

METSÄNTUTKIMUSLAITOS  
JALOSTUSASEMA  
01590 MAISALA

# METSÄNTUTKIMUSLAITOKSEN JULKAISUJA

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COMMUNICATIONES  
INSTITUTI FORESTALIS FENNIAE

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

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- 80.1 H ä m ä l ä i n e n, J o u k o. 1973. Contribution profit analysis for a fully regulated forest and its empirical application. *Seloste:* Normaalimetsän katetuottoanalyysi ja sen empiirinen sovellutus 1— 47
- 80.2 U s v a a r a, O l l i. 1974. Wood quality in plantation-grown Scots pine. *Lyhennelmä:* Puun laadusta viljelymänniköissä ..... 1—105
- 80.3 K u r k e l a, T i m o. 1974. Colonization of *Melampsora* uredia on aspen leaves by *Cladosporium* Sp ..... 1— 14
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CONTRIBUTION PROFIT  
ANALYSIS FOR A FULLY REGULATED FOREST  
AND ITS EMPIRICAL APPLICATION

JOUKO HÄMÄLÄINEN

SELOSTE:

NORMAALIMETSÄN KATETUOTTOANALYYSI JA SEN EMPIIRINEN  
SOVELLUTUS

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## PREFACE

The publication gives some results from the author's research in the economics of timber growing and from studies concerning profitability calculations applied to forest holdings and enterprises. The study was conducted at the Forest Economics Department of the Forest Research Institute, under the supervision of the head of the department Prof. Lauri Heikinheimo. The manuscript has also been read by the Director of the Forest Research Institute, Prof. Viljo Holopainen and Profs. Kullervo Kuusela, Päiviö Riihinen and Lorenzo Runeberg. To them I extend my gratitude for their constructive observations, which I have endeavoured to incorporate in my work.

The computer programming and the calculations were carried out with expertise by Yrjö Sevola, B.Sc. (Forestry), who also, in part, gathered the price and cost data. The English translation was prepared, in the main, by Mrs. Hilka Kontiopää, M. A. (Helsinki) and the language was checked by Ashley Selby, B.Sc., assisted in cross-reference to the original Finnish manuscript by Erkki Pekkinen. Mrs. Laura Collander painstakingly coped with the typing necessary throughout the production of this work. The diagrams were drawn by Miss Maija Kusijärvi. My sincere thanks to them all.

Helsinki, August 1973

*Jouko Hämäläinen*

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## 1. INTRODUCTION AND STUDY OUTLINE

The author has in an earlier study been concerned with the characteristics of calculation models employed in profitability comparisons in forestry and with their suitability in various calculation situations (H ä m ä l ä i n e n 1973, p. 46—70). These models can be applied to a single stand, a forest holding or to a whole enterprise. The aim of this study is to construct a classification of returns and costs and of annual results obtained from these and to apply it to data introduced later on. The method used is based on the normal forest <sup>1)</sup> model and on the traditional forest rent theory, with the criterion of greatest possible annual net income (the cost of capital undeducted). In the following, the limitations of the chosen method, as well as its applications, will be examined.

<sup>1)</sup> The term «fully regulated forest» is in the present study replaced, for the sake of brevity, by the term «normal forest», which is to be understood as having the same meaning.

## 2. PRINCIPLES AND FUNDAMENTALS OF PROFIT ANALYSIS

The normal forest model is an expression of the static economic theory. A normal forest is an idealized description of reality. An actual forest holding is hardly ever in a constant, unchanged »normal condition», not even as far as its forestry structure goes. The static nature is striking when the normal forest model is used to calculate the annual returns and expenditures of a »going concern» on the basis of the forest rent principle. The net returns calculated on the basis of this principle can be reviewed from the angles of ex post and ex ante calculations. Ex post studies comprise of an analysis of the result of the former period and of its revenue and expenditure components. Let us assume a number of normal forests of the same surface area, upon each of which a certain forest holding policy has been separately operated, and will continue to be operated. The results of the calculations based on the forest rent principle are usually not adequate and realistic enough for the planning of a given, real, forest holding. Planning must take into account the actual resources of the forest holding concerned as they are at the beginning of the planning period and the changing environmental conditions during this period. The forest rent theory disregards the measures and the resulting flows of expenditures and revenues by means of which it is possible to move from the actual, usually abnormal state into a normal forest state (cf. H ä m ä l ä i n e n 1973, p. 66—67). — The forest rent theory can also be used for calculating the profitability of different cutting and silvicultural policies for single stands. The objective is to find such a cutting and silvicultural alternative, that the sum of net revenue for a stand (interest on capital undeducted), obtained within a period of rotation, divided by the number of years in that period, reaches its maximum value. The forest owner endeavours to obtain the maximum absolute revenue per year of the rotation period from his stand, disregarding alternative investment possibilities, financing costs and personal requirements concerning money taken annually from the forest holding for the purpose of consumption (for the latter, see H ä m ä l ä i n e n 1973, p. 42—44).

The most appropriate methods for actual planning situations with regard to forest holdings are various budgeting methods and methods of operational analysis, which rely on the use of combined models (H ä m ä -

l ä i n e n 1973, p. 67—69). The forest rent theory suffices only to describe various static states of forest holdings. It follows that economic returns, costs and results will be determined by the state of the forest holding and its environment. With the aid of normal forest models, the research worker can, by applying the principles of the forest rent theory, provide some information on the type and amount of the revenues, expenditures and results that can be expected from the forest holding after its »normalization», provided that the forest owner aims, in the long run, at an approximately normal age group distribution. In this way the analysis helps the forest owner to define his goals. However, it is perhaps more important, that the »standardized» results of this analysis give all the interested parties in forestry, not only forest owners, at least rough estimates of the forest holdings' economic results and their components.

The present study involved the analysis of the results of two normal forests of different sizes. The one had a surface area of 37 ha and the other 9 500 ha. The former corresponds to the average size of forest holdings in the Lake District of Finland (see V u o k i l a 1967, p. 11, Fig. 1), whereas the latter approximately represents the largest size of privately owned forest holdings in Finland. This makes it possible to obtain some idea also of the effect of forest holding size on different kinds of results and on their components.

Both the 37 ha and the 9 500 ha forest holding were assumed to consist entirely of *Vaccinium* type pine stands. The reason was that the writer already had at his disposal the necessary yield, stumpage price etc. materials concerning *Vaccinium* type pine stands. In the following, the 37 ha forest holding will be called the small holding and the 9 500 ha forest holding the large holding.

Within the framework of the forest rent theory, this analysis applied the so-called contribution profit thinking which has gained ground in general business economics. It implies that in each individual case only the incremental revenues and incremental costs, the majority of which are variable, are assigned to the object of profitability calculation (H ä m ä l ä i n e n 1965, p. 1). When the profitability of the operation of an entire economic unit is to be calculated, all its revenues and costs are incremental in character as regards place. There exists no problem of allocation, such as there is when a component function of a forest holding is involved. The normal forest assumption, in turn, eliminates the problem of chronological periodicity of receipts and disbursements. This simplifies the profit calculation model greatly, since the value of forest property as an activated asset is, both in theory and practice, among the most difficult problems of forest holding profit calculation. However, this simplification also makes the model less realistic. — R u n e b e r g (1959, p. 89) obviously considers sustainment

(reserving of capital) too self-evident in forestry practise, at least from the point of view of an enterprise. He suggests, that changes in capital should not be taken into account when calculating the economic result in real situations. He avoids a central economic problem — the choice of activity policy for a forest holding — by assuming that the choice in reality will eventuate simply as a result of carrying out silvicultural activities considered sufficient for sustainment.

The contribution profit analysis assumes that the forest owner sells the roundwood by delivery sale (Item 1 of Tables 2 and 3). Calculation of various contribution profits advanced according to the principle that contribution profit was first calculated on annual roundwood sale. Incremental costs of the primary production, i.e. those arising from silvicultural activities, the overheads for the total forest holding operations, and the taxes imposed on the forest holding, must then be subtracted from this profit.

### 3. DETERMINATION OF REVENUES AND EXPENDITURES

#### 31. Revenue and expenditure components of the small holding

It was assumed that 249 different policies could alternatively be applied to the forest holding. The policy was determined by the method of regeneration, method of thinning, intensity of thinning, and the rotation applied in the stands (see Appendix-page 1). The production alternatives have been described in the writer's earlier paper in which they were applied, for example, to profitability calculations for the stands (see H ä m ä l ä i n e n 1973, p. 102—107, and the literature references therein).

To evaluate the annual pine log and pine pulpwood removals from the small holding at delivery prices, the real prices of these timber assortments, derived from the trend equations, in felling season 1967/68 were used. The factors corresponding to each forest holding policy and affecting the delivery prices and logging costs were duly taken into consideration (see H ä m ä l ä i n e n 1973, p. 119 and 130—137). All the expenditure categories of the small holding are based on the values of the same study, calculated per hectare at the felling season 1967/68 level. Contribution profits on small holdings were calculated according to two principles: ownership revenue alone, and the sum of ownership revenue and work earnings from timber harvesting. The determination of the expenditure components required for the latter calculations was also described in the writer's paper quoted above (see p. 149 in particular). The annual revenues and expenditures of the small holding, by categories, were obtained by multiplying the undiscounted sums of revenues obtained, and various types of expenditures arising, from a 1 ha stand within one rotation (the interval between final cuttings) by the ratio  $37:u'$ , in which  $u'$  = rotation.

#### 32. Revenue and expenditure categories of the large holding

The 9 500 ha normal forest was also assumed to have the 249 alternative cutting and silvicultural policies. In the contribution profit statement for the large holding (Table 4) the expenditures were grouped somewhat differ-

ently from the small holding statement. The main reason was that the real operations on the large holding are organized differently from those of the small holding. As can be seen from the following description, the figures for most expenditure categories in the contribution profit statement of the large holding are based on material collected from real forest holdings. One of these forest holdings had a surface area of about 9 500 ha (though integrated in forest industry). In the following, this is called the experimental holding. Since, on the large holding, the determination of roundwood prices and especially the expenditure categories essentially differ from those on the small holding, their determination must here be described separately. Also for the large holding, the prices and expenditures are quoted in terms of the value of money in the felling season 1967/68.

The prices of the removals per year from the large holding were also determined on the basis of the mean delivery prices of felling season 1967/68. An addition was made, however, for so-called large volume and storage of the delivered timber (Paperipuun suosituslaskelmat 1. 7. 1968—30. 6. 1969 . . . and Keski-Suomen Metsänhoitoyhdistysten Liiton . . .). This addition for pulpwood was Fmk 0.25/piled cu.m. and for pine logs 1 % of the contract price excluding the addition. The basis for the estimation of harvesting costs was the harvesting cost per volume unit given in the stand series (i.e., same as for the small holding). Owing to the more rational harvesting methods which can be practised in the large-sized timber areas marked for cutting on the large holding, these costs, however, were reduced by 11 % for the pulpwood and by 18 % for logs. The basis for these percentages was the timber contractors' total cost per solid cubic metre quoted by Väisänen (1967), in Table 8, as a function of the whole cutting volume. This total cost was reduced, with the aid of the Tables 1, 2 and 7 of the same publication, to correspond, by cost categories, approximately to the harvesting costs of the present study. Timber harvesting was considered to have been done by outsiders. Thus, for example, the costs of the necessary machines were included in the rates paid.

Incremental cost for silviculture per ha was assumed, for the large forestry model based on each of the silvicultural treatment alternatives of the stands, to be the same as for the small holding in 1967/68. Theoretically, the large forest holding should be able to be managed with lower unit costs than the small. A comparison of the mean costs of approximately similar silvicultural jobs in the private forests of the Lake District of Finland with the corresponding costs in the forests owned by forest industry enterprises and by the National Board of Forestry (Metsänviljelykustannusten toimikunnan mietintö, p. 157, 158) easily leads to an opposite conclusion. Even on the experimental holding, the costs for most jobs were higher than the respective average costs in the private forests of the Lake

District; this, however, was largely a result of the geographical location of the experimental holding.

**Salaried staff costs** as a function of the forest holding policy were determined by assessing the standard and number of the personnel required, and the annual pay for each person, including the social security dues.

The integration of the forest holding in industry made the assessment of the number and standard of personnel on the basis of the experimental holding difficult; a proportion of the personnel worked both in the industry-owned forest and in roundwood fellings from forests owned by someone else. This division of the costs was shown in the enterprise's bookkeeping, although partly based on estimates. For this reason, data on the personnel of the four forest management districts which the National Board of Forestry had in the Lake District of Finland were also used as material, taking into account only the forester and forest technician grades and the clerks. The cost for lower-degree work supervision was contained as shares in the cost of timber harvesting, in incremental cost of silviculture and in the »other overheads», which will be discussed later. Table 1 gives information on four South Finnish forest management districts of the National Board of Forestry, to serve as background for the estimation of the cost of employing administrative personnel. Although the roundwood volumes delivered by the four forest management districts have heavily decreased between 1958 to 1967 (the main trend has been one of decline), the number of officials has fallen much more slowly. This is due, at least partly, to the fact that the officials are civil servants, who are protected by law against dismissal. The present study deals with a normal forest. The problem of adapting officials to the intensity of operations with time is therefore not relevant here. The amount and composition of fellings and silvicultural work are thus static within each alternative. By 1967, the volume of roundwood delivered from the forest management districts, owing to the heavy fellings of the earlier years, had fallen to a relatively low level. Hence the mean for 1958—67, rather than the 1967 figure, indicates the mean annual roundwood felling per forest official.

The organization for the 9 500 ha normal forest was planned on the basis of the statistics of the forest management districts assuming, initially, that 8 000 solid cu.m. excluding bark is felled annually per forester or forest technician. The constraint was made, however, that even if the annual felling volume were less than 24 000 solid cu.m. excluding bark, three forest officials would be required in any case. It was also considered justifiable to diverge from the practice of the said forest management districts of the National Board of Forestry in the relative shares of foresters and forest technicians e.g. on the basis of data obtained from the experimental holding. Thus, it was assumed ultimately, that if annual felling volume (excluding logging waste) was  $\leq 28\ 000$  solid cu.m. excluding bark, the officials on the permanent staff were taken to be one forester, two C 1 wage bracket forest technicians (for wage brackets, see Puunjalostusteollisuuden Työnantajaliitto ry:n ja . . .) and a half-day clerk. The annual total of wages and social security dues would then be Fmk 66 000. A felling volume exceeding

Table 1. Data collected from four forest management districts of the National Board of Forestry in South Finland, on officials, their salaries and travelling expenses, and the fellings by the districts. The amounts in terms of Finnish marks are real values converted into the value of money in felling season 1967/68 (total index for wholesale prices, with 1949 = 100).

*Taulukko 1. Tietoja metsähallinnon neljän eteläsuomalaisen hoitoalueen toimihenkilöstöstä, sen palkka- ja matkakuluista sekä hoitoalueen suoritemääristä. Suomen markkamäärät ovat hakuvuon 1967/68 rahan arvoon muunnettuja reaaliarvoja (tukkuhintojen kokonaisindeksi, 1949 = 100).*

Calendar year Kalenterivuosi	Forest area, ha, involved in economic operations, per forest manage- ment district Talous- toiminnan piirissä ollut metsäala ha, hoitoaluetta kohden	Foresters and techni- cians, number <sup>1)</sup> Metsänhoitajia ja metsäteknikoita, henkilöä <sup>1)</sup>		Roundwood deliveries, solid cu.m. excl. bark <sup>2)</sup> Raakapuun tuovutukset k-m <sup>3</sup> k:ta <sup>2)</sup>		Silvicultural jobs, ha Metsänhoitotyöt, ha		Foresters, forest technicians and clerks Metsänhoitajien, metsäteknikoiden ja konttoristien salaries, incl. soc. sec. travel expenses and day allowances, Fmk palkat sos. maksuineen, matkakorvaukset ja päivärahat, Smk				
		per district hoitoaluetta kohden	per 1 000 ha forest 1 000 metsä-ha:ia kohden	per district hoitoaluetta kohden	per forester & technician metsän- hoitajaa ja metsä- teknikkoa kohden	per district hoitoaluetta kohden	per forester & technician hoitajaa ja metsä- teknikkoa kohden	per forester & technician hoitajaa ja metsä- teknikkoa kohden	per ha delivered tuovutettua k-m <sup>3</sup> :ia kohden	per ha delivered tuovutettua k-m <sup>3</sup> :ia kohden	per ha delivered tuovutettua k-m <sup>3</sup> :ia kohden	per m <sup>3</sup> delivered tuovutettua k-m <sup>3</sup> :ia kohden
		3	4	5	6	7	8	9	10	11	12	
1958 .....	14 505	7.3(3.3)	0.505 (0.229)	71 219	9 723	1 218	166	6.55	1.33	1.50	0.31	
1958—67, mean .....	14 095	6.7(3.0)	0.475 (0.214)	54 178	8 068	1 187	177	8.20	2.13	1.76	0.46	
1967 .....	13 482	5.8(2.5)	0.427 (0.185)	38 454	6 688	1 416	246	10.62	3.72	1.85	0.65	

Source: National Board of Forestry, Calculations and Statistical Office

Lähde: Metsähallituksen laskenta- ja tilastotoimisto

<sup>1)</sup> In addition, throughout the period 1958—67, there was one clerk per forest management district. The period of service of persons employed only for a part of the year was recorded according to the true figures. In brackets, the number of foresters calculated as having served the whole year. Two districts, in the early years of the period, employed a so-called forester trainee, mostly for a part of the year only. If they were excluded, Column 3 figures should read for 1958, 7.0 (3.0), and 1958—67 mean, 6.5 (2.8). — Lisäksi oli koko ajanjakson 1958—67 ajan yksin konttoristi hoitoalueita kohden. Osan vuotta palveluksessa olleiden henkilöiden palvelusaika olettiin vain todellisenä. Sulkeissa on nimenomaan metsänhoitajien kokonaisuus laskettu määrä. Kahdessa hoitoalueessa oli ajanjakson 1958—67 alkupuolella ns. harjoittelija-metsänhoitajia, useimmiten vain osan vuotta. Jos nämä jätettäisiin pois, olisivat sarakkeen 3 luvut v. 1958 7.0 ja (3.0) sekä keskimäärin 1958—67 keskimäärin 6.5 ja (2.8).

<sup>2)</sup> Of the roundwood volumes delivered, the following percentages were sold by delivery sales: 1958, 92 % for the period 1958—67 an average of 95 % and in 1967, 98 %. — Tuovutetusta raakapuunmäärästä oli myyty hankintakaupoin: v. 1958 92 %, v. 1958—67 keskimäärin 95 %, ja v. 1967 98 %.

28 000 solid cu.m. excl. bark would require a clerk working full hours, with the resulting annual additional cost of Fmk 5 200. Furthermore, when the felling volume exceeded 28 000 solid cu.m., one C 1 wage bracket forest technician, involving an annual total of wage and social security dues of Fmk 13 400, would be required for every additional 8 000 solid cu.m. (excl. bark). The payroll of the organization of permanent officials, as is seen, was expected to involve typical, stepwise changing fixed costs.

In the four forest management districts of the National Board of Forestry, the wages of foresters, forest technicians and clerks, including the social security dues, in 1967 (in terms of 1967/68 money) totalled Fmk 143 200 per district. The method used in the present study, assuming the same felling volume level (38 454 solid cu.m. excl. bark), would lead to a cost of Fmk 98 000. The difference is above all due to the fact that the forest management districts of the National Board of Forestry employed more personnel, especially foresters, compared with the felling volumes, than did the experimental forest holding of the present study.

The employees' travelling and daily allowance expenditures consisted of those payable to the forester and forest technicians. They were relatively reliably obtainable even for the experimental holding. Both on the experimental holding and in the four forest management districts of the National Board of Forestry these real expenditures per solid cu.m. delivered, and per ha of forest, increased in 1958—1967 (Table 1).

The volume felled from the experimental forest holding in 1966/67 was 41 500 solid cu.m. excl. bark, and the said expenditure Fmk 0.39/solid cu.m. excl. bark. In one of the four forest management districts, in which the volume delivered in 1967 was only 25 000 solid cu.m. excl. bark, the travelling and daily allowance expenditure was no less than Fmk 0.80/solid cu.m. excl. bark (in terms of 1967/68 money).

When this expenditure was constructed for the 9 500 ha normal forest, the amount of silvicultural work could not be taken into account, in absence of a better material, as a factor increasing the travelling and daily allowance expenditures. The model showing the amount of travelling and daily allowance expenditures as a function of the volume delivered was constructed so that, firstly, it gave a unit expenditure of Fmk 0.58/solid cu.m. excl. bark at the annual removal level of 20 000 solid cu.m. excl. bark. This was 90 % of the mean travelling and daily allowance expenditure (Fmk 0.65) of the four forest management districts in 1967 when the removals were small. Secondly, the formula was to give, at the 1967 removal level of the experimental holding, the true, and reasonable expenditure of Fmk 0.39/solid cu.m. excl. bark. This unit cost, and the removal on which it was based, were also fairly close to the mean 1958—67 figures of the four forest management districts. These requirements are fulfilled by the following linear equation which is suitable for removals of  $\geq 10\,000$  solid cu.m. and indicates the annual amount of travelling and daily allowance expenditure  $C_a$  (in Fmk) for the large forest holding:

$C_a = 9\,500 + 0.21(Q - 10\,000)$ , in which

Q = annual delivery cutting volume (excluding logging waste), solid cu.m. excl. bark.

The equation presupposes, thus, that if Q were  $\leq 10\,000$  (it never was in the present study), 0.21 would be replaced by 0. The fixed part of the travelling and daily allowance expenditures, Fmk 9 500, i.e. Fmk 1/ha, represents the fixed proportion of the minimum activity of the forest holding, that is to say, forest management, administration and protection, and the small-scale delivery contract felling ( $\leq 10\,000$  solid cu.m.). The annual travelling and daily allowance expenditure calculated with this formula must be considered, on the average, small rather than large.

Office expenditures are the running costs of office maintenance. Office premises were assumed to consist of a main office (75 sq.m.) owned by the forest holding, and the office rooms of two forest technicians in houses where the technicians lived and which also were owned by the forest holding. The rents received were assumed to cover the heating and management expenses of these houses. For simplicity, the rent income and these expenses, which cancelled each other, were not included in the calculations. Similarly, the rent income and the heating and management expenditures of the forester's residence were assumed to cancel each other.

For simplicity's sake, office expenditures were assumed to be fixed, and independent of the forest holding policy pursued, although they necessarily contained a minor variable component depending on the amount and type of felling and silvicultural jobs. The annual office expenditures of the large forest holding were estimated as follows:

— management and heating of the main office, and cleaning of all office premises .....	Fmk	7 300
— postage, telephone, telegrams and electricity .....	»	5 300
— purchase and repairs of office machines and equipment, and office requisites, maps, etc. ....	»	2 000
	Total	Fmk 14 600/year

For the determination of the expenditures, supporting data was obtained from the experimental holding, from the mean heating and management expenditures for buildings (Central Office of the Finnish Real Estate Association), etc. However, the postage, telephone, etc. expenses are largely based on an estimate.

When the silvicultural fee was determined, the percentage was assumed to be the same as for the small holding (3.5 %). Since the large forest holding was under continuous care of forestry experts, it was assumed

to be managed with the so-called quartered fee (Act No. 558/1950). The annual silvicultural fee, independent of the forest holding policy applied, was calculated to be Fmk 5 040 per forest holding.

Other running overheads contained the following expenditure components:

1. Cost of maintaining permanent roads
2. Cost of delimiting boundaries, and temporary mapping
3. Cost of equipment maintenance as far as it could not be distributed between roundwood harvesting and silviculture
4. Cost of heating, lighting, repairs and general maintenance of workers' barracks
5. Forest insurance premium
6. Miscellaneous overheads.

When detailed data was not available, the amount of expenditure items 1—4 and 6 was assumed to be fixed. The amounts of items 1—3 and 6 were obtained from the bookkeeping of the experimental holding. The nominal expenditures of 1960—67 were converted into the value of 1967/68 money, and the mean value was calculated (Fmk 11 500/year). The real time series of these expenditures had no discernable trend. The estimate of expenditure item 4 was based on the assumption that the forest holding required 3 transportable 10-man barracks. The annual cost of their heating, lighting etc. was estimated at Fmk 4 500, and their painting, repair etc. at Fmk 1 200 (on the basis of data supplied by Puutalo Oy, timber house manufacturers). Hence the annual total of expenditure items 1—4 and 6 was Fmk 17 200 per forest holding.

The forest insurance was determined, in principle, in the same way as for the small holding. However, a so-called large-area discount of 10 % was made in the premiums, and as far as fire insurance alone was concerned, also a so-called compartment discount of another 10 % (Metsävakuutus-sen . . .). As a result, the forest insurance premium per hectare was 13.4 % lower per unit area than on the small holding; this was valid for all forest holding policy alternatives.

The normal forest model, in principle, has no »room» for expenditures (and revenues) not recurring at equal amounts from one year to the next. For the large holding of the present study, this is a problem as regards the expenditure for purchase of buildings, and for management plans made at 10-year intervals. As to buildings (and to roads and other constructions), a forest holding cannot remain constantly in a static normal state. However, the factor costs of long-term effect can be converted into annual costs formally fitting in the normal forest model, by making them periodical, i.e. by the depreciation method. The annual revenues of a normal forest (before depreciations) are equal, in the same way as every periodically recurring investment outlay is the same from one occasion to the next. In

these conditions, straight-line depreciation of purchase price is identical with realization depreciation according to the principle of cost against income (cf. Saario 1945; Artto 1966; Hautakangas 1966), since the forest rent theory based on a normal forest model starts from the assumption that the forest owner's calculation rate of interest is zero. Depreciations of periodically recurring outlays with long-term effect can hence, in a constantly working normal forest, be made as straight-line depreciations of purchase values, at the value of money at the time of review. — The starting point here was that the forest holding operated exclusively with own capital.

Let us thus assume that the forest rent principle is adopted and the whole profit of the normal forest, after depreciations and taxes (contribution profit  $IV_0$ ) is immediately divided amongst the owners. This being so, the depreciations must be so »invested» that these funds, when required for financing of the periodically recurring investments, can be immediately converted into money. Furthermore, the real rate of interest for these »investments» must be zero.

The bases of the straight-line depreciations of building costs were the following: The total floor area of the main office building and the residential houses of the forester and the two forest technicians was 305 sq.m. and the new acquisition value Fmk 167 800 (Fmk 550/sq.m.). It may be mentioned that the building costs of the owner-occupied houses financed by Arava, the State Housing Board, averaged Fmk 470.25/sq.m. in 1967—68 at the felling year 1967/68 value of money (Statistical Yearbook of Finland 1968, p. 131, and 1969, p. 143). The life span was estimated at 50 years. The purchase value of the three 10-man barracks, including interior equipment, was Fmk 68 400 (information given by Puutalo Oy). The life span was estimated at 20 years. The annual depreciations for the buildings totalled Fmk 6 776 per forest holding.

When the costs of management planning and development were determined, it was assumed that a management plan based on field work was made every tenth year. The fixed cost recurring at 10-year intervals was Fmk 38 000 (Fmk 0.40/ha). The straight-line depreciation was Fmk 3 800/year. Development costs (Fmk 1 400/year) were caused by refresher training of the personnel, temporary use of consultants, and limited experiments for the holding's own requirements. These expenditures of the forest holding totalled Fmk 5 200/year.

When net income per hectare for surface area taxation was calculated, the method was same as for the small holding (Statute No. 352/1968). The amount of the tax was calculated assuming that the forest holding was owned by a private person.

The price of the tax unit in communal taxation was assumed to be Fmk 0.13; the mean value for the rural communes of the Southern half of the country was Fmk 0.129 (Kunnallisverotus . . . 1969). The church tax, accord-

ing to the statistics of several years for the experimental holding, was 1.3 % of the income taxable by the commune, while the national pension, child allowance and health insurance dues were 2.75 % of this income. At the high income level of the large holding, the negligible, so-called general and social reductions, varying according to the person and year involved, were disregarded. The taxable income, therefore, was assumed to be the same as the so-called net revenue for purposes of forest taxation. The State income and property tax was then determined according to the legislation in force (Act No. 613 and 614/1967). It was assumed, that the forest owner belonged to the tax class II. The total obtained for all taxes and national pension and health insurance premiums was Fmk 421 690 per annum, i.e. 84 % of the monetary value of the net revenue for purposes of forest taxation (Statute No. 352/1968).

An individual owner (or owner-family) could also carry out forestry activities on the large forest holding, for example, in a joint-stock company form. In the trade jargon this is often referred to as a »one man» joint-stock company in which a person or a family, practically speaking, totally controls the firm. In such circumstances, the owners should receive their income from the forest holding as dividends. Calculations have also been made on the sum total of taxes paid by this company and its stockholders. This being so, it was assumed that the stockholders represented one single taxpayer (i.e. a family). The company was obliged to pay various income taxes, as mentioned above in conjunction with private ownership. Furthermore, the stockholders were required to pay, besides the income taxes, State property tax. Thus, we can say, that income was taxed two-fold. — With reference to the previous paragraph, the surplus before tax of the forest holding was assumed to be equal to the taxable net revenue for purposes of forest taxation. The tax rate of the company in the State income taxation was 47 % (Act No. 614/1967). The communal and church tax rates and the national pension and health insurance percentages of the taxable income for the company and for the stockholder(s) were also assumed to be the same as for a private forest owner. The partial exemption of the stockholders' dividends from the State income tax was taken into account (Act No. 614/1967 and 364/1968). It was assumed that the stockholder(s) belong to the tax class II. — According to calculations based on the above, the sum of taxes due from the company and from the stockholder(s) would be 99 % of the taxable net revenue for purposes of forest taxation.

## 4. CONTRIBUTION PROFIT ANALYSIS

### 41. Analysis of the small forest holding

The contribution profit analysis for the small forest holding, according to the ownership revenue principle, can be seen from Table 2. The figures in columns 2—4 refer to a 37 ha normal forest policy through which contribution profit III<sub>o</sub> before taxes, and contribution profit IV<sub>o</sub> after taxes, respectively, were highest in the alternatives studied (see Tabular Appendix 1). This policy presupposed slight thinning from below, regeneration by planting, and a rotation of 93 years. Diags. 1 and 2 (see appendices) show that the maximum of the annual contribution profits for a normal forest is obtained with rotations longer than those spanned by the yield series available for the present study. The traditional rotation with the maximum forest rent, therefore, cannot be ascertained. According to K u u s e l a (1968, p. 17—19) for a *Vaccinium* forest site type supporting a normal forest of Scots pine, in Southern Finland, »The rotation of maximum gross annual income is approx. 110 years and of maximum net annual income approx. 113 years». (concerning the basic assumptions of the calculations and the terms used see K u u s e l a 1968, p. 17—19). The same normal forest policy which, among the policies studied, led to the highest contribution profits according to the principle of ownership revenue alone also gave the highest contribution profits when the sum of ownership revenue and work earnings was used as the criterion (Table 3 and Tabular Appendix 1). Tables 2 and 3 contain the numerical values of the contribution profit schedule concerning the policies which, similarly to the best alternative, practise slight thinning from below and regeneration of final cutting stands by planting, but rotations of 69 and 45 years.

The figures of Tables 2 and 3 give an idea of the effect of the length of the rotation on the varying contribution profits for a normal forest, and on their components. Shortening of the rotation produces, in normal forest management, the following, self-evident consequences:

- revenue from delivery sales of roundwood is reduced
- share of logs among delivery sales revenues falls

- share of timber harvesting expenses among delivery sales revenues increases, and the share of stumpage price revenues falls accordingly. The timber harvesting expenses per forest holding actually increase with the shortening of the rotation, until a certain rotation is reached where they again begin to fall slightly
- the relatively high fixed component of the cost of sale, marking and delivery (see H ä m ä l ä i n e n 1973, p. 150) increases the share of these costs among delivery sales revenues
- incremental cost of silviculture increases, in terms of absolute figures and especially also its relative share of the delivery sales revenues. This is particularly the case when regeneration takes place by planting
- the initial diminution of overheads as rotation is shortened is a result of the fairly steep reduction in the forest insurance premium. Delivery sales revenues in relation to the value of the insured growing stock bound to production increase, in turn, until with the adoption of very short rotations the opposite takes place
- the surface area tax is fixed, and therefore its relative share of delivery revenues and especially of contribution profit  $III_0$  b.t. increases.

The increase in delivery sales revenues and various contribution profits as a function of the rotation slows down, depending on the alternative adopted, at the age of 60—65 years. This is mainly because the current absolute value growth increment begins to increase at a slower rate.

The sum of stumpage price revenue and net work earnings from roundwood harvesting before tax, as a part of delivery sales revenues, decreases slightly as the rotation is shortened, since with increasing share of pulpwood the share of the item »expenditures for material production factors in roundwood harvesting» increases. With a shorter rotation, net work earnings from roundwood harvesting, in absolute figures, at first increase and then fall slowly. For example, in the alternative shown in Table 3, with a rotation of 45 years, they still amount to 92.6 % of the corresponding figure for the rotation alternative of 93 years, with the same cutting and silvicultural policy. The corresponding percentage, calculated on the basis of contribution profit  $I_0$ , representing ownership revenue alone, is only 39.7. The shorter the rotation applied, the larger the relative share of work earnings, so much so that work earnings, in absolute figures, may also increase as the rotation is shortened. Shortened rotations least reduce the absolute amount of net revenues obtainable from the forest for forest-owners who harvest the timber themselves (cf. section 3 in Tables 3 and 4). In practice, this shortening of rotation is associated with the cutting of the oldest age classes and thus with the diminution of the existing growing stock.

Table 2. Contribution profit schedule for a 37 ha normal pine forest based on the principle of ownership revenue, and results of the calculations concerning certain alternatives (in terms of the felling season 1967/68 money).  
*Taulukko 2. 37 ha:n mäntynormaalinetsän katetuottokaavio omistustulon periaatteella ja eräiden vaihtoehtojen laskelmien tulokset (hakkuuvuoden 1967/68 rahassa).*

Explanation <i>Setitys</i>	The best alternative 1) ( $u^1 = 93$ yrs) <i>Paras vaihtoehto 1)</i> ( $u^1 = 93$ v.)			The same alternative but $u^1 = 69$ yrs <i>Sama vaihtoehto, mutta</i> $u^1 = 69$ v.			The same alternative but $u^1 = 45$ yrs <i>Sama vaihtoehto, mutta</i> $u^1 = 45$ v.		
	Fmk per forest holding per year <i>Smk metsätöiden kolden/v.</i>	Fmk per ha of forest holding per year <i>Smk metsätöiden ha:ia kohden/v.</i>	% of delivery sale revenue <i>%:na toimitusmyyntitulosta</i>	Fmk per forest holding per year <i>Smk metsätöiden kolden/v.</i>	Fmk per ha of forest holding per year <i>Smk metsätöiden ha:ia kohden/v.</i>	% of delivery sale revenue <i>%:na toimitusmyyntitulosta</i>	Fmk per forest holding per year <i>Smk metsätöiden kolden/v.</i>	Fmk per ha of forest holding per year <i>Smk metsätöiden ha:ia kohden/v.</i>	% of delivery sale revenue <i>%:na toimitusmyyntitulosta</i>
1. Sales revenue from delivery sale of roundwood, total — <i>Myyntituotot raakapuuun toimitusmyynnistä yht.</i> .....	9 150.5	247.3	100.0	7 638.5	206.4	100.0	4 919.2	133.0	100.0
11. Sales revenue from delivery sale of logs — <i>Myyntituotot tukkien toimitusmyynnistä</i> .....	7 327.1	198.0	80.1	4 921.4	133.0	64.4	577.8	15.6	11.7
12. Sales revenue from delivery sale of pulpwood — <i>Myyntituotot paperipuuun toimitusmyynnistä</i> .....	1 823.5	49.3	19.9	2 717.1	73.4	35.6	4 341.4	117.3	88.3
2. Expenditures for harvesting, total — <i>Korjuun kulut yht.</i> .....	2 306.1	62.3	25.2	2 429.6	65.7	31.8	2 147.8	58.0	43.7
21. Expenditure for log harvesting — <i>Korjuun kulut tukeista</i> .....	1 406.1	38.0	15.4	1 143.0	30.9	15.0	150.5	4.1	3.1
22. Expenditure for pulpwood harvesting — <i>Korjuun kulut paperipuusta</i> .....	900.0	24.3	9.8	1 286.6	34.8	16.8	1 997.3	54.0	40.6
3. Stumpage price revenue, total (1—2) — <i>Kantorahatuotot yht. (1—2)</i> .....	6 844.4	185.0	74.8	5 208.9	140.8	68.2	2 771.4	74.9	56.3
31. Stumpage price revenue for logs (11—21) — <i>Kantorahatuotot tukeista (11—21)</i> .....	5 921.0	160.0	64.7	3 778.4	102.1	49.5	427.3	11.5	8.7
32. Stumpage price revenue for pulpwood (12—22) — <i>Kantorahatuotot paperipuusta (12—22)</i> .....	923.5	25.0	10.1	1 430.5	38.7	18.7	2 344.1	63.4	47.7
4. Incremental expenditure for sale, marketing and delivery — <i>Myynnin, leikkauksen ja tuovituksen erilliskulut</i> ..	110.0	3.0	1.2	108.2	2.9	1.4	97.1	2.6	2.0

5. Contribution profit I <sub>0</sub> b. t. <sup>2</sup> (3—4), i.e. the ownership contribution towards supply b. t. — <i>Katetuolto I<sub>0</sub> e. v.<sup>2</sup> (3—4) eli hankinnan omistuskate e. v.</i>	6 734.4	182.0	73.6	5 100.7	137.9	66.8	2 674.3	72.3	54.4
6. Incremental expenditure for silviculture — <i>Metsänhoidon erilliskulut</i> . . . . .	198.5	5.4	2.2	267.6	7.2	3.5	410.3	11.1	8.3
7. Contribution profit II <sub>0</sub> b. t. (5—6), i.e. the ownership contribution towards production and sale b. t. — <i>Katetuolto II<sub>0</sub> e. v. (5—6) eli tuotannon ja myynnin omistuskate e. v.</i> . . . . .	6 535.9	176.6	71.4	4 833.2	130.6	63.3	2 264.0	61.2	46.0
8. Overheads — <i>Yleiskulut</i> . . . . .	327.3	8.8	3.6	245.4	6.6	3.2	182.8	4.9	3.7
9. Contribution profit III <sub>0</sub> b. t. (7—8), i.e. the ownership contribution towards business (forest management unit) b. t. — <i>Katetuolto III<sub>0</sub> e. v. (7—8) eli liikkeen omistuskate e. v.</i> . . . . .	6 208.6	167.8	67.8	4 587.8	124.0	60.1	2 081.2	56.2	42.3
10. Surface area tax — <i>Pinta-alamero</i> . . . . .	292.3	7.9	3.2	292.3	7.9	3.8	292.3	7.9	5.9
11. Contribution profit IV <sub>0</sub> a. t. <sup>2</sup> (9—10), i.e. the ownership contribution towards forest holding a. t. — <i>Katetuolto IV<sub>0</sub> j. v.<sup>2</sup> (9—10) eli metsälön omistuskate j. v.</i> . . . . .	5 916.3	159.9	64.7	4 295.5	116.1	56.2	1 788.9	48.3	36.4

<sup>1</sup>) The alternative is slight thinning from below, rotation (u') 93 years, and regeneration by planting. — *Vaihtoehto on lievä alaharvennus, kiertoaika (u') 93 v. ja uudistaminen istutuksen avulla.*

<sup>2</sup>) b. t. = before tax, a. t. = after tax — *e. v.* = *ennen veroja*, *j. v.* = *verojen (vähentämisen) jälkeen*

Table 3. Contribution profit schedule for a 37 ha normal pine forest based on the principle of the sum of ownership revenue and work earnings, and results of the calculations concerning certain alternatives (in terms of the felling season 1967/68 money).  
Taulukko 3. 37 ha:n mäntynormaalmetsän kateuottokaarvo omistustulon ja työtulon summnan periaatteella ja eräiden vaihtoehtojen tasehlmien tulokset (hakkuuvuoden 1967/68 rahassa).

Explanation <i>Selitys</i>	The best alternative <sup>1)</sup> (u = 93 yrs) <sup>2)</sup> Paras vaihtoehto <sup>1)</sup> (u' = 93 v.)				The same alternative but u' = 69 yrs Sama vaihtoehto, mutta u' = 69 v.				The same alternative but u' = 45 yrs Sama vaihtoehto, mutta u' = 45 v.				
	2	3	4	5	6	7	8	9	10	11	12	13	14
	Fmk per forest holding per year Smk metsäntä kohden/v.	Fmk per ha of forest holding per year Smk metsäntä kohden/v.	% of delivery sale revenue %:na toimitusmyyntitulosta	Fmk per forest holding per year Smk metsäntä kohden/v.	Fmk per ha of forest holding per year Smk metsäntä kohden/v.	% of delivery sale revenue %:na toimitusmyyntitulosta	Fmk per forest holding per year Smk metsäntä kohden/v.	Fmk per ha of forest holding per year Smk metsäntä kohden/v.	% of delivery sale revenue %:na toimitusmyyntitulosta	Fmk per forest holding per year Smk metsäntä kohden/v.	Fmk per ha of forest holding per year Smk metsäntä kohden/v.	% of delivery sale revenue %:na toimitusmyyntitulosta	Fmk per forest holding per year Smk metsäntä kohden/v.
1. Sales revenue from delivery sale of roundwood, total — <i>Myyntitulo raa-kapuan toimitusmyyntistä yht.</i> . . . . .	9 150.5	247.3	100.0	7 638.5	206.4	100.0	4 919.2	133.0	100.0	4 919.2	133.0	100.0	100.0
11. Sales revenue from delivery sale of logs — <i>Myyntitulo tukkien toimitusmyyntistä</i> . . . . .	7 327.1	198.0	80.1	4 921.4	133.0	64.4	577.8	15.6	11.7	577.8	15.6	11.7	11.7
12. Sales revenue from delivery sale of pulpwood — <i>Myyntitulo paperipuu toimitusmyyntistä</i> . . . . .	1 823.5	49.3	19.9	2 717.1	73.4	35.6	4 341.4	117.3	88.3	4 341.4	117.3	88.3	88.3
2. Expenditures for material production factors in roundwood harvesting, total — <i>Aineellisten tuotannon tekijöiden kulu raa-kapuan korjauksessa yht.</i> . . . . .	276.1	7.5	3.0	295.7	8.0	3.9	268.5	7.3	5.5	268.5	7.3	5.5	5.5
21. Expenditures for material production factors in log harvesting — <i>Aineellisten tuotannon tekijöiden kulu tukkien korjauksessa</i> . . . . .	164.0	4.4	1.8	135.0	3.6	1.8	17.8	0.5	0.4	17.8	0.5	0.4	0.4
22. Expenditures for material production factors in pulpwood harvesting — <i>Aineellisten tuotannon tekijöiden kulu paperipuu korjauksessa</i> . . . . .	112.0	3.0	1.2	160.7	4.3	2.1	250.7	6.8	5.1	250.7	6.8	5.1	5.1
3. The sum of stumpage price revenue and net work earnings from roundwood harvesting, b. t. <sup>2)</sup> , total (1—2) — <i>Kantorahatuolon ja puunkorjuun työtulon (c. v.) <sup>2)</sup> summa yht. (1—2)</i> . . . . .	8 874.5	239.9	97.0	7 342.8	198.5	96.1	4 650.7	125.7	94.5	4 650.7	125.7	94.5	94.5
31. The sum of stumpage price revenue and net work earnings from log harvesting (11—21) — <i>Kantorahatuolon ja puunkorjuun työtulon (c. v.) summa tukeista (11—21)</i> . . . . .	7 163.0	193.6	78.3	4 786.4	129.4	62.7	560.0	15.1	11.4	560.0	15.1	11.4	11.4
32. The sum of stumpage price revenue and net work earnings from pulpwood harvesting (12—22) — <i>Kantorahatuolon ja puunkorjuun työtulon (c. v.) summa paperipuuista (12—22)</i> . . . . .	1 711.4	46.3	18.7	2 556.4	69.1	33.5	4 090.7	110.6	83.2	4 090.7	110.6	83.2	83.2

4. Net work earnings from roundwood harvesting, total b. t. — <i>Puunkorjuum työtulonetto yhti. e. v.</i> .....	2 030.0	54.9	22.2	2 133.9	57.7	27.9	1 879.4	50.8	38.2
41. Net work earnings from log harvesting, b. t. — <i>Puunkorjuum työtulonetto tukeista e. v.</i> .....	1 242.1	33.6	13.6	1 008.0	27.2	13.2	132.7	3.6	2.7
42. Net work earnings from pulpwood harvesting, b. t. — <i>Puunkorjuum työtulonetto paperipuusta e. v.</i> .....	787.9	21.3	8.6	1 125.9	30.4	14.7	1 746.6	47.2	35.5
5. Expenditures for sale, marking and delivery — <i>Myyntin, leimauksen ja huovutuksen kulut</i> .....	110.0	3.0	1.2	108.2	2.9	1.4	97.1	2.6	2.0
6. Contribution profit $I_{0+w}$ b. t. (3—5), i.e. the ownership and delivery work contribution towards supply b. t. — <i>Katetuotto <math>I_{0+w}</math> e. v. (3—5) eli hankinnan omistus- ja työkatte e. v.</i> .....	8 764.5	236.9	95.8	7 234.6	195.5	94.7	4 553.6	123.1	92.6
7. Incremental expenditure for silviculture — <i>Metsänhoidon erilliskulut</i> .....	198.5	5.4	2.2	267.6	7.2	3.5	410.3	11.1	8.3
8. Contribution profit $II_{0+w}$ b. t. (6—7), i.e. the ownership and delivery work contribution towards production and sale, b. t. — <i>Katetuotto <math>II_{0+w}</math> e. v. (6—7) eli tuotannon ja myynnin omistus- ja työkatte e. v.</i> .....	8 565.9	231.5	93.6	6 967.0	188.3	91.2	4 143.3	112.0	84.2
9. Overheads — <i>Yleiskulut</i> .....	327.3	8.8	3.6	245.4	6.6	3.2	182.8	4.9	3.7
10. Contribution profit $III_{0+w}$ b. t. (8—9), i.e. the ownership and delivery work contribution towards business (forest management unit) b. t. — <i>Katetuotto <math>III_{0+w}</math> e. v. (8—9) eli liikkeen omistus- ja työkatte</i> .....	8 238.6	222.7	90.0	6 721.7	181.7	88.0	3 960.5	107.0	80.5
11. Surface area tax and work income tax, total — <i>Pinta-ala- ja työtuloverot yhti.</i> .....	448.5	12.1	4.9	458.5	12.4	6.0	446.7	12.1	9.1
111. Surface area tax — <i>Pinta-alamero</i> .....	292.3	7.9	3.2	292.3	7.9	3.8	292.3	7.9	5.9
112. Work income tax — <i>Työtulovero</i> .....	156.2	4.2	1.7	166.2	4.5	2.2	154.4	4.2	3.1
12. Contribution profit $IV_{0+w}$ a. t. <sup>2)</sup> (10—11), i.e. the ownership and delivery work contribution towards forest holding a. t. — <i>Katetuotto <math>IV_{0+w}</math> j. v. <sup>2)</sup> (10—11) eli metsälön omistus- ja työkatte j. v.</i> .....	7 790.1	210.5	85.1	6 263.2	169.3	82.0	3 513.8	95.0	71.4

<sup>1)</sup> The alternative is slight thinning from below, rotation (u') 93 years, and regeneration by planting. — *Vaihtochto on lievä alaharvennus, kierto- aika (u') 93 v. ja uudistaminen istuttaen.*

<sup>2)</sup> b. t. = before tax, a. t. = after tax — *e. v.* = ennen veroja, *j. v.* = verojen jälkeen

Table 4. Contribution profit schedule for a 9 500 ha normal pine forest based on the principle of ownership revenue, and results of the calculations concerning certain alternatives (in terms of the felling season 1967/68 money). For the sake of examples, the alternatives are the same as in Tables 2 and 3.

