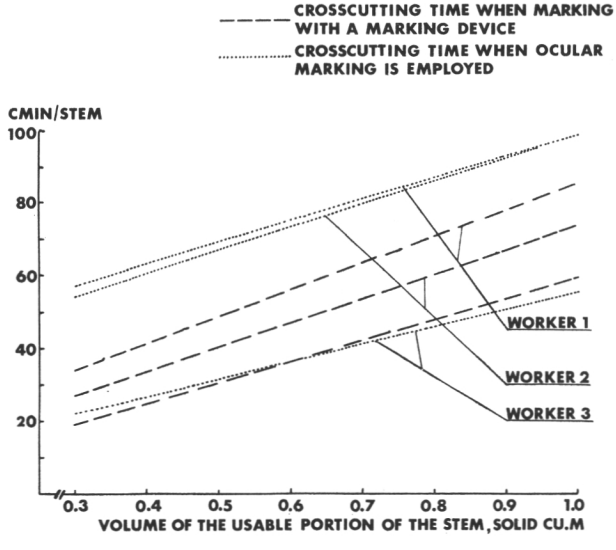


Fig. 10. Correlation between the effective time spent on the crosscutting of the sawlog portion and the volume of the usable part of the stem

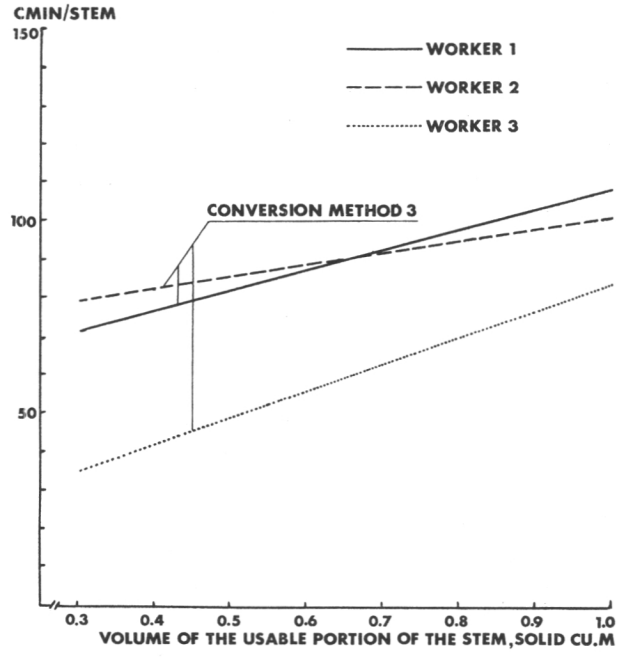


Fig. 11. Correlation between the effective time spent on the crosscutting of the usable portion of the stem (sawlog portion + pulpwood portion in the top) and the volume of the usable portion of the stem.

The crosscutting time for the sawlog portion was calculated separately for sawlogs measured by stick and ocularly. Fig. 10 shows that the crosscutting time for ocular marking was 30···50 per cent greater than for marking with a measuring device. This was due to the fact that crosscutting time includes also time expended on assessing the stem quality, which is actually marking-for-crosscutting time. The crosscutting times reported here were used in calculations of work-site time.

5106. Effective time in timber conversion and wood characteristics that describe it

Conversion of a felled tree into timber assortments, sawlogs and pulpwood comprises the following elements in the logging of saw timber:

— limbing of the sawlog portion
— limbing of the pulpwood portion in the top
— marking the sawlog portion for crosscutting
— crosscutting the sawlog portion
— measurement and crosscutting of the pulpwood portion in the top

A regression analysis was performed of the timber conversion time in the manner explained above.

The following wood characteristics describing the timber conversion time were used:

— $d_{1.3}$
— v_k
— f
— l
— h_k—l
— h_t/h_k
— s_k
— h_k
— $d_{1.3}/h_k$
— n_k

The coefficients of the correlation between these variables and the effective time of wood conversion are given in Appendix Table 22 (p. 91). Appendix Tables 11 and 16 (pp. 87 and 89) give the intercorrelations for the wood characteristics used as independent variables. Regression analysis was used to obtain the combinations of variables that explain the effective timber conversion time best. They are shown in Appendix Tables 23 and 24. The final regression equations are shown in Appendix Table 25. The following conclusions can be drawn:

1. In the traditional conversion methods, that is methods in which the stems are limbed closely, marked for crosscutting with a measuring stick and the pulpwood portion in the top is cut to bolts of fixed lengths, the volume of the usable portion of the stem by itself was the best independent variable for time expenditure in the conversion of timber.
2. In conversion methods in which the stems were marked by the eye for crosscutting and the pulpwood portion in the top was left as a pole or, in addition, the stems were rough-limbed, $d_{1.3}$ was the best independent variable for the expenditure of time.
3. Inclusion in the model of a form characteristic, slenderness or tapering, crown height, or the number of timber bolts obtained from the stem reduces the power of determination of the volume of the usable portion so much that $d_{1.3}$ enters the model and eliminates v_k from the independent. variables.
4. The equations for the conversion time for rough-limbed saw timber stems crosscut by the eye are structurally different. The equation for the time expenditure by worker III has after three steps the same

combination of variables as that for worker I in conversion method 2. This arises from the fact dead branches were also limbed in all the limbing methods at work site B, and hence conversion methods 2 and 4 are very similar especially as longer branch butts are very rarely left when the large-branched saw timber trees of North Finland are limbed. The equation for conversion method 2 for worker III suggests the same.

5. Considerably better degrees of determination were obtained from analyses of the conversion time than from analyses of individual elements. A partial reason for this is that when the 0 position method is used in a time study the relative error becomes greater when the material is divided into time elements.

The final equations have the variable groups $d_{1\cdot3}$ and f, $d_{1\cdot3}$, f and l, $d_{1\cdot3}$, f and s_k or $d_{1\cdot3}$ and l for all workers and conversion methods. They also include a height characteristic, h_k or n_k. It can be concluded from this that when it is desired to measure the timber conversion time with some definable wood characteristics the model must include in addition to $d_{1\cdot3}$ also a characteristic that explains the height and branchiness or shape of the stem. These characteristics have the advantage of being directly obtainable while measuring on the stump when it is not necessary to perform volume calculations proper in a computer, at least not for the determination of logging wages.

5107. Dragging of the portion of pulpwood in the top

In this investigation, pulpwood was collected at work site A in grapple bunches alongside the strip road and at work site B in grapple bunches scattered in the cutting area. The strip road specing was about 25 m in the former work site and the mean size of the grapple bunches was about 0.6 piled cu.m. The pulpwood collection time, which includes the moving and bunching of the bolts, movement involved in the work and preparatory measures, is given for each worker in Table 14. The pulpwood bunching time was calculated differently from the other elements by levelling the broken line that was drawn by eye on the basis of class averages and illustrates the correlation between time expenditure and the volume of the usable portion of the stem.

Data on the dimensions of the pulpwood portion in the top are given in chapter 524. The above figures were employed in the calculations of work-site time.

Table 14. Effective time for dragging the portion of pulpwood in the top

Worker	Method	Volume of the usable portion of the stem, solid cu.m.							
		0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
		min./stem							
I	1, 2 and 4	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
I	3	0.68	0.67	0.65	0.54	0.63	0.62	0.60	0.59
II	3	0.63	0.60	0.56	0.53	0.50	0.46	0.43	0.39
II	4 *)	(0.30)	(0.30)	(0.30)	(0.30)	(0.30)	(0.30)	(0.30)	(0.30)
III	2 and 4	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
III	3	0.19	0.22	0.24	0.26	0.28	0.30	0.33	0.35

*) The same dragging time as for worker I was used.

5108. Moving

Moving in connection with the work was divided into movement at the stem and random movement. Moving to the tree to be felled is always a stem element the duration of which depends on the moving distance and speed. The moving distances depend, on the other hand, on the density of the stand marked for cutting, and in comparisons of work-site times it is desirable to eliminate its effect. Hence, the average moving time was calculated separately for each worker. These times and the moving speeds are given in Table 15. Other moving was at the stem or random. The former took place when the worker moved from one felled tree to another, e.g. during limbing. They occurred only with worker I and method 3 for which the average was 0.06 min./stem for group-cutting. The random movements of worker I were 0.11 min./stem, of worker II 0.19 min./stem and worker III 0.03 min./stem.

Table 15. Moving time in connection with felling

Worker	min./stem	speed, cmin./m
I	0.40	2.4
II	0.49	2.4
III	0.43	2.1

5109. By-times

By-times included the preparation of storing, planning of the work, clearing, starting the power saw, fuelling and lubrication and other maintenance measures. Table 16 gives these times by worker and method.

Table 16. By-times by worker and conversion method

Element	Worker								
	I				II		III		
	Conversion method								
	1	2	3	4	3	4	2	3	4
	min./solid cu.m.								
Planning of work	0.13	—	0.04	0.01	0.04	—	0.13	0.17	0.10
Clearing	0.01	0.03	0.19	0.01	—	—	0.02	0.07	0.11
Starting the power saw	0.04	0.02	0.04	0.01	0.02	0.05	0.17	0.29	0.18
Refuelling	0.65	0.65	0.80	0.52	0.30	0.46	1.78	2.47	1.25
Other maintenance	0.66	0.83	0.85	0.21	0.74	0.62	—	0.28	—

Table 17. Share of the refuelling and other maintenance time in the effective power saw utilisation time

Worker	Conversion method	Share in effective utilisation time, %
I	1	18.5
I	2	17.8
I	3	21.8
I	4	12.2
II	3	18.4
II	4	14.8
III	2	20.6
III	3	28.7
III	4	18.6

The per-stem by-times were obtained by multiplying the figures in Table 16 by the volume of the usable portion of the stem when the correlation between time expenditure and the volume of the usable portion was rectilinear. This is the only way of calculating the time expended per stem on the planning of the work, clearing and starting the power saw. Refuelling and saw maintenance times, again, are in a rectilinear correlation with the effective utilisation time of the saw. The most realistic basis of distribution is the per cent proportion of these times in the effective sawing time which includes the felling, limbing and crosscutting times. These ratios are given in Table 17.

The share of the power saw refuelling and maintenance time in the effective utilisation time was smallest in conversion method 4 in which rough-limbing and ocular crosscutting were used. This was due chiefly to the smaller wear on the steel chain with this conversion method. However, it does not require release of the steel chain as often as in the customary conversion methods.

5110. Interruptions

The proportion of interruptions in the effective time and work-site time varied fairly considerably with the individual workers. Table 18 gives the interruption percentages for the different conversion methods.

Table 18. Interruptions at the three work sites

Worker	Conversion method	Interruption time : effective time, %	Interruption time : work-site time, %
I	1	29.7	22.9
I	2	19.6	16.4
I	3	18.6	15.7
I	4	13.5	11.9
II	3	2.4	2.3
II	4	1.8	1.8
III	2	13.6	12.0
III	3	18.3	15.5
III	4	23.8	19.2

Interruptions included rest and smoking breaks of under 15 min. and various avoidable lost times, e.g. the time spent on felling a hang-up felled tree.

5111. Comparison of the conversion methods studied

51111. Conversion of timber to sawlogs and pulpwood

The correlation between the work-site time for the conversion of timber (effective time + interruptions) and the volume of the usable portion of the stem was calculated for trees of 0.3···1.0 solid cu.m., and is presented in Figs. 12, 13 and 14. The bases of calculation were described in detail in the chapter on the investigation method. 18 per cent of the work-site time was used as the share of interruptions for all workers.

The share of the various elements in the work-site time of timber conversion is shown in Table 19. The conversion times of trees of 0.5 solid cu.m. were compared. Limbing was the most time-consuming element. Its share was at its greatest in conversion method 2 and at its smallest in methods 1 and 3. A change to rough-limbing and ocular crosscutting increased the share of the limbing time by 4···8 per cent units. However, the greatest part of this increase, 11 per cent units, was caused by changing from marking for crosscutting with a measuring stick to ocular marking during close-limbing.

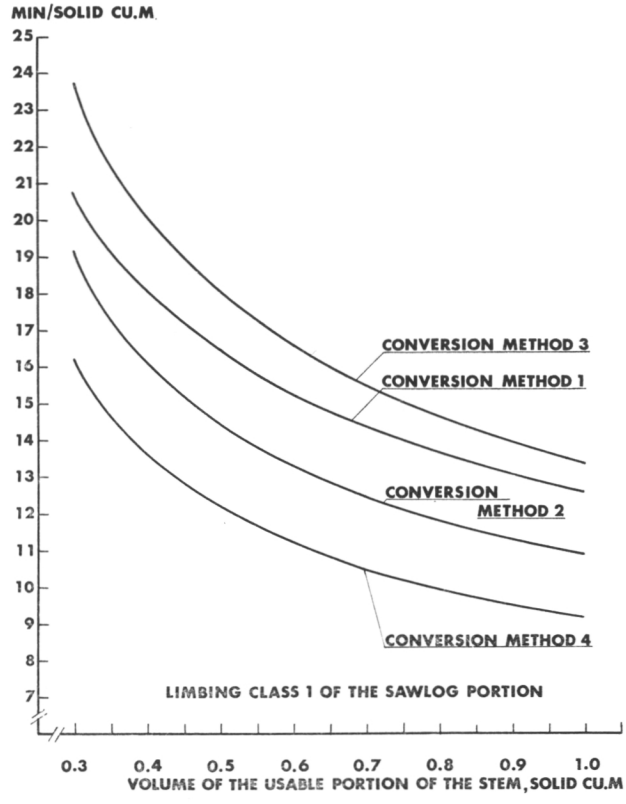


Fig. 12. Work-site time on timber conversion for worker I.

Table 19. Distribution of work-site time into elements

Element	Worker								
	I				II		III		
	Conversion method								
	1	2	3	4	3	4	2	3	4
	%								
Moving during felling	5	6	4	6	6	8	6	5	7
Other movements	1	1	2	2	2	3	—	—	1
Felling	9	11	8	12	9	13	8	7	10
Moving to the first branch to be limbed	—	4	—	6	—	5	2	—	3
Limbing	33	37	26	33	25	29	45	33	41
Marking for crosscutting	16	—	15	—	17	—	—	11	—
Crosscutting	5	9	10	11	9	11	4	6	5
Bunching of pulpwood	4	4	8	5	6	5	2	3	2
Planning of the work	—	—	—	—	—	—	1	1	1
Starting the power saw	—	—	—	—	—	—	1	2	1
Maintenance of the power saw	9	10	9	7	8	8	12	13	10
Random-by-times	—	—	—	—	—	—	1	1	1
Interruptions	18	18	18	18	18	18	18	18	18
Work-site time	100	100	100	100	100	100	100	100	100

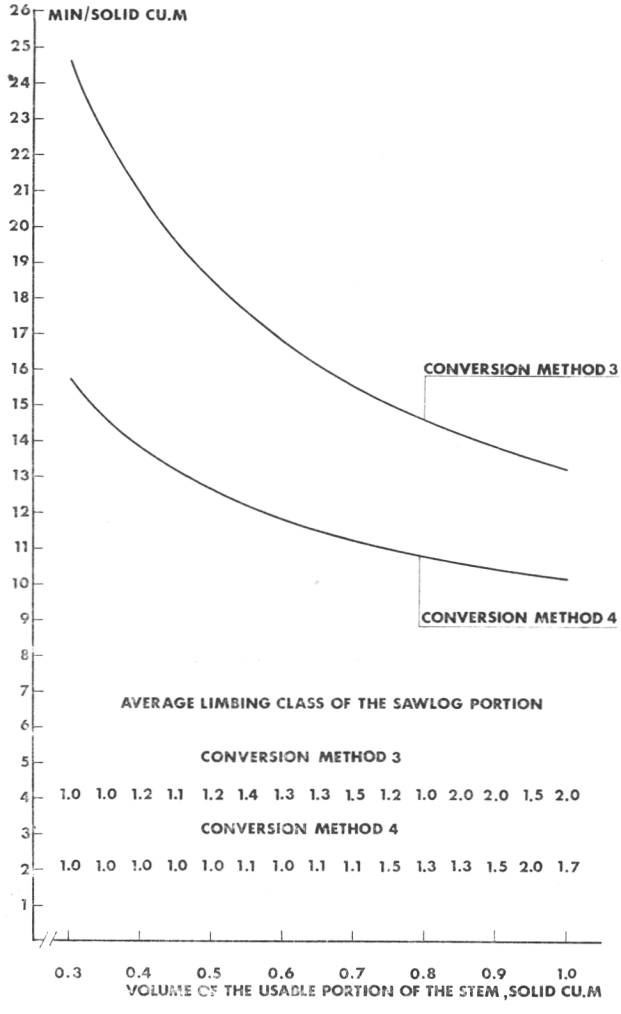


Fig. 13. Work-site time on timber conversion for worker II.

Another criterion for evaluation of the different conversion methods is the share of the effective time of use of the power saw (felling, limbing, crosscutting) in the work-site time. It is known that the worker finds uninterrupted exposure to the vibration of the power saw unpleasant, and that it may cause physical damage in the long run. Table 20 shows the proportion of this time in the various conversion methods.

Changing to rough-limbing, ocular marking for crosscutting and pulpwood pole increased the effective running time of the power saw by 10 per cent units with all the workers. The use of mere oculur marking for crosscutting also increased this time by the same percentage. However, it is

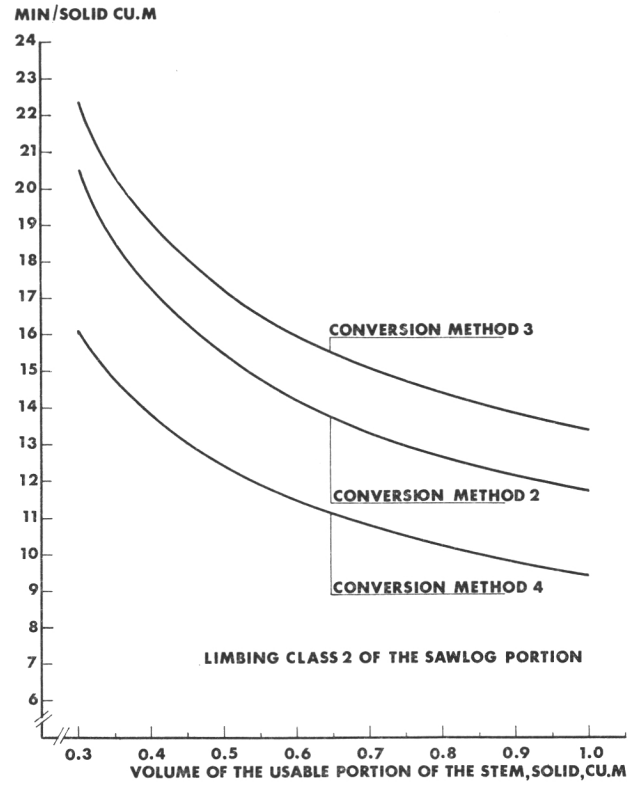


Fig. 14. Work-site time on timber conversion for worker III.

Table 20. Share of the effective utilisation time of the power saw in the work-site time

Worker	Conversion method			
	1	2	3	4
	%			
I	47	57	44	56
II	—	—	43	53
III	—	57	46	56

important for the worker that the power saw is used continously in conversion methods 2 and 4, as in methods 1 and 3 its use is split by the marking for crosscutting.

Table 21 compares the conversion methods element by element with method 3. It shows that the change from marking for crosscutting with a measuring device to ocular marking affected the relative expenditure of time between the conversion methods by 11···16 per cent units more with all the workers than the change of the limbing method from close- to rough-

Table 21. Comparison by elements of the conversion methods

Element	Worker								
	I				II		III		
	Conversion method								
	1	2	3	4	3	4	2	3	4
	%								
Moving during felling	5	5	5	5	6	6	6	6	6
Other movements	2	2	3	2	3	3	1	1	1
Felling	10	10	10	10	10	11	9	9	9
Moving to the first branch to be limbed	—	4	—	5	—	4	2	—	2
Limbing	36	36	31	27	31	24	50	41	36
Marking for crosscutting ..	18	—	18	—	20	—	—	—	—
Crosscutting	6	9	12	9	11	9	4	7	4
Bunching of pulpwood	4	4	10	4	8	4	2	3	2
Planning of the work	—	—	—	—	—	—	1	1	1
Starting the power saw ...	—	—	—	—	—	—	1	2	1
Maintenance of the power saw	10	10	11	6	10	7	13	16	9
Random by-times	—	—	—	—	—	—	1	1	1
Effective time	91	80	100	68	100	68	90	100	72

Table 22. The relative expenditure of time in the conversion methods studied (conversion method 3 = 100)

Worker	Conversion method	Volume of the usable portion of the stem, solid cu.m.					
		0.3	0.4	0.5	0.6	0.7	0.8
I	1	88	89	91	92	93	93
I	2	81	80	80	80	80	81
I	4	68	68	68	68	68	68
II	4	64	66	68	70	72	74
III	2	91	90	90	89	88	88
III	4	72	72	72	72	72	71

limbing, 4···7 per cent units. The effect of the limbing method alone emerges from comparing method 2 with method 4. The difference for worker I is 12 and for worker III 15 per cent units. The effect of mere ocular marking for crosscutting with the same limbing method is also 12 per cent units. This emerges from comparing methods 1 and 2. Comparison of conversion methods 1 and 3, again, shows how great a saving is achieved in time when the pulpwood portion in the top is left as a pole and limbing is done to the minimum top diameter. The difference is only 9 per cent.

The total effect of the limbing, crosscutting and marking-for-crosscutting methods on the work-site time in timber conversion is shown in Table 22 where methods 1, 2 and 4 are compared with conversion method 3 (= 100).

The only investigation with which the figures reported here can be compared is the study by K a h a l a and R a n t a p u u (1968) on the logging, skidding and landing-handling of stems of sawlog size and whole trees. They obtained a ratio of 69 for a method corresponding to conversion method 4 for the logging of 0.4 solid cu.m. stems when compared with one corresponding to method 3. However, close-limbing and crosscutting were performed in their study at the landing and the conversion time did not include the bunching of the pulpwood portion in the top as in the present study.

Rough limbing and ocular marking for crosscutting are thus able to reduce the conversion time per stem by about a third. The effect of ocular marking for crosscutting on the conversion time is greatly dependent on the stem form, the number of defects and the worker's marking skill. It was possible to cut the expenditure of time by a fifth in marked stand A where the stems were tall, slender and healthy. However, a part of this saving was due to the fact that when the sawlogs were marked for crosscutting by eye, ocular crosscutting had to be employed also for the conversion of the pulpwood portion in the top. Bunching of pulpwood bolts crosscut to a fixed length was a little slower than the bunching of top poles. This affected also the comparison between the conversion methods. In contrast, the saving in time achieved by ocular marking for crosscutting was only 10 per cent in stand B in which the stems were sharply tapering and thick-butted.

51112. Conversion of sawlogs

Generally, logging time studies have not distinguished between time expended on the sawlog portion and the pulpwood portion. The argument has been that it is not possible when collecting a material to divide the limbing time with sufficient accuracy between these parts of the stem. In this work, a division between the limbing of the sawlog portion and the pulpwood portion was made. As the workers limbed the upper side of the log right up to the crosscutting point of the top before they marked the top log for crosscutting, it was necessary to assess the crosscutting point between the sawlog portion and pulpwood portion by the eye. When the under side of the stem was limbed, the logs had already been marked for crosscutting and division of the limbing time was not difficult. Limbing of the sawlog portion, marking for crosscutting and crosscutting of the sawlog portion were considered to belong to the conversion time for the sawlog portion. The felling and moving times and the by-times with the exception of the maintenance of the power saw were divided between the sawlog and pulpwood portions in ratio to their volume. Maintenance times were calculated in the same way as for the work-site time of logging.

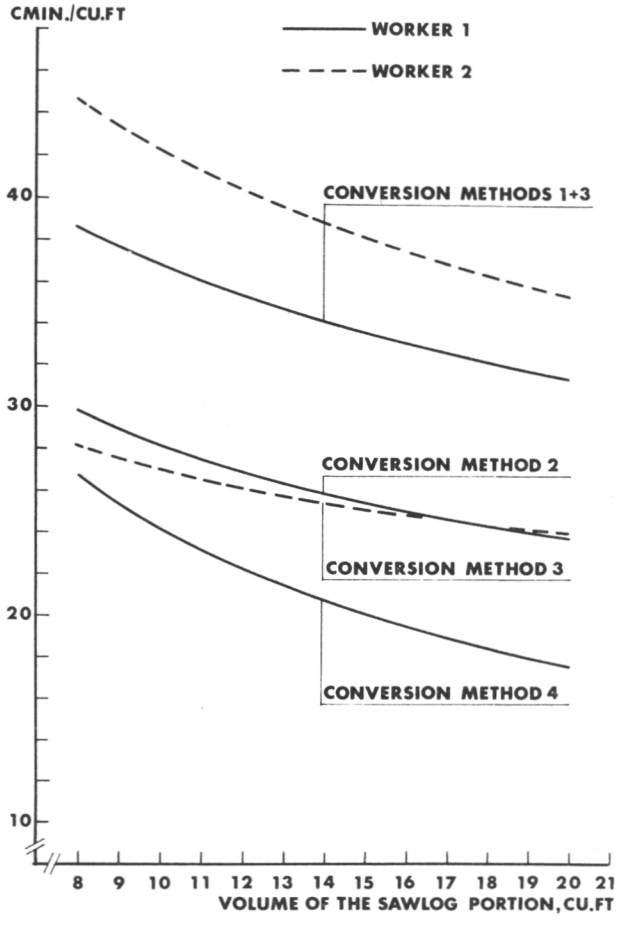


Fig. 15. Correlation between the effective time of sawlog logging and the technical cu.ft. content of the sawlog portion.

Only the effective time spent on the conversion of the sawlog portion and the relative time expenditures of the different conversion methods when the traditional log conversion method is used will be given in this connection. The traditional method is to close-limb the sawlog portion and mark it with a measuring device for crosscutting. Fig. 15 gives the effective time for the conversion of the sawlog portion expended by workers I and II who were both working in the same marked stand. The share of the time expended on converting the sawlog portion in the timber conversion time is given in Table 23.

The results for the workers are comparable in stem size classes 0.5···0.6 because for worker I the material consisted only of trees of limbing class I, whereas for worker II it comprised all trees felled whatever their limbing

Table 23. The share of the conversion time of the sawlog portion in the timber conversion time

Worker	Method	Volume of the usable portion of the stem, solid cu.m.				
		0.4	0.5	0.9	0.7	0.8
		Conversion time of the sawlog portion, %				
I	1+3	54	58	62	64	66
I	2	47	51	54	56	58
I	4	49	50	51	51	51
II	3	54	59	64	67	70
II	4	52	56	59	62	64

Table 24. Relative expenditure on the conversion of the sawlog portion for the conversion methods studied (method 1 + 3 = 100)

Worker	Method	Volume of the sawlog portion, cu.ft.					
		8	10	12	14	16	18
		Relative time expenditure, %					
I	1+3	100	100	100	100	100	100
I	2	77	77	76	76	76	76
I	4	69	66	63	61	59	57
II	3	100	100	100	100	100	100
II	4	63	64	65	66	67	68

class. It may be said by way of a general conclusion that the share of the time expended on the conversion of the sawlog portion in the stem conversion time decreased by 2···15 per cent units depending on the worker and the stem size class when the marking-for-crosscutting method was ocular and the limbing method was rough-limbing.

Table 24 shows the relative time expenditure for the different methods of converting the sawlog portion.

Comparison of these figures with the relative expenditure of time on the conversion of the whole stem in the different methods shows that the decrease in time expenditure was greater on the sawlog portion. This indicates that the work-simplification methods experimented with in the present study are not capable of influencing the conversion of the pulpwood portion in the top as much as the conversion of the sawlog poertion, although the share of the first-mentioned conversion time in the time spent on the conversion of the whole stem is 40···50 per cent on an average. To mention an example, the effective time for converting the pulpwood portion in the top of trees measuring 0.5 solid cu.m. by worker I with conversion method 1 was 2.82 min./stem, with method 2 it was 2.93 min./stem, with method 3 it was 3.49 min./stem and with method 4 it was 2.46 min./stem. Changing

Table 25. Comparison of the sawlog-portion conversion by elements

Element	Worker				
	I			II	
	Conversion method				
	1 + 3	2	4	3	4
	Relative expenditure of time, %				
Moving during felling	9.0	9.0	9.0	9.5	9.5
Other movements	4.0	2.5	2.5	4.0	4.0
Felling	17.0	16.5	16.5	16.5	16.5
Limbing of the sawlog portion	15.5	15.5	5.5	16.5	7.0
Moving to the first branch to be limbed	—	7.0	9.0	—	7.0
Marking for crosscutting	34.0	—	—	34.0	—
Crosscutting of the sawlog portion	10.0	17.0	17.0	11.0	15.0
Planning of the work	0.5	0.5	0.5	—	—
Starting the power saw	1.0	—	—	0.5	0.5
Refuelling and maintenance	9.0	8.5	5.0	8.0	5.5
Total	100.0	76.5	65.0	100.0	64.5

from timber cut into fixed lengths and close-limbed to rough-limbed pulpwood poles reduced the expenditure of time by 30 per cent, and the change from stems cut merely to fixed lengths to pulpwood poles by 18 per cent.

Table 25 presents a comparison between the sawlog-portion conversion methods by elements when the basic method employed is the customary conversion of sawlogs (conversion method 3).

52. Results of timber measurements and quality

521. Length of the logs and utilisation of the sawlog portion

When changing from marking for crosscutting with a measuring device to ocular marking the question to be settled is whether the change will affect the sawlog dimensions so significantly as to be of economic importance for the sawn goods manufacturer or forest owner. To solve this, the mean length of the logs, length distribution, number of under- and over-sized logs and the average minimum top diameter were analysed. In addition to logs converted in the investigation stand, measuring results, based on sampling, for pine sawlogs brought to Uimaharju sawmill were also available. This material includes both ocularly marked logs and logs marked for crosscutting with a measuring device from 12 marked stands in North Karelia. Table 26 gives the mean length of the logs at the various sites.

The differences between the mean lengths of ocularly marked logs and those marked with a marking device at the different investigation sites were tested by the t-test. The t-values were as follows:

Table 26. Mean length of the logs and standard deviation of length

Investigation point	Logs marked for crosscutting by measuring device			Logs marked ocularly for crosscutting		
	Logs, units	Length, ft. $\bar{x}$	s	Logs, units	Length, ft. $\bar{x}$	s
Worker I	736	16.60	±2.01	834	16.79	±1.80
» II	282	16.84	±2.10	326	17.22	±1.84
» III	310	16.67	±1.50	666	17.74	±1.74
Uimaharju sawmill	2 781	16.49	±1.97	7 316	16.53	±1.80

Table 27. T-values when mean lengths of logs marked for crosscutting ocularly and with a measuring device are compared

Investigation postnt	T-value
Worker I	1.90
» II	2.36*
» III	9.73***
Uimaharju sawmill	0.93

There was no significant statistical difference in the mean lengths of the materials from worker I and Uimaharju sawmill. The difference was almost significant for worker 2 ($t_{0.0}{}^{\circ} > / t / > t_{0.01}$) and not highly significant for worker III. The worker's skill at marking for crosscutting played a role in this, and also the circumstance that the mean length had been determined for the logs at work site B. The log length distributions are presented graphically in Fig. 16 in order to illustrate the point. It appears that the distribution pattern in marking for crosscutting with a measuring device is different from that in ocular marking, except for worker III. The reason for this is the above-mentioned mean length requirement. The attention is attracted specifically by the small share of 19-ft. logs in the total of logs marked for crosscutting with a measuring device, whereas logs of maximum (20 ft.) length were comparatively very numerous. On the other hand, the length distribution is more even in ocular marking in which the main consideration is the quality limits of the stem. Table 26 shows that the difference between the marking methods is small, under 0.2 ft., for the most skilled worker (worker I) and in the sample taken from the sawmill, whereas the mean length of the less skilled workers increased when the logs were marked ocularly. The increase for worker I was 0.19 ft. for worker II 0.38 ft. and for worker III as much as 1.07 ft. The increase in mean length was the greater the poorer the occupational skill of the worker studied. A general observation concerning the workers is that the mean length increased somewhat in all the cases and the increase seemed to be correlated with the worker's general occupational skill. However, the materials are too small for objective

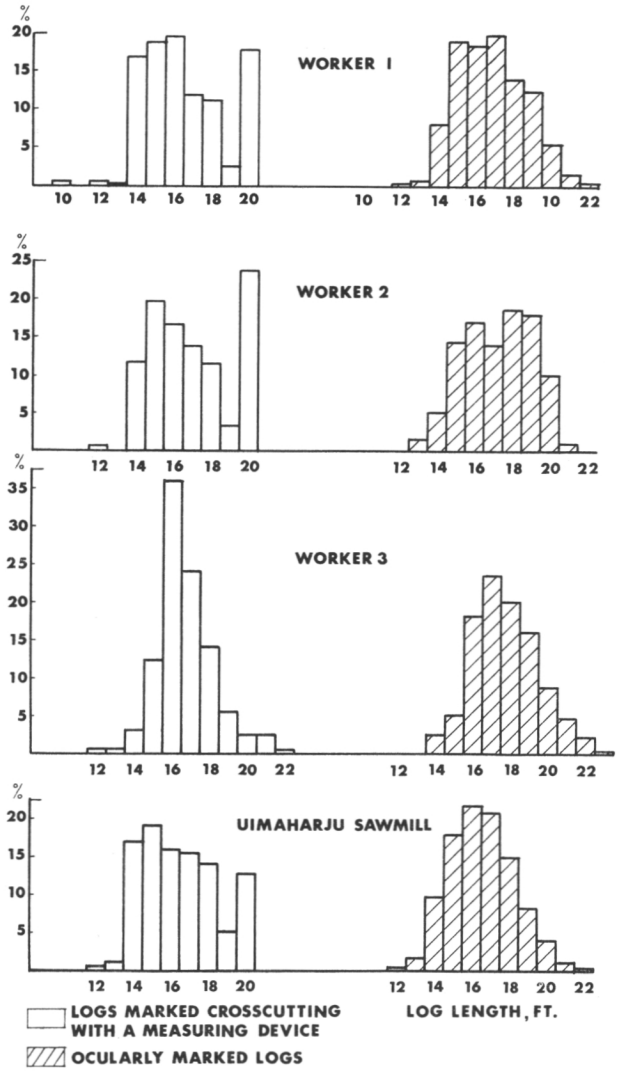


Fig. 16. Length distributions of the logs.

evaluation of this point. The material collected at Uimaharju sawmill also shows a slight increase in the mean length, 0.04 ft. This material is large enough in size to warrant the conclusion that the change in the mean length of the logs is at any rate not statistically significant.

An interesting point about the sawmill material was the occurrence of over- and under-sized logs when the marking was done by eye. Table 28 gives the share of logs under 10 ft., 10—14 ft. and over 20 ft. in length in the ocularly crosscut logs made by each worker.

Table 28. Proportion of over- and under-sized logs

Investigation point	under 10 ft.	10—13 ft.	over 20 ft.	over 22 ft.
	%			
I	—	0.8	1.9	—
II	—	1.6	0.9	—
III	—	—	7.0	0.2
Uimaharju sawmill ...	—	1.9	1.2	—

Table 29. Average minimum top diameters and the relative shares of under-sized logs

Worker	Method of marking for crosscutting	D1.3			Stems under minimum top diameter	
		24—26 cm	30—32 cm	All stems	of top logs	of all logs
		Average minimum top diameter, inches			%	
I	with measuring device	5.78	6.27	6.14	6.9	2.3
I	ocularly	5.79	6.39	6.17	7.2	1.9
II	with measuring device	5.58	5.81	5.83	8.5	3.1
II	ocularly	5.61	6.10	5.84	8.4	2.8
III	with measuring device	6.10	6.81	6.55	0.0	0.0
III	ocularly	6.01	6.55	6.27	5.6	3.2

When the marking was done with a measuring device, 0.5 per cent of the total of logs were under 14 ft. for worker I, 0.4 per cent for worker II, 1.2 per cent for worker III, and 1.4 per cent for Uimaharju sawmill. There were no logs under 10 ft. long even when the logs were marked by eye. If 14 ft. is taken as the minimum length, the share of under-sized logs was 0.3—0.5 per cent units greater when marking by eye than with a measuring device. Logs exceeding the maximum length were found only in the lots marked ocularly; their proportion ranged from 0.03 to 1.9 per cent.

The minimum top diameter of the sawlog portion is also in some degree a measure of the effect of the method of marking for crosscutting. Accordingly, the average top diameter of top logs marked for crosscutting with a measuring device and ocularly was calculated for each worker, as well as the share of logs that were under the minimum top diameter in the top logs and in all logs. As the stem volume influences the true minimum top diameter to some extent, the comparison was made for two breast height diameter classes, 25 and 31 cm.

The differences between the average top diameter marked in the two ways were small for workers I and II. On the other hand, the mean diameters of the logs marked for crosscutting by worker III who was classified as the

least skilled of the three at marking for crosscutting differed fairly considerably. When worker III was marking ocularly the minimum top diameter tended to decrease which means, as shown above, that the mean length of logs crosscut from the stem increased and in some cases also the log quality weakened.

As far as is known no earlier studies on a larger scale have been made on the effect of ocular marking for crosscutting on the sawlog measurements and sawlog quality. K a h a l a (1968) gave information on the amounts of under- and over-sized logs when different marking methods were used. In his study, 4.6 per cent of the pine logs were under 14 ft. and 2.1 per cent were over-sized 21—23 ft. logs. The sawlogs were marked ocularly for crosscutting. The share of under-sized logs was considerably greater in Kahala's than in the present investigation. Kahala also calculated the mean length of the logs with the different marking methods. The mean length of the pine logs was 16.6 ft. for both the marking methods studied by him.

522. Quality of the logs

As only 1 328 logs marked for crosscutting with a measuring device and 1 826 marked by the eye were felled in the course of the present study, it is impossible to make statistically reliable conclusions about the effect of ocular marking on the sawlog quality. If it could be assumed that the cutting strips were homogenous in their growing stock, some conclusions might be drawn. However, as this condition is not fulfilled in all respects, the comparison must be confined to logs which are affected as little as possible by the variation in growing stock characteristics. The following analysis relates only to the quality distributions of butt logs.

Fig. 17 shows the distribution of butt logs into quality classes. Table 30 shows the average quality classes and t-values.

The table indicates that the average butt log quality class deteriorated somewhat on changing to ocular marking for crosscutting. The test shows,

Table 30. Comparison of the quality of butt logs marked for crosscutting in different ways

Worker	Marking method	Butt log quality class		T-value
		$\bar{x}$	s, %	
I	by measuring device	1.56	33	
I	ocularly	1.62	34	1.55
III	by measuring device	1.76	38	
III	ocularly	1.86	32	1.59

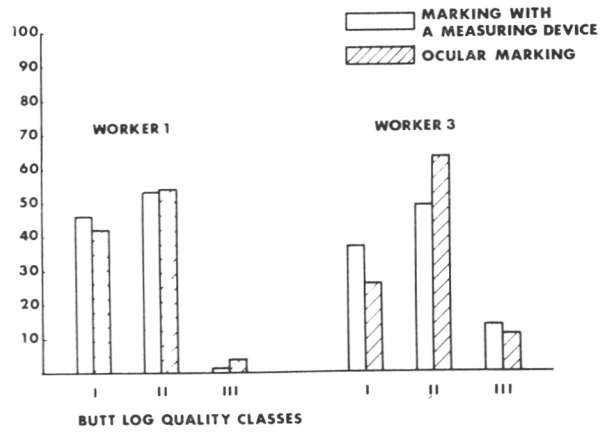


Fig. 17. Distribution of butt logs into quality classes.

on the other hand, that the difference is not statistically significant and the change to ocular marking, therefore, causes no radical changes in the quality of butt logs.

The commonest error in marking for crosscutting was that wood of a poorer quality class was left at the top 1···2 ft. of the sawlog, which means that quality trimming is necessary at any rate when heartwood is being converted. The sawlog material collected from Uimaharju sawmill was not classified by quality.

523. Trimming allowance

The sawlog must have an overrun of a fixed length, i.e. a trimming allowance, to permit its conversion into sawn goods with length and quality requirements that satisfy the buyer. Trimming may be divided into trimming proper and quality trimming. Elimination of the oblique cuts at the end of sawn piece and of checks is considered to belong to the former. It is just for these reasons that a trimming allowance is made in the log. The elimination of other factors, such as a dull edge, branches and decay, from a sawn goods piece is called quality trimming.

Timber scaling rules allow the buyer to demand a maximum trimming allowance of 4 in. or 100 mm. The length of the trimming allowance varies in practice in the range 2···5 inches. The average for the country as a whole is about 5 in. according to many studies (A r o and R i k k o n e n 1966, A s i k a i n e n 1968). The mean length of the trimming allowance in sawlogs marked for crosscutting with a measuring device varied in the present investigation in the following way for the different workers:

Table 31. Length of the trimming allowance

Investigation point	Trimming allowance and standard deviation, in.
Worker I	3.79±0.82 (±21.6%)
» II	3.81±0.69 (±18.1%)
» III	5.24±1.88 (±35.8%)
Uimaharju sawmill	4.41±1.38 (±31.3%)

In ocular marking of the logs for crosscutting the portion of the log that exceeds full feet is divided evenly among all inch classes 0···11 in. The share of the length class of each trimming allowance is thus, theoretically calculated, 8.33 per cent of the sum of trimming allowances. The theoretical mean of the trimming allowances would then be 6 in. On the other hand, a 2 inch trimming allowance is regarded in practice as the smallest useful length for trimming proper alone. The theoretical mean of the trimming allowance is then 7.5 in. as trimming allowances of 0 and 1 in. are not accepted and must consequently be regarded as 12 and 13 in. long. However, Asikainen (1968) reported that only a trimming allowance of 101 mm was sufficient even for the trimming proper of pine logs. If this is accepted, i.e. trimming allowances of 0, 1, 2 and 3 in. are rejected, the theoretical length of the trimming allowance for ocularly marked logs is 9.5 in. The trimming allowance then increases by an average of 5.5 in., which naturally increases the utilisation ratio of saving. In contrast, if an overrun of 2 in. is still accepted as the trimming allowance, when the average trimming allowance of ocularly marked logs becomes 7.5 in. and only trimming proper is performed. the utilisation ratio for 16 ft. logs increases by 1.8 per cent. It is then assumed that the mean trimming allowance for logs marked for crosscutting with a measuring device is 4 in. If the mean trimming allowance rises to 5 in., the increase in the utilisation ratio is 1.3 per cent. On the other hand, if a trimming allowance of 4 in. is the smallest acceptable, the increase in the utilisation ratios with trimming allowances of 4 and 5 in. are 2.8 and 2.3 per cent. The increase in the utilisation ratio is in fact probably 1.5···2.0 per cent.

524. Portion of pulpwood in the top

The pulpwood of fixed length was 3-m pulpwood in stand A and 2-m in stand B. The length of the pulpwood portion in stem size classes 0.4···0.8 solid cu.m. is shown in Table 32.

The mean length of the pulpwood portion of fixed length was 4.0 (± 1.1) m in stand A and 3.2 (± 0.8) m in stand B. The mean length of the poles was 4.9 (± 1.9) m in the former and 3.8 (± 1.1) m in the latter work.

Table 32. Length of the pulpwood portion in the top

Marked stand	Crosscutting	Volume of the usable portion of the stem, solid cu.m.				
		0.4	0.5	0.6	0.7	0.8
		Length of pulpwood, m				
A	fixed length	5.1	4.5	4.1	4.0	4.0
A	pole	5.9	5.3	4.8	4.8	4.8
B	fixed length	3.1	3.2	3.5	3.9	4.5
B	pole	3.7	3.8	4.1	4.5	5.0

The length of the pulpwood portion increased in stand A and decreased in stand B with the decrease in the volume of the usable portion of the stem. However, it is essential that the conversion of the pulpwood portion into a pole increases in length and the deviation of the length. This has a definite effect on limbing time, as was shown in the chapters on limbing. It means, in addition, that the utilisation ratio of vehicle space in land-borne transport is not as high as for the transport of pulpwood of fixed length or approximate length. A contributory factor is that the pile density of a pulpwood pole of free length is smaller than that of pulpwood of fixed length. Loading is also more laborious of the bolt length varies greatly. There would therefore be reason to convert the pulpwood portion into 2- or 3-m bolts of approximate length.

53. Observations on the sawing of rough-limbed sawlogs

Samples were taken by lot from rough-limbed sawlogs converted in the investigation stands and they were sawn. These lots included butt, middle and top logs in the same ratio as the distribution of the total of sawlogs in stand. The experiments were conducted at Uimaharju sawmill of Enso-Gutzeit Osakeyhtiö and Karihaara sawmill of Kemi Oy. The logs were barked by the inspection after barking that all dry branches and branch stubs that had not been limbed had broken off at the log surface. The majority of the dry branches had broken off during the truck transport phase. The longest stubs of dead branches before barking were only 0.5 cm long. The same result was arrived at in a later study on the loading and truck transport of rough-limbed and incompletely limbed spruce logs (A h o n e n 1970). Thus, it is justifiable to assume that dry branches and branch stubs at any rate are no obstacle to incomplete limbing. Nor did the stubs of living branches interfere noticeable with the barking. They were rarely over 2 cm long. When the log was barked the stubs of living branches became slightly rounded and a 4···5 sq. cm patch of bark was left at the butt of the longest ones. Similar patches of bark were seen in close-limbed logs.

In the actual sawing attention was paid specifically to the effect of green branch stubs on log feeding. No essential difference was observed compared with close-limbed logs. The logs also travelled blamelessly in the conveyors.

It would seem, then, that at least rough-limbed pine logs with small branches can be sawn without especially difficulty. The majority of the sawn logs were from stems of limbing class I and II. The situation may, however, change slightly in the conversion of rough-limbed sawlogs from stands of limbing class III or IV with numerous branches. But the majority of the pine sawlog stands in our country probably belong to limbing class II.

