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HELSINKI 1972

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THE EFFECT OF COMPETITION ON THE STRUCTURE OF SEEDLING STANDS

HANNU VÄLIAHO

Seloste

Kilpailun vaikutus taimistojen rakenteeseen

HELSINKI 1971

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Helsinki, August 1971

Hannu Väliaho

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1. INTRODUCTION

During the course of the last ten years, the methods applied for the construction of growth and yield tables have undergone major changes, mainly as a result of the progress made in the computer-treatment of research material. Whereas in the 1950's graphic fitting was applied almost exclusively, in the 1960's growth and yield tables are based upon the mathematical relationships between the various dependent and independent variables of growth and yield.

A characteristic feature of the techniques of constructing growth and yield tables in Finland is the application of an individual tree as the basic unit of calculations (cf. V u o k i l a 1965, 1967). On the assumption that the development of a stand model is a sum of the developments of its trees, growth and yield tables can be constructed from tree data more accurately measurable and compiled more cheaply than material concerned with the development of the stand as a whole.

For practical reasons of mensuration, it seems advisable to study the seedling stand separately from the later phases of stand development. Study of the structure of seedling stands at a dominant height of 5—7 m. enables inexpensive and efficient determination of the effect of various types of seedling stand treatment. The aim of this study is that of acquiring information in regard to the diameter and height distribution of trees for initial stand tables which will permit of further examination of a stand by means of tree increment functions.

The purpose of the present investigation is that of developing methods of studying the structure of seedling stands during their pre-commercial development. This leads to a detailed analysis concerned with the effect of the mutual competition of trees in stands of varying density and initial treatment. The practical goal of the study is that of providing a mathematical basis for formulation of the initial stand table applicable to subsequent construction of growth and yield tables for the commercial phases of development.

2. RESEARCH MATERIAL

Since the main emphasis is laid upon the methods of studying the structure of the seedling stand, little research material is required. Once the basic principles have been clarified, more extensive material can be compiled for the acquisition of data which can reliably be applied to the practical construction of yield tables.

The research material comprises four sample plots, called in accordance with their situation PALOHEINÄ (on the eastern outskirts of Helsinki), KANNUS (in Northern Ostrobothnia), RUOTSINKYLÄ (about 25 kilometres north from Helsinki) and NYNÄS (on the southern outskirts of the town Heinola). The first two plots are in pine, and the other two in spruce stands. PALOHEINÄ and RUOTSINKYLÄ have been subjected to detailed analysis, whereas KANNUS and NYNÄS have been used as check material (although KANNUS has been subjected to special analysis).

Basic information relating to the sample plots is listed in Table 1. It is observable that the sample stands are rather dense in view of the present trend of seedling stand treatment; the number of stems varies from 2 370 to 2 876 trees per ha., with the dominant height of 7.0—9.4 m. These figures indicate that — after an initial period — the stands studied have closed up,

Table 1. Characteristics of the sample plots

Characteristic	PALOHEINÄ	KANNUS	RUOTSIN-KYLÄ	NYNÄS
Tree species	pine	pine	spruce	spruce
Age, years	22	20	24	17
Forest site type	MT—	MT	MT	OMT
Site index (h_{100})	28	27	25	30
Area, sq. m.	30×35 = 1 050	25×40 = 1 000	25×40 = 1 000	25×40 = 1 000
Number of trees	302	257	276	237
Number of trees per ha.	2 876	2 570	2 760	2 370
Diameter (d), cm.				
— range	2.9—19.5	0.5—12.2	1.7—12.6	0.6—12.1
— mean ($\bar{d}$)	10.0	6.9	7.3	7.0
— standard deviation (s_d)	2.8	2.5	2.2	2.3
Height (h), m.				
— range	3.6— 9.6	1.6— 7.6	2.0—10.4	1.4— 9.1
— mean ($\bar{h}$)	7.6	5.2	6.9	6.3
— standard deviation (s_h)	1.1	1.3	1.7	1.5
— dominant height (h_{dom})	8.7	7.0	9.4	8.5

with the consequent creation of competition between the trees. However, it needs to be pointed out that the competition has not been of long duration, although it must be rapidly increasing at the moment. As the ages vary within a range of 17—24 years, it can be concluded that possibly the competition had a major start less than 10 years ago. From the standpoint of the present investigation, this implies that competition alone does not explain the differences between the neighbouring trees, and that additional significant variables exist which cannot be studied in this investigation.

A typical stand map is illustrated in Fig. 1. Even though the stands were established by planting, no regular row structure is detectable. This is typical of Finnish conditions, in which some terrain features normally lead to irregularities, even if endeavours are made to achieve regularity. The map indicates even major openings in the stand, again a rather typical local phenomenon. Nevertheless, irregularities and openings — if not of major extent — can be considered as an advantage from the aspect of the present study. A regular stand structure with even spacing implies rather stable conditions for tree individuals, while irregularities give more variability and thus provide enlarged scope for the investigation; within one stand, multiple competitive set-ups can be encountered.

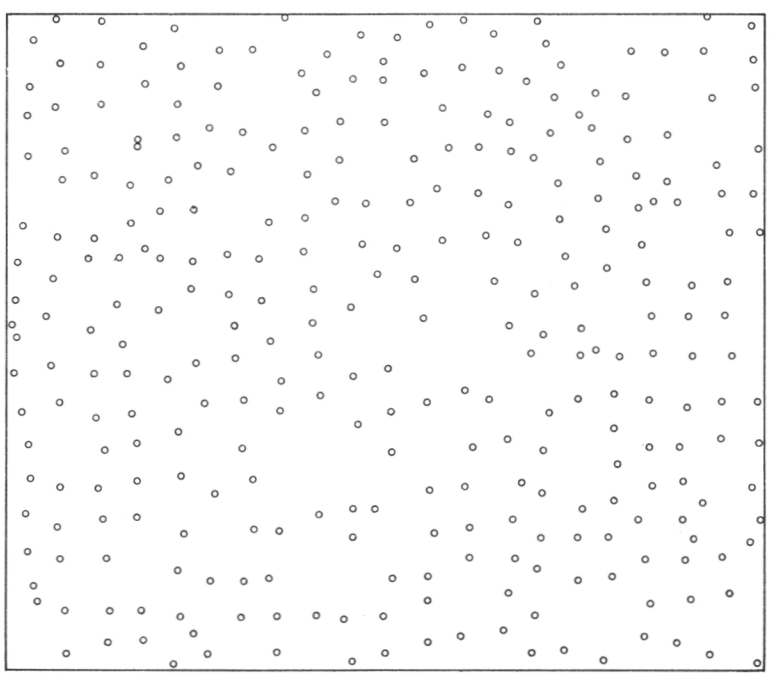

Fig. 1. Tree map over the sample plot PALOHEINÄ (35 m. × 30 m.)

The seedling stands studied have not been treated since their establishment. Consequently thinning has not interrupted the start and the intensification of the competition.

Tables 2 and 3 indicate the distribution of trees by diameter and height classes in PALOHEINÄ and RUOTSINKYLÄ, i.e. in the stands forming the main foundation for the analysis.

Table 2. Distribution of diameter and height of trees in PALOHEINÄ

h, m. \ *d*, cm.	1.6—2.5	2.6—3.5	3.6—4.5	4.6—5.5	5.6—6.6	6.6—7.5	7.6—8.5	8.6—9.5	9.6—10.5	10.6—11.5	11.6—12.5	12.6—13.5	13.6—14.5	14.6—15.5	15.6—16.5	16.6—17.5	17.6—18.5	18.6—19.5	Total
1.6— 2.0 ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2.1— 2.5 ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2.6— 3.0 ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3.1— 3.5 ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3.6— 4.0 ..	—	1	1	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	5
4.1— 4.5 ..	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	2
4.6— 5.0 ..	—	1	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
5.1— 5.5 ..	—	—	2	1	1	1	1	—	—	—	—	—	—	—	—	—	—	—	6
5.6— 6.0 ..	—	—	1	3	2	1	—	2	1	—	—	—	—	—	—	—	—	—	10
6.1— 6.5 ..	—	—	2	1	5	3	4	2	1	—	—	—	—	—	—	—	—	—	18
6.6— 7.0 ..	—	—	1	2	—	3	6	6	5	1	1	—	—	—	—	—	—	—	25
7.1— 7.5 ..	—	—	—	1	3	7	6	7	8	8	6	3	2	—	—	—	—	—	51
7.6— 8.0 ..	—	—	—	—	2	8	7	14	17	13	12	10	3	1	—	—	—	—	87
8.1— 8.5 ..	—	—	—	—	—	2	—	2	13	10	10	10	5	3	—	—	—	—	55
8.6— 9.0 ..	—	—	—	—	—	—	—	2	3	5	7	4	2	1	1	1	—	1	27
9.1— 9.5 ..	—	—	—	—	—	—	—	—	1	1	2	2	4	2	—	—	—	—	12
9.6—10.0 ..	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1
10.1—10.5 ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	—	3	8	11	14	26	24	35	49	38	38	30	16	7	1	1	—	1	302

Table 3. Distribution of diameter and height of trees in RUOTSINKYLÄ

h, m. \ *d*, cm.	1.6—2.5	2.6—3.5	3.6—4.5	4.6—5.5	5.6—6.5	6.6—7.5	7.6—8.5	8.6—9.5	9.6—10.5	10.6—11.5	11.6—12.5	12.6—13.5	13.6—14.5	14.6—15.5	15.6—16.5	16.6—17.5	17.6—18.5	18.6—19.5	Total
1.6— 2.0 ..	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
2.1— 2.5 ..	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
2.6— 3.0 ..	3	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
3.1— 3.5 ..	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
3.6— 4.0 ..	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
4.1— 4.5 ..	—	—	6	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7
4.6— 5.0 ..	—	—	5	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	14
5.1— 5.5 ..	—	—	3	12	5	—	—	—	—	—	—	—	—	—	—	—	—	—	20
5.6— 6.0 ..	—	—	—	6	15	1	1	—	—	—	—	—	—	—	—	—	—	—	23
6.1— 6.5 ..	—	—	—	2	10	9	3	—	—	—	—	—	—	—	—	—	—	—	24
6.6— 7.0 ..	—	—	—	—	10	14	6	1	—	—	—	—	—	—	—	—	—	—	31
7.1— 7.5 ..	—	—	—	—	2	15	18	4	—	—	—	—	—	—	—	—	—	—	39
7.6— 8.0 ..	—	—	—	—	—	7	14	7	1	1	—	—	—	—	—	—	—	—	28
8.1— 8.5 ..	—	—	—	—	—	2	7	15	3	—	—	—	—	—	—	—	—	—	25
8.6— 9.0 ..	—	—	—	—	—	—	2	8	8	4	1	1	—	—	—	—	—	—	24
9.1— 9.5 ..	—	—	—	—	—	—	—	3	6	2	4	—	—	—	—	—	—	—	15
9.6—10.0 ..	—	—	—	—	—	—	—	—	3	1	3	—	—	—	—	—	—	—	7
10.1—10.5 ..	—	—	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—	—	3
Total	6	7	16	31	42	44	51	38	21	10	9	1	—	—	—	—	—	—	276

3. PRINCIPLES OF COMPETITION FUNCTIONS

3.1. Setting up the problem

The scope of the present study is that of examining how the diameters, heights and some other characteristics of the trees in seedling stands are mathematically explicable by means of the characteristics of the neighbouring trees. Regression models will be constructed to describe the mutual dependence of the trees; these models will be based upon sample plots in which the locations, diameters and heights of all the trees are known.

3.2. Notations

In what follows, the following notations will be used:

x = x-coordinate of a tree, m.
y = y-coordinate of a tree, m.
d = diameter (breast high) of a tree, cm.
h = height of a tree, m.
s = slimness ($= 100d/h$) of a tree
j = (subscript) refers to the jth nearest neighbouring tree (to be called neighbour j)
r_j = $\sqrt{(x_j - x)^2 + (y_j - y)^2}$ = distance from a tree to neighbour j
m = competition factor of a tree
r_{max} = maximum distance from a tree to a neighbour to be considered
k = maximum number of neighbours to be considered
z = general notation for a dependent variable
a, b = regression coefficients
s_b = standard deviation of b
t_b = b/s_b, a test-value according to Student's distribution
f = number of degrees of freedom
R = correlation coefficient

R(I) = correlation coefficient of a model, based upon plot I, where I is replaced by P, K, R, N or T, referring to PALOHEINÄ, KANNUS, RUOTSINKYLÄ, NYNÄS or a theoretical plot, respectively

R(I/J) = correlation coefficient produced by a model based upon plot I, as applied to plot J

Accordingly, for example, d is the diameter of an observational tree, and d_j is the diameter of neighbour j. Correspondingly, x and x_j are the x-coordinate of an observational tree and that of the neighbour j, respectively.

3.3. Dependent and independent variables

An investigation will be made of the influence of competition upon the following tree variables

(1) $$d,\ h,\ s,\ \log d,\ \log h,\ \log s$$

Below, symbol z will refer to any of these six dependent variables.

The principal independent variables are

(2) d_j, h_j, r_j and their transformations

In addition, the following variables (or their transformations) will be tried out:

— basal area per ha. (measured with relascope with the observational tree as a centre)
— opening angle (the greatest angle between adjacent radii from an observational tree to the neighbours under consideration)
— δ_j = direction (from the south) of neighbour j

3.4. Hypotheses concerning competition functions

Our main hypothesis is that the effect of neighbour j upon the characteristics of an observational tree assumes the form

(3) $$m_j^{(1)} = \frac{d_j^{\alpha} h_j^{\beta}}{r_j^{\gamma}} \qquad \text{or} \qquad m_j^{(2)} = \frac{d_j^{\alpha} h_j^{\beta}}{c^{r_j}}$$

where α, β, γ and c are positive constants, and that the effects of different neighbours are additive:

$$m^{(1)} = \sum_j m_j^{(1)}, \qquad m^{(2)} = \sum_j m_j^{(2)} \tag{4}$$

Here $m = m^{(1)}$ or $m^{(2)}$ is termed the competition factor of a tree. From the k nearest neighbours those to be considered are those for which $r_j \leq r_{\max}$. Consideration will be restricted to the values $r_{\max} = 2.5$ and $k = 4$. The sample plots are isolated by a marginal »buffer zone» three metres in width. The trees inside this zone are not accepted as observational trees, although they may appear as neighbours.

The basic form of the competition functions is as follows:

$$z = a + bm \tag{5}$$

where z is one of the variables (1), m is $m^{(1)}$ or $m^{(2)}$, and a and b are regression coefficients. Model (5) may be augmented by the addition of independent variables.

It should be noted that model (5) is linear in a and b, but nonlinear in α, β, γ (or c). Consequently, different values of α, β, γ (or c) must be tried out, followed by the determination of a and b by regression analysis.

3.5. An approach with dummy variables

The distance between trees plays an important rôle in competition. Thus an endeavour will be made to discover, instead of (4), a more flexible competition factor of the form

$$m = \sum f(r_j) d_j^{\alpha} h_j^{\beta} \tag{6}$$

It is natural to require that $f(r)$ be a positive and monotonically decreasing function of r. Let

$$0 = \varrho_0 < \varrho_1 < \cdots < \varrho_p = r_{\max}$$

be a sequence of distances. A competition function is written as follows

$$z = a + \sum_{i,j} \varkappa_{ij} f_i d_j^{\alpha} h_j^{\beta} = a + \sum_j d_j^{\alpha} h_j^{\beta} \sum_i \varkappa_{ij} f_i \tag{7}$$

in which the terms $\varkappa_{ij}$ are dummy variables:

$$\varkappa_{ij} = \begin{cases} 1 & \text{if } \varrho_{i-1} < r_j \leq \varrho_i \\ 0 & \text{otherwise} \end{cases}$$

Function (7) is a regression model containing the constant term a, and p other regression coefficients $f_1 \ldots f_p$, one for each distance interval $(\varrho_{i-1}, \varrho_i]$. If the coefficients $f_1 \ldots f_p$ are subjected to some inequality constraints, such as

(8) $$f_i \geq 0 \quad \text{for } i = 1...p$$

or to

(9) $$f_2 - f_1 \geq f_3 - f_2 \geq \ldots \geq f_p - f_{p-1} \geq 0,\ f_p \geq 0$$

quadratic programming ensues. With the observational material as basis, an estimate can be made, for given α and β, of the coefficients a and $f_1 \ldots f_p$, with some algorithm being employed for quadratic programming (cf. V ä l i a h o 1970). On connection of the points

(10) $$((\varrho_{i-1} + \varrho_i)/2,\ f_i)$$

by a broken line, an approximation $\bar{f}(r)$ to $f(r)$ is obtained. A mathematical function, for example the of form

(11) $$y = ar^{-\gamma} \text{ or } y = ac^{-r}$$

may also be fitted to these points. In this way, estimates for γ and c in (3) are obtained. An illustration of this approach with dummy variables is provided in Sec. 4.3.

4. COMPETITION FUNCTIONS FOR PINE STANDS

4.1. Calculating the models

The regression models for pine stands were based upon the data concerned with PALOHEINÄ. It appeared that β in (3) could be given a value of zero. The notations adopted can consequently be:

$$m^{(1)}(\alpha, \gamma) = \Sigma d_j^{\alpha}/r_j^{\gamma}, \qquad m^{(2)}(\alpha, c) = \Sigma d_j^{\alpha}/c^{r_j} \tag{12}$$

Some of the models derived have been compiled in Table 4 (with $r_{\max} = 2.5$, $k = 4$, $f = 191$). The symbols $d_{\max}$, $h_{\max}$ denote the values of d, h, given by a model when no competition exists, i.e., when $m = 0$. Moreover, the notation is made $u = (d_{\max} - \bar{d})/s_d$ or $(h_{\max} - \bar{h})/s_h$.

The correlation coefficients are not large as could have been anticipated. However, the t-values indicate that the effect of competition is significant.

Other independent variables, mentioned in Sec. 3.3, were also tried out. The basal area (with two different constants), opening angle and moments of form $\Sigma m_j \cos\delta_j$ did not provide any significant additional explanation.

Fig. 2 illustrates the fit of model P_6 to the data. It appears that when the degree of competition is extremely weak or extremely severe, this produces a more marked effect, but that the effect of moderate competition is very ambiguous.

Table 4. Competition functions for pine stands, based upon PALOHEINÄ

Model No.	Dependent variable	Independent variable	a	$d_{\max}/h_{\max}$	u	b	t_b	R
P_1	d	$m^{(1)}(1,1)$	13.98	13.98	1.42	—0.169	5.05	0.337
P_2	d	$m^{(2)}(1,2)$	15.75	15.74	2.05	—0.487	5.46	0.361
P_3	d	$m^{(2)}(1,3)$	14.25	14.24	1.51	—0.707	5.43	0.359
P_4	$\log d$	$m^{(1)}(1,1)$	1.205	16.05	2.16	—0.00967	5.92	0.388
P_5	$\log d$	$m^{(2)}(1,2)$	1.277	18.91	3.18	—0.0252	5.73	0.377
P_6	$\log d$	$m^{(2)}(1,3)$	1.212	16.29	2.24	—0.0388	6.11	0.399
P_7	h	$m^{(1)}(1,1)$	8.690	8.69	1.05	—0.0457	3.52	0.237
P_8	$\log h$	$m^{(1)}(1,1)$	0.951	8.93	1.28	—0.00318	3.74	0.252
P_9	s	$m^{(2)}(1,3)$	1.753	..	..	—0.0760	5.99	0.392
P_{10}	$\log s$	$m^{(2)}(1,3)$	0.270	..	..	—0.0280	6.20	0.404

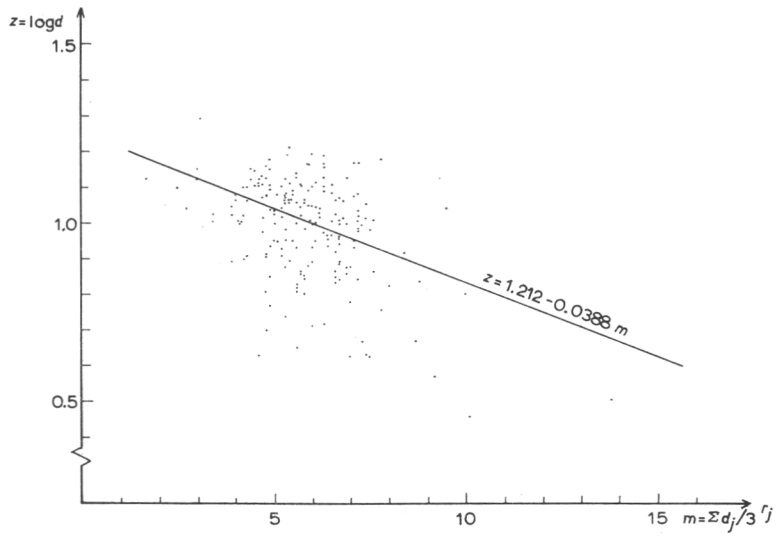

Fig. 2. Fit of model P_6 to the data

In PALOHEINÄ one pair of trees had a distance of 0.20 m. between them (see Table 5). Other distances exceeded 0.70 m. Thus, when $r < 0.70$ m. the competition functions are poorly determined.

Table 5. Distribution of distances of neighbouring trees in PALOHEINÄ and KANNUS (n. = neighbour)

Distance class	PALOHEINÄ					KANNUS				
	1. n.	2. n.	3. n.	4. n.	Total	1. n.	2. n.	3. n.	4. n.	Total
—0.100	—	—	—	—	—	2	—	—	—	2
0.101—0.200	2	—	—	—	2	10	—	—	—	10
0.201—0.300	—	—	—	—	—	6	—	—	—	6
0.301—0.400	—	—	—	—	—	—	—	—	—	—
0.401—0.500	—	—	—	—	—	5	1	—	—	6
0.501—0.600	—	—	—	—	—	2	2	—	—	4
0.601—0.700	—	—	—	—	—	6	—	—	—	6
0.701—0.800	2	—	—	—	2	—	—	—	—	—
0.801—0.900	7	—	—	—	7	—	—	—	—	—
0.901—1.000	4	—	—	—	4	6	—	—	—	6
1.001—1.100	7	1	—	—	8	6	—	—	—	6
1.101—1.200	9	2	—	—	11	17	10	1	—	28
1.201—1.300	10	4	1	—	15	19	11	3	—	33
1.301—1.400	16	—	1	—	17	20	14	7	—	41
1.401—1.500	34	17	4	—	55	20	27	6	2	55
1.501—1.600	39	21	6	1	67	13	20	19	3	55
1.601—1.700	31	41	22	2	96	11	18	19	13	61
1.701—1.800	23	49	38	13	123	4	12	22	13	51
1.801—1.900	5	30	41	38	114	6	12	15	18	51
1.901—2.000	3	11	33	27	74	3	8	11	9	31
2.001—2.100	1	8	16	29	54	3	12	11	11	37
2.101—2.200	—	3	10	22	35	—	1	8	14	23
2.201—2.300	—	4	7	18	29	—	3	12	13	28
2.301—2.400	—	1	8	17	26	—	—	4	10	14
2.401—2.500	—	—	2	8	10	—	2	2	10	14

4.2. Testing the models by means of parallel material

The structures of PALOHEINA and KANNUS differ to some extent, (see Table 1 on p. 6). This becomes even more pronounced on comparison of the distance distributions of these plots in Table 5.

In KANNUS, the models P_1—P_{10} were applied to each tree outside the margin. The actual values z were thus estimated by $\hat{z}$. Some results are given in Table 6 below. By denoting $e = \hat{z}—z$ (for each observation), the bias equals E(e), and the correlation coefficient R(P/K) is determined from

$$R(\mathrm{P/K}) = \sqrt{1—s_e^2/s_z^2} \tag{13}$$

where s_e^2 and s_z^2 denote the variances of e and z, respectively. A bar in an entry indicates that $s_e^2 > s_z^2$. For comparison, the original correlation coefficients R(P) from Table 4 have been included, along with the correlation coefficients R(K) of the corresponding models P_1'—P_{10}', based upon the KANNUS data. The extents of bias are rather great by virtue of the noticeable differences in the mean diameters and mean heights in PALOHEINÄ and KANNUS. Calculations were made of corrected bias by the application of models in which the constant a had been changed to correspond to $d_{\max} = \bar{d}+us_d$, or to $h_{\max} = \bar{h}+us_h$, where $\bar{d}$, $\bar{h}$, s_d and s_h are taken from KANNUS, and u from Table 4.

Models P_4—P_6 and P_8—P_{10} apparently have wider applicability. This offers encouragement for continued investigations relating to the competition in pine stands.

Table 6. Fit of models P_1—P_{10} to the data of KANNUS

Model No.	Bias	Corrected bias	R(P/K)	R(P)	R(K)
P_1	3.876	0.376	—	0.337	0.247
P_2	4.788	1.126	—	0.361	0.150
P_3	4.026	0.505	—	0.359	0.235
P_4	0.228	0.115	0.269	0.388	0.305
P_5	0.272	0.171	0.196	0.377	0.203
P_6	0.235	0.123	0.284	0.399	0.284
P_7	2.665	0.464	—	0.237	0.134
P_8	0.193	0.073	0.174	0.252	0.182
P_9	0.102	..	0.335	0.392	0.366
P_{10}	0.042	..	0.401	0.404	0.398

4.3. Application of dummy variables

The theory developed in Sec. 3.5 has been applied to the KANNUS data. This plot was selected since small distances are covered rather well (cf. Table 5). Model (7) is considered with $z = \log d$, $\alpha = 1$ and $\beta = 0$, taking $\varrho_1 = 0.1$, $\varrho_2 = 0.2,...,$ $\varrho_{25} = 2.5$. It is required that, on the assumption

that the normal distribution is valid, at most one per cent of the diameters in the material exceed the value d_{max} given by the model desired, i.e., that $d_{max} \geq \bar{d}+2.33s_d = 12.80$. In terms of model (7), this leads to the constraint $a \geq 1.107$.

Two different approaches are made. First, the additional constraints (8) are adopted. The set of constraints is thus:

$$\begin{aligned} & a \geq 1.107 \\ & f_i \geq 0 \qquad \text{for } i = 1...25 \end{aligned} \tag{14}$$

After this problem has been solved, the curves of forms (11) are fitted to points (10), with each point weighted by the number of observations in the corresponding distance class. These points and the resulting curves

$$f = 0.110 \times 2.724^{-r} \quad \text{and} \tag{15}$$

$$f = 0.0297 \times r^{-0.931} \tag{16}$$

are illustrated in Fig. 3.

In the second approach, the constraints (9) are adopted, and with a view to the avoidance of too rapid changes near origin, the constraints $f_{i-1}-f_i \leq 5\,(f_i-f_{i+1})$ for $i = 1...15$. The whole set of constraints is thus

$$\begin{aligned} & a \geq 1.107 \\ & f_{25} \geq 0 \\ & f_{24}-f_{25} \geq 0 \\ & f_{i-1}-f_i \geq f_i-f_{i+1} \qquad \text{for } i = 2...24 \\ & f_{i-1}-f_i \leq 5\,(f_i-f_{i+1}) \qquad \text{for } i = 2...15 \end{aligned} \tag{17}$$

The resulting competition function $f = \bar{f}(r)$, a broken line, is also shown in Fig. 3.

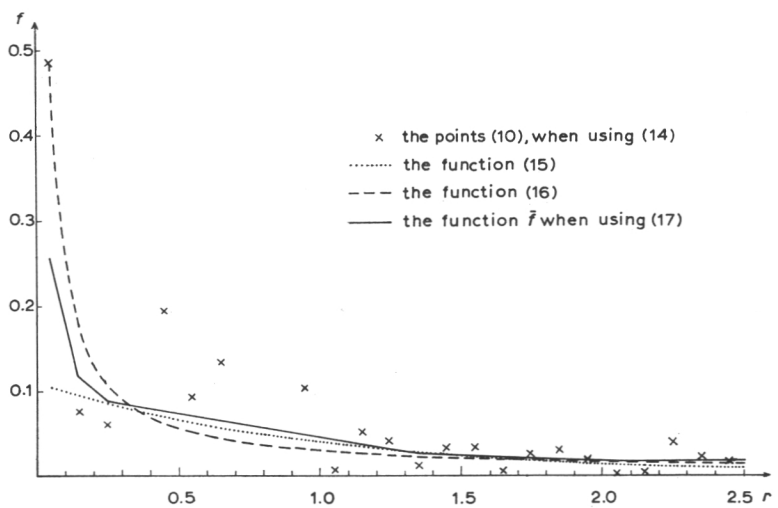

Fig. 3. The effect of distance between neighbouring trees to the competition factor ($z = \log d$, $\alpha = 1$, $\beta = 0$)

5. COMPETITION FUNCTIONS FOR SPRUCE STANDS

5.1. Calculating the models

The competition functions for spruce stands were based upon the RUOTSINKYLÄ data. Some of the models are given in Table 7 (now $r_{max} = 2.5$, $k = 4$, $f = 199$).

Table 7. Competion function for spruce stands

Model No.	Dependent variable	Independent variable	a	d_{max}	u	b	t_b	R
S_1	d	$m^{(1)}(1,1)$	8.39	8.39	0.48	—0.0536	4.54	0.299
S_2	d	$m^{(1)}(1,2)$	7.50	7.50	0.08	—0.00486	4.71	0.309
S_3	d	$m^{(1)}(0,1)$	8.29	8.29	0.44	—0.315	5.91	0.381
S_4	log$d$	$m^{(1)}(1,1)$	0.923	8.37	0.48	—0.00401	4.95	0.325
S_5	log$d$	$m^{(1)}(1,2)$	0.857	7.19	—0.06	—0.000382	5.44	0.354
S_6	log$d$	$m^{(1)}(0,1)$	0.920	8.32	0.45	—0.253	7.07	0.444
S_7	s	$m^{(1)}(1,1)$	1.120	..	..	—0.00368	6.27	0.401
S_8	log$s$	$m^{(1)}(1,1)$	0.050	..	..	—0.00163	6.72	0.426

RUOTSINKYLÄ had 6 pairs of trees separated by distances of less than 0.1 m. The approach with dummy variables (with $\alpha = 1$, $\beta = 0$) showed that these trees gave almost all the explanation. Indeed, when in addition to a, only f_1 (for $0 < r \leq 0.1$ m.) was allowed to differ from zero, the correlation coefficient was 0.385. The small u-values also provide an indicator of the great influence exercised by small trees upon the coefficients of the models. The explanation given by the above models is thus in reality extremely poor. Slight improvement in the models might perhaps be gained by subjecting a to a constraint analogous to (14 a).

5.2. Testing the models by means of parallel material

Models S_1—S_8 were applied to the NYNÄS trees. Some results are listed in Table 8 (cf. Table 6 for pine trees). It appears that the models have no wide applicability. Conceivably, the early competition in spruce

Table 8. Fit of models S_1—S_8 to the NYNÄS data

Model No.	Bias	Corrected bias	R(R/N)	R(R)	R(N)
S_1	0.494	0.156	—	0.299	0.000
S_2	0.297	—0.0375	—	0.309	0.064
S_3	0.506	0.195	—	0.381	0.037
S_4	0.0477	0.0317	—	0.325	0.000
S_5	0.0332	0.0123	—	0.354	0.000
S_6	0.0500	0.0330	—	0.444	0.000
S_7	—0.0331	..	—	0.401	0.094
S_8	—0.0085	..	—	0.426	0.074

stands is more ambiguous than that in pine stands. This may be attributable to the characteristics of the tree species and mainly to spruce demanding less light.

6. CONSTRUCTION OF THEORETICAL INITIAL STANDS

6.1. Principles

The problem involved here is the location of a given storey S of n trees, classified in conformity with diameter, into a rectangular sample plot. The trees are located in a grid of points, consisting of n_1 rows and n_2 columns (thus $n_1 \times n_2 = n$). The idea is that of dividing the points in the sample plot into two sets, A and B, and locating a subset $S_1 \subset S$ of the trees in the points of A at random, and the remaining storey $S_2 = S - S_1$ in the points of B by means of a competition function. Here the trees in S_1 and S_2 are distributed into diameter classes in the same ratio as the trees in S. Moreover, the structure of the set A must be such that if a point (i, j) belongs to B, then the four neighbouring points $(i, j-1)$, $(i, j+1)$, $(i-1, j)$ and $(i+1, j)$ belong to A. Thus, after the trees of S_1 have been located in the points of A at random, tentative diameters may be calculated for the points of B by means of some competition function. The points of B are then numbered in accordance with increasing tentative diameters, and the trees of S_2, in accordance with increasing diameter, are located at these points. After such a theoretical sample plot has been obtained, the competition relations are examined in the same way as in Sections 4.2 and 5.2. If the correlation coefficient between the actual and calculated diameters is of a magnitude approximately equivalent to the coefficient of the model in the stand that forms its basis, then the theoretical stand is reasonable. If a noticeable discrepancy is present, an endeavour may be made to vary the set A to provide a better fit.

6.2. A numerical example

Assume a storey S of 286 pines, distributed in diameter classes as indicated in Table 9. These data have been taken from V u o k i l a (1967, p. 108), medium treatment, age 23 years, by taking the bark into account. There are 2 860 trees per ha., and $\bar{d} = 8.6$, $s_d = 2.5$. The trees of S are to

be located in a plot of $40 \times 25 = 1\,000$ sq.m. in area. The distance r_0 between the nearest trees is derived from

$$r_0 = \sqrt{1\,000/286} \approx 1.85 \text{ m.}$$

Thus $n_1 = 13$ rows, and $n_2 = 22$ columns. The points are divided into three sets A, B and C, containing about 50, 25 and 25 per cent of the points, or more precisely, 143, 72 and 71 points, respectively, as illustrated in Fig. 4. The storey S is correspondingly divided into sub-stories S_1, S_2 and S_3 so that in these sub-stories the diameters are distributed into classes as closely as possible in the same ratio as in S (cf. Table 9). Moreover, an additional set D of 35 points is selected just outside the plot, and correspondingly an additional storey S_4, in which again the diameter distribution is the same as in S (cf. Table 9).

As a first approach, the trees of S_1 and S_4 are located in points of A and D at random, and the trees of S_2 and S_3 in the points of B and C by application of a competition function. It should be noted that, when models P_1—P_6 are used, the tentative diameter depends only upon the sum of the diameters of the four nearest neighbours. Thus all models P_1—P_6 produce the same Stand 1, in which consequently 50 per cent of the trees have been allotted.

If the trees in the points of B are relocated in Stand 1, by allotment, there is derived Stand 2, given in Table 10, in which 75 per cent of the trees have been allotted. Relocation of the trees in the points of C, also by allotting, yields Stand 3, where all the trees have been allotted.

Table 9. Distribution of theoretical tree storeys by diameter

d	S	S_1	S_2	S_3	S_4
2	1	—	1	—	—
3	3	2	—	1	2
4	10	5	3	2	4
5	20	10	5	5	3
6	26	13	6	7	5
7	31	15	8	8	1
8	48	24	12	12	5
9	46	23	12	10	5
10	37	19	9	9	5
11	27	13	7	7	3
12	17	9	4	4	1
13	11	5	3	3	1
14	5	3	1	1	—
15	3	1	1	1	—
16	1	1	—	—	—

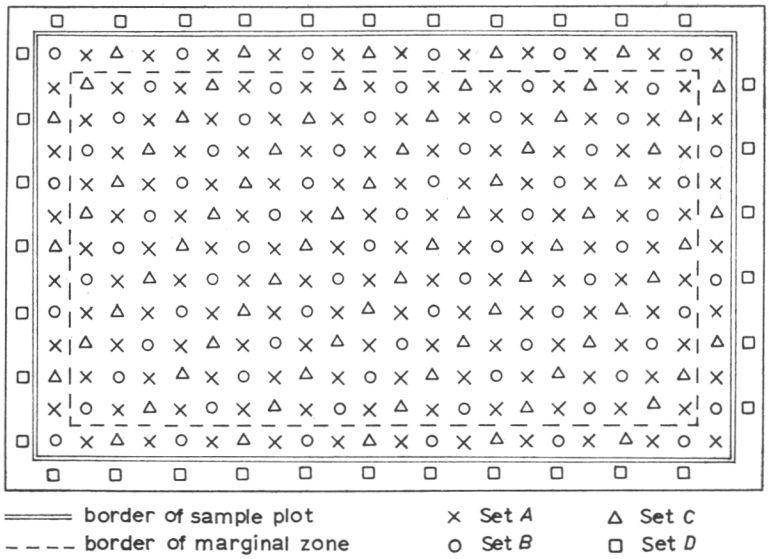

Fig. 4. Grouping of points in a theoretical sample plot

The competition relations in Stands 1—3 are indicated in Table 11.

It appears that Stand 2 is the most reasonable. Some opportunities for improvement of the results are available. For example, 87.5 per cent of the trees may be allotted. Another possibility is that of dividing, in Stand 1, the trees in sets *B* and *C* into, say, 4 diameter classes, and relocation of the trees in each class by allotment.

Table 10. Diameters of the trees in Stand 2

i \ *j*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	—	11	—	6	—	5	—	10	—	4	—	10	—	8	—	9	—	8	—	9	—	11	—	—
1	6	11	10	9	11	11	4	9	9	9	8	9	7	12	8	8	8	12	10	10	7	9	12	—
2	—	4	10	6	11	7	11	10	9	12	5	9	9	9	9	9	6	8	10	6	9	9	7	10
3	7	9	11	8	11	10	8	11	10	5	12	8	10	10	8	10	9	9	7	10	10	6	8	—
4	—	10	8	8	11	5	9	8	6	9	6	8	12	5	13	6	11	9	12	6	8	13	7	8
5	8	8	7	11	6	8	9	6	13	10	12	8	5	9	8	15	5	9	4	14	8	7	11	—
6	—	7	10	9	6	10	6	10	7	12	4	11	7	6	13	3	7	7	13	5	8	8	8	12
7	4	13	6	7	7	7	11	8	9	6	10	5	10	9	8	5	10	9	7	10	10	11	5	—
8	—	7	2	12	7	11	7	11	7	9	7	8	6	10	6	13	7	10	8	7	10	8	9	5
9	13	9	9	8	8	11	11	8	9	4	6	8	12	10	6	9	6	10	9	9	6	5	9	—
10	—	8	7	9	4	5	12	5	5	10	8	8	5	8	11	8	11	8	8	10	9	13	5	9
11	6	7	12	10	14	9	6	11	11	5	11	6	11	8	9	14	10	5	8	13	9	7	12	—
12	—	13	6	14	4	9	13	10	8	9	8	8	10	7	15	14	3	15	10	9	10	4	10	4
13	11	8	16	6	7	8	6	12	7	9	4	12	5	8	5	8	11	4	7	11	9	12	3	—
	—	3	—	4	—	10	—	3	—	9	—	10	—	8	—	5	—	6	—	6	—	9	—	—

Table 11. Fit of models P_1—P_6 to theoretical stands

Model No.	R(P)	Stand 1		Stand 2		Stand 3	
		R(P/T)	R(T)	R(P/T)	R(T)	R(P/T)	R(T)
P_1	0.337	0.602	0.836	0.448	0.556	—	0.000
P_2	0.361	0.699	0.836	0.510	0.556	—	0.000
P_3	0.359	0.605	0.836	0.449	0.556	—	0.000
P_4	0.388	0.602	0.830	0.442	0.536	—	0.000
P_5	0.377	0.676	0.830	0.487	0.536	—	0.000
P_6	0.399	0.587	0.830	0.438	0.536	—	0.000

7. DISCUSSION

This study relates to the competition between trees as a factor that affects the structure of a stand at an early stage of development. The main aim has been that of finding principles for the derivation of certain growth and yield forecasts of stands, based upon the behaviour of individual trees in a visual stand map which enables the investigator to effect theoretical thinnings, either visually or aided by computer, with the rules applied being the same as in practical operations in the field.

This basic aim implies that the neighbour relations observed are indicative not only of competition, but also of the early seedling phase after plantation during which no competition exists between tree individuals; however, the possibility of competition between seedlings and grass vegetation cannot be excluded. The question of when the competition starts between tree seedlings could not be studied on sample plots of temporary nature, but it may be pointed out that in the experiments with *Pinus patula* in South Africa reported by M a r s h (1957, pp. 7, 9) it was found that competition started at an average height of 5—6 m. in a plantation corresponding to the densities concerned in the present study. Even if this research finding is not directly applicable to northern conditions, it implies that in a Finnish seedling stand with a dominant height of 7.0—9.4 m., stand structure is explicable to no more than a minor extent by competition between neighbours.

Consequently, the present finding, that a seedling stand model can be derived with a reasonable degree of accuracy by an allotment of 75 per cent of trees in the stand table is in close conformity with the earlier finding by Marsh. Nonetheless, the degree of random variation in a seedling stand renders it rather appropriate for the construction of visual theoretical seedling stand models for subsequent growth and yield table projections of rotation-long periods, and with varying thinning programmes.

Had the objective been the competition between trees at the moment of sample plot measurement, the method of study would have been essentially different. It would have necessitated detailed measurements and analyses concerned with the current growth in diameter and height, and change in

stem form, and so on. By making analyses correlating these growth characteristics with the environmental conditions of trees, some idea could have been gained of the extent of current competition, which presumably at the dominant height of 7—9 m. is rather severe.

Another component that indicates the extent of competition during the early phase of seedling stand development is undoubtedly the size and shape of crown. Such information was not available from the temporary sample plots of the present study. However, it is likely that in the theoretical stand models underlying the forthcoming yield table calculations, it will hardly be possible to study crown development with any degree of reliability. In the later analysis of tree development, it may well be necessary to neglect the crown, and to concentrate upon the diameter, height and volume of the tree, and upon environmental factors as an indicator of competition.

The present study is methodological in nature. The functions derived may not be generally applicable in attempts to compile national growth and yield tables. It may be mentioned that comprehensive tree material is currently being measured by the Section of Growth and Yield Studies of the Finnish Forest Research Institute and comprising thousands of sample trees in all parts of the country. These will yield information on national applicability, and enable the final construction of initial stand models for yield table calculations, with the principles outlined in the present study being followed.

8. SUMMARY

During recent years, growth and yield tables have been constructed by the use of tree increment functions based upon data relating to individual trees. In this approach, an initial stand table, at a dominant height of, say, 5—7 m., is projected in time. The aim of the present investigation was that of providing a mathematical foundation for the construction of a visual initial stand map.

Special attention has been devoted to the mutual competition of trees. The main hypothesis is that the effect exerted by a neighbour upon the characteristics (diameter, height, and so on) of an observational tree assumes the form of (3) (see p. 10) and that the effects of different neighbours are additive (see Formula (4) on p. 11). In (4), m represents an approximation to the competition factor.

For both pine and spruce stands, the competition functions (regression models) were based upon one sample plot, with another plot being used as check material. The dominant height of these plots varied from 7.0 to 9.4 m.

It appeared that the effect of competition is not as great as could be anticipated; the correlation coefficients derived were at most about 0.4. The effect upon pine stands is noticeably more evident than that in spruce stands: the functions for pine fitted the check material rather well, whereas no function for spruce possessed any wider applicability.

As a special approach, a pine stand was subjected to analysis, with dummy variables and quadratic programming. This procedure might result in a clearer picture being obtained of the effect of the distance between trees upon the competition factor (cf. Fig. 3, p. 16).

Finally, the competition functions for pine were applied for the construction of theoretical initial stand tables. The basic idea was the location of a portion of a given tree storey in a plot by allotment, with the remaining trees being located with the aid of competition functions. The most reasonable stand was obtained by the allotment of 75 per cent of the trees.

REFERENCES

M a r s h, E. K. 1957. Some preliminary results from O'Connor's Correlation Curve Trend (C.C.T.) experiments on thinnings and espacements and their practical significance. Pretoria.

V u o k i l a, Y r j ö. 1965. Functions for variable density yield tables of pine based on temporary sample plots. *Metsäntutkimuslaitoksen julkaisuja (MTJ)* 60.4. Helsinki.

—»— 1967. Eriasteisin kasvatushakkuin käsiteltyjen männiköiden kasvu- ja tuotostaulukot maan eteläistä sisäosaa varten. Summary: Growth and yield tables for pine stands treated with intermediate cuttings of varying degree for southern Central-Finland. *MTJ* 63.2. Helsinki.

V ä l i a h o, H a n n u. 1969. A Synthetic Approach to Stepwise Regression Analysis. *Comment. Phys.-Math.* 34, 91—132. Helsinki.

—»— 1970. New Algorithms for Quadratic Programming. *Comment. Phys.-Math.* 36, 111—36. Helsinki.

SELOSTE

Viime vuosina on kasvu- ja tuotostaulukoita konstruoitu käyttäen hyväksi yksityisistä puista mitattuihin tietoihin perustuvia kasvufunktioita. Tässä lähestymistavassa tiettyä lähtöpuustoa projisioidaan eteenpäin ajassa. Tämän tutkimuksen tarkoituksena on muodostaa matemaattinen perusta lähtöpuustojen konstruoimiselle.

Erityistä huomiota kiinnitetään puiden keskinäiseen kilpailuun. Päähypoteesina on, että naapuripuun vaikutus havaintopuun ominaisuuksiin (läpimittaan, pituuteen jne.) on muotoa (3) (ks. s. 10) ja että eri naapureiden vaikutukset ovat additiivisia (ks. kaava (4), s. 11). Kaavassa (4) m on ns. kilpailutekijän approksimaatio.

Sekä männyille että kuusille kilpailufunktiot perustettiin yhden koealan tietoihin, ja toista koealaa käytettiin rinnakkaisaineistona. Koealojen valtapituus vaihteli 7.0 ja 9.4 metrin välillä.

Kilpailuvaikutus ei osoittautunut niin selväksi, kuin ehkä voitaisiin olettaa. Saadut korrelaatiokertoimet olivat korkeintaan 0.4. Kilpailun merkitys on mäntymetsiköissä huomattavasti selvempi kuin kuusimetsiköissä. Mäntyjen kilpailufunktiot sopivat nimittäin melko hyvin rinnakkaisaineistoon, kun taas kuusien kilpailufunktioilla ei ollut laajempaa sovellutusmahdollisuutta.

Yhtä mäntykoealaa tutkittiin lisäksi käyttäen dummy-muuttujia ja kvadraattista ohjelmointia. Tällä tavoin voitiin saada selvempi kuva puiden välisen etäisyyden vaikutuksesta kilpailutekijään (ks. kuvio 3 s. 16).

Lopuksi mäntyjen kilpailufunktioita sovellettiin teoreettisten lähtöpuustojen konstruointiin. Ajatuksena oli sijoittaa osa annetusta puuvarastosta koealalle arpomalla ja loppuosa käyttämällä hyväksi kilpailufunktioita. Paras tulos saatiin arpomalla 75 % puista.

ESTIMATION OF TIMBER REMOVALS BY DOUBLE SAMPLING BASED ON MAIL INQUIRIES

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Helsinki 1971. Valtion painatuskeskus

PREFACE

The favourable attitude of the more than 600 forest owners from whom the study material was collected played an important part in making the study a success. Nearly 83 % of them answered the mail inquiry concerning timber removals. In addition, close upon 200 owners were personally interviewed.

The enumeration of sample forest holdings took place in local tax offices. Personal interviews were made by Aake Kuntonen, forest technician. Miss Airi Martinkauppi, Miss Pirjo Nurmilaakso and Miss Ritva Väisänen assisted with the treatment of the material.

Professor Lauri Heikinheimo, Dr. Matti Palo and Acting Professor Hannu Väliaho perused the manuscript with critical eyes. Mrs. Hilkka Kontiopää, M.A., translated the manuscript into English and David Cope, A.B., checked the translation. The formulas in the text were drawn by Miss Hellin Taponen.

Grants from the Finnish Cultural Foundation and the Niilo Helander Foundation helped free me from other duties so that I could concentrate on this study.

I wish to express my gratitute and appreciation to these people and institutions and to anyone else I may have inconvenienced during the course of my study.

Helsinki, August 1971

Risto Seppälä

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1. INTRODUCTION

11. **Double sampling**

A sampling study should seek to use all the information obtainable on the object being studied. Especially in the selection of the sample and the estimation of the population parameters, auxiliary information may be of great importance.

Adequate information is often not directly available but can be produced inexpensively. In such a case, double sampling has proved useful, with the first phase consisting of a relatively large sample which supplies the necessary auxiliary information. A subsample is then selected from the first-phase sample, and the parameters of the character being studied are estimated from this subsample.

The benefit realized from double sampling depends on the increase in precision that the use of auxiliary information leads to weighed against the cost of producing it. Auxiliary information is usually employed either for stratification, for ratio, regression or difference estimation, or for producing varying selection probabilities.

The unit-cost ratio of the first- and second-phase samples is the most important cost item in the production of information by double sampling. The increase in precision is governed primarily by the degree of dependence between the auxiliary variate and the final variate being studied. In the following, the conditions associated with the cost ratio and degree of dependence are discussed on the basis of regression and ratio estimation.

A large population is surveyed. Let the objective be to estimate the population mean of variate y. A random sample of m_1 units with replacement is selected. The values of variate x are measured from this sample. In the second phase, a random sample without replacement is selected from m_1 units. Let the size of the subsample be m_2. The values of variate x are recorded and the values of variate y are measured from the subsample.

Let the expression producing minimum variance have the form

$$V_{opt} = V_2 / m_2 + V_1 / m_1 \ . \tag{1.1}$$

Let the unit cost for measuring variate x (first-phase sample) be c_1 and that for measuring variate y (second-phase sample) be c_2. The total variable costs will then be

$$(1.2) \qquad C_v = m_2 c_2 + m_1 c_1 .$$

It is easily found that

$$(1.3) \qquad m_2 / \sqrt{V_2 c_1} = m_1 / \sqrt{V_1 c_2} .$$

In other words, the subsample fraction from the first-phase sample producing minimum variance is

$$(1.4) \qquad m_2 / m_1 = \sqrt{V_2 / V_1} \sqrt{c_1 / c_2} .$$

When equation (1.2) is substituted in equation (1.3) and the result obtained is substituted in expression (1.1), it follows that (C o c h r a n 1963, p. 331)

$$(1.5) \qquad V_{opt} = (\sqrt{V_2 c_2} + \sqrt{V_1 c_1})^2 / C_v .$$

If all resources are used for a single random sample from which only y is measured, its size is $m_s = C_v/c_2$. The variance of the mean is, in that case,

$$(1.6) \qquad V(\bar{y}) = S_y^2 / m_s = c_2 S_y^2 / C_v , \quad S_y^2 = \sum_i^M (y_i - \bar{Y})^2 / (M-1) .$$

Double sampling gives a smaller variance than simple random sampling if

$$V(\bar{y}) > V_{opt}$$

or if

$$(1.7) \qquad c_2 > (\sqrt{V_2 c_2} + \sqrt{V_1 c_1})^2 / S_y^2 .$$

The result obtained from expression (1.7) is that double sampling is an economic proposition if the inequality

$$(1.8) \qquad c_2 / c_1 > V_1 / (S_y - \sqrt{V_2})^2$$

is valid for the ratio of the unit costs.

If regression estimation is used, the variances V_2 and V_1 can be expressed approximately (C o c h r a n 1963, p. 336)

$$(1.9) \qquad V_2 = S_y^2 (1 - \rho^2) \quad \text{and} \quad V_1 = \rho^2 S_y^2 \ ,$$

where ϱ is the correlation coefficient between x and y.

The expressions of the minimum cost ratio and the optimum sampling fraction of the subsample now assume the forms

$$(1.10) \qquad c_2 / c_1 = \rho^2 / (1 - \sqrt{1 - \rho^2})^2$$

and

$$(1.11) \qquad m_2 / m_1 = \sqrt{(1 - \rho^2)/\rho^2}\ \sqrt{c_1/c_2} \ .$$

If ratio estimation is used, the approximations (C o c h r a n 1963, p. 340)

$$(1.12) \qquad V_2 = S_y^2 - 2R\rho S_y S_x + R^2 S_x^2 \quad \text{and} \quad V_1 = 2R\rho S_y S_x - R^2 S_x^2 \ ,$$

where R is the population ratio Y/X, are obtained for variances V_2 and V_1.

The expressions of the minimum cost ratio and the sampling fraction now assume the forms

$$(1.13) \qquad c_2 / c_1 > (2R\rho S_y S_x - R^2 S_x^2) / (S_y - \sqrt{S_y^2 - 2R\rho S_y S_x + R^2 S_x^2})^2$$

and

$$(1.14) \qquad m_2 / m_1 = \sqrt{(S_y^2 - 2R\rho S_y S_x + R^2 S_x^2)/(2R\rho S_y S_x - R^2 S_x^2)}\ \sqrt{c_1/c_2} .$$

Regression estimators always produce estimates at least as precise as those produced by ratio estimators. In many cases, however, the regression estimators are noticeably more efficient.

12. Estimation of timber removals from a forest-holding sample

Several different populations can be used to determine timber removals (cf. S e p p ä l ä 1971, pp. 7—8). Forest holdings are an alternative capable of producing other forestry information also. Experimental studies have indicated the suitability of a forest-holding sample for the study of the volume and structure of timber removals (S a l o 1971; S e p p ä l ä 1971). Areal cluster sampling has proved to be a particularly efficient method (S e p p ä l ä 1971).

Among the major drawbacks of sampling using forest holdings is the high cost of field work, which is due to the expensive personal interview used to provide the basic information. The personal interview, however, is important for acquiring correct material; therefore it cannot be abandoned. For this reason, it is necessary to think of ways and means by which the role played by the interview can be reduced without decreasing the reliability of the results.

13. Problem of the study

The mail inquiry is currently used most often in market research, in censuses and surveys of industrial and commercial organizations, such as censuses of production (cf. Yates 1965, p. 58), and for many types of sociological studies. Compared with the personal interview, it is inexpensive. Usually, however, the mail inquiry involves a high non-response rate. In addition, the questions to be answered must be simple enough to be understood in a simple reading. Owing to these factors, studies based on the mail inquiry alone have seldom led to satisfactory results.

One possibility is to combine the mail inquiry with the personal interview in such a way as to permit utilization of the advantages of both and adequate elimination of the disadvantages of both. Double sampling provides a good basis for the combined use of the two methods. The first-phase sample is studied by mail inquiry and the subsample is selected from it for personal interviews. The mail inquiry, therefore, is used to produce auxiliary information. In this special case, the auxiliary information is information concerning the same character, the parameters of which are to be estimated.

In the review of double sampling (Section 11) it was concluded that one important condition for its use is the low cost of acquiring auxiliary information compared with the cost of producing the final information. A second condition is that a good correlation obtains between the auxiliary variate and the final variate being studied. When timber removals are studied by sampling forest holdings, the mail inquiry concerning the removals must be inexpensive compared with the cost of determining removals by interviews, and the correlation between the removal volumes recorded by mail inquiry and by interview must be high.

If expenses connected with the treatment of the material are disregarded, the costs of a mail inquiry are composed mainly of costs incurred through selecting the sample and listing the sample holdings, postage being free. In the personal interview, the interviewer's pay and travel expenses must be added.

For areal cluster sampling, after simplification of the cost categories as described above, an earlier study gave unit-cost values of c_1 = Fmk 3.8 (1 US dollar = 4.24 Fmk) and c_2 = Fmk 27.5 (S e p p ä l ä 1971, pp. 54 & 93). When equation (1.10) is expressed for ϱ, these numerical values give for correlation coefficient ϱ the minimum value at which double sampling still pays:

$$(1.15) \qquad \rho > 2\sqrt{c_2 c_1} / (c_2 + c_1) = 0.65 \quad .$$

A priori it seemed plausible that the correlation coefficient exceeds 0.65, probably even considerably. Furthermore, there was reason to assume that the cost of listing can be reduced from the Fmk 3.8 per holding mentioned above. Experimental use of a mail inquiry in the production of auxiliary information for two-phase sampling therefore seemed justified.

The present report first describes the material studied (Chapter 2). This is followed by an analysis of whether the use of a mail inquiry is an economic proposition in the study of timber removals on the basis on the forest-holding population (Chapter 3). In discussing the estimation of population parameters (Chapter 4), an effort is made to elicit the estimators that can best be used in cluster sampling. The final chapter (Chapter 5) deals with the effects of non-response on the results of the study.

The formulas of the study will not be explicitly proved, since in a generic form most of these proofs can be found in textbooks on sampling theory. The basic sampling method proposed is cluster sampling. However, since the observation material is limited, the calculations based on the experimental material are made as if simple random sampling had been used.

2. MATERIAL

21. Population

The elementary unit, which became at the same time the listing unit, was a forest holding, i.e. the forestry land of an administratively autonomous, but not necessarily territorially undivided land holding (farm). In this study the forestry land consisted of taxation classes I—IV (cf. Metsätilastollinen vuosikirja 1969, p. 47). The minimum area of a forest holding was set at 0.1 hectares. Any forests the same owner may have had in different communes were considered as separate forest holdings.

The area covered by the study belonged to the forestry board districts of Lounais-Suomi and Uusimaa-Häme (see Metsätilastollinen vuosikirja 1969, p. 40). The extent of the area was 64 km $\times$ 48 km, or 307 200 hectares. Mainly in order to reduce the cost of the experimental study it was decided to use a relatively large cluster size in the cluster sampling. The population consisted of all forest holdings in the area not controlled by the State or the member organizations of the Central Association of Finnish Woodworking Industries. State and industry holdings were excluded because total data is collected annually concerning them.

22. Mail inquiry

The first phase of the study consisted of an inquiry about removals that was mailed to the forest owners. The sampling unit chosen for the first phase was a cluster of 8×8 sq.km. The number of clusters was 12. They were placed over the study area so that the distance between reciprocal points was 16 kilometres. The centres of the clusters coincided with those of the »tracts» used in the Fifth National Forest Inventory (see K u u s e l a and S a l m i n e n 1969, pp. 9—10).

The sample holdings were selected as follows. Selection points, 81 per cluster, were placed at one-kilometre spacing in each cluster. The forest holdings of the population belonging to the farms on whose area the selection point fell were included in the sample. Of the total of $12 \times 81 = 972$ field points, 794 fell on land areas belonging to the study population. In some cases, several points fell on the area of one farm; due to this the total of the separate forest holdings in the sample was reduced to 632.

Listing of the sample holdings took place by stages. Preliminarily, the register number of the farm on which a selection point fell was determined from maps (scale 1 : 20 000) showing farm boundaries. In uncertain cases, the number was obtained from the tax-classification maps kept in the local tax or commune office. Since the map data in some cases was old, the validity of the register numbers was checked from the court-district archives where data on any changes are filed within six months. Once the valid register number and the corresponding owner were known, the forest area of the holding and the total area of the farm containing the forest holding were obtained from tax-office lists.

A questionnaire concerning removals in the felling season 1969/70, with instructions for completion, was sent to the owners of the 632 forest holdings which constituted the mail-inquiry sample. The removals were to be recorded separately for household consumption and for sale, and these two categories again by tree species (pine, spruce, birch and other) and by timber assortments (logs, fuelwood and other).

The inquiries were mailed at the end of August 1970. Replies were to be mailed back within three weeks. By the given date, 55.1 % had returned their completed questionnaires. The non-respondents were sent a reminder by letter, and this brought the response up to 82.8 %. No further reminder was sent to those who still had not replied.

23. Personal interview

A subsample of 174 forest holdings was selected randomly from among the sample holdings of the mail inquiry for the second phase of the study, the personal interview. Thirty-one of these were forest holdings in the non-response category.

Owing to factors unrelated to the study, the personal interviews did not start until January 1971. They were all carried out by one trained interviewer. The removals inquiry was made by items of use and was considerably more detailed than the mailed one. Besides removal volumes, the removals per development stage of the forest were recorded. All the owners of the sample holdings were met, and no one refused the interview.

3. PROFITABILITY OF USING THE MAIL INQUIRY

31. Basic estimators

The first phase of sampling used a selection method under which the selection probabilities of the forest holdings were proportional to the total areas of the corresponding farms (p. 10). In order to make the estimation unbiased, the calculations were based on the variate (e.g. S u k h a t m e 1954, p. 62)

$$z_j = x_j / p_j = A\, x_j / a_j \quad , \quad \text{where} \quad A = \sum_j^M a_j$$

and j = index of the forest holding (and the farm)
x = removal volume, solid m³, from the mail inquiry
a = total area, ha, of the farm connected with the forest holding
M = number of forest holdings in the population.

Since A is constant, the analyses could be based on the quotient x_j/a_j, expressed as $u_j = x_j/a_j$.

The second-phase sample was selected from the first-phase sample with equal selection probabilities. In the calculations, therefore, the variate u_j could be substituted by the corresponding second-phase variate $v_j = y_j/a_j$, where y = removal volume, solid m³, from the personal interview.

32. Minimum cost ratios

The first phase of the sampling was affected by a certain non-response rate. As a result, the material was divided into two strata: response (R) and non-response (N). The former was treated as a normal two-phase sample, the latter as if there had been a one-phase sample (only the second phase of sampling).

In the stratified sampling, the variance of the estimate of the population total with two strata (R and N) and without finite multiplier assumes the form

$$(3.1) \qquad V(Y) = M_R^2 \, (S_R^2 / m_R) + M_N^2 \, (S_N^2 / m_N) \ .$$

Compared with ordinary one-phase sampling, the cost of stratum N contains, as an additional expense, the cost of listing the forest holdings for which no reply to the mail inquiry was received and which were not included in the second-phase personal interview. If this cost is added to the cost c_1 (pp. 8—9), profitability comparisons can be based on stratum R alone.

The removal volumes were divided between removals for sale and for household consumption, and between pine, spruce, and the other tree species as a group (broad-leaved trees).

When writing in equation (1.8) $y = v$ and $x = u$, it was possible to investigate the minimum value of the unit-cost ratio c_2/c_1 required to make double sampling an economic proposition. The studies involved regression and ratio estimations for all the removal-volume groups mentioned above. The parameters for the mail inquiry were not calculated on the total mail-inquiry sample but on the subsample of the interviewed owners. The results are given in Table 1, which, in addition to cost ratios, gives some parameter estimates describing the interview and the mail inquiry.

Table 1. Minimum ratios of the unit costs in double sampling, and some parameter estimates describing the interview and the mail inquiry.

Removal group	c_2/c_1 Regression estimation	c_2/c_1 Ratio estimation	$CV(v)$ Inter-view	$CV(u)$ Mail inquiry	$r = v/u$	$\bar{v}$ Inter-view	$\varrho(u, v)$
Removals for sale	2.14	2.29	1.61	1.73	1.007	1.34	.932
Removals for household consumption	2.77	2.87	1.76	1.72	.968	.42	.883
Pine	2.26	2.32	1.90	1.91	.918	.50	.922
Spruce	2.31	2.45	1.43	1.51	1.027	1.06	.918
Broad-leaved	4.24	5.14	1.55	1.61	1.075	.20	.786
Total removal	2.33	2.52	1.28	1.38	.999	1.76	.917

CV = coefficient of variation
ϱ = coefficient of correlation

The minimum cost ratios obtained are small. They are on the average only one-third of the real ratios in the present material (see Table 3). It may thus be concluded that in this case the use of a mail inquiry in double sampling is an efficient means of increasing the precision of the results. Considered by categories of removal, double sampling is most beneficial in the estimation of removals for sale and least beneficial for estimating the removal volumes of broad-leaved trees.

The good result in removals for sale is explained by the fact that the relevant data is usually based on documentation, i.e. measurement certificates. Hence the owner is not required to remember the figures; the volumes he gives both in the mail inquiry and in the interview are often exactly the same as on the certificates. The poor result for broad-leaved trees, on the other hand, is due to the fact that the majority of this wood is fuelwood consumed at home, a concept that could not be explained to the owner in adequate detail in the mailed questionnaire. The whole group of removals for household consumption has the second poorest correlation coefficient after that of broad-leaved trees.

Excluding removals for household consumption, the relative variation (coefficient of variation) of removals in the mail inquiry was greater than in the interview. The difference was not, however, very remarkable. The ratio between total removals recorded by mail inquiry and those recorded by interview was practically unity. In the various removal categories the differences were under 10 %.

The parameters were also studied by ownership groups according to occupation and forest area. The results are presented in Table 2. These results must be taken with reserve, for the number of observations (m) in some groups was very small.

Table 2. Parameters of the interview and the mail inquiry, by ownership groups.

Ownership group	m	$CV(v)$ Interview	$CV(u)$ Mail inquiry	$r = v/u$	$\bar{v}$	$\varrho\,(u, v)$
Occupation						
— farmer	108	1.27	1.34	.964	1.77	.908
— other	35	1.29	1.49	1.132	1.76	.956
Forest area (ha)						
— 0.10—19.99	74	1.65	1.68	1.027	1.24	.981
— 20.00—49.99	28	1.03	1.37	.848	1.70	.840
— 50.00—99.99	16	1.11	1.06	.979	3.27	.931
— 100.00—	25	.68	.87	1.137	2.38	.853
Total removal	143	1.28	1.38	.999	1.76	.917

Among farmers the correlation between mail-inquiry and interview data was lower than among the other ownership groups. A partial reason is that the proportion of the uncertain removal for household consumption among farmers was 29 % whereas among the other ownership groups it averaged only 6 %. In the classification according to forest area, the only definite regularity was that the coefficients of variation diminished as the area of the forest holding increased.

33. Optimum sampling fractions

The cost data obtained from the study material was investigated next. Administrative expenses and the fixed expenses arising from the treatment of the material were excluded from the calculations.

The material was divided into groups according to the following schedule:

	Replied to mail inquiry (response)	Did not reply to mail inquiry (non-response)	Total
Mail inquiry	$m_{1R} = 523$	$m_{1N} = 109$	$m_1 = 632$
Interview	$m_{2R} = 143$	$m_{2N} = 31$	$m_2 = 174$

It was possible in the cost-ratio calculations to consider only those who had replied to the mail inquiry (p. 13). In calculating the unit cost c_1, the normal costs were then increased by the cost of listing the forest holdings which were in the non-response group and were not included in the personal interview.

The cost of the interview was composed of (1) listing the forest holdings subject to interview, and (2) the interview itself. The value obtained for the unit cost $c_2 = c_{2R} = c_{2N}$ was Fmk 27.2 per forest holding (cf. p. 9).

The separate cost of the mail inquiry was composed of (1) listing the forest holdings which were subject to the mail inquiry but not to the interview, and (2) the treatment of all replies concerning the forest holdings of the response group. Group (1) could be divided into (a) respondents and (b) non-respondents. Altogether, the unit cost c_{1R} for the mail inquiry was composed of the function

$$(3.2) \qquad c_{1R} = \left\{ [(m_{1R} - m_{2R}) + (m_{1N} - m_{2N})]\, c' + m_{1R} c'' \right\} / m_{1R} \,,$$

where c' = listing expenses per forest holding = Fmk 2.4 (cf. p. 9)
c'' = treatment expenses per forest holding in the response group = Fmk 0.8.

Equation (3.2) contains the sample sizes of both the mail inquiry and the interview. According to equation (1.4), describing the optimum second-phase sampling fraction, the optimum ratio of sample sizes depends on the ratio of unit costs. Consequently, c_{1R} had to be solved iteratively by means of equation (1.4). As a first step it was defined that $m_{2R}/m_{1R} = g$ or $m_{2R} = g\, m_{1R}$ and $m_{1N} = \lambda\, m_{1R}$ (in this experimental study, $\lambda = .208$).

If it is assumed that $m_{2R}/m_{1R} = m_{2N}/m_{1N}$, the result obtained is $m_{2N} = \lambda\, g\, m_{1R}$.

When m_{2R}, m_{1N} and m_{2N} were replaced by the functions obtained above, equation (3.2) could be reduced to the following form:

$$(3.3) \qquad c_{1R} = (1 - g + \lambda - \lambda g)\, c' + c'' .$$

As a result of iteration, the estimates of Table 3 were obtained. They are presented for both regression estimation and ratio estimation.

Table 3. The optimum second-phase sampling fractions by removal groups, the corresponding unit costs in the mail inquiry and cost ratios.

Removal group	m_{2R}/m_{1R}		c_{1R} (Fmk)		c_{2R}/c_{1R}	
	Regression estimation	Ratio estimation	Regression estimation	Ratio estimation	Regression estimation	Ratio estimation
Removal for sale	.135	.148	3.32	3.27	8.19	8.32
Removals for household consumption	.181	.187	3.17	3.15	8.58	8.63
Pine	.146	.150	3.27	3.26	8.32	8.34
Spruce	.149	.160	3.26	3.23	8.34	8.42
Broad-leaved	.259	.294	2.95	2.85	9.22	9.54
Total removal	.151	.165	3.26	3.22	8.34	8.45

The optimum second-phase sampling fractions of the total number of first-phase sampling units are below 20 %, if broad-leaved trees are excluded. With total removals as the starting point, the result obtained on the basis of equation (1.15) (p. 9) is that the use of a mail inquiry is an economic proposition when the correlation coefficient between the removal volumes in the mail inquiry and the interview exceeds 0.62. All the groups investigated exceeded this threshold value (Tables 1 & 2).

4. ESTIMATION OF POPULATION PARAMETERS

41. Basic alternatives

The estimators discussed in this chapter are based on cluster sampling. This is because in earlier studies areal cluster sampling was found to be an efficient sampling method for a forest-holding population. The optimum size of the clusters has been found to vary in different parts of the country from 5 to 11 forest holdings (S e p p ä l ä 1971, p. 85).

Information obtained from the first phase of double sampling is used for regression, difference or ratio estimation, to produce selection probabilities, or as the basis for stratification. Most common is perhaps the use of the auxiliary variate to increase the precision of the estimates by means of regression, difference or ratio estimation.

In two-phase cluster sampling there are two alternative ways of carrying through the second phase: the subsample can be selected either by clusters from among the forest holdings or as a subsample from among the clusters. If the subsample is selected by clusters from among the forest holdings, the optimum cluster size is determined by the second phase. The first-phase cluster size is obtained when both the second-phase cluster size $\bar{m}_2$ and the optimum sampling ratio m_2/m_1 are known. If the subsample is selected from clusters, the clusters must have the optimum size already in the first phase of sampling. It is not recommended that a subsample by forest holdings be taken from among clusters selected for the second-phase sample.

In the present experimental study, the clusters, for reasons of economy, were relatively large: in the first phase the average was 53 forest holdings, and in the second 14.5 forest holdings. Furthermore, the clusters were few in number: only 12. The study area was also very limited. Owing to these factors, the estimators of the two-phase cluster sampling are discussed in the following disregarding all empirical material. As for the above analysis of the economic profitability of using the mail inquiry, the calculations have been made with empirical material as if it had been selected by normal random sampling and not by cluster sampling.

42. Selecting a subsample from forest holdings by clusters

421. *Selection procedure*

Let the selection procedure for the first phase be as follows. With the aid of a map, points are selected in the field either randomly or systematically

to determine the location of sample clusters. The number of possible points, and thus also the number of clusters in the population, approaches the infinite. A cluster is formed by selecting, at regular spacing, new field points around every initial point in the field. The forest holdings of the farms, on the area of which the field points fall, are included in the sample. The sampling is carried out with replacement, and selection is continued in every cluster until the desired cluster size is reached. All the sample holdings so selected are included in the first phase of the sampling, and a removals inquiry is mailed to them.

A number of the forest holdings covered by the mail inquiry are non-respondents. The response and non-response groups form separate strata by clusters. Only the response stratum becomes part of two-phase sampling. Although in the first phase of sampling the total number of forest holdings per stratum is the same from one cluster to another, the variation in response rate has the result that, separately reviewed, the strata contain different numbers of forest holdings per cluster.

422. *Estimation method*

Let us first consider the response stratum. The first-phase selection probabilities were proportional to the total area of the farm connected with the forest holding. The starting point in the estimation of total removals therefore had to be the variate (p. 12)

$$z_j = x_j / p_j = A_R \, x_j / a_j \quad , \quad \text{where} \quad A_R = \sum_j^{M_R} a_j$$

with R = symbol for response to mail inquiry
j = index of the forest holding
M = number of forest holdings in the population
x = removal volume, solid m^3, in mail inquiry
a = total area, ha, of the farm connected with the forest holding.