Taulukko 4. 9 500 ha:n mäntynormaalmetsän katetuottokaavio omistustulon periaatteella ja eräiden vaihtoehtojen laskelmien tulokset (hakkuuvuoden 1967/68 rahassa). Tässä esimerkinomaisesti samat vaihtoehdot kuin taulukoissa 2 ja 3.

Explanation <i>Selitys</i>	Alternative 113 <sup>1)</sup> (u' = 93 yrs) Vaihtoehto 113 <sup>1)</sup> (u' = 93 v.)					The same alternative but u' = 69 yrs Sama vaihtoehto, mutta u' = 69 v.					The same alternative but u' = 45 yrs Sama vaihtoehto, mutta u' = 45 v.				
	Fmk per forest holding per year	Fmk per ha of forest holding per year	% of delivery sale revenue %:na	Fmk per forest holding per year	Fmk per ha of forest holding per year	% of delivery sale revenue %:na	Fmk per forest holding per year	Fmk per ha of forest holding per year	% of delivery sale revenue %:na	Fmk per forest holding per year	Fmk per ha of forest holding per year	% of delivery sale revenue %:na	Fmk per forest holding per year	Fmk per ha of forest holding per year	% of delivery sale revenue %:na
	Smk metsätilä kohden/v.	Smk metsätilän ha:ia kohden/v.	toimitus- myynti- tulosta	Smk metsätilä kohden/v.	Smk metsätilän ha:ia kohden/v.	toimitus- myynti- tulosta	Smk metsätilä kohden/v.	Smk metsätilän ha:ia kohden/v.	toimitus- myynti- tulosta	Smk metsätilä kohden/v.	Smk metsätilän ha:ia kohden/v.	toimitus- myynti- tulosta	Smk metsätilä kohden/v.	Smk metsätilän ha:ia kohden/v.	toimitus- myynti- tulosta
1. Sales revenue from delivery sale of roundwood, total — <i>Myyntituotot raakapuu toimitusmyynnistä yht.</i> . . . . .	2 374 127	249.9	100.0	1 982 597	208.7	100.0	1 278 453	134.6	100.0	1 278 453	134.6	100.0	1 278 453	134.6	100.0
11. Sales revenue from delivery sale of logs — <i>Myyntituotot tukkien toimitusmyynnistä</i> . . . . .	1 900 089	200.0	80.0	1 276 232	134.3	64.4	149 831	15.8	11.7	149 831	15.8	11.7	149 831	15.8	11.7
12. Sales revenue from delivery sale of pulpwood — <i>Myyntituotot paperipuun toimitusmyynnistä</i> . . . . .	474 039	49.9	20.0	706 365	74.4	35.6	1 128 621	118.8	88.3	1 128 621	118.8	88.3	1 128 621	118.8	88.3
2. Expenditures for harvesting, total — <i>Korjuun kulut yht.</i> . . . . .	501 702	52.8	21.1	534 657	56.3	27.0	488 099	51.4	38.2	488 099	51.4	38.2	488 099	51.4	38.2
21. Expenditures for harvesting the logs — <i>Korjuun kulut tukeista</i> . . . . .	296 045	31.2	12.5	240 643	25.3	12.1	31 679	3.3	2.5	31 679	3.3	2.5	31 679	3.3	2.5
22. Expenditures for harvesting the pulpwood — <i>Korjuun kulut paperipuusta</i> . . . . .	205 657	21.6	8.7	294 013	30.9	14.8	456 420	48.0	35.7	456 420	48.0	35.7	456 420	48.0	35.7
3. Stumpage price revenue, total (1—2) — <i>Kantorahatuotot yht. (1—2)</i> . . . . .	1 872 426	197.1	78.9	1 447 940	152.4	73.0	790 354	83.2	61.8	790 354	83.2	61.8	790 354	83.2	61.8
31. Stumpage price revenue for logs (11—21) — <i>Kantorahatuotot tukeista (11—21)</i> . . . . .	1 604 043	168.8	67.6	1 035 589	109.0	52.2	118 152	12.4	9.2	118 152	12.4	9.2	118 152	12.4	9.2
32. Stumpage price revenue for pulpwood (12—22) — <i>Kantorahatuotot paperipuusta (12—22)</i> . . . . .	268 382	28.2	11.3	412 351	43.4	20.8	672 202	70.8	52.6	672 202	70.8	52.6	672 202	70.8	52.6
4. Incremental expenditure for silviculture — <i>Metsänhoidon erilliskulut</i> . . . . .	50 973	5.4	2.1	68 703	7.2	3.5	105 344	11.1	8.2	105 344	11.1	8.2	105 344	11.1	8.2

5. Contribution profit A (3—4) — <i>Kate- tuotto A (3—4)</i> .....	1 821 453	191.7	76.7	1 379 238	145.2	69.6	685 009	72.1	53.6
6. Running overheads — <i>Juoksevat yleis- kulut</i> .....	213 194	22.4	9.0	194 819	20.5	9.8	165 907	17.5	13.0
61. Salaries of the employees, incl. social security dues — <i>Toimihenkilöiden palkat sos.kuluneen</i> .....	111 400	11.7	4.7	111 400	11.7	5.6	98 000	10.3	7.7
62. Travelling expenses and daily allowances of the employees — <i>Toimihenkilöiden matkakustannukset ja päivärahat</i> .....	17 096	1.8	0.7	16 950	1.8	0.9	15 345	1.6	1.2
63. Office expenditures — <i>Toimistokulut</i> .....	14 600	1.5	0.6	14 600	1.5	0.7	14 600	1.5	1.1
64. Silvicultural fee (1/4) — <i>Metsänhoitomaksu (1/4)</i> .....	5 040	0.5	0.2	5 040	0.5	0.3	5 040	0.5	0.4
65. Other running overheads — <i>Muut juoksevat yleiskulut</i> .....	65 058	6.8	2.7	46 829	4.9	2.4	32 923	3.5	2.6
7. Contribution profit B (5—6) — <i>Kate- tuotto B (5—6)</i> .....	1 608 258	169.3	67.7	1 184 418	124.7	59.7	519 102	54.6	40.6
8. Depreciations of factor costs of long- term effect — <i>Pitkävaikutteisten menojen poistot</i> .....	11 975	1.3	0.5	11 975	1.3	0.6	11 975	1.3	0.9
81. Buildings — <i>Rakennukset</i> .....	6 776	0.7	0.3	6 776	0.7	0.3	6 776	0.7	0.5
82. Management plan, development and training — <i>Taloussuunnitelma, kehitys ja koulutus</i> .....	5 199	0.5	0.2	5 199	0.5	0.3	5 199	0.5	0.4
9. Contribution profit III, b. t. (7—8), i.e. the ownership contribution towards business (forest management unit) — <i>Katetuotto III, o. v. (7—8) eli liikkeen omistuskate</i> .....	1 596 283	168.0	67.2	1 172 443	123.4	59.1	507 127	53.4	39.7
10. Surface area tax — <i>Pinta-alavero</i> .....	421 690	44.4	17.8	421 690	44.4	21.3	421 690	44.4	33.0
11. Contribution profit IV, a. t. (9—10), i.e. the ownership contribution towards forest holding — <i>Katetuotto IV, j. v. (9—10) eli metsälön omistuskate</i> .....	1 174 593	123.6	49.5	750 753	79.0	37.9	85 437	9.0	6.7

1) See appendix-p. 1. The second best alternative (same as in tables 2 and 3). — *Ks. liitteen 1. sivua. Tämä on nyt toiseksi paras vaihtoehto (sama vaihtoehto kuin taulukoissa 2 ja 3).*

The following regularities are among those found in the cutting and silvicultural policies of the normal forest on the basis of Tabular Appendix 1. When different rotations are used, thinning from below is the best alternative. This is natural since the model of the forest rent theory eliminates time and rate of interest factor. By thinnings from below, the value increment/ha/year of the normal forest can be made the highest possible. When rotation is prolonged, the thinning from above alternatives lag relatively more and more behind the thinning from below alternatives. The primary reason is the smaller stem size due to the thinning from above having started at a relatively early age of stand development (cf. Vuokila 1970, p. 25), although heavy thinnings from below also have a similar impact.

It should be pointed out that the numerical values and other facts presented for the mutual profitability of various cutting and silvicultural alternatives and for its components are applicable only insofar as the presumptions imposed by the forest rent theory are approximately fulfilled.

#### 42. Analysis of the large forest holding and its comparison with the small holding

On the large forest holding, sales revenues from delivery sales per hectare are higher than on the small holding in every policy alternative, owing to the higher delivery prices associated with large sales volumes. Since the unit costs of timber harvesting are also smaller, the stumpage price revenue per hectare is higher than in the corresponding cutting and silvicultural alternatives of the small forest holding. When rotation is shortened the relative difference still increases. Stumpage price revenue/ha, according to Tables 2—4, is on the large holding 6.5 % higher when rotation is 93 years, but no less than 11.1 % higher when rotation is 45 years. The explanation is that when rotation is shortened, the relative share of pulpwood in the cutting volume increases. On the other hand, with pulpwood the addition for large volume and storage of delivered timber is relatively higher than with logs. Furthermore, the more rational timber harvesting methods of the large forest holding become most effective when »pulpwood rotations» are used, since timber harvesting cost per cu.m. is higher for pulpwood than logs.

The following table shows the sum of the incremental expenditure for silviculture and various overheads on the small and the large forest holding with the normal forest policies of Tables 2—4.

Policy <i>Vaihtoehto</i>	Small holding <i>Pieni metsä</i>		Large holding <i>Suuri metsä</i>	
	Cost Fmk/ha <i>Kustannukset</i> Smk/ha	Cost as % of delivery sales revenue <i>Kustannukset</i> %:na <i>toimitus-</i> <i>myynti-</i> <i>tuotoista</i>	Cost Fmk/ha <i>Kustannukset</i> Smk/ha	Cost as % of delivery sales revenue <i>Kustannukset</i> %:na <i>toimitus-</i> <i>myynti-</i> <i>tuotoista</i>
Slight thinning from below, planting <i>Lievä alaharvennus, istutus</i>				
rotation 93 years — kiertoaika 93 v. . . . .	17.2	7.0	29.1	11.6
» 69 » » 69 » . . . . .	16.7	8.1	29.0	13.9
» 45 » » 45 » . . . . .	18.6	14.0	29.0	21.5

On the large holding, overheads are increased especially by the permanently employed personnel, office and building costs, and the quartered silvicultural fee, which is payable as a tax and which buys no services for the forest holding. On the small forest holding, no separate office space was foreseen and forestry experts are employed only if required, by buying their services. On the large forest holding, therefore, with the cutting and silvicultural alternatives assumed above, the contribution profit  $III_0$  per ha, as a percentage of the corresponding figure for the small holding, is with the different rotations as follows: 93 years 100.1 %, 69 years 99.5 %, and 45 years 95.0 %. Tabular Appendix 2 shows that contribution profit  $III_0$ /ha with the »ordinary» 70—95 years rotation is usually approximately the same for the small and large forest holding. When the rotation is heavily shortened the contribution profit  $III_0$  of the large forest holding becomes definitely less advantageous, due to the high fixed costs. It is evident that the above comparisons of business-economics profitability are bound to the values of the revenue and expenditure components underlying the calculations. It is a fact, however, that in the forest management districts of the National Board of Forestry shown in Table 1 the true cost of personnel, for example, was considerably higher than that assumed for the large forest holding of the present study. On the other hand, the costs of the large forest holding contain several estimated items, although of relatively small importance. The costs assumed here for the small forest holding (in particular the overheads) are, when compared to the true mean values, probably slightly underestimated rather than overestimated. In any case, the contribution profit schedules for the large forest holding provide an idea of the expenditure items which burden the economy, for example, of the »small» forest management districts of the National Board of Forestry (in South Finland, 10 000—30 000 ha). These expenditures reduce the profitability of »large-scale forestry» carried on in units which are too small and fragmented.

Tabular Appendix 2 reveals that on the privately owned large forest holding, the contribution profit  $IV_0$  a.t., with the least advantageous alterna-

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tive, becomes negative. This is a result of the Finnish forest taxation system which disregards the actual revenue per forest holding. For this very reason, the smaller the absolute cutting revenues for the policy alternatives are, the less advantageous in relative terms, are the compared alternatives, if the criterion used is contribution profit  $IV_0$  a.t. rather than contribution profit  $III_0$  b.t.

## APPENDICES — LIITTEET

Explanations of the symbols in Tabular Appendices 1 and 2 (Column »Alternative»)  
*Liitetaulukkojen 1 ja 2 sarakkeen »vaihtoehto» merkintöjen selityksiä:*

1st code number <i>1. koodinnumero</i>		2nd code number <i>2. koodinnumero</i>		3rd code number <i>3. koodinnumero</i>	
= thinning method = <i>harvennusmenetelmä</i>		= thinning intensity = <i>harvennuksen voimakkuus</i>		= regeneration method = <i>uudistusmenetelmä</i>	
Code no. <i>Koodinnumero</i>	Meaning <i>Merkitys</i>	Code no. <i>Koodinnumero</i>	Meaning <i>Merkitys</i>	Code no. <i>Koodinnumero</i>	Meaning <i>Merkitys</i>
1	Thinning from below <i>Alaharvennus</i>	1	Slight <i>Lievä</i>	1	Seed tree method <i>Siemenpuumenetelmä</i>
2	Thinning from above, slight selection cutting <i>Yläharvennus, yläharvennusmomentti lievä</i>	2	Medium <i>Keskivahva</i>	2	Seeding <i>Kylvö</i>
3	Thinning from above, heavy selection cutting <i>Yläharvennus, yläharvennusmomentti voimakkaampi</i>	3	Heavy <i>Voimakas</i>	3	Planting <i>Istutus</i>
		4	Slight/medium <i>Lievä/keskivahva</i>	4	Shelterwood and border stand regeneration <i>Uudistaminen pääly- ja reunametsän avulla</i>
		5	Radical <i>Radikaali</i>		

— In column »Alternative», the first of the two-digit figure pairs (e.g. Tabular Appendix 1, line 1: 95 and 93) refers to the age of maturity of the normal forest (the age of final cutting of the stand according to the yield tables), and the latter to the rotation, i.e. the interval between two final cuttings (for details, see H ä m ä l ä i n e n 1973, p. 103). — *Sarakkeen »vaihtoehto» kaksinumeroisista lukupareista (esim. liitetaulukon 1 ensimmäisellä rivillä: 95 ja 93) edellinen tarkoittaa normaalimetsän puuston kypsyyssikää (tuotostaulukoiden mukaista metsikön päätehakkuvuikää) ja jälkimmäinen kiertoaikaa eli päätehakkuiden välistä aikaa (ks. lähemmin H ä m ä l ä i n e n 1973, s. 103).*

— The absolute values (Fmk/ha/year) of the contribution profits of the alternatives in Tabular Appendices 1 and 2 are obtained by multiplying the relative values of the tables by the following figures. — *Liitetaulukoiden 1 ja 2 vaihtoehtojen katetuottojen absoluuttiset arvot (mk/ha/vuosi) saadaan kertomalla taulukoista näkyvät suhteelliset arvot seuraavilla luvuilla:*

Tabular Appendix <i>Liitetaulukko</i>	Contribution profit $III_0/ha$ <i>Katetuotto III<sub>0</sub>/ha</i>	Contribution profit $III_{0+w}/ha$ <i>Katetuotto III<sub>0+w</sub>/ha</i>	Contribution profit $IV_0/ha$ <i>Katetuotto IV<sub>0</sub>/ha</i>	Contribution profit $IV_{0+w}/ha$ <i>Katetuotto IV<sub>0+w</sub>/ha</i>
1	2	3	4	5
1 .....	1.6780	2.2266	1.5990	2.1054
2 .....	1.6901	..	1.2462	..

Tabular appendix 1. Profitability ranking of the alternative policies for the 37 ha normal pine forest, and the relative values of the profitability criteria (contribution profits).

*Lisätaulukko 1. 37 ha:n mäntynormaalinetsän vaihtoehtoisten politiikkajärjestys ja edullisuuskriteerien (katetuottojen) suhteelliset arvot.*

Principle of ownership revenue <i>Omistustulon periaate</i>		Principle of ownership revenue <i>Omistustulon periaate</i>		Principle of ownership revenue <i>Omistustulon periaate</i>		Principle of ownership revenue <i>Omistustulon periaate</i>											
Profitability ranking <i>Edullisuusjärjestys</i>	Alternative <i>Vaihtoehto</i>	Relative value of criteria, by alternatives <i>Kriteerien suhteellinen arvo vaihtoehtoihin</i>		Relative value of criteria, by alternatives <i>Kriteerien suhteellinen arvo vaihtoehtoihin</i>		Relative value of criteria, by alternatives <i>Kriteerien suhteellinen arvo vaihtoehtoihin</i>		Relative value of criteria, by alternatives <i>Kriteerien suhteellinen arvo vaihtoehtoihin</i>									
		III <sub>0</sub>	IV <sub>0</sub>	III <sub>0</sub>	IV <sub>0</sub>	III <sub>0</sub>	IV <sub>0</sub>	III <sub>0</sub>	IV <sub>0</sub>								
		Profitability ranking <i>Edullisuusjärjestys</i>		Profitability ranking <i>Edullisuusjärjestys</i>		Profitability ranking <i>Edullisuusjärjestys</i>		Profitability ranking <i>Edullisuusjärjestys</i>									
		Alternative <i>Vaihtoehto</i>		Alternative <i>Vaihtoehto</i>		Alternative <i>Vaihtoehto</i>		Alternative <i>Vaihtoehto</i>									
		III <sub>0</sub>	IV <sub>0</sub>	III <sub>0</sub>	IV <sub>0</sub>	III <sub>0</sub>	IV <sub>0</sub>	III <sub>0</sub>	IV <sub>0</sub>								
1	1	113	95	93	100.00	100.00	24	141	83	79	84.47	83.71	123	95	93	87.50	87.00
2	2	153	93	91	99.52	98.54	25	243	95	93	84.10	83.32	221	95	90	87.38	86.79
3	3	112	95	95	98.59	98.37	26	321	95	90	83.93	83.13	343	89	87	86.62	85.83
4	4	152	93	93	98.09	96.91	27	343	95	93	83.92	83.12	242	95	95	86.60	85.89
5	5	154	93	96	95.65	95.44	28	113	89	87	83.42	82.60	113	77	75	86.59	85.68
6	6	114	95	99	95.39	95.16	29	124	95	99	83.30	82.47	321	95	90	86.58	85.93
7	7	141	95	90	93.54	93.23	30	242	95	95	83.03	82.19	243	89	87	86.47	85.67
8	8	113	89	87	92.31	91.93	31	342	95	95	82.85	82.00	342	95	95	86.45	85.73
9	9	143	95	93	91.86	91.46	32	123	88	86	82.34	81.47	143	83	81	86.22	85.39
10	10	112	89	89	90.97	90.53	33	343	89	87	81.91	81.02	122	95	95	86.18	85.64
11	11	142	95	95	90.62	90.16	34	243	89	87	81.62	80.71	341	83	79	85.80	84.87
12	12	241	95	90	89.84	89.34	35	114	83	88	81.62	80.71	241	83	79	85.65	84.73
13	13	121	95	90	89.00	88.45	36	122	88	88	81.22	80.30	144	89	93	85.42	84.74
14	14	341	95	90	88.91	88.36	37	143	83	81	81.04	80.10	342	89	89	85.23	84.41
15	15	114	89	93	87.89	87.29	38	342	89	89	80.81	79.87	242	89	89	85.09	84.25
16	16	144	95	99	87.74	87.14	39	242	89	89	80.53	79.56	114	83	88	85.07	84.31
17	17	143	89	87	87.53	86.91	40	244	95	99	80.45	79.49	112	77	77	84.99	84.04
18	18	123	95	93	87.18	86.55	41	344	95	99	80.28	79.31	343	83	81	84.85	83.89
19	19	113	83	81	86.93	86.29	42	223	95	93	80.00	79.01	142	83	83	84.74	83.88
20	20	142	89	89	86.30	85.62	43	113	77	75	79.98	78.99	243	83	81	84.38	83.35
21	21	122	95	95	86.04	85.35	44	142	83	83	79.88	78.89	123	88	86	84.22	83.50
22	22	112	83	83	85.63	84.92	45	241	83	79	79.80	78.80	244	95	99	83.69	82.89
23	23	221	95	90	85.54	84.83	46	341	83	79	79.61	78.60	344	95	99	83.55	82.74

1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
47	323 95 93	79.56	78.55	47	342 83 83	83.41	82.41	89	231 89 83	72.59	71.24	89	343 71 69	77.35	75.92
48	121 81 77	79.36	78.34	48	124 95 99	83.25	82.61	90	154 73 77	72.40	71.04	90	142 71 71	77.23	75.86
49	222 95 95	79.01	77.97	49	153 73 71	83.18	82.09	91	222 81 81	71.27	70.90	91	322 81 81	77.21	76.01
50	112 77 77	78.76	77.71	50	242 83 83	82.94	81.88	92	322 81 81	71.77	70.38	92	144 77 82	76.98	75.77
51	322 95 95	78.58	77.52	51	223 95 93	82.93	82.12	93	144 77 82	71.51	70.10	93	222 81 81	76.87	75.72
52	343 83 81	78.55	77.49	52	122 88 88	82.88	82.11	94	133 89 87	71.48	70.07	94	324 88 92	76.82	75.74
53	124 88 92	78.48	77.42	53	143 77 75	82.75	81.70	95	331 89 83	71.19	69.76	95	224 88 92	76.61	75.52
54	344 89 93	78.17	77.09	54	121 81 77	82.70	81.82	96	132 89 89	70.62	69.16	96	344 77 82	76.20	74.90
55	244 89 93	77.90	76.80	55	323 95 93	82.65	81.82	97	124 81 86	70.58	69.13	97	242 71 71	76.08	74.63
56	342 83 83	77.45	76.34	56	344 89 93	82.16	81.28	98	143 71 69	70.27	68.80	98	244 77 82	75.93	74.59
57	243 83 81	77.42	76.31	57	244 89 93	82.06	81.13	99	144 77 82	69.90	68.42	99	342 71 71	75.88	74.42
58	323 88 86	76.90	75.76	58	343 77 75	81.89	80.74	100	244 77 82	69.28	67.76	100	131 81 76	75.57	74.45
59	131 89 83	76.80	75.65	59	222 95 95	81.70	80.87	101	123 74 72	69.26	67.74	101	123 74 72	75.26	73.95
60	153 73 71	76.78	75.63	60	243 77 75	81.60	80.40	102	142 71 71	69.22	67.70	102	231 89 83	75.19	73.95
61	223 88 86	76.58	75.42	61	113 71 69	81.59	80.40	103	134 89 92	69.07	67.54	103	113 65 63	74.75	73.20
62	224 95 99	76.55	75.39	62	152 73 73	81.58	80.46	104	224 81 86	68.89	67.35	104	331 89 83	74.59	73.41
63	242 83 83	76.36	75.19	63	322 95 95	81.43	80.58	105	243 71 69	68.64	67.09	105	223 74 72	74.55	73.14
64	143 77 75	76.30	75.13	64	142 77 77	81.24	80.16	106	243 71 69	68.60	67.04	106	223 74 72	74.49	73.07
65	144 83 88	76.19	75.02	65	323 88 86	80.96	80.01	107	324 81 86	68.42	66.86	107	114 71 77	74.47	73.09
66	324 95 99	76.14	74.96	66	223 88 86	80.74	79.76	108	122 74 74	68.28	66.71	108	124 81 86	74.40	73.21
67	322 88 88	75.90	74.71	67	144 83 88	80.57	79.58	109	114 71 77	68.02	66.44	109	122 74 74	73.90	72.56
68	222 88 88	75.59	74.38	68	114 77 82	80.50	79.41	110	242 71 71	67.64	66.04	110	143 65 63	73.80	72.18
69	152 73 73	75.58	74.37	69	342 77 77	80.41	79.23	111	342 71 71	67.59	65.99	111	324 81 86	73.34	72.03
70	142 77 77	75.17	73.95	70	242 77 77	80.12	78.90	112	223 74 72	67.54	65.93	112	133 89 87	73.30	72.17
71	123 81 79	75.11	73.88	71	112 71 71	79.99	78.77	113	223 74 72	67.34	65.73	113	112 65 65	73.22	71.64
72	114 77 82	74.88	73.64	72	124 88 92	79.87	79.01	114	233 89 87	67.17	65.55	114	322 74 74	73.21	71.77
73	343 77 75	74.55	73.29	73	123 81 79	79.70	78.65	115	231 81 76	67.07	65.44	115	222 74 74	73.15	71.71
74	122 81 81	74.07	72.79	74	322 88 88	79.69	78.70	116	331 81 76	67.02	65.39	116	224 81 86	73.02	71.75
75	344 83 88	73.90	72.61	75	222 88 88	79.47	78.46	117	133 81 79	66.67	65.02	117	142 65 65	72.29	70.65
76	113 71 69	73.89	72.60	76	344 83 88	79.31	78.19	118	322 74 74	66.60	64.95	118	243 65 63	72.24	70.51
77	243 77 75	73.86	72.57	77	224 95 99	78.95	78.03	119	222 74 74	66.41	64.75	119	343 65 63	72.23	70.51
78	342 77 77	73.47	72.16	78	244 83 88	78.88	77.70	120	232 89 89	66.40	64.74	120	132 89 89	72.21	71.05
79	324 88 92	73.39	72.07	79	143 71 69	78.75	77.40	121	132 81 81	65.84	64.15	121	144 71 77	71.92	70.41
80	221 81 79	73.27	71.95	80	324 95 99	78.69	77.75	122	333 89 87	65.82	64.13	122	331 81 76	71.46	70.09
81	223 81 79	73.26	71.94	81	323 81 79	78.53	77.36	123	113 65 63	65.68	63.96	123	231 81 76	71.46	70.09
82	224 88 92	73.09	71.76	82	221 81 77	78.42	77.29	124	332 89 89	65.08	63.38	124	244 71 77	70.87	69.27
83	244 83 88	72.87	71.53	83	122 81 81	78.34	77.26	125	234 89 92	64.99	63.26	125	242 65 65	70.79	69.04
84	242 77 77	72.80	71.46	84	321 81 77	78.33	77.15	126	144 74 79	64.85	63.11	126	342 65 65	70.77	69.04
85	323 81 79	72.75	71.41	85	131 89 83	78.24	77.12	127	144 71 77	64.77	63.03	127	344 71 77	70.68	69.08
86	112 71 71	72.74	71.40	86	223 81 79	78.19	77.06	128	112 65 65	64.67	62.93	128	233 89 87	70.54	69.22
87	131 81 76	72.66	71.30	87	154 73 77	77.91	76.69	129	143 65 63	64.13	62.35	129	134 89 92	70.42	69.22
88	321 81 77	72.63	71.28	88	243 71 69	77.57	76.14	130	334 89 92	63.71	61.92	130	123 67 65	70.38	68.72

Tabular appendix I (cont.) — *Liiitetaulukko I (jatkoa)*

	Principle of ownership revenue <i>Omistustulon periaate</i>				Principle of the sum of ownership revenue and work earnings <i>Omistustulon ja työtulon summalla periaate</i>				Principle of ownership revenue <i>Omistustulon periaate</i>				Principle of the sum of ownership revenue and work earnings <i>Omistustulon ja työtulon summalla periaate</i>							
	Profit-ability ranking <i>Edullisuusjärjestys</i>	Alternative <i>Vaihtoehto</i>	Relative value of criteria, by alternatives <i>Kriteerien suhteellinen arvo vaihtoehtoihin</i>		Profit-ability ranking <i>Edullisuusjärjestys</i>	Alternative <i>Vaihtoehto</i>	Relative value of criteria, by alternatives <i>Kriteerien suhteellinen arvo vaihtoehtoihin</i>		Profit-ability ranking <i>Edullisuusjärjestys</i>	Alternative <i>Vaihtoehto</i>	Relative value of criteria, by alternatives <i>Kriteerien suhteellinen arvo vaihtoehtoihin</i>		Profit-ability ranking <i>Edullisuusjärjestys</i>	Alternative <i>Vaihtoehto</i>	Relative value of criteria, by alternatives <i>Kriteerien suhteellinen arvo vaihtoehtoihin</i>					
			III <sub>0</sub>	IV <sub>0</sub>			III <sub>0+1</sub>	IV <sub>0+1</sub>			III <sub>0</sub>	IV <sub>0</sub>			III <sub>0+1</sub>	IV <sub>0+1</sub>	III <sub>0</sub>	IV <sub>0</sub>	III <sub>0+1</sub>	IV <sub>0+1</sub>
			Contribution profit <i>Katetuotto</i>				Contribution profit <i>Katetuotto</i>				Contribution profit <i>Katetuotto</i>				Contribution profit <i>Katetuotto</i>		Contribution profit <i>Katetuotto</i>		Contribution profit <i>Katetuotto</i>	
1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8					
131	233 81 79	63.57	61.77	131	133 81 79	70.17	68.81	157	144 65 71	58.86	56.82	157	112 59 59	65.66	63.62					
132	134 81 85	63.53	61.73	132	124 74 79	69.89	68.44	158	232 73 73	58.56	56.51	158	243 59 57	65.64	63.47					
133	244 71 77	63.31	61.50	133	333 89 87	69.65	68.26	159	333 73 71	58.34	56.28	159	244 65 71	65.58	63.70					
134	324 74 79	63.28	61.46	134	232 89 89	69.52	68.17	160	121 67 64	58.31	56.25	160	344 65 71	65.56	63.70					
135	344 71 77	63.27	61.46	135	223 67 65	69.28	67.55	161	141 65 62	57.69	55.60	161	343 59 57	65.44	63.26					
136	142 65 65	63.17	61.35	136	324 74 79	69.24	67.70	162	332 73 73	57.64	55.55	162	233 73 71	65.31	63.61					
137	224 74 79	63.10	61.28	137	224 74 79	69.19	67.64	163	124 67 73	57.22	55.11	163	142 59 59	65.24	63.13					
138	232 81 81	62.82	60.98	138	323 67 65	69.09	67.37	164	344 65 71	57.15	55.04	164	121 67 64	65.20	63.43					
139	333 81 79	62.66	60.81	139	132 81 81	69.05	67.67	165	134 73 77	57.04	54.92	165	333 73 71	65.18	63.39					
140	343 65 63	62.21	60.34	140	122 67 67	69.02	67.35	166	244 65 71	56.98	54.85	166	132 73 73	64.98	63.28					
141	123 67 63	62.20	60.33	141	332 89 89	68.64	67.23	167	234 73 77	56.39	54.24	167	234 81 85	64.74	63.14					
142	243 65 63	62.01	60.13	142	233 81 79	68.39	66.88	168	224 67 73	55.94	53.76	168	242 59 59	64.26	62.09					
143	332 81 81	61.93	60.04	143	222 67 67	67.95	66.42	169	324 67 73	55.84	53.66	169	232 73 73	64.21	62.48					
144	122 67 67	61.33	59.42	144	234 89 92	67.82	66.21	170	334 73 77	55.52	53.32	170	334 81 85	64.10	62.47					
145	342 65 65	61.31	59.40	145	114 65 71	67.80	66.09	171	113 59 57	55.24	53.03	171	332 73 73	64.07	62.27					
146	242 65 65	61.12	59.19	146	322 67 67	67.77	66.03	172	112 59 59	54.49	52.24	172	342 59 59	64.06	61.88					
147	223 67 65	60.76	58.82	147	333 81 79	67.70	66.15	173	143 59 57	54.15	51.88	173	124 67 73	64.05	62.24					
148	234 81 85	60.65	58.71	148	232 81 81	67.31	65.78	174	321 67 64	54.03	51.76	174	123 60 58	63.46	61.44					
149	323 67 65	60.65	58.70	149	113 59 57	67.09	65.06	175	123 60 58	53.81	51.53	175	224 67 73	63.07	61.20					
150	114 65 71	60.23	58.27	150	334 89 92	66.97	65.52	176	142 59 59	53.43	51.13	176	324 67 73	62.91	61.04					
151	133 73 71	59.98	58.01	151	144 65 71	66.96	65.18	177	221 67 64	53.42	51.12	177	223 60 58	62.59	60.51					
152	222 67 67	59.93	57.96	152	143 59 57	66.65	64.56	178	133 65 63	53.35	51.05	178	241 65 62	62.59	60.52					
153	322 67 67	59.82	57.84	153	332 81 81	66.64	65.08	179	233 65 63	53.24	50.93	179	323 60 58	62.51	60.34					
154	334 81 85	59.80	57.82	154	134 81 85	66.40	64.94	180	333 65 63	53.23	50.92	180	321 67 64	62.41	60.44					
155	233 73 71	59.28	57.27	155	141 65 62	66.19	64.34	181	132 60 60	53.12	50.80	181	134 73 77	62.26	60.49					
156	132 73 73	59.25	57.23	156	133 73 71	66.10	64.42	182	241 65 62	52.89	50.56	182	122 60 60	62.17	60.14					

	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8					
183	243	59	57	52.88	50.55	221	67	64	62.01	60.00	217	112	53	53	44.02	41.26	217	231	65	61	55.87
184	132	65	65	52.73	50.39	234	73	77	61.53	59.74	218	143	53	51	43.63	40.85	218	133	57	55	55.52
185	343	59	57	52.69	50.36	185	133	65	63	61.52	219	243	53	51	43.40	40.63	219	233	57	55	55.28
186	232	65	65	52.62	50.28	186	341	65	62	61.44	220	142	53	53	43.23	40.43	220	333	57	55	55.25
187	332	65	65	52.61	50.27	187	334	73	77	61.40	221	242	53	53	43.01	40.20	221	123	53	51	54.95
188	223	60	58	52.57	50.23	188	222	60	60	61.34	222	343	53	51	42.86	40.04	222	132	57	57	54.44
189	242	59	59	52.21	49.85	189	233	65	63	61.33	223	154	53	59	42.66	39.83	223	223	53	51	54.43
190	342	59	59	52.03	49.66	190	322	60	60	61.25	224	123	53	51	42.61	39.78	224	323	53	51	54.40
191	232	60	60	51.92	49.54	191	333	65	63	61.25	225	342	53	53	42.49	39.64	225	232	57	57	54.32
192	131	65	61	51.91	49.53	192	114	59	65	60.44	226	134	57	63	42.25	39.40	226	332	57	57	54.18
193	323	60	58	51.40	49.00	193	132	65	65	60.39	227	122	53	53	42.25	39.40	227	122	53	53	53.81
194	341	65	62	51.18	48.77	194	232	65	65	60.21	228	234	57	63	41.98	39.11	228	222	53	53	53.31
195	322	60	60	50.79	48.35	195	332	65	65	60.13	229	334	57	63	41.98	39.11	229	322	53	53	53.29
196	114	59	65	50.58	48.13	196	144	59	65	60.06	230	323	53	51	41.87	39.00	230	154	53	59	50.58
197	134	65	70	49.89	47.41	197	153	53	51	59.61	231	223	53	51	41.85	38.98	231	114	53	59	51.77
198	234	65	70	49.79	47.31	198	244	59	65	59.17	232	222	53	53	41.54	38.65	232	144	53	59	51.62
199	334	65	70	49.78	47.30	199	344	59	65	58.99	233	222	53	53	41.52	38.63	233	244	53	59	51.22
200	331	65	61	49.62	47.14	200	131	65	61	58.70	234	114	53	59	40.78	37.85	234	344	53	59	51.13
201	144	59	65	49.62	47.13	201	152	53	53	58.30	235	144	53	59	40.07	37.11	235	134	57	63	50.01
202	124	60	66	49.32	46.81	202	113	53	51	57.84	236	244	53	59	39.87	36.90	236	234	57	63	49.80
203	244	59	65	48.51	45.96	203	143	53	51	57.67	237	344	53	59	39.40	36.40	237	334	57	63	49.77
204	344	59	65	48.34	45.79	204	331	65	61	57.30	238	124	53	59	39.11	36.10	238	124	53	59	49.21
205	224	60	66	48.23	45.67	205	124	60	66	57.30	239	324	53	59	38.47	35.43	239	224	53	59	48.76
206	231	65	61	48.18	45.62	206	243	53	51	57.20	240	224	53	59	38.45	35.43	240	324	53	59	48.74
207	324	60	66	47.20	44.59	207	343	53	51	57.10	241	113	47	45	33.52	30.24	241	113	47	45	48.07
208	153	53	51	47.02	44.40	208	134	65	70	56.78	242	112	47	47	33.50	30.21	242	112	47	47	47.09
209	152	53	53	46.49	43.85	209	234	65	70	56.61	243	133	49	47	33.10	29.79	243	133	49	47	45.77
210	133	57	55	46.06	43.40	210	112	53	53	56.59	244	132	49	49	33.09	29.79	244	132	49	49	44.92
211	233	57	55	45.74	43.06	211	224	60	66	56.54	245	114	47	53	31.08	27.68	245	123	46	44	44.10
212	333	57	55	45.74	43.06	212	334	65	70	56.53	246	134	49	55	30.62	27.20	246	122	46	46	43.27
213	132	57	57	45.60	42.92	213	324	60	66	56.46	247	122	46	46	30.27	26.82	247	114	47	53	42.79
214	332	57	57	45.30	42.59	214	142	53	53	56.43	248	123	46	44	30.14	26.69	248	134	49	55	40.88
215	232	57	57	45.30	42.59	215	242	53	53	55.98	249	124	46	52	28.08	24.53	249	124	46	52	39.26
216	113	53	51	44.45	41.71	216	342	53	53	55.88											

1) The profitability ranking was determined here on the basis of contribution profit  $III_{0,+w}$ . The fact that the amount of tax on work earnings depends on the taxable proportion of income from work in forest harvesting can sometimes make the profitability ranking based on contribution profit  $IV_{0,+w}$  slightly different from that based on contribution profit  $III_{0,+w}$ . — *Edullisuusjärjestyks on tässä määrätty katetuotto  $III_{0,+w}$ :n perusteella. Työtuloveron määrän riippuminen puunkorjauksen veronalaisesta tulosta voi välistä tehdä edullisuusjärjestyksen katetuotto  $IV_{0,+w}$ :n perusteella hieman toiseksi kuin katetuotto  $III_{0,+w}$ :n mukaan.*

Tabular appendix 2. The mutual profitability ranking of alternative policies for the 9 500 ha normal pine forest, measured by the contribution profits, and the contribution profits per ha as a percentage of the corresponding figures for the 37 ha normal forest.