6. PRACTICAL APPLICATION OF THE RESULTS

61. Conversion of timber and wages

As has been shown in the foregoing, certain rationalisation measures can reduce the time expended on the conversion of pine sawlogs, by as much as two-thirds of the time formerly spent. Both the worker and the employer are probably interested primarily in the distribution of this rationalisation benefit. This aspect, however, is mainly a matter for the labour market organisations to work out. Yet, when wages are being fixed, the attention should not be confined to time expenditure alone. An equally important factor is the effect of the working methods on the worker's health and comfort. This is especially so in forest work which is performed in very varying conditions. Excessive monotony of work may also have a negative effect, especially when the work consists chiefly of using the saw uninterruptedly at high power as in conversion methods 2 and 4 in the present investigation. In methods 1 and 3 the power-saw handling time was broken up into parts between the logs were marked for crosscutting. After the days when logs had been cut by methods 2 and 4 the workers always experienced great fatigue and muscle ache, the latter especially in the evening 3···4 hours after the end of the working day. Because of these factors associated with the physiology of the work, no view is offered here on the level at which the wages should be fixed. This may be decided by the labour market parties concerned.

There are two wage tables for logging in current use in Finland. The so-called method tariff gives the sawlog logging wages for the traditional methods, and the work-phase tariff tabulates the wages e.g. for methods that comprise rough-limbing and ocular crosscutting. The latter tariff does not include the wages for marking with a measuring device, which precludes a comparison between the result of the present study and the wage tables. As the method tariff and the work-phase tariff have a different basis, a wage obtained from the former cannot be applied to conversion methods 1 and 3.

62. Fitting the new sawlog conversion methods into the other timber harvesting operations

For practical wood harvesting work, it is advisable to consider whether the rationalisation measures reported here will cause changes in the harvesting process as a whole. Attention should be paid above all to forest and long-distance haulage and timber scaling. At the time of writting, no studies had been published on the effect of rough-limbing on pile density. But the author formed the opinion in the course of this study that the reduction in pile density is insignificant for pine sawlogs at least. Nor has the lowering in the quality of limbing been shown to affect the timber loading time (A h o n e n 1970). For instance, it was observed when loading sawlogs that unlimbed dry branches broke off easily during winching or hoisting onto the load. The greatest difficulties lie in the organisation of scaling. The only serviceable scaling methods in use today in the harvesting of logs that have been crosscut ocularly are scaling on the stump or truck-load scalingat» the gate of the sawmill. The latter method is more cumbersome because logs converted by different workers should be transported separately right to the sawmill if no specific scaling for the payment of wages has been performed. This would increase harvesting costs. Nor is the by-log scaling at the landing worth while as it means not only the measuring of the top diameter but also the length, which is rather a time-consuming process. Scaling on the stump is thus the most serviceable method. However, if simpler wage bases could be worked out, truck-load scaling might be a more useful solution than the present method. It would be possible in measurement for payment to abandon tariffs based on volume and aim instead, for instance, at wages determined in accordance with the average breast height diameter in the cutting strip and the number of sawlog and pulpwood units converted. The benefit would be that even the workers themselves could keep a record of the number of sawlogs and pulpwood bolts converted by them.

Considered as a whole the methods presented here for simplification of work do not cause radical changes in the harvesting process and there should consequently be no impediment to their use. What changes will have to be intraduced in the actual sawmill production process is another matter. This point has already been touched upon, but it will be considered again in the next section where the economic significance of the changes is reviewed.

63. The effect of the new sawlog conversion methods on the processing costs

It is important for the sawmill industry to know how sawing costs are influenced by rough-limbing and ocular marking for crosscutting. This has

already been touched upon to some extent. The evaluation of the additional costs of direct sawing inconvenience if any is difficult without longer-term practical trials. On the other hand, it is possible to assess the significance of the average lengthening of the trimming allowance for the mill price of sawtimber.

When the trimming allowance decreases the true barkless volume of the amount of logs needed for the the sawing of a certain quantity of sawnwood increases. This must be paid for, of course, but the amount of residue suitable for chemical pulp chips and the income from it increase correspondingly. The following calculation was based on a 16 ft. sawlog with a top diameter inside the bark of 8 in. Its technical volume is 5.93 cu.ft. and the true barkless solid measure with a 4 in. trimming allowance is 7.12 actual cu.ft. (top form factor 1.28). In the example, the mill price of sawtimber was calculated in the following manner:

Sale on the stump	1.60	marks/ft.
Logging	0.17	»
Forest haulage over a distance of 0···300 m..	0.14	»
Truck transport over a distance of 100 km..	0.44	»
Total	2.35	marks/cu.ft.

The mill price per true barkless cu.ft. without barking costs is thus 1.82 marks. The corresponding price on the stump is 1.26 marks. Increasing the trimming allowance from 4 in. to an average of 7.5 in., however, increases by 1.41 per cent (the technical colume of a 3.5 in. long and 8 in. diameter log = 0.101 actual cu.ft.) the actual barkless volume (7.22 actual cu.ft.) of the log. Then the additional expenditure caused by lengthening the trimming allowance works out as follows:

7.22 · 1.26 marks/cu.ft.	= 9.097	marks/log
7.12 · 1.26 »	= 8.971	»
Difference	= 0.126	marks/log

However, as it is possible to make chemical pulp chips of the end trimmings, the additional cost to the sawmill is smaller. If the chip price is, say, 15 marks/loose cu.m. and density 0.394 (solid cu.m./loose cu.m.), one loose cu.m. of chips is obtained from 13.9 actual cu.ft. of barkless sawtimber, and the chip price is 1.08 marks/actual cu.ft. When an additional 0.101 actual cu.ft. piece is sold as chips, the income is 0.109 marks/log. This means that the loss to the sawmill is only 0.017 marks/log, i.e. 0.23 pennies/actual cu.ft., which is considerably less than the profit to be gained by rationalised logging. If, to mention an example, it is possible to lower per-unit wages by 25 per cent through changing to rough-limbing and ocular marking for crosscutting,

which is probably a conservative estimate, the benefit to the sawmill of rationalisation at the wage level of December 31, 1969, in a saw timber stand of large-sized pines of limbing class 2 and density class 1 would be about 3.5···4.0 pennies per technical and about 2.7···3.1 pennies per actual barkless cu.ft. The gain as such is very small, approx. 1···2 per cent of the mill price of saw logs. On the other hand, it was not possible to take into consideration in the calculations the fact that ocular marking for crosscutting when correctly performed offers good chances of an improvement in the log quality, which is very important for the whole of this barnch of industry.

If rough-limbing is considered to cause inconvenience to sawing, the limbing method can be changed to close-limbing of the living branches on the sawlog portion of the stem. This naturally reduces the saving in expenditure of time, but not so much as to make use of the conversion method unprofitable.

7. SUMMARY

The present study is an attempt to solve the following problems:

1. What is the effect of rough limbing and ocular marking for crosscutting on the time consumed for these parts of work in converting pine into sawlogs as well as on the work working-site time in logging [1]) pine for sawlogs?

2. What are the wood properties that best describe the logging time in the preparation of sawlogs of pine?

3. What is the effect of rough limbing and ocular marking for crosscutting on the dimensions and quality of the sawlogs prepared?

4. What will the technically best and economically most profitable methods of conversing pine into sawlogs be in the near future?

The following methods of limbing and marking for crosscutting were compared in the study:

Limbing method 1.

The usable portion of the stem was close-limbed to a minimum top diameter of 6 cm and the top pulpwood was left as a pole.

Limbing method 2.

The usable portion of the stem was close-limbed and the top pulpwood crosscut into 2- or 3-m bolts.

Limbing method 3.

The dry crown on the usable portion of the stem was not limbed and the living crown was limbed to the minimum top diameter satisfying the quality requirements of rough-limbing, i.e. branch stubs of a maximum length of 5 cm may be left on the bolts.

The methods of marking for crosscutting studied were:

1. Marking for crosscutting by the cutter with a measuring stick, including measurement of the log length, fetching the measure stick, moving along the stem to do the work, choosing the correct crosscutting point and making of the marks in the log. Controlling the top diameter of the sawlog portion was sometimes included in the time expended on marking for crosscutting.

2. Ocular marking for crosscutting which the marking time was restricted to the time expended on selecting the correct crosscutting point.

The methods of sawlog preparation presented in Table 1 are combinations of these methods of limbing and marking for crosscutting.

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[1]) In the present connection the term logging refers to the felling and conversion of trees into assortments.

Comparison between the limbing method employed in traditional preparation of pine sawlogs (limbing method 2) and rough limbing (limbing method 3) showed that time consumption for the latter was 12···26 % smaller than for the former depending on the size of the stem and the skill of the worker (Table 9). As the top wood, according to the principles of these two methods, is converted into different assortments (2- or 3-m bolts and, on the other hand, uncrosscut poles), the methods as such are not fully comparable when it is attempted to find out the effect of limbing alone on the time expended for this phase of work. For this reason limbing method 3 was also compared with limbing method 1, and now the saving of time when passing from method 1 to method 3 was 28···22 % (Table 10), depending of the skill of the worker and the volume of the usable portion of the stem. In limbing the part of the stem meeting sawlog requirements, however, the saving of time was greater, being 27···61 %, depending on the worker and the branchiness of the stem. It ought also to be noted that the gratest saving of time was obtained for trees with fine or dry branches.

In the study of the effect of ocular marking for crosscutting it was observed that the time expended for crosscutting in the portion of the stem meeting with sawlog requirements as well as the time for moving to the first limb to be removed had to be taken into consideration because, during these phases of work, the worker made observations on the quality of the stem and decided where to cut it into logs. Passing from marking for crosscutting by measuring to ocular marking led to a decrease in the amount of time required for marking and crosscutting by 41···68 %, depending on the skill of the worker and the volume of the usable portion of the stem.

The joint effect of rough limbing and ocular marking for crosscutting on the work place time was a saving of time by 28···36 %, depending on the skill of the worker and the volume of the usable portion of the stem (Table 22). Changing the limbing method, however, caused a decrease in the work place time of only 4...7 %, so passing to ocular crosscutting was the more important one of these time-saving factors (Table 21). It ought to be noted, on the other hand, that the amount of time saved by ocular crosscutting is greatly influenced by the stem form, as indicated by the results of investigations carried out in study areas A and B. The saving obtained in the work place time solely by employing ocular crosscutting was 9···20 %, depending on the skill of the worker and the volume of the usable portion of the stem (Table 22).

The second part of the study indicated that the characteristics of single trees traditionally used to describe time consumption in logging operations, i.e., the volume of the usable portion of the stem and the degree of branchiness, can be replaced by the breast height diameter, the length of the usable portion of the stem, the taper and the length of the portion of the crown to be limbed. The number of bolts that can be obtained from one stem, too, proved a good explanator. It was also observed that in using the same combinations of variables abreast, the degree of determination obtained for logging methods involved rough limbing was usually smaller than that obtained for the traditional methods. Comparison between the breast height diameter and the volume of the usable portion of the stem indicated that the former gives a higher degree of determination, particularly when logging methods are in question which involve rought limbing. Appendices 6, 7, 12, 17, 23 and 24 show the analyses step by step and Appendices 8, 13, 18 and 25, the final regression equations.

The investigations carried out into the effect of ocular marking for crosscutting on the dimensions and quality of sawlogs showed statistically significant differences in the mean lengths for one worker (no III) only, and his skill in marking for crosscutting had been classified as fair. From the viewpoint of sawmills the most important change in the dimensions took place in the length distribution; in ocular crosscutting

it approached the normal distribution. The numbers of over- and undersized logs were relatively small, 0.2···1.9 % of the total. Changes taking place in the quality of the logs could not be studied in more detail because of the smallness of the study material. On the other hand, a clear change could be observed in the mean length of the allowance for trimming. The fact that it increased proved to increase also the ratio of raw-wood consumption by 1.3···2.8 %, depending on the basis of calculation. In the degree of utilization of the portion of the stem meeting sawlog requirements no differences were observed, however, between stems marked for crosscutting by measuring and ocularly. Test sawings carried out indicated that roughly limbed sawlogs of pine can be barked and sawn without difficulty.

A few calculations were carried out in order to exemplify the effect of ocular marking for crosscutting, and they indicated that the sawmill's loss, using present-day raw-wood prices, anly is 0.55 penny per actual cuft. and this is considerably less than the profit gained by the buyer due to rationalization. With the organizing of the chain of various works involved in harvesting in mind, it was observed that measuring is the problem most difficulty to solve. The only method of measuring that can be rationally used in practical application of the logging methods studied in this connection is measuring standing trees; however, this method can be abandoned in favor of measuring trucks loads or weighing, provided that a sufficiently simple and cheap method is developed for measuring the lots of wood prepared by individual workers in the forest.

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7. TIIVISTELMÄ

Esillä olevassa tutkimuksessa pyrittiin selvittämään seuraavat seikat:

1. Millä tavoin tynkäkarsinta ja silmävarainen apteeraus vaikuttavat näiden työnosien ajanmenekkiin ja miten ne vaikuttavat hakkuun työmaa-aikaan.
2. Mitkä ovat parhaimmat mäntysahapuiden tekoaikaa kuvaavat puutunnukset.
3. Mikä on tynkäkarsinnan ja silmävaraisen apteerauksen vaikutus valmistetun puutavaran mittoihin ja laatuun.
4. Mitkä ovat teknillisesti ja taloudellisesti edullisimmat mäntysahapuun tekomenetelmät lähivuosien tarvetta ajatellen.

Tutkimuksessa olivat vertailtavina seuraavat karsinta- ja apteerausmenetelmät.

K a r s i n t a m e n e t e l m ä 1

Käyttöosa karsitaan pinnanmyötäisesti 6 cm:n minimilatvaläpimittaan ja latvakuitupuu jätetään rangaksi.

K a r s i n t a m e n e t e l m ä 2

Käyttöosa karsitaan pinnanmyötäisesti ja latvakuitupuu katkotaan 2 tai 3-metrisiksi pölkyiksi.

K a r s i n t a m e n e t e l m ä 3

Käyttöosalla olevaa kuivaa latvusta ei karsita ja elävä latvus karsitaan 6 cm:n minimilatvaläpimittaan tynkäkarsinnan laatuvaatimusten mukaisesti, jolloin pölkkyihin saa jäädä korkeintaan 5 cm:n pituisia oksantynkiä.

A p t e e r a u s m e n e t e l m ä 1

Hakkuumiehen mitalla suorittama apteeraus, johon luettiin kuuluviksi tukkien pituuden mittaus, mittausvälineen noutaminen, siirtyminen pitkin runkoa työn yhteydessä, oikean katkaisukohdan valinta sekä merkintöjen teko tukkiin. Joissakin tapauksissa apteerausaikaan liittyi tukkiosan latvaläpimitan tarkistus.

A p t e e r a u s m e n e t e l m ä 2

Silmävarainen apteeraus, jossa apteerausaika supistuu oikean katkaisukohdan valintaan kuluvaan aikaan. Näissä apteeraus- ja karsintamenetelmistä muodostettiin taulukossa 1 esitetyt sahapuun tekomenetelmät.

Verrattaessa traditionaalisessa sahapuun teossa käytettyä karsintamenetelmää (karsintamenetelmä 2) ja tynkäkarsintaa (karsintamenetelmä 3) keskenään, oli jälkimmäisen ajanmenekki 12...26 % pienempi kuin edellisen rungon koosta ja työntekijästä riippuen (taulukko 8). Koska latvakuitupuu tehdään näissä menetelmissä eri puutavaralajeiksi (3- tai 2-metrinen pölkky/ranka), eivät nämä menetelmät ole täysin

vertailukelpoisia haluttaessa tietää, mikä on pelkästään karsinnan laadun vaikutus karsinta-aikaan. Tämän vuoksi verrattiin karsintamenetelmiä 1 ja 3 keskenään, jolloin ajanmenekin säästö siirryttäessä menetelmästä 1 menetelmään 3 on ollut 28...22 % (taulukko 9) työntekijästä ja puun käyttöosan tilavuudesta riippuen. Puun tukkiosan karsinnassa oli ajanmenekin säästö kuitenkin suurempi, 27...61 % oksaisuusluokasta ja työntekijästä riippuen. Merkillepantavaa on, että ajanmenekin säästö on suurin hieno-oksaisten ja kuivia oksia sisältävien puiden karsinnassa.

Silmävaraisen apteerauksen vaikutuksesta analysoitaessa todettiin, että vertailussa on apteerausaikaan liitettävä tukkiosan katkonta-aika sekä ensimmäiselle karsittavalle oksalle siirtymiseen kulunut aika, koska näiden työvaiheiden aikana työntekijä tarkkaili rungon laatua ja teki päätöksen katkaisukohdista. Siirtyminen mitalla suoritettavasta apteerauksesta silmävaraiseen apteeraukseen vähensi apteerauksen ja katkonnan ajanmenekkiä 41...68 % työntekijästä ja puun käyttöosan tilavuudesta riippuen.

Tynkäkarsinnan ja silmävaraisen apteerauksen yhteisvaikutus hakkuun työmaa-ajan supistumiseen oli 28...36 % työntekijästä ja puun käyttöosan tilavuudesta riippuen (taulukko 17). Karsintamenetelmän muuttaminen aiheutti kuitenkin vain 4...7 %:n suuruisen vähenemisen työmaa-ajassa. Suurin ajanmenekin säästöön vaikuttanut tekijä oli silmävarainen apteeraus ja katkonta (taulukko 16). Silmävaraisella apteerauksella saavutettavaan ajanmenekin säästöön vaikuttaa kuitenkin voimakkaasti runkomuoto, kuten leimikoissa A ja B saadut tutkimustulokset osoittavat. Pelkällä silmävaraisella apteerauksella saatu säästö hakkuun työmaa-ajassa oli 9... 20 % työntekijästä ja puun käyttöosan tilavuudesta riippuen (taulukko 17).

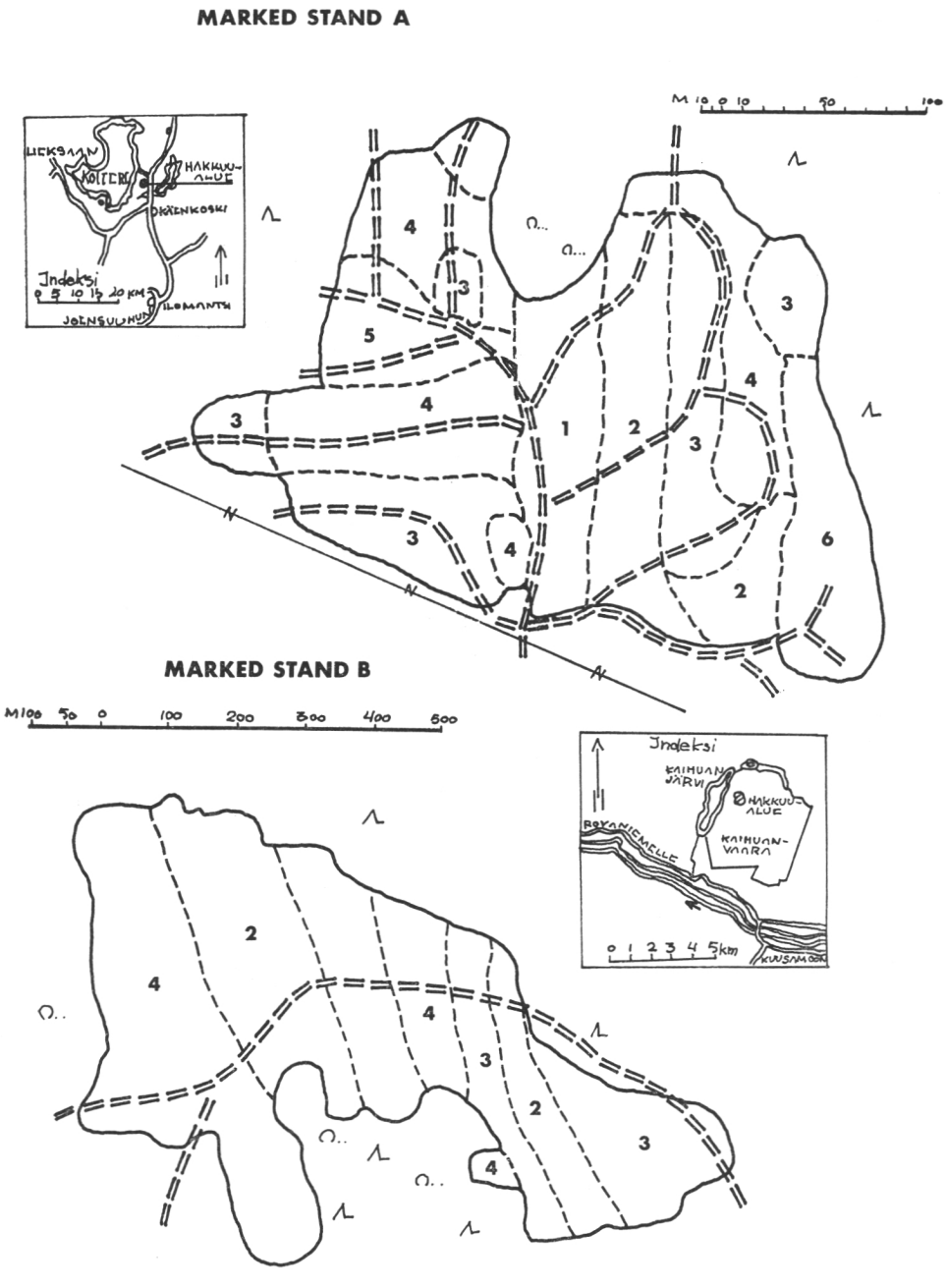
Tutkimustehtävän toinen osa osoitti, että traditionaalisten, hakkuun ajanmenekkiä selittävien puutunnusten, puun käyttöosan tilavuuden ja oksaisuusluokan, sijasta voidaan käyttää rinnankorkeusläpimittaa, puun käyttöosan pituutta, kapenemista sekä karsittavan latvuksen pituutta. Myös rungosta saatavien puutavarakappaleiden määrä osoittautui merkittäväksi selittäjäksi. Huomattavaa oli, että käytettäessä rinnakkain samoja muuttujayhdistelmiä jäivät selitysasteet tynkäkarsintaa sisältäneissä tekomenetelmissä yleensä pienemmiksi kuin traditionaalisissa menetelmissä. Rinnankorkeusläpimitan ja puun käyttöosan tilavuuden vertailu osoitti edellisellä selittäjällä saavutettavan paremman selitysasteen etenkin niissä menetelmissä, joissa käytettiin tynkäkarsintaa. Analyysit on esitetty askeleittain liitetaulukoissa 6, 7, 12, 17, 23 ja 24 ja lopulliset regressioyhtälöt liitetaulukoissa 8, 13, 18 ja 25.

Tutkittaessa silmävaraisen apteerauksen vaikutusta sahatukkien mittoihin ja laatuun todettiin, että erot keskipituuksissa olivat merkittäviä vain työntekijällä 3, jonka apteeraustaito oli luokiteltu tyydyttäväksi. Tärkein sahan kannalta tukkien mitoissa ilmennyt muutos havaittiin pituusjakautumissa, jotka silmävaraisesti apteerattaessa lähenivät normaalijakautumaa. Yli- ja alimittaisten tukkien määrät jäivät suhteellisen pieniksi, 0.a...1.9 % hakatuista tukeista. Tukkien laadussa tapahtuneita muutoksia ei aineiston vähäisyyden vuoksi voitu tarkemmin tutkia. Sen sijaan muutokset keskimääräisessä tasausvaran pituudessa olivat selvät. Sen pitenemisen laskettiin kohottavan sahauksen käyttösuhdetta 1.3...2.8 % laskentaperusteista riippuen. Sahapuuosan hyväksikäytössä ei kuitenkaan todettu mitään eroja mitalla apteerattujen ja silmävaraisesti apteerattujen runkojen välillä. Koesahaukset puolestaan osoittivat, että tynkäkarsittuja mäntytukkeja voidaan kuoria ja sahata ilman sanottavaa haittaa.

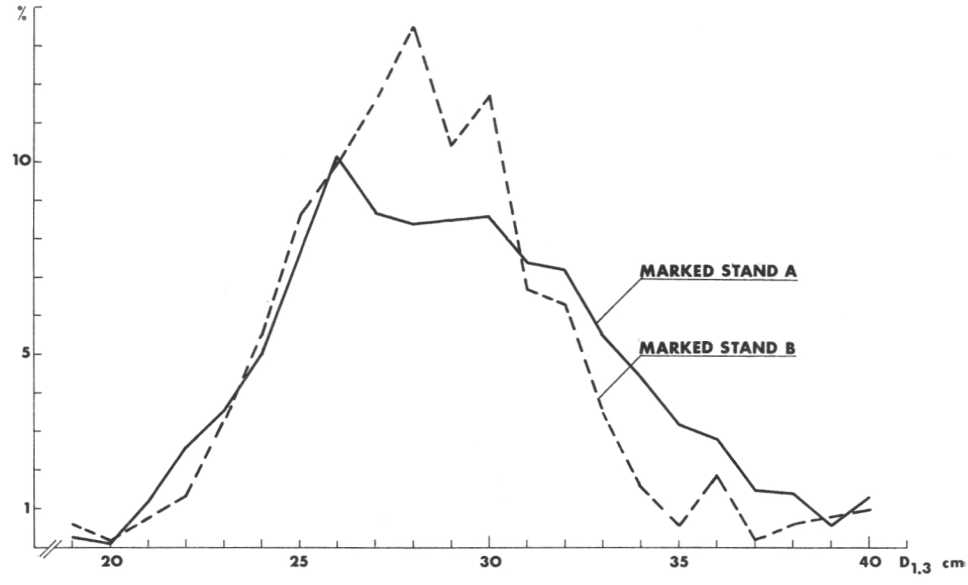
Silmävaraisen apteerauksen vaikutuksesta tehtiin eräitä esimerkkilaskelmia, joiden perusteella todettiin, että sahan kärsimä tappio on nykyisillä raaka-aineen hinnoilla vain 0.55 p/tod. j^3, mikä on huomattavasti pienempi kuin puun ostajan saavuttama

rationalisointihyöty. Korjuuketjun järjestelyä ajatellen todettiin vaikeimmaksi ongelmaksi mittaus. Ainoa tällä hetkellä rationaalisesti toteutettavissa oleva mittaustapa tutkittuja tekomenetelmiä käytännön puunkorjuuseen sovellettaessa on pystymittaus, joskin siitä voidaan luopua autokuorma- tai painomittauksen hyväksi, mikäli tekomittausta varten pystytään kehittämään riittävän yksinkertaiset ja halvat menetelmät.

Appendix 1. Investigation stand



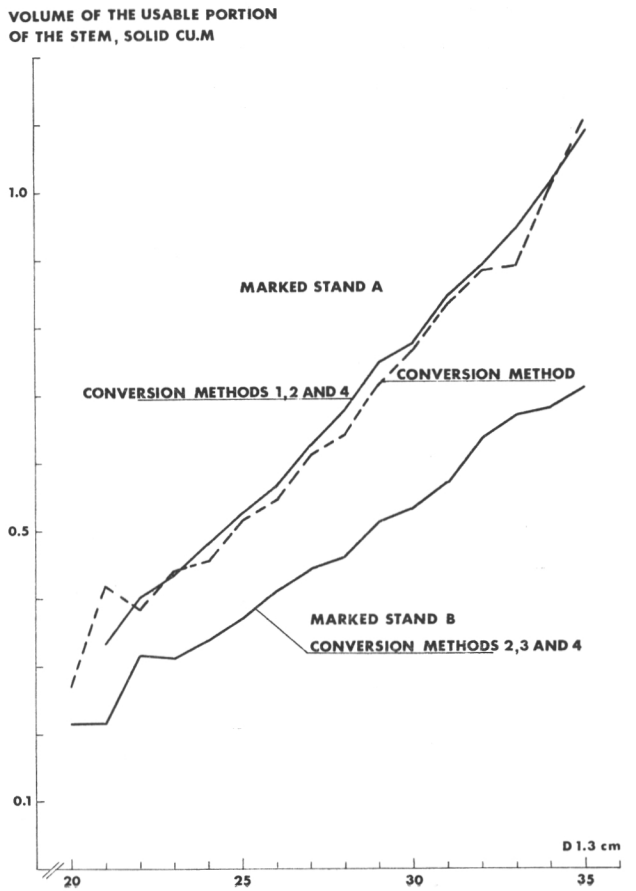
Appendix 2. Distribution of the growing stock into diameter classes in stands A and B



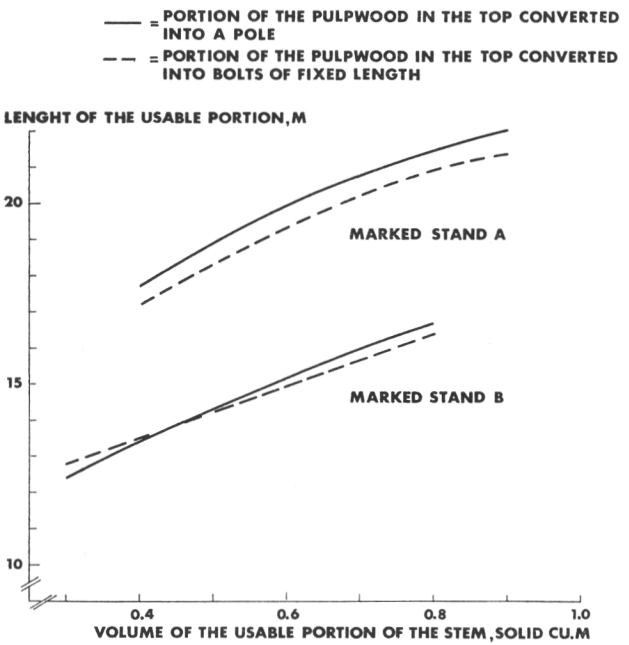
Appendix 3. Number of observations by stem size classes

Worker	Conversion method	Volume of the usable portion of the stem, solid cu.m.																				
		0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	.100	1.05	1.10	1.15	> 1.20
I	1	—	—	—	1	1	2	5	10	12	9	7	6	10	3	11	7	6	5	7	7	3	5
I	2	—	—	—	—	—	3	5	13	7	9	15	9	12	12	10	5	6	2	6	4	3	8
I	3	1	—	—	—	4	5	13	16	12	14	14	8	10	13	14	4	3	2	2	—	2	7
I	4	—	—	—	—	2	5	8	5	7	18	21	17	7	14	12	13	4	6	6	6	5	6
II	3	—	—	2	3	4	5	10	15	17	8	15	2	6	5	2	3	4	3	1	—	—	2
II	4	—	—	—	3	2	11	10	10	14	9	14	7	6	4	12	4	2	6	—	2	1	3
III	2	—	2	3	15	26	18	35	25	24	17	9	6	3	1	—	—	1	—	—	—	—	1
III	3	—	—	2	3	9	14	27	27	26	13	12	10	3	2	—	2	2	—	—	—	1	—
III	4	1	2	3	7	19	18	27	28	19	17	6	9	5	2	2	2	1	—	—	—	1	2

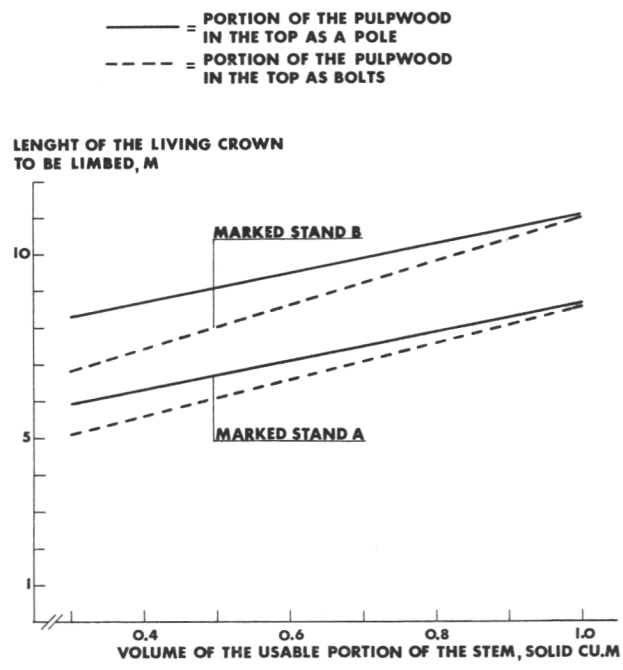
Appendix 4. Correlation between breast height diameter and the volume of the usable portion of the stem



Appendix 5. Correlation between the length and volume of the usable portion of the stem



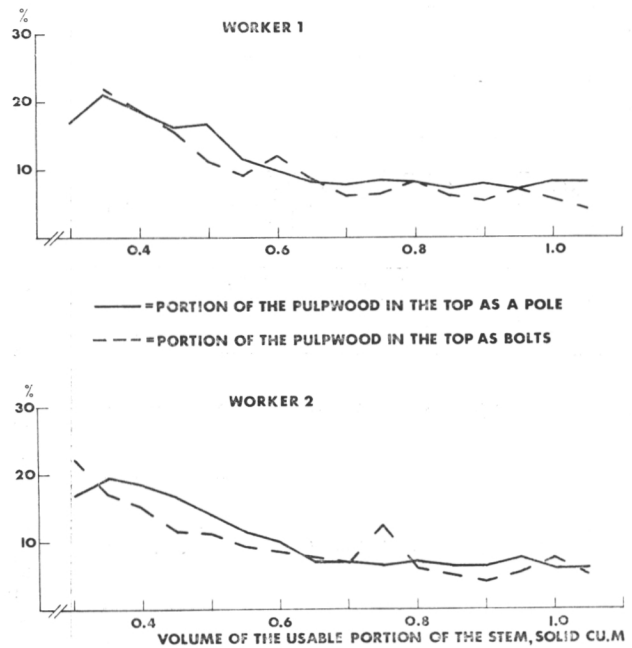
Appendix 6. Length of the crown to be limbed



Appendix 7. Correlation between tapering and the volume of the usable portion of the stem

Worker	Conversion method	Volume of the usable portion of the stem, solid cu.m.																				
		0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00	1.05	1.10	1.15	> 1.20
1	1	—	—	—	—	5.0	3.0	4.0	4.3	4.9	4.3	4.5	4.5	4.9	4.7	4.8	4.4	5.3	4.8	6.1	5.8	6.0	5.8
1	2	—	—	—	—	—	3.7	4.8	4.3	3.6	4.4	4.9	4.0	4.2	4.9	5.0	4.8	5.1	4.5	4.0	4.5	5.6	5.2
1	3	4.0	—	—	—	3.0	4.2	3.2	4.2	4.6	4.5	4.2	3.4	4.8	4.7	5.0	5.0	4.3	4.5	4.0	—	6.0	4.7
1	4	—	—	—	—	3.5	4.0	4.4	4.2	4.3	3.7	4.2	4.4	4.4	5.1	3.6	5.1	4.0	4.6	4.0	4.6	4.4	4.3
2	3	—	—	4.5	4.3	4.0	4.0	4.7	4.5	4.6	4.5	5.2	5.0	4.5	5.2	7.0	5.3	4.2	6.6	5.0	—	—	6.0
2	4	—	—	—	5.3	3.5	3.9	4.8	4.2	4.3	5.2	5.1	4.1	5.0	4.7	5.9	5.0	6.0	5.3	—	6.0	7.0	7.3
3	2	—	3.5	5.0	6.3	5.2	6.3	5.4	5.6	6.2	6.4	6.4	6.8	7.3	9.0	—	—	8.0	—	—	—	—	9.0
3	3	—	—	5.0	6.7	4.7	5.0	5.3	5.9	5.3	6.2	5.4	6.7	6.7	6.0	—	6.0	5.0	—	—	—	8.0	—
3	4	4.0	5.0	—	6.0	5.7	6.0	5.9	5.8	6.8	6.4	6.5	6.5	6.2	7.0	8.0	4.5	6.0	—	—	—	8.0	8.5

Appendix 8. Share of pulpwood in the volume of the usable portion of the stem



Appendix 9.

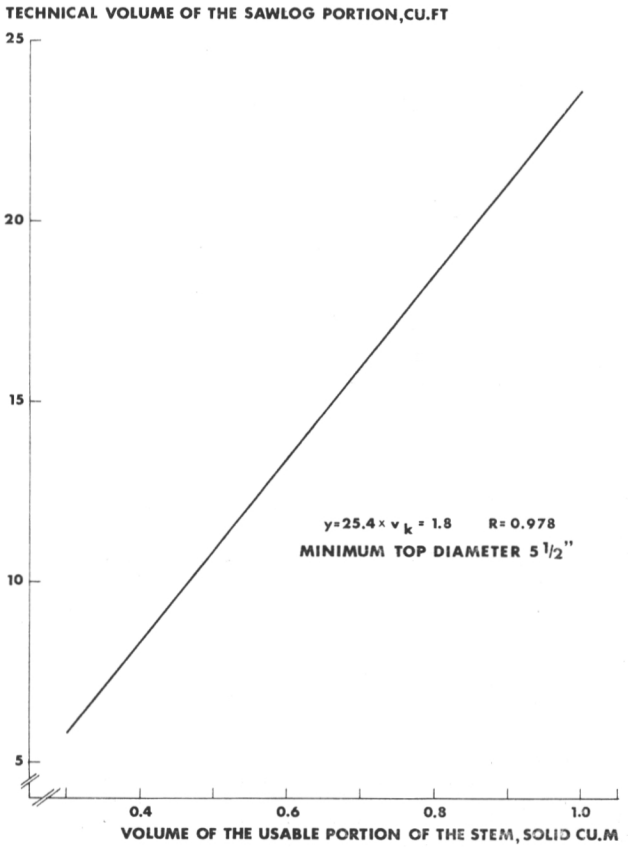


Table 1. Mean 24-hour temperature, precipitation and wind velocity in Rovaniemi on September 18—October 18, 1967

Day	Temperature °C	Precipitation mm	Wind m/s	Day	Temperature °C	Precipitation mm	Wind m/s
18. 9.	+10.2	—	—	5. 10.	+ 9.2	10.5	8
19. 9.	+ 2.6	—	—	6. 10.	+ 5.2	5.4	5
20. 9.	+ 5.1	2.0	—	7. 10.	+ 3.6	0.2	7
21. 9.	+ 6.7	0.1	—				
22. 9.	+ 5.0	—	—	9. 10.	+ 0.1	0.5	3
23. 9.	+ 4.0	—	—	10. 10.	+ 3.1	0.1	3
				11. 10.	+ 1.7	0.5	6
25. 9.	+ 7.6	0.3	—	12. 10.	+ 2.7	6.2	6
26. 9.	+ 7.4	2.4	—	13. 10.	+ 3.7	6.9	7
27. 9.	+ 3.5	—	—	14. 10.	+ 2.7	4.3	8
28. 9.	+ 1.9	0.7	—				
29. 9.	+ 2.4	—	—	16. 10.	+ 7.8	3.2	4
30. 9.	+ 0.4	—	—	17. 10.	+ 1.9	3.7	7
				18. 10.	— 0.5	1.9	3
2. 10.	+ 6.5	0.1	4				
3. 10.	+ 9.8	6.0	12				
4. 10.	+ 8.9	1.5	7				

Table 2. Mean 24-hour temperature, precipitation and wind velocity in Ilomantsi on November 13—December 30, 1967

Day	Temperature °C	Precipitation mm	Wind m/s	Day	Temperature °C	Precipitation mm	Wind m/s
13. 11.	+ 3.3	0.8	4	6. 12.	— 9.2	2.5	4
14. 11.	+ 1.1	—	1	7. 12.	—13.4	0.8	3
15. 11.	+ 0.8	5.5	4	8. 12.	—14.0	0.5	1
16. 11.	+ 2.7	0.5	4	9. 12.	—10.3	1.0	2
17. 11.	— 0.1	0.2	3				
18. 11.	— 2.5	2.5	2	11. 12.	—12.0	0.5	1
				12. 12.	—17.5	—	1
20. 11.	— 4.8	—	1	13. 12.	—18.1	—	1
21. 11.	— 0.3	4.1	2	14. 12.	—19.4	2.0	—
22. 11.	— 1.4	—	1	15. 12.	— 0.8	9.7	2
23. 11.	— 6.4	—	2	16. 12.	— 6.6	4.2	2
24. 11.	— 5.2	1.4	2				
25. 11.	— 0.4	1.1	2	18. 12.	—20.4	—	1
				19. 12.	—22.3	0.2	—
27. 11.	— 0.6	—	2	20. 12.	—24.0	—	1
28. 11.	— 4.5	—	2	21. 12.	—25.0	1.2	1
29. 11.	— 6.8	—	3	22. 12.	—26.2	—	2
30. 11.	— 3.2	—	3	23. 12.	—23.3	0.8	2
1. 12.	— 0.8	6.1	3				
2. 12.	— 5.9	0.2	1	27. 12.	—22.0	0.2	1
				28. 12.	—17.4	1.1	1
4. 12.	—17.5	0.3	—	29. 12.	— 7.8	3.2	2
5. 12.	—10.3	0.2	5	30. 12.	— 9.4	0.2	2

Depth of snow at the end of December 30 cm.