The area A_R of the response-stratum population is not known. If it is assumed that the area of the total population is known, an estimate for A_R, based on an individual cluster, is obtained from the formula (see formula (4.24), p. 25)

$$\text{est}_i (A_R) = (m_{1Ri} / \bar{m}_1) A \quad ,$$

where 1 = symbol for the first phase of sampling (mail inquiry)
i = index of the cluster
A = total area of population
m = number of sample forest holdings
$\bar{m}_1$ = constant from cluster to cluster

On the basis of a single cluster, therefore, the following unbiased estimator based on the mail inquiry is obtained for the total removals in the response stratum:

$$(4.1) \quad est_{1i}(X_R) = (1/m_{1Ri}) \sum_{j}^{m_{1Ri}} \left\{ x_{ij} / [a_{ij} / (m_{1Ri} / \bar{m}_1) A] \right\}$$

$$= (m_{1Ri} / \bar{m}_1) A \, \bar{u}_{1Ri} \quad ,$$

where $\bar{u}_{1Ri} = \sum_{j} (x_{ij} / a_{ij}) / m_{1Ri}.$

Since the sample holdings of the second phase were selected by clusters, with equal probabilities, from the first-phase forest holdings, the following estimators are obtained on the basis of the second phase for the total removals in the interview and in the mail inquiry:

$$(4.2) \quad est_{2i}(X_R) = (m_{1Ri}/m_{2Ri})(1/\bar{m}_1) A \sum_{j}^{m_{2Ri}} u_{ij} = (m_{1Ri}/\bar{m}_1) A \, \bar{u}_{2Ri}$$

where 2 = symbol for the second phase of sampling (interview);

and

$$(4.3) \quad est_{2i}(Y_R) = (m_{1Ri}/m_{2Ri})(1/\bar{m}_1) A \sum_{j}^{m_{2Ri}} v_{ij} = (m_{1Ri}/\bar{m}_1) A \, \bar{v}_{2Ri}$$

where $v_{ij} = y_{ij}/a_{ij}$

and y = removal volume, solid m³, in interview.

There are two alternatives for further developing the estimators. One is to calculate the final total-volume estimates for clusters and, on this basis, the estimate for the whole sample. The other is to start separately from the mail-inquiry and interview estimates per cluster and only combine them in

the final estimate, using regression, difference or ratio estimation. The estimators of the latter alternative are analogous in principle to the alternative according to which the subsample is selected from clusters. This particular case is discussed in Section 43, whereas in the following the development of the estimators is continued, using as the basis the first alternative mentioned above.

With regression estimation, the following final estimator is obtained in a single cluster for the response stratum:

$$(4.4) \qquad \mathrm{est}_{lr_i}(Y_R) = \mathrm{est}_{2i}(Y_R) + b_{Ri}\,[\,\mathrm{est}_{1i}(X_R) - \mathrm{est}_{2i}(X_R)\,]$$

$$= (m_{1Ri}/\bar{m}_1)\,A\,[\,\bar{v}_{2Ri} + b_{Ri}(\bar{u}_{1Ri} - \bar{u}_{2Ri})\,],$$

where $$b_{Ri} = \rho_{Ri}(s_{v_{Ri}}/s_{u_{Ri}})$$

and $$\rho_{Ri} = \rho(u_{Rij}, v_{Rij}).$$

This estimator is usually slightly biased.

If difference estimation is preferred to regression estimation, the regression coefficient b_{Ri} is replaced by the constant k_{Ri}, in which k is a good guess of the ratio Y/X in the population. In this case, the cluster estimator is unbiased.

Since there is reason to assume that the regression line on x and y passes close to the origin, ratio estimators can also be used. The estimator of a single cluster can then be expressed in the form

$$(4.5) \qquad \mathrm{est}_{r_i}(Y_R) = [\,\mathrm{est}_{2i}(Y_R)/\mathrm{est}_{2i}(X_R)\,]\,\mathrm{est}_{1i}(X_R)$$

$$= (m_{1Ri}/\bar{m}_1)\,A\,(\bar{v}_{2Ri}/\bar{u}_{2Ri})\,\bar{u}_{1Ri}.$$

In the above discussions, the second-phase sample (personal interview) was assumed to be selected with equal selection probabilities. This produces a bias to the familiar estimation. If the selection probabilities are proportional to the removal volume x obtained on the basis of the first phase (mail inquiry), this bias can be eliminated (cf. Raj 1968, p. 147; Seppälä 1971, p. 21). The selection procedure (see Lahiri 1951) presupposes sampling with replacement. The unbiased estimator is as follows:

$$(4.6) \qquad \overline{est}_{r_i}(Y_R) = (1/m_{2Ri}) \sum_{j}^{m_{2Ri}} [(m_{1Ri}/\bar{m}_1) \text{ A } v_{ij}/m_{1Ri}(u_{ij}/\sum_{j}^{m_{1Ri}} u_{ij})]$$

$$= (1/m_{2Ri})(m_{1Ri}/\bar{m}_1) \text{ A } \sum_{j}^{m_{2Ri}} (v_{ij}/u_{ij})\,\bar{u}_{1Ri} \,.$$

For the non-response stratum, the estimator obtained per cluster on the basis of the interview (cf. estimator (4.3)) is

$$(4.7) \qquad est_{2i}(Y_N) = est_i(Y_N) = (m_{1Ni}/\bar{m}_1) \text{ A } \bar{v}_{2Ni} \,,$$

where $$\bar{v}_{2Ni} = \sum_{j}^{m_{2Ni}} v_{ij}/m_{2Ni}$$

and N = symbol for non-response stratum.

After this the response and non-response strata per cluster can be combined, and the final estimator for a single cluster obtained:

$$(4.8) \qquad est_i(Y) = est_i(Y_R) + est_i(Y_N) \,.$$

In the response stratum, estimators (4.4)—(4.6) can be used.

Since the total number of sample holdings was the same per cluster, the estimator for the whole study area is obtained as the arithmetic mean of the values per cluster

$$(4.9) \qquad est(Y) = (1/n) \sum_{i}^{n} est_i(Y) \,,$$

where n = number of sample clusters.

If, in this estimator, the calculation of a cluster value for the response stratum has been based on estimators (4.4) or (4.5), the estimator is biased.

The error variance of cluster sampling is composed of the inter-cluster and intra-cluster variances:

$$V_c(Y) = V_b(Y) + V_w(Y) \,.$$

In a general form, the variance estimator based on the sample can be written as follows (S u k h a t m e 1954, p. 292):

$$(4.10) \qquad est[V_c(Y)] = (1/n)(1 - n/N)\, s_b^2 + (1/N)(1/\bar{m})(1 - \bar{m}/\bar{M})\bar{s}_w^2 \,.$$

It follows from the method of selecting the clusters that the population of the possible clusters (N) approaches the infinite. The variance estimator is therefore reduced to the form (clusters randomly selected):

$$(4.11) \qquad \text{est}\,[V_c(Y)] = v(Y) = (1/n)s_b^2$$

$$= [1/n\,(n-1)] \sum_i^n [\text{est}_1(Y) - \text{est}(Y)]^2 \quad .$$

Since the starting point for the calculation of estimates is the value per cluster and the size of a single cluster in the second phase of sampling is relatively small, the possible use of the removal data of the mail inquiry as the stratification basis was not investigated. In this case, the sampling error can apparently be reduced by both regression and ratio estimators at least as efficiently as by stratification.

43. Selecting the subsample from clusters

Instead of selecting a subsample from the forest holdings of each cluster included in the mail inquiry, let us assume that the subsample is selected from among the clusters themselves. If so, all first-phase forest holdings of the cluster included in the subsample are also included in the personal interview of the second phase of sampling. As before, response and non-response strata are formed on the basis of the mail inquiry.

Since the number of respondents varies from cluster to cluster, the size of the clusters reviewed by strata also varies. Three alternative estimators are usually presented, one of them unbiased but not very efficient (S u k h a t m e 1954, pp. 265—267; cf. S e p p ä l ä 1971, pp. 15—17 & 58—60). Of the two biased estimators, one is consistent. In it the cluster estimates are weighted with cluster size. By using this estimator, an estimator is obtained for the removals of the response stratum in the mail inquiry over the whole study area (cf. estimator (4.1)):

$$(4.12) \qquad \text{est}_1(X_R) = \sum_i^{n_1} (m_{1Ri} / \sum_i^{n_1} m_{1Ri})\, A_R\, \bar{u}_{1Ri} \quad ,$$

where n_1 = number of sample clusters in the first phase of sampling.

The estimator obtained from the sample for A_R is

$$\text{est}\,(A_R) = (1/n_1) \sum_i^{n_1} (m_{1Ri} / \bar{m}_1)\, A \,.$$

Since $\bar{m}_1$ is constant, we have

$$\mathrm{est}_1(X_R) = (1/n_1) \sum_i^{n_1} (m_{1Ri} / \bar{m}_1) \, A \, \bar{u}_{1Ri} \quad .$$

When this estimator is compared with estimator (4.1), it is seen that

$$\mathrm{est}_1(X_R) = (1/n_1) \sum_i^{n_1} \mathrm{est}_{1i}(X_R) \, . \tag{4.13}$$

Accordingly (see estimators (4.2), (4.3) and (4.7)) we have

$$\mathrm{est}_2(X_R) = (1/n_2) \sum_i^{n_2} \mathrm{est}_{2i}(X_R) \, , \tag{4.14}$$

where n_2 = number of sample clusters in the second phase of sampling,

$$\mathrm{est}_2(Y_R) = (1/n_2) \sum_i^{n_2} \mathrm{est}_{2i}(Y_R) \tag{4.15}$$

and

$$\mathrm{est}_2(Y_N) = \mathrm{est}(Y_N) = (1/n_2) \sum_i^{n_2} \mathrm{est}_{2i}(Y_N) \quad . \tag{4.16}$$

Using regression estimation, the estimator obtained for the response stratum is

$$\mathrm{est}_{1r}(Y_R) = \mathrm{est}_2(Y_R) + b_R [\mathrm{est}_1(X_R) - \mathrm{est}_2(X_R)] \, , \tag{4.17}$$

where $$b_R = \rho_R (s_{y_R} / s_{x_R}) \, , \quad \rho_R = \rho(x_{Ri} \, , \, y_{Ri}) \, .$$

Estimator (4.17) is slightly biased. An approximation of its variance estimator is obtained from expression (1.9) (clusters randomly selected):

$$v[\mathrm{est}_{1r}(Y_R)] = (1/n_2) \, s^2_{y_R} \, (1 - \rho^2_R) + (1/n_1) \, \rho^2_R \, s^2_{y_R} \, , \tag{4.18}$$

where $$s^2_{y_R} = [1/n_2 \, (n_2 - 1)] \sum_i^{n_2} [\mathrm{est}_{2i}(Y_R) - \mathrm{est}_2(Y_R)]^2 .$$

The difference estimator is obtained from this in the same way as was done with estimator (4.4).

If ratio estimation is used, we have a biased estimator

$$(4.19) \qquad est_r(Y_R) = [est_2(Y_R)/est_2(X_R)]est_1(X_R) = r_R\, est_1(X_R).$$

A first approximation to the variance estimator of (4.19) can be derived from expression (1.12):

$$(4.20) \qquad v[est_r(Y_R)] = (1/n_2)(s^2_{y_R} - 2r_R \rho_R s_{y_R} s_{x_R} + r_R^2 s^2_{x_R}) + (1/n_1)(2r_R \rho_R s_{y_R} s_{x_R} - r_R^2 s^2_{x_R}).$$

The variance estimator obtained for the estimator (4.16) of the non-response stratum is the common expression

$$(4.21) \qquad v[est(Y_N)] = [1/n_2(n_2 - 1)] \sum_i^{n_2} [est_{2i}(Y_N) - est(Y_N)]^2.$$

The final total-removal estimator is obtained by combining the response and non-response strata:

$$(4.22) \qquad est'(Y) = est(Y_R) + est(Y_N).$$

The above regression (or difference) and ratio estimators can be used in *est* (Y_R).

The variance estimator of (4.22) is of the form

$$(4.23) \qquad v[est'(Y)] = v[est(Y_R)] + v[est(Y_N)].$$

44. Estimation of areas and numbers

Usually the total area and forest area involved in the forest-holding population being studied are known, whereas the proportions according to various classifications (e.g. occupational groups or area strata) are not always known. Similarly, data on the number of forest holdings may be missing or at least obsolete. The estimation of areas and numbers is considered in the following.

Let the first-phase sampling method be that described in Section 421. The number of first-phase sample holdings is therefore *a priori* the same

($\bar{m}_1$) in all sample clusters. Since the sample is selected using selection points, of which only some fall on the area included in the population of the study, the estimate of the total area is obtained directly from the ratio of the numbers of selection points.

The estimate of total area for a given class is as follows:

$$(4.24) \qquad \text{est}\,(A_h) = \hat{A}_h = (1/n)\sum_{i}^{n}(1/\bar{m}_1)\sum_{j}^{\bar{m}_1}\alpha_{ij}^{h}\,A = (1/n)\sum_{i}^{n}\hat{A}_{hi}\,,$$

where h = index of the class studied
A = total area of forest holdings in the population (known)
$\alpha_{ij}^{h} = \begin{cases} 1 \text{ if sample holding belongs to class } h \\ 0 \text{ if sample holding does not belong to class } h. \end{cases}$

It suffices to consider only the inter-cluster variation in the variance estimator since all selection points of the sample cluster have been available:

$$(4.25) \qquad v\,(\hat{A}_h) = [\,1/n\,(\,n - 1)]\sum_{i}^{n}(\hat{A}_{hi} - \hat{A}_h)^2.$$

If simple random sampling is used instead of cluster sampling, the result will be a hyper-geometric distribution, in which case the variance estimator changes to correspond to this distribution.

The estimator of the total number of forest holdings belonging to a given class is

$$(4.26) \qquad \text{est}\,(M_h) = \hat{M}_h = (1/n)\sum_{i}^{n}(1/\bar{m}_1)\sum_{j}^{\bar{m}_1}(\alpha_{ij}^{h}/a_{ij})\,A = (1/n)\sum_{i}^{n}\hat{M}_{hi}\,.$$

The estimator of error variance is analogous to (4.25).

The mean total area per forest holding in class h is estimated as a ratio of expressions (4.24) and 4.26):

$$(4.27) \qquad \text{est}(A_h/M_h) = \hat{A}_h/\hat{M}_h = \sum_{i}^{n}\sum_{j}^{\bar{m}_1}\alpha_{ij}^{h}/\sum_{i}^{n}\sum_{j}^{\bar{m}_1}(\alpha_{ij}^{h}/a_{ij})\,.$$

If A/M is to be estimated for the whole population, $\alpha_{ij}^{h} = 1$ is always valid, and the result obtained is the expression

$$(4.28) \qquad \text{est}\,(A/M) = \hat{A}/\hat{M} = n\,\bar{m}_1/\sum_{i}^{n}\sum_{j}^{\bar{m}_1}(1/a_{ij})\,.$$

In estimator (4.27), both the numerator and the denominator are random variables. Therefore only an approximate form is obtained for the estimator of error variance (cf. R a j 1968, p. 89):

$$(4.29) \qquad v(\hat{A}_h / \hat{M}_h) = (1/\hat{M}_h^2)\,[\, v(\hat{A}_h) + (\hat{A}_h/\hat{M}_h)^2\, v(\hat{M}_h) - 2\,\rho_h\,(\hat{A}_h/\hat{M}_h)\,\sqrt{v(\hat{A}_h)\,v(\hat{M}_h)}\,]\,,$$

where $\rho_h = \rho(\hat{M}_{hi}\,,\ \hat{A}_{hi})$.

When we write

$$(1/\bar{m}_1)\sum_{j}^{\bar{m}_1}(1/a_{ij}) = \bar{e}_i \qquad \text{and} \qquad (1/n)\sum_{i}^{n}\bar{e}_i = \bar{e}$$

and bear in mind that in estimator (4.28) the variance of the numerator equals zero, we obtain by substitution into the common approximate variance estimator (e.g. estimator (4.29)):

$$(4.30) \qquad v(\hat{A}/\hat{M}) = (1/n)\,(1/\bar{e}^2)\,(\hat{A}/\hat{M})^2 \sum_{i}^{n}(\bar{e}_i - \bar{e})^2 \quad .$$

The necessary estimates of forest area are obtained analogously to removal estimates in the mail inquiry (formula (4.1)). The non-response rate plays no part now, because area and ownership data is recorded in connection with the listing.

45. Calculations based on the experimental material

For reasons of economy, the experimental study had to operate with such a small number of clusters (12 clusters) that no comparison of the efficiency of the estimators presented in Sections 42 and 43 was ventured using the material obtained. Although in Chapter 3 double sampling was found to be an efficient method for the estimation of timber removals, its relative efficiency was not analysed. In order to obtain some kind of an idea of this aspect, comparisons were made using the experimental material as if the first-phase sampling method had been simple random sampling and not cluster sampling. A similar simplification was made in the discussion in Chapter 3.

The regression estimation and ratio estimation of two-phase sampling were investigated and compared with one-phase sampling estimation. The compari-

sons were concerned with the total-removal estimate. The non-response rate for a mail inquiry was assumed to be the same as in this experimental study (17.2 %). The optimum sampling fractions and the relevant unit costs were obtained from Table 3.

The starting point was regression estimation. The first-phase sample size was fixed at 1 000 forest holdings and the second-phase sample size, according to the optimum sampling fraction (Table 3), at 151 forest holdings. The non-response of the mail inquiry was assumed to be 172 forest holdings.

When the response and non-response strata are combined, the weights have to be estimated from the sample. As a result, the error variance increases. Assuming that the first-phase sample is selected with replacement, the variance estimator obtained is (cf. C o c h r a n 1963, p. 330)

$$(4.31) \qquad v(\hat{Y}_{st}) = \sum_{h}^{L} \left\{ [w_h^2 + w_h(1 - w_h)/m_1]\, v(\hat{Y}_h) + w_h(M\bar{y}_h - \hat{Y}_{st})^2/m_1 \right\}$$

where $w_h = m_h/m_1$ and $\sum_{h}^{L} m_h = m_1$

with h = index of the stratum (response, non-response)
m_h = sample size of stratum h.

The error variance was also estimated disregarding the fact that stratum weights had to be estimated. The common expression was used (cf. estimator (4.23)):

$$(4.32) \qquad v'(\hat{Y}_{st}) = \sum_{h}^{L} v(\hat{Y}_h).$$

A comparison of the variance estimates obtained from expressions (4.31) and (4.32) revealed that the approximation formula (4.32) gave an error-variance estimate only 0.5 % lower than the precise formula (4.31). The estimation of stratum weights from the sample therefore produces no appreciable increase in sampling variance, provided the size of the first-phase sample is sufficiently large, as it was in this case. For this reason, the variance estimates of two-phase sampling in the discussion below have been calculated according to formula (4.32).

The total variable cost of sampling based on regression estimation, with the above sample sizes, was concluded to be Fmk 6 807, with a relative standard error of 6.2 %.

Ratio estimation was considered next. The grand total of the costs was assumed to be the same as it had been for regression estimation. Since the optimum second phase sampling fraction in ratio estimation exceeds that in

regression estimation (Table 3), the number of holdings fixed for the first-phase sample was 951 and for the second-phase 157. The relative standard error was 6.4 %. The difference from regression estimation was thus very small. The ratio estimator, being easier to calculate, may therefore be preferable in practice.

When the total variable costs were assumed to have been spent on simple random sampling, with personal interviews concerning all sample holdings, the number of sample holdings would have been 250. The relative standard error obtained was 8.1 %. Thus the use of double sampling with regression estimation produced a relative standard error which was less than 77 % of the standard error of a study based solely on personal interviews and involving the same cost. This means that efficient use of a mail inquiry can reduce the total variable field costs to about 59 % of the costs of a normal personal-interview study. The use of a mail inquiry in the form of two-phase sampling is therefore an economic proposition.

The above analyses did not cover cluster sampling. Even if the two-phase method in cluster sampling is not relatively as efficient as when the sample units are selected without the formation of clusters, there is no reason to believe that the use of a mail inquiry would not be helpful in cluster sampling also. It is even possible that in cluster sampling the benefit obtained from a mail inquiry exceeds that of simple random sampling. Earlier studies (S e p p ä l ä 1969, 1971) justify the assumption that the formation of clusters does not very much affect such things as the correlation of various variates. A detailed study of the issue, however, would require more extensive field studies than were possible here.

5. NON-SAMPLING ERRORS

The inquiry of removal volumes by personal interviews with forest owners has been studied several times in Finland. Some of the results reported have not been very promising (H o l o p a i n e n 1959). Non-sampling errors, especially those due to the interviewer, have proved to be a weakness in the method. Recent studies have shown, however, that by carefully choosing and effectively training the interviewers the errors due to the interviewer can be considerably eliminated (E r v a s t i *et al.* 1969; S a l o 1971; S e p p ä l ä 1971). It is necessary to specially emphasize that not too many interviewers should be employed. Otherwise their training and the supervision of the interviews cannot be made effective enough.

A mail inquiry has never before been tried in Finland in an attempt to find out the removal volumes from forest owners. No parallel could therefore be drawn with studies carried out under similar conditions. If, however, the removal volumes obtained by interview can be considered reliable, a comparison by forest holdings of the removals recorded by mail inquiry and by interview provides a basis for the assessment of the serviceability of the mail inquiry. In actual fact, the removal figures obtained by mail inquiry need not be even close to the true absolute figures as long as the correlation with the removals of the interview is high enough.

Some findings on a comparison of mail inquiry and interview were reported in Section 32 (Tables 1 & 2). The estimate of total timber removals obtained by mail inquiry was practically the same as that obtained by personal interviews. Even by removal and ownership groups, the differences were not very great. Furthermore, the correlation of removal volumes between mail inquiry and interview was remarkably high, as regards both the total removals and the various groups. On this basis, the removal volumes obtained by mail inquiry in the present study can be considered relatively reliable. Supported by personal interview, their useful value increases considerably. However, from the experience gained in the present study, it is obvious that in a mail inquiry the removal volumes should not be specified any further than they now are (p. 11).

In personal interviews with forest owners in Finland, the non-response rate has been practically zero. The same was true of the personal interview in the present study, whereas the non-response rate in the mail inquiry amount-

ed to 17.2 %. The original questionnaire sent to the forest owners was followed up by only one request addressed to non-respondents. Had a second reminder been sent to those still not replying, then non-response rate might well have fallen below 10 %. This is suggested by the fact that, in the personal interview, people who had not replied to the mail inquiry mostly claimed that they had been very busy and forgotten about the matter or that the questionnaire had been mislaid. In addition, for example, for a population of roundwood buyers (small buyers, removal quantity not more than 4 050 solid m^3 annually) the non-response rate decreased with a second reminder compared to a first reminder by about 50 % (P a l o 1967, p. 88).

In the present study, the population of forest holdings was divided into two strata according to the reaction to the mail inquiry: response and non-response. A sample was selected from both strata for personal interviews, since it was probable that the structure and cutting activities of the groups were different.

In order that the response and non-response strata could be compared, a number of parameters was estimated both separately for each stratum and for the whole population. The calculation was based on the 174 forest owners participating in the personal interviews, and the estimators were based on those described in Chapter 4. The results are presented in Table 4. The readiness to be interviewed was assessed by a score of points awarded by the interviewer, ranging from 0 (refusal) to 10 (extremely interested). The removal volumes recorded were calculated in relation to forest area (taxation classes I—IV).

Table 4. Parameters estimated for the response (R) and non-response (N) strata, and for the total population.

Stratum	Number among population (%)	Occupational group (%)		Average total area, ha/holding	Average forest area, ha/holding	Readiness to be interviewed	Removals for sale, m^3/ha	Removals for household consumption, m^3/ha	Total removals, m^3/ha
		Farmers	Others						
R	84.5	66.5	33.5	27.5	15.4	8.0	2.51	.78	3.29
N	15.5	75.8	24.2	33.1	18.8	7.4	1.69	.51	2.20
Total	100.0	67.9	32.1	28.3	15.9	7.9	2.36	.73	3.09

Summarizing, it can be seen from Table 4 that the non-respondents, compared with the respondents, are more often farmers, usually possess a larger farm as regards both total land area and forest area, but in general cut less, especially in terms of felling volumes per hectare (forest area). Furthermore, the readiness of the non-respondents to be personally interviewed, as could be expected, was less than that of the respondents.

These observations indicate that the non-response stratum clearly differed from the response stratum. Had the assumption been made that the non-respondents undertook fellings to the same degree as the respondents and had the estimation been based on the respondents alone, the estimate obtained for the total removals would have had a bias of $+2.9$ %. This percentage is not very high due to the high response rate.

6. SUMMARY

The present study is part of the work in which the Department of Forest Economics and the Department of Mathematics of the Forest Research Institute have been engaged in recent years to develop suitable methods of obtaining timber-removal statistics.

The purpose of the study was to find out whether the precision of removal-volume estimates could be improved by a mail inquiry preceding a personal interview. The method would be double sampling, with the mail inquiry constituting the first phase and the personal interview the second phase. In both phases, the elementary unit of sampling was supposed to be a forest holding.

An experimental study was launched to investigate the problems of double sampling and especially of the mail inquiry. The sample forest holdings were selected by cluster sampling. The number of clusters was 12 and they were located in the forestry board districts of Lounais-Suomi and Uusimaa-Häme. The mail inquiry covered a total of 632 forest holdings and the personal interview 174 forest holdings. In the first phase of sampling, individual holdings were selected with selection probabilities proportional to the total area of the farm of which the forest holding was a part. The second-phase holdings were selected with equal probabilities from among the first-phase holdings.

The basic sampling method proposed was cluster sampling in areal form, which in earlier studies had proved to be an efficient method. For this reason, the estimators described in the study were mainly based on cluster sampling. In the experimental material, for reasons of economy, the number of clusters was so small that the efficiency of the estimation methods proposed for cluster sampling could not be analysed.

Calculations were carried out, however, on the basis of the experimental material, which was treated as if the sample holdings had been selected without cluster formation. By this means, the optimum second-phase sampling fractions and the corresponding variable unit costs of the first and second phase of the sampling were established. At this stage, it became evident that the mail inquiry in double sampling clearly improved the precision of the estimates as compared with a study based on interviews alone. When the removal volumes from the mail inquiry and from the inter-

view were compared using the subsample interviewed, it was found that the difference in total removals calculated per forest holding was of the order of 0.1 %. For the different timber assortments and tree species, the differences, even at their maximum, were under 10 %.

One of the worst problems was non-response. It affected only the mail inquiry, since the interviewer reached all the forest owners and no one refused the interview. Replies to the first mail inquiry were received from 55 % of the recipients within the given 3-week period. After one reminding letter, the reply percentage rose to 83. Compared with results reported from other fields of study, this response rate must be considered good. If more reminders had been sent, the response percentage might have risen even more.

In the estimation, the problem produced by non-response was solved by dividing the population into two strata: response and non-response. When these strata were studied on the basis of the interview material, it was found that the non-respondents in a greater than average number of cases were farmers who owned a larger than average forest holding but removed considerably less timber than those who had answered the mail inquiry.

The relative efficiency of double sampling based on a mail inquiry as compared with one-phase sampling was preliminarily investigated on the basis of the experimental material. The result obtained from these calculations was that the use of double sampling based on a mail inquiry can reduce the total variable field costs to about 60 % of the costs of a normal personal-interview study.

REFERENCES

Cochran, W. G. 1963. Sampling techniques. John Wiley & Sons, Inc. New York —London.

Ervasti, S.—Salo, E.—Seppälä, R.—Tiililä, P. 1969. Survey of the utilization of roundwood and fuel on real estates in Finland. Methods and results for 1964—66, and plan for 1970. *Metsäntutkimuslaitoksen Julkaisuja* 68.6. Helsinki.

Holopainen, V. 1959. Suomen metsien luovutusmäärä hakkuuvuosina 1955/56 —1956/57. Hakkuutilaston metodia käsittelevä koetutkimus. Summary: Removal of Finland's forests in the felling years 1955/56—1956/57. A study in the method of compiling felling statistics. *Silva Fennica* 97.

Kuusela, K.—Salminen, S. 1969. The 5th national forest inventory in Finland. General design, instructions for field work and data processing. *Metsäntutkimuslaitoksen Julkaisuja* 69.4. Helsinki.

Lahiri, D. B. 1951. A method of sample selection providing unbiased ratio estimates. *Bull. Inst. International de Statistique* 33 (2), 133—140.

Metsätilastollinen vuosikirja 1969. Yearbook of forest statistics 1969. *Folia Forestalia* 96. Helsinki.

Palo, M. 1967. Markkinahakkuiden tilastomenetelmä ja sen suunnittelun kehysmalli. Mimeographed. Metsäntutkimuslaitos. Helsinki.

Raj, D. 1968. Sampling theory. McGraw-Hill. New York—London.

Salo, E. 1971. Hakkuupoistuman määritys metsälöotoksesta. Summary: Determination of drain from fellings by a sample of forest units. *Metsäntutkimuslaitoksen Julkaisuja* 72.5. Helsinki.

Seppälä, R. 1969. Ketjutetusta systemaattisesta ryväsotannasta ja sen käytöstä hakkuupoistuman määrityksessä. Mimeographed. Metsäntutkimuslaitos. Helsinki.

—»— 1971. Linked systematic cluster sampling for the estimation of timber removals. *Metsäntutkimuslaitoksen Julkaisuja* 72.3. Helsinki.

Sukhatme, P. V. 1954. Sampling theory of surveys with applications. The Iowa State University Press. Ames.

Yates, F. 1965. Sampling methods for censuses and surveys. Charles Griffin & Company Limited. London.

SELOSTE

Tämä tutkimus liittyy osana Metsäntutkimuslaitoksen metsäekonomian tutkimusosastossa ja matemaattisessa osastossa viime vuosina tehtyyn hakkuutilastomenetelmien kehittämistyöhön.

Tutkimustehtävänä oli selvittää, voidaanko henkilökohtaisen haastattelun rinnalla toimeenpantavalla postitiedustelulla parantaa hakkuumääräestimaattien tarkkuutta. Otantamenetelmänä olisi tällöin kaksoisotanta, jossa postitiedustelu on ensimmäisenä vaiheena ja henkilökohtainen haastattelu toisena vaiheena. Molemmissa vaiheissa otannan alkeisyksikkönä ajateltiin käyttää metsälöä.

Kaksoisotantaan ja erityisesti postitiedusteluun liittyvien kysymysten selvittämiseksi pantiin toimeen koetutkimus. Otosmetsälöt poimittiin ryväsotantaa käyttämällä. Rypäiden määrä oli 12, ja ne sijaitsivat osittain Lounais-Suomen ja osittain Uudenmaan—Hämeen piirimetsälautakunnan alueella. Postitiedustelu kohdistui yhteensä 632 metsälöön ja henkilökohtainen haastattelu 174 metsälöön. Otannan ensimmäisessä vaiheessa käytettiin yksittäisen metsälön poiminnassa poimintatodennäköisyyksiä, jotka olivat verrannollisia metsälöön liittyvän maatilan kokonaisalaan. Toisen vaiheen metsälöt poimittiin yhtä suurin todennäköisyyksin ensimmäisen vaiheen metsälöistä.

Perusotantamenetelmänä esitettiin käytettäväksi alueotannan muodossa toimeenpantavaa ryväsotantaa, joka aikaisemmissa tutkimuksissa oli osoittautunut tehokkaaksi menetelmäksi. Siksi tässä tutkimuksessa esitetyt estimaattorit perustuvat pääosalta ryväsotantaan. Koemateriaalissa rypäiden määrä oli kustannussyistä niin vähäinen, että ryväsotantaa varten esitettyjen estimointimenetelmien keskinäistä tehokkuutta ei voitu selvittää.

Koemateriaalin perusteella tehtiin kuitenkin laskelmia käsittelemällä aineistoa ikään kuin otosmetsälöt olisi poimittu ilman rypäiden muodostamista. Näin saatiin selville optimaaliset toisen vaiheen otantaosuudet ja niitä vastaavat otannan kummankin vaiheen muuttuvat yksikkökustannukset. Jo tässä vaiheessa voitiin todeta, että kaksoisotantaan liitetty postitiedustelu paransi selvästi estimaattien tarkkuutta verrattuna pelkkään haastatteluun perustuvaan tutkimukseen. Kun verrattiin haastatellun alaotoksen perusteella postitiedustelun ja haastattelun hakkuumääriä, todettiin, että kokonaishakkuissa metsälöä kohti laskettu ero oli 0.1 prosentin luokkaa. Eri puutavara- ja puulajeissa olivat erot suurimmillaankin alle 10 prosenttia.

Erään hankalimmista ongelmista muodosti kato. Katoa esiintyi vain postitiedustelussa, sillä henkilökohtaisessa haastattelussa kaikki metsänomistajat tavoitettiin, eikä kukaan kieltäytynyt haastattelusta. Ensimmäiseen postitiedusteluun saatiin määräajaksi annetun kolmen viikon kuluessa vastaus 55 prosentilta. Yhden muistutuskirjeen jälkeen vastausprosentti nousi 83:een. Verrattuna muilla aloilla saatuihin tuloksiin on todettua vastaamisalttiutta pidettävä hyvänä. Lähettämällä lisää muistutuskirjeitä olisi vastausprosenttia luonnollisesti voitu vielä nostaa.

Estimoinnissa kadon aiheuttama ongelma ratkaistiin siten, että perusjoukko jaettiin kahteen ositteeseen: vastaaviin ja ei-vastaaviin. Tutkittaessa haastetteluaineiston

perusteella näitä ositteita voitiin todeta, että ei-vastaavat ovat keskimääräistä useammin maanviljelijöitä, omistavat keskimääräistä suuremman metsälön, mutta hakkaavat huomattavasti vähemmän kuin ne, jotka vastaavat postitiedusteluun.

Koemateriaalin perusteella selvitettiin alustavasti myös postitiedusteluun perustuvan kaksoisotannan suhteellista tehokkuutta verrattuna yksivaiheiseen otantaan. Laskelmien tulokseksi saatiin, että postitiedusteluun perustuvan kaksoisotannan käyttö voi normaaliin haastattelututkimukseen verrattuna alentaa kenttätyön muuttuvia kokonaiskustannuksia noin 60 prosenttiin.

MÄNTY- JA KUUSIRUNKOJEN PUUTAVARASUHTEET JA KANTOARVOT

JOUKO LAASASENAHO YRJÖ SEVOLA

Summary:

Timber assortment relationships and stumpage value of Scots pine and Norway spruce

HELSINKI 1971

Helsinki 1971. Valtion painatuskeskus

ALKUSANAT

Metsäntutkimuslaitoksen metsänarvioimisen ja metsäteknologian tutkimusosastojen yhteistyönä aloitettiin v. 1968 pystypuiden kuutioimis- ja kuivapainotutkimus, jossa ensiksi mainitun osaston osuutena on tutkia puiden kuutiotilavuutta ja muita taksatoorisia tunnuksia sekä jälkimmäisen osaston osuutena tutkia puiden kuivapainoa. Samanaikaisesti aloitettiin professori Aarne Nyyssösen johdolla Helsingin Yliopiston metsänarvioimistieteen laitoksessa metsiköiden hakkuuarvoa ja arvonkasvua selvittävä tutkimus, jossa omien mittausten lisäksi käytetään metsäntutkimuslaitoksen metsänarvioimisen tutkimusosaston koeala-aineistoa professori Nyyssösen toimiessa metsäntutkimuslaitoksen sivullisena tutkijana.

Käsillä oleva tutkimus männyn ja kuusen puutavaralajisisällöstä ja kantoarvosuhteista on tehty osatehtävänä edellä kuvatulla tavalla syntyneessä metsänarvioimisen työryhmässä tavoitteena saada käytettävissä olevasta koepuuaineistosta metsiköiden arvonkasvututkimusta edistävä menetelmä puiden kantoarvon määrittämiseksi. Tämän lisäksi pystypuiden kuutiomäärä- ja puutavaralajisisältöä sekä kantoarvosuhteita selvittävällä tutkimuksella on nykyisessä korjuu- ja mittausmenetelmien kehitysvaiheessa yleistäkin merkitystä.

Aineiston keräyksen ja käsittelyn johtanut, kuutioimistutkimuksen vastaava tutkija Jouko Laasasenaho on kehittänyt kaikki esitettävät funktiot. Yrjö Sevola yliopiston metsänarvioimistieteen laitokselta on lähinna selvittänyt apteerauksen perusteet ja suorittanut tutkimuksen vaatimat ohjelmointityöt.

Kiitämme käsikirjoituksen tarkastaneita professoreita Kullervo Kuuselaa ja Veijo Heiskasta. Myös professori Aarne Nyyssönen, vt. apulaisprofessori Pekka Kilkki ja metsänhoitaja Sakari Salminen ovat lukeneet käsikirjoituksen. Kiitämme heitä tekemistään huomautuksista. Rouva Anja Leskinen on suorittanut konekirjoitustyön.

Helsingissä heinäkuussa 1971

Jouko Laasasenaho *Yrjö Sevola*

SISÄLTÖ

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SUMMARY

The aim of the present study was to assess the timber assortment relationships and stumpage value of Scots pine (*Pinus silvestris*) and Norway spruce (*Picea abies*). The data required for the study were collected from 95 of the survey tracts used in the Finnish national forest inventory; these were selected at random, and represented various regions of the country. From the tracts selected for the study, a maximum number of five sample trees were selected using the relascope; these groups of sample trees were located at a distance of 200 m from each other. On the sample trees, the following readings were taken: the breast height diameter, the diameter at a height of 6 m, the tree height, and the diameter and bark thickness at the relative heights of 1, 2.5, 5, 7.5, 10, 15, 20, 30, 40, 50, 60, 70, 80 and 90 % of the tree height. For the other parts of the stems, both the diameter overbark and underbark were determined at 10 cm intervals by means of a parabel function through three points. Tables 1 and 2 show the distribution of the sample trees by diameter and height classes.

The flowchart of the system employed in the study is presented on p. 15. The division of the stems into timber assortments was programmed for computer analysis. The programme aimed at finding the combination of the saw timber and pulpwood proportions which, under the conditions given, maximizes the value of the stem. The following parameters were used: the minimum diameters of the saw logs and the pulpwood, the minimum dimensions of the saw logs, the lengths of the portion of saw timber which determine the number of logs yielded, the unit prices of saw logs and pulpwood, and the corresponding top volumes (see pp. 16, 17 and 19). A total of 1 291 pine and 744 spruce stems yielding saw timber were measured employing theoretical marking for bucking. The volume equations required were calculated from the total data collected, and other equations, from the data obtained for saw logs. The variables used in developing the equations are presented on pp. 30 and 31. The letter Y indicates dependent variables, and the letter X, independent ones. The equations developed are shown on p. 31 and 32. The relative mean errors of the estimates obtained with the equations are shown in the text table on p. 34. The tables presented at the end of this paper were set up using the equations presented. The equations will be used particularly in determinations of the volume, timber assortment distribution and stumpage value of the growing stock in stands under development or marked for cutting. Volume equations based on the diameter only and the formula (9.1) for determination of the volume of the growing stock as calculated with the aid of the ratio estimate are presented on p. 41.

1. JOHDANTO

Puutavaralajien erilaisten yksikköhintojen takia runko on jaettava tukki- ja kuitupuuosaksi sen arvon määrittämiseksi. Jakamista varten on käytettävissä erilaisia taulukoita, esim. Tiihonen (1969), Nousiainen — Sorsa — Tiihonen (1970) ja Nyyssönen (1971). Lallukka (1970) esim. käytti viimemainittuja taulukoita yliopiston metsänarvioimistieteen laitoksella suorittamissaan puiden ja metsiköiden arvoa koskevissa alustavissa tutkimuksissa. Nämä taulukot ovat tarkoitetut vain suurehkojen runkomäärien apteeraukseen eivätkä tuntuneet soveltuvan puukohtaiseen tarkasteluun. Tässä vaiheessa tietokoneen tarjoama suurten aineistojen nopea käsittelymahdollisuus antoi tilaisuuden tutkia runkojen puutavaralajijakautumia käyttämällä hyväksi metsäntutkimuslaitoksen toimesta koottua, tietokoneapteeraukseen erinomaisesti soveltuvaa koepuuaineistoa. Tietokoneiden käytöstä rungon laskennalliseksi jakamiseksi puutavaralajeihin on jo aikaisempia sovellutuksia (Strand 1967; Alm — Troedsson 1969; Nousiainen et al. 1970; Heinonen 1971).

Vaikeutena tällaisessa työssä on lähinnä apteeraustulokseen vaikuttaviin tekijöihin, kuten tukkien minimimittoihin, luokitustapoihin ja järeysporrastuksiin sovellettu erilainen käytäntö eri puolilla maata ja eri ostajien tarpeiden mukaan. Myös hintasuhteet ovat erilaisia maan eri osissa. Apteerausparametrien arvot on yritetty harkita sellaisiksi, että tuloksilla olisi laajempaakin käyttökelpoisuutta. Mistään »lopullisista» tuloksista ei koskaan voi olla kysymys. Siksi on pyritty kehittämään mahdollisimman joustava laskentasysteemi, jotta koottua aineistoa voitaisiin käyttää erilaisilla laskentaperusteilla.

2. AINEISTO

Tutkimusaineiston muodostaa metsäntutkimuslaitoksessa prof. K u u s e l a n johdolla v. 1968 aloitetun pystypuiden kuutioimis- ja kuiva-ainepainotutkimukseen kerätty laaja koepuumateriaali (vrt. K u u s e l a 1965). Pääpiirteissään aineiston keräys on tapahtunut seuraavasti.

Valtakunnan metsien inventoinnin lohkoilta on alueittaista satunnaisotantaa käyttäen valittu 95 lohkoa. Kullakin lohkolla on 200 m:n välein otettu koeala, jolta koepuut on poimittu relaskoopin avulla. Yhdeltä koealalta on mitattu enintään viisi objektiivisesti valittua puuta. Puun pituus on mitattu maasta latvan huippuun desimetrin tarkkuudella. Läpimitat ja kuoren paksuudet on mitattu suhteellisilta korkeuksilta. Käytetyt suhteelliset korkeudet prosentteina puun pituudesta ovat: 1, 2.5, 5, 7.5, 10, 15, 20, 30, 40, 50, 60, 70, 80 ja 90. Lisäksi on mitattu kaatokoepuita, joista läpimitat ja kuoren paksuudet on mitattu myös 85 ja 95 %:n korkeuksilta. Läpimitat on mitattu mm:n tarkkuudella kahdelta toisiaan vastaan kohtisuoralta suunnalta. Rinnankorkeusläpimitat on mitattu 1.3 m:n korkeudelta sekä maasta että ylimmästä katkaisua haittaavasta juurenniskasta lähtien. Viimeksi mainittua on käytetty tässä tutkimuksessa. Myöskin kuuden metrin korkeudella olevien läpimittojen mittauksessa mittauskorkeus on määritetty sekä maasta että juurenniskalta lähtien. Nämä läpimitat on mitattu kaikista puista, joista ne voidaan mitata. Pituudeltaan alle 7.5 m:n puille ei ole otettu 3.5 m:n läpimittaa (vrt. I l v e s s a l o 1948). Esillä olevassa tutkimuksessa koepuumateriaalista on käytetty vain se osa, joka täyttää myyntipuun mitat.

Aineisto on alueellisesti kerätty koko Suomen alueelta. Koska Lapissa on kuusen osuus puustosta pieni, on koepuumateriaalissa kuusitukkipuita Oulun ja Lapin lääneistä vain 75 kappaletta (asetelma 1).

Asetelma 1. Tukkipuumateriaalin jakaantuminen Etelä- ja Pohjois-Suomen kesken (Pohjois-Suomi käsittää Lapin ja Oulun läänin).

	Mänty	Kuusi
Pohjois-Suomi	446	75
Etelä-Suomi	845	669
Koko maa	1 291	744

Taulukoista 1 ja 2 nähdään aineiston jakaantuminen läpimitta- ja pituusluokkiin.

Koepuun kuutiomäärä käsittää runkopuun tilavuuden latvasta ylimpään katkaisua haittaavaan juurenniskaan. Kantovähennystä ei ole tehty. Perusteluna ylimpään katkaisua haittaavaan juurenniskaan saakka kuutioimiselle voidaan mainita, että tällöin tulee kuutiomääräksi se rungon osa, joka nykyään voidaan helposti ottaa käyttöön. Koepuun kuutiomäärä on laskettu pätkittäin yhden pätkän ollessa kahden peräkkäisen suhteellisen korkeuden mittausvälin pituinen. Kukin pätkä on kuutioitu integroimalla pätkän runkokäyrä puun tyvellä ja ylempänä käyttämällä Simpsonin kaavaa

$$v = (g_0 + 4g_1 + g_2) \cdot \frac{h}{6}, \text{ missä}$$

g_0, g_1 ja g_2 ovat pätkän ala-, keski- ja yläläpimittaa vastaavat poikkileikkauspinta-alat ja h on pätkän pituus.

Rungon suhteellisilta korkeuksilta mitattujen kolmen peräkkäisen läpimitan perusteella kehitettiin toisen asteen polynomifunktio pätkän runkokäyrälle, jota käyttäen läpimitat laskettiin 10 cm:n välein kuorineen ja kuoretta juurenniskalta puun latvaan saakka. Lasketut läpimitat ja muut puusta mitatut tiedot on talletettu magneettinauhoille ja näitä nauhoja on käytetty apteerattaessa runkoja jäljempänä selostettavalla tavalla.

Koska tukkien mitat ovat kuorettomia, on kuoren mittauksen tarkkuudella suuri merkitys. Pystykoepuiden kuoren paksuus mitattiin kuorimittarilla, jota huolellisestikin käytettäessä tulokset ovat hieman epävarmoja. Osa näytteestä on kaatokoepuita, joihin kaadon jälkeen on tarkasti merkitty mittauskohdat ja -suunnat. Kuorellisten läpimittojen ristiinmittauksen jälkeen puut on katkaistu mittauskohdista moottorisahalla ja kuorettomat läpimitat on ristiinmittauksen avulla saatu tarkasti vastaavista kohdista. Vertailtaessa pysty- ja kaatokoepuiden kuoriprosentteja tukkipuilla saatiin seuraavat tulokset:

		Puita, kpl	Rungon keskikoko m³, kuorineen	Kuori-%
Mänty	Pystykoepuita	1 120	0.49429	13.61
	Kaatokoepuita	171	0.59371	11.05
		1 291	0.50746	13.21
Kuusi	Pystykoepuita	657	0.53366	13.19
	Kaatokoepuita	87	0.58266	10.65
		744	0.53939	12.87

Kaatokoepuilla kuoriprosentit ovat niin paljon alhaisemmat, ettei runkojen suurempi keskikoko pysty sitä selittämään. Tätä todennäköisesti liian korkeata kuoriprosenttia ei ole tutkimuksessa korjattu, koska asia vaatisi perusteellisempaa selvitystä. Näyttäisi kuitenkin siltä, että saadut esim. runkojen kuutiojalkamäärät, arvot ja muuntokertoimet olisivat lievästi aliarvioita.

Taulukko 1. Koepuiden jakaantuminen
Table 1. Distribution of sample trees by

D cm	Puun pituus, m —										
	5	6	7	8	9	10	11	12	13	14	15
	Puita, kpl —										
7	1	1	5	2	1						
8	10	9	21	12	4	2	1			1	
9	8	14	15	13	8	5	4	1			
10	2	10	14	13	16	2	3	2		1	
11	4	5	12	15	14	14	5	2		1	1
12	1	3	10	10	14	18	9	6	2	1	
13		2	6	9	12	16	10	8	6	3	3
14			3	7	5	8	16	9	11		3
15		2	4	9	11	15	15	9	16	8	3
16		1	1		6	8	9	7	7	7	10
17				3	1	4	12	17	15	12	11
18		1	1	1	4	8	14	9	15	11	11
19					2	8	7	8	8	12	9
20				1	3	5	6	5	14	18	14
21					2	1	3	5	5	12	12
22				1	1	2	5	10	4	8	18
23						2	6	4	16	10	15
24			1			4	2	5	5	18	9
25			1			1	2		4	5	17
26								3	4	5	6
27							2	1	6	8	12
28								2	2	5	6
29						1	1	2	2	2	2
30							2	1	3	4	5
31								2	1	4	2
32								2	2	5	5
33									4		1
34								1	2	3	2
35								1		4	3
36								1			
37									1	1	1
38					1					1	1
39											
40								1			
41											
42											
43											
44											1
45											
46											
47											
48											
50											
Yhteensä	26	48	94	96	105	124	134	124	155	170	183

läpimitta- ja pituusluokkiin. M ä n t y.
diameter and height classes. P i n e.

Tree height, m													
16	17	18	19	20	21	22	23	24	25	26	27	28	Yht. *Total*
Number of trees													
													10
													60
													68
													63
													73
													74
													75
1													63
3	1												96
5	3	1											65
3	3	2	2										85
7	10	7		2									101
9	7	8	1	1	1								81
9	3	7	5	3		1							94
5	11	12	2	5		1							76
13	13	15	2	4	2	2							100
9	20	7	4	3	2		1	1					100
13	7	10	11	7	2	4	1						99
6	9	7	9	5	7		1						80
5	8	6	12	12	6	3		3	2				75
7	6	15	6	5	6	3	5	1	1				86
7	6	9	11	7	12	1	4	1		2			75
5	3	4	7	7	5	4	6		1				52
8	10	6	2	8	7	4	4	3	1				68
4	2	7	3	4	4	5	6			1			45
2	6	5	1	5	5	1	2	1	2	1	1		46
1	1	4	4	6	9	3	6	2	1		2		44
2	6	3	2	2	2	1	6	1	2				35
1	4		4	5		2			3	1			28
2	3	3	3		2	1	2		1		1		19
	4	2	1	2	1	2	1	4	1	1	1		23
		2	1	4	5		3		1	1		1	21
1				1		1	2	1					6
1		1			4	2		2					11
1	1			3	1	2				2			10
		1				1					1		3
		1	1										2
													1
		2	1										3
1												1	2
	1				1								2
							1						1
	1												1
131	149	147	95	102	82	51	50	22	16	10	6	2	2 122

Taulukko 2. Koepuiden jakaantuminen
Table 2. Distribution of sample trees by

D cm	Puun pituus, m —											
	5	6	7	8	9	10	11	12	13	14	15	16
	Puita, kpl —											
7		3	3	5	1							
8	5	19	15	6	2	1						
9	1	5	21	12	18	6	1					
10	2		13	19	18	9	7	1				
11	1	2	7	18	12	16	7	11	3			
12	1	3	2	15	27	19	15	11	4	1		1
13				5	6	19	14	18	14	1	3	
14			1	2	6	8	16	9	18	7	4	2
15			2	2	4	5	7	14	16	14	11	3
16				1	3	8	8	12	14	13	11	7
17					3	4	11	14	10	9	14	9
18				1	1	2	6	7	12	12	12	6
19					3		3	7	7	6	12	12
20					1		1	4	12	9	14	14
21								4	6	7	17	14
22								1	3	7	8	11
23									2	6	6	17
24									1	5	3	5
25									1	1	3	8
26								2		1	1	5
27									1	2	3	3
28										1		2
29												2
30										2		2
31												
32												
33												
34									1			
35												
36												
37												
38												
39												
40												
41												
42												
43												
44												
45												
Yhteensä	10	32	64	86	105	98	96	115	125	104	122	123

läpimitta- ja pituusluokkiin. K u u s i.
diameter and height classes. S p r u c e.

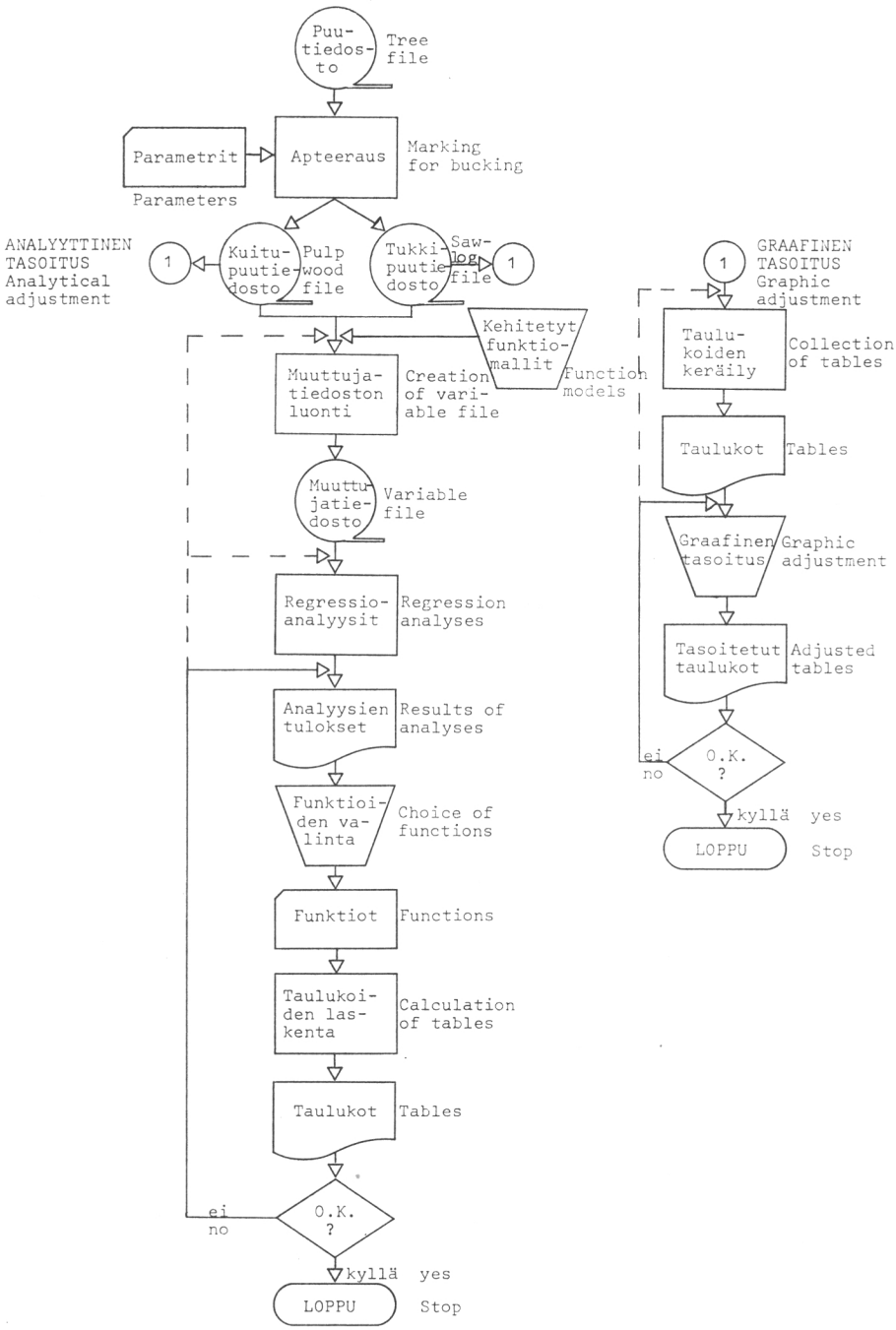
Tree height, m

17	18	19	20	21	22	23	24	25	26	27	28	29	Yht. *Total*
Number of trees													
													12
													48
													64
													69
													77
													99
													80
1													74
3													82
2		1											80
7	4												85
7	4												70
10	6	3	1	1									71
12	6	4	6	1									84
5	8	8	3	1	1								74
13	8	3	5	4	1	1							65
6	8	7	12	7	2	1							74
5	6	10	6	5	3	2							51
4	8	12	9	9	4	3							62
4	9	9	6	8	7	3	1	1					57
7	1	10	4	5	5	6	1	1					49
3	3	6	8	10	8	4	2						47
5	3	3	5	4	3	3	2	1	1				32
3	2		4	5	4	3	5	2					32
	3	2		2	3	2	2	2	1				17
		1	2	1	4	2	3		1	1			15
1	1	3	1	4	3	5		2	2		1		23
2	1		2		1	2	3	1	1				14
1			3			1	1	3					9
	1				2		2	1	2	4			12
				3				1	1	4	1	1	11
					2	1	1			1	1		6
							1		1				2
			1			2	1	2	1				7
							1				1		2
								1					1
									1	1	2		4
												1	1
						1							1
101	82	82	78	70	53	42	26	18	12	11	6	2	1 663

3. TUTKIMUKSEN SYSTEEMIKAAVIO

Systeemikaavio (s. 15) kuvaa magneettinauhoille talletetun aineiston käsittelyvaiheita. Kaaviossa olevaa analyyttistä tasoitusmenetelmää on käytetty johdettaessa tutkimuksen päätulokset. Tietokonelaskentaan perustuvalle systeemille on ominaista nopeus ja joustavuus (apteerausparametrit, valikoiva regressioanalyysi, taulukoiden laskenta). Tutkimuksen yleistä kulkua kuvaavan kaavion eri kohtia selostetaan tekstissä jäljempänä.

SYSTEEMIKAAVIO - Flowchart of the system



4. APTEERAUSMENETELMÄ

41. Apteeraus

Apteerauksella tarkoitetaan rungon jakamista tukki- ja kuituosaan. Jakaminen perustuu mainittujen puutavaralajien erilaisiin mitta- ja laatuvaatimuksiin sekä yksikköhintoihin. Tämän työn yhteydessä on myös sellaisille rungoille, joista ei tule tukkia, yritetty löytää perusteita yksikköhinnan porrastamiseksi järeyden mukaan. Tukkipuilla hinnan järeysporrastus on ollut käytössä ja on eräs apteeraustulokseen vaikuttava tekijä.

Käytetty apteerausohjelma (ks. kaavio s. 23) etsii sen tukki- ja kuituosayhdistelmän, joka annetuilla ehdoilla antaa rungolle suurimman arvon markkoina (tukkipuut). Kaikkien käyttöpuun mitat täyttävien runkojen arvo lasketaan myös kertomalla käyttöpuun määrä yksikköhinnan ja järeysporrastuskertoimen tulolla. Ohjelmassa käytetään seuraavia parametrejä: tukin ja kuitupuun minimiläpimitta, tukkien minimimitat, tukkiluvun ratkaisevat tukkiosan pituusrajat, tukin ja kuitupuun yksikköhinnat ja niiden järeysporrastus.

42. Parametrit

421. Tukkipuut

— Tukkipuun minimiläpimitta kuoren alta, cm: mänty 14, kuusi 15.
Minimum diameter (under bark) of saw timber, cm: pine 14, spruce 15.

— Kuitupuun minimiläpimitta kuoren alta: 6 cm.
Minimum diameter (under bark) of pulpwood: 6 cm.

— Tukkien minimimitat:
Minimum dimensions of logs:

Pituus, dm *Length, dm*	Läpimitta — *Diameter, cm* Tyvitukit *Butt logs*		Väli- ja latvatukit *Middle and top logs*	
	Mänty *Pine*	Kuusi *Spruce*	Mänty *Pine*	Kuusi *Spruce*
39	20	20	16	17
42	18	18	14	15
45	16	16	14	15
48	14	15	14	15
51	14	15	14	15
54	15	16	15	16
57	16	16	16	16
60	17	17	17	17
63	18	18	—	—

— Tukkiluvun määrittelevät tukkiosan pituudet, dm:
Lengths of the portion of saw timber determining the number of logs, dm:

< 83,	tukkiluku — *number of logs*	=	1
90—125,	» »	=	2
136—168,	» »	=	3
182—211,	» »	=	4
≥228,	» »	=	5

83— 89,	vuorotellen — *in turn*	1	ja — *and*	2	tukkia — *logs*
126—135,	»	2	»	3	»
169—181,	»	3	»	4	»
212—227,	»	4	»	5	»

— Tukin yksikköhintataso, mk/j³: Mänty 2.00 Kuusi 2.00
Price of log, Fmk/f³: *Pine 2.00* *Spruce 2.00*
— Kuitupuun yksikköhintataso, mk/p-m³ k:neen, Mänty 16.00 Kuusi 18.00
Price of pulpwood, Fmk/m³ incl. bark, stacked measure Pine 16.00 *Spruce 18.00*
— Tukkien järeyden mukaan porrastetut yksikköhinnat, mk/j³:
Price of logs according to their top volume, Fmk/f³:

Mänty — *Pine*		Kuusi — *Spruce*		Latvaläpimitta *Top diameter*
Tekn. j³ *Top volume*	Mk/j³ Fmk/f³	Tekn. j³ *Top volume*	Mk/j³ *Fmk/f³*	Tuumaa — *In.*
		≤ 3.1	1.92	6.0
≤ 3.7	1.79	3.7	1.89	6.5
4.3	1.85	4.3	1.91	7.0
4.9	2.00	4.9	2.00	7.5
5.6	2.02	5.5	2.02	8.0
6.3	2.10	6.3	2.07	8.5
7.1	2.13	7.1	2.13	9.0
7.9	2.20	7.9	2.18	9.5
8.8	2.25	8.8	2.22	10.0
9.7	2.39	9.6	2.26	10.5
10.7	2.49	10.7	2.30	11.0
12.7	2.63	12.6	2.37	12.0
≥15.1	2.70	≥14.8	2.41	13.0

Tukkien minimimitat vaihtelevat jonkin verran ostajien tarpeiden mukaan. Tässä käytetyt mitat edustanevat jonkinlaista keskiarvoa: sekä lievempiä että tiukempia vaatimuksia sovelletaan käytännössä. Läpimitat tarkoittavat tukkien latvaläpimittoja kuoren alta, eteen sattuvalta puolelta, 1 cm alenevalla luokituksella ja pituudet tukin pituutta ilman tasausvaraa. Tasausvarana on ollut 10 cm. Tukki on kuutioitu sylinterinä, jonka pohjan halkaisijana on em. läpimitta ja pituutena em. pituus. Muuntolukuna kuutiometristä kuutiojaloiksi on ollut 35.317 ja kiintokuutiometristä pinokuutiometriksi 1.39 männyllä sekä 1.37 kuusella. Tukkien mitat on ilmaistu tulevan käytännön mukaisesti metrijärjestelmässä. Tukkien pituudet 30 cm:n kerrannaisina ovat hyvin lähellä vallinnutta käytäntöä (1 jalka = 30.5 cm). Seuraavaan asetelmaan on merkitty mainitut minimiläpimitat tuumina.

cm	tuumaa
14	5.51
15	5.91
16	6.30
17	6.69
18	7.09
20	7.87

Tukkiluku määräytyy tukkiosan pituuden perusteella. Tukkiosalla tarkoitetaan rungon osaa, joka jää ylimmän katkaisua haittaavan juurenniskan ja sen kohdan väliin, joka on tasausvaran verran ylempänä ylintä minimiläpimitan täyttävää kohtaa. Sääntönä on ollut, että on oltava mahdollisuus yhdistelmälle, jossa on vain yksi minimipituinen tukki. Tällöin kukin tukkiluku n on sallittu tukkiosan pituusalueella $\geq n \cdot 40 + (n-1) \cdot 3$ dm. Edellä mainittujen pituusrajojen mukaisesti tukkiluku kuitenkin aina on korkein mahdollinen lukuun ottamatta tiettyä tukkilukualueen alussa olevaa tukkiluku · 3 dm pitkää vaihettumisvyöhykettä, jolla tukkiluku vuorotellen on n ja n—1. Muuten tukkiluku on yhtä pienempi kuin näin määräytynyt luku n vain silloin, kun ko. rungosta ei saada n kappaletta minimimitat täyttävää tukkia.

Puutavaralajien yksikköhinnat edustavat Etelä-Suomen kantohintatasoa hakkuuvuonna 1970—71 Metsälehden raakapuun markkinakatsausten mukaan.

Tukkien yksikköhinnan järeysporrastus perustuu Heiskasen ja Asikaisen julkaisuun (1969). Siinä on esitetty tukin latvaläpimitan funktiona tukin yksikkönettoarvo sahalla vuosien 1967 ja 1968 hinnoittelun mukaan. Hakkuuvaiheen vaikutuksen huomioonottamiselle tukkien järeyden mukaisiin arvosuhteisiin ei löytynyt perusteita. Hintaporrastus perustettiin latvaläpimitan sijasta tukin tilavuuteen, koska läpimitan mukainen porrastus olisi tässä sovellutuksessa johtanut liian yksipuolisesti lyhyiden tukkien vallitsemiseen apteerauksessa. Porrastusperusteen muuttaminen voitiin suorittaa, kun tiedettiin keskikuutio kussakin tukin latvaläpimittaluokassa edellä mainitussa Heiskasen ja Asikaisen tutkimuksen aineistossa. Porrastetut yksikköhinnat saatiin vertaamalla 5.0 j^3:n edustamaan, vuosien 1967 ja 1968 mukaisten arvosuhteitten keskiarvoon muitten keskikuutioitten edustamia arvosuhdekeskiarvoja. Hintaporrastus toteutettiin 0.1 j^3:n luokissa. Väliarvot laskettiin suoraviivaisella interpolaatiolla. Tuumina ilmoitetut läpimitat muunnettiin senttimetreiksi ja arvosuhdeluvut interpoloitiin täysille senttimetreille. Läpimitat 19 ja 33 cm vastaavat 0.5 mm:n tarkkuudella läpimittoja 7.5 ja 13.0 tuumaa. Näissä läpimittaluokissa läpimittaan ja tilavuuteen perustuvien hintaporrastusten mukaiset tukin arvot markkoina pituusluokissa 39, 48 ja 60 dm ovat seuraavat.

	19 cm			33 cm		
	39	48	60	39	48	60
Mänty						
Läpimittaporrastus	7.79	9.58	11.98	31.83	39.18	48.97
Tilavuusporrastus	7.08	9.48	12.40	30.28	38.89	48.90
Kuusi						
Läpimittaporrastus	7.79	9.58	11.98	28.43	34.99	43.74
Tilavuusporrastus	7.42	9.53	12.32	27.57	34.88	43.68

Tilavuuden mukaisessa porrastuksessa pituuskin pääsee vaikuttamaan melko voimakkaasti. Nyt valittu tapa on vain yksi mahdollisuus. Kehitetty systeemi on joka tapauksessa sellainen, että se sallii erilaiset mittayksiköt (senttimetri, tuuma) ja niiden luokitustavat (aleneva, tasaava) sekä erilaiset hinnoittelutavat; kysymys on vain valinnasta.

422. Kuitupuut

Kuitupuiden yksikköhinnan järeysporrastus perustuu työvaiheittaisiin hakkuupalkkataulukkoihin (Työvaiheittaiset hakkuupalkat 1971), joissa esitetään yksikkökorjuukustannukset mk/m³ järeysluokittain. Järeysluokan ratkaisee rungon käyttöosan kuutiomäärä. Luokkia on 14. Kaikille käyttöpuun mitat täyttäville rungoille on laskettu arvo vähentämällä rungon hankinta-arvosta kaato-, karsinta-, katkonta-, kasaus-, siirtymis- ja lähikuljetuskustannukset. Järeysluokittain on sitten laskettu puittaisten yksikköhintojen keskiarvot. Kun luokan 5 yksikköhinnaksi merkitään männyllä 16.00 ja kuusella 18.00 mk, saadaan taulukon 3 osoittamat porrastetut hinnat. Hankintahintoina oli: mänty 26.00, kuusi 30.00 mk/p-m³ k:neen.

Taulukko 3. Kuitupuun järeysluokittain porrastetut yksikköhinnat, mk/p-m³ k:neen.
Table 3. The price of pulpwood according to its true solid volume (the portion of waste wood excluded), Fmk/m³ incl. bark, stacked measure.

Järeysluokka (= käyttöosa, dm³) *Volume class, dm³*		Mänty — *Pine*		Kuusi — *Spruce*	
		Mk/p-m³ *Fmk/m³ stacked measure*	Suht.hinta *Relative price*	Mk/p-m³ *Fmk/m³ stacked measure*	Suht.hinta *Relative price*
1	— 37	13.30	.831	13.39	.744
2	38— 62	14.86	.929	15.97	.887
3	63— 87	15.71	.982	17.50	.972
4	88—112	15.84	.990	17.73	.985
5	113—137	16.00	1.000	18.00	1.000
6	138—200	16.48	1.030	18.86	1.048
7	201—250	16.78	1.049	19.21	1.067
8	251—300	17.22	1.076	19.78	1.099
9	301—350	17.31	1.082	19.94	1.108
10	351—400	17.60	1.100	20.30	1.128
11	401—500	17.82	1.114	20.48	1.138
12	501—600	18.10	1.131	20.83	1.157
13	601—700	18.35	1.147	21.13	1.174
14	701+	18.46	1.154	21.31	1.184

Laskennassa on käytetty palkkausalue 4:n taksoja ajalle 1. 1. 1971—31. 3. 1972. Tiheysluokkana on ollut 3 ja oksaisuusluokkana männyllä 3, kuusella 4. Karsinta on ollut pinnanmyötäinen, katkonta silmävarainen (noin 2 m), kasaus on tapahtunut ajourien varteen (väli 31—40 m). Lähikuljetuskustannus on otettu metsätyöpalkkataulukoista: painoluokka männyllä 7, kuusella 6, ajo palstatien varresta, ajomatka 300 m (M e t s ä a l a n . . . . 1971). Esitetty kuitupuun yksikköhinnan järeysporrastus on lähinnä laskuesimerkki. Kuitenkin on ilmeistä tarvetta porrastaa hintoja etsittäessä »oikeita» pystypuiden arvosuhteita. Tukkipuun kuituosaa hinnoiteltaessa ei hintaa ole porrastettu.

43. Apteerausohjelma

Apteerausohjelmassa käytettyä ns. dynaamisen ohjelmoinnin tekniikkaa voidaan havainnollistaa esimerkillä. Oletetaan 4:n tukin puu ja 10 mahdollista tukin pituutta: 37, 40, . . . , 64 dm.

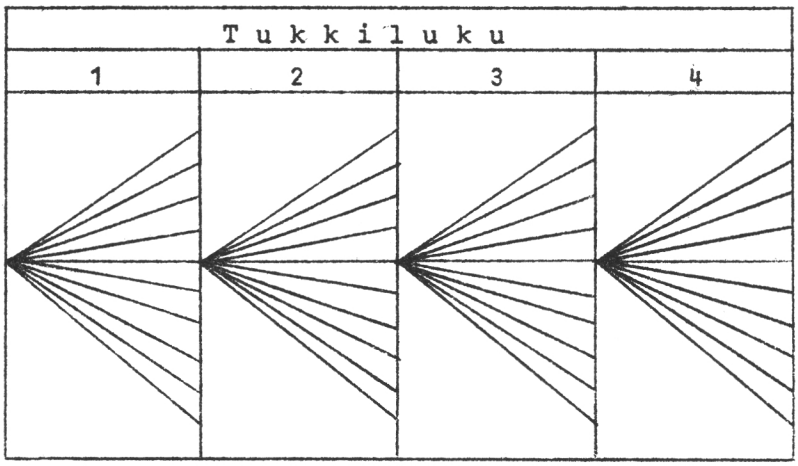
1. vaihe: lasketaan kunkin tyvitukin arvo = 10 tapausta.
2. vaihe: kunkin tyvitukin arvoon lisätään 10 eripituisen kakkostukin arvo, jolloin saadaan 100 erilaista yhdistelmää. Valitaan paras kullekin 19:lle katkaisukorkeudelle 74, 77, . . . , 128 dm.
3. vaihe: tutkitaan edelleen 19· 10 = 190 kolmen tukin kombinaatiota, joista kullekin katkaisukohdalle 111, 114, . . . , 192 etsitään korkeimman arvon antava, yhteensä 28.
4. vaihe: käydään läpi vielä 280 vaihtoehtoa, joista paras edustaa optimaalista apteeraustulosta annetuin edellytyksin ja kriteerein. Se valitaan lopulliseksi ratkaisuksi.

Dynaamisen ohjelmoinnin tehokkuus tässä tehtävässä tulee esiin tutkittavien vaihtoehtojen voimakkaana vähenemisenä. Esimerkissä käytiin läpi 580 tapausta, kun rajoittamaton kaikkien vaihtoehtojen määrä on teoriassa 10 000.

Kaavakuvassa tukkiluku on 4. Vain yhdelle katkaisukohdalle kussakin tukkiluvun vaihtumiskohdassa on esitetty kaikki 10 eripituista lisätukkia.

Taulukot 4 ja 5 selvittävät sitä, kuinka suuresta vaihtoehtojen määrästä lopullinen valinta tapahtuu ja minkälaisista arvoeroista eri vaihtoehtojen kesken on kysymys. Taulukkoihin on merkitty minimi- ja maksimiarvot (mk) ja niitä vastaavat j^3-määrät sekä minimi- ja maksimikuutiojalkamäärät ja niitä vastaavat arvot (mk) kahdestakymmenestä ensimmäisestä puutiedostojen puusta. Arvot tarkoittavat teoreettisen tukkiosan arvoa eli rungon sen osan arvoa, joka päättyy 10 cm ylempänä minimimitan viimeksi täyt-

Kaavamainen kuvaus apteerausvaihtoehtojen muodostumisesta.