*Läitetaulukko 2. 9 500 ha:n mäntynormaalmetsän vaihtoehtoisten politiikkojen katetuotoilla mitattu keskinäinen edullisuusjärjestys ja sen katetuotot hehtaaria kohden %:na 37 ha:n normaalmetsän vastaavista katetuotoista*

Profitability ranking Edullisuusjärjestyks	Alternative Vaihtoehto	Relative value of criteria, by alternatives Kriteerien suhteellinen arvo vaihtoehtoiltaan		Contribution profits per ha, % of the corresponding figures for the 37 ha forest Katetuoto/ha %:na 37 ha:n normaalmetsän vastaavista tuvuista		Profitability ranking Edullisuusjärjestyks	Alternative Vaihtoehto	Relative value of criteria, by alternatives Kriteerien suhteellinen arvo vaihtoehtoiltaan		Contribution profits per ha, % of the corresponding figures for the 37 ha forest Katetuoto/ha %:na 37 ha:n normaalmetsän vastaavista tuvuista	
		III <sub>o</sub>	IV <sub>o</sub>	III <sub>o</sub>	IV <sub>o</sub>			III <sub>o</sub>	IV <sub>o</sub>	III <sub>o</sub>	IV <sub>o</sub>
		Contribution profit Katetuotto		Contribution profit Katetuotto				Contribution profit Katetuotto		Contribution profit Katetuotto	
1	2	3	4	5	6	1	2	3	4	5	6
1	153 93 91	100.00	100.00	101.19	78.32	25	243 95 93	84.15	78.50	100.76	73.42
2	113 95 93	99.42	99.21	100.13	77.32	26	343 95 93	83.97	78.26	100.77	73.37
3	152 93 93	99.21	98.93	101.86	78.67	27	321 95 90	83.63	77.80	100.36	72.93
4	112 95 95	97.85	97.08	99.95	76.79	28	242 95 90	82.91	76.82	100.57	72.84
5	154 93 96	96.48	95.23	101.59	77.76	29	144 89 93	82.81	76.69	99.98	72.35
6	114 95 99	95.17	93.45	100.49	76.53	30	342 95 95	82.74	76.59	100.58	72.79
7	141 95 90	93.56	91.26	100.73	76.29	31	124 95 99	82.22	75.89	99.41	71.71
8	113 89 87	91.86	88.97	100.23	75.42	32	123 88 86	81.66	75.13	99.88	71.86
9	143 95 93	91.73	88.78	100.57	75.65	33	114 83 88	81.23	74.54	100.23	71.97
10	112 89 89	90.35	86.92	100.03	74.82	34	343 89 87	81.12	74.40	99.74	71.56
11	142 95 95	90.33	86.89	100.39	75.10	35	143 83 81	81.06	74.31	100.74	72.30
12	241 95 90	89.14	85.27	99.93	74.38	36	243 89 87	80.83	74.01	99.74	71.46
13	121 95 90	88.56	84.48	100.22	74.43	37	342 89 89	80.69	73.81	100.56	72.02
14	341 95 90	88.33	84.17	100.06	74.24	38	242 89 89	80.40	73.42	100.56	71.92
15	114 89 93	87.77	83.42	100.58	74.47	39	122 88 88	80.38	73.39	99.67	71.23
16	143 89 87	87.39	82.90	100.56	74.34	40	244 95 99	80.04	72.93	100.19	71.50
17	144 95 99	87.16	82.59	100.05	73.86	41	344 95 99	79.87	72.70	100.20	71.44
18	123 95 93	86.52	81.72	99.95	73.58	42	142 83 83	79.72	72.49	100.51	71.62
19	113 83 81	86.32	81.45	100.01	73.56	43	223 95 93	79.52	72.23	100.12	71.24
20	142 89 89	86.00	81.02	100.37	73.74	44	113 77 75	79.43	72.10	100.02	71.13
21	122 95 95	85.23	79.98	99.77	73.02	45	323 95 93	79.10	71.66	100.13	71.09
22	221 95 90	85.12	79.82	100.22	73.33	46	241 83 79	78.99	71.51	99.69	70.72
23	112 83 83	84.83	79.43	99.77	72.89	47	341 83 79	78.91	71.40	99.83	70.79
24	141 83 79	84.31	78.73	100.52	73.29	48	121 81 77	78.67	71.07	99.83	70.70

	1	2	3	4	5	6	1	2	3	4	5	6		
49	222	95	95	78.38	70.68	99.92	89	222	81	81	71.47	61.30	99.60	67.38
50	112	77	77	78.01	70.17	99.75	90	131	81	76	71.41	61.22	98.98	66.91
51	322	93	95	77.97	70.13	99.93	91	231	89	83	71.36	61.16	99.01	66.90
52	343	83	81	77.88	70.00	99.85	92	322	81	81	71.18	60.92	99.89	67.46
53	344	89	93	77.73	69.79	100.14	93	133	89	87	70.82	60.43	99.79	67.21
54	244	89	93	77.46	69.43	100.15	94	144	77	82	70.77	60.36	99.68	67.10
55	342	83	83	77.43	69.39	100.68	95	143	71	69	70.17	59.54	100.57	67.45
56	124	88	92	77.35	69.28	99.26	96	331	89	83	70.09	59.43	99.16	66.39
57	153	73	71	77.30	69.22	101.40	97	132	89	89	69.82	59.07	99.58	66.56
58	243	83	81	76.82	68.56	99.93	98	124	81	86	69.44	58.55	99.09	66.01
59	323	88	86	76.40	68.00	100.07	99	344	77	82	69.28	58.33	99.81	66.44
60	242	83	83	76.40	67.99	100.77	100	142	71	71	68.91	57.83	100.26	66.57
61	143	77	75	76.19	67.71	100.57	101	244	77	82	68.68	57.52	99.84	66.16
62	223	88	86	76.09	67.57	100.06	102	123	74	72	68.49	57.27	99.61	65.89
63	152	73	73	75.88	67.28	101.11	103	134	89	92	68.08	56.71	99.28	65.44
64	224	95	99	75.65	66.97	99.53	104	224	81	86	67.70	56.19	98.98	65.02
65	144	83	88	75.62	66.93	99.95	105	243	71	69	67.64	56.11	99.24	65.17
66	131	89	83	75.57	66.87	99.11	106	343	71	69	67.55	55.99	99.18	65.08
67	324	95	99	75.25	66.44	99.54	107	324	81	86	67.43	55.83	99.26	65.07
68	322	88	88	75.25	66.43	99.85	108	122	74	74	67.33	55.70	99.32	65.06
69	222	88	88	74.93	66.01	99.84	109	242	71	71	67.26	55.60	100.15	65.61
70	142	77	77	74.87	65.93	100.31	110	114	71	77	67.21	55.53	99.52	65.13
71	123	81	79	74.53	65.46	99.94	111	342	71	71	67.17	55.48	100.09	65.52
72	114	77	82	74.49	65.41	100.20	112	323	74	72	66.91	55.13	99.79	65.16
73	343	77	75	73.73	64.37	99.60	113	223	74	72	66.74	54.90	99.82	65.09
74	344	83	88	73.46	64.00	100.11	114	233	89	87	66.63	54.75	99.91	65.09
75	122	81	81	73.32	63.81	99.69	115	133	81	79	66.02	53.92	99.73	64.62
76	342	77	77	73.29	63.77	100.46	116	231	81	76	65.83	53.65	98.85	63.89
77	243	77	75	73.07	63.48	99.64	117	331	81	76	65.80	53.62	98.88	63.90
78	113	71	69	73.02	63.41	99.53	118	322	74	74	65.79	53.61	99.49	64.32
79	242	77	77	72.65	62.91	100.50	119	232	89	89	65.73	53.52	99.69	64.42
80	221	81	77	72.63	62.89	99.84	120	222	74	74	65.63	53.39	99.52	64.25
81	223	81	79	72.63	62.88	99.85	121	333	89	87	65.30	52.94	99.93	64.34
82	244	83	88	72.49	62.69	100.18	122	132	81	81	65.04	52.59	99.49	63.88
83	324	88	92	72.44	62.62	99.41	123	332	89	89	64.43	51.76	99.70	63.66
84	323	81	79	72.34	62.49	100.14	124	113	65	63	64.03	51.62	98.75	62.99
85	154	73	77	72.27	62.40	100.54	125	234	89	92	64.12	51.34	99.36	63.24
86	224	88	92	72.14	62.22	99.40	126	112	65	65	64.01	51.19	99.68	63.39
87	321	81	77	72.12	62.19	100.00	127	144	71	77	63.90	51.05	99.37	63.12
88	112	71	71	71.66	61.56	99.21	128	143	65	63	63.74	50.82	100.10	63.51

Tabular appendix 2 (cont.) — *Livitetaulukko 2 (jatkoa)*

Profit-ability ranking <i>Edullis-järjes-tys</i>	Alternative <i>Vaihtoehto</i>	Relative value of criteria, by alternatives <i>Kriteerien suhteellinen arvo vaihtoehtoihin</i>		Profit-ability ranking <i>Edullis-järjes-tys</i>	Alternative <i>Vaihtoehto</i>	Relative value of criteria, by alternatives <i>Kriteerien suhteellinen arvo vaihtoehtoihin</i>		Contribution profits per ha, % of the corresponding figures for the 37 ha forest <i>Katetuoto/ha %-na 37 ha:n normaaliomaisuuden vastaavista luuvista</i>	Contribution profit <i>Katetuotto</i>		
		III <sub>0</sub>	IV <sub>0</sub>			III <sub>0</sub>	IV <sub>0</sub>		III <sub>0</sub>	IV <sub>0</sub>	
		Contribution profit <i>Katetuotto</i>				Contribution profit <i>Katetuotto</i>			Contribution profit <i>Katetuotto</i>		
1	2	3	4	5	6	1	2	3	4	5	6
129	124 74 79	63.49	50.48	98.61	62.34	156	132 73 73	58.52	43.75	99.49	59.57
130	233 81 79	63.05	49.89	99.89	62.94	157	333 73 71	57.89	42.89	99.94	59.39
131	334 89 92	62.86	49.64	99.37	62.47	158	232 73 73	57.77	42.73	99.36	58.93
132	142 65 65	62.56	49.22	99.74	62.52	159	144 65 71	57.67	42.59	98.68	58.41
133	134 81 85	62.46	49.08	99.01	61.97	160	332 73 73	57.02	41.72	99.63	58.52
134	244 71 77	62.39	48.99	99.24	62.07	161	121 67 64	56.77	41.37	98.06	57.32
135	344 71 77	62.30	48.88	99.18	61.98	162	141 65 62	56.45	40.94	98.55	57.38
136	232 81 81	62.14	48.66	99.64	62.19	163	134 73 77	56.01	40.34	98.90	57.25
137	333 81 79	62.14	48.65	99.88	62.35	164	344 65 71	55.87	40.15	98.45	56.85
138	324 74 79	62.05	48.53	98.75	61.53	165	244 65 71	55.73	39.96	98.51	56.77
139	224 74 79	61.89	48.32	98.79	61.45	166	124 67 73	55.67	39.89	97.99	56.40
140	123 67 65	61.38	47.63	99.39	61.52	167	234 73 77	55.30	39.38	98.77	56.58
141	332 81 81	61.25	47.45	99.62	61.59	168	113 59 57	54.62	38.46	99.59	56.52
142	343 65 63	60.87	46.94	98.56	60.62	169	334 73 77	54.59	38.41	99.02	56.14
143	243 65 63	60.71	46.72	98.61	60.55	170	224 67 73	54.34	38.07	97.83	55.18
144	342 65 65	60.59	46.56	99.54	61.08	171	324 67 73	54.21	37.90	97.77	55.04
145	242 65 65	60.44	46.35	99.60	61.02	172	112 59 59	53.63	37.12	99.14	55.38
146	122 67 67	60.31	46.17	99.04	60.56	173	143 59 57	53.62	37.10	99.73	55.72
147	223 67 65	59.88	45.59	99.25	60.40	174	133 65 63	52.76	35.93	99.59	54.85
148	323 67 65	59.73	45.39	99.20	60.26	175	142 59 59	52.66	35.80	99.27	54.57
149	234 81 85	59.70	45.34	99.13	60.19	176	233 65 63	52.60	35.71	99.49	54.64
150	133 73 71	59.43	44.98	99.79	60.43	177	123 60 58	52.59	35.70	98.42	53.99
151	114 65 71	59.00	44.39	98.65	59.37	178	333 65 63	52.57	35.68	99.46	54.60
152	222 67 67	58.85	44.20	98.89	59.43	179	321 67 64	52.56	35.66	97.97	53.69
153	334 81 85	58.85	44.19	99.11	59.56	180	243 59 57	52.26	35.26	99.54	54.35
154	322 67 67	58.71	44.00	98.85	59.29	181	343 59 57	52.06	34.99	99.51	54.15
155	233 73 71	58.66	43.94	99.66	59.79	182	132 65 65	51.94	34.82	99.21	53.85

	1	2	3	4	5	6	1	2	3	4	5	6		
183	221	67	64	51.94	97.92	53.08	217	112	53	53	42.53	22.06	97.31	41.68
184	232	65	65	51.79	99.12	53.65	218	143	53	51	42.48	21.99	98.05	41.95
185	332	65	65	51.76	99.09	53.61	219	243	53	51	42.14	21.53	97.78	41.32
186	122	60	60	51.68	97.99	52.88	220	142	53	53	41.84	21.12	97.46	40.71
187	241	65	62	51.55	98.17	52.86	221	343	53	51	41.65	20.87	97.88	40.62
188	242	59	59	51.35	99.07	53.20	222	242	53	53	41.51	20.68	97.20	40.08
189	342	60	58	51.32	98.32	52.72	223	154	53	59	41.37	20.48	97.66	40.08
190	242	59	59	51.16	99.04	52.99	224	123	53	51	41.08	20.10	97.10	39.38
191	131	65	61	50.75	98.47	52.25	225	342	53	53	41.04	20.04	97.29	39.39
192	222	60	58	50.46	97.88	51.61	226	134	57	63	40.57	19.40	96.69	38.36
193	323	60	58	50.37	98.69	51.99	227	122	53	53	40.50	19.30	96.53	38.18
194	341	65	62	49.84	98.07	51.08	228	323	53	51	40.32	19.06	96.98	38.08
195	322	60	60	49.54	98.23	50.86	229	223	53	51	40.31	19.04	96.99	38.07
196	114	59	65	49.12	97.81	50.18	230	234	57	63	40.29	19.02	96.65	37.89
197	134	65	70	48.69	98.29	49.98	231	334	57	63	40.28	19.01	96.64	37.87
198	331	65	61	48.55	98.54	49.98	232	322	53	53	39.76	18.30	96.39	36.89
199	234	65	70	48.54	98.20	49.78	233	222	53	53	39.74	18.28	96.41	36.88
200	334	65	70	48.52	98.17	49.73	234	144	53	59	38.89	17.13	97.76	35.97
201	144	59	65	48.24	97.91	49.27	235	114	53	59	38.69	16.85	95.55	34.68
202	124	60	66	48.17	98.37	49.46	236	244	53	59	37.77	15.60	95.40	32.94
203	224	60	66	47.06	98.27	48.12	237	124	53	59	37.61	15.39	96.86	33.21
204	244	59	65	47.05	97.68	47.78	238	344	53	59	37.34	15.03	95.46	32.17
205	231	65	61	46.98	98.22	48.00	239	324	53	59	36.94	14.49	96.73	31.86
206	344	59	65	46.87	97.65	47.56	240	224	53	59	36.93	14.47	96.74	31.85
207	324	60	66	46.22	98.62	47.30	241	133	49	47	31.76	7.46	96.65	19.50
208	153	53	51	45.78	98.07	46.46	242	113	47	45	31.59	7.22	94.90	18.60
209	133	57	55	45.09	98.59	45.85	243	132	49	49	31.54	7.15	95.98	18.71
210	152	53	53	44.92	97.31	44.96	244	112	47	47	31.32	6.86	94.17	17.70
211	233	57	55	44.77	98.57	45.42	245	114	47	53	29.14	3.91	94.44	10.99
212	333	57	55	44.76	98.56	45.40	246	123	46	44	28.70	3.30	95.89	9.63
213	132	57	57	44.43	98.13	44.74	247	122	46	46	28.59	3.16	95.14	9.17
214	232	57	57	44.12	98.10	44.31	248	134	49	55	28.52	3.06	93.79	8.76
215	332	57	57	44.11	98.09	44.29	249	124	46	52	25.84	—	92.67	—
216	113	53	51	43.20	97.89	42.93						—		—

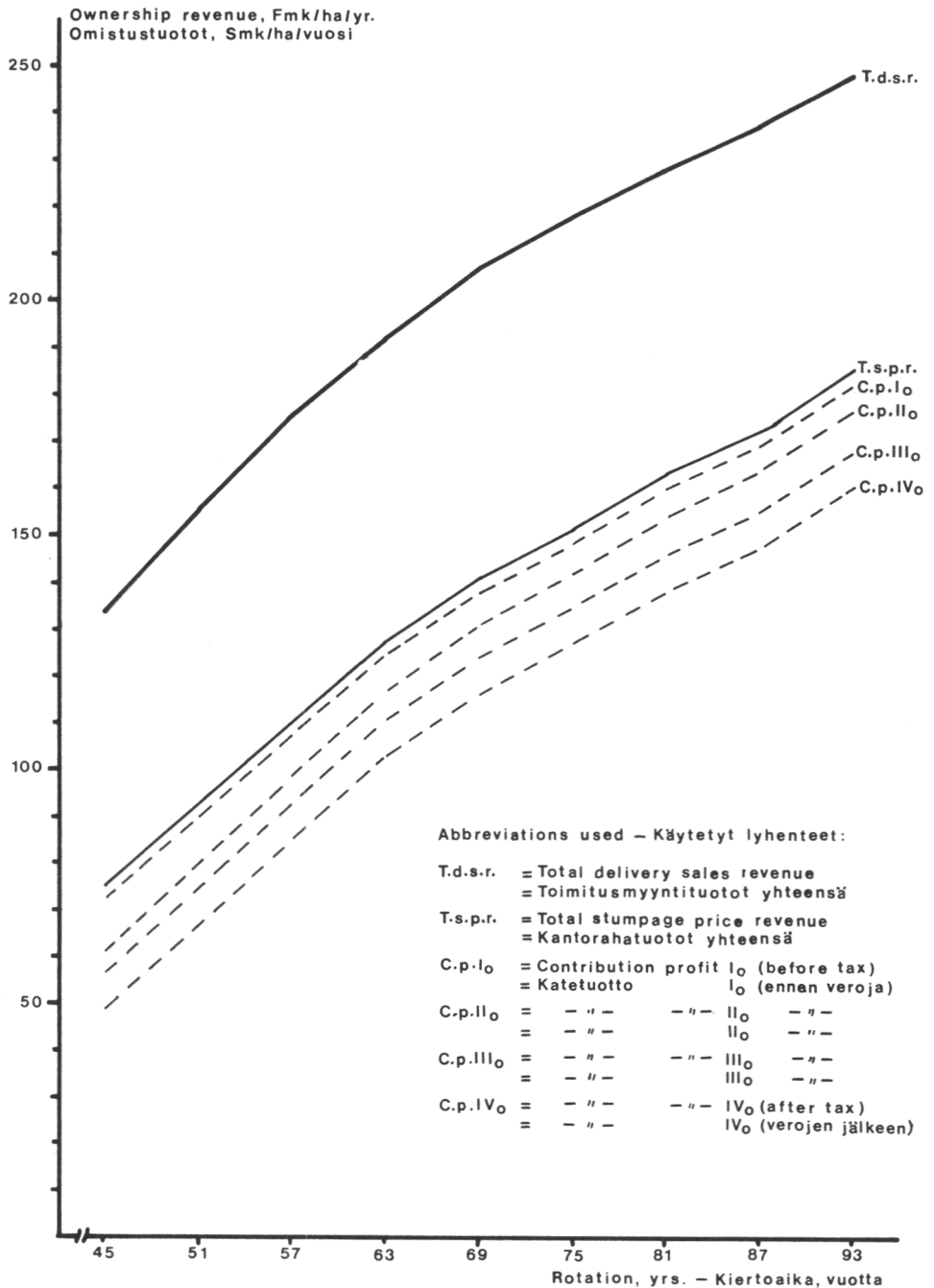


Diagram 1. The contribution profit analysis of the 37 ha normal pine forest as a function of the applied rotation, based on the principle of ownership revenue. The policy alternative is slight thinning from below, regeneration by planting and varying rotation (compare table 2 and tabular appendix 1).

Kuva 1. 37 ha:n mäntynormaalimetsän katetuottoanalyysi sovellettavan kiertoaajan funktiona. Omistustulon periaate. Sovellettu politiikkavaihtoehto on lievä alaharvennus, uudistaminen istuttaen ja vaihtelevat kiertoaajat (vrt. taulukkoa 2 sekä liitetäulukkoa 1).

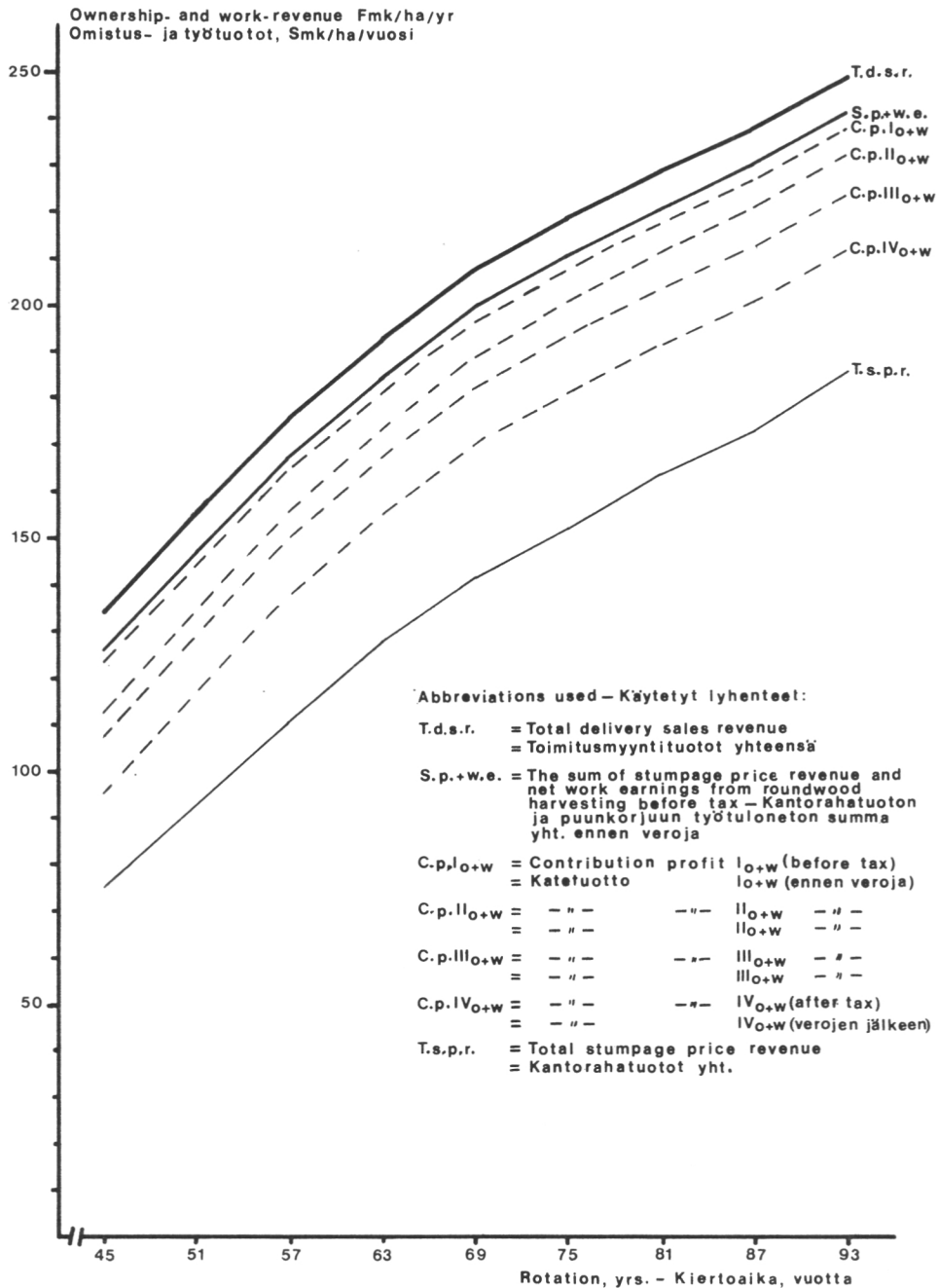


Diagram 2. The contribution profit analysis of the 37 ha normal pine forest as a function of the applied rotation, based on the principle of the sum of both ownership- and work-revenue. The policy alternative is slight thinning from below, regeneration by planting and varying rotation (compare table 3 and tabular appendix 1).

Kuva 2. 37 ha:n mäntynormaalimetsän katetuottoanalyysi sovellettavan kiertoaajan funktiona. Omistustulon ja työtulon summan periaate. Sovellettu politiikkavaihtoehto on lievä alaharvennus, uudistaminen istuttaen ja vaihtelevat kiertoaajat (vrt. taulukkoa 3 ja liitetäulukkoa 1).

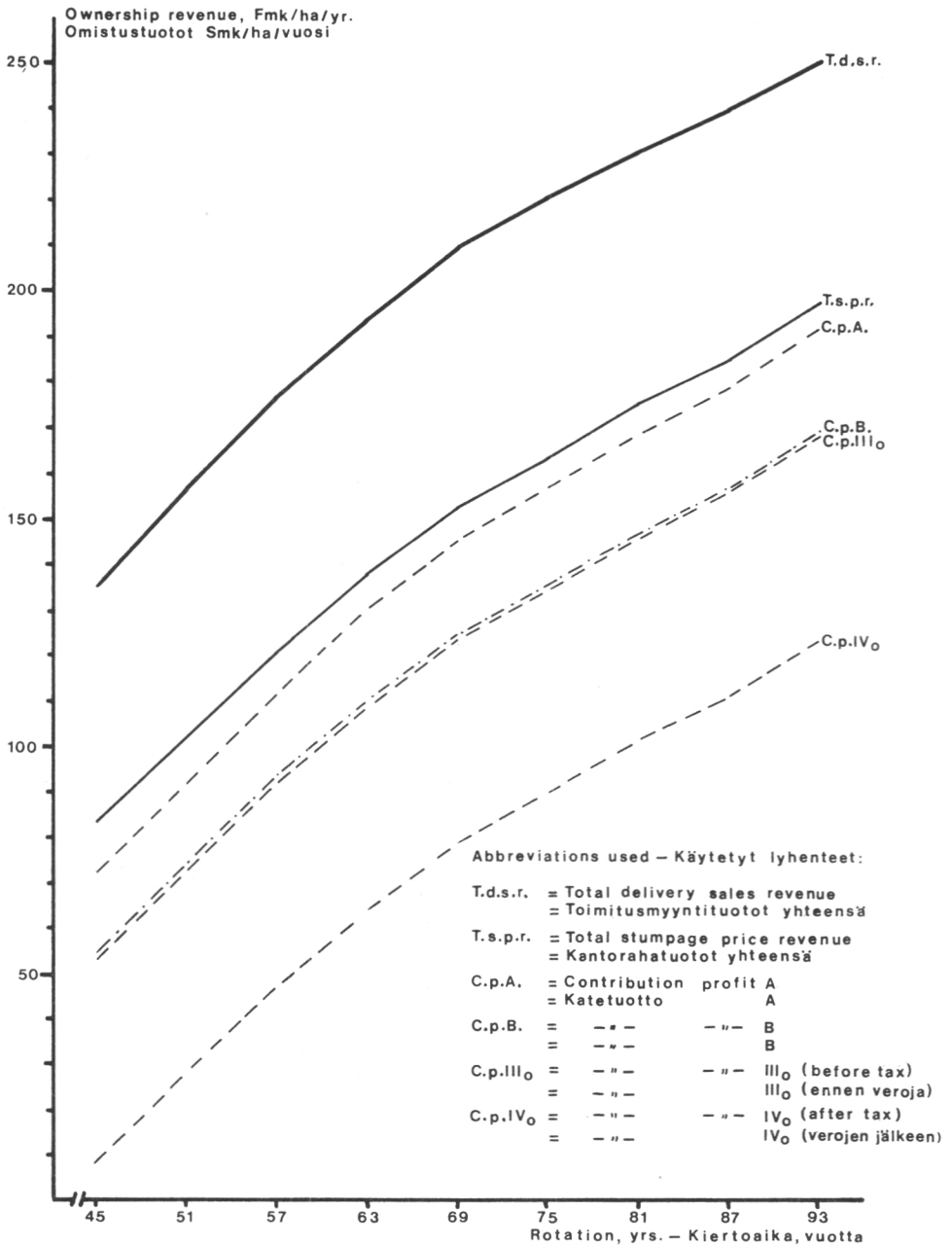


Diagram 3. The contribution profit analysis of the 9 500 ha normal pine forest as a function of the applied rotation, based on the principle of ownership revenue. The policy alternative is slight thinning from below, regeneration by planting and varying rotation (compare table 4 and tabular appendix 2).

Kuva 3. 9 500 ha:n mäntynormaalimetsän katetuottoanalyysi sovellettavan kiertoajan funktiona. Omistustulon periaate. Sovellettu politiikkavaihtoehto on lievä alaharvennus, uudistaminen istuttaen ja vaihtelevat kiertoajat (vrt. taulukkoa 4 sekä liitetäulukkoa 2).

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## SELOSTE:

### Normaalimetsän katetuottoanalyysi ja sen empiirinen sovellutus

#### 1. Johdanto ja tutkimustehtävä

Kirjoittaja on aikaisemmassa tutkimuksessaan käsitellyt metsätalouden (liike)taloudellisissa edullisuusvertailuissa käytettävien laskentamallien ominaisuuksia ja niiden sopivuutta erilaisiin laskentatilanteisiin (H ä m ä l ä i n e n 1973, erit. s. 46—70). Näitä malleja voidaan käyttää metsätaloudellisiin edullisuusvertailuihin yksittäisen metsikön, metsälön tai jopa koko yrityksen puitteissa. Tässä tutkimuksessa pyritään rakentamaan metsälön tuotto- ja kululajien sekä niiden erotuksina saatavien tulosten systematiikka ja soveltamaan sitä metsänkorkoteorian ja normaalimetsän puitteissa tiettyihin empiirisiin aineistoihin. Metsänkorkoteorian mukaan on edullisin se normaalimetsän hakkuu- ja hoitovaihtoehto, joka johtaa vuotuisten tuottojen ja kulujen erotuksen eli metsänkoron maksimiin. Pääoman korkoa ei tällöin vähennetä tuotoista.

#### 2. Tulosanalyysin periaatteet ja perusteet

Normaalimetsämallissa saa ilmauksensa staattinen talusteoria. Normaalimetsä on todellisuuden idealisoitu kuvaus. Staattisuus on silmiinpistävä silloin, kun normaalimetsämallin avulla pyritään laskemaan metsänkorkoperiaatteen mukaan metsälön vuotuistuottoja ja -kuluja. Kysymys on tällöin joukosta pinta-alaltaan samansuuruisia normaalimetsiä, joilla erikseen kullakin on toteutettu ja vastaisuudessa toteutetaan tiettyä metsälöpolitiikkaa. Metsänkorkoperiaatetta voidaan käyttää myös yksittäisten metsiköiden hakkuu- ja hoitovaihtoehtojen edullisuuden laskentaan. Tavoitteena on löytää sellainen hakkuu- ja hoitovaihtoehto, jota toteutettaessa metsiköstä kiertoajan kuluessa saatavien nettotulojen summa (pääoman korkoa vähentämättä), jaettuna kiertoajan vuosien luvulla, saavuttaa maksimin. Metsänomistaja pyrkii saamaan metsiköstä maksimaalisen absoluuttisen nettotulon vuotta kohden. Samoin kuin normaalimetsätarkastelussa jätetään siis huomiotta metsänomistajan vaihtoehtoiset sijoitusmahdollisuudet, rahoituksen kustannukset sekä se, että metsänomistaja usein haluaa metsästään kulutukseen vuosittain vaihtelevia rahamääriä.

Todellisen metsälön tuloksenlaskennan ja erityisesti suunnittelun kannalta eivät metsänkorkoperiaatteella suoritettujen laskelmien tulokset ole yleensä riittäviä ja todellisuutta vastaavia. Suunnittelussa ja tuloksenlaskennassa on otettava huomioon juuri kyseisen metsälön resurssit laskentaperiodina tai -ajankohtana, vaikkapa tavoitteena olisikin metsälön normaali tila. Metsänkorkoteoria ei kuitenkaan ota huomioon, millaisin toimenpitein ja niistä aiheutuvin meno- ja tulovirroin metsälön todellisesta tilasta päästään ajan mittaan siirtymään normaalimetsätilaan (vrt. H ä m ä l ä i n e n 1973, s. 66—67). Todellisen metsälön konkreettisiin suunnittelutilanteisiin sopivat parhaiten

erilaiset budjetointimenetelmät sekä kombinoitujen mallien käyttöön perustuvat operaatioanalyysin menetelmät (Hämäläinen 1973, s. 67—69). Metsänkorkoperiaatteen avulla voidaan vain kuvata metsälön ja sen ympäristön erilaisia staattisia tiloja. Siis: jos normaalimetsän ja sen ympäristön tila on tällainen, niin tuotot, kulut ja eriaisteiset tulokset (katteet) ovat vastaavasti tällaisia tai tulevat olemaan tällaisia metsälön saavutettua kulloisenkin normaalitilan. Siten tutkija voi, soveltamalla metsänkorkoperiaatetta normaalimetsämalliin, antaa valaisua siihen, minkä lajisia ja kuinka suuria tuottoja ja kuluja metsälöltä on odotettavissa mahdollisena tavoitteena olevan »normalisoinnin» jälkeen. Kyseinen analyysi auttaa metsänomistajaa tavoitteidensa asettamisessa. Ehkä tärkeämpää on kuitenkin se, että tämän analyysin »standardisoidut» tulokset antavat ainakin likimääräisen käsityksen metsälön taloudellisista tuloksista ja niiden komponenteista myös metsätalouden muille intressenteille kuin metsänomistajille.

Tässä tutkimuksessa suoritetaan kahden erikokoisen normaalimetsän tulosanalyysi. Toinen on pinta-alaltaan 37 ha ja toinen 9 500 ha. Ensiksi mainittu vastaa ns. Järvi-Suomen alueen (ks. Vuokila 1967, s. 11, kuva 1) metsälöiden keskikokoa. Viimeksi mainittu taas edustaa yksityismetsälöiden suurimpia kokoja Suomessa. Näin on mahdollista saada jossakin määrin käsitystä myös metsälön koon vaikutuksesta erilaisiin tuloksiin ja niiden komponentteihin. Sekä 37 ha:n metsälön että 9 500 ha:n metsälön katsottiin olevan kokonaan VT-männikköä. Syynä oli se, että kirjoittajalla oli jo käytettävissään tarpeelliset VT-männikköä koskevat tuotos-, kantohinta- yms. aineistot. Seuraavassa käytetään 37 ha:n metsälöstä nimitystä pienmetsälö ja 9 500 ha:n metsälöstä nimitystä suurmetsälö.

Analyyseissä sovelletaan metsänkorkoteorian puitteissa katetuottoajattelua. Sen mukaan edullisuuslaskelman kulloisellekin kohteelle kohdistetaan vain sen erillistuotot ja -kulut. Erilliskulut ovat enimmäkseen muuttuvia (Hämäläinen 1965, s. 1). Silloin kun on kysymys kokonaisen talousyksikön toiminnan edullisuuden laskemisesta, sen kaikki tuotot ja kulut ovat paikan suhteen luonteeltaan erillisiä. Ei synny sellaista kohdistamisongelmaa kuin kysymyksen ollessa esim. vain metsälön jostakin osatoiminnosta. Normaalimetsäoletus poistaa puolestaan tulojen ja menojen ajallisen jaksotusongelman. Tämä yksinkertaistaa suuresti tulosanalyysiä vaikkakin se toisaalta vähentää mallin realismia. — Katetuottoanalyysissä oletetaan, että metsänomistaja myy raakapuun hankintakaupoin (taulukoiden 2, 3 ja 4 kohta 1).

### 3. Tuottojen ja kulujen määrittäminen

Sekä pien- että suurmetsälöllä oletettiin sovellettavan vaihtoehtoisesti 249 erilaista hakkuu- ja hoitopolitiikkaa. Poliitiikan määritteli metsiköiden uudistusmenetelmä, harvennusmenetelmä, harvennuksen voimakkuusaste ja sovellettava kiertoaika (ks. liiteosan sivua 1). Tuotantovaihtoehdot on esitetty kirjoittajan aiemmassa tutkimuksessa, missä niitä sovellettiin mm. metsiköittäisiin edullisuuslaskelmiin (ks. Hämäläinen 1973, s. 102—107 ja siellä tehdyt kirjallisuusviittaukset).

Mäntytukkien ja -paperipuun hakkuumääriä hankintahintaan hinnoitettaessa käytettiin näiden puutavaralajien reaalisia (trendi-) hintoja hakkuuv. 1967/68. Tällöin kutakin metsälöpolitiikkaa vastaavat raakapuun hankintahintaan ja korjuukustannuksiin vaikuttavat tekijät otettiin huomioon (ks. Hämäläinen 1973, s. 119 ja 130—137). Pienmetsälön kaikki kululajit, hakkuuv. 1967/68 tasossa, perustuvat juuri mainittuun tutkimukseen (erit. sen s. 142—161).

Suurmetsälön katetuottokaaviossa (taulukko 4) suoritettiin kulujen ryhmittely osittain eri tavoin kuin pienmetsälön vastaavassa kaaviossa (taulukko 2). Pääsyynä

oli se, että myös todellisuudessa suurmetsälöiden toiminta organisoidaan eri tavalla kuin pienmetsälöiden. Myös suurmetsälön katetuottokaavion useimpien menolajien luvut perustuvat todellisilta metsälöiltä kerättyyn aineistoon. Yksi metsälö oli pinta-alaltaan 9 500 ha ja yksityisen yrityksen omistuksessa. Tiettyjen menolajien aineistoa saatiin myös neljästä eteläsuomalaisesta metsähallinnon hoitoalueesta (ks. taulukkoa 1). Hakkuumäärien hinnoituksen sekä erilaisten kululajien määrityksen periaatteet käyvät ilmi englannin kielisestä tekstistä.

#### 4. Katetuottoanalyysi

##### 4.1. Pienmetsälön analyysi

Pienmetsälön katetuottoanalyysi omistustulon periaatteella näkyy taulukosta 2. Sen sarakkeiden 2—4 luvut koskevat sellaista 37 ha:n normaalimetsän politiikkaa, mitä toteutettaessa katetuotto III<sub>0</sub> e.v. ja vastaavasti katetuotto IV<sub>0</sub> j.v. olivat tutkituista vaihtoehdoista korkeimmat (ks. liitetaulukkoa 1). Kysymyksessä oli siis toimintavaihtoehto, mikä edellytti lievää alaharvennusta, uudistamista istuttaen ja 93 v:n kiertoaikaa. Kuvista 1 ja 2 näkyy kuitenkin, että normaalimetsän vuotuisten katetuottojen maksimi saavutetaan niin pitkiä kiertoaikoja sovellettaessa, etteivät tässä tutkimuksessa käytettävissä olleet tuotossarjat yllä niin korkealle metsikön iälle. Perinteellinen korkeimman metsänkoron kiertoaika jää siis saamatta selville. Todettakoon kuitenkin, että K u u s e l a n (1968, s. 17—19) mukaan on eteläsuomalaisessa VT-männikön muodostamassa normaalimetsässä vuotuisen »bruttotulon» maksimiin johtava kiertoaika 110 v. ja vastaava vuotuisen »nettotulon» maksimi 113 v. (laskelmien perusoletuksista ja käytetyistä termeistä ks. K u u s e l a m t., s. 17—19). Sama normaalimetsän hakkuu- ja hoitopolitiikka, mikä johti tutkituista vaihtoehdoista korkeimpiin katetuottoihin pelkän omistustulon periaatteella, antoi suurimmat kate- tuotot myös omistustulon ja työtulon summaa kriteerinä käytettäessä (taulukko 3 ja liitetaulukko 1). Taulukoihin 2 ja 3 on sisällytetty katetuottokaavion numeroarvot myös sellaisista vaihtoehdoista, joissa käytetään samoin kuin parhaassa vaihtoehdossa, lievää alaharvennusta ja päätehakkuumetsiköt uudistetaan istuttaen, mutta kiertoajat ovat 69 v. ja 45 v. Tällaisessa staattisessa tarkastelussa kiertoajan lyhentäminen aiheuttaa siis normaalimetsän taloudessa seuraavat sinänsä itsestään selvät seuraukset:

- hankintatulot raakapuun myynnistä pienenevät;
- tukkien osuus hankintatuloista pienenee;
- puunkorjuukulujen osuus hankintatuloista kasvaa ja vastaavasti kantorahatulojen osuus pienenee. Puunkorjuukulut metsälöä kohden jopa kasvavat kiertoajan lyhentyessä tiettyyn kiertoaikaan saakka, mutta alkavat sitten taas lievästi pienentyä;
- myynnin, leimauksen ja luovutuksen kulujen melko suuri kiinteä komponentti (ks. H ä m ä l ä i n e n 1973, s. 150) nostaa näiden kulujen osuutta hankintamyynnituloista;
- metsänhoidon erilliskulut kasvavat absoluuttisesti ja erityisesti myös niiden osuus hankintatuloista. Näin varsinkin kun uudistaminen tapahtuu istuttaen;
- yleiskulujen pieneminen aluksi kiertoajan lyhentyessä johtuu metsävakuutusmaksun melko jyrkästä alenemisesta. Hankintatulot suhteessa tuotantoon sidotun vakuutetun puuston arvoon puolestaan kasvavat, kunnes taas aivan lyhyisiin kiertoaikoihin siirryttäessä käy päinvastoin;
- pinta-alaveron kiinteästä luonteesta johtuu, että sen suhteellinen osuus hankintatuloista ja erityisesti katetuotosta III<sub>0</sub> e.v. kasvaa.

Normaalimetsän hankintatulojen ja erilaisten katetuottojen nousu kiertoajan funktiona hidastuu vaihtoehdosta riippuen n. 60—65 vuoden iällä, mikä johtuu pääasiassa juoksevan absoluuttisen arvokasvan nousun hidastumisesta.

Kantorahatuoton ja puunkorjuun työtuloneton summan suhteellinen osuus hankintatuloista alenee lievästi kiertoajan lyhetessä, koska paperipuun osuuden kasvaessa kuluerän »Aineellisten tuotannontekijäin kulut paperipuun korjuussa» osuus kasvaa. Kiertoajan lyhetessä puunkorjuun työtulonetto kasvaa aluksi myös absoluuttisesti ja sen jälkeen pienenee vain hitaasti. Niinpä se on taulukosta 3 ilmenevässä vaihtoehdossa 45 v:n kiertoaikaa sovellettaessa vielä 92.6 % saman hakkuu- ja hoitopolitiikan 93 v:n kiertoaikavaihtoehdon vastaavasta luvusta. Pelkkää omistustuloa edustavan katetuotto  $I_0$  e.v.:n perusteella laskettu prosentti on vain 39.7. Mitä lyhyempää kiertoaikaa siis sovelletaan, sitä merkittävämmäksi työtulon suhteellinen osuus tulee. Työtulon absoluuttinenkin määrä jopa kasvaa kiertoajan lyhetessä silloin, kun kysymys on käytännössä tavallisesti sovellettavista kiertoajoista. Metsästä saatavien nettotulojen summa pienenee siis kiertoajan lyhentyessä vähiten sellaisilla pienviljelijä- ym. metsänomistajilla, jotka itse suorittavat puunkorjuun.

Liitetaulukon 1 perusteella voidaan normaalimetsän hakkuun ja hoidon vaihtoehdoissa todeta mm. seuraavia säännönmukaisuuksia: eri kiertoaikoja käytettäessä korkeimmat katetuotot saadaan alaharventaen. Näin saadaan normaalimetsän arvokasvu vuotta kohden mahdollisimman korkeaksi. Tällöin on muistettava, että metsänkorkoteoria normaalimetsämalleineen eliminoi ajan ja korkotekijän. Kiertoajan pidentyessä yläharvennusvaihtoehdot jäävät suhteellisesti yhä enemmän jälkeen alaharvennusvaihtoehdoista. Pääsyy on verraten varhaisesta metsiköiden iästä lähtien suoritettun yläharvennuksen aiheuttama tukkirunkojen koon pieneneminen (vrt. V o k i l a 1970, s. 25). Saman suuntainen vaikutus on myös voimakkailla alaharvennuksilla.

On syytä vielä korostaa, että tässä julkaisussa eri hakkuu- ja hoitovaihtoehtojen keskinäisestä edullisuudesta esitetyt numeroarvot ja edullisuuden osatekijöiden analyysin tulokset pitävät paikkansa vain silloin, kun metsänkorkoteorian staattiset perusoletukset ovat ainakin likimain täytetyt.

#### 42. Suurmetsälön analyysi ja vertailu pienmetsälöön

Suurmetsälöllä tuotot raakapuun toimitusmyynnistä/ha ovat suurten myyntierien vuoksi kussakin politiikkavaihtoehdossa korkeammat kuin pienmetsälöllä. Kun myös puunkorjuun yksikkökustannukset ovat pienemmät, ovat kantorahatuotot hehtaaria kohden korkeammat kuin pienmetsälöllä. Kiertoajan lyhentyessä tämä ero vielä kasvaa suhteellisesti. Niinpä kantorahatulo/ha on 93 v:n kiertoaikaa sovellettaessa suurmetsälöllä 6.5 % korkeampi mutta 45 v:n kiertoajalla peräti 11.1 %. Kiertoajan lyhetessä näet paperipuun suhteellinen osuus hakkuumäärästä kasvaa ja toisaalta paperipuulla on suurista luovutuseristä maksettava hankintalisä suhteellisesti korkeampi kuin tukeilla. Lisäksi suurmetsälön kustannuksia säästävät puunkorjuumenetelmät pääsevät parhaiten oikeuksiinsa »paperipuukiertoaikoja» käytettäessä, koska puunkorjuukustannukset/m<sup>3</sup> ovat paperipuulla paljon korkeammat kuin tukeilla.