Table 3. Correlation between cutting time and the volume of the usable portion of the stem

Worker	Equation	R	se
I	$y = 66.2 \cdot v_k + 42.5$ cmin./stem	0.461	30.7
II	$y = 104.9 \cdot v_k + 30.4$ cmin./stem	0.547	34.4
III	$y = 91.5 \cdot v_k + 17.2$ cmin./stem	0.588	23.9

Table 4. Coefficients of correlation between the limbing time of the usable portion of the stem and some wood characteristics

Variable	Worker I			Worker II		Worker III		
	Limbing method							
	1	2	3	1	2	1	2	3
$d_{1\cdot3}$	0.747	0.760	0.658	0.639	0.782	0.763	0.536	0.797
v_k	0.726	0.740	0.581	0.640	0.781	0.708	0.523	0.744
f	0.206	0.245	0.378	—	—	0.348	0.074	0.150
l	—0.223	—0.265	—0.412	—	—	—0.495	—0.307	—0.474
h_k—l	0.595	0.656	0.660	—	—	0.540	0.395	0.425
h_t	0.432	0.513	0.276	—	—	0.092	0.180	0.216
h_k	0.417	0.504	0.432	—	—	0.385	0.205	0.097
s_k	0.510	0.648	0.663	—	—	0.526	0.412	0.474
$d_{1\cdot3}/h_k$	0.687	0.230	0.271	—	—	0.213	0.229	0.663
h_t	0.381	0.268	—0.014	—	—	0.205	0.326	0.053
$d_{1\cdot3} \times (h_k$—l)	0.721	0.738	0.736	—	—	0.673	0.526	0.615
$d_{1\cdot3} \times h_k$ ...	0.687	0.709	0.623	—	—	0.653	0.452	0.581

Table 5. Intercorrelations of the wood characteristics in the analysis of the limbing time of the usable portion of the stem

1)	2)		d1.3	vk	f	l	hk—l	ht	hk	sk	d1.3/hk	nt	d1.3 × (hk—l)	d1.3 × hk
			Worker I											
1	$d_{1.3}$		1.000	0.934	0.519	△	0.511	0.631	0.545	0.350	0.679	0.560	0.761	0.914
2	»		1.000	—	0.460	-0.095	0.614	0.760	0.556	0.556	0.434	0.395	0.771	0.863
3	»		1.000	—	0.504	-0.007	0.538	0.678	0.577	0.426	0.434	0.263	0.734	0.885
1	v_k		0.901	1.000	0.289	0.119	(0.603)	(0.737)	(0.599)	(0.447)	(0.558)	(0.673)	—	—
2	»		0.862	1.000	(0.274)	(-0.085)	(0.601)	(0.737)	(0.611)	—	—	(0.673)	—	—
3	»		0.931	1.000	(0.113)	(0.185)	(0.449)	—	(0.650)	—	—	—	—	—
1	f		0.583	0.322	1.000	-0.109	0.150	0.073	0.055	0.144	0.543	0.095	0.304	0.365
2	»		0.560	0.204	1.000	-0.134	0.085	0.109	0.011	0.108	0.494	0.192	0.185	0.240
3	»		0.471	0.255	1.000	-0.221	0.236	0.064	0.104	0.266	0.455	0.021	0.341	0.341
1	l		-0.388	-0.282	-0.186	1.000	-0.521	0.422	0.418	-0.786	-0.342	0.242	-0.383	0.188
2	»		-0.060	0.073	-0.115	1.000	-0.256	0.164	0.293	-0.546	-0.400	-0.178	-0.231	0.110
3	»		-0.333	-0.315	-0.161	1.000	-0.433	0.422	0.219	-0.707	-0.254	0.316	-0.343	0.106
1	h_k—l		0.526	0.592	0.164	-0.591	1.000	0.387	0.558	0.930	0.032	0.183	0.939	0.610
2	»		0.309	0.417	0.012	-0.442	1.000	0.587	0.849	0.935	-0.282	-0.064	0.968	0.842
3	»		0.434	0.446	-0.002	-0.608	1.000	0.390	0.785	0.932	-0.258	-0.336	0.959	0.751
1	h_t		0.198	0.261	-0.019	0.052	0.277	1.000	0.822	0.096	0.019	0.750	0.527	0.803
2	»		0.350	0.559	-0.087	0.285	0.522	1.000	0.670	0.470	0.066	0.508	0.680	0.787
3	»	Worker III	-0.075	-0.118	-0.114	0.370	0.248	1.000	0.712	0.159	-0.007	0.504	0.506	0.766
1	h_k		0.428	0.567	0.097	-0.167	0.894	0.367	1.000	0.226	-0.234	0.430	0.627	0.833
2	»		0.291	0.504	-0.070	0.242	0.763	0.770	1.000	0.626	-0.498	-0.161	0.831	0.893
3	»		0.236	-0.267	-0.148	0.157	0.692	0.642	1.000	0.523	-0.426	-0.147	0.802	0.886
1	s_k		0.459	0.426	0.187	-0.846	-0.880	0.228	0.606	1.000	0.187	0.022	0.818	0.345
2	»		0.222	0.200	0.094	-0.831	0.855	0.146	0.326	1.000	-0.113	0.034	0.886	0.117
3	»		0.381	0.358	0.086	-0.841	0.906	0.008	0.361	1.000	-0.078	-0.358	0.860	0.537
1	$d_{1.3}/h_k$		0.345	0.134	0.330	-0.131	-0.492	-0.285	-0.674	-0.295	1.000	0.268	0.319	0.329
2	»		0.505	0.212	0.494	-0.272	-0.434	-0.414	-0.666	-0.115	1.000	0.574	-0.106	-0.070
3	»		0.703	0.604	0.474	-0.346	-0.148	-0.544	-0.496	0.026	1.000	0.451	-0.042	0.030
1	n_t		0.275	0.275	0.013	0.036	-0.072	0.734	-0.068	-0.033	0.262	1.000	0.352	0.567
2	»		0.429	0.556	-0.047	0.168	0.165	0.623	0.299	-0.003	0.086	1.000	0.048	0.099
3	»		0.190	0.168	-0.086	0.267	0.063	0.706	0.319	-0.113	-0.091	1.000	-0.199	0.048
1	$d_{1.3}$ × (h_k—l)		0.739	0.781	0.319	-0.567	0.945	0.208	0.841	0.796	-0.267	-0.014	1.000	0.809
2	»		0.635	0.675	0.217	-0.383	0.926	0.560	0.726	0.774	-0.157	0.296	1.000	0.921
3	»		0.771	0.803	0.216	-0.582	0.869	0.087	0.550	0.768	0.231	0.113	1.000	0.876
1	$d_{1.3}$ × h_k		0.793	0.850	0.363	-0.312	0.858	0.272	0.876	0.614	-0.260	0.051	0.953	1.000
2	»		0.775	0.840	0.276	0.119	0.685	0.713	0.826	0.346	-0.145	0.441	0.855	1.000
3	»		0.840	0.833	0.262	-0.178	0.698	0.295	0.704	0.474	0.216	0.296	0.885	1.000

1) Limbing method
2) Variable

Table 6. Course of the regression analysis when analysing different limbing methods for worker I

Step	Limbing method 1				Limbing method 2				Limbing method 3			
	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.
1	$d_{1\cdot3}$	—	55.5	307.2	$d_{1\cdot3}^2$	—	57.6	297.1	$d_{1\cdot3} \times (h_k - l)$	—	54.0	344.4
2	s_k	—	62.6	46.3	s_k	—	65.1	47.3	$d_{1\cdot3}/h_k$	—	63.0	72.5
3	f	—	66.4	29.1	h_t^2	—	66.1	7.6	h_t^2	—	64.5	12.3
4	h_t	—	67.1	61.8	f	—	67.1	7.9	n_t	—	66.7	20.9
5		—	—	—	n_t	—	68.1	7.6		—	—	—
6		—	—	—	h_k	—	70.7	20.2		—	—	—

T-values in the final equations:

Limbing method 1 (n = 246)		Limbing method 2 (n = 219)		Limbing method 3 (n = 294)	
$d_{1\cdot3}$	13.8***	$d_{1\cdot3}^2$	11.4***	$d_{1\cdot3} \times (h_k - l)$	18.4***
s_k	6.3***	s_k	5.2***	$d_{1\cdot3}/h_k$	4.0***
f	6.0***	h_t^2	6.5***	h_t^2	5.8***
h_t	2.5***	f	3.6***	n_t	4.6***
		n_t	5.3***		
		h_k	4.5***		

Table 7. Course of the regression analysis when analysing different limbing methods for worker III

Step	Limbing method 1				Limbing method 2				Limbing method 3			
	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.
1	$d_{1\cdot3}$	—	57.9	195.2	$d_{1\cdot3}$	—	28.3	93.4	$d_{1\cdot3}$	—	63.2	148.3
2	l^2	—	62.9	19.8	s_k	—	37.1	33.7	f	—	69.4	18.3
3	f	—	64.0	4.97	f	—	43.8	28.5	l^2	—	75.7	22.5
4		—	—	—	h_t	—	45.4	7.7	$d_{1\cdot3}$ $(h_k - l)$	—	80.5	21.1
5		—	—	—	n_t^2	—	47.5	10.1	s_k	—	82.8	12.4
6		—	—	—					—	l^2	82.6	2.1

T-values in the final equations:

Limbing method 1 (n = 142)		Limbing method 2 (n = 235)		Limbing method 3 (n = 87)	
$d_{1\cdot3}$	11.5***	$d-_{1\cdot3}$	9.3***	$d_{1\cdot3}$	15.0***
l^2	4.4***	s_k	6.8***	f	7.1***
f	2.2*	f	5.4***	$d_{1\cdot3} \times (h_k - l)$	7.3***
		$\ln_t$	4.0***	s_k	7.9***
		n_t	3.2**		

Table 8. Regression equations that describe the expenditure of time on limbing

Worker	Limbing method	Equation		R	se
I	1	$y = 36.3 \cdot d_{1.3} - 34.4 \cdot f - 11.0 \cdot h_t + 4.7 \cdot s_k - 519.5$	cmin./stem	0.819	97.2
I	2	$y = 0.5 \cdot d_{1.3}^2 - 21.3 \cdot f - 1.6 \cdot h_t^2 + 105.3 \cdot h_t + 4.1 \cdot s_k + 20.1 \cdot h_k - 466.3$	cmin./stem	0.841	86.9
I	3	$y = 1.0 \cdot {}^{\circ}d_{1.3} \cdot (h_k - l)'' + 137.6 \cdot d_{1.3}/h_k - 0.7 \cdot h_t^2 + 64.7 \cdot h_t - 155.6$	cmin./stem	0.816	70.9
III	1	$y = 25.5 \cdot d_{1.3} - 9.8 \cdot f - 2.3 \cdot l^2 - 251.1$	cmin./stem	0.800	69.8
III	2	$y = 19.4 \cdot d_{1.3} - 21.8 \cdot f - 18.5 \cdot h_t + 3.41 \cdot s_k + 16.0 \cdot n_t^2 - 176.4$	cmin./stem	0.689	66.6
III	3	$y = 33.3 \cdot d_{1.3} - 32.4 \cdot f - 1.0 \cdot {}^{\circ}d_{1.3} \cdot (h_k - l)'' + 6.3 \cdot s_k - 595.7$	cmin./stem	0.908	56.6

Table 9. Correlation between limbing time and the volume of the usable portion of the stem

Worker	Limbing method	Limbing class	Equation		R	se
I	1	I···III	$y = 516.0 \times v_k + 15.4$	cmin./stem	0.724	116.8
I	1	I	$y = 385.9 \times v_k + 73.7$	cmin./stem	0.653	83.3
I	2	I···III	$y = 488.5 \times v_k - 3.6$	cmin./stem	0.739	108.2
I	2	I	$y = 372.0 \times v_k + 43.3$	cmin./stem	0.664	78.0
I	3	I···III	$y = 296.7 \times v_k + 67.2$	cmin./stem	0.579	100.2
I	3	I	$y = 326.2 \times v_k + 34.5$	cmin./stem	0.633	85.7
II	2	I···III	$y = 333.2 \times v_k + 62.0$	cmin./stem	0.635	77.5
II	3	I···III	$y = 385.6 \times v_k - 10.3$	cmin./stem	0.780	71.3
III	1	I···IV	$y = 586.2 \times v_k + 58.9$	cmin./stem	0.706	82.4
III	1	II	$y = 371.1 \times v_k + 165.9$	cmin./stem	0.631	78.5
III	2	I···IV	$y = 365.5 \times v_k + 134.4$	cmin./stem	0.540	77.4
III	2	II	$y = 324.3 \times v_k + 124.4$	cmin./stem	0.637	91.6
III	3	I···IV	$y = 506.0 \times v_k - 29.0\ v_k^3 + 13.1$	cmin./stem	0.772	73.2
III	3	II	$y = 342.8 \times v_k - 48.6\ v_k^2 + 95.3$	cmin./stem	0.676	68.0

Table 10. Coefficients of correlation between the characteristics that describe the limbing time for the sawlog portion and the sawlog portion of the stem, worker I

Independent variable	Close-limbing	Rough limbing
$d_{1 \cdot 3}$	0.752	0.592
v_k	0.737	0.494
v_{tt}	0.754	—
h_t	0.516	0.242
l	—0.197	—0.457
h_t—l	0.627	0.712
f	0.252	0.254
s_t	0.370	0.711
$d_{1 \cdot 3}/h_t$	0.279	0.357
n_t	0.583	0.423

Table 11. Intercorrelations of the independent variables that describe the limbing time of the sawlog portion, worker I

[1])	d1.3	vk	vtt	ht	l	hk—l	f	st	d1.3/hk	nt
$d_{1 \cdot 3}$	1.000	0.925	—	0.687	—0.021	0.632	0.535	0.557	0.344	0.621
	1.000	0.907	—	0.629	—0.011	0.633	0.431	0.574	0.379	0.524
v_k	—	1.000	0.978	0.765	0.074	—	(0.28)	—	—	(0.67)
	—	1.000	0.978	0.784	0.185	—	(0.11)	—	—	—
v_{tt}	—	—	1.000	—	—	0.667	—	—	—	0.719
	—	—	1.000	—	—	—	—	—	—	—
h_t	—	—	—	1.000	0.316	0.634	0.111	0.566	—0.408	0.756
	—	—	—	1.000	0.513	0.457	—0.078	0.350	—0.473	0.703
l	—	—	—	—	1.000	—0.533	—0.098	—0.544	—0.394	0.086
	—	—	—	—	1.000	—0.523	—0.281	—0.615	—0.591	0.235
h_t—l	—	—	—	—	—	1.000	0.179	0.947	—0.043	0.604
	—	—	—	—	—	1.000	0.214	0.983	0.145	0.451
f	—	—	—	—	—	—	1.000	0.165	0.486	0.181
	—	—	—	—	—	—	1.000	0.234	0.577	0.064
s_t	—	—	—	—	—	—	—	1.000	—0.124	0.544
	—	—	—	—	—	—	—	1.000	0.198	0.402
$d_{1 \cdot 3}/h_k$	—	—	—	—	—	—	—	—	1.000	—0.187
	—	—	—	—	—	—	—	—	1.000	—0.261
n_t	—	—	—	—	—	—	—	—	—	1.000
	—	—	—	—	—	—	—	—	—	1.000

[1]) Independent variable

Table 12. Course of the regression analysis when analysing the various methods of limbing the sawlog portion, worker I

Step	Limbing method 1 + 2				Limbing method 3			
	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.
1	$d_{1\cdot3}{}^2$	—	56.6	508.3	h_t—l	—	50.4	164.5
2	h_t—l	—	60.8	42.5	$d_{1\cdot3}/h_t$	—	56.7	24.5
3	f	—	62.6	18.7	n_t	—	61.6	21.1
4	$d_{1\cdot3}/h_t$	—	64.0	17.31	f	—	62.4	4.5
5	n_t	—	66.3	26.6	—	—	—	—

T-values in the final equations:

Limbing method 1 + 2 (n = 390)

$d_{1\cdot3}{}^2$	8.7***
h_t—l	5.7***
f	5.8***
$d_{1\cdot3}/h_t$	6.2***
n_t	5.1***

Limbing method 3 (n = 162)

h_t—l	9.5***
$d_{1\cdot3}/h_t$	6.6***
n_t	5.0***
f	2.1*

Table 13. Equations that describe the expenditure of time on the limbing of the sawlog portion, worker I

Limbing method	Equation	R	se
1+2	$y = 0.3 \cdot d_{1\cdot3}{}^2 - 20.7 \cdot f + 13.2 \cdot (h_t - l) + 136.0 \cdot d_{1\cdot3}/h_t + 63.6 \cdot n_t - 441.5$ cmin./stem	0.814	75.5
3	$y = 17.9 \cdot (h_t - l) + 147.4 \cdot d_{1\cdot3}/h_t + 49.4 \cdot n_t - 7.3 \cdot f - 369.5$ cmin./stem	0.790	42.6

Table 14. Correlation between the limbing time of the sawlog portion and the volume of the usable portion of the stem

Worker	Limbing method	Limbing class	Equation	R	se
I	1+2	I···III	$y = 405.9 \times v_k - 137.0$ cmin./stem	0.736	88.2
I	1+2	I	$y = 271.0 \times v_k - 74.5$ cmin./stem	0.635	59.7
I	3	I···III	$y = 154.0 \times v_k - 49.1$ cmin./stem	0.489	60.6
I	3	I	$y = 103.3 \times v_k - 31.3$ cmin./stem	0.368	40.1
II	2	I···III	$y = 298.8 \times v_k - 76.3$ cmin./stem	0.721	55.1
II	3	I···III	$y = 276.0 \times v_k - 107.1$ cmin./stem	0.740	57.7

Table 15. Coefficients of correlation between the marking-for-crosscutting time and some wood characteristics

Variable	Worker		
	I	II	III
v_k	0.566	0.586	0.612
log v_k	0.586	0.629	0.561
$d_{1\cdot3}$	0.510	0.517	0.444
log $d_{1\cdot3}$	0.518	0.531	0.436
f	0.010	0.107	0.050
h_t	0.631	0.353	0.449
n_t	0.742	0.716	0.584

Table 16. Intercorrelations of the independent variables for the marking-for-crosscutting time

Worker	Variable	vk	log vk	d1.3	log d1.3	f	h_t	n_t
1	v_k	1.000	0.974	0.921	0.909	0.343	0.737	0.672
2	»	1.000	—	—	—	—	—	—
3	»	1.000	—	—	—	—	—	—
1	log v_k	—	1.000	0.916	0.923	0.341	0.508	0.703
2	»	—	1.000	—	—	—	—	—
3	»	—	1.000	—	—	—	—	—
1	$d_{1\cdot3}$	—	—	1.000	0.995	0.584	0.666	0.631
2	»	—	—	1.000	0.996	0.565	0.233	0.619
3	»	—	—	1.000	0.996	0.562	0.374	0.413
1	log $d_{1\cdot3}$	—	—	—	1.000	0.577	0.697	0.645
2	»	—	—	—	1.000	0.599	0.233	0.646
3	»	—	—	—	1.000	0.562	0.381	0.431
1	f	—	—	—	—	1.000	0.117	0.203
2	»	—	—	—	—	1.000	—0.025	0.196
3	»	—	—	—	—	1.000	—0.055	—0.099
1	h_t	—	—	—	—	—	1.000	0.746
2	»	—	—	—	—	—	1.000	0.251
3	»	—	—	—	—	—	1.000	0.669
1	n_t	—	—	—	—	—	—	1.000
2	»	—	—	—	—	—	—	1.000
3	»	—	—	—	—	—	—	1.000

Table 17. Course of the regression analysis in an analysis of the expenditure of time on marking for crosscutting with a measuring device

Step	Worker I				Worker II				Worker III			
	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated variable	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated variable
1	n_t^2	—	56.1	332.3	n_t	—	50.8	110.9	n_t^2	—	36.8	89.5
2	h_t^2	—	57.3	8.8	h_t^2	—	54.2	8.6	$d_{1\cdot3}^2$	—	42.1	14.8

T-values in the final equations:

Worker I (n = 261)		Worker II (n = 107)		Worker III (n = 153)	
n_t^2	10.3***	n_t	8.8***	n_t^2	7.7***
h_t^2	3.0**	h_t^2	2.9**	$d_{1\cdot3}^2$	3.8***

Table 18. Regression equations that describe the marking-for-crosscutting time

Worker	Equations	R	se
I	$y = 9.9 \cdot n_t^2 + 0.13 \cdot h_t + 48.9$ cmin./stem	0.757	28.6
II	$y = 50.2 \cdot n_t + 0.10 \cdot h_t^2 + 16.2$ cmin./stem	0.776	28.7
III	$y = 11.4 \cdot n_t^2 + 0.04 \cdot d_{1\cdot3}^2 + 19.4$ cmin./stem	0.649	20.2

Table 19. Correlation between the marking-for-crosscutting time and the volume of the usable portion of the stem

Worker	Equations	R	se
I	$y = 178.9 \cdot (10^3 \cdot \log v_k) - 347.9$ cmin./stem	0.736	35.5
II	$y = 196.6 \cdot (10^3 \cdot \log v_k) - 376.6$ cmin./stem	0.624	33.2
III	$y = 79.9 \cdot v_k + 53.4$ cmin./stem	0.612	46.4

Table 20. Correlation between the crosscutting time of the sawlog portion and the volume of the usable portion of the stem

Worker	Conversion method	Equations	R	se
I	1+3	$y = 64.7 \cdot v_k + 7.8$ cmin./stem	0.709	15.4
I	2+4	$y = 57.8 \cdot v_k + 40.1$ cmin./stem	0.577	17.1
II	3	$y = 58.9 \cdot v_k + 15.9$ cmin./stem	0.693	11.7
II	4	$y = 61.6 \cdot v_k + 35.9$ cmin./stem	0.769	11.8
III	3	$y = 57.2 \cdot v_k + 1.5$ cmin./stem	0.567	11.3
III	2+4	$y = 48.3 \cdot v_k + 7.1$ cmin./stem	0.616	12.8

Table 21. Correlation between the crosscutting time of the usable portion of the stem and the volume of the usable portion in conversion method 3

Worker	Equations	R	se
I	$y = 52.9 \cdot v_k + 55.6$ cmin./stem	0.494	20.6
II	$y = 30.7 \cdot v_k + 70.3$ cmin./stem	0.320	16.8
III	$y = 69.4 \cdot v_k + 14.3$ cmin./stem	0.565	13.8

Table 22. Coefficients of correlation between the timber conversion time and the wood characteristics

Variable	Worker I				Worker I I		
	Conversion method						
	1	2	3	4	2	3	4
$d_{1.3}$	0.849	0.741	0.776	0.591	0.693	0.639	0.814
v_k	0.860	0.732	0.765	0.443	0.665	0.646	0.781
f	0.302	0.165	0.270	0.343	0.330	0.067	0.187
h_k	0.415	0.495	0.493	0.066	0.352	0.343	0.231
l	—0.133	—0.215	—0.276	—0.472	—0.460	—0.192	—0.435
h_k—l	0.539	0.640	0.628	0.554	0.508	0.460	0.469
s_k	0.454	0.520	0.588	0.583	0.492	0.386	0.486
$d_{1.3}/h_k$	0.618	0.430	0.415	0.585	0.189	0.207	0.563
n_k	0.597	0.123	0.555	0.291	0.208	0.391	0.091
h_t/h_k	0.341	0.320	0.338	0.142	—0.103	—0.012	—0.378

Table 23. Course of the regression analysis in an analysis of the timber conversion time, worker I

Step	Conversion method 1				Conversion method 2				Conversion method 3				Conversion method 4			
	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated variable	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.
1	v_k	—	73.8	327.1	$d_{1\cdot3}^2$	—	54.8	156.0	v_k	—	63.0	245.1	$d_{1\cdot3}$	—	34.6	86.2
2	$d_{1\cdot3}/h_k$	—	76.4	13.7	s_k	—	64.8	37.2	l	—	67.4	20.1	l	—	56.0	78.7
3	f	—	77.6	7.2	f	—	67.9	13.0	n_k	—	69.4	9.8	n_k	—	57.0	4.8
4	$d_{1\cdot3}$	—	79.4	10.6					$d_{1\cdot3}$	—	71.4	11.3	h_t/h_k	—	59.8	11.9
5	—	v_k	79.4	1.2					—	v_k	71.6	0.1				
6	n_k	—	79.9	4.4					f	—	73.1	8.9				
									h_k	—	74.0	5.7				
									s_k	—	74.8	5.0				
									—	l	74.3	3.4				

T-values in the final equations:

Conversion method 1 (n = 117)

$d_{1\cdot3}$	10.8***
f	5.7***
$d_{1\cdot3}/h_k$	3.0**
n_k	2.1*

Conversion method 2 (n = 129)

$d_{1\cdot3}^2$	12.8***
f	3.6***
s_k	6.6***

Conversion method 3 (n = 147)

$d_{1\cdot3}$	12.9***
f	3.8***
s_k	2.8**
h_k	4.1***
n_k	6.0***

Conversion method 4 (n = 162)

$d_{1\cdot3}$	8.6***
l	9.5***
h_t/h_k	3.4***
n_k	4.1***

Table 24. Course of the regression analysis in an analysis of the timber conversion time, worker III

Step	Conversion method 2				Conversion method 3				Conversion method 4			
	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or eliminated independent var.	Added independent variable	Eliminated independent variable	Degree of determination %	F-value for the added or elimineted variable
1	$d_{1.3}^2$	—	48.7	176.7	v_k	—	41.3	108.3	$d_{1.3}^2$	—	66.3	333.0
2	l	—	56.7	31.7	l	—	47.5	18.9	s_k	—	69.7	19.7
3	f	—	56.9	4.3	f	—	53.7	21.1	f	—	72.3	17.2
4					$d_{1.3}$	—	57.5	14.1	$d_{1.3}/h_k$	—	74.5	14.8
5					n_k	—	60.4	11.7	h_k	—	77.4	23.0
6					—	v_k	60.5	0.5	—	$d_{1.3}^2$	77.3	2.3
7									l	—	78.0	5.7

T-values in the final equations:

Conversion method 2 (n = 186)

$d_{1.3}^2$	11.3***
f	2.1*
l	5.7***

Conversion method 3 (n = 153)

$d_{1.3}$	12.3***
f	6.1***
l	4.4***
n_k	11.4***

Conversion method 4 (n = 170)

f	5.7***
l	2.4*
s_k	4.1***
h_k	5.3***
$d_{1.3}/h_k$	19.5***

Table 25. Regression equations that describe the timber conversion time

Worker	Conversion method	Equation		R	se
1	1	$y = 37.0 \cdot d_{1.3} - 43.8 \cdot f + 176.3 \cdot d_{1.3}/n_k + 50.3 \cdot n_k - 756.3$	cmin./stem	0.894	88.1
1	2	$y = 0.6 \cdot d_{1.3}^2 - 28.9 \cdot f + 6.4 \cdot s_k - 128.6$	cmin./stem	0.823	104.2
1	3	$y = 39.8 \cdot d_{1.3} - 32.8 \cdot f + 3.1 \cdot s_k - 29.0 \cdot h_k + 172.6 \cdot n_k - 668.4$	cmin./stem	0.862	99.1
1	4	$y = 16.9 \cdot d_{1.3} - 27.3 \cdot l - 630.0 \cdot h_t/h_k + 114.9 \cdot n_k + 262.8$	cmin./stem	0.773	76.4
3	2	$y = 0.4 \cdot d_{1.3}^2 - 9.0 \cdot f - 27.2 \cdot l + 232.8$	cmin./stem	0.753	75.3
3	3	$y = 26.6 \cdot d_{1.3} - 28.2 \cdot f - 20.6 \cdot l + 47.6 \cdot n_k - 181.1$	cmin./stem	0.779	67.7
3	4	$y = 28.3 \cdot l - 20.0 \cdot f + 6.6 \cdot s_k + 26.9 \cdot h_k + 301.5 \cdot d_{1.3}/h_k - 1\,113.1$	cmin./stem	0.883	59.5

ON SELF- AND CROSS-INCOMPATIBILITY SHOWN BY BETULA VERRUCOSA EHRH. AND BETULA PUBESCENS EHRH.

MAX. HAGMAN

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Preface

The present study was carried out at the Forest Tree Breeding Station of the Forest Research Institute during the years 1961—1969. It forms part of the large series of investigations on the sexual reproduction of forest trees conducted at the institute by Professor Risto Sarvas, to whom I am very deeply indebted not only for his kindness in placing research facilities at my disposal but also for many valuable suggestions and helpful advice during the course of this research.

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It would not have been possible to carry out a study of this kind without the help of many colleagues working at the tree breeding station and elsewhere, and for this I am especially grateful to Dr. Veikko Koski, Dr. Lauri Mikkola and Mrs. Pirkko Äyräs, M. Sc., I further wish to thank Dr. Juhani Mikola for his help with electrophoresis, Assistant Professor Yrjö Mäkinen for advice on serology and Mr. Mauri Nyholm, M. Sc., for help with electron microscopy. The late Dr. Tapani Vainio introduced me to the ferritin technique; his premature death was a great loss and brought an abrupt end to our cooperative studies.

The sera were prepared at the State Serological Institute and I thank the Director of the institute, Professor Eero Uroma, and his staff for all help provided.

Work with forest trees that flower for only a few days a year requires an experienced and skilful field staff. I have been fortunate to have had as collaborators for many years Mr. Martti Jokinen, Mr. Jaakko Pajamäki, Mr. Lars Rönn, Mr. Veikko Silander and Mr. Kauko Taimi, research technicians, and Mr. Yrjö Lind, field assistant, and I am grateful for their tireless efforts in the production of the crosses and the handling of the numerous samples of pollen, flowers, seeds, and plants.

In this connection it is also a pleasure to acknowledge the help given by

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The laboratory work was carried out with the very skilful assistance of Mrs. Sylvi Lehtonen and Mrs. Rauni Ritola, and the typing and the calculation of the results was aided by Miss Ulla Hantunen and Mrs. Vuokko Nyberg. I express my sincere thanks to them all.

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Max. Hagman

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1. INTRODUCTION

The genus *Betula* L. has for a long time proved to be a taxonomically difficult genus, consisting of numerous species and sub-species whose order of ranking has been the centre of much controversy. The difficulties in the systematic ordering of the species of *Betula* are further increased by the great variability that occurs in several characters both intra- and interspecifically. This variability has sometimes been taken as an indication of introgressive hybridization, even without a knowledge of whether the species in question actually hybridize or are prevented from hybridization.

Knowledge of the breeding system of the *Betulae* would consequently increase the possibilities for experimental testing of proposed systematic values of the species and sub-species described, and in addition allow estimation of the probability that interspecific hybridization occurs in nature.

The species of birch are in many cases important timber trees and thus potential material for forest tree breeding work. From this point of view as well, knowledge of the breeding system of the birches would be of value.

The *Betulae* flower profusely and are very good seed producers and thus production of hybrid plants and self-progenies for further experiments would be possible on a large scale. Particularly the production of F_2 and further hybrid generations and inbreds could yield increased knowledge of the inheritance of quantitative characters and the possibilities for extensive selection work, perhaps much more effective than selection in equilibrial populations of the pure species (W r i g h t, 1962). Owing to their wide distribution in the form of one or a few closely related species, the *Betulas* would serve as very good experimental plants for many other kinds of experiments in forest genetics.

As pointed out elsewhere (H a g m a n, to be published), it is necessary to have a basic knowledge of as many as possible of the following main features of the flowering process and seed formation of a tree species before a picture of its breeding system can be formed:

1. The normal anatomical and morphological development of the flower and seed.
2. The occurrence of abnormal flower development, diplontic or haplontic

sterility, polyploidy or other disturbances, if any, that may effect normal development.

3. The metabolism and biochemistry of the developing reproductive organs, particularly the female structures, and the coordination of this development with the annual developmental cycle of the plant. This is particularly important in species in which the development of fruit and seed takes a long time.
4. The normal course of flowering and pollination, the behaviour of the pollen and the pollen tubes, and the biochemical composition of the pollen.
5. The presence or absence of abnormal seed development, apomixis or pseudo-incompatibility.

On the basis of this information it may be possible to estimate whether barriers to self-, and intra- or interspecific pollination exist, or whether hybrid weakness or sterility are present, and then to construct hypotheses about the genetical mechanisms responsible for such barriers. These hypotheses may then be tested through carefully designed genetical experiments.

The anatomical development of *Betula* flowers and the normal course of the fertilization process have been known for a long time (Navaschin, 1894; Benson, 1894; Kirchner, Loew and Schröter, 1914 and Håkansson, 1957).

Abnormal flower development has been reported in *Betula*, as in so many other trees, by Johnsson (1949 a), Løken (1954) and by Dellingshausen and Stern (1958). Polyploidy is a common feature in the *Betulae*, and effects of polyploidy on their fertility have been reported several times (Johnsson, 1944, 1946, 1956; Löve, 1944; Sarvas, 1958; for references to the earlier literature see these papers). Haplontic male sterility has been reported for the polyploids and also for species or subspecies, probably of hybrid origin.

There are few studies on the metabolism and biochemistry of the reproductive organs of the birch, although long ago Benson (op. cit.) noted the long interval between pollination and fertilization in this genus.

Saarnijoki (1941) studied the germination of birch pollen in artificial conditions, and Sarvas (1948, 1952, 1955 and 1956) made a thorough investigation of the general reproduction of *B. verrucosa* and *B. pubescens* and the flowering and pollination processes of these species. In 1952, he also made observations on pollen tube growth, noting slow growth in one case. Later, in 1956, in studies of single trees, he found great variation in the amount of filled seed, some trees having a high percentage even when standing far apart from each other and from the main forest. In some trees of

B. pubescens the possibility of self-compatibility was suggested. »Self-sterility» had frequently been reported earlier (K o l e s n i k o f f, 1930; A c a t a y, 1938; J o h n s s o n, 1951 and earlier).

The frequently raised question of whether *B. pubescens* and *B. verrucosa* really hybridize, and if not, what barriers prevent crossing between these species, was reviewed by E i f l e r (1958, 1960) and K l a e h n (1950, 1952). Great differences in combining ability were found between different trees and all crosses in the direction *B. verrucosa* × *B. pubescens* were more successful than the reciprocal ones. This is in general agreement with observations on other plants, in which better compatibility is found between species at different levels of polyploidy when the species with the higher chromosome number is used as the male parent. In other birch hybrids J o h n s s o n (1945) obtained similar results.

R i c h e n s (1945) and W r i g h t (1962) summarized many other features of birch breeding and reviewed the earlier literature in detail.

C l a u s e n (1970) published recently the results of his interspecific crosses carried out in the years 1962—1969. Crossability appears to be better between than within subsections. Better germination percentages of the seed were obtained from low ploidy female × high ploidy male crosses. Results of reciprocal crosses were often strikingly different. In the cross *B. pendula* × *B. pubescens* the germination of the seed was less than 1 %, and in the reciprocal cross between 0 and 0.5 %. The cross *B. nana* × *B. pendula* gave no germinable seed, whereas the cross *B. nana* × *B. pubescens* gave a seed germination of 29.4 %. The reciprocal crosses *B. pendula* × *B. nana* and *B. pubescens* × *B. nana* gave the germination percentages 3 % and 0 % respectively. Certain species are at least partially self-compatible e.g., *B. lenta*, *alleghaniensis*, *papyrifera*, *humilis*. *B. pendula* is also partly self-compatible, giving a germination percentage after selfing of between 0 and 12 %. However, most of the birch species tested appear highly self-incompatible.

In most of the studies of hybridization cited here the results were based on the production of germinable seeds, and observations on the earlier phases of pollination and fertilization were rare. E i f l e r (1964) observed that the penetration of the pollen tube of *B. verrucosa* into the styles of *B. pubescens* was very difficult and noted that the cuticula of *B. pubescens* is much stronger than that of *B. verrucosa*. Apomixis was not reported for *Betula* and no experimental studies seem to have been made with embryos after hybridization or with the object of detecting pseudoincompatibility.

In related genera, e.g. *Corylus* (J o h a n s s o n, 1935) and *Quercus* (P j a t n i t s k y, 1947) it was reported that pollen did not grow so well on styles of a selfed plant. Cross-incompatibility was also reported between cultivars of *Corylus*. S t e b b i n s et al. (1947) suggested that incompat-

ibility occurs in some oak species, and Wright (1953) and Pjatnitsky (1946) made similar observations. Dengler (1941) reported high »self-sterility» in *Quercus sessiliflora* and *Q. pedunculata*. In *Alnus* (Ljunger, 1959 and others) interspecific incompatibility was reported and self-fertility was mentioned for *A. glutinosa* by Rohmeder and Schönbach (1959). Hagman (1970) showed that the self- and interspecific incompatibility in *A. incana* and *A. glutinosa* was due to disturbed pollen tube development. Woodworth (1930 a) reported apomixis in *A. rugosa* and Gustafsson (1947) was of the opinion that the type of apomixis in this case was adventitious embryo formation.

The genetical mechanisms forming barriers to selfing, crossing or species hybridization in *Betula* are not yet confirmed.

Alnus, *Betula* in the Betulaceae and *Corylus* in the Corylaceae all have simultaneous pollen mother cell division and bi-nucleate pollen grains. The same is the case in *Fagus*, *Castanea* and *Quercus* in the Fagaceae.

Brewbaker (1957) has demonstrated that a close relationship exists between the two types of pollen grains and incompatibility systems; gametophytic species generally liberate pollen grains in the binucleate condition, while sporophytic species mostly have trinucleate grains. (See also Pandey, 1958, 1960a and 1960b). On the basis of the theories propounded by these authors it was therefore possible to suggest that the system operating in these tree species would prove to be one with gametophytic control of the pollen reaction and that probably inhibition of pollen growth occurs during the passage of the pollen tube down the style.

The object of this study was to test this hypothesis and to investigate the nature of the incompatibility mechanism in intra- and interspecific crosses of the two chief birch species of Finland.

In addition, the object is to determine the degree of incompatibility that may exist and to investigate whether the nature of the incompatibility could be related to any particular morphological or biochemical character of the gametetophyte.

A third object of the study is to develop methods with which substances involved in the incompatibility reaction could be identified and localized for further studies.

The fourth object is to produce material of known origin for later studies on the genetics of the incompatibility factors. It was hoped that these investigations would, in addition, lead to some suggestions for practical forest tree breeding in the birches.

From a general point of view, it would have been interesting to include *B. nana* L. in this study. The material of this species growing near the tree-breeding station is very scarce, and the facilities for collecting several species in the north during the winter could not be expanded. The value of this

species for forestry is also limited. It was therefore decided to concentrate the investigations to *B. verrucosa* and *B. pubescens*.

I shall in the following text, in accordance with H y l a n d e r (1966), use the names *Betula verrucosa* Ehrh. and *Betula pubescens* Ehrh., although I am aware that, according to the latest rules of nomenclature the name of *B. verrucosa* Ehrh. ought to be *B. pendula* Roth. In addition, I shall, for reasons to be explained later, include under the name *B. pubescens* Ehrh. those birches of the northern mountains of Lapland that have been called *Betula tortuosa* Ledeb. by earlier authors (F e l l m a n, 1882) or *Betula pubescens* Ehrh. subsp. *tortuosa* (Ledeb.) Nyman by later ones (T u t i n et al., 1964).

Preliminary results of my work have been reported earlier (H a g m a n, 1963, 1964, 1967a and 1967b).

2. MATERIAL AND METHODS

Trees used and treatment of the scions

Stands and trees

For this study two birch populations were selected in 1960 at the Ruotsinkylä Experimental Forest near the Maisala forest tree breeding station of the Forest Research Institute of Finland. This experimental forest is situated at latitude 60°21′ north and longitude 24°59′ east. One of the populations consisted mainly of *B. verrucosa* and the other of *B. pubescens*. These two stands, which were both rather small, originated by natural regeneration from local trees.

In isolated, unstable or temporary habitats it is positively advantageous that, through inbreeding, a large number of offspring may be produced quickly even though only a single disseminule reaches the new situation (B a k e r, 1953, 1955 and 1959). The constancy provided by self-fertilization or apomixis may in such situations have a positive selective value (S t e b b i n s, 1957, 1958 a). Since it was concluded that for such reasons the birches of northern Finland might have developed a different breeding pattern from the trees in the south, a third group of birches was selected in the Laanila Experimental Forest of the institute (lat. 68°30′ N., long. 27°30′ E.). This group included some *B. verrucosa* trees standing scattered in the pine forest and some *B. pubescens* trees of the »tortuosa» type forming a more or less continuous stand.

For similar reasons, another 14 trees were taken from the outermost archipelago southwest of the Finnish mainland, on and around the mainland of Åland, but these trees were used only as twigs.

In 1962, six trees were additionally chosen from the tree limit of *B. verrucosa* in northern Lapland and another sample of six trees representing the insular birch forest in the southwest.

In 1963 and 1964, these experiments were repeated, mainly with the same trees. For occasional observations some other trees were used, as will be described later.

Flowering

In 1961, flowering in the birch was fairly good. In 1962, flowering was not so abundant as in 1961 and the female flowers, particularly, were few. Hence, it was not possible to obtain a complete reciprocal crossing of the trees. This was especially the case in *B. pubescens*. In 1963, flowering was so poor that only a few artificial pollinations could be made. In 1964, flowering was abundant but the poor result of the out-of-door crossings this year indicate that some damage may have occurred that disturbed the normal development of the female flowers.

Forcing of twigs

Twigs used for greenhouse crosses and for pollen forcing were taken during the winter, in some cases in Lapland in 1960, as early as December 2, and stored outdoors in the snow and later in the spring in the iced plant cellar until used. Generally, twigs are easier to force when taken in shortly before the natural flowering time. Twigs taken in early usually have a very long period of development compared with twigs taken in late, although, in all cases, the temperature scheme for forcing has been kept constant.

Since it was necessary to carry out as many crosses as possible before the general start of flowering in the spring made isolation difficult, I endeavoured to prolong the period in which twigs can be forced to flush in the greenhouse. For this purpose I made the following experiment:

Birch twigs which had been exposed to cold and short-day treatment in nature until November 1961 were taken in on that day and kept in the greenhouse at a temperature of 15°C.

On January 1, the first pollen was shed in the controls.

However, three groups of the same twigs were treated at the same temperature with volatiles from apples, — probably ethylene —, by storing them for some time in a plastic bag containing apples.

These treatments gave the following results:

Treated with apples for 24 hours: flowered 2 days earlier than control
» » » » 48 » » 14 » » » »

A sample treated as the control for the first 14 days and then for 24 hours with apples flowered 4 days earlier than the control.

In the springtime, the period necessary for forcing the twigs to flower without any additional treatment was in February about 12—16 days and in April only 8—10 days.

Thus it seems that there is a natural inhibitor present in the twigs which slowly disappears during the winter in natural conditions and that this inhibitor can be suppressed by treatment with ethylene. Using this method,

it is therefore possible considerably to prolong the safe period during which crossings can be made.

In nature, the flowering of *B. verrucosa* started in Ruotsinkylä in 1961 on May 11, in 1962 on May 13 and in 1964 on May 12. In *B. pubescens* flowering begun on May 16, May 19, and May 19 respectively.

In Laanila in 1961, the only year that crosses were made there in the forest, *B. verrucosa* started flowering on June 5 and *B. pubescens* on the same day.

The mean time taken, under normal conditions, for the female flowers to develop from the point when the red tips of the styles begin to be visible to the point when the red colour of the styles starts bleaching is about 3 days. It takes some days from the opening of the bud scales and until the development of the red colour and during this time the tips of the styles are more or less green. It takes another 3—4 days from the optimum stage until the style-tips take on a brown colour and start withering.

Isolation

In the beginning greenhouse crossings were made in »cages» of thin polyethylene tubing fitted with a ventilation part and a filter at the top. The greenhouse was not thermostatically controlled, and on sunny days later in the spring, although shaded, it became fairly warm. Maximum temperatures were measured as +2° to +4°C higher than the general temperature of the greenhouse.

One cage was used for each cross and pollinations were made through a small hole and sealed immediately afterwards. This hole was made with a pollination »gun» used in general for forest tree pollination.

In 1964, it was found that pollinations could be carried out just as well on cut female catkins taken just before flowering and placed in moist sand in isolated Petri dishes. This technique, which, when tested, gave results no different from the earlier method, led to a considerable saving of both space and labour.

The pollen was forced in a separate glasshouse beforehand and stored until used at —2°C over silica gel.

In 1961 and 1962, the outdoor pollinations were made using double Pergamyne isolation bags (figure 1) applied at a stage when no signs of the female flowers could be seen in the opening buds. In 1963 and 1964, non-woven terylene bags were used to secure isolation.

For pollination in the trees the same pollination guns were used as in the greenhouse, one gun for each pollen lot.

The pollination bags were removed about two weeks after pollination, when the styles had completely withered and there were no longer any

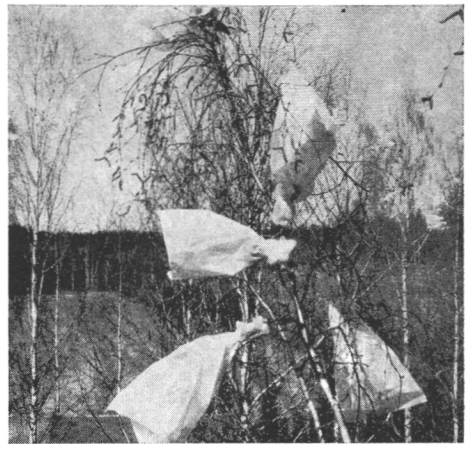


Figure 1. Isolation bags in the native *Betula verrucosa* stand at Ruotsinkylä.

signs of flowering. The greenhouse pollinations were always completed before the birch started flowering in nature outside the greenhouse.

Treatment with insecticides

During the working period of 1962 in the greenhouse, disturbances which completely inhibited pollen tube growth appeared, and considerable numbers of crosses — about 100 combinations — were spoiled until it was detected that the cause for the failure was insects feeding on the flowers. Since the insects were probably wintering in the form of eggs on the twigs taken in for forcing, we treated the twigs immediately after they were cut with a solution of a DNOC winter spray at the concentration normally used for the spraying of fruit trees. A dip in this solution removed the difficulties caused by the insects almost totally and no adverse effect of the insecticide was found when treatments were compared with controls. Unfortunately, this treatment cannot be applied to twigs taken in late, when growth has already started in nature. I have not tried to spray whole trees in the forest before the crossings, although, in view of what was later found about seed formation in the forest, this in some cases might perhaps have improved the results.

I will return to the problem of these insect attacks in greater detail later.

Numbering of trees and places

In the following discussions and in the tables, the localities and individual trees are denoted as follows:

Ru = birches from *Ru*otsinkylä
trees Nos. 1—12, 27 and 32 are *B. verrucosa*.
trees Nos. 13—23, 26, 28, 29, 30, 31 and RuKa 6 are *B. pubescens*.

La = birches from *La*anila
trees Nos. 1—5 are *B. verrucosa*.
trees Nos. 11—15 are *B. pubescens*

In and Ka = birches from *In*ari and *Ka*amanen, Lapland north of Laanila. All these trees (In 7, Ka 2, Ka 4) are *B. verrucosa*.

Ål = birches from the mainland of *Å*land, Eckerö,
trees Nos. 1, 4, 5, 9 are *B. verrucosa* and
trees Nos. 2, 3, 6, 7, 8 and 10 are *B. pubescens*.

Bö = birches from the islands of *B*rändö — Kumlinge-Sottunga in the southwestern archipelago.
trees Nos. 1, 3, 6 are *B. verrucosa* and
trees Nos. 2, 4 and 5 are *B. pubescens*.

Kö = birches from the island of *K*ökar,
trees Nos. 1—4 all being *B. pubescens*.

E 2101—E 2103 are selected *B. verrucosa* plus-trees from Pusula in S. Finland.

E 1092 is a *B. verrucosa* of curly form and in addition triploid, growing at the Punkaharju Experimental Forest in eastern Finland. The cultivar name of this tree is »Olli-visa».

E 675 and E 676 are *B. verrucosa*, also curly forms, growing at the tree-breeding station and originating from the same seed collection from one natural stand of curly birch in central Häme, S. Finland.

The hybrid trees (*B. verrucosa* × *B. pubescens*) were obtained from the Institut für Forstgenetik, Schmalenbeck, W. Germany, and originated from their cross No. 2611/68 × No. 70.

The numbers in the crossing schemes refer to the number of the particular cross. Of these, in the combined schemes for 1962 the crosses Nos. 1—372 were made in the greenhouse and No. 373 onwards in the forest.

Microscopy

The staining method for the pollen tubes used in 1961, fuchsin-light green, turned out to be a little too laborious for dealing with large amounts of

fixed tissue in serial work. In 1962, we used as a new method the fluorescent stain of L i n s k e n s (1957) with very good results and this stain was also used in subsequent years. The method as used by us is as follows:

1. Dissolve 10 g of Water Blue (E. Merck) in 100 ml distilled water.
2. Boil, and add concentrated KOH solution drop by drop until the reddish-blue colour vanishes, filter.
3. The clear brown supernatant is decanted into a chromatography glass or other big jar and the brown sediment is discarded.
4. The solution is then chromatographed on a cylinder of normal chromatography paper, e.g. Whatman No. 1.
5. The solution rises on the paper on approximately 4 different fronts. The first front, which is blue, and the second, which is dark brown, are discarded. The third, light brown, is used — it can easily be seen in ultraviolet light — and the bottom, dark brown front is also discarded.
   If a large jar is available, one can run the whole amount of solution at one time.
6. The light brown front is cut from the paper and washed so long (about 1 hour) with *cold* water that the washing water gives a neutral reaction (pH = 7).
7. The paper is transferred to another jar and the light brown colour is eluted from the paper with *hot* water.
8. With this solution steps 4—7 above are repeated.
9. The light yellow-green solution thus obtained may be concentrated on a waterbath if necessary. In ultraviolet light it is possible to measure the strength of the fluorescence.
10. This solution can be used as such for staining the styles, and it keeps well under laboratory conditions.
11. The styles can be used fresh or after fixation in acetic alcohol and storage in alcohol, but the stain is not effective if the preparation contains alcohol, so fixed and stored material must be taken down to water in the usual way before staining.
12. Preparations studied in ultraviolet light with the microscope show bright fluorescence of the pollen tubes.

The investigations were made with a Leitz Ortholux microscope fitted with a Leitz 250 lamp stand and an Osram HBO 200 W UV-lamp.

Pollen tubes were measured with an ocular micrometer and the length expressed in scale units. The combination of ocular and objective was chosen so that one unit of the scale should be equal to 30 μ. The pollen tubes were grouped by length in 7 classes: 0—0.5; 0.5—1.0; 1—2; 2—4;

4—6; 6—8; and 8 + units respectively. It was not usually possible to follow the pollen tube in the style with certainty beyond the length of 8 scale units and all tubes longer than 8 units are hence classified as 8+. The mean of each class was taken as the class mean in the calculations, but the mean for the longest class was taken as 8 units.

Immunological technique

When the first experiments were made, it was thought necessary to obtain an extract of the proteins present in the pollen in an accessible form, lest other substances in the original material might interfere with antibody production or precipitate the proteins before extraction was complete. I therefore carried out the first tests with birch pollen which had been macerated and subsequently washed with cold (—18°C) acetone. But the acetone-treated antigens gave some inconsistent reactions, probably due to variation in the method of extraction. At the suggestion of Dr. J.G. Feinberg, of Beecham Research Laboratories, Betchworth, Surrey, I began to use native birch pollen according to the following technique:

The whole undefatted pollen is suspended in saline and emulsified with Freund's complete adjuvant to produce an emulsion containing 100 mg pollen per ml of emulsion. This emulsion is injected subcutaneously in each of two sites per rabbit, 0.5 ml being injected in each site. After six weeks, 100 mg pollen in 1 ml saline is injected and after another six weeks the animal is given a booster injection of 100 mg whole pollen in saline. Thus the total amount of pollen injected is 3 × 100 mg. The animal can be bled about ten days after the booster injection.