Mahdolliset katkaisukorkeudet

tävää kohtaa. Taulukoista nähdään, että arvoerot vaihtoehtojen välillä niiden suurehkosta lukumäärästäkin huolimatta ovat vähäisiä. Näillä puilla minimiarvojen summa on maksimiarvojen summasta männyllä 89.1 % ja kuusella 91.8 %.

Taulukko 4. Muutamien mäntyjen apteerauksessa lopulliseen valintaan tulleiden vaihtoehtojen määrät ja niiden tunnuslukuja.

Puu	D cm	H m	Tukki-luku	Arvot, mk				j^3				Vaihto-ehtojen määrä
				min	j^3	max	j^3	min	arvo	max	arvo	
1 ...	36	17	2	32.87	14.37	40.62	16.17	14.37	32.87	16.17	40.62	53
2 ...	38	18	2	37.05	15.79	43.94	17.47	15.79	37.05	17.47	43.94	69
3 ...	25	17	2	12.02	6.49	12.72	6.79	6.49	12.02	6.79	12.72	3
4 ...	33	20	3	33.29	16.17	36.04	16.64	16.05	33.77	16.92	35.26	35
5 ...	42	18	3	49.58	21.65	54.30	23.01	21.65	49.58	23.01	54.30	14
6 ...	41	20	3	54.82	23.53	61.96	25.42	23.47	55.34	25.42	61.96	57
7 ...	34	17	2	30.16	13.58	35.51	14.83	13.58	30.16	14.97	35.43	66
8 ...	26	17	2	16.02	8.16	18.66	9.12	7.83	16.23	9.12	18.66	52
9 ...	27	16	2	21.40	10.15	24.66	11.44	10.14	21.94	11.52	24.46	52
10 ...	27	18	2	17.25	8.61	20.30	9.76	8.60	17.56	9.80	20.10	53
11 ...	30	16	2	19.99	9.88	23.07	10.78	9.55	20.22	10.85	22.88	52
12 ...	27	14	2	14.25	7.38	15.53	7.95	7.38	14.25	7.95	15.53	11
13 ...	40	22	4	87.44	35.99	92.41	36.80	35.51	86.24	36.99	91.63	41
14 ...	29	16	2	16.83	8.44	18.69	9.24	8.36	17.21	9.24	18.69	29
15 ...	33	21	3	37.63	17.87	42.90	19.15	17.87	38.59	19.15	42.90	56
16 ...	25	22	3	22.45	11.73	23.59	12.25	11.73	22.45	12.25	23.59	14
17 ...	31	21	3	33.47	16.17	36.62	16.68	15.92	33.50	17.11	36.14	39
18 ...	27	18	2	18.19	9.07	20.50	9.81	9.01	18.78	9.85	20.26	45
19 ...	35	19	2	31.73	14.15	36.14	15.12	13.61	32.37	15.12	36.14	68
20 ...	29	20	3	30.19	14.51	33.60	16.12	14.51	30.19	16.19	33.42	51
		Yhteensä		616.63	283.69	691.76	304.55	281.42	620.32	305.89	688.63	

Taulukko 5. Muutamien kuusien apteerauksessa lopulliseen valintaan tulleiden vaihtoehtojen määrät ja niiden tunnuslukuja.

Puu	D cm	H m	Tukkiluku	Arvot, mk				j^3				Vaihtoehtojen määrä
				min	j^3	max	j^3	min	arvo	max	arvo	
1 ...	27	13	1	7.37	3.41	8.47	3.77	3.41	7.37	3.77	8.47	4
2 ...	28	22	2	20.74	9.84	22.61	10.34	9.14	20.79	10.59	22.51	56
3 ...	27	25	3	27.23	13.03	29.21	14.19	13.03	27.23	14.19	29.21	23
4 ...	37	29	4	60.86	27.03	65.27	29.25	27.03	60.86	29.25	65.27	76
5 ...	36	27	4	51.48	24.10	55.05	25.42	23.84	51.62	25.42	55.05	33
6 ...	29	26	3	30.24	14.19	32.93	15.59	14.00	30.35	15.59	32.93	51
7 ...	27	23	3	31.83	15.30	34.71	16.38	14.97	32.14	16.38	34.71	44
8 ...	23	20	2	14.19	7.01	15.37	7.61	7.01	14.19	7.61	15.37	10
9 ...	25	18	1	9.93	3.85	11.35	4.81	3.77	10.26	4.81	11.35	7
10 ...	35	20	3	38.31	17.57	41.02	18.67	17.57	38.31	18.74	40.76	34
11 ...	30	25	3	42.46	18.78	47.13	21.21	18.78	42.46	21.21	47.13	84
12 ...	24	19	2	16.90	8.07	18.49	8.85	7.79	16.97	8.93	18.47	37
13 ...	30	24	3	34.50	16.23	36.88	17.17	15.94	34.58	17.31	36.87	44
14 ...	23	20	2	13.82	6.58	15.49	7.47	6.58	13.82	7.47	15.49	14
15 ...	26	22	3	27.47	13.59	30.62	14.79	13.33	27.59	14.79	30.62	34
16 ...	22	17	2	13.18	6.67	13.88	7.01	6.67	13.18	7.01	13.88	3
17 ...	27	23	3	27.38	13.46	29.95	14.57	13.18	27.43	14.57	29.95	26
18 ...	24	21	2	17.89	8.59	19.43	9.28	7.90	18.03	9.30	19.34	47
19 ...	33	21	3	36.11	16.74	38.17	17.60	16.74	36.11	17.84	37.66	23
20 ...	28	21	2	24.46	10.38	29.13	12.87	10.38	24.46	12.93	28.47	69
		Yhteensä		546.35	254.42	595.16	276.85	251.06	547.75	277.71	593.51	

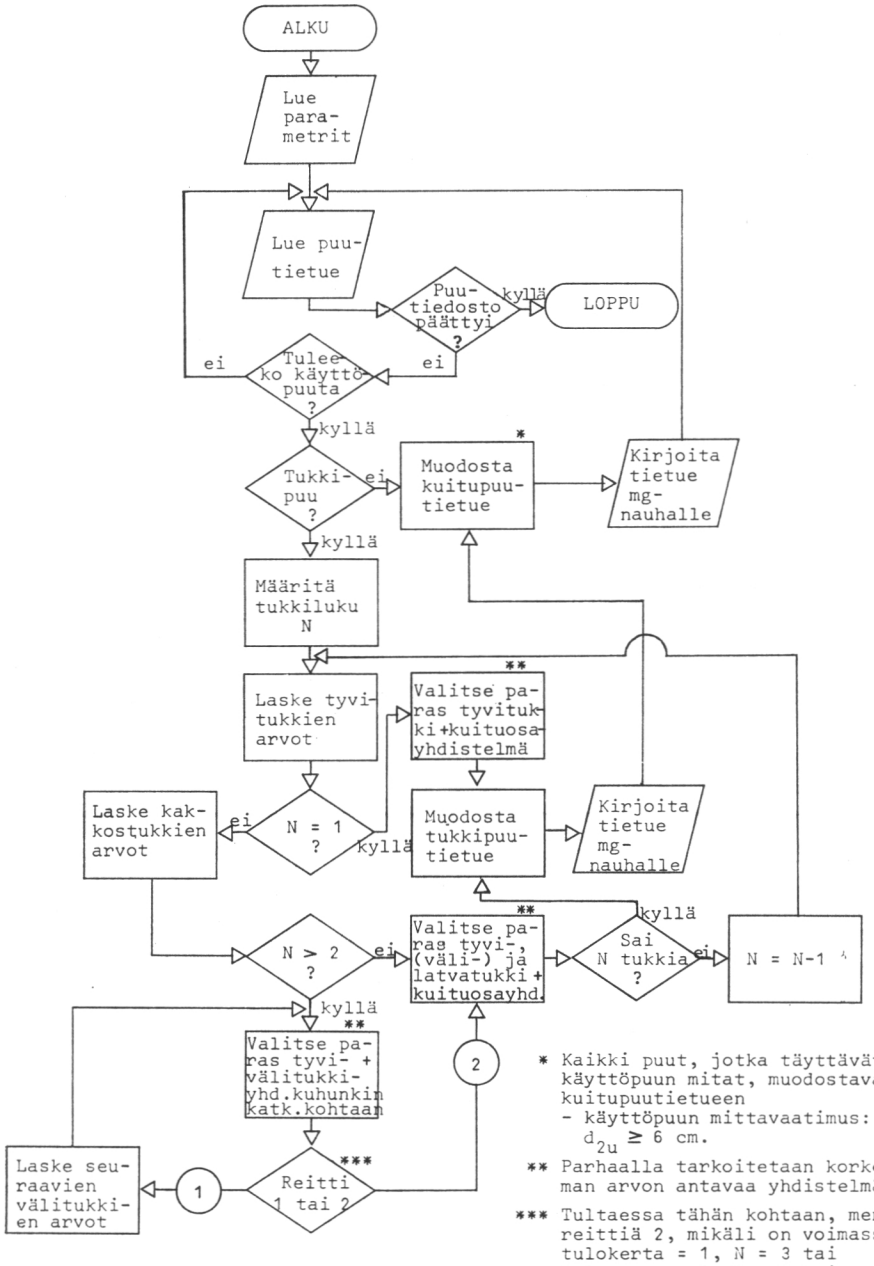
Maksimaalisen j^3-määrän antava yhdistelmä vastaa useimmiten myös korkeimman arvon antavaa kombinaatiota. Edellisiä vastaava arvosumma on maksimiarvojen summasta männyllä 99.5 % ja kuusella 99.7 % taulukoissa olevilla puilla.

Taulukossa 6 on esitetty, mikä osa teoreettisesta tukkiosan pituudesta keskimäärin tuli käytetyksi tukkiosana (koko aineisto).

Taulukko 6. Keskimääräiset tukkiosan pituudet.

Tukkiluku	Tukkiosan pituus, dm					
	Mänty			Kuusi		
	teor.	käytetty	% teor:sta	teor.	käytetty	% teor:sta
1	70.3	51.6	73	68.4	51.4	75
2	107.5	97.3	90	107.2	97.7	91
3	147.9	141.1	95	147.6	141.1	96
4	186.4	183.7	99	191.6	185.3	97
5	220.0	216.5	98	241.0	220.0	91

KAAVIO APTEERAUSOHJELMASTA



* Kaikki puut, jotka täyttävät käyttöpuun mitat, muodostavat kuitupuutietueen
- käyttöpuun mittavaatimus: $d_{2u} \geq 6$ cm.

** Parhaalla tarkoitetaan korkeimman arvon antavaa yhdistelmää.

*** Tultaessa tähän kohtaan, mennään reittiä 2, mikäli on voimassa:
tulokerta = 1, N = 3 tai
tulokerta = 2, N = 4 tai
tulokerta = 3, N = 5.
Muuten mennään reittiä 1.

5. TULOKSIA

51. Tukkien jakautuminen läpimitta- ja pituusluokkiin

Tukkipuiden apteerauksessa syntyneet tukit jakaantuivat suuruusluokkiin taulukoiden 7 ja 8 mukaisesti.

Taulukko 7. Mäntytukkien jakaantuminen läpimitta- ja pituusluokkiin.

Läpimitta, cm	Tukin pituus, dm									Yhteensä
	39	42	45	48	51	54	57	60	63	
14		230	99	58	71					458
15		67	26	23	27	36				179
16	89	42	52	36	28	12	23			282
17	58	31	24	29	23	27	14	25		231
18	47	36	21	15	15	23	15	10	14	196
19	31	22	22	17	19	9	15	15	16	166
20	30	27	36	18	8	10	7	15	9	160
21	46	16	22	17	19	11	16	9	13	169
22	46	11	16	18	9	13	11	12	8	144
23	25	30	14	7	7	12	10	9	11	125
24	24	8	9	12	5	2	8	12	8	88
25	11	12	11	5	3	10	11	3	13	79
26	9	8	4	6	6	14	9	6	13	75
27	6	5	2	4	8	10	6	8	6	55
28	5	1	5	3	8	6	4	3	1	36
29	—	2	1	2	—	5	2	2	2	16
30	2	2	6	3	4	3	1	2	6	29
31—35	10	10	10	8	7	—	3	1	2	51
36—40	2	2	1	2	1	—	1	—	—	9
41—45	—	1	—	—	—	—	—	1	—	2
Yhteensä	441	563	381	283	268	203	156	133	122	2 550

Molemmilla puulajeilla on erityisen runsaasti 42 dm pitkiä minimiläpimittaisia väli- ja latvatukkeja. Tukkien kertymisessä lyhyihin pituusluokkiin näkyy vain eräs maksimaalista arvoa etsivän apteerauksen piirre. Kasautumista lyhyimpään mahdolliseen pituusluokkaan (39 dm) on rajoitettu nostamalla minimiläpimittaa tällä kohden. Pelkkä läpimittaan perustuva järeysporrastus olisi johtanut vielä suurempaan lyhyiden tukkien määrään. Nyt on tukkien keskipituudeksi saatu molemmilla puulajeilla 47.4 dm, mikä hyvin vastaa tukkierälle yleensä esitettyjä keskipituusvaatimuksia. Kaikkien tukkien keskikuutio on 5.2 j^3 männyllä ja 5.5 j^3 kuusella.

Taulukko 8. Kuusitukkien jakautuminen läpimitta- ja pituusluokkiin.

Läpimitta, cm	Tukin pituus, dm									Yhteensä
	39	42	45	48	51	54	57	60	63	
15		109	76	39	35					259
16		51	46	29	17	10	16			169
17	41	31	22	29	17	11	9	22		182
18	14	16	12	5	14	19	9	6	1	96
19	8	16	11	17	9	7	6	7	3	84
20	21	19	10	8	13	11	5	9	9	105
21	32	13	16	8	3	14	15	8	10	119
22	19	24	7	9	5	13	10	6	12	105
23	5	10	2	10	12	6	7	3	5	60
24	5	6	8	5	2	4	1	6	3	40
25	5	5	8	4	3	5	1	2	1	34
26	6	3	3	2	5	2	3	2	2	28
27	10	3	—	5	4	1	3	4	4	34
28	5	3	1	5	2	1	—	3	1	21
29	—	2	1	3	1	1	3	1	—	12
30	3	4	3	2	2	1	2	2	—	19
31—35	4	6	9	7	4	1	2	—	—	33
36—40	5	4	2	—	—	1	—	1	—	13
41—45	—	1	1	—	—	—	—	—	—	2
46—50	—	1	—	—	—	—	—	—	—	1
Yhteensä	183	327	238	187	148	108	92	82	51	1 416

52. Hintasuhteiden vaikutuksesta apteeraustulokseen

Koska apteerausohjelma käyttää valintakriteerinään rungon arvoa, riippuu tulos jonkin verran puutavaralajien hintasuhteista ja myös järeysporrastuksesta. Hintasuhteen vaikutusta tutkittiin 300:lla sattumanvaraisesti valitulla mäntytukkipuulla. Alla olevasta asetelmasta nähdään, että tulos on jokseenkin riippumaton hintasuhteesta. Tämä johtuu lähinnä siitä, että tukkiluku määritetään kategorisesti teoreettisen tukkiosan pituuden perusteella. »Pelivara» jää tällöin pieneksi. Tarkastelussa tukin yksikköhintataso oli 2 mk/j^3 kuitupuun saadessa hintoja 10, 16 ja 22 mk/p-m^3.

Männyn tukkiosaprosentti eri hintasuhteilla:

Kuitupuun hinta, mk/p-m^3	Tukkiosa — %	Tukkien keskipituus, dm
10	88.81	47.7
16	88.44	47.3
22	87.84	46.7

Kuusella tulos olisi ilmeisestikin sama.

53. Tukkiluvun vaikutuksesta rungon arvoon

Tukkiluvun vaikutusta rungon arvoon tutkittiin apteeraamalla molemmilla mahdollisilla tukkiluvuilla ne rungot, jotka teoreettisen tukkiosan pituuden mukaan sattuivat tukkiluvun vaihettumisvyöhykkeelle. Tulokset ovat taulukossa 9.

Taulukko 9. Rungon keskimääräiset arvot ja j³-määrät eri tukkiluvuilla.

Puulaji	Tunnus	Tukkiluku					
		1 — 2		2 — 3		3 — 4	
Mänty	Arvo, mk	13.56	13.93	30.34	29.75	52.81	51.36
	Tilavuus, j³	5.4	7.0	13.0	14.3	22.2	23.2
	Puita, kpl	62	62	101	101	41	41
Kuusi	Arvo, mk	14.87	16.50	30.95	31.65	61.51	62.18
	Tilavuus, j³	5.5	7.3	13.1	14.5	26.0	27.5
	Puita, kpl	34	34	53	53	21	21

Kun kysymys on rajatapauksista tukkiluvun suhteen, saadaan tämän apteerausohjelman ehdoilla rungon arvo lähes samaksi tukkiluvusta riippumatta. Männyllä järeysporrastus aiheuttaa sen, että pienempi tukkiluku (= järeämmät tukit) useimmiten antaa korkeamman arvon muilla paitsi 1—2-tukkisilla puilla. Kuusella sen sijaan suurempi tukkiluku merkitsee useimmiten myös korkeampaa arvoa. Selvä ero on 1—2-tukkisilla kuusilla, joilla 2-tukkinen oli aina arvokkaampi kuin 1-tukkinen.

Aineistoa kuvaavina esitetään tässä yhteydessä tukkilukuluokittain eräitä keskiarvoja ja tunnuslukuja taulukossa 10. Kuusen tukeille asetetut korkeammat minimimittavaatimukset näkyvät keskimäärin suurempina mittoina (D6, H) ja myös korkeampina arvoina mäntyyn verrattuna. Keskimäärin rungot asettuvat jyrkästi eri arvoluokkiin tukkiluvun eli rungon koon mukaan. Etenkin männyllä on vaihteluväli kuitenkin laaja.

Taulukko 10. Puuluku, keskimääräiset mitat ja arvot sekä minimi- ja maksimiarvot tukkiluvuittain.

Tunnus	Mänty					Kuusi				
	Tukkiluku									
	1	2	3	4	5	1	2	3	4	5
Puita, kpl	428	527	278	56	2	287	282	138	34	3
D, cm	21.6	27.1	31.4	34.9	43.4	21.9	26.2	30.9	37.6	51.0
H, m	14.2	16.9	20.8	24.3	27.3	16.2	19.4	22.8	26.4	30.6
D—D6, cm	5.5	5.5	5.6	5.8	8.6	4.6	4.4	4.3	4.9	6.1
V, dm³	265	490	783	1 107	1 749	300	511	835	1 389	2 876
Tukkiosa, j³	3.8	9.8	17.6	26.8	44.3	4.0	9.7	18.3	32.8	68.1
Keskim.arvo, mk	8.95	21.61	39.74	62.08	109.23	10.59	21.92	40.94	75.42	163.34
Minimiarvo, mk	5.17	11.02	18.32	31.09	98.52	7.52	14.03	21.56	51.85	132.75
Maksimiarvo, mk	29.83	98.42	109.44	111.06	119.94	17.24	45.47	86.86	113.76	211.79
Tukin arvo, mk	7.03	10.14	12.88	15.32	21.71	7.78	9.87	13.02	18.43	32.10

54. Hintasuhteet, joilla rungon arvo kuitupuuna on yhtä suuri kuin tukkipuuna

Se kuitupuun yksikköhintataso (= järeysluokka 5:n hinta), joka antaa rungolle kuitupuuna saman arvon kuin tukkipuuna, on laskettu puittain yhtälöstä

$$X \cdot V1 \cdot P = TA + X \cdot V2$$

X = kuitupuun yksikköhintataso
V1 = käyttöosan tilavuus
P = kuitupuun yksikköhinnan järeysporrastuskerroin (Taulukon 3 mukainen)
TA = tukkiosan arvo, kun hintataso on 2 mk/j³
V2 = kuituosan tilavuus tukkipuuna apteerattaessa.

Tulokset on esitetty tasoitettuina puittaisina keskiarvoina taulukoissa 11 ja 12.

Hintatasosta päästään yksikköhintoihin kertomalla taulukoiden 11 ja 12 luvut järeysluokan mukaisella porrastuskertoimella (taulukko 3).

Taulukko 11. Eri läpimitta- ja pituusluokkien kuitupuun yksikköhintatasot, joilla rungon arvo kuitupuuna on yhtä suuri kuin tukkipuuna. Mänty. Mk/p-m³. Kunkin hinnan alapuolella järeysluokka.

Läpimitta, cm	Pituus, m						
	12	14	16	18	20	22	24
19	26 6	27 7	27 7	27 8	29 8		
21	25 7	26 7	27 8	28 9	29 9	29 10	
23	25 8	26 8	27 9	28 10	30 11	31 11	
25	26 9	27 9	28 10	29 11	30 11	31 12	
27	27 10	27 11	29 11	30 11	30 12	31 13	31 13
29	28 11	28 11	29 12	30 12	31 13	31 13	32 14
31	28 11	28 12	30 12	30 13	31 14	32 14	33 14
33	29 12	30 13	31 13	31 14	33 14	34 14	34 14
35		32 14	32 14	32 14	34 14	34 14	36 14
37			32 14	32 14	36 14	36 14	36 14
39					36 14	36 14	36 14

Taulukko 12. Eri läpimitta- ja pituusluokkien kuitupuun yksikköhintatasot, joilla rungon arvo kuitupuuna on yhtä suuri kuin tukkipuuna. Kuusi. Mk/p-m³. Kunkin hinnan alapuolella järeysluokka.

Läpimitta, cm	Pituus, m					
	14	16	18	20	22	24
19	29 7	29 7	29 8	29 8		
21	27 7	27 8	29 9	30 10	31 11	
23	25 8	27 9	28 10	29 11	31 11	
25	25 9	27 10	28 11	29 11	31 12	31 13
27	25 10	26 11	28 11	29 12	31 13	31 13
29		25 11	27 12	29 13	31 13	31 13
31		25 12	27 13	29 13	31 14	32 14
33		25 12	27 13	29 14	31 14	32 14
35				30 14	32 14	32 14
37					32 14	32 14

Taulukoiden 11 ja 12 arvoista ilmenee selvästi tukkien järeysporrastuksen vaikutus samoin kuin myös puun muodon vaikutus rungon arvoon. Kuusen lievempi järeysporrastus verrattuna mäntyyn näkyy selvästi. Näiden taulukoiden avulla on myös helposti ymmärrettävissä, miksi kappaleessa 52 kokeillut hintasuhteet eivät vaikuttaneet tukkipuuprosenttiin juuri lainkaan.

55. Arvot järeysluokittain (työvaihetaksat)

Taulukkoihin 13 ja 14 on laskettu työvaihetaksojen mukaisille järeysluokille puittaisina keskiarvoina rungon arvot sekä arvot käyttöosan kuutiometriä kohti erikseen kuitu- ja tukkipuuna. Samoista taulukoista käy ilmi aineiston jakautuminen ko. järeysluokkiin.

Taulukko 13. Rungon keskimääräiset arvot sekä arvot mk/käyttöosan m³ työvaihetaksojen järeysluokissa. Mänty.

Järeysluokka = käyttöosa, dm³		Kuitupuuna			Tukkipuuna		
		mk	mk/m³	puita, kpl	mk	mk/m³	puita, kpl
1	— 37	.42	18.49	213			
2	38— 62	1.00	20.66	150			
3	63— 87	1.62	21.84	113			
4	88—112	2.18	22.02	104			
5	113—137	2.77	22.24	87			
6	138—200	3.79	22.91	204	6.13	33.57	46
7	201—250	5.24	23.32	169	7.41	32.91	161
8	251—300	6.63	23.94	139	9.45	34.09	139
9	301—350	7.75	24.06	140	12.10	37.57	140
10	351—400	9.15	24.46	103	15.21	40.65	103
11	401—500	11.17	24.77	176	19.03	42.21	176
12	501—600	13.74	25.16	154	24.30	44.48	154
13	601—700	16.56	25.51	119	30.78	47.41	119
14	701+	24.70	25.66	253	52.02	54.04	253

Taulukko 14. Rungon keskimääräiset arvot sekä arvot mk/käyttöosan m³ työvaihetaksojen järeysluokissa. Kuusi.

Järeysluokka	Kuitupuuna			Tukkipuuna		
	mk	mk/m³	puita, kpl	mk	mk/m³	puita, kpl
1	.42	18.34	207			
2	1.07	21.88	158			
3	1.75	23.98	119			
4	2.41	24.29	95			
5	3.06	24.66	100			
6	4.30	25.84	187	7.72	39.25	1
7	5.96	26.32	126	8.40	35.81	69
8	7.50	27.10	100	9.84	35.52	99
9	8.88	27.32	77	11.83	36.39	77
10	10.32	27.81	59	14.69	39.58	59
11	12.49	28.06	133	18.64	41.86	133
12	15.69	28.54	102	24.07	43.77	102
13	18.86	28.95	57	29.85	45.80	57
14	30.79	29.19	147	54.10	51.27	147

6. YHTÄLÖT

Yhtälöt on laskettu Helsingin Yliopiston Laskentakeskuksen valikoivalla regressioanalyysillä. Analyyttisen tasoittamisen tärkeimpinä etuina voidaan pitää saatavien yhtälöiden joustavaa käyttömahdollisuutta tietokoneilla sekä tasoituksen objektiivisuutta ja nopeutta.

Seuraavassa on lueteltu käytetyt muuttujat ja niiden symbolit. Selitettäviä muuttujia on merkitty Y-kirjaimilla ja selittäviä X-kirjaimilla. Logaritmit ovat luonnollisen kantajärjestelmän logaritmeja.

Y1 = kuutiomäärän (dm^3) logaritmi — *logarithm of volume (dm^3)*
Y2 = tukkipuuprosentti — *saw timber percentage*
Y3 = hukkapuuprosentin logaritmi = *logarithm of waste wood percentage*
Y4 = kuutiojalkamäärän logaritmi — *logarithm of top volume (f^3)*
Y5 = arvon (mk) logaritmi — *logarithm of value (Fmk)*
Y6 = kuutiojalkamäärän suhde tukkiosan todelliseen kuutiometrimäärään — *ratio between the top volume (f^3) and the true solid volume of the saw timber portion (m^3)*
X1 = D, rinnankorkeusläpimitta, cm — *breast height diameter, cm*
X2 = H, pituus, m — *height, m*
X3 = D6, läpimitta kuuden metrin korkeudelta, cm — *diameter at 6 m height, cm*
X4 = D—D6, kapeneminen, cm — *taper, cm*
X5 = log(D)
X6 = log(H)
X7 = log(D6)
X8 = log(D—D6)
X9 = $\log(D^2-(D6)^2)$
X10 = $H^{0.1}$
X11 = H^2
X12 = $(\log(H))^{0.1}$
X13 = $(\log(H))^2$
X14 = $D^{0.1}$
X15 = $(D6/D)^2$
X16 = $1./D^2$
X17 = 1./D
X18 = H/D

X19 = 1./(D · H)
X20 = tukkiluvun logaritmi — *logarithm of the log number*
X21 = tukkiluvun neliöjuuri — *square root of the log number*
X22 = D^2
X23 = D^2—$D6^2$
X24 = log(D—D6+10)

Selitettävistä muuttujista, joiden arvojen hajonta kasvaa selittävien muuttujien arvojen kasvaessa, on otettu logaritmi hajonnan homogenisoimiseksi. Tästä on tyypillinen esimerkki puun kuutiomäärä, jonka suhteellinen hajonta on likimain sama kaikissa läpimittaluokissa. Täten puun kuutioimisyhtälöissä on käytetty tulomuotoista mallia, joka linearisoidaan logaritmin otolla. Myös hukkapuuprosenttifunktiolle on käytetty logaritmista muotoa, koska tällöin saadaan aina positiivinen prosenttiarvo. Ei-logaritminen malli, jolla olisi tämä ominaisuus, olisi melko vaikea kehittää. Koska logaritmia ei voida ottaa nollasta ja negatiivisista arvoista, niin käytettäessä yhtälöitä, joissa muuttujat X8 ja/tai X9 ovat tekijöinä, on tältä osin muuttujien loogisuus testattava. Mikäli kapeneminen on nolla, on se muutettava laskentaa varten esim. 0.5:ksi.

Yleensä funktioiden laadinnassa ja valinnassa on päädytty verraten yksinkertaisiin malleihin. Vaikka yhtälössä käytettäisiin useampia vielä merkitsevän t-arvon omaavia lisämuuttujia, ei selitysaste paljon kohoaisi, ja etenkin aineiston ulkopuolisilla alueilla systemaattisen virheen mahdollisuus saattaisi kasvaa.

Seuraavat yhtälöt valittiin:

Mänty

(6.1) Y1 = 3.428605 + 0.045668 · X4 + 2.290315 · X5—1.00746 · X6
+ 0.284933 · X13—1.638448 · X24

(6.2) Y2 = 55.28677+51.2575 · X10—13450.995 · X16+12065.305 · X19
+72.500908 · X20—66.69221 · X21

(6.3) Y3 = 13.09808—0.366495 · X9+22.3821 · X12—23.53943 · X14
—2.95606 · X15+383.15 · X16—2.161 · X18—417.3884 · X19

(6.4) Y4 = —3.672691+0.047958 · X2+1.778022 · X7—257.0026 · X16

(6.5) Y5 = —4.568147+2.074387 · X7+0.21772 · X13—27.42174 · X17
+225.23198 · X19

(6.6) Y6 = —9.6387+0.473739 · X1+0.294342 · X2—0.71596 · X3
+4.577564 · X7+21.9245 · X15+975.43 · X19

Kuusi

$$(6.7)\quad Y1 = 9.08042 + 0.045148 \cdot X2 + 0.029569 \cdot X4 + 2.386296 \cdot X5 - 5.989045 \cdot X12 - 0.000236 \cdot X22 + 0.000717 \cdot X23 - 1.863417 \cdot X24$$

$$(6.8)\quad Y2 = 181.274 - 1.20074 \cdot X1 + 0.035358 \cdot X11 - 63.30275 \cdot X18 + 65.9472 \cdot X20 - 56.2538 \cdot X21$$

$$(6.9)\quad Y3 = -359.506409 - 12.85504 \cdot X6 - 2.147173 \cdot X7 + 0.119397 \cdot X8 + 361.7478 \cdot X12 + 295.04989 \cdot X19$$

$$(6.10)\quad Y4 = -3.014993 + 0.046855 \cdot X2 + 1.382873 \cdot X7 + 0.925595 \cdot X15 - 381.96937 \cdot X16$$

$$(6.11)\quad Y5 = -4.39061 + 0.056877 \cdot X2 + 2.067734 \cdot X7 - 138.03853 \cdot X16 + 89.6828 \cdot X19$$

$$(6.12)\quad Y6 = -82.2704 - 0.360262 \cdot X3 - 15.7275 \cdot X8 + 19.22514 \cdot X9 + 24.87141 \cdot X15 + 13.39244 \cdot X18 + 3300.968 \cdot X19$$

7. YHTÄLÖIDEN LUOTETTAVUUDESTA

Kaikki luotettavuustarkastelut, joita seuraavassa esitetään, on tehty laskenta-aineiston perusteella. Ulkopuolisesta aineistosta, johon on sovellettu käytettyjä laskentaperusteita, saatu testitulos antaisi tietysti pätevämmän käsityksen yhtälöiden käyttökelpoisuudesta. Kootusta aineistosta ei jätetty osaa luotettavuustestejä varten, koska aineisto muutenkin on pienehkö, vaan se käytettiin kokonaisuudessaan yhtälöiden kehittämiseen. Yhtälöiden luotettavuutta osoittavat regressioanalyysin avulla tapahtuneen analyyttisen tasoittamisen onnistumista kuvaavat tunnusluvut. Logaritmisilla malleilla eräänä tällaisena tunnuslukuna on ennusteen suhteellinen jäännöshajonta eli variaatiokerroin, jolle voidaan, mikäli oletetaan, että logaritmisen yhtälön tulos z_i on normaalinen parametrein μ_i ja σ^2, johtaa seuraava kaava:

$$(7.1) \qquad \frac{Dy_i}{Ey_i} = \sqrt{e^{\sigma^2} - 1} \text{ , missä}$$

Ey_i = selitettävän muuttujan y odotusarvo z_i:ssä
Dy_i = selitettävän muuttujan y jäännöshajonta z_i:ssä
σ^2 = logaritmisen yhtälön jäännösvarianssi
e = 2.7182818 . . . = Neperin luku.

Mikäli σ^2 on hyvin pieni, tulos on likipitäen σ:n suuruinen. Kaavan (7.1) antama tulos voidaan estimoida laskemalla aineistosta ennusteen suhteellinen hajonta kaavalla:

$$(7.2) \qquad \sqrt{\frac{\sum_{i=1}^{N} \left(\frac{\hat{y}_i - y_i}{y_i}\right)^2}{N - 1}} \text{ , missä}$$

y_i = i:nnen havainnon mitattu arvo
$\hat{y}_i$ = i:nnen havainnon ennustettu arvo
N = havaintojen lukumäärä.

Kaavan (7.1) avulla saatiin muuttujia Y1—Y6 ennustaville yhtälöille seuraavat prosentuaaliset arvot eli kaavan (7.1) antama tulos kerrottiin sadalla.

	Selitettävä — *Dependent variable*					
	Y1	Y2	Y3	Y4	Y5	Y6
Mänty — *Pine*	4.1	3.5	19.9	12.2	8.3	4.9
Kuusi — *Spruce*	3.7	4.0	16.2	11.3	6.7	4.3

Yhtälöiden virheprosenttien keskiarvot läpimitta-, pituus- ja kapenemisluokittain laskettiin kaavalla:

$$(7.3) \qquad 100 \cdot \frac{\sum_{i=1}^{N_l} (\hat{y}_i - y_i)}{N_l} \Big/ \frac{y_i}{}, \text{ missä}$$

$\hat{y}_i$ ja y_i kuten edellä
N_l = luokan puiden lukumäärä.

Koska ennusteen suhteellinen hajonta ei ole ilmeisesti vakio eri mittaustunnusten suhteen, laskettiin se lisäksi tarkasteluluokittain kaavalla (7.2) ja muunnettiin prosenteiksi kertomalla sadalla. Tulokset ilmenevät taulukoista 15—18. Yllä olevasta asetelmasta nähdään, että luotettavimmat tulokset

Taulukko 15. Yhtälöiden virheprosenttien keskiarvot (a) ja hajonnat (b) läpimittaluokittain. Mänty.

D cm	Puita kpl	Y1		Y2		Y3		Y4		Y5		Y6	
		a	b	a	b	a	b	a	b	a	b	a	b
18 ..	36	—1.4	3.4	—0.9	5.2	6.9	23.3	—0.7	13.3	—2.4	5.0	0.6	4.0
19 ..	61	—0.5	3.0	0.4	4.9	3.1	17.0	3.5	15.4	1.0	6.6	1.2	7.0
20 ..	81	—0.0	3.0	1.5	5.8	3.3	23.8	6.5	16.4	3.2	6.8	0.7	5.1
21 ..	74	—0.5	3.5	0.7	5.8	4.0	19.4	4.2	17.6	1.7	9.4	0.2	5.9
22 ..	99	—0.0	3.7	0.7	4.5	2.7	20.2	1.9	18.2	1.0	10.2	—0.4	5.9
23 ..	98	—0.0	3.3	—0.6	4.7	4.6	18.9	2.9	15.0	1.3	8.6	0.3	4.7
24 ..	98	0.0	4.1	—0.4	4.4	3.3	22.9	1.1	15.4	0.3	10.1	0.6	5.9
25 ..	79	0.1	3.2	—0.2	4.4	1.5	16.8	—3.4	12.4	—2.3	8.3	—1.2	5.6
26 ..	75	1.0	3.9	0.2	3.0	1.6	22.4	—0.5	8.9	1.2	7.8	0.7	5.0
27 ..	86	0.5	4.1	0.4	4.0	5.7	23.5	—1.6	9.7	0.2	7.0	0.1	4.2
28 ..	75	0.5	3.4	0.3	2.5	3.5	20.6	—0.7	5.9	1.7	6.3	0.3	4.5
29 ..	52	—0.2	3.7	0.5	2.3	8.9	30.3	—1.8	9.2	—0.3	7.9	—0.8	4.9
30 ..	68	—0.1	3.6	0.3	3.4	3.6	18.9	0.9	7.8	1.4	7.2	0.5	4.2
31 ..	45	—0.8	4.3	0.2	2.9	8.1	27.4	—0.4	8.9	—0.8	10.0	—0.5	5.0
32 ..	46	0.7	5.0	—0.0	2.7	5.5	29.4	2.6	8.0	2.0	9.6	1.9	6.0
33 ..	44	0.2	4.2	—0.2	2.3	3.2	18.9	1.9	6.7	—0.6	6.0	—0.1	4.3
34 ..	35	1.3	3.8	—0.6	2.1	—1.6	20.9	5.5	11.7	2.0	9.5	1.8	5.3
35 ..	28	—1.4	4.4	—0.1	2.4	8.2	25.5	0.5	9.1	—2.8	10.8	—0.0	6.7
36 ..	19	0.7	5.2	—0.6	2.4	6.8	27.5	5.8	13.1	1.3	9.9	1.4	5.0
37 ..	23	0.2	4.4	—0.7	2.1	9.9	24.3	3.4	8.2	0.7	7.0	1.0	4.3
38 ..	21	—0.3	5.2	1.1	2.5	0.8	24.3	3.0	9.6	—0.6	11.2	—0.7	3.3
39 ..	6	—0.3	3.1	—0.5	1.6	4.9	18.5	6.4	8.4	5.3	8.6	2.5	3.7
40 ..	11	1.9	5.0	—0.2	1.5	—8.0	25.0	5.3	8.5	2.4	6.2	0.5	2.8
41 ..	10	—0.5	5.0	—0.2	1.6	9.1	33.1	2.7	8.0	1.6	8.8	—1.2	2.2
42 ..	3	—1.5	5.3	—0.3	0.4	2.1	22.1	7.7	11.8	8.2	11.6	5.9	7.4
43 ..	2	0.7	9.3	0.5	2.0	2.7	36.7	4.3	11.8	2.8	13.3	—1.3	3.5
45 ..	3	1.4	2.4	2.8	3.6	—2.7	17.2	8.1	14.6	2.8	8.7	—1.6	5.7
46 ..	2	2.7	4.7	0.2	0.9	9.2	20.4	5.2	8.0	2.2	12.1	—5.9	11.1
47 ..	2	3.7	8.9	2.0	3.0	—28.4	46.2	13.6	23.9	8.4	16.6	—2.8	4.1

Taulukko 16. Yhtälöiden virheprosenttien keskiarvot (a) ja hajonnat (b) läpimittaluokittain. Kuusi.

D cm	Puita kpl	Y1		Y2		Y3		Y4		Y5		Y6	
		a	b	a	b	a	b	a	b	a	b	a	b
18 ..	9	—0.0	3.1	—0.5	2.3	—6.2	14.2	—0.4	10.7	—3.1	6.0	—0.4	2.8
19 ..	30	0.1	2.1	0.9	5.6	3.0	11.8	1.8	13.2	1.0	5.5	1.4	4.6
20 ..	54	0.0	3.0	0.8	6.0	0.8	15.0	3.3	13.6	1.7	6.0	0.4	4.8
21 ..	59	0.5	3.0	0.3	5.6	—0.3	14.1	3.1	13.5	1.5	6.4	—0.3	4.7
22 ..	59	—0.2	2.6	0.4	5.3	3.8	14.6	1.0	14.9	0.7	7.8	0.5	5.0
23 ..	73	0.4	3.3	—0.6	5.5	1.5	16.0	2.8	13.6	1.0	6.9	0.3	4.9
24 ..	51	0.5	3.3	—0.1	5.4	4.5	17.3	—0.4	11.2	—0.9	6.7	—0.5	4.6
25 ..	62	1.2	3.9	0.6	4.6	1.6	14.5	0.8	10.7	0.1	6.4	—0.4	4.2
26 ..	57	0.0	3.0	—0.1	4.7	6.2	19.5	—1.3	8.8	—0.9	5.3	—0.0	4.8
27 ..	49	1.3	3.6	1.1	4.1	—0.2	20.3	3.1	13.5	1.2	7.2	0.2	4.7
28 ..	47	—0.2	3.0	—0.6	3.7	2.5	11.7	0.7	9.4	—1.2	5.9	0.7	3.8
29 ..	32	0.5	3.6	0.7	4.7	3.1	18.3	2.8	12.8	1.2	6.7	1.2	4.1
30 ..	32	0.7	3.4	—0.3	3.4	1.7	15.0	1.3	15.1	—0.5	8.4	0.6	5.1
31 ..	17	—0.6	4.5	—0.5	3.0	5.2	19.2	—0.9	7.9	—1.6	5.7	0.9	3.6
32 ..	15	2.5	4.3	0.9	2.0	—3.6	16.3	4.9	8.5	3.6	7.6	1.1	4.6
33 ..	23	0.0	4.1	0.3	2.3	4.2	35.5	—0.3	7.4	—0.7	6.1	—0.5	3.7
34 ..	14	—1.9	5.4	—0.5	2.2	15.1	24.6	—6.8	11.9	—5.9	9.6	—1.2	4.3
35 ..	9	—0.2	2.6	2.2	3.9	5.5	15.9	3.5	10.2	3.0	7.2	1.1	3.8
36 ..	12	0.5	4.6	0.1	2.4	2.8	20.9	1.9	13.2	1.4	10.8	0.2	5.7
37 ..	11	—0.4	3.6	0.3	1.7	1.6	15.2	1.3	8.0	1.1	7.6	—0.0	3.5
38 ..	6	0.3	3.5	—0.4	1.8	—3.9	11.2	5.0	9.0	5.1	10.1	2.9	7.3
39 ..	2	0.4	7.1	0.4	1.5	—3.8	30.9	—0.1	6.5	2.8	8.1	—0.5	1.5
40 ..	7	—2.0	4.4	0.9	3.3	1.6	22.4	0.5	3.6	0.1	6.4	—1.5	4.6
41 ..	2	—1.0	5.0	3.7	5.6	0.2	18.4	8.1	19.1	5.9	11.0	—0.2	0.8
43 ..	4	0.0	2.7	0.0	1.8	—4.1	15.9	3.7	5.6	7.4	9.8	0.2	2.6
44 ..	2	—0.6	1.6	1.7	2.7	3.5	8.6	5.0	10.6	7.5	11.7	—2.9	4.4

saadaan rungon kokonaiskuutiomäärälle (Y1), tukkipuuprosentille (Y2) ja muuntokertoimelle (Y6). Taulukoista 15—18 havaitaan, että suhteellinen tarkkuus eri läpimittaluokissa on likipitäen vakio. Edellä olevan asetelman luvut osoittavat, että kuutioitaessa puut yhtälöitä käyttäen on virheprosentti kuusella 3.7 ja männyllä 4.1 tai pienempi 68:ssa puussa sadasta. Luotettavuustarkastelut osoittavat, että näillä yhtälöillä saavutetaan ainakin yhtä suuri tarkkuus kuin Ilvessalon taulukoilla, vaikka täsmällistä vertailua on vaikea suorittaa. Keskiarvon keskivirhekaavasta $\left(s_{\bar{y}} = \frac{s}{\sqrt{n}}\right)$ nähdään, että kuutioitaessa useita puita keskiarvo saadaan huomattavan paljon tarkemmin. Metsiköittäin saattaa yhtälöillä ehkä syntyä systemaattisesti virheellisiä tuloksia, mutta virheen suuruus on ilmeisen pieni. Suurin suhteellinen virhe syntyy hukkapuuprosentissa (Y3), vaikka virhe absoluuttisesti jääkin pieneksi. Puun arvon laskeminen yhtälöllä antaa melko luotettavan tuloksen huolimatta rungon arvoon vaikuttavista »portaittaisista» tekijöistä.

Taulukko 17. Yhtälöiden virheprosenttien keskiarvot (a) ja hajonnat (b) pituusluokittain.

H m	Puita kpl	Y1		Y2		Y3		Y4		Y5		Y6	
		a	b	a	b	a	b	a	b	a	b	a	b
Mänty													
10 ..	15	—1.7	4.4	2.9	5.2	0.4	15.3	—18.0	20.8	—6.0	14.5	—0.6	11.2
11 ..	29	—2.0	4.3	0.4	6.3	6.4	24.1	—7.6	13.4	—3.1	10.1	0.4	8.9
12 ..	50	—1.7	5.1	1.1	6.1	8.5	30.3	—2.3	13.6	—1.6	9.6	—0.5	7.1
13 ..	86	0.2	3.8	—0.3	4.7	3.0	22.8	2.3	13.3	2.1	10.0	0.6	7.4
14 ..	128	0.5	4.0	—0.7	4.9	2.0	20.5	5.4	13.9	3.9	10.1	1.8	6.8
15 ..	149	0.7	4.8	0.2	4.7	4.6	21.2	4.9	13.3	2.4	7.8	—0.1	5.2
16 ..	117	0.1	3.7	0.3	4.4	6.3	25.9	4.3	13.5	1.3	8.1	0.1	5.1
17 ..	137	0.4	3.7	—0.2	3.7	1.4	18.8	2.2	14.1	0.5	8.4	0.5	4.8
18 ..	143	0.1	3.2	0.4	4.1	4.2	20.7	3.4	15.7	0.8	8.3	0.5	4.1
19 ..	94	—0.5	3.3	—0.0	2.7	5.3	22.0	—1.0	10.3	—1.5	6.6	—0.3	3.5
20 ..	101	—0.1	3.4	0.3	2.3	2.8	20.0	—1.0	9.6	—0.8	6.3	0.0	3.2
21 ..	82	—0.2	3.7	0.5	2.2	1.2	23.1	—1.9	7.4	—0.6	6.5	—0.7	2.9
22 ..	51	—0.0	3.8	0.9	2.5	8.8	26.6	—1.6	7.4	—0.4	6.2	—0.3	2.8
23 ..	50	0.3	4.0	—0.2	1.7	9.9	23.4	—0.6	8.0	0.3	7.9	—0.1	2.9
24 ..	22	1.5	5.0	0.3	2.4	—3.2	20.3	1.3	9.2	2.1	7.5	1.3	4.0
25 ..	16	0.3	2.7	—0.2	1.1	0.4	17.5	0.4	7.1	0.9	6.3	0.3	2.9
26 ..	10	2.2	4.8	—0.6	1.4	4.8	24.9	1.6	8.1	1.6	7.6	—0.2	4.0
27 ..	6	5.4	8.8	—1.1	1.3	—3.2	22.0	8.9	12.0	6.9	12.0	3.2	4.5
28 ..	2	—0.1	1.0	—0.6	0.6	10.1	20.3	6.6	9.4	5.6	10.5	0.8	2.4
Kuusi													
12 ..	3	—0.3	3.7	—1.9	6.5	7.0	25.2	—10.7	16.7	—4.7	9.1	4.7	12.9
13 ..	11	1.4	4.1	2.9	6.6	2.6	18.2	—10.4	14.4	—5.0	7.2	—2.3	11.3
14 ..	29	0.7	3.1	—0.6	6.2	—0.1	17.8	—4.4	11.3	—1.9	6.0	—0.1	4.6
15 ..	52	0.2	2.7	—0.5	6.0	2.9	14.4	—0.4	9.4	0.8	4.9	1.3	6.0
16 ..	88	0.1	2.5	0.6	6.3	3.5	15.4	5.2	14.8	2.0	7.2	—0.1	5.9
17 ..	83	0.7	3.3	1.2	5.5	1.8	14.5	6.3	16.9	3.0	8.4	0.8	5.6
18 ..	75	0.5	3.8	—0.3	5.3	2.2	16.6	3.3	14.6	1.6	7.3	0.2	4.2
19 ..	81	—0.1	3.3	0.2	4.5	3.6	17.4	—1.3	11.8	—1.3	6.7	—0.4	3.7
20 ..	78	0.4	3.3	0.3	4.2	1.9	21.7	1.3	10.8	0.0	5.9	0.3	3.2
21 ..	70	0.3	3.2	—0.0	2.9	4.1	19.7	0.6	9.0	—0.1	5.7	0.9	3.6
22 ..	54	1.2	4.4	—0.3	2.2	1.7	13.7	—1.4	7.7	—1.0	5.7	—0.6	3.0
23 ..	42	—0.2	3.7	0.4	2.3	1.6	17.0	—1.7	6.5	—1.5	5.8	—0.6	3.0
24 ..	26	0.1	4.4	—0.6	1.9	4.9	16.7	0.7	10.3	—0.7	9.4	0.6	5.3
25 ..	18	0.2	3.0	—0.1	2.2	0.9	16.8	0.4	6.1	—0.2	5.3	—0.2	2.5
26 ..	12	1.1	4.9	0.2	1.2	1.8	17.2	4.6	8.7	2.5	7.8	0.7	3.6
27 ..	11	—0.5	5.8	0.4	2.4	8.2	23.2	1.9	12.4	1.6	10.8	0.2	4.6
28 ..	6	0.1	3.2	1.1	1.9	—9.7	16.5	2.4	4.6	3.9	6.0	0.0	1.9
29 ..	2	—1.1	1.7	1.1	1.6	6.7	9.8	—0.6	0.9	5.9	8.7	0.4	6.1
30 ..	2	—2.5	5.5	—0.1	3.7	9.9	21.2	4.7	10.6	10.7	15.2	—0.4	2.2

Taulukko 18. Yhtälöiden virheprosenttien keskiarvot (a) ja hajonnat (b) kapenemisluokittain.

D—D6 cm	Puita kpl	Y1		Y2		Y3		Y4		Y5		Y6	
		a	b	a	b	a	b	a	b	a	b	a	b
Mänty													
2 ..	5	1.4	4.6	—0.7	3.2	—2.7	7.7	4.5	16.3	—1.6	6.6	—0.4	3.8
3 ..	80	0.5	4.0	0.7	4.7	1.5	19.0	—1.2	12.1	—1.9	7.3	1.1	4.8
4 ..	277	0.3	3.8	0.4	4.1	3.4	20.5	—0.4	14.4	—0.7	8.0	—0.1	4.7
5 ..	349	0.1	3.7	0.2	4.0	6.0	23.6	0.9	12.2	0.8	7.6	—0.0	4.5
6 ..	264	0.2	3.2	—0.4	3.6	2.5	21.9	2.6	11.5	1.9	7.1	0.7	4.7
7 ..	168	—0.1	4.0	0.1	4.0	4.4	22.9	3.9	12.3	3.1	9.8	0.7	6.1
8 ..	80	—0.5	4.0	0.3	3.8	2.0	19.4	3.3	10.9	1.8	9.2	0.2	6.2
9 ..	30	—1.2	5.1	0.8	3.9	7.5	28.6	0.7	14.0	—1.7	12.2	—1.9	7.4
10 ..	18	—1.4	4.3	0.9	3.1	7.0	27.6	4.1	8.5	0.7	8.8	0.1	6.2
11 ..	6	—0.1	7.7	0.1	6.9	—6.4	12.6	—1.5	20.3	—6.4	14.1	4.9	13.5
12 ..	5	—4.3	6.4	0.8	3.1	14.8	34.8	0.1	14.2	—6.9	15.9	2.0	8.9
13 ..	5	0.8	6.0	3.5	6.4	10.9	25.0	8.5	25.7	—9.3	18.5	—0.0	11.6
Kuusi													
1 ..	2	5.4	10.0	—2.4	5.7	0.8	25.7	11.5	40.1	3.9	18.9	0.9	7.6
2 ..	36	2.4	5.0	1.2	5.1	—1.1	15.7	6.6	15.9	1.6	7.6	0.7	4.1
3 ..	179	0.3	3.2	—0.1	4.1	5.1	17.3	—0.7	11.3	—1.4	6.4	—0.2	3.5
4 ..	202	0.4	3.2	0.4	4.2	1.0	14.6	1.7	11.0	0.5	6.5	0.3	4.0
5 ..	140	—0.2	2.9	—0.1	4.3	0.8	15.1	0.7	9.1	0.8	5.6	0.5	4.5
6 ..	92	0.1	2.9	0.0	5.5	1.9	18.1	1.6	11.1	1.7	6.6	—0.1	5.4
7 ..	50	0.1	3.8	1.2	5.0	4.0	25.4	2.6	12.2	1.8	7.0	—0.7	4.7
8 ..	25	—0.9	3.9	—0.1	6.6	7.1	20.4	5.8	21.8	3.6	11.1	2.1	7.5
9 ..	10	—0.3	6.7	1.7	8.2	—2.3	20.9	5.8	25.0	1.2	14.5	2.0	7.5
10 ..	3	—0.6	3.6	—4.0	5.4	9.4	19.8	—11.9	15.4	—5.7	7.6	7.1	13.5
11 ..	4	3.8	4.9	0.3	2.1	7.8	11.8	—12.0	12.9	—8.5	10.8	—5.4	7.1

8. TAULUKOIDEN JA YHTÄLÖIDEN KÄYTÖSTÄ

Taulukoiden soveltamisessa on ennen kaikkea tärkeää tuntea niiden perustana oleva apteeraussysteemi ja käytetyt rajoitukset sekä luokitustavat. Muutokset näissä tekijöissä vaikuttavat tulokseen. Hintasuhteiden pysyessä samana mutta hintojen muuttuessa voidaan arvotaulukoiden luvut kertoa hintatason muutoskertoimella ja näin saada uudet arvot. Erityisen merkityksellinen on järeysporrastus, jonka yhtenäistämiseen olisi syytä pyrkiä. Puiden laatu leimikossa vaikuttaa luonnollisesti hintoihin. Tämän tutkimuksen tulosten soveltamisessa laadun vaikutus voidaan ottaa huomioon yksikköhinnoissa joko runko- tai metsikkökohtaisesti.

Rungon kuutioimisyhtälöiden antamat luvut ovat yleensä suuremmat kuin vastaavat I l v e s s a l o n taulukoista saatavat kuutiot. Ero johtuu pääasiallisesti siitä, että rungon kuutiomäärästä ei ole vähennetty kannon osuutta. Samansuuntaista eroa aiheuttaa lisäksi mittauspätkän keskiläpimitan mukainen koepuiden kuutiointi, jota I l v e s s a l o on käyttänyt. Koepuiden yleisimmissä läpimitta-pituusluokissa yhtälöillä saadaan keskimäärin 2—4 prosenttia suurempia kuutiomääriä.

Kuitupuutaulukoissa kapenemisina ja hukkapuuprosentteina on käytetty aineiston pienten puiden kapenemista ja vastaavia hukkapuuprosentteja, mutta läpimitaltaan 18 cm ja sitä paksumpien puiden osalta tukkipuiden kapenemista ja hukkapuuprosentteja. Näillä edellytyksillä saatuihin käyttöosan kuutioihin on sovellettu järeysporrastuksen mukaisia hintoja ja saatu kuitupuiden arvotaulukot.

Tukkipuuprosentti perustuu keskimääräiseen tukkilukuun kussakin läpimitta-pituusluokassa. Se on merkitty vain kokonaisina prosentteina osoittamaan sen »epävarmuutta», koska esim. kapeneminen vaikuttaa voimakkaasti tukkilukuun ja täten tukkipuuprosenttiin. Hukkapuuprosentti on laskettu läpimitan, pituuden ja keskimääräisen kapenemisen avulla. Kuitupuuprosentti on saatu vähentämällä sadasta tukki- ja hukkapuuprosentit. Kuusen osalta tukkipuuprosentit ovat yleensä pienemmät kuin männyllä. Tämä johtuu ennen kaikkea kuusitukkien suuremmista kokovaatimuksista. Sovellettaessa 50:n kuusirungon erälle männyn tukkien vaatimuksia suureni tukkiluku neljässä rungossa ja keskimääräinen tukkipuuprosentti näillä rungoilla kasvoi 82.9:stä 92.7:ään. Koko runkoerän keskimääräinen tukkipuuprosentti kasvoi 87.1:stä 88.0:aan.

Tukkiluku vaikuttaa voimakkaasti myös rungosta saatavaan tukkiosan teknilliseen kuutiosisältöön. Koska kapeneminen tehokkaasti korvaa tukkiluvun selittävänä muuttujana ja jotta vertailukelpoisuus aikaisempiin tutkimuksiin paremmin säilyisi, ei tukkilukua ole otettu tässä yhteydessä tekijäksi. Mielenkiintoisen vertailukohdan teknillisten kuutiomäärien osalta tarjoaa vertailu PMP-systeemin avulla tehtyihin kuutiojalkamäärätaulukoihin (vrt. Nousiainen et al. 1970). Mikäli vertailukohteeksi otetaan keskimääräisellä kapenemisella lasketut taulukkoarvot ja vastaavat arvot, jotka löytyvät suoraan edellä mainitusta julkaisusta, saadaan näiden vastaavien lukujen summaksi tämän tutkimuksen mukaan männyllä 3.6 % ja kuusella 1.0 % suuremmat luvut.

Kiintokuutiometristä saatavien kuutiojalkojen määrä vaihtelee keskimääräiselläkin kapenemisella huomattavasti erikokoisilla rungoilla, kuten sivuilta 59 ja 68 nähdään, joten yleisessä käytössä olevat yhdet puulajikohtaiset muuntoluvut pätevät vain hyvin suppeilla alueilla.

Aineiston ulkopuolisilla alueilla yhtälöiden luotettavuudesta ei ole tietoa, joten yhtälöiden antamat tulokset sellaisille puille ovat epävarmoja. On selvää, että taulukoidenkin luotettavuus on suurin keskimääräisillä rungoilla, joita aineistossa on eniten.

9. MUITA SOVELTAMISMAHDOLLISUUKSIA

Kehitetty systeemi tarjoaa soveltamismahdollisuuksia myös muille puulajeille. Lehtipuiden osalta lisäaineistoa hankitaan parhaillaan, joten esim. koivurunkojen arvojen laskenta olisi helppo suorittaa, mikäli tunnettaisiin sorvipöllien arvosuhteet. Koska käytettävät mittayksiköt ja luokitustavat ovat muuttumassa eivätkä ole vielä vakiintuneet, tarjoaa magneettinauhoilla oleva perusaineisto nopean mahdollisuuden laskea uusien luokitustapojen mukaiset tulokset tarvitsematta välillä mennä metsään keräämään uutta aineistoa. Tärkeän soveltamisalueen muodostaa pystymittaus, jonka edelleen kehittämiseen tässä tutkimuksessa saadut tulokset ja tämä aineisto tarjoavat mahdollisuuden.

Eri kokoisilla tukkipuurungoilla rungon arvo vaihtelee voimakkaasti jonkin koepuutunnuksista muuttuessa. Rungon arvo muuttuu jopa kaksinkertaiseksi rinnankorkeusläpimitan ja kuuden metrin läpimitan kasvaessa neljä—viisi senttimetriä. Rungon dimensioiden kasvaessa myös rungon arvon hajonta kasvaa likipitäen samassa suhteessa kuin rungon kuutiosisältö kasvaa. Tilastotieteestä tunnettujen optimaaliseen otantaan liittyvien kaavojen perusteella tiedetään, että koepuiden lukumäärään kussakin otantaluokassa (läpimittaluokassa) vaikuttaa pääasiassa kolme tekijää: puiden luku, runkojen arvojen hajonta ja mittauskustannukset. Tutkimalla kaikkia näitä suureita voidaan kehittää yleisiä tehokkaita otantasääntöjä, joiden avulla tarkkuutta voidaan parantaa nykyisin käytössä oleviin koepuiden otannan sääntöihin verrattuna.

Erityisesti pinotavaraleimikoiden arviointiin voidaan kehittää muitakin kuin läpimittaluokkiin sidottuja kuutiointimenetelmiä. Eräs tällainen olisi suhde-estimaatin tai regressioestimaatin käyttö. Suhde-estimaattia on käytetty Keski-Euroopassa jo kontrollimenetelmän kehittämisestä lähtien. K u u s e l a (1960) on esitellyt sen käyttöä koealojen kuutioinnissa inventoinnin yhteydessä. Suhde-estimaattia käytettäessä puista mitataan läpimittaluokka rinnankorkeudelta ja kaikki puut kuutioidaan pelkkään läpimittaan perustuvan kuutioimisyhtälön avulla. Puiden luvun jälkeen koepuut valittaisiin esim. relaskoopilla leimikon eri pisteistä ja mitattaisiin mahdollisimman suurella tarkkuudella. Leimikon korjattu kuutiometrimäärä (V) saadaan seuraavan kaavan avulla:

$$(9.1) \qquad V = \frac{\sum_{i=1}^{n} V_i}{\sum_{i=1}^{n} \hat{V}_i} \cdot \sum_{k=1}^{L} N_k \hat{V}_k$$

V_i = i:nnen koepuun tarkka kuutiomäärä
exact volume of the ith sample tree

$\hat{V}_i$ = i:nnen koepuun läpimitan avulla laskettu kuutiomäärä
volume of the ith sample tree as determined on the basis of its diameter

n = koepuiden lukumäärä
number of sample trees

N_k = k:nnen läpimittaluokan puiden lukumäärä
number of sample trees in the kth diameter class

L = läpimittaluokkien lukumäärä
number of diameter classes

Etenkin pienissä leimikoissa tällainen kuutiointitapa olisi tehokas. Olettaen koepuiden valinta satunnaiseksi suhde-estimaatille voidaan laskea olemassa olevia kaavoja käyttäen (esim. Cochran 1963, s. 158) saadun kuutiomäärän virherajat, joiden tunteminen on tärkeää. Suhde-estimaattia käytettäessä on poikkeukselliset ja etenkin suuret puut syytä kuutioida erikseen, koska ne saisivat koepuina kaavan (9.1) mukaan liian suuren painon. Pelkän läpimitan avulla kuutiointi voisi tapahtua seuraavia yhtälöitä käyttäen.

Mänty — *Pine*

$$\log(V,\ dm^3) = -2.37912 + 2.62903 \cdot \log(D) - 0.000126 \cdot D^2$$

Kuusi — *Spruce*

$$\log(V,\ dm^3) = -2.59385 + 2.71757 \cdot \log(D) - 0.000097 \cdot D^2$$

Sovellettaessa tällaista suhde-estimaattimenettelyä voidaan muutaman koepuun avulla keskimääräisyhtälön antamaa tulosta tarkentaa, sillä menetelmässä jokainen koepuu antaa tietoa koko leimikosta eikä vain läpimittaluokastaan. Yhtälöitä käytettäessä voidaan koepuutunnukset mitata sillä tarkkuudella kuin se käytännössä on mahdollista ja siten saadaan myös korjauskerroin tarkemmaksi.

10. TIIVISTELMÄ

Tutkimuksen yleistä kulkua kuvaava systeemikaavio on sivulla 15. Runkojen jako puutavaralajeihin ohjelmoitiin tietokoneelle. Ohjelmalla, jossa käytetään ns. dynaamisen ohjelmoinnin tekniikkaa, on etsitty sen tukki- ja kuitupuun osan yhdistelmä, joka annetuilla ehdoilla maksimoi rungon arvon. Apteerauksen parametrit ovat olleet seuraavat: tukin ja kuitupuun minimiläpimitta, tukkien minimimitat, tukkiluvun ratkaisevat tukkiosan pituusrajat, tukin ja kuitupuun yksikköhinnat ja niiden järeysporrastus (s. 16, 17 ja 19). Kaikkiaan apteerattiin 1 291 mänty- ja 744 kuusitukkipuuta.

Tutkimuksen tulosten mukaan kuitupuun yksikköhinnan melko voimakkaat muutokset eivät juuri vaikuta tukkiosaprosenttiin tukin yksikköhintatason ollessa 2 mk/j^3 (s. 25). Kun oli kyse rajatapauksista tukkiluvun suhteen, saatiin käytetyn apteerausohjelman ehdoilla mäntyrungon arvo usein suuremmaksi pienemmällä tukkiluvulla, kun taas kuusella rungon arvo saatiin lähes poikkeuksetta suuremmaksi useampitukkisena (s. 26). Taulukoihin 11 ja 12 (s. 27 ja 28) on laskettu ne kuitupuun yksikköhintatasot, joilla rungon arvo kuitupuuna saadaan samaksi kuin tukkipuuna. Työvaihetaksojen mukaisille järeysluokille laskettiin keskimääräiset rungon arvot, erikseen kuitu- ja tukkipuuna (s. 29).

Valikoivaa regressioanalyysiä käyttäen lasketut puiden rinnankorkeus- ja kuuden metrin läpimittoihin sekä pituuteen perustuvat kuutioimisyhtälöt soveltuvat yli 7 metrin pituisten puiden kuutiointiin. Yhtälöt tukkipuu- ja hukkapuuprosenteille, rungon kuutiojalkamäärälle ja arvolle sekä tukkiosan muuntokertoimelle (kuutiojalkamäärän suhde tukkiosan todelliseen kuorelliseen kuutiometrimäärään) on esitetty sivuilla 31 ja 32 ja lasketut tulokset taulukoissa julkaisun lopussa. Yhtälöillä saatavan ennusteen suhteellinen keskivirheprosentti on asetelmassa sivulla 34. Yhtälöitä voidaan käyttää ennen kaikkea metsiköiden tai leimikoiden kuutiomäärien, puutavaramäärien ja hakkuuarvojen selvittämiseksi. Sivulla 41 on esitetty myös pelkkään läpimittaan perustuvat kuutioimisyhtälöt ja kaava (9.1) metsikön kuutiomäärän laskemiseksi suhde-estimaatin avulla.

VIITEKIRJALLISUUS

Alm, S. — Troedsson, H. 1969. Ett program för teoretisk aptering. Principiell uppbyggnad och exempel på tillämpningar. Redogörelse nr. 6. Forskningsstiftelsen Skogsarbeten.

Cochran, W. 1963. Sampling techniques. Second edition. A Wiley publication in applied statistics.

Heinonen, T. 1971. Läpimittaan ja pituuteen perustuvien puutavaralajitaulukoiden tarkkuudesta erään kuusiaineiston valossa. Metsänarvioimistieteen laudaturtyö. Käsikirjoitus.

Heiskanen, V. — Asikainen, K. 1969. Havusahatukkien järeyden mukaiset arvosuhteet ja hinnoitteluperusteet. Summary: The value relationships and pricing principles of coniferous sawlogs on the basis of their diameter. MTJ 69.3.

Ilvessalo, Y. 1948. Pystypuiden kuutioimis- ja kasvunlaskentataulukot. Helsinki.

Kuusela, K. 1960. Maan kuvioiden ja puuston vaihtelu sekä sen vaikutus metsän inventoinnin tarkkuuteen. Summary: Variation of the site pattern and growing stock and its effect on the precision of forest inventory. Acta Forestalia Fennica 72.

—»— 1965. A method for estimating the volume and taper curve of tree stem and for preparing volume functions and tables. Seloste: Menetelmä puun rungon kuutiomäärän ja kapenemiskäyrän arvioimiseksi sekä kuutioimisfunktioiden ja -taulukoiden valmistamiseksi. MTJ 60.2.

Lallukka, H. 1970. Pystypuiden ja metsiköiden arvon määrittäminen. Metsänarvioimistieteen pro gradu-tutkielma maatalous- ja metsätieteiden kandidaatin tutkintoa varten. Käsikirjoitus.

Metsäalan työehtosopimus ja sen mukaiset metsätyöpalkkojen taulukot. 1971. 1. 1. 71—31. 3. 72. Palkkausalue 4. Helsinki.

Nousiainen, J. — Sorsa, J. — Tiihonen, P. 1970. Mänty- ja kuusitukkipuiden kuutioimismenetelmä. Referat: Eine Methode zur Massenermittlung von Kiefern- und Fichtenblochholz. FF 98.

Nyyssönen, A. 1971. Metsän arvioiminen. Tapion Taskukirjan 16. uudistettu painos.

Strand, L. 1967. Pristabell for furu ved dynamisk programmering. Årsmelding 1965—1966 fra Institutt for skogtaksasjon. Vollebekk.

Tiihonen, P. 1969. Rinnankorkeusläpimittaan ja pituuteen perustuvat puutavaralajitaulukot. FF 71.

Työvaiheittaiset hakkuupalkat. 1971. 1. 1. 1971—31. 3. 1972. Palkkausalue 4. Helsinki.