Sivun 27 asetelma osoittaa metsänhoitomenojen ja erilaisten yleismenöiden summan pienellä ja suurella metsälöllä taulukoissa 2—4 esitettyjä normaalimetsän toiminta- vaihtoehtoja sovellettaessa. Suurmetsälöllä yleiskustannuksia kohottavat erityisesti vakituisesti palkattu henkilökunta, toimisto- ja rakennuskustannukset sekä veroluontoisena maksettava 1/4-metsänhoitomaksu, josta metsälö ei saa vastikkeeksi palveluksia. Sen sijaan pienmetsälöllä ei edellytetty tarvittavan erillisiä toimistotiloja ja

metsäalan toimihenkilöitä se käyttää vain tarvittaessa. Niinpä on suurmetsälöllä edellä puheena olleessa vaihtoehdossa kate III<sub>0</sub> hehtaaria kohden %:na pienmetsälön vastavasta luvusta eri kiertoajoilla: 93 v. 100.1 %, 69 v. 99.5 % ja 45 v. 95.0 %. Liitetaulukosta 2 näkyy, että kate III<sub>0</sub>/ha on yleensäkin »tavallisilla» 70—95 v:n kiertoajoilla jokseenkin sama pien- ja suurmetsälöllä. Kiertoajan lyhentyessä voimakkaasti suurmetsälön kate III<sub>0</sub> tulee selvästi epäedullisemmaksi juuri suurista kiinteistä kustannuksista johtuen. On selvää, että edellä esitetyt pien- ja suurmetsälön liikeluodellisen edullisuuden vertailut ovat sidotut laskelmien perustana olevien tuotto- ja kulukomponenttien arvoihin. Tosiasia on kuitenkin, että taulukon I osoittamissa metsähallinnon hoitoalueissa esim. todellisten henkilökuntakustannusten taso oli tun-  
tuvasti korkeampi kuin tässä tutkimuksessa suurmetsälöllä sovellettu. Toisaalta suur-  
metsälön kuluihin sisältyi eräitä arvionvaraisia mutta merkitykseltään melko vähäisiä  
eriä. Pienmetsälöön tässä sovelletut kulut (lähinnä yleiskulut) lienevät todellisiin  
keskiarvoihin verrattuina pikemminkin jonkin verran liian pieniä kuin suuria. Suur-  
metsälön katetuottokaavioiden perusteella voidaan joka tapauksessa saada käsitys  
ainakin siitä, mitkä kustannuserät rasittavat esim. metsähallinnon pienien (Etelä-  
Suomessa esim. 10 000—30 000 ha:n) hoitoalueiden taloutta; nuo kustannukset vähen-  
tävät liian pienissä ja hajallaan olevissa yksiköissä toteutettavan »suurmetsätalouden»  
kannattavuutta.

Liitetaulukosta 2 näkyy, että yksityisomistuksessa olevalla suurmetsälöllä kate-  
tuotto IV<sub>0</sub> j.v. tulee jopa negatiiviseksi huonointa vaihtoehtoa sovellettaessa. Tämä  
johtuu Suomen metsäverojarjestelmästä, mikä ei ota huomioon metsälökohtaista  
tulosta. Juuri tämä aiheuttaa sen, että mitä pienemmät absoluuttiset hakkuutulot  
toimintavaihtoehtoihin liittyvät, suhteellisesti sitä epäedullisempia nämä vaihtoehdot  
ovat, kun edullisuutta mitataan katetuotolla IV<sub>0</sub> j.v. eikä katetuotolla III<sub>0</sub> e.v.



WOOD QUALITY IN PLANTATION-  
GROWN SCOTS PINE

OLLI UUSVAARA

Lyhennelmä  
PUUN LAADUSTA VILJELYMÄNNIKÖISSÄ

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## PREFACE

The effect of reforestation on wood quality has been known to some extent for a long time, although few real studies of the problem have been conducted in Finland. Hence, as timber harvested from pine plantations will also begin before long to change somewhat the properties of the raw material utilised by the forest industry, it was natural for the Finnish Forest Research Institute, Department of Forest Technology to begin to study the quality of wood in plantation-grown pines.

The chief of the Department of Forest Technology, Professor Veijo Heiskanen, contributed valuable advice from the very beginning of the study and throughout its different phases. He also checked the manuscript. Acting Professor Pentti Hakki also checked the manuscript. His assistance in the course of the work and when the manuscript was being written was in many ways decisive for the study. Professor Bror-Anton Granvik from the Department of Logging and Utilization of Forest Products, University of Helsinki, directed the work in its later stages. Professor Pavo Yli-Vakkuri checked the manuscript especially from the silvicultural point of view. From Dr. Kari Löytty-niemä I received a great deal of help during the research project, especially with the part concerning defects.

Mr Jaakko Kaarre, Mr Sulo Kaarre, Mr Jukka Kanninen and Mr Antti Karjalainen participated in the field work of the study under my direction. A part of the field work was directed by Mr Teuri J. Salminen, M.Sc. Mr Klaus Rantapu, B.For., translated the Russian source literature.

The laboratory work was done by Mrs. Taija Havanto, Mrs. Kaarina Koskinen and Mrs. Irma Saarilahti. Miss Eija Aro-nen, M.Sc., Miss Susanna Havukkala, Mrs. Kaija Kanninen, B.A., Mrs. Ulla Knuutinen, Miss Maaret Turunen and Miss Arja Winter, M.Sc. (Pol.), participated in the calculation work. The drawings were made by Mrs. Leena Muronranta. Mrs. Aune Rytönen typed the manuscript.

The study was translated into English by Miss Päivikki Ojan-  
s u u, M.A., and checked by Mr L. A. Keyworth, M.A. (Cantab.).

Many foresters engaged in practical forestry helped in the planning  
of the investigation objects.

With the exception of N:o 4, the photographs were taken by photo-  
grapher M a t t i R u o t s a l a i n e n, the Photography Institute, Uni-  
versity of Helsinki.

I wish to express my best thanks to all the above-mentioned.

Helsinki, November 1973

*Olli Uusvaara*

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## 1. INTRODUCTION

It can be seen from the long-term reforestation programmes that wood produced by natural forests will decrease fast because of increasing reforestation activity. Hence, a growing proportion of the wood utilized for various forest industry purposes will be harvested in the future from plantations. The short time of regeneration, the possibility of selecting the tree species and of using improved seedling stock, a higher yield than in natural forests and possibly lower management and harvesting costs are strong arguments in favour of expanding reforestation activity.

However, it is impossible to be certain now about how much and what type of wood the forest industry will need in the future. Nevertheless, as far as Scots pine (*Pinus silvestris* L.) stands are concerned it may be assumed, that the species will be of considerable importance, particularly as sawlogs. In pine stands, therefore, the quality of the wood should be accorded equal consideration as fast and high yield. In fact, in addition to high yield, attention has long been paid in silviculture to the quality of the growing stock to be cultivated and the factors affecting it (e.g. Helander 1922, Jussila 1935, Laitakari 1937, Lindqvist 1939, Eriksson 1941, Sarvas 1944, 1956, Paul and Smith 1950, Andersson 1958, Heiskanen 1959, Jackson 1968).

It is also obvious that with the increasing change to reforestation the quality of the timbergoods and the wood raw material will change in many ways. When artificial regeneration is practised the growing space of the trees is generally decided immediately the stand begins to develop and it often becomes considerably more spacious than in natural forests. Moreover, overshadowing by broad-leaved trees and their competition for growing space are absent or slight. Later thinnings of plantation-grown pines affect, furthermore, both the size of the branches and the natural pruning of the stem.

The wood quality of plantation-grown pine may be influenced also by e.g. the means offered by the breeding of trees and soil improvement. If the aim is merely to increase growth, the measures may also have detrimental effects on wood quality, e.g. on branchiness and basic density

(Schöpf 1954, Nilsson 1968). Reforestation of former fields is a factor that also affects the wood of plantations, for the areas selected in the past for farming were the best in regard to soil and richest in nutrients.

Plantation-grown pines have an average yield higher than that of natural forests, which implies fast growth of individual trees also. The changes that take place in the external characteristics of wood quality, branchiness and self-pruning, cannot avoid influencing also the anatomical structure of wood and the internal characteristics that portray wood itself. It is possible to harvest timber from plantation-grown pines in a slightly earlier phase of development than from natural forests, and this too is of importance for wood quality and serviceability.

Extensive interference of man with the evolutionary process of nature often has harmful consequences. If forest regeneration work creates favourable propagation conditions for, for instance, certain injurious insect species in the form of widespread logging areas and homogeneous »cultural forests», the result may be an outbreak of unexpected devastation. Not only quantitative but also qualitative losses are always associated with phenomena of this kind, even in mild cases.

Expansion of reforestation activity and other associated measures which change growth conditions thus bring new problems related to the utilization of wood. The reforestation technique itself and soil improvement questions have been studied relatively extensively, whereas examination of the effect of the different measures on wood quality has been the subject of rather summary and inadequate studies.

The present study is in its subject matter not only wood-technological but partly also silvicultural, for the silvicultural aspects of the importance for wood quality both of the establishment of a seedling stand and its treatment cannot be totally disregarded. The effect of silvicultural measures on wood quality emerges in different connections, although the main purpose is to describe from a technical point of view the quality of wood and timber and the factors affecting it. It may be mentioned, too, that silvicultural and wood-technological points of view are closely connected especially in cultivated stands and both should be taken into consideration today and in the future e.g. when the field afforestation programme is implemented.

The aims of the study in main outline were as follows:

— To throw light on the quality of timber, chiefly with reference to sawlogs, the development of quality as judged by external stem characteristics and various factors relating to stand development.

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— To examine the variations in pine plantations of wood quality characteristics significant for the purposes of wood utilization and their correlation with environmental and other factors.

— To throw light on the connection between and interdependence of wood quality and various external characteristics illustrative of quality.

— To compare the timber and wood characteristics of natural and cultivated pine stands.

## 2. REVIEW OF THE LITERATURE

Heikinheimo (1953) mentioned branchiness and knottiness as characteristics that illustrate the amount of branches. The former denotes the abundance of branches outside the stem surface and the latter the number of branches inside the wood. Branches refer in the present work to branches outside the stem.

The stem may be divided on the basis of branches into a branchless, dry-branched part of the stem, stem with overgrown knots, and the crown (e.g. Krotkevitsš 1955, Krigul 1961, Heiskanen 1965). The longer the branchless butt and the smaller the knot bumps and branches are, the better the utilization value and quality of the stem.

The effect of habitat and the planting and seeding space on branch thickness and branchiness in cultivated stands was studied by e.g. Klem (1944 and 1952), Chroust (1958), Nylander (1959), Klebingat (1962), Richards et al. (1962), Stiell (1964), Danšín (1966), Merkel (1967), Wright (1967) and Mráček (1969). The pronounced effect of spacing at establishment on branch thickness, particularly in the young phase of the stand, has been noted (e.g. Bramble et al. 1949, Guilkey and Westing 1956, Cromer and Pawsey 1957, Stiell 1966, Lehto and Yli-Vakkuri 1969, Evert 1971). The effect of the original planting spacing on the self-pruning of the stem and on the size and shape of the crown was shown by e.g. Erteld (1967) and Berry (1970). However, thinnings and removal by self-thinning weaken the effect of the original seedling density increasingly as the stand ages (Nylander 1959).

According to Heiskanen (1954, 1955 and 1965), Nylander (1958) and Grah (1961), there is a distinct correlation between the largest branch of the pine stem, tree diameter and the quality of the butt log. Indeed, Koltzenburg (1954) stated that on better sites pine requires a dense planting spacing and that the number of stems must be kept high even in the later phases of stand development. Yli-Vakkuri (1958) stated that from the point of view of sawlog quality the selected site should at least not be better than fairly poor Myrtillus type (MT). In his study

of the effect of the nutrient content of the growing site on the quality of sawlogs from plantations growing *Pinus radiata*-pine, Wright (1967) noted that not only branch size but also bark thickness grows and the crown limit rises when the fertility of the site increases. Factors that influence growth, such as nutrient content and growing space, correlate distinctly with crown size and form (Bennett 1960, Žilkin 1960, Hall 1965). Although growing conditions in naturally regenerated forests differ from the environmental conditions of plantation forests, studies of the former yield information on the self-pruning of stems and the development of branchiness that is applicable to cultivations (Heikinheimo 1953, Koltzenburg 1954, Heiskanen 1965).

Stem taper cannot be regarded as a defect, although abnormally great tapering lowers the utilization value of wood like damage does. Taper may be considered in many respects to be one of the indicators of the quality of sawlog stems (Volkert 1941, Venet 1958, Ralston and McKinnes 1964, Turolski and Bucholz 1964, Chojnacki 1969). The development of stem form depends e.g. on the light conditions in the stand and the age of the tree (Lohrey 1961, Berry 1965).

Tree growth and the development of stem form follow certain known laws and stem form may be related to the changes that occur in crown size and the height of the branchless part of the stem (Larson 1963). Kano and Saito (1970) also observed the correlation between stem form and branch diameter.

The changes of reducing crookedness and sweep by silvicultural means are small, apart from the removal of defective trees. On the other hand, it is possible to regulate stem taper and crown shape directly by controlling the number of stems.

Great tapering of wood is regarded in Central Europe as a serious value-reducing defect, whereas in the Nordic countries, the USSR and USA this property does not affect the value of sawlogs at all in the classification instructions (Heiskanen 1968 a). The negative features of sharp tapering in the sawmill industry are, however, an increase in the number of short slabs in the sawing yield and cross-grainedness (Heiskanen 1968 b).

Defects that reduce the technical quality of the stem may be caused by various external factors which damage the tree, internal growth disturbances and environmental or genetic factors. Sweep and crookedness of the stem are the commonest and most important stem form defects. It is often difficult to draw a dividing line between the two, but sweep includes bending whereas sharp changes in the form of the stem may be called crooks.

Juutinen (1962) and Kangas (1962) studied the crookedness and forkedness of Finnish pine and the factors affecting them. Galas (1933) and Guilkey (1958) considered the snow load and fractures to be the principal reasons for crookedness and sweep. Butt crooks and sweep were observed by Moss (1971) in trees of the fastest growing provenances of *Pinus contorta*.

On a good site, sweep often appears to be a defect associated with fast growth. König (1958) stated that the correct selection of site and site and climatic strain are important for reducing sweep in pine. The importance of form defects, sweep and crooks, in sawlogs depends not only on the magnitude of the defect but also on their position in the stem. A stem crookedness is a great disadvantage especially in the mechanical forest industry. Sweeps and crooks in sawlogs increase raw material consumption by shortening and narrowing the sawing yield and lowering the quality of sawn timber (Heiskanen 1970). Crookedness is always more serious than sweep, for the quality loss in sawing swept sawlogs can be diminished at least to some extent by guiding the log (Heiskanen 1968 b).

Simes (1957) reported that the sawlog consumption in cubic feet increases by approx. 50 cu.ft./standard when the sweep of the logs increases to 6—9 cm.

Compression wood is a defect inside the stem that lowers the technical quality and utilization value of wood. The composition and properties of compression wood have been studied by e.g. Ollinmaa (1955), Dadsell et al. (1958) and Shelbourne and Ritchie (1968). There is almost always compression wood in branches and roots, but its practical significance is small there (Haught 1957 and 1958, Zobel and Haught 1962). The origin of compression wood is generally associated with stem crookedness and sweep (e.g. Jalava 1952, Vakin et al. 1969).

The worst property of compression wood for utilization value is its marked shrinkage in the longitudinal direction which causes twisting, splitting and rupturing of timber that contains it (e.g. Knigge 1958, Perem 1958, Heiskanen 1970).

Ring width depends chiefly on the tree species, growing conditions, age of the tree and mechanical effects (Jalava 1952). The width of the annual ring generally decreases from the pith to the surface as the tree becomes older (Mikola 1950, Schultze-Dewitz 1958). Variation in ring width is the cause of the difference in many physical and technical properties of wood between the inner and superficial parts of the stem. There is also longitudinal variation in ring width and in the juvenile wood zone. Wood characteristics are consequently different also at different

stem heights. The significance of ring width has been studied in investigations concerned with the percentage of late wood and basic density in pine. According to several studies, the percentage of late wood varies but is generally independent of ring width (Larson 1957, Klem 1969 and 1970, Kobylinski 1969). However, some authors have reported that the percentage of late wood decreases when ring width increases or decreases considerably (e.g. Jalava 1952, Hakkiila 1968). Pechmann (1958), on the other hand, stated that the proportion of late wood is not dependent on ring width except in extreme cases when the annual rings widen especially for some reason or the tree suffers from nutrient deficiency. When the ring width is 1.0—1.5 mm, the percentage of late wood is at its highest (e.g. Siimes 1938, Skripen and Riasova 1958).

The connection between ring width and wood density in softwood trees has been studied by, among others, Volkert (1941), Zobel and Rhodes (1955), Yandle (1956), Larson (1957), Rendle and Phillips (1957), Paul (1960), Knigge (1961), Sellers (1962), Mitchell (1964), Ralston and McGinnes (1964), Klem (1969), Kobylinski (1969).

Ring width, especially around the pith of the tree, has been shown to give the best idea not only of wood strength but also of the size of the knots inside the wood (Heiskanen 1954).

The importance of the growing rate for the mechanical properties of wood — mainly strength — has been discussed by Kramer and Smith (1956), Venet (1958) and Klem (1970). Lubardić and Nikolić (1970) reported that wood of plantation-grown pines was poorer than that of natural forests in its strength properties.

The percentage of late wood also displays variation longitudinally and transversally to the stem (e.g. Schultze-Dewitz 1958, Sellers 1962, Hakkiila 1967). The percentage of late wood rises evenly in pine from the pith towards the surface, that is, from older to younger annual rings (e.g. Hakkiila 1967).

The effect of various growth and environmental factors on the percentage of late wood has been studied by e.g. Harris (1955), Larson (1957), Pechmann (1958), Edlin (1965), Baker (1969) and Klem (1969).

Strength is an important property, especially for sawlog and sawn timber quality. Late wood with reference to strength characteristics of pine wood has been studied by Kobylinski (1969), Lubardić and Nikolić (1970), and others. The percentage of late wood determines to a great extent both the pulp yield and the properties of paper in the pulp industry (Mitchell 1961, Watson and Dadswell 1964).

Barefoot et al. (1964) mentioned that the thickness of the cell wall of late wood explains 74 per cent of the variation in strength characteristics of paper in *Pinus taeda*.

The percentage of late wood is generally also an important factor affecting basic density in the pine (e.g. Pillow 1955, Zobel and Rhodes 1955, Hakkila 1966, Schalk 1967, Kobylinski 1969, Elliott 1970, Lubardić and Nikolić 1970).

It is mainly because of the late wood percentage that basic density increases with age until a certain phase of development when the vitality of the tree begins to wane. Basic density is thus lower in young trees with a high growth rate than in old and slow-growing trees (e.g. Zobel et al. 1972). It has been noted that the basic density of plantation-grown pine trees is lower than that of naturally regenerated stands of corresponding age (Olson et al. 1947, Giordano 1951, Pillow 1952, Miyajima 1958, Baker 1967). The significance of site for basic density is pointed out in several studies (Göhre 1958, Jayne 1958, Tamminen 1962, Zobel et al. 1965).

Also regional differences and racial characteristics cause differences in basic density (Skripen and Riasova 1958, Zobel and Thorbjørnsen 1960, Goddard and Strickland 1962, Mitchell 1964, Gilmore 1968, Hakkila 1968).

In addition to stem-to-stem and stand-to-stand variation, the basic density of the pine stem changes from the pith both radially and longitudinally to the stem. Within-stem variation of basic density in pine has been studied in Finland by Jalava (1952), Hakkila (1966), and Hakkila and Panhelainen (1970), and in other countries by e.g. Spurr and Hsiung (1954), Göhre (1958), Stojanoff et al. (1958), Maeglin (1966), Okkonen (1968), Elliot (1970).

A problem of interest from the point of view of practical silviculture and for users of wood is the effect of various silvicultural measures on basic density in plantations growing different pine species (Jayne 1958, Echols 1959, Geyer and Gilmore 1965, Hamilton and Matthews 1965, Jackson 1968, Rudman and McKinnell 1970).

According to several authors (Elliott 1970), basic density decreases in young stands of some foreign conifers by 9—15 per cent in the years immediately after fertilization. Basic density reduction of about 3—5 per cent by fertilization were obtained by Saikkku (1973 b) in his roentgenological study of the density of individual annual rings. However, there are investigation results indicating that fertilization has no effect or that it even has a basic density-increasing influence (Echols 1972, Gooding and Smith 1972, Smith et al. 1972). The degree and route of influence

of fertilization obviously depend largely on the growth rate of the tree, that is the annual ring width, at the time of fertilization (cf. *Salonen 1973*).

The heartwood percentage of pine stems is also associated with the above-mentioned characteristics that describe wood quality, especially with the growth rate of wood. The physiological importance of heartwood for the tree is probably mainly the support it provides against external forces. The protection against injurious fungi provided by many substances accumulating in heartwood and their role in the chemical conversion of wood are known. Furthermore, the larval galleries of injurious insects do not generally penetrate to the region of heartwood. Heartwood is consequently also a useful property for portraying wood quality.

Heartwood is formed around the pith of a tree when the cells of the innermost parts of the sapwood die and flows of liquid cease. Heartwood and sapwood differ in, for instance, chemical composition, weight, moisture content and strength of wood (*Cohen 1962*, *Browning 1967*). The formation of heartwood begins at the age of 30—40 years in Finnish pine, but north-south geographical variations occur in the time of starting (*Bruun and Willberg 1964*). The heartwood percentage increases with age, but is correlated negatively with the growth rate (*Edlund 1966*, *Hakkila 1968*, *Heiskanen 1970*).

Studies on heartwood have been published by e.g. *Eneroth (1922)*, *Hägglund (1935)*, *Lappi-Seppälä (1952)*, *Nyländer (1961)*, *Rudman (1966)*, and *Hakkila (1967 and 1968)*. The study by *Kärkkäinen (1972)*, based on the literature deals with the within-stem and stem-to-stem variation of the heartwood percentage.

### 3. INVESTIGATION MATERIAL AND METHOD

#### 31. Investigation material

The investigations were limited regionally to plantation-grown pines in South Finland which had already reached the minimum size for harvesting. The lower age limit was thus in practice approx. 20 years, depending on the growth rate of the stand. The original intention was to accept only stands for which there was accurate information on origin, e.g. the method of establishment and treatment. However, especially for old stands, the data had often been lost or were based on faint memories of information. The requirement of complete information had therefore to be lowered in order to ensure a sufficiently comprehensive investigation material.

The material was collected in 1968—1969 from the localities shown in Fig. 1. The localities extended geographically from the 60th parallel to slightly about 63° lat. The differences in the height above sea level of the localities weaken to some extent the comparability of wood quality by locality. For example, the southernmost investigation areas, Tuusula and Bromarv, are an average of 60 and 20 m and the northernmost areas, Koli, Viitasaari, Kivijärvi and Karstula, about 145, 115, 135 and 150 m above sea level. The variations in temperature and precipitation of the localities were probably also of some significance for the increment of trees.

Of the total of 92 sample stands, 23 were situated in the experimental areas of the Finnish Forest Research Institute, 63 on land owned by the National Board of Forestry and six in areas owned by companies.

The sample stands were distributed as follows by soil type: Oxalis-Myrtillus type (OMT) 12.0 per cent, Myrtillus type (MT) 31.4 per cent and Vaccinium type (VT) 56.6 per cent. The forest site type was determined in the field from the type plants of the vegetation, using data provided by the records or reforestation blank form whenever available. The mean volume of the sample stands was 132 cu.m./hectare and basal area 20 sq.m./hectare.

The sample stands had usually been treated by normal release cutting and thinning, but this had been delayed in some stands. Only one sample plot was in a middle-aged unthinned stand which belonged to an experi-

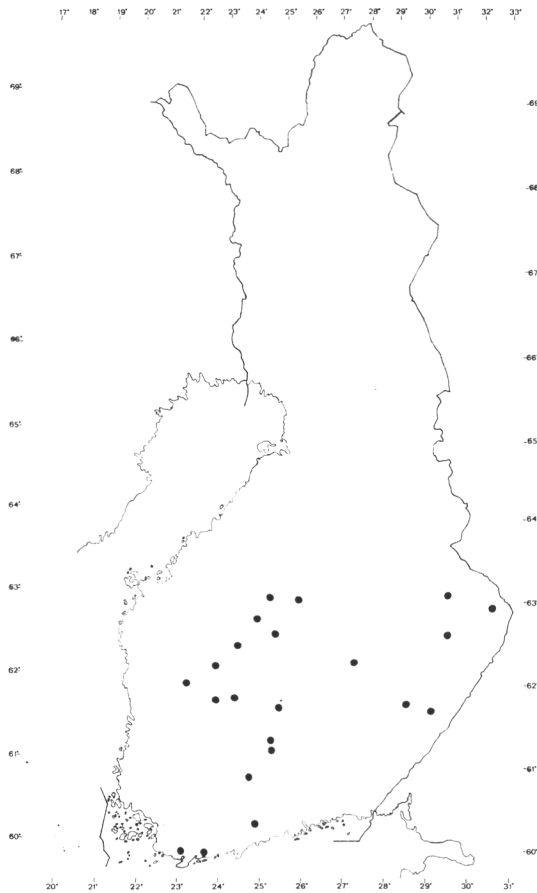


Fig. 1. Location of the investigation sites.

*Kuva 1. Tutkimuspaikkojen sijainti*

mental plot under study for the effect of thinning on yield. Pruning, too, had been carried out in some stands, but the diameter of the branches on the stem and the degree of self-pruning was not measured in these stands.

Comparison of the basal areas of pine plantations with those of Mäkinen's (1958) natural pine stands and seeded stands treated with repeated thinnings showed the sample stands to be denser at an early age and to approach normal with advancing age. If the results are compared with the target basal area values reported by Nyysönen (1954) for pine stands treated with cutting, or with the density of Kalli'o's (1960) seeded pine stands, the pine plantations of VT-type are almost normal in their basal area whereas the stands of MT-type are a little too thin (cf. also Vuokila 1967). If a similar comparison is made between the

volumes of the stands, the growing stock of 40-year-old MT-stands is also below normal whereas the volume of VT-stands is comparable with the mean presented by Nyysönen for the age class in question.

Standing and felled sample trees which totalled 2 760 and 460, respectively, gave the following core material:

Cores from standing trees .....	5 500	units
Cores from felled trees .....	3 600	»
Total .....	9 100	»

In addition, approx. 480 discs were taken from felled sample trees.

Some figures denoting the characteristics of the sample trees are given in the following. The mean diameter and height of the sample trees were slightly greater than the measuring results reported by Kallio (1960) for seeded pine stands of corresponding age.

	$\bar{x}$	s
Age, years .....	42.0	14.5
Diameter, cm .....	15.0	6.1
Height, m .....	13.4	4.7
Volume, solid cu.m. ....	0.164	0.02
Tapering, cm .....	3.4	1.3
Crown height, m .....	5.4	2.4
Crown proportion, % .....	44.2	23.9

Table 1 shows the distribution of the material by age class and forest type.

Table 1. Age class distribution of the sample trees by forest site type in accordance with measurements made at breast height and above bark

*Taulukko 1. Koepuiden ikäluokkakautuma rinnantasalta kuoren päältä suoritettun mittauksen mukaisesti metsätyyppiin*

Age, years <i>Ikä, vuotta</i>	Forest site type <i>Metsätyyppi</i>		
	VT	MT	OMT
	Number of stems, per cent of the total material <i>Runkojen lukumäärä, % kokonaismäärästä</i>		
—20 .....	2	3	1
21—30 .....	5	3	—
31—40 .....	26	9	5
41—50 .....	15	7	2
51—60 .....	5	4	—
61—70 .....	1	3	—
71—80 .....	—	3	3
80+ .....	1	—	—
Total — <i>Yhteensä</i>	56	32	12

Seedlings and seed were generally of local origin, although information was often missing on this point. The material was distributed as follows by the method of cultivation.

Method of cultivation	Sample plots, units
Planting .....	15
Patch sowing .....	52
Broadcast sowing or broadcast sowing on the snow crust .....	18
Not known .....	7
Total .....	92

Information about the density of planting and seedling was usually available from old cultivation cards, but it was necessary in some stands to measure the distances between stems and stumps. The commonest planting and seedling space was  $1.5 \times 1.5$  m, and the smallest and largest patch or planting hole distance  $1.2 \times 1.2$  m and  $2 \times 2$  m.

### 32. Investigation method

#### 321. Measurements

Plantations meeting the requirements set and for which the information was obtained were selected as the sample stands in the area of the Finnish Forest Research Institute and the companies in question. In the supervisory areas of the National Board of Forestry the stands were selected by lot from among the available plantations. The location and size of the sample stand were first determined from the map as far as possible and then by inspection in the field. The sample plot was located in a part of the stand that represented a uniform area typical of the stand in topography and growing stock. If the plantation had failed or the growing stock was seriously damaged for some reason in a part of the compartment, it was rejected as unsuitable for a sample plot. Similarly, only plantations of pure growing stock which had been established in mineral soil and had developed normally when examined by the naked eye were accepted for the study. General information on the growing stock and data on the establishment and treatment of the stand, etc., were entered for each sample plot on a separate sample plot form.

Thirty adjacent unselected stems in a restricted and unbounded area were selected at random as sample trees. The trees were numbered. In most of the sample stands 2—6 stems from among these sample trees were drawn by lot for felling.

The following measurements and classifications were made on the standing sample trees:

*Diameter* was measured on the side which the worker happened to be facing at breast height above bark to the nearest centimetre. The *height* of the tree was measured by Blume-Leiss hypsometer to an accuracy of

$\frac{1}{2}$  m. If the growing stock was short a long-shafted caliper was used to measure height.

*Crown limit* was measured at the same time as tree height.

*Crown class* and *tree class* were determined in accordance with the classification employed in the National Forest Inventory (A n o n. 1971).

*Taper* was determined as the difference of the 1.3 m and 6 (3.5) m diameters.

The lower limit of *the part of the stem with overgrown knots* (knot bumps) was measured in full decimetres.

The lower limit of the part of the stem with *dry branches* was measured in full decimetres down to the lowest dry branch. If there were no knot bumps in the stem, the point of origin of dry branches was entered as the knot bump limit.

The *quality class of the butt log*, that is the quality class of the part of the stem butt 18 ft. in height and meeting the log minimum measurement at the top was determined both on the basis of branchiness and by taking the possible stem defects into consideration. The quality classification was performed according to the recommendation made by the Committee on Business Letter Forms in 1966 and the quality classification instructions drawn up by the Finnish Forest Research Institute and the State Institute for Technical Research (H e i s k a n e n 1970).

Wood *defects* refer here chiefly to defects outside the stem that impair the technical quality of timber. Defects in the anatomical structure of wood were disregarded, with the exception of compression wood observations which were made on the stumps of felled sample trees. The main defects seen in the material may be described as follows.

*Crooks* are sharp changes in the longitudinal form of the stem which make relatively small angles with the axis of the tree (E r t e l d et al. 1964). Crooks may be grouped in many ways, according to their form, location and importance, but in this work the distinction was between *butt crooks* and *stem crooks*. The former denote a sudden bend in the root collar or its immediate proximity and the latter a bend elsewhere in the stem.

*Sweep* refers to an even deviation from the straight line formed by the pith of a tree; the degree of sweep is measured as the maximum distance from the imaginary straight line drawn between the two ends of a piece of wood.

*Fork* is formed by two or more stems that are joined at the butt or by the bifurcation of a lateral branch at some height of the stem. When the side shoot supplants the leading shoot because of damage that it has sustained, a *vertical branch* often forms. Classified as a separate defect from this is the *great-branchiness* resulting from branches that are abnormally

large. Other defects encountered in the material were *cankers*, usually the result of damage caused by an external factor, and a defect which was manifested primarily as the drying of the tree and was usually entered as a disease.

*Pine blister rust*, though a disease, was treated as a separate defect because of its lowering effect on the technical quality of timber.

In addition, the following measurements and estimates were made for felled sample trees:

*Branch diameter* was measured at the relative height of 10, 20, 30, 50 and 80 per cent in full millimetres and, to establish the size of stem branches, also at the height of 40, 60 and 70 per cent in a part of the material. Branch diameter at a given level was obtained by measuring at right angles to the longitudinal direction of the tree the thickest branch of the whorl of branches above the basal knob. *Dead or dry branches* and *living branches* were distinguished from one another.

*The thickest dry branch* of the stem was measured.

The length and diameter of the *longest living branch* and the height of the site of origin of the branch from the butt of the tree were measured.

The height of the *lowest living branch* from the butt of the tree was measured.

Observations were made on *compression wood* at the cutting height of the tree.

### 322. Collection of wood samples

Two 5.5 mm thick increment cores extending from surface to pith were taken at breast height from all the stems of the sample stand. The stem was bored on the side the worker happened to be facing, but surface defects, knots and compression wood inside the stem were avoided. The sample was usually taken by boring right through pith. The two cores made it possible to eliminate variation in the wood characteristics on different sides of the stem. In addition, cores were taken from felled sample trees at 10 per cent steps from stump height to 90 per cent height if stem diameter still satisfied the 3 cm diameter criterion at that point. The boundary between heartwood and sapwood was marked immediately on the cores on the basis of colour and moisture differences.

One to two stems were drawn by lot from among the felled trees in the sample stand and approx. 4 cm thick discs were sawn from them, likewise at 10 per cent relative height intervals. The discs were used as control material with the cores for the study of variation of longitudinal basic density and heartwood percentage.

### 323. Treatment of wood samples

As wood properties change in the radial direction of the stem they were studied separately in the outer and inner parts of the stem. The core was divided into three parts by the method worked out by Ericson (1959) to prevent the part around the pith from being over-weighted in the calculation of mean density. The parts of the core then represented 10, 40 and 50 per cent from the cross-section area of the tree as a whole. Short cores (length 2.5—4.0 cm) were divided into two parts only, representing 30 and 70 per cent, and even shorter cores were treated as such. These relative figures were used as weight figures in the calculation of the mean core density.

Basic density (kg/solid cu.m.) was determined from the cores by the mercury immersion method employed in several studies (e.g. Ericson 1960, Hakkilä 1966, Hakkilä and Uusvaara 1968). Core volume was measured when the wood was of green timber volume, and weight after the cores had been dried. Drying was done at a temperature of 104° C for 48 hours. As the cores were air-dried, in order to prevent decay, they were restored to their original green volume by soaking in water.

Disc weight was measured by weighing, also with the discs absolutely dry. Volume was determined from the displacement when the disc was immersed in water. The too high volume values for the cores given by the mercury method were corrected by using the discs as control material. The difference in the mean stem basic density with these two methods was 18 kg/solid cu.m. The core densities at different stem heights were corrected using the following regression equation (Fig. 2).

Correction equation	R	S <sub>y·x</sub>
$Y = -8.6697 + 1.0629 X \dots\dots\dots$	0.915	13.3

Y = basic density, kg/solid cu.m. on the basis of discs  
 X = basic density, kg/solid cu.m. on the basis of cores

The basic density of a pine stem is considerably greater at the butt than elsewhere in the stem and decreases evenly towards the top, depending on the species in question. Hence, a sample taken at breast height gives too high a value for average basic density compared with the mean. The mean stem basic density is generally achieved around quarter height (Nylinder 1961, Hakkilä 1966). The breast height values were corrected in the following way with the means of the disc material (Fig. 3).

Correction equation	R	S <sub>y·x</sub>
$Y = 78.4374 + 0.7905 X \dots\dots\dots$	0.849	14.2

Y = mean density on the basis of discs  
 X = mean density on the basis of breast-height cores

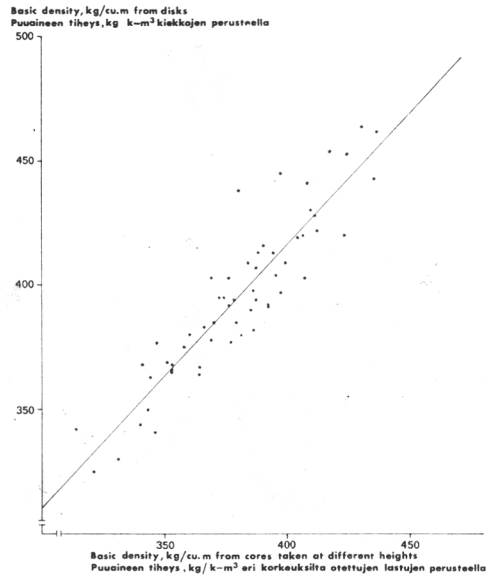


Fig. 2. Correction of basic density calculated from cores taken at different stem heights.  
*Kuva 2. Rungon eri korkeuksilta otettujen lastujen perusteella lasketun tiheyden korjaaminen*

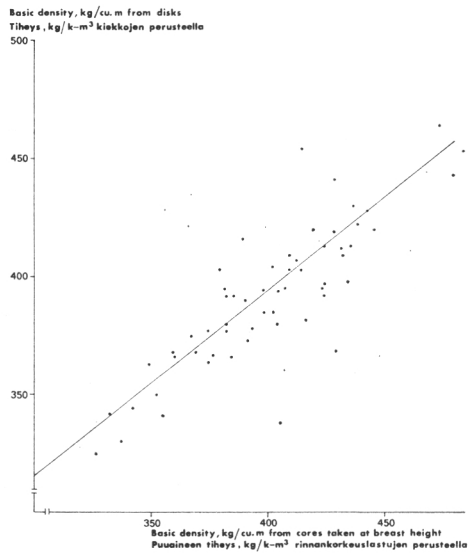


Fig. 3. Correction of basic density calculated from a core taken at breast height.  
*Kuva 3. Rinnankorkeudelta otetun lastun perusteella lasketun tiheyden korjaaminen*

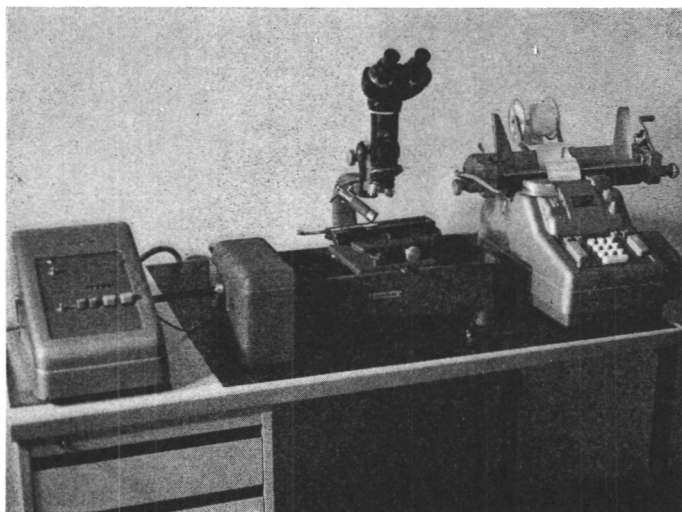


Fig. 4. Annual ring meter used for measuring the annual ring width and percentage of late wood.

*Kuva 4. Luston leveyden ja kesäpuuprosentin mittaamiseen käytetty lustomittari.*

The quantity of heartwood was first measured in accordance with the heartwood boundary made on the cores in the field at the same time as the cores were divided into 2—3 parts as described above. The length of the heartwood part and the core as a whole was measured to the nearest mm and the percentage of heartwood was calculated as the ratio of the heartwood area and the entire cross-section area of the tree.

The disc material was again used as control material and the discs were treated with benzidine which stained the heartwood part brownish red. It was now observed that the heartwood percentages obtained on the basis of the moisture boundary were slightly higher than in reality. The cores were then dipped in bromphenol solution in a test tube before the heartwood percentage was measured. The staining solution was prepared by mixing 0.0413 g of bromphenol blue in 100 ml of water; the solution stained the heartwood part yellowish colour and the sapwood blue (K u t s c h a and S a c h s 1963).

For the determination of ring width and late wood proportion the core pieces were soaked in water to restore the original dimensions of the cells and facilitate the preparation of the core surface for microscopic examination. To level the surface, the rough surface part of each core was cut away by microtome after which the ring width and late wood and early wood proportions were determined with an annual ring meter (Fig. 4). The device measures to an accuracy of 0.01 mm.

## 4. RESULTS OF THE STUDY

### 41. External characteristics illustrative of wood quality

#### 411. Defect-free stem, stem with knot bumps and dry-branched part of the stem, and crown

The results for parts of the stem of differing branchiness are given in Figs. 5—8 and Tables 2—6. The average knot bump limit of a plantation-grown pine stem at the age of 60 years is the same in practice as the branch

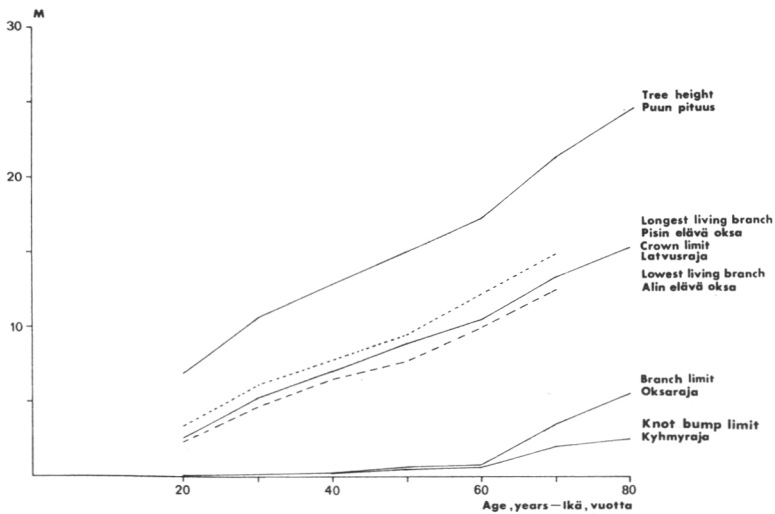


Fig. 5. Development according to age of tree height, location of the longest living and lowest living branch and stem parts of different branchiness in pine plantations.

*Kuva 5. Puun pituuden, pisimmän elävän ja alimman elävän oksan sijainnin sekä oksaisuudeltaan erilaisten rungonosien kehitys iän mukaan viljelymänniköissä*

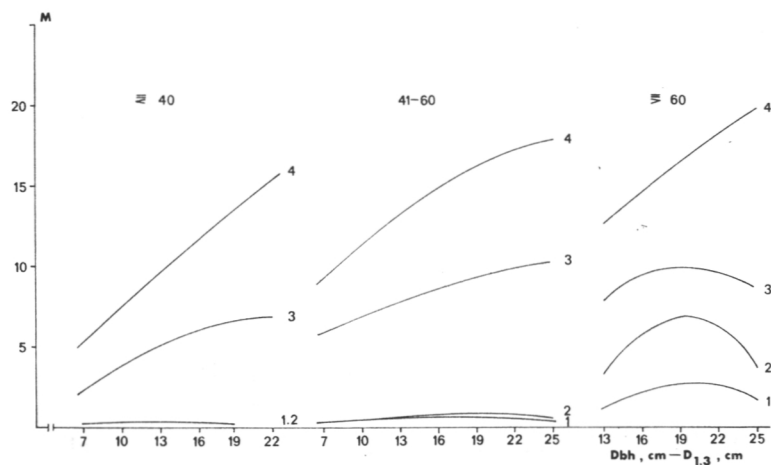


Fig. 6. Variation by Dbh (breast height diameter) and age class of the height of the knot bump-, branch- and crown limit and the tree height of plantation-grown pine stems. VT 1)

1 = knot bump limit, 2 = lower limit of dry branches, 3 = crown limit, 4 = tree height.

Kuva 6. Viljelymäntyrunkojen kyhmy-, oksa- ja latvusrajan piteuden sekä puun piteuden vaihtelu rinnankorkeusläpimitta- ja ikäluokittain. VT 1)

1 = Kyhmyraja, 2 = Kuivien oksien alaraja, 3 = Latvusraja, 4 = Puun piteus

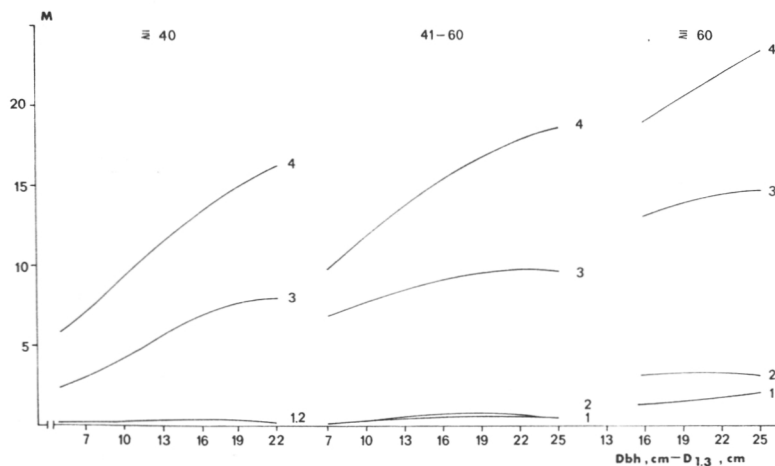


Fig. 7. Variation by Dbh and age class of the height of the knot bump-, branch- and crown limit and the tree height of plantation-grown pine stems. MT 2)

1 = knot bump limit, 2 = lower limit of dry branches, 3 = crown limit, 4 = tree height.

Kuva 7. Viljelymäntyrunkojen kyhmy-, oksa- ja latvusrajan piteuden sekä puun piteuden vaihtelu rinnankorkeusläpimitta- ja ikäluokittain. MT 2)

1 = Kyhmyraja, 2 = Kuivien oksien alaraja, 3 = Latvusraja, 4 = Puun piteus

1) Vaccinium type — Puolukkatyyppi.

2) Myrtillus type — Mustikkatyyppi.

limit, i.e., there is no stem with overgrown knots at all. The branchless part of the stem, which is then only about 3 per cent of the total stem height, is 17 per cent of it at the age of 70 and 22 per cent at the age of 80 years. However, approximately a half of this part of the stem contains knot bumps.