Precipitation in agar gel plates was carried out as double diffusions, (for general technique, see e.g. Kabat and Mayer, 1961). As a test for antigenic relationships, the method of Feinberg and Grayson (1959) was frequently used.

Material for the serological tests was the same pollen as was used in the pollination studies. When used as an antigen in the test plates, the pollen was macerated and extracted with physiological saline.

The female flowers used in these experiments were collected as whole catkins, because the very small size of the styles made collection of sufficient material from pure styles very difficult. This material was quick-frozen immediately after collection. Samples were extracted with cold acetone and the dry material remaining extracted with water at +2°C or saline.

Observations of the fluorescence of samples stained with conjugated antibodies were made with the same lamp and microscope setting as for the study of pollen tubes.

For the ferritin experiment, germinated pollen tubes of *B. verrucosa* were treated with a homologous antiserum and then with a ferritin-conjugated goat anti-rabbit serum (Microbiological Ass. Inc., Bethesda, Maryland) according to the two-layer technique (cf. e.g. Baxandall, Perlmann and Afzelius, 1962).

Parallel samples were treated with O-rabbit serum and then with the conjugated anti-rabbit serum or with the conjugated anti-rabbit serum only. The material was thereafter fixed in 2 % osmium tetroxide, dehydrated and embedded in Epon 812.

Sections were examined with a Siemens Elmicroscope.

Disc electrophoresis

For a description of staining of the electrophoretically separated material and for further references about the technique, see Hagman (1964). In the present studies the gel and sample for female flowers were mixed in the proportion 1 : 1 but for pollen samples the proportion was 7 : 1.

Seed testing

The seeds from the crosses made in the forest in the spring were collected in August of the same year. (In speaking of the »seed» of *Betula*, I am following forestry practice, although the fruits are, of course, nutlets.)

A sample of 4 ×100 seeds was taken from each seed lot, using the randomized method of repeated divisions of the whole seed lot, as in normal seed testing. If the seed lot did not contain 400 seeds, all the seeds were tested. In 1961 and 1962, the seed samples were put on glass slides in a mixture of glycerine and alcohol and counted against a strong white light. In 1964, when an X-ray apparatus designed for seed testing was available, the seeds were X-rayed and the evaluation made from the films. The number of filled and empty seeds was noted for each lot as a mean of the four replications counted and expressed as a percentage of all seeds.

In 1961, there was enough seed left for sowing after the first test had been made and in addition, as a second test, the seeds were sown in the greenhouse in boxes with standardized peat soil.

In all critical cases, where a low percentage of filled seed had been detected, the seeds were sown in 4 replications of 250 seeds each. The mean of germinated and thus filled seeds in this second test is hence based on a total number of 1 000 seeds.

Owing to limited space in the greenhouse, not all the seed lots after free pollination and cross-pollination were tested in the soil, especially when the first test had indicated a high percentage of filled seed.

3. THE INCOMPATIBILITY MECHANISM

Germination of the pollen

Since in other plants incompatibility is known to start by blockage of pollen germination on the surface of the stigmas, the first step was to study the germination of the pollen grains on the female flowers. This was done by classifying the pollen grains counted on the styles into two classes, germinated and ungerminated, and then comparing the percentages of germinated pollen for the different crosses. The germination was studied in samples taken c. 36 hours after pollination. The pollination was made at the optimal stage of development of the styles.

Cross-pollination

The germination of the pollen after cross-pollination was, in general, good. In *B. verrucosa* (table 1), the germination was 84.8 % in 1961 for all trees (S. Finland and Lapland taken together). In the greenhouse germination was somewhat lower than in the forest for the Ruotsinkylä trees. In Laanila germination was slightly less but this sample is small.

In 1962, the germination for all trees taken together was 86.1 %. The greenhouse pollinations that year germinated well, and the forest pollinations about equally well.

In *B. pubescens* (table 2) the mean germination for all the trees in 1961 was 88.4 %. The trees from Laanila had a germination of 90.6 % in the forest.

There is no significant difference in pollen germination when the species are compared. Neither is there a difference in pollen germination in 1961 when the germination of the trees in Ruotsinkylä and in Lapland is compared.

In the cross *B. pubescens*, Laanila × *B. pubescens*, Ruotsinkylä, the mean germination in 5 combinations was 92.8 %, which differs from the mean of the crosses Lapland × Lapland, 90.6 %, by only 2.2 %.

If we take the two species together, we find that the germination of the pollen in vivo when cross-pollinated in 1961 was 86.4 % and in 1962 83.7 %. There do not seem to have been very large species differences during the two years studied.

No detailed studies of the germination of the pollen were made in 1963

Table 1. Germination of the pollen of *Betula verrucosa*.

Parents		Glasshouse pollinations				Forest pollinations			
Female	Male	Number of crosses	No. of pollen grains	Germination %	Germination Confidence intervals	No. of crosses	No. of pollen grains	Germination %	Germination Confidence intervals
				Cross-pollination 1961					
Ruotsinkylä	Ruotsinkylä ..	2	100	63.0	72.8—52.6	10	614	88.9	91.7—86.4
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	—	—	—	—
Laanila	Laanila	—	—	—	—	1	18	66.6	86.7—41.0
Total and mean 1961		2	100	63.0	72.8—52.6	11	632	88.3	91.7—86.4
				Cross-pollination 1962					
Ruotsinkylä	Ruotsinkylä ..	22	1 400	85.1	87.2—82.6	16	368	85.9	89.4—82.4
Ruotsinkylä	Laanila	9	215	89.8	92.0—84.9	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	—	—	—	—
Laanila	Laanila	1	90	94.4	97.8—87.0	—	—	—	—
Total and mean 1962		32	1 705	86.2	87.9—84.5	16	368	85.9	89.4—82.4
Total and mean 1961+1962		34	1 805	84.9	85.9—84.0	27	1 000	87.4	89.3—85.0
				Self-pollination 1961					
Ruotsinkylä		3	100	89.0	94.4—81.0	7	310	85.5	89.4—81.0
Laanila		3	291	85.6	89.6—80.5	—	—	—	—
Total and mean 1961		6	391	86.5	91.0—82.1	7	310	85.5	89.4—81.0
				Self-pollination 1962					
Ruotsinkylä		12	1 945	73.2	75.4—70.0	4	156	30.1	40.0—21.2
Laanila		8	1 365	61.2	64.3—58.0	—	—	—	—
Total and mean 1962		20	3 310	68.3	70.8—65.1	4	156	30.1	40.0—21.2
Total and mean 1961+1962		26	3 701	70.2	72.9—69.0	11	466	67.0	71.1—62.8

or 1964, but pollen germination was checked in connexion with the studies of pollen tube growth and was found in general to be as good as in the earlier years.

Self-pollination

If any incompatibility occurs in the birch at the stage of pollen germination, this would be expected to appear when the trees are self-pollinated. It seems, however, that in most cases the germination of the pollen after self-pollination was just as good as after cross-pollination.

In *B. verrucosa* (table 1), the mean germination for all trees (S. Finland + Lapland) was 86.1 % in 1961.

The mean of all crosses in 1962 was 67.9 %, and the mean for 1961 and 1962 70.2 % in the greenhouse and 67.0 % in the forest.

In *B. pubescens* (table 2), the germination for all trees (S. Finland + Lapland) in 1961 was 94.1 %. When the different years are compared,

Table 2. Germination of the pollen of *Betula pubescens*.

Parents		Glasshouse pollinations				Forest pollinations			
Female	Male	Number of crosses	No. of pollen grains	Germination %	Germination Confidence intervals	No. of crosses	No. of pollen grains	Germination %	Germination Confidence intervals
				Cross-pollination 1961					
Ruotsinkylä	Ruotsinkylä ..	5	702	89.3	91.7—86.9	5	512	83.0	86.2—80.1
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	5	391	92.8	95.4—87.1
Laanila	Laanila	—	—	—	—	2	201	90.6	94.9—86.1
Total and mean 1961		5	702	89.3	91.7—86.9	12	1 104	87.9	89.0—86.0
				Cross-pollination 1962					
Ruotsinkylä	Ruotsinkylä ..	25	1 370	71.9	74.8—69.0	3	120	94.2	97.8—87.2
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	—	—	—	—
Laanila	Laanila	—	—	—	—	—	—	—	—
Total and mean 1962		25	1 370	71.9	74.8—69.0	3	120	94.2	97.8—87.2
Total and mean 1961+1962		30	2 072	77.8	79.0—75.6	15	1 224	88.5	89.9—87.2
				Self-pollination 1961					
Ruotsinkylä		12	1 147	94.2	95.1—93.8	5	204	96.6	98.6—93.2
Laanila		—	—	—	—	2	229	91.3	94.5—87.0
Total and mean 1961		12	1 147	94.2	95.1—93.8	7	433	93.8	95.9—91.0
				Self-pollination 1962					
Ruotsinkylä		9	1 548	67.7	71.0—65.0	—	—	—	—
Laanila		—	—	—	—	—	—	—	—
Total and mean 1962		9	1 548	67.7	71.0—65.0	—	—	—	—
Total and mean 1961+1962		21	2 695	79.0	80.0—77.5	7	433	93.8	95.9—91.0

there seems to have been a lower germination percentage in 1962 than in 1961.

If we take the mean germination percentage after self-pollination in all birches together, we get for the trees from Lapland a mean of 88.1 % in 1961, compared with the mean for Ruotsinkylä which is 92.7 %.

Comparison of the germination percentage for the pollen after cross-pollination with that after self-pollination gives the following results:

In 1961, the mean for cross-pollination in *B. verrucosa* was 84.5 % for all trees and 86.1 % for self-pollination. The difference between these means is only 1.6 %. The low value, 63 %, for the cross-pollination in the glasshouse seems to be an exception, perhaps due to insect damage.

In 1962, the mean for cross-pollination was 86.1 % for all trees and 67.9 % for self-pollination. The difference between these means is 18.2 % and significant at the 1 % level.

In 1961, the mean for cross-pollination in *B. pubescens* was 88.4 %for all trees and 94.1 % for self-pollination. The difference is 5.7 % but the germination percentage for the selfing is the higher one.

In 1962, the means were 81.3 % for cross-pollination and 67.7 % for self-pollination, with a difference of 13.6 %. However, the self-pollinations were made only in the greenhouse and there the cross-pollinations had a value of 71.9 %, the difference being only 4.2 %. The higher combined mean in this year is due to the good germination in the cross-pollinations in the forest. Thus, even in this case the difference between cross- and self-pollinations does not seem to be significant.

The only remaining case in which pollen germination was distinctly lower after selfing than after cross-pollination is in *B. verrucosa* in 1962. A re-examination of the different crosses showed that the reason for the very low germination percentage mean was the low value obtained in some particular crosses. However, when these crosses were later repeated, the germination percentage was just as high as in most of the normal cases and not distinctly different from the percentage obtained in cross-pollinations.

Interspecific pollination

Although no barrier to self-pollination was found to exist at the pollen germination level, there was still the possibility that this mechanism was responsible for the incompatibility between the species when these were crossed with each other. Therefore pollen germination was also studied after interspecific pollination.

In the cross *B. verrucosa* × *B. pubescens* (table 3), and again taking all the trees of S. Finland and Lapland together, the mean germination in 1961 was 91.0 % in the greenhouse and 88.0 % in the forest.

In 1962 the means were 80.6 % and 57.9 % respectively.

The overall mean for 1961 and 1962 was 82.7 % in the greenhouse and 82.5 % in the forest. Thus, the only low value is that for Ruotsinkylä in 1962.

Since the mean germination after cross-pollination in *B. pubescens* was 88.4 % in 1962 and 81.3 % in 1962, there is no significant difference in the germination of the pollen of *B. pubescens* when germinating on the style of *B. verrucosa* in comparison with the germination after normal cross-pollination within the species.

The mean germination in the cross *B. pubescens* × *B. verrucosa* (table 3) was for all trees in 1961 93.7 %. In 1962, the mean was 70.1 %. The corresponding figures for *B. verrucosa* after cross-pollination were 84.5 % in 1961 and 86.1 % in 1962.

Although the mean for the species cross was slightly lower in 1962, the opposite was the case in 1961 and there does not seem to be much dif-

Table 3. Germination of the pollen in interspecific crosses between *Betula verrucosa* and *B. pubescens*.

Parents		Glasshouse pollinations				Forest pollinations			
Female	Male	Number of crosses	No. of pollen grains	Germination %	Germination Confidence intervals	No. of crosses	No. of pollen grains	Germination %	Germination Confidence intervals
B. verrucosa	*B. pubescens*			1961					
Ruotsinkylä	Ruotsinkylä ..	2	121	89.3	99.5—81.0	27	2 113	88.0	89.5—86.5
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	2	267	91.8	95.1—87.1	1	7	85.7	99.5—44.0
Laanila	Laanila	—	—	—	—	—	—	—	—
Total and mean 1961		4	388	91.0	93.0—87.0	28	2 120	88.0	89.5—86.5
				1962					
Ruotsinkylä	Ruotsinkylä ..	23	1 497	80.6	83.0—78.0	16	478	57.9	62.8—53.0
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	—	—	—	—
Laanila	Laanila	—	—	—	—	—	—	—	—
Total and mean 1962		23	1 497	80.6	83.0—78.0	16	478	57.9	62.8—53.0
Total and mean 1961+1962		27	1 885	82.7	83.5—80.4	44	2 598	82.5	83.5—80.4
B. pubescens	*B. verrucosa*			1961					
Ruotsinkylä	Ruotsinkylä ..	10	1 241	94.4	95.9—93.1	14	1 756	95.4	95.5—94.5
Ruotsinkylä	Laanila	4	85	95.3	98.9—87.2	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	8	922	91.2	92.9—89.9
Laanila	Laanila	—	—	—	—	6	405	88.6	91.5—85.0
Total and mean 1961		14	1 326	94.5	95.2—94.8	28	3 083	93.3	93.3—92.1
				1962					
Ruotsinkylä	Ruotsinkylä ..	26	2 971	70.0	72.1—67.9	5	232	73.1	78.9—67.0
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	—	—	—	—
Laanila	Laanila	1	96	65.6	75.1—56.0	—	—	—	—
Total and mean 1962		27	3 067	69.9	71.9—67.9	5	232	73.1	78.9—67.0
Total and mean 1961+1962		41	4 393	77.3	77.9—76.5	33	3 315	91.9	92.5—91.0

ference in the germination of *B. verrucosa* pollen on the style of *B. pubescens* compared with the normal case of cross-pollination within the species.

If the two crosses for the year 1961 are compared, we get the mean 88.1 % for *B. verrucosa* × *B. pubescens* and the mean 93.7 % for the cross *B. pubescens* × *B. verrucosa*. The difference between these means is 5.6 %.

In the year 1962, however, the germination in the cross *B. verrucosa* × *B. pubescens* was 75.1 % and in the reciprocal cross 70.1 %. The difference is now 5 %, but in this year the cross *B. verrucosa* × *B. pubescens* gave the better germination percentage.

It may be concluded that no consistent difference in pollen germination in this material has been found when species crosses are compared with intraspecific cross-pollinations. Neither does the direction of the species cross seem to make any difference to the pollen germination.

Other observations on pollen germination

To observe how rapidly germination takes place, two series of fixations were made in 1962 at different times after pollination. The mean germination percentages after the different periods were:

after 24 hours	93.2 %
» 36 »	88.2 %
» 48 »	95.3 %
» 60 »	87.2 %

Thus, it seems that germination of the pollen is fairly rapid and that the process is complete within the first 24 hours, perhaps even earlier.

It has been observed in other plants that styles may react with the pollen in different ways, depending on their stage of development at the time of pollination. Styles of *B. verrucosa* Ru 4, Ru 7 were therefore pollinated in 1961 at the earliest and latest possible stages of flower development, in addition to normal pollination at the optimal stage.

The mean germination at the earliest possible stage, when the styles are just visible between the scales of the inflorescence, was 84.0 %. This value does not differ significantly from the germination percentage found in pollinations at the second stage, 96.5 %.

When pollination was done at the latest possible stage, when the styles were starting to lose their deep red colour, the mean germination was 88.4 %. This value is likewise not very different from the figure obtained in the optimal stage. The pollen seems able to germinate to about the same extent during the whole period of flowering.

No experiments were made with styles which had started to wither, since it was found that at this stage the styles no longer caught pollen properly, their stickiness having disappeared.

In the curly birches when selfed, pollen germination was 85.9 % in E 675 and 77.6 % in E 676. These figures compare well with the values for other *B. verrucosa* selfed in the year 1961.

When the triploid birch E 1092 was used as male parent in a cross with *B. verrucosa*, 75 % of the pollen germinated and in a cross with *B. pubescens* 60 %. It was only to be expected that pollen from the triploid birch would have a slightly poorer germination due to its genetic constitution but the germination capacity of the triploid birch pollen is, nevertheless, fairly good. In general, the triploid crosses do not differ very much from the normal picture.

When *B. verrucosa* pollen was used on the styles of the triploid birch, its mean germination was 75 % and when pollen of *B. pubescens* was used in the same combination, it exhibited 85 % germination.

Pollinations with mixed pollen

In 1961, a series of pollinations with pollen mixtures, all 1 : 1, were carried out to see whether the different pollens would have any influence on each other. In these experiments the mean germination percentages were as follows:

B. verrucosa × *B. verrucosa* + *B. pubescens*	87.7 %
» × *B. verrucosa self* + *B. pubescens*	84.7 %
» × » » + *B. verrucosa*	79.2 %

These values are very similar to those obtained in the corresponding pure crosses:

B. verrucosa cross	87.9 %
B. verrucosa self	85.5 %
B. verrucosa × *B. pubescens*	88.0 %

Other combinations

In a single experiment a tree of *Betula mandschurica* (Reg.) Nakai var. *japonica* (Miq.) Rehd. was pollinated with *B. verrucosa*. The pollen germination was 70.0 %. In the reciprocal cross the pollen germination was 71.4 %. However, in a cross between two trees (Nos. E 131 and E 141) both belonging to this Japanese species, the germination of the pollen of E 141 on the style of E 131 was 0 %. On a *B. verrucosa* plus-tree (No. E 999) the germination of the same pollen was 71.4 %. The reason for the failure in this intraspecific cross is not known and this case needs further investigation.

Observations on pollen quality

Artificial germination tests have not been made with the pollen used in the crosses mentioned above. The routine method, germinating the pollen in 0.1 % agar in 10 % sugar solution, has sometimes been used in testing birch pollen at the Maisala station. Observation of the frequency of filled and stained grains after treatment of the pollen with acetocarmine-glycerine was made on all trees. The pollen quality of the trees from Southern Finland, when measured as the % of well-developed grains staining with acetocarmine, was in general good. The mean value for *B. verrucosa* is 98.4 % (confidence limits 97.0—99.0) and for *B. pubescens* 99.1 (98.5—99.9). The differences between different years do not amount to more than 1 % for the trees investigated. On the other hand, the pollen quality of the trees from the north is lower. For the *B. verrucosa* trees from Lapland the percentage of well-developed and stained grains is 76.9 (74.0—81.0) and for *B. pubescens* 97.2 % (96.0—98.5). The lower quality, especially of *B. verrucosa* pollen,

in Lapland has been observed by me in other connexions also and does seem to be a character of the individuals in question and not, perhaps, so much a result of a general influence of the climate.

S a a r n i j o k i (1941) reported 73 %, as the highest germination for *B. verrucosa*, 68 % for *B. odorata* and 17 % for *B. japonica* when the pollen was tested in vitro. He pointed out that a long time of forcing has an adverse influence on the germination of the pollen grain and that exposure to coal-gas or high temperatures also decreases the pollen germination.

As seen from our material, the germination of the pollen in vivo was in most cases good and higher than the above values from artificial cultures. There are no indications that pollen from the earliest, forced, crosses germinated differently from the later ones, in which no severe forcing methods were used.

Growth of the pollen tube

Arrest of the growth of the pollen tube is a common type of incompatibility in many plant species. The a priori hypothesis based on pollen structure and pollen formation suggested that this was the critical stage in *Betula*. Thus, the second phase of the study was to measure the growth and penetration of the pollen tube after different types of pollination and to observe the differences in growth, if any.

The growth of the pollen tubes is graphically summarized for each cross in the crossing schemes (figures 6, 9). In these graphs the abscissa gives growth of the pollen tube in length classes and the ordinates the percentage of pollen tubes in each class. Observations which are in some way uncertain are marked with broken lines. In the compound table for the year 1962 observations made on crosses in the forest are marked with dotted lines.

Cross-pollination

Pollen tube growth after cross-pollination was, in general, good (figures 2 and 3).

In *B. verrucosa* (table 4a) the mean pollen tube length in 1961 for all trees (S. Finland+Lapland) was 1.12 ± 0.30 units. In 1962, the mean length was 6.18 ± 0.24 units. The mean length for the trees from Ruotsinkylä in the year 1962 was 5.63 ± 0.44 units. For the trees from Lapland when pollinated on trees from Ruotsinkylä it was 7.41 ± 0.25 units and in the cross Lapland × Lapland 5.67 ± 1.29 units. In 1964, the mean length for Ruotsinkylä was 4.80. In three crosses made with Laanila trees the corresponding figure is 5.87 ± 0.13 and in the seven crosses between *B. verrucosa*

Table 4 a. Pollen tube growth in *Betula verrucosa*.

Parents		Glasshouse pollinations				Forest pollinations			
Female	Male	No. of crosses	No. of pollen tubes	Pollen tube length		No. of crosses	No. of pollen tubes	Pollen tube length	
				units	>5 units %			units	>5 units %
					Cross-pollination 1961				
Ruotsinkylä	Ruotsinkylä ..	2	63	0.60	0	10	546	2.10	11.3
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	—	—	—	—
Laanila	Laanila	—	—	—	—	1	12	0.81	8.3
Total and mean 1961		2	63	0.60	0	11	558	2.07	11.2
					Cross-pollination 1962				
Ruotsinkylä	Ruotsinkylä ..	22	1 192	5.63	62.2	16	316	7.61	92.7
Ruotsinkylä	Laanila	9	193	7.41	92.7	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	—	—	—	—
Laanila	Laanila	1	85	5.67	63.5	—	—	—	—
Total and mean 1962		32	1 470	5.87	66.3	16	316	7.61	92.7
					Cross-pollination 1964				
Ruotsinkylä	Ruotsinkylä ..	75	1 815	4.80	60.7	—	—	—	—
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	7	140	5.51	65.7	—	—	—	—
Laanila	Laanila	3	44	5.87	77.3	—	—	—	—
Total and mean 1964		85	1 999	4.87	61.4	—	—	—	—
Total and mean 1961+1962+1964		119	3 532	5.21	62.3	27	874	4.07	40.7

Table 5 a. Pollen tube growth in *Betula pubescens*.

Parents		Glasshouse pollinations				Forest pollinations			
Female	Male	No. of crosses	No. of pollen tubes	Pollen tube length		No. of crosses	No. of pollen tubes	Pollen tube length	
				units	>5 units %			units	>5 units %
					Cross-pollination 1961				
Ruotsinkylä	Ruotsinkylä ..	4	533	1.41	0.6	5	425	4.74	55.5
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	5	363	2.13	18.5
Laanila	Laanila	—	—	—	—	2	182	1.37	7.1
Total and mean 1961		4	533	1.41	0.6	12	970	3.13	32.6
					Cross-pollination 1962				
Ruotsinkylä	Ruotsinkylä ..	25	985	3.86	42.1	3	113	7.10	84.9
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	—	—	—	—
Laanila	Laanila	—	—	—	—	—	—	—	—
Total and mean 1962		25	985	3.86	42.1	3	113	7.10	84.9
					Cross-pollination 1964				
Ruotsinkylä	Ruotsinkylä ..	56	1 204	3.00	27.2	—	—	—	—
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	21	644	3.10	32.9	—	—	—	—
Laanila	Laanila	13	370	3.26	32.4	—	—	—	—
Total and mean 1964		90	2 218	3.07	29.7	—	—	—	—
Total and mean 1961+1962+1964		119	3 736	3.04	28.8	15	1 083	3.54	38.1

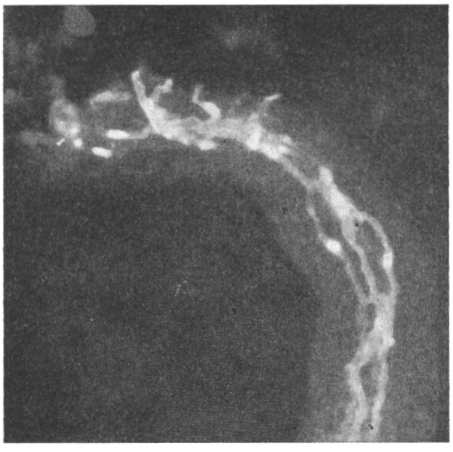


Figure 2. *Betula verrucosa*, cross-pollination. (Ru 2 × Ru 27).

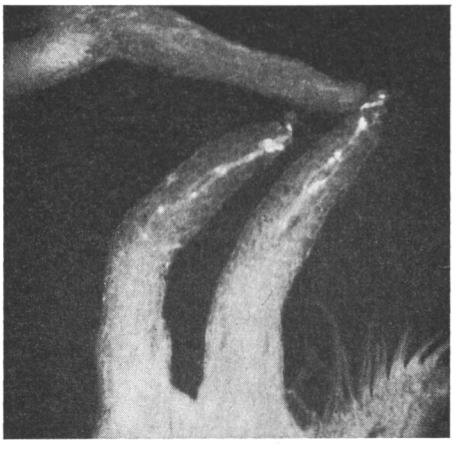


Figure 3. *Betula pubescens*, cross-pollination. (La 14 × La 11).

from Laanila and *B. verrucosa* from Ruotsinkylä = 5.51 ± 0.28. The mean length in the crosses made in the greenhouse in 1962 was 5.87 and for crosses made in the forest 7.61 units. The overall mean for 1961, 1962 and 1964 was 5.21 units in the greenhouse and 4.07 units in the forest.

In *B. pubescens* (table 5 a), the mean pollen tube length for all trees (S. Finland + Lapland) was 2.52 ± 0.40 units in 1961.

In 1962, the value for the trees from S. Finland was 4.19 ± 0.53. No flowers from the *B. pubescens* of Lapland were used in 1962. The mean length for the 25 crosses made in the greenhouse in 1962 was 3.86 ± 0.54 units and the three crosses made in the forest 7.10 ± 0.84 units.

In 1964, the mean pollen tube length was 3.00 units in all the crosses of this year made in the greenhouse with Ruotsinkylä trees. For the 13 combinations made between *B. pubescens* from Laanila in the greenhouse, the mean pollen-tube length was 3.26 ± 0.13, and for the combinations of Laanila trees with Ruotsinkylä trees the value was 3.10 ± 0.14. The total mean for the Laanila female parents was 3.09 ± 0.99 units.

The overall mean for the years 1961, 1962 and 1964 was 3.04 units in the greenhouse and 3.54 units in the forest.

Comparison of the pollen tube growth in *B. verrucosa* and *B. pubescens* reveals that the difference in 1961 was 0.60 scale units, the *B. pubescens* pollen growing better. In 1962, however, the pollen tubes of *B. verrucosa* had grown 1.99 units longer than those of *B. pubescens*. In 1964, the values were 4.80 for *B. verrucosa* and 3.00 for *B. pubescens*, the difference being 1.80 and in the same direction as in 1962.

Table 4 b. Pollen tube growth in *Betula verrucosa*.

Parents		Glasshouse pollinations				Forest pollinations			
Female	Male	No. of crosses	No. of pollen tubes	Pollen tube length		No. of crosses	No. of pollen tubes	Pollen tube length	
				units	>5 units %			units	>5 units %
				Self-pollination 1961					
Ruotsinkylä		3	89	0.46	0	7	265	0.75	0
Laanila		3	249	0.86	1.2	—	—	—	—
Total and mean 1961		6	338	0.75	0.6	7	265	0.75	0
				Self-pollination 1962					
Ruotsinkylä		12	1 423	0.56	0	4	47	0.25	0
Laanila		8	836	0.49	0.4	—	—	—	—
Total and mean 1962		20	2 259	0.53	0.2	4	47	0.25	0
				Self-pollination 1964					
Ruotsinkylä		3	70	1.20	5.7	—	—	—	—
Laanila		2	36	1.50	2.7	—	—	—	—
Total and mean 1964		5	106	1.30	4.7	—	—	—	—
Total and mean 1961+1962+1964		31	2 703	0.59	4.3	11	312	0.67	0

Thus, there seems to be a slight difference in the pollen tube growth of these two species when cross-pollinated, the *B. verrucosa* in our material giving a somewhat better pollen tube growth.

However, the mean pollen tube length does not give the best picture of the type of pollen tube growth, particularly if there happen to be two different fractions with different growth rates in the same pollen sample.

A better idea is obtained if a frequency distribution is plotted, showing the percentages of pollen tubes in the different length classes. This has been done in figures 6, 7, 9, 10, 11, 12 and 13. I will return to these distributions later.

Self-pollination

When the trees were self-pollinated, the first sign of incompatibility was that pollen tube growth was much retarded compared with cross-pollinations. The pollen tubes started to grow but clearly had some difficulty even in penetrating into the stylar tissue and pollen tube growth was retarded when the pollen tube did not penetrate into the style, as well as when it grew into the stylar tissue (figure 4).

In *B. verrucosa* (table 4 b), the mean length of the pollen tube for all trees (S. Finland + Lapland) was 0.75 ± 0.07 units in 1961. In 1962, the mean length for all trees was $0.52 + 0.002$ units. The mean length of the

Table 5 b. Pollen tube growth in *Betula pubescens*.

Parents		Glasshouse pollinations				Forest pollinations			
Female	Male	No. of crosses	No. of pollen tubes	Pollen tube length		No. of crosses	No. of pollen tubes	Pollen tube length	
				units	>5 units %			units	>5 units %
				Self-pollination 1961					
Ruotsinkylä		12	1 080	0.72	0.4	5	197	2.13	20.3
Laanila		—	—	—	—	2	209	1.21	1.9
Total and mean 1961		12	1 080	0.72	0.4	7	406	1.66	10.8
				Self-pollination 1962					
Ruotsinkylä		9	1 048	0.38	0	—	—	—	—
Laanila		—	—	—	—	—	—	—	—
Total and mean 1962		9	1 048	0.38	0	—	—	—	—
				Self-pollination 1964					
Ruotsinkylä		4	56	0.70	0	—	—	—	—
Laanila		5	132	1.20	3.8	—	—	—	—
Total and mean 1964		9	188	1.05	2.7	—	—	—	—
Total and mean 1961+1962+1964		30	2 316	0.59	0.4	7	406	1.66	10.8

pollen tubes in the trees from Ruotsinkylä was 0.46 ± 0.17 in 1961 and 0.56 ± 0.004 in 1962. In the trees from Lapland the mean pollen tube length was 0.86 ± 0.18 units in 1961 and 0.41 ± 0.01 units in 1962.

The mean pollen tube length in the pollinations in 1962 was 0.53 ± 0.002 in the greenhouse and 0.25 ± 0.00 in the forest. In 1964, the mean length was 1.20 units in the greenhouse for the Ruotsinkylä trees and in addition two trees from Laanila were selfed. In these combinations, the mean pollen tube length was 1.50 ± 0.38 units.

The general mean for the pollen tube length in self-pollinated trees in the years 1961—1964 was 0.59 ± 0.15 in the greenhouse and 0.67 ± 0.16 unit in the forest.

In *B. pubescens* (table 5 b), the mean length of the pollen tube for all trees (S. Finland + Lapland) was 0.98 ± 0.23 units in 1961. In 1962, the value was 0.38 ± 0.001 for the trees from S. Finland only.

The mean length of the pollen tubes of the trees from Ruotsinkylä pollinated in the greenhouse was 0.72 ± 0.22 in 1961 and 0.38 ± 0.00 units in 1962. In 1964, the corresponding figure was 0.70 ± 0.17.

In the trees from Lapland, the mean tube length in 1961 was 1.21 ± 0.50 in the forest. In 1964, six Laanila trees were selfed in the greenhouse, giving a pollen tube length of 1.2 ± 0.23 units.

The difference between Ruotsinkylä and Lapland was 0.92 unit in 1961 and $= 0.3$ in 1964, but these were of opposite sign in the two years.

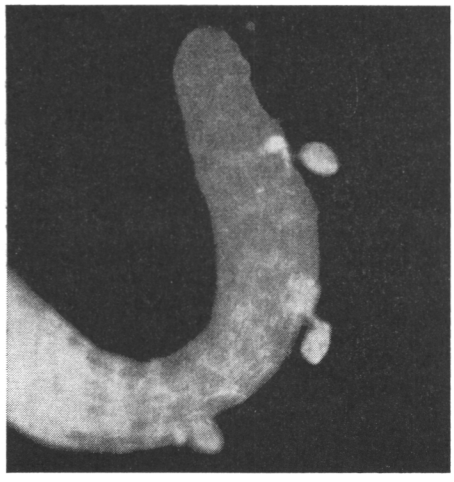


Figure 4. *Betula verrucosa*, self-pollination. (Ru 3 × Ru 3).

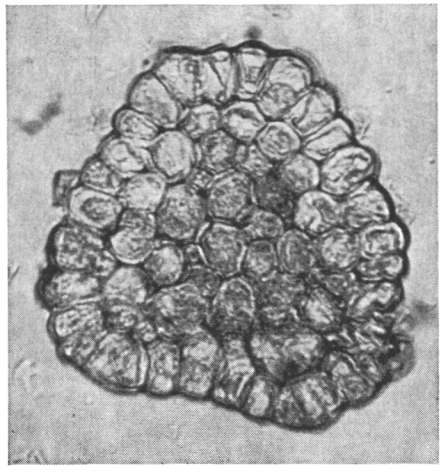


Figure 5. Cross-section of a birch style. The coarse structure of the style tissue is clearly seen.

The percentage frequency distributions of the length of the pollen tubes after selfing in *B. verrucosa* and *B. pubescens* are seen in figures 6, 7, 11 and 12.

The shape of these frequency distributions differs considerably from those of the cross-pollinations and they often give a picture of an asymmetrical, J-shaped distribution.

When pollen tube growth is compared after cross-pollination and self-pollination, the difference between the mean values in *B. verrucosa* in 1961 is found to be 1.17 units. This difference seems highly significant. The difference in the 1962 values is still greater, in that the mean for the cross-pollinations was 6.18 and for the self-pollination 0.52 units. In 1964, the values were 4.87 and 1.30, respectively, and the difference 3.57.

In *B. pubescens* we have the same picture. In 1961, the difference between cross-pollination and self-pollination was 1.54 units.

In 1962, the corresponding means were 4.19 and 0.38 units and the difference 3.81 units. In 1964, the values were 3.00 and 0.70, the difference being 2.30 for the Ruotsinkylä trees and 3.26—1.20 = 2.06 for the Laanila trees.

These results indicate a self-incompatibility mechanism both in *B. verrucosa* and in *B. pubescens*, acting at the stage of pollen tube growth and leading to the arrest of pollen tube growth after selfing.

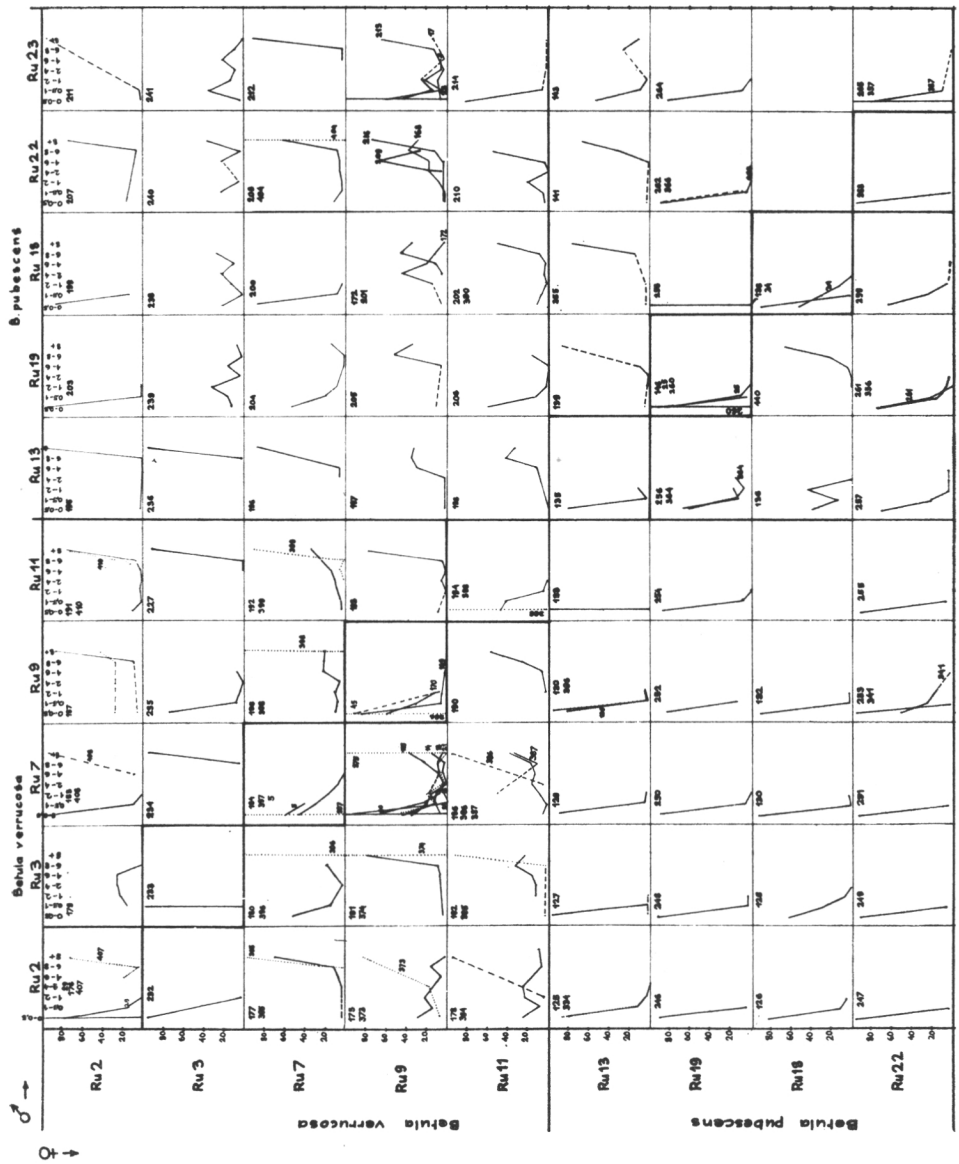


Figure 6. Birch crosses 1962 in Ruotsinkylä. Relative frequency of pollen tubes in length classes. The crosses No. 1—372 (——) were made in the glasshouse and the crosses Nos. 373—407 (.....) were made outdoors. Uncertain crosses are marked (------).

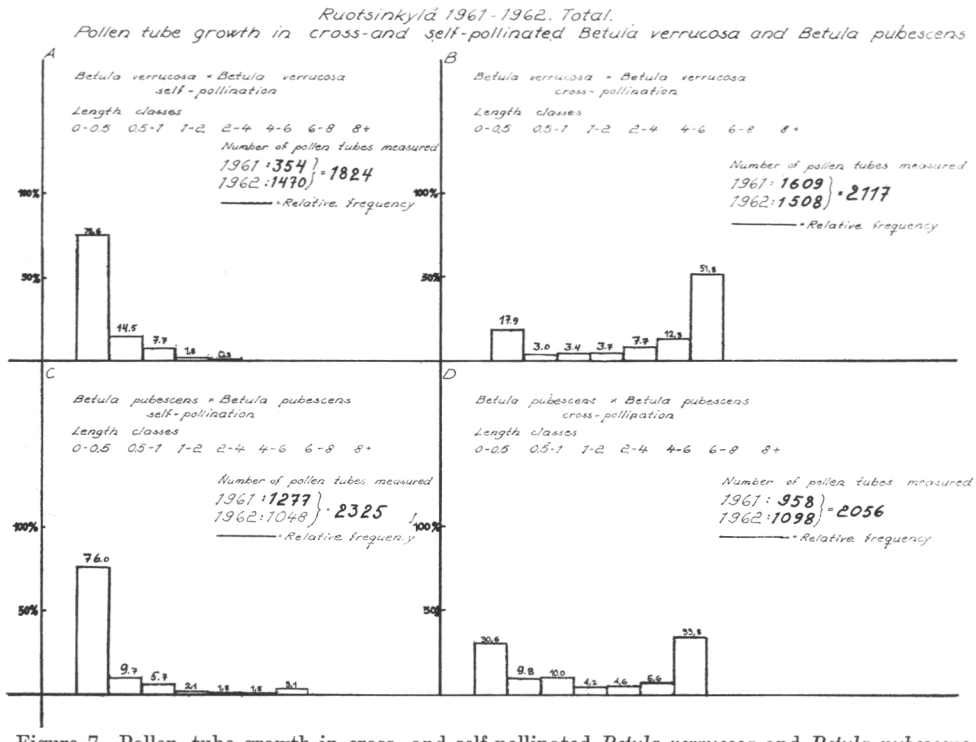


Figure 7. Pollen tube growth in cross- and self-pollinated *Betula verrucosa* and *Betula pubescens*. Ruotsinkylä 1961—1962. A. *B. verrucosa* × *B. verrucosa* self-pollination. B. *B. verrucosa* × *B. verrucosa* cross-pollination. C. *B. pubescens* × *B. pubescens* self-pollination. D. *B. pubescens* × *B. pubescens* cross-pollination.

Interspecific pollination

Since a self-incompatibility mechanism in the form of retarded pollen tube growth exists in the birch, it could be that the same form of incompatibility also appears between species of birch. The results of our interspecific crosses with *B. verrucosa* and *B. pubescens* support this hypothesis to a certain degree.

When all the trees from S. Finland and Lapland are included, the mean length of the pollen tube in the cross *B. verrucosa* × *B. pubescens* (table 6 a) was 1.72 ± 0.12 units in 1961. In 1962, the mean length of the pollen tube from the same cross was 4.96 ± 0.37 and in 1964 = 3.96 ± 0.15.

If we compare these figures with the length of the tubes produced by *B. pubescens* pollen when grown on the style of the same species after cross-pollination, we see that in 1961 the mean for the interspecific cross was 1.72 units and the mean for the intraspecific cross was 2.52 units. The dif-



Figure 8. *Betula pubescens* × *Betula verrucosa*, interspecific pollination. (Ru 14 × Ru 9).

ference is 0.80 units. In this year the pollen tubes appear to have grown less well on the styles of the other species.

In 1962, the means were 4.96 for the cross *B. verrucosa* × *B. pubescens* and 4.19 for cross-pollinated *B. pubescens*. The difference is 0.77 units but in this case the growth of the pollen tube in the interspecific cross is better than in normal cross-pollination within the species. In 1964, the interspecific cross gave a pollen tube length of 3.82 and the corresponding figure for cross-pollinated *B. pubescens* was 3.00, the difference being 0.82 units in the Ruotsinkylä trees.

In the 12 crosses made with the Laanila *B. verrucosa* as mother and Laanila *B. pubescens* as father, the pollen tube length was 5.0 ± 0.50 units and in the same cross but with Ruotsinkylä fathers 5.76 ± 0.84. The mean for the comparable *B. pubescens* cross-pollinations was 3.15 units.

Thus it appears that the growth of the pollen tube of *B. pubescens* in the interspecific cross *B. verrucosa* × *B. pubescens* is not consistently poorer than after cross-pollination of *B. pubescens*. On the contrary, in several cases the pollen tube of *B. pubescens* has grown more vigorously in the style of *B. verrucosa*.

This can also be seen in the graphs of the pollen tube distribution in figures 6, 9, 10, 11, 12, and is likewise seen in the photograph of a style in figure 8.

Among the distribution graphs for the individual crosses, there is an interesting type of curve with two peaks. This is particularly clear in the crosses of 1961 (figure 9) but also in 1962 (figure 6). This could be taken to indicate that *B. pubescens* has two kinds of pollen grains possessing different degrees of compatibility with the *B. verrucosa* styles.

Table 6 a. Pollen tube growth in interspecific crosses between *Betula verrucosa* and *B. pubescens*.

Parents		Glasshouse pollinations				Forest pollinations			
Female	Male	No. of crosses	No. of pollen tubes	Pollen tube length		No. of crosses	No. of pollen tubes	Pollen tube length	
				units	>5 units %			units	>5 units %
B. verrucosa	*B. pubescens*				1961				
Ruotsinkylä	Ruotsinkylä ..	2	108	2.18	0.9	27	1 859	1.84	7.6
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	2	245	0.6	0	1	6	1.67	16.7
Laanila	Laanila	—	—	—	—	—	—	—	—
Total and mean 1961		4	353	1.08	0.3	28	1 865	1.84	7.6
					1962				
Ruotsinkylä	Ruotsinkylä ..	23	1 207	5.06	56.2	16	277	5.41	63.2
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	—	—	—	—
Laanila	Laanila	1	63	1.11	4.8	—	—	—	—
Total and mean 1962		24	1 270	4.86	53.7	16	277	5.41	63.2
					1964				
Ruotsinkylä	Ruotsinkylä ..	137	3 244	3.82	43.9	—	—	—	—
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	5	117	5.76	70.1	—	—	—	—
Laanila	Laanila	12	241	5.00	61.8	—	—	—	—
Total and mean 1964		154	3 602	3.96	45.9	—	—	—	—
Total and mean 1961+1962+1964		182	5 225	3.98	44.7	44	2 142	2.30	14.8

In the cross *B. pubescens* × *B. verrucosa* the situation is different from the foregoing cross. When *B. pubescens* was pollinated with *B. verrucosa* (table 6 b), the mean pollen tube length in 1961 was 0.93 ± 0.12 units, when all the trees from S. Finland and Lapland were included. The mean for the Ruotsinkylä trees was 0.40 ± 0.20 in the greenhouse and 1.1 ± 0.30 in the forest. In Laanila the mean was 1.5 ± 0.17 units for the Laanila trees and 1.16 in the crosses involving Laanila and Ruotsinkylä trees.