LYHENTEET — *ABBREVIATIONS*

FF = Folia Forestalia
MTJ = Metsäntutkimuslaitoksen julkaisuja

TAULUKOT JA LIITTEET

Taulukkoluettelo

	Taulukoiden sivunumerot Mänty	Kuusi
I. Keskimääräisellä kapenemisella		
Kuitupuutaulukot		
— keskimääräinen kapeneminen	45	45
— kuutiosisältö	46	46
— hukkapuuprosentit	47	47
— arvotaulukot	48—49	50—51
Tukkipuutaulukot		
— keskimääräinen kapeneminen	52	61
— kuutiosisältö	53	62
— tukkiluku	54	63
— puutavaralajiprosentit	56—57	64—65
— rungon kuutiojalkamäärä	55	66
— rungon arvo	58	67
— kiintokuutiometri kuutiojaloiksi	59	68
— rungon yksikkökuutiometrin arvo	60	69
II. Tukkipuiden arvotaulukot	70—75	76—81
Liitteet		
Liite 1. Mäntytukkien arvot	82	
Liite 2. Kuusitukkien arvot	83	
Liite 3. Tukin kuutiosisältö, j^3	84—85	
Liite 4. Tukin kuutiosisältö, dm^3	86—87	

Kuitupuiden keskimääräinen kapeneminen — *Average taper of pulpwood*

D cm	Puun pituus, m — *Tree height, m*													
	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Kapeneminen, cm — *Taper, cm*													
Mänty — *Pine*														
8	6	5	4	3	2									
9	7	5	4	3	3	2								
10	8	6	5	4	3	3	2							
11	9	7	5	4	4	3	3	2						
12	10	8	6	5	4	3	3	2	2					
13	11	8	7	5	4	4	3	3	2	2				
14	12	9	7	6	5	4	3	3	3	2	2			
15		10	8	7	5	5	4	3	3	2	2	2		
16			9	7	6	5	4	4	3	3	2	2	2	
17				8	7	5	5	4	3	3	3	2	2	2
Kuusi — *Spruce*														
8	6	4	4	3	3									
9	7	5	4	3	3	2								
10	7	6	5	4	3	3	2							
11	8	6	5	4	4	3	3	3						
12	9	7	5	5	4	3	3	3	3					
13	10	7	6	5	4	4	3	3	3	3				
14	10	8	6	5	5	4	4	3	3	3	3			
15	11	9	7	6	5	4	4	3	3	3	3	3		
16			7	6	5	5	4	4	3	3	3	3	3	
17					6	5	4	4	4	4	3	3	3	3

Kuitupuiden kuutiosisältö — *Volume of pulpwood* (keskimääräisellä kapenemisella — *average taper*)

D cm	Puun pituus, m — *Tree height, m*													
	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Rungon kuutiomäärä, dm^3 — *Stem volume, dm^3*													
Mänty — *Pine*														
8	20	22	24	27	30									
9	25	29	32	36	37	41								
10	31	35	38	42	47	49	55							
11	37	41	48	52	54	61	63	71						
12	44	48	55	60	66	74	77	86	90					
13	51	58	62	72	80	82	92	95	108	112				
14	58	66	74	81	88	98	109	113	117	132	137			
15		74	83	89	104	107	119	133	137	155	161	167		
16			92	104	113	124	138	143	159	165	187	193	200	
17				114	123	143	148	164	183	190	197	222	230	239
Kuusi — *Spruce*														
8	20	24	24	27	28									
9	25	29	32	36	37	42								
10	32	34	38	42	47	48	55							
11	37	43	48	53	54	61	62	64						
12	43	50	59	60	66	75	76	79	81					
13	50	60	66	72	80	82	92	95	98	101				
14	60	68	79	86	88	98	100	113	116	120	123			
15	67	75	86	94	104	115	118	133	137	141	145	150		
16			101	110	121	124	137	141	159	164	169	174	180	
17					130	143	159	163	167	172	194	201	207	215

Kuitupuiden hukkapuuprosentit — *Waste wood percentage of pulpwood* (keskimääräisellä kapenemisella — *average taper*)

D cm	Puun pituus, m — *Tree height, m*													
	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Hukkapuuprosentti — *Waste wood percentage*													
Mänty — *Pine*														
8	30.2	33.0	33.5	31.5	26.8									
9	19.8	18.8	19.1	18.0	20.6	17.1								
10	13.9	13.5	14.1	13.9	12.7	14.2	11.6							
11	10.2	10.1	9.2	9.1	10.4	9.3	10.2	8.2						
12	7.8	7.9	7.4	7.4	7.1	6.4	7.0	5.7	6.0					
13	6.1	5.6	6.0	5.3	5.1	5.7	5.0	5.4	4.3	4.5				
14	4.9	4.6	4.4	4.6	4.5	4.2	3.7	4.0	4.3	3.4	3.5			
15		3.9	3.8	3.9	3.4	3.8	3.5	3.1	3.2	2.6	2.7	2.7		
16			3.3	3.0	3.0	2.9	2.7	2.9	2.5	2.6	2.1	2.1	2.2	
17				2.7	2.7	2.3	2.6	2.3	2.0	2.1	2.2	1.7	1.7	1.7
Kuusi — *Spruce*														
8	32.8	30.0	34.3	32.6	36.1									
9	22.4	21.1	21.0	19.8	21.9	19.0								
10	14.8	15.6	15.8	15.3	14.2	15.5	13.2							
11	11.3	10.7	10.8	10.5	11.6	10.6	11.5	12.3						
12	9.0	8.6	7.7	8.7	8.3	7.5	8.1	8.7	9.3					
13	7.3	6.4	6.5	6.4	6.1	6.6	6.0	6.4	6.8	7.2				
14	5.6	5.4	4.9	4.8	5.4	5.0	5.4	4.8	5.1	5.4	5.6			
15	4.8	4.7	4.3	4.3	4.1	3.9	4.2	3.7	4.0	4.2	4.4	4.5		
16			3.4	3.4	3.3	3.6	3.3	3.5	3.1	3.3	3.4	3.6	3.7	
17					3.0	2.9	2.7	2.8	3.0	3.2	2.7	2.9	2.9	3.0

Kuitupuiden arvotaulukko (keskimääräisellä kapenemisella

Mänty

D cm	Puun pituus, m — 7	8	9	10	11	12	13	14	15	16	17
	Rungon arvo, mk —										
8	0.3	0.3	0.3	0.3	0.4						
9	0.4	0.4	0.5	0.5	0.5	0.6					
10	0.5	0.6	0.6	0.7	0.9	0.9	1.0				
11	0.6	0.8	0.9	1.0	1.0	1.1	1.2	1.4			
12	0.8	0.9	1.1	1.2	1.4	1.5	1.6	1.8	1.8		
13	1.0	1.1	1.2	1.5	1.7	1.7	1.9	2.0	2.3	2.4	
14	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	2.5	2.9	3.0
15		1.6	1.8	1.9	2.2	2.3	2.6	2.9	3.0	3.5	3.6
16			2.0	2.2	2.4	2.7	3.0	3.2	3.6	3.7	4.2
17				2.4	2.7	3.2	3.3	3.7	4.1	4.3	4.4
[1] 18				3.3	3.6	3.7	4.1	4.2	4.4	5.0	5.2
19				3.5	3.8	4.2	4.3	4.9	5.0	5.2	6.0
20				3.9	4.3	4.4	5.0	5.1	5.7	6.0	6.3
21				4.4	4.5	5.0	5.5	5.7	6.1	6.8	7.0
22				4.8	5.2	5.6	5.8	6.6	6.8	7.0	7.9
23				5.3	5.7	6.1	6.6	6.8	7.6	7.9	8.1
24				5.8	6.2	6.7	7.3	7.6	8.4	8.8	9.1
25				6.3	6.8	7.4	7.6	8.4	8.8	9.7	10.2
26				6.9	7.5	8.1	8.4	9.3	9.6	10.1	11.1
27				7.6	8.1	8.4	9.3	9.6	10.6	11.0	11.4
28				7.9	8.6	9.3	10.2	10.6	11.6	12.0	12.6
29				8.7	9.3	10.2	10.6	11.5	11.9	13.2	13.7
30				9.4	10.2	11.0	11.4	12.6	13.1	14.3	14.8
31				10.3	11.0	11.4	12.3	13.6	14.1	14.6	16.2
32				10.7	11.4	12.3	13.5	13.9	15.4	15.9	16.5
33				11.5	12.3	13.4	14.5	15.0	16.5	17.1	17.7
34				12.3	13.3	14.3	14.8	16.3	16.8	18.4	19.1
35				13.3	14.3	15.5	16.1	17.4	18.1	19.7	20.4
36				13.8	14.7	15.9	17.1	18.7	19.3	20.0	21.8
37					15.9	17.0	18.4	19.0	20.6	21.3	23.2
38					16.9	18.2	19.5	20.2	21.9	22.7	23.5
39						19.3	19.9	21.5	22.2	24.1	24.9
40						20.4	21.1	22.8	23.6	25.5	26.4

[1] Tukkipuiden kapenemisella. — *Taper of saw timber stems.*

Value tables of pulpwood
average taper)

Pine

Tree height, m										
18	19	20	21	22	23	24	25	26	27	28
Stem value, Fmk										
3.7										
4.3	4.5									
5.1	5.3	5.5								
5.3	5.5	5.7	6.1							
6.2	6.4	6.7	6.9	7.2						
6.5	7.3	7.6	7.8	8.1	8.4					
7.3	7.6	7.8	8.9	9.2	9.6	10.0				
8.1	8.6	8.9	9.2	9.5	10.0	10.3	10.7			
9.2	9.5	10.0	10.3	10.7	11.1	11.5	11.8	12.2		
9.5	10.6	11.0	11.4	11.8	12.2	12.8	13.3	13.7	14.2	
10.5	10.9	11.3	12.7	13.2	13.6	14.1	14.6	15.1	15.8	16.3
11.5	12.0	12.4	13.0	13.5	14.9	15.7	16.2	16.7	17.3	17.8
12.8	13.2	13.7	14.2	14.7	15.4	16.0	16.5	17.1	17.6	18.3
13.1	14.4	14.9	15.7	16.2	16.8	17.4	18.0	18.7	19.3	19.9
14.2	14.7	16.4	17.0	17.6	18.3	18.9	19.6	20.2	20.9	21.6
15.6	16.1	16.7	18.5	19.1	19.8	20.5	21.2	21.9	22.6	23.3
16.8	17.4	18.1	18.8	20.6	21.3	22.1	22.8	23.6	24.4	25.2
18.2	18.8	19.5	20.2	20.9	21.6	22.4	24.5	25.4	26.2	27.1
19.5	20.2	20.9	21.7	22.4	23.2	24.0	24.8	25.6	26.5	27.3
19.8	21.6	22.4	23.2	24.0	24.8	25.7	26.6	27.5	28.4	29.3
21.2	21.9	24.0	24.8	25.7	26.6	27.5	28.4	29.3	30.3	31.3
22.6	23.4	24.2	26.5	27.4	28.3	29.3	30.3	31.3	32.3	33.4
24.0	24.9	25.8	26.7	27.6	30.2	31.2	32.3	33.3	34.4	35.6
25.6	26.5	27.4	28.4	29.4	30.4	31.4	34.3	35.5	36.6	37.8
25.9	28.1	29.1	30.1	31.2	32.3	33.4	34.5	35.7	36.8	38.0
27.4	29.8	30.8	31.9	33.1	34.2	35.4	36.6	37.8	39.0	40.3

Kuitupuiden arvotaulukko
(keskimääräisellä kapenemisella

Kuusi

D cm	Puun pituus, m —										
	7	8	9	10	11	12	13	14	15	16	17
	Rungon arvo, mk —										
8	0.2	0.3	0.3	0.3	0.3						
9	0.3	0.4	0.5	0.5	0.5	0.6					
10	0.5	0.5	0.6	0.7	0.9	0.9	1.0				
11	0.6	0.8	0.9	1.0	1.0	1.2	1.2	1.2			
12	0.9	1.0	1.2	1.2	1.3	1.7	1.7	1.7	1.8		
13	1.0	1.2	1.3	1.6	1.8	1.8	2.1	2.2	2.2	2.3	
14	1.2	1.5	1.8	2.0	2.0	2.3	2.3	2.6	2.7	2.8	2.9
15	1.5	1.7	2.0	2.2	2.4	2.7	2.8	3.2	3.2	3.3	3.6
16			2.4	2.6	2.9	2.9	3.3	3.4	4.0	4.1	4.2
17					3.1	3.6	4.0	4.1	4.2	4.3	4.9
[1] 18						4.1	4.2	4.7	5.4	5.5	6.3
19						4.4	4.8	5.5	5.6	6.3	6.5
20						5.0	5.1	5.7	6.3	6.5	7.5
21						5.3	5.8	6.4	6.6	7.5	7.8
22						6.0	6.5	6.9	7.6	7.8	8.7
23						6.3	7.0	7.6	7.8	8.7	9.8
24						7.2	7.8	8.0	8.7	9.8	10.1
25						7.5	8.1	8.8	9.8	10.1	11.1
26						8.4	9.0	9.9	10.2	11.1	12.2
27						9.2	9.4	10.3	11.1	12.2	12.5
28						9.8	10.4	11.3	11.6	12.5	13.6
29						10.7	10.9	11.8	12.6	13.6	14.0
30						11.3	12.0	12.7	13.7	14.3	15.4
31						12.2	12.5	13.3	14.4	15.4	16.6
32						12.9	13.5	14.6	15.5	16.0	17.1
33						13.5	14.4	15.2	16.1	17.4	18.6
34						14.8	15.5	16.4	17.6	18.6	19.2
35						15.6	16.3	17.1	18.3	19.3	20.7
36						16.8	17.8	18.6	19.5	20.8	21.5
37						18.0	18.7	19.5	20.6	21.6	22.9
38							19.7	20.7	21.6	22.6	23.8
39							21.2	22.0	23.0	24.0	25.2
40								23.2	24.1	25.1	26.3

[1]) Tukkipuiden kapenemisella. — *Taper of saw timber stems.*

Value tables of pulpwood
average taper)

Spruce

Tree height, m										
18	19	20	21	22	23	24	25	26	27	28
Stem value, Fmk										
3.7										
4.3	4.5									
5.0	5.3	5.5								
6.5	6.9	8.0	8.4							
7.6	7.9	8.2	8.5	10.0						
7.8	8.0	9.2	9.7	10.1	10.5					
8.8	9.1	9.4	10.9	11.4	11.8	12.2				
9.0	10.3	10.6	11.0	12.6	13.1	13.6	14.3			
10.2	10.5	11.9	12.3	12.7	14.7	15.3	15.8	16.4		
11.3	11.7	13.1	13.5	14.0	14.8	15.3	15.9	18.3	17.4	
11.5	12.8	13.2	15.1	15.6	16.2	16.8	17.7	18.3	19.0	19.8
12.6	14.0	14.7	15.2	17.0	17.9	18.6	19.3	20.0	20.9	21.7
13.8	14.5	16.0	16.6	17.4	19.5	20.2	21.1	21.9	22.7	23.6
14.3	15.7	16.2	18.2	18.9	19.5	22.0	22.8	23.7	24.6	25.5
15.5	17.0	17.8	18.4	20.5	21.3	22.1	24.6	25.5	26.5	27.5
16.7	17.5	19.2	19.9	22.1	22.9	23.7	24.6	27.4	28.5	29.6
17.4	18.9	19.5	21.5	22.3	24.6	25.5	26.4	27.4	30.5	31.7
18.7	20.2	21.1	23.0	23.9	24.7	27.2	28.2	29.3	30.4	33.8
20.0	20.9	22.6	23.4	25.5	26.4	29.0	30.1	31.3	32.4	33.7
20.7	22.3	23.0	24.9	25.8	28.1	29.2	32.0	33.2	34.5	35.8
22.1	22.8	24.5	26.5	27.5	29.9	31.0	32.1	35.2	36.6	38.0
22.8	24.3	26.1	27.0	29.1	30.2	32.8	34.0	37.3	38.7	40.2
24.2	25.8	26.7	28.6	29.6	32.0	34.7	36.0	37.3	40.9	42.4
25.1	26.6	28.3	29.3	31.4	33.8	35.0	38.0	39.4	40.9	44.7
26.6	28.1	29.1	31.0	33.1	34.3	36.9	38.3	41.5	43.0	47.0
27.6	29.1	30.7	32.7	33.8	36.1	38.8	40.3	43.5	45.2	47.6

Tukkipuiden keskimääräinen kapeneminen — *Average taper*

Mänty — *Pine*

D cm	Puun pituus, m — *Tree height, m*																		
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Kapeneminen, cm — *Taper, cm*																		
18	6	5	5	4	4	4	3	3	3	3	3	3							
19	7	6	5	5	4	4	4	3	3	3	3	3	3						
20	7	6	6	5	5	4	4	4	4	3	3	3	3	3					
21	7	7	6	5	5	5	4	4	4	4	4	3	3	3	3				
22	8	7	6	6	5	5	5	4	4	4	4	4	4	4	4	4			
23	8	7	7	6	6	5	5	5	4	4	4	4	4	4	4	4	4		
24	8	8	7	6	6	5	5	5	5	4	4	4	4	4	4	4	4	4	
25	9	8	7	7	6	6	5	5	5	5	5	4	4	4	4	4	4	4	4
26	9	8	7	7	6	6	6	5	5	5	5	5	5	4	4	4	4	4	4
27	9	8	8	7	7	6	6	6	5	5	5	5	5	5	5	5	5	5	5
28	10	9	8	7	7	6	6	6	6	5	5	5	5	5	5	5	5	5	5
29	10	9	8	8	7	7	6	6	6	6	5	5	5	5	5	5	5	5	5
30	10	9	8	8	7	7	6	6	6	6	6	5	5	5	5	5	5	5	5
31	10	9	9	8	7	7	7	6	6	6	6	6	5	5	5	5	5	5	5
32	11	10	9	8	8	7	7	7	6	6	6	6	6	6	6	5	5	5	5
33	11	10	9	8	8	7	7	7	6	6	6	6	6	6	6	6	6	6	6
34	11	10	9	9	8	8	7	7	7	6	6	6	6	6	6	6	6	6	6
35	11	10	9	9	8	8	7	7	7	7	6	6	6	6	6	6	6	6	6
36	12	11	10	9	8	8	8	7	7	7	7	6	6	6	6	6	6	6	6
37		11	10	9	9	8	8	7	7	7	7	7	7	6	6	6	6	6	6
38		11	10	9	9	8	8	8	7	7	7	7	7	7	7	6	6	6	6
39			10	10	9	9	8	8	8	7	7	7	7	7	7	7	7	7	7
40			10	10	9	9	8	8	8	7	7	7	7	7	7	7	7	7	7
41				10	9	9	8	8	8	8	7	7	7	7	7	7	7	7	7
42				10	10	9	9	8	8	8	8	7	7	7	7	7	7	7	7
43					10	9	9	8	8	8	8	8	7	7	7	7	7	7	7
44					10	9	9	9	8	8	8	8	8	8	7	7	7	7	7
45						10	9	9	9	8	8	8	8	8	8	8	7	7	7

Rungon kuutiosisältö — *Stem volume*
(keskimääräisellä kapenemisella — *average taper*)
Mänty — *Pine*

D cm	Puun pituus, m — *Tree height, m*																		
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Rungon kuutiomäärä, dm^3 — *Stem volume, dm^3*																		
18				181	187	194	217	225	233	241	250	259							
19			185	191	212	220	228	255	264	273	283	293	303						
20		189	196	215	223	247	256	265	275	307	318	330	341	353					
21	194	201	219	241	249	258	286	297	308	319	330	369	382	395	408				
22	206	223	244	252	277	287	298	330	342	354	367	380	394	407	421	435			
23	228	247	256	279	289	318	330	342	379	392	407	421	436	451	466	482	498		
24	252	260	282	308	319	351	363	377	390	433	448	464	480	497	514	531	549	567	
25	265	285	309	320	350	363	399	414	429	444	460	509	527	546	564	583	603	623	643
26	290	312	338	350	383	397	411	453	469	486	503	521	539	597	617	638	660	681	704
27	316	340	352	382	396	433	448	465	511	530	549	568	588	608	629	651	672	694	717
28	330	354	382	415	430	470	487	505	523	576	596	617	639	661	684	707	731	755	779
29	358	384	414	429	466	483	528	547	567	588	646	669	693	717	741	766	792	818	845
30	387	415	448	463	504	522	571	591	613	635	658	723	748	774	801	828	856	884	913
31	417	447	462	500	543	563	583	638	661	684	709	734	807	835	863	893	922	953	984
32	433	463	497	537	556	605	627	650	710	736	762	789	817	845	874	960	992	1 025	1 058
33	465	497	533	576	597	649	673	697	762	790	818	847	877	907	938	970	1 002	1 036	1 069
34	498	532	571	591	639	662	720	747	774	846	876	907	939	971	1 005	1 039	1 073	1 109	1 145
35	532	568	610	632	683	708	770	798	827	857	936	969	1 003	1 038	1 074	1 110	1 147	1 185	1 223
36	550	586	627	674	729	755	783	851	882	914	946	1 034	1 070	1 107	1 145	1 184	1 224	1 264	1 305
37		624	667	718	743	804	833	906	939	973	1 008	1 043	1 080	1 179	1 219	1 261	1 303	1 346	1 390
38		663	709	763	790	855	886	918	998	1 034	1 071	1 109	1 148	1 188	1 228	1 340	1 385	1 430	1 477
39			753	779	839	869	940	974	1 010	1 098	1 137	1 177	1 218	1 261	1 304	1 348	1 393	1 439	1 486
40			798	826	889	921	996	1 033	1 070	1 163	1 205	1 247	1 291	1 336	1 382	1 428	1 476	1 525	1 574
41				874	940	974	1 054	1 093	1 132	1 173	1 275	1 320	1 366	1 414	1 462	1 511	1 562	1 613	1 666
42				923	956	1 030	1 067	1 155	1 196	1 240	1 284	1 395	1 444	1 494	1 545	1 597	1 651	1 705	1 761
43					1 009	1 087	1 126	1 219	1 263	1 308	1 355	1 403	1 524	1 576	1 630	1 686	1 742	1 799	1 858
44					1 064	1 146	1 187	1 230	1 331	1 379	1 428	1 479	1 531	1 584	1 719	1 777	1 836	1 897	1 958
45						1 161	1 250	1 295	1 342	1 452	1 504	1 557	1 612	1 667	1 725	1 783	1 933	1 997	2 062

Keskimääräinen tukkiluku — *Average number of logs*

Mänty — *Pine*

D cm	Puun pituus, m — *Tree height, m*																		
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
18				1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0								
19			1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.2	1.5	1.9							
20		1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.3	1.4	1.7	1.9	2.0						
21	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.3	1.6	1.7	1.8	2.0	2.1	2.3					
22	1.0	1.0	1.0	1.0	1.1	1.2	1.3	1.6	1.8	1.9	2.0	2.0	2.3	2.4	2.5				
23	1.0	1.0	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.0	2.0	2.2	2.4	2.6	2.7	2.8			
24	1.0	1.0	1.0	1.1	1.3	1.5	1.7	1.9	2.0	2.0	2.2	2.3	2.5	2.7	2.9	3.0	3.1		
25	1.0	1.0	1.1	1.2	1.4	1.7	1.8	2.0	2.0	2.1	2.3	2.5	2.7	3.0	3.0	3.0	3.2	3.5	
26	1.0	1.0	1.1	1.3	1.5	1.8	2.0	2.0	2.0	2.2	2.4	2.6	2.8	3.0	3.0	3.2	3.4	3.7	4.0
27	1.0	1.0	1.2	1.4	1.6	1.8	2.0	2.0	2.1	2.4	2.6	2.8	2.9	3.0	3.0	3.4	3.5	3.8	4.0
28	1.0	1.0	1.2	1.5	1.7	2.0	2.0	2.1	2.2	2.5	2.7	2.9	3.0	3.0	3.2	3.4	3.7	4.0	4.0
29	1.0	1.0	1.3	1.6	1.7	2.0	2.0	2.2	2.3	2.6	2.8	3.0	3.0	3.2	3.3	3.5	3.8	4.0	4.0
30	1.0	1.0	1.3	1.6	1.8	2.0	2.0	2.3	2.4	2.6	2.8	3.0	3.0	3.2	3.3	3.6	3.9	4.0	4.0
31	1.0	1.0	1.3	1.7	1.9	2.0	2.0	2.3	2.5	2.7	2.9	3.0	3.0	3.2	3.4	3.7	4.0	4.0	4.0
32	1.0	1.0	1.3	1.7	1.9	2.0	2.0	2.3	2.6	2.8	3.0	3.0	3.1	3.3	3.4	3.7	4.0	4.0	4.0
33	1.0	1.0	1.4	1.7	2.0	2.0	2.1	2.4	2.7	2.8	3.0	3.0	3.2	3.3	3.4	3.8	4.0	4.0	4.0
34	1.0	1.0	1.4	1.8	2.0	2.0	2.1	2.4	2.7	2.9	3.0	3.0	3.2	3.4	3.6	4.0	4.0	4.0	4.0
35	1.0	1.0	1.4	1.8	2.0	2.0	2.1	2.4	2.7	3.0	3.0	3.1	3.3	3.5	3.8	4.0	4.0	4.0	4.1
36	1.0	1.0	1.4	1.8	2.0	2.0	2.2	2.5	2.8	3.0	3.0	3.2	3.5	3.7	3.8	4.0	4.0	4.0	4.1
37		1.0	1.4	1.8	2.0	2.0	2.2	2.5	2.8	3.0	3.0	3.2	3.5	3.8	3.9	4.0	4.0	4.1	4.2
38		1.0	1.5	1.8	2.0	2.0	2.2	2.5	2.8	3.0	3.0	3.2	3.6	3.8	4.0	4.0	4.0	4.2	4.3
39			1.5	1.9	2.0	2.0	2.3	2.6	2.9	3.0	3.1	3.3	3.7	3.8	4.0	4.0	4.1	4.3	4.4
40			1.5	1.9	2.0	2.0	2.3	2.6	2.9	3.0	3.1	3.4	3.7	3.9	4.0	4.0	4.2	4.4	4.6
41				1.9	2.0	2.0	2.3	2.7	2.9	3.0	3.1	3.4	3.8	4.0	4.0	4.0	4.3	4.5	4.6
42				1.9	2.0	2.0	2.4	2.7	3.0	3.0	3.2	3.5	3.8	4.0	4.0	4.0	4.3	4.5	4.7
43					2.0	2.0	2.4	2.7	3.0	3.0	3.2	3.5	3.9	4.0	4.0	4.1	4.3	4.6	4.8
44					2.0	2.0	2.4	2.8	3.0	3.1	3.3	3.6	3.9	4.0	4.0	4.2	4.4	4.7	4.9
45						2.0	2.5	2.8	3.0	3.1	3.3	3.6	3.9	4.0	4.0	4.2	4.5	4.8	5.0

Rungon kuutiojalkamäärä — *Top volume of saw timber stems*
(keskimääräisellä kapenemisella — *average taper*)
Mänty — *Pine*

D cm	Puun pituus, m — *Tree height, m*																		
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	j³/runko — *f³/stem*																		
18				2.3	2.5	2.6	3.1	3.2	3.4	3.5	3.7	3.9							
19			2.4	2.5	3.0	3.2	3.3	3.9	4.1	4.3	4.5	4.7	5.0						
20		2.5	2.6	3.1	3.2	3.8	4.0	4.2	4.4	5.1	5.4	5.6	5.9	6.2					
21	2.5	2.6	3.1	3.7	3.8	4.0	4.7	4.9	5.2	5.4	5.7	6.6	7.0	7.3	7.6				
22	2.6	3.1	3.7	3.9	4.5	4.7	5.0	5.8	6.0	6.3	6.6	7.0	7.3	7.7	8.1	8.5			
23	3.1	3.7	3.8	4.5	4.7	5.5	5.7	6.0	7.0	7.3	7.7	8.0	8.4	8.8	9.3	9.7	10.2		
24	3.6	3.8	4.5	5.2	5.4	6.3	6.6	6.9	7.2	8.3	8.7	9.2	9.6	10.1	10.6	11.1	11.6	12.2	
25	3.8	4.4	5.1	5.4	6.2	6.5	7.5	7.8	8.2	8.6	9.0	10.3	10.9	11.4	11.9	12.5	13.1	13.8	14.5
26	4.3	5.0	5.8	6.1	7.0	7.3	7.7	8.8	9.2	9.7	10.2	10.7	11.2	12.8	13.4	14.0	14.7	15.5	16.2
27	4.9	5.7	6.0	6.9	7.2	8.2	8.6	9.1	10.3	10.8	11.4	11.9	12.5	13.1	13.8	14.4	15.1	15.9	16.7
28	5.0	5.8	6.7	7.7	8.0	9.2	9.6	10.1	10.6	12.0	12.6	13.2	13.9	14.5	15.3	16.0	16.8	17.6	18.5
29	5.7	6.5	7.5	7.8	8.9	9.4	10.6	11.2	11.7	12.3	13.9	14.6	15.3	16.0	16.8	17.7	18.5	19.4	20.4
30	6.3	7.3	8.3	8.7	9.9	10.3	11.7	12.3	12.9	13.5	14.2	16.0	16.8	17.6	18.5	19.4	20.3	21.3	22.4
31	7.0	8.0	8.4	9.6	10.8	11.4	11.9	13.4	14.1	14.8	15.5	16.3	18.3	19.2	20.2	21.2	22.2	23.3	24.4
32	7.2	8.2	9.3	10.5	11.0	12.4	13.0	13.7	15.4	16.1	16.9	17.8	18.6	19.5	20.5	23.0	24.1	25.3	26.6
33	7.9	9.0	10.1	11.5	12.0	13.5	14.2	14.9	16.7	17.5	18.4	19.3	20.2	21.2	22.3	23.3	24.5	25.7	27.0
34	8.7	9.8	11.1	11.6	13.1	13.7	15.4	16.1	16.9	18.9	19.9	20.8	21.9	22.9	24.1	25.2	26.5	27.8	29.2
35	9.5	10.7	12.0	12.6	14.1	14.8	16.6	17.4	18.3	19.2	21.4	22.5	23.6	24.7	25.9	27.2	28.5	29.9	31.4
36	9.6	10.8	12.2	13.6	15.3	16.0	16.8	18.8	19.7	20.6	21.7	24.1	25.3	26.6	27.9	29.2	30.7	32.2	33.8
37		11.7	13.1	14.7	15.4	17.2	18.1	20.1	21.1	22.2	23.2	24.4	25.6	28.5	29.9	31.3	32.9	34.5	36.2
38		12.6	14.1	15.8	16.6	18.5	19.4	20.3	22.6	23.7	24.9	26.1	27.4	28.7	30.1	33.5	35.1	36.8	38.6
39			15.2	15.9	17.8	18.6	20.7	21.7	22.8	25.3	26.6	27.9	29.2	30.7	32.2	33.8	35.4	37.2	39.0
40			16.3	17.1	19.0	19.9	22.1	23.2	24.3	27.0	28.3	29.7	31.1	32.7	34.3	36.0	37.7	39.6	41.5
41				18.2	20.2	21.2	23.5	24.7	25.9	27.2	30.1	31.5	33.1	34.7	36.4	38.2	40.1	42.1	44.1
42				19.4	20.4	22.6	23.7	26.2	27.5	28.9	30.3	33.5	35.1	36.8	38.6	40.5	42.5	44.6	46.8
43					21.7	24.0	25.2	27.8	29.2	30.6	32.1	33.7	37.2	39.0	40.9	42.9	45.0	47.2	49.5
44					23.0	25.4	26.7	28.0	30.9	32.4	34.0	35.6	37.4	39.2	43.2	45.3	47.5	49.9	52.3
45						25.6	28.2	29.6	31.0	34.2	35.9	37.6	39.5	41.4	43.5	45.6	50.1	52.6	55.2

Puutavaralajiprosentit — *Timber assortment percentages*
(keskimääräisellä kapenemisella ja tukkiluvulla — *average taper and log number*)
Mänty — *Pine*

D cm	Puun pituus, m — *Tree height, m*																		
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
			69	65	62	59	57	55	53	51	50		tukkipuu-% — *saw timber percentage*						
18			29.2	33.3	36.2	39.1	41.3	43.3	45.3	47.3	48.3		kuitupuu-% — *pulpwood percentage*						
			1.8	1.7	1.8	1.9	1.7	1.7	1.7	1.7	1.7		hukkapuu-% — *waste wood percentage*						
		74	70	66	63	61	59	57	59	60	67	72							
19		24.5	28.5	32.3	35.5	37.4	39.3	41.6	39.5	38.5	31.6	26.6							
		1.5	1.5	1.7	1.5	1.6	1.7	1.5	1.5	1.5	1.4	1.4							
	80	75	71	68	65	62	60	62	67	68	72	74	75						
20	18.8	23.7	27.5	30.6	33.5	36.7	38.6	36.6	31.6	30.8	26.8	24.8	23.8						
	1.2	1.3	1.5	1.4	1.5	1.3	1.4	1.4	1.4	1.2	1.2	1.2	1.2						
	80	75	72	69	66	64	68	70	75	75	76	78	78	79					
21	19.0	23.8	26.8	29.8	32.7	34.7	30.8	28.8	23.8	23.8	22.8	21.0	21.0	20.0					
	1.0	1.2	1.2	1.2	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.0	1.0	1.0					
	80	76	72	69	70	71	72	78	80	80	80	79	81	82	82				
22	19.0	23.0	27.0	29.9	28.9	27.9	26.8	21.0	18.9	18.9	18.9	20.0	18.0	17.0	17.0				
	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.0				
	80	76	73	73	74	75	78	80	82	82	81	83	84	85	85	85			
23	19.2	23.1	26.0	26.0	25.0	24.0	21.0	19.0	17.1	17.1	18.1	16.1	15.1	14.1	14.2	14.2			
	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8			
	80	76	73	74	78	80	83	84	84	83	84	85	86	86	87	87	87		
24	19.3	23.1	26.1	25.2	21.1	19.2	16.1	15.1	15.1	16.2	15.2	14.2	13.2	13.2	12.3	12.3	12.3		
	0.7	0.9	0.9	0.8	0.9	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7		
	80	76	77	77	80	85	85	86	85	85	86	87	88	89	88	88	88	89	
25	19.3	23.3	22.3	22.2	19.2	14.2	14.2	13.2	14.2	14.2	13.2	12.3	11.3	10.3	11.3	11.4	11.4	10.4	
	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	
	80	76	77	80	83	87	88	87	86	87	88	89	89	90	89	90	90	90	91
26	19.4	23.4	22.4	19.3	16.3	12.3	11.3	12.3	13.3	12.3	11.3	10.3	10.3	9.4	10.4	9.4	9.4	9.5	8.5
	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5
	79	76	80	83	85	87	88	87	87	89	90	91	91	91	90	91	91	91	91
27	20.5	23.4	19.4	16.4	14.3	12.4	11.4	12.3	12.4	10.4	9.4	8.4	8.4	8.4	9.4	8.4	8.4	8.5	8.5
	0.5	0.6	0.6	0.6	0.7	0.6	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5
	79	76	80	85	87	90	89	89	89	91	91	92	92	91	92	92	92	92	92
28	20.5	23.5	19.5	14.5	12.4	9.5	10.4	10.4	8.5	10.4	8.5	7.5	7.5	8.5	7.5	7.5	7.5	7.5	7.5
	0.5	0.5	0.5	0.5	0.6	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	79	76	83	87	87	90	89	90	90	92	92	93	92	93	92	93	93	93	93
29	20.5	23.5	16.5	12.5	12.5	9.5	10.5	9.5	9.5	7.5	7.5	6.5	7.5	6.5	7.5	6.5	6.5	6.6	6.6
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
	78	75	83	87	89	90	89	91	91	92	93	93	93	93	93	93	94	94	93
30	21.6	24.6	16.6	12.5	10.5	9.5	10.6	8.5	8.5	7.5	6.5	6.6	6.6	6.6	6.6	6.6	5.6	5.6	6.6
	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

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Rungon arvo — *Stem value*
(keskimääräisellä kapenemisella — *average taper*)
Mänty — *Pine*

D cm	Puun pituus, m — *Tree height, m*																		
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	mk/runko — *Fmk/stem*																		
18				5.9	6.0	6.1	7.3	7.5	7.7	7.9	8.2	8.5							
19			6.0	6.1	7.2	7.3	7.5	8.9	9.2	9.5	9.8	10.2	10.6						
20		6.1	6.2	7.2	7.4	8.7	8.9	9.2	9.6	11.2	11.6	12.1	12.6	13.0					
21	6.2	6.2	7.3	8.5	8.7	8.9	10.5	10.8	11.2	11.6	12.1	14.2	14.7	15.3	15.9				
22	6.3	7.3	8.5	8.6	10.1	10.4	10.8	12.6	13.1	13.6	14.1	14.7	15.3	15.9	16.6	17.2			
23	7.3	8.4	8.6	10.0	10.3	12.0	12.4	12.9	15.0	15.7	16.3	17.0	17.7	18.4	19.2	20.0	20.8		
24	8.4	8.5	9.9	11.5	11.8	13.7	14.3	14.8	15.4	17.9	18.7	19.5	20.3	21.2	22.1	23.0	23.9	24.9	
25	8.5	9.8	11.3	11.7	13.5	14.0	16.2	16.9	17.6	18.4	19.2	22.1	23.1	24.1	25.2	26.2	27.3	28.5	29.7
26	9.7	11.2	12.8	13.2	15.3	15.9	16.6	19.1	19.9	20.8	21.8	22.7	23.7	27.3	28.5	29.7	31.0	32.3	33.7
27	11.0	12.6	13.0	14.9	15.5	17.9	18.7	19.5	22.4	23.5	24.5	25.6	26.8	28.0	29.2	30.5	31.8	33.2	34.6
28	11.1	12.7	14.6	16.8	17.4	20.0	20.9	21.9	22.9	26.3	27.5	28.7	30.0	31.4	32.8	34.3	35.8	37.3	38.9
29	12.5	14.3	16.3	17.0	19.5	20.3	23.3	24.4	25.6	26.8	30.6	32.0	33.5	35.1	36.6	38.3	40.0	41.7	43.5
30	14.0	15.9	18.2	18.9	21.6	22.6	25.9	27.1	28.4	29.8	31.2	35.5	37.2	38.9	40.7	42.6	44.5	46.4	48.5
31	15.5	17.7	18.3	21.0	23.9	25.0	26.2	29.9	31.4	32.9	34.5	36.2	41.1	43.0	45.0	47.1	49.2	51.4	53.7
32	15.6	17.8	20.3	23.1	24.2	27.6	29.0	30.4	34.6	36.3	38.1	39.9	41.8	43.8	45.9	51.9	54.3	56.7	59.2
33	17.3	19.6	22.3	25.4	26.6	30.3	31.8	33.4	37.9	39.8	41.8	43.9	46.0	48.2	50.5	52.8	55.2	57.7	60.3
34	19.0	21.6	24.5	25.6	29.2	30.6	34.8	36.6	38.4	43.5	45.7	48.0	50.3	52.8	55.3	57.9	60.6	63.3	66.1
35	20.9	23.6	26.8	28.1	31.9	33.5	38.0	39.9	42.0	44.1	49.9	52.4	54.9	57.6	60.4	63.2	66.2	69.2	72.3
36	21.0	23.8	27.0	30.6	34.7	36.5	38.4	43.4	45.7	48.0	50.5	56.9	59.7	62.7	65.7	68.8	72.0	75.4	78.8
37		25.9	29.3	33.2	35.0	39.6	41.7	47.1	49.6	52.1	54.8	57.6	60.5	68.0	71.3	74.7	78.2	81.8	85.5
38		28.2	31.8	36.0	37.9	42.8	45.1	47.6	53.6	56.4	59.4	62.4	65.6	68.8	72.2	80.8	84.7	88.6	92.6
39			34.4	36.2	41.0	43.2	48.8	51.4	54.2	60.9	64.1	67.4	70.9	74.4	78.1	81.8	85.7	89.7	93.9
40			37.2	39.1	44.2	46.6	52.5	55.4	58.4	65.6	69.1	72.6	76.4	80.2	84.2	88.3	92.5	96.8	101
41				42.2	47.5	50.2	56.4	59.6	62.8	66.2	74.2	78.1	82.1	86.3	90.6	95.0	99.5	104	109
42				45.3	47.8	53.9	56.9	63.9	67.4	71.1	74.9	83.7	88.1	92.6	97.2	102	107	112	117
43					51.3	57.7	61.0	68.4	72.2	76.1	80.2	84.5	94.3	99.1	104	109	115	120	126
44					54.9	61.7	65.2	68.9	77.1	81.4	85.8	90.4	95.1	100	111	117	122	128	134
45						62.1	69.6	73.6	77.7	86.8	91.6	96.5	102	107	112	118	131	137	143

Kiintokuutiometri kuutiojaloiksi — *Conversion of true solid volumes (m^3) into top volumes (f^3) of saw timber*
(keskimääräisellä kapenemisella — *average taper*)
Mänty — *Pine*

D cm	Puun pituus, m — *Tree height, m*																		
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Muuntokerroin kuutiometristä kuutiojaloiksi — *Coefficient of conversion*																		
18				22.2	22.2	22.2	23.9	24.0	24.1	24.2	24.4	24.5							
19			21.1	21.1	22.5	22.5	22.6	24.2	24.3	24.4	24.6	24.8	25.0						
20		20.3	20.2	21.4	21.4	22.8	22.9	23.0	23.1	24.6	24.8	25.0	25.2	25.4					
21	19.7	19.6	20.6	21.7	21.7	21.8	23.1	23.2	23.4	23.5	23.7	25.2	25.3	25.6	25.8				
22	19.1	19.9	20.8	20.9	22.0	22.0	22.2	23.4	23.6	23.7	23.9	24.1	24.3	24.5	24.7	24.9			
23	19.4	20.2	20.2	21.1	21.2	22.3	22.4	22.5	23.7	23.9	24.1	24.3	24.5	24.7	24.9	25.1	25.4		
24	19.7	19.6	20.4	21.4	21.4	22.5	22.6	22.7	22.9	24.1	24.3	24.5	24.7	24.9	25.1	25.3	25.6	25.8	
25	19.3	19.9	20.7	20.7	21.7	21.8	22.8	22.9	23.1	23.3	23.5	24.6	24.8	25.0	25.3	25.5	25.7	26.0	26.2
26	19.5	20.2	20.9	21.0	21.8	22.0	22.1	23.1	23.3	23.4	23.6	23.9	24.1	25.2	25.4	25.6	25.9	26.1	26.4
27	19.8	20.4	20.4	21.2	21.3	22.1	22.3	22.4	23.4	23.6	23.8	24.0	24.2	24.4	24.7	24.9	25.1	25.4	25.6
28	19.5	20.0	20.6	21.4	21.5	22.3	22.4	22.6	22.8	23.7	23.9	24.1	24.4	24.6	24.8	25.1	25.3	25.5	25.8
29	19.7	20.2	20.8	20.9	21.6	21.8	22.6	22.8	22.9	23.1	24.0	24.3	24.5	24.7	24.9	25.2	25.4	25.7	25.9
30	19.9	20.4	21.0	21.1	21.8	21.9	22.7	22.9	23.1	23.3	23.5	24.4	24.6	24.8	25.1	25.3	25.5	25.8	26.0
31	20.1	20.6	20.6	21.2	21.9	22.1	22.2	23.0	23.2	23.4	23.6	23.8	24.7	24.9	25.1	25.4	25.6	25.9	26.1
32	19.9	20.3	20.8	21.4	21.5	22.2	22.4	22.5	23.3	23.5	23.7	23.9	24.2	24.4	24.6	25.5	25.7	26.0	26.2
33	20.0	20.5	21.0	21.5	21.6	22.3	22.5	22.6	23.4	23.6	23.8	24.0	24.2	24.5	24.7	25.0	25.2	25.5	25.7
34	20.2	20.6	21.1	21.2	21.8	21.9	22.6	22.7	22.9	23.6	23.9	24.1	24.3	24.6	24.8	25.1	25.3	25.6	25.8
35	20.3	20.7	21.2	21.3	21.9	22.0	22.6	22.8	23.0	23.2	23.9	24.2	24.4	24.6	24.9	25.1	25.4	25.6	25.9
36	20.2	20.5	20.9	21.4	21.9	22.1	22.3	22.9	23.1	23.3	23.5	24.2	24.4	24.7	24.9	25.2	25.4	25.7	25.9
37		20.6	21.0	21.5	21.7	22.2	22.4	22.9	23.2	23.4	23.6	23.8	24.1	24.7	25.0	25.2	25.5	25.7	26.0
38		20.8	21.1	21.6	21.7	22.2	22.4	22.6	23.2	23.4	23.6	23.9	24.1	24.4	24.6	25.3	25.5	25.8	26.0
39			21.2	21.4	21.8	22.0	22.5	22.7	22.9	23.5	23.7	23.9	24.2	24.4	24.7	24.9	25.2	25.4	25.7
40			21.3	21.4	21.9	22.0	22.5	22.7	22.9	23.5	23.7	24.0	24.2	24.4	24.7	24.9	25.2	25.5	25.7
41				21.5	21.9	22.1	22.6	22.8	23.0	23.2	23.7	24.0	24.2	24.5	24.7	25.0	25.2	25.5	25.8
42				21.6	21.7	22.1	22.3	22.8	23.0	23.2	23.5	24.0	24.2	24.5	24.7	25.0	25.2	25.5	25.8
43					21.8	22.2	22.4	22.8	23.0	23.3	23.5	23.7	24.2	24.5	24.7	25.0	25.3	25.5	25.8
44					21.8	22.2	22.4	22.6	23.0	23.3	23.5	23.7	24.0	24.2	24.7	25.0	25.3	25.5	25.8
45						22.0	22.4	22.6	22.8	23.3	23.5	23.8	24.0	24.3	24.5	24.8	25.2	25.5	25.8

Rungon yksikkökuutiometrin arvo — *Value of stem/m³*
(keskimääräisellä kapenemisella — *average taper*)
Mänty — *Pine*

D cm	Puun pituus, m — *Tree height, m*																		
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	mk/m³ — *Fmk/m³*																		
18				32.7	32.1	31.6	33.4	33.2	33.0	32.9	32.8	32.8							
19			32.6	31.8	33.8	33.4	33.1	34.9	34.8	34.8	34.8	34.8	34.9						
20		32.3	31.5	33.6	33.1	35.1	34.9	34.8	34.7	36.5	36.6	36.7	36.8	36.9					
21	32.0	31.0	33.1	35.1	34.8	34.6	36.5	36.5	36.5	36.6	36.7	38.4	38.6	38.8	39.0				
22	30.5	32.6	34.7	34.3	36.3	36.2	36.1	38.1	38.1	38.3	38.4	38.6	38.8	39.1	39.3	39.6			
23	32.1	34.2	33.6	35.8	35.6	37.7	37.7	37.8	39.7	39.9	40.1	40.3	40.6	40.9	41.2	41.5	41.8		
24	33.6	32.9	35.2	37.3	37.2	39.1	39.2	39.4	39.6	41.4	41.7	41.9	42.3	42.6	42.9	43.3	43.6	44.0	
25	32.2	34.4	36.6	36.4	38.6	38.6	40.6	40.8	41.1	41.1	41.7	41.7	43.5	43.8	44.2	44.6	45.0	45.3	45.7	46.1
26	33.6	35.8	37.9	37.8	39.9	40.1	40.3	42.2	42.5	42.9	43.2	43.6	44.0	45.7	46.1	46.6	47.0	47.4	47.8
27	34.9	37.1	36.9	39.1	39.3	41.4	41.6	42.0	43.9	44.3	44.7	45.1	45.5	46.0	46.4	46.9	47.3	47.8	48.2
28	33.6	35.9	38.2	40.4	40.6	42.6	42.9	43.3	43.7	45.6	46.1	46.5	47.0	47.5	48.0	48.5	49.0	49.5	49.9
29	34.9	37.2	39.4	39.6	41.8	42.1	44.2	44.6	45.1	45.5	47.4	47.9	48.4	48.9	49.4	50.0	50.5	51.0	51.6
30	36.1	38.4	40.6	40.8	43.0	43.4	45.3	45.8	46.3	46.9	47.4	49.1	49.7	50.3	50.8	51.4	52.0	52.5	53.1
31	37.3	39.5	39.7	42.0	44.1	44.5	45.0	47.0	47.5	48.1	48.7	49.3	51.0	51.6	52.2	52.8	53.4	54.0	54.5
32	36.1	38.4	40.8	43.1	43.5	45.6	46.2	46.8	48.7	49.3	49.9	50.6	51.2	51.8	52.5	54.1	54.7	55.3	55.9
33	37.2	39.6	41.9	44.1	44.6	46.7	47.3	47.9	49.8	50.4	51.1	51.8	52.4	53.1	53.8	54.4	55.1	55.7	56.4
34	38.2	40.6	42.9	43.4	45.6	46.2	48.3	49.0	49.7	51.5	52.2	52.9	53.6	54.3	55.0	55.7	56.4	57.1	57.8
35	39.3	41.6	43.9	44.4	46.6	47.3	49.3	50.0	50.8	51.5	53.3	54.0	54.8	55.5	56.2	57.0	57.7	58.4	59.1
36	38.1	40.6	43.0	45.4	47.6	48.3	49.0	51.0	51.8	52.6	53.4	55.0	55.8	56.6	57.4	58.1	58.9	59.6	60.4
37		41.6	44.0	46.3	47.0	49.2	50.0	52.0	52.8	53.6	54.4	55.2	56.0	57.7	58.5	59.3	60.0	60.8	61.6
38		42.5	44.9	47.2	48.0	50.1	51.0	51.8	53.7	54.6	55.4	56.3	57.1	58.0	58.8	60.3	61.1	61.9	62.7
39			45.8	46.5	48.9	49.7	51.9	52.7	53.6	55.5	56.4	57.3	58.2	59.0	59.9	60.7	61.6	62.4	63.2
40			46.6	47.4	49.7	50.6	52.7	53.6	54.6	56.4	57.3	58.2	59.2	60.1	60.9	61.8	62.7	63.5	64.3
41				48.3	50.5	51.5	53.5	54.5	55.5	56.4	58.2	59.2	60.1	61.0	61.9	62.8	63.7	64.6	65.5
42				49.1	50.0	52.3	53.3	55.3	56.3	57.3	58.3	60.0	61.0	62.0	62.9	63.8	64.7	65.6	66.5
43					50.8	53.1	54.1	56.1	57.2	58.2	59.2	60.2	61.9	62.9	63.8	64.8	65.7	66.6	67.5
44					51.6	53.8	54.9	56.0	58.0	59.0	60.1	61.1	62.1	63.1	64.7	65.7	66.6	67.6	68.5
45						53.5	55.7	56.8	57.9	59.8	60.9	62.0	63.0	64.1	65.1	66.1	67.5	68.5	69.5

Tukkipuiden keskimääräinen kapeneminen — *Average taper*

Kuusi — *Spruce*

D cm	Puun pituus, m — *Tree height, m*																	
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	Kapeneminen, cm — *Taper, cm*																	
18	5	5	4	3	3	2	2	2	1	1								
19	6	5	4	4	3	3	2	2	2	2	1							
20	6	6	5	4	4	3	3	3	2	2	2	2						
21	7	6	5	5	4	4	3	3	3	2	2	2	2					
22	7	6	6	5	5	4	4	3	3	3	2	2	2	2				
23	8	7	6	6	5	4	4	4	3	3	3	2	2	2	2			
24	8	7	7	6	5	5	4	4	3	3	3	3	3	3	2	3		
25	9	8	7	6	6	5	5	4	4	3	3	3	3	3	3	3	3	
26	9	8	7	7	6	5	5	4	4	4	3	3	3	3	3	3	3	3
27	9	9	8	7	6	6	5	5	4	4	4	3	3	3	3	3	3	3
28	10	9	8	8	7	6	6	5	5	4	4	4	3	3	3	3	3	3
29	10	10	9	8	7	7	6	5	5	5	4	4	4	3	3	3	3	3
30	11	10	9	8	8	7	6	6	5	5	4	4	4	4	3	3	3	3
31	11	11	10	9	8	7	7	6	6	5	5	4	4	4	4	3	3	3
32	12	11	10	9	9	8	7	6	6	5	5	5	4	4	4	4	3	3
33	13	12	11	10	9	8	7	7	6	6	5	5	4	4	4	4	4	3
34	13	12	11	10	9	9	8	7	7	6	6	5	5	4	4	4	4	4
35	14	13	12	11	10	9	8	8	7	6	6	5	5	5	4	4	4	4
36	14	13	12	11	10	10	9	8	7	7	6	6	5	5	4	4	4	4
37	15	14	13	12	11	10	9	8	8	7	7	6	5	5	5	4	4	4
38		15	14	13	12	11	10	9	8	8	7	6	6	5	5	5	4	4
39		15	14	13	12	11	10	9	9	8	7	7	6	6	5	5	4	4
40			15	14	13	12	11	10	9	8	8	7	6	6	5	5	5	4
41			16	14	13	12	11	10	10	9	8	7	7	6	6	5	5	5
42				15	14	13	12	11	10	9	9	8	7	7	6	6	5	5
43				16	15	14	13	12	11	10	9	8	8	7	6	6	5	5
44					15	14	13	12	11	10	9	9	8	7	7	6	6	5
45					16	15	14	13	12	11	10	9	8	8	7	6	6	5

Rungon kuutiosisältö — *Stem volume*
(keskimääräisellä kapenemisella — *average taper*)
Kuusi — *Spruce*

D cm	Puun pituus, m — *Tree height, m*																	
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	Rungon kuutiomäärä, dm^3 — *Stem volume, dm^3*																	
18			186	209	215	245	253	261	301	311								
19		190	211	217	244	251	286	295	305	316	364							
20	195	200	220	245	252	283	292	302	343	355	367	381						
21	206	224	247	254	282	291	326	337	349	396	410	425	441					
22	230	250	257	283	291	323	334	374	387	401	455	471	489	507				
23	242	262	285	293	323	358	369	382	428	443	459	520	539	559	580			
24	268	289	297	324	356	367	407	420	470	487	504	522	542	562	637	605		
25	281	302	327	356	367	403	416	461	476	533	552	572	593	615	638	662	688	
26	309	332	358	369	401	440	454	503	520	538	601	623	646	670	695	722	749	778
27	339	347	373	402	437	451	494	511	565	585	605	676	701	727	754	783	813	845
28	355	378	406	417	451	490	506	554	573	633	656	679	758	786	816	847	879	914
29	386	396	422	453	488	504	547	599	619	641	707	733	760	847	879	912	947	984
30	405	429	457	490	504	544	590	610	667	690	761	788	817	848	944	980	1 017	1 057
31	439	450	477	508	544	586	605	656	678	741	767	845	876	909	943	1 049	1 089	1 132
32	461	486	514	547	563	603	649	703	727	793	821	851	936	971	1 008	1 046	1 163	1 208
33	485	509	537	568	605	646	695	718	777	804	877	908	998	1 035	1 074	1 115	1 158	1 285
34	523	548	576	609	647	668	714	767	793	857	888	967	1 003	1 101	1 142	1 186	1 231	1 279
35	551	575	603	635	671	713	761	786	844	912	944	1 027	1 065	1 104	1 211	1 257	1 306	1 356
36	591	616	645	678	716	739	784	837	897	928	1 002	1 038	1 128	1 170	1 281	1 330	1 381	1 435
37	624	648	677	709	745	786	834	888	918	984	1 019	1 099	1 192	1 236	1 283	1 404	1 458	1 514
38		684	711	742	777	817	862	914	973	1 007	1 078	1 160	1 203	1 304	1 353	1 405	1 535	1 594
39		730	758	790	826	867	914	967	1 000	1 064	1 137	1 178	1 268	1 315	1 424	1 478	1 613	1 675
40			799	829	864	904	948	999	1 056	1 122	1 162	1 241	1 333	1 383	1 495	1 552	1 612	1 757
41			843	881	916	957	1 003	1 054	1 091	1 152	1 223	1 305	1 353	1 451	1 506	1 627	1 689	1 755
42				927	961	1 000	1 044	1 093	1 149	1 212	1 256	1 332	1 419	1 472	1 578	1 638	1 767	1 836
43				978	1 011	1 049	1 091	1 138	1 191	1 251	1 319	1 396	1 448	1 541	1 650	1 713	1 845	1 917
44					1 069	1 107	1 150	1 198	1 252	1 313	1 382	1 433	1 516	1 611	1 672	1 788	1 857	1 998
45					1 127	1 164	1 205	1 251	1 302	1 360	1 425	1 499	1 584	1 643	1 745	1 863	1 935	2 079

Keskimääräinen tukkiluku — *Average number of logs*

Kuusi — *Spruce*

D cm	Puun pituus, m — *Tree height, m*																	
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
18			1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0								
19		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2							
20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.2	1.6	1.8	2.0						
21	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.3	1.7	2.0	2.0	2.2	2.4					
22	1.0	1.0	1.0	1.0	1.0	1.2	1.5	1.8	1.9	2.0	2.3	2.6	2.7	3.0				
23	1.0	1.0	1.0	1.0	1.0	1.3	1.6	2.0	2.0	2.1	2.4	2.6	2.8	3.0	3.0			
24	1.0	1.0	1.0	1.0	1.1	1.5	1.8	2.0	2.0	2.2	2.5	2.7	2.9	3.0	3.0			
25	1.0	1.0	1.0	1.0	1.3	1.5	1.8	2.0	2.0	2.2	2.5	2.8	2.9	3.0	3.1	3.4		
26	1.0	1.0	1.0	1.1	1.4	1.5	1.9	2.0	2.0	2.3	2.5	2.9	3.0	3.1	3.2	3.6		
27	1.0	1.0	1.0	1.3	1.5	1.7	1.9	2.0	2.0	2.3	2.6	3.0	3.0	3.2	3.4	3.7		
28	1.0	1.0	1.1	1.4	1.5	1.8	2.0	2.0	2.1	2.4	2.7	3.0	3.0	3.2	3.4	3.7	4.0	
29	1.0	1.0	1.2	1.4	1.6	1.8	2.0	2.0	2.2	2.5	2.7	3.0	3.0	3.3	3.4	3.8	4.0	
30	1.0	1.1	1.3	1.5	1.7	1.9	2.0	2.0	2.3	2.5	2.8	3.0	3.0	3.3	3.5	3.9	4.0	
31	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.1	2.4	2.7	2.8	3.0	3.0	3.4	3.5	4.0	4.0	4.0
32	1.0	1.2	1.5	1.8	1.9	2.0	2.0	2.2	2.5	2.8	2.9	3.0	3.1	3.4	3.6	4.0	4.0	4.0
33	1.1	1.3	1.7	1.9	2.0	2.0	2.1	2.3	2.6	2.8	2.9	3.0	3.1	3.5	3.6	4.0	4.0	4.0
34	1.2	1.4	1.8	1.9	2.0	2.0	2.2	2.5	2.7	2.9	2.9	3.0	3.2	3.5	3.8	4.0	4.0	4.0
35	1.2	1.4	1.8	1.9	2.0	2.0	2.3	2.6	2.7	2.9	3.0	3.0	3.2	3.6	3.9	4.0	4.0	4.0
36	1.3	1.5	1.9	2.0	2.0	2.1	2.3	2.6	2.8	2.9	3.0	3.0	3.3	3.6	3.9	4.0	4.0	4.1
37	1.3	1.6	1.9	2.0	2.0	2.1	2.4	2.6	2.8	2.9	3.0	3.0	3.3	3.6	4.0	4.0	4.0	4.2
38		1.7	1.9	2.0	2.0	2.1	2.4	2.7	2.8	3.0	3.0	3.1	3.4	3.7	4.0	4.0	4.1	4.3
39		1.8	2.0	2.0	2.0	2.2	2.5	2.7	2.9	3.0	3.0	3.1	3.4	3.7	4.0	4.0	4.1	4.4
40			2.0	2.0	2.0	2.2	2.5	2.8	2.9	3.0	3.0	3.2	3.5	3.8	4.0	4.0	4.2	4.5
41			2.0	2.0	2.0	2.3	2.6	2.8	2.9	3.0	3.0	3.2	3.5	3.8	4.0	4.0	4.3	4.6
42				2.0	2.0	2.3	2.6	2.8	3.0	3.0	3.1	3.3	3.6	4.0	4.0	4.1	4.4	4.7
43				2.0	2.0	2.4	2.7	2.9	3.0	3.0	3.1	3.3	3.6	4.0	4.0	4.1	4.5	4.8
44					2.0	2.4	2.8	2.9	3.0	3.0	3.1	3.4	3.7	4.0	4.0	4.2	4.6	4.9
45					2.0	2.5	2.8	3.0	3.0	3.0	3.1	3.5	3.8	4.0	4.0	4.2	4.7	5.0

Puutavaralajiprosentit — *Timber assortment percentages*
(keskimääräisellä kapenemisella ja tukkiluvulla — *average taper and log number*)
Kuusi — *Spruce*

D cm	Puun pituus, m — *Tree height, m*																	
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
18			61	59	56	54	52	49	47	45			tukkipuu-% — *saw timber percentage*					
			36.7	38.9	41.8	44.1	46.1	49.1	51.5	53.5			kuitupuu-% — *pulpwood percentage*					
			2.3	2.1	2.2	1.9	1.9	1.9	1.5	1.5			hukkapuu-% — *waste wood percentage*					
19		65	62	60	58	56	54	52	50	48	53							
		32.9	36.1	38.0	40.2	42.1	44.4	46.4	48.4	50.4	45.8							
		2.1	1.9	2.0	1.8	1.9	1.6	1.6	1.6	1.6	1.2							
	68	66	64	61	59	57	55	57	59	66	68	69						
20	30.3	32.0	34.2	37.3	39.2	41.4	43.4	41.4	39.7	32.7	30.7	29.7						
	1.7	2.0	1.8	1.7	1.8	1.6	1.6	1.6	1.3	1.3	1.3	1.3						
	69	67	65	63	61	59	61	65	72	75	73	74	75					
21	29.3	31.4	33.5	35.4	37.5	39.5	37.7	33.6	26.6	23.9	25.9	24.9	23.9					
	1.7	1.6	1.5	1.6	1.5	1.5	1.3	1.4	1.4	1.1	1.1	1.1	1.1					
	69	67	65	63	62	67	72	76	76	76	78	80	79	80				
22	29.6	31.7	33.5	35.6	36.5	31.7	26.7	22.8	22.8	22.8	21.0	19.0	20.1	19.1				
	1.4	1.3	1.5	1.4	1.5	1.3	1.3	1.2	1.2	1.2	1.0	1.0	0.9	0.9				
	69	68	66	64	62	70	75	80	79	79	81	81	82	82	81			
23	29.7	30.7	32.7	34.6	36.7	28.9	23.8	18.8	20.0	20.0	18.0	18.2	17.2	17.2	18.2			
	1.3	1.3	1.3	1.4	1.3	1.1	1.2	1.2	1.0	1.0	1.0	0.8	0.8	0.8	0.8			
	70	68	66	65	67	76	80	81	80	81	83	84	84	84	83			
24	28.9	30.9	32.8	33.8	31.9	22.9	19.0	18.0	19.1	18.1	16.1	15.1	15.2	15.2	16.3			
	1.1	1.1	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.7			
	70	68	66	65	73	76	80	82	81	82	84	85	85	85	85	86		
25	28.9	30.9	32.9	34.0	25.9	23.0	19.0	17.1	18.1	17.2	15.2	14.2	14.2	14.3	14.3	13.3		
	1.1	1.1	1.1	1.0	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7		
	70	68	67	69	76	77	82	83	82	84	85	87	87	87	87	88		
26	29.1	31.1	32.1	30.0	23.1	22.1	17.1	16.2	17.2	15.2	14.3	12.3	12.3	12.3	12.4	11.4		
	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6		
	70	68	67	75	78	81	83	83	82	85	87	89	88	88	89	89		
27	29.2	31.1	32.1	24.1	21.2	18.1	16.2	16.2	17.3	14.3	12.3	10.4	11.4	11.4	10.4	10.4		
	0.8	0.9	0.9	0.9	0.8	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6		
	69	68	70	77	78	83	85	84	84	86	88	89	89	89	90	90	91	
28	30.2	31.2	29.2	22.1	21.2	16.2	14.2	15.3	15.3	13.4	11.4	10.4	10.5	10.5	9.5	9.5	8.5	
	0.8	0.8	0.8	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	
	69	68	73	77	80	83	85	84	85	88	89	90	89	91	91	92	92	
29	30.3	31.2	26.2	22.2	19.3	16.2	14.3	15.4	14.4	11.4	10.4	9.4	10.4	8.5	8.5	7.5	7.6	
	0.7	0.8	0.8	0.8	0.7	0.8	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.4	
	69	71	76	79	82	84	85	84	87	88	90	90	90	91	92	93	93	
30	30.4	28.3	23.3	20.3	17.3	15.3	14.4	15.4	12.4	11.4	9.5	9.5	9.5	8.5	7.6	6.6	6.6	
	0.6	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	

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Rungon kuutiojalkamäärä — *Top volume of saw timber stems*
(keskimääräisellä kapenemisella — *average taper*)
Kuusi — *Spruce*

D cm	Puun pituus, m — *Tree height, m*																	
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	j³/runko — *f³/stem*																	
18			2.0	2.5	2.6	3.2	3.4	3.5	4.4	4.6								
19		2.0	2.5	2.6	3.2	3.4	4.2	4.4	4.6	4.8	6.0							
20	2.0	2.1	2.6	3.2	3.3	4.1	4.3	4.5	5.6	5.8	6.1	6.4						
21	2.1	2.6	3.1	3.3	4.0	4.2	5.2	5.4	5.7	6.9	7.2	7.6	7.9					
22	2.5	3.1	3.2	3.9	4.1	5.0	5.2	6.3	6.7	7.0	8.5	8.9	9.3	9.7				
23	2.6	3.2	3.8	4.0	4.8	5.8	6.1	6.4	7.7	8.1	8.5	10.2	10.7	11.2	11.7			
24	3.1	3.7	3.9	4.7	5.6	5.9	7.0	7.4	8.8	9.3	9.7	10.2	10.6	11.2	13.4	12.3		
25	3.2	3.8	4.5	5.4	5.6	6.7	7.0	8.4	8.8	10.5	11.0	11.5	12.1	12.6	13.2	13.9	14.5	
26	3.7	4.3	5.2	5.4	6.4	7.6	8.0	9.5	9.9	10.4	12.3	12.9	13.5	14.2	14.9	15.6	16.3	17.1
27	4.2	4.4	5.2	6.1	7.2	7.6	9.0	9.4	11.1	11.6	12.2	14.4	15.1	15.8	16.5	17.3	18.2	19.0
28	4.2	5.0	5.9	6.1	7.2	8.5	8.9	10.5	11.0	12.9	13.5	14.2	16.6	17.4	18.3	19.1	20.1	21.0
29	4.8	5.0	5.9	6.9	8.1	8.5	9.9	11.6	12.1	12.7	14.9	15.6	16.4	19.1	20.1	21.0	22.0	23.1
30	4.8	5.6	6.6	7.7	8.0	9.4	10.9	11.5	13.4	14.0	16.3	17.1	17.9	18.8	21.9	22.9	24.0	25.2
31	5.4	5.6	6.5	7.6	8.9	10.3	10.8	12.6	13.2	15.3	16.0	18.6	19.5	20.5	21.4	24.9	26.1	27.4
32	5.4	6.2	7.2	8.4	8.8	10.2	11.8	13.7	14.4	16.7	17.5	18.3	21.2	22.2	23.3	24.4	28.2	29.6
33	5.4	6.2	7.2	8.4	9.7	11.2	12.9	13.5	15.6	16.4	18.9	19.8	22.9	24.0	25.1	26.3	27.6	31.9
34	5.9	6.9	7.9	9.1	10.5	11.1	12.7	14.7	15.4	17.7	18.6	21.4	22.4	25.8	27.0	28.3	29.7	31.1
35	5.9	6.8	7.9	9.1	10.4	12.0	13.8	14.5	16.6	19.1	20.0	23.0	24.1	25.2	29.0	30.4	31.8	33.3
36	6.5	7.5	8.6	9.9	11.3	11.9	13.6	15.6	17.9	18.8	21.5	22.5	25.8	27.0	31.0	32.4	34.0	35.6
37	6.5	7.5	8.6	9.8	11.2	12.8	14.7	16.8	17.6	20.1	21.1	24.1	27.5	28.9	30.2	34.6	36.2	38.0
38		7.4	8.5	9.7	11.1	12.7	14.5	16.5	18.9	19.8	22.6	25.7	27.0	30.7	32.2	33.7	38.5	40.3
39		8.1	9.2	10.5	12.0	13.7	15.6	17.7	18.6	21.1	24.1	25.2	28.7	30.1	34.2	35.8	40.8	42.7
40			9.2	10.4	11.9	13.5	15.4	17.5	19.8	22.5	23.6	26.8	30.4	31.9	36.2	38.0	39.8	45.2
41			9.1	11.2	12.8	14.5	16.4	18.7	19.5	22.2	25.1	28.5	29.8	33.8	35.4	40.1	42.1	44.1
42				11.2	12.6	14.3	16.2	18.4	20.8	23.5	24.7	27.9	31.6	33.1	37.4	39.2	44.4	46.5
43				11.1	12.5	14.2	16.1	18.1	20.5	23.2	26.2	29.5	31.0	35.0	39.5	41.4	46.7	48.9
44					13.4	15.1	17.1	19.3	21.8	24.6	27.7	29.0	32.7	36.9	38.6	43.5	45.6	51.4
45					13.3	15.0	16.9	19.1	21.5	24.2	27.2	30.6	34.5	36.1	40.6	45.7	47.9	53.9

Rungon arvo — *Stem value*
(keskimääräisellä kapenemisella — *average taper*)
Kuusi — *Spruce*

D cm	Puun pituus, m — *Tree height, m*																	
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	mk/runko — *Fmk/stem*																	
18			6.0	7.2	7.4	8.8	9.2	9.6	11.3	11.9								
19		6.0	7.1	7.3	8.7	9.1	10.7	11.2	11.7	12.2	14.4							
20	5.9	6.1	7.2	8.6	8.9	10.5	11.0	11.5	13.5	14.1	14.8	15.5						
21	6.0	7.1	8.4	8.7	10.3	10.7	12.6	13.2	13.8	16.2	16.9	17.8	18.7					
22	7.0	8.2	8.5	10.0	10.5	12.3	12.8	15.0	15.7	16.5	19.2	20.2	21.2	22.3				
23	7.1	8.3	9.8	10.2	11.9	13.9	14.5	15.2	17.7	18.6	19.5	22.7	23.8	25.1	26.4			
24	8.1	9.5	9.9	11.6	13.5	14.1	16.4	17.1	19.9	20.9	21.9	23.0	24.2	25.4	29.5	28.2		
25	8.2	9.6	11.2	13.1	13.6	15.8	16.5	19.2	20.1	23.2	24.4	25.6	27.0	28.4	29.9	31.5	33.1	
26	9.3	10.9	12.6	13.2	15.3	17.6	18.5	21.3	22.3	23.5	27.0	28.4	29.9	31.5	33.1	34.9	36.8	38.7
27	10.5	10.9	12.7	14.7	17.0	17.8	20.5	21.5	24.7	25.9	27.3	31.3	32.9	34.7	36.5	38.5	40.6	42.8
28	10.6	12.3	14.2	14.8	17.1	19.7	20.6	23.7	24.9	28.5	30.0	31.6	36.1	38.1	40.1	42.2	44.5	46.9
29	11.9	12.3	14.3	16.4	18.9	19.8	22.7	26.1	27.4	28.7	32.9	34.6	36.4	41.6	43.8	46.2	48.7	51.3
30	11.9	13.7	15.8	18.2	19.0	21.8	25.0	26.2	29.9	31.5	35.9	37.8	39.7	41.9	47.7	50.3	53.0	55.9
31	13.2	13.8	15.9	18.2	20.9	23.9	25.1	28.6	30.1	34.3	36.1	41.0	43.2	45.5	48.0	54.5	57.5	60.6
32	13.3	15.3	17.5	20.0	21.0	24.0	27.4	31.2	32.8	37.2	39.2	41.2	46.8	49.3	52.0	54.8	62.2	65.6
33	13.3	15.3	17.5	20.1	23.0	26.2	29.8	31.3	35.6	37.4	42.4	44.7	50.6	53.3	56.2	59.2	62.5	70.7
34	14.7	16.8	19.3	22.0	25.0	26.3	29.9	33.9	35.7	40.5	42.6	48.2	50.8	57.4	60.5	63.8	67.3	71.0
35	14.7	16.9	19.3	22.0	25.1	28.5	32.4	34.0	38.6	43.6	45.9	51.9	54.7	57.6	65.0	68.6	72.3	76.3
36	16.2	18.5	21.1	24.0	27.3	28.6	32.5	36.8	41.6	43.8	49.4	52.0	58.7	61.9	69.7	73.5	77.5	81.8
37	16.2	18.5	21.1	24.0	27.3	31.0	35.1	39.6	41.7	47.0	49.5	55.9	62.9	66.3	69.9	78.6	82.9	87.5
38		18.5	21.1	24.0	27.3	31.0	35.1	39.7	44.8	47.2	53.1	59.8	63.0	70.8	74.7	78.8	88.4	93.3
39		20.2	23.0	26.1	29.6	33.5	37.8	42.7	44.9	50.6	56.9	59.9	67.3	71.0	79.6	84.0	94.1	99.4
40			23.0	26.1	29.6	33.5	37.9	42.7	48.1	54.1	57.0	64.0	71.7	75.7	84.7	89.4	94.4	106
41			23.0	28.3	31.9	36.1	40.7	45.8	48.2	54.2	60.8	68.2	71.9	80.5	84.9	95.0	100	106
42				28.3	32.0	36.1	40.7	45.8	51.5	57.8	60.9	68.3	76.5	80.6	90.2	95.2	106	112
43				28.3	32.0	36.1	40.7	45.9	51.6	57.9	64.9	72.6	76.6	85.6	95.6	101	113	119
44					34.4	38.8	43.6	49.0	55.0	61.6	69.0	72.7	81.3	90.7	95.7	107	113	126
45					34.4	38.8	43.7	49.1	55.1	61.7	69.0	77.2	86.1	90.9	101	113	119	133

Kiintokuutiometri kuutiojaloiksi — *Conversion of true solid volumes (m^3) into top volumes (f^3) of saw timber*
(keskimääräisellä kapenemisella — *average taper*)
Kuusi — *Spruce*