Crown limit rises evenly with the age of the tree and the crown proportion of tree height decreases. For instance, the crown proportion is 63 per cent at the age of 20 years and decreases to 41 and 27 per cent of the tree height by the time it reaches 50 and 80 years, respectively. The following regression equations can be used to illustrate the correlation between the height of stem parts with differing branchiness and the age of the tree.

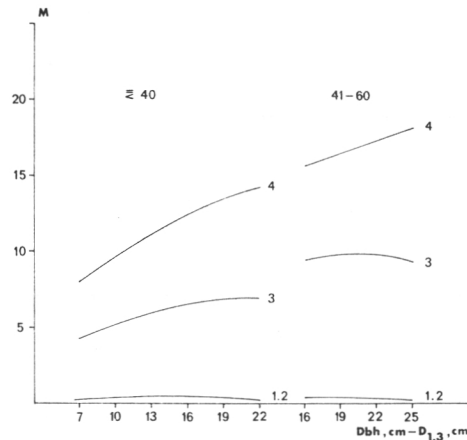


Fig. 8. Variation by Dbh and age class of the height of the knot bump-, branch- and crown limit and the tree height of plantation-grown pine stems. OMT<sup>1)</sup>

1 = knot bump limit, 2 = lower limit of dry branches, 3 = crown limit, 4 = tree height.

*Kuva 8. Viljelymäntyrunkojen kyhmy-, oksa- ja latvusrajan piteuden sekä puun piteuden vaihtelu rinnankorkeusläpimittä- ja ikäluokittain. OMT<sup>1)</sup>*

1 = Kyhmyraja, 2 = Kuivien oksien alaraja, 3 = Latvusraja, 4 = Puun pituus

Part of stem	Regression equation	$\bar{x}$	R	$S_{y-x}$
Knot bump limit . . . . .	$Y_1 = -0.944 + 0.034 X$	0.48	0.656	0.572
Branch limit . . . . .	$Y_2 = -1.412 + 0.048 X$	0.60	0.600	0.935
Crown limit . . . . .	$Y_3 = -1.064 + 0.203 X$	7.43	0.791	2.284
Tree height . . . . .	$Y_4 = 1.867 + 0.275 X$	13.38	0.854	2.441

$Y_1$  = height of the part of the stem with knot bumps, m

$Y_2$  = height of the dry-branched part, m

$Y_3$  = height of the crown limit, m

$Y_4$  = tree height, m

X = age of the tree, years

Age explains only 36 per cent of the variation in the height of the branchless part of the stem and 43 per cent of that in the height of the knot bump-free part. The explanation percentages arrived at when the effect of different factors illustrating stem on the height of the branchless stem part was tested by regression analysis were not superior to these percentages. The low correlation was probably due to the minimal variation of the height of the branch limit, the great number of zero observations, that is of stems branched down to the ground, measuring errors and genetic factors.

<sup>1)</sup> Oxalis-Myrtillus type — Käenkaali-Mustikkatyppi.

Table 2. Tree height, knot bump limit and the lower limit of dead and living branches, by age classes

Taulukko 2. Puun pituus, kyhmyraja sekä kuolleitten ja elävien oksien alaraja ikäluokittain

Age, years <i>Ikä, vuotta</i>	Knot bump limit, dm <i>Kyhmy- raja, dm</i>		Lower limits of branches, dm <i>Oksavyöhykkeiden alaraja, dm</i>			Lowest branches, dm <i>Alimmat oksat, dm</i>		Tree height, dm <i>Puun pituus, dm</i>		
			Dead <i>Kuolleet</i>		Living <i>Elävät</i>	Dead <i>Kuolleet</i>	Living <i>Elävät</i>	$\bar{x}$	s	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$			s
20 .....	1	1	1	1	27	9	1	1	69	14
30 .....	3	2	3	2	54	19	3	3	107	26
40 .....	3	2	3	4	70	17	2	2	129	25
50 .....	5	4	6	5	89	40	6	5	150	27
60 .....	3	2	4	4	105	11	4	5	173	17
70 .....	21	13	36	23	133	25	35	17	214	31
80 .....	27	11	56	9	154	20	53	1	244	21

The equations illustrate the development of different branchiness characteristics and height only in the present material and the results are not applicable to pine stands in general. The development of the height and branchiness characteristics of pine stands has been studied by e.g. Nyysönen (1954) and Kallio (1960). Vuokila (1965) compiled increment functions for density yield tables of pine.

The absolute height of stem parts differing in quality and branchiness increases with age, but their relative height depends on the growth rate, that is, the nature of the growing site and the growing space (cf. Heiskanen 1965, Vencenosceva 1967). The thinnest trees have relatively the smallest crown within a certain age class and, correspondingly, the longest dry-branched part of stem and the smallest length of branchless stem and part of the stem with knot bumps (Figs. 6—8). However, very young trees whose branches have not yet begun to die and whose crown is relatively high are an exception. When the stem diameter increases, the crown decreases to begin with and at the same time the self-pruned and dry-branched part lengthens correspondingly until a certain diameter when the relative branchiness of the stem increases again. Trees of medium diameter have the best stems as regards branches within the age class. Thin trees are either suppressed trees, individuals suffering from lack of light or otherwise slow-growing trees whose branches, though obviously thin, fail to heal over an account of poor growth. On the other hand, the branches of especially thick trees are thick and thus remain alive for a long time or keep on the stem as dry branch stubs.

The branchless part of the stem and stem without knot bumps is considerably longer in the Vaccinium-type than in coeval Myrtillus-type stands. The difference is particularly evident in mature pine stands over

Table 3. Height of the knot bump-, branch- and crown limit and the tree height, by diameter and age classes. VT<sup>1)</sup>  
*Taulukko 3. Kyhmy-, oksa- ja latvusrajan korkeus sekä puun pituus läpimitä- ja ikälukokittain. VT<sup>1)</sup>*

Dbh, cm <i>DI.3, cm</i>	Knot bump limit — <i>Kyhmyrāja</i>				Branch limit — <i>Oksarāja</i>				Crown limit — <i>Latvusrāja</i>				Tree height, dm <i>Puun pituus, dm</i>	
	dm		%		dm		%		dm		%		$\bar{x}$	s
	$\bar{x}$	s	x	s	$\bar{x}$	s	x	s	$\bar{x}$	s	$\bar{x}$	s		
— 5	2	2	2	2	1	2	2	2	24	11	43	12	54	11
6—8	2	2	2	2	2	2	2	2	35	17	50	48	71	16
9—11	2	2	2	2	1	2	2	2	49	16	50	12	97	17
12—14	2	2	2	2	2	2	2	2	61	16	51	11	119	15
15—17	3	3	2	2	3	3	2	2	64	16	48	9	132	14
18—20	2	2	1	1	2	2	2	2	68	16	48	9	142	14
21—23	3	2	2	2	3	2	2	2	69	19	44	8	155	21
6—8	3	2	3	3	3	2	2	2	58	16	52	12	92	13
9—11	3	3	3	3	3	3	3	3	72	18	62	10	115	15
12—14	4	3	3	3	4	4	3	3	79	18	60	11	131	15
15—17	5	4	3	3	5	5	4	3	83	19	56	10	148	18
18—20	5	4	3	3	6	6	4	3	91	20	56	10	161	15
21—23	5	4	3	3	7	6	4	3	97	18	56	11	172	14
24—26	4	4	2	2	6	6	4	3	103	25	58	16	178	11
12—14	11	6	1	5	32	30	23	21	79	12	62	2	127	20
15—17	41	30	3	20	68	5	45	3	100	20	65	11	153	12
18—20	25	21	2	13	67	14	41	9	99	11	61	8	162	9
21—23	25	18	1	9	63	12	35	7	97	9	54	5	179	9
24—26	17	6	1	2	34	27	19	18	97	9	60	4	198	38

<sup>1)</sup> Vaccinium type

<sup>1)</sup> Puolukkatyyppi

Table 4. Height of the knot bump, branch- and crown limit and the tree height, by diameter and age classes. MT<sup>1)</sup>  
*Taulukko 4. Kyhmy-, oksa- ja latvusrajan korkeus sekä puun pituus läpimittain- ja ikäluokittain. MT<sup>1)</sup>*

Dbh, cm D1.3, cm	Knot bump limit — <i>Kyhmyraja</i>			Branch limit — <i>Oksaraja</i>			Crown limit — <i>Latvusraja</i>			Tree height, dm <i>Puun pituus, dm</i>	
	dm		%	dm		%	dm		%	$\bar{x}$	s
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s			
— 5	1	1	1	1	1	1	21	6	40	53	8
6— 8	1	1	1	1	1	1	31	13	43	70	12
9—11	1	2	2	2	2	2	42	21	46	86	19
12—14	2	2	2	2	2	2	63	22	52	118	21
15—17	3	2	2	3	2	2	71	15	52	134	18
18—20	2	2	2	2	2	2	78	10	52	149	12
21—23	2	2	2	2	2	2	78	12	48	162	10
6— 8	2	2	3	2	2	3	69	18	69	98	15
9—11	3	3	3	3	3	3	78	18	62	125	17
12—14	3	2	2	4	3	2	86	12	62	138	15
15—17	5	4	3	7	4	6	89	11	57	157	11
18—20	4	3	3	5	4	3	94	16	56	166	13
21—23	6	3	3	7	5	4	99	13	55	179	13
24—26	5	3	3	5	4	3	97	17	52	186	17
15—17	14	8	8	36	29	20	128	17	68	188	22
18—20	16	11	8	30	23	16	142	28	68	209	23
21—23	17	9	8	34	24	17	142	24	66	214	22
24—26	24	15	10	27	18	12	146	16	62	234	14

<sup>1)</sup> Myrtillus type.

<sup>1)</sup> *Mustikkatyppi*

Table 5. Height of the knot bump, branch- and crown limit and the tree height, by diameter and age classes. OMT <sup>1)</sup>  
*Taulukko 5. Kyhmy-, oksa- ja latvusrajan korkeus sekä puun pituus läpimitta- ja ikäluokittain. OMT <sup>1)</sup>*

Dbh, cm <i>DI.3, cm</i>	Knot bump limit — <i>Kyhmyraja</i>			Branch limit — <i>Oksaraja</i>			Crown limit — <i>Latvusraja</i>			Tree height, dm <i>Puun pituus, dm</i>			
	dm		%	dm		%	dm		%	$\bar{x}$	s		
	x	s	x	x	s	x	s	x	s	$\bar{x}$	s		
6—8	2	3	2	2	3	2	3	42	6	52	6	80	18
9—11	3	2	3	3	2	3	2	53	12	54	8	97	13
12—14	3	3	3	3	2	3	2	59	10	52	7	113	13
15—17	3	2	3	3	2	3	2	63	12	51	7	122	15
18—20	3	2	2	3	2	2	1	59	10	48	7	124	13
21—23	2	1	1	2	1	2	1	69	11	48	9	143	15
								Age, years — <i>Ikä, vuotta</i>					
								—40					
15—17	3	2	2	3	3	2	2	93	12	60	8	157	13
18—20	3	2	2	4	3	2	2	100	12	60	5	165	13
21—23	2	2	1	2	2	1	2	95	11	56	6	171	13
24—26	2	1	1	2	1	1	1	92	6	51	3	182	9
								41—60					
21—23	2	1	11	2	—	—	—	129	23	58	8	221	16
24—26	3	8	13	4	—	—	—	141	18	63	7	224	13

<sup>1)</sup> Oxalis-Myrtillus type.

<sup>1)</sup> *Käenkaali-Mustikkatyppi.*

60 years old. The height of the dry-branched part of the stem and the crown also increase on moving from *Vaccinium*-type to *Oxalis*-*Myrtillus*-type stands, and the difference is the greater the older the stand.

There are not only stand-to-stand but also within-stand variations in branchiness (Table 6). The knot bump and branch limits of the largest trees of a stand, those of the 1st crown class, are slightly higher than the corresponding branchiness zones of trees of the 3rd and 4th crown classes, whereas no noteworthy difference is seen in stems of the 2nd crown class. On the other hand, as regards the relative height of the branchless part of the stem, the 3rd and 4th crown classes are better self-pruned at an early age than the dominant trees, but the difference is reversed at a later age.

Self-pruning of stems was considerably faster in the sown pine stands studied by Kallio (1960), for the 4-m self-pruning height was achieved already at the age of 55, against about 70 years in this study. The effect of the growing rate on crown height gave similar results when stem taper was used to illustrate growth rate. Krigul (1961) mentioned that the death of the lowest branches of the crown was fastest at the age of 20—30 years and that the height of the branchless zone reached a relative height of 24—35 per cent at the age of 100. Zilkin (1960), Hall (1965) and Evert (1971) associated growth rate and crown development chiefly with the age of the stand, nature of the soil and growing space.

#### *412. Size of branches*

##### **4121. Branch diameter at different heights**

As the branches of the butt portion of the stem are the first branches to grow during the life of a tree they also die and fall first and their diameter remains smaller than that of the upper branches. Branches that grow later survive longer and also have more time to grow in thickness. In the later years of life, on the other hand, the branches that originate in the crown portion of the stem develop very slowly and when the vitality of the tree wanes remain thinner than the branches of the other parts of the crown. The fact that the lower branches of the stem are left without sufficient light when the stand closes in furthers their drying and falling.

Table 7 and Fig. 9 show the correlation between the diameter growth of branches and stand age. Branches grow in diameter in all parts of the stem, but the diameter differences increase towards the crown. For instance, there is no great difference at the relative height of 10 per cent in the branch diameter of trees between the youngest and oldest age classes. The branch diameter of young trees at relative heights is much more even than that of

Table 6. Height of the knot bump-, branch- and crown limit and the tree height, by age classes and crown classes  
Taulukko 6. *Kyhmy-, oksa- ja latvusrajan korkeus sekä puun pituus ikäluokittain ja latvuserroksittain*

Age, years <i>Ikä, vuotta</i>	Knot bump limit — <i>Kyhmyraja</i>				Branch limit — <i>Oksaraja</i>				Crown limit — <i>Latvusraja</i>				Tree height, dm <i>Puun pituus, dm</i>		
	dm		%		dm		%		dm		%		x	s	
	x	s	x	s	x	s	x	s	x	s	x	s			
Crown class — <i>Latvuserros</i>															
1															
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
40	2	2	2	2	4	2	3	7	2	4	2	16	52	7	138
50	5	4	3	2	7	5	4	3	89	20	56	10	160	22	180
60	3	2	2	1	5	5	3	3	106	12	52	8	180	12	160
70	22	13	10	6	34	22	17	13	137	24	61	8	223	24	223
80	26	10	10	4	56	9	22	3	154	20	62	5	246	19	246
2															
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
40	3	2	4	3	3	3	3	3	69	16	56	8	122	20	98
50	5	4	4	3	6	5	4	3	85	21	58	12	142	23	142
60	2	2	2	1	3	3	2	2	102	11	62	7	164	5	164
70	22	15	12	9	41	25	24	16	127	24	65	8	195	30	195
80	35	19	14	8	56	2	22	1	159	23	68	9	235	16	235
3															
20	1	1	2	2	1	1	2	2	25	1	45	8	55	12	55
30	2	2	3	2	2	2	3	2	49	19	56	17	88	22	88
40	2	2	2	2	2	2	2	3	64	19	66	58	105	24	105
50	4	3	3	2	4	4	3	3	82	19	63	10	128	20	128
60	2	1	1	1	3	3	2	2	106	9	71	6	150	16	150
70	12	8	7	4	39	30	23	20	131	22	72	12	182	25	182
4															
30	2	1	3	2	2	1	3	2	51	21	58	13	85	18	85
40	2	2	2	2	2	2	2	2	63	16	68	10	92	17	92
50	4	3	4	3	4	3	4	3	108	141	107	156	105	27	105
60	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70	10	64	8	5	24	28	18	20	76	13	62	3	123	19	123

Table 7. Branch diameter at different relative heights, by age classes and crown classes  
*Taulukko 7. Oksan paksuus rungon eri suhteellisilla korkeuksilla ikäluokittain ja latvuserroksittain*

Crown class <i>Latvuserros</i>	Relative height, per cent — Suhteellinen korkeus, %															
	10	20		30		40		50		60		70		80		
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s		
	Branch diameter, mm — Oksan paksuus, mm															
	Age, years — Ikä, vuotia															
	—30															
1 .....	14	5	16	5	19	5	24	7	24	6	23	4	21	5	16	4
2 .....	11	3	13	3	15	4	21	5	17	4	22	10	19	3	13	3
3 .....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4 .....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	31—50															
1 .....	13	5	18	6	21	7	23	6	26	7	27	8	27	7	23	6
2 .....	12	4	15	4	17	5	17	4	20	5	19	3	19	5	18	5
3 .....	10	3	13	4	14	4	16	4	17	4	18	3	18	3	16	4
4 .....	9	3	11	4	12	3	13	3	14	3	15	3	14	3	14	4
	51+															
1 .....	14	8	17	6	21	6	28	6	26	8	30	10	28	9	26	6
2 .....	12	3	14	4	18	6	21	2	21	6	26	5	27	5	23	6
3 .....	9	2	11	4	12	2	13	4	15	5	19	2	19	3	16	5
4 .....	8	2	11	2	11	1	10	0	12	2	17	0	12	0	14	2

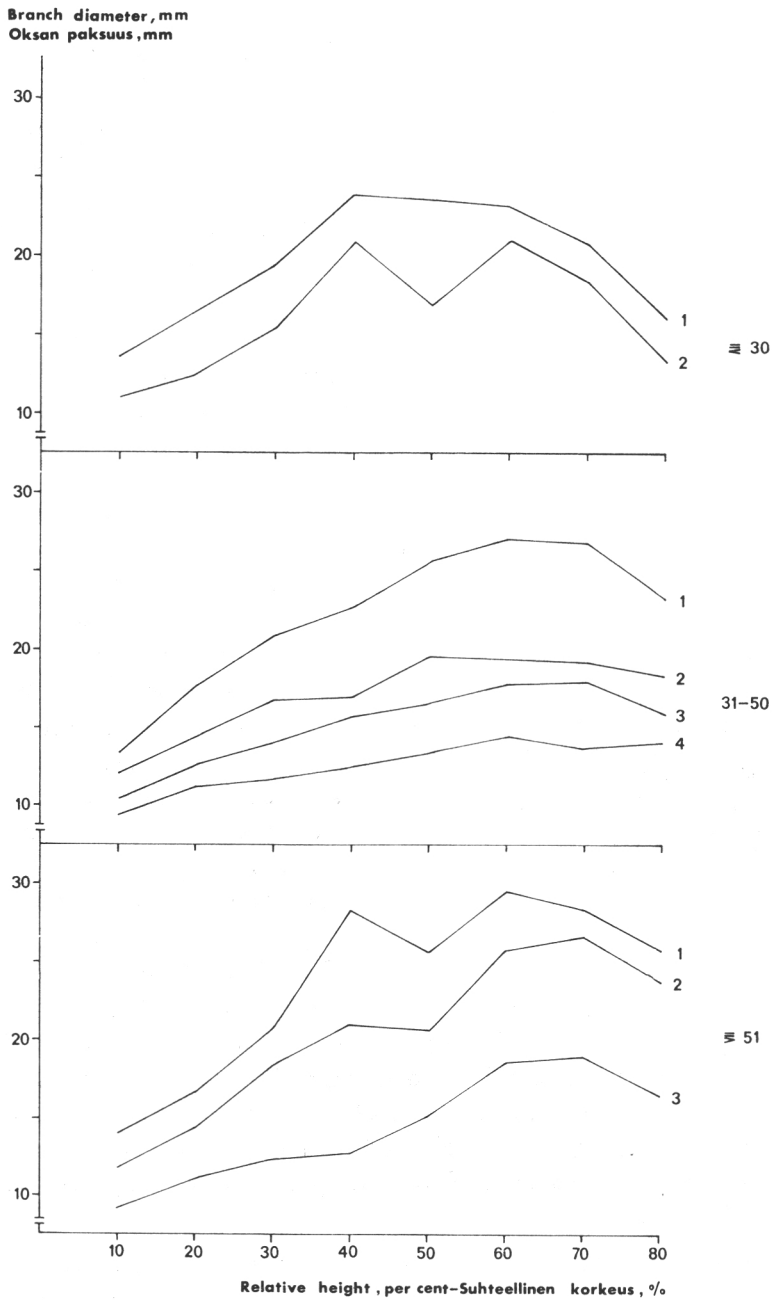


Fig. 9. Branch diameter at relative heights of 30, 30—50 and over 50 year old plantation-grown pine stems, by crown classes (1, 2, 3, 4).

Kuva 9. Oksan paksuus 30, 30—50 ja yli 50 vuotiaiden viljelymäntyrunkojen suhteellisilla korkeuksilla latvuserroksittain (1, 2, 3, 4).

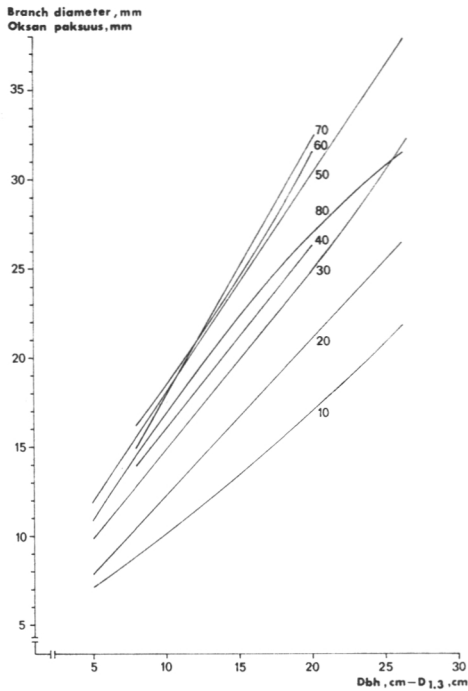


Fig. 10. Correlation between Dbh and branch diameter at different relative heights in 30—50 year old plantation-grown pines.

*Kuva 10. Oksan paksuuden riippuvuus läpimitasta eri suhteellisilla korkeuksilla 30—50 vuotiaissa viljelymänniköissä*

It proved impossible in this work to study the effect of the original planting space on branch diameter as the planting spacings varied very little. The branches that originate during the early development of the stand influence the quality of the most valuable butt portion of the stem, whereas later thinnings are capable of regulating only the development of upper branches. The branches of the butt part have already died and partly fallen off by this time.

Stiell (1966) reported that the crown size of an individual tree is directly proportional to the growing space of the tree in *Pinus resinosa*, and that the crown size is reflected in the characteristics that portray the quality of the stem and wood. The effect of silvicultural measures on wood quality is probably relatively small, except in the initial stage of stand development (Klem 1969). An exception from this is, however, the pruning

the stems of older stands. Branch diameter increases with age more steeply toward the crown.

The thickest branches are encountered in the oldest age class at the relative height of 60 per cent, in the youngest stands at the 40 per cent height.

Branch diameter not only diminishes on moving from the first crown class to lower classes but also levels out at different heights and the difference between the thickest branch of the stem and the thinnest branch of minimum size decreases (Fig. 9). The co-dominant trees of plantation-grown pine seem to be superior to dominant trees not only in pruning but also in branch diameter.

Branch diameter grows steeply with the growth rate. The effect is greatest in the upper parts of the crown. However, the increase in diameter growth ceases to have the same effect at the relative height of 80 per cent (Figs. 10 and 11 and Table 8).

Table 8. Branch diameter at relative heights of trees of differing heights, by forest site types  
*Taulukko 8. Oksan paksuus eri pituisten puiden suhteellisilla korkeuksilla metsätyyppittäin*

Tree height, m <i>Puun pituus, m</i>	Relative height, per cent — <i>Suhteellinen korkeus, %</i>															
	10		20		30		40		50		60		70		80	
	x	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
	Branch diameter, mm — <i>Oksan paksuus, mm</i>															
	VT															
6–10	4	12	3	4	17	6	18	6	18	5	17	5	17	5	14	4
11–15	4	15	4	5	20	5	21	6	23	7	24	7	24	7	20	5
16–20	7	17	5	6	23	7	26	7	27	9	31	8	31	8	25	5
	MT															
6–10	4	15	5	6	21	7	20	7	21	7	19	6	19	6	15	4
11–15	3	15	5	5	16	7	21	9	21	7	20	5	20	5	20	6
16–20	4	17	7	6	25	5	26	7	29	7	25	7	25	7	24	6
21–25	—	15	3	5	—	—	25	7	—	—	—	—	—	—	31	5
	OMT															
6–10	4	18	7	6	—	—	23	8	—	—	—	—	—	—	20	7
11–15	4	23	6	7	—	—	27	5	—	—	—	—	—	—	25	6
16–20	5	25	4	30	7	31	9	31	6	33	7	27	4	24	5	
21–25	—	19	10	27	4	—	26	6	—	—	—	—	—	31	6	

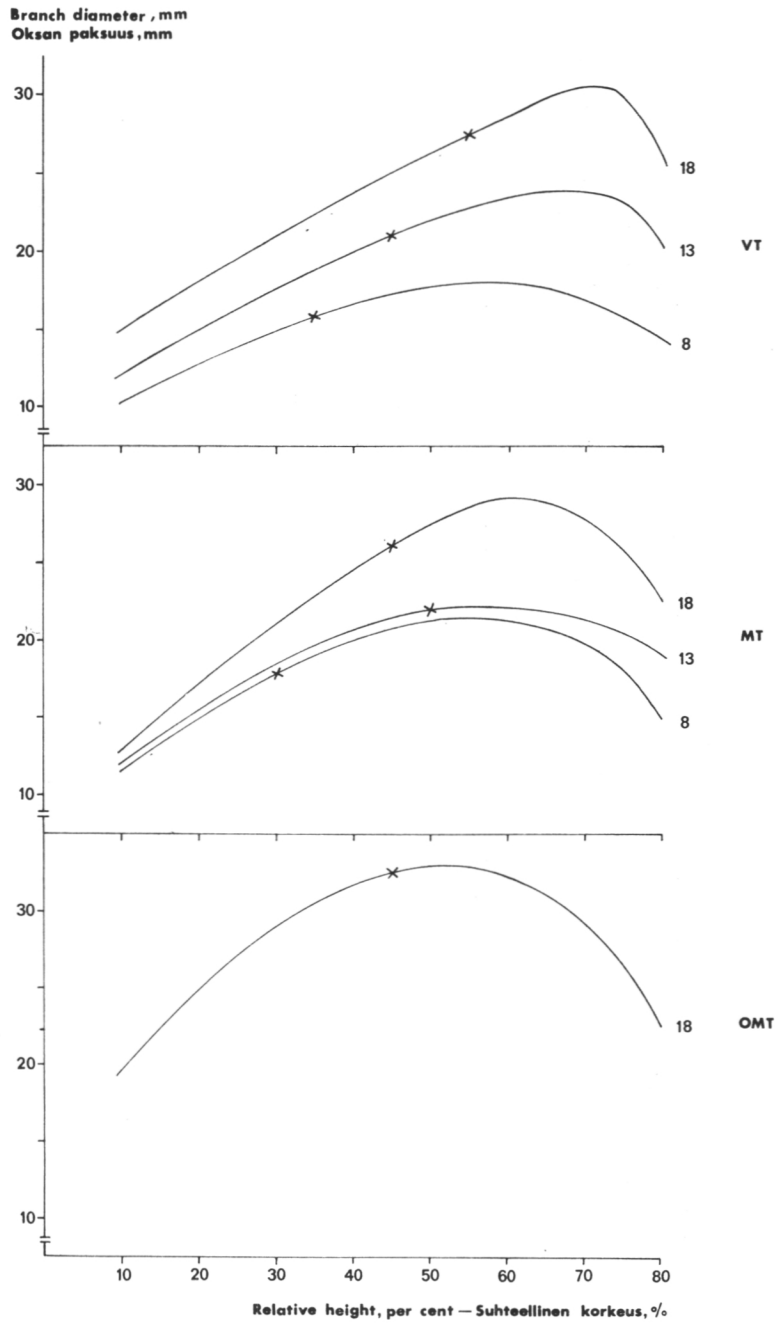


Fig. 11. Branch diameter at relative heights of 8, 13 and 18 m high plantation-grown pine stems (x = highest measured dry branch).

Kuva 11. Oksan paksuus 8, 13 ja 18 metrin pituisten viljelymäntyrunkojen suhteellisilla korkeuksilla (x = ylin mitattu kuiva oksa)

of selected trees of the stand which naturally has a favourable effect on stem branchiness.

Genetic factors also affect branchiness, branch size and crown form. Strains with thick and those with slender branches can be distinguished in pine (S c h ö p f 1954, M r á č e k 1969). O l d e n k a m p (1968) stresses the necessity of selecting the right tree species and strains for the growing of good quality trees if sparser plantation densities are used.

Selection of the right pine strain and tree breeding thus offer possibilities for raising wood quality. Several investigators are of the opinion, however, that pruning should be used for pine, too, in growing quality wood (e.g. S a r v a s 1956, K r i g u l 1958, H e i s k a n e n and T a i p a l e 1963, B e n n e t 1969, L e h t o and Y l i - V a k k u r i 1969).

#### 4122. Largest dry and living branch

The largest dry and living branch are characteristics that represent the quality and useful value of the tree as a whole. All the branches of the stem, but more especially its largest branches, are indicators of its growth rate and thus illustrate both sawlog quality and the quality of the tree stem in general, e.g. crown height and form (H a l l 1965). The growth of branches is commonly associated with diameter growth, i.e., stem growth rate (N y l i n d e r 1959, S t o u t 1964). But growth rate and crown development are dependent also on the age of the stand and the nature of its site (E v e r t 1971). M e r k e l (1967) noted in his studies on spruce that the maximum branch diameter increases by 3.5 mm and length by 35 cm when the mean spacing of the trees is increased by 1 m.

The diameter of the thickest dry branch and the diameter and length of longest living branch were studied by means of various external characteristics portraying the stem. Stepwise regression analysis was used in the study. Stem volume, taper, age, height, diameter and crown proportion and their various variants were the independent variables. Breast height diameter proved to be the best variable and it explained 63 per cent of the diameter variation of the thickest dry branch. The regression equation then takes the form  $Y = 7.314 + 1.153 X$ , in which  $Y$  = the thickest branch of the stem, mm;  $X$  = the breast height diameter of the stem, cm;  $R = 0.795$ .

The best correlations were given by the following variables singly for a linear correlation between them and the diameter of the thickest dry branch.

Independent variable	Coefficient of correlation
Breast height diameter .....	0.796
Breast height diameter <sup>2</sup> .....	0.777
Volume growth .....	0.772
Logarithm of volume .....	0.727
Diameter growth .....	0.650

The part of the variation in the diameter of the largest dry branch of the stem that is explained by quantities illustrating the stem was as follows when the number of independent variables was increased.

Independent variable	R	Explained variance, %
Diameter .....	.796	63
+ radial increment .....	.821	67
+ crown proportion .....	.828	69
+ 1/tree length .....	.832	69

The best degree of explanation, 70 per cent, was obtained by the following equation:

$$Y = 0.703 X_1 - 0.184 X_2 - 0.123 X_3 + 1.423 X_4 + 26.838 X_5, \text{ when } R = 0.837.$$

$X_1$  = tapering, cm

$X_2$  = age, years

$X_3$  = crown proportion, %

$X_4$  = breast height diameter, cm

$X_5$  = reciprocal of height

When corresponding regression analysis was performed for the diameter and length of the longest living branch, breast height diameter was again the best variable. The following regression equations were obtained.

Regression equation	$\bar{y}$	s	$\bar{x}$	s	R
$Y_1 = 7.801 + 1.340 X$ .....	25.5	8.8	13.2	4.8	0.737
$Y_2 = 0.696 + 0.092 X$ .....	1.9	0.57			0.777

$Y_1$  = diameter of longest living branch, mm

$Y_2$  = length of the longest living branch, m

$X$  = breast height diameter of the stem, cm

The following variables show the best correlation with the diameter and length of the longest living branch.

Branch diameter		Branch length	
Independent variable	R	Independent variable	R
Diameter .....	0.737	Diameter .....	0.777
Logarithm of volume growth	0.724	Logarithm of volume growth	0.772
Diameter <sup>2</sup> .....	0.721	Diameter <sup>2</sup> .....	0.765
Logarithm of volume .....	0.662	Logarithm of volume .....	0.703
Volume .....	0.651	Volume .....	0.694
Logarithm of taper .....	0.519	Logarithm of taper .....	0.685

The following combinations of independent variables explain best the diameter and length of the longest branch of a tree when regression analysis is applied.

Diameter of the longest living branch, mm			Length of the longest living branch, m		
Independent variable	R	Explained variance, %	Independent variable	R	Explained variance, %
Diameter . . . . .	.737	54	Diameter . . . . .	.777	60
+ Logarithm of age . . . . .	.784	61	+ Diameter growth . . . . .	.820	67
+ Age/length . . . . .	.790	62	+ Crown proportion . . . . .	.826	68
+ Logarithm/ (age/diameter) . . . . .	.795	63			

The dimensions of the largest branches are thus explained best by stem diameter and age in one form or another (cf. also Figs. 12—13), although stem volume and taper also correlate closely with these characteristics. A tree consequently grows bigger branches the older and faster-growing it is. Heiskanen (1965) found a linear correlation also in every age class between the stem breast height diameter and the largest branch of the butt log. When the variation in the diameter of the largest dry branch of the stem and the diameter and length of the longest living one in different age classes was analysed, the development in pine plantations was

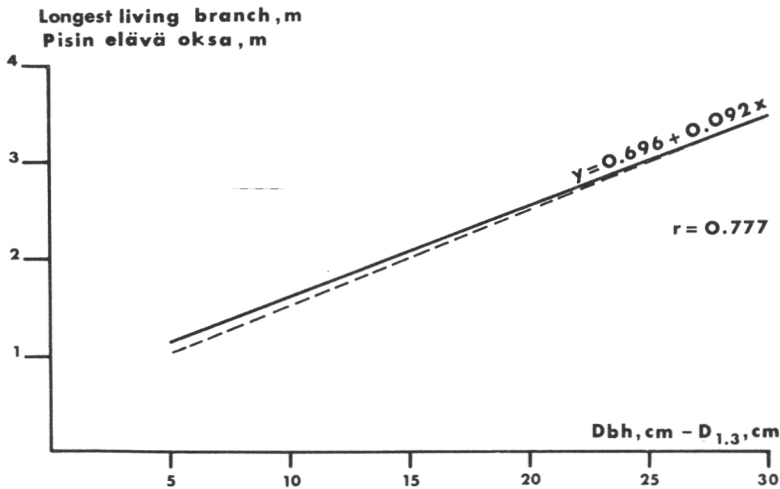


Fig. 12. Correlation between the length of the longest branch and Dbh.

— — — — — Longest branch of the tree in naturally regenerated pine stands according to HAKKILA (1971).

*Kuva 12. Männyn pisimmän elävän oksan pituuden riippuvuus rinnankorkeusläpimitasta*

— — — — — Puun pisin oksa luonnonmäkkiköissä HAKKILAN (1971) mukaan

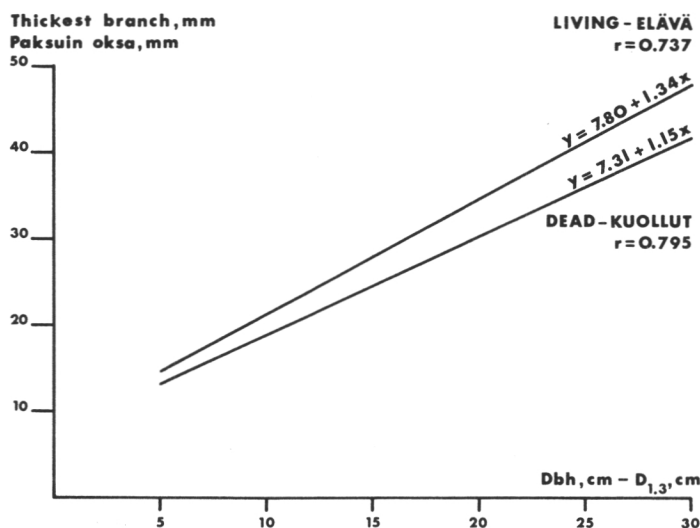


Fig. 13. Correlation between the diameter of the longest living and thickest dead branch of stem and Dbh in pine plantations.

*Kuva 13. Rungon pisimmän elävän ja paksuimman kuolleen oksan paksuuden riippuvuus rinnankorkeusläpimitasta viljelymänniköissä*

found to be somewhat different (Figs. 14—16). Branch diameter and length increase steeply at first with stem diameter growth, but then slow down when maximal diameter growth values are achieved.

Trees of the poorest quality as regards branchiness are the fastest-growing individual trees of the 1st crown class, and their dry branches are very low, particularly thick and heal over slowly.

The thickest dry branch of a plantation-grown pine stem is located on average slightly below the lowest living branches, and the thickest green branch in the lower portion of the crown (Fig. 5). The longest branch of the stem on average is also the thickest, except in the small-crown trees of the 4th crown class. Hence, the thickest branch in small trees is roughly half way up the stem, but higher as the tree ages, and at approx. the  $\frac{2}{3}$  height of the stem at the age of 70. Ager et. al. (1964) reported that the thickest branch of the pine usually develops slightly below the middle of the stem. As with the crown limit, the height of the longest living branch in a certain age class rises at first as the diameter increases but falls again when the growth rate becomes especially fast.

The effect of the forest type on the diameter growth of branches is seen in the following table which shows the diameter and length of the largest branches of 30—40-year-old pine stems.

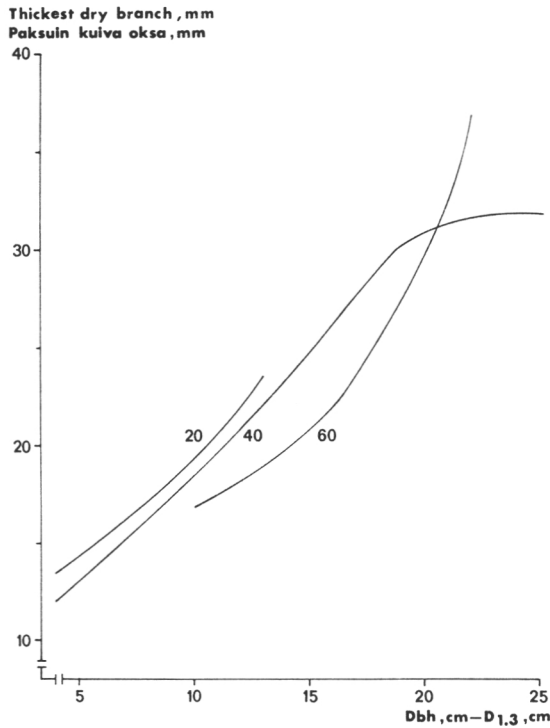


Fig. 14. Correlation between the diameter of the thickest dry branch of the stem and Dbh in pine plantations aged 20, 40 and 60 years.

*Kuva 14. Rungon suurimman kuivan oksan paksuuden riippuvuus rinnankorkeuspimitasta 20-, 40- ja 60-vuotiaissa viljelymänniköissä*

	VT		MT		OMT	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Largest dry branch, mm . . . . .	20.7	5.8	24.6	7.3	30.2	6.2
Longest living branch, mm ..	23.7	7.9	27.5	11.5	30.4	7.5
Longest living branch, m . . . . .	1.8	0.5	2.1	0.7	2.3	0.6

H a k k i l a (1972) in his study of the correlation between the diameter and length of the thickest branch and different factors noted breast height diameter and tree height to be the best variables explaining branch dimensions. The development of the length of the longest branch in natural pine stands of an average age of 107 years as a function of breast height diameter was similar to the results obtained in the present study (Fig. 12).

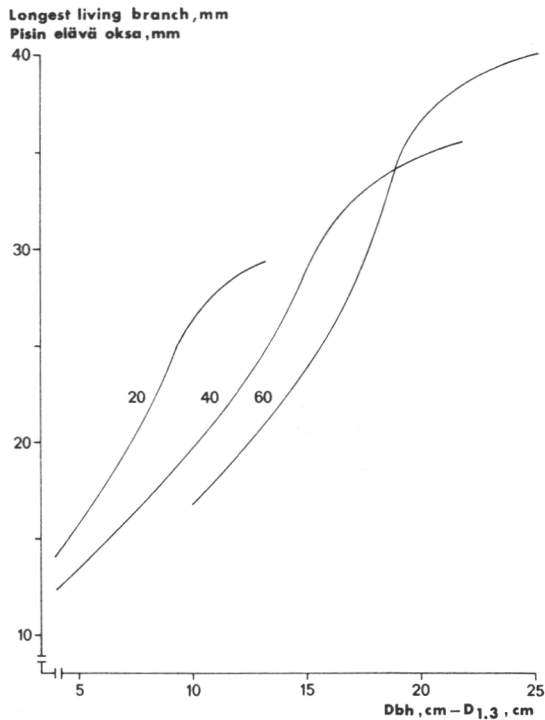


Fig. 15. Correlation between the diameter of the longest living branch of the stem and Dbh in pine plantations aged 20, 40 and 60 years.

Kuva 15. Rungon pisimmän elävän oksan paksuuden riippuvuus rinnankorkeustäpimitasta 20-, 40- ja 60-vuotiaissa viljelymänniköissä

### 413. Tapering

Tapering is the decrease in stem diameter from the butt towards the crown. A decrease in the diameter of an adult tree by 1 cm per linear metre is defined as normal in Central European conditions, while more pronounced taper is regarded as characteristic of young stand or as a defect when it occurs in trees of the older age classes (Durst 1955, Erteld et al. 1964).

Taper is affected by age, diameter growth, stand density, site and generally the height ratio of the living crown (Kallio 1960, Chojnacki 1969, Ipatov 1970). Many of these factors are inter-related; diameter growth and crown ratio are accelerated when the stand density decreases.

Intensive logging is usually followed by growth reactions which concentrate diameter growth chiefly in the butt section of the tree. However, according to Nyysönen (1954) and Lohrey (1961), the effect of these measures is generally relatively small and of short duration.

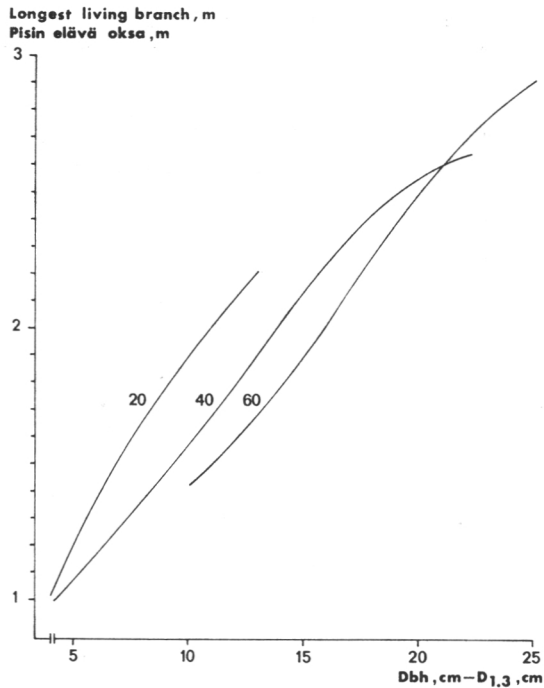


Fig. 16. Correlation between the length of the longest living branch of the stem and Dbh in pine plantations aged 20, 40 and 60 years.

Kuva 16. Rungon pisimmän elävän oksan pituuden riippuvuus rimankorkeustäpimitasta 20-, 40- ja 60-vuotiaissa viljelymänniköissä

Tapering increases within a certain age class when the tree diameter increases (Table 9). The trees of smallest diameter and lower crown classes in a stand consequently taper least and have the best stem form (cf. also Table 10). Heiskanen (1955) also noted a strong correlation between taper, breast height diameter and branchiness, especially in forests of logging age.