In 1962, the mean length was 0.35 ± 0.25 in the greenhouse and 0.70 ± 0.25 in the forest, the total mean being 0.36 ± 0.21.

In 1964, the Ruotsinkylä trees gave a mean of 1.30 ± 0.12 units and the Laanila trees in 11 combinations with northern specimens of *B. verrucosa* a mean of 1.76 ± 0.09. In the crosses Laanila × Ruotsinkylä (n = 13), the corresponding value was 1.26 ± 0.08.

When these results are compared with the mean for cross-pollinated *B. verrucosa* it is seen that for 1961 the difference was 1.92—0.93 = 0.99 units. This difference is rather small. But in 1962, the difference between the same means was as much as 6.18—0.36 = 5.82.

In 1964, the difference was 4.80—1.30 = 3.50, i.e. again great, for the

Table 6 b. Pollen tube growth in interspecific crosses between *Betula verrucosa* and *B. pubescens*.

Parents		Glasshouse pollinations				Forest pollinations			
Female	Male	No. of crosses	No. of pollen tubes	Pollen tube length		No. of crosses	No. of pollen tubes	Pollen tube length	
				units	>5 units %			units	>5 units %
B. pubescens	*B. verrucosa*				1961				
Ruotsinkylä	Ruotsinkylä ..	10	1 172	0.40	0.25	14	1 675	1.11	7.2
Ruotsinkylä	Laanila	4	81	0.62	0	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	8	841	1.16	1.2
Laanila	Laanila	—	—	—	—	6	359	1.5	1.7
Total and mean 1961		14	1 253	0.41	0.23	28	2 875	1.17	4.8
					1962				
Ruotsinkylä	Ruotsinkylä ..	26	2 080	0.35	0	5	98	0.70	0
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	—	—	—	—	—	—	—	—
Laanila	Laanila	—	—	—	—	—	—	—	—
Total and mean 1962		26	2 080	0.35	0	5	98	0.70	0
					1964				
Ruotsinkylä	Ruotsinkylä ..	55	1 499	1.30	3.2	—	—	—	—
Ruotsinkylä	Laanila	—	—	—	—	—	—	—	—
Laanila	Ruotsinkylä ..	13	407	1.26	1.9	—	—	—	—
Laanila	Laanila	11	318	1.76	14.9	—	—	—	—
Total and mean 1964		79	2 224	1.36	4.6	—	—	—	—
Total and mean 1961+1962+1964		119	5 557	0.77	2.36	33	2 973	1.15	0.5

Ruotsinkylä trees, and $5.87 - 1.76 = 4.11$ for the Laanila trees. Except for the year 1961, the mean pollen tube length for this type of cross does differ from the corresponding value in a normal cross-pollination.

Figures 10, 11 and 12, giving the distribution of the pollen tubes in length classes, also indicate that the pollen tube of *B. verrucosa* does not function properly in the styles of *B. pubescens*. This cross also differs from the reciprocal in that there does not seem to be any fraction of the pollen capable of producing pollen tubes that grow well in the style of *B. pubescens*.

It may thus be concluded that interspecific incompatibility at the stage of pollen tube growth exists in the cross *B. pubescens* × *B. verrucosa*.

There are, however, individual exceptions to this rule. The behaviour of the *B. pubescens* No. Ru 17 is particularly different in this respect, and so is the behaviour of *B. pubescens* No. Ru 22. These trees will be discussed in greater detail later.

Pollen tube growth in some other cases

In 1961, two series of fixations were made in order to study the rate at which the pollen tube penetrates the style. One of these represented

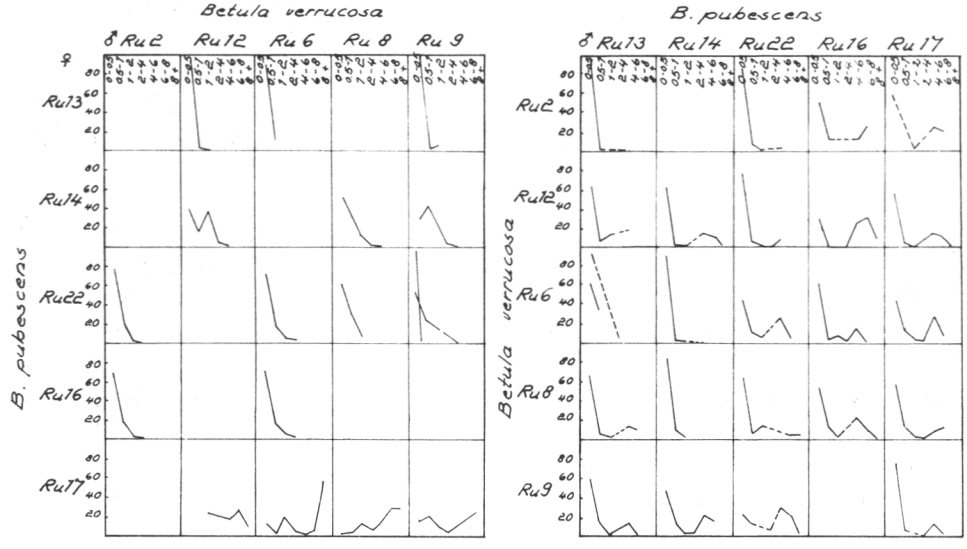


Figure 9. Birch crosses 1961 in Ruotsinkylä. Relative frequency of pollen tubes in length classes. All these crosses were made outdoors.

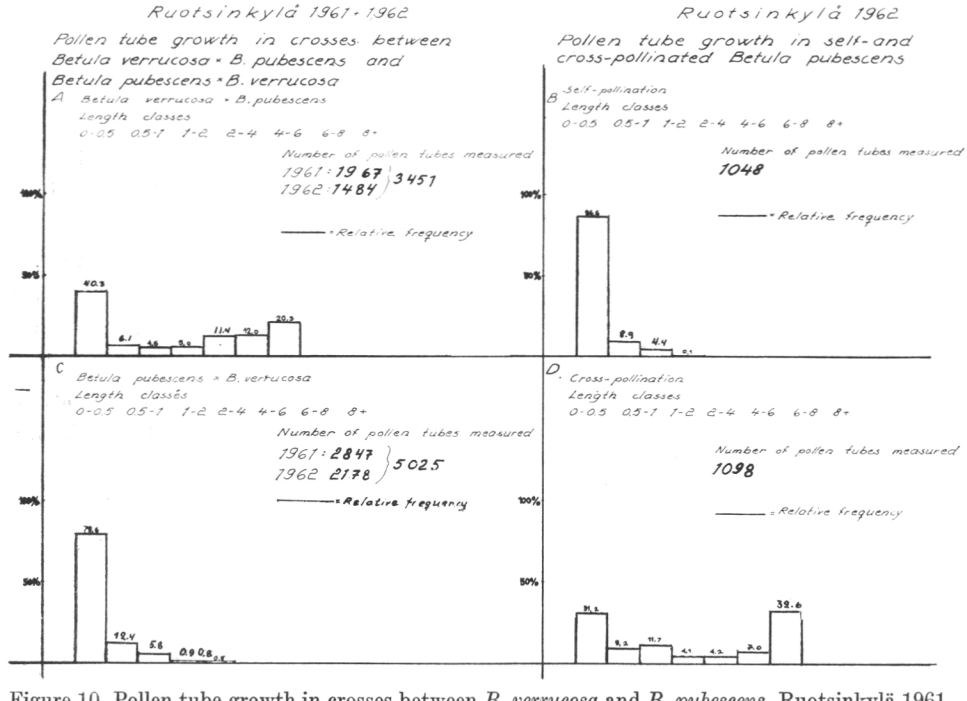


Figure 10. Pollen tube growth in crosses between *B. verrucosa* and *B. pubescens*. Ruotsinkylä 1961—1962. A. *B. verrucosa* × *B. pubescens*. C. *B. pubescens* × *B. verrucosa*. Compare with B, *B. pubescens* self-pollination 1962 and D. *B. pubescens* cross-pollination 1962.

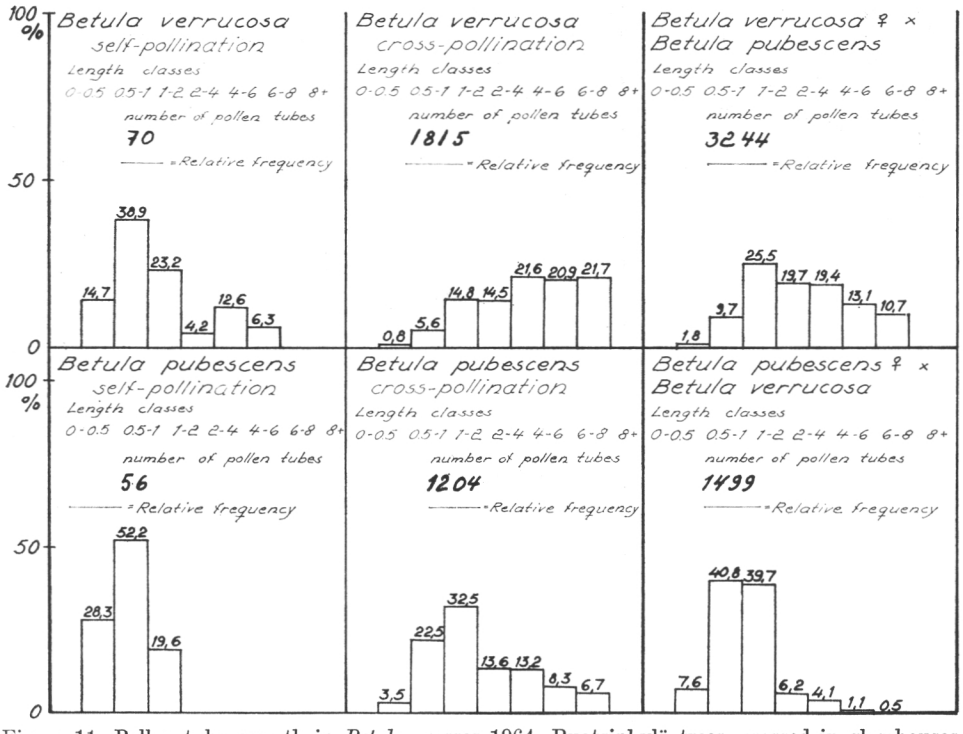


Figure 11. Pollen tube growth in *Betula* crosses 1964. Ruotsinkylä trees, crossed in glasshouses.

cross-pollinated *B. verrucosa* (Ru 9 × Ru 11) and the other the cross *B. verrucosa* × *B. pubescens* (Ru 9 × Ru 22).

Fixations were made 24, 36, 48 and 60 hours after pollination.

The average length of the pollen tubes in the two crosses was:

	Ru 9 x Ru 11	Ru 9 x Ru 22
24 hours	7.1	5.7
36 »	7.1	6.6
48 »	5.9	3.9
60 »	not observed	3.1

It seems that the pollen tube grows very rapidly through the upper part of the style and that the incompatibility mechanism, if any, must be able to come into effect immediately after the pollen has started to germinate. The slight trend towards shorter pollen tubes after later fixation might be because some pollen grains germinate later than the main group and are thus included in the first length classes when measured simultaneously with the more vigorously growing tubes. The rate at which the pollen tube grows during the first 24 hours was not investigated. Nor have I studied the later phases of pollen tube growth, although these might show interesting features,

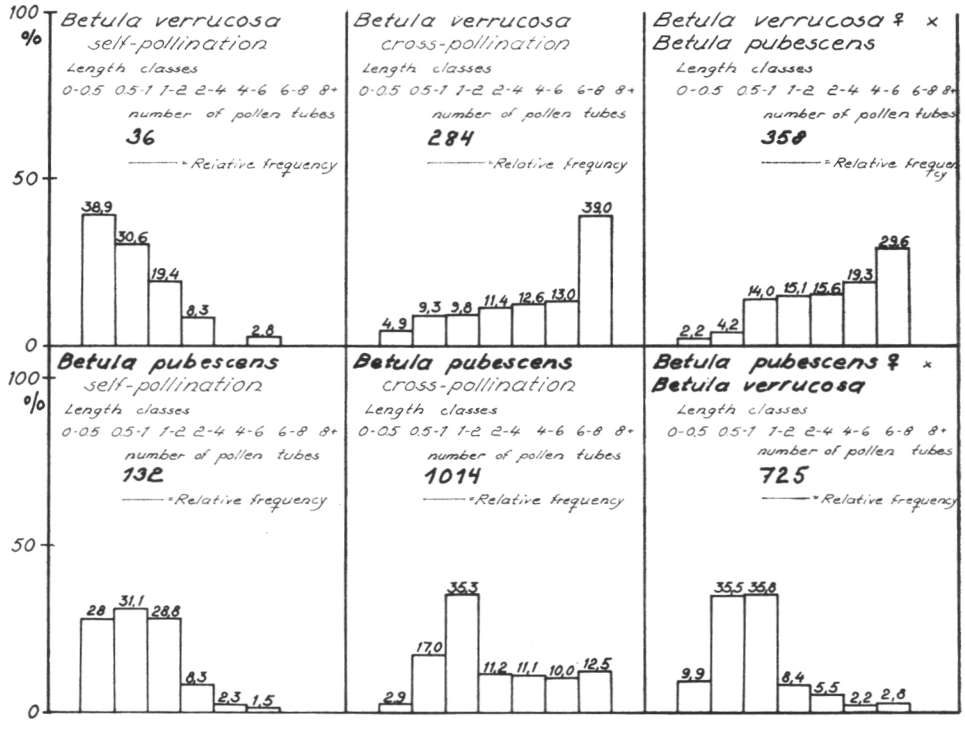


Figure 12. Pollen tube growth in *Betula* crosses 1964. Laanila trees, crossed in glasshouses.

since, as mentioned in the introduction, the time taken for fertilization is rather long, and Nawaschin (1894, p. 20) mentioned the important fact that the pollen tube stops growth at the base of the style for some time and resumes growth when division of the primary embryo-sac nucleus begins.

There is sometimes a tendency to increased compatibility in otherwise incompatible crosses when pollination is carried out at a late stage of flower development. Hence it was of interest to observe pollen tube growth after pollination at different stages of flower development.

In the self-pollinated *B. verrucosa* Ru 4 in 1961 the mean pollen tube length when pollinated at the first developmental stage was 0.43 units. When the same tree was selfed at the late stage of flower development the mean pollen tube length was 1.72 units. The same was the case with the tree Ru 7, where the figures for self-pollination were 0.25 and 2.43 respectively.

In the cross Ru 20 × Ru 6 (*B. pubescens* × *B. verrucosa*) there was also a slight tendency for better compatibility in the late cross. The mean pollen tube length in the first stage was 0.29, in the second 0.36 and in the third (late) stage 1.62.

The two curly birches E 675 and E 676 showed the same features as normal *B. verrucosa*. The mean pollen tube length after selfing was 0.80 for E 675 and 0.73 for E 676. The corresponding value for all the other *B. verrucosa* after selfing was 0.64.

In 1961, the triploid *B. verrucosa* No. E 1092 was used as the male parent in a cross with the tree La 1. The mean pollen tube length in this cross was 0.36, although 4 % of the pollen tubes reached the length class 2—4 units. The reciprocal cross gave a pollen tube length of 1.37 units.

In an interspecific cross triploid × *B. pubescens* the mean pollen tube length was 2.05, which does not differ significantly from the comparable general mean for the pollen tube length in the cross *B. verrucosa* × *B. pubescens* (1.75 ± 0.12).

In 1962, the triploid *B. verrucosa* was used as the male parent in a cross with one *B. pubescens* (Ru 18). The mean pollen tube length from this cross was 0.33 units. In a cross normal *B. verrucosa* × triploid, the mean pollen tube length was 4.60 units.

Unfortunately, the triploid self-pollinations in 1962 were disturbed by insects and these have not yet been repeated.

If the incompatibility mechanism were non-specific, one would expect that pollination with an incompatible pollen would completely block the function of compatible pollen also. If, on the contrary, the incompatibility mechanism is specific for the tree's own pollen and for pollen of another species, the results with mixed pollen should not differ from those obtained with compatible pollen used alone.

When *B. verrucosa* was pollinated with a mixture of *B. verrucosa* and *B. pubescens* pollen in 1961, the mean pollen tube length in five different combinations was 1.53 units. This is a little less than the value obtained from cross-pollinated *B. verrucosa* in general that year (1.92).

The tree Ru 10, when pollinated in 1962 with a mixture of its own pollen and that of another tree,gave a mean pollen tube length of 6.47 units. The mean for cross-pollinated *B. verrucosa* in that year was 6.76. The tree Ru 5, when pollinated with a mixture of self-pollen and *B. pubescens* pollen, showed a pollen tube length of 1.07 units compared with 0.64 for selfed and 1.65 for the cross *B. verrucosa* × *B. pubescens*.

The relative frequencies of pollen tubes in the different length classes in these crosses were:

	0.25	0.75	1.5	3.0	5.0	7.0	8+
B. verrucosa × self + cross	67.2	4.5		13.4		14.9	
» × self + *pubesc.*	66.4	9.6	10.9	13.1			
» × cross + *pubesc.*	42.5	11.3	3.8	10.4		22.6	9.4
» × cross (1962)	6.1	0.8	2.5	4.7	8.7	14.9	62.3

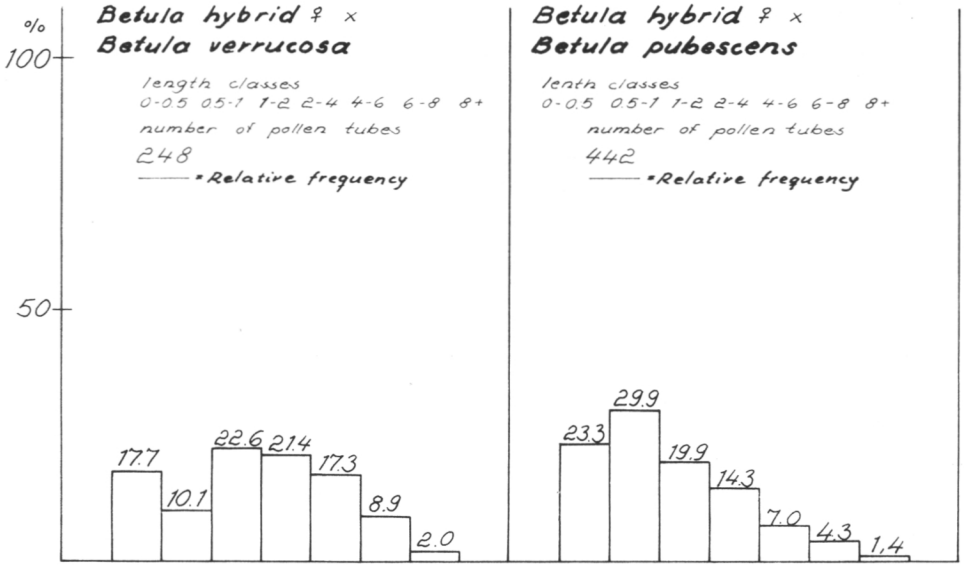


Figure 13. Pollen tube growth in *Betula* crosses. Hybrid trees crossed in glasshouses.

These results, although limited in number, seem to indicate that the incompatibility mechanism is specific for each case and that, at the stage of pollen tube growth, the incompatible pollen does not interfere with the growth of the compatible pollen when flowers are pollinated with pollen mixtures.

In 1964, it was possible to make some crosses with artificial hybrids between *B. verrucosa* and *B. pubescens* (cross No. 2611/68 × No. 70) made in Schmalenbeck, W. Germany.

When 8 different hybrid plants were pollinated with three *B. verrucosa* trees in 13 combinations, the mean pollen tube length was 2.5 ± 0.12 units.

When 7 of the same hybrid plants were pollinated with 4 *B. pubescens* in 17 combinations, the mean tube length was 1.8 ± 0.06 units. The difference is 0.7 units and the pooled standard error ± 0.36. Further crosses are necessary before one can say whether there are significant differences in the pollen tube growth of the two pure species in the styles of their hybrid. No other hybrid plants have so far been available for pollen tube studies. During the course of this work, however, plants have been produced that will give opportunities for further experiments when they have reached the flowering stage.

4. THE DEGREE OF INCOMPATIBILITY

Pollen tube growth

In judging the degree of incompatibility, one has to remember that it is difficult to be certain about the degree of incompatibility in compatible crosses, since pollen tube growth may be inhibited for various other reasons in addition to the possible presence of a common genetical S factor. Damage to the female flowers, by insects or abnormal temperatures, infertile pollen, errors in pollination or other disturbances will lead to negative results. On the other hand, signs of compatibility in cases where the general impression is of incompatibility, such as selfing or interspecific crosses — or, when genetically known material is available, after crosses between identical genotypes — are easier to detect. Nevertheless, when crosses are made out of doors the problem of contamination is important and special climatic conditions may also disturb the reactions.

Self-incompatibility

When *B. verrucosa* was selfed in 1961, all seven trees were incompatible.

In 1962, the degree of self-incompatibility was also virtually complete. Only in one case (Ru 12), which was self-incompatible in the greenhouse, was there compatibility in forest pollination. One explanation for this exceptional case is the possibility of contamination in the forest.

In 1964, there was one case (Ru 27) indicating a slight degree of self-compatibility.

In the *B. verrucosa* trees selected in the Laanila area in 1961 three individuals flowered well enough to be selfed. Two of them were highly self-incompatible. The third (La 3) showed some features of increased self-compatibility, the pollen tubes in this case reaching the length of 1.92 units. In the cross made in Laanila with the tree La 1 there was also a less strongly expressed incompatibility.

In 1962, the five *B. verrucosa* from Laanila were again selfed in the greenhouse and all were then highly self-incompatible.

In 1964, two of the Laanila trees (La 1 and La 5) were again selfed and La 1 was highly self-incompatible. On the other hand, in the tree La 5 the self-incompatibility was slightly decreased.

In *B. pubescens* in 1962 the degree of self-incompatibility in the nine trees tested in Ruotsinkylä was total. In 1964, only one additional tree was self-pollinated and showed the same feature.

In the *B. pubescens* from the Laanila area in 1961 the self-incompatibility reaction was not so pronounced as in the *B. verrucosa* trees and the pollen tubes were somewhat longer. These self-pollinations were made in the forest, and, as will be discussed later, the weather was rather cold up there at the time of pollination.

In 1962, there were no selfed Laanila trees of *B. pubescens* but in 1964 five trees could be selfed in the greenhouse at Ruotsinkylä. Of these five selfings, the trees La 11 and La 15 have a somewhat lesser degree of self-incompatibility than the others.

As described earlier (Hagman, 1967a), certain growth conditions and dispersal habits give selective advantages to inbreeders. The hypothesis could be proposed that natural selection could have favoured self-compatibility in birch populations where the trees grow in small isolated groups either at the northern limit of the range of the species or in the southwestern archipelago, where the isolated islands may initially have been populated by very few individuals. To test this hypothesis, some trees were selected.

In 1961, six trees from the Åland islands were selfed but there was little indication of increased self-compatibility. The only one which had a rather good pollen tube growth after selfing was the tree Ål 7, but when this selfing was repeated in 1962 the inhibition of pollen tube growth was almost total. Pollen tube growth in two of the Åland trees, Ål 6 and Ål 2, was somewhat more vigorous than in normal selfings in 1961, and in 1962 pollen tube growth in the tree Ål 6 was again a little better. However, even in this case the pollen tube length was only 0.37 units.

Of the three *B. pubescens* from the island of Kökar, all were self-incompatible in 1961, the pollen tube length being 0.25—0.27 units. In 1962, five trees from the Brändö-Sottunga-Kökar archipelago (Bö 1—Bö 5) were tested and found to be highly self-incompatible. The only exception to all these observations was the tree Ål 10 in 1962, which, although self-incompatible the year before, now gave a nearly self-compatible reaction (pollen tube length = 5.56 units). I am inclined to attribute this anomalous result to a mistake in pollination, but of course there is always the possibility that some unknown factor may disturb the incompatibility mechanism in one particular year.

The birches from the northern limit of the range of *B. verrucosa* in Lapland did not show increased compatibility. The trees Ka 2, Ka 4 and In 7 were all highly self-incompatible. When crossed with other *B. verrucosa* they were fertile in all the combinations hitherto made.

The possibility remains, however, that these northern trees are self-

compatible to some extent in their natural environment, where the temperatures might be lower than in the greenhouse in the south. Other cases are known in which selection has favoured a specific interaction between temperatures and flowering behaviour in Arctic conditions.

Cross-incompatibility

In *B. verrucosa* in 1961 some combinations indicated cross-incompatibility. These were Ru 12 × Ru 6 in the greenhouse and Ru 6 × Ru 8, Ru 9 × Ru 8 and Ru 7 × Ru 4 in the forest. In addition, the cross between the curly birches E 675 and E 676 in the forest showed signs of cross-incompatibility.

In 1962, five *B. verrucosa* trees from the same stand were crossed in all the 25 possible combinations. In three of these (Ru 2 × Ru 7, Ru 3 × Ru 2 and Ru 3 × Ru 9) cross-incompatibility was indicated. In nine other cases (Ru 2 × Ru 3, Ru 7 × Ru 3, Ru 7 × Ru 9, Ru 7 × Ru 11, Ru 9 × Ru 12, Ru 9 × Ru 7, Ru 11 × Ru 7, Ru 11 × Ru 3 and Ru 11 × Ru 9) there was an indication of a compatibility of about 50 %. All the other combinations were compatible.

Six of these combinations could be repeated in 1964 and then it was found that three of them, Ru 3 × Ru 2, Ru 7 × Ru 3 and Ru 7 × Ru 9, were again cross-incompatible. In addition, in this year several other crosses were incompatible (Ru 3 × Ru 4, Ru 3 × Ru 5, Ru 3 × Ru 11, Ru 7 × Ru 2, Ru 10 × Ru 3, Ru 10 × Ru 24, Ru 12 × Ru 10 and Ru 12 × Ru 8). There were not enough combinations available to give a sufficiently clear picture of the crossability relationships between the *B. verrucosa* trees from Ruotsinkylä, but the following repeatedly appearing features may, nevertheless, be mentioned:

In two years the cross Ru 2 × Ru 3 has shown semi-incompatibility, and the cross Ru 3 × Ru 2 total incompatibility. Ru 7 × Ru 3 was semi-incompatible in 1962 and 1964. Ru 7 × Ru 9 was semi-incompatible in 1962 and incompatible in 1964. The cross Ru 7 × Ru 2 was incompatible in the only year it was tested. The S genotype of the trees Ru 2 and Ru 7 may thus be identical. This idea is supported by the observation that the cross Ru 2 × Ru 7 in 1962 and the cross Ru 7 × Ru 2 in 1964 are both incompatible. The trees Ru 2 and Ru 7 also gave the same incompatible reaction with the tree Ru 9 in 1962, but in 1964 the cross Ru 2 × Ru 9 was compatible. The cross Ru 9 × Ru 7 is at least semi-compatible but the cross Ru 9 × Ru 2 has not yet been obtained.

When the *B. verrucosa* trees from Laanila were crossed, the few combinations available from the years 1961—1964 were all fairly compatible.

In *B. pubescens*, in 1961, the crosses made with the Ruotsinkylä trees

indicated cross-incompatibility in three combinations (Ru 17 × Ru 13, Ru 16 × Ru 17 and Ru 13 × Ru 14). In addition, in the forest the cross Ru 22 × Ru 16 was semi-compatible.

Of the Laanila trees the cross La 12 × La 13 was incompatible, and the cross La 14 × La 15 perhaps semi-incompatible.

When the Ruotsinkylä trees were cross-pollinated in 1962, four trees crossed in all 16 different combinations gave nine combinations with indications of cross-incompatibility (Ru 13 × Ru 23, Ru 19 × Ru 13, Ru 19 × Ru 18, Ru 19 × Ru 22, Ru 19 × Ru 23, Ru 18 × Ru 13, Ru 22 × Ru 13, Ru 22 × Ru 19 and Ru 22 × Ru 18). When it was possible to repeat six of them in 1964, five repeatedly showed cross-incompatibility, namely Ru 22 × Ru 19, Ru 19 × Ru 13, Ru 22 × Ru 13, Ru 19 × Ru 22 and Ru 13 × Ru 23. The cross Ru 19 × Ru 23 was the only exception, but, as will be shown later, the seed-setting from this cross was low. It may be noted that the incompatible crosses in 1962 concentrate on two mother trees, Ru 19 and Ru 22.

In addition to the crosses mentioned above, which were made in the years 1962 and 1964, 11 of the 33 new combinations made in 1964 showed indications of cross-incompatibility. Of these 3 had Ru 19 as mother tree. In addition, a cross with Ru 22 as the female parent was incompatible, as had also been the case in 1961. The cross Ru 17 × Ru 22 was likewise incompatible.

In the Laanila birches, there was one incompatible cross, La 12 × La 13, in 1961, and in the combination La 14 × La 15 an indication of semi-incompatibility. When, in 1964, more crosses were available from the same stand, indications of semi-incompatibility were again found in the cross La 14 × La 15 and of incompatibility in the cross La 12 × La 13. In addition, the crosses La 11 × La 12, La 11 × La 15, La 13 × La 15 and La 14 × La 18 were incompatible and La 11 × La 13, La 13 × La 12 and La 13 × La 14 semi-incompatible.

Whether, in all cases, this indicates a high degree of cross-incompatibility in the *B. pubescens* trees from Laanila is, nevertheless, uncertain, since cross-pollinations made on the Laanila females with *B. pubescens* from Ruotsinkylä in some cases also indicated incompatibility and it is difficult to suppose that such close relationships exist between these two stands growing so far apart, unless the incompatibility mechanism in *B. pubescens* is based on factors from a very remote common ancestor.

The origin of the Laanila stand is natural and it might well be that conditions have favoured regeneration from a single tree or a very few trees, thus establishing close relationships between the Laanila trees. However, it has not yet been possible to repeat the crosses in the forest and obtain seed for studies.

In view of the results presented above, it is not so easy to state the degree of cross-incompatibility. There are, no doubt, cases indicating common genetical factors, but in many other combinations the crossing schemes are not complete enough to give a clear picture. The observed cross-incompatibilities may, nevertheless, support the conclusion that the fertility of a cross-pollination within a stand of *Betula verrucosa* or *B. pubescens* should not be taken for granted.

In the tables the values for the percentage of pollen tubes longer than 5 units has been chosen, somewhat arbitrarily, to give an idea of the compatibility when selfing and crossing are compared. However, even for compatible crosses the value may vary considerably, so I do not suggest that the figure of less than five units should be taken as the sole index of incompatibility. The best idea is undoubtedly obtained by looking at the pollen tube frequency polygons for each cross.

It has been seen that no clear evidence was found of increased self-compatibility in the particular areas where such a feature could have had selective advantages. In addition, it would be interesting to know whether populations growing far from each other have built up a system of increased cross-incompatibility as a sign of increased independence, in addition to the geographical isolation barrier. It has been suggested that evolution towards new species formation has worked in this way for many plants.

From this point of view, the crosses between the populations in Ruotsinkylä and Laanila are of interest. As can be seen from tables 4a and 5a, there is no clear evidence that the long-distance cross behaves in a different manner from the local ones. In 1964, there was an opportunity to repeat some of the earlier investigations with the trees from the Laanila area, but again there was no indication of a reproductive isolation mechanism at work at the incompatibility level.

Interspecific incompatibility

As mentioned above in the description of pollen tube growth, the cross *B. verrucosa* × *B. pubescens* in many cases gave good pollen tube growth. The combinations are too numerous to be listed here in detail, but the general impression is as follows:

In 1961, 25 combinations were made and of these 13 were compatible, 9 semi-compatible and 3 incompatible.

In 1962, 23 combinations were made in the greenhouse and 16 in the forest. Of these 25 were compatible, 8 semi-compatible and 6 incompatible.

In 1963 no crosses of *B. verrucosa* × *B. pubescens* were made, but in 1964 a great number of replicates of this cross were made in the greenhouse. Of the 105 combinations then made, 50 were compatible, 47 semi-compatible and 17 incompatible.

It is not possible to say for certain from these combinations that any particular tree, either as male or as female parent, was especially compatible, since the results vary very greatly between the individual combinations.

It is interesting to note, however, the ratio of compatible : semi-compatible : incompatible in the different years

1961 = 52 % : 36 % : 12 %
1962 = 64 % : 21 % : 15 %
1964 = 47 % : 45 % : 8 %

the proportions in the different years being very similar. Taking all years together, we get the figures 52 %: 38 %: 10 %, respectively, for the compatible, semi-incompatible and incompatible crosses.

This constancy of the proportions suggest that *B. pubescens* has a distinct background for its behaviour when crossed with *B. verrucosa*. The mechanism for this conspicuous feature is as yet totally unknown.

Taken in general, the degree of incompatibility in the cross *Betula pubescens* × *B. verrucosa* as seen from the growth of the pollen tubes, was much higher than in the reciprocal combination. There are, as we shall see, exceptions.

In 1961, most of the crosses made in the greenhouse were highly incompatible and only in two cases was pollen tube growth a little better. These were two combinations with a Laanila tree as male parent and one tree from Åland and the other from Ruotsinkylä as female parent.

In the crosses made in the forest, 10 out of 14 combinations were highly incompatible but the remaining four combinations were all highly compatible. In all these cases the mother tree was the same, namely Ru 17.

In the Laanila crosses pollen tube growth was in general somewhat better. Of the five crosses with Laanila trees, La 14 was less incompatible than the others. In the eight combinations involving Laanila and Ruotsinkylä trees, two cases were rather less incompatible (La 13 × Ru 8 and La 15 × Ru 8).

In 1962, in Ruotsinkylä in the forest four combinations were more compatible, one partly (Ru 22 × Ru 3) and three others very compatible. In these trees Ru 17 was again the mother. In the pollinations in the greenhouse this year all the 26 combinations with Ruotsinkylä trees were highly incompatible. Ru 17, however, was not tested in the greenhouse. The cross with the tree La 13 was also slightly compatible, as in 1961.

In 1964, the growth of the pollen tubes in the greenhouse was rather better than in earlier years. Of the 55 combinations made, 10 were more compatible. Of these 10, the tree Ru 17 was the female parent in 8 cases, the remaining 2 combinations having Ru 22 as the female parent.

Of the Laanila trees crossed with each other, 9 combinations indicated

compatibility. Of these the tree La 11 was the female parent in 4 combinations and the trees La 12, La 13 and La 14 in the others.

Hence,it may be concluded that in the species cross *B. pubescens* × *B. verrucosa*, trees showing a higher degree of compatibility in the form of pollen tube growth are less frequent than in the reciprocal cross, but that some exceptional individuals do exist. One particularly conspicuous tree, when used as the female parent, is *B. pubescens* Ru 17. I will discuss this tree in greater detail.

This tree was very compatible in an interspecific cross with *B. verrucosa* in 1961 and the frequency distribution of the pollen tubes is similar type to that obtained after cross-pollination of *B. pubescens* × *B. pubescens.*

In 1961, the mean pollen tube length in the styles of this tree after combinations with 4 different *B. verrucosa* was 4.84 units, compared with the mean 1.16 for all combinations.

In 1962, the mean pollen tube length in the styles of this tree when pollinated with three further trees of *B. verrucosa* was 5.14 and again very different from the general mean of the cross *B. pubescens* × *B. verrucosa*, which was 0.41 units.

In 1964, eight crosses with this tree as female parent were again compatible, as mentioned above.

One might, of course, take the view that the tree Ru 17 was not a *B. pubescens*, although phenotypically it behaves in all respects as a tree of this species.

However, when the tree Ru 17 was used as male parent in crosses with *B. pubescens*, the mean pollen tube length for four different crosses in 1962 was 4.77 units, which differs considerably from the general mean of the cross *B. pubescens* × *B. verrucosa* and is of the same magnitude as the normal cross *B. pubescens* × *B. pubescens.*

On the other hand, in 1961 the cross between Ru 17 and the *B. pubescens* Ru 13 gave a pollen tube length of only 0.78. On another *B. pubescens*, Ru 14, the same pollen of Ru 13 gave a pollen tube length of 5.56 units.

Thus it seems that in the tree Ru 17 the species incompatibility barrier is removed or that the incompatibility mechanism is in some way arrested. The general condition of growth of this tree is rather poor and the flowering irregular. Grafts have been made for later studies.

Other trees, which through the years have shown a somewhat lower degree of incompatibility as the female parent, are Ru 22, La 11, La 13 and La 14 and perhaps also La 12.

Seed formation

The results of the seed studies are summarized in table 7.

Table 7. The seed development in *Betula verrucosa* and *Betula pubescens* after different kinds of pollination.

Parents	1961			1962			1964		
	Number of crosses	Empty seed %	Confidence intervals	Number of crosses	Empty seed %	Confidence intervals	Number of crosses	Empty seed %	Confidence intervals
B. verrucosa cross-pollin.	29	51.2	46.5—56.0	6	87.2	83.5— 90.5	10	93.7	91.0—95.4
B. verrucosa self-pollin.	8	99.4	99.5—98.7	2	99.8	99.0—100	7	85.9	82.1—89.1
B. pubescens cross-pollin.	20	71.9	67.0—76.1	—	—	—	16	86.4	83.8—90.9
B. pubescens self-pollin.	6	88.3	85.0—91.5	—	—	—	4	97.7	96.0—93.9
B. verrucosa wind-pollin.	9	31.5	73.0—63.9	—	—	—	7	44.1	60.5—51.0
B. pubescens wind-pollin.	5	74.3	69.9—78.5	—	—	—	5	46.2	58.5—48.5
B. verrucosa × *B. pubescens*	25	96.2	94.5—97.9	10	99.2	98.0— 99.8	18	97.3	95.1—98.5
B. pubescens × *B. verrucosa*	51	99.1	98.0—99.9	4	97.1	95.1— 98.5	6	90.6	85.4—99.2
B. verrucosa control	10	98.2	96.5—99.5	2	100.0		13	98.8	97.3—99.3
B. pubescens control	10	98.9	97.5—99.6	—	—	—	10	96.4	94.9—97.1
Mean		82.8			96.0			87.4	

Cross-pollinations

In 1961, after cross-pollination, seed-setting (by which I mean the setting of filled seed, since, as is well known, birches form empty nutlets even without pollination or fertilization) was in general good.

The mean percentage of empty seed in *B. verrucosa* crosses was 51.0 ± 3.4 %. The seed-setting after the crosses between trees from Ruotsinkylä compared with the seed obtained from the cross Ruotsinkylä × Lapland did not show any significant difference between these two groups. The mean empty seed percentage is 49.3 % for the cross Ruotsinkylä × Ruotsinkylä and 55.7 % for the cross Ruotsinkylä × Lapland. The mean empty seed percentage for the *B. verrucosa* unpollinated controls was 98.2 %. The field germination with cross-pollinated *B. verrucosa* seed was made only with weighed and not with counted lots, but in general germination was good.

In 1962, the mean percentage of empty seed was 87.2 ± 0.36 %, and thus the seed-setting rather low for a *B. verrucosa* cross-pollination. This seed consisted of the crosses Ru 2 × Ru 7, Ru 2 × Ru 9, Ru 3 × Ru 2, Ru 3 × Ru 5, Ru 3 × Ru 7 and Ru 3 × Ru 11.

When the lots were investigated more carefully, it was found that the high value was mostly due to two crosses with very low seed setting: Ru 2 × Ru 7, giving 97 % empty seed, and Ru 3 × Ru 2, giving 95.5 % empty seed. As mentioned above in the discussion of pollen tube growth, in these two cases pollen tube growth indicated a high degree of cross-incompatibility. A third case, Ru 2 × Ru 9, gave 87.8 % empty seed and, as was also mentioned, even in this cross there is an indication of cross-incompatibility. In the other crosses the percentage of empty seed varied between 75 and 82 %.

In 1963, the number of crosses was limited, owing to the poor production of both male and female flowers. This is also reflected in the low quality of the seed from wind-pollinations. Of eight wind-pollinated trees the mean percentage of empty seed is as high as 90.5 ± 0.13 %. No cross-pollinated seed was available that year.

In 1964, wind-pollinated trees (n = 7) had a mean of 44.1 % empty seed.

In cross-pollinations (10 combinations) the corresponding value was 93.7 %. In this case, particularly high values were obtained in crosses with the tree Ru 3 as female parent, which in three combinations gave 98.7—99.7 % of filled seed.

In *B. pubescens* a total of 20 cross-pollinated combinations was available, of which 2 crosses were of the type Ruotsinkylä × Ruotsinkylä and had an empty seed percentage of 67.2 ± 6.4 %. In the cross Lapland × Ruotsinkylä there were 11 combinations and the mean for them was 66.6 ± 0.99 %.

In the crosses Lapland × Lapland (n = 7) the result was 81.44 ± 0.44 %. The difference between these two groups is 14.5 %, and thus in this year the fertility in Lapland was rather reduced.

The germination of the two lots tested in soil was 27.63 %, which agrees well with the proportion of filled seed in the same lots, 20.37 %.

The proportion of empty seed after wind-pollination in the forest for the *B. pubescens* in Ruotsinkylä was 74.2 ± 1.3 % (n = 5).

The *B. pubescens* controls in Ruotsinkylä (n = 3) gave 99.0 ± 0.44 % and in Laanila (n = 4) 98.7 ± 0.01 % empty seed, indicating somewhat more contamination in Laanila. This is understandable from the rather severe weather conditions during the time of pollination in Lapland that year.

In 1962, no cross-pollinated *B. pubescens* seed was collected.

In 1963, the wind-pollinated trees (n = 3) gave 95.6 ± 0.04 % empty seed and the cross-pollinated trees (n = 2) gave 96.7 ± 0.01 % empty seed. The controls had 99.96 % empty seed for the tree Ru 30 and 100 % empty seed for the tree Ru 31.

In 1964, wind-pollinated seed from five trees had a mean of 46.2 % empty seed. In this year flowering, as mentioned, was good. In cross-pollinations (n = 16) the corresponding figure was 86.4 %. One tree, Ru 19, gave a very high proportion of empty seed (91.0—99.1 %) in all crosses. The cross Ru 17 × Ru 23 was also poor. Three other crosses with the tree Ru 23 as male parent also gave rather high values, 91.0—93.9 %.

The control for *B. pubescens* in 1964 gave 96.4 %, this being due to the poor isolation of the trees, Ru 21 (72.2 %) Ru 14 (86.2 %) and Ru 29 (93.7 %). If the value for Ru 21 is omitted, the mean for the other eight controls is 96.8 %.

Self-pollinations

Seed setting after self-pollination was in general much poorer than after wind- or cross-pollination.

For *B. verrucosa* the mean percentage of empty seed was 99.8 ± 0.03 % in 1961 for the 6 lots from Ruotsinkylä. The only tree having less than 100 % empty seed was Ru 1.

For the two lots from Laanila, 93.6 ± 1.6 % of the seed was empty. This is mostly due to the low value of 85.9 % for the tree La 1. The reason in this case could well be contamination. In the germination tests with the seed from the same Laanila tree, a single plant was obtained from the 1 000 seeds sown. It may be remembered that the tree La 1 indicated somewhat less self-incompatibility when pollen tube growth was examined.

For the other five trees tested after selfing, germination of sown seed

was in general poor. The mean for them is 0.3 % germinated plants. The tree Ru 9 gave a value as high as 1.4 %.

In *B. pubescens*, the mean percentage of empty seed after selfing was 88.3 ± 8.7 % in 1961. This rather low value was due to the great variation in the different lots. In Ruotsinkylä the lowest value was that of the tree Ru 14, with 60.3 %, and the highest value was 99.75 %. In Lapland, the corresponding values were 75% for the tree La 12 and 98 % for the tree La 15. The seed lot of the tree La 15 (400 seeds only) gave the value 0.75 % when germinated. As the corresponding value of filled seed was 2 %, this could indicate that, as in many other cross-breeding plants, there is some degree of embryo mortality after selfing in *Betula*. The large lots of selfed seeds sown from the trees Ru 14, La 13 and La 14 gave in the first case 215 plants from 3 g of seed, in the second case 87 plants from 1.62 g of seed and in the third case 72 plants from 1.3 g of seed. It is not quite clear whether all these results are to be dismissed as due to poor isolation. There was a note attached to the seed of Ru 14 that some of the filled seeds were poorly developed.

In 1962, no selfed seed of *B. pubescens* was available and in 1963 only one tree was selfed and gave no filled seed at all.

In 1964, the amount of empty seed in the four trees tested was 97.7 %. The tree Ru 19 had the lowest value (94.2 %) and Ru 18 (97.3 %). However, there was no indication that these trees had less self-incompatibility when the pollen tubes were studied.

The degree of self-compatibility, judged from the production of good seed after selfing, must be considered very low in both *B. verrucosa* and *B. pubescens*. There are cases in which one or a few filled seeds per 1 000 seeds are produced and in addition some very exceptional values, of which it is not known whether they should be regarded as contaminations or as indications of some disturbance of the self-incompatibility mechanism.

The low germination of the selfed seed, even when the amount of filled seed was somewhat higher, might indicate that in selfing, in addition to the incompatibility mechanism, the process of embryo inviability was at work. Since the results of selfings are highly sensitive to contamination, the best way of studying the process closer would be to have the pollinations made on grafts brought to flowering in good time before the birch trees in the forest start shedding their pollen.

Interspecific crosses

In 1961, the mean percentage of empty seed after the cross *B. verrucosa* × *B. pubescens* was 96.2 ± 0.21 % in the 25 combinations tested. The mean for the Ruotsinkylä trees was 96.0 ± 0.15. The best result

was given by the cross Ru 2 × Ru 22 (53.5 % empty seed). The corresponding value for another cross with the tree Ru 2 as female parent (Ru 2 × Ru 14) was 93.0 %. Of the Laanila crosses the mean was 99.8 % empty seed.

The germination percentage for the 7 lots tested in soil was 4.53 %, the highest value being observed in the cross La 1 × La 14. The female parent used in this cross in general gave a fairly high percentage of filled seed.

In 1962, the mean for the same type of cross was 99.2 ± 0.22 % empty seed in the 10 combinations tested. Of these, two crosses (Ru 2 × Ru 21 and Ru 2 × Ru 22) were relatively fertile, having empty seed percentages of 89.8 % and 89.5 % respectively.