D cm	Puun pituus, m — *Tree height, m*																	
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	Muuntokerroin kuutiometristä kuutiojaloiksi — *Coefficient of conversion*																	
18			22.7	24.0	24.0	25.3	25.4	25.6	26.2	26.5								
19		21.6	22.7	22.6	23.9	24.0	25.2	25.4	25.6	25.9	26.4							
20	20.7	20.3	21.5	22.7	22.7	23.9	24.1	24.2	25.4	25.7	26.0	26.3						
21	19.6	20.6	21.6	21.5	22.7	22.8	24.0	24.2	24.4	25.5	25.8	26.1	26.4					
22	19.9	20.8	20.6	21.7	21.6	22.8	23.0	24.1	24.3	24.6	25.6	25.9	26.2	26.6				
23	19.1	19.8	20.8	20.7	21.8	22.9	23.0	23.2	24.3	24.5	24.8	25.7	26.0	26.4	26.7			
24	19.4	20.1	19.9	20.9	21.9	22.0	23.1	23.2	24.3	24.5	24.8	25.0	25.4	25.7	26.5	26.4		
25	18.7	19.4	20.2	21.1	21.1	22.1	22.2	23.3	23.5	24.5	24.7	25.0	25.3	25.6	25.9	26.3	26.6	
26	19.0	19.7	20.4	20.3	21.3	22.3	22.4	23.4	23.5	23.7	24.7	24.9	25.2	25.5	25.8	26.2	26.5	26.9
27	19.3	19.0	19.8	20.6	21.5	21.5	22.5	22.6	23.6	23.8	24.0	24.9	25.2	25.5	25.8	26.1	26.4	26.8
28	18.7	19.3	20.0	19.9	20.8	21.7	21.8	22.7	22.9	23.8	24.0	24.3	25.1	25.4	25.7	26.0	26.3	26.7
29	19.1	18.8	19.5	20.2	21.0	21.1	22.0	22.8	23.0	23.2	24.1	24.3	24.6	25.3	25.6	25.9	26.2	26.6
30	18.6	19.1	19.7	20.4	20.4	21.3	22.1	22.2	23.1	23.3	24.1	24.3	24.6	24.8	25.6	25.8	26.1	26.5
31	18.9	18.7	19.2	19.9	20.7	21.4	21.5	22.4	22.5	23.4	23.6	24.3	24.6	24.8	25.1	25.8	26.1	26.4
32	18.5	19.0	19.5	20.2	20.2	20.9	21.7	22.5	22.6	23.4	23.6	23.8	24.6	24.8	25.1	25.4	26.0	26.3
33	18.2	18.6	19.1	19.7	20.4	21.1	21.9	22.0	22.8	22.9	23.7	23.9	24.6	24.8	25.1	25.3	25.6	26.2
34	18.5	18.9	19.4	20.0	20.6	20.7	21.4	22.1	22.3	23.0	23.2	23.9	24.2	24.8	25.1	25.3	25.6	25.9
35	18.2	18.6	19.0	19.6	20.2	20.9	21.5	21.7	22.4	23.1	23.3	24.0	24.2	24.4	25.0	25.3	25.6	25.8
36	18.5	18.8	19.3	19.8	20.4	20.5	21.1	21.8	22.5	22.7	23.4	23.6	24.2	24.4	25.0	25.3	25.5	25.8
37	18.2	18.6	19.0	19.5	20.1	20.7	21.3	22.0	22.1	22.8	22.9	23.6	24.2	24.5	24.7	25.2	25.5	25.7
38		18.3	18.7	19.2	19.7	20.3	20.9	21.6	22.2	22.4	23.0	23.7	23.9	24.5	24.7	24.9	25.4	25.7
39		18.6	19.0	19.4	19.9	20.5	21.1	21.7	21.8	22.5	23.1	23.3	23.9	24.1	24.7	24.9	25.4	25.6
40			18.7	19.2	19.7	20.2	20.8	21.3	22.0	22.6	22.7	23.3	23.9	24.1	24.7	24.9	25.1	25.6
41			18.5	19.4	19.9	20.4	20.9	21.5	21.6	22.2	22.8	23.4	23.6	24.2	24.4	24.9	25.1	25.3
42				19.2	19.6	20.1	20.6	21.2	21.7	22.3	22.5	23.1	23.6	23.8	24.4	24.6	25.1	25.3
43				19.0	19.4	19.9	20.4	20.9	21.4	22.0	22.6	23.1	23.3	23.9	24.4	24.6	25.0	25.3
44					19.6	20.0	20.5	21.0	21.6	22.1	22.7	22.8	23.4	23.9	24.1	24.6	24.8	25.2
45					19.4	19.8	20.3	20.8	21.3	21.8	22.3	22.9	23.4	23.6	24.1	24.6	24.8	25.2

Rungon yksikkökuutiometrin arvo — *Value of stem/m³*
(keskimääräisellä kapenemisella — *average taper*)
Kuusi — *Spruce*

D cm	Puun pituus, m — *Tree height, m*																	
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	mk/m³ — *Fmk/m³*																	
18			32.3	34.3	34.5	36.0	36.3	36.7	37.7	38.1								
19		31.4	33.6	33.8	35.7	36.1	37.5	37.9	38.3	38.7	39.6							
20	30.3	30.4	32.9	35.1	35.4	37.2	37.6	38.0	39.4	39.8	40.3	40.8						
21	29.2	31.8	34.1	34.4	36.5	36.9	38.6	39.1	39.6	40.3	41.3	41.9	42.4					
22	30.5	32.9	33.2	35.5	35.9	38.0	38.4	40.0	40.6	41.1	42.2	42.8	43.4	44.0				
23	29.2	31.9	34.3	34.7	37.0	38.9	39.4	39.9	41.4	42.0	42.6	43.6	44.2	44.8	45.5			
24	30.4	32.9	33.3	35.7	37.9	38.4	40.3	40.8	42.2	42.8	43.4	44.0	44.7	45.3	46.3	46.6		
25	29.1	31.8	34.3	36.7	37.1	39.3	39.8	41.6	42.2	43.6	44.2	44.8	45.5	46.1	46.8	47.5	48.2	
26	30.2	32.8	35.2	35.7	38.0	40.1	40.6	42.4	43.0	43.6	44.9	45.6	46.3	46.9	47.6	48.3	49.0	49.8
27	31.1	31.5	34.1	36.6	38.8	39.4	41.4	42.0	43.7	44.4	45.0	46.3	47.0	47.7	48.4	49.1	49.9	50.6
28	29.8	32.4	35.0	35.5	37.9	40.2	40.8	42.8	43.4	45.1	45.8	46.5	47.7	48.4	49.1	49.9	50.6	51.4
29	30.7	31.1	33.7	36.3	38.7	39.3	41.6	43.5	44.2	44.9	46.5	47.2	47.9	49.1	49.8	50.6	51.4	52.1
30	29.3	32.0	34.6	37.1	37.7	40.1	42.3	42.9	44.9	45.6	47.2	47.9	48.6	49.4	50.5	51.3	52.1	52.9
31	30.2	30.6	33.3	35.9	38.4	40.8	41.5	43.7	44.3	46.3	47.0	48.6	49.3	50.1	50.9	52.0	52.8	53.6
32	28.8	31.4	34.1	36.7	37.2	39.8	42.2	44.4	45.1	47.0	47.7	48.5	50.0	50.8	51.6	52.4	53.5	54.3
33	27.4	30.0	32.7	35.3	38.0	40.5	42.9	43.6	45.7	46.5	48.4	49.2	50.7	51.5	52.3	53.1	54.0	55.0
34	28.1	30.7	33.4	36.1	38.7	39.3	41.9	44.3	45.0	47.2	47.9	49.8	50.7	52.2	53.0	53.8	54.7	55.5
35	26.7	29.3	32.0	34.7	37.4	40.0	42.6	43.3	45.7	47.9	48.6	50.5	51.3	52.2	53.7	54.5	55.4	56.3
36	27.4	30.0	32.7	35.4	38.1	38.7	41.4	44.0	46.4	47.1	49.3	50.1	52.0	52.9	54.4	55.3	56.1	57.0
37	26.0	28.5	31.2	33.9	36.6	39.4	42.1	44.6	45.4	47.8	48.6	50.8	52.7	53.6	54.5	56.0	56.9	57.8
38		27.1	29.7	32.4	35.2	38.0	40.7	43.4	46.1	46.8	49.3	51.5	52.4	54.3	55.2	56.1	57.6	58.5
39		27.7	30.3	33.0	35.8	38.6	41.4	44.1	44.9	47.5	50.0	50.8	53.1	54.0	55.9	56.8	58.4	59.3
40			28.8	31.5	34.3	37.1	39.9	42.8	45.5	48.2	49.0	51.6	53.8	54.7	56.7	57.6	58.6	60.1
41			27.3	32.1	34.9	37.7	40.6	43.4	44.2	47.0	49.7	52.3	53.1	55.5	56.4	58.4	59.3	60.3
42				30.5	33.3	36.1	39.0	41.9	44.8	47.7	48.5	51.3	53.9	54.8	57.2	58.1	60.2	61.1
43				28.9	31.6	34.5	37.4	40.3	43.3	46.3	49.2	52.0	52.9	55.5	57.9	58.9	61.0	62.0
44					32.2	35.0	37.9	40.9	43.9	46.9	49.9	50.8	53.6	56.3	57.3	59.7	60.7	62.9
45					30.5	33.3	36.2	39.2	42.3	45.4	48.4	51.5	54.4	55.3	58.1	60.6	61.6	63.7

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Mänty — *Pine*

D-luokka *class* cm	H-luokka *class* m	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*						
		2	3	4	5	6	7	8
		mk/runko — *Fmk/stem*						
19	12	9.0	7.9	6.9	6.0	5.2		
	13	9.1	8.0	7.0	6.1	5.2		
	14	9.3	8.2	7.2	6.2	5.3		
	15	9.5	8.4	7.3	6.4	5.5		
	16	9.8	8.6	7.5	6.5	5.6		
	17	10.1	8.9	7.8	6.7	5.8		
	18	10.4	9.2	8.0	7.0	6.0		
	19	10.8	9.5	8.3	7.2	6.2		
	20	11.2	9.8	8.6	7.5			
	21	11.6	10.2	8.9				
	22	12.0	10.6					
	23	12.4						
21	11	11.7	10.5	9.3	8.2	7.2	6.2	5.3
	12	11.8	10.6	9.4	8.3	7.3	6.3	5.4
	13	12.1	10.8	9.6	8.5	7.4	6.4	5.5
	14	12.4	11.1	9.8	8.7	7.6	6.6	5.6
	15	12.8	11.4	10.1	8.9	7.8	6.8	5.8
	16	13.2	11.8	10.5	9.2	8.1	7.0	6.0
	17	13.6	12.2	10.8	9.5	8.3	7.2	6.2
	18	14.1	12.6	11.2	9.9	8.7	7.5	6.4
	19	14.7	13.1	11.6	10.3	9.0	7.8	
	20	15.2	13.6	12.1	10.7	9.3		
	21	15.8	14.2	12.6	11.1			
	22	16.5	14.7	13.1				
	23	17.1	15.3					
	24	17.8						

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Mänty — *Pine*

D-	H-luokka *class*	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*								
		2	3	4	5	6	7	8	9	10
cm	m	mk/runko — *Fmk/stem*								
	10		13.3	12.0	10.7	9.5	8.4	7.3	6.3	5.4
	11	14.8	13.4	12.1	10.8	9.6	8.4	7.4	6.4	5.5
	12	15.1	13.7	12.3	11.0	9.7	8.6	7.5	6.5	5.6
	13	15.5	14.0	12.6	11.3	10.0	8.8	7.7	6.7	5.7
	14	16.0	14.4	13.0	11.6	10.3	9.1	7.9	6.9	5.9
	15	16.5	14.9	13.4	12.0	10.7	9.4	8.2	7.1	6.1
	16	17.1	15.5	13.9	12.4	11.1	9.7	8.5	7.4	6.3
	17	17.8	16.1	14.5	12.9	11.5	10.1	8.9	7.7	6.6
23	18	18.5	16.7	15.0	13.4	11.9	10.5	9.2	8.0	
	19	19.3	17.4	15.7	14.0	12.4	11.0	9.6		
	20	20.1	18.1	16.3	14.6	12.9	11.4			
	21	20.9	18.9	17.0	15.2	13.5				
	22	21.8	19.7	17.7	15.8					
	23	22.7	20.5	18.4						
	24	23.6	21.3							
	25	24.6								
	10		16.5	15.0	13.5	12.2	10.9	9.7	8.5	7.4
	11		16.7	15.2	13.7	12.4	11.0	9.8	8.6	7.6
	12	18.8	17.2	15.6	14.1	12.7	11.3	10.0	8.9	7.7
	13	19.4	17.7	16.1	14.5	13.0	11.7	10.4	9.1	8.0
	14	20.1	18.3	16.6	15.0	13.5	12.1	10.7	9.5	8.3
	15	20.8	19.0	17.2	15.6	14.0	12.5	11.1	9.8	8.6
	16	21.7	19.8	17.9	16.2	14.6	13.0	11.6	10.2	8.9
	17	22.6	20.6	18.7	16.9	15.2	13.6	12.1	10.6	9.3
25	18	23.5	21.5	19.5	17.6	15.8	14.2	12.6	11.1	9.7
	19	24.6	22.4	20.3	18.4	16.5	14.8	13.1	11.6	
	20	25.6	23.4	21.2	19.2	17.2	15.4	13.7		
	21	26.7	24.4	22.1	20.0	18.0	16.1			
	22	27.9	25.5	23.1	20.9	18.8				
	23	29.1	26.6	24.1	21.8					
	24	30.4	27.7	25.2						
	25	31.7	28.9							
	26	33.0								

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Mänty — *Pine*

D-	H-luokka *class*	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*								
		2	3	4	5	6	7	8	9	10
cm	m	mk/runko — *Fmk/stem*								
27	10		20.0	18.3	16.7	15.2	13.7	12.3	11.0	9.8
	11		20.5	18.7	17.1	15.5	14.0	12.6	11.3	10.0
	12		21.1	19.3	17.6	16.0	14.4	13.0	11.6	10.3
	13	23.7	21.8	20.0	18.2	16.5	14.9	13.4	12.0	10.7
	14	24.7	22.7	20.8	18.9	17.2	15.5	14.0	12.5	11.1
	15	25.7	23.6	21.6	19.7	17.9	16.2	14.5	13.0	11.5
	16	26.8	24.6	22.5	20.6	18.7	16.9	15.2	13.6	12.0
	17	28.0	25.7	23.5	21.5	19.5	17.6	15.8	14.2	12.6
	18	29.2	26.9	24.6	22.4	20.4	18.4	16.6	14.8	13.1
	19	30.6	28.1	25.7	23.5	21.3	19.2	17.3	15.5	13.7
	20	32.0	29.4	26.9	24.5	22.3	20.1	18.1	16.2	
	21	33.4	30.7	28.1	25.6	23.3	21.0	18.9		
	22	34.9	32.1	29.4	26.8	24.3	22.0			
	23	36.5	33.5	30.7	28.0	25.4				
	24	38.1	35.0	32.0	29.2					
	25	39.8	36.5	33.4						
	26	41.5	38.1							
	27	43.3								
29	10			22.1	20.3	18.6	16.9	15.4	13.9	12.5
	11		24.6	22.7	20.8	19.1	17.4	15.8	14.3	12.8
	12		25.4	23.5	21.6	19.7	18.0	16.3	14.8	13.3
	13		26.4	24.4	22.4	20.5	18.7	17.0	15.3	13.8
	14	29.8	27.5	25.4	23.3	21.4	19.5	17.7	16.0	14.4
	15	31.1	28.8	26.5	24.4	22.3	20.3	18.5	16.7	15.0
	16	32.5	30.1	27.7	25.5	23.3	21.3	19.3	17.5	15.7
	17	34.0	31.5	29.0	26.7	24.4	22.3	20.2	18.3	16.4
	18	35.6	33.0	30.4	27.9	25.6	23.3	21.2	19.1	17.2
	19	37.3	34.5	31.8	29.2	26.8	24.4	22.2	20.0	18.0
	20	39.1	36.1	33.3	30.6	28.0	25.5	23.2	21.0	
	21	40.9	37.8	34.9	32.0	29.3	26.7	24.3		
	22	42.8	39.6	36.5	33.5	30.7	28.0			
	23	44.8	41.4	38.2	35.1	32.1				
	24	46.8	43.3	39.9	36.6					
	25	48.9	45.2	41.7						
	26	51.1	47.2							
	27	53.3								

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Mänty — *Pine*

D-	H-luokka *class*	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*								
		2	3	4	5	6	7	8	9	10
cm	m	mk/runko — *Fmk/stem*								
	11		29.1	27.0	25.0	23.0	21.2	19.4	17.7	16.0
	12		30.2	28.0	25.9	23.9	22.0	20.1	18.3	16.7
	13		31.5	29.2	27.0	24.9	22.9	21.0	19.1	17.4
	14		32.9	30.6	28.3	26.0	23.9	21.9	20.0	18.1
	15	37.1	34.5	32.0	29.6	27.3	25.0	22.9	20.9	19.0
	16	38.9	36.1	33.5	31.0	28.6	26.2	24.0	21.9	19.9
	17	40.7	37.9	35.1	32.5	29.9	27.5	25.2	23.0	20.9
	18	42.7	39.7	36.8	34.1	31.4	28.9	26.4	24.1	21.9
31	19	44.8	41.7	38.6	35.7	32.9	30.3	27.7	25.3	22.9
	20	47.0	43.7	40.5	37.5	34.5	31.7	29.0	26.5	24.0
	21	49.2	45.8	42.4	39.2	36.2	33.2	30.4	27.8	
	22	51.6	47.9	44.5	41.1	37.9	34.8	31.9		
	23	54.0	50.2	46.5	43.0	39.7	36.5			
	24	56.5	52.5	48.7	45.0	41.5				
	25	59.1	54.9	50.9	47.1					
	26	61.7	57.4	53.2						
	27	64.5	60.0							
	11			31.8	29.5	27.4	25.3	23.3	21.5	19.6
	12		35.5	33.1	30.8	28.5	26.4	24.3	22.3	20.5
	13		37.1	34.6	32.2	29.8	27.6	25.4	23.4	21.4
	14		38.9	36.2	33.7	31.2	28.9	26.6	24.5	22.4
	15	43.6	40.8	38.0	35.3	32.8	30.3	27.9	25.7	23.5
	16	45.8	42.8	39.9	37.1	34.4	31.8	29.3	26.9	24.7
	17	48.1	44.9	41.9	39.0	36.1	33.4	30.8	28.3	25.9
	18	50.5	47.2	44.0	40.9	37.9	35.1	32.3	29.7	27.2
33	19	53.0	49.6	46.2	42.9	39.8	36.8	33.9	31.2	28.6
	20	55.7	52.0	48.5	45.1	41.8	38.7	35.6	32.7	30.0
	21	58.4	54.6	50.9	47.3	43.9	40.5	37.4	34.3	
	22	61.2	57.2	53.3	49.6	46.0	42.5	39.2		
	23	64.2	60.0	55.9	52.0	48.2	44.6			
	24	67.2	62.8	58.5	54.4	50.5				
	25	70.3	65.7	61.2	56.9					
	26	73.5	68.7	64.0						
	27	76.9	71.8							

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Mänty — *Pine*

D-luokka *class* cm	H-luokka *class* m	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*							
		3	4	5	6	7	8	9	10
		mk/runko — *Fmk/stem*							
	12		38.6	36.0	33.6	31.2	29.0	26.8	24.7
	13	43.2	40.4	37.8	35.2	32.7	30.3	28.1	25.9
	14	45.3	42.4	39.6	36.9	34.4	31.9	29.5	27.2
	15	47.6	44.6	41.7	38.8	36.1	33.5	31.0	28.5
	16	50.1	46.9	43.8	40.8	38.0	35.2	32.6	30.0
	17	52.7	49.3	46.1	42.9	39.9	37.0	34.2	31.6
	18	55.4	51.8	48.4	45.1	42.0	38.9	36.0	33.2
	19	58.2	54.5	50.9	47.5	44.1	40.9	37.8	34.9
35	20	61.1	57.3	53.5	49.9	46.4	43.0	39.7	36.6
	21	64.2	60.1	56.2	52.4	48.7	45.1	41.7	38.5
	22	67.4	63.1	58.9	54.9	51.1	47.4	43.8	
	23	70.7	66.2	61.8	57.6	53.6	49.7		
	24	74.1	69.3	64.8	60.4	56.1			
	25	77.5	72.6	67.8	63.2				
	26	81.2	76.0	71.0					
	27	84.9	79.4						
	28	88.7							
	12			41.7	39.1	36.5	34.0	31.6	29.3
	13		46.7	43.8	41.0	38.4	35.7	33.2	30.8
	14	52.3	49.2	46.1	43.2	40.3	37.6	35.0	32.4
	15	55.1	51.7	48.5	45.5	42.5	39.6	36.8	34.1
	16	58.0	54.5	51.1	47.9	44.7	41.7	38.8	35.9
	17	61.0	57.4	53.8	50.4	47.1	43.9	40.8	37.8
	18	64.3	60.4	56.7	53.0	49.6	46.2	43.0	39.8
	19	67.6	63.5	59.6	55.8	52.1	48.6	45.2	41.9
37	20	71.1	66.8	62.7	58.7	54.8	51.1	47.5	44.1
	21	74.7	70.2	65.9	61.7	57.6	53.7	49.9	46.3
	22	78.5	73.8	69.2	64.8	60.5	56.4	52.5	48.6
	23	82.3	77.4	72.6	68.0	63.5	59.2	55.0	
	24	86.3	81.2	76.1	71.3	66.6	62.1		
	25	90.5	85.0	79.8	74.7	69.8			
	26	94.7	89.0	83.5	78.2				
	27	99.1	93.2	87.4					
	28	104	97.4						

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Mänty — *Pine*

D-luokka *class* cm	H-luokka *class* m	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*							
		3	4	5	6	7	8	9	10
		mk/runko — *Fmk/stem*							
	12			47.9	45.0	42.3	39.6	37.0	34.4
	13			50.4	47.4	44.5	41.6	38.9	36.2
	14		56.4	53.1	49.9	46.8	43.9	41.0	38.2
	15	63.1	59.5	56.0	52.6	49.4	46.2	43.2	40.3
	16	66.5	62.7	59.0	55.5	52.1	48.8	45.5	42.5
	17	70.1	66.1	62.2	58.5	54.9	51.4	48.0	44.8
	18	73.9	69.7	65.6	61.7	57.8	54.2	50.6	47.2
	19	77.8	73.4	69.1	64.9	60.9	57.0	53.3	49.7
39	20	81.9	77.2	72.7	68.3	64.1	60.0	56.1	52.3
	21	86.1	81.2	76.5	71.9	67.4	63.1	59.0	55.0
	22	90.5	85.3	80.4	75.5	70.9	66.3	62.0	57.8
	23	95.0	89.6	84.4	79.3	74.4	69.7	65.1	60.7
	24	99.7	94.0	88.5	83.2	78.1	73.1	68.3	
	25	105	98.6	92.8	87.2	81.8	76.6		
	26	110	103	97.2	91.4	85.7			
	27	115	108	102	95.7				
	28	120	113	106					
	12				51.4	48.4	45.5	42.7	40.0
	13			57.5	54.2	51.1	48.0	45.0	42.2
	14			60.7	57.2	53.9	50.6	47.5	44.5
	15		67.8	64.0	60.4	56.9	53.5	50.2	47.0
	16	75.6	71.6	67.6	63.8	60.0	56.4	52.9	49.6
	17	79.8	75.5	71.3	67.3	63.4	59.6	55.9	52.3
	18	84.2	79.6	75.2	71.0	66.8	62.8	58.9	55.2
	19	88.7	83.9	79.3	74.8	70.4	66.2	62.1	58.2
41	20	93.4	88.4	83.5	78.8	74.2	69.7	65.4	61.3
	21	98.3	93.0	87.9	82.9	78.1	73.4	68.9	64.5
	22	103	97.8	92.4	87.2	82.1	77.2	72.4	67.8
	23	109	103	97.1	91.6	86.3	81.1	76.1	71.2
	24	114	108	102	96.2	90.6	85.1	79.9	
	25	120	113	107	101	95.0	89.3		
	26	125	119	112	106	99.5			
	27	131	124	117	111				
	28	137	130	123					

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Kuusi — *Spruce*

D-luokka *class* cm	H-luokka *class* m	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*						
		1	2	3	4	5	6	7
		mk/runko — *Fmk/stem*						
19	12	9.8	8.7	7.7	6.7	5.8		
	13	10.0	8.9	7.9	6.9	6.0		
	14	10.3	9.2	8.1	7.1	6.2		
	15	10.7	9.5	8.4	7.3	6.4		
	16	11.1	9.9	8.7	7.6	6.6		
	17	11.6	10.3	9.1	7.9	6.9		
	18	12.1	10.7	9.4	8.3	7.2		
	19	12.6	11.2	9.9	8.6			
	20	13.2	11.7	10.3				
	21	13.8	12.2					
	22	14.4						
21	12	12.5	11.3	10.1	9.0	7.9	6.9	6.0
	13	12.9	11.6	10.4	9.2	8.1	7.1	6.2
	14	13.4	12.0	10.7	9.5	8.4	7.4	6.4
	15	13.9	12.5	11.1	9.9	8.7	7.6	6.6
	16	14.4	13.0	11.6	10.3	9.1	7.9	6.9
	17	15.0	13.5	12.1	10.7	9.5	8.3	7.2
	18	15.7	14.1	12.6	11.2	9.9	8.6	
	19	16.4	14.7	13.2	11.7	10.3		
	20	17.1	15.4	13.8	12.3			
	21	18.0	16.2	14.4				
	22	18.8	16.9					
	23	19.8						

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Kuusi — *Spruce*

D-	H-luokka *class*	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*								
		1	2	3	4	5	6	7	8	9
cm	m	mk/runko — *Fmk/stem*								
	12			12.8	11.5	10.3	9.2	8.1	7.1	6.1
	13		14.6	13.2	11.9	10.6	9.5	8.3	7.3	6.3
	14	16.7	15.2	13.7	12.3	11.0	9.8	8.6	7.6	6.6
	15	17.3	15.7	14.2	12.8	11.5	10.2	9.0	7.9	6.8
	16	18.1	16.4	14.8	13.3	11.9	10.6	9.3	8.2	7.1
	17	18.8	17.1	15.5	13.9	12.4	11.1	9.8	8.5	
23	18	19.7	17.9	16.2	14.5	13.0	11.6	10.2		
	19	20.6	18.7	16.9	15.2	13.6	12.1			
	20	21.6	19.6	17.7	15.9	14.3				
	21	22.6	20.6	18.6	16.7					
	22	23.8	21.6	19.5						
	23	25.0	22.7							
	24	26.2								
	12			15.8	14.4	13.0	11.7	10.4	9.3	8.2
	13		17.9	16.4	14.9	13.4	12.1	10.8	9.6	8.5
	14	20.3	18.6	17.0	15.4	13.9	12.5	11.2	10.0	8.8
	15	21.2	19.4	17.7	16.1	14.5	13.1	11.7	10.4	9.2
	16	22.1	20.2	18.4	16.7	15.1	13.6	12.2	10.8	9.5
	17	23.1	21.1	19.3	17.5	15.8	14.2	12.7	11.3	10.0
	18	24.1	22.1	20.1	18.3	16.5	14.9	13.3	11.8	10.4
25	19	25.3	23.1	21.1	19.2	17.3	15.6	13.9	12.4	
	20	26.5	24.3	22.1	20.1	18.2	16.3	14.6		
	21	27.8	25.5	23.2	21.1	19.1	17.2			
	22	29.2	26.7	24.4	22.2	20.0				
	23	30.7	28.1	25.6	23.3					
	24	32.3	29.6	27.0						
	25	34.0	31.1							
	26	35.8								

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Kuusi — *Spruce*

D-	H-luokka *class*	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*								
		2	3	4	5	6	7	8	9	10
cm	m	mk/runko — *Fmk/stem*								
	12			17.5	16.0	14.5	13.1	11.8	10.5	9.4
	13		19.8	18.1	16.6	15.0	13.6	12.2	10.9	9.7
	14	22.4	20.6	18.9	17.2	15.6	14.1	12.7	11.4	10.1
	15	23.3	21.5	19.6	17.9	16.3	14.7	13.2	11.8	10.5
	16	24.4	22.4	20.5	18.7	17.0	15.4	13.8	12.4	11.0
	17	25.5	23.4	21.4	19.6	17.8	16.1	14.4	12.9	11.5
	18	26.7	24.5	22.5	20.5	18.6	16.8	15.1	13.5	12.0
	19	28.0	25.7	23.5	21.5	19.5	17.6	15.9	14.2	12.6
27	20	29.4	27.0	24.7	22.5	20.5	18.5	16.6	14.9	
	21	30.8	28.3	25.9	23.7	21.5	19.4	17.5		
	22	32.4	29.8	27.3	24.9	22.6	20.4			
	23	34.1	31.3	28.7	26.2	23.8				
	24	35.8	32.9	30.2	27.5					
	25	37.7	34.7	31.8						
	26	39.7	36.5							
	27	41.9								
	12			20.9	19.2	17.6	16.1	14.6	13.2	11.9
	13		23.6	21.7	20.0	18.3	16.7	15.1	13.7	12.3
	14	26.5	24.5	22.6	20.8	19.0	17.4	15.8	14.3	12.8
	15	27.6	25.6	23.6	21.7	19.8	18.1	16.4	14.9	13.4
	16	28.9	26.7	24.6	22.6	20.7	18.9	17.2	15.5	14.0
	17	30.2	28.0	25.8	23.7	21.7	19.8	18.0	16.3	14.6
	18	31.7	29.3	27.0	24.8	22.7	20.7	18.8	17.0	15.3
	19	33.2	30.7	28.3	26.1	23.9	21.8	19.8	17.9	16.1
29	20	34.9	32.3	29.8	27.4	25.0	22.8	20.8	18.8	16.9
	21	36.7	33.9	31.3	28.7	26.3	24.0	21.8	19.7	
	22	38.6	35.7	32.9	30.2	27.7	25.2	22.9		
	23	40.6	37.5	34.6	31.8	29.1	26.6			
	24	42.7	39.5	36.4	33.5	30.6				
	25	45.0	41.6	38.3	35.2					
	26	47.4	43.8	40.4						
	27	49.9	46.2							
	28	52.6								

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Kuusi — *Spruce*

D-	H-	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*								
	luokka *class*	2	3	4	5	6	7	8	9	10
cm	m	mk/runko — *Fmk/stem*								
	12				22.8	21.0	19.3	17.7	16.1	14.7
	13			25.6	23.7	21.8	20.1	18.4	16.8	15.2
	14		28.8	26.7	24.7	22.7	20.9	19.1	17.5	15.9
	15	32.3	30.0	27.8	25.8	23.7	21.8	20.0	18.2	16.6
	16	33.8	31.4	29.1	26.9	24.8	22.8	20.9	19.1	17.3
	17	35.4	32.9	30.5	28.2	26.0	23.9	21.9	20.0	18.1
	18	37.1	34.5	32.0	29.6	27.3	25.1	23.0	20.9	19.0
	19	38.9	36.2	33.6	31.0	28.6	26.3	24.1	22.0	20.0
31	20	40.9	38.0	35.3	32.6	30.1	27.6	25.3	23.1	21.0
	21	43.0	40.0	37.1	34.3	31.6	29.1	26.6	24.3	22.0
	22	45.2	42.0	39.0	36.1	33.3	30.6	28.0	25.5	
	23	47.6	44.2	41.0	38.0	35.0	32.2	29.5		
	24	50.1	46.6	43.2	40.0	36.9	33.9			
	25	52.8	49.1	45.5	42.1	38.8				
	26	55.6	51.7	48.0	44.4					
	27	58.6	54.5	50.6						
	28	61.8	57.5							
	13			29.8	27.7	25.7	23.8	21.9	20.1	18.4
	14		33.3	31.1	28.9	26.8	24.8	22.8	21.0	19.2
	15	37.2	34.8	32.4	30.2	28.0	25.9	23.9	21.9	20.1
	16	39.0	36.4	34.0	31.6	29.3	27.1	25.0	23.0	21.0
	17	40.9	38.2	35.6	33.1	30.7	28.4	26.2	24.1	22.0
	18	42.9	40.1	37.3	34.7	32.2	29.8	27.5	25.2	23.1
	19	45.0	42.1	39.2	36.5	33.8	31.3	28.9	26.5	24.3
	20	47.3	44.2	41.2	38.3	35.6	32.9	30.3	27.9	25.5
33	21	49.8	46.5	43.3	40.3	37.4	34.6	31.9	29.3	26.8
	22	52.4	48.9	45.6	42.4	39.3	36.4	33.6	30.8	28.2
	23	55.1	51.5	48.0	44.7	41.4	38.3	35.3	32.5	
	24	58.1	54.3	50.6	47.0	43.6	40.4	37.2		
	25	61.2	57.2	53.3	49.6	46.0	42.5			
	26	64.5	60.3	56.2	52.3	48.5				
	27	68.0	63.5	59.2	55.1					
	28	71.7	67.0	62.5						

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Kuusi — *Spruce*

D-	H-	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*								
	luokka *class*	2	3	4	5	6	7	8	9	10
cm	m	mk/runko — *Fmk/stem*								
	13	39.0	36.6	34.3	32.0	29.8	27.8	25.7	23.8	22.0
	14	40.7	38.2	35.8	33.4	31.1	29.0	26.9	24.9	22.9
	15	42.5	39.9	37.4	34.9	32.6	30.3	28.1	26.0	24.0
	16	44.6	41.8	39.2	36.6	34.1	31.7	29.4	27.2	25.1
	17	46.7	43.8	41.1	38.4	35.8	33.3	30.9	28.5	26.3
	18	49.0	46.0	43.1	40.3	37.5	34.9	32.4	30.0	27.6
	19	51.5	48.3	45.3	42.3	39.4	36.7	34.0	31.5	29.0
35	20	54.2	50.8	47.6	44.5	41.5	38.6	35.8	33.1	30.5
	21	57.0	53.5	50.1	46.8	43.6	40.6	37.6	34.8	32.1
	22	60.0	56.3	52.7	49.3	45.9	42.7	39.6	36.6	33.8
	23	63.2	59.3	55.5	51.9	48.4	45.0	41.7	38.6	35.6
	24	66.6	62.5	58.5	54.7	51.0	47.4	44.0	40.7	
	25	70.2	65.8	61.7	57.6	53.7	50.0	46.3		
	26	74.0	69.4	65.0	60.8	56.6	52.7			
	27	78.0	73.2	68.6	64.1	59.7				
	28	82.3	77.2	72.3	67.6					
	14	46.0	43.4	40.8	38.3	35.8	33.5	31.2	29.0	26.9
	15	48.2	45.4	42.7	40.0	37.5	35.0	32.7	30.4	28.2
	16	50.5	47.5	44.7	41.9	39.3	36.7	34.2	31.8	29.5
	17	53.0	49.9	46.9	44.0	41.2	38.5	35.9	33.4	31.0
	18	55.6	52.4	49.2	46.2	43.3	40.4	37.7	35.1	32.5
	19	58.5	55.1	51.8	48.6	45.5	42.5	39.6	36.9	34.2
	20	61.5	57.9	54.4	51.1	47.8	44.7	41.7	38.8	36.0
37	21	64.7	60.9	57.3	53.8	50.3	47.0	43.9	40.8	37.8
	22	68.1	64.2	60.3	56.6	53.0	49.5	46.2	43.0	39.8
	23	71.8	67.6	63.6	59.6	55.9	52.2	48.7	45.3	42.0
	24	75.6	71.2	67.0	62.9	58.9	55.0	51.3	47.7	44.2
	25	79.8	75.1	70.6	66.3	62.1	58.0	54.1	50.3	
	26	84.1	79.2	74.5	69.9	65.4	61.2	57.0		
	27	88.7	83.6	78.6	73.7	69.0	64.5			
	28	93.6	88.2	82.9	77.8	72.8				

Tukkipuiden arvotaulukot — *Value tables for saw timber stems*

Kuusi — *Spruce*

D-luokka *class* cm	H-luokka *class* m	Kapenemisluokka (D—D6), cm — *Taper (D—D6), cm*								
		2	3	4	5	6	7	8	9	10
		mk/runko — *Fmk/stem*								
39	14			46.1	43.4	40.8	38.3	35.9	33.5	31.2
	15		51.2	48.3	45.5	42.7	40.1	37.5	35.1	32.7
	16	56.8	53.6	50.6	47.7	44.8	42.0	39.4	36.8	34.3
	17	59.6	56.3	53.1	50.0	47.0	44.1	41.3	38.6	36.0
	18	62.6	59.1	55.8	52.5	49.4	46.4	43.4	40.6	37.8
	19	65.8	62.2	58.7	55.3	51.9	48.7	45.6	42.7	39.8
	20	69.2	65.4	61.7	58.1	54.7	51.3	48.0	44.9	41.8
	21	72.9	68.9	65.0	61.2	57.5	54.0	50.6	47.2	44.0
	22	76.8	72.5	68.4	64.5	60.6	56.9	53.3	49.8	46.4
	23	80.9	76.4	72.1	67.9	63.9	59.9	56.1	52.4	48.9
	24	85.3	80.6	76.0	71.6	67.3	63.2	59.1	55.3	51.5
	25	89.9	85.0	80.2	75.5	71.0	66.6	62.4	58.3	
	26	94.9	89.6	84.6	79.6	74.9	70.3	65.8		
	27	100	94.6	89.2	84.0	79.0	74.1			
	28	106	99.8	94.1	88.7	83.4				
41	14				48.9	46.1	43.4	40.8	38.3	35.9
	15			54.2	51.2	48.3	45.5	42.8	40.1	37.6
	16		60.1	56.9	53.7	50.7	47.7	44.9	42.1	39.4
	17	66.6	63.1	59.7	56.4	53.2	50.1	47.1	44.2	41.4
	18	70.0	66.3	62.7	59.3	55.9	52.7	49.5	46.5	43.5
	19	73.6	69.7	66.0	62.4	58.8	55.4	52.1	48.9	45.8
	20	77.4	73.4	69.4	65.6	61.9	58.3	54.8	51.4	48.2
	21	81.5	77.3	73.1	69.1	65.2	61.4	57.7	54.2	50.7
	22	85.9	81.4	77.0	72.8	68.7	64.7	60.8	57.1	53.4
	23	90.5	85.8	81.2	76.7	72.4	68.2	64.1	60.1	56.3
	24	95.5	90.5	85.6	80.9	76.3	71.9	67.6	63.4	59.4
	25	101	95.4	90.3	85.3	80.5	75.8	71.3	66.9	62.6
	26	106	101	95.3	90.0	84.9	80.0	75.2	70.6	
	27	112	106	101	95.0	89.6	84.4	79.3		
	28	118	112	106	100	94.6	89.1			

Liite 1. Mäntytukkien arvot, mk/tukki

Latvaläpimitta, cm	Tukin pituus, dm								
	39	42	45	48	51	54	57	60	63
14	—	4.10	4.39	4.68	4.97	—	—	—	—
15	—	4.70	5.04	5.37	5.71	6.05	—	—	—
16	4.97	5.35	5.73	6.11	6.50	6.92	7.37	—	—
17	5.61	6.04	6.47	6.94	7.48	7.99	8.78	9.48	—
18	6.29	6.81	7.36	7.96	8.81	9.69	10.27	10.86	11.50
19	7.08	7.73	8.54	9.48	10.23	10.89	11.60	12.40	13.22
20	7.99	9.07	9.99	10.70	11.50	12.37	13.26	14.06	14.86
21	9.41	10.30	11.11	12.05	13.00	13.92	14.82	15.77	16.82
22	10.50	11.39	12.47	13.53	14.50	15.50	16.70	17.82	18.88
23	11.63	12.84	13.92	14.97	16.21	17.43	18.63	19.81	21.37
24	12.99	14.17	15.37	16.73	18.02	19.31	20.91	22.76	24.46
25	14.32	15.64	17.10	18.49	19.89	21.92	23.81	25.61	27.39
26	15.71	17.33	18.80	20.52	22.70	24.60	26.66	28.51	30.36
27	17.35	18.96	20.89	23.18	25.29	27.39	29.37	31.42	33.53
28	18.93	20.97	23.49	25.70	27.97	30.09	32.35	34.45	36.42
29	20.89	23.51	25.95	28.31	30.65	33.05	35.21	37.34	39.47
30	23.25	25.92	28.40	30.94	33.51	35.78	38.02	40.35	42.43
31	25.59	28.30	30.97	33.70	36.11	38.55	40.99	43.15	45.31
32	27.94	30.73	33.67	36.21	38.85	41.38	43.68	45.98	48.28
33	30.28	33.39	36.10	38.89	41.56	44.01	46.45	48.90	51.34
34	32.74	35.74	38.64	41.53	44.12	46.72	49.31	51.91	54.50
35	35.09	38.19	41.25	44.00	46.75	49.50	52.25	55.01	57.76
36	37.40	40.74	43.64	46.55	49.46	52.37	55.28	58.19	61.10
37	39.84	43.03	46.10	49.18	52.25	55.32	58.40	61.47	64.54
38	42.15	45.39	48.63	51.87	55.11	58.35	61.60	64.84	68.08
39	44.39	47.81	51.22	54.64	58.05	61.47	64.88	68.30	71.71
40	46.70	50.29	53.88	57.47	61.07	64.66	68.25	71.84	75.44

Liite 2. Kuusitukkien arvot, mk/tukki

Latvaläpimitta, cm	Tukin pituus, dm								
	39	42	45	48	51	54	57	60	63
15	—	5.02	5.38	5.74	6.09	—	—	—	—
16	—	5.71	6.11	6.50	6.87	7.28	7.70	—	—
17	5.99	6.42	6.85	7.30	7.78	8.27	8.92	9.53	—
18	6.67	7.16	7.69	8.24	8.95	9.69	10.27	10.88	11.50
19	7.42	8.02	8.73	9.53	10.23	10.91	11.60	12.32	13.03
20	8.26	9.17	9.99	10.73	11.50	12.28	13.07	13.95	14.80
21	9.46	10.30	11.13	12.00	12.85	13.79	14.77	15.71	16.71
22	10.51	11.43	12.38	13.36	14.39	15.46	16.59	17.64	18.66
23	11.63	12.70	13.79	14.92	16.12	17.29	18.42	19.53	20.69
24	12.84	14.06	15.33	16.63	17.84	19.07	20.33	21.66	22.93
25	14.21	15.58	16.98	18.29	19.61	21.04	22.43	23.80	25.19
26	15.65	17.18	18.58	20.05	21.61	23.07	24.56	26.12	27.64
27	17.21	18.74	20.31	21.96	23.55	25.18	26.86	28.54	30.22
28	18.71	20.39	22.17	23.88	25.66	27.43	29.30	31.03	32.74
29	20.31	22.20	24.06	25.96	27.89	29.88	31.70	33.54	35.39
30	22.02	24.03	26.04	28.14	30.20	32.19	34.15	36.10	37.90
31	23.79	25.95	28.16	30.38	32.46	34.60	36.62	38.54	40.47
32	25.63	27.96	30.34	32.56	34.85	36.96	39.02	41.07	43.13
33	27.57	30.09	32.46	34.88	37.13	39.31	41.49	43.68	45.86
34	29.61	32.16	34.69	37.09	39.41	41.73	44.05	46.37	48.68
35	31.59	34.28	36.85	39.31	41.76	44.22	46.68	49.13	51.59
36	33.59	36.39	38.99	41.58	44.18	46.78	49.38	51.98	54.58
37	35.69	38.44	41.18	43.93	46.67	49.42	52.16	54.91	57.65
38	37.65	40.54	43.44	46.33	49.23	52.13	55.02	57.92	60.81
39	39.65	42.70	45.75	48.80	51.85	54.91	57.96	61.01	64.06
40	41.71	44.92	48.13	51.34	54.55	57.76	60.97	64.17	67.38

Liite 3. Tukin

Lpm, cm	Pituus,							
	30	33	36	39	42	45	48	51
12	1.20	1.32	1.44	1.56	1.68	1.80	1.92	2.04
13	1.41	1.55	1.69	1.83	1.97	2.11	2.25	2.39
14	1.63	1.79	1.96	2.12	2.28	2.45	2.61	2.77
15	1.87	2.06	2.25	2.43	2.62	2.81	3.00	3.18
16	2.13	2.34	2.56	2.77	2.98	3.20	3.41	3.62
17	2.40	2.65	2.89	3.13	3.37	3.61	3.85	4.09
18	2.70	2.97	3.24	3.50	3.77	4.04	4.31	4.58
19	3.00	3.30	3.60	3.91	4.21	4.51	4.81	5.11
20	3.33	3.66	3.99	4.33	4.66	4.99	5.33	5.66
21	3.67	4.04	4.40	4.77	5.14	5.50	5.87	6.24
22	4.03	4.43	4.83	5.24	5.64	6.04	6.44	6.85
23	4.40	4.84	5.28	5.72	6.16	6.60	7.04	7.48
24	4.79	5.27	5.75	6.23	6.71	7.19	7.67	8.15
25	5.20	5.72	6.24	6.76	7.28	7.80	8.32	8.84
26	5.63	6.19	6.75	7.31	7.88	8.44	9.00	9.56
27	6.07	6.67	7.28	7.89	8.49	9.10	9.71	10.31
28	6.52	7.18	7.83	8.48	9.13	9.79	10.44	11.09
29	7.00	7.70	8.40	9.10	9.80	10.50	11.20	11.90
30	7.49	8.24	8.99	9.74	10.48	11.23	11.98	12.73
31	8.00	8.80	9.60	10.40	11.20	12.00	12.79	13.59
32	8.52	9.37	10.23	11.08	11.93	12.78	13.63	14.49
33	9.06	9.97	10.87	11.78	12.69	13.59	14.50	15.41
34	9.62	10.58	11.54	12.51	13.47	14.43	15.39	16.35
35	10.19	11.21	12.23	13.25	14.27	15.29	16.31	17.33
36	10.78	11.86	12.94	14.02	15.10	16.18	17.26	18.33
37	11.39	12.53	13.67	14.81	15.95	17.09	18.23	19.37
38	12.02	13.22	14.42	15.62	16.82	18.02	19.23	20.43
39	12.66	13.92	15.19	16.45	17.72	18.99	20.25	21.52
40	13.31	14.65	15.98	17.31	18.64	19.97	21.30	22.63
41	13.99	15.39	16.79	18.18	19.58	20.98	22.38	23.78
42	14.68	16.15	17.61	19.08	20.55	22.02	23.49	24.95
43	15.39	16.92	18.46	20.00	21.54	23.08	24.62	26.16
44	16.11	17.72	19.33	20.94	22.55	24.17	25.78	27.39
45	16.85	18.54	20.22	21.91	23.59	25.28	26.96	28.65
46	17.61	19.37	21.13	22.89	24.65	26.41	28.17	29.93
47	18.38	20.22	22.06	23.90	25.73	27.57	29.41	31.25
48	19.17	21.09	23.01	24.92	26.84	28.76	30.68	32.59
49	19.98	21.98	23.98	25.97	27.97	29.97	31.97	33.97
50	20.80	22.88	24.96	27.04	29.12	31.21	33.29	35.37

tilavuus, j^3

dm							Lpm, cm
54	57	60	63	66	69	72	
2.16	2.28	2.40	2.52	2.64	2.76	2.88	12
2.53	2.67	2.81	2.95	3.09	3.23	3.38	13
2.94	3.10	3.26	3.43	3.59	3.75	3.91	14
3.37	3.56	3.74	3.93	4.12	4.31	4.49	15
3.83	4.05	4.26	4.47	4.69	4.90	5.11	16
4.33	4.57	4.81	5.05	5.29	5.53	5.77	17
4.85	5.12	5.39	5.66	5.93	6.20	6.47	18
5.41	5.71	6.01	6.31	6.61	6.91	7.21	19
5.99	6.32	6.66	6.99	7.32	7.66	7.99	20
6.61	6.97	7.34	7.71	8.07	8.44	8.81	21
7.25	7.65	8.06	8.46	8.86	9.26	9.67	22
7.92	8.36	8.80	9.24	9.68	10.12	10.56	23
8.63	9.11	9.59	10.07	10.54	11.02	11.50	24
9.36	9.88	10.40	10.92	11.44	11.96	12.48	25
10.13	10.69	11.25	11.81	12.38	12.94	13.50	26
10.92	11.53	12.13	12.74	13.35	13.95	14.56	27
11.74	12.40	13.05	13.70	14.35	15.01	15.66	28
12.60	13.30	14.00	14.70	15.40	16.10	16.80	29
13.48	14.23	14.98	15.73	16.48	17.23	17.97	30
14.39	15.19	15.99	16.79	17.59	18.39	19.19	31
15.34	16.19	17.04	17.89	18.75	19.60	20.45	32
16.31	17.22	18.12	19.03	19.94	20.84	21.75	33
17.32	18.28	19.24	20.20	21.16	22.12	23.09	34
18.35	19.37	20.39	21.41	22.43	23.45	24.46	35
19.41	20.49	21.57	22.65	23.73	24.80	25.88	36
20.51	21.64	22.78	23.92	25.06	26.20	27.34	37
21.63	22.83	24.03	25.23	26.44	27.64	28.84	38
22.78	24.05	25.31	26.58	27.84	29.11	30.38	39
23.97	25.30	26.63	27.96	29.29	30.62	31.95	40
25.18	26.58	27.98	29.38	30.77	32.17	33.57	41
26.42	27.89	29.36	30.83	32.29	33.76	35.23	42
27.70	29.23	30.77	32.31	33.85	35.39	36.93	43
29.00	30.61	32.22	33.83	35.44	37.05	38.66	44
30.33	32.02	33.70	35.39	37.07	38.76	40.44	45
31.69	33.46	35.22	36.98	38.74	40.50	42.26	46
33.09	34.93	36.76	38.60	40.44	42.28	44.12	47
34.51	36.43	38.34	40.26	42.18	44.10	46.01	48
35.96	37.96	39.96	41.96	43.96	45.95	47.95	49
37.45	39.53	41.61	43.69	45.77	47.85	49.93	50

Liite 4. Tukin

Lpm, cm	Pituus,							
	30	33	36	39	42	45	48	51
12	34	37	41	44	48	51	54	58
13	40	44	48	52	56	60	64	68
14	46	51	55	60	65	69	74	79
15	53	58	64	69	74	80	85	90
16	60	66	72	78	84	90	97	103
17	68	75	82	89	95	102	109	116
18	76	84	92	99	107	115	122	130
19	85	94	102	111	119	128	136	145
20	94	104	113	123	132	141	151	160
21	104	114	125	135	145	156	166	177
22	114	125	137	148	160	171	182	194
23	125	137	150	162	174	187	199	212
24	136	149	163	176	190	204	217	231
25	147	162	177	191	206	221	236	250
26	159	175	191	207	223	239	255	271
27	172	189	206	223	240	258	275	292
28	185	203	222	240	259	277	296	314
29	198	218	238	258	277	297	317	337
30	212	233	254	276	297	318	339	360
31	226	249	272	294	317	340	362	385
32	241	265	290	314	338	362	386	410
33	257	282	308	334	359	385	411	436
34	272	300	327	354	381	409	436	463
35	289	317	346	375	404	433	462	491
36	305	336	366	397	428	458	489	519
37	323	355	387	419	452	484	516	548
38	340	374	408	442	476	510	544	578
39	358	394	430	466	502	538	573	609
40	377	415	452	490	528	565	603	641
41	396	436	475	515	555	594	634	673
42	416	457	499	540	582	623	665	707
43	436	479	523	566	610	653	697	741
44	456	502	547	593	639	684	730	775
45	477	525	573	620	668	716	763	811
46	499	548	598	648	698	748	798	848
47	520	573	625	677	729	781	833	885
48	543	597	651	706	760	814	869	923
49	566	622	679	735	792	849	905	962
50	589	648	707	766	825	884	942	1 001

tilavuus, dm^3

dm							Lpm, cm
54	57	60	63	66	69	72	
61	64	68	71	75	78	81	12
72	76	80	84	88	92	96	13
83	88	92	97	102	106	111	14
95	101	106	111	117	122	127	15
109	115	121	127	133	139	145	16
123	129	136	143	150	157	163	17
137	145	153	160	168	176	183	18
153	162	170	179	187	196	204	19
170	179	188	198	207	217	226	20
187	197	208	218	229	239	249	21
205	217	228	239	251	262	274	22
224	237	249	262	274	287	299	23
244	258	271	285	299	312	326	24
265	280	295	309	324	339	353	25
287	303	319	334	350	366	382	26
309	326	344	361	378	395	412	27
333	351	369	388	406	425	443	28
357	376	396	416	436	456	476	29
382	403	424	445	467	488	509	30
408	430	453	476	498	521	543	31
434	458	483	507	531	555	579	32
462	488	513	539	564	590	616	33
490	518	545	572	599	626	654	34
520	548	577	606	635	664	693	35
550	580	611	641	672	702	733	36
581	613	645	677	710	742	774	37
612	646	680	714	749	783	817	38
645	681	717	753	788	824	860	39
679	716	754	792	829	867	905	40
713	753	792	832	871	911	951	41
748	790	831	873	914	956	998	42
784	828	871	915	958	1 002	1 046	43
821	867	912	958	1 004	1 049	1 095	44
859	907	954	1 002	1 050	1 097	1 145	45
897	947	997	1 047	1 097	1 147	1 197	46
937	989	1 041	1 093	1 145	1 197	1 249	47
977	1 031	1 086	1 140	1 194	1 249	1 303	48
1 018	1 075	1 131	1 188	1 245	1 301	1 358	49
1 060	1 119	1 178	1 237	1 296	1 355	1 414	50

VARIABLE PROBABILITIES IN SAMPLE-TREE SELECTION

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SELOSTE

VAIHTELEVAT POIMINTATODENNÄKÖISYYDET KOEPUUOTANNASSA

HELSINKI 1971

Helsinki 1971. Valtion painatuskeskus

PREFACE

This paper is connected with the studies in which the Department of Mathematics of the Forest Research Institute has been engaged in recent years to develop statistical methods used in forest research.

The Department of Forest Mensuration and Management at the University of Helsinki made available stand sample plot material it had collected. Dr. P e k k a K i l k k i from this department kindly devoted some of his time to reading and discussing the paper. Professor L a u r i H e i k i n h e i m o and Acting Professor H a n n u V ä l i a h o perused the manuscript.

Mrs. H i l k k a K o n t i o n p ä ä, M.A., translated the manuscript into English and D a v i d C o p e, A.B., checked the translation.

I wish to express my sincere appreciation to these people and institutions and to all others who have assisted me.

Helsinki, September 1971

Risto Seppälä

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1. SAMPLING ESTIMATION OF GROWING STOCK IN SMALL AREAS

11. The current situation in Finland

The growing-stock population is usually so large and the characteristics of interest so difficult to measure that sampling is necessary on even such small areas as growing stands and stands marked for cutting. In a growing stand, the stock characteristics of interest are usually estimated on the basis of a sample plot. The sample plot is in most cases subjectively located, which means that it is not an unbiased sample of the whole stand. As a result, the growing stock of a stand sample plot is treated computationally as an independent population. The desired charcteristics of this population are investigated in two phases: tallying the trees and measuring the sample trees. The tree tally icludes the classification of characteristics (tree species and wood quality) of trees exceeding a given minimum diameter. The sample trees subjected to detailed measurement are selected as a sample from among the counted trees.

The measuring of standing trees is gaining ground as a means of measuring the stock of stands marked for cutting. Standing trees are measured by the same phases as the growing stock of a stand. Usually the trees of the whole marked stand, and not only of a sample plot, are tallied. This often takes place in connection with marking.

The selection of sample trees is a serious problem in the estimation of the growing-stock characteristics of stand sample plots and stands marked for cutting. The sample trees can be selected either in connection with or after the tree tally. Stratified systematic sampling is most often used for selection. The strata are usually formed on the basis of diameter breast height. An optimum allocation of sample trees into strata is attempted on the basis of the standard deviation of volume (K i l k k i 1970, p. 37).

When the sample trees are selected in connection with the tallying of trees, the low cost of the selection is an advantage. If the stem distribution series is not known in advance, a disadvantage is that allocation into strata is far from optimal. When sample trees are selected after tallying, it is possible to approach the optimum allocation. An adverse factor increasing the cost is, however, the necessity of numbering and marking all trees for the selection and measurement of sample trees, and of re-visiting the sample plot or the marked stand (K i l k k i 1970, p. 49).

Relascope sampling (e.g. K u u s e l a 1966) is an alternative in which sample trees can be selected rather efficiently without depending on the tree tally. It is based on circular plots. The probability for a tree to be included in the sample is proportional to the breast-height cross section.

12. The use of variable selection probabilities

Since the measuring of stand sample plots, and especially of trees in stands marked for cutting, is done very frequently, there is every reason to give attention to the shortcomings of current methods of selecting sample trees. A sample combining low cost and ease of selection with good precision in the estimates of the important growing-stock characteristics should be the goal. Furthermore, selecting the sample trees and calculating the estimates should take place so that the sampling error can be estimated from the sample. The use of variable selection probabilities affords a possibility of meeting these requirements.

If the selection probabilities are proportional to a suitable power of the *dbh*, the optimum allocation of the stratified sampling in current use is approached. If the method of sampling, furthermore, permits an unbiased selection of the sample trees in connection with the tree tally, the cost of selection and measurement can be kept reasonable.

The use of variable selection probabilities, especially those proportional to the size of the sampling unit, has been known for decades. With the exception of modifications of areal sampling, the methods used have required a list of the population units and the relevant selection probabilities for the selection of the sample. In the case of sample-tree selection, this normally presupposes a tallying of the trees before the selection. It is thus necessary to find methods under which the selection of sampling units (sample trees) can be effected without bias in connection with the enumeration of the population (tree tally). Relascope sampling offers a possibility for this. However, it is not always efficient enough since, besides the breast-height cross section being not the optimal variate for selection probabilities and the clustering (using circular plots) increasing the variance, it rarely can take advantage of complete knowledge of information on selection probabilities.

A method which avoids the drawbacks connected with relascope sampling is available. It is called sampling with »probability proportional to prediction», or briefly 3-P sampling. Results obtained from the use of the 3-P method in the United States have been very favourable. It was therefore thought to be useful to study its applicability to Finnish conditions. At the same time, a comparison was to be carried out between this method and the methods currently being used.

2. 3-P SAMPLING

21. The nature of the variable selection probabilities

Stratification usually considerably improves the precision of estimates compared with unrestricted simple random sampling. For practical reasons, however, the number of strata must be relatively limited. For example, if sample trees in a stand sample plot are selected in connection with the tree tally, it may be necessary to restrict the selection to two strata (K i l k k i 1970, p. 37). Allocation in such a case is far from optimal, for the strata remain highly heterogeneous.

A suitable function of the stratification variate can be used as the basis of selection probabilities. In principle, this means approaching a situation in which the number of strata is equal to the number of population units, or at least to the number of units used for measurement precision (e.g. centimetre or inch). It is then possible to improve the precision of the estimates in the same way as by increasing the number of strata. It is an advantage that the auxiliary variate used as the basis of selection probability correlates strongly with the variate studied. There are cases, however, in which the use of variable selection probabilities leads to a loss of precision although the correlation is perfect (R a j 1968, p. 50).

When variable probabilities are used, it becomes important from the estimation point of view whether the selection is carried out with or without replacement. If selection without replacement is used, the probabilities change in the course of selection. The result is that the probabilities studied will be conditional. Under most of the routine methods this makes the estimation of population parameters difficult (cf. S e p p ä l ä 1971, pp. 23 & 55—57).

22. Selection of the sample

G r o s e n b a u g h has outlined a method by which the sample can be selected by variable probabilities and simultaneously with the enumeration of the population. The main features of this method are (G r o s e n b a u g h 1965, p. 1):

(1) Of a population of N units, all units (trees of a stand sample plot or a marked stand) are selected in any order (tree tally). At the same time, an easily established character x_i (e.g. *dbh*), of a kind highly proportional to the character under estimation (e.g. tree volume), is measured for every tree. An alternative to measuring the auxiliary character is making a good guess of the value of the character being studied.

(2) When the value of the auxiliary character x_i has been measured, the value is compared with an integer τ_i selected at random from the range $[1, L]$, where L is an integer selected prior to sampling.

(3) If $\tau_i \leq x_i$, the unit i is selected for the sample (sample tree), and the value of character y is measured from it.

When $L \geq x_{max}$, the selection probabilities π_i are exactly proportional to the auxiliary-variate value x_i. When $L < x_{max}$, the units in which $x_i \geq L$ are certainly included in the sample; for the other units, the selection probabilities are still proportional to the value of the auxiliary variate.

Owing to the sampling method, the sample size varies also with identical values of L. It is easy to show (S c h r e u d e r, S e d r a n s k & W a r e, 1968, p. 436) that

$$(1) \qquad E(n) = n_e = \sum_i^N x_i / L$$

and

$$(2) \qquad V(n) = \sum_i^N x_i / L - \sum_i^N x_i^2 / L^2 = n_e - n_e^2 \left\{ 1 + [CV(x)]^2 \right\} / N \,,$$

where $CV(x)$ is the coefficient of variation of the random variate x.

23. Estimation of population parameters

Let $p_i = x_i / \sum_i^N x_i$ be the probability that the ith population unit is selected with the first draw of the sampling. Let the sampling be done with replacement. It can be shown (e.g. S u k h a t m e 1954, p. 62) that an unbiased estimator of the population total of the character being studied is

$$(3) \qquad \hat{Y} = (1/n) \sum_i^n (y_i / p_i) = (1/n)\, X \sum_i (y_i / x_i) \,, \qquad X = \sum_i^N x_i \,.$$

When the selection method is that described under Section 22, the units selected for the sample are not replaced to the population. In spite

of this, the true overall selection probabilities $\pi_i = x_i/L$ do not in practical situations differ from the probabilities of the first draw, $n_e p_i$ (S c h r e u d e r, S e d r a n s k & W a r e 1968, p. 434). When the assumption in the 3-P sampling is $L \geq x_{max}$, an unbiased estimator for the population total is

$$(4) \qquad \hat{Y}_u = \sum_i^n (y_i/\pi_i) = L \sum_i (y_i/x_i) \ .$$

The true variance associated with the unbiased estimator is (S c h r e u d e r, S e d r a n s k & W a r e 1968, p. 435)

$$(5) \qquad V(\hat{Y}_u) = L \sum_i^N (y_i^2/x_i) - \sum_i^N y_i^2 \ .$$

The obtained expression of the variance is independent of the observed size n of the sample. This variance has been found to produce relatively large values (S c h r e u d e r, S e d r a n s k & W a r e 1968, p. 443—447); hence, estimator (4) is not efficient. A partial reason is that the population total of variate x, known in the estimation phase, is not utilized in the estimation.

Substitution of L in equation (4) by the term X/n, in which n is the observed sample size, leads to an »adjusted» estimator in accordance with equation (3):

$$(6) \qquad \hat{Y}_a = (1/n) X \sum_i^n (y_i/x_i) .$$

In principle, the estimator obtained is a ratio estimator since the observed sample size n is a random variable. Therefore, this estimator is biased. For practical purposes, however, the bias is small, especially when the relationship between x and y is linear and the regression line passes close to the origin. In addition, estimator (6) is consistent; therefore the bias is reduced with increasing sample size.

It is impossible in practice to formulate a precise variance expression for estimator (6). The following approximation has proved to be relatively good (S c h r e u d e r, S e d r a n s k & W a r e 1968, p. 447):

$$(7) \qquad V(\hat{Y}_a) = [(1/n_e) \sum_i^N p_i (y_i/p_i - Y)^2] [1 + V(n)/n_e^2] [1 - n_e/N] .$$

Usually this approximation produces too great sampling variances. Deviations from the true variance, in general, are not substantial (S c h r e u d e r, S e d r a n s k & W a r e, 1968, p. 447).

The right-hand side of expression (7) is composed of three factors. The first two are correction factors. The factor $[1+V(n)/n_e^2]$ arises from the fact that the true sample size varies around the expected value. It increases the variance, the increasing effect being reduced as the sample size grows. The factor $[1+n_e/N]$ again is the finite multiplier, and it has a reducing effect on variance. With increasing sample size, the reducing effect of this multiplier naturally grows. The effect of the correction factors may be summarized as follows. When the sample size is small, the aggregate effect usually tends to increase the variance, but with increasing sample size it becomes variance-reducing. When the sampling fraction is small, the aggregate effect of the correction factors can be expected to be very small.

When the sampling fraction is small, the following expression is a good approximation to the variance of $\hat{Y}_a$:

$$(8) \qquad V'(\hat{Y}_a) = (1/n_e)\sum_i^N p_i (y_i/p_i - Y)^2 = L\sum(y_i^2/x_i) - Y^2/n_e \ .$$

When this variance approximation is compared with the variance of the »unadjusted» estimator [formula (5)], the result obtained is that $V'(\hat{Y}_a)$ yields smaller values than $V(\hat{Y}_u)$, provided that

$$\sum_i^N y_i^2 < Y^2/n_e \ .$$

In other words, with increasing sample size the relative difference of the variances is reduced. In the more precise approximation formula (7), however, the finite multiplier has a reducing effect on the variance with increasing sample size. Consequently, the sample size affects the mutual efficiency of the unadjusted and adjusted estimators only if the populations are infinite or very large. On the other hand, it is always true that the loss of efficiency produced by the use of the unadjusted estimator increases when the correlation between x and y increases (S c h r e u d e r, S e d r a n s k & W a r e 1968, p. 444).

The customary expression

$$(9) \qquad v'(\hat{Y}_a) = [1/n(n-1)]\sum_i^n (Xy_i/x_i - \hat{Y}_a)^2$$

can be used as a sample-based estimator of variance $V'(\hat{Y}_a)$.

This estimator is unbiased only if the sample has been selected with replacement and the sample size can be considered fixed.

The simulation experiments of S c h r e u d e r, S e d r a n s k and W a r e revealed that in 14 out of 20 cases approximation $V(\hat{Y}_a)$ was better than approximation $V'(\hat{Y}_a)$ (S c h r e u d e r, S e d r a n s k & W a r e 1968, p. 448). It could also be calculated from the same simulation material that when the finite multiplier was added to $V'(\hat{Y}_a)$, i.e. when the approximation

$$(10) \quad V''(\hat{Y}_a) = (1 - n_e/N)\, V'(\hat{Y}_a)$$

was used, the result, again in 14 out of 20 cases, was a better approximation than could be obtained from variance $V'(\hat{Y}_a)$. In addition, in 13 out of 20 cases (one was a draw), $V''(\hat{Y}_a)$ was better than $V(\hat{Y}_a)$. This was because $V(\hat{Y}_a)$ is conservative and in most cases (16 out of 20 in the material of S c h r e u d e r, S e d r a n s k and W a r e) produces over-estimates.

When the sampling fraction is large, estimator $v'(\hat{Y}_a)$, on the basis of the above, can be improved by adding the finite multiplier:

$$(11) \quad v''(\hat{Y}_a) = (1 - n/N)\, v'(\hat{Y}_a) \quad .$$

Bias can be avoided only when the sample size n is fixed.

3. EXPERIMENTS WITH EMPIRICAL MATERIAL

31. Material

In order to obtain an idea of the efficiency of the 3-P procedure under Finnish conditions, calculations were made using six actual stand sample plots. The material had been collected by N y y s s ö n e n and K i l k k i in the 1960s (N y y s s ö n e n & K i l k k i 1965, Table 1, stands 5, 6, 8, 9, 11 & 12).

The sample plots were slightly larger than the average for stand sample plots but were definitely smaller than the average for stands marked for cutting. The area of every plot was 0.4 hectares (80 metres by 50 metres), i.e. about one acre. Numerous characteristics of every tree from every sample plot were known; the most important for the present study were the diameter at breast height including bark, and the gross volume. The diameter had been measured with a precision of one centimeter. The volume was defined in litres as a function of the *dbh*, taper and height with the aid of I l v e s s a l o's tables (I l v e s s a l o 1947).

The only parameter to be estimated in the following tests was the gross volume. The volume is usually by far the most important of the parameters to be studied, and therefore the sampling must be so planned that as precise an estimate as possible is obtained for it.

Table 1 illustrates certain characteristics of the stand sample plots which were studied.

Table 1. Characteristics of the study material.

Sample plot	Number of trees	Main tree species	Arithmetic mean of *dbh*, cm	Arithmetic mean of gross volume, litres	Variance of gross volume	Variation coefficient of gross volume
1	141	Pine	26.45	646.2	63 125	.389
2	186	Spruce + Pine	25.88	697.6	342 377	.839
3	167	Spruce	21.73	393.4	34 326	.471
4	207	Pine + Spruce	19.96	339.7	55 638	.694
5	363	Pine + Spruce	17.31	224.8	21 990	.660
6	201	Spruce + Birch	20.67	341.5	42 595	.604

32. The optimal powers of diameter breast height

When *dbh* is used as the basis of selection probabilities, it is not necessary to be satisfied with the diameter as such. Of the functions of the diameter, it seems most natural to examine the powers. Owing to the conical shape of a tree, the tree volume depends most strongly on some power higher than the first order of the diameter.

In order to find out in which way the volume depends on the *dbh*, correlation coefficients were calculated between the volume and the different powers of the diameter. The results are given in Table 2. The tree species were not specified either in this or the other calculations of the study; instead, the whole sample plot was treated as a single unit.

Apart from sample plot 1, all the higher diameter powers examined produced larger values for the correlation coefficient than power 1.0. Judging by the average, the maximum correlation-coefficient value fell slightly below power 2.0. The size of trees affected the determination of the power producing the highest correlation: the larger the tree size of the growing stock on the plot, the smaller the power of *dbh* which produced the highest value of the correlation coefficient for volume. It should be remembered, however, that the highest correlation often does not indicate the best variate on which selection probabilities should be based (cf. p. 7).

The next step was an attempt to determine which power of the *dbh* produces the most precise estimate. Using variable selection probabilities, the estimates, with other factors undergoing no change, are more exact (1) the stronger is the linear dependence between the auxiliary variate x and the variate of interest y, (2) the closer to the origin passes the line describing the regression, and (3) the closer to unity is the slope of the regression line. If the linear relationship is complete and the regression line has the shape $y = x$, the value of the variance is reduced to zero (however, not the variance value of the unadjusted estimator (4)). Sampling variance develops immediately if any one of the conditions (1)—(3) is not satisfied.

Table 2. Correlation coefficients between gross volume and the different powers of *dbh*, by sample plots.

Sample plot	Powers of diameter breast height											
	1.0	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5
1	.974	.975	.975	.975	.974	.974	.973	.972	.971	.970	.969	.967
2	.981	.989	.990	.990	.990	.989	.988	.987	.986	.985	.983	.981
3	.961	.976	.978	.978	.979	.979	.978	.977	.976	.975	.973	.971
4	.953	.972	.974	.976	.978	.979	.980	.980	.980	.980	.980	.980
5	.964	.976	.977	.978	.979	.979	.979	.979	.979	.978	.978	.977
6	.944	.965	.967	.969	.970	.971	.971	.971	.970	.970	.969	.967

When the *dbh* power was the independent variable and the gross volume was the dependent variable, the regression line for most of the diameter powers studied intersected the ordinate axis underneath the origin. A distinct regularity could be noted: the higher the power of *dbh*, the higher the point where the regression line intersected the ordinate axis. Up to the power 1.9, the slope of the regression line exceeded unity. It was closest to unity on every sample plot when the power was 2.0. With powers higher than this, the slope continued to diminish.

When the regression line first intersected the ordinate axis above the origin, the minimum error variance was obtained on every sample plot. The power of the *dbh* ranged from 2.1 to 2.4, with the mean being 2.3. The result obtained suggests that of conditions (1)—(3) above, condition (2) is the most important, i.e. the closer the line indicating the linear regression of the auxiliary variate and the variate of interest passes to the origin (above the origin), the better suited is the auxiliary variate for use as a basis of selection probability. This presupposes, however, that the linear correlation between the variates is at the same time strong enough and that the slope of the regression line does not differ too much from unity.

The sampling variances corresponding to the different powers were calculated in order to find out which *dbh* power produces the most precise estimate. The starting point was the adjusted estimator (6). Since no exact computational variance formula can be presented, an adequate number of simulation experiments is the only possible means of estimating the true variance without bias. No such experiments were made in the present study but the variance was calculated using estimator (7), which in earlier Monte-Carlo studies had proved to be a good approximation (S c h r e u d e r, S e d r a n s k & W a r e 1968, p. 448).

Table 3 presents the smallest error variances obtained, with the corresponding *dbh* powers and relative standard errors. For comparison, the table also gives the variances corresponding exactly to power 1.0 and power 2.0. The sample size per plot was 30 sample trees.

Table 3. The approximate variances per plot corresponding to power 1.0 ($V_{aD}{}^{1}$), power 2.0 ($V_{aD}{}^{2}$) and the optimum power ($V_{aD}{}^{opt}$) of *dbh*.

Sample plot	Optimum power	$^{-10\,000}V_{aD}{}^{opt}$	$\sqrt{V_{aD}{}^{opt}}/Y$	$^{-10\,000}V_{aD}{}^{1}$	$^{-10\,000}V_{aD}{}^{2}$	$V_{aD}{}^{1}/V_{aD}{}^{opt}$	$V_{aD}{}^{2}/V_{aD}{}^{opt}$
1	2.1	173	1.44	998	179	5.77	1.03
2	2.3	778	2.15	9 192	1 091	11.81	1.40
3	2.3	113	1.62	853	151	7.55	1.34
4	2.4	192	1.97	2 237	362	11.65	1.89
5	2.4	302	2.13	2 964	503	9.81	1.67
6	2.4	244	2.28	1 612	339	6.61	1.39

The variance diminished considerably on every plot on transition from power 1.0 to 2.0. On further transition from power 2.0 to the optimum power, the reduction in variance was no longer so pronounced, but was nevertheless substantial, apart from sample plot 1. It is easy to see that giving excessive attention to a high value of the correlation coefficient may be seriously misleading. For example, on sample plot 1 the correlation coefficient (see Table 2) corresponding to power 1.0 (0.974) exceeds the coefficient corresponding to the optimum power (0.972), but the sampling variance obtained on the basis of the former is nearly six times that of the latter.