Comparison of the taper figures in Table 9 with Figs. 6—8 and 10 which illustrate natural pruning and branch thickness shows that taper is associated with branchiness, branch thickness and crown height (cf. also Turolski and Buchholz 1964). In *Pinus contorta* bark thickness also has been found to correlate with stem form; the more slowly the tree tapers, the smaller is the bark percentage (Hakkila and Pannelainen 1970). Stem form of a tree and the factors influencing it, especially growth rate, are associated also with wood properties. The following cor-

Table 9. Correlation between taper and Dbh, by age classes  
 Taulukko 9. Kapenemisen <sup>1)</sup> riippuvuus rinnankorkeusläpimitasta ikäluokittain

Age, years <i>Ikä, vuotta</i>	Dbh, cm — <i>D1.3</i> , cm													
	< 6		6—10		11—15		16—20		21—25		26—30		31—35	
	Taper, cm — <i>Kapeneminen</i> , cm													
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
21—40 .....	1.9	0.7	3.0	1.0	3.5	1.1	4.2	1.1	5.6	1.3	—	—	—	—
41—60 .....	1.9	0.5	2.5	0.7	3.0	0.8	3.5	0.9	4.2	0.9	—	—	—	—
61—80 .....	—	—	—	—	3.0	0.9	3.8	0.9	4.6	1.1	5.5	1.3	6.3	1.4

Table 10. Tapering by age classes and crown classes  
 Taulukko 10. Kapeneminen ikäluokittain ja latvuseroksittain

Age, years <i>Ikä, vuotta</i>	Crown class — <i>Latvuserros</i>							
	1		2		3		4	
	Taper, cm — <i>Kapeneminen</i> , cm							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
21—40 .....	3.5	1.1	2.7	1.0	2.6	0.9	2.3	0.8
41—60 .....	3.4	1.0	2.8	0.8	2.9	1.0	2.5	0.8
61—80 .....	4.8	1.4	3.7	1.2	3.9	1.1	3.0	1.4

relation coefficients denote the correlations between taper and various factors which illustrate the external and internal characteristics of plantation-grown pine stems.

	Correlation coefficient
Tree volume, solid cu.m. ....	0.479
Largest dry branch, mm .....	0.206
Longest living branch, m .....	0.198
Basic density, kg/solid cu.m. ....	0.044
Percentage of late wood .....	— 0.121
Diameter growth .....	0.481
Height growth .....	0.230
Ring width, mm .....	0.131

The correlations would be considerably greater if the effect of the age factor were excluded and the connections between different variables and taper in certain age classes were examined.

Taper expresses also the internal properties of wood. V o l k e r t (1941), L a r s o n (1963) and K a n o and S a i t o (1970) observed that an increase in taper reduced the proportion of late wood and basic density.

<sup>1)</sup> The taper of trees shorter than 8 m was determined as the difference of the 1.3 m and 3.5 m diameters.

<sup>1)</sup> 8 metriä lyhyempien puiden kapeneminen määritettiin 1.3 metrin korkeuden ja 3.5 metrin korkeuden läpimittojen erotuksena.

#### 414. Defects

Defects refer here to deviations from the quality and usability of a normal, good-quality stem. The analysis is concerned chiefly with external stem defects and, except for compression wood, defects of wood are outside its scope. Defects were grouped according to their type when the material was collected and thus the total of defects in a stem was not taken into consideration.

A defect or a combination of defects may recur at different stem heights if the stand is damaged several times during its development. Defects of this type are crookedness of stem and a vertical branch often associated with it as the result of the change of the annual shoot. Log quality is then weakened decisively, especially if the crooks are so located that several defects occur in a single log length. A tree with sweep tends to bend the longitudinal axis of the stem again to the vertical plane. The stem may grow beyond its axis in another direction, leading to double sweep in the same stem.

The relative frequency histograms in Figs. 17 and 18 illustrate the presence of defects of different types in plantation-grown pines by age groups and forest site types. The commonest defect is crookedness of the stem, with the crook usually located above the butt section. The defects in order of frequency are as follows: crookedness of stem, butt crook, vertical branch and sweep (Figs. 20—21, 24, 26, 28). They represent together 95 per cent of all defects (cf. Fig. 19). K a n g a s (1962) reported the following distribution of defects that lower the technical usability of pine: crooks of varying degrees 81 per cent, sweep 12 per cent and open cankers 7 per cent.

Almost every other plantation-grown pine on average reveals crookedness of stem, every fifth butt crook, every seventh sweep, and only approx. one-third have no defect that weakens technical quality. The proportion of defects is smallest in Vaccinium type and greatest in Oxalis-Myrtillus type soil. Hence, an increase in the nutrient content of the soil increases crookedness, forks, sweep and branchiness. On the other hand, no correlation was observed between stand density and the frequency of defects. Nor did C r o m e r and P a w s e y (1957) in their study on *Pinus radiata* observe a correlation between sweep or crookedness and growing space, whereas forks increased when the growing space was more open.

The same trend was not seen for other defects, mainly cankers, pine blister rust and other diseases and, exceptionally, long and thick branches («wolf trees», Fig. 22), and their overall importance is small.

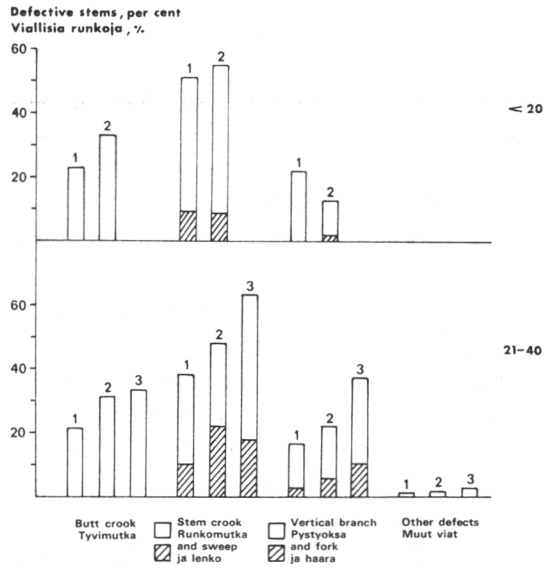


Fig. 17. Share of different defects in sample trees, by age classes and forest site types (1 = VT, 2 = MT, 3 = OMT).

Kuva 17. Eri vikojen osuus koepuista ikäluokittain ja metsätyypeittäin (1 = VT, 2 = MT, 3 = OMT)

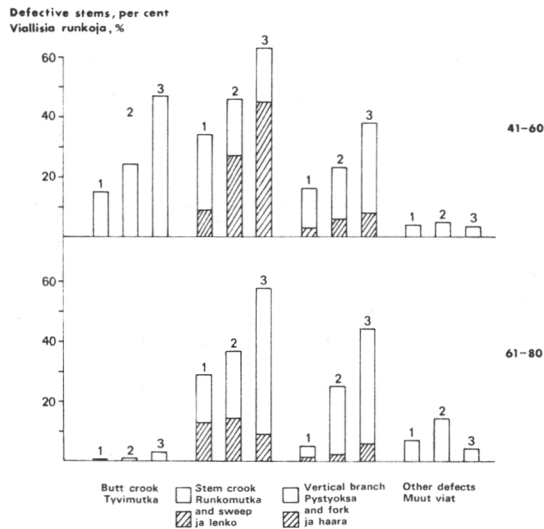


Fig. 18. Share of different defects in sample trees, by age classes and forest site types (1 = VT, 2 = MT, 3 = OMT).

Kuva 18. Eri vikojen osuus koepuista ikäluokittain ja metsätyypeittäin (1 = VT, 2 = MT, 3 = OMT)

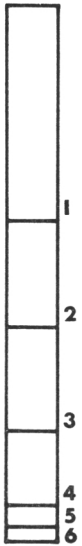


Fig. 19. Per cent share of different defects in defective stems (1 = stem crook, 2 = butt crook, 3 = vertical branch, 4 = sweep, 5 = fork, 6 = other defects).

*Kuva 19. Eri vikojen osuus prosentteina viallisista rungoista*

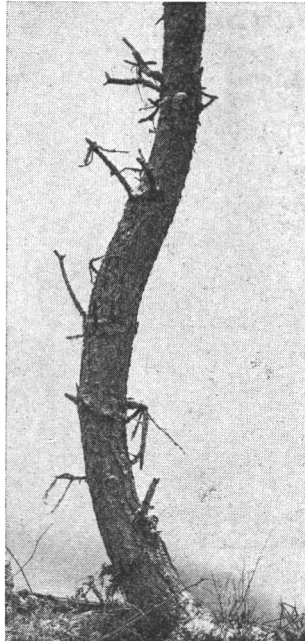


Fig. 20. Sweep is a common defect especially in pine stands on good soil.

*Kuva 20. Lenkous on yleinen vika nimenomaan hyvän maapohjan männiköissä*



Fig. 21. A fork originates when two shoots compete for equal longitudinal growth.

*Kuva 21. Haaroittuma syntyy kahden verson kilpaillessa tasavertaisesta pituuskasvusta*

The number of defective stems decreases with the increasing age of the stand (Fig. 23). This is due primarily to silvicultural loggings undertaken to remove defective stems. A part of the defects, especially slight crooks, also disappear gradually as the tree grows.

Although crookedness of stem and sweep contribute notably to the deterioration of quality, the sawlog quality class is determined first and foremost by the number and diameter of branches on the stem. This is shown by e.g. Heiskanen's (1955) study in which branchiness accounted for 81 per cent and sweep and crookedness for 8 per cent of the different quality characteristics that determine log quality. The significance of branchiness was accentuated in young stands. The corresponding figures according to Lappalainen (1949) were 86 and 7 per cent.

The proportion of defects in the different crown classes of pine stands of 40—60 years was as follows by forest site types.



Fig. 22. Trees that have gained a leading position compared with other stems usually become exceptionally branchy.

*Kuva 22. Muihin runkoihin nähden johtoaseman saavuttaneet puut kehittyvät tavallisesti poikkeuksellisen oksikkaitiksi*

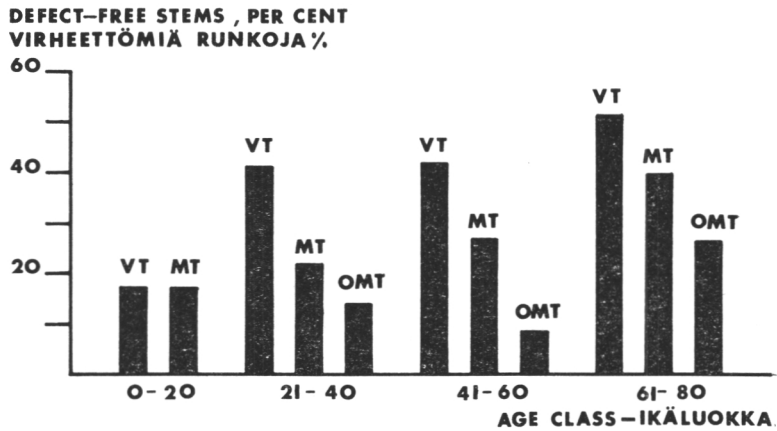


Fig. 23. Proportion of defect-free stems in the measured sample trees, by age classes and forest site types.

*Kuva 23. Virheettömien runkojen suhteellinen osuus mitatuista koepuista ikäluokittain ja metsätyypeittäin*

Crown class	Defects, per cent		
	VT	MT	OMT
1 .....	13.8	20.5	28.0
2 .....	15.6	20.8	30.8
3 .....	15.1	21.0	—
4 .....	16.4	28.2	—

The higher proportion of defects in the lower crown classes was probably due in part to the failure of the stems, because of their poorer growth than that of the dominant trees, to heal over the crooks and vertical branches. The trees in the poorest condition in the stand were probably also more susceptible to various external injurious agents, e.g. insect damage. Among other authors, K a n g a s (1962) reported that defects arising from injuries to the stem are more serious the lower the crown class and more common the better the site quality of the stand.

Stem defects are caused by many external injurious and genetic factors. According to K a l e l a (1937) and S a r v a s (1964), pine forms several geographical clines and strains which differ both morphologically and physiologically. Mistakes made during the nursery establishment phase or during primary treatment, and damage caused by the elements such as snow and storms, may give rise to defects. G u i l k e y (1958) regards sweep in *Pinus resinosa* as damage caused chiefly by snow in the seedling stage.

Pine plantations, especially in the early phases of growth, are also exposed to damage by some animals. Y l i - V a k k u r i (1955) reported moose damage in 20 per cent of the pine seedling stands in the Ostrobothnian region. More susceptible to damage were seedling stands in poor condition containing a hardwood mixture (cf. K a n g a s 1949).

However, K a n g a s (1962) stated that some insects, especially the pitch gall spinner moth (*Evetria resinella*) and the European pine shoot moth (*Evertria buoliana*) were almost the sole agents causing damage that resulted in crookedness of stem in 1—8 m tall pines. Damage leading to stem crookedness in pine stands can also be caused by e.g. squirrels and gallinaceous birds (S e i s k a r i 1962, P u l l i a i n e n and S a l o n e n 1965) and rust fungus (*Melampsora pinitorqua*) (e.g. S y l v e n 1924). As described by K a n g a s, the main development of crook caused by insect damage is as follows:

— The terminal bud dies, the side bud continues the height growth and a slight crook generally ensues (Figs. 24—25).

— The leading shoot as a whole dies and the side shoot continues the height growth. The crook thus originating is worse than the above (Figs. 26—27).

— The top of the tree dies over more than the length of the shoot to the side of the previous shoot or even including it. The side shoot which has already become a branch then becomes the top and the resulting crook is from the outset worse than those described above (Fig. 28).

According to J u u t i n e n (1962) every third pine in 10—12 years old plantations reveals form defects, and the main factor causing crooks is ground vegetation.

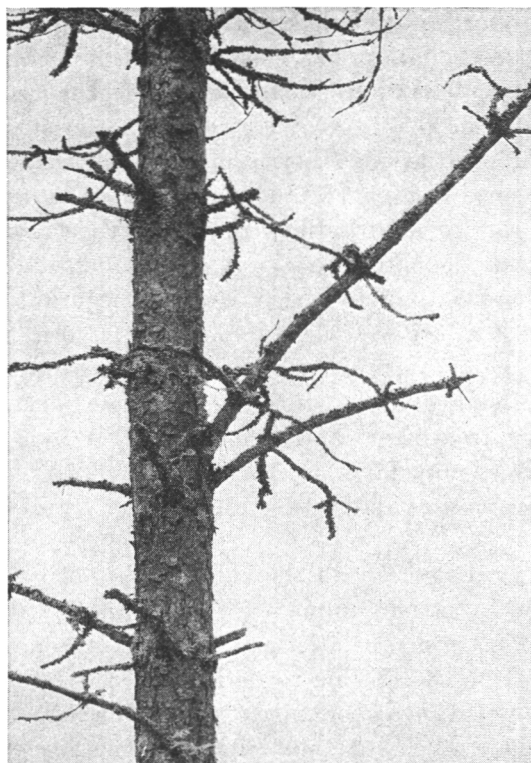


Fig. 24. Vertical branch which is associated with terminal bud change.

*Kuva 24. Silmunvaihdokseen liittyvä pystyoksa*

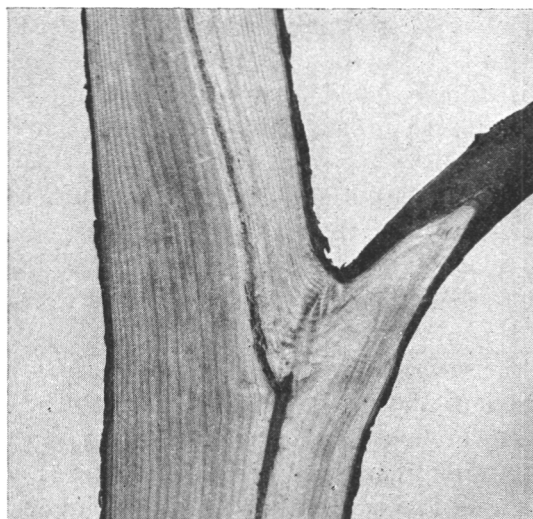


Fig. 25. Change of the bud and slight crook resulting from the destruction of a terminal bud.

*Kuva 25. Latvasilmun tuhoutumisen seurauksena syntynyt silmunvaihdos ja lievä mutka*



Fig. 26. Vertical branch.  
*Kuva 26. Pystyjoksa*



Fig. 27. Crown change and a relatively serious crook resulting from destruction of the leading shoot.

*Kuva 27. Päärangan tuhoutumisen seurauksena syntynyt latvanvaihdos ja verrattain paha mutka*

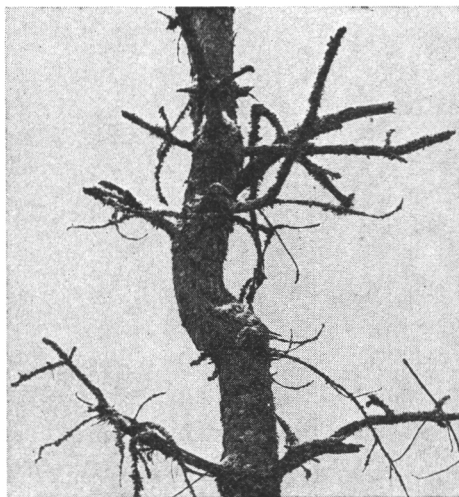


Fig. 28. When a shoot that has achieved the position of a branch continues its longitudinal growth a crook originates which makes the log technically unfit for use.

*Kuva 28. Oksan aseman saavuttaneen verson jatkaessa pituuskasvua syntyy mutka, joka tekee tukin teknisesti käyttökelttomaksi*

Cellular tissue called compression wood in which the tracheids are abnormally short and irregularly arranged generally appears in the underside of softwood stems that are leaning for some reason, in the crooked and sweeping parts of stems and as supporting cellular tissue (Ollinmaa 1955). The primary function of compression wood is probably to straighten the stem and support the branches, but compression wood has been produced also experimentally by centrifugal force in seedlings of *Pinus Strobus* (Scott and Preston 1955, Wardrop 1964). Compression wood is encountered also in straight stems. Zobel and Hought (1962) stated that 6 per cent of the volume of straight *Pinus Taeda* stems is compression wood, while in crooked stems the content is 16 and even 67 per cent.

In this work the occurrence of compression wood was studied only at the cutting height. It was found to be associated expressly with butt crooks and sweep. 30.4 per cent of all stems studied contained compression wood in the stump cross-section. The proportion rose to 46.2 per cent in trees with butt crook and to 48.7 per cent in trees with sweep. Crookedness and sweep are particularly common in pine stands on good soil. Similarly to the defects discussed in the foregoing, the proportion of stems which contain compression wood decreases with age due to silvicultural measures. This is apparent from the following table.

Age of stand, years	Proportion of stems containing compression wood at cutting height, per cent
—30 .....	38.8
31—40 .....	35.9
41—50 .....	24.4
51—60 .....	11.6
61— .....	14.3

#### 415. Butt log quality

Pine begins to enter a diameter class meeting sawlog measurements in South Finland at about the age of 30—35 years. If a height of 18 ft. and top diameter of  $5\frac{1}{2}$ " are taken as the minimum sawlog measurements, 9 per cent of 30—35-year-old plantation-grown pines reach sawlog size in VT, but 40 per cent in MT and OMT type soil. Value increment on good soil is thus very great at this age.

However, fast diameter growth and concentration of growth in the butt section of the tree are not advantages for wood quality. This will be seen in Fig. 29 which shows the correlation of the proportion of sawlogs in different quality classes and cull stems and the breast height diameter

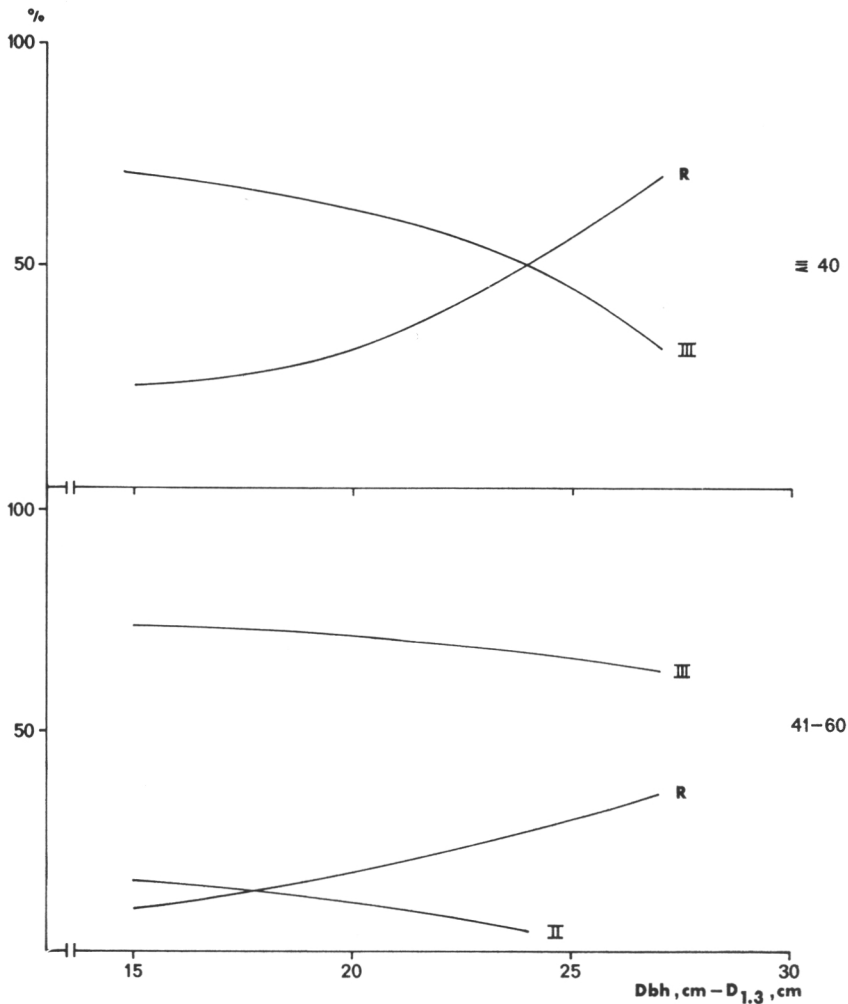


Fig. 29. Correlation between quality classes II and III of butt logs and cull stems and Dbh by age classes (R = cull stem).

*Kuva 29. Tyvitukkien II ja III laatuluokan sekä raakkien osuuksien riippuvuus rinnankorkeusläpimitasta ikäluokittain (R = raakkitukki)*

in different age classes. Quality class III is the commonest for pines under 40 years. When Dbh<sup>1)</sup> grows the proportion of butts in the cull class increases and that of class III logs decreases sharply. When Dbh is 24 cm half of the logs belong to the culls and half to class III.

The quality of trees older than 40 years is no longer equally poor, for the branches self-prune and heal over earlier than before. Culls stems are

<sup>1)</sup> Dbh = stem diameter at breast height.

<sup>1)</sup> Dbh = puun rinnankorkeusläpimitta.

fewest (10 per cent) among the thinnest trees of stands of a certain age and most numerous among the thickest, i.e., fastest growing (35 per cent). The quality of the butt log of a plantation-grown pine stem is thus better on average the older the stem of certain diameter. Hence, trees of the highest crown class in a relatively homogeneous pine plantation are not the best qualitatively even for sawlogs. It is possible to evaluate the quality of other logs obtained from the stem on the basis of the quality of the butt log; in other words, the butt log quality illustrates well the average quality of the whole stem. Heiskanen (1954) stated that the real branchiness of top logs in a certain branchiness class is smaller and the quality higher, the better the branchiness class to which the butt log of the stem belongs.

Fig. 30 shows the proportion of various defects in butt logs of different quality. Crookedness of stem together with vertical branch are of the greatest significance for rejection of a log. The proportion of crooks in sawlog stems does not, true, give a correct idea of the true effect of the defect, as defects were estimated from the whole stem while sawlog quality was assessed from the butt log only. Sarvas (1944) regarded sweep, branchiness and canker as the most important of the defects lowering sawlogs to class III in selection stands. Sweep was found in 50 per cent of the trees in class III. The incidence of defects in stems of different quality classes is shown by the following table which gives the average number of defects in butt logs of different quality by forest site type.

Butt log quality class	Forest site type		
	VT	MT	OMT
	Number of defects/stem		
II .....	0.4	0.7	0.7
III .....	0.8	1.1	1.6
R .....	2.0	2.0	2.2

Tables 11 and 12 present the distribution of sawlogs into quality classes evaluated on the basis of both branchiness and all defects. If stem defects are excluded, the quality class distribution is considerably better. Stem defects appear to influence specifically the change from quality class II to III. The average distributions between classes I, II and III and culls for Vaccinium type were 5.6, 22.1, 68.6 and 3.7 per cent according to branchiness, and 2.0, 12.0, 71.9 and 14.1 per cent judged by all defects. The proportion of class III and culls decreases with age. A considerable proportion of the material from older MT and OMT stands is placed in quality class I when evaluated solely by branchiness, but the knot bumps of poorly healed over, large branches lowered the true quality. The proportions of all accepted butt logs according to quality class was as follows:

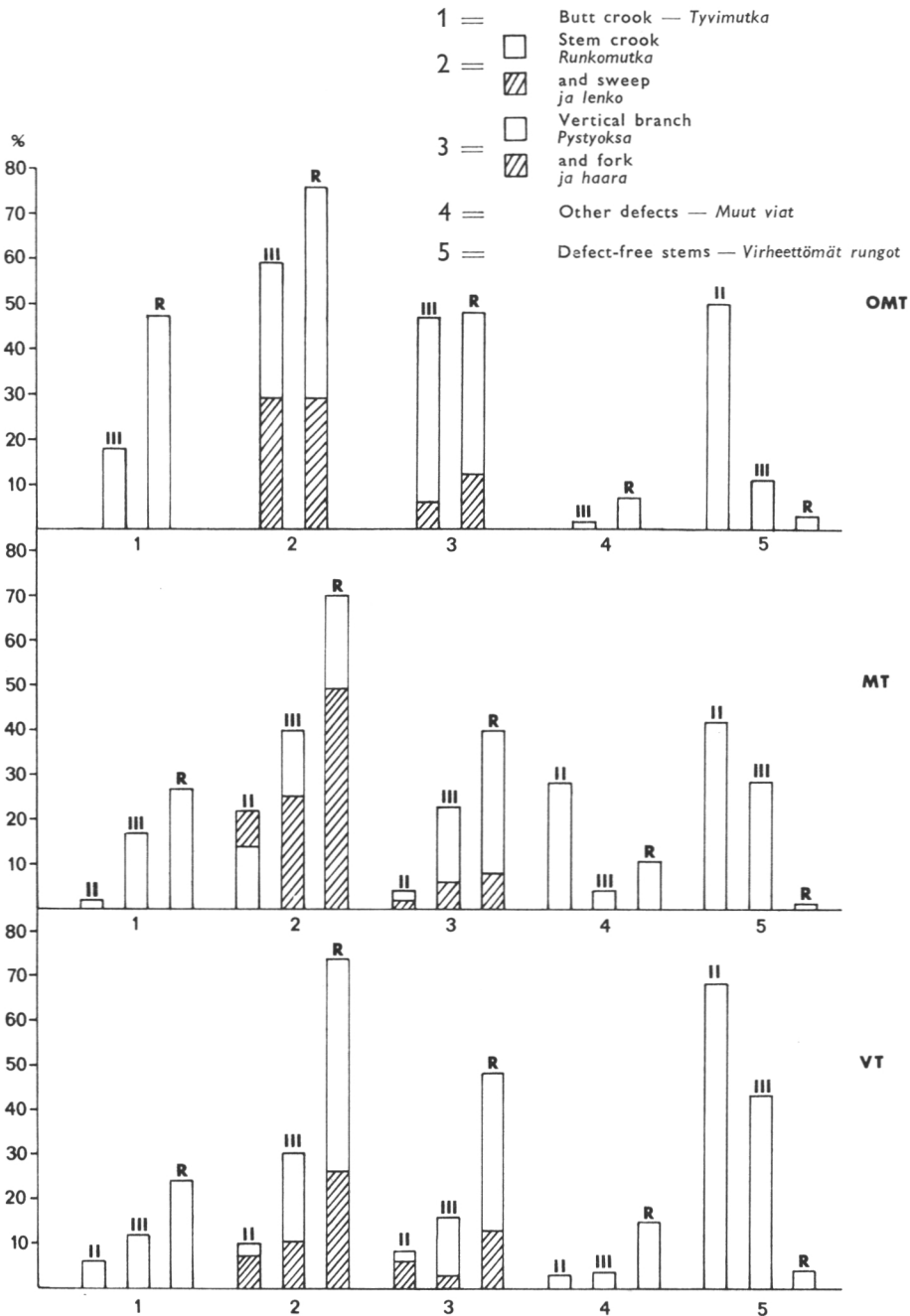


Fig. 30. Share of different defects and defect-free stems in butt logs of different quality classes (R = cull stem).

Kuva 30. Eri vikojen sekä virheettömien runkojen osuus tyytukin laatuluokaltaan erilaisissa rungoissa (R = raakkitukki)

Table 11. Distribution of butt logs into quality classes and cull stems according to branchiness, by forest site types

Taulukko 11. Tyvitukkien jakautuminen laatuluokkiin ja hylkytukkeihin oksaisuuden perusteella metsätyypeittäin

Age, years <i>Ikä, vuotta</i>	Butt log quality <i>Tyvitukin laatuluokka</i>			
	I	II	III	Cull — <i>Raakki</i>
	VT			
	%			
35 .....	—	10	84	6
45 .....	—	33	65	2
55 .....	—	21	75	4
65 .....	96	4	—	—
75 .....	—	—	—	—
Total — <i>Yhteensä</i>	6	22	69	4
	MT			
35 .....	—	5	88	7
45 .....	—	10	90	—
55 .....	—	24	74	3
65 .....	11	43	46	—
75 .....	24	52	24	—
Total — <i>Yhteensä</i>	5	22	71	2
	OMT			
35 .....	—	—	89	11
45 .....	—	6	79	15
55 .....	—	—	—	—
65 .....	—	—	—	—
75 .....	56	21	15	8
Total — <i>Yhteensä</i>	16	9	64	12

Forest type	Quality class, %		
	I	II	III
VT .....	2	14	84
MT .....	1	15	84
OMT .....	—	18	81

Sawlog stems of different qualities also differ as regards the internal qualitative characteristics of wood. Appendices 1—3 present indicators of the average stem characteristics of trees of different quality classes, that is branchiness, degree of self-pruning and wood quality.

According to Kallio (1960), 7, 65 and 18 per cent of the sawlog portion of the stem of MT plantation-grown pines in South Finland belong to quality classes I, II and III at the age of 50. In Heiskanen's (1965) studies the share of class II in the sawlog portion in under 60-year-old VT stands was 57 per cent at its highest and then decreased as Dbh increased. The share of class III increased correspondingly, while the proportion of class I was no higher than 1—2 per cent.

Table 12. Distribution of butt logs into quality classes and cull stems according to branchiness and stem defects, by forest site types

Taulukko 12. Tyvitukkien jakautuminen laatuluokkiin ja hylkytukkeihin sekä oksaisuuden että runkovikojen perusteella metsätyypeittäin

Age, years <i>Ikä, vuotta</i>	Butt log quality <i>Tyvitukkien laatuluokka</i>			
	I	II	III	Cull — <i>Raakki</i>
	VT			
	%			
35 .....	—	5	75	20
45 .....	—	14	75	11
55 .....	—	9	76	15
65 .....	34	42	25	—
75 .....	—	—	—	—
Total — <i>Yhteensä</i>	2	12	72	14
	MT			
35 .....	—	1	71	28
45 .....	—	2	80	18
55 .....	—	9	74	18
65 .....	—	13	67	21
75 .....	7	64	21	7
Total — <i>Yhteensä</i>	1	12	68	20
	OMT			
35 .....	—	—	41	59
45 .....	—	—	55	46
55 .....	—	—	—	—
65 .....	—	—	—	—
75 .....	3	36	41	21
Total — <i>Yhteensä</i>	1	10	46	43

## 42. Indicators of the quality of defect-free wood

### 421. Ring width

Ring width varies with the tree species, age, growth conditions and external stimuli. Ring width is in many respects an indicator of the utilizability of wood from the point of view of strength, basic density and the nature and volume of the pulp obtained. Variations in ring width are connected in many studies also with the amount of certain chemical components contained in wood (Hata 1949, Worster and Sugiyama 1962). It has been possible to demonstrate a distinct correlation between the internal knottiness of wood, quality and strength of sawlog and sawn goods and especially the annual rings in the vicinity of the pith (Heiskanen 1954 and 1965, Nylander 1959).

Ring width decreases with age and the widest annual rings of a tree are consequently to be found in the vicinity of the pith (Table 13). As the age of rings decreases from the butt of the tree upwards, ring width is different at different heights of the tree and smallest in the butt section (Table 14).

Table 13. Annual ring width at breast height in different parts of the core, by age classes and forest site types

Taulukko 13. *Luston leveys rinnankorkeudella lastun eri osissa ikäluokittain ja metsätyypeittäin*

Age, years Ikä, vuotta	Part of the core — <i>Lastun osa</i>							
	Outer — <i>Pinta</i>		Middle — <i>Keski</i>		Inner — <i>Ydin</i>		Average — <i>Keskimäärin</i>	
	Ring width, mm — <i>Luston leveys, mm</i>							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
	VT							
21—40 .....	1.6	0.5	2.5	0.6	3.3	0.9	2.0	0.5
41—60 .....	1.1	0.4	2.2	0.6	3.4	1.0	1.7	0.4
61—80 .....	1.3	0.4	1.4	0.3	2.4	0.7	1.5	0.3
	MT							
21—40 .....	1.8	0.7	3.1	0.6	4.0	0.9	2.5	0.6
41—60 .....	1.2	0.6	2.4	0.6	3.7	0.8	1.9	0.4
61—80 .....	1.2	0.4	1.9	0.5	3.6	0.9	1.8	0.3
	OMT							
21—40 .....	2.0	0.6	3.3	0.8	4.1	0.9	2.7	0.6
41—60 .....	—	—	—	—	—	—	—	—
61—80 .....	1.4	0.3	1.9	0.4	2.7	0.5	1.7	0.2

Table 14. Annual ring width at relative stem heights, by age classes

Taulukko 14. *Luston leveys rungon suhteellisilla korkeuksilla ikäluokittain*

Relative height, per cent <i>Suhteellinen korkeus, %</i>	Age, years — <i>Ikä, vuotta</i>							
	21—40		41—60		61—80		Average <i>Keskimäärin</i>	
	Ring width, mm — <i>Luston leveys, mm</i>							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
0 .....	2.2	1.0	1.9	1.1	1.6	0.4	2.0	1.0
10 .....	2.0	0.7	1.9	1.0	1.5	0.3	2.0	0.8
20 .....	2.2	0.7	1.9	0.8	1.7	0.4	2.1	0.8
30 .....	2.5	0.8	2.0	0.6	1.7	0.4	2.2	0.8
40 .....	2.5	0.9	2.0	0.5	1.9	0.2	2.3	0.8
50 .....	2.7	0.8	2.0	0.5	2.0	0.7	2.4	0.8
60 .....	2.8	0.9	2.0	0.5	2.0	0.5	2.4	0.9
70 .....	2.9	1.0	2.1	0.6	2.3	0.6	2.6	0.9
80 .....	3.0	0.9	2.2	0.7	2.3	0.8	2.7	0.9
90 .....	3.2	1.0	2.6	0.8	2.0	0.8	2.9	1.0

Ring width distinctly affects at least the branch diameter and the length of the self-pruned part of the stem. Table 15 shows that branch diameter is greater the faster the diameter growth of the tree at different ages (cf. Fig. 10). Ring width close to the pith does not correlate directly with branch diameter in the top parts of the stem, as the branches there have originated later. On the other hand, ring width in the outer parts does not affect branch diameter at the butt as the branches there are already dead. The fact that

Table 15. Correlation between branch diameter and annual ring width at breast height in pine stands aged 30—50 years  
*Taulukko 15. Oksan paksuuden riippuvuus luston leveydestä rinnankorkedella 30—50-vuotiaissa männiköissä*

Ring width, mm <i>Luston leveys, mm</i>	Relative height, per cent — <i>Suhteellinen korkeus, %</i>																	
	10		20		30		40		50		60		70		80			
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s		
	Branch diameter, mm — <i>Oksan paksuus, mm</i>																	
	Outer — <i>Pinta</i>																	
—2.0 .....	12	4	15	5	18	6	19	6	21	6	22	8	22	8	22	8	20	6
2.1—4.0 .....	15	6	20	7	25	6	23	3	30	7	32	9	29	9	29	9	26	7
4.1— .....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Middle — <i>Keski</i>																	
—2.0 .....	11	3	13	3	15	3	19	4	20	5	22	5	24	5	24	5	20	5
2.1—4.0 .....	14	4	18	5	22	6	23	5	25	6	27	9	27	9	27	9	23	6
4.1— .....	20	8	25	3	29	3	—	—	33	11	—	—	—	—	—	—	28	9
	Inner — <i>Ydin</i>																	
—2.0 .....	9	2	10	1	12	3	10	1	17	5	13	3	15	3	15	3	16	4
2.1—4.0 .....	12	4	15	5	18	5	19	5	21	6	22	6	22	6	22	7	20	6
4.1— .....	15	4	20	6	24	6	25	6	27	7	31	11	31	11	31	7	23	6

Table 16. Correlation between the defect-free part of the stem and annual ring width at breast height for 15, 20, 25 cm trees

Taulukko 16. Virheettömän rungonosan pituuden riippuvuus luston leveydestä rinnan-korkeudelta 15, 20, 25 cm:n puilla

Dbh, cm <i>D1.3, cm</i>	Ring width, mm — <i>Luston leveys, mm</i>									
	1		2		3		4		5	
	To the knot bumps, dm, — <i>Virheetön rungonosa, dm</i>									
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
15 .....	3	3	9	13	3	3	3	2	2	2
20 .....	4	3	18	10	7	9	2	2	3	2
25 .....	4	4	25	6	19	14	5	5	—	—

there is a difference also in branch diameter between the ring width groups around the pith is probably due to the relatively great diameter growth also in later age generally seen in trees which grow fast when young.

The effect of growth rate on branchiness is illustrated by Table 16 which presents the correlation between the branch-free part of the stem and ring width in trees of a certain diameter. Relatively slow-growing trees are qualitatively the best (cf. Figs. 6—8).

The effect of the growth rate of trees on indicators of the internal quality of wood has been studied extensively. According to especially the earlier studies, ring width has a considerable effect on e.g. basic density (Larson 1957, Miyajima 1958, Knigge 1961, etc). However, variations in basic density are often associated primarily with age (Cooper 1960, Echols 1960, Paul 1960, Sellers 1962, Hakikila 1966, Fielding 1967). Pine wood density was reported by Hakikila (1966) to decrease when ring width increases, but when the effect of the structurally exceptional juvenile wood zone was eliminated the correlation weakened considerably.

Although ring width increases somewhat in thinnings, some studies on exotic pine species have revealed that normal silvicultural treatment does not notably reduce basic density or the strength properties of wood (Turnbull et al. 1946, Nichols and Fielding 1965, Ericson 1966, Schalek 1967, Choong et al. 1970). Klem (1969) noted that ring widths doubled under the effect of fertilisation before any appreciable changes occurred in the wood properties of pine or spruce. According to Saikkula (1973 a), bark thickness also decreased slightly when the growth rate was increased by fertilisation.

In this study by regression analysis of the correlation between basic density and indicators of the stem, the correlation between basic density and ring width was  $-0.210$  in the per-stem analysis and  $-0.755$  in the between-stand analysis. Ring width was a good indicator of basic density

in the analysis by experimental plot and a fair one also in the per-stem analysis (cf. pp. 72 and 71). On the other hand, the logarithm of ring width was the best indicator of the percentage of late wood in the stem (p. 65).

#### *422. Percentage of late wood*

Softwood tracheids with cell vacuoles wider in the radial direction than double the cell wall thickness are generally regarded as early wood. Variation in the middle layer thickness of the secondary cell wall causes the main difference between early and late wood.

The volume ratios of the walls and vacuoles vary within an individual annual ring under the influence of precipitation and dry periods during the growing season (e.g. H a r r i s 1955, L a r s o n 1957). The effect of the percentage of late wood on the structure of wood is great, although the connection is confused by the juvenile wood zone. There is a correlation between ring width and late wood percentage (S c h u l t z e - D e w i t z 1958, C o r o n a 1966) and the significance of the latter as an indicator of basic density variations has been shown to be decisive (L a r s o n 1957, H a k k i l a 1966 and 1968, Y a o 1970). However, it is impossible to explain total basic density with the variation of early wood and late wood as the internal density of early and late wood also varies.

The percentage of late wood decreases in the stem from the butt upwards and is also lower on average the younger the tree (Table 17). The mean of the stem latewood percentage coincides on average with the 30 per cent relative height. The fibre wall thickness and the percentage of late wood thus increase with age and are at their highest in the butt of the stem and in the outer parts of the tree (e.g. L a r s o n 1957, S e l l e r s 1962, S a i k i 1965, H a k k i l a 1966).

Fig. 31 shows the variation in the latewood percentage at different heights of pine stems of differing lengths. As a taller tree is generally also older, the latewood percentage increases with tree height. Changes in the percentage of late wood in the longitudinal direction of the tree are linear, declining evenly except in the upper part of the stem. The percentage of late wood is highest in slow-growing trees and reaches its maximum values in a pine stand in the stems of the lowest crown classes (Table 18).

Ring width was the best indicator of the percentage of late wood in the stem, although the degree of explanation was relatively low throughout. The logarithm of ring width explained 41 per cent of the total variation

Tabla 17. Percentage of late wood at relative heights of stems of different ages and in different parts of the core

Taulukko 17. Kesäpuuprocentti eri ikäisten runkojen suhteellisilla korkeuksilla sekä lastun eri osissa

Age, years Ikä, vuotta	Relative height, per cent — Suhteellinen korkeus, %									
	0	10	20	30	40	50	60	70	80	90
	Latewood, per cent — Kesäpuuta, %									
	Outer — <i>Pinta</i>									
—40 .....	32.8	33.9	32.0	30.2	28.8	27.2	25.6	23.4	22.0	20.0
41—60 .....	37.6	37.8	36.8	35.6	34.2	32.5	32.0	29.5	26.7	23.8
61—80 .....	36.8	38.2	36.5	36.3	32.8	33.6	31.0	28.9	26.5	23.0
	Middle — <i>Keski</i>									
—40 .....	28.1	26.5	23.3	22.4	22.1	21.5	20.5	21.4	—	—
41—60 .....	31.4	29.0	27.0	25.8	25.7	25.8	26.2	24.4	—	—
61—80 .....	34.2	31.4	30.8	28.7	26.6	24.2	23.8	24.0	21.4	—
	Inner — <i>Ydin</i>									
—40 .....	26.4	21.9	19.7	19.4	19.4	20.2	19.9	20.5	20.6	—
41—60 .....	27.6	22.3	20.6	21.0	20.0	20.4	22.2	23.3	22.9	—
61—80 .....	26.0	21.5	18.9	17.0	18.1	17.2	19.0	19.6	18.9	—
	Average — <i>Keskimäärin</i>									
—40 .....	30.6	30.2	17.9	26.7	26.0	25.2	24.1	23.0	23.2	20.0
41—60 .....	34.3	33.0	31.7	30.6	29.8	29.1	29.1	28.1	26.8	23.8
61—80 .....	34.6	33.6	32.4	31.3	29.1	28.2	27.1	26.6	24.0	23.0

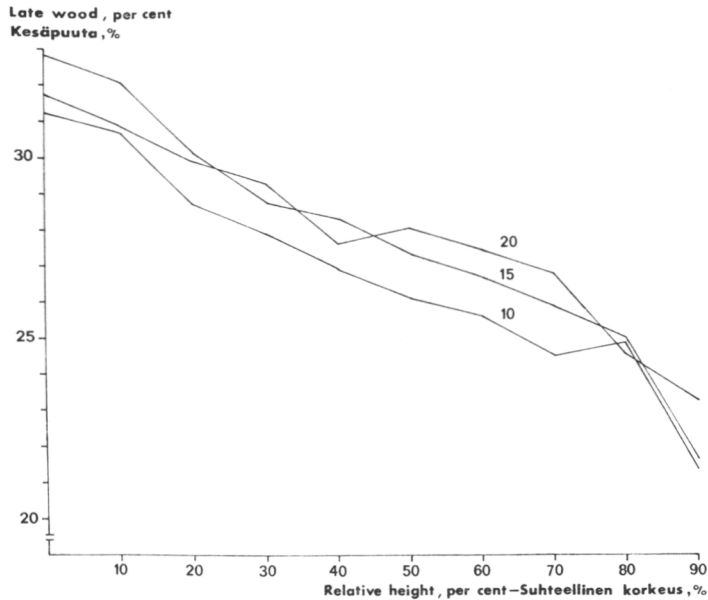


Fig. 31. Variation in the percentage of late wood at relative heights in 10-, 15- and 20-m plantation-grown pine stems.

Kuva 31. Kesäpuuprocentin vaihtelu 10-, 15- ja 20-metrysten viljelymäntyrunkojen suhteellisilla korkeuksilla

Table 18. Percentage of late wood in different crown classes, by age classes  
*Taulukko 18. Kesäpuuprosentti eri latvuserroksissa ikäluokittain*

Age, years <i>Ikä, vuotta</i>	Crown class — <i>Latvuserros</i>							
	1		2		3		4	
	Latewood, per cent — <i>Kesäpuuta, %</i>							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
—40 .....	26.3	3.6	27.6	3.6	30.0	3.6	30.5	1.6
41—60 .....	30.1	2.9	31.3	2.9	31.5	3.1	32.5	3.0
61—80 .....	29.4	2.9	32.4	3.2	—	—	—	—

in the stem late wood percentage and the equation thus assumes the form  $Y = 0.539 - 82.013 X$ , in which  $R = 0.636$ .