In a third cross (Ru 2 × Ru 18) the result was 93 %. In all the others the percentage of empty seed was above 99.5 %.

In 1964, the mean for all crosses (n = 18) was 97.3 %.

The crosses with Ru 8 and Ru 9 as mother tree and with the Ru 23 as pollen parent were better than the mean (89.7—92 %). When Ru 23 was used as pollen parent on the other trees (Ru 2, Ru 10 and Ru 11) the infertility was even greater (100—96.7 %). Complete failures occurred in the crosses Ru 11 × Ru 19 and Ru 11 × Ru 21. The most fertile cross was Ru 10 × Ru 13 (85.5 %).

The seed setting in this cross *B. verrucosa* × *B. pubescens* must in general be considered low. This stands in sharp contrast to the results of the pollen tube growth studies, where, as has been seen, there is in many combinations a fraction of about 50 % of the pollen tubes that shows a high degree of compatibility. Barriers to hybridization between the two species, when made in this direction, must therefore be considered to exist at two different levels, and perhaps to be due to two different mechanisms. At which level the second mechanism acts, I do not know.

In the cross *B. pubescens* × *B. verrucosa* the seed set was still lower than in the reciprocal cross. The mean empty seed for all the trees in 1961 (n = 45) was 99.05 %. Of this group 33 lots were tested in the soil. These lots were all from the Laanila trees and gave a mean germination of 1.71 %. The means for the trees La 13 and La 14, in which the pollen tube growth has shown an indication of increased compatibility, were 2.5 % and 2.97 % respectively. However, the value for the control lots of La 13 had a field germination of 2 %, so again contamination may be the cause of the increased compatibility.

The mean for the 13 000 seeds tested in the 13 combinations made with the tree La 11 as female parent was = 1.71 % germination. In 1964, when this tree was pollinated with *B. verrucosa* in the greenhouse, there was an indication of increased compatibility, the pollen tube length being 1.71 units.

In 1962, the mean for the four combinations made was 97.1 ± 0.82 %.

In this year one combination (Ru 22 × Ru 13) was responsible for the low mean, having a value of 83 % empty seed. The mean for the other combinations was 98.9 %. The tree Ru 22, which on several occasions was found to be different in the pollen tube studies also, merits further study.

In 1964, the cross Ru 21 × Ru 27 had the rather low value of 80.5 % empty seed. The corresponding pollen tube length figure was 1.0 unit. Unfortunately, the controls in 1964 were not so good as in earlier years, and particularly the mother tree Ru 21 has a low control value (72.2 %). This may perhaps explain the high compatibility obtained in this species cross.

No seed was available for the tree Ru 17 in 1961 but in 1964 the cross Ru 17 × Ru 4 gave 99.0 % empty seed, and the cross Ru 17 × Ru 27 100 %. The amount of empty seed in the corresponding intraspecific cross Ru 17 × Ru 22 was 59.2 %.

Seed setting in some other cases

Unfortunately, there were not enough catkins in 1961 for a complete evaluation of the seed setting after pollination at different times of flower development. In cross-pollination only two combinations were made at the first and the last stage of flower development. The mean percentage of empty seed in the former case was 34 % and in the latter 52 %.

In self-pollination only one cross (Ru 7 × Ru 7) was made and there the amount of filled seed in the early stage was 4.75 % and in the late stage 0.25 %. The corresponding germination values in the greenhouse were 34.9 % and 0 %.

These figures are in contrast to the observations on pollen tube length where in this cross, the mean pollen tube length after selfing at an early stage was 0.25 units but at a late stage 2.43 units.

In the cross *B. verrucosa* × *B. pubescens* the mean of five combinations made at the first stage was 99.4 % empty seed, of the same combination in the second stage 95.0 % and in the third stage 98.1 %. These figures must thus be regarded as only tentative.

In this respect the curly birches E 675 and E 676 did not differ from normal *B. verrucosa*. The mean percentage of empty seed after the cross-pollination in both directions was 36.7 % and after both self-pollinations 100 %. The triploid curly birch has not yet been tested for seed setting after artificial pollination, since it grows far away from the tree-breeding station and the grafts made are not yet flowering.

The analysis of the seeds after different types of mixed pollinations confirmed the results regarding pollen tube growth. In the cross *B. verrucosa* × *B. verrucosa* + *B. pubescens* the mean value was 62.06 % empty seed ($n = 4$).

In the cross *B. verrucosa* × self + *B. verrucosa* the mean was 56.25 %. *B. verrucosa* × self + *B. pubescens* gave 99.5 % empty seed (n = 2) and *B. pubescens* × *B. pubescens* + *B. verrucosa* gave 73.0 % empty seed.

Thus the incompatibility mechanism seems to be specific and does not interfere with the function of the compatible pollen grain in producing filled seed.

Chromosome numbers

In order to confirm the hybridity of the progenies, it was necessary to carry out chromosome studies. However, this has been done only in a limited number of plants and has in all cases been done on cells from root tips.

The results are summarized in table 8.

In the artificially crossed and self-pollinated *B. verrucosa* progenies the 9 plants so far investigated had the chromosome number 2n = 28. The same was true of the progeny of plants from 10 different mother trees after wind pollination.

In the *B. pubescens* plants all the progenies after artificial crossing, selfing or wind-pollination had the chromosome number 2n = 56.

In the species crosses the results were inconsistent. In the cross *B. verrucosa* × *B. pubescens* there were 11 plants with the chromosome number 2n = 28, 9 with 2n = 42 and one with 2n = 32.

In the reciprocal cross there were 6 plants with 2n = 28, 17 plants with 2n = 42 and 1 plant with 2n = 56.

When the chromosome numbers after the individual crosses were investigated, some interesting facts emerged. In the progenies of the tree Ru 22 after wind-pollination the chromosome number was 2n = 56, which supports the contention that this tree is a *B. pubescens*. This is further supported by the fact that the progeny after a cross between this tree and a *B. verrucosa* (Ru 22 × La 2) gave the chromosome number 2n = 42. However, when the tree Ru 22 was used as pollen parent in the combination *B. verrucosa* × *B. pubescens*, all the progenies (4 plants) had the chromosome number 2n = 28.

Thus the conclusion would seem to be that, when used as the female parent the tree Ru 22 behaves as a *B. pubescens* but when used as male parent it behaves as a *B. verrucosa*. These observations seem, nevertheless, to fit with the observations earlier made about the seed setting in crosses with this particular tree. In 1961 the cross Ru 2 × Ru 22 gave only 53.5 % empty seed, which indicates a high degree of compatibility. In 1962 the same cross gave 89.5 % empty seed, which is also a fairly low figure for this type of cross.

The other extraordinary tree, Ru 17, shows the same feature:

Table 8. The number of chromosomes in plants from different kinds of pollination in *Betula verrucosa* and *Betula pubescens*.

	Total number of plants	Distribution according to chromosome number			
		28	42	56	32
B. verrucosa cross-pollin.	5	5	0	0	0
B. verrucosa self-pollin.	4	4	0	0	0
B. pubescens cross-pollin.	10	0	0	10	0
B. pubescens self-pollin.	12	0	0	12	0
B. verrucosa wind-pollin.	10	10	0	0	0
B. pubescens wind-pollin.	12	0	0	12	0
B. verrucosa × *B. pubescens*	21	11	9	0	1
B. pubescens × *B. verrucosa*	24	6	17	1	0

The chromosome number after wind-pollination is 2n = 56, which supports the idea that the tree is *B. pubescens*.

When pollinated with *B. verrucosa* (Ru 17 × Ru 9), the chromosome number of the only plant in the progeny tested is 2n = 42, as would be expected. But again in the two combinations with Ru 17 as male parent (in the Ru 9 × Ru 17, Ru 12 × Ru 17), i.e. a cross of *B. verrucosa* × *B. pubescens*, the chromosome number is 2n = 28. Thus, Ru 17 also behaves as a *B. pubescens* when used as the female parent but as a *B. verrucosa* when used as the male parent, just as in the case Ru 22 above. We must now remember that these two trees are the ones that show increased compatibility when used as female parents in the generally very difficult cross *B. pubescens* × *B. verrucosa*.

A third interesting tree is the *B. pubescens* La 11. In the progeny of this tree, when used as the female parent, in the interspecific cross *B. pubescens* × *B. verrucosa*, six plants have the chromosome number 2n = 28, but 7 others 2n = 42.

Unfortunately, chromosome numbers for La 11 wind-pollinated and La 11 cross-pollinated with another *B. pubescens* are missing.

Although preliminary, the chromosome studies seem to support the statement made on the basis of pollen tube and seed-set studies, that the trees Ru 22, Ru 17 and La 11 possess an extraordinary genetical constitution.

All the chromosome numbers are to be taken as preliminary, since variable chromosome numbers have often been found in root tips, and aneuploids have frequently been observed. In addition, the chromosomes of *Betula* are small and rather difficult to stain and to observe. The presence of additional chromosomes or the absence of some of the normal set may easily be overlooked. From the point of view of incompatibility, single additional chromosomes or chromosome fragments are of interest, since such distur-

bances have been found to upset the normal incompatibility mechanisms in other plants (Brewbaker and Natarajan, 1960). Such details, however, can best be observed at meiosis. When the progenies from the crosses have reached the mature stage and flowers are available, the chromosome studies will be continued, but this will take some years yet.

All attempts to shorten the rotation period artificially and to bring the plants to early flowering by the methods of Longman and Wareing (1959) have, so far, met with no success in our material.

5. EXTERNAL FACTORS AFFECTING INCOMPATIBILITY

Insects

As mentioned briefly above, it was found that insects attacked the styles, causing serious disturbances in the germination and growth of the pollen.

This was first observed when there was no sign of pollen germination on certain styles that had been cross-pollinated. When a larger number of styles of this sort were compared with normal ones, it was observed that the tissue at the base of the styles stained abnormally (figure 14). In normal cases the basal part of the style and the upper part of the ovary, when seen in ultra-violet light, have a light blue-green fluorescence. In all cases where inhibition of pollen germination was observed there was a brownish-stained layer at the base of the styles and at later stages a brown zone developed across the style. Even when there was the smallest trace of this brown staining the pollen usually remained ungerminated.

When the flowers were studied, it was found that there were two genera of insects living on them. These insects overwintered in the form of eggs on the buds and developed immediately after the twigs were taken into the warm greenhouse.

One of the insects was found to be an aphid, *Euceraphis punctipennis* (Zett.). This aphid is well known to live on birch in Finland. The other insects were found to belong to the genus *Oncopsis* (Homoptera, Cicadoidea), of which four different species are known to live on birch. Without rearing the insects it is difficult to say which of these species was present in this case. Entomological experts consulted considered it probable that the disturbances were caused by *Oncopsis* rather than by the aphids.

The insect attack was, as mentioned, rather severe and caused severe failures in the crossing programme. It is possible that such an attack might reduce fertility in natural conditions, even if the amount of pollination were sufficient. But, as the temperature was higher in the greenhouse than in the forest, it might also be that the lower temperature conditions in nature prevent the development of the insects from keeping pace with the development of the flowers. This might lead to irregular attacks, depending on whether the temperatures each year are suitable for the trees alone or for both trees and insects.

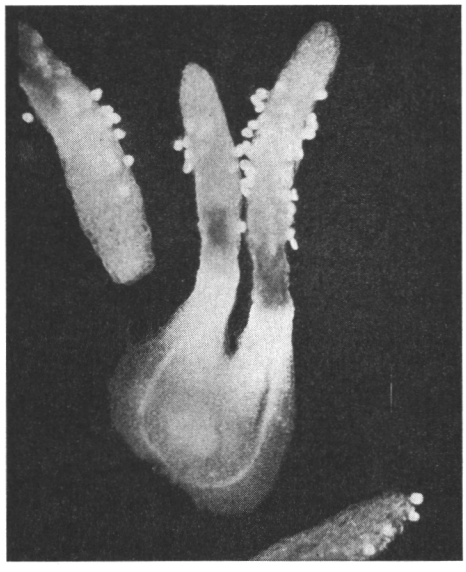


Figure 14. Damage to styles caused by insects (*Oncopsis* sp.), dark zones leading to complete prevention of pollen germination.

Damage to seed-setting caused by these insects seems not to have been reported before. The nature of the damage is such that the results may easily be mistaken for signs of incompatibility. In incompatibility studies it is therefore necessary to keep in mind the possibility of disturbances of this kind.

In tree breeding work, the insects, as has been stated (p. 15), can easily be destroyed by treating the twigs with DNOC winter spray. When this was done in our experiments the pollen germination that occurred in the cases where it had previously failed, was normal.

It is biochemically interesting that even the first signs of insect damage are correlated with inhibition of pollen germination, before any major morphological disturbances can be seen. It seems possible that the insect, when starting to feed on the tissue, secretes some substances which prevents pollen germination. Biologically very specific substances secreted by insects and leading to particular reactions are well known, for instance, from galls on many trees. From the point of view of the general process of pollen germination and pollen tube growth, the inhibitory substances produced by insects may form an interesting field of study. It is also possible, of course, that the inhibition is due to some phytoalexins produced by the plant in response to the attack.

Whether, in 1964, pollen tube growth was also disturbed by insects or by some other unknown factor is not clear. In this year the pollen tube measurements made after fixations in the forest did not show any significant

differences between the different types of crosses. In all cases the mean pollen tube length was short. The values were for *B. verrucosa* cross-pollination 0.7 units (5 crosses), for *B. pubescens* cross-pollination 0.8 units (21 crosses), *B. verrucosa* × *B. pubescens* 0.7 units (11 crosses) and *B. pubescens* × *B. verrucosa* 0.7 units (10 crosses). These observations are based on measurements of between 100 and 800 pollen tubes for each type of cross.

On account of these disturbances, the data from the forest crosses in 1964 have been omitted from the tables.

From what has been said above, one explanation for the disturbances could be that in this particular year insect damage occurred too late for complete prevention of pollen germination but, nevertheless, led to inhibition of pollen tube growth. It might be noted that in 1964 the pollen tubes in the greenhouse crosses were also somewhat short. Thus another possible reason for the disturbances seen that year might be that the female flowers had in general incurred earlier damage, e.g. by frost.

Temperature

In the greenhouse the temperature during forcing of the twigs and at the time of pollination was kept constantly above +10°C. Temporarily, on sunny days, the temperature reached +27° to +30°C in the pollination cages.

In the forest the temperatures in 1961, at the time of flowering of *B. verrucosa*, were fairly high, the maximum being +12° to +14°C. The minimum at Ruotsinkylä that year was +5° to +7°C.

At the flowering of *B. pubescens* the temperature was about the same as for *B. verrucosa*.

In Lapland in 1961, the temperature rose rapidly and brought the two species to flowering simultaneously in a very short time. (I have seen this happen in several other years in far northern conditions.) However, the night temperatures in Laanila were much lower than in Ruotsinkylä and minima down to +1°C were observed at the measuring points and might have been even lower.

In 1962, the temperature scheme for the greenhouse was the same, and in the Ruotsinkylä forest a maximum temperature of +12°C was observed at the time of *B. verrucosa* flowering. In the evening and night the temperature fell to a minimum of +1.5° to +0.5°C at the time of pollination. At the flowering time of *B. pubescens* the maximum temperatures were between +13° and +14°C and the minimum temperature +5°C.

In other plants it has been shown that at high temperatures the incompatibility reaction is increased but that a low temperature at the time of

pollination might remove the incompatibility barrier to a certain extent (Lewis, 1942).

It was therefore of interest to see whether our data would reveal similar features. In 1962 in some of the *B. verrucosa* × *B. verrucosa* crosses there were crosses which were incompatible in the greenhouse but less incompatible in the forest. Such cases include Ru 2 × Ru 2, Ru 7 × Ru 9, Ru 7 × Ru 3 and Ru 9 × Ru 2. As we have seen, these combinations are best explained as signs of a genetic incompatibility mechanism at work, and thus the reaction of the mechanism towards temperature follows the general pattern.

If we compare the crosses made in the forests of Ruotsinkylä and Laanila in 1961, we also find that the slope of the frequency curve is less marked in Laanila, which indicates a slower development of the incompatibility reaction. This is seen especially in the cross *B. pubescens* × *B. verrucosa*.

The same feature is also observed in the seed-setting, where we have the following filled seed percentages for the crosses

but for	Ruotsinkylä	*B. pubescens*	× Ruotsinkylä	*B. verrucosa*	0.64 %
	Ruotsinkylä	»	× Laanila	»	0.16 %
	Laanila	»	× Ruotsinkylä	»	0.89 %
	Laanila	»	× Laanila	»	2.29 %

All these data could, perhaps, be interpreted as evidence that temperature has an effect on the incompatibility mechanism in the birch. Reliable results can, however, be obtained only after pollinations at different temperatures in controlled conditions in vitro. Since the crosses reported here involve different trees in the different localities, more experiments are needed.

Where large growth chambers or phytotrons are available confirmation of these observations may lead to the development of a method for producing hybrids in considerable numbers: low temperature pollination of grafted trees.

Other external factors

In some cases, as was mentioned, pollination at early or late stages of development has given exceptional results. The production of a large number of seedlings after self-pollination of the tree Ru 7 at an early stage of flower development could be taken as an indication of other factors influencing the degree of self-incompatibility. Bud pollinations are known to produce fertile seed after selfing in other plants (East, 1923; Pandey, 1963). It is impossible to say whether this phenomenon is to be considered an effect of real external factors or a result of the delayed expression of the genetical constitution of the plant.

Radiation from X-ray equipment or gamma-irradiation sources has been used in many cases to abolish the incompatibility mechanism. The nature of the effect caused by the radiation is not known but it is obvious that it can only be a question of released mutation in exceptional cases. In some cases ultraviolet radiation has a similar effect (K u m a r and H e c h t, 1965). In order to test whether a similar phenomenon could be observed in *Betula*, I made a small experiment in 1966 in which twigs of the *B. verrucosa* Ru 32 were irradiated with a dose of 1 000 rad at the gamma-source of the Radiobiological Institute of the University of Helsinki. Immediately after irradiation the flowers were selfed. The growth of the pollen tubes was observed after 36 hours.

The mean length of the pollen tube in the irradiated styles was 1.6 units $\pm$ 0.12 and for the pollinated controls that had been kept in the greenhouse of the institute the mean pollen tube length was 0.9 $\pm$ 0.67 units.

Thus it seems that irradiation has suppressed the incompatibility. Whether this effect is enough for the production of fertile seed is not yet known. For such studies grafts are necessary and preferably also a radiation source in the field, where growth conditions are more normal and different amounts of irradiation can be applied at the same time to different members of a clone.

Nutritional conditions

In the different years, except for 1964, greenhouse pollinations have in general given shorter pollen tubes than pollinations in the forest. As I just said, for the incompatible crosses this could be explained as exaggeration of the incompatibility mechanism by the higher temperatures in the greenhouse. For the compatible crosses, however, this explanation does not apply and one might have expected a better tube growth in the higher temperatures in the greenhouse.

In these cases another factor that may be responsible is the food supply. The twigs, when cut, are removed from the continuous supply of nutrients provided by the tree and although amounts of reserve food seem sufficient for the development of the flower buds and leaves, limitations for particular organs may, nevertheless, be present. Therefore in 1964, a small experiment was made in which a commonly used plant nutrient solution was added to the containers in which the twigs were growing. The twigs were given nutrient solution from the beginning of the period of forcing and 13 combinations of *B. verrucosa* cross-pollinations and 7 combinations of the interspecific cross *B. verrucosa* $\times$ *B. pubescens* were made on them. The same pollinations were also made on control twigs standing in pure water.

The mean pollen tube lengths for this experiment were

	Nutrient	Control
B. verrucosa cross-pollinated	6.1 ± 1.87	5.6 ± 1.78
B. verrucosa × *B. pubescens*	4.6 ± 1.92	3.7 ± 1.78

Thus there was a slight improvement in pollen tube growth but the difference was not great and cannot be shown to be significant.

The relation between the cross-pollination and the species cross remained approximately unchanged and it cannot be concluded that the addition of the nutrient improved the result of the interspecific cross particularly. On the other hand, it is obvious that when the aim is to produce as much fertile seed as possible in a difficult cross, one must provide the plants with optimal growth conditions.

Weak pollen tubes are probably more sensitive to deficiencies and with the long time taken before the pollen tube reaches the embryo sac in the birch, such deficiencies may have a considerable influence on the results.

6. THE NATURE OF THE INCOMPATIBILITY

Serological investigations

Gel diffusion studies

In two earlier papers (H a g m a n, 1964 and 1967b) I have discussed the general value of serological studies in the study of incompatibility mechanisms, and here it is not necessary to recapitulate the many advantages offered by these methods. It might, however, be repeated that the serological reactions are highly specific and that probably no other analytical technique is able to specifically detect complicated polymer molecular structures such as, for example, proteins or polysaccharides in such small amounts and without extensive purification and separation processes.

Serological techniques have, consequently, been increasingly used in phytotaxonomy (H a w k e s, 1968; F a i r b r o t h e r s, 1968) in addition to bacteriology and virology, where these methods are today almost indispensable. The many features of the incompatibility reactions similar to those of other immunological phenomena indicate that complicated molecules are involved in specific ways in the incompatibility mechanisms (L i n s k e n s and K r o h, 1967).

It is obvious, however, that it is not sufficient to determine that antigens capable of antibody production exist in the plant studied and that these antigens cross-react with antibodies produced by other antigens. Even a single antigen produces a heterogeneous array of antibodies differing in reactive capacity.

When the active group of one antigen closely resembles, but is not identical with, that of another, some of the antibodies produced to each may be capable of reacting with the other but the remaining antibodies will be incapable of such a cross reaction.

A single antigen may also carry several antibody-determining groups, thus giving rise to a complex spectrum of antibodies. Hence, two antigens from different pollens may have one or more antibody-determining groups in common, yet differ sharply in their other determinant groups.

Without a more exact knowledge of whether it is the specific similarity or the specific diversity of the reacting substance which cause the incompatibility reaction, it is difficult to say whether similarity or diversity in serolo-

gical behaviour is the aspect to stress. A combined analysis of the substances in style and pollen with the aid of biochemical and serological methods might be a useful tool for solving this problem.

If the serological reactions could be shown to be absolutely specific for certain alleles and additionally it were possible to give a biochemical definition of the substance-fraction reacting in an immunological way, much light would be thrown on the processes leading to incompatibility.

For such an analysis it is necessary to have, in addition to the immunological method, a separation technique suitable for the handling of small samples of plant substances of a complex nature. Disc electrophoresis (Ornstein, 1964) has been used successfully for the separation of plant proteins (Steward and Barber, 1964; Mikola, 1965) and this method is suitable for small samples. This technique was therefore chosen for the fractionation required in connexion with the serological studies.

The first experiments already showed that it was possible to produce fairly good antisera in rabbits against pollen antigens of *Betula*. When an antiserum (AS) was tested against an antigen (AG) from the same or some related pollen sample with the tannic acid test (Boyden, 1951), dilutions at which agglutination still occurred were 1/2048 for AS *B. verrucosa* Ru 4 with the identical AG Ru 4 and 1/1024 with the related AG *B. verrucosa* Ru 7. There were, nevertheless, differences in the responses to the different antigens which may have been due to the particular antigens being poor or to different responses in the rabbits. Varying responses in rabbits are common, and whenever possible at least two rabbits were used for the production of each antiserum.

Agglutination tests also showed that antigens from different trees gave fairly good cross-reactions, thus indicating that the antigens had one or more determining factors in common.

In *B. verrucosa* precipiting analyses in agar gels showed that antigens from different trees might have several bands in common but that, in addition, specific bands, formed only in certain reactions, were present. For example, AG Ru 4, AG Ru 7 and AG Ru 12, when used side by side against AS Ru 7, gave four identical bands but in addition there was one band specific for the reaction AS Ru 7—AG Ru 7.

During the course of this study several trees were tested against each other. Within species the degree of similarity was usually higher, although it is uncertain whether absolute intraspecific identity was ever observed. It was not uncommon that an AS gave more precipitating bands with a heterologous AG.

One of the best groups analysed were the trees Ru 2, 3, 7, 9 and 11, for which detailed pollen tube growth studies were also made. In this group the serological studies show the features summarized in table 9 and table

Table 9. Serological reactions with pollen of *B. verrucosa*. Identity of the precipitates is marked +, partial identity o and non-identity —. The figure after the sign indicates the number of precipitates.

Antiserum	Antigen				
	Ru 2	Ru 3	Ru 7	Ru 9	Ru 11
Ru 2	+3	+2	+1 o 3 —1	+1 o 2	+3
Ru 3	+3	+3	+1 —1	+2	+1 —1
Ru 7	+1 —1		+3	+2 o 1 —2	+2 o 1
Ru 9	+1 —2	+2 —1	+1 —2	+4	+2 —1
Ru 11	+1 —1	o 2	o 2	+1	+2

10. It may be remembered that these trees, when tested against each other in the pollination experiments, showed various degrees of cross-incompatibility. It is not possible, however, to say that the serological reactions in all cases exactly matched the incompatibilities. Thus, for instance, the AGs Ru 2 and Ru 11 give very similar reactions but these trees are only semi-incompatible, whereas the trees Ru 3, Ru 7 and Ru 2, which are completely incompatible, whichever way the cross is made, show a high degree of similarity but not an exact identity in serological reaction. The discrepancies found between these reactions and the observations made in the crosses may, of course, also partly depend on differences in the antisera due to uneven responses in the rabbits.

In order to see whether similarities could also be detected between pollen and female flowers, antisera made against pollen antigens were tested with female flower parts as antigens. In these reactions the sensitivity was much lower and only one or two precipitating bands were found in agar gel plates. These bands were very similar for the different trees and could not be put into any definite relation to the compatible versus incompatible reactions between the pollen and the particular style.

Since our experiments, as mentioned, were made with antigens from whole female flower structures and not from styles alone, there is the possibility that substances common to all tissues mask the specific reactions or

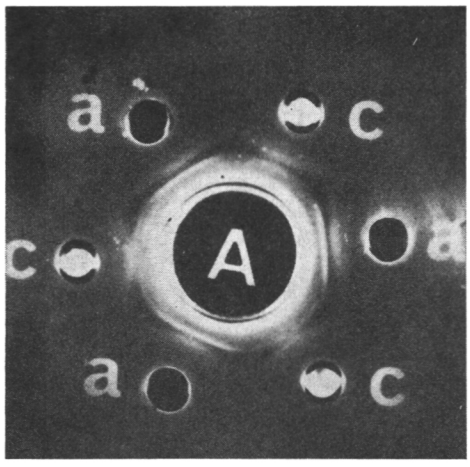


Figure 15. Serological reaction between two *Betula verrucosa* with cross-incompatibility reaction. A = antiserum Ru 7; a = antigen, pollen Ru 7; c = antigen, pollen Ru 3.

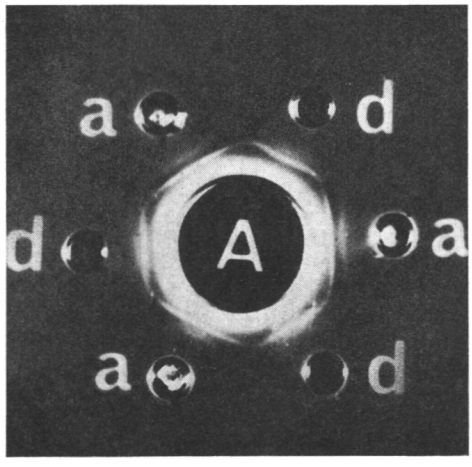


Figure 16. Serological reaction between two cross-compatible *Betula verrucosa*. A = antiserum Ru 7; a = antigen, pollen Ru 7; d = antigen, pollen Ru 2.

Table 10. Serological reactions with *B. verrucosa* pollen. The degree of identity between different pollen antigens when tested against the homologous antiserum for one of them. Strong similarity is indicated with =, similarity with +, weak similarity with (+) and non-similarity with —.

Antiserum	Antigen				
	Ru 2	Ru 3	Ru 7	Ru 9	Ru 11
Ru 2	=	+	+	=	=
Ru 3	=	=	+	=	+
Ru 7	+	+	=	(+)	=
Ru 9	(+)	+	(+)	=	+
Ru 11	+	+	+	(+)	=

that the specific substances were not present in sufficient amounts. When more material of known genotype is available, these experiments must be repeated.

When self-reactions were tried, i.e. AS tested against the homologous AG, identical or very similar results were obtained with different batches of pollen from the same tree. This indicates that the pollen, as an antigen, is fairly constant for the same individual.

Since no self-compatible trees have been detected in this study, it has not been possible to study whether the serological pattern of trees with self-incompatibility differs from the pattern of trees having a self-compatible reaction.

In *B. pubescens* the reactions within species were similar to those found

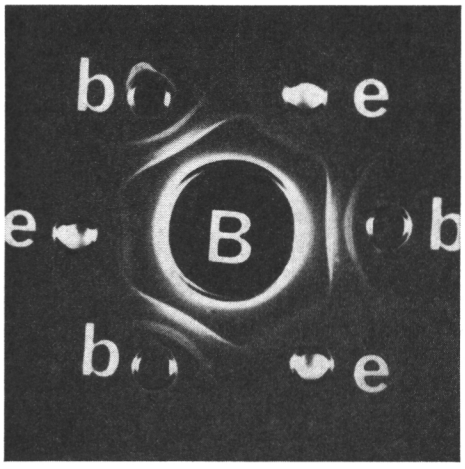


Figure 17. Serological reaction between *Betula verrucosa* and *Betula pubescens*. B = antiserum *B. pubescens* Ru 13; b = antigen, pollen Ru 13; e = antigen, pollen *B. verrucosa* Ru 3.

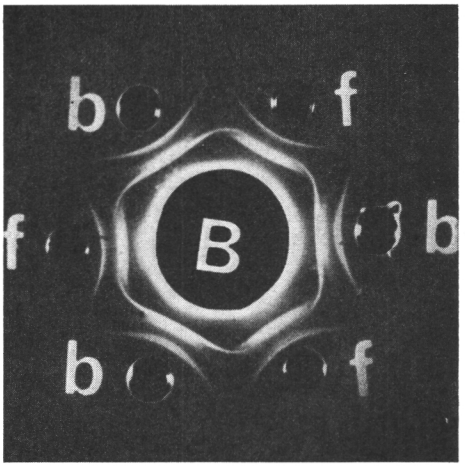


Figure 18. Serological reaction between two trees of *Betula pubescens*. B = antiserum Ru 13; b = antigen, pollen Ru 13; f = antigen, pollen Ru 19.

in *B. verrucosa* (table 11). Homologous antisera usually detected two to four precipitating bands in an Ouchterlony plate and heterologous antisera gave two to three bands.

Great similarity was found between the trees Ru 13 and Ru 19, Ru 23 and Ru 19.

When antisera for *B. verrucosa* were tested with antigens from *B. pubescens* and vice versa, the serological pattern differed considerably from that obtained in intraspecific reactions (table 12).

It was clear that the two species differed from each other serologically but, on the other hand, there were also similarities. In general, AS *B. verrucosa* detects one or two common antigens in AG *B. pubescens*. AS *B. pubescens* likewise detects at least one or two precipitates common to AG *B. verrucosa*.

Pollen of the hybrid *B. verrucosa* × *B. pubescens* has been tested as antigen only and with AS *B. verrucosa* Ru 11 gave two similar precipitating bands and one new one as compared with AG Ru 11. With AS *B. pubescens* Ru 23, the hybrid AG produced one similar, one partly overlapping and three different bands as compared with the homologous antigen of Ru 23.

No great geographical differences in serological behaviour have been detected. The AG *B. verrucosa* Ka 1, Ka 2, In 5, In 6 and In 8 were tested against AS Ru 9 and all had two common precipitates and in addition AG Ru 9 gave one precipitate with itself. The second common band in In 8 and In 5 is somewhat less pronounced than in the other trees. These results

Table 11. Serological reactions with pollen of *B. pubescens*. Identity of the precipitates is marked +, partial identity o and non-identity —. The figure after the sign indicates the number of precipitates.

Antiserum	Antigen								
	Ru 13	Ru 17	Ru 18	Ru 19	Ru 22	Ru 23	Ru 26	La 11	La 15
Ru 13	+3	(+1)	+2	+3	+3				
Ru 17		+1			o 1		o 2		o 1
Ru 18			+3						
Ru 22	+3	+1		o 2	+3	+2	+2		+2
Ru 23	+2	( )	+2	+2		+2		+1 —3	
Ru 26	+1				(o 2)		+4		+2
La 15		o 1			+2	+2	+2		+2

would indicate similarity but not identity between the *B. verrucosa* from Lapland and Ruotsinkylä. The same degree of similarity was found between many southern trees as well.

In *B. pubescens* only two trees from Lapland have been tested. In AG La 11, the AS Ru 23 from southern Finland detects one common and three different bands compared with AG Ru 23. An AS for *B. verrucosa* Ru 11, however, also gives one common and three different bands with the AG La 11. The *B. pubescens* La 15, which was tested as antiserum, has one band in common with *B. verrucosa* Ru 8 and two with *B. pubescens*.

Absorption tests made in order to distinguish the serologically active substances in *B. verrucosa* and *B. pubescens* from each other have not given consistent results.

Homologous absorptions generally removed all reactive substances. When AS *B. verrucosa* is absorbed with AG *B. pubescens* all reactions in the Feinberg plates often disappear. In Ouchterlony plates the AS Ru 2 absorbed with AG *B. pubescens* still gave two precipitation bands with the homologous AG Ru 2. Non-absorbed AS Ru 2 detected 4 bands in this experiment. AS *B. pubescens* Ru 23 absorbed with AG Ru 9 gives no reaction in Feinberg plates. When this *B. verrucosa* Ru 9 is used as AS Ru 9 and absorbed with *B. pubescens* AG Ru 23, two precipitating bands remain against AG Ru 9.

Experiments in which one of the antigens or one of the antisera was

Table 12. Serological reactions with pollen of *B. verrucosa* and B. *pubescens*. Identity of the precipitates is marked +, partial identity o and non-identity —. The figure after the sign indicates the number of precipitates.

Antiserum	Antigen							
	B. verrucosa			*B. pubescens*				
	Ru 7	Ru 8	Ru 11	Ru 13	Ru 22	Ru 23	Ru 26	La 11
Ru 7	+5	+2			o 4		o 3	
Ru 8	+3	+3						
Ru 11			+4			+1 —3		+1 —3
Ru 13	o 3	o 3		+3	+3			
Ru 22	o 3	o 3			+3			
Ru 23			o 1 —3					+1 —3
Ru 26	o 3 —1	o 3 —1		+1	+2	o 1	+4	

mixed with the agar before the test was made have been performed on a limited scale only. AG Ru 11 in agar did not specifically inhibit all the AS Ru 11 reactions from the Feinberg plate, neither did this treatment remove a precipitate from the reaction AS Ru 13—AG Ru 13. The same tree used as AG Ru 11 in the agar left three bands for the reaction AS Ru 18—AG Ru 18 but reciprocal treatment with AG Ru 18 in the agar removed all the reactions from AS Ru 11—AG Ru 11 as well as from the AS Ru 18—AG Ru 18 combination.

One gains the impression that antigens for *B. pubescens* in mixing experiments seem to be slightly more efficient as absorbents than antigens for *B. verrucosa*.

When trees of *B. pubescens* were tested against each other in the same way, it was found that the *B. pubescens* Ru 17, which, as mentioned earlier, showed peculiar features in the interspecific crosses, also behaved in a different way serologically.

AG Ru 17 in agar removed all the reactions from the test AS Ru 17—AG Ru 17, as would be expected, but AG Ru 17 in agar did not prevent the reaction between the AS and AG of another *B. pubescens*, Ru 26. When AG Ru 26 was added to the agar, one band from the reaction AS Ru 17—AG Ru 17 was left, although in the same absorption test AG Ru 26 prevented all the reactions for the other *B. pubescens* tested.

The serological activity of the tree Ru 17 was in general weak. Cross-reaction with AS Ru 13 and AS Ru 23 gave only very slight precipitation. With its own antigen, AS Ru 17 gave only one precipitating band compared with the two to four usually obtained in homologous combinations. When tested with other *B. pubescens*, AS Ru 17 gave two bands with AG Ru 26, one with AG La 15 and one with AG Ru 22. On the other hand, AS Ru 17 detected one band in reaction with *B. verrucosa* antigens, as most of the *B. pubescens* antisera did. In the reciprocal reaction AS *B. verrucosa* Ru 7 gives two precipitates with AG Ru 17.

In general, one gains the impression that the tree Ru 17 lacks some of the normal serological reactivity. In this it has something in common with Ru 22, a tree which gives only one band against Ru 17 in reciprocal experiments and whose antigen is also weak in its reactions with other *B. pubescens* antisera. The tree Ru 22 is another tree in which interspecific crosses have given somewhat unusual results. The peculiarity of the tree Ru 17 was still more pronounced in one test in which AG Ru 17 together with one *B. verrucosa* Ru 7 and another *B. pubescens* Ru 13 were tested against antisera produced with antigens of completely different origin, namely with *Salmonella* bacteria. The *Salmonella* antigens are known to have very specific serological reactions, depending on the highly complicated polysaccharides in the bacterial cell wall. In this experiment antisera to four *Salmonella* strains were used and the following number of precipitating bands were observed:

	AG Ru 7	AG Ru 13	AG Ru 17
AS *Salmonella* type C_1	4	3	0
» » » T_1	2	2	0
» » » *typhi*	3	3	0
» » » *paratyphi* B	2	2	0

Thus it really seems that some reactive substances are lacking in the tree Ru 17. The antigen from Ru 22 has not yet been tested against *Salmonella* antisera. Owing to lack of pollen, no serological experiments have been made with the *B. pubescens* La 11.

The experiments described hitherto were all made in agar gel plates without prior separation. The method of immunoelectrophoresis, in which the antigens are separated by electrophoresis before being exposed to the antisera, has in many cases increased the sensitivity of the serological tests.

So far, only a few immunoelectrophoretic tests have been made with our material, but it seems that the sensitivity of this method for the birch antigens is somewhat higher than that of the Ouchterlony or Feinberg plates. With *B. verrucosa* antigens antisera for *B. verrucosa* give three to five distinct lines of precipitation and with *B. pubescens* antigens three to four lines. The AS *B. pubescens* tested gave three to four lines with AG *B. verru-*

cosa and two to four lines with AG *B. pubescens*. In our material it is difficult to say whether general differences between *B. pubescens* and *B. verrucosa* occur, although the results indicate differences as well as similarities between the different trees.

Electrophoretic separations

Although electrophoretic separation in an immunoelectrophoretic test plate allows the detection and partial separation of specifically reacting substances, the method offers few possibilities for further investigation of the separate precipitates or the substances forming them. The lines of precipitate are often very thin and sometimes diffuse, and they frequently cross each other, thus making elution of the separate lines very difficult. In order to obtain more material for further studies, other methods must be applied.

As mentioned in the beginning of this section, I had chosen disc electrophoresis as the general separation method.

Electrophoretic separation on acrylamide gels proved to be a rapid and convenient method for the separation of components from pollen as well as from female flowers. The degree of resolution on these gels was better than on starch gels.

Some of the typical patterns obtained with pollen substances are seen in figure 19. When interpreted visually, up to 19—22 distinct bands of varied density could be seen in the pollen extracts. Common bands were seen but differences in the band pattern were observed between species as well as between individuals. No absolutely definite species-specific patterns could be detected in the material, despite several repeated runs.

In general, pollen of *B. verrucosa* seemed to contain a smaller number of components than pollen of *B. pubescens*.

The *B. pubescens* Ru 17 differed from the other trees in having fewer bands and these less distinct. Only six to nine bands could be stained for this tree.

In material from the female flowers different bands were similarly seen but the number of bands was, perhaps, smaller than in the pollen samples. Slight differences could be detected between samples collected at the early, optimal and late stages of floral development. Particularly the late stage differed from the others in having fewer bands.

When Coomassie brilliant blue was used instead of amido black as a stain for protein, the bands in the gels were more distinct and thus this seems to be a more sensitive staining method for the material.

Staining the gels with periodic-acid-Schiff (PAS) reagent for neutral polysaccharides and with dialysed Fe for mucopolysaccharides (P e a r s e,

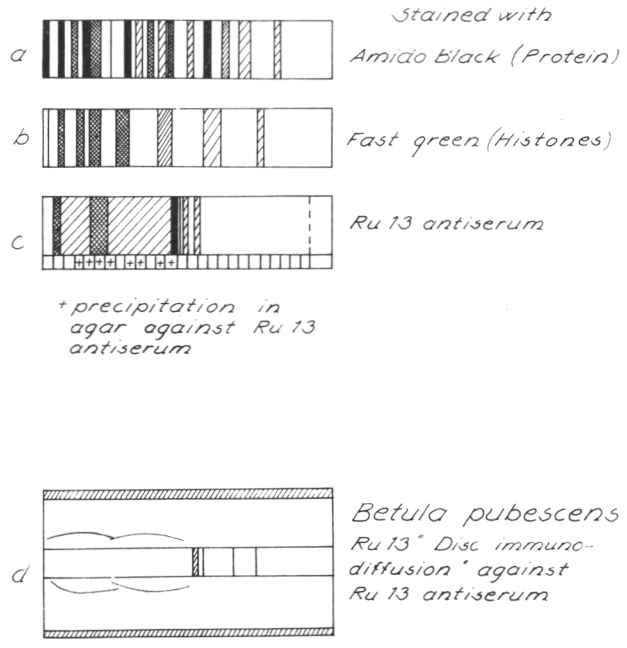


Figure 19. Disc electrophoresis of *Betula pubescens*, Ru 13 pollen. a = gel stained with amido black for proteins. b = gel stained with fast green for histones. c = gel treated with antiserum Ru 13. d = disc immunodiffusion against antiserum Ru 13.

1961) disclosed that the substances separated on the gels were not all pure proteins.

Although some of the bands stained with Coomassie brilliant blue were serologically detectable, more of the serologically active fractions, as will be described below, seemed to concentrate in those parts of the gel tube where the bands stained with the PAS reagent or the dialysed Fe stain were present. This indicates that at least some of the serologically active substances are polysaccharides or glucoproteins. The number of bands stained with the polysaccharide stains was between six and eight for *B. pubescens* and five to six for *B. verrucosa*.

The fast green stain for histone-like proteins disclosed up to 11 bands but these did not seem to coincide especially well with the serologically active fractions.

Without more fractioning experiments with the pollen substances, it is not possible to say how *B. pubescens* and *B. verrucosa* differ from each other in the composition of the polysaccharide or glucoprotein fractions.

The separation of the constituents of pollen and female flowers on acrylamide gels seemed to disclose greater differences in the substances than

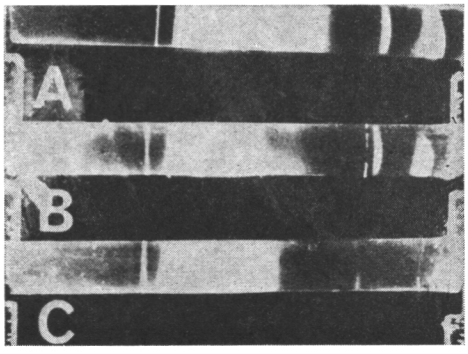


Figure 20. Disc electrophoresis tubes treated with antisera. A = style extract of *Betula verrucosa* Ru 2 + antiserum against pollen Ru 2. B = style extract of Ru 2 + antiserum against *B. verrucosa* Ru 9 pollen. C = style extract of Ru 2 + antiserum against *B. verrucosa* Ru 11.

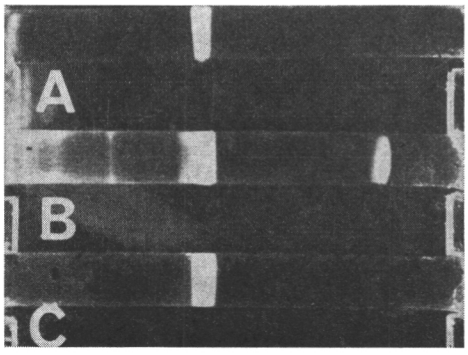


Figure 21. Disc electrophoresis tubes treated as in figure 20. A = pollen of Ru 2 + antiserum Ru 2. B = pollen of Ru 2 + antiserum against *B. pubescens* Ru 13. C = pollen of Ru 2 + antiserum against *B. verrucosa* Ru 11.

hitherto shown with any other methods. A combination of the serological and electrophoretic steps was therefore deemed a logical procedure to follow.

Holland et al. (1962) showed that immunodiffusion studies could be made on antigens separated by disc electrophoresis and I thought it worth trying whether serological reactions could be obtained with pollen and with flower material separated in the same way. The extracts to be investigated were therefore run in pairs, and when one of the gels was stained the other was directly submerged in the antiserum for a period of about 24 hours. As seen by comparing figure 19 c with the stained gel in figure 19 a, visible precipitin bands were formed in the gel. However, not all of the bands that stained gave serological reactions, nor was there in every case a stained band where a precipitate could be seen.

From the different comparative experiments made with ASs and AGs it could be seen that the serological method detects between four and six different bands in a sample run in the acrylamide gel tube. In one case, in which fluorescent conjugated AS was used, eight bands were detectable. Although in general the homologous combinations gave more bands than the heterologous ones, exceptions were found. The reactivity seemed to depend greatly on the activity of the antisera, some of which were more sensitive than others.

Extracts of female flowers were also tested in the same way, and the pollen antisera gave immunological reaction with these samples as well. In some cases the antisera formed just as many precipitates with the female substances as with the pollen substances. Thus in this method the sensitivity to female flower substances was greater than in the gel-diffusion tests.