33. Comparison of the unadjustef and adjusted estimators

The next step was to compare the efficiencies of the unadjusted and adjusted estimators. According to the preceding section, the optimum power of *dbh* was slightly above 2.0. To simplify, the following calculations were based on power 2.0, for of all integer powers, its use produces the most precise estimates.

The variance of the adjusted estimator was approximated using expression (7). In addition, the variance obtained for a sample selected by simple unrestricted random sampling with equal selection probabilities was calculated. The sample size per plot was 30 sample trees. The variances obtained are given in Table 4.

The unadjusted estimator proved to be surprisingly inefficient. The use of this estimator did not even lead to the precision obtained for sampling carried out with equal selection probabilities. Compared with both V and V_{aD^2}, the inefficiency of V_{uD^2} increased when the relative standard deviation of tree volume (coefficient of variation, see Table 1) diminished. Accordingly, the efficiency of the adjusted estimator, compared with simple random sampling, was greatest on sample plot 2, which had the highest coefficient of variation on y.

Table 4. Variances of a simple random sampling (V) and the unadjusted estimator (V_{uD^2}), and the approximations calculated for the variance of the adjusted estimator (V_{aD^2}), by sample plots.

Sample plot	$V^{-10\,000}$	$V_{uD^2}^{-10\,000}$	$V_{aD^2}^{-10\,000}$	V/V_{aD^2}	V_{uD^2}/V_{aD^2}	V_{uD^2}/V
1	3 293	21 122	179	18.40	118.00	6.41
2	33 115	42 003	1 091	30.35	38.50	1.27
3	2 618	11 409	151	17.34	75.56	4.36
4	6 795	13 360	362	18.77	36.91	1.97
5	8 860	20 095	503	17.61	39.95	2.27
6	4 880	12 896	339	14.40	38.04	2.64

34. Truncating the values of the auxiliary variate

When a sample is selected by the 3-P method, random numbers with a range of [1, L] and not fewer than the number of the population units are required (p. 8). For practical purposes, the selection is easier the smaller the range, i.e. the smaller the value of L. If the expected value of the sample size is fixed at n_e, we obtain (p. 8) $L = X/n_e$; that is to say, the width of the range depends on the sum of the population values of variate x which is used as the selection variate. The ease of selection is therefore improved if variate x does not acquire particularly high values.

It was shown above that powers of *dbh* exceeding power 1.0 gave the most precise results. If the precision of measuring the *dbh* is 1 cm, as it was in the present material, the result is that, when power 2.0 of the diameter is used as variate x and the expected value of the sample size is 30, the value of L on the samp leplot varies from 2 729 (Plot 3) to 4 750 (Plot 2).

If the diameters are raised to power 2.0 and the figures obtained are truncated by dropping the last digit, the range of the random numbers is reduced to less than one-tenth of the original range. For the present sample-plot material this means that three digits is the maximum number length which need be used. However, the condition for the use of truncation is that the precision of the estimates does not diminish substantially.

The effect of truncation was studied by means of the available material. The expected value of the sample size was 30. On truncation, the last digit of the value of the *dbh* power 2.0 was dropped without raising the preceding digit. Estimator (7) was used in the calculation. The results are presented in Table 5. For comparison, the table also gives the variances obtained with untruncated values, and the values of L for the truncated variates x.

On the whole, truncation did not appreciably reduce the efficiency; on two sample plots, the variance even diminished. For the plots on which the mean *dbh* (the arithmetic mean, see Table 1) was large, the precision either increased or was very slightly reduced (Sample plots 1, 2 & 3).

Table 5. Approximate variances produced by the untruncated (D^2) and truncated ($\dot{D}^2$) *dbh* power 2.0.

Sample plot	$\varrho(D^2, Y)$	$\varrho(\dot{D}^2, Y)$	$^{-10\,000}V_{aD^2}$	$^{-10\,000}V_{a\dot{D}^2}$	$V_{a\dot{D}^2}/V_{aD^2}$	$L_{\dot{D}^2}$
1	.973	.973	179	181	1.01	337
2	.988	.988	1 091	1 038	.95	472
3	.978	.978	151	146	.97	270
4	.980	.979	362	414	1.14	292
5	.979	.979	503	535	1.06	383
6	.971	.971	339	463	1.37	305

Truncation may be continued by eliminating the last two digits of the power of the diameter. The result would be, however, that by using power 2.0 only trees with a minimum *dbh* of 10 cm could be selected as sample trees, or that all diameters under 10 cm must be given a value of unity for variate x. When only the last digit is truncated, the minimum diameter will be 4 cm. The test material (a total of 1 265 trees) contained 4 trees with *dbh* under 4 cm. In the calculation of variances, the variate x of these trees was given the value unity.

35. Random variation of sample size

Perhaps the greatest weakness of 3-P sampling is that the true size of the sample usually differs from the planned sample size. If the realized sample size is below the expected value, the estimates obtained are not as precise as planned. If, on the other hand, the realized sample size is larger than the expected size, the cost of sampling is unnecessarily high for the precision desired.

Random sample size, furthermore, makes it difficult to find the true variance. The variance of the adjusted estimator [formula (6)] can only have approximate expressions. Random sample size also increases the variance. Especially in the unadjusted estimator [formula (4)], the effort to reduce the effect of random sample size on the estimation resulted in a considerable loss of precision.

In order to have an idea of the strength of the randomness of the sample size, variances were calculated for different sample sizes. The sample size per plot ranged from 20 to 50 sample trees. The auxiliary variate used was again, for the sake of simplicity, the *dbh* power 2.0 instead of the optimum power. The variance of the sample size was calculated on the basis of expression (2).

Confidence intervals corresponding to 95 % probability were calculated for sample sizes 30 and 50. In reality, the distribution of the sample size is close to binomial, and therefore the confidence limits are not symmetrical. Since, however, the calculated sample-size variance, even at its lowest, exceeded 16 (cf. H a l d 1962, p. 680, where the minimum of variance is given the value 9), it was considered that an approximation of the normal distribution could be used. The confidence limits given here are therefore symmetrical.

The results are presented in Table 6. The table also gives the values of the correction factor $[1+V(n)/n_e^2]$ connected with the approximation (7) of the variance of the adjusted estimator. The expected value of the sample size in calculating this term was set at 30.

Table 6. Variances corresponding to the various expected values of sample size, 95 % confidence intervals for sample sizes 30 and 50, and the correction factor connected with estimator (7).

Sample plot	$V(n)$				95 % confidence intervals		$1 + V(n)/n_e^2$
	$n_e = 20$	$n_e = 30$	$n_e = 40$	$n_e = 50$	$n_e = 30$	$n_e = 50$	$n_e = 30$
1	16.8	22.8	27.1	29.9	20.7—39.3	39.3—60.7	1.025
2	16.6	22.4	26.5	28.9	20.7—39.3	39.5—60.5	1.025
3	17.2	23.7	28.9	32.6	20.5—39.5	38.8—61.2	1.026
4	17.5	24.3	29.9	34.2	20.3—39.7	38.5—61.5	1.027
5	18.6	26.8	34.3	41.1	19.9—40.1	37.4—62.6	1.030
6	17.5	24.4	30.0	34.4	20.3—39.7	38.5—61.5	1.027

The differences in variances compared between the sample plots were not very large. As a natural result, the variance increased as the number of sample trees grew, but not very much. The intervals widened only a little on transition from an expected sample size of 30 to one of 50. The values of the correction factor connected with estimator (7) were very small. At its maximum, its variance-increasing effect was only 3 %. On the basis of this result, it seems justifiable to replace estimator (7) by estimator (10). On the other hand, the influence of the finite multiplier on the sampling variance in the sample plots of the size studied was so great that estimator (8) cannot enter into question.

36. Comparison with other methods

In order for the use of the 3-P procedure to be profitable, its advantages compared with other methods must exceed the disadvantages. The greatest adverse factor is variation of the real sample size around the desired size. On the credit side, the most important factors are that the sample trees can be selected in connection with the tallying of the trees, and that the sampling error can be kept reasonable. This last assertion, however, requires some detailed discussion.

Table 4 showed that 3-P sampling based on the *dbh* power 2.0 (adjusted estimator) was, on the sample plots studied, 14—30 times more efficient than the simple unrestricted random sampling, which is not, however, the most efficient of the methods using equal selection probabilities. Regression, difference and ratio estimation, and stratified sampling often make it possible to increase precision considerably.

Studies based on simulation experiments in the United States have demonstrated that ratio and regression estimation, in a forest population, produce no more precise estimates than 3-P sampling. In many cases, the efficiency of ratio estimation in particular has been considerably lower than

that of a sampling method based on variable selection probabilities (Schreuder, Sedransk, Ware & Hamilton 1971, p. 117). In addition, bias involved expressly in ratio estimation may in some cases be considerable. If the auxiliary variate used in growing-stock measurement is *dbh* power 2.0 or a higher optimum power, the bias apparently remains small since the line indicating regression passes close to the origin (p. 14).

In Finland, the sample trees are mainly selected by means of stratified sampling. Usually the strata on stand sample plots are in 1-cm *dbh* classes and in stands marked for cutting in 2-cm classes. The number of sample trees on stand sample plots is normally 30—35 trees, and therefore a 1-cm diameter-class stratum seldom contains more than one sample tree.

Owing to the low number of sample observations per diameter class, sampling variance usually cannot be calculated for stand sample plots. Nor were the variances calculated in the present study for the 1-cm diameter-class strata. However, calculations were made concerning the sampling variance of stratified sampling with class intervals of 5 cm. Information was obtained at the same time on the influence of the reduction of measurement precision on the results.

The results per sample plot are given in Table 7. In 3-P sampling, the value of variate x given to each measured diameter of a 5 cm diameter class (1—5, 6—10, . . .) was the power 2.0 of the mean of the class (3, 8, . . .). Variance $V_{aD_5^2}$ was calculated from expression (7). The expected value of the sample size on all plots was 30.

This method was compared with stratified sampling (variance V_{st}). An effort was made to imitate the selection method prevailing in practice by first selecting one sample tree for each stratum, after which the remaining number of sampling units was divided into strata according to optimum allocation. The total number of sample trees per sample plot was the same as in the 3-P sampling.

If the sample trees are selected in connection with tree tally, the method now most frequently used on stand sample plots is to enter as sample trees every third tree exceeding the estimated mean diameter and every sixth tree with a diameter smaller than the estimated mean (Kilkki 1970, p. 37). The growing-stock parameters are estimated by the auxiliary-curve method. This method is based on freehand smoothing, and therefore no error variance for the estimates can be calculated from the sample. It is evident, however, that the estimates obtained in this way cannot be so precise as in stratified sampling with a dense diameter classification. Also, the estimation easily becomes biased.

Apart from sample plot 2, the variances of 3-P sampling, and those of stratified sampling with 5-cm diameter classes, were very close to each other. The good result of the stratified sampling on sample plot 2 is under-

Table 7. Variances per sample plot in 3-P sampling and stratified sampling calculated by 5-cm *dbh* classes (D_5).

Sample plot	$\varrho(D_5, Y)$	$\varrho(D_5^2, Y)$	$V_{aD^2}^{-10\,000}$	$V_{st}^{-10\,000}$	$V_{aD_5^2}/V_{st}$	$V_{aD_5^2}/V_{aD^2}$
1	.921	.928	462	447	1.03	2.58
2	.969	.978	1 699	1 143	1.49	1.56
3	.917	.939	326	345	.94	2.16
4	.933	.963	504	435	1.16	1.39
5	.923	.942	1 033	948	1.09	2.05
6	.922	.946	530	500	1.06	1.56

standable when the distribution of the trees of this sample plot is examined in some detail. On sample plot 2, the proportion of trees exceeding 30 cm *dbh* was 30 %, against an average of 5 % on the other sample plots. The relative standard deviation diminished with larger diameters. In the over-30-cm diameter classes (class interval 5 cm), the mean coefficient of variation (arithmetic mean) in the present material was 0.12, whereas in the under-30-cm classes it was 0.34.

Table 7 does not show how precise the estimates in stratified sampling become if the class interval is reduced to 1 cm. In principle, the 3-P sampling used here (selection probabilities proportional to the power 2.0 of *dbh*) approaches a stratified sampling in which allocation to strata takes place proportionally to the sums of diameter power 2.0 of trees belonging to the stratum. Allocation, therefore, follows the ratio of characters $N_h\bar{D}_h^2$, where N_h is the number of trees in class h, and $\bar{D}_h$ is the diameter mean of class h (5-cm classes, $\bar{D}_h = 3, 8, \ldots$).

When the sampling units were allocated into strata according to the proportion of variates $N_h\bar{D}_h^2$, the allocation on every sample plot was very close to the optimum. It could therefore be concluded that the 3-P method and optimally stratified sampling were very nearly identical in their efficiency. This assertion is supported by the finding of Table 7 concerning the small differences between variances $V_{aD_5^2}$ and V_{st}. Consequntly, it is justifiable to assume that on transition to smaller diameter classes, with the extreme case of 1-cm classes, the precision of the estimates of 3-P sampling and optimally stratified sampling are of the same order. Furthermore, sampling is usually systematic; the optimum allocation can only approximately be taken into account.

The efficiency of 3-P sampling can be increased by using the optimum *dbh* powers instead of the power 2.0 (p. 14). Then 3-P sampling becomes clearly more efficient than relascope sampling, which at its best is at the most only as precise as the 3-P sampling with selection probabilities proportional to diameter power 2.0.

The calculation of 3-P estimates in 5-cm diameter classes made it possible to study how the reduced precision in measurement affects the precision of the estimates. Variance $V_{aD_5^2}$ was calculated using a classification, where the observations (*dbh* values) in each class were given the value of the class mean. The 5-cm measurement precision produced error variances nearly twice those of the 1-cm precision (variance V_{aD^2}). This led to the conclusion that, when 3-P sampling is used, relatively precise measurement is required to ensure adequate precision of the results.

4. CONCLUSION

A few of the disadvantages accompanying ordinary 3-P sampling were repeatedly pointed out in the foregoing: random sample size, and the approximate nature of the variance expressions of the adjusted estimator, which is the most efficient. In other contects (Schreuder, Sedransk & Ware 1968; Schreuder, Sedransk, Ware & Hamilton 1971), it could be shown that the approximation used in this study is adequate for practical requirements. Although the adjusted estimator, in principle, is biased, the bias is not significant since the relationship between the higher *dbh* powers used as the auxiliary variate and the gross volume to be estimated is strongly linear, and since, furthermore, the line describing the regression passes very close to the origin (p. 14).

The only disadvantage of practical importance in 3-P sampling is the random sample size. The »incorrect» sample size may be partly due to the fact that the population total of the auxiliary variate required for the estimation of figure L (p. 8) must be determined before the sample is selected. Usually, however, the basal area of a growing or marked stand is easy to estimate roughly, and this estimate can be used in the estimation of the population total of the auxiliary variate.

With a larger sample size, the relative standard error connected with the sample-size estimate is greatly reduced (Table 6). When the expected value was 50 sample trees, the 95 % confidence interval for the present sample plots, even at its poorest, was 37—63 sample trees. For practical purposes, the number of excessive trees in the sample is not yet alarming, and if the trees are too few the sample can be supplemented (cf. Schreuder, Sedransk, Ware & Hamilton 1971, p. 104).

Alternatives have been proposed for fixing the sample size. These suggest that selection takes place either at random or systematically from the cumulated values of the auxiliary variate (Schreuder, Sedransk, Ware & Hamilton 1971). The systematic sampling from the cumulated values of the auxiliary variate has proved to be more efficient than the customary 3-P method. However, systematic sampling carried out in this way easily involves a selection bias which may make it impracticable (cf. Grosenbaugh 1968, p. 453). In addition, cumulation of the auxiliary-variate values requires arithmetic calculations in the field. Unless



Figure. A one digit version (operating in the range [0,9]) of a series of battery-operated electronic random-number generators for generating equally distributed random numbers. Ease of use and high reliability is achieved by using integrated-circuit technology. The manufacturer: Insinööritoimisto Kaje, Laine ja Tuomola Oy.

unwieldy calculation equipment is carried, the surveyor must rely on his mental arithmetic, which is highly susceptible to miscalculation.

A practical problem in 3-P sampling stems from the advantage of basing the selection on diameter powers higher than 1.0. For this reason, in selecting the sample trees the surveyor must have a table in which the higher power required is indicated as a function of the result of measurement (power 1.0).

Another practical problem is the production of the necessary random numbers. The simplest way is to use random-number tables prepared for field use, or to generate the necessary figures by computer expressly for the purpose (see G r o s e n b a u g h 1965, pp. 30—33). Portable generation equipment has also been designed. The equipment described in the literature has been mechanical (G r o s e n b a u g h 1965, pp. 33—36); the operational reliability, therefore, cannot be very good. In co-operation with the author,

there has now been developed a portable electronic random-number generator, which is sufficiently small and lightweight (see Figure).

Whenever the population, for one reason or another, has been listed, there is no point in using 3-P sampling. Stratified sampling, regression and ratio estimation, or the ordinary use of variable selection probabilities lead to just as good estimates.

When it is not advisable, for reasons of economy or otherwise, to enumerate the population (tally the trees) before the selection of sampling units (sample trees), the 3-P method is a good way of achieving sufficiently efficient sampling. The estimates it produces are at least as precise as those of the stratified sampling methods now most frequently used in Finland. For these methods to be efficient, the trees must be tallied beforehand. The ordinary 3-P procedure is free from selection bias, which is possible under the other methods when the sample trees are selected at the same time as the trees are tallied.

In addition to the gross volume of the growing stock, it is normally necessary to estimate the volume in given *dbh* classes (e.g. pulpwood and saw timber), and other parameters of the growing stock such as age and increment. Under the 3-P procedure these other parameters are estimated in exactly the same way as the gross volume. The volumes per diameter class are estimated in each class as if the class were an independent population. Difficulties may arise if the sample size is small and the classes numerous, with the result that some classes are perhaps without sample trees. The mean volume of these classes can be estimated by interpolation or extrapolation based on the mean volumes of the other classes, for example.

The stratified sampling currently being used on stand sample plots is associated with the disadvantage that the sampling variance, owing to the small number of observations, usually cannot be estimated. In 3-P sampling the variance estimates and population-total estimates are easily calculated by a computer.

5. SUMMARY

The selection of sample trees constitutes a serious sampling problem in the estimation of the growing-stock characteristics of stand sample plots and stands marked for cutting. When the sample trees are selected in connection with the tree tally, the advantage is a low cost of selection. The disadvantage of the methods generally used in Finland is that the estimates are not very precise. The precision of the results is considerably improved if sample trees are selected after the counting. A disadvantage involving additional costs, however, is that in most cases all trees must be numbered and marked for the selection and measurement of sample trees, which necessitates a second visit to the sample plot or stand marked for cutting.

The current methods of selecting sample trees in Finland are not optimal on every point. The goal should be a method combining low cost and ease of selection with good precision in the estimates of growing-stock characteristics. This was the starting point for the present study.

The 3-P sampling (sampling with »probability proportional to prediction») used as the selection method was first discussed. The selection method itself was outlined in brief. Its most essential feature is that the sample trees can be efficiently selected in connection with the tree tally. The estimation of population parameters was discussed, and two alternative estimators reviewed. Particular attention was given to the calculation of the sampling variance of the more efficient »adjusted» estimator, since only approximate expressions can be presented for this variance.

The study itself consists of a series of experiments carried out with empirical material. Six stand sample plots, with the number of standing trees ranging from 141 to 363, were studied. The 3-P sampling is carried out with variable selection probabilities. The basis chosen for the selection probabilities was the diameter at breast height (*dbh*). The first step was to determine which of the *dbh* powers produced the lowest error variance. The optimum powers for the different sample plots varied between 2.1 and 2.4.

Subsequently, two alternative basic estimators were compared. Of these two, the slightly biased »adjusted» estimator proved to be considerably more efficient than the unbiased »unadjusted» estimator. At the same time, it could be seen that, compared with simple unrestricted random sampling in which the sample is selected with equal probabilities, 3-P sampling gave by far the more precise estimates.

The ease of sample-tree selection in the sampling method reviewed depends very much on the range of values for the auxiliary variate underlying the selection probability. Tests were therefore made concerning the effect of truncating these values on the precision of the estimates. It was seen that the error variance underwent no substantial change when the last digit was dropped after raising the *dbh* (in centimetres) by a power. By truncation, the random numbers used in the selection of the sample could be reduced to one-tenth of the original numbers.

The most serious problem in the customary 3-P sampling is the random sample size. This random variation was examined and it was found that the variation was not overwhelmingly great. In addition, its relative proportion of the sample size was found to diminish rapidly as the expected value of the sample size increased.

Finally, the 3-P sampling was compared with a method used in Finland at present, according to which the sample trees, after tallying, are selected as a stratified sample. The stratification is based on *dbh* and aims at optimum allocation. It was seen that the precision of the estimates produced by 3-P sampling was of the same order as that obtained by the stratified sampling after tree tally.

Summarizing, it was seen that the 3-P method is a very efficient way of carrying out the sampling whenever the population has not been enumerated (trees have not been tallied) before the selection of the sampling units (sample trees).

REFERENCES

Grosenbaugh, L. R. 1965. Three-pee sampling theory and program 'THRP' for computer generation of selection criteria. *U. S. Forest Service Research Paper* PSW-21. Berkeley.

—»— 1968. On »3-P -sampling and some alternatives, I». *Forest Science* 14.4, 453—454.

Hald, A. 1962. Statistical theory with engineering applications. John Wiley & Sons, Inc. New York.

Ilvessalo, Y. 1947. Pystypuiden kuutioimistaulukot. Summary: Volume tables for standing trees. *Metsäntutkimuslaitoksen Julkaisuja* 34.4. Helsinki.

Kilkki, P. 1970. Puunmittausoppi. Mimeographed. Department of Forest Mensuration and Management, University of Helsinki.

Kuusela, K. 1966. A basal area-mean tree method in forest inventory. *Metsäntutkimuslaitoksen Julkaisuja* 61.2. Helsinki.

Nyyssönen, A. & Kilkki, P. 1965. Sampling stand in forest survey. *Acta Forestalia Fennica* 79.

Raj, D. 1968. Sampling theory. McGraw-Hill. New York.

Schreuder, H. T., Sedransk, J. & Ware, K. D. 1968. 3-P sampling and some alternatives, I. *Forest Science* 14.4, 429—453.

Schreuder, H. T., Sedransk, J., Ware, K. D. & Hamilton, D. A. 1971. 3-P sampling and some alternatives, II. *Forest Science* 17.1, 103—118.

Seppälä, R. 1971. Linked systematic cluster sampling for the estimation of timber removals. *Metsäntutkimuslaitoksen Julkaisuja* 72.3. Helsinki.

Sukhatme, P. V. 1954. Sampling theory of surveys with applications. The Iowa State University Press. Ames.

SELOSTE

Metsikkökoealojen ja pystymittausleimikoiden puustotunnusten estimoinnissa muodostaa koepuiden poiminta vakavan otantaongelman. Kun koepuut poimitaan puiden luvun yhteydessä, on etuna poiminnan helppous. Haittana Suomessa tällä hetkellä eniten käytetyissä menetelmissä on se, että estimaatit eivät ole kovin tarkkoja. Kun koepuut poimitaan puiden luvun jälkeen, paranee tulosten tarkkuus huomattavasti. Kustannuksia lisäävänä haittatekijänä on kuitenkin tällöin se, että useimmissa tapauksissa koepuiden poimintaa ja mittausta varten joudutaan puut numeroimaan ja merkitsemään sekä käymään toistamiseen koealalla tai leimikossa.

Nykyisin Suomessa käytetyt koepuiden poimintamenetelmät eivät ole joka suhteessa optimaalisia. Tavoitteena tulisi olla sellainen menetelmä, jossa yhdistyvät toisaalta poimintamenettelyn vaivattomuus ja toisaalta puustotunnusten estimaattien hyvä tarkkuus. Tämä oli tutkimuksen lähtökohtana.

Aluksi tarkasteltiin otantamenetelmänä käytettävää 3-P otantaa (sampling with »probability proportional to prediction»). Itse poimintamenettely esitettiin lyhyesti. Sen olennaisimpana piirteenä on, että koepuut voidaan poimia tehokkaasti jo puiden luvun yhteydessä. Perusjoukon parametrien estimoinnin yhteydessä tarkasteltiin kahta vaihtoehtoista estimaattoria. Erityisesti kiinnitettiin huomiota tehokkaampaan »tarkennettuun» estimaattoriin liittyvän virhevarianssin laskentaan, koska varianssille voidaan esittää vain aproksimatiivisia lausekkeita.

Varsinainen tutkimus koostui sarjasta empiirisellä materiaalilla tehtyjä kokeita. Tarkastelun kohteena oli kuusi metsikkökoealaa, joissa puiden lukumäärä vaihteli 141:stä 363:een. 3-P -otanta tapahtuu vaihtelevin poimintatodennäköisyyksin. Poimintatodennäköisyyden perustaksi valittiin rinnankorkeusläpimitta. Aluksi tutkittiin, mikä rinnankorkeusläpimitan potensseista tuottaa pienimmän virhevarianssin. Eri koealoilla tämä potenssi vaihteli 2.1:stä 2.4:ään.

Tämän jälkeen verrattiin kahta vaihtoehtoista perusestimaattoria. Näistä lievästi harhainen »tarkennettu» estimaattori osoittautui huomattavasti tehokkaammaksi kuin harhaton »tarkentamaton» estimaattori. Samalla saatettiin todeta, että verrattuna yksinkertaiseen rajoittamattomaan satunnaisotantaan, jossa otos poimitaan yhtä suurin todennäköisyyksin, 3-P -otanta tuotti huomattavasti tarkempia estimaatteja.

Koska koepuiden poiminnan helppous tarkastellussa otantamenetelmässä suuresti riippuu poimintatodennäköisyyden perustana käytetyn apumuuttujan arvojen vaihteluvälin laajuudesta, tehtiin kokeiluja näiden arvojen typistämisen vaikutuksesta estimaattien tarkkuuteen. Kävi ilmi, että kun poistettiin senttimetreissä ilmaistun rinnankorkeusläpimitan neliön arvosta viimeinen numero, ei virhevarianssi olennaisesti muuttunut. Otoksen poiminnassa käytetyt satunnaisluvut saatiin typistämisellä pienenemään kymmenenteen osaan alkuperäisistä.

Vakavimman ongelman tavanomaisessa 3-P -otannassa muodostaa otoskoon satunnaisvaihtelu. Tutkittaessa otoskoon varianssia voitiin todeta, että otoskoon vaihtelu ei ole liian suuri käytännön tilanteita ajatellen. Lisäksi havaittiin sen suhteellisen osuuden otoksen koosta pienenevän nopeasti otoskoon odotusarvon kasvaessa.

Lopuksi verrattiin 3-P -otantaa sellaiseen Suomessa tällä hetkellä käytössä olevaan menetelmään, jossa koepuut poimitaan puiden luvun jälkeen ositettuna otantana. Ositus perustuu rinnankorkeusläpimittaan ja siinä tavoitellaan optimaalista kiintiöintiä. Osoittautui, että 3-P -otannan tuottamien estimaattien tarkkuus oli samaa luokkaa kuin vertauskohtana olleessa puiden luvun jälkeen tapahtuvassa ositetussa otannassa.

Yhteenvetona saatettiin todeta, että milloin ei ole luetteloitu perusjoukkoa (luettu puita) ennen otosyksiköiden (koepuiden) poimintaa, on 3-P -menetelmä hyvin tehokas tapa toteuttaa otanta.

Corrections — Korjauksia:

74.5: p. 22 4.00—5.00 per mille read ≥ 5.00 per mille

p. 31 k-67/Ca_{10} r = —0.29*** read k-67/Ca_{10} r = 0.29***

p. 42 N, K, Ca, Mg and ... read N, P, K, Ca, Mg and ...

s. 22 4.00—5.00 per mille po. ≥ 5.00 per mille

s. 31 k-67/Ca_{10} r = —0.29*** po. k-67/Ca_{10} r = 0.29***

s. 42 N, K, Ca, Mg and ... po. N, P, K, Ca, Mg and ...

NUTRITIONAL DIAGNOSIS OF SCOTS PINE STANDS BY NEEDLE AND PEAT ANALYSIS

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SELOSTE

HELSINKI 1971

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FOREWORD

The purpose of this study was to clarify the correlations between the height growth of drained and fertilized peatland forests and the nutrient content of needles and peat, and to obtain information as to what values given by needle and peat analyses indicate in themselves which nutrient is the minimum growth factor. A further aim was to develop a method for the determination of fertilization requirements.

The study was carried out as a joint project of the Peatland Department of the Finnish Forest Research Institute, and Viljavuuspalvelu Oy. The former collected the material and analysed the results, and the latter performed the chemical analyses. The working plan was prepared by Kimmo Paarlahti, Lic.For., and Antti Reinikainen, Lic.Phil., Department of Botany, University of Helsinki. The latter was also in charge of the organization of the field work. Heikki Veijalainen, B.Sc., analysed most of the material, in cooperation with Paarlahti and Reinikainen. A part of the material (Muhos) was analysed by Erkki Ahti, B.F. The finnish manuscript was written by Reinikainen and checked by Paarlahti and Veijalainen.

The manuscript was read by Prof. P. J. Viro and Martti Kurki, M.Agr. Sc., who proposed valuable improvements. The study was supported financially by the Foundation for Research of Natural Resources in Finland with a grant. We express our best thanks to all who supported the work.

Helsinki, November 30, 1971

The authors

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1. INTRODUCTION

In the last part of the 19th century, study of the nutritional physiology and ecology of trees was understood to be associated closely with forest fertilization experiments (e.g. K o d e r l e 1865, G i e r s b e r g 1901). The determination and prediction of the nutrient status and requirements of trees and sites (nutrient diagnostics) as a result of favourable experimental progress and successful practical fertilization projects, have become an important part of the array of problems concerned with nutrient economy. The need for elucidation of the qualitative and quantitative nutrient status has provided the impetus for the development of the diagnostics.

Prediction of the fertilization requirements has taken on new shades of meaning now that re-fertilization has become broadly topical in the course of the relatively short history of forest fertilization. It may be difficult to assess the re-fertilization requirement in peatland forests if drainage and fertilization have altered the situation for the use of diagnostic aids. The changes that have occured in vegetation (e.g. S a r a s t o 1957, R e i n i k a i n e n 1965, P ä i v ä n e n 1970, M a n n e r k o s k i 1970) may be such that use of the data on the fertilization requirement of habitats according to the type classification of virgin peatlands cannot be ventured (H u i k a r i & P a a v i l a i n e n 1968). This is true especially when no specifically identifiable symptoms of nutrient deficiency are observable or when fertilization etc. has altered the visible symptoms (e.g. T h e m l i t z 1958 a, R e i n i k a i n e n 1967) by revealing new symptomatic or latent deficiency states (trace element deficiencies in cultivated plants due to fertilization, e.g. J o h a n s s o n 1963). Present day knowledge suggests that it is unlikely that the above expedients can produce more than a crude qualitative diagnosis. Chemical analysis of soil and foliage, accepted as a diagnostic method first in agriculture but later in different forms also in forestry (e.g. O v i n g t o n 1956, H ö h n e 1963 b), has thus, along with fertilization experiments (e.g. B r ü n i n g 1959, W i t t i c h 1964), a special role in the study of the nutrient status of fertilized forests.

Soil analysis has long been used as a method for mapping nutrient economy. Some workers (e.g. A a l t o n e n 1950, W i l d e 1958) regard it as superior to needle analysis. For instance, S m i t h (1962) and W e h r m a n n (1963) consider that soil analysis supplements needle analysis, but it is also held that soil analysis is not suitable for application in forest (L e y t o n & A r m s o n 1955, L e y t o n 1957).

Growth diagnostic experiments using soil analysis have hitherto been concentrated on mineral soils, with disappointing results. The disappointments have been attributed to soil stratification, microvariation and the extent of the root systems which make the results unreliable (Troedsson & Tamm 1969), or to the inadequacy of the leaching methods (e.g. van Goor 1967, Themlitz 1967). Tree roots are generally fairly close to the surface in peatlands (Heikurainen 1955, Paavilainen 1966, 1968) and vertical variation is therefore probably smaller in the growth environment of roots than it is in mineral soils.

On the other hand, the interpretation of the results obtained in needle analyses of forests on firm soil have been encouraging in the nutrient diagnostic sense (Leyton & Armson 1955). It has been possible to state the optimum range for the main nutrients, below which is the deficiency range and above which is the luxury consumption (Smith 1962, Wehrmann 1963). The growth result is highest in the optimum range (Puustjärvi 1965). The optimum range is generally fairly wide as trees obviously achieve maximum growth with slightly differing nutrient contents depending on other nutrients and also other growth factors (Mitscherlich 1909).

Finding the correlation between the nutrient content and growth by needle analysis requires elimination of the variation caused by all other growth factors. It is impossible in practice to standardize the experimental conditions of fullgrown trees and stands. Variation can nevertheless be reduced by sampling arrangements. Seasonal fluctuations in the nutrient contents have been noted previously (McHarque & Roy 1932, Alway & Maki & Mathley 1934, Chandler 1939). The conclusion has been reached that needle samples must be collected in the autumn or winter (White 1954, Leyton 1958, Wehrmann 1963, Tamm 1968) and that the analyses must be made of needles from the topmost crowns of trees (Höhne 1963 a) that are in a similar sociological position (Leyton & Armson 1955, Tamm 1968, Wehrmann 1963, Strebel 1960, etc.) and of uniform exposition (Höhne 1963 a). The youngest needles are most suitable for analysis (Wehrmann 1963, Höhne 1962, Tamm 1968). Among other authors, Wehrmann (1963) considered it to be self-evident that the information given by a single tree is not reliable and that a pooled sample from at least some ten trees is required. In diagnostics the nutrient content of needles is usually expressed in percentage of dry weight, although there has been considerable criticism of this in recent times and a preference shown for using absolute nutrient quantities (e.g. Wehrmann 1963, Krauss 1967).

The information on correlation between the nutrient content of needles and that of soil is relatively meagre. Aaltonen (1950), for instance, reported that the nitrogen content of needles varies with the nitrogen content of the

soil. On the other hand, Puustjärvi (1962 b) found no fixed correlation between pine needle and peat nutrient contents in peatlands, at any rate not for phosphorus and potassium, nor did Viro (1961) between the results of needle analysis and site index. In contrast, Walker (1955) and Zech (1968) among other authors, noted a firm relationship between the exchangeable potassium of the soil and the potassium of needles, and Heinsdorf (1962) observed the same relationship between total potassium and needle potassium. These scattered observations show that the correlations between soil analysis and foliar analysis are obviously dependent on habitat and that the nutrient diagnostic application of these two methods rests in any case on a different basis. The complexity of the problems is revealed clearly by, e.g., the following statement by Puustjärvi (1962 a): »A point to be noted especially as regards needle analysis is that the amount of a certain nutrient taken up by the plant is not decided solely by the concentration of the nutrient in usable form in the nutrient layer of the soil; the uptake is influenced also by the amounts of many other nutrients. The richness or scarcity of one nutrient may promote or obstruct the uptake of another. If a plant shows several nutrient deficiencies, growth is slow but the nutrient content of the needles may be normal. Needle analysis is then incapable of disclosing the deficiency of any nutrient.»

The fertilization requirement may be determined not only by means of soil and needle analyses but also by root analyses (Paavilainen 1969). Their position as a parallel method to needle and soil analyses has not been studied sufficiently. In fertilization experiments the object is to determine the fertilization requirement in almost the opposite way, that is by giving different nutrients. Observation of the reactions provoked by them shows which nutrients were in short supply. In addition, symptoms of the nutrient deficiency of plants can be detected visually, and it can be concluded which nutrient is lacking. Deficiency symptoms in pines have been previously described by Möller (1904) and by many investigators after him, some of whom have even published symptom monographs (e.g. Truman 1958, Ashby 1959, Hacskaylo 1960, Walker & Beacher 1963, Penningsfeld 1964). Symptoms encountered in Finnish peatlands were described by Reinikainen (1967, 1968). It is probably possible with the technique of false colour photography also to register the preliminary stages of deficiency symptoms (Paarlahti 1970) and thus to arrive at the fertilization requirement.

The aim of this study was to examine the effects that needle and soil nutrient concentrations exert on the variations of the height growths of pines *(Pinus silvestris L.)* in peatland drainage areas, and to discover whether needle and soil analyses can make the nutritional diagnosis based on (site classification) peatland type and deficiency symptoms more accurate.

2. MATERIAL AND METHODS

2.1. Field and laboratory work

Many workers (L e y t o n 1958 etc.) have obtained fairly high correlations between the growth and needle concentrations over homogenous areas. As the aim of this study was to clarify the usefulness of soil and needle analysis, as a diagnostic indicator, for determining the nutrient status and further, fertilization requirements, it seemed to be necessary to collect a sample, where stands, as heterogenous as possible in their nutrient status and growth, would be represented. In order to estimate the possibilities of using needle and soil analysis for elucidation of disharmonies among different nutrients, which are suggested particularly in areas requiring refertilization, the sample was collected from 19 drained fertilization experimental areas with different combinations of N, P and K. The experiments were located in 10 places between 61—66°N and approx. 22—27°E (Fig. 1 p. 10). 67 unferti-



Fig. 1. Location of the experimental areas
Kuva 1. Koealueiden sijainti

Table 1. Experimental areas and some of their properties
Taulukko 1. Koekentät ja eräitä niiden ominaisuuksia

Experiment *Koekenttä*	Original type of peatland *Alkuperäinen suotyyppi* [1]	Year of ditching *Ojitusvuosi*	Strip width *Sarkaleveys, m*	Year of fertilization *Lannoitusvuosi*	Fertilization applications *Lannoitus*								Experimental plots total *Koealoja yhteensä, kpl*	Stand—*Puuston*		Site index *Boniteetti* [1]
					O	N	P	K	NP	NK	PK	NPK		age *ikä v.*	average height *keskipituus, m*	
					Experimental plots — *Koealoja, kpl*											
Yläne 5b	VSN	1938	60	1952	4	—	1	1	—	—	1	1	8	36	7.5	6
Yläne 7	VSN	1951	50	1952	3	—	1	1	—	—	1	—	6	32	4.5	6
Honkajoki	RLkN	1954	80	1959	5	—	2	2	—	—	—	2	11	15	1.0	1
Parkano	ITR	1953	40	1953	3	—	1	1	—	—	1	—	6	15	4.5	3
Kuru	VSN	1935	30	1953	4	—	2	2	—	—	2	—	10	—	7.5	6
Leivonmäki	—	1947	10	1959	5	2	2	2	2	2	2	2	19	9	2.0	—
Ähtäri	TKN	1929	30	1959	5	2	2	2	2	—	2	2	17	38	5.0	3
Sievi	SiKN	1925	50	1949	1	—	3	3	—	—	3	—	10	37	3.5	4
Haapavesi 23	RiRhSN	1936	10	1954	4	—	2	2	—	—	2	2	12	30	7.0	5
Haapavesi 28	RiRhSN	1931	50	1961	5	—	2	2	—	—	2	2	13	28	3.5	5
Muhos 34 e	SiKN	1932	50	1953	5	—	1	1	—	—	1	1	9	32	3.0	4
Muhos 36 a	TSR	1933	140	1950	5	—	1	1	—	—	1	—	8	32	3.5	4
Muhos 36 b	TSR	1933	100	1952	5	—	1	1	—	—	1	1	9	32	5.0	4
Muhos 36 d	TSR	1933	80	1952	5	—	1	1	—	—	1	1	9	31	7.0	4
Muhos 55 a	RiSN	1939	20	1957	5	—	4	3	—	—	3	3	18	28	4.0	5
Muhos 55 c	TSN	1939	75	1952	5	—	1	1	—	—	1	1	9	28	2.5	3
Muhos 70, 74, 77	SiKN	1939	80	1956	15	—	2	2	—	2	—	6	27	13—20	3.5	4
Muhos 82 a	RPsR	1955	40	1957	5	—	4	3	—	—	4	—	16	12	1.0	2
Kivalo 47	RiSiKN	1933	40	1952	5	—	1	1	—	1	—	1	9	9	2.5	3
			Total	Yhteensä	92	4	34	32	4	5	28	25	226			

Site types in English: RLkN = *Sphagnum fuscum* - rich low - sedge swamp, RPsR = *Sphagnum fuscum* - rich *Carex globularis* pine swamp, ITR = dwarf - shrub - rich cottongrass pine swamp, TKN = cottongrass - rich *Sphagnum papillosum* swamp, TSR = cottongrass - rich sedge pine swamp, TSN = cottongrass - rich sedge swamp, SiKN = *Molinia* - *Sphagnum papillosum* swamp, RiSiKN = *Molinia* - *Sphagnum papillosum* swamp with rimpis, VSN = ordinary sedge swamp, RiSN = sedge swamp with rimpis, RiRhSN = herb - rich sedge swamp with rimpis.

[1]) Heikurainen (1960, 1964)

lized sample plots were taken from outside the experimental areas to complement the rather small number of control plots. Table 1 (p. 11) gives more detailed information about the material. The symbols of the experiments are those used in the records of the Peatland Department. The peatland types are those employed by Heikurainen (1960) and the English type nomenclature is based on Heikurainen (1964).

For the needle analysis, ten trees of the dominant crown class were selected from each sample plot. They were taken at even spacing from different parts of the plot except for a 5-m margin at the edges. The needles were collected from as homogenous a growing stock as possible. All the needles were taken from the highest branch of each sample tree on the southern side (SW—SE) of the whorl of branches that had grown in summer 1966. The needles from each sample plot were mixed. The material for the needle analyses was collected in March 1967 except at Leivonmäki where the needles were collected in the last week of August 1966, that is before the planning phase of the present investigation.

For the analysis of the nutrient content of peat, 10 samples were taken from each of the sample plots, from 0—10 and 10—20 cm strata so that one pair of samples was taken from the root space of each needle sample tree. The 10 peat samples thus obtained were combined and homogenised per depth strata for analysis.

The needle and peat analysis material is the same as that used by Reinikainen in his future paper about the correlations between nutrient factors and deficiency symptoms.

Height growths were measured from 20 trees in each sample plot. Ten of them were the above-mentioned needle sample trees; the remainder were selected from the dominant crown class. The height growth in the years 1966—1969, and before fertilization, was measured to an accuracy of 1 cm. The arithmetic mean was calculated for each year and was the only growth characteristic used in this work.

The material also includes an ocular site class estimate (Heikurainen 1959) based on the peatland site type and the development of the ground vegetation, and data on the type, quantity and year of spreading of the fertilizers.

The needle samples were analysed in the laboratory of Viljavuuspalvelu Oy with the exception of those from Leivonmäki which were analysed by Satoturve Oy. The needle nitrogen was determined by the Kjeldahl method; phosphorus was determined colorimetrically by an autoanalyzer using the molybdenum blue method; potassium, calcium, magnesium, and the trace elements manganese, zinc, iron and boron were determined flame photometrically by an atomic absorption spectrophotometer. The copper analysis was omitted by mistake.

Total nitrogen was determined from the peat samples. The exchangeable nutrients phosphorus, potassium, calcium and magnesium were extracted with ammonium acetate (pH = 4.65). The pH and the conductance of the samples were also determined. The so-called storage nutrients were determined flame photometrically from a part of the material (45 sample plots). They were extracted with 2-n hydrochloric acid. The trace elements of peat, i.e. copper, manganese, zinc, iron and boron, were determined for the Ähtäri, Honkajoki, Haapavesi 28 and Muhos 55 and 82 (66 complete series) experiments. The determination methods were the same as for the needle analyses.

A list of the variables measured and the measuring units is presented in Appendix 1 (p. 57).

The number of the sample plots was 226. Trace elements were analysed from only 64 needle samples and 66 peat samples. Thus, the conclusions must be based to a considerable extent on more concise but thoroughly analysed material.

2.2. Statistical treatment of the material

Multiple regression analysis (the library programme of the State Computer Centre) was considered to be suitable as the principal method of analysing the material (cf. Leyton & Armson 1955, Leyton 1958, etc.). The preliminary treatment was performed by plotting correlation diagrams to explain the relationship between the different variables. On the basis of these analyses the most suitable groups of independent variables were selected for analyses of height growth variation as a function of the nutrient concentrations of peat and needles.

Regression analysis was performed first at random by using all the direct and indirect characteristics of the nutritional state as variables (see App. 1 p. 57). The outcome was an equation which gave a fairly high degree of determination of the growth variance. However, it seemed impossible to find true correlations from it, i.e. the physiological causal relationships:

$k\text{-}67 = 3.662^{***}X_1 + 0.012^{***}X_2 + 5.577^{***}X_3 + 3.694^{***}X_4 - 2.330$

where X_1 = site class, $X_2 = Ca_{10}$, X_3 = P-fertilization/age (10 kg P/ha/annum) and X_4 = K-fertilization/age (10 kg K/ha/annum), n = 226, R = 0.71^{***}, S = 7.554, 100 R^2 = 50.4 %.

The correlation between needle phosphorus and growth was $r = 0.34^{**}$, while the correlations between the other needle nutrient contents were considerably smaller. *It seemed on the basis of this analysis that it is possible using material from fairly young peatland stands that comprise sample plots fertilized 8—18*

years ago, to explain a considerable proportion of the variation in height growth by means of the original site class and the calcium content of the surface peat that is obviously in correspondence with it (cf. Kotilainen 1928, Kivinen 1933, etc.) and fertilization by the most likely minimum factor nutrients. In order to clarify the significance of the nutrient content of needles and peat, regression analyses were made using them only as independent variables for growth variation. After examining the material graphically it was necessary to stratify it.

The symbols and abbreviations used in the calculations and other analysis of the material and in the various methods of graphic illustration are explained below.

N_n = needle nitrogen
P_n = needle phosphorus
K_n = needle potassium
Ca_n = needle calcium
Mg_n = needle magnesium
Zn_n = needle zinc
Mn_n = needle manganese
Fe_n = needle iron
B_n = needle boron
$N_{10}P_{10} \ldots B_{10}$ = nutrients in the 0—10 cm peat layer
$N_{20}P_{20} \ldots B_{20}$ = nutrients in the 10—20 cm peat layer
N, P, K and 0 = fertilization treatment
n = number of observations
r = coefficient of correlation
R = coefficient of multiple correlation
$100\ R^2$ = degree of determination
S = standard deviation
* = significant with 5.0 per cent risk
** = significant with 1.0 per cent risk
*** = significant with 0.1 per cent risk
k-66, k-67, k-68, k-69 = height growth for the year.

The statistical significances of the regression coefficients were expressed in connection with the coefficients in accordance with the t-values. The significances of the correlation coefficients (r and R) are also based on the t-test and they are expressed in the same way. Only the independent variables that added significantly to the degree of determination ($F \geq 4.0$) were accepted for the regression equation.

3. HEIGHT GROWTH AS A FUNCTION OF NEEDLE NUTRIENT CONTENTS

Stepwise regression analysis for the total material (n = 226) in which the macronutrient concentrations N, P, K, Ca and Mg of the needles were the independent variables gave the following equation:

$k\text{-}67 = 10.024^{***}P_n - 4.672^{***}Mg_n + 8.941^{**}N_n + 2.563^{***}K_n - 2.632^{*}Ca_n - 0.418$; $R = 0.58^{***}$, $S = 9.334$

The result shows that *the concentrations of all macronutrients determine significantly the variation in height growth even in as heterogeneous material as this.* However, the degree of determination remains low (33.3 per cent) and the correlations between individual nutrients and growth leave a great risk in making conclusions: ($k\text{-}67/N_n$, $r = 0.19^{**}$; $k\text{-}67/P_n$, $r = 0.45^{***}$; $k\text{-}67/K_n$, $r = 0.16^{*}$; $k\text{-}67/Ca_n$, $r = -0.14^{*}$; $k\text{-}67/Mg_n$, $r = -0.28^{***}$). The result differs from that obtained by e.g. L e y t o n (1958) in a similar analysis, but his material was different, too.

3.1. Correlations in a material stratified according to fertilization treatments and site class

The variation in peatland site type and fertilization treatment are probably the greatest of the known sources of growth variation in this material. The effect of fertilization 8—18 years earlier continues, as the mean of the height growth in fertilized plots in 1967 was 26.3 cm against 16.1 cm in unfertilized sample plots.

fertilization	k-67 (cm)
control	16.1
K	21.8
P	25.2
PK	29.9
NPK	29.1

The effect of fertilization is also visible after 8—18 years in the phosphorus and potassium contents of the needles; these were the nutrients used in the majority of the fertilization treatments (see also Table 3 p. 41).

	fertilized	unfertilized
N_n	1.39 %	1.43 %
P_n	1.50 o/oo	1.20 o/oo
K_n	4.00 o/oo	3.40 o/oo
Ca_n	2.20 o/oo	2.10 o/oo
Mg_n	1.50 o/oo	1.70 o/oo

The obvious influence of site class on growth and on the nitrogen and phosphorus content of the needles is depicted crudely in the following table in which the material was divided into three site classes by combining Heikurainen's (1959) classes: 1 = 1—2, 2 = 3—4 and 3 = 5—6 (see p. 12). The three site classes correspond to Huikari's (1952) nutrient classes in approximately the following way: 1 = VI, 2 = V—IV, 3 = III—II.

	Site class 3	2	1	total material
k-67, cm	29.7	18.4	13.1	21.4
N_n %	1.44	1.37	1.18	1.37
P_n o/oo	1.60	1.30	1.40	1.40
K_n o/oo	3.70	3.60	3.90	3.60
Ca_n o/oo	1.90	2.20	2.60	2.10
Mg_n o/oo	1.70	1.80	1.30	1.70

Graphic analysis of the correlations between pine height growth -67 and the macronutrient concentrations of the needles was performed on the basis of the above by distinguishing site classes 1, 2 and 3 and fertilizations with 0, P, K, PK and NPK in the diagrams (Figs. 2—6). The points for the Leivonmäki material differed as a rule from the other observations, that was evidently attributed to the different sampling time. For this reason the observations for Leivonmäki were omitted in the following analyses.

There was no correlation between needle nitrogen and growth (Fig. 2 p. 17) on control plots, although the N_n concentration in fact varied over a considerably broader range (about 1.0—2.0 per cent) than on fertilized plots (1.0—1.8 per cent). On the other hand, the fertilized plots displayed a positive correlation between height growth and the N_n content, especially in site class 2. Oksbjerg (1956) established that a linear correlation in peatland spruces began at the N_n level from 0.8 per cent. The material gives no information about > 1.6 per cent N_n values on fertilized plots. The highest site class observations lie in the upper right of the diagram, i.e. where growth and the N_n content are at their greatest. Taking into account the great age of the fertilization treatments in the material and the low N amounts as regards the relatively fast-disappearing N effect (e.g. Viro, 1966), the distribution of the N_n concentrations must

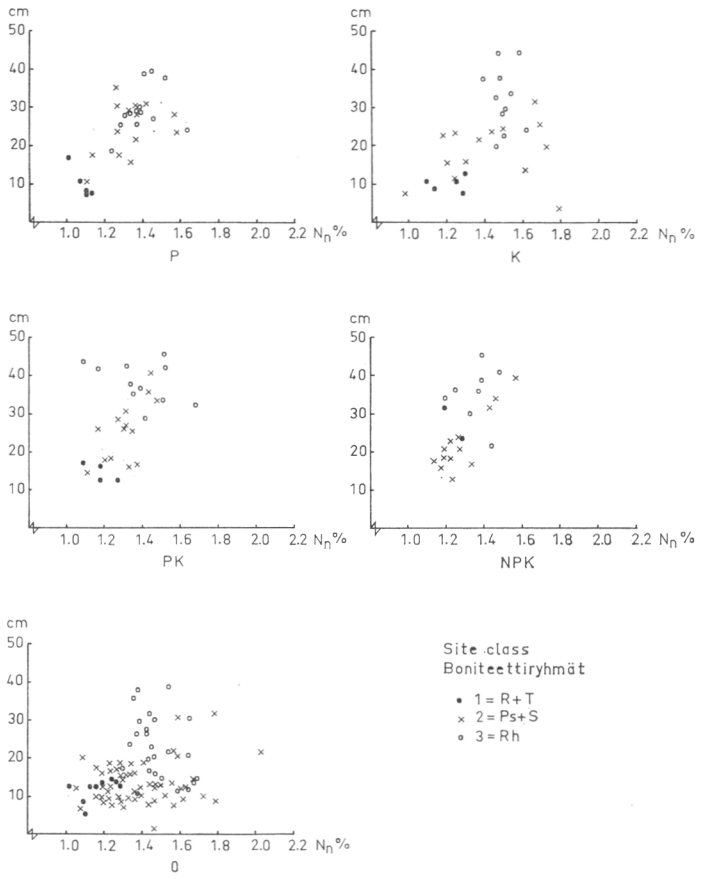

Fig. 2. Correlation between the N_n content and height growth in sample plots given different fertilization treatment.

Kuva 2. Neulasten N-pitoisuuden ja pituuskasvun välinen korrelaatio erilaisen lannoituksen saaneilla koealoilla.

in fact be regarded as determined by the original site class (e.g. P u u s t j ä r v i 1962 a) and the effect of N fertilization is no longer discerned (Fig. 2 p. 17).

The steadily growing idea that p h o s p h o r u s is the general minimum factor in peatlands (e.g. M a l m s t r ö m 1935, B j ö r k m a n 1942, L u k k a l a 1951, V a l m a r i 1956, H u i k a r i 1961) gave occasion to anticipate distinct positive correlations between height growth and P_n concentrations. All the diagrams did in fact display a positive trend (Fig. 3 p. 18). The correlations were most pronounced in the PK and NPK areas, but fairly poor in the control, P and K areas. Fertilization containing the P

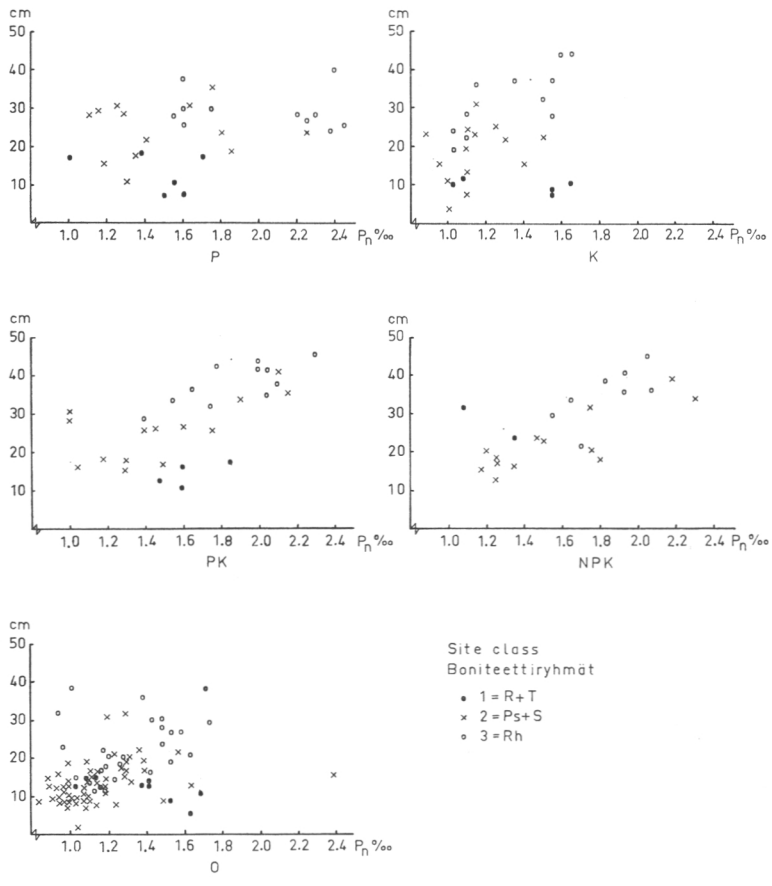

Fig. 3. Correlation between the P_n content and height growth in sample plots given different fertilization treatment.

Kuva 3. Neulasten P-pitoisuuden ja pituuskasvun välinen korrelaatio erilaisen lannoituksen saaneilla koealoilla.

factor altered the range of variation in the P values. It was about 0.80—1.70 per mille in the control and K plots and about 1.10—2.50 per mille in the P, PK and NPK areas. This observation tends to show the long-term character of the effect of P fertilization. B a r t h o l i n (1969) observed P fertilization effect after 20 years in both growth and P_n concentrations. Especially in the P, PK and NPK plots in the best site classes, observations lie in the same way as in the N_n diagrams, within the area of good growth and a high nutrient content. The high P_n content and growth seems thus to be the result not only of P fertilization but also of the original site class.

Correlation between t h e n e e d l e p o t a s s i u m c o n t e n t a n d g r o w t h was positive only in the control plots on the best site class.

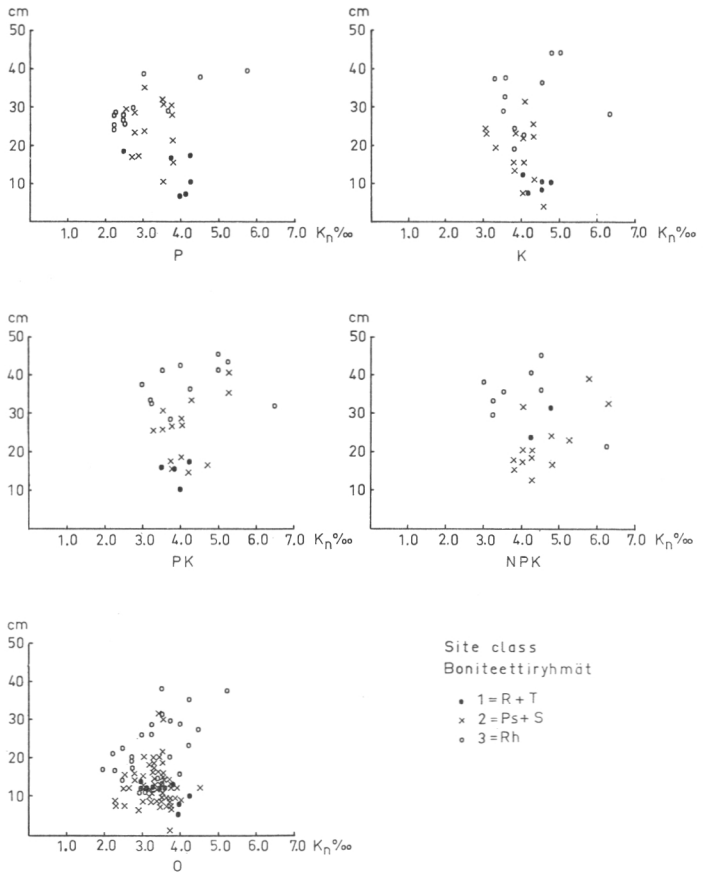

Fig. 4. Correlation between the K_n content and height growth in sample plots given different fertilization treatment.

Kuva 4. Neulasten K-pitoisuuden ja pituuskasvun välinen korrelaatio erilaisen lannoituksen saaneilla koealoilla.

(Fig. 4 p. 19). The observations of the different site classes formed groups of their own according to the growth but not to K_n concentration in the plots given P, K, PK and NPK treatment. The location of some observations is remarkable for the highest site class in the area of very low K_n content but good growth (cf. Valmari 1956). Fertilizer combinations containing the K factor changed the range of variation in the K_n concentrations somewhat: in control and P plots 2.00—6.00 per mille and in PK and NPK plots 3.00—6.50 per mille. Heiberg & Madgwick & Leaf (1964) reported K fertilization effects after twenty years.

The material included no Ca and Mg fertilizations. However, rock phosphate, for instance, contains a considerable amount (36 per

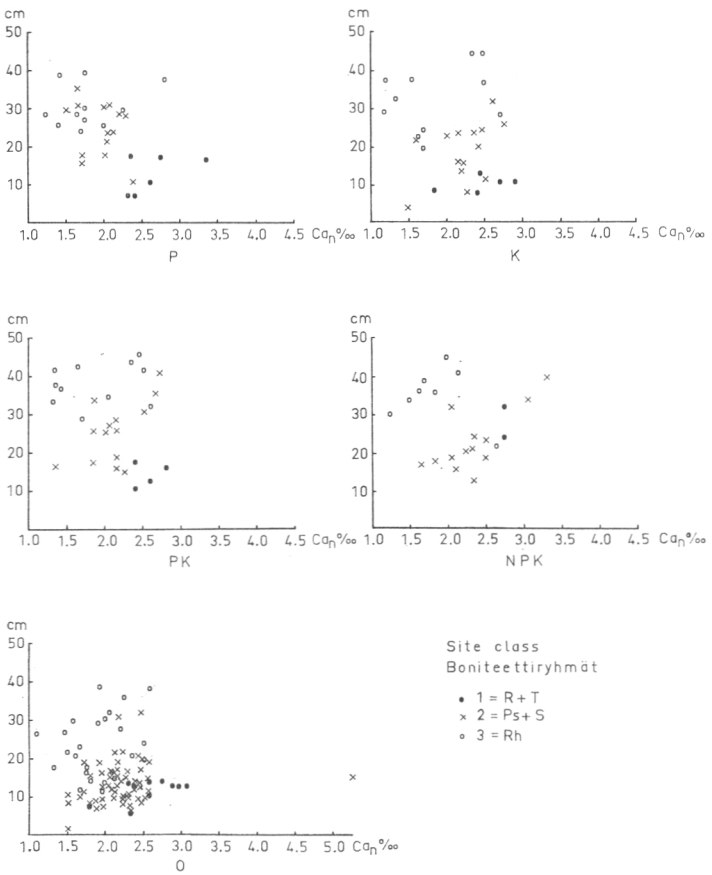

Fig. 5. Correlation between the Ca_n content and height growth in sample plots given different fertilization treatment.

Kuva 5. Neulasten Ca-pitoisuuden ja pituuskasvun välinen korrelaatio erilaisen lannoituksen saaneilla koealoilla.

cent) of calcium. Classification based on fertilization, clarifies the picture of the relationship between the Ca_n and Mg_n contents and growth.

There is a positive correlation between the Ca concentration and growth within the site classes in the fertilized plots, especially in the NPK plots (Fig 5 p. 20). The calcium concentrations of the needles show, somewhat surprisingly, a negative correlation with site class; cf. the observations made by e.g. A a l t o n e n (1950) for the site-class series of forest types.

No correlations were observed between the Mg_n c o n c e n t r a t i o n s and growth (Fig. 6 p. 21).

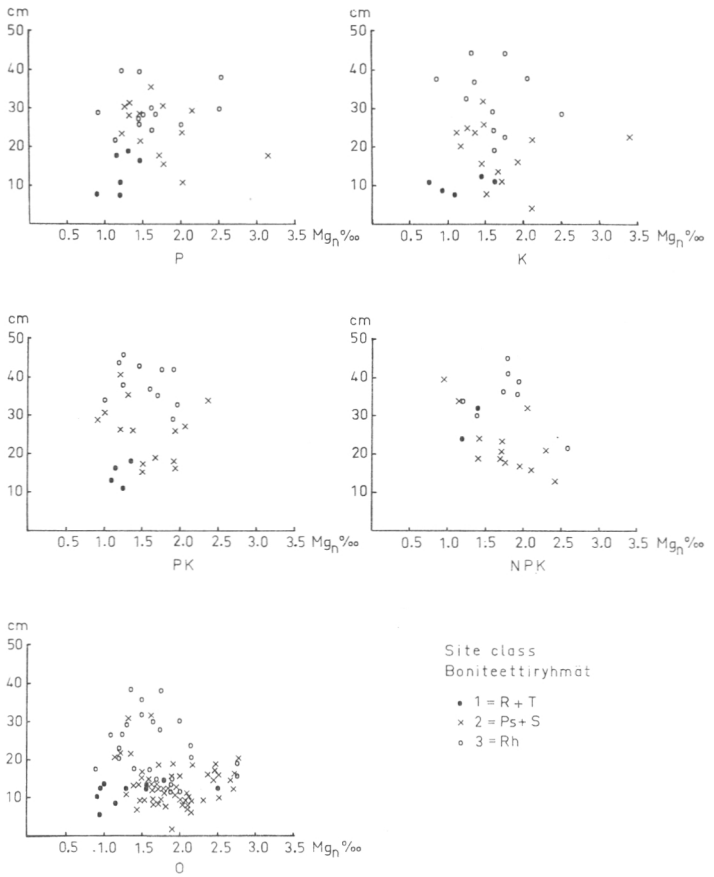

Fig. 6. Correlation between the Mg_n content and height growth in sample plots given different fertilization treatment.

Kuva 6. Neulasten Mg-pitoisuuden ja pituuskasvun välinen korrelaatio erilaisen lannoituksen saaneilla koealoilla.

3.2. Correlations in a material stratified according to the N_n, P_n and K_n concentrations

Classification is based in the following on the contents of the macronutrients, and growth is studied as a function of the other nutrients. Earlier investigations (e.g. Schönnamsgruber 1957, Heiberg & Leyton & Loevenstein 1959, Tamm 1968) have revealed correlations between the macronutrient concentrations of the needles.

3.21. The N_n, P_n and K_n concentrations and growth in the total material

Fig. 7 (p. 22) which was constructed in accordance with the explanation model given by covariance analysis, provides a general outline of the overall effects and interactions between the macronutrients in the total material. The degree of determination of the model as a whole was relatively low (41.3 per cent), as could be expected from Chapter 3. Nevertheless, some diagnostically usable data were obtained. Increase of the P_n content exerts a positive influence on growth up to a P_n level of 1.90—2.09 per mille (the only statistically significant effect $F = 14.26^{***}$), the greatest difference being between the levels 1.70—1.89 and 1.90—2.09 per mille. The significance of the P/K-relation is indicated by the fact that the growth of the P_7 level remains smaller than that of the P_6 level. The reason is that the observations representing the P_7 level are concentrated on the areas without K fertilization. There is an interaction between the P_n content and both the N_n and K_n contents on growth (N_n effect $F = 2.01$, K_n effect $F = 1.17$); that is, the best growth result is achieved at nearly all P_n levels when N_n is 1.5—1.59 per cent (see Fig. 2 p. 17). The N_n values over 1.6 per cent are concentrated on the areas without P + K fertilization. That is why the growth seems to be slower, when N_n exceeds 1.6 per cent. The PK interaction is seen in the graph as a rise in the group of curves and as a dispersion of them when the K_n level rises in four steps; i.e., the P_n factor has the most intensive effect at the highest K_n level, 4.00—5.00 per mille. The existence

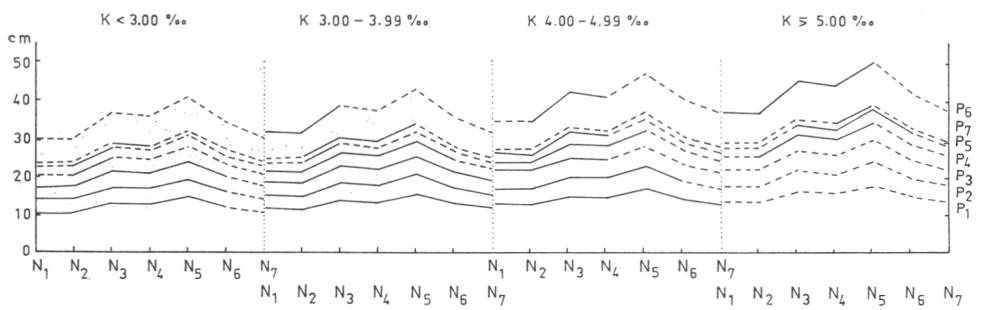

Fig. 7. The effect of the N_n and P_n contents on the height growth at different K_n levels.
Kuva 7. Neulasten N- ja P-pitoisuuksien vaikutus pituuskasvuun eri K-pitoisuuden tasoilla.

N_n levels, per cent N-tasot, %	P_n levels, per mille P-tasot, ‰
1 = —1.19	1 = —1.09
2 = 1.20—1.29	2 = 1.10—1.29
3 = 1.30—1.39	3 = 1.30—1.49
4 = 1.40—1.49	4 = 1.50—1.69
5 = 1.50—1.59	5 = 1.70—1.89
6 = 1.60—1.69	6 = 1.90—2.09
7 = 1.70—	7 = 2.10—

------ = no observations, *ei havaintoja*

of NPK interaction may be assumed on the grounds that the growth increase caused by the N_n content seems to be most obvious at the highest P_n and K_n level.

According to the covariance model, the best height growth (> 40 cm) is thus achieved by the following combination of macronutrients: N_n 1.5—1.59 per cent, P_n 1.90—2.09 per mille and $K_n > 5.00$ per mille. Chapter 3.1 (Figs. 2—6 pp. 17—21) indicates the conditions in which such concentrations are possible in peatland forests.

3.22. The macronutrients and growth in the Muhos material

As the analysis of the total material gave too low a degree of determination for diagnosis, possibly because of the heterogeneity of the material as regards climate, the effect of drainage, age and volume of the growing stock, etc., the influence of classification based on the nutrient content of the needles was studied in the more concise Muhos material in which the variation caused by the above factors, especially that due to climate, was smaller. The regression model, corresponding to the analysis presented in Chapter 3. for the Muhos material, also indicated the need for classification as the degree of determination was very small. The equation took the following form:

$k\text{-}67 = 12.109^{***}P_n - 4.608^{**}Ca_n + 2.976^{*}Mg_n + 5.145;$
$R = 0.595^{***}$, $100\ R^2 = 35\ \%$, $S = 6.603$, $n = 105$.

Classification was performed by dividing the N_n, P_n and K_n concentrations, after graphic examination, into two groups each with the limit values $N_n = 1.30$ per cent, $P_n = 1.40$ per mille and $K_n = 3.50$ per mille. All the paired combinations formed from these limit values were then employed as units of analysis in accordance with the following table:

Class	N_n %	P_n ‰	K_n ‰	observations
1.	compulsory	≥ 1.40	≥ 3.50	33
2.	independent	≥ 1.40	< 3.50	9
3.	vari-	< 1.40	≥ 3.50	35
4.	able	< 1.40	< 3.50	28
				total 105
5.	≥ 1.30	compulsory	≥ 3.50	27
6.	≥ 1.30	independent	< 3.50	22
7.	< 1.30	vari-	≥ 3.50	41
8.	< 1.30	able	< 3.50	15
				total 105
9.	≥ 1.30	≥ 1.40	compulsory	16
10.	≥ 1.30	< 1.40	independent	33
11.	< 1.30	≥ 1.40	vari-	26
12.	< 1.30	< 1.40	able	30
				total 105

The compulsory independent variable used in the regression analyses was thus the unclassified macronutrient in each individual case and other nutrients were employed as selective regressors.

The N_n concentration was found to be the best regressor ($r = 0.70^{***}$) of growth in the class 1, where P_n and K_n were on the higher level, $P_n \geq 1.40$ and $K_n \geq 3.50$ per mille.

The equation as a whole was as follows:

$k\text{-}67 = 47.520^{***}N_n + 21.288^{**}P_n - 9.045^{*}Ca_n + 7.834^{*}K_n - 86.872^{***}$; $R = 0.84^{***}$, $100\ R^2 = 70.1\ \%$.

Classes ($P_n < 1.40$, $K_n \geq 3.50$) and ($P_n < 1.40$, $K_n < 3.50$) had a significant positive regressor N_n, too, but the coefficients of correlation were low ($r = 0.29$ and $r = 0.38^{*}$).

There was a positive correlation between height growth and the N_n content in the classes obtained from the N_n and K_n, and N_n and P_n concentrations only when $N_n < 1.30$ and $P_n \geq 1.40$. The correlation was negative in the classes $N_n \geq 1.30$, $K_n < 3.50$, $r = -0.46^{*}$ and $N_n \geq 1.30$, $P_n < 1.40$, $r = -0.23$. The effect of the nitrogen content on height growth is thus very strongly dependent on the P_n and K_n levels.

The correlation between the P_n content and height growth was strongest also in this material. The closest correlation was established when $N \geq 1.30$ and $K \geq 3.50$ ($r = 0.75^{***}$). The regression equation was:

$k\text{-}67 = 20.964^{***}P_n - 16.273^{***}Ca_n + 26.115^{**}$; $R = 0.86^{***}$, $100\ R^2 = 74.5\ \%$, $S = 5.140$.