$Y$  = stem late wood percentage  
 $X$  = logarithm of ring width

The degree of explanation rose to 45 per cent when the stem diameter growth and the diameter of the thickest dry branch were added to ring width as indicators of the variation of latewood percentage. The equation then took the form  $Y = 0.155 - 355.517 X_1 - 317.002 X_2 - 48.764 X_3 - 3934.092 X_4 + 0.070 X_5$  and  $R = 0.666$ .

$X_1$  = the logarithm of ring width,  
 $X_2$  = the reciprocal of the diameter of the thickest dry branch  
 $X_3$  = the logarithm of Dbh/age  
 $X_4$  = the reciprocal of ring width  
 $X_5$  = the square of ring width

In his study of the correlation of the latewood percentage of pine pulpwood with different factors *Hakkila* (1968) did not find ring width to affect appreciably the variation in the percentage of late wood in a material collected from all over Finland. However, the coefficient of correlation was  $-0.580$  in the southernmost part of the country.

The mean latewood percentage for plantation-grown pine stems was found to be 28.6 and its deviation 1.6. *Jalava* (1934) stated the percentage of late wood in pine to be 28.2 in South Finland. The percentage of late wood in pine pulpwood was reported by *Hakkila* (1968) to be 26 (deviation 1.9) south of the 64th parallel. *Hakkila* (1967) obtained results of the same magnitude for growing pine. There is thus no noteworthy difference between plantation-grown pines and naturally regenerated pine stands in the percentage of late wood.

Several studies have shown that age is the most important factor regulating the variation in the percentage of late wood (e.g. *Larson* 1957, *Sellers* 1962 and *Saiki* 1965). However, a negative correlation was

established also between growth rate and late wood percentage in a study of the wood qualities of pine from cultivated stands (H a m i l t o n and M a t h e w s 1965, B a k e r 1969). The percentage of late wood in *Pinus Taeda* was reported by YAO (1970) to increase significantly when the ring width contracted from 8 to 3 mm; after this the narrowing of the annual ring no longer had any effect.

### 423. Basic density

#### 4231. Density variation within the stem

The percentage of late wood is the most significant factor that affects the change in wood density in pine because of the notable weight difference between late and early wood (e.g. P i l l o w 1955, Z o b e l and R h o d e s 1955, E i n s p a h r et al. 1964, Z o b e l et al. 1965, M a n w i l l e r 1972). However, the percentage of late wood is not the sole indicator of basic density, for it varies also within the cellular tissue of early wood and late wood. In his study of the effect of the anatomic factors of wood on the basic density of *Pinus Elliottii* van B u i j t e n e n (1964) observed that the most important were the thickness of the cell wall in late wood, the early wood percentage and the diameter of late wood fibres.

When basic density was studied as a function of late wood percentage determined at breast height an equation was obtained which explains 42 per cent of the variation of basic density (Fig. 32).

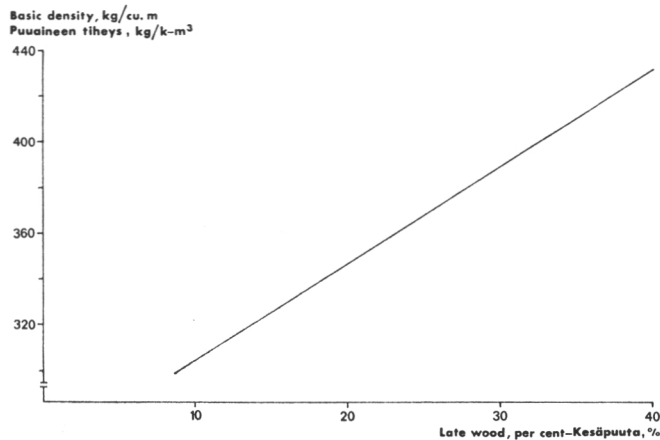


Fig. 32. Correlation between the basic density (kg/solid cu.m.) of the stem and the percentage of late wood at breast height in plantation-grown pine.

Kuva 32. Rungon puuaineen tiheyden ( $\text{kg/k-m}^3$ ) riippuvuus kesäpuuprosentista rinnankorkeudella viljelymänniköissä

Regression equation	R	S <sub>y-x</sub>
$Y = 262.881 - 4.228 X$ . . . . .	0.650	21.5

H a k k i l a (1966) explained by means of the percentage of late wood 53 per cent of the density of pine cores taken with an increment borer, and L a r s o n (1957) 60 per cent of the basic density variation of *Pinus ponderosa*. Y A O ' s (1970) studies on *Pinus Taeda* also revealed a strong correlation between the percentage of late wood and basic density. The degree of explanation of late wood percentage at breast height was 49 per cent, and it rose further when the correlation was studied at the relative heights of 30 and 50 per cent.

The percentage of late wood and the density of the late wood part rise with age and basic density may therefore be associated also with the age of the tree (S e l l e r s 1962, M i t c h e l l 1964). Hence, basic density increases with age and reaches its maximum at a certain age and in an annual ring of a certain width (S k r i p e n and R i a s o v a 1958). Fig. 33 shows the variation of basic density in the longitudinal direction of pine stems of different age classes.

Both radial and longitudinal variation can be distinguished in the basic density of stems. Density generally increases from the pith towards the surface and decreases from the butt towards the top. Variations in basic density within the stem thus follow the variations in late wood percentage (cf. p. 64). The cellular tissue of juvenile wood causes an exceptionally

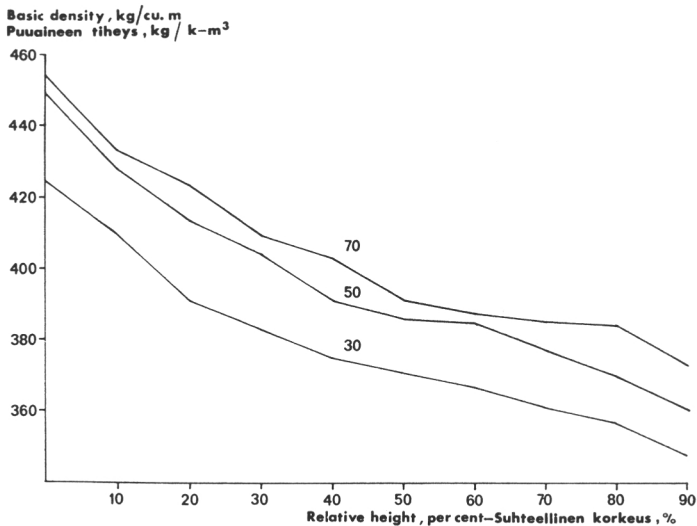


Fig. 33. Basic density (kg/solid cu.m.) by age classes in plantation-grown pine.

Kuva 33. Puuaineen tiheys (kg/k-m<sup>3</sup>) ikäluokittain viljelymänniköissä

Table 19. Basic density at relative heights of stems of different ages in different parts of the core

Taulukko 19. Puuaineen tiheys eri ikäisten runkojen suhteellisilla korkeuksilla lastun eri osissa

Age, years Ikä, vuotta	Relative height, per cent — Suhteellinen korkeus, %									
	0	10	20	30	40	50	60	70	80	90
	Basic density, kg/cu.m. — Puuaineen tiheys, kg/k-m <sup>3</sup>									
	Outer — <i>Pinta</i>									
—40	442.5	432.5	413.6	399.7	387.6	379.9	371.8	362.5	357.1	348.1
41—60	469.4	457.3	443.1	429.6	409.3	401.6	396.8	382.5	372.6	361.8
61—80	465.7	458.8	449.0	433.9	422.1	405.8	401.9	394.1	395.2	374.5
	Middle — <i>Keski</i>									
—40	404.8	381.8	360.2	357.9	352.2	352.2	348.6	355.0	366.5	—
41—60	427.1	399.0	379.5	374.6	365.9	365.3	369.7	357.8	360.0	—
61—80	455.2	422.6	413.4	397.9	394.6	381.0	377.9	384.2	366.1	—
	Inner — <i>Ydin</i>									
—40	407.1	371.8	354.8	354.5	350.5	352.1	350.4	349.6	342.6	—
41—60	421.8	368.4	362.0	358.2	356.1	357.0	361.2	362.2	356.3	—
61—80	432.3	361.6	354.7	348.5	355.1	366.6	374.8	358.6	359.7	—
	Average — <i>Keskimäärin</i>									
	Outer — <i>Pinta</i>									
	454.0	443.4	426.8	412.8	397.5	389.4	382.8	371.9	365.2	356.2
	Middle — <i>Keski</i>									
	416.4	391.8	371.6	367.7	361.0	360.2	361.9	362.3	365.6	—
	Inner — <i>Ydin</i>									
	413.8	369.9	357.7	355.8	353.0	354.7	356.3	356.4	353.2	—

low basic density in the vicinity of pith. Density in the juvenile wood zone is at the same time abnormally low and relatively even. Table 19 shows the variation in basic density in radial zones and at different relative heights of the stem. It is greatest in the outer part of the tree butt and declines from the surface towards the pith the more steeply the older the age class. The corresponding decrease in density is smaller at the top of the tree than in the butt section.

Figs. 33 and 35 present the mean basic density at different relative heights of the stem by age classes and density in pine stands aged 30—50 years on different forest site types. Fig. 34 compares basic density in the longitudinal direction of the stem in plantation-grown and naturally regenerated pines (cf. Hakki 1966). The decrease in density longitudinally is steepest in the vicinity of the butt and approaching the tree top. The mean density of the stem is 395 kg/solid cu.m., and this falls at the 25 per cent height of the stem. Okkonen et al. (1972) distributed softwoods into two groups according to the quantity of late wood; one group was characterised by a high and the other by a low percentage of late wood.

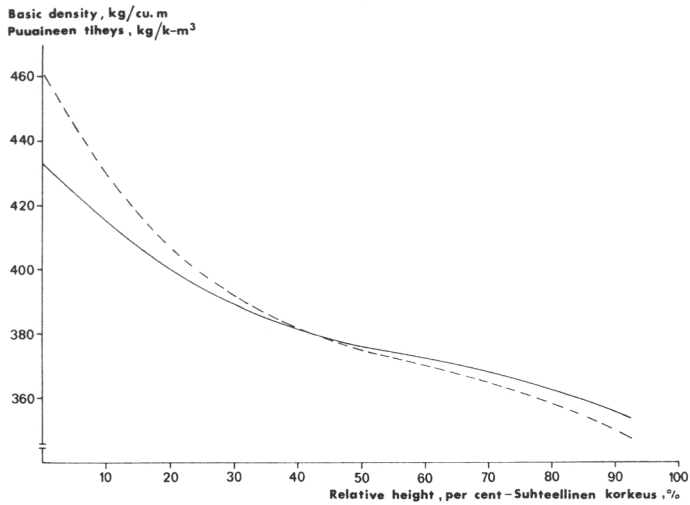


Fig. 34. Basic density (kg/solid cu.m.) at relative heights of plantation-grown pine. — — — Basic density (kg/solid cu.m.) of pine stem according to HAKKILA (1966).

*Kuva 34. Puuaineen tiheys (kg/k-m<sup>3</sup>) viljelymäntyrunkojen suhteellisilla korkeuksilla. — — — Mäntyrunгон puuaineen tiheys (kg/k-m<sup>3</sup>) HAKKILAN (1966) mukaan*

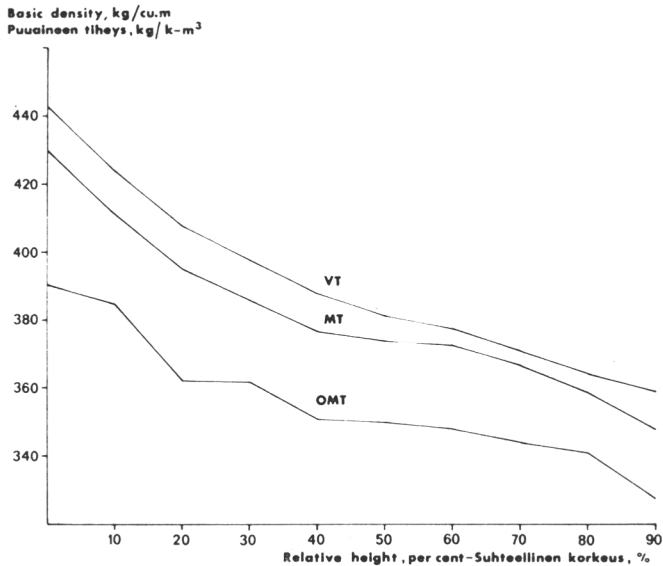


Fig. 35. Basic density (kg/solid cu.m.) by forest site type in plantation-grown pine aged 30—50 years.

*Kuva 35. Puuaineen tiheys (kg/k-m<sup>3</sup>) metsätyypeittäin 30—50 vuotiaissa viljelymänniköissä*

A higher basic density in the butt than elsewhere in the stem was typical of the former group which included all the 11 American pine species studied, while the latter group was characterised by an increase in density in the opposite direction, from butt to top.

According to Fig. 35 basic density is exceptionally low for OMT because of the high growth rate. The average density difference between OMT and MT stems is about 20 kg/solid cu.m., against only 10 kg/solid cu.m. between MT and VT. The concentration of growth in the butt in OMT is seen also from the low density at 0 height compared with MT and VT.

The importance of growth rate for wood properties, specifically density, has been studied extensively. Opinions as to its role are partly contradictory. However, the thought has been commonly accepted in the literature that if the changes in growth rate are not particularly steep their effect on basic density remains relatively small (Zobel and Rhodes 1955, Paul 1960, Sellers 1962, Mitchell 1964, Ralston and McGinness 1964). Yet, it has been found that the nutrient content of the soil lowers basic density (Jayne 1958).

It has also been observed that slight changes in the planting spacing affect pine density but little (Echols 1960, Geyer and Gilmore 1965, Hamilton and Mathews 1965, Baker 1969).

#### 4232. Density variation between the stems

Stem-to-stem variation of the average basic density in a stem depends on different environmental and genetic factors and age. The logarithm of age was found to be the best variable for explaining the variation; it explained 37 per cent of the total variation in stem density.

Regression equation	R	S <sub>y·x</sub>
$Y = 212.880 + 49.601 \log X$ . . . . .	0.610	22.3

Y = basic density of stem, kg/solid cu.m.

X = age of tree, years

The mean of basic density of the total material of 2 747 stems was 395.2 kg/solid cu.m. and the standard deviation 28.1 kg/solid cu.m., i.e. 7.1 per cent of the mean. The corresponding mean stem density and deviation in naturally regenerated pine stands were 408.6 and 32.8 kg/solid cu.m. (Hakkila 1966). It is natural that wood quality is more homogeneous and stem-to-stem variation of density smaller in plantation forests than in naturally regenerated forests. Age explained 32 per cent of the stem density variation in natural stands.

If the ratio between Dbh and age, i.e. growth rate, is adopted as the explanatory factor, the degree of explanation rises to 40 per cent. It rises further to some extent if the number of indicators is increased. In addition to the logarithm of age, the best indicators are the following.

Independent variable	R	Explained variance, %
Breast height diameter/age . . . . .	0.632	40
+ (tree height/age) <sup>2</sup> . . . . .	0.640	41
+ logarithm of ring width . . . . .	0.647	42

The degree of explanation was not improved by the addition of several independent variables to the equation. H a k k i l a (1966) explained 40 per cent of the total variation of pine stem density with the help of external tree characteristics and environmental factors. The best equation explained 37 per cent of the density variation in spruce stems from cultivated spruce stands and the variation was considerably lower than that for naturally regenerated stems (H a k k i l a and U s v a a r a 1968). H a k k i l a and P a n h e l a i n e n (1970) explained 35 per cent of the wood density variation of *Pinus contorta* grown in Finland. Longitudinal growth, bark percentage and indicators of stem form turned out to be the best independent variables.

Age and growth rate were the best factors explaining the basic density of plantation-grown pine stems in the present study. The results obtained by regression analysis are thus in good agreement with the conclusions drawn on stem-to-stem variation in the previous chapter. Acceleration of growth reduces basic density and the wood quality can consequently be affected by regulating growth.

#### 4233. Density variation between the stands

If, instead of stem-to-stem wood density variation, stand-to-stand variation is examined, the results are different. Variation between stems is excluded and the results are levelled. The minimum and maximum values for basic density in a material from 90 sample stands were 340 and 432 kg/solid cu.m. and the standard deviation was 21.8 kg/solid cu.m. (5.5 per cent of the mean), i.e. lower than in the stem-to-stem comparison.

Stand-to-stand and within-stand variation of basic density was studied by variance analysis. According to the analysis, within-stand variation was significant at the 0.01 per cent risk level.

Variation	Sum of squares	Degree of freedom	Mean square	F-value
Stand-to-stand . . . . .	1 240 900	89	13 942	38.47***
Within-stand . . . . .	926 980	2 558	362	
Total . . . . .	2 167 900	2 647		

The between-stand basic density variation was studied by means of stepwise regression analysis, using the variables that were used before; it gave logarithm of breast height diameter divided by the age of the stem as the best variable. The correlations were considerably greater than earlier. The variable mentioned explained 72 per cent of the total variation of density and the regression equation assumed the following form:

Regression equation	R	S <sub>y-x</sub>
$Y = 468.302 - 1066.817 X$ . . . . .	0.854	11.5
Y = basic density of stand, kg/solid cu.m.		
X = logarithm of Dbh/age		

When the number of independent variables was increased further an 83 per cent degree of explanation was achieved by means of five variables. Stand-to-stand basic density variation is thus explained best when the following variables are added to the variable logarithm of breast height diameter divided by age.

Independent variable	R	Explained variance, %
Logarithm of the mean ring width . . . . .	0.879	77
+ (Mean age/mean diameter) <sup>2</sup> . . . . .	0.891	79
+ Mean branch diameter at 20 % relative height, mm . . . . .	0.896	80
+ Mean diameter of the longest living branch, mm . . . . .	0.909	83

The residual deviation of the equation was 9.3 kg/solid cu.m., i.e., 2.4 per cent of the average basic density of the stands. A considerable proportion of the unexplained variance was probably due to genetic factors that affect basic density, but measuring errors also cause unexplained variation.

The following table presents some correlations between basic density by stem and by stand and between some variables.

Independent variable	Coefficient of correlation	
	By stem	By stand
Reciprocal of age . . . . .	- 0.599	- 0.813
Square root of age . . . . .	0.600	0.811
Logarithm of crown proportion	0.501	0.706
Diameter growth . . . . .	- 0.295	- 0.507
Height . . . . .	0.464	0.657
Logarithm of volume . . . . .	0.365	0.640

#### 424. Percentage of heartwood

There is no heartwood in pines of seedling age; it begins to develop, depending on e.g. the latitude, at the age of approx. 25 years in the southern part of, say, Sweden and at about 70 years of age in the northern part (H ä g g l u n d 1935). Heartwood formation is accelerated and its pro-

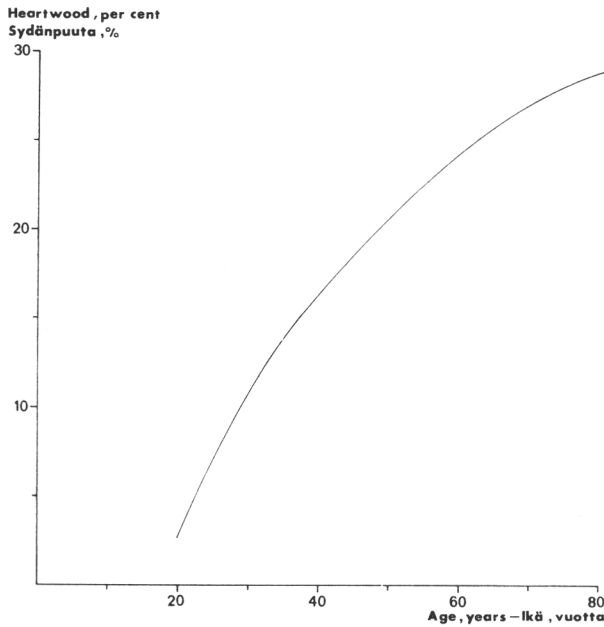


Fig. 36. Correlation between percentage of heartwood at breast height of the tree and age in pine plantations.

Kuva 36. Puun rinnankorkeudelta mitatun sydänpuuprosentin riippuvuus iästä viljelymänniköissä

portion in the stem grows sharply with age. The development is illustrated by a curve (Fig. 36) plotted from the Dbh measurements of the percentage of heartwood. This curve shows that heartwood begins to develop in plantation-grown pines on average at the age of somewhat under 20 years. The heartwood percentage increases steeply at first, more gently later. The proportion of heartwood at the age of 80 years is 29 per cent.

Regression equation	$\bar{y}$	$\bar{x}$	R	$S_{y-x}$
$Y = -55.508 + 19.514 \log X$ . . . . .	16.5	36.8	0.610	8.81

Y = heartwood at breast height, per cent

X = tree age, years

Age explains 37 per cent of the heartwood percentage of plantation-grown pine stems. H a k k i l a (1968) observed the logarithm of age to be the best independent variable for explaining the variation of the percentage of heartwood in pine pulpwood by locality. The heartwood percentage of pine pulpwood bolts at the age of 80 years was approx. 4 per cent higher than the same percentage determined at breast height for plantation-grown pine stems. The significance of age for the heartwood percentage has been reported in many other studies (L a p p i - S e p p ä l ä 1952, T a m m i n e n 1962, H e i s k a n e n 1970). E d l u n d

(1966) reported that pine contains almost 20 per cent heartwood at breast height at the age of 40 years. According to the studies conducted by E n e r o t h (1922) on old trees, the percentage of heartwood rises continuously with age though the increase slows down slightly at the age of about 100.

In addition to age, heartwood percentage depends on e.g. soil, growth rate, genetic factors and geographical location. As many indicators of branchiness and stem form describe expressly the growth rate, old, narrow-ringed, small-crowned and slender, slightly tapering stems contain on average the greatest quantity of heartwood (L a p p i - S e p p ä l ä 1952, K ä r k k ä i n e n 1972). In his study of the correlation between the percentage of heartwood and various stem indicators N y l i n d e r (1961) noted the strongest correlation between heartwood percentage on one side and, on the other, diameter, width of annual rings close to the surface and relative crown height.

The heartwood percentage rises from the butt of the stem up to a relative height of about 15 per cent where it reaches its maximum and then decreases sharply towards the top. The percentage is only about 1 at 80 per cent height (Fig. 37). The heartwood percentage is lower in shorter trees than in taller and older stems.

The variation with age of the heartwood percentage can also be seen from Table 20. Although the percentage of heartwood in older stems is a little higher on average than in younger stems, the growth rate influences the fact that the heartwood content of the faster-growing of two stems may be greater than that of the slow-growing stem.

N y l i n d e r (1961), E r i c s o n (1966) and H a k k i l a (1967) found the highest heartwood percentage at the 20—30 per cent height of the pine. The highest heartwood percentage of the *Pinus contorta* is at the 20 per cent height of the smallest stems of the stand, but closer to the butt when the tree height grows (H a k k i l a and P a n h e l a i n e n 1970). The curves illustrating longitudinal changes in heartwood percentage in the above study were similar to the curves for plantation-grown stems, but the actual percentage of heartwood was considerably higher.

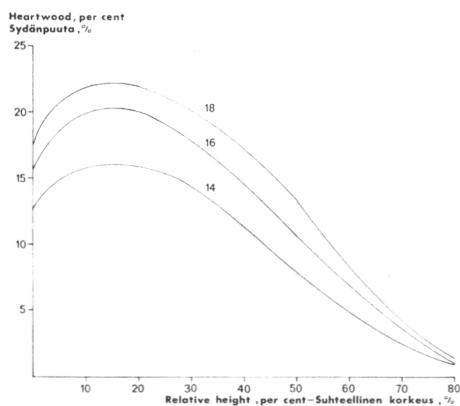


Fig. 37. Percentage of heartwood at relative heights in 14-, 16- and 18-m plantation-grown pine stems.

Kuva 37. Sydänpuuprosentti 14-, 16- ja 18-metrinen viljelmäntyrunkojen suhteellisilla korkeuksilla

Table 20. Percentage of heartwood at relative heights of stems of different ages  
*Taulukko 20. Sydänpuuprosentti eri ikäisten runkojen suhteellisilla korkeuksilla*

Relative height, per cent <i>Suhteellinen korkeus, %</i>	Age, years — <i>Ikä, vuotta</i>						Average <i>Keskimäärin</i>	
	21—40		41—60		61—80			
	Heartwood, per cent — <i>Sydänpuuta, %</i>							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
0 .....	6.6	7.6	14.4	11.0	19.5	14.5	10.2	10.3
10 .....	9.6	8.6	18.2	10.4	22.0	16.9	13.4	10.7
20 .....	9.2	8.5	17.9	10.1	25.8	16.3	13.3	10.7
30 .....	8.4	8.3	16.2	10.5	26.8	16.1	12.2	10.8
40 .....	6.4	7.4	14.3	9.7	18.7	13.4	10.0	9.6
50 .....	4.6	6.6	10.6	8.8	17.3	10.5	7.5	8.5
60 .....	2.0	3.8	7.0	8.4	13.3	7.6	4.4	6.9
70 .....	1.2	3.7	3.5	5.5	5.3	4.8	2.3	4.7
80 .....	0.4	1.5	1.3	5.1	1.5	2.4	0.8	3.6

### 43. Comparison between naturally regenerated and plantation-grown pines

Fig. 38 shows the development of the lower limit of dead and living branches and of the tree height in plantation-grown and naturally regenerated pine stems as a function of breast height diameter (H a k k i l a et al. 1972). The latter material was collected from South Finland in the National Forest Inventory. The growing stock and the crown limit are both higher in cultivated than in naturally regenerated pine stands. As the point of origin of dry branches is lower in the former, the part of the stem with dry branches is considerably longer in plantation than in naturally regenerated pines. The branchless part of the stem is correspondingly shorter although the difference decreases as the diameter grows.

The crown proportion is greater in naturally regenerated than in cultivated pine stands (Fig. 39). When the diameter grows the crown proportion is shortened evenly in the former, while in the latter it is first shortened and then lengthens in the highest diameter stems.

The results taken in the foregoing as references for comparison with plantation-grown pines apply equally well to the results obtained for mixed forests and pure pine stands. Although self-pruning is slower in plantation-grown pines than in naturally regenerated stems, a partial explanation of the great differences in the height of the pruned part and of the branchy part is that a stem of certain diameter in a naturally regenerated stand is usually older than a plantation-grown pine of the same diameter, but of faster growth. These results are compared in the following table with N y y s s ö n e n's (1954) findings for the development of branchiness in pine stands aged 60 and 80 years treated with cuttings (cf. Fig. 5).

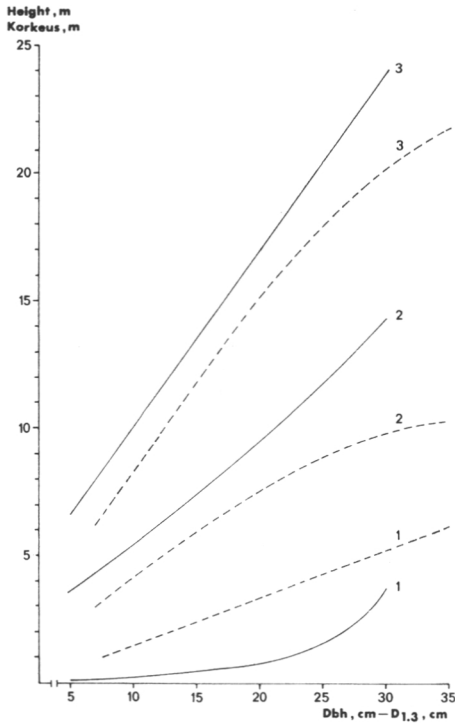


Fig. 38. Lower limit (1) of dry branches of the tree, crown limit (2) and the overall height of the tree (3) as a function of Dbh in pine plantations.

— — — Corresponding parts of the stem in naturally regenerated pine stands (HAKKILA et al. 1972).

*Kuva 38. Puun kuivien oksien alaraja (1), latvusraja (2) sekä puun koko pituus (3) rinnankorkeusläpimitan funktiona viljelymänniköissä*

— — — *Vastaavat rungon osat luonnonmänniköissä (HAKKILA ym. 1972)*

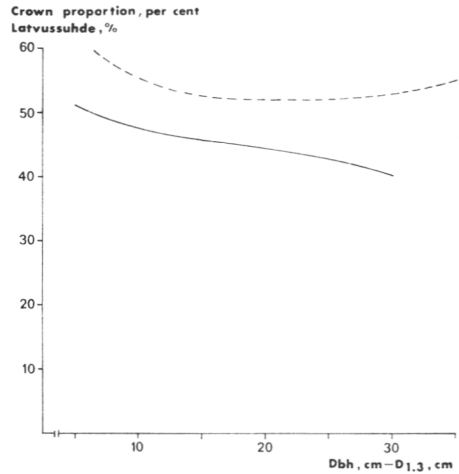


Fig. 39. Crown proportion as a function of Dbh in pine plantations.

— — — Crown proportion in naturally regenerated pine stands (HAKKILA et al. 1972).

*Kuva 39. Latvussuhde rinnankorkeusläpimitan funktiona viljelymänniköissä*

— — — *Latvussuhde luonnonmänniköissä (HAKKILA ym. 1972)*

	Naturally regenerated stands		Plantations			
	MT	VT	60	80		
	60	80	60	80		
	Per cent of the stem height					
Branchless part of stem	13	17	15	19	6	22
Dry-branched part of the stem	48	43	44	38	56	41
Crown	41	39	41	40	38	37

The branchless part and the crown of plantation-grown pines are thus shorter and the dry-branched part of the stem longer than in naturally regenerated pine stands.

K r o t k e v i t š (1955) reported the length of the self-pruned and dry-branched part of the stem and the crown height of 60-year-old pine stands to be 13, 42 and 31 per cent of the tree height. Similar results were obtained for naturally regenerated forests by H e i k i n h e i m o (1953) and H e i s k a n e n (1965). According to N y y s s ö n e n (1954), the crown proportion at the age of 40 is 45 per cent and then decreases evenly to 39 per cent for VT and 35 for MT at the age of 100 years. S a r v a s (1944) studied the crown proportion of pine stands treated with selection cutting and found it to be 35 per cent for VT.

Comparison with naturally regenerated pine stands shows that plantation-grown pine stems are poorly self-pruned, especially at the age of 40—60 years when the butt section has already attained sawlog dimensions. The branch limit rises at an older age in plantation-grown pines to the level of naturally regenerated stems, but even then about a half of the self-pruned part of the stem contains knot bumps.

The poor self-pruning of plantation-grown pines is due partly to the slow decay and falling of abnormally thick branches. The studies made by H a k k i l a (1971) show that Dbh is the best indicator of branch diameter and height also in naturally regenerated pine stands, i.e., the branch dimensions develop in ratio to the stem diameter. As diameter growth is faster in cultivated stands, branches, too, grow thicker than they do in naturally regenerated stems. There are not very many points of reference with the branch diameters of naturally regenerated stands. A comparison is made in Fig. 40 between the diameter of the thickest branch at 70 per cent height in naturally regenerated stands and plantations (H a k k i l a et al. 1972). Although the objects of comparison were plantation-grown pines of under 50 years which were in the best growth rate phase and a material comprising numerous old and slow-growing naturally regenerated pines, the diameters were almost equally great. Branch diameter increases sharply in the top parts of the tree only at a higher age (Fig. 9).

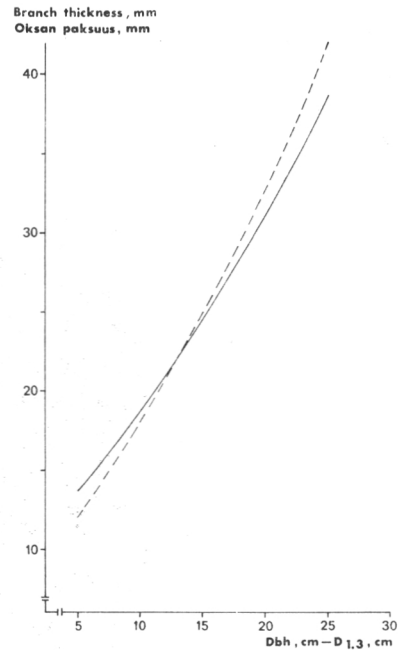


Fig. 40. Branch diameter at 70 per cent height of the tree as a function of Dbh in plantation-grown pine.

— — — Branch diameter in naturally regenerated pine stands (HAKKILÄ et al. 1972).

Kuva 40. Oksan paksuus puun 70 %:n korkeudella rinnankorkeusläpimitan funktiona viljelymänniköissä — — — Oksan paksuus luonnonmänniköissä (HAKKILÄ ym. 1972)

A comparison is made in the following table between branch diameters at the 10 and 50 per cent stem heights in plantations and natural pine stands by crown classes (Heikinheimo 1953). Some of the naturally regenerated stands are mixed spruce-birch stands and their mean age, 30 years, is slightly lower than that of the plantations. In the former, dead and living branches were also distinguished between.

Crown class	Naturally regenerated stands		Plantations
	Mean diameter of the branches, mm		
	Living	Dead	
1 .....	10	12	19
2 .....	7	9	15
3 .....	6	7	13
4 .....	4	4	11

Light conditions in the forest have been found to be decisive for the quality development of pine (Chojnacki 1969). There are many pine plantation experiments in which the seeding and planting spacings have been varied. The experiments demonstrated that branch diameter increases when the cultivation spacing is lengthened.



Fig. 41. Pine plantations usually develop in homogenous conditions compared with naturally regenerated pine stands.

*Kuva 41. Viljelymänniköt kehittyvät tavallisesti luonnonmänniköihin verrattuna tasaisissa olosuhteissa*

The slow development of sown plants restricts the use of sowing on fertile sites, whereas a planted seedling usually tends to grow branches. However, it was pointed out by Yli-Vakkuri (1968) in his study of the establishment density of a seedling stand that little can be done about this, not even by increasing the planting spacing on fertile sites. Branch development is affected not only by the planting or seedling spacing but also by the homogeneity of the growing stock. Branch development in pine plantations must probably be related to the fact that it is not possible with anything like the same frequency to create in natural stands homogeneous growth environments with similar light and growth conditions (Fig. 41).

Stem taper was mentioned as being associated with the stem growth rate, branch diameter and crown size and shape. Hence, primarily a low number of stems per unit of area and thinnings of growing stock increase taper. Larson (1963) stated that every silvicultural measure which causes changes in crown growth is reflected immediately as changes in stem form. Taper is dependent on the intensity of the thinnings, and this increases the growth of taper only until the crown reaches again its most meaningful dimensions (Flury 1903 and Krahli-Urban 1939). The effect of growth rate is greatest in young stands (Fig. 42).

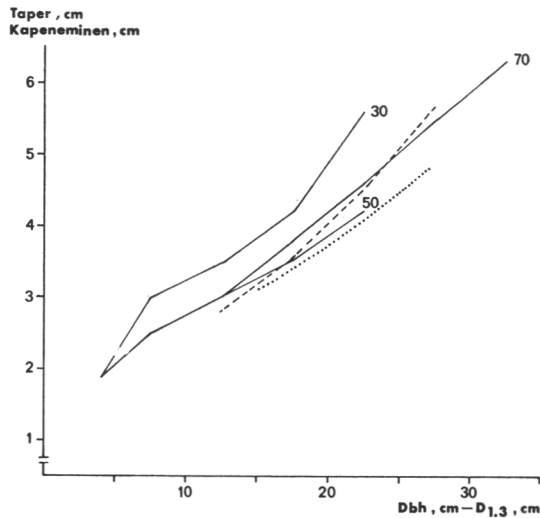


Fig. 42. Correlation between the taper and Dbh of plantation-grown pines aged 30, 50 and 70 years.  
 ... taper according to NYSSÖNEN (1954)  
 --- taper according to SARVAS (1944)

Kuva 42. 30-, 50- ja 70-vuotiaiden viljelymäntyjen kapenemisen riippuvuus rinnankorkeusläpimitästä  
 ... kapeneminen NYSSÖSEN (1954) mukaan  
 --- kapeneminen SARVAAN (1944) mukaan

A comparison is made in Fig. 42 of tapering in plantations, thinned forests of natural origin (Nyysönen 1954) and pine stands treated with selective cuttings (Sarvas 1944). The curves for naturally regenerated pine stands are based on a material collected only from VT forests. The difference would be reduced slightly had the comparison material included also growing stock from better forest site types. The difference in the stem taper of MT and VT stands was, however, extremely small in pine stands subjected to cutting (Nyysönen 1954).

According to Tiihonen (1972), tapering of the pine stem in diameter classes 13—24 cm is 4 cm.

The commonest defect in plantation-grown pines impairing its technical quality was either a stem crook or a crook in the butt. The observations made by Kangas (1962) on naturally regenerated pine stands were similar, but are not comparable as such. It thus remains uncertain whether there are essential differences in the quantity and quality of the defects encountered in naturally regenerated and plantation-grown pine stands. It seems, nevertheless, that growth disturbances, particularly sweep, are associated with the high growth rate of plantation-grown pines.

Heiskanen's (1955 and 1965) studies give the best reference points for a comparison of the butt log quality in cultivated pine stands. The quality class per cent distribution for butt logs was: I 11.2, II 63.4 and III 25.5 in the 1955 study. In the present study the same distribution was 1.4, 14.8 and 83.6 per cent.

The absence of age distribution data alone prevents direct comparison of the results with those obtained in this study. However, they indicate the difference in standard between the quality of logs from plantations and from naturally regenerated forests. When diameter growth is accelerated, especially in young stands, the proportion of the poorer quality class increases strongly (Heiskanen 1965). According to that study, the share of class III butt logs is at its best 55 per cent in stands of under 60 years and rises sharply with the increase in diameter. The proportion of class III butts is very small in the age class 81—100 years.

The log diameter class also affects the quality class distribution: the share of logs of quality classes I and II in the volume decreases fast when the diameter diminishes.

According to the Third National Forest Inventory (Ilvessalo 1957), the average shares of quality classes I, II and III in the total of standing saw timber was 16.3, 32.7 and 51.0 per cent. The figures are for the same district forestry boards from which the data on plantation-grown pines were collected.

According to the Sixth National Forest Inventory the shares of quality classes I, II and III in the sawlog growing stock were 14.2, 30.0 and 55.7

per cent. However, the figures were calculated only from the area of three district forestry boards in the southern half of Finland as technical cubic metres per hectare (Tiihonen 1973, cf. also Anon. 1971).

It is rather difficult to make comparison with the above figures as the plantation-grown pine material also derived from young forests on the whole. However, the poorer self-pruning than in naturally regenerated forests and thick-branchiness alone indicate that the formation of better quality saw timber begins later in plantation pines than in naturally regenerated pine stands, and that the quality is lower even then.

Conclusions can be drawn also on within-stem wood properties on the basis of the external stem characteristics and the timber quality. According to the comprehensive review of the literature presented by Larson (1963), stem form may be regarded at least in some degree as a criterion for the evaluation of basic density.

The percentage of late wood in a plantation-grown pine stem at different heights may be compared with the values reported by Hakkiila (1967) for naturally regenerated pine stands. The difference in the late wood percentage varies from 2 to 5 per cent units in different parts of the stem; this may be due to the measuring method and the measurer's principles for evaluating late wood and early wood. The mean late wood percentage for plantation-grown pines was 29 per cent; this is 2—3 per cent units more than the values reported by Hakkiila (1968) for pine pulpwood between the 62nd and 64th parallels.

As basic density is strongly dependent on the late wood percentage, no noteworthy difference can be seen in the basic density of naturally regenerated pine stands and plantations when judged by the density/age ratio. The most detailed data on the basic density of naturally regenerated pine stands are to be found in the studies conducted by Hakkiila (1966). Fig. 43 shows the correlation between basic density and age in plantations and natural pine stands. The regression equation illustrating the former is as follows:

Regression equation	R	S <sub>y.x</sub>
$Y = 212.880 + 49.601 \log X$	0.609	22.3

Y = basic density of stem, kg/solid cu.m.

X = tree age, years

The basic density was slightly higher in plantation-grown pines, but the results of the two studies were close.

However, growth and development are faster on average in pine plantations than in naturally regenerated pine stands and it is consequently possible to harvest timber faster in the former. If it is assumed that stems

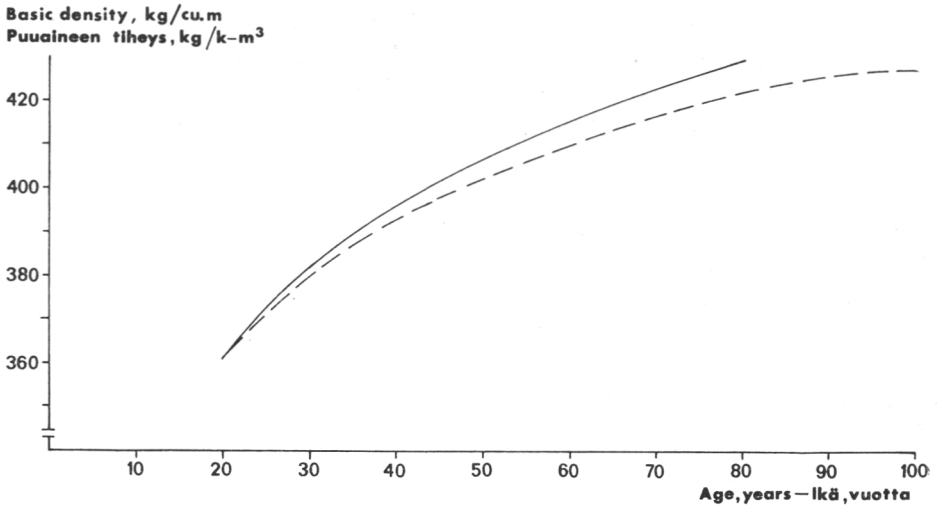


Fig. 43. Correlation between the basic density and age of plantation-grown pine stems.  
 ——— Basic density in naturally regenerated pine stands according to HAKKILA (1966).

*Kuva 43. Viljelymäntyrunon puuaineen tiheyden riippuvuus iästä  
 ——— Puuaineen tiheys luonnonmänniköissä HAKKILAN (1966) mukaan*

develop to a certain dimension and to the logging stage is 10 years faster in pine plantations than in naturally regenerated pine stands, basic density in the former will be approx. 10 kg/solid cu.m. lower than in natural pine stands.

Although there was no difference in the average basic density of the two types of pine stand, the fact remains that growth rate has a strong effect on density. This appears from the following table in which basic density is compared at the age of about 40 years in plantations and natural pine stands on VT, MT and OMT soil. The basic density of plantation-grown pines from a very favourable site may be considerably lower than that of pines from naturally regenerated forests.

	Plantations	Naturally regenerated stands
	Basic density, kg/solid cu.m.	
VT .....	400	406
MT .....	390	386
OMT .....	370	385

Several investigators have arrived at the conclusion that basic density is lower in plantation-grown pine stands than in stands of natural origin (e.g. Pillow 1952, Miyajima 1958, Baker 1967). The reverse has also been stated in studies of the effect of growth rate on basic density (Sellers 1962, Nichols and Fielding 1965, Schalck 1967).

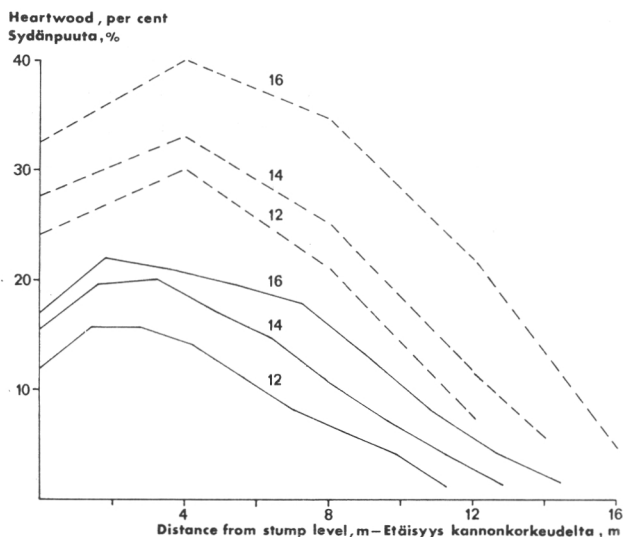


Fig. 44. Percentage of heartwood at different heights of a plantation-grown pine stem the height of whose utilizable part is 12, 14 and 16 m.