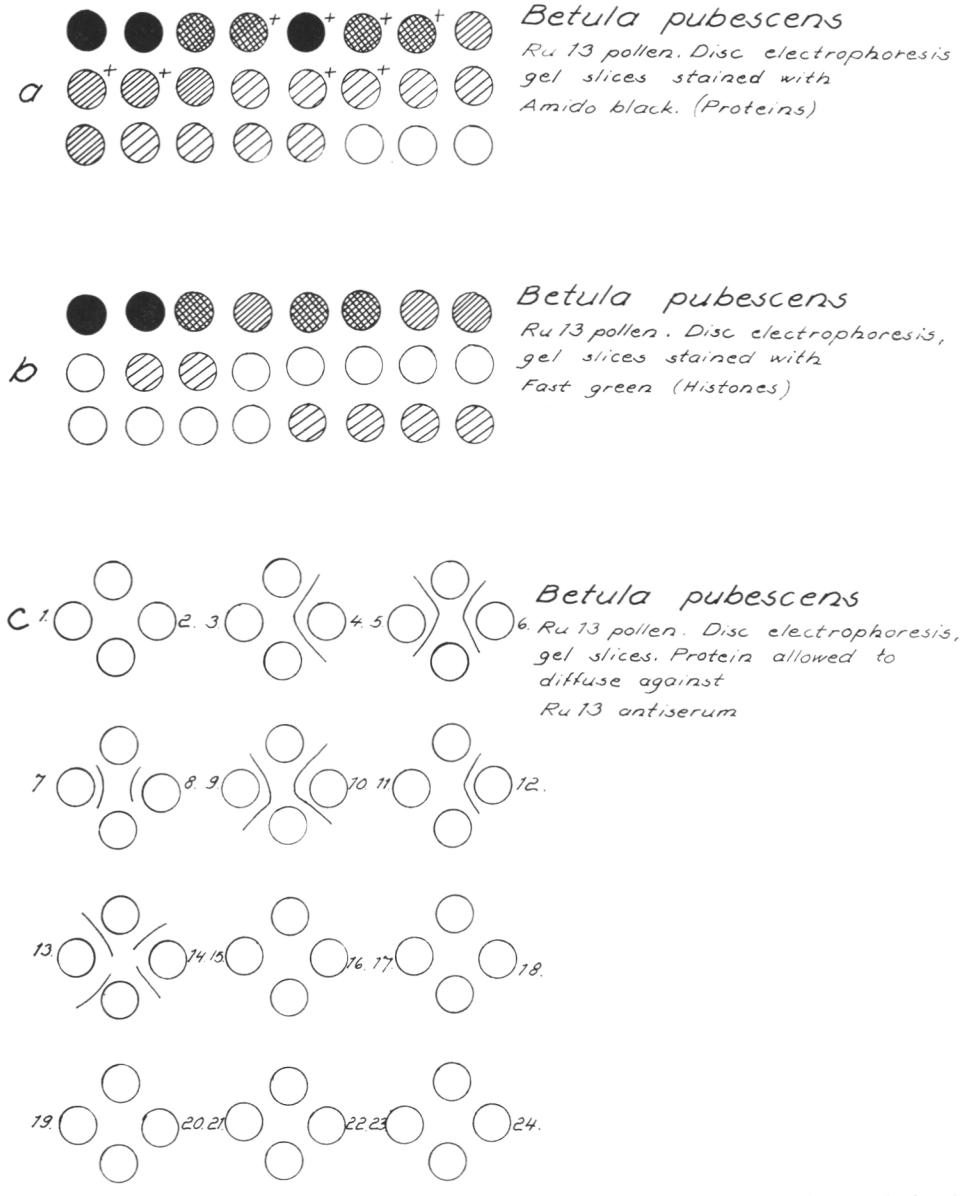


Figure 22. Disc electrophoresis of *Betula pubescens* Ru 13 pollen. Gel slices stained with amido black (a), with fast green (b), and treated with antiserum Ru 13 (c).

Figure 20 shows very similar reactions given by AS *B. verrucosa* Ru 2 and AS Ru 9 when these sera were used on a gel containing substances from the female flower of Ru 2. But the reactions of AS Ru 11 were different from those of AS Ru 2 and AS Ru 9. As stated earlier, these trees showed indications of cross-incompatibility.

In another experiment, Ru 2, Ru 5 and Ru 11 were found to give similar reactions with AS Ru 5. The AS for partly cross-incompatible individuals, such as Ru 9 and Ru 7, also gave similar reactions with female flower substances from the tree Ru 9. Interspecific reactions were not consistently less specific than intraspecific reactions.

In one experiment, in which pollen antigens of the *B. verrucosa* Ru 3 and the *B. pubescens* Ru 18 were run both separately and mixed together, and then tested with AS Ru 3 and AS Ru 18, five of the bands produced were common to both sera. In addition, AS Ru 3 detected one band specific for AG Ru 3 in samples run separately as well as mixed with AG Ru 18.

In the AG Ru 18 run separately as well as mixed with AG Ru 3, the AS Ru 3 also detected one specific band which did not appear in the homologous treatment of AG Ru 18 with AS Ru 18. Thus AS Ru 3 was able to detect two separate specific bands in a mixture of AG Ru 3 + AG Ru 18. When, on the other hand, AS Ru 18 was tested on the mixture AG Ru 3 + AG Ru 18, a further band was detected, which coincided with the *B. pubescens* band detected by AS Ru 3. This the AS Ru 18 did not detect when run separately on its homologous AG. The reason for this unexpected increase in the reactivity of the AS Ru 18 is unknown.

The result of the experiment with the samples Ru 3 and Ru 18 could be taken to indicate the occurrence of at least one substance specific to each of the two birch species.

The work with whole gel tubes had the disadvantage that large amounts of antisera were needed for the reactions. In addition, diffusion into the gel tubes and within the gel tubes was sometime irregular. The whole tube can, of course, also be put in agar gel and then run as a diffusion sample against smaller wells with antisera (figure 19 d) but this method is cumbersome.

The method was therefore modified by cutting the gel tube into equal slices and staining these with the protein stain. Slices from a parallel tube were likewise cut and inserted into agar gel for an Ouchterlony test. As seen in figure 22, with this method it was possible to obtain single precipitations in the agar gel which could be related to specific parts of the gel tube. When a gel was sliced into 24 pieces, 21 stained with the protein stain, 14 with fast green, 9 with PAS and 8 were serologically active.

In another experiment five to six slices gave serological reactions but it is obvious that the number of precipitating bands formed depends on the

spread of the substances in the gel tube and on the accuracy with which the slices match the bands. Several adjoining slices may well contain the same serologically active fraction if the slice is thin in relation to the spread of the substance in the gel tube.

A refinement of the technique in this direction would make it possible to test each separate fraction individually with relatively small amounts of substances and, above all, with small amounts of the antisera, availability of the antisera usually being the limiting factor in this type of work.

Little is yet known about the nature of the serologically active substances separated. Some of them may be proteins, others are obviously polysaccharides or glucoproteins. Preliminary experiments with separation on Sephadex gels indicate that on Sephadex 50 as well as on Sephadex 200 some of the fractions of the serologically active materials are separated earlier than the main body of the proteins. The rest, however, move at the same rate as the proteins and glucoproteins. When larger amounts of the pollen samples are available, advanced separation techniques (cf. Granath, 1964; Andrews, 1964) will give better estimates of the molecular weight of the substances.

Localization of the serologically active sites

The positive results obtained in the immunodiffusion experiments prompted a study of whether the sites of the serologically active substances could be localized with immunohistological methods (Coons, 1956, 1958; Clayton, 1960; Nairn, 1962).

Antisera against pollen of *B. verrucosa*, Ru 7, was therefore conjugated with isothiocyanate (Campbell et al., 1963) for the first experiments. In later experiments the two-layer or »double sandwich» method (Nairn, op. cit.) was used instead of conjugated specific rabbit-AS, the fluorescent medium being conjugated goat anti-rabbit serum. The use of an anti-rabbit serum removes the need for the conjugation of each specific antiserum.

Dormant pollen treated with the conjugated antiserum did not show any fluorescence. Pollen of *B. verrucosa* and *B. pubescens* were therefore germinated in 10 % sugar solution and the germinated pollen grains with their elongated pollen tubes were transferred to the conjugated serum for about 24 hours. (In the case of the double-layer technique the first treatment was with the specific AS and, after washing, with the conjugated anti-rabbit serum.) After appropriate washing for about 16 hours the pollen tubes were observed in ultraviolet light.

When pollen tubes of *B. verrucosa* were so treated, a specific fluorescent colour was observed in the pollen tube (figure 23). This fluorescence was concentrated to the tip of the pollen tube but some fluorescent grains could

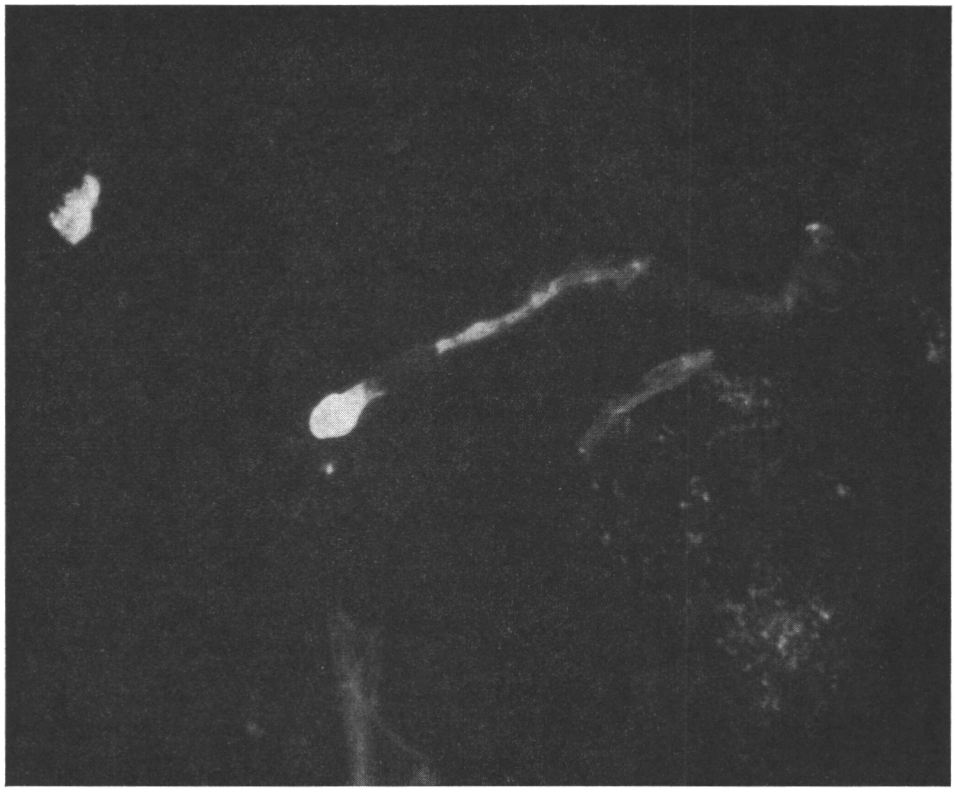


Figure 23. *Betula verrucosa*, germinating pollen grain stained with fluorescent conjugated antiserum against the same pollen as the antigen. (Ru 7).

also be seen in other parts of the tube. No fluorescence was visible when pollen tubes were treated with the conjugated 0-rabbit antiserum used as control for the specific conjugated serum, nor when pollen tubes were treated with 0-rabbit serum and subsequently with the conjugated anti-rabbit serum. The anti-rabbit serum when used alone did not give any specific staining of the pollen tubes either.

In *B. verrucosa* fluorescence was visible in all the pollen tubes treated with the conjugated AS *B. verrucosa* (Ru 7) or the specific AS *B. verrucosa* + the anti-rabbit serum, but with the same sera the pollen tubes of *B. pubescens* behaved differently.

When *B. pubescens* (Ru 19) pollen tubes were treated, they did not all give a fluorescent reaction. Of the fluorescent tubes there was a strong reaction in only 8 % of the total number of pollen tubes observed and a weak reaction in 40 % of the tubes, whereas 52 % of the tubes did not give any reaction at all. About half of the weakly fluorescing tubes were stained at the tip only. This staining of the *B. pubescens* pollen with conjugated

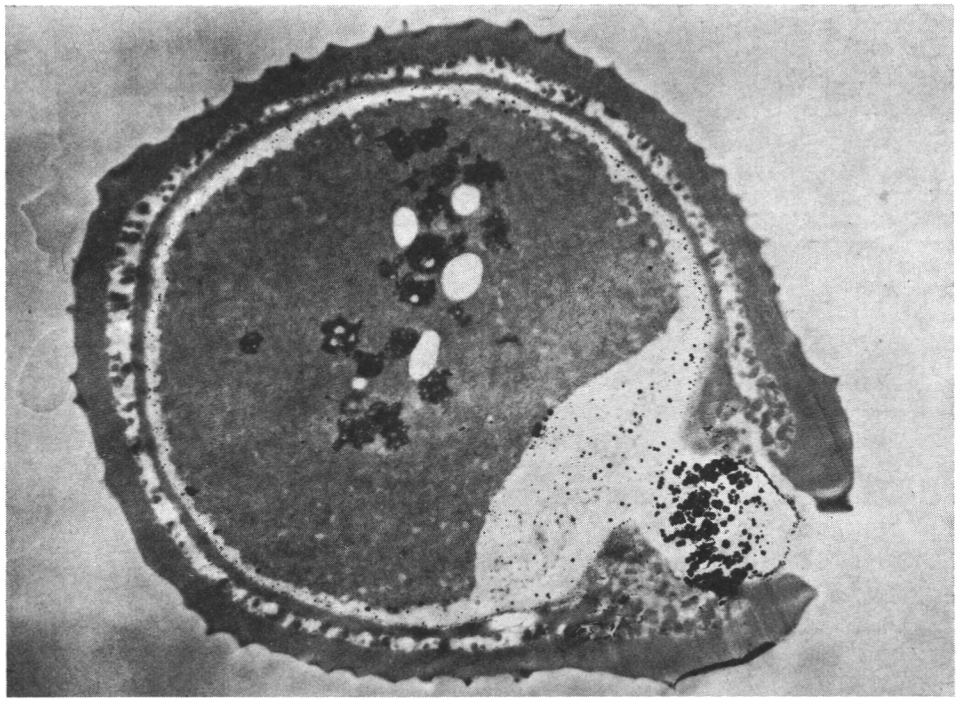


Figure 24. *Betula verrucosa*, electron micrograph of a germinating pollen grain at an early stage of germination. Note electron-dense material at the germination pore. (La 2).

antiserum against *B. verrucosa* is of some interest in the light of the earlier observation that of crosses with *B. pubescens* Ru 19 pollen growing on *B. verrucosa* Ru 7 styles the frequency of pollen tubes less than 4 units long was 52 % and the frequency of pollen tubes 4 units or longer was 48 % in the year 1961. In 1962 the corresponding figures were 83 % and 17 % respectively. If we take the combined value for 1961 and 1962 the proportions are 63.5 % of the shorter and 36.5 % of the longer pollen tubes. In general, if all the 6 553 pollen tubes of the crosses in 1961—1964 are taken into account, 46.1 % of the *B. pubescens* pollen growing on *B. verrucosa* styles produced pollen tubes shorter than 4 units and 53.9 % pollen tubes 4 units or longer.

When *B. pubescens* (Ru 22, Ru 26) pollen tubes were treated with conjugated *B. pubescens* antiserum (Ru 22, Ru 26), the fluorescence of the pollen tubes was good.

It must be stressed that the experiments, so far, have been made on very limited material. Pollen tubes from many trees with known incompatibility reactions should be cross-tested with different antisera in order to see if segregation figures fitting genetical assumptions can be found.

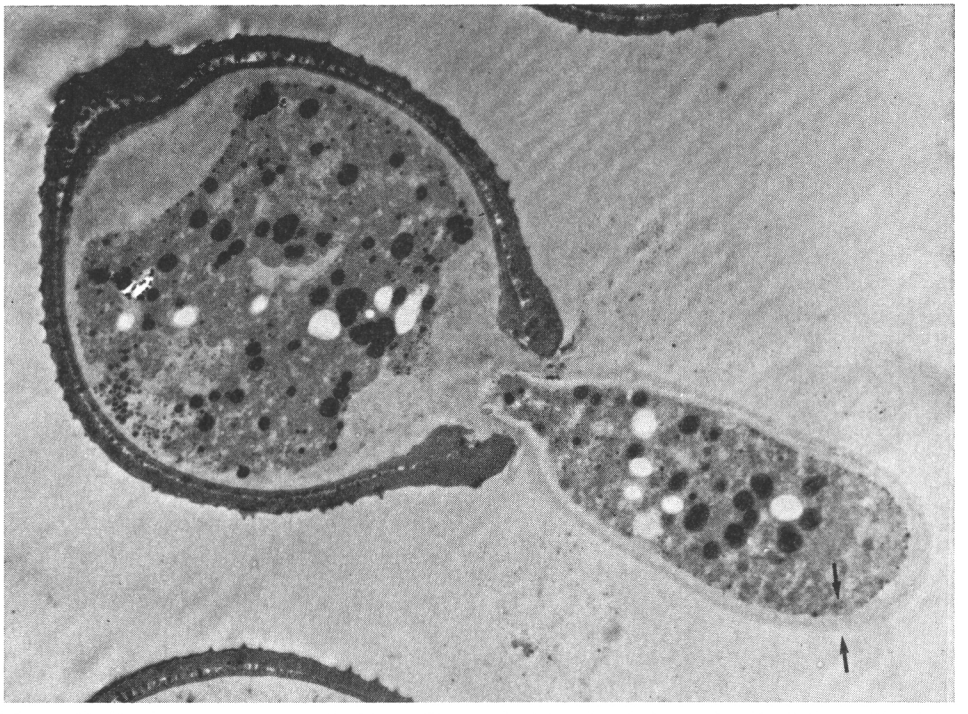


Figure 25. *Betula verrucosa*, germinating pollen grain. The double-layered wall of the pollen tube is clearly visible. (Ru 6).

When discussing the preliminary results of these studies (H a g m a n, 1964), I suggested the possibility of labelling the serologically active substances by using antibodies conjugated with ferritin (S i n g e r, 1959; S i n g e r and S c h i c k, 1961). Using electron microscopy, the site of these substances could perhaps be localized, for instance in the primary wall of the growing pollen tube. As briefly reported already (H a g m a n, 1967 b), such experiments have now been made.

As seen in figures 24—25, the germination of a *Betula* pollen grain starts with accumulation of an electron-dense substance (lipids?) at the germ pore, after which the dense material disappears and a pollen tube with a wall having a bi-layered structure is formed. The pollen tube is rapidly filled with a complex content of cellular structures, among them the Golgi bodies known to participate actively in the production of cell polysaccharides (N o r t h c o t e and P i c k e t t - H e a p s, 1966). Cytochemical staining of pollen tubes with PAS had earlier revealed a concentration of polysaccharides at the tip of the pollen tube.

When pollen tubes had been treated with the ferritin-conjugated antiserum, most of the ferritin molecules could be seen agglomerating at the outer

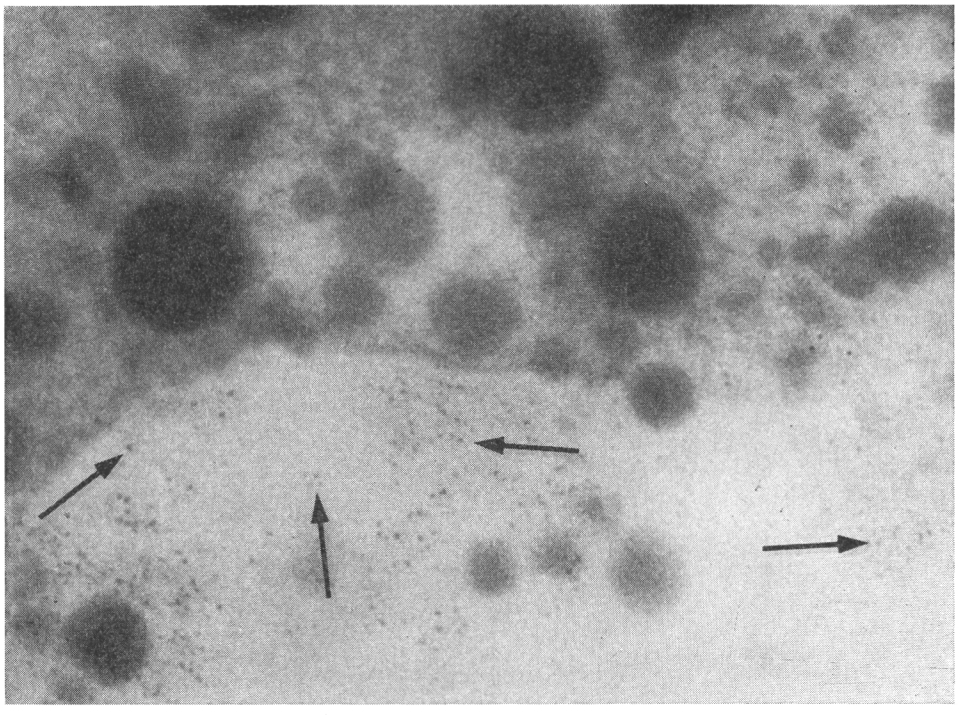


Figure 26. Part of the outer border of the tip of a *Betula verrucosa* pollen tube. The tube was first treated with antiserum against its own pollen and then with ferritin-conjugated anti-rabbit serum. Note accumulation of ferritin molecules (←) in the outermost layer of the pollen tube wall. Magnification ca. 100 000 x.

layer of the pollen tube wall (figure 26). In the middle part of the tube no great accumulation of the ferritin molecules could be seen. None of the control treatments showed any attachment of ferritin molecules to the pollen tube wall.

Since pollen tubes sliced before treatment with the antibodies were not used, I cannot say whether perhaps parts of the contents of the pollen tube would also have reacted with the conjugated antibody, such reactions being prevented in our experiment by the intact tube wall.

From the pictures it is difficult to say whether the ferritin molecules are specifically attached to the inner or to the outer part of the bi-layered wall structure.

From these studies it may be inferred that some of the serologically active fractions of birch pollen are associated with the pollen tube wall.

This, of course, does not simply mean that these are the particular substances involved in the incompatibility mechanism but they could well be active in this connexion. Cross-reactions made with *B. pubescens* and *B.*

verrucosa antisera and ferritin-conjugated antibodies would show whether the ferritin attachment is specific for homologous sera only.

Serologically active substances were detected in pollen as well as in female flowers. In order to see whether serological reactions could be observed at earlier stages of development, embryos of *B. verrucosa* and *B. pubescens* were collected in 1964 on July 1 and July 30 and tested against AS *B. verrucosa* and AS *B. pubescens*. The embryos from July 1 did not show any reaction but the embryos from July 30 gave a very slight reaction, especially with the AS *B. pubescens*. Disc electrophoresis of the embryonal matter revealed only a few stained bands in the sample from July 1 but up to 10 bands in the sample from July 30. *B. verrucosa* and *B. pubescens* embryos of the later date differed slightly in their »band spectra».

The result of this experiment could be taken as evidence of the lack of immunological specificity of embryonal tissues in the birch — a feature found generally in other embryos, especially those of animal origin. The amount of extractable substances obtained from the diminutive birch embryos may, however, have been insufficient to allow good serological reactions.

On the basis of the serological investigations one may conclude, that although the results are from a limited amount of material, they indicate that disc electrophoresis and serological methods separately, and especially when used together, are useful tools in research on reproduction.

The birches used here are not the very best for testing the method, since the genetic background of the trees is not known. Other species, such as *Petunia*, *Oenothera*, *Trifolium* and *Nicotiana*, in which clones with known combinations of S alleles are obtainable, are, no doubt, better suited for this type of methodological research. Work carried further in these species would show whether these methods are universally applicable, and results could then be brought back into forest genetics and tree breeding at a time when progenies with a better known genetical background might be available.

Using large amounts of material separated in different ways, it might be possible to make a more detailed study of the nature and constitution of the substances effective in the incompatibility processes. Enzymatic tests have hardly been tried at all. Only ribonuclease has been used and this enzyme did not remove more than one serologically active fraction from the gel tube. The possibilities for testing several other enzymes of metabolic importance and for the detection of iso-enzymes are numerous.

Once specific reactions are obtained and antibodies against antigens of known genotype are produced, the use of conjugated antibodies will offer many promising lines along which research could progress. Two different antisera conjugated with dyes of different colours and each specific to one pollen type would make it possible to follow a mixture of pollen in a style.

The use of the same single or double-staining method on germinating pollen in vitro would make differentiation of pollen types possible, perhaps allowing identification of pollen genotypes. In this way it might be possible to reduce the laborious crossing work and provide short-cuts for the selection of material for further breeding.

Several compounds with serological activity have been extracted from birch pollen and from female birch flowers. There are differences between the two birch species studied here and trees within each species also show some individual variation. The observation that some of the trees displaying cross-incompatibility are more similar in serological reactions than those showing cross-compatibility would perhaps make it possible later to distinguish on a serological basis between compatible and incompatible trees in a breeding programme.

The nature of the substances responsible for these reactions, and supposedly also acting differentially in the incompatibility mechanism, are so far unknown. Although I have developed combined techniques with which the substances may be separated and detected, I have considered it better to postpone the study of them until the progenies of the crosses made in this study have grown up and are flowering.

Investigations on differentiation of species are not possible without a knowledge of of the genetical background. When material is available of which the genotype is known or can to a certain extent be anticipated, it will be possible to study the chemical basis in greater detail and in addition to investigate the genetics of the biochemistry of incompatibility.

The genetical background

The results obtained agree, in general, fairly well with observations hitherto made about fertility in birches. There seems to be no doubt that an incompatibility mechanism exists at the level of pollen tube growth, a mechanism which fits the hypothesis for plants having binucleate pollen grains.

In both species the incompatibility barrier against selfing is rather strong. In none of the trees studied has there been a totally self-compatible individual, and thus the material does not allow for much testing of the genetical background to self-incompatibility. At the moment, it is not clear what is the genetical basis of the cross-incompatibilities observed. Failure of a cross may in some cases have been caused by external disturbances, but since the same feature has occurred when a cross has been repeated many times, for instance in the combination Ru 3 $\times$ Ru 2 and Ru 2 $\times$ Ru 3, a genetical background seems more likely.

The cases of 50 % incompatibility could best be explained by the assump-

tion that the trees have one S allele in common. This would lead to inhibition of the growth of half the pollen tubes. Such a situation was seen in the combinations of Ru 7 × Ru 9, and perhaps in Ru 7 × Ru 11 and Ru 11 × Ru 2. The cross Ru 3 × Ru 2 was 100 % incompatible but the reciprocal cross only about 50 %. A possible explanation for this case would be that the tree Ru 2 is homozygous for an allele shared with Ru 3.

In *B. pubescens* there are also indications of partial cross-incompatibility. The results of the crosses Ru 19 × Ru 13, Ru 19 × Ru 18, Ru 22 × Ru 13 and Ru 22 × Ru 18 could likewise best be explained as due to the trees having one allele in common with their respective partners. Such a situation is not unexpected if one supposes that the *B. pubescens* stand originated from a few mother trees only.

It seems that similar observations have seldom been made before, but in nature and also in artificial crossings the pollen generally occurs in abundance compared with the ovules and it is clear that cases of 50 % incompatibility are not usually revealed by reduced seed-setting, since there are enough functional pollen tubes to fertilize all the ovules available. A final decision about the genetical background of the half-compatible crosses must wait until progenies are available for reciprocal crossings and back-crossings with the parent trees.

Since the trees in this study represent the parent generation only, they do not provide opportunities for a rigorous genetical analysis. The only material available that could be used for such studies was the self-progeny of a *B. pubescens*, E 880. This material was bred by Sarvas (unpubl.), who in the year 1947 made a controlled selfing of a *B. pubescens* tree brought into the greenhouse of the Botanical Garden in Helsinki early in the spring. Professor Sarvas has kindly informed me that the germination of the seed after this self-pollination was extremely low, 0.49 %, the corresponding percentage of seedlings being 0.4 %. Nevertheless, when the seed was sown in two replications in the autumn of 1947 a total of 98 + 115 = 213 plants were obtained. When I planted out the material in the Ruotsinkylä Experimental Forest on May 20, 1952, there were 182 plants left.

A limited number of the trees had reached flowering age in 1964—1965 and to test the hypothesis that the incompatibility system in birch is based on the one-locus S allele system the inbred progeny was tested in a back-cross with E 880 as female parent. (Male flowers of the parent tree were not available.) All the 16 back-crosses that could be made were incompatible. For this test the genetical structure of E 880 could have been, say, S_1S_1, S_1S_2 or S_2S_2.

Of the 23 I_1 individuals selfed, all were incompatible, which could indicate that the tree E 880 did not possess a fertility-restoring allele S_f.

One of the I_1 trees (No. 195) produced enough pollen to be used as pollen

parent on 23 other I_1 trees and the growth of the pollen tubes was observed.

These crosses gave 18 combinations which were 100 % incompatible and 5 which, judged from the pollen tube growth, indicated compatibility.

Supposing that the mother tree E 880 was heterozygous for the gene S, and denoting it, say, by S_1S_2, its progeny would consist of the types S_1S_1, S_1S_2 (and S_2S_1) and S_2S_2.

If the structure of the tree No. 195 had been S_1S_1 and the female I_1 population normally divided into the progeny classes just mentioned, one would expect the I_1 cross to have given the following result:

$$\left.\begin{array}{l} 25\ \%\ S_1S_1 \times S_1S_1 = 100\ \% - \\ 50\ \%\ S_1S_2 \times S_1S_1 = 100\ \% - \\ 25\ \%\ S_2S_2 \times S_1S_1 = 100\ \% + \end{array}\right\} = \tfrac{3}{4} - \text{and } \tfrac{1}{4} +$$

For 23 combinations this would give the theoretical segregation of 17.25 — and 5.75 +.

In the other alternative, No. 195 = S_1S_2, one would expect

$$\begin{array}{l} 25\ \%\ S_1S_1 \times S_1S_2 = 50\ \% + \text{ and } 50\ \% - \\ 50\ \%\ S_1S_2 \times S_1S_2 = 100\ \% - \\ 25\ \%\ S_2S_2 \times S_1S_2 = 50\ \% + \text{ and } 50\ \% - \end{array}$$

Since the identification of the fractions of compatible and incompatible pollen tubes might be uncertain with small amounts of pollen tubes, the 50 % compatible crosses were taken as phenotypically fertile. Thus we obtain the figures

$$\tfrac{1}{2} + \text{ and } \tfrac{1}{2} -$$

For the 23 combinations this would give the theoretical segregation of

$$11.5 + \text{ and } 11.5 -$$

As mentioned, the figures found were 18 incompatible and 5 compatible. The adjusted chi^2 value for the alternative A was 0.010 and the adjusted chi^2 value for the alternative B was 6.26.

Thus the results support the hypothesis that incompatibility is produced by a single-locus multiple allele system and the hypothesis that the I_1 tree No. 195 has the genetical structure S_1S_1. However, this involves the assumption that in *B. pubescens* there is not a tetrasomal segregation at the S locus.

The best interpretation for Stern's figures for *B. verrucosa* (1963a) is likewise that his progenies are from a cross between two individuals having one S allele in common.

The possibilities of using the known homozygote No. 195 in further tests for the detection of more alleles of the S gene in *B. pubescens* are good, and

measures have been taken for the vegetative propagation of this tree in order to increase pollen production and female flowering.

In *B. verrucosa* however, no further genetical analyses will be possible until the first flowering of the plants obtained from the self- and cross-pollinations.

7. DISCUSSION

Intra- and interspecific incompatibility

The degree of self-incompatibility in both *B. verrucosa* and *B. pubescens* was found to be high but not total. These results agree with the earlier observations by K l a e h n (1950 and 1952), J o h n s s o n (1951), B e h r n d t (1952) and S t e r n (1963 a), all based on studies of seed-setting after self-pollination.

Different individuals show slightly different degrees of self-compatibility. Increased self-compatibility when pollinations were made on one side of the crown with pollen collected from the other side (F r o l o v a, 1956) could not be found in our material but this point has not been tested intensively.

The material available for genetical analysis is limited but may best be interpreted as supporting the idea that in these species incompatibility is based on a single-locus multiple allele system.

In *B. pubescens* slightly better self-compatibility was found than in *B. verrucosa*. If *B. pubescens* had been an autotetraploid, self-compatibility would have been expected. But this has not been found to be the case. However, as will be discussed later, an amphidiploid situation in *B. pubescens* could in some cases lead to allosyndesis and to chromosome segregation bringing about pollen grains in which the allelic situation for the S gene could be similar to that in an autopolyploid and thus give the pollen grain a disturbed incompatibility reaction due to competition.

J o h n s s o n (1951) has also observed that *B. pubescens* has a somewhat better self-fertility than *B. verrucosa* (germination 0.3—7.3 %) and stated that this is theoretically understandable, because polyploids have higher self-fertility than diploids.

The compatibility found in almost every self-pollination, which, although small, led to the formation of fertile seed, can be explained in three ways:

1. The amount of filled seed in the unpollinated controls is of a small but nevertheless appreciable magnitude, and it is not clear whether in all cases contamination was responsible for the filled seed found. As has been mentioned earlier, apomixis has been reported in the related genus *Alnus*. Although C l a u s e n (1966) did not find apomixis in his birch crosses, several other authors have considered this phenomenon possible. If there is

a tendency to apomixis, the induction of apomixis as a response to the stimulation of incompatible pollination could to a certain extent be understood. The triggering of development by pollination is well known in many other plants.

2. The second possibility is that in birches there is a low but constant — mutation rate toward the fertility-restoring S allele S_f. It is clear that self-compatible mutants will immediately have an effective selective advantage even though their frequency is low.

In the long run this could lead to accumulation of individuals having the S_f constitution, unless for other reasons, e.g. inbreeding depression, high sterility, etc., selfed individuals have a negative selection value.

In my, albeit small, material I have not found self-compatible trees but a wider search may reveal some. The trees mentioned by Sarvas (1956, table 1), especially *B. pubescens* No. 9 and No. 23 and *B. verrucosa* No. 10 and No. 22, may perhaps be such self-compatible individuals. These trees may either be in possession of an S_f allele or be aneuploids having accessory chromosome fragments known to affect the incompatibility mechanism (Brewbaker and Natarajan, 1960). In the population studied by Sarvas there is another tree, *B. pubescens* No. 51, which is highly sterile, even though it stands close to several others of the same species.

3. The function of the S alleles may also well be dependent on the polygenic background. Segregation of such quantitative modifying genes may explain the existence of differences in self-incompatibility. Variation of self-compatibility and sensitivity to environmental differences are considered to be conditioned by genes which modify the incompatibility expression of the S alleles (Nasrallah and Wallace, 1968).

The presence of modifiers would also explain the results observed here about the temperature effect giving increased compatibility when the temperature has been low. Flowering at high temperature followed by pollination at low temperature increases the amount of seed set after selfing in the Cruciferae (Nasrallah and Wallace, op.cit.).

The identification of genotypes homozygous for S alleles is a first requirement for the study of modifier genes. With such individuals sib- and self-pollination can provide material for the analysis of the intensity and stability of the incompatibility.

There are few observations on compatibility in the autotetraploids of birch. For two trees of Co-tetraploids of *B. verrucosa*, Johnsson (1951) found that fertility, although reduced, was high enough to yield large progenies. After open pollination the number of empty nutlets was 33—20.7 %.

He does not mention whether there was controlled self-pollination but the progenies were approximately triploids, suggesting that *B. verrucosa*

with a normal chromosome number from the surroundings may have been the pollen parent.

It would be extremely interesting to try to make an autotetraploid *B. verrucosa* and see whether it would be self-compatible. Autopolyploidization of *B. pubescens*, would, of course, lead to the same result. The chromosome number in such an individual would be so large, however, that it might affect the vitality of the progeny. But large chromosome numbers are found in the *Betulae*, so such an autopolyploid might not be impossible to obtain.

Cross-incompatibility has been found in both the *B. verrucosa* and *B. pubescens* populations studies. The cross-incompatibilities observed also seem to fit the hypothesis of a one-locus system.

As pointed out earlier, incompatibility dependent on the alleles present in half the pollen grains is not easily detected if only the production of fertile seed is observed, since the number of pollen grains is always great compared with the number of ovules that can be fertilized, and so even half-incompatible combinations may give 100 % fertility. On the other hand, observations of the pollen tubes reveal such S-allele interactions, if present, and also other factors disturbing the proper pollen function, such as haploid sterility.

The semi-incompatibility observed can be interpreted as the result of pollination between trees having one allele in common. Progenies and backcrosses are necessary before the number of such factors can be established.

In every species that has been adequately tested for incompatibility genes (L e w i s, 1949) the number of alleles has been large. This is understandable, since a large number of different alleles in the population is an advantage. Until progenies from known crosses are available, it is difficult to estimate the number of alleles that might be effective in the populations studied here. The finding of some completely incompatible crosses in such a small sample as five × five trees in *B. verrucosa* seems to suggest that the number of alleles may be small, but it is to be remembered that the populations so far studied are limited and may well consist of individuals with a high degree of relationship.

The finding of trees homozygous for the S_t allele, and thus self-compatible, would provide possibilities for further breeding. For large species like *B. verrucosa* and *B. pubescens* it may, nevertheless, prove difficult to ascertain the total number of alleles. Studies of this type in limited isolated populations might, however, give indications about the multiple or single provenance of these populations and thus throw light on the mode of dispersal and the habits of occupation of the species.

In the trees investigated here, there did not appear to be any tendency toward increased self-compatibility in conditions in which such a character would appear to be of selective value in facilitating the establishment of new populations after long-distance dispersal (see B a k e r, 1955). The

absence of such a mechanism in *Betula* is perhaps explained by the profuse seed production and the ease with which the light seed can be carried over long distances. Pollen of *Betula* is also small and thus would appear eminently suited for long-distance transport. On the other hand, Sarvas's (1956) observations of reduced seed-set in single trees indicates that the effective population size, measured in terms of pollen dispersal, is not large.

The similarity in the type of manifestation observed between intraspecific and interspecific incompatibility makes it appear probable that the basic nature of the incompatibility phenomenon is the same in both cases.

In the species cross *B. verrucosa* × *B. pubescens* and its reciprocal there is a difference in the result, depending on which species is used as the mother tree. When *B. verrucosa* is the female parent the frequently occurring »double-top» curve in the pollen tube length frequencies may be taken to indicate that among the pollen tubes of *B. pubescens* there is a certain fraction that is more or less compatible on *B. verrucosa* styles. This feature is not found in the reciprocal cross when the pollen spender is *B. verrucosa*. An exception to this is the tree Ru 17, to be discussed separately.

My observations agree fairly well with the results of others, in which seed-setting is usually better in the species cross when *B. pubescens* is used as the pollen parent. (Eifler, 1956 and 1960; Johnsson, 1945). It will be remembered that *B. pubescens* has a higher chromosome number ($2n = 56$) than *B. verrucosa* ($2n = 28$).

The compatibility between different trees differs greatly in Eifler's material, as in mine, and the proportion of seed set is very much the same. Eifler (1964) also observed that in all cases of intraspecific as well as interspecific crosses pollen germination was good, 70—90 %. Pollen tube growth was good in the intraspecific crosses and in the cross *B. pendula* × *B. pubescens*. In the reciprocal cross, however, the penetration of the pollen tube was very limited and only in rare cases was growth of a pollen tube observed in the style. These results are in full accord with my observations, although, as I have shown, the pollen tube growth of *B. pubescens* on *B. verrucosa* is variable.

The greater compatibility of *B. pubescens* pollen tubes would be understandable, if *B. pubescens* were an autotetraploid of some *verrucosa*-like ancestor, being in general agreement with the observations in fruit trees and other plants that polyploidy usually upsets incompatibility at the tetraploid stage. However, if so, *B. pubescens* would probably also be at least partly self-compatible, which, as I mentioned, is not the case.

The practically complete self-incompatibility of *B. pubescens* points toward the possibility that *B. pubescens* is not an autopolyploid but an allopolyploid made up of a *verrucosa*-like type and another diploid species. Such a view, based on study of the meiosis in *B. verrucosa* × *B. pubescens*,

has been expressed by Johnsson (1945, 1949 b). Klaehn (1950) came to the same conclusion and mentions as possible parent species *B. verrucosa* and some ancient pre-glacial and now extinct species. Stern (1965) found indications of tetrasomic inheritance in *B. pubescens*.

If *B. pubescens* were an amphidiploid, this could lead to various segregations of the chromosomes. The most probable separation leading to gametes with non-homologuous sets of chromosomes and to heteroallelic pollen grains would explain through competition or dominance in the pollen, the functional ability found in some of the pollen tubes. Since these factors are found not to be effective in the style, this would also explain the greater incompatibility in the reciprocal cross.

The observations of the chromosome numbers after interspecific hybrization also point to complexity in the genomes of the birch species. If we summarize the numbers reported we find:

Eifler (1960)	*verrucosa* × *pubescens*	54	plants	2n = 28
		58	»	2n = 42
		0	»	2n = 56
	pubescens × *verrucosa*	10	»	2n = 28
		6	»	2n = 42
		6	»	2n = 56
Klaehn (1950)	*pubescens* × *verrucosa*	3	»	2n = 56
Johnsson (1945)	*verrucosa* × *pubescens*	2	»	2n = 42
	pubescens × *verrucosa*	10	»	2n = 56
	but stated as uncertain due to apomixis or unreduced pollen grains in *verrucosa*.			
This study	*verrucosa* × *pubescens*	11	»	2n = 28
		9	»	2n = 42
		1	»	2n = 32
		0	»	2n = 56
	pubescens × *verrucosa*	6	»	2n = 28
		17	»	2n = 42
		1	»	2n = 56

The very similar results of Eifler's crosses and my own work, indicating that about 50 % of the male gametes of *B. pubescens* have the chromosome number n = 14, the other half having n = 28, and the presence in the female of *B. pubescens* of gametes with n = 14 may be an indication of non-bivalent chromosome segregation.

It might be possible that trees of *B. pubescens* have the capacity of producing pollen grains with the reduced chromosome number n = 14. Cases of premeiotic reduction have been reported for other plants (Carlbom, 1969; Gottschalk, 1958, 1966). Unfortunately it has not been possible to make a closer study of the meiosis of the *B. pubescens* trees used in these investigations.

The nuclei of the pollen tubes of birch are very small and the detailed investigation of their chromosome components is difficult. These nuclei are, nevertheless, observable and stainable in their interphase state. The employment of the scanning densitometry method, as recently applied by G r a n t (1969) to the study of cell nuclei of birch root tips, would perhaps solve the question of whether pollen grains containing an amount of DNA equal to 14 chromosomes occur in *B. pubescens* together with pollen grains containing an amount of DNA equal to 28 chromosomes. If staining with the Feulgen method proves difficult, and the results have, so far, been rather irregular in my laboratory, the use of spectrophotometry in ultraviolet light might be a solution.

The cases in which plants with 2 n = 56 are obtained after pollination with *B. verrucosa* pollen could be explained if *B. verrucosa* produces some pollen grains with the unreduced chromosome number.

Such a phenomenon might occur as a result of disturbed meiosis, due, for instance, to temperature shocks during meiosis. Low temperatures and frost are common in early August at the time of meiosis in the male catkins of *Betula*. Another possibility would be that an unreduced egg cell of *B. pubescens* develops apomictically.

The explanation in all these cases, including the observation of the ca. 50 % incompatible pollen tubes in intraspecific pollinations in *B. pubescens*, must await further analysis of the progenies before conclusions concerning this interesting question can be reached.

The variable but in some cases good compatibility of the *B. pubescens* pollen tube does not explain why, in the cross *B. verrucosa* × *B. pubescens*, fertility is nevertheless very low. One must here assume that other barriers to hybridization are at work, in addition to the incompatibility mechanism. The first phases of the development of the embryo have not been studied, so I have no experimental evidence of the stage of development at which inviability sets in or of whether fertilization has taken place at all.

The phenomenon could perhaps be explained as a result of increased inviability in the developing embryo due to disharmony between the different chromosome sets combined in the zygote. If the pollen grains functioning in the crosses were aneuploids, with different degrees of uni- and multivalents, the low viability could be attributed to this disturbance and to lack of vital chromosomes. Since triploid hybrids are found in nature, the inviability of the triploid as such might not be sufficient to explain the poor seed-setting fully.

Another possible explanation, which could be tested experimentally in a laboratory where facilities for embryo culture are available, is that we have to do with a more or less pronounced »pseudo-incompatibility» between the embryo and the endosperm, the latter being the result of the double fertilization and perhaps thus possessing an abnormal chromosome set.

The difference in chromosome number between the gamete provided by the male and the embryo sac could in this case cause disturbances in the development of the endosperm, the constellation between endosperm and zygote, 56: 42, being perhaps less suitable for development of the embryo than the ratio 84 : 56 which occurs in a normal *B. pubescens* × *B. pubescens* cross.

It is not known whether in the reciprocal cross *B. pubescens* × *B. verrucosa*, giving the chromosome ratio between endosperm and zygote = 70 : 42, the conditions for embryo development are still worse, because the high degree of incompatibility already acting at the pollen tube stage makes observations of a small additional increase or decrease in fertility very difficult.

It is, of course, also possible that the conditions in the endosperm per se produced by the abnormal double fertilization could lead to malfunction of the endosperm and later to death of the embryo. For a discussion of all the cases of this and similar types that have been found, the reader is referred to the comprehensive review by Stebbins (1958 b).

Screening of seed for the early stages of embryonal development with a rapid X-ray technique and subsequent cultivation of the hybrid embryos in vitro, thus removing the pseudo-incompatibility effect, if any, is an inviting line to follow and might lead to increased production of triploid hybrids.

Whether or not incompatibility exists at stages later than pollen tube growth is not known. The interesting question of why only one of the two embryos in the nutlet of *Betula* ever develops, although obviously in most cases both of the ovules are fertilized, is another matter calling for investigation. Whether this is due to a selection mechanism and, if so, how it works are other unsolved problems. Similar phenomena are known in other forest trees.

The question of possible apomixis in connexion with interspecific crosses cannot be excluded. As mentioned, a certain small degree of seed- setting has been observed in many controls and not all of them can be explained by long-distance pollination of early-flowering trees before isolation or the late development of male flowers in the isolation bags. The presence of foreign pollen has been found to induce apomictic seed development in other plants (Gustafsson, 1946 and 1947). Since it is characteristic of *Betula* that it takes the pollen tube a relatively long time to reach the ovule, there it the possibility that in illegitimate pollinations, such as species crosses, the foreign pollen may induce pseudogamic development. Adventitious embryonal development could then, as in *Alnus*, lead to the development of plants with the chromosome set of the mother. Such plants might then, after species crosses, be the apomictic offspring of *B. pubescens* females giving the progenies with 2 n = 56 mentioned above or of *B. verrucosa* females, giving the progenies with 2 n = 28.