The correlation was only insignificant in class ($N_n < 1.30$, $K_n \geq 3.50$) in which the P_n content was omitted from the final regression model. The P_n content showed a positive correlation with growth in the classes obtained from the P_n and K_n and P_n and N_n contents. This concurred with the positive trend perceived in the undivided material.

K_n content occurred in classes ($N_n \geq 1.30$, $P_n \geq 1.40$) and ($N_n \geq 1.30$, $P_n < 1.40$) as an independent variable in the regression equations. Again, the positive correlation coefficient was greatest when the other two macronutrients were at their highest levels. In class ($N_n < 1.30$, $K_n \geq 3.50$) the K_n factor displaced P_n which had been the compulsory independent variable and showed a fairly marked correlation with growth ($r = 0.46^{**}$).

The Ca_n and Mg_n concentrations for which no classification was performed appeared in many classes as significant independent variables of growth. The correlation of the calcium content with growth was negative throughout (cf. equation in Chapter 3. p. 15) and calcium occurred as an independent variable in all the equations with a higher degree of determination, especially in the highest classes of N_n, P_n and K_n concentrations.

The Mg_n concentration was included as a positive regressor in the determination equations only in the classes ($P_n \geq 1.40$, $K_n < 3.50$) and ($N_n < 1.30$, $K_n \geq 3.50$), and was the only factor in the first-mentioned ($r = 0.73$*). The number of observations was smallest in this class, only nine.

The results of regression analysis showed that the linear correlation between the compulsory independent variable (N_n, P_n or K_n, in turn) and height growth was greatest when the classified nutrient factors were at their higher level. There was also a tendency for the degree of determination of the compulsory regressor to decrease when the classified nutrient factors were at their lower level. This suggested that when the nutrient status of the tree was satisfactory, except for one nutrient, there was a relatively close correlation between this nutrient and growth. When both classified nutrients were at their lower level, the correlation between the unclassified nutrient concentration and growth was not as distinct. These conclusions are in agreement with Mitscherlich's (1909) law of minimum.

3.3. Needle trace elements as complementary factors

The Mn, Zn, Fe and B contents of the needles were analysed from a part of the material comprising five experiments; the total number of sample plots was 64. On the basis of graphic analysis the correlation between the phosphorus content and growth seemed even in this case to be the closest. Accordingly, this factor was selected as the compulsory independent variable for the regression analysis in which the N_n, K_n, Ca_n, Mg_n, Mn_n, Fe_n, Zn_n and B_n contents were the selective independent variables. The following equation was obtained:

$k\text{-}67 = 10.080^{***}P_n - 0.862^{**}B_n - 11.309^{***}Ca_n + 3.309^{*}K_n + 0.087^{*}Zn_n + 16.560^{*}$; $R = 0.75^{***}$, $S = 6.289$ and the degree of determination was 56.8 per cent.

The simple correlation coefficients for the various nutrients and height growth were as follows (Fig. 8 p. 26):

P_n	0.49***	Mg_n	—0.10	Ca_n	—0.30*
K_n	0.29*	Mn_n	—0.22	Zn_n	—0.35**
N_n	0.24	Fe_n	—0.25*	B_n	—0.63***

The high correlations between the independent variables confused the interpretation of the analysis:

Ca_n/Zn_n	0.78***	Mn_n/Bn	0.47***
Ca_n/K_n	0.54***	Mn_n/Mg_n	—0.44***
P_n/Zn_n	—0.47***	K_n/B_n	—0.44***

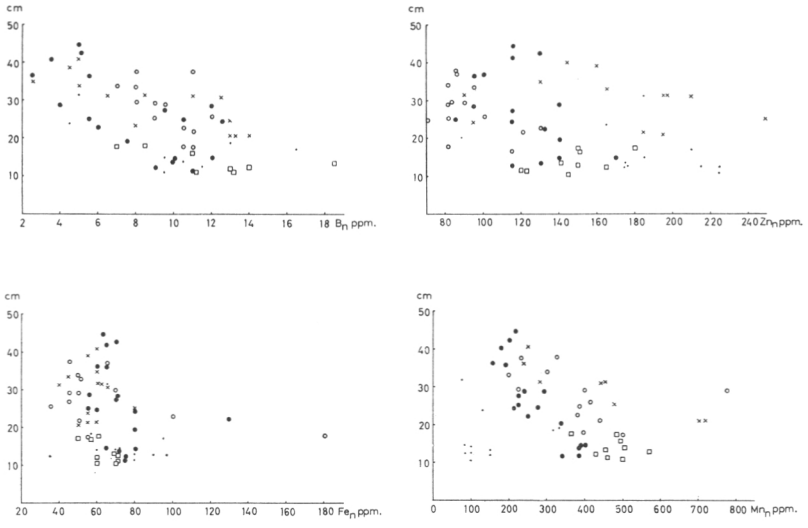

Fig. 8. Correlation between the Mn_n, Zn_n, Fe_n and B_n content and height growth.
Kuva 8. Neulasten hivenainepitoisuuksien ja pituuskasvun väliset korrelaatiot.

Legend, *Selitykset*
- • Honkajoki
- × Ähtäri
- ○ Haapavesi 28
- ● Muhos 55 a
- □ Muhos 82

The inclusion of trace element concentrations raises the degree of determination considerably, the B_n factor most of all. Moreover, the correlation k-67/B_n is the strongest of the simple correlations ($r = -0.63^{***}$) (Fig. 8 p. 26). A high needle boron concentration appears to be characteristic of trees of poor growth, regardless of the factor causing the poor growth. There was also a negative correlation between other trace elements and growth, and the highest trace element concentrations were encountered in the needles of poorly growing trees. The B_n content was not correlated with any of the macronutrients so specifically that its concentrations would be of diagnostic value. The use of trace element concentrations as regressors thus raises numerically the degree of determination of growth variations, but does not facilitate the physiological interpretation of the analysis.

3.4. Annual and total height growth in 1966—1969 as a function of the macro- and micronutrient contents of the needles

An endeavour was made on the basis of the results of the needle analysis to explain, with the help of regression analysis, the variations in the height growth in 1966, 1967, 1968 and 1969, and the variations in total height

growth during the time span 1966—1969. The stepwise course of the analysis is shown in the following.

Growing season		1966	1967	1968	1969	1966—69
Height growth, cm		19.4	23.6	20.5	18.0	81.6
I independent variable ...		P_n	P_n	P_n	P_n	P_n
	R =	0.44***	0.47***	0.42**	0.44***	0.53***
II » ..		B_n	B_n	K_n	B_n	B_n
	R =	0.66***	0.68***	0.50***	0.62***	0.68***
III » ..		Ca_n	Ca_n		Zn_n	Mg_n
	R =	0.75***	0.71***		0.68***	0.72***
IV » ..		K_n	K_n		Mg_n	
	R =	0.79***	0.73***		0.71***	
V » ..			Zn_n		Mn_n	
	R =		0.75***		0.74***	
VI » ..					N_n	
	R =				0.79***	
Standard deviation of residuals, S,	cm	4.949	6.289	10.400	4.385	21.690
	,%	25.5	26.6	50.7	24.4	26.6

Coefficients of regression

standard	22.591***	16.560*	—10.695	10.747	129.875***
I independent variable	4.732**	10.080***	10.674***	6.642***	20.645**
II »	—0.574*	—0.862**	4.156**	—0.668***	—4.460***
III »	—8.101***	—11.309***		0.052**	—25.710**
IV »	3.472**	3.309*		—8.661***	
V »		0.087*		—0.020***	
VI »				10.807**	

P_n was used as the compulsory independent variable in all the analyses and it was therefore the first regressor in each run.

A general observation was the relatively great uniformity of the regression models and the statistical equivalence of the coefficients of correlation. The explanatory equations displaying the greatest resemblance were those which had the three most important regressors, P_n, B_n and Ca_n in common. It can be concluded from the low degree of explanation of the growth in 1968 that the ratio of the nutrient composition of the needles does not change gradually, but that other growth factors obviously cause spurts in one direction or another. The highest explanatory power of the two most important inde-

pendent variables, P_n and B_n, when total growth in 1966—1969 is the function, is understandable although the differences between successive years in the nutrient contents of the needles are probable (P l i c e 1944). Some of the differences in growth factors that vary from year to year may be levelled out in the sum growth.

3.5. Nutrition diagnostic conclusions based on needle analysis

T h e n i t r o g e n f e r t i l i z a t i o n r e q u i r e m e n t may be said on the strength of the material to appear only in concentrations of $N_n < 1.3$ per cent, and then in by no means all of them. N_n content of > 1.3 per cent, however, does not guarantee that there is no demand for N fertilization. $N_n < 1.3$ per cent concentrations seem to have an indicative value only if the supply of P, but preferably also of K, is ensured. This, on the other hand, only occurs in PK fertilized areas. In addition, the diagnostic reliability of these concentrations ($N_n < 1.3$ per cent) seems to be adequate in very poor peatlands (classes 1 and 2 H e i k u r a i n e n). N_n concentration optima of *Pinus silvestris* reported by other authors (T a m m 1956 a, I n g e s t a d 1962, K e a y 1964, P u u s t j ä r v i 1965) lie on a higher level than those observed in this data. These optimum values derive to all appearances from conditions in which the P_n and K_n factors are closer to the optimum, from fairly good firm forest lands. A similar situation was reported by P u u s t j ä r v i (1965) who used an N/P ratio which is probably neither formally nor physiologically any more appropriate as a regressor than the one presented here, for the correlation between the N_n/P_n ratio and P_n was highly significant (0.50***) in this study. The correlation between the N_n/P_n ratio and height growth was lower (—0.36**). *Needle analysis determination of the N fertilization requirement of peatlands presupposes in practice that PK fertilization had been performed at least a couple of years before the needle analysis.*

T h e p h o s p h o r u s f e r t i l i z a t i o n r e q u i r e m e n t is the one that can be predicted most reliably. The risk is smallest in areas that have already received PK and NPK and in site classes 4—5 (H e i k u r a i n e n). For needle analysis this means the most reliable phosphorus values in classes ($N_n \geq 1.30$ %, $K_n \geq 3.50$ ‰). Raising the P_n level to 2.10 per mille seems expedient in these conditions. The phosphorus requirement can be predicted more reliably from the individual P_n concentration value than the nitrogen requirement from the N_n value. Height growths over 30 cm were rare at P_n levels of 1.40 per mille in a potentially vigorous pine seedling stand (the highest value on unfertilized peatland reported by P u u s t j ä r v i 1962 b on Molinia swamp was 1.35 per mille). No growth in excess of 40 cm

occurred when P_n content was < 1.70 per mille. It is only useful to aim at P_n values of well over 2.10 per mille when the harmony of the nutrient economy of N and K factors has been established by needle analysis (e.g. $N_n > 1.6$ per cent, $K_n \geq 4.50$ per mille).

The potassium fertilization requirement has perhaps been determined most often on the basis of the limit value, without taking the other macronutrients into consideration. This is seen from studies conducted at sites in which potassium is most markedly at a minimum and in which the connection between growth and potassium deficiency symptoms and the K_n concentrations is the closest (van Goor 1956, Tamm 1956 b, Schönnamsgruber 1962, Krauss 1962, Zech 1968). Information about the potassium fertilization requirement, obtained by needle analysis, is the most unclear of all the macronutrient requirements investigated. Some parts of the material do reveal the conditionality, in accordance with Mitscherlich's principle, of the needle-analytical indication value of the potassium concentration. Observations in the highest site class especially suggest that it would be wisest in areas with a secured NP economy to raise the K concentration of the needles to the 4.00—5.50 per mille. When the K_n value is under 3.00 per mille, it is a minimum factor to be corrected by fertilization (e.g. van Goor 1956, Schönnamsgruber 1962, Puustjärvi 1965, Reinikainen 1967).

The material is not rewarding as regards the determination of the calcium fertilization requirement. However, it gives indications that a needle calcium content above a certain minimum level (2.00 per mille) is a condition for good stand growth when NPK nutrition is satisfactory. However, too high a Ca_n level may be injurious.

There is no magnesium fertilization requirement in peatland pine stands such as is seen in cultivated peatland fields (e.g. Heinonen 1956). The Mg concentrations of the needles are higher than commonly reported deficiency limit values in the literature (van Goor 1956, Brüning 1959, Schönnamsgruber 1962, Krauss 1962), and although the role of the Mg and Ca concentrations of peat as indicators of the peatland site character is known (Tolonen 1966) they are not elicited by needle analysis.

Contrary to the observations of e.g. Mayer-Krapoll (1956) the only indication of any trace element fertilization requirement is that all the trace element contents of needles and especially the B_n content are in negative correlation with growth. However, boron probably cannot be regarded as an indirect indicator either. Ahrens (1964) gave 14 ppm as the minimum B_n necessary for growth. His figure was considerably higher than the mean for the present material (9.6 ppm). Although the material contains a great many experimental areas given a single fertili-

zation, the anticipated disturbances in the trace element economy (e.g. Johansson 1963) resulting from the fertilization are impossible to detect by needle analysis. Hence, the statements made by e.g. Björkman (1954) and Tamm (1954), contrary to the presentiments of Malmström (1935), concerning the trace element fertilization requirement of pine on peatlands must be concurred with.

Obviously, if it had been possible to measure the growth factors more thoroughly, more could have been said about the diagnostic interpretation of the needle analysis values. For instance, the needle nutrient concentration combination N_n = 1.6—1.8 per cent, P_n = 1.70—2.10 per mille and K_n = 4.00—5.50 per mille may be said to indicate the absence of fertilization requirement when the other minimum growth factors have been sufficiently corrected.

In this material, fertilization increased the needle nutrient content. Moreover, as fairly close correlations were observed between growth and the nutrient concentrations of needles by stratifying the material, the nutrient diagnostic validity of the individual concentration values of needle analysis must be admitted. The fertilization requirement in peatland pine stands can be determined by needle analysis at small risk, only when each sample plot has been measured with regard to the following factors (cf., for instance, van Goor 1967): (1) the age and volume of the growing stock, its productive status and growth; (2) the peatland type of the site and site class determined on the basis of vegetation; (3) the drainage effect (strip width, ditch depth, condition of ditches, etc.); (4) the occurrence of specific nutrient deficiency phenomena; (5) possible earlier fertilization; (6) needle analysis results at least for macronutrients.

4. HEIGHT GROWTH AS A FUNCTION OF PEAT NUTRIENT CONTENTS

4.1. Nitrogen, exchangeable nutrients and growth

Stepwise regression analyses in which the contents of the exchangeable macronutrients P, K, Ca and Mg and total peat nitrogen in the 0—10 cm layer were used as selective independent variables gave the following equation:

$k\text{-}67 = 0.992^{***}P_{10} + 0.032^{***}Ca_{10} - 0.066^{***}Mg_{10} - 0.104^{**}K_{10} + 13.115^{***}$; $R = 0.58^{***}$, $S = 9.270$, $n = 207$.

The degree of determination was 34.2 per cent, which was about the same as when the needle concentrations were used as independent variables. Even the highest simple correlations between growth and the nutrient concentrations of peat remained low in the diagnostic sense:

$k\text{-}67/P_{10}$ $r = 0.39^{***}$, $k\text{-}67/Ca_{10}$ $r = -0.29^{***}$, $k\text{-}67/N_{10}$ $r = 0.15$.

According to H a v e r a a e n (1964) the total N, P and Ca content of peat showed the best correlation with growth.

The correlations between the macronutrient concentrations of needles and peat are given in the following table.

	Peat	
	0—10 cm	10—20 cm
N_n	0.07	0.02
P_n	0.54***	0.48***
K_n	—0.19	—0.15
Ca_n	0.03	0.04
Mg_n	0.25***	0.09

Only the P and Mg concentrations of needles and peat are correlated. The ambiguity of the situation resembles that established by e.g. P u u s t j ä r v i (1962 b) and H o l m e n (1964).

Graphical analysis (Figs. 9—14 pp. 32—37) reveals some obvious correlations that can be compared with the needle nutrients/growth correlations. They are, however, looser throughout.

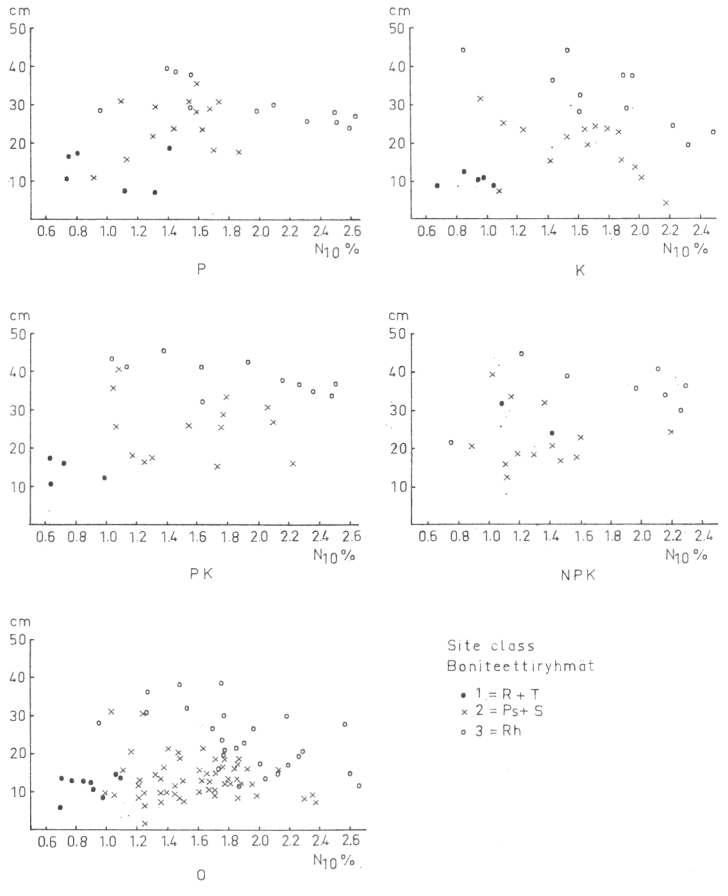

Fig. 9. Correlation between the N_{10} content and height growth in sample plots given different fertilization treatment.

Kuva 9. Pintaturpeen N-pitoisuuden ja pituuskasvun välinen korrelaatio erilaisen lannoituksen saaneilla koealoilla.

A slight positive correlation (Fig. 9 p. 32) is seen between the total nitrogen content of surface peat (N_{10}) and height growth and the fertilization combinations P (the closest) and PK and NPK, that is in the sample plots in which the correlation N_n/k-67 was most obvious (cf. Fig. 2 p. 17). The diagrams show the effect of site class on these correlations; the observations for the different site classes emerge as separate islets in the clusters of points. Attention is drawn to the uniform occurrence of observations, especially the highest site class, in all the diagrams; growth is impaired when the N_{10} values of peat rise to >1.8 per cent. On the other hand, here, as in the corresponding needle analysis diagrams, the sample plots of the poorest site class fall mainly in an area in which both the N_{10}

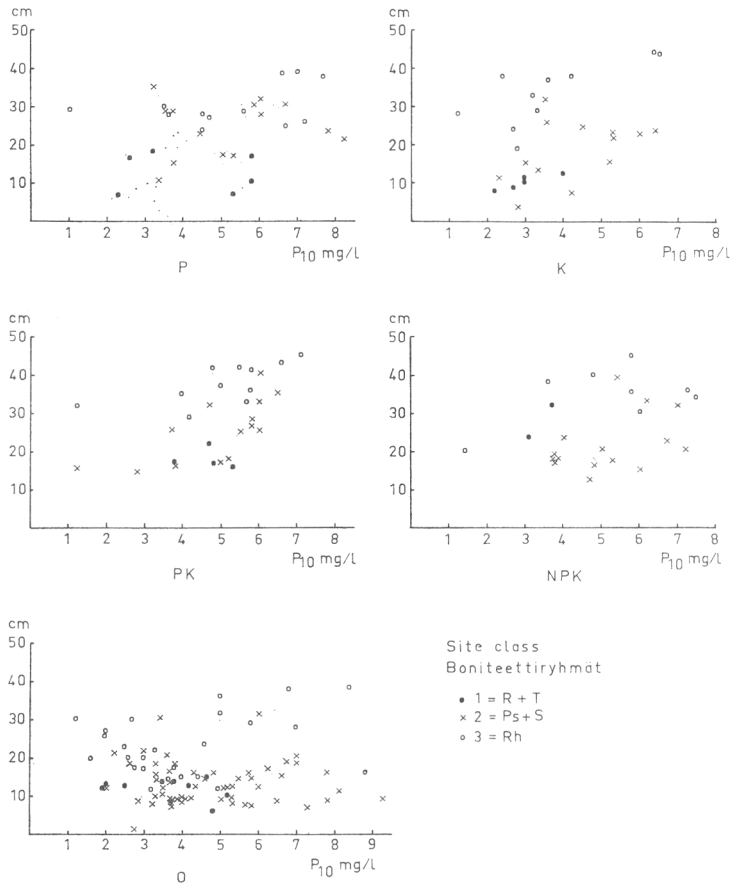

Fig. 10. Correlation between the P_{10} content and height growth in sample plots given different fertilization treatment.

Kuva 10. Pintaturpeen P-pitoisuuden ja pituuskasvun välinen korrelaatio erilaisen lannoituksen saaneilla koealoilla.

values and growth readings are the lowest, mostly N_{10} <1.0 per cent. Generally speaking, fertilization has not affected the range of variation of the N_{10} values. The material warrants no definite conclusions as to the effect of N fertilization on the N_{10} values.

Compared with needle analysis, the observations for the N factor were similar to those for the correlations (Fig. 10 p. 33) between exchangeable phosphorus (P_{10}) and height growth. Classification by site class and fertilization gives closer correlations and these are obtained using the same fertilization combinations as the P_n/k-67 correlations, i.e. PK (the closest) and P (cf. Fig. 3 p. 18). The clusters of points are similar, especially in the PK plots. In plots treated in this way growths of under

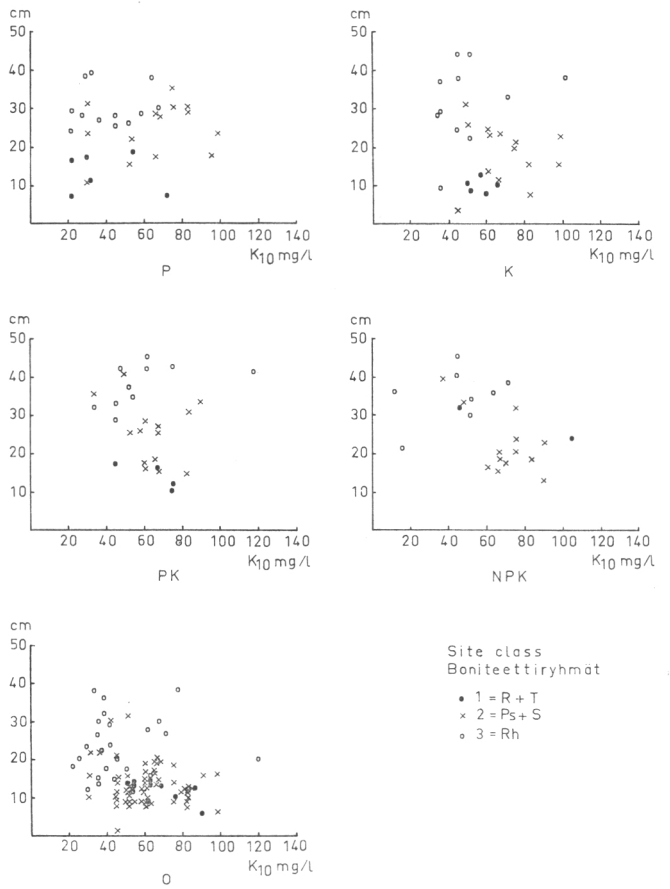

Fig. 11. Correlation between the K_{10} content and height growth in sample plots given different fertilization treatment.

Kuva 11. Pintaturpeen K-pitoisuuden ja pituuskasvun välinen korrelaatio erilaisen lannoituksen saaneilla koealoilla.

30 cm hardly occur when P_n rises above 1.80 per mille and P_{10} above 6 mg/l. The effect of P fertilization on the P content of peat is visible, especially at the lowest P_{10} values.

As regards the K factor the needle and peat analysis diagrams (Figs. 4 and 11 pp. 19 and 34) are similar. The K_{10}/k-67 correlation diagrams are even less rewarding diagnostically, than the K_n/k-67 diagrams. Haveraaen (1964), for instance, also found that K content of the peat shows the weakest correlation with growth.

The pictures given by needle and peat analyses differ distinctly on the role of calcium. Whereas Ca_n generally appeared as a negative regressor in the equations explaining growth, the Ca_{10} of peat was the

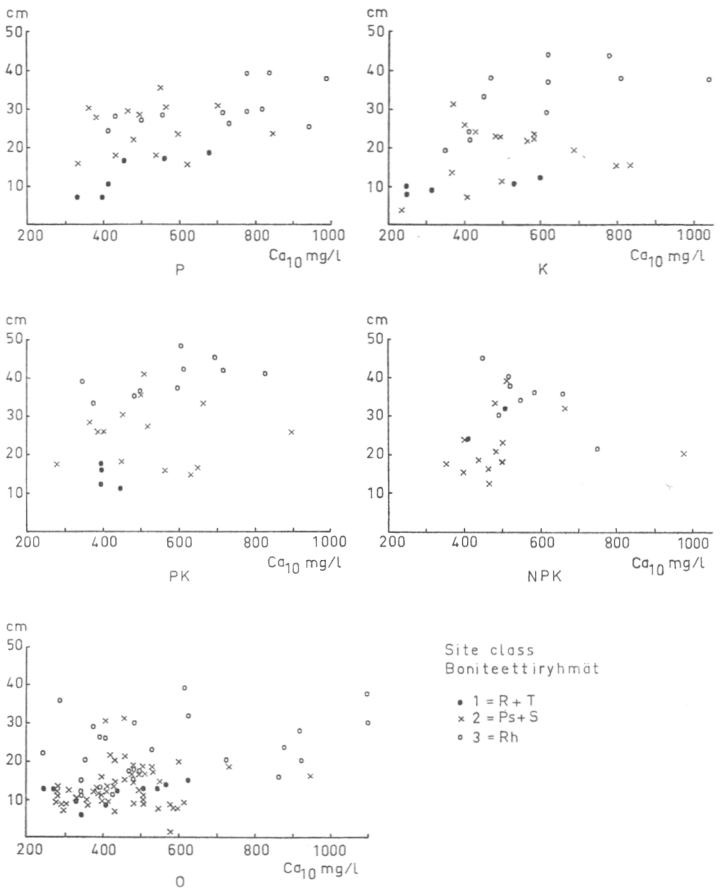

Fig. 12. Correlation between the Ca_{10} content and height growth in sample plots given different fertilization treatment.

Kuva 12. Pintaturpeen Ca-pitoisuuden ja pituuskasvun välinen korrelaatio erilaisen lannoituksen saaneilla koealoilla.

strongest positive regressor in the regression analyses of the total material. This was corroborated in the analysis according to site classes and fertilization (Fig. 12 p. 35). The positive trend was apparent with all combinations of fertilization, and the correlation was closest in the sample plots given P fertilization alone. The interaction between site class and the Ca_{10} of peat appears in this diagram as successive overlapping of the point clusters of site classes 1—3. The connection between Ca_{10} and growth is more distinct within each site class than in the cluster as a whole.

No diagnostically significant correlations were established between the Mg_{10} content and growth (Fig. 13 p. 36), even when the material was grouped by site class and fertilization treatment; the same was true of needle analysis.

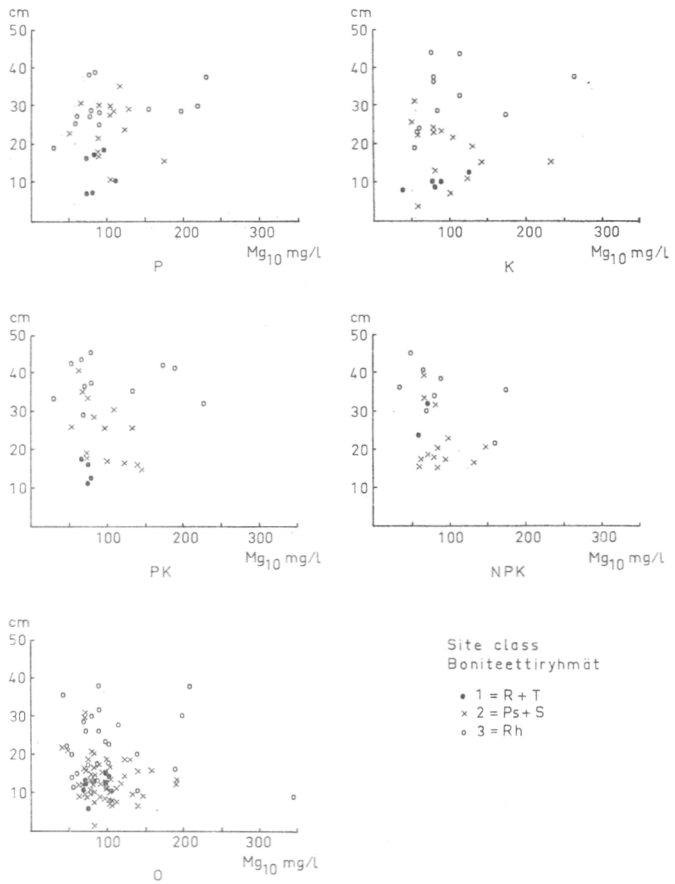

Fig. 13. Correlation between the Mg_{10} content and height growth in sample plots given different fertilization treatment.
Kuva 13. Pintaturpeen Mg-pitoisuuden ja pituuskasvun välinen korrelaatio erilaisen lannoituksen saaneilla koealoilla.

Inclusion of the trace element concentrations of peat in the selective independent variables does not clarify the situation to any appreciable extent. However, the degree of determination of the equation $k\text{-}67 = 3.007\ P_{10} + 1.578\ Mn_{10} - 0.161\ Mg_{20} + 14.759$ in the sub-sample of five experiments (n = 66) was higher (44.9 per cent) than in the total material and individual correlations were also higher than in the total material: Ca_{10} 0.48***, K_{20} −0.46***, P_{10} 0.42**, Mg_{20} −0.42**, Mn_{10} 0.39**. Thus, Mn_{10} showed a significant correlation (Fig. 14 p. 37). The situation is complicated by some relatively high correlations between trace element concentrations, the highest being Cu_{10}/Zn_{10} r = 0.55***. The picture of the significance of trace elements is complemented by the analysis in

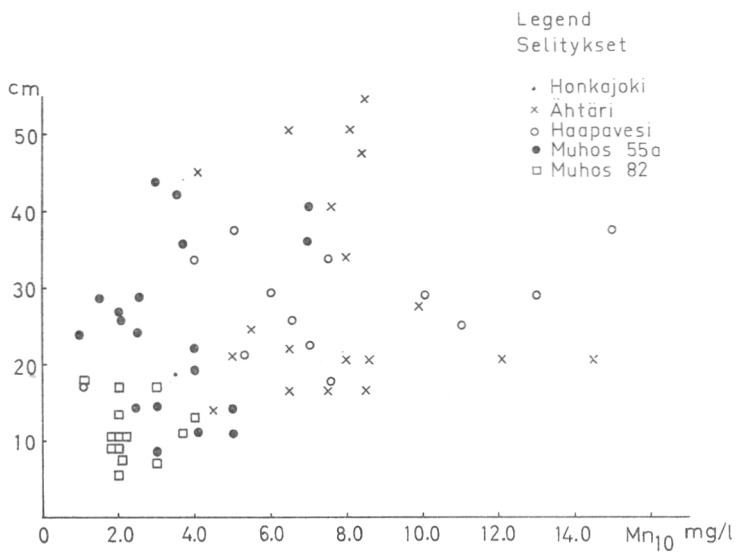

Fig. 14. Correlation between the Mn_{10} content and height growth.
Kuva 14. Pintaturpeen Mn-pitoisuuden ja pituuskasvun välinen korrelaatio.

Table 2. Nutrient concentrations of peat on areas with different leader growth in 1967
Taulukko 2. Turpeen ravinteet erilaisilla kasvun alueilla v. 1967

Nutrient of the peat *Turpeen ravinne*	Leader growth over 35 cm (n = 13) *Kasvu yli 35 cm (n = 13)*	Leader growth under 15 cm (n = 18) *Kasvu alle 15 cm (n = 18)*	Whole material Average *Koko aineisto Keskiarvo*
N_{10}	1.57 %	1.26 %	1.54 %
N_{20}	1.59 %	1.29 %	1.56 %
P_{10}	5.31 mg/l	3.91 mg/l	4.30 mg/l
P_{20}	3.17 »	4.14 »	3.25 »
K_{10}	42.00 »	54.92 »	44.18 »
K_{20}	14.38 »	40.61 »	23.27 »
Ca_{10}	540.38 »	376.33 »	468.01 »
Ca_{20}	379.62 »	408.28 »	426.58 »
Mg_{10}	69.23 »	92.22 »	79.48 »
Mg_{20}	52.15 »	86.06 »	70.79 »
Cu_{10}	2.12 »	1.26 »	1.62 »
Cu_{20}	0.94 »	1.25 »	1.24 »
Mn_{10}	6.65 »	2.97 »	5.18 »
Mn_{20}	3.08 »	2.19 »	3.71 »
Zn_{10}	11.88 »	11.07 »	11.19 »
Zn_{20}	8.90 »	12.58 »	10.20 »
Fe_{10}	0.44 »	0.37 »	0.46 »
Fe_{20}	0.28 »	0.27 »	0.32 »
B_{10}	0.15 »	0.18 »	0.16 »
B_{20}	0.18 »	0 19 »	0.17 »

Table 2 of peat nutrient concentrations in sample plots of good (>35 cm) and poor (<15 cm) growth. P_{10}, Ca_{10} and Mn_{10} emerge as the most distinct positive factors. In addition, N_{10}, N_{20}, Ca_{10}, Mn_{20} and Fe_{10} appear to be nutrients with a somewhat positive effect. In these circumstances, the results of peat analysis do not support the negative correlation established between trace elements and growth given by needle analysis.

4.2. Storage nutrients of peat and growth

The effect of the extraction method on the fairly weak correlation between the results of the peat analyses and growth was not studied. However, a stronger extraction method (2-n HCl) was used experimentally to find the correlations between nutrient content and growth in regard to P, K, Ca and Mg factors in material comprising 45 randomized sample plots. Only a graphical analysis was performed.

The correlation between the phosphorus contents and growth was considerably weaker than in the corresponding analysis of exchangeable nutrients. The P values ranged from 27 to 118 mg/ml and k-67<15 cm appeared throughout the variation range. On the other hand, growth of over 35 cm fell in the range 43—86 mg/l.

The range of variation of potassium was 34—162 mg/l within which, with the exception of 34—54 mg/l, growths of under 15 cm were seen. Growths in excess of 35 cm occurred over the range 52—82 mg/l.

Calcium showed a positive correlation with growth, but it was weaker than for exchangeable Ca_{10}.

Nothing indicative of correlation was seen between growth and the magnesium concentrations which were distributed relatively evenly over the range 87—310 mg/l.

Analysis of storage nutrients gave no diagnostically serviceable information.

5. COMBINED APPLICATION OF NEEDLE AND PEAT ANALYSIS IN NUTRITIONAL DIAGNOSIS

Correlations between the (exchangeable) nutrient concentrations of peat and the needle nutrient concentrations were relatively loose for most nutrients. Similarly, the determination equations for growth variations had only few common independent variables in the models constructed from peat and needle analysis. Insertion of the macronutrient concentrations of peat (0—10 cm layer) and needles as independent variables in the same analysis gave the following equation:

$k\text{-}67 = 3.907^{**}P_n - 8.269^{***}Mg_n + 0.032^{***}Ca_{10} + 0.515^{***}P_{10} - 0.059^{***}Mg_{10} + 2.72^{***}K_n + 4.501^{***}N_{10} - 0.264$; $R = 0.70^{***}$, $S = 8.173$, $n = 207$ and a degree of determination of 48.9 per cent.

Adding the exchangeable nutrients of the 10—20 cm layer of peat to the analysis changed the equation to some extent:

$k\text{-}67 = 4.457^{***}P_n - 6.737^{***}Mg_n + 0.030^{***}Ca_{10} - 0.139^{***}K_{20} + 3.344^{***}K_n - 0.071^{***}Mg_{20} + 4.316^{***}N_{10} + 1.252^{***}P_{20} - 1.750$; $R = 0.74^{***}$, $S = 7.742$, $n = 207$ and a degree of determination of 54.1 per cent.

The regression that corresponds to the positive correlation between Ca_{10} and growth (Fig. 12 p. 35) is also seen in these equations. However, as the results of needle analysis suggest that the question in most cases (cf. Fig. 5 p. 20) is not the need for Ca as a nutrient, the correlation between growth and Ca_{10} depends on the correlation between the Ca of peat and the natural site class ($r = 0.37^{***}$). However, should there occur a need for Ca nutrient or to reduce the acidity of peat, it would seem that it could only be diagnosed by means of peat analysis. No correlation between Ca_{10} and the peat pH (e.g. Kotilainen 1928, Wilson & Staker & Townsend 1932, Kivinen 1935, Lakanen et.al., 1970) was established in this material ($r = -0.05$).

Despite the increase in the degree of determination, the equations give no indication speaking in favour of either peat analysis or the joint use of both analyses.

6. EXAMPLES OF PRACTICAL APPLICATION

Four experiments were selected from the material as examples of determination of the fertilization requirement in individual peatland habitats. These experiments were satisfactory as regards the fertilization experimental arrangements.

Hence, the needle analysis values N_n, P_n and K_n in accordance with the previously described diagnostics are used as the bases of the two-level fertilization requirements, ++ = necessary, + = recommendable. The limit values are as follows, and it is possible to digress from the indication given by them only if growth has been exceptionally good or poor:

recommendable	necessary
N_n = 1.20—1.30 %	N_n < 1.20 %
P_n = 1.40—1.70 o/oo	P_n < 1.40 o/oo
K_n = 3.50—4.00 o/oo	K_n < 3.50 o/oo

In addition to the fertilization requirements, Table 3 (p. 41) presents the following points which have already been partially established: (1) Growth and the variations in the needle nutrient concentrations may be explained to a very considerable extent by P and K fertilization treatments; (2) The effect of fertilization on the corresponding nutrient contents of the needles is very distinct with the P and K factors, but the effect of N fertilization is not seen in the N_n values although the relatively recent experiments Muhos 55 a and Haapavesi 28, which were given strong N fertilization, are included. (3) The increase in the P_n values with increasing P fertilization is seen very clearly, even ten years after fertilization, in habitats which differ appreciably from one another (Muhos 55 a and 82 a). The corresponding phenomenon is not equally clear in the K_n figures. Nevertheless, both the P and K fertilization effect weakened distinctly in the oldest experiment (18 years). This observation was also most reliable for the P_n values; (4) The order of the minimum factors at the different sites may be said to be roughly as follows: Muhos 55 a (RiSN) $P \geq K > (N)$; Haapavesi 28 (RiRhSN): $K > P > (N)$; Muhos 82 a (RPsR) $P \geq N > K$ and Sievi (SiKN) $P > K > N$. (N) denotes that nitrogen has remained distinctly a minimum factor, at least after PK fertilization; (5) Concerning the recommendable fertilization quantities, 40 kg K/ha in cases of pronounced potassium deficiency is

Table 3. Fertilization instructions for some sample plots
Taulukko 3. Eräiden koekenttien lannoitusohje

Experiment and peatland type *Koe ja suotyyppi*	Fertilization *Lannoituksen*				Needle — *Neulasten*			Height growth (cm) in 1967 *Pituuskasvu (cm) v. 1967*	Fertilization recommendation *Lannoitussuositus*		
	Age years *Ikä v.*	Amount *Annostus* kg/ha			N %	P %	K %		N	P	K
		N	P	K							
Muhos 55 a RiSN	10	—	—	—	1.62	0.115	0.315	13.3		++	++
		—	24	—	1.30	0.155	0.225	28.0	+	+	++
		—	49	—	1.46	0.225	0.250	27.0			++
		—	73	—	1.64	0.238	0.225	24.0			++
		—	122	—	1.37	0.245	0.250	25.6			++
		—	—	66	1.50	0.110	0.400	22.4		++	
		—	—	100	1.62	0.103	0.375	24.1		++	+
		—	—	166	1.46	0.103	0.375	19.1		++	+
		—	24	100	1.42	0.120	0.345	28.7		+	++
		—	49	100	1.39	0.145	0.425	36.3		+	
		—	73	100	1.32	0.178	0.400	42.3			
		25	73	100	1.25	0.208	0.450	36.0	+		
		50	73	100	1.39	0.205	0.450	44.9			
		100	73	100	1.48	0.193	0.425	40.3			
Haapavesi 28 RiRhSN	6	—	—	—	1.40	0.123	0.245	21.0		++	++
		—	56	—	1.34	0.195	0.238	26.8			++
		—	—	40	1.45	0.122	0.350	33.3		++	+
		—	56	40	1.42	0.192	0.312	35.2			++
		100	56	40	1.26	0.160	0.325	31.7	+	+	++
Sievi SiKN	18	—	—	—	1.08	0.109	0.290	6.8	++	++	++
		—	21	—	1.39	0.121	0.333	29.0		++	++
		—	—	100	1.55	0.101	0.308	22.4		++	++
		—	21	100	1.25	0.115	0.358	28.1	+	++	+
Muhos 82 a RPsR	10	—	—	—	1.17	0.152	0.381	11.2	++	+	+
		—	24	—	1.10	0.150	0.400	7.0	++	+	
		—	49	—	1.10	0.160	0.400	7.2	++	+	
		—	73	—	1.07	0.155	0.425	10.5	++	+	
		—	122	—	1.13	0.170	0.425	17.2	++		
		—	—	66	1.29	0.155	0.400	7.7	+	+	
		—	—	100	1.10	0.165	0.450	10.4	++	+	
		—	—	166	1.14	0.155	0.425	8.7	++	+	
		—	24	100	1.27	0.148	0.375	12.3	+	+	+
		—	49	100	1.18	0.160	0.400	10.7	++	+	
		—	73	100	1.18	0.160	0.350	16.0	++	+	+
		—	122	100	1.09	0.185	0.425	17.2	++		

absolutely insufficient and the highest amounts of phosphorus used (73—122 k P/ha) in combination with K fertilization is not too high a phosphorus quantity, and that these large amounts help to keep the P_n level higher for a longer time.

7. DISCUSSION

The purpose of this study was to ascertain the correlation between the N, K, Ca, Mg and trace element contents of needle and peat samples collected from drainage-fertilization-peatland sample plots and the pine growth on the same plots. Because of the nature of the task, the material was selected from samples as different as possible in regard to fertilization and growth so that the differences would be maximal and the resulting correlations if any could be elicited. The material was certainly heterogeneous genetically.

A general need for nitrogen fertilization was observed, due in many cases as a consequence of PK fertilization. The degree of N deficiency can be determined by needle analysis, but the need for N fertilization can often be concluded simply from the peatland type (cf. Huikari and Paavilainen 1968). The total nitrogen values of peat by themselves are generally fairly poor indicators of the N economy in individual cases. The optimum nitrogen concentration of the needles lies above 1.3 per cent. Wehrmann (1963) reported 1.6—1.8 per cent as an optimum, which is lower than the values recorded for heath soils in Scandinavia. Tamm (1956 a) and Ingestad (1962) reported optimum N_n values of around $N \geq 2.0$ per cent.

The effects of excessive nitrogen (in ratio to phosphorus and potassium) are often negative; over-fertilization is known to cause growth anomalies (Reinikainen 1966) and a tendency for freezing and drying (Shirley & Meuli 1939, Pharis & Kramer 1964, Koskela 1970). N fertilizers are also relatively expensive and consequently only the most barren peatlands in which N_n often seems to be < 1.2 per cent are fertilized immediately with NPK. The N fertilization requirement can otherwise be decided by needle analysis performed 3—4 years after the PK fertilization, if the growth reactions give cause to suspect a nitrogen deficiency.

The need for phosphorus fertilization was very common. The optimum needle phosphorus was in the range 1.60—2.10 per mille. An accurate determination of the upper limit, however, was impossible in this data. The optimum P_n range of pine on heath soils seems to be broader, according to e.g. Krauss (1962) and Wehrmann (1963) 1.00—2.00 per mille.

P fertilization must almost always be given to peatlands at the first fertilization. Thus the question of needle analysis arises chiefly when the need for re-fertilization is assessed; in other words, when P_n drops below 1.30 per mille.

The potassium requirement was obvious in the majority of the sample plots, judging by the needle analysis. The peat potassium level explained growth poorly. Nor were the correlations necessary for diagnosis found between growth and K_n at the same significance levels, as in the case of N_n/growth and P_n/growth. The patchy alternation of K deficiency (Valmari 1956) and extreme K deficiency (op.cit.) which is characteristic of e.g. »rimpi» peatlands, and the manifest depressive effect of P and NP fertilization on the K_n values (Tamm 1956 b, Themlitz 1958 a, Themlitz & Baule 1960) are probably represented in the material. So-called, general, mostly asymptomatic K deficiency (in which, usually, $K < P$ as a minimum factor) appears from the needle analysis, so that K_n is seldom over 4.50 per mille in sample plots not fertilized with potassium. Extreme deficiencies, when $K \geq P$ as a minimum factor (see Puustjärvi 1962 b), are manifested as K_n values of under 3.00 per mille which is commonly regarded as the upper limit of specific K deficiency symptoms (e.g. van Goor 1956, Schönnamsgruber 1962, Reinikainen 1967). The K content of the needles can be raised to 6.00 per mille even by light K fertilization and even great amounts of K fertilizers have no detrimental effects (Puustjärvi 1965). Especially susceptible to the effects of one-sided P fertilization are the sites naturally poorest in potassium (e.g. Reinikainen 1966). It is not possible on the strength of the present study to state accurately the conditions in which K fertilization could be omitted completely, but some fertilization experiments (Paarlahti 1967) have shown the unimportance of including potassium in the first fertilization. The PK combination has been generally recommended as the basic fertilization for peatlands (Huikari & Paavilainen 1968, etc.). The K component could perhaps be omitted in pine swamps of nutrient classes V—III (cotton-grass —sedge levels, Huikari 1952). The economic benefit that can be achieved by this omission is questionable as K fertilizers are cheap and the use of multinutrient fertilizers saves spreading costs. To try and work out the possibility of omitting K fertilization as the sole aim of needle analysis must therefore be regarded as scientific precociousness.

The diagnostic significance of the Ca_n values of peatland pines is manifestly small. Even the correlation between Ca_{10} and growth is so loose that it probably cannot be used to recommend liming as a soil improvement measure. In fact, both the poor results of forest liming experiments on peatlands (Lukkala 1951) and the effect of the increase

in Ca and pH on the binding of P in peat (Gaardner 1934) are well known. A high Ca level is known to have detrimental effects also on the K economy (Themlitz 1958 b).

The need for magnesium fertilization was not elicited by the methods employed. The relative paucity of the magnesium stores in peatlands, which has been established on the agricultural side (Heinonen 1956), has had no fatal results on pine; on the contrary, it has been possible, with the help of the natural capacity of Mg to keep Mg_n at a level which according to earlier needle-analytical studies (van Goor 1956, Krauss 1962, Brüning 1959, Schönnamsgruber 1962) indicates a state above the deficiency limit.

The present work failed to clarify the picture of the need of pine for the trace elements, Mn, Zn, B, Fe and Cu on peatlands where their content has been found to be generally small (Vuorinen 1958). The incompatibility of the needle and peat analysis results was apparent; according to the indications of peat analysis, the addition of e.g. Mn to peat might be useful for growth, but the needle analyses revealed highest Mn concentrations in poorly productive trees. The concentrations were always above the deficiency limits stated in the literature (Wehrmann 1963, Ahrens 1964, Zech 1968).

The negative correlation of growth with the total of needle trace elements and especially with needle boron is probably comparable with the disharmony of the needle nutrient contents seen in other connections (Mulder 1953) in trees that suffer from nutrient deficiencies. Elevation of the trace element level, especially has often been noted to be a characteristic feature of this situation. It is not clear whether a mere so-called »Verdünnungseffekt» (Wittich 1958, Smith 1962) is involved.

It seems that interpretation of the correlations between the results of needle and, partly, peat analyses and the height growth of pine can be based fairly readily, on the law of minimum factors reported by Mitscherlich (1909) (cf. for instance Nebe 1963). The recommendation to fertilize with a nutrient which is the strongest minimum factor can then be applied as the theoretical fertilization rule. Finnish peatlands are in a special position in that they often have several manifest minimum nutrient factors simultaneously. Although P is most often furthest from the optimum, the order of importance of the minimum factors may vary considerably. This makes it more difficult to find diagnostically serviceable growth/nutrient correlations than when one strong minimum factor exists (e.g. Leyton & Armson 1955, Heinsdorf 1964, Zech 1968). Opinions differ about how to determine the strongest minimum factor from the needle analysis results. Puustjärvi (1962 b and 1965) recommends the use of arithmetic N/P and P/K ratios, and Leyton (1957) and Krauss (1959) also refer

to them. It has been difficult to take into account the minimum levels of needle concentrations of all macronutrients, yet their existence is most obvious in the present study. For instance, the needle N—P—K optimum concentration obtained from the covariance model presented in Chapter 3.21 reveals $N/P \approx 8$ and $N/K \lesssim 3.2$, both of which indicate a nitrogen deficiency according to Puustjärvi. It is obvious, in fact, that the use of ratios to decide the order of power — if they are used at all — must be limited at any rate to a certain range of variation of individual nutrient concentrations.

The application of Mitscherlich's thinking to the determination of the chemical fertilization requirement presupposes the use of crop data, i.e. growth results, and correlation studies. They are lacking in e.g. Puustjärvi's (1965) publication, although he refers to Mitscherlich's classical law. The results of the present study suggest that the establishment of correlations and regressions between growth and nutrient contents are indispensable for explaining the order of the minimum factors of growth. As, moreover, knowledge about the effect of factors other than mere nutrient factors must be regarded as essential, reference is made here only to what was stated in Chapter 3.5 (1)—(6), p. 30.

It is a part of the present work to conclude how far needle and/or peat analysis parallel with or instead of conventional methods, may be recommended as a method for determining the practical fertilization requirement of peatland pine stands. As the result of the analyses, N, P and K fertilization is recommended on the basis of certain needle analytical arguments. At the practical level, unambiguous instructions on fertilization with macronutrients have been given during the 10 years that forest fertilization has been used in Finland. The general rule for PK fertilization in peatland forests is not faulted by this study; the same must be said of the necessity for N fertilization on more barren soils and of the rule to avoid at any rate, surface liming in peatland forests. Needle analysis offers additional features for prediction of the nutrient requirement at the following levels: (1) It is possible to determine the order of importance between the minimum factor nutrients; (2) Qualitative and to some extent also quantitative information is obtained for repeated treatment with fertilizations at different ages.

With reference to certain NE American forest habitats Wilde (1958) likened needle analysis as a diagnostic method to killing a fly with a cannon, meaning that diagnostic results are achieved, but at a cost that is incompatible with the complexity and expense of the method. In part, a similar conclusion could be drawn from this material. Nevertheless, there is reason to adopt as the aim of the accumulation of needle analysis material the establishment of a complete observation network for different peatland habitats. A point to be borne in mind when collecting this material is that both the needle

and peat analysis results are of little value if they are isolated. The same completeness of information that is aimed at for needle analysis should be the target of describing habitats and plant associations.

Fertilization instructions (Table 3 p. 41) for sample plots based on the investigation results, direct the thoughts to the possibility of creating, by the concomitant use of several diagnostic expedients, a key of the investigation formula type for the determination of the fertilization requirement of peatland pine stands. The publication of such a key, after possibly supplementing the material, would seem to constitute a natural continuation to this study.

REFERENCES

Aaltonen, V. T. 1950. Die Blattanalyse als Bonitierungsgrundlage des Waldbodens. MTJ 37. 8: 1—41.

Ahrens, E. 1964. Untersuchungen über den Gehalt von Blättern un Nadeln verschiedener Baumarten an Kupfer, Zink, Bor, Molybdän und Mangan. Allg. Forst- und Jagdzeitung 135. Heft 1: 8.

Alway, F. J. & Maki, T. E. & Mathley, W. J. 1934. Composition of the leaves of some forest trees. Bull. Amer. Soil Surv. Ass. XV.

Ashby, W. C. 1959. Limitation to growth of basswood from mineral nutrient deficiencies. Bot. Gaz. 121: 22—28.

Bartholin, T. S. 1969. Revision af fladrodplantningsforsøg med henblik på at konstatere langtidisvirkning af fosforgødskning. English summary. Det forstlige forsøgsvaesen i Danmark XXXII (1): 169—188.

Björkman, E. 1942. Über die Bedingungen der Mykorrhizabildung bei Kiefer und Fichte. Symb. Bot. Ups. 6. 2.

—»— 1954. Om gödsling av skogsmark. VNN 10. 2: 1—7.

Brüning, D. 1959. Forstdüngung. Ergebnisse älterer und jüngerer Versuche. 219 pp. Leipzig.

Chandler, R. F. Jr. 1939. The calcium content of the foliage of forest trees. Corn. Univ. Agr. Exp. Sta. Mem. 228.

Gaardner, T. 1934. Fosforsyrens bindning och frigjøring i jorden. Nord. Jordbr. Forskn. 16: 197—216.

Giersberg, Fr. 1901. Künstliche Düngung im forstlichen Betriebe. 103 pp.

Goor, G. P. van. 1956. Kaligebrek als oorzaak van gelepuntziekte van groveden (*Pinus silvestris*) en Corsicaanse den (*Pinus nigra var. corsicana*). Ned. Boschb. Tijdschr. 28: 21—31.

—»— 1967. Kriterien zur Feststellung des Düngungsbedürfnisses in der Forstwirtschaft. Proc. of the Vth Colloquium of the Int. Potash Inst. 55—64.

Hacskaylo, Jr. 1960. Deficiency symptoms in forest trees. 7th Int. Cong. Soil Sci. 3: 393—405.

Haveraaen, O. 1964. Orienterende undersøkelse over sammenhengen mellom skogproduksjon på myr og myrjordars innhold av ulike naeringemner. Tidskrift for Skogbruk 1.

Heiberg, S. O. & Leyton, L. & Loewenstein, H. 1959. Influence of potassium fertilizer level on red pine planted at various spacings on a potassium deficient site. Forest Science, Vol. 5: 142—153.

Heiberg, S. O. & Madgwick, H. A. I. & Leaf, A. L. 1964. Some Longtime Effects of Fertilization on Red Pine Plantations. Forest Science 10. 1: 17—23.

Heikurainen, L. 1955. Rämemännikön juuriston rakenne ja kuivatuksen vaikutus siihen. Referat: Der Wurzelaufbau der Kiefernbestände auf Reisermoorböden und seine Beeinflussung durch die Entwässerung. AFF 65. 3: 1—76.

Heikurainen, L. 1959. Tutkimus metsäojitusalueiden tilasta ja puustosta. Referat: Über waldbaulich entwässerte Flächen und ihre Waldbestände in Finnland. AFF 69.1.

—»— 1960. Metsäojitus ja sen perusteet. 378 pp. Helsinki.

—»— 1964. Improvement of Forest Growth on Poorly Drained Peat Soils. Intern. Rev. of Forestry Research, Vol. 1: 39—113.

Heinonen, R. 1956. Magnesiumin tarpeesta Suomen pelloissa. Agrogeol. julk. 65.

Heinsdorf, D. 1962. Beitrag über die Beziehungen zwischen dem Gehalt an Makronährstoffen N, P, K, Mg in Boden und Nadeln und der Wuchsleistung von Kiefernkulturen in Mittelbrandenburg. »Albrecht-Thaer-Archiv», Bd 7, Heft 4.

—»— 1964. Über die Zusammenhängen des Nährstoffgehaltes in Böden und Nadeln und des Wachstums von Kiefernkulturen auf grundwasserfernen Sanden. Archiv für Forstwesen 13.8: 865—888.

Höhne, H. 1962. Blattanalytische Untersuchungen an jüngeren Fichtenbeständen. In: Ernährung der Waldbäume und Forstdüngung. Deutsche Akad. der Landwirtsch.-wissensch. zu Berlin.

—»— 1963 a. Blattanalytische Untersuchungen an jüngeren Fichtenbeständen. Arch. Forstw. 12: 341—360.

—»— 1963 b. Die Mineralstoff- und Stickstoffgehalt von Waldbodenpflanzen in Abhängigkeit vom Standort. Arch. Forstw. 12: 791—805.

Holmen, H. 1964. Forest ecological studies on drained peatland in the province of Uppland, Sweden. Parts I—III. Studia forest. suec. 16.

Huikari, O. 1952. Suotyypin määritys maa- ja metsätaloudellista käyttöarvoa silmälläpitäen. SF 75: 1—22.

—»— 1961. Koetuloksia metsäojitettujen soiden ravinnetalouden keinollisesta parantamisesta. MA 61.5.

Huikari, O & Paavilainen, E. 1968. Metsänlannoitus. 55 pp. Helsinki.

Ingestad, T. 1962. Macro element nutrition of pine, spruce and birch seedlings in nutrient solutions. Medd. fr. Statens Skogsforskn. Inst. 51 (7): 150 pp.

Johansson, O. 1963. Balansproblem i växtodlingen med särskild hänsyn till mikronäringsämnen och sekundära växtnäringsämnen. VNN 19.2.

Keay, J. 1964. Nutrient deficiencies in conifers. Scot. For. 18: 22—29.

Kivinen, E. 1933. Suokasvien ja niiden kasvualustan kasvinravintoainesuhteista. Referat: Untersuchungen über den Gehalt an Pflanzennährstoffen in Moorpflanzen und an ihren Standorten. AAF 27: 1—141.

—»— 1935. Über die Elektrolytgehalt und Reaktion der Moorwässer. Agrogeol. julk. 38: 1—71.

Koderle, J. K. 1865. Die Grundsätze der künstlichen Düngung im Forstkulturwesen. Wien.

Koskela, V. 1970. Havaintoja kuusen, männyn, rauduskoivun ja siperialaisen lehtikuusen halla- ja pakkaskuivumusvauroista Kivisuon metsänlannoituskoekentällä. English summary. FF 78.

Kotilainen, M. J. 1928. Untersuchungen über die Beziehungen zwischen der Pflanzendecke der Moore und der Beschaffenheit, besonders der Reaktion des Torfbodens. Suomen suovilj.yhd. tiet. julk. 7: 1—219.

Krauss, H. H. 1959. Eberswalde: Beitrag zur Kenntnis der Wechselbeziehungen zwischen den Hauptnährstoffen, Stickstoff, Phosphorsäure und Kali bei der Düngung von Forstpflanzen. Archiv für Forstwesen 8. 6/7: 592—649.

Krauss, H. H. 1962. Die Anfangsentwicklung von Kiefern-Vollumbruchkulturen auf degradierten mittleren Sandstandorten nach Kalkmelioration und Düngung mit N, P, K und Mg. In: Ernährung der Waldbäume und Forstdüngung. Deutsche Akad. der Landwirtsch.-wissensch. zu Berlin. Tagungsberichte Nr. 50: 117—133.

—»— 1967. Kaliernährung und Wachstum von Kiefernkulturen und -beständen auf den verbreiteten Standorten im norddeutschen Tiefland. Proc. of the Vth Colloquim of the Int. Potash Inst. 206—216.

Lakanen, E. & Sillanpää, M. & Kurki, M. & Hyvärinen, S. 1970. Maan viljavuustekijäin keskinäiset vuorosuhteet maalajeittain. Summary: On the interrelations of pH, calcium, potassium and phosphorus in finnish soil tests. Maataloustiet. Aikakauskirja 42.1: 59—67.

Leyton, L. 1957. The Diagnosis of Mineral Deficiencies in Forest Crops. British Commonwealth Forestry Conference, Seventh Conference.

—»— 1958. The relationship between the growth and mineral nutrition of conifers. In: Thimann, K. V.: The Physiology of Forest Trees. 323—345. Ron. Press. N. Y.

Leyton, L. & Armson, K. A. 1955. Mineral composition of the foliage in relation to the growth of Scots pine. Forest Science 1: 210—218.

Lukkala, O. J. 1951. Kokemuksia Jaakkoinsuon koeojitusalueelta. Summary: Experiences from Jaakkoinsuo experimental drainage area. MTJ 39.6: 1—53.

Malmström, C. 1935. Om näringsförhållandenas betydelse för torvmarkens skogsproduktiva förmåga. Medd. Stat. Skogsförsökanstalt 28.6: 571—650.

Mannerkoski, H. 1970. Lannoituksen vaikutuksesta kylvölaikkujen kasvillisuuteen. Summary: On the influence of fertilization on the vegetation appearing in seed spots. Suo 21.5: 80—86.

Mayer-Krapoll, H. 1956. Die Anwendung von Handelsdüngemitteln insbesondere von Stickstoff in der Forstwirtschaft. Ruhr Stickstoff. Bochum.

McHarque, J. S. & Roy, W. R. 1932. Mineral and nitrogen content of the leaves of some forest trees at different times in the growing season. Bot. Gaz. XCIV.

Mitscherlich, E. A. 1909. Das Gesetz des Minimums und das Gesetz des abnehmenden Bodenertrages. Landw. Jb. 38.

Möller, A. 1904. Karenzerscheinungen bei der Kiefer. Zeitschrift für Forst- und Jagdwesen 36: 745—756.

Mulder, D. 1953. Magnesiummangel im Obstbaum. In Kali und Magnesium 91—102. Deutsche Waren-Vertriebsges. Berlin.

Nebe, W. 1963. Über die Beurteilung der Düngebedurftigkeit von Mittelgebirgstandorten durch Blattanalysen. Arch. Forstw. 12: 1024—1052.

Oksbjerg, E. 1956. Om rødgranens naeringsoptagelse på fattig jord. Hedeselsk. Tidsskr. 77: 103—116.

Ovington, J. D. 1956. Studies of the Development of woodland conditions under different trees. V. Mineral composition of the ground flora. Journal of Ecology 44: 597—604.

Paarlahti, K. 1967. Lannoitusajankohdan vaikutus rämemännikön kasvureaktioihin. Summary: Influence of the time of fertilization on the growth reactions in a pine stand on peat soil. MTJ 63.4: 1—20.

—»— 1970. Lannoitustarpeen määrittäminen. Soiden lannoituksen tutkimisohjelma vuosille 1970—75. Stenciled copy (Helsinki).

Paavilainen, E. 1966. Maan vesitalouden järjestelyn vaikutuksesta rämemänniköiden juurisuhteisiin. Summary: On the effect of drainage on root systems of Scots pine on peat soils. MTJ 61.1.

—»— 1968. Juuristotutkimuksia Kivisuon metsänlannoituskoekentällä. Summary: Root studies at the Kivisuo forest fertilization area. MTJ 66.1.

—»— 1969. Juuristojen ja kasvualustan hivenainepitoisuuksien välisistä suhteista suometsissä. Summary: On the correlation between the contents of trace elements in roots and growth substratum in certain peatland sites. Suo 20.2: 25—29.

Päivänen, J. 1970. Hajalannoituksen vaikutus lyhytkortisen nevan pintakasvillisuuden kenttäkerrokseen. Summary: On the influence of broadcast fertilization on the field layer of the vegetation of open low-sedge bog. Suo 21.1: 18—24.

Penningsfeld, F. 1964. Nährstoffmangelerscheinungen bei Baumschulgehölzen. Phosphorsäure 24 (3/4): 199—212.

Pharis, R. P. & Kramer, P. J. 1964. The Effects of Nitrogen and Drought on Loblolly Pine Seedlings. Forest Science 10.2: 143—150.

Plice, M. J. 1944. Uptake of minerals by trees in successive years. Proc. of the Oklahoma Acad. of Sci. 24B.

Puustjärvi, V. 1962a. Turpeen typen mobilisoitumisesta ja sen käyttökelpoisuudesta suometsissä neulasanalyysin valossa. Suo 13 (1): 2—11.

—»— 1962b. Suometsien fosforiravitsemuksesta ja neulasten P/N-suhteesta neulasanalyysin valossa. Suo 13: 21—24.

—»— 1965. Neulasanalyysi männyn lannoitustarpeen ilmentäjänä. Summary: The analysis of needles as an exponent for the need of fertilization of Scotch pine. MA 65.1.

Reinikainen, A. 1965. Vegetationsuntersuchungen auf dem Walddüngungs-Versuchsfeld des Moores Kivisuo, Kirchsp. Leivonmäki, Mittelfinnland. MTJ 59.5: 1—62.

—»— 1966. Puulajien ja eräiden metsä- ja suokasvien ekologiasta ja erityisesti niiden ravinnepuute- ja tasapainottomuusoireista Kivisuon metsänlannoituskokeiden valossa. 159 pp. Typewritten copy, Department of Botany, University of Helsinki.

—»— 1967. The appearance of nutrient deficiency in plants growing in the experimental area for forest fertilization at Kivisuo. Proc. of the Vth Colloquim of the Int. Potash Inst. 345—361.

—»— 1968. Ravinteiden puuteoireista puulajeilla. In E. A. Jamalainen: Kasvien puutostaudit 101—109, 123—124. Helsinki.

Sarasto, J. 1957. Metsän kasvattamiseksi ojitettujen soiden kasvillisuuden rakenteesta ja kehityksestä Suomen eteläpuoliskossa. Referat: Über Struktur- und Entwicklung der Bodenvegetation auf für Walderziehung entwässerten Mooren in der südlichen Hälfte Finnlands. AFF 65: 1—108.

Schönnamsgruber, H. 1957. Düngungsversuche mit Phosphat bei Pappeljungpflanzen. In S. Gericke: Düngung in der Forstwirtschaft.

—»— 1962. Kali-Mangelerscheinungen bei Kiefern in Holland. Allgemeine Forstzeitschrift 27.

Shirley, H. L. & Meuli, L. J. 1939. The influence of soil nutrients on drought resistance of two-year-old red pine. Amer. Jour. Bot. 26: 355—360.

Smith, P. F. 1962. Mineral analysis of plant tissues. Annual review of plant physiology 13.

Strebel, O. 1960. Mineralstoffnährung und Wuchsleistung von Fichtenbeständen (*Picea abies*) in Bayern. Forstwiss. Cbl. 79. 1—2.

Tamm, C. O. 1954. Svenska undersökningar över skogens näringstillstånd. VNN 10.2: 14—18.

—»— 1956a. Studier över skogens näringsförhållanden III. Försök med tillförsel av växtnäringsämnen till ett skogsbestånd på mager sandmark. Medd. fr. Statens Skogsforskn. inst. 46 (3): 84 pp.

—»— 1956b. Studier över skogens näringsförhållanden IV. Effekten av kalium- och fosfortillförsel till ett oväxtligt bestånd på dikad myr. Medd. fr. Statens Skogsforskn. inst. 46 (7): 27 pp.

—»— 1968. An attempt to assess the optimum nitrogen level in Norway spruce under field conditions. Studia Forestalia Suecica 61.

Themlitz, R. 1958a. Untersuchungen zur Nährstoffwanderungen in einem Heidenboden und Nährstoffdynamik junger Kiefern (*Pin.silv.*). Kali-Briefe 6.2.

—»— 1958b. Ein Beitrag zur Düngung in forstlichen Pflanzgärten. Beobachtungen zum Kalk-Kali Antagonismus bei jungen Nadelholzpflanzen. Kali-Briefe 6.1.

—»— 1967. Aussagewert von Boden- und Nadelanalysen. Proc. of the Vth Colloquium of the Int. Potash Inst. 80—90.

Themlitz, R. & Baule, H. 1960. Über das Auftreten von Nährstoffmangelsymptomen an jungen Kiefern als Folge unausgeglicher Düngung. Der Forst- und Holzwirt. 15.1.

Tolonen, K. 1966. Soiden kehityshistorian tutkimusmenetelmistä. English summary. Suo 17.6: 93—102.

Troedsson, T. & Tamm, C. O. 1969. Small scale spatial variation in forest soil properties and its implications for sampling procedures. Studia Forestalia Suecica 74: 1—30.

Truman, R. 1958. The Diagnosis of mineral deficiencies in tree seedlings by visual symptoms. New South Wales Forestry Commission. Div. of Wood Techn. Project No. FP 16.

Valmari, A. 1956. Über die edaphische Bonität von Mooren Nordfinnlands. AAF 88.1: 1—126.

Viro, P. J. 1961. Evaluating of site fertility. Unasylva 15: 91—97.

—»— 1966. Metsän lannoituksen kannattavuudesta. Summary: The profitability of forest fertilization. MA 3.66.

Vuorinen, J. 1958. On the amounts of minor elements in Finnish soils. Maatal. tiet. aikak.kirja 1: 30—35.

Walker, L. C. 1955. Foliar analysis as a method of indicating potassium deficient soils for reforestation. Proc. Soil Sci. Amer. 19: 233—236.

Walker, L. C. & Beacher, R. L. 1963. Fertilizer response with forest trees in North America. Nat. Plant Food Inst. Washington D.C.

Wehrmann, J. 1963. Möglichkeiten und Grenzen der Blattanalyse in der Forstwirtschaft. Landw. Forsch. 16: 130—145.

White, D. P. 1954. Variation in the nitrogen, phosphorus and potassium contents of pine needles with season, crown position and sample treatment. Soil Sci. Soc. Amer. Proc. 18.

Wilde, S. A. 1958. Diagnosis of Nutrient Deficiencies by Foliar and Soil Analyses in Silvicultural Practice. First North American Forest Soils Conference. Agr. Exp. Sta. Mich. State Univ. 138—140.

Wilson, B. D. & Staker, E. V. & Townsend, G. R. 1932. Reaction and calcium content of drainage water from peat deposits in New York. Journ. Am. Soc. of Agr. 24: 589—593.

Wittich, W. 1958. Auswertung eines forstlichen Düngungsversuches auf einem Standort mit für weite Gebiete Deutschlands typischen Nährstoffhaushalt. In: Auswertung von Düngungs- und Meliorationsversuchen in der Forstwirtschaft. Ruhr-Stickstoff AG Bochum.

—»— 1964. Die Düngung in der Forstwirtschaft. Ve. Congres mondial des fertilisants. Zürich.

Zech, W. 1968. Über die Kaliumernährung von Koniferen auf kalkhaltigen Böden. Int. Kali-Institut. Bern 80 pp.

Abbreviations — *Lyhenteet:*

AAF = Acta Agralia Fennica
AFF = Acta Forestalia Fennica
FF = Folia Forestalia
MA = Metsätaloudellinen Aikakauslehti
MTJ = Communicationes Instituti Forestalis Fenniae
SF = Silva Fennica
VNN = Växtnäringsnytt

MAA- JA NEULASANALYYSI TURVEMAIDEN MÄNNIKÖIDEN RAVITSEMUSTILAN MÄÄRITYKSESTÄ

Seloste

Tutkittiin maa- ja neulasanalyysin diagnostista käyttökelpoisuutta ravinnetaseen ja edelleen lannoitustarpeen määrityksessä. Aineisto sisälsi erilaisia suotyyppejä, ojitusvuosia ja sarkaleveyksiä. Lannoituksen laatu ja ikä ja siten myös puuston kasvu poikkesivat toisistaan mahdollisimman paljon (taul. 1). Tutkimuksessa käytettiin yhteensä 19 lannoituskoetta (kuva 1), joilta tutkittiin 226 ruutua. Neulaset kerättiin kymmenestä vallitsevan latvuskerroksen puusta niiden ylimmistä, kesällä 1966 kehittyneistä oksakiehkuroista, etelänpuoleisista oksista. Keräys tapahtui maaliskuussa 1967.

Turvenäytteet otettiin kesällä 1967 0—10 cm:n ja 10—20 cm:n kerroksista jokaisen neulasnäytepuun juuristotilasta.

Pituuskasvut mitattiin 20:stä puusta kultakin koealalta. Liitteessä 1 ovat käytetyt muuttujat, joiden lisäksi 45:stä satunnaisesti valitusta ruudusta määritettiin turpeen varastoravinteet liekkifotometrisesti. Uutto tapahtui 2-n suolahapolla.

Esitutkimuksena suoritettiin regressioanalyysi, jossa vuoden 1967 kasvun vaihtelua selitettiin kaikilla liitteessä 1 mainituilla muuttujilla. Todettiin että boniteetti, pintaturpeen kalsium, P-lannoitus/ikä sekä K-lannoitus/ikä selittivät 50.4 % varianssista (s. 13).