— — — Percentage of heartwood in naturally regenerated pine stands according to HAKKILA (1967).

*Kuva 44. Käyttöosaltaan 12-, 14- ja 16-metrin pituisen viljelymättyrungon sydänpuuprosentti eri korkeuksilla*  
— — — *Sydänpuuprosentti luonnonmänniköissä HAKKILAN (1967) mukaan*

According to Elliot's (1970) review of the literature, dense establishment of a pine stand reduces the juvenile wood zone of low density and the growth of branches and taper. Intensive thinnings of young seedling stands increase crown size in ratio to stem volume and decrease the late wood percentage and basic density immediately after the thinning.

The average heartwood percentage of plantation-grown pine stems is low, only about a half of that of naturally regenerated stems (Fig. 44). The heartwood percentage peak, too, is somewhat lower in a plantation-grown than in naturally regenerated pine. The longitudinal variation in the heartwood percentage of pine was very similar in studies made in Sweden; the highest stem heartwood values were encountered at the relative height of 20 per cent (Nylinder 1961, Tamminen 1962). These studies give a maximum heartwood percentage range of 23 to 70, but note that age strongly influences the quantity of heartwood.

According to Hakkila (1968), the average heartwood percentage of pine pulpwood south of the 62nd parallel is 16 and between the 62nd and 64th parallel 21. Bruun (1965 and 1967) reported heartwood percentages of 14 to 41 in different parts of the country.

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Little is known about the reasons for the formation of heartwood. However, the proportion of heartwood depends to a certain extent on the vitality and growth rate of the tree: the heartwood percentage of fast-growing trees is smaller than that of slow-growing. As the amount of heartwood seems to be associated simultaneously with age, growth rate and site type, wood with a particularly low heartwood percentage will be obtained from young, fast-growing pine plantations.

## 5. SUMMARY

The quality of timber harvested from forests and wood quality will change in many ways with the yearly expansion of the area of artificial reforestation. Selection of seedling material, deciding the growing space of trees at the beginning of the development of a stand, more homogeneous growing conditions than in naturally regenerated forests, and possibly, more intensive silvicultural measures distinguish pine plantations from natural pine stands in their development.

If high yield is the sole aim for cultivated pine stands, at least some compromise will have to be made with the quality of timber. Studies to date have disclosed the negative influence of fast growth on the self-pruning of the stem and diameter growth of the branches, negative, that is, for sawlog quality. But trees are grown today in pine stands and will be grown in the immediate future with sawlogs as the ultimate aim.

The purpose of this work was to study the quality of timber and wood in plantation-grown pines, chiefly for use as sawlogs, and the development of quality as judged by external characteristics and factors associated with stand development. In addition, wood characteristics and the correlation between them and various indicators of external quality were examined. The results were compared with corresponding data on naturally regenerated pine stands.

The material comprised 30 stems per stand collected in the southern part of Finland from sample stands located in pure pine plantations. For the investigation of wood characteristics, two cores were taken by increment borer and the branchiness, defects, etc. of the stem were measured and noted. A part of the sample trees were felled for study of the longitudinal variations in the different stem characteristics. Cores were taken as control material from the felled sample trees, and from a part of the material disks were also taken from different relative heights. 2 760 stems from 92 sample stands were studied and 460 of them were felled for additional studies.

The main results were as follows:

- 1) Formation of the branchless part of the stem is a slow process in pine plantations until the age of 60 years when the healing over of the branches is accelerated. The crown proportion decreases evenly with age,

whereas the relative height of the dry-branched part of the stem grows at first and decreases later, and the relative height of the branchless part of the stem increases. At 80 years, the stems are self-pruned to an average height of 22 per cent. The self-pruning rate, however, also depends on the rate of diameter growth, and trees of medium diameter are the best pruned within each age class.

2) The branch diameter at different stem heights increases with age, but diameter differences between the different age classes are very small in the butt section and increase towards the top. The maximum diameter branches of the stem are at the relative height of 60 per cent in trees aged over 50 years, in stands of under 30 years at the 40 per cent height. The better the forest site type, the thicker are the branches. Concentration of the diameter growth of branches in the butt section of the tree is then the most negative factor for wood quality. Stems of crown class I are the largest-branched trees of the stand; branch diameter decreases in the lower crown classes.

3) Of the indicators describing stem, the length and diameter of the longest branch of the stem and the diameter of the thickest dry branch are explained best by stem diameter at breast height. In addition to diameter radial increment, the quantities that explain best the length and diameter of the largest branches are crown proportion and age in different forms. The best degrees of explanation obtained by regression analysis for the diameter of the thickest branch and the length and diameter of the longest living branch were 70, 68 and 63 per cent.

4) Stem taper increases within a certain age class as the tree diameter grows. Trees of the lowest crown classes of the stand thus display the least taper and have the best stem form. Stem taper correlated with the indicators of branchiness and the characteristics illustrating the internal quality of wood.

5) The commonest defects in plantation-grown pine stands lowering technical quality are crookedness of stem, butt crook, vertical branch and sweep. Together they cover about 95 per cent of all the defects observed. The proportion of all defects is smallest in VT (*Vaccinium* type) stands and highest in all age classes in OMT (*Oxalis-Myrtillus* type) stands. The incidence of defects in the stem is higher the lower the crown class to which it belongs.

Compression wood was seen at stump height in 30.4 per cent of all the sample trees felled. The proportion of stems containing compression wood rose to 46.2 per cent in crooked stems and to 48.7 per cent in stems with sweep.

6) Sawlogs harvested from pine plantations are of poor quality in general. The proportion of sawlogs of quality class I in the growing stock of

even the oldest stands is very small. Log quality deteriorates when the nutrient content of the soil increases, and the technical quality of butt logs harvested from OMT pine stands is especially poor. Butt logs that meet sawlog dimensions are distributed according to branchiness into classes I, II and III and cull stems as follows: 6.7, 19.8, 69.4 and 4.2 per cent. If, in addition to branchiness, all defects are taken into account in the quality assessment, the distribution becomes 1.3, 11.7, 66.2 and 20.8 per cent. The proportions of all accepted butt logs in quality classes I, II and III are 1.4, 14.8 and 83.6 per cent.

7) Branch diameter at different heights of the stem increases with the diameter growth rate of the tree at different ages, i.e., with the width of the annual rings. There is a correlation between ring width and self-pruning; relatively slow-growing stems show the best self-pruning, while both very fast-growing and very slow-growing trees show the worst degree of self-pruning. Ring width proved to be a good independent variable of total basic density variation in stand-to-stand analysis and a moderately good one also in stem-to-stem analysis.

8) The percentage of late wood decreases in the stem from the butt towards top and is generally lower the younger or faster-growing the tree is. The mean late wood percentage occurs at 30 per cent relative height. Ring width in one form or another was a fairly good independent variable of the late wood percentage of the stem. However, when stem diameter growth and diameter of the largest dry branch were added as independent variables, ring width explained only 45 per cent of the total variation of the late wood percentage.

9) The basic density of the stem decreases evenly from the butt upwards and the mean stem basic density, 395 kg/solid cu.m., coincides with the relative stem height of 25 per cent. The effect of the forest site type on basic density is pronounced if the nutrient content of the soil is abnormally high.

In stem-to-stem regression analysis, age, growth of tree diameter, height and ring width proved to be the best independent variables of basic density. The explained variance was 42 per cent.

When stand-to-stand variation of density is explained by the same variables, the correlations are considerably closer. The best degree of explanation, 83 per cent, was achieved with the independent variables ring width and growth rate variance and branch diameter.

10) The heartwood percentage of a plantation-grown pine stem increases from stem butt to a relative height of about 15 per cent where it reaches its maximum and then decreases sharply towards the top. The average heartwood percentage is higher the older the tree.

11) Comparison with naturally regenerated pine stands shows that self-pruning is poorer in plantation-grown pine stems, particularly at the age of 40—60 when the butt portion of the stem already meets sawlog dimension requirements. The quality of the butt portion of a stem self-pruned at a later age is lowered by large and long-lasting knott bumps. Although direct points of comparison with naturally regenerated pine stands are few, the development of branch thickness in plantation-grown pine stands seems to be stronger on average than in natural pine stands.

The quality of sawlogs from cultivated pine stands is poorer than that of naturally regenerated pine stands, chiefly because of poor branchiness but also on account of various technical defects. Approximately one-fifth of stems of sawlog size are not acceptable even as sawlogs of quality class III. The stems also taper more than naturally regenerated stems, and this affects e.g. the raw material consumption.

12) There is no appreciable difference between the late wood percentages and basic density of wood produced by cultivated and naturally regenerated pine stands. However, if stands are established on especially good sites and the number of stems is kept small, basic density decreases notably. As cultivated forests grow fast, it is possible to harvest wood from them earlier than from naturally regenerated forests. As basic density rises sharply with age in young stands, the pulp yield per unit of volume is somewhat lower for plantation-grown than for naturally regenerated pines.

The average percentage of heartwood in plantation-grown pine is only a half of the percentage in stems of natural origin.

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Appendix I. Average properties of sawlog stems of different quality classes and cull stems (R)  
*Liitetäulukko I. Laatuokaltaan erilaisten tukkirunkojen sekä hyllytykkeihin (R) kuuluvien runkojen keskimääräisiä ominaisuuksia*

Quality class <i>Laatuluokka</i>	Dbh, cm <i>D1.3, cm</i>		Tree height, m <i>Puun pituus, m</i>		Taper, cm <i>Kapeneminen, cm</i>		To the knot bumps, m <i>Oksakyyhmyihin, m</i>		Stem with over- grown knots, m <i>Kuhmyosa, m</i>		Stem with dry branches, m <i>Kuivaoksainen osa, m</i>		Crown, m <i>Latvuksen pituus, m</i>		Lowest dry branch, m <i>Alin kuiva oksa, m</i>		Lowest living branch, m <i>Alin elävä oksa, m</i>	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Age, years — <i>Ikä, vuotta</i>																		
—40																		
I	16.6	1.2	14.1	1.5	3.7	1.1	0.5	0.4	—	—	6.6	1.2	5.7	1.1	—	—	—	—
II	18.0	2.2	14.2	1.3	3.6	1.0	0.3	0.2	0.1	0.6	6.8	1.3	5.7	1.2	0.2	0.1	6.3	1.4
III	18.9	2.7	13.7	1.7	4.4	1.4	0.2	0.2	—	—	6.6	1.6	5.4	1.4	0.2	0.2	6.4	1.4
R																		
41—60																		
I	18.6	2.3	16.5	1.3	3.2	0.8	0.5	0.4	0.2	0.4	8.5	1.3	7.5	1.3	0.9	0.6	8.5	0.9
II	19.4	3.0	16.4	1.8	3.4	1.0	0.4	0.3	0.1	0.5	8.6	1.9	7.6	1.8	0.5	0.5	8.6	1.4
III	19.9	3.0	16.6	1.6	3.7	1.0	0.4	0.3	0.1	0.2	8.9	1.7	7.7	1.4	0.4	0.4	8.3	1.9
R																		
61—80																		
I	23.3	5.6	19.5	3.5	3.8	1.3	4.0	2.2	2.9	2.7	4.0	2.4	8.9	2.0	—	—	—	—
II	25.5	6.0	21.9	3.8	4.6	1.6	2.4	1.1	2.5	2.0	8.6	3.6	11.3	2.3	4.3	2.5	—	—
III	26.7	5.5	23.1	2.8	5.0	1.5	1.7	0.7	1.5	1.5	11.3	3.3	12.1	2.3	3.2	3.2	1.5	0.4
R	23.6	4.8	22.5	1.9	4.8	1.4	1.5	1.0	0.6	1.1	12.8	3.4	12.5	2.5	—	—	1.9	0.6

Appendix 2. Average properties of sawlog stems of different quality classes and cull stems (R)  
*Liitetaulukko 2. Laatuokkaltaan erilaisten tukkirunkojen sekä hylkytukkien (R) kuuluvien runkojen keskimääräisiä ominaisuuksia*

Quality class <i>Laatuokkka</i>	Largest dry branch, mm <i>Suurin kuiva oksa, mm</i>		Longest living branch <i>Pisin elävä oksa</i>		Heartwood, per cent <i>Sydänpuuta, %</i>	Basic density, kg/cu.m. <i>Puunaineen tiheys, kg/k-m<sup>3</sup></i>	Ring width, mm <i>Luston levyys, mm</i>	Latewood, per cent <i>Kesäpuuta, %</i>	
	$\bar{x}$	s	$\bar{x}$	s					$\bar{x}$
					Length, m <i>Pituus, m</i>	Diameter, mm <i>Paksuus, mm</i>			
I	—	—	—	—	7.9	414.3	2.4	33.0	
II	—	—	—	—	14.5	384.1	2.6	30.1	
III	29.5	5.4	2.6	8.4	6.8	372.1	0.5	3.8	
R	33.4	6.5	2.8	6.5	8.9	—	2.8	3.9	
Age, years — <i>Ikä, vuotta</i>									
—40									
I	—	—	—	—	7.9	414.3	2.4	33.0	
II	—	—	—	—	14.5	384.1	2.6	30.1	
III	27.2	4.7	2.2	5.7	6.9	410.8	1.9	33.2	
R	27.7	5.5	2.3	8.0	7.9	405.6	2.0	33.2	
I	—	—	—	—	24.6	398.2	2.0	32.7	
II	—	—	—	—	19.3	410.8	1.9	33.2	
III	32.5	9.7	2.5	8.6	11.7	—	0.4	3.8	
R	—	—	—	—	6.9	410.8	1.9	33.2	
41—60									
I	—	—	—	—	24.6	398.2	2.0	32.7	
II	—	—	—	—	19.3	410.8	1.9	33.2	
III	27.0	7.0	2.3	11.2	10.6	428.8	1.6	37.5	
R	32.0	5.7	2.3	3.5	12.9	417.0	1.8	34.9	
I	—	—	—	—	37.8	414.0	1.8	34.4	
II	—	—	—	—	24.6	428.8	1.6	37.5	
III	27.0	7.0	2.3	11.2	10.6	428.8	1.6	37.5	
R	32.0	5.7	2.3	3.5	12.9	417.0	1.8	34.9	
I	—	—	—	—	37.8	414.0	1.8	34.4	
II	—	—	—	—	24.6	428.8	1.6	37.5	
III	27.0	7.0	2.3	11.2	10.6	428.8	1.6	37.5	
R	32.0	5.7	2.3	3.5	12.9	417.0	1.8	34.9	
I	—	—	—	—	37.8	414.0	1.8	34.4	
II	—	—	—	—	24.6	428.8	1.6	37.5	
III	27.0	7.0	2.3	11.2	10.6	428.8	1.6	37.5	
R	32.0	5.7	2.3	3.5	12.9	417.0	1.8	34.9	
I	—	—	—	—	37.8	414.0	1.8	34.4	

Appendix 3. Average properties of sawlog stems of different quality classes and cull stems (R)  
*Liitetaulukko 3. Laatuluokaltaan erilaisten tukkirunkojen sekä hylkytukkeihin (R) kuuluvien runkojen keskimääräisiä ominaisuuksia*

Quality class <i>Laatuluokka</i>	Relative height, per cent — <i>Suhteellinen korkeus, %</i>																																															
	10						20						30						40						50						60						70						80					
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s														
	Branch diameter, mm — <i>Oksan paksuus, mm</i>																																															
	Age years — <i>Ikä, vuotta</i>																																															
	—40																																															
II	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
III	15	4	21	5	26	5	26	5	30	3	30	9	31	10	32	9	31	10	32	9	32	10	31	10	32	9	32	10	31	10	32	9	32	9	32	10	31	10	32	9	32	10	31	10				
R	19	6	26	7	29	6	29	6	34	5	34	6	35	16	34	6	35	16	34	6	34	6	35	16	34	6	34	6	35	16	34	6	34	6	34	6	35	16	34	6	34	6	35	16				
	41—60																																															
II	13	4	16	5	18	6	18	6	26	4	26	6	25	3	26	6	25	3	26	6	26	6	25	3	26	6	26	6	25	3	26	6	26	6	26	6	25	3	26	6	26	6	25	3				
III	13	5	17	5	21	5	21	5	26	6	26	6	30	7	28	6	30	7	28	6	28	6	30	7	28	6	28	6	30	7	28	6	28	6	28	6	30	7	28	6	28	6	30	7				
R	17	8	18	6	21	6	21	6	31	8	30	6	28	9	33	8	28	9	33	8	33	8	28	9	33	8	33	8	28	9	33	8	33	8	33	8	28	9	33	8	33	8	28	9				
	61—80																																															
II	14	0	22	14	19	11	19	11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
III	—	—	22	1	25	7	25	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
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## LYHENNELMÄ

Keinollisesti uudistettujen metsien pinta-alan vuosittain laajentuessa tulee mestistä korjattavan puutavaran laatu ja puuaineen laatu monin tavoin muuttumaan. Taimiaineuksen valinta, puiden kasvutilan määrääminen jo metsikön kehitysvaiheen alussa, luonnonmetsiä tasaisemmat kasvuolot ja mahdollisesti entistä intensiivisemät hoitotoimenpiteet erottavat viljelymänniköt kehitykseltään luonnonmänniköistä.

Mikäli viljelymänniköissä tähdätään vain korkeaan tuotokseen, joudutaan ainakin jossakin määrin tinkimään puutavaran laadusta. Tähän astisista tutkimuksista näkyvät mm. nopean kasvun rungon karsiutumisen ja oksien paksuuskasvulle aiheuttamat haitat. Tällä hetkellä ja vielä lähitulevaisuudessakin tullaan männiköissä kuitenkin kasvattamaan puuta pääasiassa sahapuuksi.

Tutkimuksen tavoitteena on ollut selvittää viljelymänniköiden puuraaka-aineen laatu puutavaraa, lähinnä sahatukkeja, silmällä pitäen ja laadun kehitys rungon ulkoisten tunnusten sekä metsikön kehitykseen liittyvien tekijöiden perusteella. Lisäksi on tutkittu puuaineen ominaisuuksia ja niiden sekä erilaisten ulkoista laatua kuvaavien tunnusten riippuvuutta toisistaan. Tuloksia on vertailtu vastaaviin luonnonmetsikköjä koskeviin tietoihin.

Aineisto kerättiin Suomen eteläosissa puhtaisiin männiköihin sijoitetuilta koealoilta, joista kussakin oli 30 runkoa. Puuaineen ominaisuuksien selvityksiä varten kustakin rungosta otettiin rinnantasalta kaksi lastua kasvukairalla, sekä tehtiin rungon oksaisuutta, vikaisuutta ym. koskevia mittauksia ja havaintoja. Rungon eri ominaisuuksien pituussuuntaisten vaihteluiden selvittämiseksi kaadettiin osa koepuista. Kaadetuista koepuista otettiin vertailumateriaaliksi lastut, sekä osasta aineistoa myös kiekkoja eri suhteellisilta korkeuksilta. Kaikkiaan 92 koealalta tutkittiin 2 760 runkoa, joista lisätutkimuksia varten kaadettiin 460.

Tutkimuksen tulokset olivat pääkohdittain seuraavat:

1) Oksattoman rungonosan muodostuminen on viljelymänniköissä hidasta aina 60 ikävuoteen asti, jolloin oksien kylestyminen nopeutuu. Iän lisääntyessä latvussuhde tasaisesti pienenee, kun taas kuivaoksaisten rungonosan suhteellinen pituus aluksi kasvaa, mutta myöhemmin pienenee, ja oksattoman rungonosan suhteellinen pituus kasvaa. 80 vuoden iässä ovat rungot karsiutuneet keskimäärin 22 %:n korkeudelle. Karsiutumisen nopeus riippuu kuitenkin myös läpimitan kasvunopeudesta siten, että kunkin ikäluokan sisällä läpimitaltaan keskikokoiset puut ovat parhaiten karsiutuneita.

2) Oksan paksuus rungon eri korkeuksilla kasvaa iän mukana, mutta rungon tyviosassa eri ikäluokkien väliset paksuserot ovat hyvin pienet, ja ne kasvavat latvaa kohti. Rungon maksimipaksuiset oksat ovat yli 50 vuotisissa puissa 60 %:n suhteellisella korkeudella, kun sen sijaan alle 30 vuotiaissa metsiköissä paksuimmat oksat ovat 40 %:n korkeudella. Mitä paremmasta metsätypistä on kysymys, sitä

paksummiksi oksat kehittyvät. Puun laadun kannalta on tällöin vahingollisinta oksien paksuuskasvun keskittyminen puun tyviosaan. Metsikön suurioksisimpia puita ovat I latvuserrokseen kuuluvat rungot; oksat ohenevat alempiin latvuserroksiin päin.

3) Rungon pisimmän oksan pituutta ja läpimittaa sekä paksuimman kuivan oksan paksuutta voidaan parhaiten selittää rinnankorkeusläpimitan avulla. Suurimpien oksien pituutta ja paksuutta parhaiten selittäviä suureita ovat läpimitan lisäksi sädekasvu, latvussuhde ja ikä eri muodoissaan. Parhaat regressioanalyysin avulla saatavat paksuimman kuivan oksan paksuuden sekä rungon pisimmän elävän oksan pituuden ja paksuuden selityksasteet olivat 70, 68 ja 63 %.

4) Tietyn ikäluokan sisällä rungon kapeneminen suurenee puun läpimitan kasvaessa. Metsikön alimpiin latvuserroksiin kuuluvat puut ovat siten myös vähiten kapenevia ja runkomuodoltaan parhaita. Rungon kapenemisella huomattiin olevan yhteys oksaisuutta kuvaaviin tunnuksiin sekä puuaineen sisäisiin laatua kuvaaviin ominaisuuksiin.

5) Viljelymänniköiden yleisimmät teknistä laatua alentavat vikaisuudet ovat runkomutka, tyvimutka, poikaoksa ja lenkous, jotka yhteensä kattavat noin 95 % kaikista esiintyvistä vioista. Kaikkien vikojen osuus on puolukkatyyppin (VT) metsiköissä pienin ja käenkaali-mustikkatyyppillä (OMT) suurin kaikissa ikäluokissa. Rungossa on vikoja sitä runsaammin mitä alempaan latvuserrokseen se kuuluu.

Kaikista kaadetuista koepuista 30.4 %:ssa todettiin lylyä kannon korkeudella. Lylyä sisältävien runkojen osuus sen sijaan nousi tyvimutkaisissa puissa 46.2 %:in ja lengoissa puissa 48.7 %:in.

6) Viljelymänniköistä korjattava sahapuu on keskimäärin huonolaatuista, sillä I laatuluokan sahapuun osuus on vanhimpienkin metsiköiden puustosta erittäin vähäinen. Tukan laatu huononee maapohjan ravinteisuuden kasvaessa, ja OMT:n männiköistä korjattavien tyvitukkien tekninen laatu on erityisen heikko. Sahapuun mitat täyttävät tyvitukit jakaantuvat oksaisuuden perusteella I, II, III luokkaan sekä raakkeihin seuraavasti: 6.7, 19.8, 69.4, ja 4.2 %. Jos laadun arvioinnissa otetaan oksaisuuden lisäksi huomioon kaikki muutkin viat, on jakautuma seuraava: I.3, 11.7, 66.2 ja 20.8 %. I, II ja III laatuluokkien osuudet kaikista kelpollisista tyvitukeista olivat 1.4, 14.8 ja 83.6 %.

7) Oksan paksuus rungon eri korkeuksilla on sitä suurempi mitä nopeammin puu on kasvanut paksuutta eri ikäkausina eli mitä leveämpiä vuosilustot ovat. Vuosiluston paksuuden ja rungon karsiutumisen välillä vallitsee sellainen riippuvuus, että karsiutuneisuudeltaan parhaita runkoja ovat suhteellisen hidaskasvuiset ja huonoimpia erittäin nopeakasvuiset ja toisaalta erittäin hidaskasvuiset puut. Luston leveys osoittautui koalojen välisessä tarkastelussa hyväksi ja rungottaisessa analyysissäkin kohtalaiseksi puuaineen tiheyden kokonaisvaihtelun selittäjäksi.

8) Kesäpuuprosentti pienenee rungossa tyvestä latvaan päin ja on keskimäärin sitä alhaisempi mitä nuorempi tai mitä hidaskasvuisempi puu on. Rungon kesäpuuprosentin keskiarvo rungossa sijoittuu 30 %:n suhteelliselle korkeudelle. Luston leveys osoittautui muodossa tai toisessa varsin hyväksi rungon kesäpuuprosentin selittäjäksi. Rungon kesäpuuprosentin kokonaisvaihtelusta voitiin selittää kuitenkin vain 45 %, kun selittäviksi muuttujiksi otettiin luston leveyden lisäksi rungon läpimitan kasvu ja suurimman kuivan oksan paksuus.

9) Rungon puuaineen tiheys laskee tasaisesti tyvestä latvaa kohti, ja rungon keskimääräinen tiheys, 395 kg/k-m<sup>3</sup> sijoittuu rungon 25 %:n suhteelliselle korkeudelle. Metsätyyppin vaikutus puuaineen tiheyteen on suuri mikäli maapohjan rehevyys kasvaa erityisen paljon normaalia suuremmaksi.

Rungottaisessa regressioanalyysissä osoittautuivat ikä, puun läpimitan ja pituuden kasvu sekä luston leveys parhiksi puuaineen tiheyttä selittäviksi muuttujiksi. Selitetty varianssi oli 42 %.

Kun tiheyden metsiköittäistä vaihtelua selitettiin samojen muuttujien avulla, nousivat korrelaatiot huomattavasti korkeammiksi. Paras selitysprosentti (83) saavutettiin luston leveyden ja kasvunopeuden muunnelmien sekä oksien paksuuden avulla.

10) Viljelymäntyrunгон sydänpuuprosentti kasvaa rungon tyvestä noin 15 %:n suhteelliselle korkeudelle, jossa se saavuttaa maksiminsa, ja laskee sen jälkeen jyrkästi latvaa kohti. Keskimäärin on sydänpuuprosentti sitä korkeampi mitä vanhempi puu on.

11) Vertailu luonnonmänniköihin osoittaa, että viljelymäntyrungot ovat luontaisesti syntyneitä puita huonommin karsiutuneita nimenomaan 40—60 vuoden iässä, jolloin rungon tyviosa jo mittojensa puolesta täyttäisi tukkipuun vaatimukset. Myöhemmällä iällä oksista karsiutuneen rungon tyviosan laatua alentavat suuret ja kauan säilyvät oksakyhmyt. Vaikka suoranaisia vertailukohtia luonnonmänniköistä onkin niukasti, voidaan oksien paksuuden kehityksen viljelymänniköissä todeta olevan keskimäärin luonnonmänniköitä nopeampaa.

Pääasiassa huonon oksaisuuden, mutta lisäksi erilaisten teknisten vikaisuuksien johdosta on viljelymänniköiden sahapuun laatu luontaisten männiköiden tukkipuuston laatua huonompi. Noin viidesosa tukkipuukokoisista rungoista ei kelpaa edes III laatuluokan sahapuuksi. Puut ovat lisäksi luontaisia runkoja kapenevampia, mikä vaikuttaa mm. raaka-aineen menekin kasvuun.

12) Viljely- ja luonnonmänniköiden tuottaman puuaineen kesäpuuprosenteissa ja tiheyksissä ei ole sanottavaa eroa. Mikäli metsiköitä kuitenkin perustetaan erityisen hyvälle kasvupaikalle ja runkoluku jätetään alhaiseksi, puuaineen tiheys laskee huomattavasti. Koska viljelymetsät kasvavat nopeasti, voidaan niistä korjata puuta aiemmin kuin luonnonmetsiköistä. Koska puuaineen tiheys nousee nuorissa metsiköissä jyrkästi iän mukana, on tilavuusyksiköstä saatavan massan saanto viljelymänniköissä luonnonpuustoa jonkin verran alhaisempi.

Viljelymäntyrunkojen sydänpuuprosentti on keskimäärin vain noin puolet luontaista alkuperää olevien runkojen sydänpuuprosentista.



COLONIZATION OF *MELAMPSORA*  
UREDIA ON ASPEN LEAVES  
BY *CLADOSPORIUM* SP.

TIMO KURKELA

HELSINKI 1974

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*Timo Kurkela*

COLONIZATION OF MELAMPSORA UREDIA  
ON ASPEN LEAVES BY CLADOSPORIUM SP.  
Comm. Inst. For. Fenn. 80.3 (1974).

## ABSTRACT

Comparing the numbers of airborne spores of *Cladosporium* sp. in 1970 and 1971, an extremely large difference in spore dispersal was observed. The abundance of the fungus during the second year apparently was dependent on the large amount of suitable substrate for the fungus created as a result of cleaning a pine sapling stand. *Cladosporium* infected the uredia of *Melampsora* sp. on aspen leaves. The secondary infection of the uredia apparently reduced the number of airborne uredospores. Thus secondary infection seemed to partly inhibit the multiplication of the uredial state of the rust on the aspen leaves.

## INTRODUCTION

In connection with studies on spore dispersal of the *Melampsora* -rusts of aspen (K u r k e l a 1973), it was found that *Cladosporium* sp. infected the uredia on aspen leaves. In the present paper some preliminary observations made on the relationship between *Cladosporium* and *Melampsora* are reported. The secondary saprophytes or parasites are interesting because they may in one way or another affect the development of the disease (P o w e l l 1971 a, b, B y l e r et al. 1972, v a n d e r W a l et al. 1970). In some cases secondary colonizers may be used to control the primary parasites (R i s h b e t h 1963, K a l l i o 1971, B i e r 1965, V a s i l j e v et al. 1970).

## MATERIAL AND METHODS

Investigations were conducted in the Ruotsinkylä Experimental Forest of the Finnish Forest Research Institute in southern Finland (N 60°38', E 25°09') in 1970 and 1971.

Spores were collected with the aid of a Hirst spore trap (Burkard Manufacturing Co.) (H i r s t 1952) located in an opening, about 20 m in diameter, in a 4—6 m high mixed stand of pine and larch. A large number of aspen suckers, 0.5—1 m high, grew in the opening. The orifice of the spore trap was about 80 cm above the ground. The number of *Cladosporium* conidia and uredo- and aeciospores of *Melampsora* on the tapes were counted at one-hour intervals using a microscope. The rainfall and air temperature were registered at the experimental area. The temperature was measured in a standard weather chamber located 2 m above the ground. The data for spore dispersal were collected between June 18 and September 10.

For investigations on dispersal of aspen rust, leaf samples of aspen were collected during the summer of 1971. Three different groups of suckers were sampled at one-week intervals. Each time three branches were collected, and from 15 leaves the number of uredia per unit area was counted. From each branch the five lowest leaves on the current year's shoot were sampled. The count was made with a stereomicroscope using  $\times 25$  magnification. Since it had been found previously that *Cladosporium* frequently infected uredia, these were classified according to three groups: 1) healthy sporulating uredia, 2) infected uredia with no apparent spore production, generally visible mycelium, and the margins of the uredia light brown in color, and 3) uredia surrounded by dead tissue. The classification of groups 1 and 2 was checked by microscopic examination of fresh samples.

## RESULTS

### *Cladosporium* in uredia of *Melampsora*

It was found that, without exception, the uredia of classes 2 and 3 contained mycelia of *Cladosporium* producing large numbers of conidia (Figure 1). In uredia of class 1 hyphae were usually not found even in the more detailed investigations. Infection by *Cladosporium* appeared to interrupt development of the uredia. This could not be studied more in detail

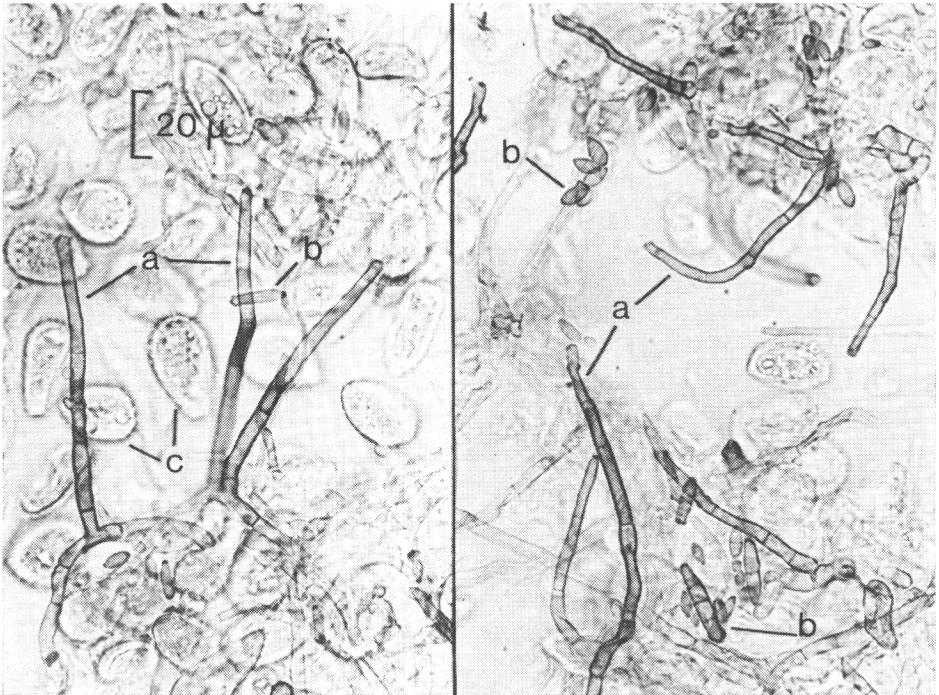


Figure 1. A crude preparat from a *Melampsora* uredium infected by *Cladosporium* sp., a) conidiophores and b) conidia of *Cladosporium* sp. and c) uredospores of *Melampsora* sp.

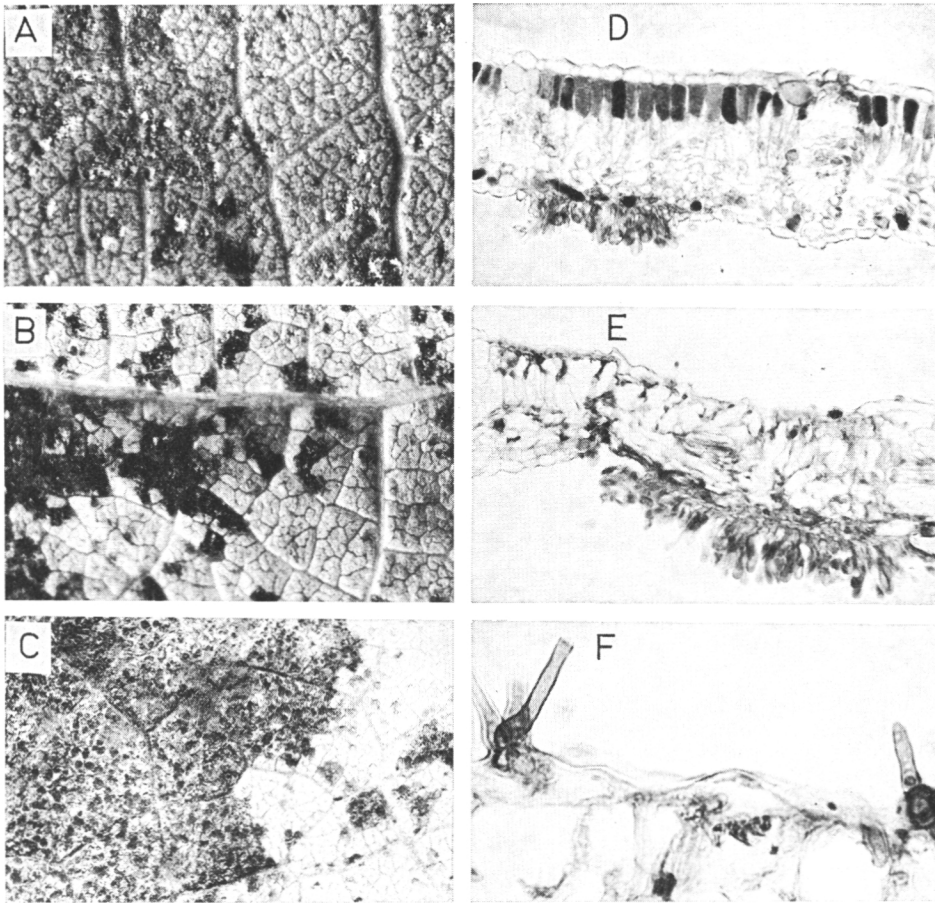


Figure 2. *Cladosporium* sp. colonizing uredia of *Melampsora* on aspen leaves. A) Healthy and infected uredia. B) Infected uredia surrounded by dead aspen leaf tissue. C) A section of a dead aspen leaf bearing abundant sporulating *Cladosporium* and newly-formed telia of *Melampsora*. D) A cross-section of a healthy uredium of *Melampsora* on an aspen leaf. E) A uredium infected by *Cladosporium* with collapsed leaf tissue. F) Conidiophores of *Cladosporium* on dead tissue surrounding the uredium. A—C)  $\times 2$ , D—E)  $\times 130$ , F)  $\times 400$ .

in the field, however. Apparently, the secondary infection by *Cladosporium* was the main cause for death of the tissue around the uredia (Figure 2).

Uredia formation commenced in the beginning of July. As the number of uredia increased on the aspen leaves, the proportion of those infected also increased. At the end of August when there were 10—20 uredia/cm<sup>2</sup>, about 80 % of them were infected by *Cladosporium*, and 5 % were surrounded by necrotic tissue. Figure 3 shows the number of uredia and the proportion of infected ones on weekly samples.

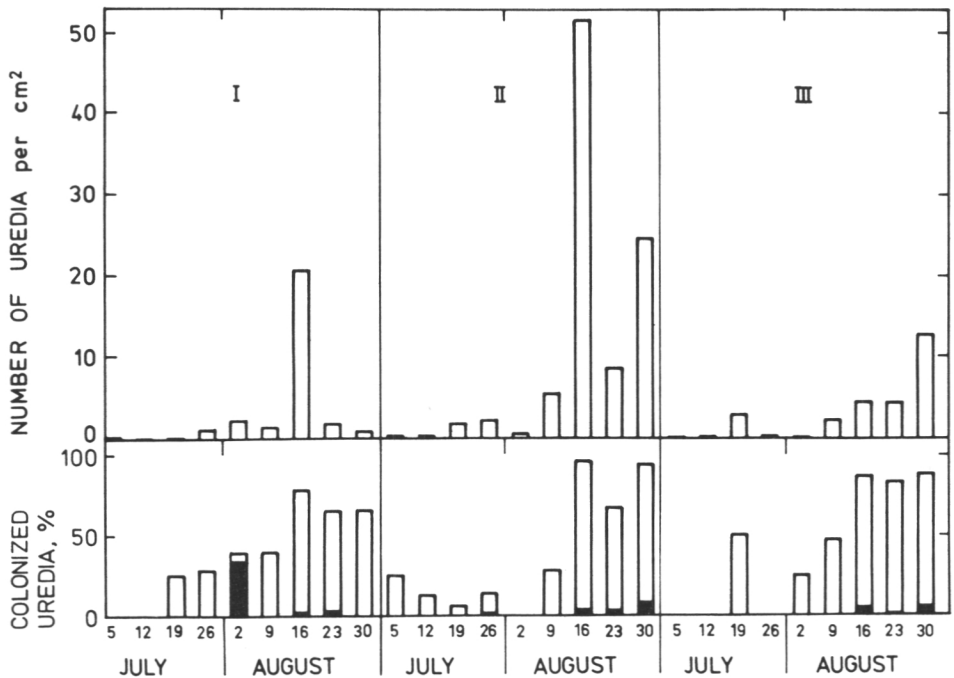


Figure 3. Number of uredia of *Melampsora* (uredia/cm<sup>2</sup>) on aspen leaves sampled at weekly intervals (upper section of figure). Percentage of all examined uredia colonized by *Cladosporium* (lower section of figure). The black part of the bars indicate the portion of uredia surrounded by necrotic tissue. The data were collected in 1971. I—III indicate the group of suckers sampled.

When the *Cladosporium* infection interrupted the production of uredospores in the uredia, it also seemed to stimulate the rust mycelia to produce telia, which occurred profusely on the dead leaf areas colonized by *Cladosporium*.

#### Spore dispersal of *Cladosporium* and *Melampsora*

The number of spores for both *Cladosporium* and *Melampsora* were very different during the two years (Figure 4). In the summer of 1970 the last aeciospores were found on July 7. Soon after this, uredospores appeared in the air. They reached a maximum at the end of August. The maximum average daily number of spores, 400 spores/m<sup>3</sup>, occurred on August 23. During June—July the number of *Cladosporium* spores was considerably larger than that of *Melampsora* during the same time. In August—September there were still ten times more *Cladosporium* spores than spores of *Melampsora*. On July 19 the spore density of *Cladosporium*



reached a maximum of 7 000 spores/m<sup>3</sup>. In the summer of 1971 aeciospores of *Melampsora* still were found at the end of July. The total number, however, was much smaller than during the previous year. The rust seemed to spread on aspen leaves as profusely as usual. In spite of the fact that uredia occurred, no uredospores were trapped. Conidia of *Cladosporium* occurred many times more densely during the summer of 1971 compared to the previous summer. The maximum density of *Cladosporium* spores occurred at the end of July and beginning of August. The daily average number of spores reached a maximum, 20 000 spores/m<sup>3</sup>, on August 7.

When analyzing the variation in numbers of airborne spores during the growing season (Figure 4), it was found that conidia of *Cladosporium* occurred in the greatest numbers during rainy periods when the average daily temperature was fairly high, over +15 °C. In the summer of 1970 the precipitation was, especially in July, fairly abundant; but at the same time, the periods of warm (over +15 °C) and cold weather alternated at intervals of a few days, which may have slowed down the development of the fungus.

In the summer of 1971 the warm periods were longer than during the previous summer. The rains were not very heavy, but frequent. During two rainless periods in the beginning and end of July the number of airborne spores dropped well below that of the rainy periods. In the fall, at the end of August and the beginning of September when the daily mean temperature had dropped below +15 °C, not even abundant rains increased the number of airborne spores.

## DISCUSSION

Some of the *Cladosporium* species that occur as secondary parasites in the pustules of rust species have been described in the literature. De Vries (1952) reports that *C. cladosporioides* (Fres.) Vries has often been found on leaves infected by rust and even in the rust pustules. Spegazzini (1912, 1923) described two species of *Cladosporium*, *C. uredinicola* and *C. urediniphilum*, which lived in uredia. One species of *Cladosporium* parasitizes the uredospores of *Hemileia vastatrix* Berk. & Br. (Steyaert 1930). Powell (1971) found that some previously unknown species of *Cladosporium* colonized the eaciospores of *Cronartium comandrae* Pk. and the tissue hypertrophied by the fungus. Sutton (1973) named this species *C. gallicola*.

Magnani (1971) found that *Ramularia uredinis* (Voss) Sacc. parasitized the uredia of *Melampsora* on aspen leaves. This fungus appears to be very similar to the fungus found in the uredia of *Melampsora* and identified as *Cladosporium* in the present paper. This *Cladosporium* species forms nearly unbranched and smooth conidiophores, and the conidia are only slightly verrucose. It appears that this fungus may belong to the species *C. cladosporioides*.

The number of airborne spores of *Cladosporium* has usually reached a maximum during mid-summer or in the fall (Ainsworth 1952, Hyde and Williams 1953, Corbaz 1971, Mäkinen and Ollikainen 1972). The number of conidia may vary considerably during different years due to many environmental factors. The prerequisite for profuse formation of spores is warm and humid weather. Apparently, only when there is an unusually large amount of dead plant material as a substrate for the fungus can the *Cladosporium* population and consequently, the number of airborne spores become very large. Such a situation may occur in the forest in connection with cleaning of a sapling stand if large numbers of leaf-bearing hardwood suckers are felled. On the experimental area of this study the hardwoods were cleared away in June of 1971. Due to the subsequent abundant rainfall the species of *Cladosporium* spread rapidly on the ground foliage. Due to the large spore density, *Cladosporium* was able

to effectively infect the uredia of *Melampsora* already in the initial stage of the epiphytotic. The secondary infection of the uredia apparently suppressed sporulation, which resulted in a low density of uredia (about 10—20 uredia/cm<sup>2</sup>) at the end of the growing season. In the studies made in Ikaalinen (Kurkela 1973) it was found that the usual amount of rust at the end of a season was 40—50 uredia/cm<sup>2</sup>.

These and the previously mentioned studies (cf. above) on *Cladosporium* sp. suggest that these fungi may possibly be applied in biological control of the rust. However, more detailed investigations are required for understanding the role of *Cladosporium* fungi in *Melampsora* leaf rust epiphytotics.

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M. SÄNTUTKIMUSLAITOS  
JALOSTUSASEMA  
01590 MAISALA