Eifler (1960) found that the progenies after the cross *B. verrucosa* × *B. pubescens* having 2 n = 28 chromosomes were all similar to the mother. Whether certain individuals possess the tendency for apomixis in a higher degree than others, and thus phenotypically would appear to be more fertile than other trees after interspecific crosses is not known at present. It could be that the exceptional trees Ru 17 and Ru 22 are able to induce apomixis in the crosses in which they are used as male parents.

When grafted trees are available that can be isolated effectively, e.g. by bringing them to flowering in the greenhouse in winter, this interesting problem will merit further study.

The formation of a barrier to crossability between two populations, especially when the isolation mechanism is based on physiological conditions, often leads to the formation of new species. Where no barrier of this type exists, it may in some cases be asked whether the upholding of the status of two species is necessary. In the present study no reproductive isolation could be detected in crosses between the northern and southern populations of birch when taken intraspecifically. In the case of *B. tortuosa* some additional experiments may be mentioned: In 1964, two planted plots of *B. tortuosa* growing at the Ruotsinkylä Experimental Forest were emasculated and the trees allowed to be wind-pollinated by the local *B. pubescens* (and perhaps also by some *B. verrucosa*, since the *B. tortuosa* flowered early).

In the *B. tortuosa* plantation of origin Savukoski, northeastern Lapland, the mean filled seed after this wind-pollination was 44 %. In *B. tortuosa* from Utsjoki, northernmost Lapland, the corresponding value was 30 %. These figures are fully comparable with those obtained from commensurable trees of local *B. pubescens*.

Thus it seems that *B. tortuosa* hybridized well with *B. pubescens*. In the light of all the results given earlier and the observations reported above, I am inclined to include the northern, montane form in the species *B. pubescens*. Perhaps this can be taken as evidence for the view expressed nearly a century ago by Kihlman (1890, p. 163): »Ich kann meine Auffassung der nordischen Birken dahin präcisiren, das ich den Eindruck gewonnen habe, das die systematische Trennung der subalpinen Birke von dem thalabwärts und weiter gegen Süden waldbildenden Form einer natürlichen Gruppierung nicht entspricht. Bindende Beweise für diese Ansicht kann ich freilicht nicht geben.«

The ancestors of »*B. tortuosa*« as well as of *B. pubescens* are unknown. One may, like Klaehn (1950), speculate that if the development of the allopolyploid took place early, one of the ancestors may have been a *verrucosa* type and the other a diploid type with a more *pubescens*-like appearance. One possible species would be *B. nana*, for which the chromosome number is 2 n = 28, or an extinct ancestor similar to it. One could imagine *B. nana*

being a bog plant and so ecologically different from *B. verrucosa* that some of the adaptibility found in *B. pubescens* and in »*B. tortuosa*» may have come from *B. nana*. I am not aware of any description of an experimental cross of *B. nana* with B. *verrucosa*, although reports of natural crosses between these two species, as well as between *B. nana* and both the northern and southern forms of *B. pubescens*, are known from the literature.

This raises the question of how the alloploid *B. pubescens* came into existence. A normal F_1 hybrid between two 2 n = 28 ancestors would probably have been rather sterile. The chances for two such F_1 plants to produce an 2 n = 56 offspring by crossing must be considered small, although not improbable, since such a cross would originate through the conjugation of unreduced gametes occurring in the F_1 plants. However, it has recently been reported (Johnson and Packer, 1968), that *B. nana* can also have 2 n = 42 chromosomes, and a possibility exists that unreduced gametes may occur in such plants. Then a combination with a partner having n = 14 would lead to an offspring with 2 n = 56 chromosomes.

If, as a second alternative, the amphidiploid doubling originated through somatic doubling of the hybrid, establishement of a plant with 56 chromosomes would also have been achieved.

Now it is well known that birches frequently produce stump-shoots, for instance after damage by forest fire. Such shoots occurring from callus tissues could well be the sources for cells with complex chromosome conditions leading in some cases to chimeras, and hence to the possibility of the formation of a fertile shoot with the tetraploid chromosome number. Once established in some cases, these individuals would be fertile and able to reproduce generatively through seed. The well-known *Primula kewensis* is a case analogous to the second alternative. Other examples are frequently to be found in nature. For a review see e.g. Clausen, Keck and Hiesey (1945).

As mentioned, there are two exceptions to the rule that pollen of *B. verrucosa* is incompatible on the styles of *B. pubescens*. These compatible *B. pubescens*, Ru 17 and Ru 22, have shown this feature in many combinations, and the compatibility seems to be 50 % or more. It is difficult to explain this case as due to a mutation in the pollen of *B. verrucosa*, since the frequency is much higher than generally expected. No mutation which would alleviate the effect of the presence of the S allele in the style has yet been observed in any plant in the cases of one-locus incompatibility.

In the light of what has been said about the allopolyploidy of *B. pubescens*, some explanations may be advanced for the trees Ru 17 and Ru 22. On several occasions the tree La 11 has also differed from the normal behaviour of *B. pubescens* in interspecific crosses, but at present the data for this tree are meagre.

The trees Ru 17 and Ru 22 do not appear to be hybrids, since the chromosome number of offspring after free pollination and cross-pollinations is that of *B. pubescens*. In addition, the pollen quality of the trees is good, as judged from the percentage of filled, well-stained pollen. In Ru 17 the pollen quality in 1962 was 99.5 % and in 1964 100 %. For Ru 22 the corresponding figures were 98.5 % and 99.0 %, respectively. The pollen quality for the tree La 11 was 94 %.

In general, both auto- and allotriploids have poor and highly variable pollen. For the hybrid *B. verrucosa* × *B. pubescens* from Schmalenbeck the pollen quality for the plant No. 6 was 54 %. Inbred progenies of the *B. pubescens* E 880 showed a pollen quality varying between 69 and 99.5 %.

It is evident from the serological experiments that the tree Ru 17 and to a certain extent also the tree Ru 22 differ from the others in serological behaviour.

The hypothesis could be advanced that the action of the S allele or some factor coupled to this allele or the complete absence of the factor could have led to a specific block in the biochemical synthesis building up the incompatibility mechanism.

In Ru 17 there is an indication that blockage of the serological activity is more primary and that some factor for the building up of serological activity in the pollen grain is missing. Such a blockage could supposedly also lead to less specific conditions in the styles and to less specific incompatibility, if, as has been postulated, the incompatibility mechanism is dependent on highly specific surface reactions at the cell membrane level.

Even if the molecular structure leading to serological specificity is not directly responsible for the incompatibility mechanism, our results point towards a high degree of linkage between these two characters.

The establishment of the chromosome conditions in our trees must await cytological studies, although these may prove difficult. The chromosomes of *Betula* are very small (Woodworth, 1931), and as Johnsson (1944) stated: »... it is very difficult — not to say impossible — to distinguish with certainty in birch between trivalents, bivalents and univalents in the IM polar view». Perhaps crosses of Ru 17, Ru 22, La 11 with *B. nana* would give interesting results.

The observations suggesting that *B. pubescens* is an allopolyploid raise the question of whether the small but nevertheless detectable self-compatibility in *B. verrucosa* could not be due to alloploid segregation. Very little is known about this subject, but it may be mentioned that Löve (1944) is of the opinion that even *B. verrucosa* is to be regarded as an allopolyploid, the basic number of chromosomes in the genus *Betula* being considered to be n = 7. Grant (op.cit.), who made spectrophotometric measurements on root cells of Canadian *Betula* of different ploidy,

also reached the conclusion that the genomic number for *Betula* might be n = 7.

For the other species of *Betula* little is known of the incompatibility mechanism. Johnsson (1945 and 1949 b), on the basis of cytological observations, mentions the possibility that the North American species *B. papyrifera* March. could have had some *verrucosa* genome introduced into it during the course of its evolution. The cross *B. papyrifera* × *B. verrucosa* behaves differently according to whether *B. papyrifera* is used as the male or female parent. Johnsson (1955) noted than when *B. papyrifera* is used as the mother tree the cross is almost incompatible, whereas, as the pollen parent, *B. papyrifera* gives a percentage of filled seed up to the level of normal *B. verrucosa* cross-pollinations. This is a case fairly analogous to observations for the *B. verrucosa* × *B. pubescens* cross.

It would be of great interest for the evolutionary study of these birch species if behaviour of the pollen tubes similar to that observed in my study could also be observed in crosses between *B. papyrifera* and other members of the North American birches. Many are found to be *verrucosa*-like, with the chromosome number 2 n = 28, e.g. *B. fontinalis* Sarg. and *B. populifolia* March. Since the closely related Japanese White Birch, *B. japonica* Sieb. var. *mandschurica* (Regel) H. Winkl. is reported to have individuals with the chromosome number 2 n = 28 as well as 2 n = 56, this species should, if possible, also be included in the tests. In addition, the northern form *B. platyphylla* Sukatchew, which is very similar to the Alaskan species *B. kenaica* Evans and *B. neoalaskana* Sarg. must be studied. During the course of the present study, Clausen (1966) published the results of his investigations on the compatibility of several, mainly American species of *Betula*. His results for the European birches, based on seed studies only, are in good agreement with mine. In *B. verrucosa* the germination of the seed was less than 1 % after selfing and in *B. pubescens* 0.5 %. Self-incompatibility in the other species was generally high, except for *B. papyrifera* Marsh. and *B. alleghaniensis* Britt. Intraspecific crosses were mostly successful but individual differences were found. Interspecific crosses varied greatly, *B. nigra* appearing difficult to cross with other species. Great differences were found between reciprocal crosses. Clausen said that insufficient information was available to determine whether compatibility increased with increasing ploidy levels. Two combinations supporting this view, *B. glandulosa* (2n) × *B. pubescens* (4n) and *B. lenta* (2n) × *B. alleghaniensis* (6n) were compatible, while the reciprocals were practically incompatible. On the other hand, *B. papyrifera* (4—6 n) × *B. pendula* (2n) was more successful than the reciprocal cross. This result is at variance with the findings of Johnsson.

The polyploidy conditions of the American birches are complicated (Woodworth, 1929, 1930 b) and the American birches as well as the

Eastern Asiatic ones deserve further study. Since many of the species hybrids show marked heterosis, it would also be important for the practical breeder to know in which direction the best seed-setting is obtainable.

As a summary of the present situation in the interspecific crosses in birch we may therefore conclude with S t e b b i n s (1958 b) that successful pollination, fertilization and embryo development in crosses within a species depend upon a delicate balance between the action of many different genes. The upset of this balance which results from interspecific pollinations can be corrected in certain respects by changing the chromosomal and genetic balance of one of the parental species, but the establishment of a new balanced condition is very difficult.

Nature of the incompatibility mechanism

The nature of the incompatibility mechanism found in *Betula* in connection with this study has many features in common with mechanisms found in other plants (cf. L i n s k e n s and K r o h, 1967). Pollen tube growth is arrested at an early stage, interspecific crosses succeed better if the polyploid species is the pollen parent, allopolyploid grains grow better, etc.

Furthermore, in this study the incompatibility mechanism has shown many features which are common to immunological processes: increased incompatibility at high and decreased incompatibility at low temperature, suppression of the incompatibility reaction by radiation, less reactivity in immature tissues, and serologically poor activity in young embryos, and the incompatibility reaction has proved to be endothermal in nature, thus requiring increased respiration.

L i n s k e n s (1955) for example, found that there was increased oxygen consumption during the first period of development of an incompatible cross compared with a compatible one, but that in the later phases of development the condition was reversed.

Preliminary experiments made with birch flowers in 1961—1963 indicated the same phenomenon (cf. table 13). When the oxygen consumption was measured in a Warburg respirometer, it was found that when self-pollinated and cross-pollinated flowers were taken six hours after pollination, respiration was higher for the self-pollinated flowers for the first one to two hours. Later, the oxygen consumption of the self-pollinated flowers decreased, whereas that of the cross-pollinated ones rose steadily. In interspecific crosses there was also an indication of higher oxygen consumption in the first hours.

Pollen germination and pollen tube growth are complex processes in which several systems of reactions, biochemical as well as biophysical, are involved (S t a n l e y, 1967; R o s e n, 1968). One can therefore suppose

Table 13. Oxygen consumption of female flowers of *B. verrucosa* and *B. pubescens* after different kinds of pollination.

Type of cross	Accumulated consumption µl O_2/mg fresh weight	
	6 hours from pollination	9 hours from pollination
B. verrucosa self	1.31±0.12	2.68±0.13
B. verrucosa cross	1.03±0.14	3.55±0.19
B. pubescens self	1.03±0.19	1.72±0.21
B. pubescens cross	0.71±0.13	1.74±0.11
B. pubescens × *verrucosa*	1.22±0.19	3.16±0.14
B. verrucosa × *pubescens*	1.42±0.11	3.71±0.19

that a blocking of normal development leading to disturbed pollen tube growth may occur at many different levels of development and owing to many different factors of an internal as well as an external nature.

As we have seen, the external factors which affect pollen tube development and the specific incompatibility reaction may lead to phenomena that may be difficult to separate. If we start with the external disturbances, the nature of the factors leading to the prevention of pollen germination and pollen tube growth after insect attacks could be explained in the following way.

Host plants produce antibiotic substances as a result of infection. Many of these phytoalexins are responses to infection or injury. They are typically absent from the healthy plant. Many of the known phytoalexins are polyphenols and, as such, highly active in their reaction with growth processes. The synthesis of phytoalexins is in general a nonspecific response of the host, provoked not only by invasion of micro-organisms but also by mechanical damage and by contact with many different chemical substances. It may be that after an insect attack on the styles the plant reacts by production of phytoalexin, which in turn damages the highly sensitive enzyme system responsible for the activation of pollen tube germination.

Another possible explanation, as mentioned earlier, is that the insects introduce into the plant specific substances of a hormonal nature that interfere with the development of the style as well as with the pollen.

As Schoch-Bodmer (1933) observed, the osmotic pressure of the stigmas in birch regulates the turgor pressure in the pollen grains and optimum conditions for break-through of the pollen germ pore are usually attained at the time of anthesis. It might be thought that as a result of attack by insects the physological conditions for production of the right osmotic pressure in the stigma are disturbed. This could also lead to disturbances in pollen germination if the stylar capacity for maintaining the necessary osmotic conditions was destroyed by some other external

factor, for example hard frost during the course of development of the female flower.

Such responses to external disturbances, simulating incompatibility reactions, should obviously affect all crosses equally, irrespective of the nature of the cross. That such may happen is shown from the figures for forest pollinations in 1964.

The specific incompatibility in *Betula* is expressed as the inhibition of pollen tube growth. This phenomenon is in most cases connected with inability of the pollen tube to penetrate into the stylar tissue. Even when this occasionally occurs, the growth of the incompatible pollen tube is fairly soon arrested.

In the inability of the pollen tubes to penetrate into the stylar tissue, the situation in *Betula* shows a great similarity to the incompatibility mechanism found in the Cruciferaee.

It might be thought that the ability of the pollen grain to function properly is dependent on the pollen tube having a system for dissolution of the cuticular layer of the style. The cutins are polymeric substances made from higher lipids and the composition of these substances is highly variable (H e i n e n, 1960). Cutinase has been found in pollen (L i n s k e n s and H e i n e n, 1962). The penetration of a pollen tube into the style tissue has many similarities to the manner in which pathogens enter the host plant. Cutin-degrading enzymes have been found in lower fungi, as well as in pollen.

The epidermal cell wall is a highly complex system but the walls between the cells and especially the middle lamellae, which contain pectic substances, also have a complicated structure, the details of which are in many cases not yet known (see e.g. D o b y, 1965; G o o d m a n, K i r á l y and Z a i t l i n, 1967). Specific enymes are known to be responsible for degrading pectins at different points (A l b e r s h e i m and K i l l i a s, 1962).

If the pectic substances are genetically specific — which is not known but may well be assumed — the penetration of a pollen tube, which seems to take place by dissolution of the middle lamellae between adjacent cells, might be dependent on the production by the pollen tube of some specific enzyme or enzymes, e.g. a pectin methylesterase, capable of altering the solubility of the pectin and thus predisposing the pectin to degradation by other pectin-decomposing enzymes.

The growth of the pollen tube through the style is accompanied by several kinds of metabolic activities. Pollen tubes contain numerous enzymes for the production of the material necessary for growth and for the dissolution of stylar wall material (L i n s k e n s, 1967). The interaction between the stylar tissue and the pollen tube is intensive and exchange of substances has been found to occur even between the pollen tube and the untouched

section of the style where the pollen tube has not yet grown (R o g g e n, 1967). It is also documented that during its growth the pollen tube exchanges nutrient material with the style and it is obvious that this exchange depends on close contact and good interaction between the tubular and stylar structures involved.

There is wide acceptance of the view that mediated transport of substances is due to the action of enzymes situated within the cell membrane (cf. S t e i n, 1967). A substrate-induced conformational change in the enzyme or enzymes could thus prevent or induce such transport as would be necessary for appropriate interaction between the pollen tube and the stylar tissue.

In this study, serological reactions with distinct patterns have been found in the different combinations of pollen and female flower antigens with antisera against pollen. These patterns of reaction were of the same type as those obtained for *Oenothera* and *Petunia* in incompatibility studies of these species (L e w i s, 1952; M ä k i n e n and L e w i s, 1962 and L i n s k e n s 1960), and in general showed increasing similarity correlated with increasing incompatibility.

The results of M ä k i n e n and L e w i s (op.cit.) support the view that the S protein has its site of action on or near the membrane of the pollen tube. L e w i s, B u r r a g e and W a l l s (1967) were able to show that specific immunological reactions related to the S incompatibility gene can be demonstrated with single pollen grains. A highly significant correlation is probable between the immunological reaction and the incompatibility relations. It is not known whether the S protein in *Oenothera* is an enzyme.

The attempts I have made to localize the antigens responsible for the serological reactions to the pollen tube also support the view that the differences, at least between species, are due to substances situated in the wall of the tube. One could, of course, say that the structural antigens of the cell wall substances, for example in pollen tubes, are normal products of plant specificity and that they have nothing to do with the incompatibility mechanism. Since, of necessity, however, the contact established between cells first occurs at the cell surfaces, one could find much support for the hypothesis that even the incompatibility factors are situated at the pollen tube membrane.

If the penetrating pollen tube has on its surface a complicated many-dimensional structure of proteins, polysaccharides and linking lipids, all leading to specific and site-bound reactions, one is inclined to link the whole problem of incompatibility with the more general problem of antigenic properties and reactions and the recognition of self or non-self.

The surface-bound reactions in connexion with these problems are numerous. Specific agglutination of opposite mating types due to the pres-

ence on cell surfaces of complementary macromolecules, glycoproteins, has been observed by Crandall and Brock (1968) in yeast.

In addition, there is increasing evidence that the specificity of plant organs is maintained though the presence of specific barriers operating between the cells. Lamport (1967) observed glycoproteins of plant cell membranes, the »extensins», which are considered important for the permeability and extension of plant cell walls. In these substances a polypeptide backbone with hydroxyproline residues is linked with arabinose oligosaccharides. Several other studies have shown the occurrence in plant cell walls of polysaccharides of very complex structure, and of specific enzymes involved in the hydrolysis of these structures. The genetical background to these complicated wall structures in higher plants is completely unknown, but the presence of specific polysaccharides in particular plant species suggests genetical control.

In lower organisms, on the other hand, there is already much evidence for the genetical control of wall structures. One of the best known systems in this connexion is that of the 0-antigen structures in the cell envelope of the *Salmonella* bacteria.

In these, a lipopolysaccharide-phospolipid complex forms the active acceptor for the enzymes catalysing the incorporation of sugars into the bacterial cell wall. The core of the structure consists of glucose, galactose glucosamine and heptose, but a single lipopolysaccharide may contain as many as 14 different structural components and carry several different antigenic determinants. 0-Antigenic structures are under genetic control and determined by the presence or absence of specific transfer enzymes coded by structural genes (Horecker, 1966).

Mutation of these bacteria to »rough» states results in loss of other components in addition to the 0-specific antigens, indicating that specific sugars are components of specific side chains attached to the basal core structure. In »rough» states it may be that only the core remains.

The appearance of electron-dense substances, thought to be lipids, at the very beginning of pollen tube growth in *Betula* may thus be of some significance. It could well be that these lipids, which are generally known to form part of the complex cell membrane structure, function here, as in the above-mentioned case of the bacterial envelope, as a nucleus for the accumulation of specific carbohydrates forming the pollen tube membrane.

Sassen (1964), studying *Petunia* pollen, likewise concludes that lipids are involved in its metabolism and perhaps play a part in building up the membrane system of the cytoplasm. The different roles of the generative and vegetative cell in pollen tube growth are discussed by Larson (1963).

The accumulation of sugar molecules on the lipid structures could then be the way in which a highly specific surface is formed on the pollen tube.

There is already some evidence to suggest that the plasma membrane may be the source of the cell wall polysaccharide-synthesizing system (V i l l e m e z et al. 1967).

If the incompatibility reaction depends on a highly specific complementary matrix that is the end product of a complicated construction procedure directed by specific gene-dependent enzymes, compatibility would easily be restored by any change in the process earlier or later. Support for this hypothesis is provided by the fact that mutations of the S gene have always resulted in removal of incompatibility and not in restoration of incompatibility or even in production of another allele of the S gene, when artificial induction of mutations has been tried.

Using an analogy from the *Salmonella* bacteria, the difference between compatible and incompatible species could be thought of as a difference of chemotypes and the difference between the incompatibility alleles as one of serotypes. It is interesting to compare this analogy with the hypothesis of S a m p s o n (1962) on the nature of the intraspecific and interspecific structures of the S allele. Each serotype within a chemotype would then correspond either to a difference in the fine structure of a polysaccharide constructed from the same building blocks or, in some instances, to the substitution of, for instance, acetyl groups on the sugar units.

If negative affinity is the specific reaction, this would fit in well with the theories that a complementary reaction is needed before the growth reaction is triggered off to an extent sufficient for the fertilization process to be effected.

If compatibility is found in a certain member of an otherwise incompatible species, one would therefore suspect that this individual lacks some of the enzymes necessary for the building of the complex polysaccharide matrices and that this would then also show up in some general feature of the plant's biochemical structure, especially if the cause is lack of an enzyme responsible for an early event in the developmental chain.

If we now return to our tree Ru 17, in which the very typical interspecific incompatibility reaction of *B. pubescens* was lacking, we remember that this tree was also characterized by a much less pronounced serological activity. One is inclined to speculate that in Ru 17 the metabolic chain for the formation of the polysaccharide structure was broken at a relatively early stage, owing to lack of some transfer enzyme and that this lack in turn was the cause of the absence or suppression of the corresponding gene. In bacteriological terms, one could, perhaps, call the tree Ru 17 a »rough» type.

It is well known that the *Salmonella* antisera are able to react with plant polysaccharides (H e i d e l b e r g e r, 1960), among them arabogalactans. These reactions can be very specific and provide clues even to polysaccharide

linkages. *Salmonella typhi*, for instance, reacts with mannan 1.2—1.3 but less strongly with mannan 1.4—1.6 (H e i d e l b e r g e r, 1964).

When birch pollen antigens were treated with *Salmonella* antisera, the *B. pubescens* and *B. verrucosa* AG differed in their reactions with the *Salmonella* type C_1 but gave similar reactions to the other types. But the Ru 17 antigen did not react with any of these *Salmonella* sera, which, indeed, supports the hypothesis that in this case the specific chain for the building up of the antigenic substance may have been broken at an early stage.

This example, of course, is of very limited value as evidence for the hypothesis that the incompatibility mechanism functions on the basis of complex structural conformations of the cell membrane. But the observation that in the electrophoretic experiments several of the serologically active substances were connected with polysaccharides or glucoproteins from the pollen and styles lends some additional support.

Demonstration that a specific incompatibility type was connected with a specific pattern of polysaccharide molecules in the cell membrane would be much more convincing. In my material the genotypes are so far unknown but the results certainly point to the need for further serological studies when flowering progenies are available.

The very specific reactions, of the various *Salmonella* sera towards sugar molecules would obviously be of great help in enabling further distinctions to be made between the structures and substances involved.

A problem of great importance in connexion with the nature of incompatibility is the question of when the specific reaction pattern is imposed upon the plant. Immunological tolerance in animals is an induced state in which the organism, after exposure to an antigen early in life, is unable to recognize it as foreign on exposure later in life. Tolerance is an ideal built-in natural safeguard against the danger that an animal might become sensitized to or immunized by the constituents of its own body (M e d a w a r, 1961).

Although plants do not seem to have a free-moving antibody-producing system like animals, there are nevertheless several features common to the organisms of both kingdoms which indicate that plants also have mechanisms for immunological response and the achievement of tolerance.

In plants the stimuli which provide the initial impetus to development derive not only from the genetic nature of the cell but also from specialized or comprehensive nurture, which is best provided by the fluids of the endosperm which normally nourish the zygotes (S t e w a r d and M o h a n R a m, 1961). This »epigenetic» control (W a d d i n g t o n, 1957) seems to operate through an array of compounds whose identification and mode of action still remain to be investigated.

The immunological indifference of embryonic tissue in general, the

success of distant hybridization in plants after embryo transplantation (see e.g. W a r d l a w, 1968) and the lack of serological activity observed in young birch embryos all indicate that embryonal development is of importance for the development of specificity in plants.

Since the embryo acquires from its environment the impression of tolerance towards what is recognized as self or like self, and since this impression of tolerance may be retained during the development of the plant, it is necessary for the plant to have a system that protects the gametes from the influence of the endogenous environment of the plant at the time when they, have to develop an independent system of reactivity. Exposure at this particular moment to the tolerance-inducing mechanism would be disastrous for the whole system.

As H e s l o p - H a r r i s o n (1964) has stated, the expression of genetic individuality in each spore must obviously depend upon isolation from the others. Around the pollen mother cell, there is, during the course of its development, formation of callose. The most reasonable interpretation of the function of this callose cell wall is that it acts as a molecular filter, permitting the passage into the spores of essential nutrients, but excluding larger molecules whose intrusion at this early stage might impair the capacity of the haploid spore nucleus to establish autonomy within its own cytoplasm.

In addition, M a c k e n z i e et al. (1967) have found that the cytoplasm received by the spores is not merely a portion of that present in the mother cell. The wholesale elimination of the ribosomes of the diploid cell might be understandable if it were essential for the initiation of the haploid phase that a new protein-synthesizing system should be established. This could be a device for ridding the cell of long-lived messengers or for restoring a norm, whatever controls of gene action transmissible through mitotic cycles may be effective in the diploid cell lineages.

In the formation of birch pollen there is (H a g m a n, unpubl.) very obvious formation of a callose wall around the pollen mother cell when it is approaching meiosis, and this structure is also seen between the four different parts of the tetrad until the late stages when the pollen grain wall is formed. Thus, in the developmental stages of birch pollen a mechanism is present that could provide the pollen grain with the necessary protection for the realization of its independence. I do not know whether a callose structure is missing in compatible plant species.

The physiological functions of the callose in plants are at present still very largely unknown but callose has long been known to be produced by plant cells in connection with injury, perhaps as a protection against infection.

The callose substances thus seem to be connected with several features of an immunological and differentiative nature. Callose is often found in

sieve tubes. Bodies containing RNA are found in sieve elements and may have an unrecognized function, and transcellular strands in sieve elements may play an important role in carbohydrate translocations (T h a i n e et al., 1967). Is the phloem, perhaps, part of the plant's immunological system?

Rapid changes in callose production have been found to occur in the ovules of *Petunia* at the time of fertilization and to be initiated by pollination, even though the pollen tube has not yet reached the ovaries (E s s e r, 1963). Thus a selective action of the callose could be postulated in the female tissues as well. (See also L i n s k e n s and E s s e r, 1957.)

One might argue that if polysaccharides are capable of selecting one reproductive part of a plant from the specific activity of the rest, substances of the same type might also be responsible, at the membranes between cells, for the selective activation of vegetative cells by gene products, thus forming the basis for differentiation.

The incompatibility mechanism requires, in addition to the male gametes, the functional partnership of the style. In the incompatibility system which we are studying here, this part is bound to the genetical structure of the sporophyte. The behaviour of the stylar part must involve a feature of differentiation and attainment of competence. This predetermination establishes in advance of any overt differentiation that the cell or tissue will react in a particular way to stimuli received at a particular time (H e s l o p - H a r r i s o n, 1967). The capacity to react is different, however, from the reaction to a stimulus and the potentialities produced by earlier interaction must await subsequent signals for their realization.

Now we know from the birch styles and from several other plants that the capacity to react to an incompatibility stimulus is expressed mainly at the very moment of optimal stylar development. Early pollinations (and bud pollinations) as well as late pollinations lead to decreased incompatibility. It thus seems that in the style the receptional features are not ready to respond to the signal until a very specific moment.

One would think that the female tissue could not develop the rigid mechanism necessary for the incompatibility reaction because their own cells are developing and the final stage would fix a certain structure not permitting further development. A developing organ could thus be thought to be less specific for incompatibility — or for that matter for immunity — reactions owing to the need for maintaining a degree of flexibility for development. In this pattern plants could well be different from animals, since the growth of plants is to a certain extent »open-ended» and indefinite, in contrast to that of animals, in which organs are only formed once and cell specialization is extreme and begins early. It could, of course, also be argued that if the tolerance-inducing mechanism is still operating in the adult plant, expo-

sure of the incompatibility centres at too early a date might lead to disturbances of the mechanism.

External factors, such as irradiation, known to affect both immunological responses and incompatibility, could prevent final differentiation by blocking the mechanism laying bare the reactive sites or by changing the configuration present, so that the reactive part was inactived. Birch styles are red. Since the genus is anemophilous, the colour seems to have no role as an insect attractant. But perhaps the anthocyanin does have a function of protecting the tissues from ultraviolet light that could upset the incompatibility reaction of the style, and at the same time act as an attractant for heat. The warming of the style might assist its general physiological development and at the same time give a guarantee that the endothermal system of incompatibility would remain functional.

Intergeneric and in some cases also interspecific pollination may bring together components so foreign that no self-recognition is possible when the partners approach each other, and thus the plant reacts — as in general against non-self — inhibitively. Tolerance induced by embyonal grafting may lead to the formation of a pattern in the foreign individual that allows a certain degree of self-recognition to take place and thus will increase compatibility. Non-identical S alleles could likewise be thought to be working within the self-reocognition pattern by blocking the final complementary structure. The effect of an identical S allele must then be explained as the production of a complementary pattern so »anti-identical» that the action system is completely blocked. A steric configuration in which the gaps in one molecule were occupied by groups of atoms belonging to the other molecule would leave no space structures for specific enzymes to work on, or work from.

Perhaps the incompatibility system in plants is a more primitive form of immunological activity than that developed later in animals. If I may be allowed to speculate, it could be imagined that the formation, in the very early stages of life, of a selective structural barrier, composed of, say, carbohydrates, against the surroundings predisposed towards the later development of factors capable of directing the development of the cell and its interactions with its neighbours in a heritable way, thus leading to the development of the multicellular organism. B u r n e t (1961) said: »There is an insistent suggestion that immunological self-recognition is derived from processes by which morphological and functional integrity is maintained in large and long-lived multicellular organisms.» ». . . we have a shadow of justification for wondering whether the antibody-producing system in the immunologically competent cell may not have been derived phylogenetically and ontogenetically, from cells which had once had, as it were, morphological responsibilities.»

Table 14. Plants obtained after different kinds of pollinations in *Betula verrucosa* and *Betula pubescens*.

Parents	Number of lots	Seed sown g 1)	Number of plants obtained	
			Total	Plants per g
B. verrucosa cross-pollin.	28	73.4	5 182	71
B. verrucosa self-pollin.	9	17.8	554	32
B. pubescens cross-pollin.	19	19.0	1 971	104
B. pubescens self-pollin.	7	5.9	365	62
B. verrucosa × *B. pubescens*	32	64.3	1 237	19
B. pubescens × *B. verrucosa*	48	59.5	948	16
B. verrucosa and *B. pubescens* wind-pollinated parents	16	73.5	5 003	68
Special crosses, pollen mixtures and curly birch	25	100.1	4 290	42
Controls	19	31.5	144	5

1) The weight of the scales of the catkins is included in the weight of the seed.

Incompatibility and forest tree breeding

The detection in the birch of an incompatibility mechanism similar to those observed in other, genetically better known, plants enables it to be predicted that normal breeding methods will be found to be applicable in birch breeding and that the methods employed by plant breeders in agriculture and horticulture for the removal of barriers to selfing and crossing will prove useful in birch breeding as well.

The observation that, despite the high degree of self-incompatibility found, progenies can to a certain degree be obtained after selfing, makes possible the inclusion of inbreeding in a breeding programme for birch. Species crosses show marked hybrid vigour in many cases and overcoming the interspecific incompatibility barrier might increase the number of combinations considerably. Crosses between species with different chromosome numbers might produce polyploids which, although sterile, could be propagated vegetatively.

In species of some cultivated plants the use of inbreeding has met with great success. The families from crosses between inbred lines frequently show very great variation, so that selection from families produced after crossing inbred lines is likely to yield better results than selection from material that is not inbred.

Continued selfing is the quickest way to obtain high degrees of homozygosity. The experiments made here, and the results obtained by others, show that, although self-incompatibility is present in both *B. verrucosa* and *B. pubescens*, almost every tree can be selfed to a certain degree. Although the seed set after selfing is small relative to the normal crop, the abundant seed production of birch makes the breeding of inbred plants possible on a

Table 15. Fertility in I_1 progenies of the selfed *B. pubescens* E 880. Observations from Ruotsinkylä Experimental Forest, 1964.

I_1 tree No	Filled seed after wind-pollination %	Pollen quality: % of well developed grains staining with aceto-carmine
25	50	95.5
27	26	93.0
29	15	—
64	12	72.0
75	19	94.5
95	21	91.5
103	50	90.0
122	21	93.5
159	29	—
163	28	—
168	21	—
174	11	—
188	8	87.5
195	22	95.5
229	20	69.0
232	13	—
234	27	—
N = 17	Mean 23 %	Mean 88.2 % N = 10

scale that can be used in practical breeding. As seen in table 14, plant production after selfing can be about half that of crossing. One birch graft may well produce up to 5 kg of seed. Single trees planted in good isolation conditions could thus produce up to 100 000 inbred progeny plants in a good seed year. The possibilities for further crossing between inbred lines of birch thus seem good.

The question of whether all the progenies of a selfing are viable and fertile is the other condition for the inbreeding method and must be tested by growing the progenies. If this is done on a large scale, there will probably be enough fertile plants, despite the occurrence of weak and sterile types.

As a first report about the degree of fertility in inbred birch, the figures in table 15 give the quality of wind-pollinated seed and the quality of pollen in the I_1 progeny of the *B. pubescens* E 880. Taken as a mean, the seed-setting for the I_1 plants is = 23 %, which is not so poor compared with an adjacent plot of planted *B. pubescens*, a progeny of half-sibs, where wind-pollinated seed had 52 % filled seed.

When selection is made on the basis of family means, the amount of gain expected usually increases as the within-family genetic correlation increases. Selfing is one method of developing a high within-family genetic relationship. Several characters of value in forestry have a low heritability and the breeding value is poorly defined on the basis of a single phenotype. In such cases, and when inbreeding depression is not excessive, so that

selection is not much biased, selection using selfed families is a method worthy of serious consideration (B a r k e r, 1967).

In species hybrids (cf. e.g. table 7) the production of good seed is much lower, but in this case, too, hybrid plants might be produced on a practical scale. In this case the differences observed between the different crosses stress the need for using as many partners as possible. The best results would probably be obtained from pollinations in which the *B. verrucosa* used as mother tree was already self-fertile or less self-incompatible. S t e r n (1960) stated that hybrid weakness was frequently found in the interspecific cross *B. verrucosa* × *B. pubescens* and explained it as an effect of polygenes. However, major genes responsible for hybrid weakness were also found in some cases.

The growth of the hybrids between *B. verrucosa* and *B. pubescens* is not inferior to intraspecific progenies in all cases (E i f l e r, 1956). In cross-fertilized organisms no sharp distinction can be drawn between auto- and allopolyploids. Alloploids have the gene complement of both parental species and consequently have a reaction norm which may be either intermediate between, or a combination of, various characters of the parental forms. The combination may possess a high adaptive value, particularly if, as sometimes but not always happens, the allopolyploid possesses the environmental tolerances of both parents. Thus allopolyploids have advantages in nature (D o b z h a n s k y, 1951).

We know that *B. pubescens* is more tolerant than *B. verrucosa* but that in good growing conditions the production of *B. verrucosa* is superior. To what extent the adaptation and coadaptation processes have developed in these two species is not well known and consequently it is impossible to guess to what extent specialization has proceeded beyond the point where few if any hybrids without hybrid weakness are obtainable. Since hybrid weakness and hybrid heterosis are by no means equally distributed among all the individual members of a species cross but the parental constitution is responsible for the reaction, there seems to be room for further experiments, perhaps with some useful results.

It is not clear whether the allotriploids obtained from the hybridization between *B. verrucosa* and *B. pubescens* will have characters superior to those of their parents, but these two species differ so greatly, both anatomically and physiologically (K u j a l a, 1946), that some interesting intermediate forms may be expected. The production of such hybrids on a scale large enough for field experiments in different conditions seems quite possible.

One could imagine the value of such hybrids in the severe conditions of the far north or at the timberline along the Baltic. Perhaps such hybrids could also be used on very poor peat soils, at least as a primary forest. What could be obtained from outcrossings of such hybrids with their parent species

or further crossings of the F_2 and F_3 is another matter. According to Stern (1963 b), the cross hybrid × hybrid was just as fertile as the cross hybrid × *B. pubescens*. The cross hybrid × *B. verrucosa* had low fertility but the cross hybrid × *B. pubescens* gave between 43.5 and 65 % of filled seed.

Possibilities for success of polyploid breeding are more favourable in angiosperms than in conifers (Eifler, 1967; Johnsson, 1956). Polyploidization in the birches could increase self- and interspecific compatibility and polyploidization of an alloploid hybrid could give a true-breeding new species with 2 n = 84 chromosomes and perhaps make many desirable characters permanent. The possibilities of further interspecific hybridization in birch are beyond the scope of this paper. (See e.g. Stern, 1963 c.)

The presence of self-incompatibility alleles will obviously affect the segregation for all genes linked with the S gene. Forest geneticists working with birch must be prepared to encounter disturbed ratios as a result of linkage between morphological genes and self-incompatibility alleles. This has especially to be kept in mind when crossings are carried out on a large scale between trees belonging to limited, small stands, which may well have originated from very few parents. Among other effects, one has to observe that if a common allele is present, the class to which the mother belongs is never present in the offspring.

If random mating of members of a polymorphic species is restricted by the constraint of self-incompatibility, the equilibrium frequencies of the genotypes in a large population will not be determined simply according to the Hardy-Weinberg law (Finney, 1952). Calculations derived by Workman (1964) and Karlin and Feldman (1968 a, 1968 b) could serve as methods for analysis of the populations.

When the number of alleles is great, complex situations occur and the determination of the rate at which stationary states are reached and at which distributions of the frequencies for each allele are established, must be based on mathematical models, many of which have not yet reached definite solutions. For a discussion of this very interesting problem the reader is referred to the book by Moran (1962).

If more self-progenies could be produced by early or late pollination, low-temperature treatment or irradiation, the possibilities of obtaining plants homozygous for the S allele would increase. Such plants could easily be detected by back-crossing with the parent as male. If performed with a great number of individuals from different populations, the progenies of which would allow estimation of the number of different alleles, this method would give information about differences in and between populations.

The use of trees of known S genotypes could also be of help in solving other problems in tree breeding. Counts of the number of compatible and incompatible pollen tubes on styles of different clones in a birch seed

orchard and the use of clones of known genetical composition in different combinations would give a fairly good picture of the number of self- versus cross-pollinations and thus an idea of the pollen dispersal and the degree of panmixy that can be achieved.

In general, it must be admitted that the set of good seeds after different kinds of artificial pollination in connexion with this study has remained low. Perhaps this was due to insufficient pollination. In several other forest trees artificial pollination likewise, in my experience, frequently gives a seed set much too low compared with wind pollination. Before large-scale practical programmes are started on controlled crossbreeding and inbreeding in birch, all phases of the artificial pollination procedure, including floral development in isolation bags, pollination technique and post-anthesial development, must be studied more closely. With the improvement of the technique — for which there is much room — better results may be expected.

In passing, it may be noted that as a result of the crossings a large number of progenies have been obtained after long-distance intraspecific crosses. These plants have been observed for several years and display interesting phenological traits. In general, the northern provenances from Lapland shed their leaves about seven to ten days earlier than the southern provenances and the combinations northern × southern and reciprocals are intermediate. But there are also maternal effects. These progenies have been planted out in northern as well as in southern localities and I hope later to be able to report the results of the analysis of these experiments.

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8. CONCLUSIONS

On the basis of this study one may conclude that:

1. In *B. verrucosa* and *B. pubescens*, the presence of an incompatibility system operating by arrest of the growth of the pollen tube has been established.
2. Evidence has been presented that the genetical basis for this incompatibility mechanism is not inconsistent with the hypothesis of the S allele, one-locus system. This fits the general picture of a species having simultaneous pollen mother cell division and binucleate pollen grains.
3. Interspecific incompatibility has been found, which at least in part is dependent on a similar mechanism, but in addition may depend on barriers effective at the level of embryo development. The stages of birch fertilization should therefore be investigated.
4. Individual variation in the incompatibility mechanism occurs, the species *B. pubescens* being in this connexion more variable and suggesting an allopolyploid structure of this species.
5. The development of serological methods in connexion with electrophoretic techniques for separation has provided a useful tool for the further study of the substances involved in the pollen and style relationships. Application of the technique has brought the possibilities of localization to the level of electron microscopy.
6. On the basis of the results, the hypothesis is presented that the incompatibility reaction in *Betula* is dependent on highly specific structures situated at, or in the immediate neighbourhood of, the cell membranes. There is some evidence presented that these structures are connected with the conformation of polysaccharides.
7. Genetical conclusions must await further analysis of flowering progenies. When plants of known S genotype are available, there will be possibilities for the collection of more detailed information on the substances actually involved in the incompatibility reaction. Other plants should be tested to prove whether the techniques and results are universally applicable.

8. Theories concerning the nature of the incompatibility mechanism have been discussed in the light of the results. There is much evidence suggesting that the incompatibility mechanism is connected with very basic aspects of the development and differentiation of plants and animals.

9. Knowledge of the breeding system of the birches offers possibilities for several methods to be applied in further birch breeding. These methods include inbreeding, hybridization and polyploidization. Knowledge of the breeding system likewise provides a basis for considerations about the genetical structure of birch populations.

9. SUMMARY

The main object of this study was to investigate the nature of the incompatibility mechanism in intra- and interspecific crosses of the two chief birch species of Finland. Knowledge of the breeding system in the *Betulae* is of importance for the taxonomy of this genus and in addition of value for the programming of the tree breeding with timber species of birch. Self-incompatibility was found in both *Betula verrucosa* and *B. pubescens*. The incompatibility occurs in the style and is expressed through retarded growth of the pollen tube. Interspecific incompatibility of the same type occurs when the two species are crossed. However, the incompatibility reaction is more pronounced when *B. verrucosa* is used as male parent. In the reciprocal cross, many of the combinations show a certain percentage of good growth of the *B. pubescens* pollen tubes in the styles of *B. verrucosa*. These observations agree with earlier reports that more filled seed is obtained when the species cross is made in the direction *B. verrucosa* female × *B. pubescens* male.

Intraspecific cross-incompatibility also occurs to a certain degree. In 25 combinations made between 5 *B. verrucosa* trees growing in the same stand, there were 7 combinations indicating cross-incompatibility in 1962. When 6 of these crosses were repeated in 1964, 3 of them indicated persistent cross-incompatibility, whereas the other 3 did not. In 1964, 12 other cases indicating cross-incompatibility were found in a total of 84 combinations. In *B. pubescens* 9 out of 16 crosses made in 1962 showed cross-incompatibility and 6 of them were repeated in 1964. In this year 5 were still cross-incompatible. In 15 *B. verrucosa* trees from the limit of the range of this species either at the northern border in Lapland or from the south-western border in the archipelago, there was no tendency towards increased self-compatibility. Neither was there any increase in cross-incompatibility when the trees from Lapland were crossed with the southern trees.

The genetical background for the incompatibility mechanism in *Betula* is not yet experimentally confirmed. Back-crosses made with the only selfed progeny available indicate that the system is a one-locus multiple allele system. Chromosome studies have in some cases confirmed interspecific hybridization between *B. verrucosa* and *B. pubescens*. However, there are also indications of an imbalance in the chromosomal behaviour whose nature has, so far, not been investigated.

External factors influence the growth of the pollen tube. At low temperatures the incompatibility reaction is slowed down, thus increasing the possibility for selfing. The same effect may be achieved by pollinating at an early or late stage of development of the female flower. These conditions may allow interspecific crosses to take place in nature, especially in years when the weather at the time of flowering of the two birch species is such that some overlapping occurs.

Insects feeding on the female flowers may considerably reduce fertilization and seed-setting by preventing the growth of the pollen tube. The biochemical conditions leading to this pollen inhibition are not known.

The pollens of the two birch species studied here exhibit detectable differences in serological tests. Pollens from incompatible trees of the same species show a greater identity when tested as pollen antigens. In interspecific crosses, on the other hand, pollen from individuals showing greater serological identity with the pollen of the other species seems to be more compatible.

The serologically active substances are present in the pollen tube, and it is suggested that the reactions leading to compatibility or incompatibility take place at the tip of the pollen tube and that these reactions are in some way bound to the pollen tube wall or membrane.

From the pratical point of view, knowledge of the breeding system of birches will allow the breeder to design methods for by-passing the incompatibility barriers present. Suggested methods are pollination at low temperatures and irradiation of the styles. The use of the exceptional individuals found as partners in a breeding programme for the introduction of compatibility factors into otherwise incompatible combinations is another method that deserves attention.

The abundant seed production of the birch would make it possible to produce inbred plants and species hybrids on a scale sufficient for further selectional, combinational or other breeding work.

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