Neulasten pääravinteiden pitoisuudet selittivät 33.3 % varianssista. Kiintein yksittäinen korrelaatio vallitsi kasvun ja neulas-P:n välillä (0.45***) ,mikä on nähtävissä myös kuvista 2—7. Kuvat osoittavat myös, että Mitscherlich'in minimitekijäin laki on sovellettavissa aineistoon (kuva 7). Niinpä lineaarinen regressiomalli olikin huonompi kuin kovarianssimalli, jonka selitysaste nousi 41.3 %:in. Mallin mukaan paras pituuskasvu saatiin kombinaatiolla: N_n = 1.50—1.59 %
P_n = 1.90—2.09 ‰
K_n = 5.00—6.50 ‰

Kuvat 2—4 antavat viitteitä siitä, millaisissa olosuhteissa tällaiset pitoisuudet suometsissä ovat mahdollisia.

Muhoksen osa-aineiston perusteella pyrittiin eliminoimaan ilmaston sekä kahden pääravinteen vaihtelut ja tutkimaan, nouseeko selitysaste tällöin yhtä korkealle kuin eräät kangasmaiden tutkimukset antavat syytä odottaa. Tulos oli positiivinen. Samalla havaittiin, että N-pitoisuuden vaikutus pituuskasvuun oli voimakkaasti riippuvainen neulasten P- ja K-tasosta siten, että paras positiivinen korrelaatio saatiin silloin, kun P ja K olivat korkeammalla tasollaan (ks. s. 24). Vastaavanlainen tulos oli myös P:n ja K:n kohdalla. Tämä osoittaa, että puun ravinnetilan ollessa yhtä ravinnetta lukuunottamatta tyydyttävä, tämän ravinteen ja kasvun välinen riippuvuus on suhteellisen kiinteä. Mikäli muistakin ravinteista on puutetta, ts. neulasanalyysitulokset ovat alhaiset, korrelaatiot jäävät epämääräisiksi.

Neulasten hivenaineet, jotka oli määritetty 64:ltä ruudulta, selittivät 56.8 % hajonnasta yhdessä makroravinteiden kanssa. Tärkeimmäksi hivenaineiden ominaisuudeksi osoittautui niiden kaikkien negatiivinen korrelaatio kasvun kanssa (kuva 8) ts. ne olivat diagnostisesti käyttökelvottomia, mikä saattoi johtua ns. verdünnungseffektistä, pääravinteiden ja hivenravinteiden puutteen päällekkäisyydestä tai mahdollisesti analyysimenetelmistä. Voimakkain negatiivinen korrelaatio oli boorilla (—0.63***).

Perättäisten vuosien 1966—1969 kasvun sekä vuosikasvainten summan hajontaa voitiin selittää vuoden 1966 neulasten ravinnepitoisuuksilla noin 50 %, mutta vuoden 1968 selitysmalli poikkesi muista huomattavasti. Tämä osoittaa, että vuosittain ravinnepitoisuudet voivat vaihdella huomattavasti tai, että neulasten ravinnepitoisuuksien osuus kokonaisvaihtelun selittäjänä saattaa vaihdella 25—50 % (s. 27).

Neulasanalyysien perusteella todettiin typpilannoituksen tarve N-pitoisuuksilla <1.3 %, kun P- ja K-talous on tasapainossa. Fosforilannoituksen tarve näytti ilmeiseltä silloin, kun P-arvo oli <1.40‰, mutta jopa P-arvoilla <1.70‰ lannoitus on tarkoituksenmukaista, jos N- ja K-talous on vahva. K-lannoitustarve katsottiin olevan K-arvoilla <3.50‰, mutta NP-taloudeltaan hyvillä paikoilla K-lukemasta 4.00‰ alaspäin.

Kalsium- ja magnesiumlannoituksen suhteen aineisto ei antanut diagnostiikassa tarvittavia lähtötietoja. Hivenlannoitustarvetta ei voitu aineiston perusteella havaita, koska kaikki korrelaatiot kasvuun olivat negatiivisia (kuva 8).

Turpeen pintakerroksen makroravinteet selittävät kasvun varianssista saman verran kuin neulasten makroravinteet. Tärkein regressori oli P, jonka korrelaatio kasvuun oli myös paras (0.39***) (kuvat 9—13). Tämä on ymmärrettävää sillä neulasten ja pintaturpeen P-arvojen välinen korrelaatio oli 0.54*** (ks. liite 2).

Pintaturpeen hivenainepitoisuuksien ottaminen selittäjiksi ei sanottavasti parantanut selitysastetta. Kuitenkin havaittiin, että pintaturpeen Mn-pitoisuus oli positiivinen selittäjä, korrelaatio kasvuun oli 0.39** (kuva 14). Kuvaa hivenaineiden merkityksestä täydentää taulukossa 2 s. 37 esitetty tarkastelu. Siitä ilmenee, että pintaturpeen Cu ja Zn ovat hyväkasvuisilla ruuduilla korkeampia kuin huonokasvuisilla ruuduilla. Näin ollen neulasanalyyttisesti todettu hivenlannoituksen tarpeettomuus kääntyykin eräissä tapauksissa hivenlannoitustarpeeksi, kun tarkastellaan asiaa maaanalyysin tulosten perusteella.

Turpeen varastoravinteiden ja kasvun välisiä korrelaatioita ei saatu esille minkään ravinteen kohdalla, joten väkevämmän uuttoliuoksen käyttö ei lisännyt ravinteisuusdiagnostisia mahdollisuuksia.

Neulas- ja turveanalyysin yhteiskäyttö kasvun vaihtelun selittäjänä — selitysaste 48.9 % (turpeen pintakerros), 54.1 % (molemmat turvekerrokset) — osoittautui teoriassa tehokkaimmaksi kasvunvaihtelun selitysmateriaaliksi. Kuitenkin näytteenottotekniikka, analyysikustannukset ja mallissa esiintyvät monet negatiiviset selittäjät, aiheuttavat sen, että toinen yksittäismenetelmistä on valittava lannoitustarpeen määrityksen pohjaksi. Päädyttiin neulasanalyysiin.

Taulukossa 3 s. 41 esitetään neljälle lannoituskoekentälle uusintalannoitussuositukset, jotka myös toteutetaan diagnoosin testaamiseksi. Kuitenkin jo tämän tutkimuksen perusteella havaitaan, että neulasanalyysitulokset mahdollistavat minimitekijäravinteiden keskinäisen tärkeysjärjestyksen määrittämisen käytännön lannoitustai uusintalannoitusohjeita silmälläpitäen.

APPENDICES

Appendix 1. Parameters of the variables
Liite 1. Muuttujien tunnuslukuja

	Measuring unit *Laatu*	Mean *Keskiarvo*	Deviation *Hajonta*	n
Height growths				
Pituuskasvut				
before fertilization — *ennen lannoitusta*	cm	10.7	4.1	226
1966	»	18.7	8.3	226
1967	»	22.1	10.8	226
1968	»	20.5	12.0	63
1969	»	18.0	7.1	63
1966—69	»	81.6	31.0	63
Needle nutrients				
Neulasten ravinteet				
N	%	1.40	0.24	226
P	o/oo	1.36	0.45	226
K	»	3.72	0.92	226
Ca	»	2.15	0.53	226
Mg	»	1.61	0.49	226
Mn	ppm	328	157	63
Zn	»	141	43.2	63
Fe	»	64.1	16.0	63
B	»	9.64	3.83	63
Peat nutrients				
Turpeen ravinteet				
N_{10}	%	1.51	0.49	226
N_{20}	%	1.56	0.76	66
P_{10}	mg/l	4.58	1.74	226
P_{20}	»	3.25	1.89	66
K_{10}		55.3	20.4	226
K_{20}	»	23.3	19.9	66
Ca_{10}	»	518	172	226
Ca_{20}	»	426	120	66
Mg_{10}	»	95.5	42.0	226
Mg_{20}	»	70.8	25.1	66
Mn_{10}	»	5.18	3.31	66
Mn_{20}	»	3.71	3.47	66
Zn_{10}	»	11.2	3.48	66
Zn_{20}	»	10.2	3.94	66
B_{10}	»	0.16	0.09	66
B_{20}	»	0.17	0.09	66
Cu_{10}	»	1.62	0.87	66
Fe_{10}	%	0.46	0.26	66
Fe_{20}	%	0.32	0.19	66
Other variables				
Muut muuttujat				
site class — *boniteetti*	(Heikurainen, 1959)	3.50	0.95	226
N fertilization — *N-lannoitus*	10 kg/ha	1.55	4.25	226
P fertilization — *P-lannoitus*	»	5.56	7.68	226
K fertilization — *K-lannoitus*	»	6.13	8.48	226

Appendix 2. Correlations between height growth 1967 and macronutrients of needles and peat.

Liite 2. Vuoden 1967 pituuskasvun sekä neulasten ja turpeen makroravinteiden väliset korrelaatiot.

N_{10}	N_{20}	P_{10}	P_{20}	K_{10}	K_{20}	Ca_{10}	Ca_{20}	Mg_{10}	Mg_{20}	N_n	P_n	K_n	Ca_n	Mg_n	
.82															
.30	.42														
.25	.38	.95													
.14	.25	.41	.34												
.11	.24	.77	.83	.48											
—.03	—.05	—.09	—.17	.05	—.14										
—.08	—.08	—.14	—.13	—.08	—.10	.64									
—.08	.00	—.13	—.15	.19	—.07	.56	.38								
.12	.20	.50	.54	.26	.54	.23	.48	.41							
.07	.02	.08	.12	—.35	—.06	—.04	—.06	—.14	—.01						
.21	.25	.54	.48	.16	.41	.16	.00	—.05	.23	—.14					
—.43	—.44	—.25	—.24	—.19	—.15	.18	.15	.08	.00	.07	—.06				
—.46	—.44	—.25	—.23	—.09	—.11	.03	.04	.01	—.12	—.05	—.21	.41			
.20	.18	—.16	—.23	.20	—.15	.32	.38	.25	.09	—.22	—.04	—.08	—.01		
.15	.15	.39	.34	—.02	.14	.29	—.02	—.07	.06	.19	.45	.16	—.14	—.28	k-67

*** = 0.21
** = 0.17
* = 0.13

ABSTRACTS

OF THE PAPERS PRESENTED AT THE MEETING OF

IUFRO SECTION 22 WORKING GROUP ON

SEXUAL REPRODUCTION OF

FOREST TREES

AT VARPARANTA, FINLAND, 1970

HELSINKI 1971

The original papers in their entirety have been published in the special proceedings: IUFRO Section 22 Working Group on Sexual Reproduction of Forest Trees, Proceedings of the Meeting at Varparanta, Finland, 1970, Vols. I—III. This publication has been distributed only to the participants in the meeting and to some institutes and libraries. Copies of the original papers are available from the Forestry Library, University of Helsinki (address: Unioninkatu 40 B, 00170 HELSINKI 17, Finland) at cost price, 0:20 Fmk/page.

Helsinki 1971. Valtion painatuskeskus

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INAUGURATION ADDRESS OF THE VARPARANTA MEETING BY PROF., DR. RISTO SARVAS

Ladies and Gentlemen,

In my capacity first and foremost of a research worker I have pleasure in bidding welcome to this meeting all our respected quests from near and far and the members of their families. The closer this moment approached, the more acutely I felt that we Finns had taken a great responsibility in organising such a very exacting international meeting with our small number of researchers in a small rural locality.

Yet, even while my anxiety has grown, I have seen increasingly clearly, especially when perusing the reports submitted for this meeting, that our best quarantee, and it is an exceedingly good one, of the success of the meeting is you, our valued quests. We constitute a group of researchers in quite a compact, fairly circumscribed sphere of research. We could certainly manage to spend a very rewarding week scientifically even without any advance arrangements.

Our invitations to attend this meeting have had a surprisingly good reception. I believe that the fundamental reason is that the subject range of the meeting, that is the sexual reproduction of forest trees, has come more and more distinctly and simultaneously in different parts of the world to occupy a key position in endeavours to raise the production of forests. In nature the ultimate aim of sexual reproduction is to ensure evolution. It is therefore almost self-evident that the range of topics at our meeting occupies a focal position in forest genetics and forest tree improvement. Almost equally important, however, is controlling the phenomena of sexual reproduction in silviculture in which it is becoming more and more difficult to ensure an adequate supply of seeds. But perhaps more than by these rational arguments the researchers are urged on by the many extremely fascinating research problems and comprehensive, as yet almost completely unmapped branches of knowledge that are offered by the sexual reproduction of forest trees.

I return to the reports submitted to our meeting. I have found all of them to be extremely interesting matter, an imposing cross section of what is happening today in the forefront of research concerned with the sexual

reproduction of forest trees. We know that in their final printed form many such leading ideas as the reports present now often do not come into our hands for 5—10 years. I have the impression, indeed, that freshness is a particular feature of the collection of reports we have here. And we can expect to progress one more step forward in this respect during the discussions ahead.

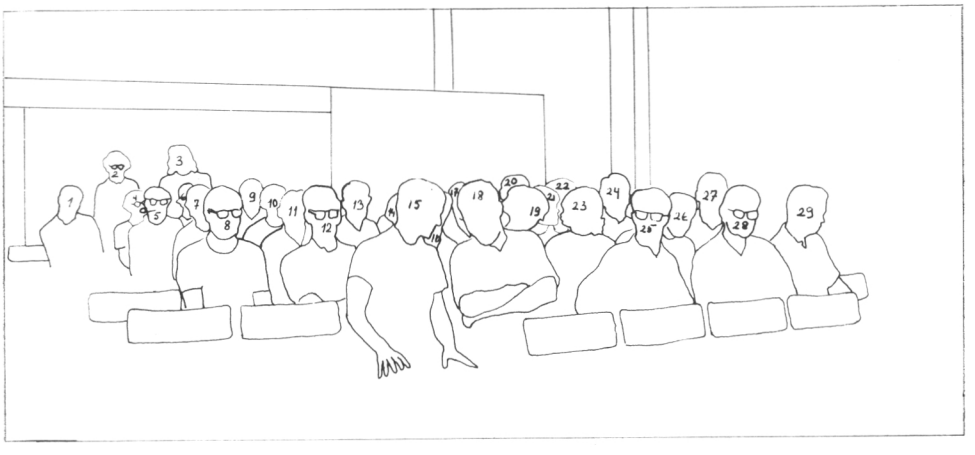
Most of the participants at this meeting will surely share the opinion that the main emphasis in our work during the days ahead of us should be placed on discussion. The Organising Committee therefore suggests that the following procedure should be applied in the treatment of the reports: First, the author will read an abstract of his report or review it at similar length; second, the chairman will open the discussion, either immediately after the reading of the abstract or later if he thinks it suitable, paying special attention to details deserving of discussion; third, a written summary of the contributions to the discussion will be submitted to the secretary of the meeting either immediately after the session or later. The summaries will subsequently be duplicated and distributed to the participants in this meeting in Volume III of its proceedings.

The primary purpose of the discussions is to exchange ideas both on research methods and on the investigation results. The intention is not to arrive at so-called recommendations as the result of the discussion. We are of the opinion that they belong more to the meetings of the IUFRO sections and that the time available to the meetings of the Working Groups must preferably be spent as thoroughly as possible in the climate of research proper. However, if certain proposals for recommendations that are close to this Working Group arise spontaneously, it is requested that they be submitted in writing to the Secretary. They should be addressed to Section 22 and will be dealt which on the last meeting day.

Our first task to get started is the organization of the meeting. This icludes adoption of the agenda, and nomination of chairmen for the sessions and nomination of chairmen for the excursions.

First, a few words about our Working Group itself. The idea was formulated, as many of those present will probably recall, during the Munich IUFRO-meeting in 1967. Dr. Callaham, Chairman of Section 22, later asked Professor Simak and myself to be chairmen of the Working Group. I should mention in this connection that as the membership of IUFRO has grown immensely the actual scientific work is being concentrated more and more in the working groups. In fact, the working groups are tending to assume the position that formerly belonged to the sections, and the sections are becoming more and more organs that hold together and coordinate the working groups. A plan is being prepared in the supreme administration of IUFRO for de jure confirmation of the development that is already largely de facto established procedure.





The working group on a session at Varparanta.

1. Dr Aleksander Tucovic 2. Mrs Marja Dethlefsen 3. Mrs Aino Lukkala 4. Mrs Inger Ekberg 5. Dr Mirko Vidacovic 6. Dr R. P. Pharis 7. Mr Milutin Jovanovic 8. Dr Lauri Mikkola 9. Dr D. P. Fowler 10. Mr Eero Malmivaara 11. Dr Knud Clausen 12. Dr Ian Brown 13. Dr John O'Driscoll 14. Miss Ch. Plym-Forshell 15. Dr Veikko Koski 16. Dr Laurence Roche 17. Dr C. J. Jensen 18. Dr Asbjørn Løken 19. Dr Lennart Eliasson 20. Dr Ingegerd Dormling 21. Mr John Murphy 22. Dr Robert Stanley 23. Miss Christel Palmberg 24. Mr Sang Y. Shim 25. Dr Risto Sarvas 26. Mrs Alena Johnsson 27 Mr Milan Simak 28. Dr Howard Kriebel 29. Dr Gösta Eriksson.

Photo by Max. Hagman.

As far as I can see, it would be quite practical if the chairman of this Working Group always changed at IUFRO meetings, preferably by electing the new chairman from among the researchers of the host country for the next meeting. This would help to ensure that the next meeting or meetings are confirmed in good time. This is a point which, in my opinion, should be deliberated during the next few days and we might try to prepare a recommendation on the matter. With this question is associated closely the motion by Dr Simancik which will be taken up for detailed discussion at a time to be announced later.

The meeting will comprise 9 sessions and 2 intrameeting excursions. The order of discussion on the subjects is: flower induction — meiosis — flowering — seed development. We have tried to make each session as compact as possible in its range of topics. The proposal for the agenda has been distributed to the participants.

Is any change desirable? If not, the agenda is apprised.

The Organising Committee of this meeting considered it desirable that a chairman be nominated for each of the 9 sessions and, in addition, 2 chairmen be elected for each intrameeting excursion. We shall thus need 13 chairmen in all. The Organising Committee set up a working group to prepare the nomination of these chairmen. This working Group consisted of professor Simak, Mr. Hagman and me. Prof. Simak will present the proposal of this working group.

The organization of the meeting having thus been completed, we can move on to our actual work, the examination of reports and the ensuing discussions. The session is closed.

IUFRO, Section 22,
Working Group on Sexual Reproduction of Forest Trees Meeting at Varparanta, Finland, 28. 5.—5. 6. 1970

ORGANISATION AND DAILY PROGRAM

Committee for the Organisation of the Meeting: Professor Viljo Holopainen, Director of the Finnish Forest Research Institute; Mr. Terho Luostarinen, Chief Forest Officer on the Board of the Forest District of Eastern Savo; Professor Risto Sarvas, Finnish Forest Research Institute; Ass. Professor Milan Simak, Royal College of Forestry, Stockholm; The Section Leader is represented by Mr. Max. Hagman, Deputy Section Leader.

Secretary of the meeting: Mr. Eero Malmivaara, Forest Officer; *Treasurer:* Mrs. Aino Lukkala; *Clerks:* Mrs. Marja Dethlefsen and Miss Raija Öhman; *Technical assistant:* Mr. Jaakko Pajamäki.

Principal of the Eastern Savo School of Forestry: Pekka Pesonen, Forest Officer.

Thursday, May 28th

Arrival. Registration at Varparanta.

Friday, May 29th

10.00—11.30 Opening of the Meeting: Professor Viljo Holopainen, Director, Forest Research Institute.
Mr. Terho Luostarinen, Chairman of the Board of Eastern Savo School of Forestry, bids the participants welcome to the school.
Introduction: Dr. R. Sarvas
Adoption of Agenda: Mr. M. Hagman
Nomination of Chairmen for the sessions: Dr. M. Simak
Announcements: Mr. E. Malmivaara

13.30—15.00 Floral induction, juvenility.
Chairman: Dr. R. P. Pharis
Papers: Bonnet-Masimbert, Brøndbo, Dormling, Ebell, Kupila-Ahvenniemi, Mergen and Burley, Stanley and Smith.

15.30—17.30 Floral induction, juvenility (continuation).

19.00 Dinner, given by the Forest Research Institute.

Saturday, May 30th

8.30—11.30 Sporogenesis.
Chairman: Dr. G. Eriksson
Papers: Ekberg and Eriksson and Jonsson, Greguss, Tucovic and Jovanovic

13.30—15.00 Physiology of flowering proper.
Chairman: Dr. I. Brown
Papers: Brown, Koski, Sweet and Bollman

15.30—17.30 Controlled crossing, physiology and technique (demonstration of methods, introduction: Dr. V. Koski).
Chairman: Dr. S. Krugman

Sunday, May 31st

13.00—19.00 Excursion by boat to Linnasaari natural park. Courtesy Enso-Gutzeit Company.

Monday, June 1st

All day excursion to the Forest Research Institute's experimental area in Punkaharju. Demonstration in the field of the investigational methods and data pertaining to the physiology of flowering.

10.00—12.00 Excursion (points 1—3)
Chairman: Dr. C. Ehrenberg
12.30—17.00 Excursion (points 4—8)
Chairman: Dr. L. Roche

Tuesday, June 2nd

8.30—11.30 Pollen physiology, pollen dispersal.
Chairman: Dr. O. Sziklai
Papers: Jensen I and II, Stanley, Stettler, Sziklai and Ronghui
13.00—18.00 Visit to the city and castle of Savonlinna. Reception, host the mayor of the city of Savonlinna.

Wednesday, June 3rd

All day excursion to the Punkaharju experimental area; demonstration of the investigational data concerning the abundance of flowering and the seed crop.

10.00—12.00 Excursion (points 9—10)
Chairman: Dr. I. Dormling
13.00—17.00 Excursion (points 11—12)
Chairman: Dr. S. Krugman
17.00—18.30 Boat tour from Punkaharju to Savonlinna. Courtesy Pilot District of Saimaa.

Thursday, June 4th

8.30—11.30 Syngamy, inbreeding, outbreeding, incompatibility, lethal load.
Chairman: Dr. M. Vidakovic
Papers: Clausen, King and Jeffers and Nienstaedt, Kriebel (a), Krugman, Hagman, Vidacovic and Jurcovic-Bevilacqua
13.00—15.00 Development of embryo, seed production.
Chairman: Dr. A. Løken
Papers: Fowler, Kriebel (b), Minina, Nekrasova, Skoklefald, Simak
15.30—17.30 Development of embryo, seed production (continuation).

Friday, June 5th

8.30—11.30 Annual cycle of generative development, seed dormancy.
Chairman: Mr. M. Hagman
Papers: Katsuta and Løken, Roche, Sarvas
13.30—15.00 Business meeting.
Chairman: Dr. H. Kriebel
15.30—16.00 Closing of the meeting.

The meeting was followed by a two day tour June 6.—7. 1970 to seed orchards and field experiments in Central Finland.

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A GENERAL METHOD FOR COMPUTATION OF FINAL GENETIC GAINS IN THE CASE OF SEVERAL GENERATIONS OF SELECTION WITH A RISK OF POLLUTION BY FOREIGN POLLEN

Ph. Baradat

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Station de Recherches forestières de Bordeaux, France

This paper gives general formulas for computing final (or total) genetic gains when several »generation steps» occur in a forest tree breeding program each of wich can produce a genetic gain loss by pollution from »wild» pollen.

The model is built under simplifying assumptions which are pointed out in the text.

ARTIFICIAL INDUCTION OF MALE AND FEMALE FLOWERS ON YOUNG SEEDLINGS OF CUPRESSUS ARIZONICA (GREENE) AND CHAMAECYPARIS LAWSONIANA (PARL)

M. Bonnet-Masimbert

Station d'amélioration des arbres forestiers
I.N.R.A. — C.N.R.F. — Nancy, France

Early flowering (male and female strobili) was obtained with foliar application of gibberellic acid (GA) on plants, seven to twelve months old, of *Cupressus arizonica* Greene and *Chamaecyparis lawsoniana* Parl. It appeared that a single spray of a GA solution at 50 mg/l was sufficient to induce flowers of both sexes.

It has been possible to enhance markedly the flower inducing effect of GA by Ethrel (2-chloro-ethane-phosphonic acid) which releases ethylene in the tissues. An auxin (NAA) and a growth retardant (CCC) did not increase flowering. Benzyladenin (BA) favoured branching and was able to erase a certain toxicity produced by GA treatments on *Cupressus arizonica*.

It also appeared an important requirement for photoperiodic conditions, especially in *Chamaecyparis lawsoniana*. A sequence of long days → short days → long days was necessary for proper maturation and fruiting of the female strobili.

PREMATURE CONE LOSS IN GRAFTED CLONES OF SCOTS PINE

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Premature drop of cones was studied in grafted clones of Scots pine in the National Tree Bank in Morayshire, Scotland. The study is part of a long term programme to investigate yield of seed from grafted clones of Scots pine.

The results show that cone drop following control pollination varies within and between clones but is not related to differences in the quantity of applied pollen. Maternal and environmental factors play a large part in determining the degree of cone drop.

The pattern of cone drop within the cycle of cone development varies between clones and between the same clones in different years. It is suggested that different mechanisms control the degree of drop at different points in the growth cycle.

THE EFFECT OF METEOROLOGICAL FACTORS ON THE FLOWERING INTENSITY AND CONE CROP OF PICEA ABIES IN SOUTHEASTERN NORWAY

Per Brøndbo

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The environmental influence on flowering and cone crop of *Picea abies* has been studied by means of regression analyses of Norwegian cone crop records and meteorological data. The study has been restricted to Ås, a district presumably representative of the lowland in southeastern Norway.

A pronounced, positive effect on female flowering and cone crop is brought about by high air temperature in a certain period during the summer preceding flowering. This thermal influence was calculated to occur within the period 10. 6—9. 7. A heavy cone crop the year before flowering and a a high temperature sum during the summer two years before flowering have moderate, negative effects.

In an experiment with spruce grafts, the temperature requirements for male flower bud formation were studied. Here the thermal influence was confined to the period 21. 6—5. 7, which coincided with the shoot extension interval from 30 to 60 % of full shoot extension of the grafts. It is suggested that some kind of temperature treatment may provide an increased pollen supply for breeding purposes in spruce.

INTERSPECIFIC CROSSABILITY TESTS IN BETULA

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Interspecific crosses were made during 1962—1969 among 12 species of *Betula* representing three subsections of the genus. An average of 59 percent of the pollinated female catkins set seed but only 25 percent produced viable seed and individual species combinations varied greatly. Combinations with *Nanae* as female parents generally produced lower percentages of fertile catkins than other combinations and high ploidy female × low ploidy male crosses generally gave more than reciprocals.

Of the 487 crosses attempted, 28 percent set no seed, 42 percent produced inviable seed, and 30 percent gave viable seed, but proportions varied greatly with individual combinations. Fewer combinations with *Nanae* as female parents produced viable seed than did most other combinations and again high ploidy female × low ploidy male crosses were generally more successful than reciprocals.

Germination percentages of the seed varied greatly with species combinations. Many crosses had less than one percent germination and were essentially incompatible while others ranged as high as 85 percent. Considerable variation occurred within successful combinations, apparently due to differences in compatibility of individual parents.

Crosses between female *Costatae* and male *Albae* were generally more successful than crosses within either *Costatae* or *Albae*. Similarly, crosses within *Nanae* were less successful than *Costatae* × *Nanae* and *Nanae* × *Albae*. Thus, crossability appears to be better between than within subsections.

In crosses between parents of similar ploidy, the crossability increases with increasing ploidy. In contrast to the greater proportions of catkins and crossing attempts producing viable seeds from crosses between high ploidy female and low ploidy males, better germination percentages were obtained from low ploidy female × high ploidy male crosses. Thus, the latter combinations were, in fact, the more successful.

Results of reciprocal crosses were often strikingly different. In about half the attempts the greater success of a cross over its reciprocal appears due to differences in ploidy levels of the parents. No evidence of unilateral incompatibility was found.

The barriers to interspecific hybridization in *Betula* are unknown but it has been suggested that incompatibility reactions take place on or in the pollen tube membrane and that pollen tubes and stylar tissues must be in intimate contact for the inhibition to occur.

STUDIES ON FLOWER PRODUCTION IN CONNECTION WITH TOPOPHYSIS TEST IN PICEA ABIES (L.) KARST.

Ingegerd Dormling

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Ten trees of Norway spruce served as ortets in a test in which ramets were taken from each branch whorl. Four terminals and two laterals from the same branches of each whorl were used. Low and high grafting was tried on the four to five year old stocks. Flowering in 4—8 year old grafts was followed.

The earliest flowering occurred on four year old grafts and consisted mainly of male flowers. Ramets from the lowest branches had fewer flowers than those from the higher branches but flowers were observed on grafts from the lowest branches, too. This difference seems to be quantitative rather than qualitative, i.e. lower branches merely had fewer flowers.

The top grafts were superior in flowering, survival and earliness of flushing as well as being more vigorous than the side grafts, the last perhaps being the reason why they attain the flowering stage earlier.

MORPHOGENESIS IN CELL CULTURES OF GYMNOSPERMS: SOME GROWTH PATTERNS

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Cells of spruce and pine, derived from proliferating callus of hypocotyls, were grown in liquid suspension culture in a modified White's basal medium supplemented with a balance of coconut milk and α-naphthalene acetic acid. Callus was best obtained from hypocotyls after 4 to 5 days of germination, but not earlier, and success was fostered by the depletion of food reserves in the cells and by the development of plastids. Compared to pine, the growth of spruce cells in the same media was greater by two fold and both cultures showed somewhat orderly patterns of cell growth. The heterogeneity of the cultures was evident in freely suspended cells and cell masses which were variable in cell size, contents, cytoplasmic movements, and also in patterns

of cell division and elongation. When the growth of the cells was more organized, the observed patterns presented features superficially reminiscent of the embryogeny of all plants i.e. polarity, symmetry, and the occurrence of suspensorlike cells.

In both spruce and pine cultures, apart from the continual production of callus, about 20 to 30 % of the cell masses showed orderly signs of organization with about 2 % resembling proembryolike structures. Free cells from pine tended to be spherical and formed clumps which were more homogeneous than the typically elongated cells and clumps of spruce. Thus cell suspension cultures appear to be useful as a means to investigate vegetative propagation and, ultimately, the adventive embryogeny of conifers from somatic cells. If successful, these techniques would increase the range of products that could be obtained in the laboratory from the growth of these cells and in so doing greatly contribute to research on forest trees.

PHYSIOLOGY AND BIOCHEMISTRY OF FLOWERING OF DOUGLAS FIR

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Natural cone crop periodicity of physiologically mature Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and responses to stimulatory treatments appear to be correlated with a greater proportion, out of a predetermined number, of lateral buds which develop normally during the period of new shoot elongation. Susceptibility to failure of reproductive buds appears to start after about 1 week of shoot growth. Optimum timing of girdling treatment was about 1 month before vegetative bud break and treatment later than 1 week after bud break reduced cone production. A reduced stimulus resulted from nitrogen fertilization much before or after bud break. Changes in carbohydrate status as a result of girdling did not appear closely related to reproductive bud survival. Cone production was increased 5-fold on 20-year-old trees and 10-fold on 13-year-old trees by nitrate nitrogen treatment, while response to ammonium nitrogen was negligible. Changes in total nitrogen in buds and foliage and shoot growth responses were similar from the two forms. Nitrate nutrition favored accumulation of soluble nitrogen substances, particularly arginine, lysine and several guanidines, whereas trees treated with ammonium nitrogen incorporated most of their foliar nitrogen increases as protein. Parallel relationships have also been

found in seedlings receiving well-watered vs. cone-inducing moisture stress treatment. The need for more complete understanding of the relationships of nitrogen metabolism to reproductive bud development is stressed, and also the possibility of applying this information toward effective control of flowering on seedling material.

MEIOTIC INVESTIGATIONS IN POLLEN MOTHER CELLS OF LARCH AND NORWAY SPRUCE

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The extension in time for the frost sensitive phase of development (diakinesis — telophase II) in larch pollen mother cells was demonstrated for materials growing at six different localities in Sweden. The influence of temperature on the point of time for the initiation of further development from diplotene was stressed. The temperature response differed from species to species but a variation within a species was also noted. The fitness of a locality regarding the possibilities for a proper pollen production in *Larix* was discussed. The meiotic pattern of development in PMC of Norway spruce grafts growing in a plastic green house was presented. The amount of irregularity appearing during different meiotic stages was illustrated.

BREEDING SYSTEM OF EUCALYPTUS REGNANS

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Eucalyptus regnans is sexually reproduced and monoecious. Its flowers are bisexual, protandrous, and open. The flowers are not specifically adapted to pollination by any one vector. Pollination is probably by many species of insects, and to a smaller extent by birds and wind. The mean free path of genes of *E. regnans* is probably of the order of 60 to 300 metres and effective population size 200 to 3 000 trees.

A successfull technique of self-pollination was developed using unwoven terylene sleeves and blowflies. Of 16 trees examined, 15 were self-fertile to some extent, and the self-fertility of the other tree was uncertain. It appears that selfing is possible in most individuals of this species.

Observations on the degree of selfing from the study of a marker gene on one tree suggest a small proportion of self-pollination in natural populations. The large proportion of small seedlings found in the nursery, and the presence of runts in the field experiments could also result partly from self-pollination.

During natural selection homozygous progeny from selfing are likely to be eliminated due to the effect of inbreeding depression. As a result the remaining trees which reproduce the forest would be heterozygous.

MATERNAL EFFECTS IN RED PINE, PINUS RESINOSA (ait.) AND THEIR IMPLICATIONS TO PROVENANCE AND PROGENY TESTING

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In a species such as red pine, in which genetic variation is comparatively small, the presence of significant amounts of non-genetic variation caused by environmental preconditioning may result in an incorrect interpretation of results from provenance and one-parent progeny tests.

This paper presents the results from three small experiments designed to elucidate the significant maternal effects previously reported by the author.

It is concluded that maternal effects, other than seed size, can cause approximately 10 % variation in height growth of young red pine seedlings. Estimates of genetic variation based on evaluation of young provenance or one-parent progeny materials should be reduced accordingly. It is recommended that controlled pollination studies, including reciprocal crossing, should be employed in future genetic evaluation of this species.

Although the three experiments reported in this paper indicate that maternal effects, other than seed size, are no longer significant after the first or second growth cycle, it is suggested that they could have a prolonged influence on seedling or tree growth under adverse growing conditions.

TEMPERATURE RESPONSE OF POLLEN MOTHER CELLS IN ULMUS

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During the investigations of the temperature response of PMC at three *Ulmus* species growing in the botanical garden of the Secondary Forestry School in Banská Štiavnica it was stated that there was no uniformity in the dormancy stability of PMC, but that there were to be distinguished two fundamental types concerning their dormancy stability:

1. the first type with a short dormancy period;
2. the second type with a long dormancy period.

The pollen mother cells of the first type were capable of a normal evolution on cut branches placed in water at a temperature around 10°C in an extreme case immediately after the autumnal defoliation.

The PMC of the second type transferred during the dormancy in more favourable circumstances (10°C) were capable of a normal evolution for the first time only on branches placed in water cut off from the tree at the beginning of January. On earlier cut branches the meiosis did not even commence.

The consequence of the aforesaid is that the meiosis of the first type having a labile dormancy may already begin under favourable weather conditions in autumn or at the beginning of the winter whereby at an unexpected temperature decline frost damages of the PMC occur. Therefore this type is more labile against frost damages. The second type is more stable against frost damages, although occasional disturbances are not excluded at a fall of night temperatures or at a cooling lasting some days that may occur in the spring after the beginning of the meiosis. However the second type is more resistant against the frost damages because its meiosis begins at a higher temperature and the evolution of the susceptible meiosis stages in a favourable weather is rapid, whereas the precocious meiosis of the first type is often interrupted by low temperatures.

Under artificial conditions the microsporogenesis has its most favourable course at the first type and we may obtain the most fertile pollen in water cultures from branches cut at the end of autumn before the beginning of permanent frosts, while at the second type we may obtain a fertile pollen only from branches cultivated at the end of winter in a time when the meiosis begins on the trees outdoors or a little earlier.

Generally the pollen obtained on cut branches placed in water presents a higher fertility than that matured on the trees.

The frost damages caused irregularities; stickiness, degeneration, polyspory, monads, dyads occur most frequently.

Irregularities during meiosis can cause in an extreme case a total pollen sterility as it has been proved at *Ulmus carpinifolia* of the first type in 1964.

OBSERVATIONS ON THE INCOMPATIBILITY IN ALNUS

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The type of crossability barrier in *Alnus glutinosa* and *Alnus incana* has been investigated. It has been found that self-incompatibility occurs in both species and that the mechanism works through the arrestment of the pollen tube growth.

In interspecific crosses a similar phenomenon is observed but it is not certain if this is the only barrier to the formation of species hybrids.

Seed quality after different kinds of pollination is also reported and the results discussed. Seed fertility after selfing or after interspecific pollination is generally low.

The many good characters of the alders make them suitable for further basic investigations on these questions and also for applied research in tree breeding.

CONTRIBUTIONS TO THE UNDERSTANDING OF CHEMISTRY AND BIOCHEMISTRY OF SEED RIPENING IN NORWAY SPRUCE (PICEA ABIES) AND OTHER CONIFERS OF INTEREST IN NORWEGIAN AND NORDIC FORESTRY (A WORKING PROGRAM)

Arne Jensen and Asbjørn Løken

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It is common knowledge that the usual criterions for estimating the grade of ripening in Norway spruce are insufficient. The need for more dependable criterions is pressing and it seems logical to base such criterions on a better knowledge of the chemistry and biochemistry of seed ripening.

It will be necessary to provide reliable figures of the most important elements in seed samples as: dry matter, ash, fat, cellulose and protein together with data for the composition and nature of carbohydrates. Enzymatic activity in ripe and unripe Norway spruce seeds. Determination of enzymes associated with synthesis and conversion among other things of carbo-hydrates, fat, phenols and proteins in ripe and unripe seeds. Investigation of possible germination-retarding elements in seeds of different provenances.

Our purpose, with the experiments, is to prepare chemical and biochemical methods designed to estimate the degree of ripening in Norway spruce and other conifer seeds.

In 1967 we published 3 preliminary reports on the aforementioned subjects.

ASPECTS AND PROBLEMS OF POLLEN STORAGE AND ASSESSMENT OF POLLEN QUALITY FOR FOREST TREE BREEDING AND GENETICS

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Preserving the life of pollen for genetic and physiological studies is a need, in intermittantly flowering species, for understanding the male gametophyte and for breeding purposes.

Storing the pollen for any desired period to recover it in a genetically and physiologically unaltered state presents certain basic problems caused by:

i) Genotypic differences embodied in species, types and individuals, and environmental influences during pollen formation and maturation.

ii) Processing procedures and their effect on pollen quality during handling stages, i.e. collecting, extracting, drying, freezing, storage, and reconstitution.

The ability to fertilize and to produce viable seed is an essential criterion for assessing pollen viability. However, lack of suitable female flowers, the time factor involved, as well as possible interactions during fertilization, should give the following in vitro tests possibilities to recognise pollen quality: (a) specific staining, (b) pollen tube or tissue growth, (c) nuclear division, (d) respiration, (e) enzyme activity, (f) rate of incorporation of labelled metabolites, (g) membrane permeability.

The potential of controlling viability and recognising quality of pollens are considerable, e.g. establishment of pollen banks to facilitate a broadening of the genetic base and estimation of pollen inherent characters. Knowledge of the genetic make-up of pollen from examination of individuals or populations would allow prediction in advance of some characters of the tree.

SOME FACTORS INFLUENCING SURVIVAL OF POLLEN ON STORAGE PROCEDURES

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The pollen of *Thuja* has been used to describe some of the factors influencing survival on storage procedures. Moisture content was found decisive in determining survival to temperature shock. Samples treated in an inert atmosphere (vacuum) and in air behaved differently when exposed to a range of temperatures. The differences in treatment became more pronounced with low temperature shocks. Survival curves are given for pollen irradiated and assessed for: viable seed setting ability, nuclear division in vitro, and germination.

Reconditioning of pollen to certain atmospheres is a vital factor for survival of stored and processed pollen.

Attention is drawn to differential survival of pollen genotypes due to handling and storage procedures.

Long-term storage of pollen has been successful in terms of viable seed setting ability for Thuja (5 years) and Douglas fir, larch and beech (3 years).

CONE DEVELOPMENT OF PINUS THUNBERGII PARL. IN RESPONSE TO CHILLING AND DAY LENGTH

Masaki Katsuta

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All cones developed rapidly in the next spring, when they were put in the open with natural winter coldness, regardless to day length.

Most cones developed soon under continuous light after summer chilling (dark) for 10 weeks, and occasionally after summer chilling with continuous light for 5 weeks.

EFFECTS OF VARYING PROPORTIONS OF SELF-POLLEN ON SEED YIELD, SEED QUALITY AND SEEDLING DEVELOPMENT IN PICEA GLAUCA

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Using eight *Picea glauca* (Moench) Voss clones controlled pollinations were made with pollen lots containing 0, 12, 50, 90 and 100 percent self-pollen. The seedlots were counted, X-rayed and germinated. Measurements of the seedlings were made after 6 months in the greenhouse. Increased proportions of self-pollen led to a reduced percent of filled seed and reduced epicotyl growth of the seedlings. There was no indication that outcross pollen is favored over self-pollen when the two pollens are applied in a mixture. It is concluded that self-sterility in white spruce is solely a function of the number of heterozygous deleterious genes present in the parent. Implications for white spruce clonal seed orchard management are discussed.

MEASURING THE CATCH OF FOREST TREE POLLEN

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The paper describes measurements of forest tree pollen by means of the pollen catch. The concepts efficiency of trapping and the pollen catch, which are frequently used in studies of this kind, are defined. The main features of the development of the methods of measurement are presented. The dependence of the efficiency of trapping, which is of importance for the magnitude of the pollen catch, on various factors is dealt with against the background formed by the formula for determination of the so-called S e l l's constant. According to this formula, the efficiency of trapping increases with increasing size of the particles to be measured and with decreasing trap diameter. In order to support this model a comparison is presented between the theoretical expectation and the actual results of measurement. An increase in the velocity of the wind improves the efficiency of trapping. The interaction between the velocity of the wind, the height of measurement and the pollen catch is an intricate question. To shed light on this problem the

pollen catch values obtained at various altitudes in pure stands there different tree species are presented. Furthermore, attention is paid to the fact that there is a variation in the pollen catch in respect to time and space. A meter for measuring the total pollen catch and a pollen-registering meter, both of which are of Finnish manufacture, are described. Finally, the statement is made that the density of pollen grains in the air cannot be determined by means of pollen catch measurements.

THE METABOLISM AND ULTRASTRUCTURE OF THE MICROSTROBILES OF THE SCOTS PINE

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The dynamics of biologically important reserve substances in the male buds and microstrobiles of the Scotch pine was studied. The ultrastructure of the pine microstrobiles in the process of their morphogenesis was studied simultaneously.

It has been ascertained that the primordias of microstrobiles are set in the end of June and may be distinguished already in the middle of July. By the autumn the microsporophylls have an epidermis, subepidermal layer, tapetum and microsporocytes.

During the winter there are large nuclei, many proplastids and mitochondria in the microsporocytes and tapetum cells. Endoplasmatic reticulum is weakly developed. There are few dictyosomes. Ribosomes are numerous and lay, mainly, freely in the cytoplasm. During this period complexes of spiral strands of reticulum are found in the cells.

The cells of the subepidermal layer are richest in cytoplasmic organelles. They have many amyloplasts and chloroplasts. Dictyosomes are often clustered in groups and have hypersecretory activity. There are many lipid inclusions in the cytoplasm. The structure of the cells of the epidermis is similar, but they contain much less plastids.

In the autumn the activity of peroxidase, polyphenol oxidase, catalase, lipase and protease grows in the male buds. With the beginning of cold weather the activity of peroxidase and polyphenol oxidase grows but of the other ferments — drops. The content of starch and saccharides also is in its maximum in September but later starch disappears.

The content of aminoacids is maximum in the end of winter, microsporocytes are especially rich in nucleic acids. In DNA/RNA ratio RNA predominates.

In the spring the activity of succinodehydrase, catalase, protease rises, the content of starch and saccharides grows; the activity of peroxidase and polyphenoloxidase drops sharply.

The separating of microsporocytes is accompanied by an activity of cell metabolism. In the prophase of meiosis »lampbrush» chromosomes were observed. The tapetum cells go through two phases: 1) metabolic activity accompanied by an accumulation of starch and proteins and 2) secretory with growth in the length of the smooth-surfaced reticulum and hypersecretion of dictyosomes.

Processes of assimilation take place in the cells of the subepidermal layer in the spring.

The increased activity of the fermentive systems and the accumulation of RNA, carbohydrates and lipids provide a quick spring development of microstrobiles.

The study of the ultrastructure of pine microstrobiles showed that the higher the gradient of cell sexualization — the lower the metabolic activity of the cytoplasmic organelles is observed in them.

EMBRYO DEVELOPMENT AND HYBRIDITY BARRIERS IN THE WHITE PINES (SECTION STROBUS)

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This abstract is from a paper to be published in Silvae Genetica (in press). Published in condensed form in the Proceedings of the Meeting at Varparanta, Finland, 1970.

A study of crossability barriers in the white pines was conducted over a 3-year period. Controlled pollinations of *Pinus strobus* L. were made with pollens of *Pinus cembra* L., *Pinus koraiensis* Sieb. & Zucc., *Pinus flexilis* James and *Pinus strobus* L. Strobili were collected and fixed at daily intervals during the second growth period. Records were taken of the stage of ovule development, in order to obtain quantitative estimates of the degree of development possible in non-crossable, weakly crossable and readily crossable species combinations.

In nearly all of the ovules collected around the end of June, at least one embryo had penetrated the archegonial wall and extended tubular embryonal segments into the corrosion region before collapsing. The percentage of ovules that developed to this point was slightly lower in *P. strobus* × *koraiensis*

than in the other species crosses. The rate of embryo development was about the same in *P. strobus* × *cembra* and *P. strobus* × *flexilis* as it was in *P. strobus* × *strobus*. Development was slower in crosses with *P. koraiensis*.

Both microtechnique and X-ray radiography were used for analysis of immature seed. Corrosion cavities, when present, were visible on the radiographs. Analysis of divided samples by microtechnique and radiography showed that the presence of a corrosion cavity was correlated with the presence of an early-stage embryo. X-ray analysis provided a rapid method of estimating within definable confidence limits the extent of embryo formation in a sample of immature seed.

Abnormalities were found in ovules from most trees and from all species crosses. There was no apparent relation to species combination, however.

The results, together with previous work, indicate that embryo inviability, rather than gametic incompatibility, is the critical factor limiting species crossability in the white pines.

INCOMPATIBILITY AND INVIABILITY SYSTEMS AMONG SOME WESTERN NORTH AMERICAN PINES

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In the exploratory hybridization program of the Institute of Forest Genetics, Placerville, California, most crosses between species failed to yield sound seed. The developmental bases for some of these reproductive failures are being investigated. In this paper I summarize and report the reproductive barriers encountered in the species-reciprocal crossing of four western hard pines — Jeffrey, ponderosa, Rocky Mountain ponderosa, and Coulter pine — and one soft pine, western white pine. The most critical period in the development of a hybrid seed for most hard and soft pines occurs before fertilization and is associated with inability of pollen tube to maintain a normal growth rate in the nucellus during the first year. For hard pine crosses — ponderosa × Coulter pine or Jeffrey × Coulter — prefertilization barriers may account for the complete failure of the cross. For other hard pine crosses — Jeffrey × ponderosa, Jeffrey × Rocky Mountain ponderosa — and the reciprocal crosses of Jeffrey and Coulter pine, postfertilization barriers accounted for additional reproductive failures. Postfertilization barriers accounted for a significant portion of the reproductive failures among the crosses with western white pine.

MORPHOGENESIS AND NUCLEIC ACID CONTENT OF DEVELOPING VEGETATIVE AND FLORAL PRIMORDIA OF THE SCOTS PINE

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The morphogenesis and development of the vegetative and floral primordia of the Scots Pine has been followed during the summer and fall. It is possible to divide the period of new bud development into three phases: 1) origin and early growth of undifferentiated primordia, 2) differentiation of axillaries to spur shoot primordia or — in other types of buds — to male flower primordia and 3) differentiation of axillaries to female flower primordia or — in other types of buds — to spur shoot primordia. Attention is paid to the fact that there are two periods when a switch appeares in the development of terminal buds. The first switch appears when undifferentiated axillaries begin to differentiate forming either vegetative or floral primordia. The second switch causes the end of production of vegetative primordia and the beginning of production of flower primordia or — in other kinds of buds — vice versa. The switches can be timed and it is possible that they can be affected by certain treatments.

The later development of the spur shoot and male flower primordia has been studied and the morphological changes compared with the changes in the amounts of nucleic acids. The growth and mitotic activity of different primordia is in good correlation with the increase in DNA. In the spur shoots RNA continues to increase for several more weeks but after the peak is reached the activity in the primordia seems to slow down. In the male flower primordia the first peak in RNA occurs simultaneously with the levelling off of DNA. It seems as if this period markes the end of growth and preparation for dormancy. However, in contrast to the beliefs commonly held, the present study suggests that the microsporangiate strobilus primordia are not in a state of true dormancy during late fall and early winter. Both the cytological observations and nucleic acid determinations indicate that certain changes are taking place in the pollen sac nuclei.

EFFECT OF RINGING AND OTHER TREATMENTS ON THE FLOWERING OF FOREST TREES

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The original paper was not presented at the Varparanta meeting, 1970, and is not included in the Proceedings of the meeting.

Ringing of branches near the base has been shown clearly to stimulate flower initiation in »mature» grafts and cuttings of a number of species. The effect is generally most marked when a complete ring of bark is removed, with a smaller effect when two ½-rings are used.

In *Pinus sylvestris*, a »shy» flowering clone has produced abundant male buds on 5—6 year old branches, and the buds also appear to be unusually large. In *Thuja plicata*, over 90 per cent of completely ringed branches produced female cones, up to 100 or more in some cases, whereas the whole of the untreated parts of the trees were virtually without flowers.

In *Larix kaempferi*, the percentage of buds which form cones has been increased from 33 per cent in control branches to 59 per cent with complete ringing. Moreover, six times as high a proportion of the flower buds were female with complete ringing. Attempts will be reported to alter the sex ratio in *Larix decidua* by gravimorphic and ringing treatments, and by applying growth substances to potential flower buds before the cone initials have been formed.

Preliminary results indicate that the time of flower opening and pollination may be affected by previous treatment. Assessments of *L. kaempferi* and *L. x. eurolepis* progenies showed that the male and probably also the female cones were at a more advanced stage on trees which had been previously partially ringed on the main stem.

Young seedlings of *Betula pubescens* growing rapidly under greenhouse conditions were induced by complete ringing of the main stem to initiate flowers when less than 8 months old. Flowers of both sexes have also occurred on one-year-old cuttings of *Metasequoia glyptostroboides* kept under greenhouse conditions, and pollen from the male cones has been used to pollinate female cones on the same plant. These results will be discussed in relation to the twin problems of ascertaining the external and internal factors which control flower initiation in forest trees, and the factors influencing the attainment of »ripeness-to-flower».

CONTRIBUTIONS TO THE SEXUAL REPRODUCTION OF BROADLEAVED FOREST TREES

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Floral induction in nature. There are great differences in flowering ability among individuals. Some aged, seed-bearing individuals flower sparsely or only at wide intervals, other often, do even annually bear flowers. Nevertheless there exist a wide variation also among the flowering intensity of different years. Formation of male or female primordia is influenced by weather, temperature, precipitation, etc. conditions of different periods. Besides flowering intensity, seed yield is determined by weather conditions during the pollination period and is strongly affected also by biotic and abiotic damages during fruit development. Late frosts and summer drought often annihilate the yield under continental climatic conditions. Pollination of early flowering individuals is more endangered under our conditions, than that of later flowering ones. Fertilization is considerably influenced by the phenological behaviour of individuals in the stand as well. Biotic damages occure especially in years with smaller crops and dry weather. The periodicity of flowering and fruiting cannot be determined by rigid periods. Well fructifying individuals need resting periods in general. These cannot be eliminated by application of fertilizers. Individuals in the stand flower and fructify alternating in different years.

Manuring and seed production in nature. Sparsely and rarely yielding trees do not react on manuring. Uniform manuring of stands is not reasonable, only the individuals with good flowering abilities should be treated. Only suitably thinned stands after reaching seed-bearing age respond to manuring. Manuring brings results only on soils with favourable water supply, or if irrigation is possible. On dry sites manuring is only exceptionally effective in years with precipitation well above the average. The crown projection of manured trees should be hoed. Data concerning applicable fertilizers and possible doses may be found in the paper »Erdészeti Kutatások» 1969 Nr. 2—3 p. 161—181 (Oak and Beech floral Induction and its Connection with climatic Conditions).

TIME OF FLORAL INITIATION IN PINUS GRIFFITHII McLELLAND × P. STROBUS L. HYBRIS

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To examine the date of initiation of reproductive structures in Haploxylon pines, seedlings of *Pinus griffithii* McLelland × *P. strobus* L. two to six years old were transferred from an outdoor nursery in Connecticut to two controlled environments at various times during the autumn and winter of four successive years. Discussion is concentrated on material four years old but the results in other years were comparable.

Material transferred on October 1 produced few strobili and these required six months to appear. Plants transferred in November—January produced male and female flowers, indicating that floral initiation occurred during October. Extended photoperiod hastened both flowering and vegetative flushing but there was evidence of a chilling requirement of at least one month for both processes.

THE SIGNIFICANCE OF GROWTH SUBSTANCES FOR SEXUAL REPRODUCTION OF FOREST TREES

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Female strobiles of Pinus silvestris in the first days of its life suffer geotropic movements. Primary negative geotropism after pollination changes on positive geotropism. The period of these movements, in the conditions of Siberian climate, constitutes about two weeks.

In negative geotropism there are some auxins and inhibitors in female strobiles. In positive geotropism, that is after pollination in female strobiles the number and activity of indole auxins are considerably increasing.

DEVELOPMENT OF SEEDS AND SEED PRODUCTION IN CEDAR PINE

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The sexual reproduction and the seed crop of cedar pine (*Pinus Sibirica* Du Tour) in the southern forest zone of Western Siberia were studied in 1957—1966.

Some characteristics and times of the development of female strobili and ovules, pollination and formation of seeds are shown. The whole cycle from the initiation of cones to the maturation of seeds makes about 2 years; the period from pollination to fertilization lasts 12.5 months and that from fertilization to seed maturation 2 months. The seeds of cedar pine are rich in fats, the mean percentage of which varies from 55.58 to 64.36 to the dry weight without shells. The weight of 1 000 seeds in the West Siberian plain decreases from 245 g. in the South to 220 g. in the North of the areal; with higher altitude the weight also decreases.

Vitality of embryos is as high as 94—97 %. The following classification of seeds is offered: 1. normally developed (healthy and injured), 2. defective (empty, decayed, without embryo), 3. insufficiently developed. Causes and times of these categories have been considered. The classification is useful in clearing up the causes of seed crop losses in the course of seed formation.

Insufficient pollination of ovules has been found to be a factor of great importance for the seed crop. Two of the five stages making a cycle of the development of generative organs are of critical value for the seed crop: the first stage is initiation of cones in summer and the second one is differentiation of primordia and sporogenesis in spring. The second stage coincides with the fourth (development of ovules and fertilization) in the preceding generation of cones. The influence of weather is most significant in spring during the second and the fourth stages, extreme variations of temperature being most unfavourable.

The analysis of data over the past twenty years showed that seed production in cedar pine was cyclic. The first seed cycle was in 1949—1951, the second in 1955—1962 with an interval in 1959. As to the continuation and absolute value of seed crops, the seed cycles are not similar. The seed productivity in cedar pine widely varies depending on a geographical situation and the taxation data of stands. The average productivity is 40—80 kg/ha and in cultivated stands during the seed years it is 300—500 kg/ha.

THE ROLES OF GIBBERELLIN AND OTHER PHYTOHORMONES IN STROBILUS INDUCTION, SEXUALITY AND DEVELOPMENT

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Past work concerning the induction of flowering in conifers is briefly reviewed. Factors affecting development and sexuality of the induced strobilus are discussed. A hypothesis based primarily on hormonal factors is developed to explain termination of juvenility in nature.

THE EFFECT OF PHOTOPERIOD ON VEGETATIVE GROWTH AND GENERATIVE DEVELOPMENT IN CONIFEROUS TREE SPECIES

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In assessing the effect of photoperiod on the vegetative growth and generative cycle of coniferous trees a distinction is made between dormancy release and flushing, and between cessation of shoot elongation and true winter dormancy. It is suggested that under natural conditions temperature is the most important environmental factor influencing dormancy release and flushing and that cessation of shoot elongation with the formation of a terminal bud, which is closely linked to the onset of the generative cycle, is under the control of photoperiod. The view, therefore, that all theories and concepts of flowering are theories and concepts of photoperiodism could equally apply to coniferous tree species. Both dormancy, and dormancy release are discussed in relation to the microevolution of the species. It is suggested that because cessation of shoot elongation is closely linked with the onset of the generative cycle, and because of the temperature conditions prevailing in the fall, the photoperiodic control of growth cessation confers a survival advantage on the species. A similar survival advantage is not conferred on the species by the photoperiodic control of dormancy release and flushing. The period during which there is gradual cessation of shoot elongation with the formation of a terminal bud is synchronized with the period during which primordia are most plastic in regard to their future development. There is marked meristematic activity during the period prior to true winter dormancy, and it is suggested that at this time substances are

synthesized which mediate the onset of the generative cycle. It is during this period, therefore, that treatment could have maximum effect on the development of reproductive buds. In any study designed to influence the periodicity of cone crops it is necessary to distinguish between initiation of reproductive buds and their development and maturation. Factors which may influence initiation may have no effect on development and maturation and *vice versa*. It is possible that for many coniferous species cone crop periodicity is more closely related to development and maturation rather than to initiation of reproductive buds.

THE ANNUAL DEVELOPMENTAL CYCLE OF FOREST TREES

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The annual developmental cycle of forest trees is divided into three phases: 1. the active period, 2. dormancy and 3. the equalising mechanism, which together form a firm whole. It is hardly possible to study the different phases of the cycle successfully if they are separated from this entirety. A model for the timetable of the cycle is presented and tested with three differing methods.

In the section dealing with the active period it was possible to refer largely to earlier publications. It is essential that the rate of progress of the active period can be determined experimentally to clarify the principle of a physiological clock synchronising the active period of a certain population. The readings of the clock are denoted in period units (p.u.).

The active period of the cells and organs coming within the cycle ends every year the same sum of p.u. and they then pass directly into dormancy.

Dormancy is divided into two essentially differing parts: dormancy I (D I) is a static condition in relation to the timetable of the cycle, and dormancy II (D II) is released as a function of time and temperature. Perhaps the most interesting event in the entire cycle is the first spell of cold weather in the autumn under the influence of which the cells and organs covered by the cycle move from D I to D II.

The regression between the release rate of D II and time and temperature was established experimentally. Release is followed by applying the principle of the physiological clock, with the readings expressed as dormancy units (d.u.). D II ends for cells and organs in the cycle with the same d.u. sum

every year. D II ensures that the protection of dormancy against the severe cold weather of the winter does not end too early, but does end early enough for trees to make full use of the warm period.

The equalising mechanism is indispensable for the constant synchronisation of the annual developmental cycle of trees and the annual climatic cycle. D I functions as the equalising system.

NEW USES OF X-RAY METHOD FOR THE ANALYSIS OF FOREST SEED

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In this paper some new results about X-ray radiographic method used for seed testing are presented.

1. Making anatomical structure of seed distinct on X-ray picture

In the first place this includes the weakly developed Scots pine and Norway spruce seeds from Northern Sweden (polyembryony, dried embryo and endosperm, dry residues in empty seeds etc.). Through soaking in water the small embryos in seed swell up, so that they appear more distinct on the X-ray radiographs than when radiographed in the dry condition. Seeds with dry rests through soaking in water in most cases can reveal the original shape which they had before they collapsed. Moreover, X-ray pictures of seed taken in water have shown better contrast than those of the same seed taken without water. This opens new possibilities for the embryologists to study the different stages of the seed development with the help of X-ray radiography. The geneticist can, for instance, get better information about seed development or abortion after selfing, different cross combinations, etc.

2. Improvement of contrast on X-ray pictures of impregnated seeds

Impregnation method reveals which of the seeds in a sample are living or dead (the dead seeds get impregnated with $BaCl_2$ but not the living ones). While interpreting an X-ray film of seeds treated with barium chloride difficulties can in some cases arise to distinguish the impregnated seeds from the non-impregnated ones, among other reasons due to secondary radiation. This disadvantage can be eliminated when the seeds are irradiated through a »water filter» which absorbs the secondary radiation. In this way, the contrast between the impregnated and the unimpregnated seeds is better.

3. Study of some physiological processes in seed in connection with water absorption

Due to high ability of water to absorb X-rays, the absorption and evaporation of water in a seed can be studied on an X-ray radiograph. Some relationship between the viability of a seed and water evaporation from it when water-saturated has been observed.

CONTRIBUTION TO THE POSSIBILITY OF INTERNATIONAL COOPERATION ON THE RESEARCH OF THE BIOLOGY OF WOODY PLANT SEEDS

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On the basis of the discussion at the International Symposium on Biology of Woody Plants held in Czechoslovakia in 1967, 120 workers from 15 countries expressed their interest in establishing an international organization on the biology of woody-plant seeds. The organization should work either separately or as a section of some international scientific association. The aim of the organization would be to improve the acquaintance with present results and plans in the field of the research of the biology of woody-plant seeds, to secure the exchange of experiences in the form of bulletins, international symposia respectively, and to prepare a long-termed concept of the research of the biology of woody-plant seeds.

DORMANCY OF WOODY PLANT SEEDS IN RELATION TO MORPHOLOGY AND DEVELOPMENT OF EMBRYO

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On wood seeds there was studied the influence of the development stage of the embryo on the seed dormancy. By the study of the embryo development in vivo and in vitro it has been found that from the morphological point of view the rudimentary shape is not able to germinate and its development before the seed germination transfers into the linear or spatulate shapes. The linear shape finishes its development by reaching about $\frac{2}{3}$ of the seed length, the spatulate one by reaching the length of the whole seed.

The other embryo shapes, most often occurring in the wood seed, have from morphological point of view their development finished (bent, folded, investing shapes). The radicle growth which represents the proper germination, begins only after the growth of the cotyledons having been finished. The stage of the embryo development is not a cause of dormancy but it affects the length of its duration. As the main cause of dormancy are to be considered ecological conditions to which the plant adapts by the change of the level, activity of the growth substances respectively.

THE EFFECT OF NITROGEN-PHOSPHORUS FERTILIZATION ON CONE AND SEED PRODUCTION IN SHELTERWOOD STANDS OF NORWAY SPRUCE. PRELIMINARY RESULTS

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Fertilization in shelterwood stands of Norway spruce with nitrogen and phosphorus corresponding to 200 kg N and 30 kg P per hectare gave increases in cone lengths and cone weights, 1 year after the fertilizer application.

No effects were found with respect to cone production, number of seeds per cone, seed weight per cone and upon the distribution of seeds on embryo-endosperm classes.

The 1 000-grain weight of all seeds (including empty seeds and seeds damaged by insects), collected from fertilized trees was significantly higher than for seeds from control trees on 2 of the sample plots.

There was a clear tendency to greater 1 000-grain weights of filled seeds from fertilized trees, and seeds collected from fertilized trees also produced somewhat taller and heavier seedlings.

GROWTH AND METABOLIC CHANGES IN PINE POLLEN WITH AGING

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A study was made of proteins and UV adsorbing materials rapidly washing off the surface of pine pollens. At least two successive 15 second washings are required to elute materials from the pollen. In almost all pollens tested, the older the pollen, the higher the amounts of material diffusing into the

medium. Although dead pollen more rapidly yields water soluble components, the loss from aged pollen is not merely a function of percent non-viable pollen. In some pine pollens, after the first washings, a considerable increase in percent germination occurs; in almost all pollens a modest increase in tube length occurs when compared after 48 hours germination. Fresh pine pollen loses relatively little protein or UV absorbing material, and tube length and percent germination are seldom affected by elution.

By using ^{14}C-glucose it was shown that uptake of sugars and pollen respiration is considerably more rapid in the older, non-washed pollen than in washed or fresh, non-washed pollen. Eluting fresh pollen three times did not affect respiration or sugar uptake. Sugars and phosphorus, as well as proteins and amino acids, rapidly diffuse out of old pollen. Membrane breakdown and lack of retension or selectivity in uptake characterize old stored pine pollen.

Forest tree breeding programs sometimes use older stored pollens as diluents, or in water spray applicators for pollinations. The possible significance of differential pollen surface elution should be recognized in such applications.

PROTEIN RELATED CHANGES IN RESPONSE TO NITROGEN STIMULATED CONE PRODUCTION IN SLASH PINE

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These studies follow chemical changes in pine tissues (*Pinus elliottii*) stimulated to produce cone initials by added nitrogen fertilizers. Earlier reports showed that nitrogen concentrations increased in tissues after treatment, and characteristic differences occurred among the shoot parts subtending the developing buds. Among the several substances assayed, diffusable phosphorus was decreased by N-treatment and diffusable ions were less in the genetically high flowering ovulate, cone-bearing trees. Levels and patterns of free amino acids and sugars were characterized during vegetation and of reproductive growth periods. Buds of flowering trees were active sinks incorporating nitrogen into stable or less mobile materials, presumably proteins and nucleotides.

Gel acrylamide patterns showed that proteins increased in the acetone powder extracts of ovulate buds induced by nitrogen fertilization compared to non-ovulate buds. Leucine-^{14}C incorporation showed details of bud pro-

tein not detected by staining. Some protein isozymes, i.e. oxidases, reflect modified nitrogen nutrition. Amino acid composition of proteins revealed no difference in nitrogen induced flowering buds and buds from trees already flowering; but, the amino acids in ovulate buds differed from those in non-ovulate pine buds. Studies in progress are characterizing the bud nucleotide and m-RNA patterns. This assumes that the levels of nutrition characterized in the tissue, produce specific proteins which reflect induction of messenger-type RNA(s) involved in the floral responses.

EXPERIMENTAL INDUCTION OF HAPLOIDY IN POPULUS

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The original paper is not included in the Proceedings of the Meeting at Varparanta, Finland, 1970. It was published in Silvae Genetica 20: 15—25 (1971).

After introductory remarks on the merits of the haploidbreeding approach and on general experimental strategy, data are given from experiments aimed at inducing haploid parthenogenesis in *Populus trichocarpa* T. & G. ex Hook. Nine trees from nine geographically separate natural populations in the State of Washington served as female parents. They were treated with irradiated pollen (20, 40, 80, 100 KR) alone or in combination with pollen from any of five different species of the genus *Populus*. Intensive cytological examinations were performed on immature embryos and on seedlings. Haploids were found at low frequencies both among embryos and seedlings. Furthermore, maternal-species phenotypes were found with diploid chromosome numbers resulting either from contamination of from spontaneous chromosome doubling of haploids. Several embryos contained both haploid and diploid cells indicating that spontaneous chromosome doubling can occur during embryogeny. The most responsive female produced haploid embryos at an average rate of 0.3 percent, in the optimum treatment (80 KR, mix ratio of foreign-species pollen to irradiated pollen, 4 : 1) at a rate of 1.7 percent. Irradiated pollen alone was successful, too, in inducing haploid embryogeny. Exploratory studies with toluidin-blue treated pollen have been initiated. The merits of androgenesis *in vitro*, as an alternative approach to the production of haploids, are discussed. In all approaches, the variable response by different genotypes clearly indicates the importance of choosing the proper material for experimental studies.

INVESTIGATIONS INTO THE CAUSES OF CONELET DROP IN PINUS RADIATA IN NEW ZEALAND

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The process of conelet drop in *Pinus radiata*, as it occurs in New Zealand, is briefly described. In a series of investigations it was shown that, at the time of conelet drop, competition for carbohydrate nutrients exists between strobili and vegetative branch apices. An experimental reduction in the amount of vegetative growth occurring at that time increased the quantity of assimilate moving into developing strobili, which in turn increased their size and markedly reduced the incidence of drop. The application of a mineral fertiliser to the trees also reduced conelet drop.

It could not be shown that pollinated strobili obtained larger quantities of carbohydrate than unpollinated strobili. Nor could it be shown that the drop of unpollinated conelets during the first six to eight weeks after receptivity, was higher than that of pollinated ones.

It is hypothesised from the above results that there are two separate and distinct stages of conelet drop in *Pinus*. During an initial period after receptivity the drop of conelets results from their inability to compete successfully with vegetative apices for carbohydrates, and possibly also for mineral nutrients. During that stage, pollination levels are unimportant. During the second stage of drop, however, pollination levels do become important, and extensive loss of unpollinated strobili occurs.

DEVELOPMENT OF THE MALE GAMETOPHYTE OF LODGEPOLE PINE *IN VITRO*

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Mature pollen grains of lodgepole pine, containing two prothallial cells, a generative cell, and a tube cell, were incubated in stock solution B for periods of up to seven days. In five days, the generative cell divided into the stalk cell and the body cell, and two days later the body nucleus divided to form two male nuclei of either equal or unequal sizes. As the body cell and the stalk cell entered the pollen tube they lost their cytoplasm. No

stimulation of pollen germination occurred but an inhibition of pollen tube growth was obtained in a culture containing sucrose. A slight promotion of pollen tube growth resulted from an IAA solution, but no increase was achieved in germination percentage. Stock solution B was the optimum solution with respect to the pollen germination and the growth of the pollen tube. Two basic types of pollen tube development and pollen tube branching were discussed in the text. An abnormal development of the pollen tube, protruding through the pollen sac, was recorded.

SOME CHARACTERISTICS OF MEIOSIS IN COMMON OAK (QUERCUS ROBUR L.)

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Genus *Quercus* L. in Yugoslavia comprises over 10 native species and several interspecific hybrids. Great interest for oaks by different investigations in the field of tree breeding, has proved to be indispensable to study more completely flowering biology and generative reproduction of oaks. Among oak species, the priority was given to the common oak with its two varieties (var.*praecox* Černj. and var.*tardiflora* Černj.), in which process of microsporogenesis was investigated.

It was established that the approximative time of occuring of meiosis was in the moment of bursting of protective scales of floral buds. In the precocious variety microsporogenesis started at the beginning of April, and in the trees of late flowering oak at the end of April or beginning of May, i.e. 20 to 30 days later.

Formation of microspore tetrads from mother cells follows a simultaneous type of development. After first nuclei division the protoplasm of the mother cell remains undivided and the interphase between first and second division is usually very shortened or can not be seen at all. The arrangement of spores in tetrads is tetrahedric, isobilateral, or rarely in the form of cross.

Study of microsporogenesis in common oak is only a part of the work on developing breeding techniques for oaks, performed under United States financial support.

OBSERVATIONS ON THE OVULE DEVELOPMENT FOLLOWING CROSS POLLINATION BETWEEN AUSTRIAN AND SCOTS PINES USING IRRADIATED AND NON-IRRADIATED POLLEN

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The physiology of irradiated pollen may be altered sufficiently to overcome or prevent the formation of barriers. Pollen given different irradiation treatments should be used in attempt to cross incompatible species. Irradiated pollen may be useful in overcoming genetic barriers that prevent crossing some species. These investigations are concerned with the problem of interspecific crossing of the Austrian and Scots Pine (*Pinus nigra* and *Pinus silvestris*) using pollen which was previously irradiated with various doses of gamma-rays.

The ovules of Austrian Pine derived from pollen irradiated with various doses of gamma-rays were used. We noticed that the effect of irradiated pollen on the ovules was very irregular depending on the irradiation dose. However, we noticed that the dose of 1 kR contrasted with this rule because most of the ovules derived from it followed normal development until eleven and a half months following pollination which was not the case with non-irradiated pollen and pollen irradiated with other doses.

The break-down of the ovules in interspecific crossing of Austrian Pine and Scots Pine is most probably due to failure of the pollen tube to grow in coordination with the development of the egg cell.